Impacts of climate-related geo-engineering on biological diversity
Annotated Bibliography and other Relevant Citations

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Abate, R. S. and A. B. Greenlee (2010). "Sowing Seeds Uncertain: Ocean Iron Fertilization, Climate Change , and the International Environmental Law Framework." Pace Environmental Law Review **27** (2)
Open Access Article* Available at: http://digitalcommons.pace.edu/pelr/vol27/iss2/5

Agrawal, A. (1995). "Indigenous and Scientific Knowledge: Some Critical Comments." Indigenous Knowledge and Development Monitor **3**: 3-6
Open Access Article* Available at: http://www.fisip.ui.ac.id/antropologi/httpdocs/jurnal/1998/55/diskusi%20arun.pdf

Allenby, B. (2010). "Climate change negotiations and geoengineering: Is this really the best we can do?" Environmental Quality Management **20**: 1-16 DOI: 10.1002/tqem.20276
Available at: http://doi.wiley.com/10.1002/tqem.20276

Alley, R. B., J. Marotzke, et al. (2003). "Abrupt climate change." Science **299**: 2005-2010 DOI: 10.1126/science.1081056
Available at: http://www.sciencemag.org/content/299/5615/2005.abstract

> Large, abrupt, and widespread climate changes with major impacts have occurred repeatedly in the past, when the Earth system was forced across thresholds. Although abrupt climate changes can occur for many reasons, it is conceivable that human forcing of climate change is increasing the probability of large, abrupt events. Were such an event to recur, the economic and ecological impacts could be large and potentially serious. Unpredictability exhibited near climate thresholds in simple models shows that some uncertainty will always be associated with projections. In light of these uncertainties, policy-makers should consider expanding research into abrupt climate change, improving monitoring systems, and taking actions designed to enhance the adaptability and resilience of ecosystems and economies.

Álvaro-Fuentes, J. and K. Paustian (2010). "Potential soil carbon sequestration in a semiarid Mediterranean agroecosystem under climate change: Quantifying management and climate effects." Plant and Soil **338**: 261-272 DOI: 10.1007/s11104-010-0304-7
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s11104-010-0304-7

> Climate change is projected to significantly impact vegetation and soils of managed ecosystems. In this study we used the ecosystem Century model together with climatic outputs from different atmosphere-ocean general circulation models (AOGCM) to study the effects of climate change and management on soil organic carbon (SOC) dynamics in semiarid Mediterranean conditions and to identify which management practices have the greatest potential to increase SOC in these areas. Five climate scenarios and seven management scenarios were modeled from 2010 to 2100. Differences in SOC sequestration were greater among management systems than among climate change scenarios. Management scenarios under continuous cropping yielded greater C inputs and SOC gain than scenarios under cereal-fallow rotation. The shift from rain-fed conditions to irrigation also resulted in an increase of C inputs but a decrease in the SOC sequestered during the 2010-2100 period. The effects of precipitation and temperature change on SOC dynamics were different depending on the management system applied. Consequently, the relative response to climate and management depended on the net result of the influences on C inputs and decomposition. Under climate change, the adoption of certain management practices in semiarid Mediterranean agroecosystems could be critical in maximizing SOC sequestration and thus reducing CO2 concentration in the atmosphere.

America's Climate Choices: Panel on Advancing the Science of Climate Change; National Research Council. (2010) Advancing the Science of Climate Change. Washington, DC, National Academies Press.
Open Access Article* Available at: http://www.nap.edu/catalog/12782.html

> Climate change is occurring, is caused largely by human activities, and poses significant risks for-and in many cases is already affecting-a broad range of human and natural systems. The compelling case for these conclusions is provided in Advancing the Science of Climate Change, part of a congressionally requested suite of studies known as America's Climate Choices. While noting that there is always more to learn and that the scientific

process is never closed, the book shows that hypotheses about climate change are supported by multiple lines of evidence and have stood firm in the face of serious debate and careful evaluation of alternative explanations. As decision makers respond to these risks, the nation's scientific enterprise can contribute through research that improves understanding of the causes and consequences of climate change and also is useful to decision makers at the local, regional, national, and international levels. The book identifies decisions being made in 12 sectors, ranging from agriculture to transportation, to identify decisions being made in response to climate change. Advancing the Science of Climate Change calls for a single federal entity or program to coordinate a national, multidisciplinary research effort aimed at improving both understanding and responses to climate change. Seven cross-cutting research themes are identified to support this scientific enterprise. In addition, leaders of federal climate research should redouble efforts to deploy a comprehensive climate observing system, improve climate models and other analytical tools, invest in human capital, and improve linkages between research and decisions by forming partnerships with action-oriented programs.

Ammann, C. M., W. M. Washington, et al. (2010). "Climate engineering through artificial enhancement of natural forcings: Magnitudes and implied consequences." Journal of Geophysical Research **115**: 1-17 DOI: 10.1029/2009jd012878

Open Access Article* Available at: http://www.agu.org/pubs/crossref/2010/2009JD012878.shtml

Explosive volcanism and solar activity changes have modulated the Earth's temperature over short and century time scales. Associated with these external forcings were systematic changes in circulation. Here, we explore the effect of similar but artificially induced forcings that mimic natural radiative perturbations in order to stabilize surface climate. Injection of sulfate aerosols into the stratosphere, not unlike the effects from large volcanic eruptions, and a direct reduction of insolation, similar to total solar irradiance changes, are tested in their effectiveness to offset global mean temperature rise resulting from a business-as-usual scenario, thereby reducing surface temperatures to conditions associated with committed warming of a year 2000 stabilization scenario. This study uses a coupled Atmosphere-Ocean General Circulation Model to illustrate the character of resulting climate and circulation anomalies when both enhanced greenhouse (A2 scenario) and opposing geoengineering perturbations are considered. First we quantify the magnitude of the required perturbation and compare these artificial perturbations to the natural range of the respective forcing. Then, we test the effectiveness of the "correction" by looking at the regional climate response to the combined forcing. It is shown that widespread warming could be reduced, but overcompensation in the tropics is necessary because sea ice loss in high latitudes cannot be reversed effectively to overcome higher ocean heat content and enhanced zonal winter circulation as well as the continuous IR forcing. The magnitude of new, greenhouse gas-countering anthropogenic forcing would have to be much larger than what natural forcing from volcanoes and solar irradiance variability commonly provide.

Amonette, J. E. and S. Joseph (2009). "Characteristics of biochar: microchemical properties" in Biochar for environmental management: science and technology. J. Lehmann and S. Joseph. London, United Kingdom, Earthscan: 33-52.

Anderson, K. and A. Bows (2011). "Beyond 'dangerous' climate change: emission scenarios for a new world." Philosophical Transactions of the Royal Society A **369**: 20-44 DOI: 10.1098/rsta.2010.0290

Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/369/1934/20.short

The Copenhagen Accord reiterates the international community's commitment to 'hold the increase in global temperature below 2 degrees Celsius'. Yet its preferred focus on global emission peak dates and longer-term reduction targets, without recourse to cumulative emission budgets, belies seriously the scale and scope of mitigation necessary to meet such a commitment. Moreover, the pivotal importance of emissions from non-Annex 1 nations in shaping available space for Annex 1 emission pathways received, and continues to receive, little attention. Building on previous studies, this paper uses a cumulative emissions framing, broken down to Annex 1 and non-Annex 1 nations, to understand the implications of rapid emission growth in nations such as China and India, for mitigation rates elsewhere. The analysis suggests that despite high-level statements to the contrary, there is now little to no chance of maintaining the global mean surface temperature at or below 2(°)C. Moreover, the impacts associated with 2(°)C have been revised upwards, sufficiently so that 2(°)C now more appropriately represents the threshold between 'dangerous' and 'extremely dangerous' climate change. Ultimately, the science of climate change allied with the emission scenarios for Annex 1 and non-Annex 1 nations suggests a radically different framing of the mitigation and adaptation challenge from that accompanying many other analyses, particularly those directly informing policy.

Anderson, K. and A. Bows (2008). "Reframing the climate change challenge in light of post-2000 emission trends." Philosophical Transactions of the Royal Society A **366**: 3863-3882 DOI: 10.1098/rsta.2008.0138
Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/366/1882/3863.short

The 2007 Bali conference heard repeated calls for reductions in global greenhouse gas emissions of 50 per cent by 2050 to avoid exceeding the 2 degrees C threshold. While such endpoint targets dominate the policy agenda, they do not, in isolation, have a scientific basis and are likely to lead to dangerously misguided policies. To be scientifically credible, policy must be informed by an understanding of cumulative emissions and associated emission pathways. This analysis considers the implications of the 2 degrees C threshold and a range of post-peak emission reduction rates for global emission pathways and cumulative emission budgets. The paper examines whether empirical estimates of greenhouse gas emissions between 2000 and 2008, a period typically modelled within scenario studies, combined with short-term extrapolations of current emissions trends, significantly constrains the 2000-2100 emission pathways. The paper concludes that it is increasingly unlikely any global agreement will deliver the radical reversal in emission trends required for stabilization at 450 ppmv carbon dioxide equivalent (CO2e). Similarly, the current framing of climate change cannot be reconciled with the rates of mitigation necessary to stabilize at 550 ppmv CO_2e and even an optimistic interpretation suggests stabilization much below 650 ppmv CO_2e is improbable.

Andersson, A. J., F. T. Mackenzie, et al. (2011). Effects of ocean acidification on benthic processes, organisms and ecosystems in Ocean Acidification. J. P. Gattuso and L. Hansson. Oxford, United Kingdom, Oxford University Press**:** 122-153.

Arnell, N. (2011). "Policy: The perils of doing nothing." Nature Climate Change **1**: 193-195 DOI: 10.1038/nclimate1157
Available at: http://www.nature.com/doifinder/10.1038/nclimate1157

A lack of buy-in by the United States arguably represents the greatest obstacle to tackling climate change. A major new report urges America to take action to cut emissions and begin adapting to climate change.

Asai, H., B. Samson, et al. (2009). "Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield." Field Crops Research **111**: 81-84 DOI: 10.1016/j.fcr.2008.10.008
Available at: http://www.sciencedirect.com/science/article/pii/S0378429008002141

The objective of this study was to investigate the effect of biochar application (CA) on soil physical properties and grain yields of upland rice (Oryza sativa L.) in northern Laos. During the 2007 wet season, three different experiments were conducted under upland conditions at 10 sites, combining variations in CA amounts (0–16 t ha□1), fertilizer application rates (N and P) and rice cultivars (improved and traditional) in northern Laos. CA improved the saturated hydraulic conductivity of the top soil and the xylem sap flow of the rice plant. CA resulted in higher grain yields at sites with low P availability and improved the response to N and NP chemical fertilizer treatments. However, CA reduced leaf SPAD values, possibly through a reduction of the availability of soil nitrogen, indicating that CA without additionalNfertilizer application could reduce grain yields in soils with a low indigenous N supply. These results suggest that CA has the potential to improve soil productivity of upland rice production in Laos, but that the effect of CA application is highly dependent on soil fertility and fertilizer management.

Asilomar Scientific Organizing Committee. (2010) “The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques”. Conference Report. Climate Institute. Washington DC
Open Access Article* Available at: http://climateresponsefund.org/images/Conference/finalfinalreport.pdf

Despite ongoing efforts to reduce emissions and adapt to the changing climate, global greenhouse gas emissions are far above what is required to reverse the increasing changes in atmospheric composition. In response to growing calls for research to explore the potential for climate engineering to provide additional options for responding, the Asilomar International Conference on Climate Intervention Technologies was held at the Asilomar Conference Center in California from March 22 to 26, 2010. The conference attracted a diverse group of experts from fifteen countries on six continents. Presentations and discussions covered the two major categories of climate engineering: (a) remediation technologies, such as afforestation, carbon removal, and ocean fertilization, that attempt to reduce the causes of climate change, and so represent an extension of mitigation, and (b) intervention technologies, such as solar radiation management, that attempt to moderate the results of having altered atmospheric composition, and so represent an extension of adaptation to climate change. To promote the responsible conduct of research on climate engineering, recommendations were made to adopt five principles: (1) climate engineering research should be aimed at promoting the collective benefit of humankind and the

environment; (2) governments must clarify responsibilities for, and, when necessary, create new mechanisms for the governance and oversight of large-scale climate engineering research activities; (3) climate-engineering research should be conducted openly and cooperatively, preferably within a framework that has broad international support; (4) iterative, independent technical assessments of research progress will be required to inform the public and policymakers; and (5) public participation and consultation in research planning and oversight, assessments, and development of decision-making mechanisms and processes must be provided. The conferees concluded that expanding and continuing the discussion with an even broader set of participants will be an essential step in moving forward to explore the potential benefits, impacts, and implications of climate engineering.

Aumont, O. and L. Bopp (2006). "Globalizing results from ocean in situ iron fertilization studies." Global Biogeochemical Cycles **20**: 1-15 DOI: 10.1029/2005gb002591
Available at: http://www.agu.org/pubs/crossref/2006/2005GB002591.shtml

Despite the growing number of in situ iron fertilization experiments, the efficiency of such fertilization to sequester atmospheric CO_2 remains largely unknown. For the first time, a global ocean biogeochemical model has been evaluated against those experiments and then used to estimate the effect of a long-term and large-scale iron addition on atmospheric CO_2. The model reproduces the observed timing and amplitude in chlorophyll, the shift in ecosystem composition, and the pCO_2 drawdown; it also proves to be of utility in interpreting the observations. However, a full ocean fertilization during 100 years results in a 33 matm decrease in atmospheric CO2, that is 2 to 3 times smaller than found previously.

Azar, C., K. Lindgren, et al. (2010). "The feasibility of low CO2 concentration targets and the role of bio-energy with carbon capture and storage (BECCS)." Climatic Change **100**: 195-202 DOI: 10.1007/s10584-010-9832-7
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-010-9832-7

The United Nations Framework Convention on Climate Change (UN FCCC 1992) calls for stabilization of atmospheric greenhouse gas (GHG) concentrations at a level that would prevent dangerous anthropogenic interference with the climate system. We use three global energy system models to investigate the technological and economic attainability ofmeeting CO_2 concentration targets below current levels. Our scenario studies reveal that while energy portfolios from a broad range of energy technologies are needed to attain low concentrations, negative emission technologies—e.g., biomass energy with carbon capture and storage (BECCS)— significantly enhances the possibility to meet low concentration targets (at around 350 ppm CO_2).

Bäckstrand, K., J. Meadowcroft, et al. (2011). "The politics and policy of carbon capture and storage: Framing an emergent technology." Global Environmental Change **21**: 275-281 DOI: 10.1016/j.gloenvcha.2011.03.008
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959378011000355

Over the past decade carbon capture and storage (CCS) has attracted increasing international attention as a climate change mitigation option and moved into the center of climate policy debates and negotiations. This special issue of Global Environmental Change brings together leading scholars to analyze the politics, policy and regulation of CCS in cross-country comparisons as well as in a global context. The aim is to contribute on two fronts: first, by applying concepts, theories and methodologies from the social and policy sciences, to elucidate how societies are engaging with CCS as a mitigation option; and secondly, to point toward a future research agenda which, while exploring basic aspects of technology development as situated in a social context, would also be aligned with the needs of the climate and environmental policy community. The contributions address at least one of three inter-related research areas; CCS and the emergence of long-term climate and energy strategies; regulation, policy instruments and public acceptance; and international politics and CCS in developing countries.

Badescu, V. and Cathcart, R.B. (2011). Macro-engineering Seawater in Unique Environments. Arid Lowlands and Water Bodies Rehabilitation. Berlin, Heidelberg, Springer Berlin Heidelberg. DOI: 10.1007/978-3-642-14779-1
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/978-3-642-14779-1

Bala, G., K. Caldeira, et al. (2011). "Albedo enhancement of marine clouds to counteract global warming: impacts on the hydrological cycle." Climate Dynamics **37**: 915-931 DOI: 10.1007/s00382-010-0868-1
Open Access Article* Available at: http://www.springerlink.com/content/9569172415150486/

Recent studies have shown that changes in solar radiation affect the hydrological cycle more strongly than equivalent CO2 changes for the same change in global mean surface temperature. Thus, solar radiation management ‘‘geoengineering’’ proposals to completely offset global mean temperature increases by reducing the

amount of absorbed sunlight might be expected to slow the global water cycle and reduce runoff over land. However, pro- posed countering of global warming by increasing the albedo of marine clouds would reduce surface solar radiation only over the oceans. Here, for an idealized scenario, we analyze the response of temperature and the hydro- logical cycle to increased reflection by clouds over the ocean using an atmospheric general circulation model coupled to a mixed layer ocean model. When cloud drop- lets are reduced in size over all oceans uniformly to offset the temperature increase from a doubling of atmospheric CO_2, the global-mean precipitation and evaporation decreases by about 1.3% but runoff over land increases by 7.5% primarily due to increases over tropical land. In the model, more reflective marine clouds cool the atmospheric column over ocean. The result is a sinking motion over oceans and upward motion over land. We attribute the increased runoff over land to this increased upward motion over land when marine clouds are made more reflective. Our results suggest that, in contrast to other proposals to increase planetary albedo, offsetting mean global warming by reducing marine cloud droplet size does not necessarily lead to a drying, on average, of the continents. However, we note that the changes in precipitation, evaporation and P-E are dominated by small but significant areas, and given the highly idealized nature of this study, a more thorough and broader assessment would be required for proposals of altering marine cloud properties on a large scale.

Bala, G., P. B. Duffy, et al. (2008). "Impact of geoengineering schemes on the global hydrological cycle." Proceedings of the National Academy of Sciences of the United States of America **105**: 7664-7669 DOI: 10.1073/pnas.0711648105

Open Access Article* Available at: http://www.pnas.org/content/105/22/7664.full

The rapidly rising $CO(_2)$ level in the atmosphere has led to proposals of climate stabilization by "geoengineering" schemes that would mitigate climate change by intentionally reducing solar radiation incident on Earth's surface. In this article we address the impact of these climate stabilization schemes on the global hydrological cycle. By using equilibrium climate simulations, we show that insolation reductions sufficient to offset global-scale temperature increases lead to a decrease in global mean precipitation. This occurs because solar forcing is more effective in driving changes in global mean evaporation than is $CO(_2)$ forcing of a similar magnitude. In the model used here, the hydrological sensitivity, defined as the percentage change in global mean precipitation per degree warming, is 2.4% K(-1) for solar forcing, but only 1.5% K(-1) for $CO(_2)$ forcing. Although other models and the climate system itself may differ quantitatively from this result, the conclusion can be understood based on simple considerations of the surface energy budget and thus is likely to be robust. For the same surface temperature change, insolation changes result in relatively larger changes in net radiative fluxes at the surface; these are compensated by larger changes in the sum of latent and sensible heat fluxes. Hence, the hydrological cycle is more sensitive to temperature adjustment by changes in insolation than by changes in greenhouse gases. This implies that an alteration in solar forcing might offset temperature changes or hydrological changes from greenhouse warming, but could not cancel both at once.

Ban-Weiss, G. and K. Caldeira (2010). "Geoengineering as an optimization problem." Environmental Research Letters **5**: 034009-034009 DOI: 10.1088/1748-9326/5/3/034009

Open Access Article* Available at: http://iopscience.iop.org/1748-9326/5/3/034009/fulltext

There is increasing evidence that Earth’s climate is currently warming, primarily due to emissions of greenhouse gases from human activities, and Earth has been projected to continue warming throughout this century. Scientists have begun to investigate the potential for geoengineering options for reducing surface temperatures and whether such options could possibly contribute to environmental risk reduction. One proposed method involves deliberately increasing aerosol loading in the stratosphere to scatter additional sunlight to space. Previous modeling studies have attempted to predict the climate consequences of hypothetical aerosol additions to the stratosphere. These studies have shown that this method could potentially reduce surface temperatures, but could not recreate a low-CO_2 climate in a high-CO_2 world. In this study, we attempt to determine the latitudinal distribution of stratospheric aerosols that would most closely achieve a low-CO_2 climate despite high CO_2 levels. Using the NCAR CAM3.1 general circulation model, we find that having a stratospheric aerosol loading in polar regions higher than that in tropical regions leads to a temperature distribution that is more similar to the low-CO_2 climate than that yielded by a globally uniform loading. However, such polar weighting of stratospheric sulfate tends to degrade the degree to which the hydrological cycle is restored, and thus does not markedly contribute to improved recovery of a low-CO_2 climate. In the model, the optimal latitudinally varying aerosol distributions diminished the rms zonal mean land temperature change from a doubling of CO_2 by 94% and the rms zonal mean land precipitation minus evaporation change by 74%. It is important to note that this idealized study represents a first attempt at optimizing the engineering of climate using a general circulation model; uncertainties are high and not all processes that are important in reality are modeled.

Barnett, J. and W. Adger (2007). "Climate change, human security and violent conflict." Political Geography **26**: 639-655 DOI: 10.1016/j.polgeo.2007.03.003

Available at: http://www.sciencedirect.com/science/article/pii/S096262980700039X

Climate change is increasingly been called a 'security' problem, and there has been speculation that climate change may increase the risk of violent conflict. This paper integrates three disparate but well- founded bodies of research e on the vulnerability of local places and social groups to climate change, on livelihoods and violent conflict, and the role of the state in development and peacemaking, to offer new insights into the relationships between climate change, human security, and violent conflict. It explains that climate change increasingly undermines human security in the present day, and will increas- ingly do so in the future, by reducing access to, and the quality of, natural resources that are important to sustain livelihoods. Climate change is also likely to undermine the capacity of states to provide the oppor- tunities and services that help people to sustain their livelihoods. We argue that in certain circumstances these direct and indirect impacts of climate change on human security may in turn increase the risk of violent conflict. The paper then outlines the broad contours of a research programme to guide empirical investigations into the risks climate change poses to human security and peace.

Barrett, S. (2007). "The Incredible Economics of Geoengineering." Environmental and Resource Economics **39**: 45-54 DOI: 10.1007/s10640-007-9174-8

Open Access Article* Available at: http://www.springerlink.com/content/a91294x25w065vk3/

The focus of climate policy so far has been on reducing the accumulation of greenhouse gases. That approach, however, requires broad international cooperation and, being expensive, has been hindered by free riding; so far, little action has been taken. An alternative approach is to counteract climate change by reducing the amount of solar radiation that strikes the Earth—"geoengineering." In contrast to emission reductions, this approach is inexpensive and can be undertaken by a single country, unilaterally. But geoengineering also has worrying consequences: it may harm some countries; it would not address ocean acidification; it would pose new risks. The fundamental challenge posed by this new technology is not free riding but governance: who should decide if and under what circumstances geoengineering should be used?

Barreto de Castro, L. A. (2010). "Climatic changes: what if the global increase of CO_2 emissions cannot be kept under control?" Brazilian Journal of Medical and Biological Research **43**: 230-233 DOI: 10.1590/s0100-879x2010007500010

Open Access Article* Available at: http://www.scielo.br/pdf/bjmbr/v43n3/7949.pdf

Climatic changes threaten the planet. Most articles related to the subject present estimates of the disasters expected to occur, but few have proposed ways to deal with the impending menaces. One such threat is the global warming caused by the continuous increase in CO_2 emissions leading to rising ocean levels due to the increasing temperatures of the polar regions. This threat is assumed to eventually cause the death of hundreds of millions of people. We propose to desalinize ocean water as a means to reduce the rise of ocean levels and to use this water for populations that need good quality potable water, precisely in the poorest regions of the planet. Technology is available in many countries to provide desalinated water at a justifiable cost considering the lives threatened both in coastal and desertified areas.

Barry, J. P., K. R. Buck, et al. (2004). "Effects of Direct Ocean CO_2 Injection on Deep-Sea Meiofauna." Journal of Oceanography **60**: 759-766 DOI: 10.1007/s10872-004-5768-8

Available at: http://www.springerlink.com/content/t153708141867p52/

Purposeful deep-sea carbon dioxide sequestration by direct injection of liquid CO_2 into the deep waters of the ocean has the potential to mitigate the rapid rise in atmospheric levels of greenhouse gases. One issue of concern for this carbon sequestration option is the impact of changes in seawater chemistry caused by CO_2 injection on deep-sea ecosystems. The effects of deep-sea carbon dioxide injection on in faunal deep- sea organisms were evaluated during a field experiment in 3600 m depth off California, in which liquid CO_2 was released on the seafloor. Exposure to the dissolution plume emanating from the liquid CO_2 resulted in high rates of mortality for flagellates, amoebae, and nematodes inhabiting sediments in close proximity to sites of CO_2 release. Results from this study indicate that large changes in seawater chemistry (i.e. pH reductions of ~0.5–1.0 pH units) near CO_2 release sites will cause high mortality rates for nearby in faunal deep-sea communities.

Beaugrand, G., M. Edwards, et al. (2010). "Marine biodiversity , ecosystem functioning , and carbon cycles." Proceedings of the National Academy of Sciences of the United States of America **107**: 10120-10124 DOI: 10.1073/pnas.0913855107/-/DCSupplemental.www.pnas.org/cgi/doi/10.1073/pnas.0913855107

Open Access Article* Available at: http://www.pnas.org/content/107/22/10120.full

Although recent studies suggest that climate change may substantially accelerate the rate of species loss in the biosphere, only a few studies have focused on the potential consequences of a spatial reorganization of biodiversity with global warming. Here, we show a pronounced latitudinal increase in phytoplanktonic and zooplanktonic biodiversity in the extratropical North Atlantic Ocean in recent decades.We also show that this rise in biodiversity paralleled a decrease in the mean size of zooplanktonic copepods and that the reorganization of the planktonic ecosystem toward dominance by smaller organisms may influence the networks in which carbon flows, with negative effects on the downward biological carbon pump and demersal Atlantic cod (*Gadus morhua*). Our study suggests that, contrary to the usual interpretation of increasing biodiversity being a positive emergent property promoting the stability/resilience of ecosystems, the parallel decrease in sizes of planktonic organisms could be viewed in the North Atlantic as reducing some of the services provided by marine ecosystems to humans.

Beaugrand, G., P. C. Reid, et al. (2002). "Reorganization of North Atlantic marine copepod biodiversity and climate." Science **296**: 1692-1694 DOI: 10.1126/science.1071329
Available at: http://www.sciencemag.org/content/296/5573/1692.short

We provide evidence of large-scale changes in the biogeography of calanoid copepod crustaceans in the eastern North Atlantic Ocean and European shelf seas. We demonstrate that strong biogeographical shifts in all copepod assemblages have occurred with a northward extension of more than 10 degrees latitude of warm-water species associated with a decrease in the number of colder-water species. These biogeographical shifts are in agreement with recent changes in the spatial distribution and phenology detected for many taxonomic groups in terrestrial European ecosystems and are related to both the increasing trend in Northern Hemisphere temperature and the North Atlantic Oscillation.

Berkes, F. (2008). Sacred Ecology. New York, Routledge.

Berkes, F., J. Colding, et al. (2004). Navigating Social-Ecological Systems – Building Resilience for Complexity and Change. Cambridge, Cambridge University Press.

Bertram, C. (2011). The Potential of Ocean Iron Fertilization as an Option for Mitigating Climate Change, In: Emissions Trading. Berlin, Heidelberg, Springer Berlin Heidelberg.
Available at: http://www.springerlink.com/index/10.1007/978-3-642-20592-7

Ocean iron fertilization is currently being discussed as one measure that could contribute to climate change mitigation by stimulating the growth of phytoplankton in certain parts of the ocean and enhancing oceanic CO2 uptake. Its implementation is greatly debated however and its mitigation potential has not yet been explored well. At present, it is still not possible to use carbon offsets generated through iron fertilization projects for complying with the Kyoto Protocol as trading these offsets is currently only possible on voluntary carbon markets. Company interests in such a commercial use of ocean iron fertilization do however already exist. Consequently, there is a need to explore the potential of ocean iron fertilization as a climate change mitigation option as well as regulatory issues connected with its implementation. This article combines these two aims by first examining the scientific background, quantitative potential, side effects and costs of ocean iron fertilization. In a second step, regulatory aspects such as its legal status and open access issues are reviewed. Moreover, the chapter analyses how the regulations for afforestation and reforestation activities within the framework of the Kyoto Clean Development Mechanism (CDM) could be applied to ocean iron fertilization. The main findings of this chapter are that the quantitative potential of ocean iron fertilization is limited, that potential adverse side effects are severe, and that its costs are higher than it was initially hoped. Moreover, the legal status of ocean iron fertilization is currently not well defined, open access might cause inefficiencies, and the CDM regulations could not be easily applied to ocean iron fertilization.

Bertram, C. and K. P. Brief (2009). "Kiel Policy Brief Ocean Iron Fertilization : An Option for Mitigating Climate Change ?" Marine Ecology
Open Access Article* Available at: www.ifw-kiel.de/.../kiel-policy-brief/kiel_policy_brief_3.pdf

Betts, R. A. (2000). "Offset of the potential carbon sink from boreal forestation by decreases in surface albedo." Nature **408**: 187-190 DOI: 10.1038/35041545
Available at: http://www.nature.com/nature/journal/v408/n6809/abs/408187a0.html

Carbon uptake by forestation is one method proposed to reduce net carbon dioxide emissions to the atmosphere and so limit the radiative forcing of climate change. But the overall impact of forestation on climate will also depend on other effects associated with the creation of new forests. In particular, the albedo of a forested landscape is generally lower than that of cultivated land, especially when snow is lying, and decreasing albedo exerts a positive radiative forcing on climate. Here I simulate the radiative forcings associated with changes in surface albedo as a result of forestation in temperate and boreal forest areas, and translate these forcings into equivalent changes in local carbon stock for comparison with estimated carbon sequestration potentials. I suggest that in many boreal forest areas, the positive forcing induced by decreases in albedo can offset the negative forcing that is expected from carbon sequestration. Some high-latitude forestation activities may therefore increase climate change, rather than mitigating it as intended.

Betts, R. A., M. Collins, et al. (2011). "When could global warming reach 4◦C?" Philosophical Transactions of the Royal Society A **369**: 67-84 DOI: 10.1098/rsta.2010.0292

Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/369/1934/67.full

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) assessed a range of scenarios of future greenhouse-gas emissions without policies to specifically reduce emissions, and concluded that these would lead to an increase in global mean temperatures of between 1.6°C and 6.9°C by the end of the twenty-first century, relative to pre-industrial. While much political attention is focused on the potential for global warming of 2°C relative to pre-industrial, the AR4 projections clearly suggest that much greater levels of warming are possible by the end of the twenty-first century in the absence of mitigation. The centre of the range of AR4-projected global warming was approximately 4°C. The higher end of the projected warming was associated with the higher emissions scenarios and models, which included stronger carbon-cycle feedbacks. The highest emissions scenario considered in the AR4 (scenario A1FI) was not examined with complex general circulation models (GCMs) in the AR4, and similarly the uncertainties in climate-carbon-cycle feedbacks were not included in the main set of GCMs. Consequently, the projections of warming for A1FI and/or with different strengths of carbon-cycle feedbacks are often not included in a wider discussion of the AR4 conclusions. While it is still too early to say whether any particular scenario is being tracked by current emissions, A1FI is considered to be as plausible as other non-mitigation scenarios and cannot be ruled out. (A1FI is a part of the A1 family of scenarios, with 'FI' standing for 'fossil intensive'. This is sometimes erroneously written as A1F1, with number 1 instead of letter I.) This paper presents simulations of climate change with an ensemble of GCMs driven by the A1FI scenario, and also assesses the implications of carbon-cycle feedbacks for the climate-change projections. Using these GCM projections along with simple climate-model projections, including uncertainties in carbon-cycle feedbacks, and also comparing against other model projections from the IPCC, our best estimate is that the A1FI emissions scenario would lead to a warming of 4°C relative to pre-industrial during the 2070s. If carbon-cycle feedbacks are stronger, which appears less likely but still credible, then 4°C warming could be reached by the early 2060s in projections that are consistent with the IPCC's 'likely range'.

Bewick, R., C. Lucking, et al. (2011) Geo-engineering Using Dust Grains in Heliotropic Elliptical Orbits, In: 62nd International Astronautical Congress 2011, Cape Town, Strathprints Institutional Repository.

Open Access Article* Available at:

http://strathprints.strath.ac.uk/33361/1/Bewick_R_et_al_Pure_Geo_engineering_using_dust_grains_in_heliotropic_elliptical_orbits_Oct_2011.pdf

This paper examines the concept of a Saturn-like Earth ring comprised of dust grains to offset global warming. A new family of non-Keplerian periodic orbits, under the effects of solar radiation pressure and the Earth’s oblateness J2 perturbation, is selected to increase the lifetime of the passive cloud of particles and, thus, increase the efficiency of this geo-engineering strategy. An analytical model is used to predict the evolution of the dust due to solar-radiation pressure and the J2 effect. The attenuation of the solar radiation can then be calculated from the ring model. In comparison to circular orbits, eccentric orbits yield a more stable environment for small grain sizes and therefore achieve higher efficiencies when the orbital decay of the material is considered. Moreover, the special orbital dynamics experienced by high area-to-mass ratio objects, influenced by solar radiation pressure and the J2 effect, ensure the ring will maintain a permanent heliotropic shape, with dust spending the largest portion of time on the Sun facing side. It is envisaged that small dust grains can be released with an initial Δv to enter an eccentric orbit with Sun-facing apogee. Finally, an estimate of 5.94x1011 kg is computed as the total mass required to offset the effects of global warming.

Bewick, R., J. P. Sanchez, et al. (2010) An L1 positioned dust cloud as an effective method of space-based

geoengineering, In: International Astronautical Congress, IAC 2010,.Prague, Czech Republic.
Open Access Article* Available at: http://strathprints.strath.ac.uk/27439/

In this paper a method of geoengineering is proposed involving clouds of dust placed in the vicinity of the L1 point as an alternative to the use of thin film reflectors. The aim of this scheme is to reduce the manufacturing requirement for space-based geoengineering. It has been concluded that the mass requirement for a cloud placed at the classical L1 point, to create an average solar insolation reduction of 1.7%, is 2.93x109 kg yr-1 whilst a cloud placed at a displaced equilibrium point created by the inclusion of the effect of solar radiation pressure is 8.87x108 kg yr-1. These mass ejection rates are considerably less than the mass required in other unprocessed dust cloud methods proposed and, for a geoengineering period of 10 years, they are comparable to thin film reflector geoengineering requirements. It is envisaged that the required mass of dust can be extracted from captured near Earth asteroids, whilst stabilised in the required position using the impulse provided by solar collectors or mass drivers used to eject material from the asteroid surface.

Blackstock, J. J. and J. C. S. Long (2010). "The Politics of Geoengineering." Science **327**: 527-527
Available at: http://www.sciencemag.org/content/327/5965/527.short

Despite mounting evidence that severe climate change could emerge rapidly, the global reduction of carbon emissions remains alarmingly elusive (1, 2). As a result, concerned scientists are now asking whether geoengineering—the intentional, large-scale alteration of the climate system—might be able to limit climate change impacts. Recent prominent reviews have emphasized that such schemes are fraught with uncertainties and potential negative effects and, thus, cannot be a substitute for comprehensive mitigation (3, 4). But as unabated climate change could itself prove extremely risky, these reviews also recommend expanding geoengineering research. As such research is considered (5–7), a process for ensuring global transparency and cooperation is needed.

Blaustein, R. (2011). "Fertilizing the Seas with Iron." BioScience **61**: 840-840 DOI: 10.1525/bio.2011.61.10.21
Available at: http://www.jstor.org/stable/info/10.1525/bio.2011.61.10.21

Bodansky, D. (2011). Governing Climate Engineering: Scenarios for Analysis. The Harvard Project on Climate Agreements
Open Access Article* Available at: http://belfercenter.ksg.harvard.edu/files/bodansky-dp-47-nov-final.pdf

Geoengineering is a broad concept that encompasses a variety of large-scale, intentional, and "unnatural" technologies to control climate change, including both techniques to limit how much sunlight reaches the earth (usually referred to as "solar radiation management") as well techniques to remove carbon dioxide from the atmosphere ("carbon dioxide removal"). The potential of geoengineering to reverse global warming rapidly and cheaply makes it alluring to groups across the political spectrum, in particular, as a means of addressing rapid, catastrophic climate change. But geoengineering also poses significant risks, and raises the spectre of technology gone awry. This discussion paper for the Harvard Project on Climate Agreements reviews the various geoengineering approaches, analyzes their permissibility under existing international law, and explores the governance issues raised by four scenarios of particular concern: premature rejection, inadequate funding, unilateral action by an individual, and unilateral action by a single state or small group of states.

Boé, J., A. Hall, et al. (2009). "September sea-ice cover in the Arctic Ocean projected to vanish by 2100." Nature Geoscience **2**: 341-343 DOI: 10.1038/ngeo467
Available at: http://www.nature.com/ngeo/journal/v2/n5/abs/ngeo467.html

The Arctic climate is changing rapidly1. From 1979 to 2006, September sea-ice extent decreased by almost 25% or about 100,000km2 per year (ref. 2). In September 2007, Arctic sea-ice extent reached its lowest level since satellite observations began3 and in September 2008, sea-ice cover was still low. This development has raised concerns that the Arctic Ocean could be ice-free in late summer in only a few decades, with important economic and geopolitical implications. Unfortunately, most current climate models underestimate significantly the observed trend in Arctic sea- ice decline4, leading to doubts regarding their projections for the timing of ice-free conditions. Here we analyse the simulated trends in past sea-ice cover in 18 state-of-art-climate models and find a direct relationship between the simulated evolution of September sea-ice cover over the twenty-first century and the magnitude of past trends in sea-ice cover. Using this relationship together with observed trends, we project the evolution of September sea-ice cover over the twenty-first century. We find that under a scenario with medium future greenhouse-gas emissions, the Arctic Ocean will probably be ice-free in September before the end of the twenty-first century.

Bonan, G. B. (2008). "Forests and climate change: forcings, feedbacks, and the climate benefits of forests." Science **320**: 1444-1449 DOI: 10.1126/science.1155121

Available at: http://www.sciencemag.org/content/320/5882/1444.short

The world's forests influence climate through physical, chemical, and biological processes that affect planetary energetics, the hydrologic cycle, and atmospheric composition. These complex and nonlinear forest-atmosphere interactions can dampen or amplify anthropogenic climate change. Tropical, temperate, and boreal reforestation and afforestation attenuate global warming through carbon sequestration. Biogeophysical feedbacks can enhance or diminish this negative climate forcing. Tropical forests mitigate warming through evaporative cooling, but the low albedo of boreal forests is a positive climate forcing. The evaporative effect of temperate forests is unclear. The net climate forcing from these and other processes is not known. Forests are under tremendous pressure from global change. Interdisciplinary science that integrates knowledge of the many interacting climate services of forests with the impacts of global change is necessary to identify and understand as yet unexplored feedbacks in the Earth system and the potential of forests to mitigate climate change.

Bony, S. C. R. K. V. and et al. (2006). "How Well Do We Understand and Evaluate Climate Change Feedback Processes?" Journal of Climate: 3445-3482

Open Access Article* Available at: http://journals.ametsoc.org/doi/abs/10.1175/JCLI3819.1

Processes in the climate system that can either amplify or dampen the climate response to an external perturbation are referred to as climate feedbacks. Climate sensitivity estimates depend critically on radiative feedbacks associated with water vapor, lapse rate, clouds, snow, and sea ice, and global estimates of these feedbacks differ among general circulation models. By reviewing recent observational, numerical, and theoretical studies, this paper shows that there has been progress since the Third Assessment Report of the Intergovernmental Panel on Climate Change in (i) the understanding of the physical mechanisms involved in these feedbacks, (ii) the interpretation of intermodel differences in global estimates of these feedbacks, and (iii) the development of methodologies of evaluation of these feedbacks (or of some components) using observations. This suggests that continuing developments in climate feedback research will progressively help make it possible to constrain the GCMs' range of climate feedbacks and climate sensitivity through an ensemble of diagnostics based on physical understanding and observations.

Bopp, L., C. Le Quéré, et al. (2002). "Climate-induced oceanic oxygen fluxes: Implications for the contemporary carbon budget." Global Biogeochemical Cycles **16**: 1022-1022

Available at: http://www.agu.org/pubs/crossref/2002/2001GB001445.shtml

Atmospheric O_2 concentrations have been used to estimate the ocean and land sinks of fossil fuel CO_2. In previous work, it has been assumed that the oceans have no long-term influence on atmospheric O2. We address the validity of this assumption using model results and observations. Oceanic O_2 fluxes for the 1860–2100 period are simulated using a coupled climate model in which is nested an ocean biogeochemistry model. Simulated oceanic O_2 fluxes exhibit large interannual (±40 Tmol yr□1) and decadal (±13 Tmol yr□1) variability, as well as a net outgassing to the atmosphere caused by climate change (up to 125 Tmol yr□1 by 2100). Roughly one quarter of this outgassing is caused by warming of the ocean surface, and the remainder is caused by ocean stratification. The global oceanic O_2 and heat fluxes are strongly correlated for both the decadal variations and the climate trend. Using the observed heat fluxes and the modeled O_2 flux/heat flux relationship, we infer the contribution of the oceans to atmospheric O_2 and infer a correction to the partitioning of the ocean and land CO_2 sinks. After considering this correction, the ocean and land sinks are 1.8 ± 0.8 Pg C yr□1 and 0.3 ± 0.9 Pg C yr□1, respectively, for the 1980s (a correction of 0.1 from ocean to land) and are 2.3 ± 0.7 Pg C yr□1 and 1.2 ± 0.9 Pg C yr□1, respectively, in the 1990–1996 period (a correction of 0.5 from land to ocean). This correction reconciles the 1990s ocean sink estimated by the Intergovernmental Panel on Climate Change Third Assessment Report with ocean models.

Bothe, M. (2011). "Law of the Sea in Dialogue." Beiträge zum ausländischen öffentlichen Recht und Völkerrecht **221**: 31-45 DOI: 10.1007/978-3-642-15657-1

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/978-3-642-15657-1

The excessive man-made greenhouse effect that is generally supposed to bring about climate change in the form of global warming has a number of different reasons. There is a balance sheet of greenhouse gas emissions and of the sequestration of these gases by sinks. The Kyoto Protocol deals with this problem by selecting, in order to reduce the greenhouse gas concentration in the global atmosphere, a particular part of the problem, namely

emissions of greenhouse gases from the territory of the developed industrial States listed in Annex I to the UNFCCC and sinks which function due to measures taken by these States. These emissions and activities are a significant contribution to the problem of climate change, but not the only one.

Boucher, O., et al. (2008). "Implications of delayed actions in addressing carbon dioxide emission reduction in the context of geo-engineering." Climatic Change **92**: 261-273 DOI: 10.1007/s10584-008-9489-7

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-008-9489-7

Carbon dioxide emissions need to be reduced well below current emissions if atmospheric concentrations are to be stabilised at a level likely to avoid dangerous climate change. We investigate how delays in reducing CO_2 emissions affect stabilisation scenarios leading to overshooting of a target concentration pathway. We show that if geo-engineering alone is used to compensate for the delay in reducing CO_2 emissions, such an option needs to be sustained for centuries even though the period of overshooting emissions may only last for a few decades. If geo-engineering is used for a shorter period, it has to be associated with emission reductions significantly larger than those required to stabilise CO_2 without overshooting the target. In the presence of a strong climate–carbon cycle feedback the required emission reductions are even more drastic.

Bowen, F. (2011). "Carbon capture and storage as a corporate technology strategy challenge." Energy Policy **39**: 2256-2264 DOI: 10.1016/j.enpol.2011.01.016

Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421511000267

Latest estimates suggest that widespread deployment of carbon capture and storage (CCS) could account for up to one-fifth of the needed global reduction in CO_2 emissions by 2050. Governments are attempting to stimulate investments in CCS technology both directly through subsidizing demonstration projects, and indirectly through developing price incentives in carbon markets. Yet, corporate decision-makers are finding CCS investments challenging. Common explanations for delay in corporate CCS investments include operational concerns such as the high cost of capture technologies, technological uncertainties in integrated CCS systems and underdeveloped regulatory and liability regimes. In this paper, we place corporate CCS adoption decisions within a technology strategy perspective. We diagnose four underlying characteristics of the strategic CCS technology adoption decision that present unusual challenges for decision-makers: such investments are precautionary, sustaining, cumulative and situated. Understanding CCS as a corporate technology strategy challenge can help us move beyond the usual list of operational barriers to CCS and make public policy recommendations to help overcome them.

Boyero, L., R. G. Pearson, et al. (2011). "A global experiment suggests climate warming will not accelerate litter decomposition in streams but might reduce carbon sequestration." Ecology letters **14**: 289-294 DOI: 10.1111/j.1461-0248.2010.01578.x

Available at: http://www.ncbi.nlm.nih.gov/pubmed/21299824

The decomposition of plant litter is one of the most important ecosystem processes in the biosphere and is particularly sensitive to climate warming. Aquatic ecosystems are well suited to studying warming effects on decomposition because the otherwise confounding influence of moisture is constant. By using a latitudinal temperature gradient in an unprecedented global experiment in streams, we found that climate warming will likely hasten microbial litter decomposition and produce an equivalent decline in detritivore-mediated decomposition rates. As a result, overall decomposition rates should remain unchanged. Nevertheless, the process would be profoundly altered, because the shift in importance from detritivores to microbes in warm climates would likely increase $CO(_2)$ production and decrease the generation and sequestration of recalcitrant organic particles. In view of recent estimates showing that inland waters are a significant component of the global carbon cycle, this implies consequences for global biogeochemistry and a possible positive climate feedback.

Brooke, L. H. and S. W. H. Gayle (2011). Geoengineering: Direct Mitigation of Climate Warming. F. Princiotta. Dordrecht, Springer Netherlands. **38**.

Available at: http://www.springerlink.com/index/10.1007/978-90-481-3153-2

With the concentrations of atmospheric greenhouse gases (GHGs) rising to levels unprecedented in the current glacial epoch, the earth’s climate system appears to be rapidly shifting into a warmer regime. Many in the international science and policy communities fear that the fundamental changes in human behavior, and in the global economy, that will be required to meaningfully reduce GHG emissions in the very near term are unattainable. In the 1970s, discussion of “geoengineering,” a radical strategy for arresting climate change by intentional, direct manipulation of the Earth’s energy balance began to appear in the climate science literature.

With growing international concern about the pace of climate change, the scientific and public discourse on the feasibility of geoengineering has recently grown more sophisticated and more energetic. A wide array of potential geoengineering projects have been proposed, ranging from orbiting space mirrors to reduce solar flux to the construction of large networks of processors that directly remove carbon dioxide from the atmosphere. Simple estimates of costs exist, and some discussion of both the potentially negative and "co-beneficial" consequences of these projects can be found in the scientific literature. The critical, missing piece in the discussion of geoengineering as a strategy for managing climate is an integrated evaluation of the downstream costs-versus-benefits inter-comparing all available climate management options, including geoengineering. Our examination of the literature revealed a number of substantial gaps in the knowledge base required for such an evaluation. Therefore, to ensure that the decision framework arising from this analysis is well founded, a focused program of scientific research to fill those gaps is also essential. As with any sound engineering plan, international decisions on how to address human-induced climate warming must be founded on a thoughtful and well-informed analysis of all of the available options.

Burton, E., et al. (2011). "Accelerating Carbon Capture and Sequestration Projects: Analysis and Comparison of Policy Approaches." Energy Procedia **4**: 5778-5785 DOI: 10.1016/j.egypro.2011.02.574

Open Access Article* Available at: http://linkinghub.elsevier.com/retrieve/pii/S1876610211008538

Many states and countries have adopted or are in the process of crafting policies to enable geologic carbon sequestration projects. These efforts reflect the recognition that existing statutory and regulatory frameworks leave ambiguities or gaps that elevate project risk for private companies considering carbon sequestration projects, and/or are insufficient to address a government's mandate to protect the public interest. We have compared the various approaches that United States' state and federal governments have taken to provide regulatory frameworks to address carbon sequestration. A major purpose of our work is to inform the development of any future legislation in California, should it be deemed necessary to meet the goals of Assembly Bill 1925 (2006) to accelerate the adoption of cost-effective geologic sequestration strategies for the long-term management of industrial carbon dioxide in the state. Our analysis shows that diverse issues arecovered by adopted and proposed carbon capture and sequestration (CCS) legislation and that many of the new laws focus on defining regulatory frameworks for underground injection of CO_2, ambiguities in property issues, or assigning legal liability. While these approaches may enable the progress of early projects, future legislation requires a longer term and broader view that includes a quantified integration of CCS into a government's overall climate change mitigation strategy while considering potentially counterproductive impacts on CCS of other climate change mitigation strategies. Furthermore, legislation should be crafted in the context of a vision for CCS as an economically viable and widespread industry. In California, CCS is not included quantitatively as a strategy to reduce future greenhouse gas (GHG) emissions. In part, this reflects the focus of most state agencies on short term goals, such as the AB 32 goal to return California emissions to 1990 levels by 2020. It also reflects the lack of data necessary to predict how rapidly and to what degree CCS could be deployed to meet short or long term goals. The lack of timely consideration of CCS as a mitigation alternative, however, has the potential to lead, albeit unintentionally, to policies which may make CCS adoption less likely and more expensive in the long run. For example, consideration of the economic and other risks associated with CCS is presently a disincentive to adopt CCS if other alternatives, such as fuel switching, can meet legislated requirements to reduce carbon emissions. While an important function of new CCS legislation is enabling early projects, it must be kept in mind that applying the same laws or protocols in the future to a widespread CCS industry may result in business disincentives and compromise of the public interest in mitigating GHG emissions, particularly in cases where different stakeholders are responsible for capture, transport, and sequestration elements of a project. Protection of the public interest requires that monitoring and verification track the long term fate of pipelined CO_2 regardless of its end use in order to establish that climate change goals are being met. Legislative mandates that require CO_2 producers to verify carbon reductions via sequestration, and which are crafted under the assumption that CO_2 capture, transport and storage is linear and maintained under a single stewardship, may result in reducing the incentive to participate in the efficiencies of a collective transport and sequestration system.

Boyd, P. W. (2008). "Ranking geo-engineering schemes." Nature Geoscience **1**: 722-724 DOI: 10.1038/ngeo348

Available at: http://www.nature.com/ngeo/journal/v1/n11/full/ngeo348.html

Geo-engineering proposals for mitigating climate change continue to proliferate without being tested. It is time to select and assess the most promising ideas according to efficacy, cost, all aspects of risk and, importantly, their rate of mitigation.

Boyd, P. W. (2009). "Geopolitics of geoengineering (Letter to Ed.)." Nature Geoscience **2**: 812-812 DOI: 10.1038/ngeo710
Available at: http://www.nature.com/ngeo/journal/v2/n12/full/ngeo710.html
The report on geoengineering the climate by the Royal Society1 acknowledges that the deleterious impacts of climate change will be unevenly distributed across the planet. Similarly, the beneficial and detrimental effects of geoengineering will not be evenly spread.

Boyd, P. W. and S. C. Doney (2002). "Modelling regional responses by marine pelagic ecosystems to global climate change." Geophysical Research Letters **29**: 1-4 DOI: 10.1029/2001gl014130
Available at: http://www.agu.org/pubs/crossref/2002/2001GL014130.shtml
Current coupled ocean-atmosphere model (COAM) projections of future oceanic anthropogenic carbon uptake suggest reduced rates due to surface warming, enhanced stratification, and slowed thermohaline overturning. Such models rely on simple, bulk biogeochemical parameterisations, whereas recent ocean observations indicate that floristic shifts may be induced by climate variability, are widespread, complex, and directly impact biogeochemical cycles. We present a strategy to incorporate ecosystem function in COAM's and to evaluate the results in relation to region-specific ecosystem dynamics and interannual variability using a template of oceanic biogeographical provinces. Illustrative simulations for nitrogen fixers with an off- line multi-species, functional group model suggest significant changes by the end of this century in ecosystem structure, with some of the largest regional impacts caused by shifts in the areal extent of biomes.

Boyd, P. W. and M. J. Ellwood (2010). "The biogeochemical cycle of iron in the ocean." Nature Geoscience **3**: 675-682 DOI: 10.1038/ngeo964
Available at: http://www.nature.com/ngeo/journal/v3/n10/full/ngeo964.html
Advances in iron biogeochemistry have transformed our understanding of the oceanic iron cycle over the past three decades: multiple sources of iron to the ocean were discovered, including dust, coastal and shallow sediments, sea ice and hydrothermal fluids. This new iron is rapidly recycled in the upper ocean by a range of organisms; up to 50% of the total soluble iron pool is turned over weekly in this way in some ocean regions. For example, bacteria dissolve particulate iron and at the same time release compounds — iron-binding ligands — that complex with iron and therefore help to keep it in solution. Sinking particles, on the other hand, also scavenge iron from solution. The balance between these supply and removal processes determines the concentration of dissolved iron in the ocean. Whether this balance, and many other facets of the biogeochemical cycle, will change as the climate warms remains to be seen.

Boyd, P. W., T. Jickells, et al. (2007). "Mesoscale iron enrichment experiments 1993-2005: synthesis and future directions." Science **315**: 612-617 DOI: 10.1126/science.1131669
Available at: http://www.sciencemag.org/content/315/5812/612.short
Since the mid-1980s, our understanding of nutrient limitation of oceanic primary production has radically changed. Mesoscale iron addition experiments (FeAXs) have unequivocally shown that iron supply limits production in one-third of the world ocean, where surface macronutrient concentrations are perennially high. The findings of these 12 FeAXs also reveal that iron supply exerts controls on the dynamics of plankton blooms, which in turn affect the biogeochemical cycles of carbon, nitrogen, silicon, and sulfur and ultimately influence the Earth climate system. However, extrapolation of the key results of FeAXs to regional and seasonal scales in some cases is limited because of differing modes of iron supply in FeAXs and in the modern and paleo-oceans. New research directions include quantification of the coupling of oceanic iron and carbon biogeochemistry.

Boyd, P. W., C. S. Law, et al. (2004). "The decline and fate of an iron-induced subarctic phytoplankton bloom." Nature **428**: 549-553 DOI: 10.1038/nature02437
Available at: http://www.ncbi.nlm.nih.gov/pubmed/15058302
Iron supply has a key role in stimulating phytoplankton blooms in high-nitrate low-chlorophyll oceanic waters. However, the fate of the carbon fixed by these blooms, and how efficiently it is exported into the ocean's interior, remains largely unknown. Here we report on the decline and fate of an iron-stimulated diatom bloom in the Gulf of Alaska. The bloom terminated on day 18, following the depletion of iron and then silicic acid, after which mixed-layer particulate organic carbon (POC) concentrations declined over six days. Increased particulate silica export via sinking diatoms was recorded in sediment traps at depths between 50 and 125 m from day 21, yet increased POC export was not evident until day 24. Only a small proportion of the mixed-layer POC was intercepted by the traps, with more than half of the mixed-layer POC deficit attributable to bacterial

remineralization and mesozooplankton grazing. The depletion of silicic acid and the inefficient transfer of iron-increased POC below the permanent thermocline have major implications both for the biogeochemical interpretation of times of greater iron supply in the geological past, and also for proposed geo-engineering schemes to increase oceanic carbon sequestration.

Boyd, P. W., D. S. Mackie, et al. (2010). "Aerosol iron deposition to the surface ocean — Modes of iron supply and biological responses." Marine Chemistry **120**: 128-143 DOI: 10.1016/j.marchem.2009.01.008
Available at: http://www.sciencedirect.com/science/article/pii/S0304420309000103

In the last two decades the role of aerosol iron supply to the ocean has received growing attention. Research has mainly focused on three themes—how much iron is supplied to the ocean from dust; where this aerosol iron is deposited (depositional models); and modelling of the biogeochemical impact of iron supply to the ocean in the past, present and future. Here, we investigate the relationship between modes of iron supply (mechanisms, dissolution rate and timescales) to the upper ocean and the subsequent biological responses in the present day. The reported solubility of iron from dust ranges from0.001–90%, and this variability appears to be linked to both aerosol properties and leaching schemes employed. Consequently, biogeochemical modelling studies have used a wide range of iron dissolution rates (1–12%) and have reported a broad suite of biogeochemical responses. Re-examination of evidence, from ocean observations, of enhanced biological and/or biogeochemical response to aerosol iron supply in the modern ocean suggests that much of it is flawed, and that there are only a few cases in which there is a causative link between dust supply and biological response. The resulting small size of this dataset is due to a wide range of confounding factors including seasonality of environmental factors controlling phytoplankton production (light, silicic acid, phosphate, iron), and the elemental stoichiometry of the aerosols (iron and other nutrients) during dissolution. Thus, the main impact of aerosol iron supply appears to be an initial rapid release of iron, followed by a slow and sustained release of iron during its mixed layer residence time, which may result in small increases in the dissolved iron mixed-layer inventory. The implications of such a mode of iron release from aerosol dust are explored using a simple dust/biota assessment test for both contemporary and paleoceanographic case-studies. We conclude that dust deposition can easily be mistakenly attributed as a primary cause of enhanced biological activity and that, due to the slow dissolution of iron, dust-mediated phytoplankton blooms are probably rare in the modern ocean.

Brooker, R. W., J. M. J. Travis, et al. (2007). "Modelling species' range shifts in a changing climate: the impacts of biotic interactions, dispersal distance and the rate of climate change." Journal of theoretical biology **245**: 59-65 DOI: 10.1016/j.jtbi.2006.09.033
Available at: http://www.sciencedirect.com/science/article/pii/S0022519306004577

There is an urgent need for accurate prediction of climate change impacts on species ranges. Current reliance on bioclimatic envelope approaches ignores important biological processes such as interactions and dispersal. Although much debated, it is unclear how such processes might influence range shifting. Using individual-based modelling we show that interspecific interactions and dispersal ability interact with the rate of climate change to determine range-shifting dynamics in a simulated community with two growth forms--mutualists and competitors. Interactions determine spatial arrangements of species prior to the onset of rapid climate change. These lead to space-occupancy effects that limit the rate of expansion of the fast-growing competitors but which can be overcome by increased long-distance dispersal. As the rate of climate change increases, lower levels of long-distance dispersal can drive the mutualists to extinction, demonstrating the potential for subtle process balances, non-linear dynamics and abrupt changes from species coexistence to species loss during climate change.

Brovkin, V., V. Petoukhov, et al. (2008). "Geoengineering climate by stratospheric sulfur injections: Earth system vulnerability to technological failure." Climatic Change **92**: 243-259 DOI: 10.1007/s10584-008-9490-1
Open Access Article* Available at: http://www.springerlink.com/content/271270616u1x1666/

We use a coupled climate–carbon cycle model of intermediate complexity to investigate scenarios of stratospheric sulfur injections as ameasure to compensate for CO2-induced global warming. The baseline scenario includes the burning of 5,000 GtC of fossil fuels. A full compensation of CO2-induced warming requires a load of about 13 MtS in the stratosphere at the peak of atmospheric CO2 concentration. Keeping global warming below 2◦C reduces this load to 9 MtS. Compensation of CO2 forcing by stratospheric aerosols leads to a global reduction in precipitation, warmer winters in the high northern latitudes and cooler summers over northern hemisphere landmasses. The average surface ocean pH decreases by 0.7, reducing the calcifying ability of marine organisms. Because of the millennial persistence of the fossil fuel CO_2 in the atmosphere, high levels of stratospheric aerosol loading would have to continue for thousands of years until CO_2 was removed from the atmosphere. A

termination of stratospheric aerosol loading results in abrupt global warming of up to 5◦C within several decades, a vulnerability of the Earth system to technological failure.

Brown, L. R. (2011). World on the Edge. How to Prevent Environmental and Economic Collapse, Earth Policy Institute.
Open Access Book* Available at: http://www.earth-policy.org/books/wote
We are facing issues of near-overwhelming complexity and unprecedented urgency. Our challenge is to think globally and develop policies to counteract environmental decline and economic collapse. The question is: Can we change direction before we go over the edge?

Brownsort, P., S. Carter, et al. (2009). An Assessment of the Benefits and Issues Associated with the Application of Biochar to Soil: A report commissioned by the United Kingdom Department for Environment , Food and Rural Affairs , and Department of Energy and Climate Change, UK Biochar Research Centre.
Open Access Article* Available at: http://www.biochar.org.uk/abstract.php?id=25

Brush, S. B. (2001). "Genetically Modified Organisms in Peasant Farming: Social Impact and Equity." Indiana Journal of Global Legal Studies **9**: 135-162
Available at: http://www.jstor.org/pss/20643823

Bunzl, M. (2009). "Researching geoengineering: should not or could not?" Environmental Research Letters **4**: 045104-045104 DOI: 10.1088/1748-9326/4/4/045104
Open Access Article* Available at: http://iopscience.iop.org/1748-9326/4/4/045104
Is geoengineering a feasible, sensible, or practical stopgap measure for us to have in our arsenal of potential responses to global warming? We do not know at this point and so it seems hardly contentious to claim that we should find out. I evaluate a moral argument that we should not try to find out and a methodological argument that even if we try, we cannot find out. I reject the first but end up as agnostic on the second, outlining the burden of proof that it creates for proponents of geoengineering research.

Cairns, J. (2010). "Co-evolving with the Present Biosphere." Asian J. Exp. Sci. **24**: 185-188
Open Access Article* Available at: http://www.johncairns.net/Papers/Co-evolving with the Present Biosphere.pdf
Lovelock (2009) hopes that a few million Homo sapiens will survive the climate changes and will find some “ecological lifeboats” to preserve civilization: “As part of Gaia, our presence begins to make the planet sentient. We should be proud that we could be part of this huge step, one that may help Gaia survive as the sun continues its slow but ineluctable increase of heat output, making the solar system an increasingly hostile future environment.” Lovelock (2009) is clearly aware of the difficulties of developing a mutualistic relationship between humans and Gaia: “There is no set of rules or prescription for living with Gaia, there are only consequences.” Gaia is a unifying concept in a sea of highly specialized information. Specialized information is essential, but is most effectively integrated within a particular context.

Caldeira, K. (2009). Geoengineering : Assessing the Implications of Large-Scale Climate Intervention. Stanford CA, USA.
Open Access Article* Available at: www.agci.org/docs/Caldeira_Testimony.pdf

Caldeira, K. (2005). "Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean." Journal of Geophysical Research **110**: 1-12 DOI: 10.1029/2004jc002671
Available at: http://www.agu.org/pubs/crossref/2005/2004JC002671.shtml
We present ocean chemistry calculations based on ocean general circulation model simulations of atmospheric CO_2 emission, stabilization of atmospheric CO_2 content, and stabilization of atmospheric CO_2 achieved in total or in part by injection of CO_2 to the deep ocean interior. Our goal is to provide first-order results from various CO_2 pathways, allowing correspondence with studies of marine biological effects of added CO_2. Parts of the Southern Ocean become undersaturated with respect to aragonite under the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (SRES) A1, A2, B1, and B2 emission pathways and the WRE pathways that stabilize CO_2 at 650 ppm or above. Cumulative atmospheric emission of 5000 Pg C produces aragonite undersaturation in most of the surface ocean; 10,000 Pg C also produces calcite undersaturation in most of the surface ocean. Stabilization of atmospheric CO_2 at 450 ppm produces both calcite and aragonite undersaturation in most of the deep ocean. The simulated SRES pathways produce global surface pH reductions of □0.3–0.5 units by year 2100. Approximately this same reduction is produced by WRE650 and WRE1000 stabilization scenarios

and by the 1250 Pg C emission scenario by year 2300. Atmospheric emissions of 5000 Pg C and 20,000 Pg C produce global surface pH reductions of 0.8 and 1.4 units, respectively, by year 2300. Simulations of deep ocean CO2 injection as an alternative to atmospheric release show greater chemical impact on the deep ocean as the price for having less impact on the surface ocean and climate. Changes in ocean chemistry of the magnitude shown are likely to be biologically significant.

Caldeira, K. and G. H. Rau (2000). "Accelerating carbonate dissolution to sequester carbon dioxide in the ocean: Geochemical implications." Geophysical Research Letters **27**: 225-228
Available at: http://www.agu.org/journals/ABS/2000/1999GL002364.shtml

Various methods have been proposed for mitigating release of anthropogenic CO_2 to the atmosphere, including deep-sea injection of CO_2 captured from fossil-fuel fired power plants. Here, we use a schematic model of ocean chemistry and transport to analyze the geochemical consequences of a new method for separating carbon dioxide from a waste gas stream and sequestering it in the ocean. This method involves reacting CO_2-rich power-plant gases with seawater to produce a carbonic acid solution which in turn is reacted on site with carbonate mineral (e.g., limestone) to form Ca2+ and bicarbonate in solution, which can then be released and diluted in the ocean. Such a process is similar to carbonate weathering and dissolution which would have otherwise occurred naturally, but over many millennia. Relative to atmospheric release or direct ocean CO_2 injection, this method would greatly expand the capacity of the ocean to store anthropogenic carbon while minimizing environmental impacts of this carbon on ocean biota. This carbonate-dissolution technique may be more cost-effective and less environmentally harmful, and than previously proposed CO_2 capture and sequestration techniques.

Caldeira, K. and M. E. Wickett (2003). "Anthropogenic carbon and ocean pH." Nature **425**: 365-365
Available at: http://www.nature.com/nature/journal/v425/n6956/abs/425365a.html

Most carbon dioxide released into the atmosphere as a result of the burning of fossil fuels will eventually be absorbed by the ocean1, with potentially adverse consequences for marine biota. Here we quantify the changes in ocean pH that may result from this continued release of CO_2 and compare these with pH changes estimated from geological and historical records. We find that oceanic absorption of CO_2 from fossil fuels may result in larger pH changes over the next several centuries than any inferred from the geological record of the past 300 million years, with the possible exception of those resulting from rare, extreme events such as bolide impacts or catastrophic methane hydrate degassing.

Caldeira, K. and L. Wood (2008). "Global and Arctic climate engineering: numerical model studies." Philosophical Transactions of the Royal Society A **366**: 4039-4056 DOI: 10.1098/rsta.2008.0132
Available at: http://www.ncbi.nlm.nih.gov/pubmed/18757275

We perform numerical simulations of the atmosphere, sea ice and upper ocean to examine possible effects of diminishing incoming solar radiation, insolation, on the climate system. We simulate both global and Arctic climate engineering in idealized scenarios in which insolation is diminished above the top of the atmosphere. We consider the Arctic scenarios because climate change is manifesting most strongly there. Our results indicate that, while such simple insolation modulation is unlikely to perfectly reverse the effects of greenhouse gas warming, over a broad range of measures considering both temperature and water, an engineered high CO_2 climate can be made much more similar to the low CO_2 climate than would be a high CO_2 climate in the absence of such engineering. At high latitudes, there is less sunlight deflected per unit albedo change but climate system feedbacks operate more powerfully there. These two effects largely cancel each other, making the global mean temperature response per unit top-of-atmosphere albedo change relatively insensitive to latitude. Implementing insolation modulation appears to be feasible.

Cao, L. and K. Caldeira (2008). "Atmospheric CO_2 stabilization and ocean acidification." Geophysical Research Letters **35**: 1-5 DOI: 10.1029/2008gl035072
Available at: http://www.agu.org/pubs/crossref/2008/2008GL035072.shtml

We use a coupled climate/carbon-cycle model to examine the consequences of stabilizing atmospheric CO_2 at different levels for ocean chemistry. Our simulations show the potential for major damage to at least some ocean ecosystems at atmospheric CO_2 stabilization levels as low as 450 ppm. Before the industrial revolution, more than 98% of corals reefs were surrounded by waters that were >3.5 times saturated with respect to their skeleton materials (aragonite). If atmospheric CO_2 is stabilized at 450 ppm only 8% of existing coral reefs will be surrounded by water with this saturation level. Also at this CO_2 level 7% of the ocean South of 60□S will become undersaturated with respect to aragonite, and parts of the high latitude ocean will experience a decrease in pH by

more than 0.2 units. Results presented here provide an independent and additional basis for choosing targets of atmospheric CO_2 stabilization levels.

Cao, L. and K. Caldeira (2010). "Can ocean iron fertilization mitigate ocean acidification?" Climatic Change **99**: 303-311 DOI: 10.1007/s10584-010-9799-4

Open Access Article* Available at: http://www.springerlink.com/content/2r37548186250768/

Ocean iron fertilization has been proposed as a method to mitigate an- thropogenic climate change, and there is continued commercial interest in using iron fertilization to generate carbon credits. It has been further speculated that ocean iron fertilization could help mitigate ocean acidification. Here, using a global ocean car- bon cyclemodel, we performed idealized ocean iron fertilization simulations to place an upper bound on the effect of iron fertilization on atmospheric CO_2 and ocean acidification. Under the IPCC A2 CO2 emission scenario, at year 2100 the model simulates an atmospheric CO_2 concentration of 965ppmwith the mean surface ocean pH 0.44 units less than its pre-industrial value of 8.18. A globally sustained ocean iron fertilization could not diminish CO2 concentrations below 833 ppm or reduce the mean surface ocean pH change to less than 0.38 units. This maximum of 0.06 unit mitigation in surface pH change by the end of this century is achieved at the cost of storing more anthropogenic CO_2 in the ocean interior, furthering acidifying the deep- ocean. If the amount of net carbon storage in the deep ocean by iron fertilization produces an equivalent amount of emission credits, ocean iron fertilization further acidifies the deep ocean without conferring any chemical benefit to the surface ocean.

Chan, F., J. A. Barth, et al. (2008). "Emergence of anoxia in the California current large marine ecosystem." Science **319**: 920-920 DOI: 10.1126/science.1149016

Available at: http://www.sciencemag.org/content/319/5865/920.short

Eastern boundary current systems are among the world's most productive large marine ecosystems. Because upwelling currents transport nutrient-rich but oxygen-depleted water onto shallow seas, large expanses of productive continental shelves can be vulnerable to the risk of extreme low-oxygen events. Here, we report the novel rise of water-column shelf anoxia in the northern California Current system, a large marine ecosystem with no previous record of such extreme oxygen deficits. The expansion of anoxia highlights the potential for rapid and discontinuous ecosystem change in productive coastal systems that sustain a major portion of the world's fisheries.

Chen, I. C., J. K. Hill, et al. (2011). "Rapid Range Shifts of Species Associated with High Levels of Climate Warming." Science **333**: 1024-1026 DOI: 10.1126/science.1206432

Available at: http://www.sciencemag.org/content/333/6045/1024.short

The distributions of many terrestrial organisms are currently shifting in latitude or elevation in response to changing climate. Using a meta-analysis, we estimated that the distributions of species have recently shifted to higher elevations at a median rate of 11.0 meters per decade, and to higher latitudes at a median rate of 16.9 kilometers per decade. These rates are approximately two and three times faster than previously reported. The distances moved by species are greatest in studies showing the highest levels of warming, with average latitudinal shifts being generally sufficient to track temperature changes. However, individual species vary greatly in their rates of change, suggesting that the range shift of each species depends on multiple internal species traits and external drivers of change. Rapid average shifts derive from a wide diversity of responses by individual species.

Cheng, C.-H., J. Lehmann, et al. (2008). "Stability of black carbon in soils across a climatic gradient." Journal of Geophysical Research **113**: G02027-G02027 DOI: 10.1029/2007jg000642

Available at: http://www.agu.org/pubs/crossref/2008/2007JG000642.shtml

The recalcitrant properties of black carbon (BC) grant it to be a significant pool of stable organic C (OC) in soils. Up to now, however, the longevity of BC under different climates is still unclear. In this study, we used BC samples from historical charcoal blast furnace sites to examine the stability of BC across a climatic gradient of mean annual temperatures (MAT) from 3.9 to 17.2□C. The results showed that OC concentration and OC storage in the BC-containing soils at a soil depth of 0–0.2 m were 9.0 and 4.7 times higher than those in adjacent soils, respectively. Organic C in the BC-containing soils was more stable, with a significantly lower amount of the labile OC fraction (4.4 mg g□1 OC versus 27.5 mg g□1 OC) and longer half-life of the recalcitrant OC fraction (59 years versus 9 years) than the adjacent soils determined by incubation experiments. The stability of BC was primarily due to its inherently recalcitrant chemical composition as suggested by short-term incubation and solid state 13C nuclear magnetic resonance spectra of isolated BC particles. A significant negative relationship between OC storage and MAT further indicated that OC storage was decreased with warmer climate. However, the lack of

a relationship between MAT and BC mineralization suggested that the stability of the remaining BC was similar between sites with very different MAT. Despite the fact that warming or cooling result in immediate consequences for BC stocks, it may have little impact on the stability of remaining BC over the period studied.

Chevin, L.-M., R. Lande, et al. (2010). "Adaptation, plasticity, and extinction in a changing environment: towards a predictive theory." PLoS biology **8**: e1000357-e1000357 DOI: 10.1371/journal.pbio.1000357

Open Access Article* Available at:

http://www.plosbiology.org/article/info%3Adoi%2F10.1371%2Fjournal.pbio.1000357

Many species are experiencing sustained environmental change mainly due to human activities. The unusual rate and extent of anthropogenic alterations of the environment may exceed the capacity of developmental, genetic, and demographic mechanisms that populations have evolved to deal with environmental change. To begin to understand the limits to population persistence, we present a simple evolutionary model for the critical rate of environmental change beyond which a population must decline and go extinct. We use this model to highlight the major determinants of extinction risk in a changing environment, and identify research needs for improved predictions based on projected changes in environmental variables. Two key parameters relating the environment to population biology have not yet received sufficient attention. Phenotypic plasticity, the direct influence of environment on the development of individual phenotypes, is increasingly considered an important component of phenotypic change in the wild and should be incorporated in models of population persistence. Environmental sensitivity of selection, the change in the optimum phenotype with the environment, still crucially needs empirical assessment. We use environmental tolerance curves and other examples of ecological and evolutionary responses to climate change to illustrate how these mechanistic approaches can be developed for predictive purposes.

Ciais, P., M. Reichstein, et al. (2005). "Europe-wide reduction in primary productivity caused by the heat and drought in 2003." Nature **437**: 529-533 DOI: 10.1038/nature03972

Available at: http://www.nature.com/nature/journal/v437/n7058/abs/nature03972.html

Future climate warming is expected to enhance plant growth in temperate ecosystems and to increase carbon sequestration. But although severe regional heat waves may become more frequent in a changing climate, their impact on terrestrial carbon cycling is unclear. Here we report measurements of ecosystem carbon dioxide fluxes, remotely sensed radiation absorbed by plants, and country-level crop yields taken during the European heat wave in 2003. We use a terrestrial biosphere simulation model to assess continental-scale changes in primary productivity during 2003, and their consequences for the net carbon balance. We estimate a 30 per cent reduction in gross primary productivity over Europe, which resulted in a strong anomalous net source of carbon dioxide (0.5 Pg C yr(-1)) to the atmosphere and reversed the effect of four years of net ecosystem carbon sequestration. Our results suggest that productivity reduction in eastern and western Europe can be explained by rainfall deficit and extreme summer heat, respectively. We also find that ecosystem respiration decreased together with gross primary productivity, rather than accelerating with the temperature rise. Model results, corroborated by historical records of crop yields, suggest that such a reduction in Europe's primary productivity is unprecedented during the last century. An increase in future drought events could turn temperate ecosystems into carbon sources, contributing to positive carbon-climate feedbacks already anticipated in the tropics and at high latitudes.

Cicerone, R. J. (2006). "Geoengineering: Encouraging Research and Overseeing Implementation." Climatic Change **77**: 221-226 DOI: 10.1007/s10584-006-9102-x

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-006-9102-x

Ideas on how to engineer Earth’s climate, or to modify the environment on large scales to counter human impacts, do not enjoy broad support from scientists. Refereed publications that deal with such ideas are not numerous nor are they cited widely. Paul Crutzen (2006) analyzes the idea of intentionally injecting sulfur into the stratosphere, to enhance the albedo of Earth, so as to slow the warming of the planet due to greenhouse gases. He notes that such an intervention might become necessary unless the world becomes more successful in limiting greenhouse gas emissions and/or if global warming should proceed faster than currently anticipated partly due to cleaning the lower atmosphere of sulfur pollution (Andreae et al., 2005; Charlson et al., 1991). I am aware that various individuals have opposed the publication of Crutzen’s paper, even after peer review and revisions, for various and sincere reasons that are not wholly scientific. Here, I write in support of his call for research on geo- engineering and propose a framework for future progress in which supporting and opposing viewpoints can be heard and incorporated. I also propose that research on geoengineering be considered separately from actual implementation, and I suggest a path in that direction.

Cooley, S. R. and S. C. Doney (2009). "Anticipating ocean acidification's economic consequences for commercial fisheries." Environmental Research Letters **4**: 024007-024007 DOI: 10.1088/1748-9326/4/2/024007
Open Access Article* Available at:
http://stacks.iop.org/1748-9326/4/i=2/a=024007?key=crossref.f754b6890a5d753438b12eee546dfcb9
Ocean acidification, a consequence of rising anthropogenic CO2 emissions, is poised to change marine ecosystems profoundly by increasing dissolved CO2 and decreasing ocean pH, carbonate ion concentration, and calcium carbonate mineral saturation state worldwide. These conditions hinder growth of calcium carbonate shells and skeletons by many marine plants and animals. The first direct impact on humans may be through declining harvests and fishery revenues from shellfish, their predators, and coral reef habitats. In a case study of US commercial fishery revenues, we begin to constrain the economic effects of ocean acidification over the next 50 years using atmospheric CO2 trajectories and laboratory studies of its effects, focusing especially on mollusks. In 2007, the $3.8 billion US annual domestic ex-vessel commercial harvest ultimately contributed $34 billion to the US gross national product. Mollusks contributed 19%, or $748 million, of the ex-vessel revenues that year. Substantial revenue declines, job losses, and indirect economic costs may occur if ocean acidification broadly damages marine habitats, alters marine resource availability, and disrupts other ecosystem services. We review the implications for marine resource management and propose possible adaptation strategies designed to support fisheries and marine-resource-dependent communities, many of which already possess little economic resilience.

Crutzen, P. J. (2006). "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma? (Editorial Essay)." Climatic Change **77**: 211-220 DOI: 10.1007/s10584-006-9101-y
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-006-9101-y

Cunningham, S. A., T. Kanzow, et al. (2007). "Temporal variability of the Atlantic meridional overturning circulation at 26.5 degrees N." Science **317**: 935-938 DOI: 10.1126/science.1141304
Available at: http://www.sciencemag.org/content/317/5840/935.short
The vigor of Atlantic meridional overturning circulation (MOC) is thought to be vulnerable to global warming, but its short-term temporal variability is unknown so changes inferred from sparse observations on the decadal time scale of recent climate change are uncertain. We combine continuous measurements of the MOC (beginning in 2004) using the purposefully designed transatlantic Rapid Climate Change array of moored instruments deployed along 26.5 degrees N, with time series of Gulf Stream transport and surface-layer Ekman transport to quantify its intra-annual variability. The year-long average overturning is 18.7 +/- 5.6 sverdrups (Sv) (range: 4.0 to 34.9 Sv, where 1 Sv = a flow of ocean water of 10(6) cubic meters per second). Interannual changes in the overturning can be monitored with a resolution of 1.5 Sv.

Dawson, T. P., S. T. Jackson, et al. (2011). "Beyond predictions: biodiversity conservation in a changing climate." Science **332**: 53-58 DOI: 10.1126/science.1200303
Available at: http://www.sciencemag.org/content/332/6025/53.short
Climate change is predicted to become a major threat to biodiversity in the 21st century, but accurate predictions and effective solutions have proved difficult to formulate. Alarming predictions have come from a rather narrow methodological base, but a new, integrated science of climate-change biodiversity assessment is emerging, based on multiple sources and approaches. Drawing on evidence from paleoecological observations, recent phenological and microevolutionary responses, experiments, and computational models, we review the insights that different approaches bring to anticipating and managing the biodiversity consequences of climate change, including the extent of species' natural resilience. We introduce a framework that uses information from different sources to identify vulnerability and to support the design of conservation responses. Although much of the information reviewed is on species, our framework and conclusions are also applicable to ecosystems, habitats, ecological communities, and genetic diversity, whether terrestrial, marine, or fresh water.

Davidson, E. A. and I. A. Janssens (2006). "Temperature sensitivity of soil carbon decomposition and feedbacks to climate change." Nature **440**: 165-173 DOI: 10.1038/nature04514
Open Access Article* Available at: http://www.nature.com/nature/journal/v440/n7081/full/nature04514.html
Significantly more carbon is stored in the world's soils--including peatlands, wetlands and permafrost--than is present in the atmosphere. Disagreement exists, however, regarding the effects of climate change on global soil carbon stocks. If carbon stored belowground is transferred to the atmosphere by a warming-induced acceleration of its decomposition, a positive feedback to climate change would occur. Conversely, if increases of plant-derived carbon inputs to soils exceed increases in decomposition, the feedback would be negative. Despite much research,

a consensus has not yet emerged on the temperature sensitivity of soil carbon decomposition. Unravelling the feedback effect is particularly difficult, because the diverse soil organic compounds exhibit a wide range of kinetic properties, which determine the intrinsic temperature sensitivity of their decomposition. Moreover, several environmental constraints obscure the intrinsic temperature sensitivity of substrate decomposition, causing lower observed 'apparent' temperature sensitivity, and these constraints may, themselves, be sensitive to climate.

de Baar, H. J. W., P. W. Boyd, et al. (2005). "Synthesis of iron fertilization experiments: From the Iron Age in the Age of Enlightenment." Journal of Geophysical Research **110**: 1-24 DOI: 10.1029/2004jc002601
Available at: http://www.agu.org/pubs/crossref/2005/2004JC002601.shtml

Comparison of eight iron experiments shows that maximum Chl a, the maximum DIC removal, and the overall DIC/Fe efficiency all scale inversely with depth of the wind mixed layer (WML) defining the light environment. Moreover, lateral patch dilution, sea surface irradiance, temperature, and grazing play additional roles. The Southern Ocean experiments were most influenced by very deep WMLs. In contrast, light conditions were most favorable during SEEDS and SERIES as well as during IronEx-2. The two extreme experiments, EisenEx and SEEDS, can be linked via EisenEx bottle incubations with shallower simulated WML depth. Large diatoms always benefit the most from Fe addition, where a remarkably small group of thriving diatom species is dominated by universal response of *Pseudonitzschia* spp. Significant response of these moderate (10–30 mm), medium (30–60 mm), and large (>60 mm) diatoms is consistent with growth physiology determined for single species in natural seawater. The minimum level of ‘‘dissolved’’ Fe (filtrate < 0.2 mm) maintained during an experiment determines the dominant diatom size class. However, this is further complicated by continuous transfer of original truly dissolved reduced Fe(II) into the colloidal pool, which may constitute some 75% of the ‘‘dissolved’’ pool. Depth integration of carbon inventory changes partly compensates the adverse effects of a deep WML due to its greater integration depths, decreasing the differences in responses between the eight experiments. About half of depth-integrated overall primary productivity is reflected in a decrease of DIC. The overall C/Fe efficiency of DIC uptake is DIC/Fe □ 5600 for all eight experiments. The increase of particulate organic carbon is about a quarter of the primary production, suggesting food web losses for the other three quarters. Replenishment of DIC by air/sea exchange tends to be a minor few percent of primary CO_2 fixation but will continue well after observations have stopped. Export of carbon into deeper waters is difficult to assess and is until now firmly proven and quite modest in only two experiments.

de Coninck, H. and K. Bäckstrand (2011). "An International Relations perspective on the global politics of carbon dioxide capture and storage." Global Environmental Change **21**: 368-378 DOI: 10.1016/j.gloenvcha.2011.03.006
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959378011000331

With the publication of the IPCC Special Report on Carbon dioxide Capture and Storage (CCS), CCS has emerged as a focal issue in international climate diplomacy and energy collaboration. This paper has two goals. The first goal is to map CCS activities in and among various types of intergovernmental organisations; the second goal is to apply International Relations (IR) theories to explain the growing diversity, overlap and fragmentation of international organisations dealing with CCS. Which international organisations embrace CCS, and which refrain from discussing it at all? What role do these institutions play in bringing CCS forward? Why is international collaboration on CCS so fragmented and weak? We utilise realism, liberal institutionalism and constructivism to provide three different interpretations of the complex global landscape of CCS governance in the context of the similarly complicated architecture of global climate policy. A realist account of CCS's fragmented international politics is power driven. International fossil fuel and energy organisations, dominated by major emitter states, take an active role in CCS. An interest-based approach, such as liberal institutionalism, claims that CCS is part of a “regime complex” rather than an integrated, hierarchical, comprehensive and international regime. Such a regime complex is exemplified by the plethora of international organisations with a role in CCS. Finally, constructivism moves beyond material and interest-based interpretations of the evolution of the institutionally fragmented architecture of global CCS governance. The 2005 IPCC Special Report on CCS demonstrates the pivotal role that ideas, norms and scientific knowledge have played in transforming the preferences of the international climate-change policy community.

Deschenes, O. and M. Greenstone (2006). The Economic Impacts of Climate Change: Evidence from Agricultural Profits and Random Fluctuations in Weather.
Open Access Article* Available at: http://mit.dspace.org/bitstream/handle/1721.1/45048/2006-001.pdf?sequence=1

This paper measures the economic impact of climate change on US agricultural land by estimating the effect of the presumably random year-to-year variation in temperature and precipitation on agricultural profits. Using

long-run climate change predictions from the Hadley 2 Model, the preferred estimates indicate that climate change will lead to a $1.1 billion (2002$) or 3.4% increase in annual profits. The 95% confidence interval ranges from -$1.8 billion to $4.0 billion and the impact is robust to a wide variety of specification checks, so large negative or positive effects are unlikely. There is considerable heterogeneity in the effect across the country with California's predicted impact equal to -$2.4 billion (or nearly 50% of state agricultural profits). Further, the analysis indicates that the predicted increases in temperature and precipitation will have virtually no effect on yields among the most important crops. These crop yield findings suggest that the small effect on profits is not due to short-run price increases. The paper also implements the hedonic approach that is predominant in the previous literature. We conclude that this approach may be unreliable, because it produces estimates of the effect of climate change that are very sensitive to seemingly minor decisions about the appropriate control variables, sample and weighting. Overall, the findings contradict the popular view that climate change will have substantial negative welfare consequences for the US agricultural sector.

Deutsch, C. A., J. J. Tewksbury, et al. (2008). "Impacts of climate warming on terrestrial ectotherms across latitude." Proceedings of the National Academy of Sciences of the United States of America **105**: 6668-6672 DOI: 10.1073/pnas.0709472105

Open Access Article* Available at: http://www.pnas.org/content/105/18/6668.full

The impact of anthropogenic climate change on terrestrial organisms is often predicted to increase with latitude, in parallel with the rate of warming. Yet the biological impact of rising temperatures also depends on the physiological sensitivity of organisms to temperature change. We integrate empirical fitness curves describing the thermal tolerance of terrestrial insects from around the world with the projected geographic distribution of climate change for the next century to estimate the direct impact of warming on insect fitness across latitude. The results show that warming in the tropics, although relatively small in magnitude, is likely to have the most deleterious consequences because tropical insects are relatively sensitive to temperature change and are currently living very close to their optimal temperature. In contrast, species at higher latitudes have broader thermal tolerance and are living in climates that are currently cooler than their physiological optima, so that warming may even enhance their fitness. Available thermal tolerance data for several vertebrate taxa exhibit similar patterns, suggesting that these results are general for terrestrial ectotherms. Our analyses imply that, in the absence of ameliorating factors such as migration and adaptation, the greatest extinction risks from global warming may be in the tropics, where biological diversity is also greatest.

Doney, S. C. (1996). "A synoptic atmospheric surface forcing data set and physical upper ocean model for the U.S. JGOFS Bermuda Atlantic Time-Series Study site." Journal of Geophysical Research **101**: 25615-25634 DOI: 10.1029/96jc01424

Available at: http://www.agu.org/pubs/crossref/1996/96JC01424.shtml

An atmospheric surface forcing data set with synoptic temporal resolution is constructed (ECMWF) operational analysis, daily cloud fraction and surface, for the U.S. Joint Global Ocean Flux Study (JGOFS) Bermuda Atlantic Time Series (BATS) site for 1988-1992. The forcing data set is based primarily on the 6-hourly European Centre for Medium Range Weather Forecasts air temperature) and synoptic meteorological Comprehensive Ocean-Atmosphere insolation estimates from the International Satellite Cloud Climatology Project, and monthly derived satellite precipitation estimates from the microwave sounding unit. Good agreement is found between the ECMWF surface properties (e.g., wind speed, data from the Bermuda airport and Data Set (COADS) ship reports, though the analysis tends to damp the amplitude of extreme weather events. Monthly air-sea heat and fleshwater flux estimates are generally consistent with climatological estimates for the BATS region. The diagnosed net heat and fleshwater fluxes from the BATS conductivity-temperature-depth data show significant additional month to month variability that is not related to local atmospheric forcing but appears to arise from mesoscale coupled to a one-dimensional simulations quantitatively reproduce much of the observed advection. The surface forcing data set is then upper ocean boundary layer model, and the resulting behavior of sea surface temperature, heat content, and mixed layer depth for the BATS site for the period October 1988 through September 1992. The induced variability in the ocean model on diurnal and storm timescales is analyzed, and the impact of using the ECMWF analysis data rather than synoptic ship or mooring observations is also examined. The main deficiencies in the simulation are related to the influence of advective events in the BATS record and to possible shifts in the ECMWF model, and preliminary techniques for addressing these problems by incorporating the horizontal advective effects are presented. The difficulties associated with directly verifying local one-dimensional models using coarsely sampled time-series data is also discussed.

Doney, S. C. (2006). "Oceanography: Plankton in a warmer world." Nature **444**: 695-696 DOI: 10.1038/444695a
Available at: http://www.nature.com/nature/journal/v444/n7120/full/444695a.html

Satellite data show that phytoplankton biomass and growth generally decline as the oceans' surface waters warm up. Is this trend, seen over the past decade, a harbinger of the future for marine ecosystems? Oranges in Florida, wildfires in Indonesia, plankton in the North Pacific — what links these seemingly disparate items is that they are all affected by year-to-year fluctuations in global-scale climate. On page 752 of this issue, Behrenfeld et al.1 describe how such fluctuations, especially in temperature, are connected to the productivity of phytoplankton in the world's oceans.

Doney, S. C. (2010). "The growing human footprint on coastal and open-ocean biogeochemistry." Science **328**: 1512-1516 DOI: 10.1126/science.1185198
Available at: http://www.sciencemag.org/content/328/5985/1512.short

Climate change, rising atmospheric carbon dioxide, excess nutrient inputs, and pollution in its many forms are fundamentally altering the chemistry of the ocean, often on a global scale and, in some cases, at rates greatly exceeding those in the historical and recent geological record. Major observed trends include a shift in the acid-base chemistry of seawater, reduced subsurface oxygen both in near-shore coastal water and in the open ocean, rising coastal nitrogen levels, and widespread increase in mercury and persistent organic pollutants. Most of these perturbations, tied either directly or indirectly to human fossil fuel combustion, fertilizer use, and industrial activity, are projected to grow in coming decades, resulting in increasing negative impacts on ocean biota and marine resources.

Doney, S. C., V. J. Fabry, et al. (2009). "Ocean Acidification: The Other CO 2 Problem." Annual Review of Marine Science **1**: 169-192 DOI: 10.1146/annurev.marine.010908.163834
Available at: http://www.annualreviews.org/doi/abs/10.1146/annurev.marine.010908.163834

Rising atmospheric carbon dioxide (CO2), primarily from human fossil fuel combustion, reduces ocean pH and causes wholesale shifts in seawater carbonate chemistry. The process of ocean acidification is well documented in field data, and the rate will accelerate over this century unless future CO2 emissions are curbed dramatically. Acidification alters seawater chemical speciation and biogeochemical cycles of many elements and compounds. One well-known effect is the lowering of calcium carbonate saturation states, which impacts shell-forming marine organisms from plankton to benthic molluscs, echinoderms, and corals. Many calcifying species exhibit reduced calcification and growth rates in laboratory experiments under high-CO2 conditions. Ocean acidification also causes an increase in carbon fixation rates in some photosynthetic organisms (both calcifying and noncalcifying). The potential for marine organisms to adapt to increasingCO2 and broader implications for ocean ecosystems are not well known; both are high priori- ties for future research. Although oceans have varied in the geological past, paleo-events may be only imperfect analogs to current conditions.

Dooley, J. J. and K. V. Calvin (2011). "Temporal and spatial deployment of carbon dioxide capture and storage technologies across the representative concentration pathways." Energy Procedia **4**: 5845-5852 DOI: 10.1016/j.egypro.2011.02.583
Open Access Article* Available at: http://linkinghub.elsevier.com/retrieve/pii/S1876610211008629

The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment (to be published in 2013- 2014) will to a significant degree be built around four Representative Concentration Pathways (RCPs) that are intended to represent four scenarios of future development of greenhouse gas emissions, land use, and concentrations that span the widest range of potential future atmospheric radiative forcing. Under the very stringent climate policy implied by the 2.6 W/m2 overshoot scenario, all electricity is eventually generated from low carbon sources. However, carbon dioxide capture and storage (CCS) technologies never comprise more than 50% of total electricity generation in that very stringent scenario or in any of the other cases examined here. There are significant differences among the cases studied here in terms of how CCS technologies are used, with the most prominent being is the significant expansion of biomass+CCS as the stringency of the implied climate policy increases. Cumulative CO_2 storage across the three cases that imply binding greenhouse gas constraints ranges by nearly an order of magnitude from 170GtCO2 (radiative forcing of 6.0W/m2 in 2100) to 1600GtCO2 (2.6W/m2 in 2100) over the course of this century. This potential demand for deep geologic CO2 storage is well within published estimates of total global CO_2 storage capacity.

Doughty, C. E., C. B. Field, et al. (2010). "Can crop albedo be increased through the modification of leaf trichomes, and could this cool regional climate?" Climatic Change **104**: 379-387 DOI: 10.1007/s10584-010-9936-0

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-010-9936-0

Managing the land surface to increase albedo to offset regional warming has received less attention than managing the land surface to sequester carbon. We test whether increasing agricultural albedo can cool regional climate. We first used the Community Atmosphere Model (CAM 3.0) coupled to the Community Land Model (CLM 3.0) to assess the broad climatic effects of a hypothetical implementation of a strategy in which the albedo of cropland regions is increased using high albedo crops. Simulations indicate that planting brighter crops can decrease summertime maximum daily 2 m air temperature by 0.25°C per 0.01 increase in surface albedo at high latitudes (>30°). However, planting brighter crops at low latitudes (<30°) may have negative repercussions including warming the land surface and decreasing precipitation, because increasing the land surface albedo tends to preferentially decrease latent heat fluxes to the atmosphere, which decreases cloud cover and rainfall. We then test a possible method for increasing crop albedo by measuring the range of albedo within 16 isolines of soybeans that differ only with trichome color, orientation, and density but find that such modifications had only minor impacts on leaf albedo. Increasing agricultural albedo may cool high latitude regional climate, but increasing plant albedo sufficiently to offset potential future warming will require larger changes to plant albedo than are currently available.

Downing, A. and A. Cuerrier (2011). "A synthesis of the impacts of climate change on the First Nations and Inuit of Canada." Indian Journal of Traditional Knowledge **10**: 57-70

Open Access Article* Available at: http://nopr.niscair.res.in/handle/123456789/11066

Climate change is impacting multiple aspects of life, many of which resonate with the wellbeing of humankind. Indigenous peoples, including First Nations and Inuit communities around the world are more vulnerable to the risks associated with global warming. In this synthesis, examples of direct and indirect impacts and vulnerabilities on First Nations and Inuit people inhabiting Canada have been provided. Examples from other countries as a reminder that these populations are not alone have also been included. After visiting the topics of biophysical environment, cultural identity, cultural activities, food security and health with respect to First Nations and Inuit peoples conclusion on adaptation within the context of change has been given. The paper stresses also the importance of linking health to cultural identity and land use. To fully grasp the impact of climate change on First Nations and the Inuit, government stakeholders, policy makers, as well as researchers need to understand the connection that these people retain with their land. Reports from the Nunatsiaq News related to climate change to reiterate the concerns of Inuit people have been compiled. Graphs, stemming from the compilation, indicate what are perceived as the growing problems linked to climate changes in these communities. In order to take a positive, forward thinking, inclusive action, at the local level science will need to team up with traditional knowledge.

Duce, R. A., J. LaRoche, et al. (2008). "Impacts of atmospheric anthropogenic nitrogen on the open ocean." Science **320**: 893-897 DOI: 10.1126/science.1150369

Available at: http://www.sciencemag.org/content/320/5878/893.short

Increasing quantities of atmospheric anthropogenic fixed nitrogen entering the open ocean could account for up to about a third of the ocean's external (nonrecycled) nitrogen supply and up to approximately 3% of the annual new marine biological production, approximately 0.3 petagram of carbon per year. This input could account for the production of up to approximately 1.6 teragrams of nitrous oxide (N2O) per year. Although approximately 10% of the ocean's drawdown of atmospheric anthropogenic carbon dioxide may result from this atmospheric nitrogen fertilization, leading to a decrease in radiative forcing, up to about two-thirds of this amount may be offset by the increase in N2O emissions. The effects of increasing atmospheric nitrogen deposition are expected to continue to grow in the future.

Durner, G. M., D. C. Douglas, et al. (2009). "Predicting 21st-century polar bear habitat distribution from global climate models." Ecological Monographs **79**: 25-58 DOI: 10.1890/07-2089.1

Available at: http://www.esajournals.org/doi/abs/10.1890/07-2089.1

Projections of polar bear (*Ursus maritimus*) sea ice habitat distribution in the polar basin during the 21st century were developed to understand the consequences of anticipated sea ice reductions on polar bear populations. We used location data from satellite-collared polar bears and environmental data (e.g., bathymetry, distance to coastlines, and sea ice) collected from 1985 to 1995 to build resource selection functions (RSFs). RSFs described habitats that polar bears preferred in summer, autumn, winter, and spring. When applied to independent data from 1996 to 2006, the RSFs consistently identified habitats most frequently used by polar bears. We applied the RSFs to monthly maps of 21st-century sea ice concentration projected by 10 general circulation models (GCMs) used in the Intergovernmental Panel of Climate Change Fourth Assessment Report, under the A1B greenhouse gas

forcing scenario. Despite variation in their projections, all GCMs indicated habitat losses in the polar basin during the 21st century. Losses in the highest-valued RSF habitat (optimal habitat) were greatest in the southern seas of the polar basin, especially the Chukchi and Barents seas, and least along the Arctic Ocean shores of Banks Island to northern Greenland. Mean loss of optimal polar bear habitat was greatest during summer; from an observed 1.0 million km2 in 1985–1995 (baseline) to a projected multi-model mean of 0.32 million km2 in 2090–2099 (□68% change). Projected winter losses of polar bear habitat were less: from 1.7 million km2 in 1985–1995 to 1.4 million km2 in 2090–2099 (□17% change). Habitat losses based on GCM multi-model means may be conservative; simulated rates of habitat loss during 1985–2006 from many GCMs were less than the actual observed rates of loss. Although a reduction in the total amount of optimal habitat will likely reduce polar bear populations, exact relationships between habitat losses and population demographics remain unknown. Density and energetic effects may become important as polar bears make long-distance annual migrations from traditional winter ranges to remnant high-latitude summer sea ice. These impacts will likely affect specific sex and age groups differently and may ultimately preclude bears from seasonally returning to their traditional ranges

E.T.C. Group (2010). Geopiracy (Report). Ottawa, ON**:** 48 pp.
Open Access Article* Available at: http://www.etcgroup.org/en/node/5217

E.T.C. Group (2011). Open Letter to IPCC on Geoengineering
Open Access Article* Available at:
http://www.etcgroup.org/upload/publication/pdf_file/IPCC_Letter_with_Signatories_-_7-29-2011.pdf

Edenhofer, O. (2010). "IPCC yet to assess geoengineering (correspondence)." Nature **468**: 508-508 DOI: 10.1038/468508a
Available at: http://www.nature.com/nature/journal/v468/n7323/full/468508a.html http://www.ncbi.nlm.nih.gov/pubmed/21107411
As co-chair of Working Group III of the Intergovernmental Panel on Climate Change (IPCC), I would like to clarify your misleading implication that I recommend geoengineering as an option for attaining ambitious climate targets (Nature 468, 13–14; 2010). The IPCC does not have a mandate to recommend or dismiss specific policies or technologies. It aims to assess all relevant climate-change mitigation options on the basis of peer-reviewed scientific literature. This assessment must be unbiased, factual and policy-relevant, without being prescriptive.

Elliott, S., K. S. Lackner, et al. (2001). "Compensation of Atmospheric Chemical Sinkage Buildup through Engineered." Geophysical Research Letters **28**: 1235-1238
Available at: http://www.agu.org/journals/ABS/2001/2000GL011572.shtml
Retrieval of background carbon dioxide into regional chemical extractors would counter anthropogenic inputs in a manner friendly to established industries. We demonstrate via atmospheric transport/scaling calculations that for idealized flat removal units, global coverage could be less than two hundred thousand square kilometers. The disrupted area drops to a small fraction of this with engineering into the vertical to bypass laminarity. Fence structures and artificial roughness elements can both be conceived. Sink thermodynamics are analyzed by taking calcium hydroxide as a sample reactant. Energy costs could be minimized at near the endothermicity of binding reversal. In the calcium case the value is 25 kcal mole -•, as against carbon content of 150 in the same units. Aqueous kinetics are less than favorable for the hydroxide, but misting could counteract slow liquid phase transfer. Properties of superior scrubbers are outlined.

Ellis, E. C. (2011). "Anthropogenic transformation of the terrestrial biosphere." Philosophical Transactions of the Royal Society A **369**: 1010-1035 DOI: 10.1098/rsta.2010.0331
Available at: http://rsta.royalsocietypublishing.org/content/369/1938/1010.abstract
Human populations and their use of land have transformed most of the terrestrial biosphere into anthropogenic biomes (anthromes), causing a variety of novel ecological patterns and processes to emerge. To assess whether human populations and their use of land have directly altered the terrestrial biosphere sufficiently to indicate that the Earth system has entered a new geological epoch, spatially explicit global estimates of human populations and their use of land were analysed across the Holocene for their potential to induce irreversible novel transformation of the terrestrial biosphere. Human alteration of the terrestrial biosphere has been significant for more than 8000 years. However, only in the past century has the majority of the terrestrial biosphere been transformed into intensively used anthromes with predominantly novel anthropogenic ecological processes. At present, even were human populations to decline substantially or use of land become far more efficient, the current global extent,

duration, type and intensity of human transformation of ecosystems have already irreversibly altered the terrestrial biosphere at levels sufficient to leave an unambiguous geological record differing substantially from that of the Holocene or any prior epoch. It remains to be seen whether the anthropogenic biosphere will be sustained and continue to evolve.

Engelhaupt, E. (2010). "Engineering a cooler Earth: Researchers brainstorm radical ways to counter climate change (Feature)." Science News **177**: 16-20 DOI: 10.1002/scin.5591771220
Available at: http://doi.wiley.com/10.1002/scin.5591771220

European Commission. (2007). Limiting Global Climate Change to 2 degrees Celsius: The way ahead for 2020 and beyond. Brussels**:** 1-13.
Open Access Report* Available at:
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52007DC0002:EN:NOT
Climate change is happening. Urgent action is required to limit it to a manageable level. The EU must adopt the necessary domestic measures and take the lead internationally to ensure that global average temperature increases do not exceed pre-industrial levels by more than 2°C.
This Communication and the accompanying impact assessment show that this is technically feasible and economically affordable if major emitters act swiftly. The benefits far outweigh the economic costs.
This Communication is addressed to the Spring 2007 European Council which should decide on an integrated and comprehensive approach to the EU's energy and climate change policies. It follows up on the 2005 Communication "Winning the Battle against Global Climate Change" , which provided concrete recommendations for EU climate policies and set out key elements for the EU's future climate strategy. In deciding the next steps in our climate change policy the European Council should take decisions which will enhance the conditions for reaching a new global agreement to follow on from the Kyoto Protocol's first commitments after 2012.
This Communication proposes that the EU pursues in the context of international negotiations the objective of 30 % reduction in greenhouse gas emissions (GHG) by developed countries by 2020 (compared to 1990 levels). This is necessary to ensure that the world stays within the 2ºC limit. Until an international agreement is concluded, and without prejudice to its position in international negotiations, the EU should already now take on a firm independent commitment to achieve at least a 20 % reduction of GHG emissions by 2020, by the EU emission trading scheme (EU ETS), other climate change policies and actions in the context of the energy policy. This approach will allow the EU to demonstrate international leadership on climate issues. It will also give a signal to industry that the ETS will continue beyond 2012 and will encourage investment in emission reduction technologies and low carbon alternatives.
After 2020, developing country emissions will overtake those of the developed world. In the meanwhile, the rate of growth of overall developing country emissions should start to fall, followed by an overall absolute reduction from 2020 onwards. This can be achieved without affecting their economic growth and poverty reduction, by taking advantage of the wide range of energy and transport related measures that not only have a major emissions reduction potential, but also bring immediate economic and social benefits in their own right.
By 2050 global emissions must be reduced by up to 50 % compared to 1990, implying reductions in developed countries of 60-80 % by 2050. Many developing countries will also need to significantly reduce their emissions.
Market based instruments such as the EU ETS will be a key tool to ensure that Europe and other countries reach their targets at least cost. The post-2012 framework should enable comparable domestic trading schemes to be linked with one another, with the EU ETS as the pillar of the future global carbon market. The EU ETS will continue to be open after 2012 to carbon credits from the Clean Development Mechanism and Joint Implementation projects under the Kyoto Protocol.
The EU and its Member States should decide on a very significant increase in investment in research and development in the areas of energy production and saving.

Fabry, V. J., B. A. Seibel, et al. (2008). "Impacts of ocean acidification on marine fauna and ecosystem processes." ICES Journal of Marine Science **65**: 414-432 DOI: 10.1093/icesjms/fsn048
Open Access Article* Available at: http://icesjms.oxfordjournals.org/content/65/3/414.full
Oceanic uptake of anthropogenic carbon dioxide (CO_2) is altering the seawater chemistry of the world's oceans with consequences for marine biota. Elevated partial pressure of CO_2 (pCO_2) is causing the calcium carbonate saturation horizon to shoal in many regions, particularly in high latitudes and regions that intersect with pronounced hypoxic zones. The ability of marine animals, most importantly pteropod molluscs, foraminifera, and

some benthic invertebrates, to produce calcareous skeletal structures is directly affected by seawater CO_2 chemistry. CO2 influences the physiology of marine organisms as well through acid-base imbalance and reduced oxygen transport capacity. The few studies at relevant pCO_2 levels impede our ability to predict future impacts on foodweb dynamics and other ecosystem processes. Here we present new observations, review available data, and identify priorities for future research, based on regions, ecosystems, taxa, and physiological processes believed to be most vulnerable to ocean acidification. We conclude that ocean acidification and the synergistic impacts of other anthropogenic stressors provide great potential for widespread changes to marine ecosystems.

Feely, R. a., S. R. Alin, et al. (2010). "The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary." Estuarine, Coastal and Shelf Science **88**: 442-449 DOI: 10.1016/j.ecss.2010.05.004

Available at: http://linkinghub.elsevier.com/retrieve/pii/S027277141000185X

Puget Sound is a large estuary complex in the U.S. Pacific Northwest that is home to a diverse and economically important ecosystem threatened by anthropogenic impacts associated with climate change, urbanization, and ocean acidification. While ocean acidification has been studied in oceanic waters, little is known regarding its status in estuaries. Anthropogenically acidified coastal waters upwelling along the western North American continental margin can enter Puget Sound through the Strait of Juan de Fuca. In order to study the combined effects of ocean acidification and other natural and anthropogenic processes on Puget Sound waters, we made the first inorganic carbon measurements in this estuary on two survey cruises in February and August of 2008. Observed pH and aragonite saturation state values in surface and subsurface waters were substantially lower in parts of Puget Sound than would be expected from anthropogenic carbon dioxide (CO_2) uptake alone. We estimate that ocean acidification can account for 24e49% of the pH decrease in the deep waters of the Hood Canal sub-basin of Puget Sound relative to estimated pre-industrial values. The remaining change in pH between when seawater enters the sound and when it reaches this deep basin results from remineralization of organic matter due to natural or anthropogenically stimulated respiration processes within Puget Sound. Over time, however, the relative impact of ocean acidification could increase significantly, accounting for 49e82% of the pH decrease in subsurface waters for a doubling of atmospheric CO_2. These changes may have profound impacts on the Puget Sound ecosystem over the next several decades. These estimates suggest that the role ocean acidification will play in estuaries may be different from the open ocean.

Field, C. B., M. J. Behrenfeld, et al. (1998). "Primary Production of the Biosphere: Integrating Terrestrial and Oceanic Components." Science **281**: 237-240 DOI: 10.1126/science.281.5374.237

Available at: http://www.sciencemag.org/cgi/doi/10.1126/science.281.5374.237

Integrating conceptually similar models of the growth of marine and terrestrial primary producers yielded an estimated global net primary production (NPP) of 104.9 petagrams of carbon per year, with roughly equal contributions from land and oceans. Approaches based on satellite indices of absorbed solar radiation indicate marked heterogeneity in NPP for both land and oceans, reflecting the influence of physical and ecological processes. The spatial and temporal distributions of ocean NPP are consistent with primary limitation by light, nutrients, and temperature. On land, water limitation imposes additional constraints. On land and ocean, progressive changes in NPP can result in altered carbon storage, although contrasts in mechanisms of carbon storage and rates of organic matter turnover result in a range of relations between carbon storage and changes in NPP.

Field, C. B., D. B. Lobell, et al. (2007). "Feedbacks of Terrestrial Ecosystems to Climate Change." Annual Review of Environment and Resources **32**: 1-29 DOI: 10.1146/annurev.energy.32.053006.141119

Available at: http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.32.053006.141119

Most modeling studies on terrestrial feedbacks to warming over the twenty-first century imply that the net feedbacks are negative—that changes in ecosystems, on the whole, resist warming, largely through ecosystem carbon storage. Although it is clear that potentially impor tant mechanisms can lead to carbon storage, a number of less well- understood mechanisms, several of which are rarely or incompletely modeled, tend to diminish the negative feedbacks or lead to positive feedbacks. At high latitudes, negative feedbacks from forest expansion are likely to be largely or completely compensated by positive feedbacks from decreased albedo, increased carbon emissions from thawed permafrost, and increased wildfire. At low latitudes, negative feedbacks to warming will be decreased or eliminated, largely through direct human impacts. With modest warming, net feedbacks of terrestrial ecosystems to warming are likely to be negative in the tropics and positive at high latitudes. Larger amounts of warming will generally push the feedbacks toward the positive.

Fin, S. M. I. (2011). "Geo-engineering: The Cure-all for Climate Change?" GLG216 Journal: 40-43
Open Access Article* Available at:
http://www.geology.utoronto.ca/students/undergraduate-students/glg216_Journal.pdf#page=43
Geo-engineering is an emerging field with very little research done on the full efficacy and ecological consequences of many of the methods that are currently being proposed. Some methods prove to be more reliable than others; however, it should be approached with extreme caution, and should only be used as a last resort. This paper reviews some of the main methods of geo-engineering and evaluates their risks and effectiveness. Ethical and environmental impacts will also be reviewed, as well as the implications of what it means to engineer the climate.

Finzi, A. C. , et al. (2011). "Responses and feedbacks of coupled biogeochemical cycles to climate change: examples from terrestrial ecosystems." Frontiers in Ecology and the Environment **9**: 61-67 DOI: 10.1890/100001
Open Access Article* Available at: http://www.esajournals.org/doi/abs/10.1890/100001

Fitzgerald, J., DellaSala, D. A., et al. (2011). A Global Strategy for Rainforests in the Era of Climate. **In:** Temperate and Boreal Rainforests of the World: Ecology and Conservation Change. Washington, DC, Island Press/Center for Resource Economics. DOI: 10.5822/978-1-61091-008-8_11
Available at: http://www.springerlink.com/content/m600n6576l5w1514/
Like their tropical counterparts, temperate and boreal rainforests arose from a tightly knit association with climate (see chapter 1). Global climate disruptions are therefore likely to result in dire consequences to rainforests, particularly as temperature and precipitation levels are affected by climate change as discussed in the earlier chapters. Notably, declines in snow pack (thereby affecting water supply and aquatic organisms—see Mote et al. 2005) and recent increases in the duration of the fire seasons (Westerling et al. 2006) are already affecting regions with temperate and boreal rainforests. Particularly vulnerable are food-web dynamics involving woodland caribou and rainforest lichens (see chapter 3) and large carnivores and salmon (see chapter 2). The loss of keystone taxa at lower levels (lichens, salmon) in temperate and boreal rainforests may ultimately create the "perfect storm" whereby climatic thresholds for keystone species reverberate across food chains (e.g., see Lichatowich 1999 for how the loss of salmon could affect food-web dynamics in the Pacific Coast of North America).

Fleming, J. R. (2006). "The pathological history of weather and climate modification: Three cycles of promise and hype." Historical Studies in the Physical and Biological Sciences **37**: 3-25 DOI: 10.1525/hsps.2006.37.1.3
Available at: http://www.jstor.org/pss/10.1525/hsps.2006.37.1.3
The checkered history of weather and climate modification exhibits a modicum of promise and an excess of hype. This paper examines two completed historical cycles: the first, dating from 1839, involved western proprietary rainmaking or "pluviculture;" the second, from 1946 to 1978 involved "cloud seeding," commercial rainmaking, and the attempted weaponization of the clouds. Recently, discussion of weather and climate modification has returned to the science-policy agenda, framed as seemingly inevitable responses to killer storms and global warming. The long history of deceptive and delusional attempts to "control" nature, however, raised serious questions about the rationality of these options.

Fleming, J. R. (2010). Fixing the Sky: The Checkered History of Weather and Climate Control. New York, Columbia University Press.

Fleming, J. R. (2011). "Iowa Enters the Space Age: James Van Allen, Earth's Radiation Belts, and Experiments to Disrupt Them." Annals of Iowa **70**

Flynn, P. C. Z. J. S. (2011). Can Geoengineering Sustain Critical Ocean Currents? V. Badescu and R. B. Cathcart. Berlin, Heidelberg, Springer Berlin Heidelberg.
Available at: http://www.springerlink.com/index/10.1007/978-3-642-14779-1

Folke, C., C. Fabricius, et al. (2005). Communities, Ecosystems , and Livelihoods. M. Giampietro, T. Wilbanks and X. Jianchu. Washington, DC, Island Press.
Open Access Article* Available at: http://www.maweb.org/documents/document.349.aspx.pdf

Friedlingstein, P., S. Solomon, et al. (2011). "Long-term climate implications of twenty-first century options for carbon

dioxide emission mitigation." Nature Climate Change **1**: 1-5 DOI: 10.1038/nclimate1302
Available at: http://www.nature.com/doifinder/10.1038/nclimate1302

Long-term future warming is primarily constrained by cumulative emissions of carbon dioxide1–4. Previous studies have estimated that humankind has already emitted about 50% of the total amount allowed if warming, relative to pre-industrial, is to stay below 2 C (refs 1,2). Carbon dioxide emissions will thus need to decrease substantially in the future if this target is to be met. Here we show how links between nearterm decisions, long-term behaviour and climate sensitivity uncertainties constrain options for emissions mitigation. Using a model of intermediate complexity5,6, we explore the implications of non-zero long-term global emissions, combined with various near-term mitigation rates or delays in action. For a median climate sensitivity, a long-term 90% emission reduction relative to the present-day level is incompatible with a 2 C target within the coming millennium. Zero or negative emissions can be compatible with the target if medium to high emission-reduction rates begin within the next two decades. For a high climate sensitivity, however, even negative emissions would require a global mitigation rate at least as great as the highest rate considered feasible by economic models7,8 to be implemented within the coming decade. Only a low climate sensitivity would allow for a longer delay in mitigation action and a more conservative mitigation rate, and would still require at least 90% phase-out of emissions thereafter.

Frol'kis, V. and I. L. Karol' (2011). "Simulation of the effect of stratospheric aerosol dimming parameters on the efficiency of offsetting global greenhouse climate warming." Atmospheric and Oceanic Optics **24**: 74-87 DOI: 10.1134/s1024856011010064
Open Access Article* Available at: http://www.springerlink.com/index/10.1134/S1024856011010064

We considered different properties of stratospheric sulfate aerosols and their size distributions and estimated how efficient they are at compensating for the changes in radiative fluxes at different atmospheric levels and deviation of air temperature during greenhouse warming and upon aerosol dimming. A two-dimensional zonally averaged model of the annually average radiative and thermal regime of the troposphere and stratosphere (the Energy Balance Radiative Convective Model, EBRCM) is used for this. This model allows for assessing the direct effects of changes in many parameters of atmospheric aerosols and the underlying surface, as well as characteristics of aerosol screens. We estimate the sulfate aerosol optical depths and masses for offsetting the annually and zonally averaged increases in the near-ground air temperature, caused by increases in the greenhouse gas content, according to measurements and the IPCC A2 scenario for 1970–2050. No offset is indicated if aerosol screens are emplaced in the polar zones (poleward of 70° N–70° S), and a screen emplaced in just one hemisphere is shown to be incapable of producing total offsetting of global warming.

Fujii, Y. (2011). "The role of atmospheric nuclear explosions on the stagnation of global warming in the mid 20th century." Journal of Atmospheric and Solar-Terrestrial Physics **73**: 643-652 DOI: 10.1016/j.jastp.2011.01.005
Available at: http://linkinghub.elsevier.com/retrieve/pii/S136468261100006X

This study suggests that the cause of the stagnation in global warming in the mid 20th century was the atmospheric nuclear explosions detonated between 1945 and 1980. The estimated GST drop due to fine dust from the actual atmospheric nuclear explosions based on the published simulation results by other researchers (a single column model and Atmosphere-Ocean General Circulation Model) has served to explain the stagnation in global warming. Atmospheric nuclear explosions can be regarded as full-scale in situ tests for nuclear winter. The non-negligible amount of GST drop from the actual atmospheric explosions suggests that nuclear winter is not just a theory but has actually occurred, albeit on a small scale. The accuracy of the simulations of GST by IPCC would also be improved significantly by introducing the influence of fine dust from the actual atmospheric nuclear explosions into their climate models; thus, global warming behavior could be more accurately predicted.

Gage, J. D. and P. A. Tyler (1991). Deep-Sea Biology: A Natural History of Organisms at the Deep-Sea Floor. Cambridge, Cambridge University Press.

Gao, G., G. Ding, et al. Carbon Sequestration Forestry - A Sustainable Choice for Combating Climate Change, IEEE.
Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5781329

United Nations Climate Change Conference 2009 in Copenhagen makes global warming become a hot and controversial topic. The paper briefly reviews the controversial causes of the problem, and cites many evidences to show the objective existence of it. The reasons for global warming are explained, and its serious harm that could bring to the planet and humanity are also analyzed. The paper introduces the human's main measures response to global warming, especially including the carbon sequestration forestry. And it particularly introduces

the concept, the main contents and its superiority in the measures system that responses to the global warming. Analysis obtains that global warming is the most direct manifestations and trends of climate change at this stage, people must take active measures; carbon sequestration forestry is an efficient, clean but low-cost measures to reduce emissions and increase sinks, and has multiple ecological benefits and the huge social and economic benefits. Carbon sequestration forestry is an important way to slow the process of global warming and combat global climate change.

Gardiner, S. M. (2011). "Some Early Ethics of Geoengineering the Climate: A Commentary on the Values of the Royal Society Report." Environmental Values **20**: 163-188 DOI: 10.3197/096327111x12997574391689
Open Access Article* Available at:
http://openurl.ingenta.com/content/xref?genre=article&issn=0963-2719&volume=20&issue=2&spage=163
The Royal Society's landmark report on geoengineering is predicated on a particular account of the context and rationale for intentional manipulation of the climate system, and this ethical framework probably explains many of the Society's conclusions. Critical reflection on the report's values is useful for understanding disagreements within and about geoengineering policy, and also for identifying questions for early ethical analysis. Topics discussed include the moral hazard argument, governance, the ethical status of geoengineering under different rationales, the implications of understanding geoengineering as a consequence of wider moral failure, and ethical resistance to invasive interventions in environmental systems.

Gehlen, M., N. Gruber, et al. (2009). “Biogeochemical consequences of ocean acidification and feedbacks to the earth system” in Ocean Acidification. J.-P. Gattuso and L. Hansson. Oxford, United Kingdom, Oxford University Press**:** 230-248.

Glaser, J. A. (2010). "Climate geoengineering." Clean Technologies and Environmental Policy **12**: 91-95 DOI: 10.1007/s10098-010-0287-3
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10098-010-0287-3

Glenk, K. and S. Colombo (2010). "Designing policies to mitigate the agricultural contribution to climate change: an assessment of soil based carbon sequestration and its ancillary effects." Climatic Change **105**: 43-66 DOI: 10.1007/s10584-010-9885-7
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-010-9885-7

Glibert, P. M., R. Azanza, et al. (2008). "Ocean urea fertilization for carbon credits poses high ecological risks." Marine pollution bulletin **56**: 1049-1056 DOI: 10.1016/j.marpolbul.2008.03.010
Available at: http://www.sciencedirect.com/science/article/pii/S0025326X08001392
The proposed plan for enrichment of the Sulu Sea, Philippines, a region of rich marine biodiversity, with thousands of tonnes of urea in order to stimulate algal blooms and sequester carbon is flawed for multiple reasons. Urea is preferentially used as a nitrogen source by some cyanobacteria and dinoflagellates, many of which are neutrally or positively buoyant. Biological pumps to the deep sea are classically leaky, and the inefficient burial of new biomass makes the estimation of a net loss of carbon from the atmosphere questionable at best. The potential for growth of toxic dinoflagellates is also high, as many grow well on urea and some even increase their toxicity when grown on urea. Many toxic dinoflagellates form cysts which can settle to the sediment and germinate in subsequent years, forming new blooms even without further fertilization. If large-scale blooms do occur, it is likely that they will contribute to hypoxia in the bottom waters upon decomposition. Lastly, urea production requires fossil fuel usage, further limiting the potential for net carbon sequestration. The environmental and economic impacts are potentially great and need to be rigorously assessed.

Gnanadesikan, A., K. Emanuel, et al. (2010). "How ocean color can steer Pacific tropical cyclones." Geophysical Research Letters **37**: L18802-L18802 DOI: 10.1029/2010gl044514
Open Access Article* Available at: http://www.agu.org/pubs/crossref/2010/2010GL044514.shtml
Because ocean color alters the absorption of sunlight, it can produce changes in sea surface temperatures with further impacts on atmospheric circulation. These changes can project onto fields previously recognized to alter the distribution of tropical cyclones. If the North Pacific subtropical gyre contained no absorbing and scattering materials, the result would be to reduce subtropical cyclone activity in the subtropical Northwest Pacific by 2/3, while concentrating cyclone tracks along the equator. Predicting tropical cyclone activity using coupled models may thus require consideration of the details of how heat moves into the upper thermocline as well as

biogeochemical cycling.

Gnanadesikan, a. and I. Marinov (2008). "Export is not enough: nutrient cycling and carbon sequestration." Marine Ecology Progress Series **364**: 289-294 DOI: 10.3354/meps07550

Open Access Article* Available at: http://www.int-res.com/abstracts/meps/v364/p289-294/

The question of whether ocean iron fertilization (OIF) can yield verifiable carbon sequestration is often cast in terms of whether fertilization results in enhanced particle export. How- ever, model studies show that oceanic carbon storage is only weakly related to global particle export—depending instead on an increase in the carbon associated with the pool of remineralized nutrients. The magnitude of such an increase depends on circulation, stoichiometric ratios and gas exchange. We argue that this puts serious challenges before efforts to properly credit OIF that must be taken into account at the design stage.

Goes, M., N. Tuana, et al. (2011). "The economics (or lack thereof) of aerosol geoengineering." Climatic Change DOI: 10.1007/s10584-010-9961-z

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-010-9961-z

Anthropogenic greenhouse gas emissions are changing the Earth's cli- mate and impose substantial risks for current and future generations. What are scientifically sound, economically viable, and ethically defendable strategies to manage these climate risks? Ratified international agreements call for a reduction of greenhouse gas emissions to avoid dangerous anthropogenic interference with the climate system. Recent proposals, however, call for a different approach: to geoengineer climate by injecting aerosol precursors into the stratosphere. Published economic studies typically neglect the risks of aerosol geoengineering due to (i) the potential for a failure to sustain the aerosol forcing and (ii) the negative impacts associated with the aerosol forcing. Here we use a simple integrated assessment model of climate change to analyze potential economic impacts of aerosol geo- engineering strategies over a wide range of uncertain parameters such as climate sensitivity, the economic damages due to climate change, and the economic damages due to aerosol geoengineering forcing. The simplicity of the model provides theadvantages of parsimony and transparency, but it also imposes severe caveats on the interpretation of the results. For example, the analysis is based on a globally aggregated model and is hence silent on intragenerational distribution of costs and benefits. In addition, the analysis neglects the effects of learning and has a very simplistic representation of climate change impacts. Our analysis suggests three main conclusions. First, substituting aerosol geoengineering for CO2 abatement can be an economically ineffective strategy. One key to this finding is that a failure to sustain the aerosol forcing can lead to sizeable and abrupt climatic changes. The monetary damages due to such a discontinuous aerosol geoengineering can dominate the cost- benefit analysis because the monetary damages of climate change are expected to increase with the rate of change. Second, the relative contribution of aerosol geoengineering to an economically optimal portfolio hinges critically on, thus far, deeply uncertain estimates of the damages due to aerosol forcing. Even if we assume that aerosol forcing could be deployed continuously, the aerosol geoengineering does not considerably displace CO2 abatement in the simple economic optimal growth model until the damages due to the aerosol forcing are rather low. Third, substituting aerosol geoengineering for greenhouse gas emission abatement can fail an ethical test regarding intergenerational justice. Substituting aerosol geoengineering for greenhouse gas emissions abatements constitutes a conscious risk transfer to future generations, in violation of principles of intergenerational justice which demands that present generations should not create benefits for themselves in exchange for burdens on future generations.

Goldblatt, C. and K. J. Zahnle (2011). "Faint young Sun paradox remains." Nature **474**: E3-4; discussion E4-5 DOI: 10.1038/nature09961

Available at: http://www.ncbi.nlm.nih.gov/pubmed/21637210

The Sun was fainter when the Earth was young, but the climate was generally at least as warm as today; this is known as the 'faint young Sun paradox'. Rosing et al.1 claim that the paradox can be resolved by making the early Earth's clouds and surface less reflective. We show that, even with the strongest plausible assumptions, reducing cloud and surface albedos falls short by a factor of two of resolving the paradox. A temperate Archean climate cannot be reconciled with the low level of CO2 suggested by Rosing et al.; a stronger greenhouse effect is needed.

Goldstein, B., et al. (2010). Unintended Consequences of Atmospheric Injection of Sulphate Aerosols. Albuquerque, New Mexico.

Open Access Article* Available at: http://prod.sandia.gov/techlib/access-control.cgi/2010/107571.pdf

Golomb, D. and A. Angelopoulos (2001) “A Benign Form of CO2 Sequestration in the Ocean” in Proceedings of the 5th International Greenhouse Gas Technology Congress, CSIRO Publications.

Open Access Article* Available at: http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/p55.pdf

It is proposed that liquid CO is mixed with pulverized limestone (CaCO) and seawater in a pressure23 vessel. An emulsion is created which is piped to intermediate depth in the ocean, where the emulsion is released through a diffuser. The emulsion plume has a bulk density of 1.4 kg m , thus it will sink as a gravity current to greater depth from the release point. Several kinetic processes occur -3 simultaneously: (a) the entrainment of seawater by the emulsion plume, (b) the dissolution of CaCO ,3 (c) the dissolution of CO , and (d) the reaction of dissolved CO with CaCO to form bicarbonate.22 3 In the presence of CaCO , the plume around the release point has a pH 5 instead of 3 around the release point of liquid CO2. Subsequent entrainment of seawater brings rapidly the pH to near 3 ambient values. The resulting calcium and bicarbonate ions are available nutrients for marine organisms. The bicarbonate solution will stay in the ocean indefinitely as contrasted with carbonic acid which eventually would resurface and equilibrate with the atmosphere. Most importantly, the emulsion can be released slightly below 500 m, as the emulsified CO will not phase-separate and 2 ascend to a depth where it would flash into vapor. This makes the release depth accessible to many more coastal power plants than the previously thought minimum depth of 1000 m for the release of pure liquid CO_2.

Gooday, A. J. (2002). "Biological Responses to Seasonally Varying Fluxes of Organic Matter to the Ocean Floor: A Review." Journal of Oceanography **58**: 305-332

Available at: http://www.springerlink.com/content/xw6x7j80d25gvrw8/

Deep-sea benthic ecosystems are sustained largely by organic matter settling from the euphotic zone. These fluxes usually have a more or less well-defined seasonal component, often with two peaks, one in spring/early summer, the other later in the year. Long time-series datasets suggest that inter-annual variability in the intensity, timing and composition of flux maxima is normal. The settling material may form a deposit of “phytodetritus” on the deep-seafloor. These deposits, which are most common in temperate and high latitude regions, particularly the North Atlantic, evoke a response by the benthic biota. Much of our knowledge of these responses comes from a few time-series programmes, which suggest that the nature of the response varies in different oceanographic settings. In particular, there are contrasts between seasonal processes in oligotrophic, central oceanic areas and those along eutrophic continental margins. In the former, it is mainly “small organisms” (bacteria and protozoans) that respond to pulsed inputs. Initial responses are biochemical (e.g. secretion of bacterial exoenzymes) and any biomass increases are time lagged. Increased metabolic activity of small organisms probably leads to seasonal fluctuations in sediment community oxygen consumption, reported mainly in the North Pacific. Metazoan meiofauna are generally less responsive than protozoans (foraminifera), although seasonal increases in abundance and body size have been reported. Measurable population responses by macrofauna and megafauna are less common and confined largely to continental margins. In addition, seasonally synchronised reproduction and larval settlement occur in some larger animals, again mainly in continental margin settings. Although seasonal benthic responses to pulsed food inputs are apparently widespread on the ocean floor, they are not ubiquitous. Most deep-sea species are not seasonal breeders and there are probably large areas, particularly at abyssal depths, where biological process rates are fairly uniform over time. As with other aspects of deep-sea ecology, temporal processes cannot be encapsulated by a single paradigm. Further long time-series studies are needed to understand better the nature and extent of seasonality in deep-sea benthic ecosystems.

Gough, C. and P. Upham (2011). "Biomass energy with carbon capture and storage (BECCS or Bio-CCS)." Greenhouse Gases: Science and Technology **1**: 324-334 DOI: 10.1002/ghg.34

Available at: http://doi.wiley.com/10.1002/ghg.34

In terms of climate mitigation options, the theoretical potential of biomass energy with carbon capture and storage (BECCS) is substantial; introducing the prospect of negative emissions, it offers the vision of drawing atmospheric CO2 concentrations back down to pre-industrial levels. This paper reviews issues raised at a workshop on BECCS, convened in Scotland in late 2009. Presentations by bioenergy and CCS specialists covered topics including the climate policy rationale for BECCS, global biomass CCS potential, the UK potential for BECCS, the risk of fossil fuel lock-in via coal co-firing, and carbon market issues. In practice, the scale of the forestry and accessible CCS infrastructure required are among the obstacles to the large-scale deployment of BECCS in the near term. While biomass co-firing with coal offers an early route to BECCS, a quite substantial (>20%) biomass component may be necessary to achieve negative emissions in a co-fired CCS system. Smaller scale BECCS, through co-location of dedicated or co-combusted biomass on fossil CCS CO2 transport pipeline

routes, is easier to envisage and would be potentially less problematic. Hence, we judge that BECCS can, and likely will, play a role in carbon reduction, but care needs to be taken not to exaggerate its potential, given that (i) there are few studies of the cost of connecting bio-processing (combustion, gasification or other) infrastructure with CO2 storage sites and (ii) that scenarios of global bioenergy potential remain contentious.

Grace, J. R., C.M. Ryan, et al. (2010). "A pilot project to store carbon as biomass in African woodlands." Carbon Management **1**: 227-235

Available at: http://www.future-science.com/doi/abs/10.4155/cmt.10.22

Capturing carbon by planting trees or avoiding deforestation is thought to be a cost-effective way to reduce the inexorable rise in CO2 in the atmosphere. We describe a way to motivate African farmers to plant trees and protect woodland, based on a Mozambican pilot project in the voluntary carbon market. By late 2009, 1510 farmers were enrolled. Between 2003 and 2009, the project was able to sell carbon credits totaling approximately US$1.3 million on the voluntary carbon market, corresponding to 156,000 tCO2, at a price that averaged US$9.0 per ton. Moreover, the effect of the carbon project was to increase rural employment from 8.6 to 32%, whilst 73% of households raised commercial crops compared with 23% previously. There was also a notable development of social capital, with a measurable increase in literacy and the development of a business ethos with associated practical skills.

Grace, P. R. and B. Basso (2012). "Offsetting greenhouse gas emissions through biological carbon sequestration in North Eastern Australia." Agricultural Systems **105**: 1-6 DOI: 10.1016/j.agsy.2011.08.006

Available at: http://linkinghub.elsevier.com/retrieve/pii/S0308521X1100120X

The Kyoto Protocol recognises trees as a sink of carbon and a valid means to offset greenhouse gas emissions and meet internationally agreed emissions targets. This study details biological carbon sequestration rates for common plantation species Araucaria cunninghamii (hoop pine), *Eucalyptus cloeziana, Eucalyptus argophloia, Pinus elliottii* and *Pinus caribaea var hondurensis* and individual land areas required in north-eastern Australia to offset greenhouse gas emissions of 1000 t CO2e. The 3PG simulation model was used to predict above and below-ground estimates of biomass carbon for a range of soil productivity conditions for six representative locations in agricultural regions of north-eastern Australia. The total area required to offset 1000 t CO2e ranges from 1 ha of *E. cloeziana* under high productivity conditions in coastal North Queensland to 45 ha of hoop pine in low productivity conditions of inland Central Queensland. These areas must remain planted for a minimum of 30 years to meet the offset of 1000 t CO2e.

Greene, C. H., A. J. Pershing, et al. (2008). "Arctic Climate Change and Its Impacts on the Ecology of the North Atlantic." Ecology **89**: S24-S38 DOI: 10.1890/07-0550.1

Open Access Article* Available at: http://www.esajournals.org/doi/abs/10.1890/07-0550.1

Arctic climate change from the Paleocene epoch to the present is reconstructed with the objective of assessing its recent and future impacts on the ecology of the North Atlantic. A recurring theme in Earth's paleoclimate record is the importance of the Arctic atmosphere, ocean, and cryosphere in regulating global climate on a variety of spatial and temporal scales. A second recurring theme in this record is the importance of freshwater export from the Arctic in regulating global- to basin-scale ocean circulation patterns and climate. Since the 1970s, historically unprecedented changes have been observed in the Arctic as climate warming has increased precipitation, river discharge, and glacial as well as sea-ice melting. In addition, modal shifts in the atmosphere have altered Arctic Ocean circulation patterns and the export of freshwater into the North Atlantic. The combination of these processes has resulted in variable patterns of freshwater export from the Arctic Ocean and the emergence of salinity anomalies that have periodically freshened waters in the North Atlantic. Since the early 1990s, changes in Arctic Ocean circulation patterns and freshwater export have been associated with two types of ecological responses in the North Atlantic. The first of these responses has been an ongoing series of biogeographic range expansions by boreal plankton, including renewal of the trans-Arctic exchanges of Pacific species with the Atlantic. The second response was a dramatic regime shift in the shelf ecosystems of the Northwest Atlantic that occurred during the early 1990s. This regime shift resulted from freshening and stratification of the shelf waters, which in turn could be linked to changes in the abundances and seasonal cycles of phytoplankton, zooplankton, and higher trophic-level consumer populations. It is predicted that the recently observed ecological responses to Arctic climate change in the North Atlantic will continue into the near future if current trends in sea ice, freshwater export, and surface ocean salinity continue. It is more difficult to predict ecological responses to abrupt climate change in the more distant future as tipping points in the Earth's climate system are exceeded. Read More: http://www.esajournals.org/doi/full/10.1890/07-0550.1

Gu, L., D. D. Baldocchi, et al. (2003). "Response of a deciduous forest to the Mount Pinatubo eruption: enhanced photosynthesis." Science **299**: 2035-2038 DOI: 10.1126/science.1078366

Open Access Article* Available at: http://www.sciencemag.org/content/299/5615/2035.long

Volcanic aerosols from the 1991 Mount Pinatubo eruption greatly increased diffuse radiation worldwide for the following 2 years. We estimated that this increase in diffuse radiation alone enhanced noontime photosynthesis of a deciduous forest by 23% in 1992 and 8% in 1993 under cloudless conditions. This finding indicates that the aerosol-induced increase in diffuse radiation by the volcano enhanced the terrestrial carbon sink and contributed to the temporary decline in the growth rate of atmospheric carbon dioxide after the eruption.

Güssow, K., A. Proelss, et al. (2010). "Ocean iron fertilization: Why further research is needed." Marine Policy **34**: 911-918 DOI: 10.1016/j.marpol.2010.01.015

Available at: http://linkinghub.elsevier.com/retrieve/pii/S0308597X10000163

Despite large uncertainties in the fertilization efficiency, natural iron fertilization studies and some of the purposeful iron enrichment studies have demonstrated that Southern Ocean iron fertilization can lead to a significant export of carbon from the sea surface to the ocean interior. From an economic perspective the potential of ocean iron fertilization (OIF) is far from negligible in relation to other abatement options. Comparing the range of cost estimates to the range of estimates for forestation projects they are in the same order of magnitude, but OIF could provide more carbon credits even if high discount rates are used to account for potential leakage and non-permanence. However, the uncertainty about undesired adverse effects of purposeful iron fertilization on marine ecosystems and biogeochemistry has led to attempts to ban commercial and, to some extent, scientific experiments aimed at a better understanding of the processes involved, effectively precluding further consideration of this mitigation option. As regards the perspective of public international law, the pertinent agreements dealing with the protection of the marine environment indicate that OIF is to be considered as lawful if and to the extent to which it represents legitimate scientific research. In this respect, the precautionary principle can be used to balance the risks arising out of scientific OIF activities for the marine environment with the potential advantages relevant to the objectives of the climate change regime. As scientific OIF experiments involve only comparatively small negative impacts within a limited marine area, further scientific research must be permitted to explore the carbon sequestration potential of OIF in order to either reject this concept or integrate it into the flexible mechanisms contained in the Kyoto Protocol.

Ha-Duong, M. and R. Loisel (2009). "Zero is the only acceptable leakage rate for geologically stored CO_2: an editorial comment." Climatic Change **93**: 311-317 DOI: 10.1007/s10584-009-9560-z

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-009-9560-z

Leakage is one of the main concerns of all parties involved with the development of Carbon Capture and Storage. From an economic point of view, van der Zwaan and Gerlagh (2009) suggest that CCS remains a valuable option even with CO2 leakage rate as high as of a few % per year. But what is valuable is, ultimately, determined by social preferences and parameters that are beyond economic modeling. Examining the point of view of four stakeholder groups: industry, policy-makers, environmental NGOs and the general public, we conclude that there is a social agreement today: zero is the only acceptable carbon leakage rate.

Hale, B. and L. Dilling (2010). "Geoengineering, Ocean Fertilization, and the Problem of Permissible Pollution." Science, Technology & Human Values **36**: 190-212 DOI: 10.1177/0162243910366150

Available at: http://sth.sagepub.com/cgi/doi/10.1177/0162243910366150

Many geoengineering projects have been proposed to address climate change, including both solar radiation management and carbon removal techniques. Some of these methods would introduce additional compounds into the atmosphere or the ocean. This poses a difficult conundrum: Is it permissible to remediate one pollutant by introducing a second pollutant into a system that has already been damaged, threatened, or altered? We frame this conundrum as the ‘‘Problem of Permissible Pollution.’’ In this paper, we explore this problem by taking up ocean fertilization and advancing an argument that rests on three moral claims. We first observe that pollution is, in many respects, a context-dependent matter. This observation leads us to argue for a ‘‘justifiability criterion.’’ Second, we suggest that remediating actions must take into account the antecedent conditions that have given rise to their consideration. We call this second observation the ‘‘antecedent conditions criterion.’’ Finally, we observe that ocean fertilization, and other related geoengineering technologies, propose not strictly to clean up carbon emissions, but actually to move the universe to some future, unknown state. Given the introduced criteria, we impose a ‘‘future-state constraint’’. We conclude that ocean fertilization is not an acceptable solution for

mitigating climate change. In attempting to shift the universe to a future state (a) geoengineering sidelines consideration of the antecedent conditions that have given rise to it —conditions, we note, that in many cases involve unjustified carbon emissions —and (b) it must appeal to an impossibly large set of affected parties.

Hall, A. (2004). "The Role of Surface Albedo Feedback in Climate." Journal of Climate **17**: 1550-1568 DOI: 10.1175/1520-0442(2004)017<1550:trosaf>2.0.co;2

Open Access Article* Available at:
http://journals.ametsoc.org/doi/pdf/10.1175/1520-0442%282004%29017%3C1550%3ATROSAF%3E2.0.CO%3B2

A coarse resolution coupled ocean–atmosphere simulation in which surface albedo feedback is suppressed by prescribing surface albedo, is compared to one where snow and sea ice anomalies are allowed to affect surface albedo. Canonical CO_2-doubling experiments were performed with both models to assess the impact of this feedback on equilibrium response to external forcing. It accounts for about half the high-latitude response to the forcing. Both models were also run for 1000 yr without forcing to assess the impact of surface albedo feedback on internal variability. Surprisingly little internal variability can be attributed to this feedback, except in the Northern Hemisphere continents during spring and in the sea ice zone of the Southern Hemisphere year round. At these locations and during these seasons, it accounts for, at most, 20% of the variability. The main reason for this relatively weak signal is that horizontal damping processes dilute the impact of surface albedo feedback. When snow albedo feedback in Northern Hemisphere continents is isolated from horizontal damping processes, it has a similar strength in the CO_2-doubling and internal variability contexts; a given temperature anomaly in these regions is associated with approximately the same change in snow depth and surface albedo whether it was externally forced or internally generated. This suggests that the presence of internal variability in the observed record is not a barrier to extracting information about snow albedo feedback's contribution to equilibrium climate sensitivity. This is demonstrated in principle in a ''scenario run,'' where estimates of past, present, and future changes in greenhouse gases and sulfate aerosols are imposed on the model with surface albedo feedback. This simulation contains a mix of internal variations and externally forced anomalies similar to the observed record. The snow albedo feedback to the scenario run's climate anomalies agrees very well with the snow albedo feedback in the CO_2-doubling context. Moreover, the portion of the scenario run corresponding to the present day satellite record is long enough to capture this feedback, suggesting this record could be used to estimate snow albedo feedback's contribution to equilibrium climate sensitivity.

Hamme, R. C., P. W. Webley, et al. (2010). "Volcanic ash fuels anomalous plankton bloom in subarctic northeast Pacific." Geophysical Research Letters **37**: L19604-L19604 DOI: 10.1029/2010gl044629

Available at: http://www.agu.org/pubs/crossref/2010/2010GL044629.shtml

Using multiple lines of evidence, we demonstrate that volcanic ash deposition in August 2008 initiated one of the largest phytoplankton blooms observed in the subarctic North Pacific. Unusually widespread transport from a volcanic eruption in the Aleutian Islands, Alaska deposited ash over much of the subarctic NE Pacific, followed by large increases in satellite chlorophyll. Surface ocean pCO2, pH, and fluorescence reveal that the bloom started a few days after ashfall. Ship based measurements showed increased dominance by diatoms. This evidence points toward fertilization of this normally iron limited region by ash, a relatively new mechanism proposed for iron supply to the ocean. The observations do not support other possible mechanisms. Extrapolation of the pCO2 data to the area of the bloom suggests a modest ~0.01 Pg carbon export from this event, implying that even large scale iron fertilization at an optimum time of year is not very efficient at sequestering atmospheric CO2.

Hansen, P. (2002). "Effect of high pH on the growth and survival of marine phytoplankton: implications for species succession." Aquatic Microbial Ecology **28**: 279-288 DOI: 10.3354/ame028279

Open Access Article* Available at: http://www.int-res.com/abstracts/ame/v28/n3/p279-288/

Ten years of pH measurements (1990 to 1999) in the surface waters of the eutrophic Mariager Fjord, Denmark, revealed profound seasonal variation. Typically, pH was relatively constant around 8 from January to March, increased during spring, reached maximum levels in July to August (9 to 9.7), and declined during autumn to about 8 in October. The influence of pH on the growth rate of phytoplankton was tested on 3 species (*Ceratium lineatum*, *Heterocapsa triquetra* and *Prorocentrum minimum*) in laboratory experiments. The growth rate was highest at pH 7.5 to 8.0 in all species. The growth rate of *C. lineatum* declined by ~20% at pH 8.3 to 8.5, while a similar reduction in the growth rate in *H. triquetra* and *P. minimum* was observed at pH 8.8 to 8.9. *C. lineatum* stopped growing above pH 8.8, while growth ceased at about pH 9.45 in *H. triquetra* and 9.6 in *P. minimum*. Compilation of literature data on pH and phytoplankton growth suggested that while some species cannot grow at

pH 8.4, others are able to grow up to pH 10. However, none of the species studied can attain their maximum growth rate above pH 9. Competition experiments using a mixture *of C. lineatum, H. triquetra* and *P. minimum* always resulted in the species with the highest pH tolerance (*P. minimum*) outcompeting the other species, irrespective of the initial pH value. The role of high pH in the succession of marine phytoplankton in nature is discussed.

Hansen, J., M. Sato, et al. (2011). "Climate Variability and Climate Change : The New Climate Dice." Most: 1-12
Open Access Article* Available at: http://www.columbia.edu/~jeh1/mailings/2011/20111110_NewClimateDice.pdf

Hansen, J., M. Sato, et al. (2008). "Target Atmospheric CO2: Where Should Humanity Aim?" The Open Atmospheric Science Journal **2**: 217-231 DOI: 10.2174/1874282300802010217
Open Access Article* Available at:
http://benthamscience.com/open/openaccess.php?toascj/articles/V002/217TOASCJ.htm
Paleoclimate data show that climate sensitivity is ~3°C for doubled CO2, including only fast feedback processes. Equilibrium sensitivity, including slower surface albedo feedbacks, is ~6°C for doubled CO2 for the range of climate states between glacial conditions and ice-free Antarctica. Decreasing CO2 was the main cause of a cooling trend that began 50 million years ago, the planet being nearly ice-free until CO2 fell to 450 ± 100 ppm; barring prompt policy changes, that critical level will be passed, in the opposite direction, within decades. If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO2 will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that. The largest uncertainty in the target arises from possible changes of non-CO2 forcings. An initial 350 ppm CO2 target may be achievable by phasing out coal use except where CO2 is captured and adopting agricultural and forestry practices that sequester carbon. If the present overshoot of this target CO2 is not brief, there is a possibility of seeding irreversible catastrophic effects.

Harvey, L. D. D. (2008). "Mitigating the atmospheric CO 2 increase and ocean acidification by adding limestone powder to upwelling regions." Journal of Geophysical Research **113**: 1-21 DOI: 10.1029/2007jc004373
Available at: http://www.agu.org/pubs/crossref/2008/2007JC004373.shtml
The feasibility of enhancing the absorption of CO_2 from the atmosphere by adding calcium carbonate ($CaCO_3$) powder to the ocean and of partially reversing the acidification of the ocean and the decrease in calcite supersaturation resulting from the absorption of anthropogenic CO_2 is investigated. $CaCO_3$ could be added to the surface layer in regions where the depth of the boundary between supersaturated and unsaturated water is relatively shallow (250–500 m) and where the upwelling velocity is large (30–300 m a−1). The $CaCO_3$ would dissolve within a few 100 m depth below the saturation horizon, and the dissolution products would enter the mixed layer within a few years to decades, facilitating further absorption of CO_2 from the atmosphere. This absorption of CO_2 would largely offset the increase in mixed layer pH and carbonate supersaturation resulting from the upwelling of dissolved limestone powder. However, if done on a large scale, the reduction in atmospheric CO_2 due to absorption of CO_2 by the ocean would reduce the amount of CO_2 that needs to be absorbed by the mixed layer, thereby allowing a larger net increase in pH and in supersaturation in the regions receiving $CaCO_3$. At the same time, the reduction in atmospheric pCO2 would cause outgassing of CO_2 from ocean regions not subject to addition of $CaCO_3$, thereby increasing the pH and supersaturation in these regions as well. Geographically optimal application of 4 billion t of CaCO3 a−1 (0.48 Gt C a−1) could induce absorption of atmospheric CO_2 at a rate of 600 Mt CO_2 a−1 after 50 years, 900 Mt CO_2 a−1 after 100 years, and 1050 Mt CO_2 a−1 after 200 years.

Heckendorn, P., D. Weisenstein, et al. (2009). "The impact of geoengineering aerosols on stratospheric temperature and ozone." Environmental Research Letters **4**: 045108-045108 DOI: 10.1088/1748-9326/4/4/045108
Open Access Article* Available at:
http://stacks.iop.org/1748-9326/4/i=4/a=045108?key=crossref.dade9338b483538df3be60e23373263c
Anthropogenic greenhouse gas emissions are warming the global climate at an unprecedented rate. Significant emission reductions will be required soon to avoid a rapid temperature rise. As a potential interim measure to avoid extreme temperature increase, it has been suggested that Earth's albedo be increased by artificially enhancing stratospheric sulfate aerosols. We use a 3D chemistry climate model, fed by aerosol size distributions from a zonal mean aerosol model, to simulate continuous injection of 1–10 Mt/a into the lower tropical stratosphere. In contrast to the case for all previous work, the particles are predicted to grow to larger sizes than are observed after volcanic eruptions. The reason is the continuous supply of sulfuric acid and hence freshly

formed small aerosol particles, which enhance the formation of large aerosol particles by coagulation and, to a lesser extent, by condensation. Owing to their large size, these particles have a reduced albedo. Furthermore, their sedimentation results in a non-linear relationship between stratospheric aerosol burden and annual injection, leading to a reduction of the targeted cooling. More importantly, the sedimenting particles heat the tropical cold point tropopause and, hence, the stratospheric entry mixing ratio of H2O increases. Therefore, geoengineering by means of sulfate aerosols is predicted to accelerate the hydroxyl catalyzed ozone destruction cycles and cause a significant depletion of the ozone layer even though future halogen concentrations will be significantly reduced.

Hoegh-Guldberg, O. and J. F. Bruno (2010). "The impact of climate change on the world's marine ecosystems." Science **328**: 1523-1528 DOI: 10.1126/science.1189930

Open Access Article* Available at: http://www.sciencemag.org/content/328/5985/1523.short

Marine ecosystems are centrally important to the biology of the planet, yet a comprehensive understanding of how anthropogenic climate change is affecting them has been poorly developed. Recent studies indicate that rapidly rising greenhouse gas concentrations are driving ocean systems toward conditions not seen for millions of years, with an associated risk of fundamental and irreversible ecological transformation. The impacts of anthropogenic climate change so far include decreased ocean productivity, altered food web dynamics, reduced abundance of habitat-forming species, shifting species distributions, and a greater incidence of disease. Although there is considerable uncertainty about the spatial and temporal details, climate change is clearly and fundamentally altering ocean ecosystems. Further change will continue to create enormous challenges and costs for societies worldwide, particularly those in developing countries.

Hoegh-Guldberg, O., L. Hughes, et al. (2008). "Ecology. Assisted colonization and rapid climate change." Science **321**: 345-346 DOI: 10.1126/science.1157897

Available at: http://www.sciencemag.org/content/321/5887/345.short

Horton, J. B. (2011). “Geoengineering and the Myth of Unilateralism : Pressures and Prospects for International Cooperation”. Stanford Journal of Law, Science & Policy **IV**: 56-69

Open Access Article* Available at: http://media.cigionline.org/geoeng/2011 - Horton - Geoengineering and the Myth of Unilateralism Pressures and Prospects for International Cooperation.pdf

House of Commons Science and Technology Committee (2010). “The Regulation of Geoengineering”. Fifth Report of Session 2009–10

Open Access Article* Available at:

http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/221.pdf

Geoengineering describes activities specifically and deliberately designed to effect a change in the global climate with the aim of minimising or reversing anthropogenic (that is human caused) climate change. Geoengineering covers many techniques and technologies but splits into two broad categories: those that remove carbon dioxide from the atmosphere such as sequestering and locking carbon dioxide in geological formations; and those that reflect solar radiation. Techniques in this category include the injection of sulphate aerosols into the stratosphere to mimic the cooling effect caused by large volcanic eruptions.

The technologies and techniques vary so much that any regulatory framework for geoengineering cannot be uniform. Instead, those techniques, particularly carbon removal, that are closely related to familiar existing technologies, could be regulated by developing the international regulation of the existing regimes to encompass geoengineering. For other technologies, especially solar refection, new regulatory arrangements will have to be developed.

There are three reasons why, we believe, regulation is needed. First, in the future some geoengineering techniques may allow a single country unilaterally to affect the climate. Second, some—albeit very small scale—geoengineering testing is already underway. Third, we may need geoengineering as a “Plan B” if, in the event of the failure of “Plan A”—the reduction of greenhouse gases—we are faced with highly disruptive climate change. If we start work now it will provide the opportunity to explore fully the technological, environmental, political and regulatory issues.

We are not calling for an international treaty but for the groundwork for regulatory arrangements to begin. Geoengineering techniques should be graded with consideration to factors such as trans-boundary effect, the dispersal of potentially hazardous materials in the environment and the direct effect on ecosystems. The regulatory regimes for geoengineering should then be tailored accordingly. The controls should be based on a set of principles that command widespread agreement—for example, the disclosure of geoengineering research and

open publication of results and the development of governance arrangements before the deployment of geoengineering techniques. The UN is the route by which, eventually, we envisage the regulatory framework operating but first the UK and other governments need to push geoengineering up the international agenda and get processes moving. This inquiry was innovative in that we worked collaboratively with the US House of Representatives Science and Technology Committee, the first international joint working of this kind for a House of Commons select committee. We found the experience constructive and rewarding and, we hope, successful. We are enthusiastic supporters of collaborative working between national legislatures on topics such as geoengineering with international reach. Our Report covering the regulation of geoengineering will now dovetail into a wider inquiry that the House of Representatives Committee is carrying out on geoengineering. Science, technology and engineering are key to solving global challenges and we commend to our successor committee international collaboration as an innovative way to meet these challenges

House, K. Z., A.C. Baclig, et al. (2011) . Economic and energetic analysis of capturing CO_2 from ambient air. PNAS Published online before print December 5, 2011, doi: 10.1073/pnas.1012253108
Available at:

Capturing carbon dioxide from the atmosphere ("air capture") in an industrial process has been proposed as an option for stabilizing global CO_2 concentrations. Published analyses suggest these air capture systems may cost a few hundred dollars per tonne of CO_2, making it cost competitive with mainstream CO_2 mitigation options like renewable energy, nuclear power, and carbon dioxide capture and storage from large CO_2 emitting point sources. We investigate the thermodynamic efficiencies of commercial separation systems as well as trace gas removal systems to better understand and constrain the energy requirements and costs of these air capture systems. Our empirical analyses of operating commercial processes suggest that the energetic and financial costs of capturing CO_2 from the air are likely to have been underestimated. Specifically, our analysis of existing gas separation systems suggests that, unless air capture significantly outperforms these systems, it is likely to require more than 400 kJ of work per mole of CO_2, requiring it to be powered by CO_2-neutral power sources in order to be CO_2 negative. We estimate that total system costs of an air capture system will be on the order of $1,000 per tonne of CO_2, based on experience with as-built large-scale trace gas removal systems.

House, K. Z., C. H. House, et al. (2007). "Electrochemical acceleration of chemical weathering as an energetically feasible approach to mitigating anthropogenic climate change." Environmental science & technology **41**: 8464-8470
Open Access Article* Available at: http://pubs.acs.org/doi/full/10.1021/es0701816

We describe an approach to CO_2 capture and storage from the atmosphere that involves enhancing the solubility of CO_2 in the ocean by a process equivalent to the natural silicate weathering reaction. HCl is electrochemically removed from the ocean and neutralized through reaction with silicate rocks. The increase in ocean alkalinity resulting from the removal of HCI causes atmospheric CO_2 to dissolve into the ocean where it will be stored primarily as HCO_3- without further acidifying the ocean. On timescales of hundreds of years or longer, some of the additional alkalinity will likely lead to precipitation or enhanced preservation of $CaCO_3$, resulting in the permanent storage of the associated carbon, and the return of an equal amount of carbon to the atmosphere. Whereas the natural silicate weathering process is effected primarily by carbonic acid, the engineered process accelerates the weathering kinetics to industrial rates by replacing this weak acid with HCI. In the thermodynamic limit--and with the appropriate silicate rocks--the overall reaction is spontaneous. A range of efficiency scenarios indicates that the process should require 100-400 kJ of work per mol of CO_2 captured and stored for relevant timescales. The process can be powered from stranded energy sources too remote to be useful for the direct needs of population centers. It may also be useful on a regional scale for protection of coral reefs from further ocean acidification. Application of this technology may involve neutralizing the alkaline solution that is coproduced with HCI with CO_2 from a point source or from the atmosphere prior to being returned to the ocean.

House, K. Z., D. P. Schrag, et al. (2006). "Permanent carbon dioxide storage in deep-sea sediments." Proceedings of the National Academy of Sciences of the United States of America **103**: 12291-12295 DOI: 10.1073/pnas.0605318103
Open Access Article* Available at:
http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1567873&tool=pmcentrez&rendertype=abstract

Stabilizing the concentration of atmospheric CO(2) may require storing enormous quantities of captured anthropogenic CO(2) in near-permanent geologic reservoirs. Because of the subsurface temperature profile of terrestrial storage sites, CO(2) stored in these reservoirs is buoyant. As a result, a portion of the injected CO(2) can escape if the reservoir is not appropriately sealed. We show that injecting CO(2) into deep-sea sediments below [corrected] 3,000-m water depth and a few hundred meters of sediment provides permanent geologic storage even with large geomechanical perturbations. At the high pressures and low temperatures common in

deep-sea sediments, CO(2) resides in its liquid phase and can be denser than the overlying pore fluid, causing the injected CO(2) to be gravitationally stable. Additionally, CO(2) hydrate formation will impede the flow of CO(2)(l) and serve as a second cap on the system. The evolution of the CO(2) plume is described qualitatively from the injection to the formation of CO(2) hydrates and finally to the dilution of the CO(2)(aq) solution by diffusion. If calcareous sediments are chosen, then the dissolution of carbonate host rock by the CO(2)(aq) solution will slightly increase porosity, which may cause large increases in permeability. Karst formation, however, is unlikely because total dissolution is limited to only a few percent of the rock volume. The total CO(2) storage capacity within the 200-mile economic zone of the U.S. coastline is enormous, capable of storing thousands of years of current U.S. CO(2) emissions.

Hsiang, S. M., K. C. Meng, et al. (2011). "Civil conflicts are associated with the global climate." Nature **476**: 438-441 DOI: 10.1038/nature10311

Available at: http://www.nature.com/doifinder/10.1038/nature10311

It has been proposed that changes in global climate have been responsible for episodes of widespread violence and even the collapse of civilizations. Yet previous studies have not shown that violence can be attributed to the global climate, only that random weather events might be correlated with conflict in some cases. Here we directly associate planetary-scale climate changes with global patterns of civil conflict by examining the dominant interannual mode of the modern climate, the El Niño/Southern Oscillation (ENSO). Historians have argued that ENSO may have driven global patterns of civil conflict in the distant past, a hypothesis that we extend to the modern era and test quantitatively. Using data from 1950 to 2004, we show that the probability of new civil conflicts arising throughout the tropics doubles during El Niño years relative to La Niña years. This result, which indicates that ENSO may have had a role in 21% of all civil conflicts since 1950, is the first demonstration that the stability of modern societies relates strongly to the global climate.

Huang, W., P. Zhou, et al. (2010). "A bright water: Hydrosols, Water Conservation and Climate Change." Journal of environmental monitoring : JEM **11**: 330-335 DOI: 10.1039/b814890m

Open Access Article* Available at: http://www.springerlink.com/content/672772206p58k1wr/

Since air-water and water-air interfaces are equally refractive, cloud droplets and microbubbles dispersed in bodies of water reflect sunlight in much the same way. The lifetime of sunlight-reflecting microbubbles, and hence the scale on which they may be applied, depends on Stokes Law and the influence of ambient or added surfactants. Small bubbles backscatter light more efficiently than large ones, opening the possibility of using highly dilute micron-radius hydrosols to substantially brighten surface waters. Such microbubbles can noticeably increase water surface reflectivity, even at volume fractions of parts per million and such loadings can be created at an energy cost as low as J m-2 to initiate and milliwatts m-2 to sustain. Increasing water albedo in this way can reduce solar energy absorption by as much as 100 W m-2, potentially reducing equilibrium temperatures of standing water bodies by several Kelvins. While aerosols injected into the stratosphere tend to alter climate globally, hydrosols can be used to modulate surface albedo, locally and reversibly, without risk of degrading the ozone layer or altering the color of the sky. The low energy cost of microbubbles suggests a new approach to solar radiation management in water conservation and geoengineering: Don’t dim the Sun; Brighten the water.

Huntingford, C., P. M. Cox, et al. (2011). "Highly contrasting effects of different climate forcing agents on terrestrial ecosystem services." Philosophical Transactions of the Royal Society A **369**: 2026-2037 DOI: 10.1098/rsta.2010.0314

Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/369/1943/2026.long

Many atmospheric constituents besides carbon dioxide (CO(2)) contribute to global warming, and it is common to compare their influence on climate in terms of radiative forcing, which measures their impact on the planetary energy budget. A number of recent studies have shown that many radiatively active constituents also have important impacts on the physiological functioning of ecosystems, and thus the 'ecosystem services' that humankind relies upon. CO(2) increases have most probably increased river runoff and had generally positive impacts on plant growth where nutrients are non-limiting, whereas increases in near-surface ozone (O(3)) are very detrimental to plant productivity. Atmospheric aerosols increase the fraction of surface diffuse light, which is beneficial for plant growth. To illustrate these differences, we present the impact on net primary productivity and runoff of higher CO(2), higher near-surface O(3), and lower sulphate aerosols, and for equivalent changes in radiative forcing. We compare this with the impact of climate change alone, arising, for example, from a physiologically inactive gas such as methane (CH(4)). For equivalent levels of change in radiative forcing, we show that the combined climate and physiological impacts of these individual agents vary markedly and in some cases actually differ in sign. This study highlights the need to develop more informative metrics of the impact of

changing atmospheric constituents that go beyond simple radiative forcing.

IAASTD (2008). International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) Executive Summary of the Synthesis Report.
Open Access Article* Available at: http://www.agassessment.org/docs/SR_Exec_Sum_280508_English.htm

I. C. F. Consulting (2006). Human Health Benefits of Stratospheric Ozone Protection. Washington, DC.
Open Access Article* Available at: www.epa.gov/ozone/science/effects/AHEFApr2006.pdf

IPCC (2000). Emissions Scenarios. Cambridge, United Kingdom, Cambridge University Press.
Open Access Article* Available at: http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0

IPCC (2001). Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge,United Kingdom, and New York, NY, USA, Cambridge University Press.
Open Access Article* Available at: http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html

IPCC (2005). Special Report on Carbon Dioxide Capture and Storage - Prepared by Working Group III of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.
Open Access Article* Available at: http://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf

IPCC (2007). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, USA., Cambridge University Press.
Open Access Article* Available at: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

IPCC (2007). Climate Change 2007 – Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland, IPCC.
Open Access Article* Available at: http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html

Irvine, P. J., D. J. Lunt, et al. (2009). "The fate of the Greenland Ice Sheet in a geoengineered, high CO 2 world." Environmental Research Letters **4**: 045109-045109 DOI: 10.1088/1748-9326/4/4/045109
Open Access Article* Available at:
http://stacks.iop.org/1748-9326/4/i=4/a=045109?key=crossref.b08f7e648632a600a4d840c4463134f2
Solar radiation management (SRM) geoengineering has been proposed as one means of helping avoid the occurrence of dangerous climate change and undesirable state transitions (‘tipping points’) in the Earth system. The irreversible melting of the Greenland Ice Sheet is a case in point—a state transition that could occur as a result of CO2-driven elevated global temperatures, and one leading to potentially catastrophic sea-level rise. SRMschemes such as the creation of a ‘sunshade’ or injection of sulfate aerosols into the stratosphere could reduce incoming solar radiation, and in theory balance, in a global mean, the greenhouse warming resulting from elevated concentrations of CO2 in the atmosphere. Previous work has highlighted that a geoengineered world would have: warming towards the poles, cooling in the tropics, and a reduction in the global hydrological cycle, which may have important implications for the Greenland Ice Sheet. Using a fully coupled global climate model in conjunction with an ice sheet model, we assess the consequences for the mass balance of the Greenland Ice Sheet of the reorganization of climate patterns by the combination of high CO2 and geoengineering. We find that Greenland surface temperature and precipitation anomalies, compared to the pre-industrial situation, decrease almost linearly with increasing levels of SRM geoengineering, but that these combine to create a highly non-linear response of the ice sheet. The substantial melting of the Greenland Ice Sheet predicted for four times pre-industrial CO2 levels is prevented in our model with only a partial application of SRM, and hence without having to fully restore the global average temperature back to pre-industrial levels. This suggests that the degree of SRM geoengineering required to mitigate the worst impacts of greenhouse warming, such as sea-level rise, need not be as extensive as generally assumed.

Irving, A. D., S. D. Connell, et al. (2011). "Restoring coastal plants to improve global carbon storage: reaping what we sow." PloS one **6**: e18311-e18311 DOI: 10.1371/journal.pone.0018311
Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3066232&tool=pmcentrez&rendertype=abstract

Long-term carbon capture and storage (CCS) is currently considered a viable strategy for mitigating rising levels of atmospheric CO(2) and associated impacts of global climate change. Until recently, the significant below-ground CCS capacity of coastal vegetation such as seagrasses, salt marshes, and mangroves has largely gone unrecognized in models of global carbon transfer. However, this reservoir of natural, free, and sustainable carbon storage potential is increasingly jeopardized by alarming trends in coastal habitat loss, totalling 30-50% of global abundance over the last century alone. Human intervention to restore lost habitats is a potentially powerful solution to improve natural rates of global CCS, but data suggest this approach is unlikely to substantially improve long-term CCS unless current restoration efforts are increased to an industrial scale. Failure to do so raises the question of whether resources currently used for expensive and time-consuming restoration projects would be more wisely invested in arresting further habitat loss and encouraging natural recovery.

Irvine, P. J., A. Ridgwell, et al. (2010). "Assessing the regional disparities in geoengineering impacts." Geophysical Research Letters **37**: 1-6 DOI: 10.1029/2010gl044447

Available at: http://www.agu.org/pubs/crossref/2010/2010GL044447.shtml

Solar Radiation Management (SRM) Geoengineering may ameliorate many consequences of global warming but also has the potential to drive regional climates outside the envelope of greenhouse-gas induced warming, creating 'novel' conditions, and could affect precipitation in some regions disproportionably. Here, using a fully coupled climate model we explore some new methodologies for assessing regional disparities in geoengineering impacts. Taking a $4 \times CO_2$ climate and an idealized 'sunshade' SRM strategy, we consider different fractions of the maximum theoretical, $4 \times CO_2$-cancelling global mean cooling. Whilst regional predictions in particularly relatively low resolution global climate models must be treated with caution, our simulations indicate that it might be possible to identify a level of SRM geoengineering capable of meeting multiple targets, such as maintaining a stable mass balance of the Greenland ice sheet and cooling global climate, but without reducing global precipitation below pre-industrial or exposing significant fractions of the Earth to 'novel' climate conditions.

Irvine, P., A. Ridgwell, et al. (2010). "What Is The Optimal Level of Solar Radiation Management ?" Geophysical Research Abstracts **12**

Open Access Article* Available at : http://meetingorganizer.copernicus.org/EGU2010/EGU2010-5986.pdf

Isbell, F., V. Calcagno, et al. (2011). "High plant diversity is needed to maintain ecosystem services." Nature **477**: 199-202 DOI: 10.1038/nature10282

Available at: http://www.nature.com/doifinder/10.1038/nature10282

Biodiversity is rapidly declining worldwide1, and there is consensus that this can decrease ecosystem functioning and services. It remains unclear, though, whether few8 or many9 of the species in an ecosystem are needed to sustain the provisioning of ecosystem services. It has been hypothesized that most species would promote ecosystem services if many times, places, functions and environmental changes were considered9; however, no previous study has considered all of these factors together. Here we show that 84% of the 147 grassland plant species studied in 17 biodiversity experiments promoted ecosystem functioning at least once. Different species promoted ecosystem functioning during different years, at different places, for different functions and under different environmental change scenarios. Furthermore, the species needed to provide one function during multiple years were not the same as those needed to provide multiple functions within one year. Our results indicate that even more species will be needed to maintain ecosystem functioning and services than previously suggested by studies that have either (1) considered only the number of species needed to promote one function under one set of environmental conditions, or (2) separately considered the importance of biodiversity for providing ecosystem functioning across multiple years, places, functions or environmental change scenarios. Therefore, although species may appear functionally redundant when one function is considered under one set of environmental conditions, many species are needed to maintain multiple functions at multiple times and places in a changing world.

Ito, A. (2011). "Mega fire emissions in Siberia: potential supply of soluble iron from forests to the ocean." Biogeosciences Discussions **8**: 1483-1527 DOI: 10.5194/bgd-8-1483-2011

Available at: http://www.biogeosciences-discuss.net/8/1483/2011/

Significant amounts of carbon and nutrients are released to the atmosphere due to large fires in forests. Characterization of the spatial distribution and temporal variation of the intense fire emissions is crucial for assessing the atmospheric loadings of aerosols and trace gases. This paper discusses issues of the representation of forest fires in the estimation of emissions and the application to an atmospheric chemistry transport model (CTM).

The potential contribution of forest fires to the deposition of soluble iron (Fe) into the ocean is highlighted, with a focus on mega fires in eastern Siberia. Satellite products of burned area, active fire, and land cover are used to estimate biomass burning emissions in conjunction with a biogeochemical model. Satellite-derived plume height from MISR is used for the injection height of boreal forest fire emissions. This methodology is applied to quantify fire emission rates in each three-dimensional grid location in the high latitude Northern Hemisphere (> 30° N latitude) over a 5-year period from 2001 to 2005. There is large interannual variation in forest burned area during 2001-2005 (13-51 × 103 km2 yr-1) which results in a corresponding variation in the annual emissions of carbon monoxide (CO) (12-78 Tg CO yr-1). Satellite observations of CO from MOPITT are used to evaluate the model performance in simulating the spatial distribution and temporal variation of the fire emissions. During the major Siberian fire seasons in the summer of 2002 and in the spring of 2003, the model results for CO enhancements due to intense fires are in good agreement with MOPITT observations. These fire emission rates are applied to the aerosol chemistry transport model to examine the relative importance of biomass burning sources of soluble iron compared to those from dust sources. Compared to the dust sources without the atmospheric processing by acidic species, extreme fire events contribute to a significant deposition of soluble iron (10-60%) to downwind regions over the western North Pacific Ocean. It may imply that the supply of nutrients from large forest fires plays a role as a negative biosphere-climate feedback with regards to the ocean fertilization.

Jackson, R. B., E. G. Jobbágy, et al. (2005). "Trading water for carbon with biological carbon sequestration." Science **310**: 1944-1947 DOI: 10.1126/science.1119282

Open Access Article* Available at: http://www.sciencemag.org/content/310/5756/1944.long

Carbon sequestration strategies highlight tree plantations without considering their full environmental consequences. We combined field research, synthesis of more than 600 observations, and climate and economic modeling to document substantial losses in stream flow, and increased soil salinization and acidification, with afforestation. Plantations decreased stream flow by 227 millimeters per year globally (52%), with 13% of streams drying completely for at least 1 year. Regional modeling of U.S. plantation scenarios suggests that climate feedbacks are unlikely to offset such water losses and could exacerbate them. Plantations can help control groundwater recharge and upwelling but reduce stream flow and salinize and acidify some soils.

Jackson, S. T. and J. T. Overpeck (2000). "Responses of plant populations and communities to environmental changes of the late Quaternary environmental changes of the late Quaternary." Paleobiology **26**: 194-220 DOI: 10.1666/0094-8373(2000)26

Available at: http://www.bioone.org/doi/abs/10.1666/0094-8373%282000%2926%5B194:ROPPAC%5D2.0.CO%3B2

The environmental and biotic history of the late Quaternary represents a critical junction between ecology, global change studies, and pre-Quaternary paleobiology. Late Quaternary records indicate the modes and mechanisms of environmental variation and biotic responses at timescales of 101–104 years. Climatic changes of the late Quaternary have occurred continuously across a wide range of temporal scales, with the magnitude of change generally increasing with time span. Responses of terrestrial plant populations have ranged from tolerance in situ to moderate shifts in habitat to migration and/or extinction, depending on magnitudes and rates of environmental change. Species assemblages have been disaggregated and recombined, forming a changing array of vegetation patterns on the landscape. These patterns of change are characteristic of terrestrial plants and animals but may not be representative of all other life-forms or habitats. Complexity of response, particularly extent of species recombination, depends in part on the nature of the underlying environmental gradients and how they change through time. Environmental gradients in certain habitats may change in relatively simple fashion, allowing long-term persistence of species associations and spatial patterns. Consideration of late Quaternary climatic changes indicates that both the rate and magnitude of climatic changes anticipated for the coming century are unprecedented, presenting unique challenges to the biota of the planet.

Jasanoff, S. (2003). Technologies of Humility: Citizen participation in governing Science.

Open Access Article* Available at: http://sciencepolicy.colorado.edu/students/envs_5100/jasanoff2003.pdf

Jin, X., N. Gruber, et al. (2008). "The impact on atmospheric CO2 of iron fertilization induced changes in the ocean's biological pump." Biogeosciences **5**: 385-406 DOI: 10.5194/bg-5-385-2008

Open Access Article* Available at: http://www.biogeosciences.net/5/385/2008/

Using numerical simulations, we quantify the impact of changes in the ocean’s biological pump on the air-sea balance of CO2 by fertilizing a small surface patch in the high-nutrient, low-chlorophyll region of the eastern tropical Pacific with iron. Decade-long fertilization experiments are conducted in a basin-scale, eddy-permitting

coupled physical/biogeochemical/ecological model. In contrast to previous studies, we find that most of the dissolved inorganic car- bon (DIC) removed from the euphotic zone by the enhanced biological export is replaced by uptake of CO2 from the atmosphere. Atmospheric uptake efficiencies, the ratio of the perturbation in air-sea CO2 flux to the perturbation in export flux across 100 m, integrated over 10 years, are 0.75 to 0.93 in our patch size-scale experiments. The atmospheric uptake efficiency is insensitive to the duration of the experiment. The primary factor controlling the atmospheric uptake efficiency is the vertical distribution of the enhanced biological production and export. Iron fertilization at the surface tends to induce production anomalies primarily near the surface, leading to high efficiencies. In contrast, mechanisms that in- duce deep production anomalies (e.g. altered light availability) tend to have a low uptake efficiency, since most of the removed DIC is replaced by lateral and vertical transport and mixing. Despite high atmospheric uptake efficiencies, patch- scale iron fertilization of the ocean's biological pump tends to remove little CO2 from the atmosphere over the decadal timescale considered here.

Joint, I., S. C. Doney, et al. (2011). "Will ocean acidification affect marine microbes?" The ISME journal **5**: 1-7 DOI: 10.1038/ismej.2010.79

Open Access Article* Available at: http://www.nature.com/ismej/journal/v5/n1/full/ismej201079a.html

The pH of the surface ocean is changing as a result of increases in atmospheric carbon dioxide (CO(2)), and there are concerns about potential impacts of lower pH and associated alterations in seawater carbonate chemistry on the biogeochemical processes in the ocean. However, it is important to place these changes within the context of pH in the present-day ocean, which is not constant; it varies systematically with season, depth and along productivity gradients. Yet this natural variability in pH has rarely been considered in assessments of the effect of ocean acidification on marine microbes. Surface pH can change as a consequence of microbial utilization and production of carbon dioxide, and to a lesser extent other microbially mediated processes such as nitrification. Useful comparisons can be made with microbes in other aquatic environments that readily accommodate very large and rapid pH change. For example, in many freshwater lakes, pH changes that are orders of magnitude greater than those projected for the twenty second century oceans can occur over periods of hours. Marine and freshwater assemblages have always experienced variable pH conditions. Therefore, an appropriate null hypothesis may be, until evidence is obtained to the contrary, that major biogeochemical processes in the oceans other than calcification will not be fundamentally different under future higher CO(2)/lower pH conditions.

Jones, I. S. F. (2011). "Contrasting micro- and macro-nutrient nourishment of the ocean." Marine Ecology Progress Series **425**: 281-296 DOI: 10.3354/meps08882

Open Access Article* Available at: http://www.int-res.com/abstracts/meps/v425/p281-296/

There have been suggestions that an increase in the productivity of the ocean would store more carbon in the ocean organic carbon cycle, as well as enhancing the higher trophic levels of the marine food web. Proposals have included fertilisation of regions low in one or more of nitrogen, phosphorus or iron, the latter being termed a micronutrient. Iron is available from mining, phosphorus from mining or artificially induced upwelling, and the provision of nitrogen involves using either cyanobacteria, the Haber-Bosch process or artificially induced upwelling. All these fertilisation methods can be effective in locally increasing new primary production, but the global impact varies because of iron scavenging, nutrient stealing or the role of regenerative primary production. Examination of these concepts leads to the conclusion that macronutrient nourishment supplied by the Haber-Bosch process is an attractive approach for slowing climate change and increasing marine productivity. The carbon storage capacity of nitrogen fertilisation appears to be limited by the supply of phosphorus to support additional new primary production.

Jones, A., J. Haywood, et al. (2011). "A comparison of the climate impacts of geoengineering by stratospheric SO2 injection and by brightening of marine stratocumulus cloud." Atmospheric Science Letters **12**: 176-183 DOI: 10.1002/asl.291

Available at: http://onlinelibrary.wiley.com/doi/10.1002/asl.291/full

We examine the climate impact of geoengineering via two different methods, namely, stratospheric SO2 injection and increasing reflectivity of marine stratocumulus clouds. Although both methods appear capable, in principle, of counteracting the global mean warming due to increases in greenhouse gas concentrations, significant changes in regional climate still result. The extent of this regional climate change appears linked to the location and degree of inhomogeneity of the radiative flux perturbations produced by each geoengineering method.

Jones, A., J. Haywood, et al. (2009). "Climate impacts of geoengineering marine stratocumulus clouds." Journal of

Geophysical Research **114**: D10106-D10106 DOI: 10.1029/2008jd011450
Available at: http://www.agu.org/pubs/crossref/2009/2008JD011450.shtml

Theoretical potential geoengineering solutions to the global warming problem have recently been proposed. Here, we present an idealized study of the climate response to deliberately seeding large-scale stratocumulus cloud decks in the North Pacific, South Pacific, and South Atlantic, thereby inducing cooling via aerosol indirect effects. Atmosphere-only, atmosphere/mixed-layer ocean, and fully coupled atmosphere/ocean versions of the Met Office Hadley Centre model are used to investigate the radiative forcing, climate efficacy, and regional response of temperature, precipitation, and net primary productivity to such geoengineering. The radiative forcing simulations indicate that, for our parameterization of aerosol indirect effects, up to 35% of the radiative forcing due to current levels of greenhouse gases could be offset by stratocumulus modification. Equilibrium simulations with the atmosphere/mixed-layer ocean model, wherein each of the three stratocumulus sheets is modified in turn, reveal that the most efficient cooling per unit radiative forcing occurs when the South Pacific stratocumulus sheet is modified. Transient coupled model simulations suggest that geoengineering all three stratocumulus areas delays the simulated global warming by about 25 years. These simulations also indicate that, while some areas experience increases in precipitation and net primary productivity, sharp decreases are simulated in South America, with particularly detrimental impacts on the Amazon rain forest. These results show that, while some areas benefit from geoengineering, there are significant areas where the response could be very detrimental with implications for the practical applicability of such a scheme.

Jones, A., J. Haywood, et al. (2010). "Geoengineering by stratospheric SO_2 injection: results from the Met Office HadGEM2 climate model and comparison with the Goddard Institute for Space Studies ModelE." Atmospheric Chemistry and Physics **10**: 5999-6006 DOI: 10.5194/acp-10-5999-2010
Open Access Article* Available at: http://www.atmos-chem-phys.net/10/5999/2010/

We examine the response of the Met Office Hadley Centre's HadGEM2-AO climate model to simulated geoengineering by continuous injection of SO_2 into the lower stratosphere, and compare the results with those from the Goddard Institute for Space Studies ModelE. The HadGEM2 simulations suggest that the SO_2 injection rate considered here (5 Tg[SO2] yr−1) could defer the amount of global warming predicted under the Intergovernmental Panel on Climate Change's A1B scenario by approximately 30–35 years, although both models indicate rapid warming if geoengineering is not sustained. We find a broadly similar geographic distribution of the response to geo engineering in both models in terms of near-surface air temperature and mean June- August precipitation. The simulations also suggest that significant changes in regional climate would be experienced even if geoengineering was successful in maintaining global-mean temperature near current values

Jones, C., J. Lowe, et al. (2009). "Committed terrestrial ecosystem changes due to climate change." Nature Geoscience **2**: 484-487 DOI: 10.1038/ngeo555
Available at: http://www.nature.com/doifinder/10.1038/ngeo555

Targets for stabilizing climate change are often based on considerations of the impacts of different levels of global warming, usually assessing the time of reaching a particular level of warming. However, some aspects of the Earth system, such as global mean temperatures1 and sea level rise due to thermal expansion2 or the melting of large ice sheets3, continue to respond long after the stabilization of radiative forcing. Here we use a coupled climate–vegetation model to show that in turn the terrestrial biosphere shows significant inertia in its response to climate change. We demonstrate that the global terrestrial biosphere can continue to change for decades after climate stabilization. We suggest that ecosystems can be committed to long-term change long before any response is observable: for example, we find that the risk of significant loss of forest cover in Amazonia rises rapidly for a global mean temperature rise above 2 °C. We conclude that such committed ecosystem changes must be considered in the definition of dangerous climate change, and subsequent policy development to avoid it.

Joos, F., T. L. Frölicher, et al. (2011). Impact of climate change mitigation on ocean acidification projections in Ocean Acidification. J.-P. Gattuso and L. Hansson. Oxford, United Kingdom, Oxford University Press**:** 272-290

Karl, D. and R. Letelier (2008). "Nitrogen fixation-enhanced carbon sequestration in low nitrate, low chlorophyll seascapes." Marine Ecology Progress Series **364**: 257-268 DOI: 10.3354/meps07547
Open Access Article* Available at: http://www.int-res.com/abstracts/meps/v364/p257-268/

The magnitude of fluxes in the carbon cycle of subtropical and tropical marine habitats is determined by the supply of inorganic nutrients. These habitats have low sea-surface concentrations of nitrate (NO_3 matter production and export, and represent global ocean minima in carbon sequestration potential. The low NO_3 –,

phosphate –) and chlorophyll (dubbed LNLC regions), sustain relatively low rates of organic – resupply should select for nitrogen (N_2)-fixing bacteria, termed diazotrophs, provided all other growth-limiting nutrients are available. Several recent field efforts have been aimed at enhancing N_2 fixation in LNLC regions through mesoscale fertilization with iron and phosphorus (or both) and we hypothesize herein that controlled upwelling of nutrient-enriched deep water may also be effective. Based on a quantitative assessment of the vertical distribution of NO_3 (PO_4 that the process of controlled upwelling of low NO3 3–) and dissolved inorganic carbon (DIC) at Station ALOHA (22°45' N, 158°W), we hypothesize –:PO4 3– seawater may lead to enhanced N_2 fixation, organic matter production and net carbon sequestration. Furthermore, based on a long-term (20 yr) data set from Station ALOHA, we predict that the upwelling of water from a depth of 300 to 350 m during summer months will trigger a 2-stage phytoplankton bloom. The first stage will be characterized by a NO3 quantitative NO_3 – -supported Redfield ratio (e.g. C106:N16:P by atoms) diatom bloom. Following removal, the residual PO4 3– from the low N:P (<16:1) upwelled nutrient pulse will stimulate a N_2-fixing bacterial bloom, leading to net sequestration of carbon. However, any strategic benefit of controlled upwelling for enhancing the long-term carbon sequestration will depend on the spatial and temporal uncoupling of organic matter production and remineralization, which is ultimately controlled by the microbial response to these perturbations.

Katz, J. I. (2010). "Stratospheric albedo modification." Energy & Environmental Science **3**: 1634-1634 DOI: 10.1039/c002441d

Available at: http://xlink.rsc.org/?DOI=c002441d

The possibility of offsetting greenhouse gas warming by introducing artificial aerosols into the stratosphere to increase the Earth's albedo has been widely discussed, but little attention has been given to the details of its implementation. It is usually assumed that the aerosols would be sulfuric acid droplets (hydrated sulfur trioxide), like natural volcanic aerosols. Other materials may be more advantageous, but sophisticated "engineered" particles probably cannot be produced in sufficient quantity. I consider a variety of possible injection vehicles. Aircraft are unlikely to have sufficient lift capability to the necessary altitudes, guns are inefficient, and exotic methods like balloons and chimneys face daunting difficulties. Simple rockets are proven and economical, and can deliver material to any desired altitude. Artificial injection begins at a much higher aerosol (or precursor) density than a volcanic plume, raising novel issues of chemical kinetics and particle agglomeration. Detailed experimental and theoretical investigation are required to establish the feasibility of stratospheric aerosol geoengineering. An appendix argues that natural, as well as anthropogenic, climate change may pose challenges that could be met by these methods.

Kauppi, P.E. and Sedjo, R. (2001). Technological and Economic Potential of Options to Enhance, Maintain, and Manage Biological Carbon Reservoirs and Geo-engineering. Climate Change (Mitigation): 301-343

Open Access Article* Available at: https://helda.helsinki.fi/handle/1975/316

Keith, D. W. (2000). " Geoengineering the Climate: History and Prospect 1." Annual Review of Energy and the Environment **25**: 245-284

Available at: http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.25.1.245

Geoengineering is the intentional large-scale manipulation of the environment, particularly manipulation that is intended to reduce undesired anthropogenic climate change. The post-war rise of climate and weather modification and the history of U.S. assessments of the CO2-climate problem is reviewed. Proposals to engineer the climate are shown to be an integral element of this history. Climate engineering is reviewed with an emphasis on recent developments, including low-mass space-based scattering systems for altering the planetary albedo, simulation of the climate's response to albedo modification, and new findings on iron fertilization in oceanic ecosystems. There is a continuum of human responses to the climate problem that vary in resemblance to hard geoengineering schemes such as space-based mirrors. The distinction between geoengineering and mitigation is therefore fuzzy.A definition is advanced that clarifies the distinction between geoengineering and industrial carbon management. Assessment of geoengineering is reviewed under various framings including economics, risk, politics, and environmental ethics. Finally, arguments are presented for the importance of explicit debate about the implications of countervailing measures such as geoengineering.

Keith, D. W. (2010). "Photophoretic levitation of engineered aerosols for geoengineering." Proceedings of the National Academy of Sciences of the United States of America **107**: 16428-16431 DOI: 10.1073/pnas.1009519107

Open Access Article* Available at:

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2944714&tool=pmcentrez&rendertype=abstract

Aerosols could be injected into the upper atmosphere to engineer the climate by scattering incident sunlight so as to produce a cooling tendency that may mitigate the risks posed by the accumulation of greenhouse gases. Analysis of climate engineering has focused on sulfate aerosols. Here I examine the possibility that engineered nanoparticles could exploit photophoretic forces, enabling more control over particle distribution and lifetime than is possible with sulfates, perhaps allowing climate engineering to be accomplished with fewer side effects. The use of electrostatic or magnetic materials enables a class of photophoretic forces not found in nature. Photophoretic levitation could loft particles above the stratosphere, reducing their capacity to interfere with ozone chemistry; and, by increasing particle lifetimes, it would reduce the need for continual replenishment of the aerosol. Moreover, particles might be engineered to drift poleward enabling albedo modification to be tailored to counter polar warming while minimizing the impact on equatorial climates.

Keith, D. W., M. Ha-Duong, et al. (2005). "Climate Strategy with Co2 Capture from the Air." Climatic Change **74**: 17-45 DOI: 10.1007/s10584-005-9026-x

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-005-9026-x

It is physically possible to captureCO2 directly from the air and immobilize it in geological structures. Air capture differs from conventional mitigation in three key aspects. First, it removes emissions from any part of the economy with equal ease or difficulty, so its cost provides an absolute cap on the cost of mitigation. Second, it permits reduction in concentrations faster than the natural carbon cycle: the effects of irreversibility are thus partly alleviated. Third, because it is weakly coupled to existing energy infrastructure, air capture may offer stronger economies of scale and smaller adjustment costs than the more conventional mitigation technologies. We assess the ultimate physical limits on the amount of energy and land required for air capture and describe two systems that might achieve air capture at prices under 200 and 500 $/tC using current technology. Like geoengineering, air capture limits the cost of a worst-case climate scenario. In an optimal sequential decision framework with uncertainty, existence of air capture decreases the need for near-term precautionary abatement. The long-term effect is the opposite; assuming that marginal costs of mitigation decrease with time while marginal climate change damages increase, then air capture increases long-run abatement. Air capture produces an environmental Kuznets curve, in which concentrations are returned to preindustrial levels.

Keith, D. W., E. Parson, et al. (2010). "Research on global sun block needed now." Nature **463**: 426-427 DOI: 10.1038/463426a

Available at: http://www.ncbi.nlm.nih.gov/pubmed/20110972

Geoengineering studies of solar-radiation management should begin urgently, argue David W. Keith, Edward Parson and M. Granger Morgan — before a rogue state decides to act alone. Summary •Field testing is required to understand the risks of solar-radiation management (SRM) •Linked activities must create norms and understanding for international governance of SRM •If SRM is unworkable, the sooner we know, the less moral hazard it poses.

Keller, K., D. McInerney, et al. (2008). "Carbon dioxide sequestration: how much and when?" Climatic Change **88**: 267-291 DOI: 10.1007/s10584-008-9417-x

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-008-9417-x

Carbon dioxide (CO_2) sequestration has been proposed as a key component in technological portfolios for managing anthropogenic climate change, since it may provide a faster and cheaper route to significant reductions in atmospheric CO_2 concentrations than abating CO_2 production. However, CO_2 sequestration is not a perfect substitute for CO_2 abatement because CO_2 may leak back into the atmosphere (thus imposing future climate change impacts) and because CO_2 sequestration requires energy (thus producing more CO_2 and depleting fossil fuel resources earlier). Here we use analytical and numerical models to assess the economic efficiency of CO_2 sequestration and analyze the optimal timing and extent of CO_2 sequestration. The economic efficiency factor of CO_2 sequestration can be expressed as the ratio of the marginal net benefits of sequestering CO_2 and avoiding CO_2 emissions. We derive an analytical solution for this efficiency factor for a simplified case in which we account for CO2 leakage, discounting, the additional fossil fuel requirement of CO_2 sequestration, and the growth rate of carbon taxes. In this analytical model, the economic efficiency of CO_2 sequestration decreases as the CO_2 tax growth rate, leakage rates and energy requirements for CO_2 sequestration increase. Increasing discount rates increases the economic efficiency factor. In this simple model, short-term sequestration methods, such as afforestation, can even have negative economic efficiencies. We use a more realistic integrated-assessment model to additionally account for potentially important effects such as learning-by-doing and socio-economic inertia on optimal strategies. We measure the economic efficiency of CO_2 sequestration by the ratio of the marginal costs of

CO_2 sequestration and CO_2 abatement along optimal trajectories.We show that the positive impacts of investments in CO_2 sequestration through the reduction of future marginal CO_2 sequestration costs and the alleviation of future inertia constraints can initially exceed the marginal sequestration costs. As a result, the economic efficiencies of CO_2 sequestration can exceed 100% and an optimal strategy will subsidize CO_2 sequestration that is initially more expensive than CO_2 abatement. The potential economic value of a feasible and acceptable CO_2 sequestration technology is equivalent – in the adopted utilitarian model – to a one-time investment of several percent of present gross world product. It is optimal in the chosen economic framework to sequester substantial CO_2 quantities into reservoirs with small or zero leakage, given published estimates of marginal costs and climate change impacts. The optimal CO_2 trajectories in the case of sequestration from air can approach the pre-industrial level, constituting geoengineering. Our analysis is silent on important questions (e.g., the effects of model and parametric uncertainty, the potential learning about these uncertainties, or ethical dimension of such geoengineering strategies), which need to be addressed before our findings can be translated into policy-relevant recommendations.

Keller, M., D. S. Schimel, et al. (2008). "A continental strategy for the National Ecological Observatory Network." Frontiers in Ecology and the Environment **6**: 282-284

Open Access Article* Available at: http://www.treesearch.fs.fed.us/pubs/30433

One of the great realizations of the past half-century in both biological and Earth sciences is that, throughout geologic time, life has been shaping the Earth's surface and regulating the chemistry of its oceans and atmosphere (eg Berkner and Marshall 1964). In the present Anthropocene Era (Crutzen and Steffen 2003; Ruddiman 2003), humanity is directly shaping the biosphere and physical environment, triggering potentially devastating and currently unpredictable consequences (Doney and Schimel 2007). While subtle interactions between the Earth's orbit, ocean circulation, and the biosphere have dominated climate feedbacks for eons, now human perturbations to the cycles of CO_2, other trace gases, and aerosols regulate the pace of climate change. Accompanying the biogeochemical perturbations are the vast changes resulting from biodiversity loss and a profound rearrangement of the biosphere due to species movements and invasions. Scientists and managers of biological resources require a stronger basis for forecasting the consequences of such changes.

Kenzelmann, P., D. Weissenstein, et al. (2009). "Geo-engineering side effects: Heating the tropical tropopause by sedimenting sulphur aerosol?" IOP Conference Series: Earth and Environmental Science **6**: 452017-452017 DOI: 10.1088/1755-1307/6/5/452017

Open Access Article* Available at:

http://stacks.iop.org/1755-1315/6/i=45/a=452017?key=crossref.4e75134aa088179a284755de9962013a

Anthropogenic greenhouse gas emissions tend to warm the global climate. Countermeasures must be taken in order to minimize the harm for humans and environment. Various geo-engineering ideas are currently discussed that might help in this respect, besides politically and socially difficult to achieve reductions of greenhouse gases. Crutzen [2006] initiated a lively scientific discussion by proposing to consider enhancing stratospheric sulphate aerosols. Sulphate aerosols may cool the Earth surface by reflecting solar short wave radiation back to space. A part of the anthropogenic climate warming might be compensated by increasing the amount of sulphate aerosols in the stratosphere, for example by sulphur injections. The scientific community is challenged to answer the question, whether we understand the involved processes enough to predict all important consequences of such a geo-engineering project. In nature tremendous enhancement of stratospheric aerosol could be observed after strong volcanic eruptions in the tropics. Mt. Pinatubo eruption in 1991 is the best observed eruption in the past. Up to 20 Mt of SO2 was blown to the stratosphere [Bluth et al., 1992]. A cooling of about 1.5 °K on surface was attributed to Mt. Pinatubo eruption [Robock, 2000 and references herein]. We investigate to which extent the effects on climate after Mt. Pinatubo eruption serve as an analogue for the consequences of geo-engineering. We present modelling results of Mt. Pinatubo and anthropogenic sulphur injections in the lower stratosphere with AER 2D aerosol model [Weisenstein et al. 1997, 1998, 2005] and chemistry climate model SOCOL [Egorova et. al 2005, Schraner et al. 2008]. Even if the main goal, the cooling of the global mean temperatures can be achieved by enhanced stratospheric aerosols, the possible side effects are considerable [e.g. Trenberth and Dai 2007, Robock et al. 2008, Solomon 1999]. One possible side effect of such a geo-engineering fix might be the warming of the tropical tropopause and consequently the increase of the amount of stratospheric water vapour. A scenario with continuous SO2 injections into the lower stratosphere may provide conditions for efficient condensation of H2SO4 onto pre-existing stratospheric aerosols, which subsequently grow to large sizes and sediment into the tropical tropopause region. The absorption of long wave radiation by the aerosol increase tropopause temperatures rise and as a consequence the entry mixing ratio of water vapour increases. However uncertainties in the

modelling are remarkable. Uncertainties in total sulphur mass, particle size distribution and resulting effect on optical properties after Mt. Pinatubo eruption plus the uncertainties of aerosol and climate models add up to uncertainties which should be taken as a warning. Do we really want to jeopardize Earth future on such high uncertainties?

Kheshgi, H. S. (1995). "Sequestering Atmospheric Carbon Dioxide by Increasing Ocean Alkalinity." Energy **20**: 915-922
Available at: http://www.sciencedirect.com/science/article/pii/036054429500035F

We present a preliminary analysis of a geoengineering option based on the intentional increase of ocean alkalinity to enhance marine storage of atmospheric CO_2. Like all geoengineering techniques to limit climate change, with today's limited understanding of the climate system, this approach must be regarded as a potential strategic option that requires ongoing assessment to establish its potential benefits and side effects. CO_2 would be absorbed from the atmosphere by the oceans at an increased rate if ocean alkalinity were raised. Ocean alkalinity might be raised by introducing the dissolution products of alkaline minerals into the oceans. The limited deposits of naturally occurring soda ash (Na_2CO_3) are readily soluble and easily mined. Limestone ($CaCO_3$) is abundant in the Earth's crust but is not readily soluble. This analysis explores the potential feasibility and limits of such approaches.

Kiehl, J. T. (2006). "Geoengineering climate Change: Treating the symptom over the cause? (Editorial Comment)." Climatic Change **77**: 227-228 DOI: 10.1007/s10584-006-9132-4
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-006-9132-4

The present article by Crutzen (2006) on the use of albedo enhancement to address the problem of greenhousewarming is bound to evoke diverse reactions among the community. It is important to note that Crutzen argues that this idea be studied in depth and openly before any large scale action is taken. A basic assumption to this approach is that we, humans, understand the Earth system sufficiently to modify it and 'know' how the system will respond. Cicerone in his article argues that open discussion of these ideas is an appropriate means to explore engineering solutions to climate change, and further proposes a protocol to prevent inadvertent abuse of geoengineering experiments. These papers evoke both scientific and ethical issues that should stimulate discussions on the engineering of Earth's climate system. We have already 'chosen' to geoengineer our climate system through our use of fossil fuels, where the engineering of the climate system is an inadvertent by product of our values around forms of consumption. Proposals to consciously alter the climate system to treat the symptom of our behaviors imply we understand all of the complexities of Earth as a system. At times Earth performs a stratospheric albedo enhancement experiment through the eruption of volcanoes. As pointed out by Crutzen, the Earth does cool due to this experiment, but this experiment also provides ample evidence of the non-local and non-linear response of Earth's climate system, e.g. winter NH warming. This example exhibits how Earth's climate system is far more complex than a simple energy balance picture. For this reason, I support Crutzen's argument that more detailed and comprehensive modeling studies be carried out with regards to experiments. But my concern is that all models have their limitations (e.g. note the inability of models to predict the appearance of the Antarctic ozone hole before it was observed). When will we know a model is 'good enough' to go out and perform a real experiment? On the issue of ethics, I feel we would be taking on the ultimate state of hubris to believe we can control Earth. We (the industrially developed world) would essentially be telling the (rest of the) world not to worry about our insatiable use of energy. In essence we are treating the symptom, not the cause. Our species needs to begin to address the cause(s) behind the problem. For example, an analysis of the U.S. contribution to CO_2 emissions indicates that these emissions in part arise from three factors: the large number of SUVs, the size of homes, and distance we drive to work. I would argue that the first two of these factors are ones of choice, and not necessity. Yet, the American public chooses to buy SUVs and build large homes. Why? It seems that we need to address the fundamental issue of value, before tinkering with a system that we do not completely understand. I recognize that Crutzen's proposal comes from his deep concern for Earth. I also recognize his concern arises from our species reluctance to address the cause(s) of our dilemma. But I feel that treating the cause(s) rather than the symptom is the more appropriate approach to the problem. However, as a scientist, I also recognize the importance of exploration of ideas, and that open dialogue and study of this issue (as proposed by Crutzen and seconded by Cicerone) is an important part of Earth studies. Let the dialogue begin.

Kintisch, E. (2010). "'Asilomar 2' Takes Small Steps Toward Rules for Geoengineering (ScienceNews)." Science **328**: 22-23
Available at: http://www.sciencemag.org/content/328/5974/22.short

In 1975, molecular biologists grappling with how to unlock the secrets of recombinant DNA without creating infectious, runaway bioagents laid the groundwork for a regulatory framework that allowed research—and

ultimately the biotech industry—to flourish. Last week, nearly 200 experts in geosciences and other scientific and policy disciplines met in the same spot to confront a new kind of risky research: large-scale geoengineering projects aimed at countering the buildup of greenhouse gases in the atmosphere. And although the climate scientists may have accomplished less in a week than did their biologist forebears, they did make progress. The conference organizers declared that geoengineering research is "indispensable" but said that it should be done with "humility." Governments and the public should work together to decide what schemes are "viable, appropriate, and ethical," the statement added. Cuts in greenhouse emissions should be a priority, it said, mirroring statements by the American Geophysical Union and the U.K. Royal Society.

Kintisch, E. (2010). "The Latest on Geoengineering (ScienceNews)." Science **327**: 1070-1071
Available at: http://www.sciencemag.org/content/327/5969/1070.2.short

Preliminary findings presented at the annual meeting of the American Association for the Advancement of Science (the publisher of Science) suggest that some proposed techniques to cool the planet manually may have fewer barriers than previously thought. But many technical and societal barriers remain, and the environmental effects of planet-hacking techniques remain uncertain.

Knight, C. G. (2010). "Curing the climate? (Essay)." Physics Education **45**: 13-17 DOI: 10.1088/0031-9120/45/1/f02
Available at: http://stacks.iop.org/0031-9120/45/i=1/a=F02?key=crossref.98c25c02f13343661cfec65131c8bfa2

Köhler, P., J. Hartmann, et al. (2010). "Geoengineering potential of artificially enhanced silicate weathering of olivine." Proceedings of the National Academy of Sciences of the United States of America **107**: 20228-20233 DOI: 10.1073/pnas.1000545107
Open Access Article* Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2996662/

Geoengineering is a proposed action to manipulate Earth's climate in order to counteract global warming from anthropogenic greenhouse gas emissions. We investigate the potential of a specific geoengineering technique, carbon sequestration by artificially enhanced silicate weathering via the dissolution of olivine. This approach would not only operate against rising temperatures but would also oppose ocean acidification, because it influences the global climate via the carbon cycle. If important details of the marine chemistry are taken into consideration, a new mass ratio of CO(2) sequestration per olivine dissolution of about 1 is achieved, 20% smaller than previously assumed. We calculate that this approach has the potential to sequestrate up to 1 Pg of C per year directly, if olivine is distributed as fine powder over land areas of the humid tropics, but this rate is limited by the saturation concentration of silicic acid. In our calculations for the Amazon and Congo river catchments, a maximum annual dissolution of 1.8 and 0.4 Pg of olivine seems possible, corresponding to the sequestration of 0.5 and 0.1 Pg of C per year, but these upper limit sequestration rates come at the environmental cost of pH values in the rivers rising to 8.2. Open water dissolution of fine-grained olivine and an enhancement of the biological pump by the rising riverine input of silicic acid might increase our estimate of the carbon sequestration, but additional research is needed here. We finally calculate with a carbon cycle model the consequences of sequestration rates of 1-5 Pg of C per year for the 21st century by this technique.

Koehler, A.-K., M. Sottocornola, et al. (2011). "How strong is the current carbon sequestration of an Atlantic blanket bog?" Global Change Biology **17**: 309-319 DOI: 10.1111/j.1365-2486.2010.02180.x
Available at: http://doi.wiley.com/10.1111/j.1365-2486.2010.02180.x

Although northern peatlands cover only 3% of the land surface, their thick peat deposits contain an estimated one-third of the world's soil organic carbon (SOC). Under a changing climate the potential of peatlands to continue sequestering carbon is unknown. This paper presents an analysis of 6 years of total carbon balance of an almost intact Atlantic blanket bog in Glencar, County Kerry, Ireland. The three components of the measured carbon balance were: the land-atmosphere fluxes of carbon dioxide (CO_2) and methane (CH_4) and the flux of dissolved organic carbon (DOC) exported in a stream draining the peatland. The 6 years C balance was computed from 6 years (2003–2008) of measurements of meteorological and eddy-covariance CO2 fluxes, periodic chamber measurements of CH4 fluxes over 3.5 years, and 2 years of continuous DOC flux measurements. Over the 6 years, the mean annual carbon was −29.7±30.6 (±1 SD) g C m−2 yr−1 with its components as follows: carbon in CO_2 was a sink of −47.8±30.0 g C m−2 yr−1; carbon in CH4 was a source of 4.1±0.5 g C m−2 yr−1 and the carbon exported as stream DOC was a source of 14.0±1.6 g C m−2 yr−1. For 2 out of the 6 years, the site was a source of carbon with the sum of CH_4 and DOC flux exceeding the carbon sequestered as CO_2. The average C balance for the 6 years corresponds to an average annual growth rate of the peatland surface of 1.3 mm yr−1.

Kravitz, B., A. Robock, et al. (2011). "The Geoengineering Model Intercomparison Project (GeoMIP)." Atmospheric Science Letters **12**: 162-167 DOI: 10.1002/asl.316

Available at: http://onlinelibrary.wiley.com/doi/10.1002/asl.316/abstract

To evaluate the effects of stratospheric geoengineering with sulphate aerosols, we propose standard forcing scenarios to be applied to multiple climate models to compare their results and determine the robustness of their responses. Thus far, different modeling groups have used different forcing scenarios for both global warming and geoengineering, complicating the comparison of results. We recommend four experiments to explore the extent to which geoengineering might offset climate change projected in some of the Climate Model Intercomparison Project 5 experiments. These experiments focus on stratospheric aerosols, but future experiments under this framework may focus on different means of geoengineering.

Kravitz, B., A. Robock, et al. (2009). "Sulfuric acid deposition from stratospheric geoengineering with sulfate aerosols." Journal of Geophysical Research **114**: 1-19 DOI: 10.1029/2009jd011918

Available at: http://www.agu.org/pubs/crossref/2009/2009JD011918.shtml

We used a general circulation model of Earth's climate to conduct geoengineering experiments involving stratospheric injection of sulfur dioxide and analyzed the resulting deposition of sulfate. When sulfur dioxide is injected into the tropical or Arctic stratosphere, the main additional surface deposition of sulfate occurs in midlatitude bands, because of strong cross-tropopause flux in the jet stream regions. We used critical load studies to determine the effects of this increase in sulfate deposition on terrestrial ecosystems by assuming the upper limit of hydration of all sulfate aerosols into sulfuric acid. For annual injection of 5 Tg of SO2 into the tropical stratosphere or 3 Tg of SO2 into the Arctic stratosphere, neither the maximum point value of sulfate deposition of approximately 1.5 mEq m−2 a−1 nor the largest additional deposition that would result from geoengineering of approximately 0.05 mEq m−2 a−1 is enough to negatively impact most ecosystems.

Kroeker, K. J., R. L. Kordas, et al. (2010). "Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms." Ecology letters **13**: 1419-1434 DOI: 10.1111/j.1461-0248.2010.01518.x

Open Access Article* Available at: http://onlinelibrary.wiley.com/doi/10.1111/j.1461-0248.2010.01518.x/full

Ocean acidification is a pervasive stressor that could affect many marine organisms and cause profound ecological shifts. A variety of biological responses to ocean acidification have been measured across a range of taxa, but this information exists as case studies and has not been synthesized into meaningful comparisons amongst response variables and functional groups. We used meta-analytic techniques to explore the biological responses to ocean acidification, and found negative effects on survival, calcification, growth and reproduction. However, there was significant variation in the sensitivity of marine organisms. Calcifying organisms generally exhibited larger negative responses than non-calcifying organisms across numerous response variables, with the exception of crustaceans, which calcify but were not negatively affected. Calcification responses varied significantly amongst organisms using different mineral forms of calcium carbonate. Organisms using one of the more soluble forms of calcium carbonate (high-magnesium calcite) can be more resilient to ocean acidification than less soluble forms (calcite and aragonite). Additionally, there was variation in the sensitivities of different developmental stages, but this variation was dependent on the taxonomic group. Our analyses suggest that the biological effects of ocean acidification are generally large and negative, but the variation in sensitivity amongst organisms has important implications for ecosystem responses.

Kung, C. C. (2011). "Climate Change Mitigation from Pyrolysis." Advanced Materials Research **347-353**: 2630-2634 DOI: 10.4028/www.scientific.net/AMR.347-353.2630

Available at: http://www.scientific.net/AMR.347-353.2630

In the report 2001 by the Intergovernmental Panel on Climate Change (IPCC) projects that climate could warm by as much as 10º F over the next 100 years and we already observed a warming of about 1º F since 1900. Therefore, how to mitigate the greenhouse gas effect is a very important issue since it affects everyone alive and not born. This paper mainly discusses the impacts of greenhouse gas emission that affects people the most. This paper mainly discusses the following questions: 1) what factors lead to the greenhouse gas effect? 2) How can pyrolysis become a potential source to mitigate the greenhouse gas effect and what are the choices we may have? Pyrolysis, as another bioenergy alternative, helps climate change mitigation while it also produces biochar that fixes carbon as a more stable form that has additional value when applied in agricultural land. GHGs come from the use of fossil fuel (CO2), nitrogen fertilizer application (N2O), and livestock enteric fermentation (NH4) and we need to find some strategies to reduce the emissions of GHGs such as crop fertilization alteration, crop tillage alteration, livestock management, manure management and biofuel production. Since CO2 play the most important role in

the GHG effects, the goal of this paper is to find the alternative energy to help mitigate the GHG effects by reducing the amount of CO2 emissions. The forest can be a candidate because it has the function of carbon sink and is able to produce energy biomass. Forests really do a good job that reduce the amount of CO2 in the air, however, since the carbon value and interest rate will affect the optimal rotation length, it becomes uncertain whether or not the forest will be able to provide a stable input for energy production

Kumar, B. M. and P. K. R. Nair (2011). Carbon Sequestration Potential of Agroforestry Systems. Dordrecht, Springer Netherlands.
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/978-94-007-1630-8

Lackner, K. S. (2003). "Climate change. A guide to CO_2 sequestration." Science **300**: 1677-1678 DOI: 10.1126/science.1079033
Available at: http://www.sciencemag.org/content/300/5626/1677.short
Carbon capture and storage (or sequestration) is receiving increasing attention as one tool for reducing carbon dioxide concentrations in the atmosphere. In his Perspective, Lackner discusses the advantages and disadvantages of different methods of carbon sequestration. He advises against sequestration in environmentally active carbon pools such as the oceans, because it may merely trade one environmental problem for another. Better sequestration options include underground injection and (possibly underground) neutralization. Taking into account carbon capture, transport, and storage, the author concludes that in the short and medium term, sequestration would almost certainly be cheaper than a full transition to nuclear, wind, or solar energy.

Lal, R. (2010). "Beyond Copenhagen: mitigating climate change and achieving food security through soil carbon sequestration." Food Security **2**: 169-177 DOI: 10.1007/s12571-010-0060-9
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s12571-010-0060-9
This article explains the technical potential of C (carbon) sequestration in world soils for mitigating climate change and describes its positive impacts on agronomic productivity and global food security through the improvement of soil quality. It also supports the idea of economic development through the provision of payments to farmers in developing countries for their stewardship and enhancement of ecosystem services. These would be generated by their use of recommended management practices for improved agriculture. The technical potential of C sequestration in soils of terrestrial ecosystems and restoration of peat soils is ~3 Petagram (Pg) C/yr (i.e. 3×1015 g=3× 109 tonnes C/yr) or 50 ppm draw down of atmospheric CO2 by the end of the 21st century by increasing the soil C pool at a rate of 1 Mg/ha/yr. Depending upon climate and other variables, this could increase cereal and food legume production in developing countries by 32 million Mg/yr and roots and tubers by 9 million Mg/yr. It is precisely this strategy which would have received broad political support at the COP-15 meeting in Copenhagen in December 2009 from developing countries, emerging economies and the industrialized world. Addressing the issue of food- insecurity and global warming through sequestration of C in soils and the biota, along with payments to resource-poor farmers for the ecosystem services rendered, would be a timely win-win strategy.

Lamb, H. H. (1977). Climatic History and the Future, Parts III and IV. Princeton, Princeton University Press.

Lampitt, R. S., E. P. Achterberg, et al. (2008). "Ocean fertilization: a potential means of geoengineering?" Philosophical Transactions of the Royal Society A **366**: 3919-3945 DOI: 10.1098/rsta.2008.0139
Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/366/1882/3919.long
The oceans sequester carbon from the atmosphere partly as a result of biological productivity. Over much of the ocean surface, this productivity is limited by essential nutrients and we discuss whether it is likely that sequestration can be enhanced by supplying limiting nutrients. Various methods of supply have been suggested and we discuss the efficacy of each and the potential side effects that may develop as a result. Our conclusion is that these methods have the potential to enhance sequestration but that the current level of knowledge from the observations and modelling carried out to date does not provide a sound foundation on which to make clear predictions or recommendations. For ocean fertilization to become a viable option to sequester CO_2, we need more extensive and targeted fieldwork and better mathematical models of ocean biogeochemical processes. Models are needed both to interpret field observations and to make reliable predictions about the side effects of large-scale fertilization. They would also be an essential tool with which to verify that sequestration has effectively taken place. There is considerable urgency to address climate change mitigation and this demands that new fieldwork plans are developed rapidly. In contrast to previous experiments, these must focus on the specific

objective which is to assess the possibilities of CO_2 sequestration through fertilization.

Lansing, S. (2006). Perfect Order – Recognizing Complexity in Bali. Princeton, Princeton University Press.

Latham, A. J., K. Bower, et al. (2011). Marine cloud brightening**.** 1-32.
Open Access Article* Available at:
http://www.atmos.washington.edu/~robwood/papers/geoengineering/final_jl_philtv17101104.pdf
The idea behind the marine cloud brightening (MCB) geoengineering technique is that seeding marine stratocumulus clouds with copious quantities of roughly monodisperse sub-micrometre seawater particles could significantly enhance the cloud droplet number concentration thus increasing the cloud albedo and longevity – thereby producing a cooling, which computations suggest could be adequate to balance the warming associated with a doubling of atmospheric carbon dioxide. We review herein recent research on a number of critical issues associated with MCB: (1) general circulation model (GCM) studies, which are our primary tools to evaluate globally the effectiveness of marine cloud brightening and to assess its climate impacts on rainfall amounts and distribution, as well as on polar sea-ice cover and thickness: (2) high resolution modeling of the effects of seeding on marine stratocumulus, which are required to understand the complex array of interacting cloud processes involved in brightening: (3) microphysical modelling sensitivity studies examining the influence of seeding amount, seed-particle salt-mass, air-mass characteristics, updraught speed and other parameters on cloud-albedo change: (4) sea-water spray production by controlled electrohydrodynamic instability, and by microfabrication lithography: (5) computational fluid dynamics studies of possible large-scale periodicities in Flettner rotors: and (6) the planning of a three-stage limited-area field research experiment, which has the objective of developing our fundamental knowledge of marine stratocumulus clouds, testing the technology developed for the MCB geoengineering application, and ultimately, if deemed justifiable, field-testing the idea quantitatively, on a limited (perhaps 100km) spatial scale.

Latham, J. (2002). "Amelioration of global warming by controlled enhancement of the albedo and longevity of low-level maritime clouds." Atmospheric Science Letters **3**: 52-58 DOI: 10.1006/asle.2002.0048
Open Access Article* Available at: http://onlinelibrary.wiley.com/doi/10.1006/asle.2002.0099/abstract
A technique is proposed for controlled enhancement of droplet concentrations in low-level maritime clouds, with corresponding increase in their albedo and longevity, thereby producing a cooling effect. It involves dissemination at the ocean surface of small seawater droplets which act as cloud condensation nuclei (CCN), Ut has low ecological impact.

Latham, J. (1990). "Control of global warming? (Letter to ed.)." Nature **347**: 339-340
Available at: http://www.nature.com/nature/journal/v347/n6291/abs/347339b0.html

Latham, J., P. Rasch, et al. (2008). "Global temperature stabilization via controlled albedo enhancement of low-level maritime clouds." Philosophical Transactions of the Royal Society A **366**: 3969-3987 DOI: 10.1098/rsta.2008.0137
Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/366/1882/3969.long
An assessment is made herein of the proposal that controlled global cooling sufficient to balance global warming resulting from increasing atmospheric CO2 concentrations might be achieved by seeding low-level, extensive maritime clouds with seawater particles that act as cloud condensation nuclei, thereby activating new droplets and increasing cloud albedo (and possibly longevity). This paper focuses on scientific and meteorological aspects of the scheme. Associated technological issues are addressed in a companion paper. Analytical calculations, cloud modelling and (particularly) GCM computations suggest that, if outstanding questions are satisfactorily resolved, the controllable, globally averaged negative forcing resulting from deployment of this scheme might be sufficient to balance the positive forcing associated with a doubling of CO2 concentration. This statement is supported quantitatively by recent observational evidence from three disparate sources. We conclude that this technique could thus be adequate to hold the Earth's temperature constant for many decades. More work--especially assessments of possible meteorological and climatological ramifications--is required on several components of the scheme, which possesses the advantages that (i) it is ecologically benign--the only raw materials being wind and seawater, (ii) the degree of cooling could be controlled, and (iii) if unforeseen adverse effects occur, the system could be immediately switched off, with the forcing returning to normal within a few days (although the response would take a much longer time).

Law, C. S. (2008). "Predicting and monitoring the effects of large-scale ocean iron fertilization on marine trace gas

emissions." Marine Ecology Progress Series **364**: 283-288 DOI: 10.3354/meps07549
Open Access Article* Available at: http://www.int-res.com/abstracts/meps/v364/p283-288/

Large-scale (>40000 km2, >1 yr) ocean iron fertilization (OIF) is being considered as an option for mitigating the increase in atmospheric CO2 concentrations. However OIF will influence trace gas production and atmospheric emissions, with consequences over broad temporal and spatial scales. To illustrate this, the response of nitrous oxide (N2O) and dimethylsulphide (DMS) in the mesoscale iron addition experiments (FeAXs) and model scenarios of large-scale OIF are examined. FeAXs have shown negligible to minor increases in N2O production, whereas models of long-term OIF suggest significant N2O production with the potential to offset the benefit gained by iron-mediated increases in CO2 uptake. N2O production and emission will be influenced by the magnitude and rate of vertical particle export, and along-isopycnal N2O transport will necessitate monitoring over large spatial scales. The N2O–O2 relationship provides a monitoring option using oxygen as a proxy, with spatial coverage by Argo and glider-mounted oxygen optodes. Although the initial FeAXs exhibited similar increases (1.5- to 1.6-fold) in DMS, a subsequent sub-arctic Pacific experiment observed DMS consumption relative to unfertilized waters, highlighting regional variability as a complicating factor when predicting the effects of large-scale OIF. DMS cycling and its influence on atmospheric composition may be studied using naturally occurring blooms and be constrained prior to OIF by pre-fertilization spatial mapping and aerial sampling using new technologies. As trace gases may have positive or negative synergistic effects on atmospheric chemistry and climate forcing, the net effect of altered trace gas emissions needs to be considered in both models and monitoring of large-scale OIF.

Lawrence, M. G. (2006). "The Geoengineering Dilemma: To Speak or not to Speak (Editorial Comment)." Climatic Change **77**: 245-248 DOI: 10.1007/s10584-006-9131-5
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-006-9131-5

Lenton, T. M., H. Held, et al. (2008). "Tipping elements in the Earth's climate system." Proceedings of the National Academy of Sciences of the United States of America **105**: 1786-1793 DOI: 10.1073/pnas.0705414105
Open Access Article* Available at:

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2538841&tool=pmcentrez&rendertype=abstract
The term "tipping point" commonly refers to a critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system. Here we introduce the term "tipping element" to describe large-scale components of the Earth system that may pass a tipping point. We critically evaluate potential policy-relevant tipping elements in the climate system under anthropogenic forcing, drawing on the pertinent literature and a recent international workshop to compile a short list, and we assess where their tipping points lie. An expert elicitation is used to help rank their sensitivity to global warming and the uncertainty about the underlying physical mechanisms. Then we explain how, in principle, early warning systems could be established to detect the proximity of some tipping points.

Lenton, T. M. and N. E. Vaughan (2009). "The radiative forcing potential of different climate geoengineering options." Atmospheric Chemistry and Physics Discussions **9**: 2559-2608 DOI: 10.5194/acpd-9-2559-2009
Open Access Article* Available at: http://www.atmos-chem-phys-discuss.net/9/2559/2009/

Climate geoengineering proposals seek to rectify the Earth's current radiative imbalance, either by reducing the absorption of incoming solar (shortwave) radiation, or by removing CO_2 from the atmosphere and transferring it to long-lived reservoirs, thus increasing outgoing longwave radiation. A fundamental criterion for evaluating geoengineering options is their climate cooling effectiveness, which we quantify here in terms of radiative forcing potential. We use a simple analytical approach, based on the global energy balance and pulse response functions for the decay of CO_2 perturbations. This aids transparency compared to calculations with complex numerical models, but is not intended to be definitive. Already it reveals some significant errors in existing calculations, and it allows us to compare the relative effectiveness of a range of proposals. By 2050, only stratospheric aerosol injections or sunshades in space have the potential to cool the climate back toward its pre-industrial state, but some land carbon cycle geoengineering options are of comparable magnitude to mitigation "wedges". Strong mitigation, i.e. large reductions in CO_2 emissions, combined with global-scale air capture and storage, afforestation, and bio-char production, i.e. enhanced CO_2 sinks, might be able to bring CO_2 back to its pre-industrial level by 2100, thus removing the need for other geoengineering. Alternatively, strong mitigation stabilising CO_2 at 500 ppm, combined with geoengineered increases in the albedo of marine stratiform clouds, grasslands, croplands and human settlements might achieve a patchy cancellation of radiative forcing. Ocean fertilisation options are only worthwhile if sustained on a millennial timescale and phosphorus addition probably

has greater long-term potential than iron or nitrogen fertilisation. Enhancing ocean upwelling or downwelling have trivial effects on any meaningful timescale. Our approach provides a common framework for the evaluation of climate geoengineering proposals, and our results should help inform the prioritisation of further research into them.

Le Quéré, C., M. R. Raupach, et al. (2009). "Trends in the sources and sinks of carbon dioxide." Nature Geoscience **2**: 831-836 DOI: 10.1038/ngeo689

Available at: http://www.nature.com/doifinder/10.1038/ngeo689

Efforts to control climate change require the stabilization of atmospheric CO_2 concentrations. This can only be achieved through a drastic reduction of global CO_2 emissions. Yet fossil fuel emissions increased by 29% between 2000 and 2008, in conjunction with increased contributions from emerging economies, from the production and international trade of goods and services, and from the use of coal as a fuel source. In contrast, emissions from land-use changes were nearly constant. Between 1959 and 2008, 43% of each year's CO_2 emissions remained in the atmosphere on average; the rest was absorbed by carbon sinks on land and in the oceans. In the past 50 years, the fraction of CO_2 emissions that remains in the atmosphere each year has likely increased, from about 40% to 45%, and models suggest that this trend was caused by a decrease in the uptake of CO_2 by the carbon sinks in response to climate change and variability. Changes in the CO_2 sinks are highly uncertain, but they could have a significant influence on future atmospheric CO_2 levels. It is therefore crucial to reduce the uncertainties.

Le Quesne, W. J. F. and J. K. Pinnegar (2011). "The potential impacts of ocean acidification: scaling from physiology to fisheries." Fish and Fisheries DOI: 10.1111/j.1467-2979.2011.00423.x

Available at: http://doi.wiley.com/10.1111/j.1467-2979.2011.00423.x

Views expressed on the potential impact of ocean acidification range from wholesale degradation of marine ecosystems through to no discernable impact with minimal consequences. Constraining this range of predictions is necessary for the development of informed policy and management. The direct biological impacts of acidification occur at the molecular and cellular level; however, it is the expression of these effects at the population and ecosystem level that is of societal concern. Here, we consider the potential impact of ocean acidification on fisheries with particular emphasis on approaches to scaling from physiological responses to population- and ecosystem-level processes. In some instances, impacts of ocean acidification may lead to changes in the relative species composition at a given trophic level without affecting the overall productivity, whilst in other instances, ocean acidification may lead to a reduction in productivity at a given tropic level. Because of the scale at which ecological processes operate, modelling studies are required. Here, ocean acidification is situated within ongoing research into the ecological dynamics of perturbed systems, for which many models have already been developed. Whilst few existing models currently explicitly represent physiological processes sensitive to ocean acidification, some examples of how ocean acidification effects may be emulated within existing models are discussed. Answering the question of how acidification may impact fisheries requires the integration of knowledge across disciplines; this contribution aims to facilitate the inclusion of higher trophic level ecology into this ongoing debate and discussion

Lin, A. C. (2009). "Geoengineering Governance; Balancing the Risk : Managing Technology and Dangerous Climate Change." Issues in Legal Scholarship **8**

Available at: http://www.bepress.com/ils/vol8/iss3/art2/?sending=10708

The difficulties encountered in accomplishing the drastic greenhouse gas emissions reductions necessary to avoid dangerous anthropogenic interference with the Earth’s climate system have led to incipient interest in geoengineering. Geoengineering proposals, such as the release of sulfur into the stratosphere in order to block sunlight, might serve as an emergency option should emissions reductions efforts fail, or even as a nonemergency policy alternative to emission reductions. This article examines the largely unexplored issue of geoengineering governance, namely, questions regarding who should decide whether geoengineering research or deployment should go forward, how such decisions should be made, and what mechanisms should be in place to address the risk of deployment by rogue actors. The article recommends that the international community begin to address geoengineering governance promptly through the Framework Convention on Climate Change and the bodies established by that agreement, and that geoengineering governance be treated as a series of adaptive management decisions to be reviewed periodically. Such an approach will allow the incorporation of new information into the decisionmaking process and promote the development of consensus and international norms with respect to geoengineering techniques.

Liu, E. and S. R. Liu (2011). "Climate Change Mitigation through Forest-Based Carbon Sequestration Projects in China: Potential Benefits and Challenges." Advanced Materials Research **255-260**: 2949-2952 DOI: 10.4028/www.scientific.net/AMR.255-260.2949
Available at: http://www.scientific.net/AMR.255-260.2949

The CDM-AR project is a market-oriented approach to absorb carbon dioxide through afforestation and reforestation according to the Kyoto Protocol. This paper analysised the status of the CDM-AR projects in China, and asked why there are so few CDM-AR projects in China even in the world? The reasons include: Financial constraints, Constraints associated with knowledge, skills and other social factors. The particular reasons for China include: the specific terrains and soil fertility in China, the ownership of the forest land and so on. The CDM-AR project which can offer many economic, social and environmental benefits, is at the initial stage. It has great potential. The potentials of the CDM-AR project include: introduction of foreign capital and advanced technology from developed countries; establish of the forest ecological compensation mechanism in China; lower cost than the cutting emission ways at home for the developed countries.

Lovelock, J. (2008). "A geophysiologist's thoughts on geoengineering." Philosophical Transactions of the Royal Society A **366**: 3883-3890 DOI: 10.1098/rsta.2008.0135
Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/366/1882/3883.long

The Earth is now recognized as a self-regulating system that includes a reactive biosphere; the system maintains a long-term steady-state climate and surface chemical composition favourable for life. We are perturbing the steady state by changing the land surface from mainly forests to farm land and by adding greenhouse gases and aerosol pollutants to the air. We appear to have exceeded the natural capacity to counter our perturbation and consequently the system is changing to a new and as yet unknown but probably adverse state. I suggest here that we regard the Earth as a physiological system and consider amelioration techniques, geoengineering, as comparable to nineteenth century medicine.

Lovelock, J. E. and C. G. Rapley (2007). "Ocean pipes could help the Earth to cure itself." Nature **449**: 403-403 DOI: 10.1038/449403a
Available at: http://www.ncbi.nlm.nih.gov/pubmed/17898747

We propose a way to stimulate the Earth's capacity to cure itself, as an emergency treatment for the pathology of global warming. Measurements of the climate system show that the Earth is fast becoming a hotter planet than anything yet experienced by humans.

MacCracken, M. C. (2010). Beyond Mitigation Potential Options for Counter-Balancing the Climatic and Environmental Consequences of the Rising Concentrations of Greenhouse Gases. Washington DC**:** 42-42.
Open Access Article* Available at: ftp://ftp.worldbank.org/pub/repec/SSRN/staging/4938.pdf

Global climate change is occurring at an accelerating pace, and the global greenhouse gas (GHG) emissions that are forcing climate change continue to increase. Given the present pace of international actions, it seems unlikely that atmospheric composition can be stabilized at a level that will avoid “dangerous anthropogenic interference” with the climate system, as called for in the UN Framework Convention on Climate Change. Complicating the situation, as GHG emissions are reduced, reductions in the offsetting cooling influence of sulfate aerosols will create an additional warming influence, making an early transition to climate stabilization difficult. With significant reductions in emissions (mitigation) likely to take decades, and with the impacts of projected climate change—even with proactive adaptation—likely to be quite severe over the coming decades, additional actions to offset global warming and other impacts have been proposed as important complementary measures. Although a number of possible geoengineering approaches have been proposed, each has costs and side effects that must be balanced against the expected benefits of reduced climate impacts. However, substantial new research is needed before comparison of the relative benefits and risks of intervening is possible. A first step in determining whether geoengineering is likely to be a useful option is the initiation of research on four interventions to limit the increasing serious impacts: limiting ocean acidification by increasing the removal of carbon dioxide from the atmosphere and upper ocean; limiting the increasing intensity of tropical cyclones; limiting the warming of the Arctic and associated sea level rise; and sustaining or enhancing the existing sulfate cooling influence. In addition, in depth consideration is needed regarding the governance structure for an international geoengineering decision-making framework in the event that geoengineering becomes essential.

MacCracken, M. (2009). "Impact intervention: Regional geo-engineering as a complementary step to aggressive mitigation." IOP Conference Series: Earth and Environmental Science **6**: 452003-452003 DOI:

10.1088/1755-1307/6/5/452003
Open Access Article* Available at:
http://stacks.iop.org/1755-1315/6/i=45/a=452003?key=crossref.c0cc1a1cba3da27b8930fc6cd52b738d

MacCracken, M. C. (2006). "Geoengineering: Worthy of Cautious Evaluation? (Editorial)." Climatic Change **77**: 235-243 DOI: 10.1007/s10584-006-9130-6
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-006-9130-6
If the increasing concentrations of greenhouse gases due to human activities are indeed causing inadvertent change in the climate, then can we not counter these influences by advertent changes of some type, deliberately geoengineering the climate to ensure optimal conditions? This is a question that was first considered several decades ago, soon after acceptance of indications that it was indeed likely that human activities could affect the global climate (e.g., Marchetti, 1975; NAS, 1992). Scientific evidence now clearly indicates that human activities have initiated significant climatic change and that much greater change lies ahead (IPCC, 2001a), that the impacts of these changes will cause significant consequences for the environment and society (IPCC, 2001b), and that switching the global energy system away from its heavy dependence on fossil fuels is likely to require more than a century (IPCC, 2001c). With the Kyoto Protocol proving to be a difficult first step to slowing the rate of growth in emissions and with slow progress on moving to second and third steps that would actually start to reduce emissions, Crutzen (2006) argues that it may be time to think much more seriously about geoengineering the Earth's climate. In addition to undertaking geoengineering to avoid the "dangerous anthropogenic interference with the climate system," which the international community of nations agreed in 1992 was their objective in the UN Framework Convention on Climate Change, Crutzen proposes to offset the warming influence of removing the loading of tropospheric aerosols so as to alleviate their deleterious health effects, which is an interesting new aspect meriting consideration. In addition to the many scientific, legal, ethical, and societal issues that he raises with respect to undertaking such efforts, this note offers a few additional thoughts and comments.

MacCracken, M. C. (2009). "On the possible use of geoengineering to moderate specific climate change impacts." Environmental Research Letters **4**: 045107-045107 DOI: 10.1088/1748-9326/4/4/045107
Open Access Article* Available at:
http://stacks.iop.org/1748-9326/4/i=4/a=045107?key=crossref.da5ed101ba1ff398d9f9a3684bb03f3f
With significant reductions in emissions likely to require decades and the impacts of projected climate change likely to become more and more severe, proposals for taking deliberate action to counterbalance global warming have been proposed as an important complement to reducing emissions. While a number of geoengineering approaches have been proposed, each introduces uncertainties, complications and unintended consequences that have only begun to be explored. For limiting and reversing global climate change over periods of years to decades, solar radiation management, particularly injection of sulfate aerosols into the stratosphere, has emerged as the leading approach, with mesospheric reflectors and satellite deflectors also receiving attention. For a number of reasons, tropospheric approaches to solar radiation management present greater challenges if the objective is to reduce the increase in global average temperature. However, such approaches have a number of advantages if the objective is to alleviate specific consequences of climate change expected to cause significant impacts for the environment and society. Among the most damaging aspects of the climate that might be countered are: the warming of low-latitude oceans that observations suggest contribute to more intense tropical cyclones and coral bleaching; the amplified warming of high latitudes and the associated melting of ice that has been accelerating sea level rise and altering mid-latitude weather; and the projected reduction in the loading and cooling influence of sulfate aerosols, which has the potential to augment warming sufficient to trigger methane and carbon feedbacks. For each of these impacts, suitable scientific, technological, socioeconomic, and governance research has the potential to lead to tropospheric geoengineering approaches that, with a well-funded research program, could begin playing a moderating role for some aspects of climate change within a decade.

Maclean, I. M. D. and R. J. Wilson (2011). "Recent ecological responses to climate change support predictions of high extinction risk." Proceedings of the National Academy of Sciences of the United States of America **2011**: 1-6 DOI: 10.1073/pnas.1017352108
Available at: http://www.pnas.org/content/108/30/12337.abstract
Predicted effects of climate change include high extinction risk for many species, but confidence in these predictions is undermined by a perceived lack of empirical support. Many studies have now documented ecological responses to recent climate change, providing the opportunity to test whether the magnitude and nature of recent responses match predictions. Here, we perform a global and multitaxon metaanalysis to show that

empirical evidence for the realized effects of climate change supports predictions of future extinction risk. We use International Union for Conservation of Nature (IUCN) Red List criteria as a common scale to estimate extinction risks from a wide range of climate impacts, ecological responses, and methods of analysis, and we compare predictions with observations. Mean extinction probability across studies making predictions of the future effects of climate change was 7% by 2100 compared with 15% based on observed responses. After taking account of possible bias in the type of climate change impact analyzed and the parts of the world and taxa studied, there was less discrepancy between the two approaches: predictions suggested a mean extinction probability of 10% across taxa and regions, whereas empirical evidence gave a mean probability of 14%. As well as mean overall extinction probability, observations also supported predictions in terms of variability in extinction risk and the relative risk associated with broad taxonomic groups and geographic regions. These results suggest that predictions are robust to methodological assumptions and provide strong empirical support for the assertion that anthropogenic climate change is now a major threat to global biodiversity.

Mahowald, N., D. S. Ward, et al. (2011). "Aerosol Impacts on Climate and Biogeochemistry." Annual Review of Environment and Resources **36**: 45-74 DOI: 10.1146/annurev-environ-042009-094507

Open Access Article* Available at: http://www.annualreviews.org/doi/abs/10.1146/annurev-environ-042009-094507

Aerosols are suspensions of solid and/or liquid particles in the atmosphere and modify atmospheric radiative fluxes and chemistry. Aerosols move mass from one part of the earth system to other parts of the earth system, thereby modifying biogeochemistry and the snow surface albedo. This paper reviews our understanding of the impacts of aerosols on climate through direct radiative changes, aerosol-cloud interactions (indirect effects), atmospheric chemistry, snow albedo, and land and ocean biogeochemistry. Aerosols play an important role in the preindustrial (natural) climate system and have been perturbed substantially over the anthropocene, often directly by human activity. The most important impacts of aerosols, in terms of climate forcing, are from the direct and indirect effects, with large uncertainties. Similarly large impacts of aerosols on land and ocean biogeochemistry have been estimated, but these have larger uncertainties.

Major, J., J. Lehmann, et al. (2010). "Fate of soil-applied black carbon: downward migration, leaching and soil respiration." Global Change Biology **16**: 1366-1379 DOI: 10.1111/j.1365-2486.2009.02044.x

Available at: http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2009.02044.x/full

Black carbon (BC) is an important pool of the global C cycle, because it cycles much more slowly than others and may even be managed for C sequestration. Using stable isotope techniques, we investigated the fate of BC applied to a savanna Oxisol in Colombia at rates of 0, 11.6, 23.2 and 116.1 t BC ha−1, as well as its effect on non-BC soil organic C. During the rainy seasons of 2005 and 2006, soil respiration was measured using soda lime traps, particulate and dissolved organic C (POC and DOC) moving by saturated flow was sampled continuously at 0.15 and 0.3 m, and soil was sampled to 2.0 m. Black C was found below the application depth of 0–0.1 m in the 0.15–0.3 m depth interval, with migration rates of 52.4±14.5, 51.8±18.5 and 378.7±196.9 kg C ha−1 yr−1 (±SE) where 11.6, 23.2 and 116.1 t BC ha−1, respectively, had been applied. Over 2 years after application, 2.2% of BC applied at 23.2 t BC ha−1 was lost by respiration, and an even smaller fraction of 1% was mobilized by percolating water. Carbon from BC moved to a greater extent as DOC than POC. The largest flux of BC from the field (20–53% of applied BC) was not accounted for by our measurements and is assumed to have occurred by surface runoff during intense rain events. Black C caused a 189% increase in aboveground biomass production measured 5 months after application (2.4–4.5 t additional dry biomass ha−1 where BC was applied), and this resulted in greater amounts of non-BC being respired, leached and found in soil for the duration of the experiment. These increases can be quantitatively explained by estimates of greater belowground net primary productivity with BC addition.

Major, J., M. Rondon, et al. (2010). "Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol." Plant and Soil **333**: 117-128 DOI: 10.1007/s11104-010-0327-0

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s11104-010-0327-0

The application of biochar (biomass-derived black carbon) to soil has been shown to improve crop yields, but the reasons for this are often not clearly demonstrated. Here, we studied the effect of a single application of 0, 8 and 20 t ha−1 of biochar to a Colombian savanna Oxisol for 4 years (2003–2006), under a maize-soybean rotation. Soil sampling to 30 cm was carried out after maize harvest in all years but 2005, maize tissue samples were collected and crop biomass was measured at harvest. Maize grain yield did not significantly increase in the first year, but increases in the 20 t ha−1 plots over the control were 28, 30 and 140% for 2004, 2005 and 2006, respectively. The availability of nutrients such as Ca and Mg was greater with biochar, and crop tissue analyses

showed that Ca and Mg were limiting in this system. Soil pH increased, and exchangeable acidity showed a decreasing trend with biochar application. We attribute the greater crop yield and nutrient uptake primarily to the 77–320% greater available Ca and Mg in soil where biochar was applied.

Malhi, Y., J. T. Roberts, et al. (2008). "Climate change, deforestation, and the fate of the Amazon." Science **319**: 169-172 DOI: 10.1126/science.1146961

Available at: http://www.ncbi.nlm.nih.gov/pubmed/18048654

The forest biome of Amazonia is one of Earth's greatest biological treasures and a major component of the Earth system. This century, it faces the dual threats of deforestation and stress from climate change. Here, we summarize some of the latest findings and thinking on these threats, explore the consequences for the forest ecosystem and its human residents, and outline options for the future of Amazonia. We also discuss the implications of new proposals to finance preservation of Amazonian forests.

Mamadou, D. and C. J. Brinker (2011). "Nanotechnology for Sustainability: Environment, Water, Food, Minerals, and Climate." Nanotechnology Research Directions for Societal Needs in 2020 **1**: 221-259

Open Access Article* Available at: http://www.springerlink.com/content/t46j5546412hg0t7/

The global sustainability challenges facing the world are complex and involve multiple interdependent areas. Chapter “Nanotechnology for Sustainability: Envi-ron-ment, Water, Food, Minerals, and Climate” focuses on sustainable nanotechnology solutions for a clean environment, water resources, food supply, mineral resources, green manufacturing, habitat, transportation, climate change, and biodiversity. It also discusses nanotechnology-based energy solutions in terms of their interdependence with other sustainability target areas such as water, habitat, transportation, and climate change. Chapter “Nanotechnology for Sustainability: Energy Conversion, Storage, and Conservation” is dedicated to energy resources.

Manfready, R. A. (2011). "Assessing the Impacts of Desert Afforestation on the Spread of Infectious Agents." International Journal of Environmental Sciences **1**: 901-910

Open Access Article* Available at: http://ipublishing.co.in/jesvol1no12010/EIJES2045.pdf

Afforestation of the Sahara and Australian deserts has been proposed as a geoengineering technique by which to mitigate the effects of greenhouse gases in the Earth's atmosphere. The afforestation proposal entails planting and irrigating eucalyptus forests on a massive scale in the present day arid Sahara desert—an expensive but potentially effective way to sequester atmospheric CO2. Several unintended consequences have been associated with this technique, to include salt deposition, decreased oceanic fertilization by dust, and locust swarms. However, the effect of desert afforestation on the propagation of disease carrying avian species has not been studied. It is hypothesized that afforestation of the Sahara will increase the number of avian species carrying disease to European and subSaharan regions. To assess this possibility, a field test scheme is presented to measure avian flux through the transSaharan region via radar based monitoring. The test will assess flux for both arid and afforested conditions at several points along major transSaharan flyways, with emphasis on zones known to be fatal for Sahara crossing birds. Results from the field experiments will be input into an in silico model that will extrapolate the findings over the entire Sahara region and incorporate other parameters such as breeding. The preliminary model described here will simulate flux of disease carrying avian species across the Sahara for a user defined number of migratory seasons, and will compare changes in species specific flux, migratory patterns, and crossinfection between arid and afforested scenarios. It is expected that desert afforestation will heighten transSaharan flux of disease carrying avian species. If this prediction is validated by the simulation, then European and subSaharan regions may be at greater risk of avian borne disease if Sahara afforestation is implemented. Desert afforestation as a geoengineering technique must be critically assessed with respect to its potential effects on disease vector propagation before its implementation is considered. The proposed experiments provide an outline with which to effectively estimate such effects, should the need for long term risk assessment arise.

Manizza, M., M. J. Follows, et al. (2009). "Modeling transport and fate of riverine dissolved organic carbon in the Arctic Ocean." Global Biogeochemical Cycles **23**: GB4006-GB4006 DOI: 10.1029/2008gb003396

Available at: http://www.agu.org/pubs/crossref/2009/2008GB003396.shtml

The spatial distribution and fate of riverine dissolved organic carbon (DOC) in the Arctic may be significant for the regional carbon cycle but are difficult to fully characterize using the sparse observations alone. Numerical models of the circulation and biogeochemical cycles of the region can help to interpret and extrapolate the data and may ultimately be applied in global change sensitivity studies. Here we develop and explore a regional,

three-dimensional model of the Arctic Ocean in which, for the first time, we explicitly represent the sources of riverine DOC with seasonal discharge based on climatological field estimates. Through a suite of numerical experiments, we explore the distribution of DOC-like tracers with realistic riverine sources and a simple linear decay to represent remineralization through microbial degradation. The model reproduces the slope of the DOC-salinity relationship observed in the eastern and western Arctic basins when the DOC tracer lifetime is about 10 years, consistent with published inferences from field data. The new empirical parameterization of riverine DOC and the regional circulation and biogeochemical model provide new tools for application in both regional and global change studies.

Marchetti, C. (1977). "On geoengineering and the CO2 problem." Climatic Change **1**: 59-68 DOI: 10.1007/bf00162777
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/BF00162777

The problem of CO s control in the atmosphere is tackled by proposing a kind of 'fuel cycle' for fossil fuels where CO~ is partially or totally collected at certain transformation points and properly disposed of. CO 2 is disposed of by injection into suitable sinking thermohaline currents that carry and spread it into the deep ocean that has a very large equilibrium capacity. The Mediterranean undercurrent entering the Atlantic at Gibraltar has been identified as one such current; it would have sufficient capacity to deal with all CO 2 produced in Europe even in the year 2100.

Martin, J. H., R. M. Gordon, et al. (1990). "Iron in Antarctic waters." Nature **345**: 156-158 DOI: 10.1038/345156a0
Available at: http://www.nature.com/doifinder/10.1038/345156a0

E are testing the hypothesis that Antarctic phytoplankton suffer from iron deficiency1–3 which prevents them from blooming and using up the luxuriant supplies of major nutrients found in vast areas of the southern ocean. Here we report that highly productive4 (~3 g C m−;2 day−1), neritic Gerlache Strait waters have an abundance of Fe (7.4 nmol kg−1) which facilitates phytoplankton blooming and major nutrient removal, while in low-productivity4 (~0.1 g C m−2 day−1), offshore Drake Passage waters, the dissolved Fe levels are so low (0.16 nmol kg−1) that the phytoplankton are able to use less than 10% of the major nutrients available to them. The verification of present-day Fe deficiency is of interest as iron-stimulated phytoplankton growth may have contributed to the drawing down of atmospheric CO2 during glacial maxima2,3; it is also important because oceanic iron fertilization aimed at the enhancement of phytoplankton production may turn out to be the most feasible method of stimulating the active removal of greenhouse gas CO2 from the atmosphere, if the need arises (J.H.M., manuscript in preparation).

Maruyama, S., T. Yabuki, et al. (2011). "Evidences of increasing primary production in the ocean by Stommel's perpetual salt fountain." Deep Sea Research Part I: Oceanographic Research Papers **58**: 567-574 DOI: 10.1016/j.dsr.2011.02.012
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0967063711000574

The American physical oceanographer Henry Stommel and co-workers proposed “the perpetual salt fountain” and suggested the possibility of upwelling deep seawater without an energy source. In the open ocean, deep seawater containing rich nutrients becomes a source of primary production. Previously, we have tested Stommel's hypothesis by numerical simulations and in ocean experiments, and confirmed the upwelling of a perpetual salt fountain. In the present study, we conducted an open-ocean experiment in the Philippines Sea, and succeeded to demonstrate an increase in chlorophyll concentration. The chlorophyll concentration at the pipe outlet was much greater than that in the surrounding seawater. Satellite ocean-color image around the pipe was analyzed, and the signal of artificial upwelling is investigated. Composite analysis of satellite chlorophyll image indicates an increased surface chlorophyll distribution in the vicinity of pipe position, in which the increasing signal is much larger than the expected production based on nutrient supply. Although the problem must be further discussed, this increased signal is shown to be statistically significant. This mechanism may contribute to effective utilization of fishery resources in subtropical oligotrophic region.

Matear, R. J. and B. Elliot (2004). "Enhancement of oceanic uptake of anthropogenic CO 2 by macronutrient fertilization." Journal of Geophysical Research **109**: C04001-C04001 DOI: 10.1029/2000jc000321
Available at: http://www.agu.org/pubs/crossref/2004/2000JC000321.shtml

A global three-dimensional ocean carbon cycle model was used to investigate the use of macronutrient fertilization of the ocean to increase the oceanic uptake of CO2.To simulate macronutrient fertilization, phosphate was added to the 18□–50□S surface ocean. The carbon sequestration efficiency of fertilization was determined from the ratio of increased ocean uptake of anthropogenic CO2 to the rate of phosphate addition to the upper ocean (converted to carbon units using the C/P ratio of organic matter, 106). The model simulation produced a

maximum efficiency of 78%. However, the simulations demonstrated that changes in calcium carbon production with macronutrient fertilization could significantly reduce carbon sequestration efficiency. When calcium carbonate production increases at the same rate as export production, the carbon sequestration efficiency is reduced by 25% when compared to a simulation where calcium carbonate production is held constant. The study also discusses several other potential process that could impact the efficiency phosphate fertilization to sequester carbon in the ocean and the potential consequences of large-scale macronutrient fertilization of the ocean

Matear, R. J., Y.-P. Wang, et al. (2010). "Land and ocean nutrient and carbon cycle interactions." Current Opinion in Environmental Sustainability **2**: 258-263 DOI: 10.1016/j.cosust.2010.05.009

Available at: http://linkinghub.elsevier.com/retrieve/pii/S1877343510000448

The biosphere's uptake and storage of carbon have the potential to either slow or amplify global warming providing a carbon-climate feedback to global warming. The interactions between carbon (C) and the nutrient cycles, especially nitrogen (N) and phosphorus (P), are important to the biosphere's storage of carbon. The century-scale carbon-climate feedback of the land is projected to be an order of magnitude greater than the ocean; however, the land's importance may have been overestimated as they are based on models that neglect nutrient limitation. The omission of N limitation reduces the negative carbon-climate feedback by up to 30%, and further, we postulate as N-deposition and N-fixation increase, P limitation will become important in limiting the future land carbon-climate feedback. Process-based C, N and P land models are needed to realistically project this century carbon-climate feedback. In the ocean, the carbon and nutrient cycles are tightly coupled as a result of low living biomass relative to its annual turnover. With rapid recycling of carbon and nutrients, the ocean carbon-climate feedback is weak at the century time-scale. The land and ocean C, N and P cycle models (earth system models) are needed for both improvement of projections of climate change and more realistic investigation of the impact of climate change on land and ocean ecosystems. An earth system modelling approach can also help to assess the impact of different processes on carbon and nutrient cycling, and identify where improved process-understanding is needed.

Matthews, H. D. (2010). "Can carbon cycle geoengineering be a useful complement to ambitious climate mitigation?" Carbon Management **1**: 135-144 DOI: 10.4155/cmt.10.14

Available at: http://www.future-science.com/doi/abs/10.4155/cmt.10.14

Any human intervention in environmental systems carries risk of adverse consequences. Planetary-scale intervention carries the potential for planetary-scale risk. Continued emissions of greenhouse gases represent an unintentional planetary-scale human intervention in the climate system, which is resulting in global consequences that will become increasingly harmful to both human and environmental systems. The most appropriate response to this problem is to decrease the level of overall human intervention in the climate system by decreasing greenhouse gas emissions. However, owing to the slow progress of mitigation efforts, many scientists are starting to suggest alternate climate interventions as a strategy to decrease or avert some of the anticipated impacts of global warming. In this review, I will consider the role of some forms of climate intervention – those aimed at accelerating the slow natural removal of atmospheric CO2 – as possible complements to aggressive mitigation policy, for the purpose of expanding the range of attainable long-term climate targets.

Matthews, H. D. and K. Caldeira (2007). "Transient climate-carbon simulations of planetary geoengineering." Proceedings of the National Academy of Sciences of the United States of America **104**: 9949-9954 DOI: 10.1073/pnas.0700419104

Open Access Article* Available at:

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1885819&tool=pmcentrez&rendertype=abstract

Geoengineering (the intentional modification of Earth's climate) has been proposed as a means of reducing CO2-induced climate warming while greenhouse gas emissions continue. Most proposals involve managing incoming solar radiation such that future greenhouse gas forcing is counteracted by reduced solar forcing. In this study, we assess the transient climate response to geoengineering under a business-as-usual CO2 emissions scenario by using an intermediate-complexity global climate model that includes an interactive carbon cycle. We find that the climate system responds quickly to artificially reduced insolation; hence, there may be little cost to delaying the deployment of geoengineering strategies until such a time as "dangerous" climate change is imminent. Spatial temperature patterns in the geoengineered simulation are comparable with preindustrial temperatures, although this is not true for precipitation. Carbon sinks in the model increase in response to geoengineering. Because geoengineering acts to mask climate warming, there is a direct CO2-driven increase in carbon uptake without an offsetting temperature-driven suppression of carbon sinks. However, this strengthening

of carbon sinks, combined with the potential for rapid climate adjustment to changes in solar forcing, leads to serious consequences should geoengineering fail or be stopped abruptly. Such a scenario could lead to very rapid climate change, with warming rates up to 20 times greater than present-day rates. This warming rebound would be larger and more sustained should climate sensitivity prove to be higher than expected. Thus, employing geoengineering schemes with continued carbon emissions could lead to severe risks for the global climate system.

Matthews, H. D., L. Cao, et al. (2009). "Sensitivity of ocean acidification to geoengineered climate stabilization." Geophysical Research Letters **36**: L10706-L10706 DOI: 10.1029/2009gl037488
Available at: http://www.agu.org/pubs/crossref/2009/2009GL037488.shtml

Climate engineering has been proposed as a possible response to anthropogenic climate change. While climate engineering may be able to stabilize temperatures, it is generally assumed that this will not prevent continued ocean acidification. However, due to the strong coupling between climate and the carbon cycle, climate engineering could indirectly affect ocean chemistry. We used a global Earth- system model to investigate how climate engineering may affect surface ocean pH and the degree of aragonite saturation. Climate engineering could significantly re-distribute carbon emissions among atmosphere, land and ocean reservoirs. This could slow pH decreases somewhat relative to the non- engineered case, but would not affect the level of aragonite saturation due to opposing responses of pH and aragonite saturation to temperature change. However, these effects are dependent on enhanced carbon accumulation in the land biosphere; without this, climate engineering has little effect on pH, and leads to accelerated declines in aragonite saturation.

Matthews, H. D. and S. E. Turner (2009). "Of mongooses and mitigation: ecological analogues to geoengineering." Environmental Research Letters **4**: 045105-045105 DOI: 10.1088/1748-9326/4/4/045105
Open Access Article* Available at:
http://stacks.iop.org/1748-9326/4/i=4/a=045105?key=crossref.fcbbb36b1cde9e42b85293f14aecbb14

Anthropogenic global warming is a growing environmental problem resulting from unintentional human intervention in the global climate system. If employed as a response strategy, geoengineering would represent an additional intentional human intervention in the climate system, with the intent of decreasing net climate impacts. There is a rich and fascinating history of human intervention in environmental systems, with many specific examples from ecology of deliberate human intervention aimed at correcting or decreasing the impact of previous unintentionally created problems. Additional interventions do not always bring the intended results, and in many cases there is evidence that net impacts have increased with the degree of human intervention. In this letter, we report some of the examples in the scientific literature that have documented such human interventions in environmental systems, which may serve as analogues to geoengineering. We argue that a high degree of system understanding is required for increased intervention to lead to decreased impacts. Given our current level of understanding of the climate system, it is likely that the result of at least some geoengineering efforts would follow previous ecological examples where increased human intervention has led to an overall increase in negative environmental consequences.

May, C. and S. E. E. L. Page (2010). "Climate Change and the Integrity of Science." Science
Open Access Article* Available at: http://www.sciencemag.org/content/328/5979/689.short

McCray, W. P. (2011). "Weathering Defeats." Science **331**: 148-149 DOI: 10.1126/science.1201627
Open Access Article* Available at: http://www.sciencemag.org/cgi/doi/10.1126/science.1201627

McFedries, P. (2010). "Hacking the planet (technically speaking)." IEEE Spectrum **47**: 23-23 DOI: 10.1109/mspec.2010.5520622
Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5520622

McHenry, M. P. (2012). Practicalities of establishing forestry carbon sequestration projects in the agricultural sector: a technical and economic analysis with implications, In: Carbon Sequestration. Hauppauge, New York, Nova Science Publishers.
Available at: http://researchrepository.murdoch.edu.au/6035/

This research reviews existing climate change literature and quantifies the climate change mitigation and adaptation potential of specific agricultural forestry diversification activities at the regional level. It comprises modelling of net emission reductions and discounted market values for six agroforestry carbon sequestration projects. The research aim was to describe a simple method of enabling private agricultural entities and

governments to compare alternative investment options for both climate change mitigation and adaptation with limited data availability. The forestry sequestration project examples for the higher rainfall regions of Western Australia show large differences in total discounted project costs over time. These costs were highly dependent on the project financing arrangements, while the tree species selection, and the previous land use were primary determinants of the biomass growth and the total carbon sequestered. The results indicate that the most productive agricultural lands in the region might be permanently retired from food production and replaced by single species tree plantations, although the viability of this option is dependent on future carbon market eligibility rules and carbon values.

Meleshko, V. P., V. M. Kattsov, et al. (2010). "Is aerosol scattering in the stratosphere a safety technology preventing global warming?" Russian Meteorology and Hydrology **35**: 433-440 DOI: 10.3103/s1068373910070010
Available at: http://www.springerlink.com/index/10.3103/S1068373910070010

In accordance with numerous investigations, global climate warming due to the increased greenhouse gas content in the atmosphere can significantly influence the environment already in the near decades. In order to mitigate or prevent possible adverse consequences of this warming the technologies on reducing greenhouse gas emissions as well as a deliberate interference with climate, including its control, are under consideration. Let us analyze the present investigations on the estimate of the influence of a simultaneous increase in the atmospheric CO2 concentration and in the stratospheric aerosol on the global and regional climate, ozone layer, and World Ocean acidification. It is noted that the production and subsequent maintenance of the artificial aerosol layer in the stratosphere could, in principle, eliminate or retard climate warming, but it would be accompanied by a decrease in the global precipitation, especially in the tropical zone. Furthermore, the stratospheric aerosol screen does not solve the problem of the atmospheric CO2 increase, which in turn results in the further World Ocean acidification, and thus has an adverse effect on the marine part of the biosphere. Political and ethic issues connected with the deliberate global man interference with the natural environment are also under considerations.

Melillo, J. M., P. A. Steudler, et al. (2002). "Soil warming and carbon-cycle feedbacks to the climate system." Science **298**: 2173-2176 DOI: 10.1126/science.1074153
Available at: http://www.ncbi.nlm.nih.gov/pubmed/12481133

In a decade-long soil warming experiment in a mid-latitude hardwood forest, we documented changes in soil carbon and nitrogen cycling in order to investigate the consequences of these changes for the climate system. Here we show that whereas soil warming accelerates soil organic matter decay and carbon dioxide fluxes to the atmosphere, this response is small and short-lived for a mid-latitude forest, because of the limited size of the labile soil carbon pool. We also show that warming increases the availability of mineral nitrogen to plants. Because plant growth in many mid-latitude forests is nitrogen-limited, warming has the potential to indirectly stimulate enough carbon storage in plants to at least compensate for the carbon losses from soils. Our results challenge assumptions made in some climate models that lead to projections of large long-term releases of soil carbon in response to warming of forest ecosystems.

Melillo, J. M., A. C. Gurgel, et al. (2009). Unintended Environmental Consequences of a Global Biofuels Program. Cambridge, MA, United States**:** 32 pp.
Open Access Article* Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt168.pdf

Biofuels are being promoted as an important part of the global energy mix to meet the climate change challenge. The environmental costs of biofuels produced with current technologies at small scales have been studied, but little research has been done on the consequences of an aggressive global biofuels program with advanced technologies using cellulosic feedstocks. Here, with simulation modeling, we explore two scenarios for cellulosic biofuels production and find that both could contribute substantially to future global-scale energy needs, but with significant unintended environmental consequences. As the land supply is squeezed to make way for vast areas of biofuels crops, the global landscape is defined by either the clearing of large swathes of natural forest, or the intensification of agricultural operations worldwide. The greenhouse gas implications of land-use conversion differ substantially between the two scenarios, but in both, numerous biodiversity hotspots suffer from serious habitat loss. Cellulosic biofuels may yet serve as a crucial wedge in the solution to the climate change problem, but must be deployed with caution so as not to jeopardize biodiversity, compromise ecosystems services, or undermine climate policy.

Mendelsohn, R., W. Morrison, et al. (2000). "Country-specific market impacts of climate change." Climatic Change **45**: 553-569 DOI: 10.1023/a:1005598717174

Open Access Article* Available at: http://www.springerlink.com/content/wj835313u172l412/

We develop a new climate-impact model, the Global Impact Model (GIM), which combines future scenarios, detailed spatial simulations by general circulation models (GCMs), sectoral features, climate-response functions, and adaptation to generate country-specific impacts by market sector. Estimates are made for three future scenarios, two GCMs, and two climate-response functions – a reduced-form model and a cross-sectional model. Combining empirically based response functions, sectoral data by country, and careful climate forecasts gives analysts a more powerful tool for estimating market impacts. GIM predicts that country specific results vary, implying that research in this area is likely to be policy-relevant.

Mercado, L. M., N. Bellouin, et al. (2009). "Impact of changes in diffuse radiation on the global land carbon sink." Nature **458**: 1014-1017 DOI: 10.1038/nature07949

Available at: http://www.ncbi.nlm.nih.gov/pubmed/19396143

Plant photosynthesis tends to increase with irradiance. However, recent theoretical and observational studies have demonstrated that photosynthesis is also more efficient under diffuse light conditions. Changes in cloud cover or atmospheric aerosol loadings, arising from either volcanic or anthropogenic emissions, alter both the total photosynthetically active radiation reaching the surface and the fraction of this radiation that is diffuse, with uncertain overall effects on global plant productivity and the land carbon sink. Here we estimate the impact of variations in diffuse fraction on the land carbon sink using a global model modified to account for the effects of variations in both direct and diffuse radiation on canopy photosynthesis. We estimate that variations in diffuse fraction, associated largely with the 'global dimming' period, enhanced the land carbon sink by approximately one-quarter between 1960 and 1999. However, under a climate mitigation scenario for the twenty-first century in which sulphate aerosols decline before atmospheric CO(2) is stabilized, this 'diffuse-radiation' fertilization effect declines rapidly to near zero by the end of the twenty-first century.

Mercer, A. M., D. W. Keith, et al. (2011). "Public understanding of solar radiation management." Environmental Research Letters **6**: 044006-044006 DOI: 10.1088/1748-9326/6/4/044006

Open Access Article* Available at:

http://stacks.iop.org/1748-9326/6/i=4/a=044006?key=crossref.0f9ca3ba8da0b53b500c2b5793f1d1de

We report the results of the first large-scale international survey of public perception of geoengineering and solar radiation management (SRM). Our sample of 3105 individuals in the United States, Canada and the United Kingdom was recruited by survey firms that administer internet surveys to nationally representative population samples. Measured familiarity was higher than expected, with 8% and 45% of the population correctly defining the terms geoengineering and climate engineering respectively. There was strong support for allowing the study of SRM. Support decreased and uncertainty rose as subjects were asked about their support for using SRM immediately, or to stop a climate emergency. Support for SRM is associated with optimism about scientific research, a valuing of SRM's benefits and a stronger belief that SRM is natural, while opposition is associated with an attitude that nature should not be manipulated in this way. The potential risks of SRM are important drivers of public perception with the most salient being damage to the ozone layer and unknown risks. SRM is a new technology and public opinions are just forming; thus all reported results are sensitive to changes in framing, future information on risks and benefits, and changes to context.

Metzger, R. A. and G. Benford (2001). "Sequestering of atmospheric carbon through permanent disposal of crop residue." Climatic Change **49**: 11-19 DOI: 10.1023/a:1010765013104

Open Access Article* Available at: http://www.springerlink.com/content/n3t2198q717p7752/

We propose the sequestering of crop residues to capture a significant fraction (12%) of the present U.S. atmospheric carbon emission through disposal in deep oceans below the thermocline or in river deltas. In the United States, the annual carbon content in residues from corn, soybeans and wheat crops is approximately 250 million tonnes. Globally, an additional 1 billion tonnes of carbon in the form of crop residues may be available. Implementation of this sequestering proposal would allow the US to approach the CO2 reductions stipulated under the Kyoto Protocol.

Millard-Ball, A. (2011). "The Tuvalu Syndrome - Can geoengineering solve climate's collective action problem?" Climatic Change DOI: 10.1007/s10584-011-0102-0

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-011-0102-0

Geoengineering research has historically been inhibited by fears that the perceived availability of a technological fix for climate change, such as the deployment of space-based deflectors, may undermine greenhouse gas

abatement efforts. I develop a game theoretic model to show that the credible threat of unilateral geoengineering may instead strengthen global abatement and lead to a self-enforcing climate treaty with full participation. A 'rogue nation' may wish to unilaterally geoengineer if it faces extreme climate damages (as with Tuvalu), or if there are minimal local side effects from geoengineering, such as hydrological cycle disruption or stratospheric ozone depletion. However, the costly global side effects of geoengineering may make it individually rational for other countries to reduce emissions to the level where this rogue nation no longer wishes to unilaterally geoengineer. My results suggest a need to model the impacts of a "selfish geoengineer" intent only on maximizing net domestic benefits, as well as a "benevolent geoengineer" out to restore global mean temperature and minimize global side effects.

Mitchell, D. L. and W. Finnegan (2009). "Modification of cirrus clouds to reduce global warming." Environmental Research Letters **4**: 045102-045102 DOI: 10.1088/1748-9326/4/4/045102

Open Access Article* Available at:

http://stacks.iop.org/1748-9326/4/i=4/a=045102?key=crossref.3584698c81f720db89cc63a8ede2c467

Greenhouse gases and cirrus clouds regulate outgoing longwave radiation (OLR) and cirrus cloud coverage is predicted to be sensitive to the ice fall speed which depends on ice crystal size. The higher the cirrus, the greater their impact is on OLR. Thus by changing ice crystal size in the coldest cirrus, OLR and climate might be modified. Fortunately the coldest cirrus have the highest ice supersaturation due to the dominance of homogeneous freezing nucleation. Seeding such cirrus with very efficient heterogeneous ice nuclei should produce larger ice crystals due to vapor competition effects, thus increasing OLR and surface cooling. Preliminary estimates of this global net cloud forcing are more negative than −2.8W m−2 and could neutralize the radiative forcing due to a CO2 doubling (3.7W m−2). A potential delivery mechanism for the seeding material is already in place: the airline industry. Since seeding aerosol residence times in the troposphere are relatively short, the climate might return to its normal state within months after stopping the geoengineering experiment. The main known drawback to this approach is that it would not stop ocean acidification. It does not have many of the drawbacks that stratospheric injection of sulfur species has.

Montagnini, F. and C. F. Jordan (2005). Tropical Forest Ecology: The Basis for Conservation and Management. Berlin, Springer.

Mooney, H., A. Larigauderie, et al. (2009). "Biodiversity, climate change, and ecosystem services." Current Opinion in Environmental Sustainability **1**: 46-54 DOI: 10.1016/j.cosust.2009.07.006

Available at: http://linkinghub.elsevier.com/retrieve/pii/S1877343509000086

The capacity of ecosystems to deliver essential services to society is already under stress. The additional stresses imposed by climate change in the coming years will require extraordinary adaptation. We need to track the changing status of ecosystems, deepen our understanding of the biological underpinnings for ecosystem service delivery and develop new tools and techniques for maintaining and restoring resilient biological and social systems. We will be building on an ecosystem foundation that has been radically compromised during the past half century. Most rivers have been totally restructured, oceans have been severely altered and depleted, coral reefs are near the tipping point of disappearing as functional ecosystems, over half of the land surface is devoted to livestock and crop agriculture, with little consideration for the ecosystem services that are being lost as a consequence, some irrevocably so. We have already seen many regime shifts, or tipping points, due to human activity, even before the onset of measurable climate change impacts on ecosystems. Climate change, caused mainly by anthropogenic greenhouse gas emissions, will disrupt our ecosystem base in new ways. Already we are seeing widespread signs of change. Species behaviors are altering and disrupting mutualisms of long standing. We are seeing extinctions within vulnerable habitats and conditions where migrations are necessary for survival but where often there are no pathways available for successful movement in the fragmented world of today. These challenges represent an extraordinary threat to society and a call for urgent attention by the scientific community

Moore, J. C., S. Jevrejeva, et al. (2010). "Efficacy of geoengineering to limit 21st century sea-level rise." Proceedings of the National Academy of Sciences of the United States of America **107**: 15699-15703 DOI: 10.1073/pnas.1008153107

Open Access Article* Available at:

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2936649&tool=pmcentrez&rendertype=abstract

Geoengineering has been proposed as a feasible way of mitigating anthropogenic climate change, especially increasing global temperatures in the 21st century. The two main geoengineering options are limiting incoming solar radiation, or modifying the carbon cycle. Here we examine the impact of five geoengineering approaches on

sea level; SO(2) aerosol injection into the stratosphere, mirrors in space, afforestation, biochar, and bioenergy with carbon sequestration. Sea level responds mainly at centennial time scales to temperature change, and has been largely driven by anthropogenic forcing since 1850. Making use a model of sea-level rise as a function of time-varying climate forcing factors (solar radiation, volcanism, and greenhouse gas emissions) we find that sea-level rise by 2100 will likely be 30 cm higher than 2000 levels despite all but the most aggressive geoengineering under all except the most stringent greenhouse gas emissions scenarios. The least risky and most desirable way of limiting sea-level rise is bioenergy with carbon sequestration. However aerosol injection or a space mirror system reducing insolation at an accelerating rate of 1 W m(-2) per decade from now to 2100 could limit or reduce sea levels. Aerosol injection delivering a constant 4 W m(-2) reduction in radiative forcing (similar to a 1991 Pinatubo eruption every 18 months) could delay sea-level rise by 40-80 years. Aerosol injection appears to fail cost-benefit analysis unless it can be maintained continuously, and damage caused by the climate response to the aerosols is less than about 0.6% Global World Product.

Morgera, E. (2011). Faraway, So Close: A Legal Analysis of the Increasing Interactions between the Convention on Biological Diversity and Climate Change Law. Edinburgh**:** 39-39.
Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1753810

The legal and policy implications of the impacts on biodiversity of climate change, as well as of mitigation and adaptation measures, have been progressively addressed by the Convention on Biological Diversity (CBD). This process experienced a steep acceleration at the tenth meeting of the CBD Conference of the Parties (COP X - 18-29 October 2010 in Nagoya, Japan) that resulted in a host of unprecedented and far-reaching decisions related to climate change. This article will first discuss the increasing understanding of the links between global biodiversity loss and climate change, and then review the main climate change-related outcomes of the CBD COP X. It will conclude by discussing the legal relevance of this significant rapprochement of international biodiversity law to climate change law.

Morgera, E. and E. Tsioumani (2011). Yesterday, Today and Tomorrow: Looking Afresh at the Convention on Biological Diversity.
Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1914378

In light of almost twenty years of implementation, this article looks afresh at the Convention on Biological Diversity (CBD), by assessing its evolution and current legal significance with a view to better understanding its immediate future. To this end, the article critically analyses the outcomes of the tenth meeting of the CBD Conference of the Parties, in order to determine progress in the development and implementation of the Convention at the level of both international cooperation and national implementation.

Mori, I. (2010). Experiment Earth? Report on a Public Dialogue on Geoengineering**:** 84-84.
Open Access Article* Available at: http://www.nerc.ac.uk/about/consult/geoengineering-dialogue-final-report.pdf

Moss, J. (2011). "Addressing the Ethical Dimension." Science **332**: 1382-1383 DOI: 10.1126/science.1205393
Open Access Article* Available at: http://www.sciencemag.org/cgi/doi/10.1126/science.1205393

Muller, C. J. and P. A. O'Gorman (2011). "An energetic perspective on the regional response of precipitation to climate change." Nature Climate Change **1**: 266-271 DOI: 10.1038/nclimate1169
Available at: http://www.nature.com/doifinder/10.1038/nclimate1169

Mueller, R., J. Trentmann, et al. (2011). "The Role of the Effective Cloud Albedo for Climate Monitoringand Analysis." Remote Sensing **3**: 2305-2320 DOI: 10.3390/rs3112305
Open Access Article* Available at: http://www.mdpi.com//2072-4292/3/11/2305/

Abstract: Cloud properties and the Earth's radiation budget are defined as essential climate variables by Global Climate Observing System (GCOS). The cloud albedo is a measure for the portion of solar radiation reflected back to space by clouds. This information is essential for the analysis and interpretation of the Earth's radiation budget and the solar surface irradiance. We present and discuss a method for the production of the effective cloud albedo and the solar surface irradiance based on the visible channel (0.45–1 μm) on-board of the Meteosat satellites. This method includes a newly developed self-calibration approach and has been used to generate a 23-year long (1983–2005) continuous and validated climate data record of the effective cloud albedo and the solar surface irradiance. Using these records we demonstrate the ability of the method to provide these essential

variables in high accuracy and homogeneity. Further on, we discuss the role of the cloud albedo within climate monitoring and analysis. We found trends with opposite sign in the observed effective cloud albedo resulting in positive trends in the solar surface irradiance over ocean and partly negative trends over land. Ground measurements are scarce over the ocean and thus satellite-derived effective cloud albedo and solar surface irradiance constitutes a unique observational data source. Within this scope it has to be considered that the ocean is the main energy reservoir of the Earth, which emphasises the role of satellite-observed effective cloud albedo and derived solar surface irradiance as essential climate variables for climate monitoring and analysis.

Murray, C. N., L. Visintini, et al. (1996). "Permanent Storage of Carbon Dioxide in the Marine Environment: The Solid CO2 Penetrator." Energy Conversion and Management **37**: 1067-1072

Available at: http://www.sciencedirect.com/science/article/pii/0196890495002995

To circumvent the uncertainty related to presently studied ocean disposal options based on pumping of liquid carbon dioxide or hydrate slurry injection at depth, with the associated risk of short term physical and biological oceanographic processes returning an important fraction of it to the atmosphere, a disposal technique using the natural geochemical storage properties of deep marine (carbonate or alumino-silicate rich) sedimentary formations is suggested. solid by cooling to -78.5 C. The overall density is approximately one and a half times - 1.56 kg.dm "3 that of seawater. If the solid was shaped as a torpedo and then left to fall through the water column it would penetrate quite deeply into soft underlying sediments. This conclusion is based on in-situ investigations using penetrators that were studied as a disposal option for other solid wastes. The technique proposed would depend on the fact that carbon dioxide can be obtained as a 0 This concept should, therefore, provide permanent storage as the emplaced carbon dioxide will be chemically sequestered by the sediments (via the formation of an intermediate ciathrate). Other than secure segregation of the emplaced CO 2, the penetrator option has a further major advantage in that there should be no long-term effects to biological systems: penetrator disposal is deep within sedimentary formations which have zero or very low biological activity.

Nibleus, K. and R. Lundin (2010). "Climate Change and Mitigation." AMBIO **39**: 11-17 DOI: 10.1007/s13280-010-0058-8

Available at: http://www.springerlink.com/index/10.1007/s13280-010-0058-8

Planet Earth has experienced repeated changes of its climate throughout time. Periods warmer than today as well as much colder, during glacial episodes, have alternated. In our time, rapid population growth with increased demand for natural resources and energy, has made society increasingly vulnerable to environmental changes, both natural and those caused by man; human activity is clearly affecting the radiation balance of the Earth. In the session “Climate Change and Mitigation” the speakers offered four different views on coal and CO2: the basis for life, but also a major hazard with impact on Earth’s climate. A common denominator in the presentations was that more than ever science and technology is required. We need not only understand the mechanisms for climate change and climate variability, we also need to identify means to remedy the anthropogenic influence on Earth’s climate.

Naik, V., D. J. Wuebbles, et al. (2003). "Influence of geoengineered climate on the terrestrial biosphere." Environmental management **32**: 373-381 DOI: 10.1007/s00267-003-2993-7

Open Access Article* Available at: http://www.springerlink.com/content/nffpj86jp0kfyfle/

Various geoengineering schemes have been proposed to counteract anthropogenically induced climate change. In a previous study, it was suggested that a 1.8% reduction in solar radiation incident on the Earth's surface could noticeably reduce regional and seasonal climate change from increased atmospheric carbon dioxide (CO2). However, the response of the terrestrial biosphere to reduced solar radiation in a CO2-rich climate was not investigated. In this study, we hypothesized that a reduction in incident solar radiation in a Doubled CO2 atmosphere will diminish the net primary productivity (NPP) of terrestrial ecosystems, potentially accelerating the accumulation of CO2 in the atmosphere. We used a dynamic global ecosystem model, the Integrated Biosphere Simulator (IBIS), to investigate this hypothesis in an unperturbed climatology. While this simplified modeling framework effectively separated the influence of CO2 and sunlight on the terrestrial biosphere, it did not consider the complex feedbacks within the Earth's climate system. Our analysis indicated that compared to a Doubled CO2 scenario, reduction in incident solar radiation by 1.8% in a double CO2 world will have negligible impact on the NPP of terrestrial ecosystems. There were, however, spatial variations in the response of NPP-engineered solar radiation. While productivity decreased by less than 2% in the tropical and boreal forests as hypothesized, it increased by a similar percentage in the temperate deciduous forests and grasslands. This increase in productivity was attributed to an approximately 1% reduction in evapotranspiration in the Geoengineered scenario relative to

the Doubled CO2 scenario. Our initial hypothesis was rejected because of unanticipated effects of engineered solar radiation on the hydrologic cycle. However, any geoengineering approaches that reduce incident solar radiation need to be thoroughly analyzed in view of the implications on ecosystem productivity and the hydrologic cycle.

Naqvi, S. W. A. S. V. (2011). Ocean iron fertilization. P. Jacquet, R. K. Pachauri and L. Tubiana. New Delhi**:** 197-206.
Open Access Article* Available at: http://drs.nio.org/drs/bitstream/2264/3885/1/Oceans_New_Frontier_2011_197p.pdf
In 2009 and 2010, an Indo-German scientific expedition dusted the ocean with iron to stimulate the biological pump that captures atmosphereic carbon dioxide. Two onboard scientists tell the story of this controversial project. Besides raising the polemic on using geo-engineering to combat global warming, the expedition provided unprecedented knowledge about oceans' biogeochemistry.

Nelson, E., G. Mendoza, et al. (2009). "Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales." Frontiers in Ecology and the Environment **7**: 4-11 DOI: 10.1890/080023
Open Access Article* Available at: http://www.esajournals.org/doi/abs/10.1890/080023
Nature provides a wide range of benefits to people. There is increasing consensus about the importance of incorporating these “ecosystem services” into resource management decisions, but quantifying the levels and values of these services has proven difficult. We use a spatially explicit modeling tool, Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), to predict changes in ecosystem services, biodiversity conservation, and commodity production levels. We apply InVEST to stakeholder-defined scenarios of land-use/land-cover change in the Willamette Basin, Oregon. We found that scenarios that received high scores for a variety of ecosystem services also had high scores for biodiversity, suggesting there is little tradeoff between biodiversity conservation and ecosystem services. Scenarios involving more development had higher commodity production values, but lower levels of biodiversity conservation and ecosystem services. However, including payments for carbon sequestration alleviates this tradeoff. Quantifying ecosystem services in a spatially explicit manner, and analyzing tradeoffs between them, can help to make natural resource decisions more effective, efficient, and defensible.

New, M., D. Liverman, et al. (2011). "Four degrees and beyond: the potential for a global temperature increase of four degrees and its implications." Philosophical transactions. Series A, Mathematical, physical, and engineering sciences **369**: 6-19 DOI: 10.1098/rsta.2010.0303
Open Access Article* Available at: http://www.ncbi.nlm.nih.gov/pubmed/21115510
The 1992 UN Framework Convention on Climate Change commits signatories to preventing 'dangerous anthropogenic interference with the climate system', leaving unspecified the level of global warming that is dangerous. In the late 1990s, a limit of 2(°)C global warming above preindustrial temperature was proposed as a 'guard rail' below which most of the dangerous climate impacts could be avoided. The 2009 Copenhagen Accord recognized the scientific view 'that the increase in global temperature should be below 2 degrees Celsius' despite growing views that this might be too high. At the same time, the continued rise in greenhouse gas emissions in the past decade and the delays in a comprehensive global emissions reduction agreement have made achieving this target extremely difficult, arguably impossible, raising the likelihood of global temperature rises of 3(°)C or 4(°)C within this century. Yet, there are few studies that assess the potential impacts and consequences of a warming of 4(°)C or greater in a systematic manner. Papers in this themed issue provide an initial picture of the challenges facing a world that warms by 4(°)C or more, and the difficulties ahead if warming is to be limited to 2(°)C with any reasonable certainty. Across many sectors-coastal cities, agriculture, water stress, ecosystems, migration-the impacts and adaptation challenges at 4(°)C will be larger than at 2(°)C. In some cases, such as farming in sub-Saharan Africa, a +4(°)C warming could result in the collapse of systems or require transformational adaptation out of systems, as we understand them today. The potential severity of impacts and the behavioural, institutional, societal and economic challenges involved in coping with these impacts argue for renewed efforts to reduce emissions, using all available mechanisms, to minimize the chances of high-end climate change. Yet at the same time, there is a need for accelerated and focused research that improves understanding of how the climate system might behave under a +4(°)C warming, what the impacts of such changes might be and how best to adapt to what would be unprecedented changes in the world we live in.

Norby, R. J., J. M. Warren, et al. (2010). "CO2 enhancement of forest productivity constrained by limited nitrogen availability." Proceedings of the National Academy of Sciences of the United States of America **107**: 19368-19373 DOI: 10.1073/pnas.1006463107

Open Access Article* Available at:

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2984154&tool=pmcentrez&rendertype=abstract
Stimulation of terrestrial plant production by rising CO(2) concentration is projected to reduce the airborne fraction of anthropogenic CO(2) emissions. Coupled climate-carbon cycle models are sensitive to this negative feedback on atmospheric CO(2), but model projections are uncertain because of the expectation that feedbacks through the nitrogen (N) cycle will reduce this so-called CO(2) fertilization effect. We assessed whether N limitation caused a reduced stimulation of net primary productivity (NPP) by elevated atmospheric CO(2) concentration over 11 y in a free-air CO(2) enrichment (FACE) experiment in a deciduous Liquidambar styraciflua (sweetgum) forest stand in Tennessee. During the first 6 y of the experiment, NPP was significantly enhanced in forest plots exposed to 550 ppm CO(2) compared with NPP in plots in current ambient CO(2), and this was a consistent and sustained response. However, the enhancement of NPP under elevated CO(2) declined from 24% in 2001-2003 to 9% in 2008. Global analyses that assume a sustained CO(2) fertilization effect are no longer supported by this FACE experiment. N budget analysis supports the premise that N availability was limiting to tree growth and declining over time--an expected consequence of stand development, which was exacerbated by elevated CO(2). Leaf- and stand-level observations provide mechanistic evidence that declining N availability constrained the tree response to elevated CO(2); these observations are consistent with stand-level model projections. This FACE experiment provides strong rationale and process understanding for incorporating N limitation and N feedback effects in ecosystem and global models used in climate change assessments.

Nordhaus, W. D. (1975). Can we control carbon dioxide?
Open Access Article* Available at: http://www.iiasa.ac.at/Admin/PUB/Documents/WP-75-063.pdf

Nuorteva, P., M. Keskinen, et al. (2010). "Water, livelihoods and climate change adaptation in the Tonle Sap Lake area, Cambodia: learning from the past to understand the future." Journal of Water and Climate Change **01**: 87-87 DOI: 10.2166/wcc.2010.010

Open Access Article* Available at: http://www.iwaponline.com/jwc/001/jwc0010087.htm
The changing environment is expected to intensify the challenges that people in developing countries are facing, particularly among the groups whose livelihoods depend on natural resources. The adaptive capacity of livelihoods largely defines the extent to which people can cope with future environmental changes, whether caused by climate change or other factors such as land use changes and water resources development. This article analyses the resilience and adaptive capacity of rural livelihoods around Cambodia's Tonle Sap Lake, an exceptional lake-floodplain system dominated by flood pulse. The research findings demonstrate that despite the people's tradition of adapting to the remarkable seasonal variation of water and related resources, their capacity to adapt to unusual environmental changes is weak, with the poorest being clearly the most vulnerable group. Reasons for the weak resilience include villages' relatively homogenous livelihood structures, unjust governance practices, increasing inequality and the lack of opportunities for livelihood diversification. It is concluded that while climate change is likely to pose a remarkable challenge to people's livelihoods in the longer term, climate change adaptation activities should also take into account other environmental changes. Equally critical is the understanding of the broader socio-political context and its dynamics in increasing—and decreasing—livelihood resilience.

Olgun, N., S. Duggen, et al. (2011). "Surface ocean iron fertilization: The role of airborne volcanic ash from subduction zone and hot spot volcanoes and related iron fluxes into the Pacific Ocean." Global Biogeochemical Cycles **25** DOI: 10.1029/2009gb003761

Available at: http://www.agu.org/pubs/crossref/2011/2009GB003761.shtml
Surface ocean iron (Fe) fertilization can affect the marine primary productivity (MPP), thereby impacting on CO2 exchanges at the atmosphere-ocean interface and eventually on climate. Mineral (aeolian or desert) dust is known to be a major atmospheric source for the surface ocean biogeochemical iron cycle, but the significance of volcanic ash is poorly constrained. We present the results of geochemical experiments aimed at determining the rapid release of Fe upon contact of pristine volcanic ash with seawater, mimicking their dry deposition into the surface ocean. Our data show that volcanic ash from both subduction zone and hot spot volcanoes (n = 44 samples) rapidly mobilized significant amounts of soluble Fe into seawater (35–340 nmol/g ash), with a suggested global mean of 200 ± 50 nmol Fe/g ash. These values are comparable to the range for desert dust in experiments at seawater pH (10–125 nmol Fe/g dust) presented in the literature (Guieu et al., 1996; Spokes et al., 1996). Combining our new Fe release data with the calculated ash flux from a selected major eruption into the ocean as a case study demonstrates that single volcanic eruptions have the potential to significantly increase the surface

ocean Fe concentration within an ash fallout area. We also constrain the long-term (millennial-scale) airborne volcanic ash and mineral dust Fe flux into the Pacific Ocean by merging the Fe release data with geological flux estimates. These show that the input of volcanic ash into the Pacific Ocean (128–221 × 1015 g/ka) is within the same order of magnitude as the mineral dust input (39–519 × 1015 g/ka) (Mahowald et al., 2005). From the similarity in both Fe release and particle flux follows that the flux of soluble Fe related to the dry deposition of volcanic ash (3–75 × 109 mol/ka) is comparable to that of mineral dust (1–65 × 109 mol/ka). Our study therefore suggests that airborne volcanic ash is an important but hitherto underestimated atmospheric source for the Pacific surface ocean biogeochemical iron cycle.

Orkwor, G. C., R. Asiedu, et al. (1998). Food yams : advances in research. Ibadan, International Institute of Tropical Agriculture.

Orr, D. (2010). "Two views of our planet's future." Nature **464**: 1273-1274 DOI: 10.1038/4641273a
Available at: http://www.nature.com/doifinder/10.1038/4641273a

David Orr explains how two environmentalists' manifestos bracket the debate on climate change — one favouring technological solutions, the other local interventions.

Oschlies, a., W. Koeve, et al. (2010). "Side effects and accounting aspects of hypothetical large-scale Southern Ocean iron fertilization." Biogeosciences **7**: 4017-4035 DOI: 10.5194/bg-7-4017-2010
Open Access Article* Available at: http://www.biogeosciences.net/7/4017/2010/

Recent suggestions to slow down the increase in atmospheric carbon dioxide have included ocean fertilization by addition of the micronutrient iron to Southern Ocean surface waters, where a number of natural and artificial iron fertilization experiments have shown that low ambient iron concentrations limit phytoplankton growth. Using a coupled carbon-climate model with the marine biology's response to iron addition calibrated against data from natural iron fertilization experiments, we examine biogeochemical side effects of a hypothetical large-scale Southern Ocean Iron Fertilization (OIF) that need to be considered when attempting to account for possible OIF-induced carbon offsets. In agreement with earlier studies our model simulates an OIF-induced increase in local air-sea CO_2 fluxes by about 60 GtC over a 100-year period, which amounts to about 40% of the OIF-induced increase in organic carbon export. Offsetting CO_2 return fluxes outside the region and after stopping the fertilization at 1, 7, 10, 50, and 100 years are quantified for a typical accounting period of 100 years. For continuous Southern Ocean iron fertilization, the return flux outside the fertilized area cancels about 8% of the fertilization-induced CO_2 air-sea flux within the fertilized area on a 100-yr timescale. This "leakage" effect has a similar radiative impact as the simulated enhancement of marine N_2O emissions. Other side effects not yet discussed in terms of accounting schemes include a decrease in Southern Ocean oxygen levels and a simultaneous shrinking of tropical suboxic areas, and accelerated ocean acidification in the entire water column in the Southern Ocean on the expense of reduced globally averaged surface water acidification. A prudent approach to account for the OIF-induced carbon sequestration would account for global air-sea CO_2 fluxes rather than for local fluxes into the fertilized area only. However, according to our model, this would underestimate the potential for offsetting CO_2 emissions by about 20% on a 100 year accounting timescale. We suggest that a fair accounting scheme applicable to both terrestrial and marine carbon sequestration has to be based on emission offsets rather than on changes in individual carbon pools.

Oschlies, a., M. Pahlow, et al. (2010). "Climate engineering by artificial ocean upwelling: Channelling the sorcerer's apprentice." Geophysical Research Letters **37**: 1-5 DOI: 10.1029/2009gl041961
Available at: http://www.agu.org/pubs/crossref/2010/2009GL041961.shtml

Recent suggestions to reduce the accumulation of anthropogenic carbon dioxide in the atmosphere have included ocean fertilization by artificial upwelling. Our coupled carbon-climate model simulations suggest that artificial upwelling may, under most optimistic assumptions, be able to sequester atmospheric CO_2 at a rate of about 0.9 PgC/yr. However, the model predicts that about 80% of the carbon sequestered is stored on land, as a result of reduced respiration at lower air temperatures brought about by upwelling of cold waters. This remote and distributed carbon sequestration would make monitoring and verification particularly challenging. A second caveat predicted by our simulations is that whenever artificial upwelling is stopped, simulated surface temperatures and atmospheric CO_2 concentrations rise quickly and for decades to centuries to levels even somewhat higher than experienced in a world that never engaged in artificial upwelling.

Ortiz, M. J. (2011). "Legislation and Policy: Aichi Biodiversity Targets on Direct and Indirect Drivers of Biodiversity

Loss." Environmental Law Review **13**: 100-106 DOI: 10.1350/enlr.2011.13.2.121
Available at: http://www.atypon-link.com/VAT/doi/abs/10.1350/enlr.2011.13.2.121

PaCFA (2009). Global Partnership for Climate, Fisheries and Aquaculture. Fisheries and Aquaculture in our Changing Climate.
Open Access Article* Available at: ftp://ftp.fao.org/FI/brochure/climate_change/policy_brief

Pan, A., B. Pourziaei, et al. (2011). Effect of Ocean Iron Fertilization on the Phytoplankton Biological Carbon Pump**.** 1-20.
Open Access Article* Available at: http://www.math.yorku.ca/~hhuang/preprints/AAMMr1v2.pdf

Pandolfi, J. M., S. R. Connolly, et al. (2011). "Projecting Coral Reef Futures Under Global Warming and Ocean Acidification." Science **333**: 418-422 DOI: 10.1126/science.1204794
Available at: http://www.sciencemag.org/cgi/doi/10.1126/science.1204794

Many physiological responses in present-day coral reefs to climate change are interpreted as consistent with the imminent disappearance of modern reefs globally because of annual mass bleaching events, carbonate dissolution, and insufficient time for substantial evolutionary responses. Emerging evidence for variability in the coral calcification response to acidification, geographical variation in bleaching susceptibility and recovery, responses to past climate change, and potential rates of adaptation to rapid warming supports an alternative scenario in which reef degradation occurs with greater temporal and spatial heterogeneity than current projections suggest. Reducing uncertainty in projecting coral reef futures requires improved understanding of past responses to rapid climate change; physiological responses to interacting factors, such as temperature, acidification, and nutrients; and the costs and constraints imposed by acclimation and adaptation.

Park, Y., D.-Y. Kim, et al. (2006). "Sequestering carbon dioxide into complex structures of naturally occurring gas hydrates." Proceedings of the National Academy of Sciences of the United States of America **103**: 12690-12694 DOI: 10.1073/pnas.0602251103
Open Access Article* Available at:

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1568911&tool=pmcentrez&rendertype=abstract
Large amounts of CH_4 in the form of solid hydrates are stored on continental margins and in permafrost regions. If these CH_4 hydrates could be converted into CO_2 hydrates, they would serve double duty as CH_4 sources and CO_2 storage sites. We explore here the swapping phenomenon occurring in structure I (sI) and structure II (sII) CH_4 hydrate deposits through spectroscopic analyses and its potential application to CO_2 sequestration at the preliminary phase. The present 85% CH_4 recovery rate in sI CH4 hydrate achieved by the direct use of binary N2+CO_2 guests is surprising when compared with the rate of 64% for a pure CO_2 guest attained in the previous approach. The direct use of a mixture of N_2+CO_2 eliminates the requirement of a CO_2 separation/purification process. In addition, the simultaneously occurring dual mechanism of CO_2 sequestration and CH_4 recovery is expected to provide the physicochemical background required for developing a promising large-scale approach with economic feasibility. In the case of sII CH_4 hydrates, we observe a spontaneous structure transition of sII to sI during the replacement and a cage-specific distribution of guest molecules. A significant change of the lattice dimension caused by structure transformation induces a relative number of small cage sites to reduce, resulting in the considerable increase of CH_4 recovery rate. The mutually interactive pattern of targeted guest-cage conjugates possesses important implications for the diverse hydrate-based inclusion phenomena as illustrated in the swapping process between CO_2 stream and complex CH_4 hydrate structure.

Parkhill, K.A and Pidgeon, N.F. (2011) “Public engagement on geoengineering research: preliminary report on the SPICE deliberative workshops”. Technical Report (Understanding Risk Group Working Paper, 11-01). Cardiff University School of Psychology.
Open Access Article* Available at: http://psych.cf.ac.uk/understandingrisk/docs/spice.pdf

Parmesan, C. and G. Yohe (2003). "A globally coherent fingerprint of climate change impacts across natural systems." Nature **421**: 37-42 DOI: 10.1038/nature01286
Available at: http://www.nature.com/nature/journal/v421/n6918/full/nature01286.html

Causal attribution of recent biological trends to climate change is complicated because non-climatic influences dominate local, short-term biological changes. Any underlying signal from climate change is likely to be revealed by analyses that seek systematic trends across diverse species and geographic regions; however, debates within

the Intergovernmental Panel on Climate Change (IPCC) reveal several definitions of a 'systematic trend'. Here, we explore these differences, apply diverse analyses to more than 1,700 species, and show that recent biological trends match climate change predictions. Global meta-analyses documented significant range shifts averaging 6.1 km per decade towards the poles (or metres per decade upward), and significant mean advancement of spring events by 2.3 days per decade. We define a diagnostic fingerprint of temporal and spatial 'sign-switching' responses uniquely predicted by twentieth century climate trends. Among appropriate long-term/large-scale/multi-species data sets, this diagnostic fingerprint was found for 279 species. This suite of analyses generates 'very high confidence' (as laid down by the IPCC) that climate change is already affecting living systems.

Payne, C. R. (2009). "Balancing the risks: Choosing climate alternatives." IOP Conference Series: Earth and Environmental Science **8**: 012001-012001 DOI: 10.1088/1755-1315/8/1/012001

Open Access Article* Available at:

http://stacks.iop.org/1755-1315/8/i=1/a=012001?key=crossref.c5cfa67efaaffbffcf1650ddaa9ea125

Very aggressive reductions in greenhouse gas emissions are needed over the next ten years to avoid a “planet on fire.” Current sub-national, national and international policy assumes that carbon sequestration, biofuels, nuclear power, ocean fertilization, atmospheric aerosols, and other such technologies, which heretofore have been considered too novel or too dangerous to use, will have to be deployed at large scale, globally. Moving forward with promising technologies that might preserve us from the consequences of global warming will be difficult because they also pose potential hazards, promise uncertain benefits, and in some cases are already burdened with restrictive legislation and poor public image. The lack of a rational process of risk assessment and public decision making is likely to lead to a poor longterm outcome. Moreover, the standard administrative and political processes used to assess such risks can take years, time that we do not have. Principled and practical policymaking demand citizens participate in the decision to develop and use these novel technologies. Environmental assessment, horizon scanning, and new research on human and organizational factors suggest techniques to improve technology development decisions.

Pearce, F. (2010). "What the UN ban on geoengineering really means." The New Scientist **208**: 15-15 DOI: 10.1016/s0262-4079(10)62730-3

Available at: http://linkinghub.elsevier.com/retrieve/pii/S0262407910627303

The agreement last week at the UN Convention on Biodiversity appeared to outlaw geoengineering – but its wording is vague and contradictory.

Pelley, J. (2009). "Potential of geoengineering highly uncertain (News)." Environmental science & technology **43**: 8472-9473 DOI: 10.1021/es902776s

Open Access Article* Available at: http://pubs.acs.org/doi/abs/10.1021/es902776s

Pereira, H. M., P. W. Leadley, et al. (2010). "Scenarios for global biodiversity in the 21st century." Science **330**: 1496-1501 DOI: 10.1126/science.1196624

Available at: http://www.sciencemag.org/content/330/6010/1496.short

Quantitative scenarios are coming of age as a tool for evaluating the impact of future socioeconomic development pathways on biodiversity and ecosystem services. We analyze global terrestrial, freshwater, and marine biodiversity scenarios using a range of measures including extinctions, changes in species abundance, habitat loss, and distribution shifts, as well as comparing model projections to observations. Scenarios consistently indicate that biodiversity will continue to decline over the 21st century. However, the range of projected changes is much broader than most studies suggest, partly because there are major opportunities to intervene through better policies, but also because of large uncertainties in projections.

Perry, A. L., P. J. Low, et al. (2005). "Climate change and distribution shifts in marine fishes." Science **308**: 1912-1915 DOI: 10.1126/science.1111322

Open Access Article* Available at: http://www.sciencemag.org/content/308/5730/1912.long

We show that the distributions of both exploited and nonexploited North Sea fishes have responded markedly to recent increases in sea temperature, with nearly two-thirds of species shifting in mean latitude or depth or both over 25 years. For species with northerly or southerly range margins in the North Sea, half have shown boundary shifts with warming, and all but one shifted northward. Species with shifting distributions have faster life cycles and smaller body sizes than nonshifting species. Further temperature rises are likely to have profound impacts on

commercial fisheries through continued shifts in distribution and alterations in community interactions.

Pielke, R. A., G. Marland, et al. (2002). "The influence of land-use change and landscape dynamics on the climate system: relevance to climate-change policy beyond the radiative effect of greenhouse gases." Philosophical Transactions of the Royal Society A **360**: 1705-1719 DOI: 10.1098/rsta.2002.1027

Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/360/1797/1705.short

Our paper documents that land-use change impacts regional and global climate through the surface-energy budget, as well as through the carbon cycle. The surface-energy budget effects may be more important than the carbon-cycle effects. However, land-use impacts on climate cannot be adequately quantified with the usual metric of 'global warming potential'. A new metric is needed to quantify the human disturbance of the Earth's surface-energy budget. This 'regional climate change potential' could offer a new metric for developing a more inclusive climate protocol. This concept would also implicitly provide a mechanism to monitor potential local-scale environmental changes that could influence biodiversity.

Pielke, R., T. Wigley, et al. (2008). "Dangerous assumptions." Nature **452**: 531-532 DOI: 10.1038/452531a

Available at: http://www.ncbi.nlm.nih.gov/pubmed/18385715

How big is the energy challenge of climate change? The technological advances needed to stabilize carbon-dioxide emissions may be greater than we think, argue Roger Pielke Jr, Tom Wigley and Christopher Green. The United Nations Climate Conference in Bali in 2007 set the world on a two-year path to negotiate a successor to the 1997 Kyoto Protocol. Yet not even the most rosy-eyed delegate could fail to recognize that stabilizing atmospheric carbon-dioxide concentrations is an enormous undertaking.

Piñol, J., J. Terradas, et al. (1998). "Climate Warming, Wildfire Hazard, and Wildfire Occurrence in Coastal Eastern Spain." Climatic Change **38**: 345-357 DOI: 10.1023/a:1005316632105

Open Access Article* Available at: http://www.springerlink.com/content/uj7703576542q8qq/

A climatic series (1941 to 1994) from a Mediterranean locality of NE Spain was used to calculate two wildfire hazard indices based on daily meteorological data. Both fire hazard indices increased over this period, as a consequence of increasing mean daily maximum temperature and decreasing minimum daily relative humidity. These trends were observed in both mean values of the indices and in the number of very high risk days. Annual data on the number of wildfires and burned area also show an increase from 1968 to 1994, and are significantly correlated with both fire hazard indices. Although other nonmeteorological causes (e.g., human activities, fuel accumulation) have likely contributed to the observed increase of wildfires, an effect of climatic warming on wildfire occurrence is supported by this relationship.

Pires, J. C. M., F. G. Martins, et al. (2011). "Recent developments on carbon capture and storage: An overview." Chemical Engineering Research and Design **89**: 1446-1460 DOI: 10.1016/j.cherd.2011.01.028

Available at: http://linkinghub.elsevier.com/retrieve/pii/S0263876211000554

The Intergovernmental Panel on Climate Change assumes the warming of the climate system, associating the increase of global average temperature to the observed increase of the anthropogenic greenhouse gas (GHG) concentrations in the atmosphere. Carbon dioxide (CO2) is considered the most important GHG, due to the dependence of world economies on fossil fuels, since their combustion processes are the most important sources of this gas. CO2 concentrations are increasing in the last decades mainly due to the increase of anthropogenic emissions. The processes involving CO2 capture and storage is gaining attention on the scientific community as an alternative for decreasing CO2 emission, reducing its concentration in ambient air. However, several technological, economical and environmental issues as well as safety problems remain to be solved, such as the following needs: increase of CO2 capture efficiency, reduction of process costs, and verification of environmental sustainability of CO2 storage. This paper aims to review the recent developments (from 2006 until now) on the carbon capture and storage (CCS) methodologies. Special attention was focused on the basic findings achieved in CCS operational projects.

Plieninger, T. (2011). "Capitalizing on the Carbon Sequestration Potential of Agroforestry in Germany's Agricultural Landscapes: Realigning the Climate Change Mitigation and Landscape Conservation Agendas." Landscape Research **36**: 435-454 DOI: 10.1080/01426397.2011.582943

Available at: http://www.tandfonline.com/doi/abs/10.1080/01426397.2011.582943

The potential of agriculture, forestry, and other land uses to sequester carbon offers a powerful tool for controlling the global climate regime, but practices capable of creating ‘collateral’ benefits for landscape conservation have

thus far been disregarded. This paper calls for greater integration of scattered trees into agricultural landscapes, hypothesizing that agroforestry practices effectively store carbon and deliver other important ecosystem services as well. Several agroforests from the Upper Lusatia area in eastern Germany have been selected for analysis. They cover relatively large areas of land (8.2%), even within this intensively used agricultural landscape, and their extent increased from 1964–2008 by 19.4%. Practices of conserving or promoting six agroforest classes are compared with a catalogue of essential properties for becoming effective 'carbon offset projects'. Criteria from mandatory and voluntary carbon markets for carbon sequestration are then applied (additionality, baselines, permanence, and carbon leakage). The study concludes that steps towards realization of 'carbon sequestration projects' should include collecting empirical evidence regarding the carbon sequestration potential of temperate agroforestry systems, developing localized demonstration projects, and upscaling these projects to participate in established carbon markets.

Pollak, M., S. J. Phillips, et al. (2011). "Carbon capture and storage policy in the United States: A new coalition endeavors to change existing policy." Global Environmental Change **21**: 313-323 DOI: 10.1016/j.gloenvcha.2011.01.009
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959378011000100

Carbon capture and storage (CCS) is considered by some to be a promising technology to reduce greenhouse gas emissions, and advocates are seeking policies to facilitate its deployment. Unlike many countries, which approach the development of policies for geologic storage (GS) of carbon dioxide (CO_2) with nearly a blank slate, the U.S. already has a mature policy regime devoted to the injection of CO_2 into deep geologic formations. However, the existing governance of CO_2 injection is designed to manage enhanced oil recovery (EOR), and policy changes would be needed to manage the risks and benefits of CO_2 injection for the purpose of avoiding GHG emissions. We review GS policy developments at both the U.S. federal and state levels, including original research on state GS policy development. By applying advocacy coalition framework theory, we identify two competing coalitions defined by their beliefs about the primary purpose of CO_2 injection: energy supply or greenhouse gas (GHG) emission reductions. The established energy coalition is the beneficiary of the current policy regime. Their vision of GS policy is protective: to minimize harm to fossil energy industries if climate policy were to be enacted. In contrast, the newly formed climate coalition seeks to change existing GS policy to support their proactive vision: to maximize GHG reductions using CCS when climate policy is enacted. We explore where and at what scale legislation emerges and examine which institutions gain prominence as drivers of policy change. Through a detailed textual analysis of the content of state GS legislation, we find that the energy coalition has had greater success than the climate coalition in shaping state laws to align with its policy preferences. It has enshrined its view of the purpose of CO_2 injection in state legislation, delegated authority for GS to state agencies aligned with the existing policy regime, and protected the EOR status quo, while creating new opportunities for EOR operators to profit from the storage of CO_2 The climate coalition's objective of proactively putting GS policy in place has been furthered, and important progress has been made on commonly held concerns, such as the resolution of property rights issues, but the net result is policy change that does not significantly revise the existing policy regime.

Poumadère, M., R. Bertoldo, et al. (2011). "Public perceptions and governance of controversial technologies to tackle climate change: nuclear power, carbon capture and storage, wind, and geoengineering." Wiley Interdisciplinary Reviews: Climate Change: in press-in press DOI: 10.1002/wcc.134
Available at: http://onlinelibrary.wiley.com/doi/10.1002/wcc.134/full

The role carbon emissions play in contributing to climate change makes clear the necessity for a global reconsideration of current modes of energy production. In recent years, as concerns over the threats of climate change (CC) have become more acute, four technologies have notably risen to the forefront of academic and public discourse: nuclear power, carbon capture and storage (CCS), wind power, and geoengineering. The particular interest of these four approaches lies in the fact that they reflect both energy production and climate control technologies, are often socially controversial, and present complex challenges of governance. Nuclear and wind power both deserve an important place among the variety of low-carbon energy options. In countries where public acceptance is evaluated, although, support for nuclear energy appears to be conditional upon simultaneous development of other renewable energies alongside a feasible plan to address the disposal of nuclear waste. The Fukushima accident sharply increased public concern about the safety and vulnerability of nuclear reactors. While wind power receives general public support, issues of accommodation can arise when it comes to siting wind farms. Persistent dependency upon carbon-producing energy has made favorable the option of CCS. However, in addition to technical and geological factors, social resistance to the placement of carbon storage units remains a key obstacle. Geoengineering offers the technological capacity to directly act on the climate should levels of

atmospheric CO_2 become dangerously high. Public perception regarding the risk of climate change can be labile, and the alternatives reviewed here share the characteristic that their technical and political dimensions are intertwined. The variety of options for combining and implementing these technologies, coupled with the inherently time-sensitive nature of CC, underscore the complexity of the endeavor. In order to bridge these various levels of analysis and decision making, and to better understand and integrate people's involvement, exercises in risk governance could be developed at both the national and international levels

Powlson, D. S., a. P. Whitmore, et al. (2011). "Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false." European Journal of Soil Science **62**: 42-55 DOI: 10.1111/j.1365-2389.2010.01342.x

Open Access Article* Available at: http://doi.wiley.com/10.1111/j.1365-2389.2010.01342.x

The term ‘carbon sequestration’ is commonly used to describe any increase in soil organic carbon (SOC) content caused by a change in land management, with the implication that increased soil carbon (C) storage mitigates climate change. However, this is only true if the management practice causes an additional net transfer of C from the atmosphere to land. Limitations of C sequestration for climate change mitigation include the following constraints: (i) the quantity of C stored in soil is finite, (ii) the process is reversible and (iii) even if SOC is increased there may be changes in the fluxes of other greenhouse gases, especially nitrous oxide (N_2O) and methane. Removing land from annual cropping and converting to forest, grassland or perennial crops will remove C from atmospheric CO_2 and genuinely contribute to climate change mitigation. However, indirect effects such as conversion of land elsewhere under native vegetation to agriculture could negate the benefit through increased CO2 emission. Re-vegetating degraded land, of limited value for food production, avoids this problem. Adding organic materials such as crop residues or animal manure to soil, whilst increasing SOC, generally does not constitute an additional transfer of C from the atmosphere to land, depending on the alternative fate of the residue. Increases in SOC from reduced tillage now appear to be much smaller than previously claimed, at least in temperate regions, and in some situations increased N_2O emission may negate any increase in stored C. The climate change benefit of increased SOC from enhanced crop growth (for example from the use of fertilizers) must be balanced against greenhouse gas emissions associated with manufacture and use of fertilizer. An over-emphasis on the benefits of soil C sequestration may detract from other measures that are at least as effective in combating climate change, including slowing deforestation and increasing efficiency of N use in order to decrease N_2O emissions.

Prantl, J. (2011). Debating Geoengineering Governance : How it Matters to the Asia - Pacific Region. **2011**.

Open Access Article* Available at: http://www.rsis.edu.sg/nts/HTML-Newsletter/Alert/pdf/NTS_Alert_apr_1102.pdf

The debate on the risks and opportunities of geoengineering is currently gaining momentum. The Intergovernmental Panel on Climate Change is, for the first time, assessing the scientific basis as well as the potential impacts and side effects of geoengineering proposals in their Fifth Assessment Report, which is scheduled to be finalised in 2014. The Asia0-Pacific region needs to participate in this debate. This NTS Alert highlights the climate change challenges in the Asia-Pacific and their likely impacts. It identifies three initial steps that may facilitate a discussion to investigate the potential role of geoengineering techniques in response to those challenges: regional consultations, scenario-building, and public and civil society engagement.

Quaas, J. (2011). "Global warming: The soot factor." Nature **471**: 456-457 DOI: 10.1038/471456a

Available at: http://www.ncbi.nlm.nih.gov/pubmed/21430770

The surface warming due to emissions of black-carbon aerosols over the second half of the twentieth century has been identified in observations. These findings will inform debate over the climatic effects of controlling such emissions.

Quinn, P. K. and T. S. Bates (2011). "The case against climate regulation via oceanic phytoplankton sulphur emissions." Nature **480**: 51-56 DOI: 10.1038/nature10580

Available at: http://www.nature.com/doifinder/10.1038/nature10580

More than twenty years ago, a biological regulation of climate was proposed whereby emissions of dimethyl sulphide from oceanic phytoplankton resulted in the formation of aerosol particles that acted as cloud condensation nuclei in the marine boundary layer. In this hypothesis—referred to as CLAW—the increase in cloud condensation nuclei led to an increase in cloud albedo with the resulting changes in temperature and radiation initiating a climate feedback altering dimethyl sulphide emissions from phytoplankton. Over the past two decades, observations in the marine boundary layer, laboratory studies and modelling efforts have been

conducted seeking evidence for the CLAW hypothesis. The results indicate that a dimethyl sulphide biological control over cloud condensation nuclei probably does not exist and that sources of these nuclei to the marine boundary layer and the response of clouds to changes in aerosol are much more complex than was recognized twenty years ago. These results indicate that it is time to retire the CLAW hypothesis.

Ramanamanjato, J.-B. and J. U. Ganzhorn (2001). "Effects of forest fragmentation, introduced Rattus rattus and the role of exotic tree plantations and secondary vegetation for the conservation of an endemic rodent and a small lemur in littoral forests of southeastern Madagascar." Animal Conservation **4**: 175-183 DOI: 10.1017/s1367943001001202
Available at: http://onlinelibrary.wiley.com/doi/10.1017/S1367943001001202/abstract

We sought to assess the effects of forest fragmentation, introduced *Rattus rattus*, exotic tree plantations and secondary vegetation on the endemic rodent *Eliurus webbi* (Nesomyinae) and the lemur *Microcebus murinus* in the littoral forests of southern Madagascar. For *E. webbi* the number of individuals caught, the body mass of males and the percentage of females in the population were positively correlated with the size of the forest fragments. Capture rates and population characteristics of the other two species were uncorrelated with fragment size. None of the endemic species was caught outside the native forest while *R. rattus* inhabited all vegetation formations except for a newly planted corridor of tree saplings. Capture rates of both endemic species were uncorrelated with the number of *R. rattus* caught at the same site and thus did not indicate replacement of native species by *R. rattus*. The study demonstrated negative effects of fragmentation on capture rates of *E. webbi* and changes in their population characteristics. Exotic tree plantations or secondary vegetation seem to represent unsuitable or marginal habitats for the endemic species.

Rasch, P. J., J. Latham, et al. (2009). "Geoengineering by cloud seeding: influence on sea ice and climate system." Environmental Research Letters **4**: 045112-045112 DOI: 10.1088/1748-9326/4/4/045112
Open Access Article* Available at:
http://stacks.iop.org/1748-9326/4/i=4/a=045112?key=crossref.d83e267554a572f6a1c5f18f936bd999

General circulation model computations using a fully coupled ocean–atmosphere model indicate that increasing cloud reflectivity by seeding maritime boundary layer clouds with particles made from seawater may compensate for some of the effects on climate of increasing greenhouse gas concentrations. The chosen seeding strategy (one of many possible scenarios) can restore global averages of temperature, precipitation and sea ice to present day values, but not simultaneously. The response varies nonlinearly with the extent of seeding, and geoengineering generates local changes to important climatic features. The global tradeoffs of restoring ice cover, and cooling the planet, must be assessed alongside the local changes to climate features.

Rasch, P. J., S. Tilmes, et al. (2008). "An overview of geoengineering of climate using stratospheric sulphate aerosols." Philosophical Transactions of the Royal Society A **366**: 4007-4037 DOI: 10.1098/rsta.2008.0131
Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/366/1882/4007.long

We provide an overview of geoengineering by stratospheric sulphate aerosols. The state of understanding about this topic as of early 2008 is reviewed, summarizing the past 30 years of work in the area, highlighting some very recent studies using climate models, and discussing methods used to deliver sulphur species to the stratosphere. The studies reviewed here suggest that sulphate aerosols can counteract the globally averaged temperature increase associated with increasing greenhouse gases, and reduce changes to some other components of the Earth system. There are likely to be remaining regional climate changes after geoengineering, with some regions experiencing significant changes in temperature or precipitation. The aerosols also serve as surfaces for heterogeneous chemistry resulting in increased ozone depletion. The delivery of sulphur species to the stratosphere in a way that will produce particles of the right size is shown to be a complex and potentially very difficult task. Two simple delivery scenarios are explored, but similar exercises will be needed for other suggested delivery mechanisms. While the introduction of the geoengineering source of sulphate aerosol will perturb the sulphur cycle of the stratosphere signicantly, it is a small perturbation to the total (stratosphere and troposphere) sulphur cycle. The geoengineering source would thus be a small contributor to the total global source of 'acid rain' that could be compensated for through improved pollution control of anthropogenic tropospheric sources. Some areas of research remain unexplored. Although ozone may be depleted, with a consequent increase to solar ultraviolet-B (UVB) energy reaching the surface and a potential impact on health and biological populations, the aerosols will also scatter and attenuate this part of the energy spectrum, and this may compensate the UVB enhancement associated with ozone depletion. The aerosol will also change the ratio of diffuse to direct energy reaching the surface, and this may influence ecosystems. The impact of geoengineering on these components of the Earth system has not yet been studied. Representations for the formation, evolution and removal of aerosol

and distribution of particle size are still very crude, and more work will be needed to gain confidence in our understanding of the deliberate production of this class of aerosols and their role in the climate system.

Rau, G. H. (2011). "CO_2 mitigation via capture and chemical conversion in seawater." Environmental science & technology **45**: 1088-1092 DOI: 10.1021/es102671x

Available at: http://pubs.acs.org/doi/abs/10.1021/es102671x

A lab-scale seawater/mineral carbonate gas scrubber was found to remove up to 97% of CO(2) in a simulated flue gas stream at ambient temperature and pressure, with a large fraction of this carbon ultimately converted to dissolved calcium bicarbonate. After full equilibration with air, up to 85% of the captured carbon was retained in solution, that is, it did not degas or precipitate. Thus, above-ground CO(2) hydration and mineral carbonate scrubbing may provide a relatively simple point-source CO(2) capture and storage scheme at coastal locations. Such low-tech CO(2) mitigation could be especially relevant for retrofitting to existing power plants and for deployment in the developing world, the primary source of future CO(2) emissions. Addition of the resulting alkaline solution to the ocean may benefit marine ecosystems that are currently threatened by acidification, while also allowing the utilization of the vast potential of the sea to safely sequester anthropogenic carbon. This approach in essence hastens Nature's own very effective but slow CO(2) mitigation process; carbonate mineral weathering is a major consumer of excess atmospheric CO(2) and ocean acidity on geologic times scales.

Rau, G. H. (2008). "Electrochemical splitting of calcium carbonate to increase solution alkalinity: implications for mitigation of carbon dioxide and ocean acidity." Environmental science & technology **42**: 8935-8940

Available at: http://pubs.acs.org/doi/abs/10.1021/es800366q

Electrochemical splitting of calcium carbonate (e.g., as contained in limestone or other minerals) is explored as a means of forming dissolve hydroxides for absorbing, neutralizing, and storing carbon dioxide, and for restoring, preserving, or enhancing ocean calcification. While essentially insoluble in water, CaCO3 can be dissolved in the presence of the highly acidic anolyte of a water electrolysis cell. The resulting charged constituents, Ca_2+ and $C0_3$ (2-), migrate to the cathode and anode, respectively, forming $Ca(OH)_2$ on the one hand and H_2CO_3 (or H_2O and CO_2) on the other. By maintaining a pH between 6 and 9, subsequent hydroxide reactions with CO_2 primarily produce dissolved calcium bicarbonate, $Ca(HCO_3)2aq$. Thus, for each mole of $CaCO_3$ split there can be a net capture of up to 1 mol of CO_2. $Ca(HCO_3)2aq$ is thus the carbon sequestrant that can be diluted and stored in the ocean, in natural or artificial surface water reservoirs, or underground. The theoretical work requirement for the reaction is 266 kJe per net mole CO_2 consumed. Even with inefficiencies, a realized net energy expenditure lower than the preceding quantity appears possible considering energy recovery via oxidation of the H_2 produced. The net process cost is estimated to be <$100/tonne CO_2 mitigated. An experimental demonstration of the concept is presented, and further implementation issues are discussed.

Rau, G. (1999). "Enhanced carbonate dissolution: a means of sequestering waste CO2 as ocean bicarbonate." Energy Conversion and Management **40**: 1803-1813 DOI: 10.1016/s0196-8904(99)00071-0

Available at: http://linkinghub.elsevier.com/retrieve/pii/S0196890499000710

The reaction of a mineral carbonate, such as limestone, with water and CO2 to form bicarbonate in solution, is explored as a CO_2 mitigation strategy. Initial cost estimates for such a process range from $18 to $128 per tonne CO_2 sequestered, with an energy penalty of about 8% and with relatively low environmental impact. The regional availability and transport of water and mineral carbonate appear to be the primary determinants of the strategy's cost and applicability. The bicarbonate-rich waste effluent would be released into rivers or coastal waters, ultimately adding a small amount to the existing, very large bicarbonate reservoir in the ocean. For many applications, this form of 'marine' carbon sequestration appears to be less costly, less affected by national and international regulations, more environmentally friendly and more effective over the long term than direct CO_2 injection into the ocean.

Raupach, M. R., P. J. Rayner, et al. (2005). "Model-data synthesis in terrestrial carbon observation: methods, data requirements and data uncertainty specifications." Global Change Biology **11**: 378-397 DOI: 10.1111/j.1365-2486.2005.00917.x

Available at: http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2005.00917.x/abstract

Systematic, operational, long-term observations of the terrestrial carbon cycle (including its interactions with water, energy and nutrient cycles and ecosystem dynamics) are important for the prediction and management of climate, water resources, food resources, biodiversity and desertification. To contribute to these goals, a terrestrial carbon observing system requires the synthesis of several kinds of observation into terrestrial biosphere models

encompassing the coupled cycles of carbon, water, energy and nutrients. Relevant observations include atmospheric composition (concentrations of CO_2 and other gases); remote sensing; flux and process measurements from intensive study sites; in situ vegetation and soil monitoring; weather, climate and hydrological data; and contemporary and historical data on land use, land use change and disturbance (grazing, harvest, clearing, fire). A review of model–data synthesis tools for terrestrial carbon observation identifies 'nonsequential' and 'sequential' approaches as major categories, differing according to whether data are treated all at once or sequentially. The structure underlying both approaches is reviewed, highlighting several basic commonalities in formalism and data requirements. An essential commonality is that for all model–data synthesis problems, both nonsequential and sequential, data uncertainties are as important as data values themselves and have a comparable role in determining the outcome. Given the importance of data uncertainties, there is an urgent need for soundly based uncertainty characterizations for the main kinds of data used in terrestrial carbon observation. The first requirement is a specification of the main properties of the error covariance matrix. As a step towards this goal, semi-quantitative estimates are made of the main properties of the error covariance matrix for four kinds of data essential for terrestrial carbon observation: remote sensing of land surface properties, atmospheric composition measurements, direct flux measurements, and measurements of carbon stores.

Ravindranath, N. H. and M. Ostwald (2008). Carbon Inventory Methods Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Roundwood Production Projects, Springer Verlag, Advances in Global Change Research.

Rayner, S., C. Redgwell, et al. (2009) Memorandum on draft principles for the conduct of geoengineering research.
Open Access Article* Available at: http://www.sbs.ox.ac.uk/centres/insis/Documents/regulation-of-geoengineering.pdf

Reiner, D. (2011). "Sociology: Learning lessons on carbon storage." Nature Climate Change **1**: 96-98 DOI: 10.1038/nclimate1103
Available at: http://www.nature.com/doifinder/10.1038/nclimate1103
Carbon capture and storage demonstration projects are focused on learning about technologies through conventional 'learning by doing'. Analysis of three case studies indicates that including other types of learning could bring significant rewards.

Reynolds, J. (2011). "The Regulation of Climate Engineering." Law, Innovation and Technology **3**: 113-136 DOI: 10.5235/175799611796399821
Available at: http://openurl.ingenta.com/content/xref?genre=article&issn=1757-9961&volume=3&issue=1&spage=113
Intentional interventions in global physical, chemical, and biological systems on a massive scale are receiving increasing attention in hopes of reducing the threat of anthropogenic climate change. Known as climate engineering, or geoengineering, research is moving forward, but regulation remains inadequate, due in part to significant regulatory challenges. This essay asserts that key to overcoming these regulatory challenges is distinguishing between the two primary forms of climate engineering, and between deployment and research. One of climate engineering's two primary forms, carbon dioxide removal, can largely be addressed through existing legal instruments. In the case of solar radiation management, the other primary form, focusing initially on research can bypass the geopolitical quagmire of deployment. Two other major challenges to developing regulation for solar radiation management research remain: establishing regulatory legitimacy, and developing an appropriate definition of research. Potential regulatory forms include centralized international legal instruments, fully or partially private transnational networks, and norms developed from the bottom up.

Richardson, A. J. and D. S. Schoeman (2004). "Climate impact on plankton ecosystems in the Northeast Atlantic." Science **305**: 1609-1612 DOI: 10.1126/science.1100958
Open Access Article* Available at: http://www.sciencemag.org/content/305/5690/1609.long
It is now widely accepted that global warming is occurring, yet its effects on the world's largest ecosystem, the marine pelagic realm, are largely unknown. We show that sea surface warming in the Northeast Atlantic is accompanied by increasing phytoplankton abundance in cooler regions and decreasing phytoplankton abundance in warmer regions. This impact propagates up the food web (bottom-up control) through copepod herbivores to zooplankton carnivores because of tight trophic coupling. Future warming is therefore likely to alter the spatial distribution of primary and secondary pelagic production, affecting ecosystem services and placing additional stress on already-depleted fish and mammal populations.

Ricke, K. L., M. G. Morgan, et al. (2010). "Regional climate response to solar-radiation management." Nature Geoscience

3: 537-541 DOI: 10.1038/ngeo915
Available at: http://www.nature.com/doifinder/10.1038/ngeo915

Concerns about the slow pace of climate mitigation have led to renewed dialogue about solar-radiation management, which could be achieved by adding reflecting aerosols to the stratosphere. Modelling studies suggest that solar-radiation management could produce stabilized global temperatures and reduced global precipitation4, 5, 6. Here we present an analysis of regional differences in a climate modified by solar-radiation management, using a large-ensemble modelling experiment that examines the impacts of 54 scenarios for global temperature stabilization. Our results confirm that solar-radiation management would generally lead to less extreme temperature and precipitation anomalies, compared with unmitigated greenhouse gas emissions. However, they also illustrate that it is physically not feasible to stabilize global precipitation and temperature simultaneously as long as atmospheric greenhouse gas concentrations continue to rise. Over time, simulated temperature and precipitation in large regions such as China and India vary significantly with different trajectories for solar-radiation management, and they diverge from historical baselines in different directions. Hence, it may not be possible to stabilize the climate in all regions simultaneously using solar-radiation management. Regional diversity in the response to different levels of solar-radiation management could make consensus about the optimal level of geoengineering difficult, if not impossible, to achieve.

Ricke, K., M. G. Morgan, et al. (2008) Unilateral Geoengineering, Washington, DC, Council on Foreign Relations.
Open Access Article* Available at: http://www.cfr.org/content/thinktank/GeoEng_Jan2709.pdf

There are a variety of strategies, such as injecting light-reflecting particles into the stratosphere, that might be used to modify the Earth's atmosphere-ocean system in an attempt to slow or reverse global warming. All of these "geoengineering" strategies involve great uncertainty and carry significant risks. They may not work as expected, imposing large unintended consequences on the climate system. While offsetting warming, most strategies are likely to leave other impacts unchecked, such as acidification of the ocean, the destruction of coral reefs, and changes in composition of terrestrial ecosystems. Yet, despite uncertain and very negative potential consequences, geoengineering might be needed to avert or reverse some dramatic change in the climate system, such as several meters of sea level rise that could impose disaster on hundreds of millions of people. Unlike the control of greenhouse gas emissions, which must be undertaken by all major emitting nations to be effective and is likely to be costly, geoengineering could be undertaken quickly and unilaterally by a single party, at relatively low cost. Unilateral geoengineering, however, is highly likely to impose costs on other countries and run risks with the entire planet's climate system. This workshop will focus on the question of strategies for constraining and shaping geoengineering. We will explore formal, legal strategies as well as informal efforts to create norms that could govern testing and deployment of geoengineering systems and their possible undesirable consequences. We will probe whether it is possible to limit the use of geoengineering to circumstances of collective action by the international community in the face of true global emergencies and what might happen when there are disputes over when the emergency "trigger" should be pulled.

Rickels, W., K. Rehdanz, et al. (2011). "Economic prospects of ocean iron fertilization in an international carbon market." Resource and Energy Economics **34**: 129-150 DOI: 10.1016/j.reseneeco.2011.04.003
Open Access Article* Available at: http://linkinghub.elsevier.com/retrieve/pii/S0928765511000261

Staying within the 2 C temperature increase target for climate change requires for ambitious emission reduction targets for the 2012–2020 compliance period. Cost-efficiency is a crucial criterion for the achievement of such targets, requiring analyses of all possible options. Enhancing the oceanic carbon sink via ocean iron fertilization (OIF) provides such an option. Our analysis reveals that the critical unit costs per net ton of CO2 sequestered by OIF range from 22 to 28 USD (price level 2000) in a post-Kyoto compliance scenario. The critical unit costs are defined as those that would make an emitter indifferent between various abatement options. With reference to hypothetical short-term large-scale Southern Ocean OIF we are able to show that seven years of OIF provide a number of credits exceeding those obtainable from global forestation projects lasting 20 years. From an economic perspective, our results indicate that OIF can be considered a potentially viable carbon-removal option. However, further research is needed, especially on adverse side-effects and their ecological and economical consequences.

Ridgwell, A., T. J. Rodengen, et al. (2011). "Geographical variations in the effectiveness and side effects of deep ocean carbon sequestration." Geophysical Research Letters **38** DOI: 10.1029/2011gl048423
Available at: http://www.agu.org/pubs/crossref/2011/2011GL048423.shtml

The capture and injection of carbon dioxide (CO2) into the deep ocean could provide a relatively long-term mitigation of climate change, but would come at the expense of enhancing acidification at the seafloor. We

employ an Earth system model to survey the regional differences in the effectiveness and side effects of CO_2 injection. Sequestration efficiency, as calculated relative to the 'natural' invasion from the atmosphere that would occur in the absence of mitigation, is highest for injection in the deep NW Pacific, but can be negative for shallow sites. For higher climate sensitivities and greater total emissions, sequestration efficiency is enhanced, decreasing the relative cost and increasing its potential value as a form of mitigation. However, CO_2 injection increases the total area of seafloor bathed in under-saturated waters, with Atlantic sites inducing particularly large increases in seafloor undersaturation as well as having less favorable sequestration efficiency.

Ridgwell, A., J. S. Singarayer, et al. (2009). "Tackling regional climate change by leaf albedo bio-geoengineering." Current biology **19**: 146-150 DOI: 10.1016/j.cub.2008.12.025

Open Access Article* Available at: http://www.cell.com/current-biology/retrieve/pii/S0960982208016801

The likelihood that continuing greenhouse-gas emissions will lead to an unmanageable degree of climate change has stimulated the search for planetary-scale technological solutions for reducing global warming ("geoengineering"), typically characterized by the necessity for costly new infrastructures and industries. We suggest that the existing global infrastructure associated with arable agriculture can help, given that crop plants exert an important influence over the climatic energy budget because of differences in their albedo (solar reflectivity) compared to soils and to natural vegetation. Specifically, we propose a "bio-geoengineering" approach to mitigate surface warming, in which crop varieties having specific leaf glossiness and/or canopy morphological traits are specifically chosen to maximize solar reflectivity. We quantify this by modifying the canopy albedo of vegetation in prescribed cropland areas in a global-climate model, and thereby estimate the near-term potential for bio-geoengineering to be a summertime cooling of more than 1 degrees C throughout much of central North America and midlatitude Eurasia, equivalent to seasonally offsetting approximately one-fifth of regional warming due to doubling of atmospheric CO(2). Ultimately, genetic modification of plant leaf waxes or canopy structure could achieve greater temperature reductions, although better characterization of existing intraspecies variability is needed first.

Robock, A (2008) Whither geoengineering? Science 320:1166-1167

Open Access Article* Available at:
ftp://ccar.colorado.edu/pub/thayerj/CEDAR/Habitability%20and%20sustainability%20section/stratosphere%20geoengineering/Robock%20science%20article%20whither%20geoengineering.pdf

Robock, A. (2008). "20 reasons why geoengineering may be a bad idea." Bulletin of the Atomic Scientists **64**: 14-18 DOI: 10.2968/064002006

Open Access Article* Available at: http://www.thebulletin.org/files/064002006_0.pdf

Robock, A. (2008). "Atmospheric science. Whither geoengineering?" Science **320**: 1166-1167 DOI: 10.1126/science.1159280

Available at: http://www.ncbi.nlm.nih.gov/pubmed/18511675

Costs, benefits, and harms associated with geoengineering must be assessed before it is used to mitigate climate change.

Robock, A. (2011). "Bubble, bubble, toil and trouble." Climatic Change **105**: 383-385 DOI: 10.1007/s10584-010-0017-1

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-010-0017-1

Robock, A., M. Bunzl, et al. (2010). "Atmospheric science. A test for geoengineering?" Science **327**: 530-531 DOI: 10.1126/science.1186237

Available at: http://www.sciencemag.org/content/327/5965/530.short

Scientific and political interest in the possibility of geoengineering the climate is rising (1). There are currently no means of implementing geoengineering, but if a viable technology is produced in the next decade, how could it be tested? We argue that geoengineering cannot be tested without full-scale implementation. The initial production of aerosol droplets can be tested on a small scale, but how they will grow in size (which determines the injection rate needed to produce a particular cooling) can only be tested by injection into an existing aerosol cloud, which cannot be confined to one location. Furthermore, weather and climate variability preclude observation of the climate response without a large, decade-long forcing. Such full-scale implementation could disrupt food production on a large scale.

Robock, A., A. Marquardt, et al. (2009). "Benefits, risks, and costs of stratospheric geoengineering." Geophysical Research Letters **36**: 1-9 DOI: 10.1029/2009gl039209

Open Access Article* Available at: http://www.agu.org/journals/gl/gl0919/2009GL039209/

Injecting sulfate aerosol precursors into the stratosphere has been suggested as a means of geoengineering to cool the planet and reduce global warming. The decision to implement such a scheme would require a comparison of its benefits, dangers, and costs to those of other responses to global warming, including doing nothing. Here we evaluate those factors for stratospheric geoengineering with sulfate aerosols. Using existing U.S. military fighter and tanker planes, the annual costs of injecting aerosol precursors into the lower stratosphere would be several billion dollars. Using artillery or balloons to loft the gas would be much more expensive. We do not have enough information to evaluate more exotic techniques, such as pumping the gas up through a hose attached to a tower or balloon system. Anthropogenic stratospheric aerosol injection would cool the planet, stop the melting of sea ice and land-based glaciers, slow sea level rise, and increase the terrestrial carbon sink, but produce regional drought, ozone depletion, less sunlight for solar power, and make skies less blue. Furthermore it would hamper Earth-based optical astronomy, do nothing to stop ocean acidification, and present many ethical and moral issues. Further work is needed to quantify many of these factors to allow informed decision-making.

Robock, A., L. Oman, et al. (2008). "Regional climate responses to geoengineering with tropical and Arctic SO_2 injections." Journal of Geophysical Research **113**: D16101-D16101 DOI: 10.1029/2008jd010050

Available at: http://www.agu.org/pubs/crossref/2008/2008JD010050.shtml

Anthropogenic stratospheric aerosol production, so as to reduce solar insolation and cool Earth, has been suggested as an emergency response to geoengineer the planet in response to global warming. While volcanic eruptions have been suggested as innocuous examples of stratospheric aerosols cooling the planet, the volcano analog actually argues against geoengineering because of ozone depletion and regional hydrologic and temperature responses. To further investigate the climate response, here we simulate the climate response to both tropical and Arctic stratospheric injection of sulfate aerosol precursors using a comprehensive atmosphere-ocean general circulation model, the National Aeronautics and Space Administration Goddard Institute for Space Studies ModelE. We inject SO_2 and the model converts it to sulfate aerosols, transports the aerosols and removes them through dry and wet deposition, and calculates the climate response to the radiative forcing from the aerosols. We conduct simulations of future climate with the Intergovernmental Panel on Climate Change A1B business-as-usual scenario both with and without geoengineering and compare the results. We find that if there were a way to continuously inject SO_2 into the lower stratosphere, it would produce global cooling. Tropical SO_2 injection would produce sustained cooling over most of the world, with more cooling over continents. Arctic SO_2 injection would not just cool the Arctic. Both tropical and Arctic SO_2 injection would disrupt the Asian and African summer monsoons, reducing precipitation to the food supply for billions of people. These regional climate anomalies are but one of many reasons that argue against the implementation of this kind of geoengineering.

Rockström, J., W. Steffen, et al. (2009). "Planetary Boundaries : Exploring the Safe Operating Space for Humanity." Ecology And Society **14**: 32-32

Open Access Article* Available at: http://www.ecologyandsociety.org/vol14/iss2/art32/main.html

we propose quantifications for seven of them. These seven are climate change (CO_2 concentration in the atmosphere <350 ppm and/or a maximum change of +1 W m-2 in radiative forcing); ocean acidification (mean surface seawater saturation state with respect to aragonite ≥ 80% of pre-industrial levels); stratospheric ozone (<5% reduction in O_3 concentration from pre-industrial level of 290 Dobson Units); biogeochemical nitrogen (N) cycle (limit industrial and agricultural fixation of N2 to 35 Tg N yr-1) and phosphorus (P) cycle (annual P inflow to oceans not to exceed 10 times the natural background ABSTRACT. Anthropogenic pressures on the Earth System have reached a scale where abrupt global environmental change can no longer be excluded. We propose a new approach to global sustainability in which we define planetary boundaries within which we expect that humanity can operate safely. Transgressing one or more planetary boundaries may be deleterious or even catastrophic due to the risk of crossing thresholds that will trigger non-linear, abrupt environmental change within continental- to planetary-scale systems. We have identified nine planetary boundaries and, drawing upon current scientific weathering of P); global freshwater use (<4000 km3 yr-1 of consumptive use of runoff resources); land system change (<15% of the ice-free land surface under cropland); and the rate at which biological diversity is lost (annual rate of <10 extinctions per million species). The two additional planetary boundaries for which we have not yet been able to determine a boundary level are chemical pollution and atmospheric aerosol loading. We estimate that humanity has already transgressed three planetary boundaries: for climate change, rate of

biodiversity loss, and changes to the global nitrogen cycle. Planetary boundaries are interdependent, because transgressing one may both shift the position of other boundaries or cause them to be transgressed. The social impacts of transgressing boundaries will be a function of the social–ecological resilience of the affected societies. Our proposed boundaries are rough, first estimates only, surrounded by large uncertainties and knowledge gaps. Filling these gaps will require major advancements in Earth System and resilience science. The proposed concept of "planetary boundaries" lays the groundwork for shifting our approach to governance and management, away from the essentially sectoral analyses of limits to growth aimed at minimizing negative externalities, toward the estimation of the safe space for human development. Planetary boundaries define, as it were, the boundaries of the "planetary playing field" for humanity if we want to be sure of avoiding major human-induced environmental change on a global scale.

Rose, S. K. and B. Sohngen (2011). "Global forest carbon sequestration and climate policy design." Environment and Development Economics: 1-26 DOI: 10.1017/s1355770x11000027

Available at: http://www.journals.cambridge.org/abstract_S1355770X11000027

Global forests could play an important role in mitigating climate change. However, there are significant implementation obstacles to accessing the world's forest carbon sequestration potential. The timing of regional participation and eligibility of sequestration activities are issues. The existing forest carbon supply estimates have made optimistic assumptions about immediate, comprehensive, and global access. They have also assumed no interactions between activities and regions, and over time. We use a global forest and land use model to evaluate these assumptions with more realistic forest carbon policy pathways. We find that an afforestation only policy is fundamentally flawed, accelerated deforestation may be unavoidable, and a delayed comprehensive program could reduce, but not eliminate, near-term accelerated deforestation and eventually produce sequestration equivalent to idealized policies – but with a different sequestration mix than previously estimated by others and thereby different forests. We also find that afforestation and avoided deforestation increase the cost of one another.

Ross, A. and H. Damon Matthews (2009). "Climate engineering and the risk of rapid climate change." Environmental Research Letters **4**: 045103-045103 DOI: 10.1088/1748-9326/4/4/045103

Open Access Article* Available at:

http://stacks.iop.org/1748-9326/4/i=4/a=045103?key=crossref.a779f8e536316a2ab72c782972a5a6cb

Recent research has highlighted risks associated with the use of climate engineering as a method of stabilizing global temperatures, including the possibility of rapid climate warming in the case of abrupt removal of engineered radiative forcing. In this study, we have used a simple climate model to estimate the likely range of temperature changes associated with implementation and removal of climate engineering. In the absence of climate engineering, maximum annual rates of warming ranged from 0.015 to 0.07 ◦C/year, depending on the model's climate sensitivity. Climate engineering resulted in much higher rates of warming, with the temperature change in the year following the removal of climate engineering ranging from 0.13 to 0.76 ◦C. High rates of temperature change were sustained for two decades following the removal of climate engineering; rates of change of 0.5 (0.3, 0.1) ◦C/decade were exceeded over a 20 year period with 15% (75%, 100%) likelihood. Many ecosystems could be negatively affected by these rates of temperature change; our results suggest that climate engineering in the absence of deep emissions cuts could arguably constitute increased risk of dangerous anthropogenic interference in the climate system under the criteria laid out in the United Nations Framework Convention on Climate Change. Keywords: geoengineering, climate engineering, rapid climate.

Rotenberg, E. and D. Yakir (2010). "Contribution of semi-arid forests to the climate system." Science **327**: 451-454 DOI: 10.1126/science.1179998

Open Access Article* Available at: http://www.sciencemag.org/content/327/5964/451.short

Forests both take up CO2 and enhance absorption of solar radiation, with contrasting effects on global temperature. Based on a 9-year study in the forests' dry timberline, we show that substantial carbon sequestration (cooling effect) is maintained in the large dry transition zone (precipitation from 200 to 600 millimeters) by shifts in peak photosynthetic activities from summer to early spring, and this is counteracted by longwave radiation (L) suppression (warming effect), doubling the forestation shortwave (S) albedo effect. Several decades of carbon accumulation are required to balance the twofold S + L effect. Desertification over the past several decades, however, contributed negative forcing at Earth's surface equivalent to approximately 20% of the global anthropogenic CO2 effect over the same period, moderating warming trends.

Roy, T., L. Bopp, et al. (2011). "Regional Impacts of Climate Change and Atmospheric CO 2 on Future Ocean Carbon Uptake: A Multimodel Linear Feedback Analysis." Journal of Climate **24**: 2300-2318 DOI: 10.1175/2010jcli3787.1
Available at: http://journals.ametsoc.org/doi/abs/10.1175/2010JCLI3787.1

The increase in atmospheric CO_2 over this century depends on the evolution of the oceanic air–sea CO_2 uptake, which will be driven by the combined response to rising atmospheric CO_2 itself and climate change. Here, the future oceanic CO_2 uptake is simulated using an ensemble of coupled climate–carbon cycle models. The models are driven by CO_2 emissions from historical data and the Special Report on Emissions Scenarios (SRES) A2 high-emission scenario. A linear feedback analysis successfully separates the regional future (2010–2100) oceanic CO_2 uptake into a CO_2-induced component, due to rising atmospheric CO_2 concentrations, and a climate-induced component, due to global warming. The models capture the observation-based magnitude and distribution of anthropogenic CO_2 uptake. The distributions of the climate-induced component are broadly consistent between the models, with reduced CO_2 uptake in the subpolar Southern Ocean and the equatorial regions, owing to decreased CO_2 solubility; and reduced CO_2 uptake in the midlatitudes, owing to decreased CO_2 solubility and increased vertical stratification. The magnitude of the climate-induced component is sensitive to local warming in the southern extratropics, to large freshwater fluxes in the extratropical North Atlantic Ocean, and to small changes in the CO_2 solubility in the equatorial regions. In key anthropogenic CO_2 uptake regions, the climate-induced component offsets the CO_2-induced component at a constant proportion up until the end of this century. This amounts to approximately 50% in the northern extratropics and 25% in the southern extratropics and equatorial regions. Consequently, the detection of climate change impacts on anthropogenic CO_2 uptake may be difficult without monitoring additional tracers, such as oxygen.

Running, S. W. and J. S. Kimball (2005). Satellite-Based Analysis of Ecological Controls for Land-Surface Evaporation. M. G. Anderson. New York, John Wiley & Sons, Ltd.
Open Access Article* Available at: http://onlinelibrary.wiley.com/doi/10.1002/0470848944.hsa110/full

Lack of available water constrains ecological processes for two-thirds of the earth's biosphere. These water limitations are manifested as either physical water deficiency or as a chemical unavailability of water as a result of being frozen. This article summarizes global principles of water limitations on the biosphere, and physiological limitations on plants. It presents hydrometeorological principles of evapotranspiration and organizing logic of the soil–vegetation–atmosphere transfer models commonly used to compute evapotranspiration. We then introduce remote sensing from both optical/thermal and active/passive microwave sensors for calculating landscape scale evapotranspiration. Finally, we offer a multisensor-based integrated surface resistance to define landscape water availability under all conditions.

Russell, B. D. and S. D. Connell (2010). "Honing the Geoengineering Strategy (Letter to ed.)." Science **327**: 144-145
Available at: http://www.sciencemag.org/content/327/5962/144.3.full

Saba, V. S., M. A. M. Friedrichs, et al. (2010). "Challenges of modeling depth-integrated marine primary productivity over multiple decades: A case study at BATS and HOT." Global Biogeochemical Cycles **24**: GB3020-GB3020 DOI: 10.1029/2009gb003655
Available at: http://www.agu.org/pubs/crossref/2010/2009GB003655.shtml

The performance of 36 models (22 ocean color models and 14 biogeochemical ocean circulation models (BOGCMs)) that estimate depth integrated marine net primary productivity (NPP) was assessed by comparing their output to in situ 14C data at the Bermuda Atlantic Time series Study (BATS) and the Hawaii Ocean Time series (HOT) over nearly two decades. Specifically, skill was assessed based on the models' ability to estimate the observed mean, variability, and trends of NPP. At both sites, more than 90% of the models underestimated mean NPP, with the average bias of the BOGCMs being nearly twice that of the ocean color models. However, the difference in overall skill between the best BOGCM and the best ocean color model at each site was not significant. Between 1989 and 2007, in situ NPP at BATS and HOT increased by an average of nearly 2% per year and was positively correlated to the North Pacific Gyre Oscillation index. The majority of ocean color models produced in situ NPP trends that were closer to the observed trends when chlorophyll-a was derived from high performance liquid chromatography (HPLC), rather than fluorometric or SeaWiFS data. However, this was a function of time such that average trend magnitude was more accurately estimated over longer time periods. Among BOGCMs, only two individual models successfully produced an increasing NPP trend (one model at each site). We caution against the use of models to assess multiannual changes in NPP over short time periods. Ocean color model estimates of NPP trends could improve if more high quality HPLC chlorophyll a time series were available.

Sabine, C. L., R. a. Feely, et al. (2004). "The oceanic sink for anthropogenic CO2." Science **305**: 367-371 DOI: 10.1126/science.1097403

Open Access Article* Available at: http://www.sciencemag.org/content/305/5682/367.long

Using inorganic carbon measurements from an international survey effort in the 1990s and a tracer-based separation technique, we estimate a global oceanic anthropogenic carbon dioxide (CO_2) sink for the period from 1800 to 1994 of 118 +/- 19 petagrams of carbon. The oceanic sink accounts for approximately 48% of the total fossil-fuel and cement-manufacturing emissions, implying that the terrestrial biosphere was a net source of CO_2 to the atmosphere of about 39 +/- 28 petagrams of carbon for this period. The current fraction of total anthropogenic CO_2 emissions stored in the ocean appears to be about one-third of the long-term potential.

Sabine, C. L., M. Heimann, et al. (2004). Current Status and Past Trends of the Global Carbon Cycle in The Global Caron Cycle: Integrating Humans, Climate, and the Natural World. C. B. Field and M. R. Raupach. Washington, DC, Island Press**:** 17-44.

Salter, S. H. A 20 GW Thermal 300-metre3/sec Wave-energised, Surge-mode Nutrient-pump for Removing Atmospheric Carbon dioxide, Increasing Fish Stocks and Suppressing Hurricanes.

Open Access Article* Available at: https://www.see.ed.ac.uk/~shs/EWTEC 09/Salter Stephen A 20 GW thermal 4.pdf

As an outcome of a workshop following Hurricane Katrina this paper extends ideas submitted to the Royal Society Call for Submissions on geoengineering. The frequency and severity of hurricanes rise sharply if the surface temperature of the sea exceeds 26.5 C. This is because of our definition of hurricane categories rather than having anything to do with atmospheric physics. If we can pump warm water downwards to below the thermocline perhaps we can have gentle hurricanes. Designers of overtopping wave plant for energy generation want a high product of head and flow. But the head of water needed to overcome the density difference due to the temperature drop with depth in many hurricane breeding sites is often less than 200 mm. This means that we can use the horizontal movement of sea waves to move water through a wall of non-return valves into an enclosure with a down-tube reaching to the thermocline. The warm water from above will mix with cold, nutrient- rich water, giving a mixture of an intermediate temperature which will rise until it reaches the level of the same density, from where it will spread sideways. If this layer is at 100 metres below the surface there will be enough daylight to allow the growth of phytoplankton. These are efficient carbon absorbers and the start of the marine food chain.

Salter, S., G. Sortino, et al. (2008). "Sea-going hardware for the cloud albedo method of reversing global warming." Philosophical Transactions of the Royal Society A **366**: 3989-4006 DOI: 10.1098/rsta.2008.0136

Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/366/1882/3989.long

Following the review by Latham et al. (Latham et al. 2008 Phil. Trans. R. Soc. A 366) of a strategy to reduce insolation by exploiting the Twomey effect, the present paper describes in outline the rationale and underlying engineering hardware that may bring the strategy from concept to operation. Wind-driven spray vessels will sail back and forth perpendicular to the local prevailing wind and release micron-sized drops of seawater into the turbulent boundary layer beneath marine stratocumulus clouds. The combination of wind and vessel movements will treat a large area of sky. When residues left after drop evaporation reach cloud level they will provide many new cloud condensation nuclei giving more but smaller drops and so will increase the cloud albedo to reflect solar energy back out to space. If the possible power increase of 3.7W m-2 from double pre-industrial CO_2 is divided by the 24-hour solar input of 340W m-2, a global albedo increase of only 1.1 per cent will produce a sufficient offset. The method is not intended to make new clouds. It will just make existing clouds whiter. This paper describes the design of 300 tonne ships powered by Flettner rotors rather than conventional sails. The vessels will drag turbines resembling oversized propellers through the water to provide the means for generating electrical energy. Some will be used for rotor spin, but most will be used to create spray by pumping 30 kgs-1 of carefully filtered water through banks of filters and then to micro-nozzles with piezoelectric excitation to vary drop diameter. The rotors offer a convenient housing for spray nozzles with fan assistance to help initial dispersion. The ratio of solar energy reflected by a drop at the top of a cloud to the energy needed to make the surface area of the nucleus on which it has grown is many orders of magnitude and so the spray quantities needed to achieve sufficient global cooling are technically feasible.

Sanderson, M. G., D. L. Hemming, et al. (2011). "Regional temperature and precipitation changes under high-end (≥4°C) global warming." Philosophical Transactions of the Royal Society A **369**: 85-98 DOI: 10.1098/rsta.2010.0283

Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/369/1934/85.long

Climate models vary widely in their projections of both global mean temperature rise and regional climate changes, but are there any systematic differences in regional changes associated with different levels of global climate sensitivity? This paper examines model projections of climate change over the twenty-first century from the Intergovernmental Panel on Climate Change Fourth Assessment Report which used the A2 scenario from the IPCC Special Report on Emissions Scenarios, assessing whether different regional responses can be seen in models categorized as 'high-end' (those projecting 4(°)C or more by the end of the twenty-first century relative to the preindustrial). It also identifies regions where the largest climate changes are projected under high-end warming. The mean spatial patterns of change, normalized against the global rate of warming, are generally similar in high-end and 'non-high-end' simulations. The exception is the higher latitudes, where land areas warm relatively faster in boreal summer in high-end models, but sea ice areas show varying differences in boreal winter. Many continental interiors warm approximately twice as fast as the global average, with this being particularly accentuated in boreal summer, and the winter-time Arctic Ocean temperatures rise more than three times faster than the global average. Large temperature increases and precipitation decreases are projected in some of the regions that currently experience water resource pressures, including Mediterranean fringe regions, indicating enhanced pressure on water resources in these areas.

Sarmiento, J. L., R. D. Slater, et al. (2010). "Efficiency of small scale carbon mitigation by patch iron fertilization" Biogeosciences **7**: 3593-3624 DOI: 10.5194/bg-7-3593-2010

Open Access Article* Available at: http://www.biogeosciences.net/7/3593/2010/

While nutrient depletion scenarios have long shown that the high-latitude High Nutrient Low Chlorophyll (HNLC) regions are the most effective for sequestering atmospheric carbon dioxide, recent simulations with prognostic biogeochemical models have suggested that only a fraction of the potential drawdown can be realized. We use a global ocean biogeochemical general circulation model developed at GFDL and Princeton to examine this and related issues. We fertilize two patches in the North and Equatorial Pacific, and two additional patches in the Southern Ocean HNLC region north of the biogeochemical divide and in the Ross Sea south of the biogeochemical divide. We evaluate the simulations using observations from both artificial and natural iron fertilization experiments at nearby locations. We obtain by far the greatest response to iron fertilization at the Ross Sea site, where sea ice prevents escape of sequestered CO2 during the wintertime, and the CO_2 removed from the surface ocean by the biological pump is carried into the deep ocean by the circulation. As a consequence, CO_2 remains sequestered on century time-scales and the efficiency of fertilization remains almost constant no matter how frequently iron is applied as long as it is confined to the growing season. The second most efficient site is in the Southern Ocean. The North Pacific site has lower initial nutrients and thus a lower efficiency. Fertilization of the Equatorial Pacific leads to an expansion of the suboxic zone and a striking increase in denitrification that causes a sharp reduction in overall surface biological export production and CO_2 uptake. The impacts on the oxygen distribution and surface biological export are less prominent at other sites, but nevertheless still a source of concern. The century time scale retention of iron in this model greatly increases the long-term biological response to iron addition as compared with simulations in which the added iron is rapidly scavenged from the ocean.

Schellnhuber, H. J. (2011). Geoengineering: The good, the MAD, and the sensible. PNAS; published ahead of print December 12, 2011. DOI: 10.1073/pnas.1115966108

Available at: http://www.pnas.org/content/early/2011/12/06/1115966108.long

Schmidt, H., A. Aaheim, et al. (2010). IMPLICC Implications and risks of engineering solar radiation to limit climate change; Publishable summary of the intermediate report for the period 1 July 2009 to 31 December 2010 1 : Max Planck Institute for Meteorology: Cicero , O. Hamburg, Germany.

Open Access Article* Available at: implicc.zmaw.de/.../user.../implicc_report_dec2010_summary.pdf

Schneider, S. H. (2008). "Geoengineering: could we or should we make it work?" Philosophical Transactions of the Royal Society A **366**: 3843-3862 DOI: 10.1098/rsta.2008.0145

Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/366/1882/3843.long

Schemes to modify large-scale environment systems or control climate have been proposed for over 50 years to (i) increase temperatures in high latitudes, (ii) increase precipitation, (iii) decrease sea ice, (iv) create irrigation opportunities, or (v) offset potential global warming by injecting iron in the oceans or sea-salt aerosol in the marine boundary layer or spreading dust in the stratosphere to reflect away an amount of solar energy equivalent

to the amount of heat trapped by increased greenhouse gases from human activities. These and other proposed geoengineering schemes are briefly reviewed. Recent schemes to intentionally modify climate have been proposed as either cheaper methods to counteract inadvertent climatic modifications than conventional mitigation techniques such as carbon taxes or pollutant emissions regulations or as a counter to rising emissions as governments delay policy action. Whereas proponents argue cost-effectiveness or the need to be prepared if mitigation and adaptation policies are not strong enough or enacted quickly enough to avoid the worst widespread impacts, critics point to the uncertainty that (i) any geoengineering scheme would work as planned or (ii) that the many centuries of international political stability and cooperation needed for the continuous maintenance of such schemes to offset century-long inadvertent effects is socially feasible. Moreover, the potential exists for transboundary conflicts should negative climatic events occur during geoengineering activities.

Schuiling, R. D. and P. L. de Boer (2011). "Rolling stones; fast weathering of olivine in shallow seas for cost-effective CO_2 capture and mitigation of global warming and ocean acidification." Earth System Dynamics Discussions **2**: 551-568 DOI: 10.5194/esdd-2-551-2011

Open Access Article* Available at: http://www.earth-syst-dynam-discuss.net/2/551/2011/

Human CO_2 emissions may drive the Earth into a next greenhouse state. They can be mitigated by accelerating weathering of natural rock under the uptake of CO_2. We disprove the paradigm that olivine weathering in nature would be a slow process, and show that it is not needed to mill olivine to very fine, 10 µm-size grains in order to arrive at a complete dissolution within 1–2 year. In high-energy shallow marine environments olivine grains and reaction products on the grain surfaces, that otherwise would greatly retard the reaction, are abraded so that the chemical reaction is much accelerated. When kept in motion even large olivine grains rubbing and bumping against each other quickly produce fine clay- and silt-sized olivine particles that show a fast chemical reaction. Spreading of olivine in the world's 2%most energetic shelf seas can compensate a year's global CO_2 emissions and counteract ocean acidification against a price well below that of carbon credits.

Schuiling, R. D. and P. Krijgsman (2006). "Enhanced Weathering: An Effective and Cheap Tool to Sequester CO_2." Climatic Change **74**: 349-354 DOI: 10.1007/s10584-005-3485-y

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-005-3485-y

Weathering and subsequent precipitation of Ca- and Mg-carbonates are the main processes that control the CO_2-concentration in the atmosphere. It seems logical, therefore, to use enhanced weathering as a tool to reduce rising CO_2-levels. This can be applied as a technology, by reacting captured CO_2 with olivine or calcium-silicates in autoclaves. It can also be applied extensively, by spreading fine-powdered olivine on farmland or forestland. Measures to control the CO_2-levels of the atmosphere will be adopted more readily if they also serve some broader economic goals. An effective strategy for CO_2 control will require many parallel approaches simultaneously.

Schwaiger, H. P. and D. N. Bird (2010). "Integration of albedo effects caused by land use change into the climate balance: Should we still account in greenhouse gas units?" Forest Ecology and Management **260**: 278-286 DOI: 10.1016/j.foreco.2009.12.002

Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378112709008718

Due to impacts of albedo on climate change, benefits of afforestation/reforestation regimes are under debate. In this paper we investigate how to incorporate albedo changes in a carbon accounting tool to show the net effect of land use change on the climate. Using a study area in southern Europe, albedo and carbon sequestration modelling results are linked to determine the combined radiative forcing balance. The results show that under specific circumstances afforestation/reforestation measures may not automatically have positive impacts in a global warming context because the cooling effect of most of the carbon sequestered is neutralized by the warming effect of albedo changes. However, sensitivity analyses lead to the conclusion that improved albedo data from satellite images (MODIS) could influence and enhance outputs significantly. The paper points out that accounting based exclusively on GHG units does not, in the case of land use change, reflect the entire picture. It is highly recommended that in future global warming impacts of land use systems and biogenic products (e.g. solid biomass, liquid biofuels) should be studied using life cycle assessments (LCA) and should include these additional—non-GHG effects—on climate change.

Searchinger, T. D., S. P. Hamburg, et al. (2009). "Fixing a Critical Climate Accounting Error." Science **326**: 527-528

Available at: http://www.sciencemag.org/content/326/5952/527.short

The accounting now used for assessing compliance with carbon limits in the Kyoto Protocol and in climate

legislation contains a far-reaching but fixable flaw that will severely undermine greenhouse gas reduction goals (1). It does not count CO_2 emitted from tailpipes and smokestacks when bioenergy is being used, but it also does not count changes in emissions from land use when biomass for energy is harvested or grown. This accounting erroneously treats all bioenergy as carbon neutral regardless of the source of the biomass, which may cause large differences in net emissions. For example, the clearing of long-established forests to burn wood or to grow energy crops is counted as a 100% reduction in energy emissions despite causing large releases of carbon.

Secretariat of the Convention on Biological Diversity (2009). Report of the Regional Workshop for Asia and the Pacific on Ways and Means to Promote the Sustainable Production and Use of Biofuels.
Open Access Article* Available at:
http://www.cbd.int/doc/meetings/agr/rwspubio-ap-01/official/rwspubio-ap-01-01-add1-en.pdf

Secretariat of the Convention on Biological Diversity. (2009). Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. Montreal, QC.
Open Access Article* Available at: http://www.cbd.int/doc/publications/cbd-ts-41-en.pdf

Secretariat of the Convention on Biological, D. (2009). Scientific Synthesis of the Impacts of Ocean Fertilization on Marine Biodiversity. Montreal, QC.
Open Access Article* Available at: http://www.cbd.int/doc/publications/cbd-ts-45-en.pdf

Sedlacek, L., D. Thistle, et al. (2009) Effects of carbon dioxide on deep-sea harpacticoids, ICES International Symposium – Issues confronting the deep oceans. Azores, Portugal.

Seitz, R. (2010). "Bright water: hydrosols, water conservation and climate change." Climatic Change **105**: 365-381 DOI: 10.1007/s10584-010-9965-8
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-010-9965-8
Because air–water and water–air interfaces are equally refractive, cloud droplets and microbubbles dispersed in bodies of water reflect sunlight in much the same way. The lifetime of sunlight-reflecting microbubbles, and hence the scale on which they may be applied, depends on Stokes Law and the influence of ambient or added surfactants. Small bubbles backscatter light more efficiently than large ones, opening the possibility of using highly dilute micron-radius hydrosols to substantially brighten surface waters. Such microbubbles can noticeably increase water surface reflectivity, even at volume fractions of parts per million and such loadings can be created at an energy cost as low as J m^{-2} to initiate and mW m^{-2} to sustain. Increasing water albedo in this way can reduce solar energy absorption by as much as 100Wm^{-2}, potentially reducing equilibrium temperatures of standing water bodies by several Kelvins. While aerosols injected into the stratosphere tend to alter climate globally, hydrosols can be used to modulate surface albedo, locally and reversibly, without risk of degrading the ozone layer or altering the color of the sky. The low energy cost of microbubbles suggests a new approach to solar radiation management in water conservation and geoengineering: Don't dim the Sun; Brighten the water.

Shiva, V (1993) Monocultures of the Mind: Perspectives on Biodiversity and Biotechnology. Penang, Malaysia, Third World Network.

Silver, M. W., S. Bargu, et al. (2010). "Toxic diatoms and domoic acid in natural and iron enriched waters of the oceanic Pacific." Proceedings of the National Academy of Sciences of the United States of America **107**: 20762-20767 DOI: 10.1073/pnas.1006968107
Open Access Article* Available at:
http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2996450&tool=pmcentrez&rendertype=abstract
Near-surface waters ranging from the Pacific subarctic (58°N) to the Southern Ocean (66°S) contain the neurotoxin domoic acid (DA), associated with the diatom *Pseudo-nitzschia*. Of the 35 stations sampled, including ones from historic iron fertilization experiments (SOFeX, IronEx II), we found *Pseudo-nitzschia* at 34 stations and DA measurable at 14 of the 26 stations analyzed for DA. Toxin ranged from 0.3 fg·cell(-1) to 2 pg·cell(-1), comparable with levels found in similar-sized cells from coastal waters. In the western subarctic, descent of intact *Pseudo-nitzschia* likely delivered significant amounts of toxin (up to 4 μg of DA·m(-2)·d(-1)) to underlying mesopelagic waters (150-500 m). By reexamining phytoplankton samples from SOFeX and IronEx II, we found substantial amounts of DA associated with *Pseudo-nitzschia*. Indeed, at SOFeX in the Antarctic Pacific, DA

reached 220 ng·L(-1), levels at which animal mortalities have occurred on continental shelves. Iron ocean fertilization also occurs naturally and may have promoted blooms of these ubiquitous algae over previous glacial cycles during deposition of iron-rich aerosols. Thus, the neurotoxin DA occurs both in coastal and oceanic waters, and its concentration, associated with changes in *Pseudo-nitzschia* abundance, likely varies naturally with climate cycles, as well as with artificial iron fertilization. Given that iron fertilization in iron-depleted regions of the sea has been proposed to enhance phytoplankton growth and, thereby, both reduce atmospheric CO(2) and moderate ocean acidification in surface waters, consideration of the potentially serious ecosystem impacts associated with DA is prudent.

Smith, C. R. and A. W. Demopoulos (2003). "Ecology of the deep Pacific Ocean floor" in Ecosystems of the Deep Ocean, P. A. Tyler. Amsterdam, Elsevier**:** 179-218.

Smith, J. B., H. J. Schellnhuber, et al. (2001). "Vulnerability to climate change and reasons for concern: a synthesis" in IPCC Third Assessment Report, Working Group II. Cambridge, UK, Cambridge University Press**:** 913-967.
Open Access Article* Available at: http://www.grida.no/publications/other/ipcc_tar/

Smith, J. B., S. H. Schneider, et al. (2009). "Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) "reasons for concern"." Proceedings of the National Academy of Sciences of the United States of America **106**: 4133-4137 DOI: 10.1073/pnas.0812355106
Open Access Article* Available at:
http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2648893&tool=pmcentrez&rendertype=abstract
Article 2 of the United Nations Framework Convention on Climate Change [United Nations (1992) http://unfccc.int/resource/docs/convkp/conveng.pdf. Accessed February 9, 2009] commits signatory nations to stabilizing greenhouse gas concentrations in the atmosphere at a level that "would prevent dangerous anthropogenic interference (DAI) with the climate system." In an effort to provide some insight into impacts of climate change that might be considered DAI, authors of the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) identified 5 "reasons for concern" (RFCs). Relationships between various impacts reflected in each RFC and increases in global mean temperature (GMT) were portrayed in what has come to be called the "burning embers diagram." In presenting the "embers" in the TAR, IPCC authors did not assess whether any single RFC was more important than any other; nor did they conclude what level of impacts or what atmospheric concentrations of greenhouse gases would constitute DAI, a value judgment that would be policy prescriptive. Here, we describe revisions of the sensitivities of the RFCs to increases in GMT and a more thorough understanding of the concept of vulnerability that has evolved over the past 8 years. This is based on our expert judgment about new findings in the growing literature since the publication of the TAR in 2001, including literature that was assessed in the IPCC Fourth Assessment Report (AR4), as well as additional research published since AR4. Compared with results reported in the TAR, smaller increases in GMT are now estimated to lead to significant or substantial consequences in the framework of the 5 "reasons for concern."

Snelgrove, P. V. R. and C. R. Smith (2002). "A riot of species in an environmental calm: The paradox of the species rich deep-sea floor." Oceanography and Marine Biology, An Annual Review **40**: 311-342
Available at: Deep-sea ecosystems are the most extensive and remote ecosystems on Earth. Perception of the deep-sea benthic environment has changed dramatically in the last century from one of an azoic, or at least species-poor habitat to one that is rich in species. The early misconception was created, in part, by evidence of vast, monotonous expanses of cold, dark sediment plains with little obvious spatial or temporal heterogeneity. Given that many species-rich ecosystems on Earth are obviously heterogeneous, it is surprising that some estimates of species numbers in the deep sea (e.g. ~107 macrofaunal species) rival those for tropical rainforests. Although other estimates are more conservative (e.g. 5 x 105 macrofaunal species), it is clear that deep-sea benthic habitats contain many species. The paradox of high deep-sea diversity has generated a number of explanatory hypotheses, including some that are currently difficult to test and others that are the focus of ongoing study. Approaches include analyses of local, regional, and global patterns, and experimental manipulations within habitats. Mechanistic generalisations are difficult to make because experimentation and sampling coverage are spatially and temporally limited, but evidence to date suggests that small-scale habitat variability and patchy disturbance, as well as global and regional variability, may play roles in maintaining deep-sea diversity. The importance of small-scale habitat variability and patchy disturbance has been demonstrated for only a small subset of species, many of which are opportunists. Broad inferences from global and regional patterns of species diversity are debatable because many areas remain poorly sampled and causes of patterns are ambiguous.

Nonetheless, our understanding of diversity patterns in the deep-sea benthos has increased dramatically in the last three decades. If the approaching decades hold even a portion of the surprises seen in the recent past, then science can expect very exciting discoveries from the deep ocean in the near future.

Socolow, R., M. Desmond, et al. (2011). Direct Air Capture of CO2 with Chemicals A Technology Assessment for the APS Panel on Public Affairs.

Open Access Article* Available at:

http://www.aps.org/policy/reports/popa-reports/loader.cfm?csModule=security/getfile&PageID=244407

Key Messages: Implications of direct air capture of CO2 by chemicals (DAC) for climate and energy policy

• DAC is not currently an economically viable approach to mitigating climate change.

• In a world that still has centralized sources of carbon emissions, any future deployment that relies on low-carbon energy sources for powering DAC would usually be less cost-effective than simply using the low-carbon energy to displace those centralized carbon sources. Thus, coherent CO2 DAC until large, centralized CO2 mitigation postpones deployment of sources have been nearly eliminated on a global scale.

• DAC may have a role to play eventually in countering emissions from some decentralized emissions of CO2 such as from buildings and vehicles (ships, planes) that prove expensive to reduce by other means.

• Given the large uncertainties in estimating the cost of DAC, century-scale economic models of global CO2 emissions that feature “overshoot trajectories” and rely on DAC should be viewed with extreme caution

• High-carbon energy sources are not viable options for powering DAC systems, because their CO2 captured. may exceed the CO2

• The storage part of CO2 be economically viable. capture and storage (CCS) must be inexpensive and feasible at huge scale for DAC to

• This report provides no support for arguments in favor of delay in dealing with climate change that are based on the availability of DAC as a compensating strategy. emissions

Soden, B. J., R. T. Wetherald, et al. (2002). "Global cooling after the eruption of Mount Pinatubo: a test of climate feedback by water vapor." Science **296**: 727-730 DOI: 10.1126/science.296.5568.727

Open Access Article* Available at: http://www.sciencemag.org/content/296/5568/727.long

The sensitivity of Earth's climate to an external radiative forcing depends critically on the response of water vapor. We use the global cooling and drying of the atmosphere that was observed after the eruption of Mount Pinatubo to test model predictions of the climate feedback from water vapor. Here, we first highlight the success of the model in reproducing the observed drying after the volcanic eruption. Then, by comparing model simulations with and without water vapor feedback, we demonstrate the importance of the atmospheric drying in amplifying the temperature change and show that, without the strong positive feedback from water vapor, the model is unable to reproduce the observed cooling. These results provide quantitative evidence of the reliability of water vapor feedback in current climate models, which is crucial to their use for global warming projections.

Solomon, S., J. S. Daniel, et al. (2011). "The Persistently Variable "Background" Stratospheric Aerosol Layer and Global Climate Change." Science (New York, N.Y.) **866** DOI: 10.1126/science.1206027

Open Access Article* Available at: http://www.ncbi.nlm.nih.gov/pubmed/21778361

Recent measurements demonstrate that the "background" stratospheric aerosol layer is persistently variable rather than constant, even in the absence of major volcanic eruptions. Several independent data sets show that stratospheric aerosols increased in abundance since 2000. Near-global satellite aerosol data imply a negative radiative forcing due to stratospheric aerosol changes over this period of about -0.1 W/m(2), reducing the recent global warming that would otherwise have occurred. Observations from earlier periods are limited but suggest an additional negative radiative forcing of about -0.1 W/m(2) from 1960 to 1990. Climate model projections neglecting these changes would continue to overestimate the radiative forcing and global warming in coming decades if these aerosols remain present at current values or increase.

Solomon, S., G.-K. Plattner, et al. (2009). "Irreversible climate change due to carbon dioxide emissions." Proceedings of the National Academy of Sciences of the United States of America **106**: 1704-1709 DOI: 10.1073/pnas.0812721106

Open Access Article* Available at:

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2632717&tool=pmcentrez&rendertype=abstract

The severity of damaging human-induced climate change depends not only on the magnitude of the change but also on the potential for irreversibility. This paper shows that the climate change that takes place due to increases in carbon dioxide concentration is largely irreversible for 1,000 years after emissions stop. Following cessation of

emissions, removal of atmospheric carbon dioxide decreases radiative forcing, but is largely compensated by slower loss of heat to the ocean, so that atmospheric temperatures do not drop significantly for at least 1,000 years. Among illustrative irreversible impacts that should be expected if atmospheric carbon dioxide concentrations increase from current levels near 385 parts per million by volume (ppmv) to a peak of 450-600 ppmv over the coming century are irreversible dry-season rainfall reductions in several regions comparable to those of the "dust bowl" era and inexorable sea level rise. Thermal expansion of the warming ocean provides a conservative lower limit to irreversible global average sea level rise of at least 0.4-1.0 m if 21st century CO(2) concentrations exceed 600 ppmv and 0.6-1.9 m for peak CO(2) concentrations exceeding approximately 1,000 ppmv. Additional contributions from glaciers and ice sheet contributions to future sea level rise are uncertain but may equal or exceed several meters over the next millennium or longer.

Somsen, H. (2011). "When Regulators Mean Business: Regulation in the Shadow of Environmental Armageddon." Rechtsfilosofie & Rechtstheorie **4**: 47-57
Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1804114

In this article, I argue that impending ecological catastrophe invites regulators a) to focus on regulatory effectiveness, and b) to afford little significance to the legitimacy of regulatory action designed to avert such a catastrophe. This implies that regulators will resort to 'techno-regulation' or 'code,' leaving regulatees no option but to comply with the rules. In addition, regulators must adopt a much more sympathetic attitude towards new 'high risk technologies.' In effect, against the background of impending catastrophe, the precautionary principle will instruct that scientific uncertainty about the risks of new technologies, such as geoengineering or synthetic biology, is no reason not to give those technologies the green light.

Song, X., G. Zhou, et al. (2011). "Carbon sequestration by Chinese bamboo forests and their ecological benefits: assessment of potential, problems, and future challenges." Environmental Reviews **19**: 418-428 DOI: 10.1139/a11-015
Available at: http://www.nrcresearchpress.com/doi/abs/10.1139/a11-015

Bamboo is widely distributed in Southeast Asia, Africa, and Latin America. As a major non-wood forest product and wood substitute, bamboo is of increasing interest to ecologists owing to its rapid growth and correspondingly high potential for mitigating climate change. With a long history of production and utilization of bamboo, China is one of the countries with the richest bamboo resources and largest area of bamboo forest, and has paid unprecedented attention in recent decades to management of its bamboo forests. This review summarizes the versatility of bamboo in terms of its ecological benefits including carbon sequestration, water and soil conservation, its benefits for socioeconomic development, and its potential to mitigate climate change. Current problems, and the future potential of and challenges to rapidly expanding bamboo forests under both wider use of intensive management and the effects of global warming, are also discussed.

Spokas, K. (2010). "Review of the stability of biochar in soils: predictability of O:C molar ratios." Carbon Management **1**: 289-330
Available at: http://www.future-science.com/doi/full/10.4155/cmt.10.32

Biochar is not a structured homogeneous material; rather it possesses a range of chemical structures and a heterogeneous elemental composition. This variability is based on the conditions of pyrolysis and the biomass parent material, with biochar spanning the range of various forms of black carbon. Thereby, this variability induces a broad spectrum in the observed rates of reactivity and, correspondingly, the overall chemical and microbial stability. From evaluating the current biochar and black carbon degradation studies, there is the suggestion of an overall relationship in biochar stability as a function of the molar ratio of oxygen to carbon (O:C) in the resulting black carbon. In general, a molar ratio of O:C lower than 0.2 appears to provide, at minimum, a 1000-year biochar half-life. The O:C ratio is a function of production temperature, but also accounts for other impacts (e.g., parent material and post-production conditioning/oxidation) that are not captured solely with production temperature. Therefore, the O:C ratio could provide a more robust indicator of biochar stability than production parameters (e.g., pyrolysis temperature and biomass type) or volatile matter determinations.

Spracklen, D. V., B. Bonn, et al. (2008). "Boreal forests , aerosols and the impacts on clouds and climate Boreal forests, aerosols and the impacts on clouds and climate." Philosophical Transactions of the Royal Society A **366**: 4613-4626 DOI: 10.1098/rsta.2008.0201
Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/366/1885/4613.full

Previous studies have concluded that boreal forests warm the climate because the cooling from storage of carbon in vegetation and soils is cancelled out by the warming due to the absorption of the Sun’s heat by the dark forest

canopy. However, these studies ignored the impacts of forests on atmospheric aerosol. We use a global atmospheric model to show that, through emission of organic vapours and the resulting condensational growth of newly formed particles, boreal forests double regional cloud condensation nuclei concentrations (from approx. 100 to approx. 200 cmK3). Using a simple radiative model, we estimate that the resulting change in cloud albedo causes a radiative forcing of betweenK1.8 andK6.7WmK2 of forest. This forcing may be sufficiently large to result in boreal forests having an overall cooling impact on climate. We propose that the combination of climate forcings related to boreal forests may result in an important global homeostasis. In cold climatic conditions, the snow–vegetation albedo effect dominates and boreal forests warm the climate, whereas in warmer climates they may emit sufficiently large amounts of organic vapour modifying cloud albedo and acting to cool climate.

Steffen, W., J. Grinevald, et al. (2011). "The Anthropocene: conceptual and historical perspectives." Philosophical transactions. Series A, Mathematical, physical, and engineering sciences **369**: 842-867 DOI: 10.1098/rsta.2010.0327

Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/369/1938/842.full.pdf+html

The human imprint on the global environment has now become so large and active that it rivals some of the great forces of Nature in its impact on the functioning of the Earth system. Although global-scale human influence on the environment has been recognized since the 1800s, the term Anthropocene, introduced about a decade ago, has only recently become widely, but informally, used in the global change research community. However, the term has yet to be accepted formally as a new geological epoch or era in Earth history. In this paper, we put forward the case for formally recognizing the Anthropocene as a new epoch in Earth history, arguing that the advent of the Industrial Revolution around 1800 provides a logical start date for the new epoch. We then explore recent trends in the evolution of the Anthropocene as humanity proceeds into the twenty-first century, focusing on the profound changes to our relationship with the rest of the living world and on early attempts and proposals for managing our relationship with the large geophysical cycles that drive the Earth's climate system.

Steffen, W., Å. Persson, et al. (2011). "The Anthropocene: From Global Change to Planetary Stewardship." AMBIO **40**: 739-761 DOI: 10.1007/s13280-011-0185-x

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s13280-011-0185-x

Over the past century, the total material wealth of humanity has been enhanced. However, in the twenty-first century, we face scarcity in critical resources, the degradation of ecosystem services, and the erosion of the planet’s capability to absorb our wastes. Equity issues remain stubbornly difficult to solve. This situation is novel in its speed, its global scale and its threat to the resilience of the Earth System. The advent of the Anthropence, the time interval in which human activities now rival global geophysical processes, suggests that we need to fundamentally alter our relationship with the planet we inhabit. Many approaches could be adopted, ranging from geo-engineering solutions that purposefully manipulate parts of the Earth System to becoming active stewards of our own life support system. The Anthropocene is a reminder that the Holocene, during which complex human societies have developed, has been a stable, accommodating environment and is the only state of the Earth System that we know for sure can support contemporary society. The need to achieve effective planetary stewardship is urgent. As we go further into the Anthropocene, we risk driving the Earth System onto a trajectory toward more hostile states from which we cannot easily return.

Steinacher, M., F. Joos, et al. (2009). "Imminent ocean acidification in the Arctic projected with the NCAR global coupled carbon cycle-climate model." Biogeosciences **6**: 515-533 DOI: 10.5194/bg-6-515-2009

Open Access Article* Available at: http://www.biogeosciences.net/6/515/2009/

Ocean acidification from the uptake of anthropogenic carbon is simulated for the industrial period and IPCC SRES emission scenarios A2 and B1 with a global coupled carbon cycle-climate model. Earlier studies identified seawater saturation state with respect to aragonite, a mineral phase of calcium carbonate, as a key variable governing impacts on corals and other shell-forming organisms. Globally in the A2 scenario, water saturated by more than 300%, considered suitable for coral growth, vanishes by 2070 AD ($CO2 \approx 630$ ppm), and the ocean volume fraction occupied by saturated water decreases from 42% to 25% over this century. The largest simulated pH changes worldwide occur in Arctic surface waters, where hydrogen ion concentration increases by up to 185% ($\Delta pH = -0.45$). Projected climate change amplifies the decrease in Arctic surface mean saturation and pH by more than 20%, mainly due to freshening and increased carbon uptake in response to sea ice retreat. Modeled saturation compares well with observation-based estimates along an Arctic transect and simulated changes have been corrected for remaining model-data differences in this region. Aragonite undersaturation in Arctic surface waters is projected to occur locally within a decade and to become more widespread as atmospheric CO_2 continues to grow. The results imply that surface waters in the Arctic Ocean will become corrosive to aragonite, with

potentially large implications for the marine ecosystem, if anthropogenic carbon emissions are not reduced and atmospheric CO2 not kept be- low 450 ppm.

Steiner, C., B. Glaser, et al. (2008). "Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal." Journal of Plant Nutrition and Soil Science **171**: 893-899 DOI: 10.1002/jpln.200625199

Available at: http://onlinelibrary.wiley.com/doi/10.1002/jpln.200625199/abstract

Leaching losses of N are a major limitation of crop production on permeable soils and under heavy rainfalls as in the humid tropics. We established a field trial in the central Amazon (near Manaus, Brazil) in order to study the influence of charcoal and compost on the retention of N. Fifteen months after organic-matter admixing (0–0.1 m soil depth), we added 15N-labeled (NH4)2SO4 (27.5 kg N ha–1 at 10 atom% excess). The tracer was measured in top soil (0–0.1 m) and plant samples taken at two successive sorghum (Sorghum bicolor L. Moench) harvests. The N recovery in biomass was significantly higher when the soil contained compost (14.7% of applied N) in comparison to only mineral-fertilized plots (5.7%) due to significantly higher crop production during the first growth period. After the second harvest, the retention in soil was significantly higher in the charcoal-amended plots (15.6%) in comparison to only mineral-fertilized plots (9.7%) due to higher retention in soil. The total N recovery in soil, crop residues, and grains was significantly ($p < 0.05$) higher on compost (16.5%), charcoal (18.1%), and charcoal plus compost treatments (17.4%) in comparison to only mineral-fertilized plots (10.9%). Organic amendments increased the retention of applied fertilizer N. One process in this retention was found to be the recycling of N taken up by the crop. The relevance of immobilization, reduced N leaching, and gaseous losses as well as other potential processes for increasing N retention should be unraveled in future studies.

Steiner, C., W. G. Teixeira, et al. (2007). "Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil." Plant and Soil **291**: 275-290 DOI: 10.1007/s11104-007-9193-9

Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s11104-007-9193-9

Application of organic fertilizers and charcoal increase nutrient stocks in the rooting zone of crops, reduce nutrient leaching and thus improve crop production on acid and highly weathered tropical soils. In a Weld trial near Manaus (Brazil) 15 different amendment combinations based on equal amounts of carbon (C) applied through chicken manure (CM), compost, charcoal, and forest litter were tested during four cropping cycles with rice (Oryza sativa L.) and sorghum (Sorghum bicolor L.) in Wve replicates. CM amendments resulted in the highest ($P < 0.05$) cumulative crop yield (12.4Mg ha¡1) over four seasons. Most importantly, surface soil pH, phosphorus (P), calcium (Ca), and magnesium (Mg) were significantly enhanced by CM. A single compost application produced fourfold more grain yield ($P < 0.05$) than plots mineral fertilized in split applications. Charcoal significantly improved plant growth and doubled grain production if fertilized with NPK in comparison to the NPK-fertilizer without charcoal. The higher yields caused a significantly greater nutrient export in charcoal-amended Welds, but available nutrients did not decrease to the same extent as on just mineral fertilized plots. Exchangeable soil aluminum (Al) was further reduced if mineral fertilizer was applied with charcoal (from 4.7 to 0mg kg¡1). The resilience of soil organic matter (SOM) in charcoal amended plots (8 and 4% soil C loss, mineral fertilized or not fertilized, respectively) indicates the refractory nature of charcoal in comparison to SOM losses over 20 months in CM (27%), compost amended (27%), and control plots (25% loss).

Stenchikov, G. L., I. Kirchner, et al. (1998). "Radiative forcing from the 1991 Mount Pinatubo volcanic eruption." Journal of Geophysical Research **103**: 13837-13857 DOI: 10.1029/98jd00693

Available at: http://www.agu.org/pubs/crossref/1998/98JD00693.shtml

Volcanic sulfate aerosols in the stratosphere produce significant long-term solar and infrared radiative perturbations in the Earth's atmosphere and at the surface, which cause a response of the climate system. Here we study the fundamental process of the development of this volcanic radiative forcing, focusing on the eruption of Mount Pinatubo in the Philippines on June 15, 1991. We develop a spectral-, space-, and time-dependent set of aerosol parameters for 2 years after the Pinatubo eruption using a combination of SAGE II aerosol extinctions and UARS-retrieved effective radii, supported by SAM II, AVHRR, lidar and balloon observations. Using these data, we calculate the aerosol radiative forcing with the ECHAM4 general circulation model (GCM) for cases with climatological and observed sea surface temperature (SST), as well as with and without climate response. We find that the aerosol radiative forcing is not sensitive to the climate variations caused by SST or the atmospheric response to the aerosols, except in regions with varying dense cloudiness. The solar forcing in the near infrared contributes substantially to the total stratospheric heating. A complete formulation of radiative forcing should

include not only changes of net fluxes at the tropopause but also the vertical distribution of atmospheric heating rates and the change of downward thermal and net solar radiative fluxes at the surface. These forcing and aerosol data are available for GCM experiments with any spatial and spectral resolution.

Stephens, J. C., A. Hansson, et al. (2011). "Characterizing the international carbon capture and storage community." Global Environmental Change **21**: 379-390 DOI: 10.1016/j.gloenvcha.2011.01.008
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959378011000094

Carbon capture and storage (CCS) is a controversial climate change mitigation technology that has been receiving increased public and private investment over the past decade in several countries. During this time, a diverse international network of professionals focused on the advancement of CCS technology has emerged. Within this international CCS community, a shared perception of the value of advancing CCS technology is generally assumed, and this community has been influential in lobbying for increased support for the development of CCS in many countries and at the international level. The phenomenon of an apparently shared perspective within a specific community relates to Haas' (1992a) description of the evolution of an epistemic community, or a knowledge-based network of recognized experts who "not only hold in common a set of principled and causal beliefs but also have shared notions of validity and a shared policy enterprise". Understanding the extent to which a given community can be characterized as an epistemic community can provide insights about the effectiveness of its policy intervention, its association with the broader public, and the success of communicating the messages that it wants to convey. The goal of this research is to begin to explore the nature of the CCS community; to provide a preliminary characterization of the community, and to consider whether and in what ways the community might be considered to be an epistemic community or a compilation of multiple different epistemic communities. This characterization suggests that although the CCS community may be influencing decision-makers and successfully garnering political support for advancing CCS technology, a potential disconnect with the concerns of a broader public is deserving of more attention and social science research.

Stern, N. (2006). Stern Review on The Economics of Climate Change. Executive Summary. HR Treasury, London, United Kingdom.
Open Access Article* Available at:
http://siteresources.worldbank.org/INTINDONESIA/Resources/226271-1170911056314/3428109-1174614780539/SternReviewEng.pdf

Stevens, B. and M. Ragheb Atmospheric heat fluxes and restoration of the circumglobal equatorial current, Urbana, IL, USA, IEEE.
Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5462597

An analytical model is developed for estimating the heat fluxes in the lower and upper parts of the atmosphere that would result from possible increases in the carbon dioxide (CO_2) concentrations and the ensuing temperature changes. For a doubling of the CO_2 concentration by volume, the net heat flux to the troposphere is estimated to increase by 22 percent, and for a quadrupling of the concentration, the net heat flux increases by 39 percent, implying an enhanced energy input to the troposphere where weather phenomena are initiated. As a contingency measure in case efforts to reduce emissions are unsuccessful, a geoengineering project is considered to mitigate the effects of a possible runaway global change. The goal is the restoration of the ancient circumglobal equatorial current by digging a trans-isthmian sea level canal through the Isthmus of Panama using conventional and nuclear civil engineering methods. This would restore the temperate climatic conditions that existed 3 million years ago. Other alternatives involving ocean iron seeding, atmospheric injection of sulfates to increase reflectivity to solar radiation and shading the Earth with Mylar disc reflectors, are discussed.

Stilgoe, J. (2011). "A question of intent." Nature Climate Change **1**: 325-326 DOI: 10.1038/nclimate1225
Available at: http://www.nature.com/doifinder/10.1038/nclimate1225

As the emerging field of geoengineering gains momentum, researchers must question the motivations behind their experiments and maintain an open dialogue with the public.

Stone, R. (2010). "Marine biogeochemistry. The invisible hand behind a vast carbon reservoir." Science (New York, N.Y.) **328**: 1476-1477 DOI: 10.1126/science.328.5985.1476
Available at: http://web.bio.utk.edu/wilhelm/MCP.pdf

Strand, S. E. and G. Benford (2009). "Ocean sequestration of crop residue carbon: recycling fossil fuel carbon back to

deep sediments." Environmental science & technology **43**: 1000-1007
Open Access Article* Available at: http://pubs.acs.org/doi/full/10.1021/es8015556

For significant impact any method to remove CO_2 from the atmosphere must process large amounts of carbon efficiently, be repeatable, sequester carbon for thousands of years, be practical, economical and be implemented soon. The only method that meets these criteria is removal of crop residues and burial in the deep ocean. We show here that this method is 92% efficient in sequestration of crop residue carbon while cellulosic ethanol production is only 32% and soil sequestration is about 14% efficient. Deep ocean sequestration can potentially capture 15% of the current global CO_2 annual increase, returning that carbon back to deep sediments, confining the carbon for millennia, while using existing capital infrastructure and technology. Because of these clear advantages, we recommend enhanced research into permanent sequestration of crop residues in the deep ocean.

Stull, E., X. Sun, and D. Zaekle (2011). "Enhancing Urban Albedo to Fight Climate Change and Save Energy." Sustainable Development Law & Policy **11**
Open Access Article* Available at: http://digitalcommons.wcl.american .edu/sdlp/vol11/iss1/5

Sutton, M. A., O. Oenema, et al. (2011). "Too much of a good thing." Nature **472**: 159-161 DOI: 10.1038/472159a
Available at: http://www.nature.com/nature/journal/v472/n7342/full/472159a.html
http://www.ncbi.nlm.nih.gov/pubmed/21478874

Curbing nitrogen emissions is a central environmental challenge for the twenty-first century, argue Mark Sutton and his colleagues

Swart, R. and N. Marinova (2010). "Policy options in a worst case climate change world." Mitigation and Adaptation Strategies for Global Change **15**: 531-549 DOI: 10.1007/s11027-010-9235-0
Available at: http://www.springerlink.com/index/10.1007/s11027-010-9235-0

Climatic changes more rapid and extreme than assessed by the IPCC cannot be excluded, because of the possibility of positive earth system feedbacks and thresholds. Do today's policy makers have to take these into account, and if so, are the options different from those considered today? The paper briefly summarizes the types of extreme climatic changes noted in the literature and then evaluates the options to address them in a what-if manner. Different from other studies, which usually look at only one type of measure, we consider a broader portfolio of options: drastic emissions reduction programmes, drawing greenhouse gases from the atmosphere ("carbon dioxide removal"), "emergency cooling" through influencing the radiative balance of the atmosphere ("solar radiation management"), and finally adaptation beyond the options considered seriously today. Politics will have to decide on the choice or mix of "emergency" measures, but research can ensure that such decisions are based on the best scientific information. If through concerted international efforts to mitigate greenhouse emissions low stabilization levels could be reached, such decisions may never have to be made. However, research in support of some form of a "plan B" is now warranted, focusing on those options that have the most positive ratio between potential effectiveness and feasibility on the one hand, and environmental and political risks on the other hand. Such plan should not be limited to one set of options such as geo-engineering and should explicitly take into account not only the relationships between the options but also the wide variety in characteristics of the individual options in terms of effectiveness, feasibility, environmental risks, and political implications.

Tamburri, M. N., E. T. Peltzer, et al. (2000). "A field study of the effects of CO2 ocean disposal on mobile deep-sea animals." Marine Chemistry **72**: 95-101 DOI: 10.1016/s0304-4203(00)00075-x
Available at: http://linkinghub.elsevier.com/retrieve/pii/S030442030000075X

Before the feasibility of ocean sequestration of anthropogenic carbon dioxide can be evaluated completely, there is a clear need to better understand the potential biological impacts of CO_2-enriched (low pH and high pCO_2) seawater in regions of proposed disposal. We describe here the first empirical study directly examining animal responses to dissolving CO_2 hydrates on the deep-sea floor. Using a remotely operated vehicle (ROV) to conduct experiments within Monterey Canyon, CA, we found that several species (both invertebrate and vertebrate) did not avoid rapidly dissolving flocculent hydrates when attracted by the scent of food. Furthermore, while there were no apparent short-term effects of decreased pH, mobile animals appeared to suffer from respiratory distress due to increased pCO_2 when in close proximity to hydrates. Losses of higher organisms as a result of CO_2 disposal in the deep-sea may therefore be more extensive than previously predicted from toxicological models. However, the extent of changes to surrounding seawater chemistry, and thus biological impact, is largely dependent on CO_2 release method or the type of hydrate formed.

TEEB (2009). TEEB Climate Issues Update**:** September 2009.
Open Access Article* Available at:
http://www.teebweb.org/LinkClick.aspx?fileticket=L6XLPaoaZv8%3d&tabid=1278&language=en-US

Tengö, M., K. Johansson, et al. (2007). "Taboos and Forest Governance : Informal Protection of Hot Spot Dry Forest in Southern Madagascar." Ambio **36**: 683-691 DOI: 10.1579/0044-7447(2007)36
Available at: http://www.bioone.org/doi/abs/10.1579/0044-7447%282007%2936%5B683:TAFGIP%5D2.0.CO%3B2
In the dry forest of southern Madagascar, a region of global conservation priority, formally protected areas are nearly totally absent. We illustrate how the continued existence of unique forest habitats in the Androy region is directly dependent on informal institutions, taboos, regulating human behavior. Qualitative interviews to map and analyze the social mechanisms underlying forest protection have been combined with vegetation analyses of species diversity and composition. Of 188 forest patches, 93% were classified as protected, and in Southern Androy all remaining forest patches larger than 5 ha were protected. Eight different types of forests, with a gradient of social fencing from open access to almost complete entry prohibitions, were identified. Transgressions were well enforced with strong sanctions of significant economic as well as religious importance. Analyses of species diversity between protected and unprotected forests were complicated because of size differences and access restrictions. However, since, for example, in southern Androy >90% of the total remaining forest cover is protected through taboos, these informal institutions represent an important, and presently the only, mechanism for conservation of the highly endemic forest species. We conclude that social aspects, such as local beliefs and legitimate sanctioning systems, need to be analyzed and incorporated along with biodiversity studies for successful conservation.

The Royal Society (2001). The role of land carbon sinks in mitigating global climate change. RS Policy document 10/01. London, United Kingdom.
Open Access Article* Available at: http://royalsociety.org/policy/publications/2001/land-carbon-sinks/

The Royal Society (2005). Ocean acidification due to increasing atmospheric carbon dioxide. RS Policy document 12/05 London, United Kingdom**:** 60 pp.
Open Access Article* Available at:
http://royalsociety.org/Ocean-acidification-due-to-increasing-atmospheric-carbon-dioxide

The Royal Society (2009). Geoengineering the climate: science, governance and uncertainty. RS Policy document 10/09. London, United Kingdom**:** 82 pp.
Open Access Article* Available at: http://royalsociety.org/policy/publications/2009/geoengineering-climate/

Tilmes, S., R. Müller, et al. (2008). "The Sensitivity of Polar Ozone Depletion to Proposed Geoengineering Schemes." Science **320**: 1201-1204
Open Access Article* Available at: http://www.sciencemag.org/content/320/5880/1201.full
The large burden of sulfate aerosols injected into the stratosphere by the eruption of Mount Pinatubo in 1991 cooled Earth and enhanced the destruction of polar ozone in the subsequent few years. The continuous injection of sulfur into the stratosphere has been suggested as a “geoengineering” scheme to counteract global warming. We use an empirical relationship between ozone depletion and chlorine activation to estimate how this approach might influence polar ozone. An injection of sulfur large enough to compensate for surface warming caused by the doubling of atmospheric CO_2 would strongly increase the extent of Arctic ozone depletion during the present century for cold winters and would cause a considerable delay, between 30 and 70 years, in the expected recovery of the Antarctic ozone hole.

Tollefson, J. (2010). "Geoengineers get the fear (Nature News)." Nature **464**: 656-656 DOI: 10.1038/464656a
Open Access Article* Available at: http://www.nature.com/news/2010/100330/full/464656a.html

Trenberth, K. E. (2010). "Fixing the Planet?" Science **330**: 1178-1179 DOI: 10.1126/science.1197874
Open Access Article* Available at: http://www.sciencemag.org/cgi/doi/10.1126/science.1197874

Trenberth, K. E. and A. Dai (2007). "Effects of Mount Pinatubo volcanic eruption on the hydrological cycle as an analog of geoengineering." Geophysical Research Letters **34**: L15702-L15702 DOI: 10.1029/2007gl030524

Available at: http://www.agu.org/pubs/crossref/2007/2007GL030524.shtml

The problem of global warming arises from the buildup of greenhouse gases such as carbon dioxide from burning of fossil fuels and other human activities that change the composition of the atmosphere and alter outgoing longwave radiation (OLR). One geoengineering solution being proposed is to reduce the incoming sunshine by emulating a volcanic eruption. In between the incoming solar radiation and the OLR is the entire weather and climate system and the hydrological cycle. The precipitation and streamflow records from 1950 to 2004 are examined for the effects of volcanic eruptions from El Chicho ´n in March 1982 and Pinatubo in June 1991, taking into account changes from El Nin ˜o-Southern Oscillation. Following the eruption of Mount Pinatubo in June 1991 there was a substantial decrease in precipitation over land and a record decrease in runoff and river discharge into the ocean from October 1991–September 1992. The results suggest that major adverse effects, including drought, could arise from geoengineering solutions.

Tretkoff, E. (2010). "Research Spotlight: Assessing regional impacts of geoengineering (News)." Eos, Transactions American Geophysical Union **91**: 428-428 DOI: 10.1029/EO091i045p00428-04

Available at: http://www.agu.org/pubs/crossref/2010/EO091i045p00428-04.shtml

As the climate warms along with rising levels of atmospheric carbon dioxide (CO2), geoengineering has been suggested as an emergency option to cool the planet. One possibility is implementing a solar radiation management project, such as injecting sulfate aerosols into the stratosphere or deploying a solar “sunshade,” to counteract global warming by decreasing the amount of sunlight that reaches Earth's surface. However, a global intervention would have different regional impacts. For instance, geoengineering could result in decreased precipitation and increased droughts in some regions, with serious consequences for some human populations.

Trick, C. G., B. D. Bill, et al. (2010). "Iron enrichment stimulates toxic diatom production in high-nitrate, low-chlorophyll areas." Proceedings of the National Academy of Sciences of the United States of America **107**: 5887-5892 DOI: 10.1073/pnas.0910579107

Open Access Article* Available at:

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2851856&tool=pmcentrez&rendertype=abstract

Oceanic high-nitrate, low-chlorophyll environments have been highlighted for potential large-scale iron fertilizations to help mitigate global climate change. Controversy surrounds these initiatives, both in the degree of carbon removal and magnitude of ecosystem impacts. Previous open ocean enrichment experiments have shown that iron additions stimulate growth of the toxigenic diatom genus *Pseudonitzschia*. Most *Pseudonitzschia* species in coastal waters produce the neurotoxin domoic acid (DA), with their blooms causing detrimental marine ecosystem impacts, but oceanic *Pseudonitzschia* species are considered nontoxic. Here we demonstrate that the sparse oceanic *Pseudonitzschia* community at the high-nitrate, low-chlorophyll Ocean Station PAPA (50 degrees N, 145 degrees W) produces approximately 200 pg DA L(-1) in response to iron addition, that DA alters phytoplankton community structure to benefit *Pseudonitzschia*, and that oceanic cell isolates are toxic. Given the negative effects of DA in coastal food webs, these findings raise serious concern over the net benefit and sustainability of large-scale iron fertilizations.

Trumper, K., M. Bertzky, et al. (2009). The Natural Fix? The role of ecosystems in climate mitigation. Cambridge, UK, United Nations Environment Programme, UNEP- WCMC.

Open Access Article* Available at: http://www.grida.no/publications/rr/natural-fix/

A rapid response assessment report released by UNEP to mark World Environment Day 2009 indicates that that boosting investments in conservation, restoration and management of natural ecosystems will not only become important, but will provide our best and most effective way to slow down climate change and accelerate sustainable development and the achievement of the poverty-related Millennium Development Goals.

Tuana, N. S. R. S. T. and et al. (2011). Towards Integrated Ethical and Scientific Analysis of Geoengineering: A Research Agenda**:** 1-23.

Open Access Article* Available at: http://www3.geosc.psu.edu/~kzk10/Tuana_elsi_11.pdf

Concerns about the risks of unmitigated greenhouse gas emissions are growing. At the same time, confidence that international policy agreements will succeed in considerably lowering anthropogenic greenhouse gas emissions is declining. Perhaps as a result, various geoengineering solutions are gaining attention and credibility as a way to manage climate change. Serious consideration is currently being given to proposals to cool the planet through solar-radiation management (SRM). Here we analyze how the unique and nontrivial risks of geoengineering

strategies pose fundamental questions at the interface between science and ethics. To illustrate the importance of integrated ethical and scientific analysis, we define key open questions and outline a coupled scientific-ethical research agenda to analyze SRM geoengineering proposals. We identify nine key fields of coupled research including whether SRM can be tested, how quickly learning could occur, normative decisions embedded in how different climate trajectories are valued, and justice issues regarding distribution of the harms and benefits of geoengineering. To ensure that ethical analyses are coupled with scientific analyses of this form of geoengineering, we advocate that funding agencies recognize the essential nature of this coupled research by establishing an Ethical, Legal, and Social Implications (ELSI) program for SRM.

Tuck, a. F., D. J. Donaldson, et al. (2008). "On geoengineering with sulphate aerosols in the tropical upper troposphere and lower stratosphere." Climatic Change **90**: 315-331 DOI: 10.1007/s10584-008-9411-3
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-008-9411-3
This paper is in response to the Editorial Essay by Crutzen and the Editorial Comment by Cicerone in the August 2006 issue of Climatic Change. We reprise the evidence from atmospheric nuclear weapon testing in the 1950s and 1960s which is salient to the mooted maintenance of an artificial sulphate aerosol layer in the lower stratosphere, including a hitherto and now posthumous unpublished analysis of the 185W Hardtack data. We also review recent investigations by ourselves, which have considerable bearing on some relevant questions concerning meteorological dynamics, aerosol chemistry and physics and the photo-dissociation of stratospheric sulphuric acid.

Turley, C. and H. S. Findlay (2009). “Ocean acidification as an indicator for climate change”. in Climate change: observed impacts on planet Earth. T. M. Letcher. Elsevier, Amsterdam,**:** 367-390.

Turley, C., M. Eby, et al. (2010). "The societal challenge of ocean acidification." Marine pollution bulletin **60**: 787-792 DOI: 10.1016/j.marpolbul.2010.05.006
Available at: http://www.sciencedirect.com/science/article/pii/S0025326X1000192X

Turley, CM. and P. Williamson (in press) "Ocean acidification in a geoengineering context." Philosophical Transactions of the Royal Society A

U.S. Government Accountability Office (2011). Technology Assessment: Climate engineering. Technical status, future directions, and potential responses.
Open Access Article* Available at: www.gao.gov/new.items/d1171.pdf

UNFCCC (2010). Copenhagen Accord.
Open Access Article* at: http://unfccc.int/resource/docs/2009/cop15/eng/107.pdf

UNFCCC Subsidiary Body for Scientific and Technological Advice (2011). Technological Report on the Workshop on the Research Dialogue. FCCC/SBSTA/2011/INF.6 (paras 19-23 and 37-38).
Open Access Article* Available at: http://unfccc.int/resource/docs/2011/sbsta/eng/inf06.pdf

UNFF (2011). Cultural and Social Values of Forests and Social Development. UN Economic and Social Council. New York, USA: E/CN.18/2011/5.
Open Access Article* at: http://daccess-ods.un.org/access.nsf/Get?OpenAgent&DS=E/CN.18/2011/5&Lang=E

United Nations Environment Programme. (2009). Climate Change Science Compendium. Nairobi, Kenya, UNEP.
Open Access Article* Available at: www.unep.org/compendium2009/

United States Government Accountability O . (2011). Climate engineering: Technical status, future directions, and potential responses.
Open Access Article* Available at: http://www.gao.gov/products/GAO-11-71
Reports of rising global average surface temperature have raised interest in the potential for engineering Earth’s climate, supplementary to ongoing efforts to reduce greenhouse gas emissions and prepare for climate change through adaptation. Proposed climate engineering technologies, or direct, deliberate, large-scale interventions in Earth’s climate, generally aim at either carbon dioxide removal (CDR) or solar radiation management (SRM). Whereas CDR would reduce the atmospheric concentration of carbon dioxide (CO_2), thus reducing greenhouse

warming, SRM would either deflect sunlight before it reaches Earth or otherwise cool Earth by increasing the reflectivity of its surface or atmosphere. In conducting this technology assessment, we focused primarily on the technical status of climate engineering and the views of a wide range of experts on the future of research.1 Our findings indicate that • climate engineering technologies are not now an option for addressing global climate change, given our assessment of their maturity, potential effectiveness, cost factors, and potential consequences. Experts told us that gaps in collecting and modeling climate data, identified in government and scientific reports, are likely to limit progress in future climate engineering research. • the majority of the experts we consulted supported starting significant climate engineering research now. Advocates and opponents of research described concerns about its risks and the possible misuse of its results. Research advocates supported balancing such concerns against the potential for reducing risks from climate change. They further envisioned a future federal research effort that would emphasize risk management, have an international focus, engage the public and national leaders, and anticipate new trends and developments. • a survey of the public suggests that the public is open to climate engineering research but is concerned about its possible harm and supports reducing CO_2 emissions.

Valdes, P. (2011). "Built for stability." Nature Geoscience **4**: 414-416 DOI: 10.1038/ngeo1200
Available at: http://www.nature.com/doifinder/10.1038/ngeo1200

State-of-the-art climate models are largely untested against actual occurrences of abrupt change. It is a huge leap of faith to assume that simulations of the coming century with these models will provide reliable warning of sudden, catastrophic events.

van den Broek, M., P. Veenendaal, et al. (2011). "Impact of international climate policies on CO2 capture and storage deployment - Illustrated in the Dutch energy system." Energy Policy **39**: 2000-2019 DOI: 10.1016/j.enpol.2011.01.036
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421511000462

A greenhouse gas emission trading system is considered an important policy measure for the deployment of CCS at large scale. However, more insights are needed whether such a trading system leads to a sufficient high CO_2 price and stable investment environment for CCS deployment. To gain more insights, we combined WorldScan, an applied general equilibrium model for global policy analysis, and MARKAL-NL-UU, a techno-economic energy bottom-up model of the Dutch power generation sector and CO_2 intensive industry. WorldScan results show that in 2020, CO_2 prices may vary between 20 €/tCO_2 in a Grand Coalition scenario, in which all countries accept greenhouse gas targets from 2020, to 47 €/tCO_2 in an Impasse scenario, in which EU-27 continues its one-sided emission trading system without the possibility to use the Clean Development Mechanism. MARKAL-NL-UU model results show that an emission trading system in combination with uncertainty does not advance the application of CCS in an early stage, the rates at which different CO_2 abatement technologies (including CCS) develop are less crucial for introduction of CCS than the CO_2 price development, and the combination of biomass (co-)firing and CCS seems an important option to realise deep CO_2 emission reductions.

Vanderzwaag, D. L. (2009). "Ocean Dumping and Fertilization in the Antarctic : Tangled Legal Currents , Sea of Challenges." Environmental Protection
Available at: http://gocompose.net/media/book-30.pdf

The law and policy framework governing potential ocean disposals in the Antarctic is surveyed using two nautical images. First, the “tangle of legal currents” is described with a focus on six global agreements relevant to ocean dumping and the 1991 Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol). The Madrid Protocol strictly controls the disposal of wastes generated in the Antarctic region through various removal obligations. Second, the “sea of challenges” surrounding effective control of ocean dumping is highlighted. Those challenges include ensuring full adoption and implementation of international agreements relevant to ocean dumping, getting an effective governance grip on ocean fertilization projects, and securing strong compliance with the two key global agreements targeting ocean dumping, the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Convention) and the 1996 Protocol to the London Convention.

Verlaan, P. P. (2009). "Geo-engineering, the Law of the Sea, and Climate Change." CCLR The Carbon & Climate Law Review **3**: 446-458
Available at: http://www.ingentaconnect.com/content/lex/cclr/2009/00000003/00000004/art00007

Plans to address climate change increasingly include proposals for geo-engineering projects, whose effects are likely to be global, at best only partly predictable, not necessarily wholly benign, and extend beyond their

objective. Geo-engineering proposals should receive detailed, precautionary scrutiny by the international community, which requires sophisticated international legal instruments and implementation systems. Most advanced are proposals for climate-related geo-engineering projects that involve or affect the ocean, requiring assessment of their compatibility with international law of the sea. This paper summarizes these proposals, reviews the applicable legally binding global instruments and their mechanisms to assess and regulate geo-engineering, and examines their implications for geo-engineering in responding to climate change. It concludes that geo-engineering projects must satisfy a suite of mandatory international legal requirements that are dedicated to protect and preserve the marine environment, or they cannot legally proceed

Veron, J. E. N., O. Hoegh-Guldberg, et al. (2009). "The coral reef crisis: the critical importance of<350 ppm CO2." Marine pollution bulletin **58**: 1428-1436 DOI: 10.1016/j.marpolbul.2009.09.009

Open Access Article* Available at: http://www.sciencedirect.com/science/article/pii/S0025326X09003816

Temperature-induced mass coral bleaching causing mortality on a wide geographic scale started when atmospheric CO(2) levels exceeded approximately 320 ppm. When CO(2) levels reached approximately 340 ppm, sporadic but highly destructive mass bleaching occurred in most reefs world-wide, often associated with El Niño events. Recovery was dependent on the vulnerability of individual reef areas and on the reef's previous history and resilience. At today's level of approximately 387 ppm, allowing a lag-time of 10 years for sea temperatures to respond, most reefs world-wide are committed to an irreversible decline. Mass bleaching will in future become annual, departing from the 4 to 7 years return-time of El Niño events. Bleaching will be exacerbated by the effects of degraded water-quality and increased severe weather events. In addition, the progressive onset of ocean acidification will cause reduction of coral growth and retardation of the growth of high magnesium calcite-secreting coralline algae. If CO(2) levels are allowed to reach 450 ppm (due to occur by 2030-2040 at the current rates), reefs will be in rapid and terminal decline world-wide from multiple synergies arising from mass bleaching, ocean acidification, and other environmental impacts. Damage to shallow reef communities will become extensive with consequent reduction of biodiversity followed by extinctions. Reefs will cease to be large-scale nursery grounds for fish and will cease to have most of their current value to humanity. There will be knock-on effects to ecosystems associated with reefs, and to other pelagic and benthic ecosystems. Should CO(2) levels reach 600 ppm reefs will be eroding geological structures with populations of surviving biota restricted to refuges. Domino effects will follow, affecting many other marine ecosystems. This is likely to have been the path of great mass extinctions of the past, adding to the case that anthropogenic CO(2) emissions could trigger the Earth's sixth mass extinction.

Vezzulli, L., I. Brettar, et al. (2011). "Long-term effects of ocean warming on the prokaryotic community: evidence from the vibrios." The ISME journal: 1-10 DOI: 10.1038/ismej.2011.89

Available at: http://www.ncbi.nlm.nih.gov/pubmed/21753799

The long-term effects of ocean warming on prokaryotic communities are unknown because of lack of historical data. We overcame this gap by applying a retrospective molecular analysis to the bacterial community on formalin-fixed samples from the historical Continuous Plankton Recorder archive, which is one of the longest and most geographically extensive collections of marine biological samples in the world. We showed that during the last half century, ubiquitous marine bacteria of the *Vibrio* genus, including *Vibrio cholerae*, increased in dominance within the plankton-associated bacterial community of the North Sea, where an unprecedented increase in bathing infections related to these bacteria was recently reported. Among environmental variables, increased sea surface temperature explained 45% of the variance in *Vibrio* data, supporting the view that ocean warming is favouring the spread of vibrios and may be the cause of the globally increasing trend in their associated diseases.

Victor, D. G. (2008). "On the regulation of geoengineering." Oxford Review of Economic Policy **24**: 322-336 DOI: 10.1093/oxrep/grn018

Available at: http://oxrep.oxfordjournals.org/cgi/doi/10.1093/oxrep/grn018

New evidence that the climate system may be especially sensitive to the build-up of greenhouse gases and that humans are doing a poor job of controlling their effluent has animated discussions around the possibility of offsetting the human impact on climate through ‘geoengineering’. Nearly all assessments of geoengineering have concluded that the option, while ridden with flaws and unknown side effects, is intriguing because of its low cost and the ability for one or a few nations to geoengineer the planet without cooperation from others. I argue that norms to govern deployment of geoengineering systems will be needed soon. The standard instruments for establishing such norms, such as treaties, are unlikely to be effective in constraining geoengineers because the

interests of key players diverge and it is relatively easy for countries to avoid incon- venient international commitments and act unilaterally. Instead, efforts to craft new norms ‘bottom up’ will be more effective. Such an approach, which would change the underlying interests of key countries and thus make them more willing to adopt binding norms in the future, will require active, open research programmes and assessments of geoengineering. Meaningful research may also require actual trial deployment of geo- engineering systems so that norms are informed by relevant experience and command respect through use. Standard methods for international assessment organized by the Intergovernmental Panel on Climate Change (IPCC) are unlikely to yield useful evaluations of geoengineering options because the most important areas for assessment lie in the improbable, harmful, and unexpected side effects of geoengineering, not the ‘consensus science’ that IPCC does well. I also suggest that real-world geoengineering will be a lot more complex and expensive than currently thought because simple interventions—such as putting reflective particles in the stratosphere—will be combined with many other costlier interventions to offset nasty side effects.

Victor, D. G., M. G. Morgan, et al. (2009). "The Geoengineering Option (Magazine)." Foreign Affairs **April/Marc**: 1-5 **Available at**:
http://www.foreignaffairs.com/articles/64829/david-g-victor-m-granger-morgan-jay-apt-john-steinbruner-and-kat/the-geo engineering-option

As climate change accelerates, policymakers may have to consider "geoengineering" as an emergency strategy to cool the planet. Engineering the climate strikes most as a bad idea, but it is time to start taking it seriously.

Virgoe, J. (2009). "International governance of a possible geoengineering intervention to combat climate change." Climatic Change **95**: 103-119 DOI: 10.1007/s10584-008-9523-9
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s10584-008-9523-9

This article explores international governance issues related to a possible future use of geoengineering techniques. Despite the serious arguments against geoengineering, policy-makers may start to take an interest in it in the medium term. The article identifies non-technical characteristics of geoengineering which might influence governance models, and then discusses three broad approaches: through the United Nations, by one state unilaterally, and through a consortium of states. An examination of international legal instruments reveals none that would pose an insuperable barrier to geoengineering. Finally, the article argues for early exploration of the technological, environmental, political and regulatory issues raised by geoengineering, to maximize the chances of good, science-based multilateral decision making if and when geoengineering’s day arrives.

Volodin, E. M., S. V. Kostrykin, et al. (2011). "Climate response to aerosol injection at different stratospheric locations." Atmospheric Science Letters **12**: 381-385 DOI: 10.1002/asl.351
Available at: http://doi.wiley.com/10.1002/asl.351

The effect of altitude and latitude of sulfate aerosol injection into the stratosphere on climate is studied with Earth system model INMCM. The model includes the general circulation of the atmosphere and oceans as well as a sulfate aerosol component, and is used to determine the most effective injection scenario for reducing changes in temperature and precipitation at a global level and in the Arctic

Volodin, E. M., S. V. Kostrykin, et al. (2011). "Simulation of climate change induced by injection of sulfur compounds into the stratosphere." Izvestiya, Atmospheric and Oceanic Physics **47**: 430-438 DOI: 10.1134/s0001433811040116
Available at: http://www.springerlink.com/index/10.1134/S0001433811040116

An atmosphere-ocean general circulation model including the atmospheric chemistry and carbon cycle was used to perform numerical experiments to simulate the consequences of geoengineering. Out of the five emission scenarios considered here, the scenario where the injection of sulfur compounds occurs near the equator at an altitude between 22 and 24 km can be considered the most efficient in the sense of a maximum decrease in globally averaged surface temperature. We consider the equilibrium distribution of the sulfate aerosol and changes in temperature at the Earth’s surface and at different altitudes, in precipitation, in ozone concentration, and in primary plant productivity caused by geoengineering.

von Neumann, J. (1955). "Can We Survive Technology?" Fortune: 106-108

Wallace, D. W. R., C. S. Law, et al. (2010). Ocean fertilization: A scientific summary for policy makers. IOC/UNESCO, Paris**:** IOC/BRO/2010/2012.
Open Access Article* Available at: http://unesdoc.unesco.org/images/0019/001906/190674e.pdf

Walther, G.-R., E. Post, et al. (2002). "Ecological responses to recent climate change." Nature **416**: 389-395 DOI: 10.1038/416389a
Available at: http://www.ncbi.nlm.nih.gov/pubmed/11919621
There is now ample evidence of the ecological impacts of recent climate change, from polar terrestrial to tropical marine environments. The responses of both flora and fauna span an array of ecosystems and organizational hierarchies, from the species to the community levels. Despite continued uncertainty as to community and ecosystem trajectories under global change, our review exposes a coherent pattern of ecological change across systems. Although we are only at an early stage in the projected trends of global warming, ecological responses to recent climate change are already clearly visible.

Wang, Y., B. Fu, et al. (2011). "Effects of vegetation restoration on soil organic carbon sequestration at multiple scales in semi-arid Loess Plateau, China." CATENA **85**: 58-66 DOI: 10.1016/j.catena.2010.12.003
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0341816210001803
Soil organic carbon (SOC) sequestration by vegetation restoration is the theme of much current research. Since 1999, the program of “Grain for Green” has been implemented in the semi-arid Loess Plateau, China. Its scope represents the largest vegetation restoration activity in China. However, it is still unclear for the SOC sequestration effects of vegetation cover change or natural succession promoted by the revegetation efforts at different scales under the semi-arid conditions. In this study, the changes in SOC stocks due to the vegetation restoration in the middle of Loess Plateau were estimated at patch, hill slope transect and small watershed scale from 1998 to 2006. Soil samples were taken from field for the determination of cesium-137 (137Cs) and SOC contents. Vegetation cover change from 1998 to 2006 at the small watershed scale was assessed using Geographic Information System. The results showed that cropland transforming to grassland or shrubland significantly increased SOC at patch scale. Immature woodland, however, has no significant effect. When vegetation cover has no transformation for mature woodland (25 years old), SOC has no significant increase implying that SOC has come to a stable level. At hill slope scale, three typical vegetation cover patterns showed different SOC sequestration effects of 8.6%, 24.6%, and 21.4% from 1998 to 2006, and these SOC increases mainly resulted from revegetation. At the small watershed scale, SOC stocks increased by 19% in the surface soil layer at 0–20 cm soil depth from 1998 to 2006, which was equivalent to an average SOC sequestration rate of 19.92 t C y− 1 km− 2. Meanwhile, SOC contents showed a significant positive correlation ($P < 0.001$) with the 137Cs inventory at every soil depth interval. This implied significant negative impacts of soil erosion on SOC sequestration. The results have demonstrated general positive effects of vegetation restoration on SOC sequestration at multiple scales. However, soil erosion under rugged topography modified the spatial distribution of the SOC sequestration effects. Therefore, vegetation restoration was proved to be a significant carbon sink, whereas, erosion could be a carbon source in high erosion sensitive regions. This research can contribute to the performance assessment of ecological rehabilitation projects such as “Grain to Green” and the scientific understanding of the impacts of vegetation restoration and soil erosion on soil carbon dynamics in semi-arid environments.

Wang, G. and D. Schimel (2003). "Climate Change, Climate Modes, and Climate Impacts." Annual Review of Environment and Resources **28**: 1-28 DOI: 10.1146/annurev.energy.28.050302.105444
Available at: http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.28.050302.105444
Variability of the atmospheric and oceanic circulations in the earth system gives rise to an array of naturally occurring dynamical modes. Instead of being spatially independent or spatially uniform, climate variability in different parts of the globe is orchestrated by one or a combination of several climate modes, and global changes take place with a distinctive spatial pattern resembling that of the modes-related climate anomalies. Climate impact on the dynamics of terrestrial and marine biosphere also demonstrates clear signals for the mode effects. In this review, we view modes as an important attribute of climate variability, changes, and impact and emphasize the emerging concept that future climate changes may be manifest as changes in the leading modes of the climate system. The focus of this review is on three of the leading modes: the North Atlantic Oscillation, the El Ni˜ Decadal Oscillation. no-Southern Oscillation, and the Pacific

Warnock, D. D., J. Lehmann, et al. (2007). "Mycorrhizal responses to biochar in soil – concepts and mechanisms." Plant and Soil **300**: 9-20 DOI: 10.1007/s11104-007-9391-5
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s11104-007-9391-5
Experiments suggest that biomass-derived black carbon (biochar) affects microbial populations and soil biogeochemistry. Both biochar and mycorrhizal associations, ubiquitous symbioses in terrestrial ecosystems, are

potentially important in various ecosystem services provided by soils, contributing to sustainable plant production, ecosystem restoration, and soil carbon sequestration and hence mitigation of global climate change. As both biochar and mycorrhizal associations are subject to management, understanding and exploiting interactions between them could be advantageous. Here we focus on biochar effects on mycorrhizal associations. After reviewing the experimental evidence for such effects, we critically examine hypotheses pertaining to four mechanisms by which biochar could influence mycorrhizal abundance and/or functioning. These mechanisms are (in decreasing order of currently available evidence supporting them): (a) alteration of soil physico-chemical proper- ties; (b) indirect effects on mycorrhizae through effects on other soil microbes; (c) plant–fungus signalling interference and detoxification of allelochemicals on biochar; and (d) provision of refugia from fungal grazers. We provide a roadmap for research aimed at testing these mechanistic hypotheses.

Watanabe, M., H. Shiogama, et al. (2011). "Fast and slow timescales in the tropical low-cloud response to increasing CO2 in two climate models." Climate Dynamics DOI: 10.1007/s00382-011-1178-y
Open Access Article* Available at: http://www.springerlink.com/index/10.1007/s00382-011-1178-y

Watson, A. J., P. W. Boyd, et al. (2008). "Designing the next generation of ocean iron fertilization experiments." Marine Ecology Progress Series **364**: 303-309 DOI: 10.3354/meps07552
Open Access Article* Available at: http://www.int-res.com/abstracts/meps/v364/p303-309/

The first generation of open-ocean iron enrichments (1993 to 2005) have all had broadly the same design. Enrichment of patches of ocean was typically on a 10 km length-scale, and experiments were of a duration of weeks. These scales were dictated by what could conveniently be achieved from research vessels, using tracers to track Lagrangian patches. The extrapolation of experimental findings to the larger scales required for carbon sequestration by ocean iron fertilization (OIF) leaves many uncertainties, to answer which, longer duration (i.e. months) and larger scale observations (100 to 200 km length-scale) are required. However, to extrapolate to a timescale of decades and to the scale of ocean basins, such observations must be conducted in parallel (and where possible assimilated into) detailed models of the physics and biogeochemistry of the fertilized waters. Our present understanding suggests that any carbon sequestration will occur as the net result of changes in the air–sea flux integrated over millions km2 and many years, and can only realistically be assessed by modelling. A central role of the observational studies will be to make such models as accurate as possible in their simulations and predictions. We present a scheme for the design of a second generation of ocean iron-enrichments and discuss the challenges that are evident in linking the modelling and observational components of such studies.

Wei, X., C. Declan, et al. (2009). "Future cereal production in China: The interaction of climate change, water availability and socio-economic scenarios." Global Environmental Change **19**: 34-44 DOI: 10.1016/j.gloenvcha.2008.10.006
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959378008000988

Food production in China is a fundamental component of the national economy and driver of agricultural policy. Sustaining and increasing output to meet growing demand faces significant challenges including climate change, increasing population, agricultural land loss and competing demands for water. Recent warming in China is projected to accelerate by climate models with associated changes in precipitation and frequency of extreme events. How changes in cereal production and water availability due to climate change will interact with other socio-economic pressures is poorly understood. By linking crop and water simulation models and two scenarios of climate (derived from the Regional Climate Model PRECIS) and socio-economic change (downscaled from IPCC SRES A2 and B2) we demonstrate that by the 2040s the absolute effects of climate change are relatively modest. The interactive effects of other drivers are negative, leading to decreases in total production of −18% (A2) and −9% (B2). Outcomes are highly dependent on climate scenario, socio-economic development pathway and the effects of CO_2 fertilization on crop yields which may almost totally offset the decreases in production. We find that water availability plays a significant limiting role on future cereal production, due to the combined effects of higher crop water requirements (due to climate change) and increasing demand for non-agricultural use of water (due to socio-economic development). Without adaptation, per capita cereal production falls in all cases, by up to 40% of the current baseline. By simulating the effects of three adaptation scenarios we show that for these future scenarios China is able to maintain per capita cereal production, given reasonable assumptions about policies on land and water management and progress in agricultural technology. Our results are optimistic because PRECIS simulates much wetter conditions than a multi-model average, the CO_2 crop yield response function is highly uncertain and the effects of extreme events on crop growth and water availability are likely to be underestimated.

White, A., K. Björkman, et al. (2010). "An Open Ocean Trial of Controlled Upwelling Using Wave Pump Technology." Journal of Atmospheric and Oceanic Technology **27**: 385-396 DOI: 10.1175/2009jtecho679.1
Available at: http://journals.ametsoc.org/doi/abs/10.1175/2009JTECHO679.1

In 1976, John D. Isaacs proposed to use wave energy to invert the density structure of the ocean and pump deep, nutrient-rich water into the sunlit surface layers. The basic principle is simple: a length of tubing attached to a surface buoy at the top, and a one-way valve at the bottom can be extended below the euphotic zone to act as a conduit for deep water. The vertical motion of the ocean forces the attached valve to open on the downslope of a wave and close on the upslope, thus generating upward movement of deep water to the surface ocean. Although Isaacs's wave-powered pump has taken many forms, from energy production to aquaculture to the more recent suggestion that artificial upwelling could be used to stimulate primary productivity and carbon sequestration, the simple engineering concept remains the same. In June 2008, the authors tested a commercially available wave pump (Atmocean) north of Oahu, Hawaii, to assess the logistics of at-sea deployment and the durability of the equipment under open ocean conditions. This test was done as part of an experiment designed to evaluate a recently published hypothesis that upwelling of water containing excess phosphate (P) relative to nitrogen (N) compared to the canonical "Redfield" molar ratio of 16N:1P would generate a two-phased phytoplankton bloom. The end result of this field experiment was rapid delivery (<2 h for a 300-m transit) of deep water to the surface ocean followed by catastrophic failure of pump materials under the dynamic stresses of the oceanic environment. Wave-driven upwelling of cold water was documented for a period of 17 h, with a volumetric upwelling rate of 45 m3 h−1 and an estimated total input of 765 m3 of nutrient-enriched deep water. The authors discuss the deployment of a 300-m wave pump, the strategy to sample a biogeochemical response, the engineering challenges faced, and the implications of these results for future experiments aimed at stimulating the growth of phytoplankton.

Widdicombe, S., J. I. Spicer, et al. (2011). "Effects of ocean acidification on sediment fauna" in Ocean Acidification. J. P. Gattuso and L. Hansson. Oxford, United Kingdom, Oxford University Press**:** 176-191.

Wigley, T. M. L. (2006). "A combined mitigation/geoengineering approach to climate stabilization." Science **314**: 452-454 DOI: 10.1126/science.1131728
Open Access Article* Available at: http://www.sciencemag.org/content/314/5798/452.short

Projected anthropogenic warming and increases in CO2 concentration present a twofold threat, both from climate changes and from CO_2 directly through increasing the acidity of the oceans. Future climate change may be reduced through mitigation (reductions in greenhouse gas emissions) or through geoengineering. Most geoengineering approaches, however, do not address the problem of increasing ocean acidity. A combined mitigation/geoengineering strategy could remove this deficiency. Here we consider the deliberate injection of sulfate aerosol precursors into the stratosphere. This action could substantially offset future warming and provide additional time to reduce human dependence on fossil fuels and stabilize CO_2 concentrations cost-effectively at an acceptable level.

Williams, J. W. and S. T. Jackson (2007). "Novel climates, no-analog communities, and ecological surprises." Frontiers in Ecology and the Environment **5**: 475-482 DOI: 10.1890/070037
Available at: http://www.esajournals.org/doi/abs/10.1890/070037

No-analog communities (communities that are compositionally unlike any found today) occurred frequently in the past and will develop in the greenhouse world of the future. The well documented no-analog plant communities of late-glacial North America are closely linked to "novel" climates also lacking modern analogs, characterized by high seasonality of temperature. In climate simulations for the Intergovernmental Panel on Climate Change A2 and B1 emission scenarios, novel climates arise by 2100 AD, primarily in tropical and subtropical regions. These future novel climates are warmer than any present climates globally, with spatially variable shifts in precipitation, and increase the risk of species reshuffling into future no-analog communities and other ecological surprises. Most ecological models are at least partially parameterized from modern observations and so may fail to accurately predict ecological responses to these novel climates. There is an urgent need to test the robustness of ecological models to climate conditions outside modern experience.

Wilson, E. J., T. L. Johnson, et al. (2003). "Regulating the ultimate sink: managing the risks of geologic CO2 storage." Environmental science & technology **37**: 3476-3483
Open Access Article* Available at: http://pubs.acs.org/doi/full/10.1021/es021038%2B

The geologic storage (GS) of carbon dioxide (CO2) is emerging as an important tool for managing carbon. While

this Journal recently published an excellent review of GS technology (Bruant, R. G.; Guswa, A. J.; Celia, M. A.; Peters, C. A. Environ. Sci. Technol. 2002, 36, 240A-245A), few studies have explored the regulatory environment for GS or have compared it with current underground injection experience. We review the risks and regulatory history of deep underground injection on the U.S. mainland and surrounding continental shelf. Our treatment is selective, focusing on the technical and regulatory aspects that are most likely to be important in assessing and managing the risks of GS. We also describe current underground injection activities and explore how these are now regulated.

Wolff, G. a., D. S. M. Billett, et al. (2011). "The effects of natural iron fertilisation on deep-sea ecology: the crozet plateau, southern Indian ocean." PloS one **6**: e20697-e20697 DOI: 10.1371/journal.pone.0020697

Open Access Article* Available at:

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3114783&tool=pmcentrez&rendertype=abstract

The addition of iron to high-nutrient low-chlorophyll (HNLC) oceanic waters stimulates phytoplankton, leading to greater primary production. Large-scale artificial ocean iron fertilization (OIF) has been proposed as a means of mitigating anthropogenic atmospheric CO(2), but its impacts on ocean ecosystems below the photic zone are unknown. Natural OIF, through the addition of iron leached from volcanic islands, has been shown to enhance primary productivity and carbon export and so can be used to study the effects of OIF on life in the ocean. We compared two closely-located deep-sea sites (~400 km apart and both at ~4200 m water depth) to the East (naturally iron fertilized; +Fe) and South (HNLC) of the Crozet Islands in the southern Indian Ocean. Our results suggest that long-term geo-engineering of surface oceanic waters via artificial OIF would lead to significant changes in deep-sea ecosystems. We found that the +Fe area had greater supplies of organic matter inputs to the seafloor, including polyunsaturated fatty acid and carotenoid nutrients. The +Fe site also had greater densities and biomasses of large deep-sea animals with lower levels of evenness in community structuring. The species composition was also very different, with the +Fe site showing similarities to eutrophic sites in other ocean basins. Moreover, major differences occurred in the taxa at the +Fe and HNLC sites revealing the crucial role that surface oceanic conditions play in changing and structuring deep-sea benthic communities.

Woodward, F. I., R. D. Bardgett, et al. (2009). "Biological approaches to global environment change mitigation and remediation." Current biology **19**: R615-623 DOI: 10.1016/j.cub.2009.06.012

Open Access Article* Available at: http://www.cell.com/current-biology/retrieve/pii/S0960982209012512

One of the most pressing and globally recognized challenges is how to mitigate the effects of global environment change brought about by increasing emissions of greenhouse gases, especially CO(2). In this review we evaluate the potential contribution of four biological approaches to mitigating global environment change: reducing atmospheric CO(2) concentrations through soil carbon sequestration and afforestation; reducing predicted increases in global surface temperatures through increasing the albedo of crop plants; and fertilizing the oceans to increase primary productivity and CO(2) drawdown. We conclude that none of these biological approaches are 'magic bullets' capable of reversing environmental changes brought about by increasing emissions of greenhouse gases. However, it is possible that increasing crop albedo and soil carbon sequestration might contribute towards mitigation on a regional scale. In the absence of legally binding international agreements to reduce CO(2) emissions, we propose that: increased efforts are made to identify novel biological mitigatory strategies; further research is conducted to minimise the uncertainties present in all four of the biological approaches described; and pilot-level field work is conducted to examine the feasibility of the most promising strategies. Finally, it is essential to engage with the public concerning strategies for mitigating the effects of climate change because the majority of the biological approaches have effects, quite possibly of a negative nature, on ecosystem services and land usage.

Woolf, D., J. E. Amonette, et al. (2010). "Sustainable biochar to mitigate global climate change." Nature communications **1**: 56-56 DOI: 10.1038/ncomms1053

Open Access Article* Available at:

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2964457&tool=pmcentrez&rendertype=abstract

Production of biochar (the carbon (C)-rich solid formed by pyrolysis of biomass) and its storage in soils have been suggested as a means of abating climate change by sequestering carbon, while simultaneously providing energy and increasing crop yields. Substantial uncertainties exist, however, regarding the impact, capacity and sustainability of biochar at the global level. In this paper we estimate the maximum sustainable technical potential of biochar to mitigate climate change. Annual net emissions of carbon dioxide (CO(2)), methane and nitrous oxide could be reduced by a maximum of 1.8 Pg CO(2)-C equivalent (CO(2)-C(e)) per year (12% of current

anthropogenic CO(2)-C(e) emissions; 1 Pg=1 Gt), and total net emissions over the course of a century by 130 Pg CO(2)-C(e), without endangering food security, habitat or soil conservation. Biochar has a larger climate-change mitigation potential than combustion of the same sustainably procured biomass for bioenergy, except when fertile soils are amended while coal is the fuel being offset.

Yool, A., J. G. Shepherd, et al. (2009). "Low efficiency of nutrient translocation for enhancing oceanic uptake of carbon dioxide." Journal of Geophysical Research **114**: 1-13 DOI: 10.1029/2008jc004792
Available at: http://www.agu.org/pubs/crossref/2009/2008JC004792.shtml

Anthropogenic emissions of carbon dioxide (CO2) are steadily increasing the concentration of this greenhouse gas in the Earth's atmosphere. The possible long-term consequences of this elevated concentration have led to proposals for a number of large-scale geoengineering schemes that aim to enhance or augment natural sinks for CO2. One such scheme proposes deploying a large number of floating “pipes” in the ocean that act to translocate nutrient-rich seawater from below the mixed layer to the ocean's surface: the nutrient supplied should enhance the growth of phytoplankton and consequently the export of organic carbon to the deep ocean via the biological pump. Here we examine the practical consequences of this scheme in a global ocean general circulation model that includes a nitrogen-based ecosystem and the biogeochemical cycle of carbon. While primary production is generally enhanced by the modeled pipes, as expected, the effect on the uptake of CO2 from the atmosphere is much smaller, may be negative, and shows considerable spatiotemporal variability.

Zeebe, R. E. and D. Archer (2005). "Feasibility of ocean fertilization and its impact on future atmospheric CO 2 levels." Geophysical Research Letters **32**: L09703-L09703 DOI: 10.1029/2005gl022449
Available at: http://www.agu.org/pubs/crossref/2005/2005GL022449.shtml

Iron fertilization of macronutrient-rich but biologically unproductive ocean waters has been proposed for sequestering anthropogenic carbon dioxide (CO_2). The first carbon export measurements in the Southern Ocean (SO) during the recent SO-Iron Experiment (SOFeX) yielded □900 t C exported per 1.26 t Fe added. This allows the first realistic, data-based feasibility assessment of large-scale iron fertilization and corresponding future atmospheric COv prognosis. Using various carbon cycle models, we find that if 20% of the world’s surface ocean were fertilized 15 times per year until year 2100, it would reduce atmospheric CO_2 by]15 ppmv at an expected level of □700 ppmv for business-as-usual scenarios. Thus, based on the SOFeX results and currently available technology, large–scale oceanic iron fertilization appears not a feasible strategy to sequester anthropogenic CO_2.

Zelazowski, P., Y. Malhi, et al. (2011). "Changes in the potential distribution of humid tropical forests on a warmer planet." Philosophical Transactions of the Royal Society A **369**: 137-160 DOI: 10.1098/rsta.2010.0238
Open Access Article* Available at: http://rsta.royalsocietypublishing.org/content/369/1934/137.long

The future of tropical forests has become one of the iconic issues in climate-change science. A number of studies that have explored this subject have tended to focus on the output from one or a few climate models, which work at low spatial resolution, whereas society and conservation-relevant assessment of potential impacts requires a finer scale. This study focuses on the role of climate on the current and future distribution of humid tropical forests (HTFs). We first characterize their contemporary climatological niche using annual rainfall and maximum climatological water stress, which also adequately describe the current distribution of other biomes within the tropics. As a first-order approximation of the potential extent of HTFs in future climate regimes defined by global warming of 2(°)C and 4(°)C, we investigate changes in the niche through a combination of climate-change anomaly patterns and higher resolution (5 km) maps of current climatology. The climate anomalies are derived using data from 17 coupled Atmosphere-Ocean General Circulation Models (AOGCMs) used in the Fourth Assessment of the Intergovernmental Panel for Climate Change. Our results confirm some risk of forest retreat, especially in eastern Amazonia, Central America and parts of Africa, but also indicate a potential for expansion in other regions, for example around the Congo Basin. The finer spatial scale enabled the depiction of potential resilient and vulnerable zones with practically useful detail. We further refine these estimates by considering the impact of new environmental regimes on plant water demand using the UK Met Office land-surface scheme (of the HadCM3 AOGCM). The CO(2)-related reduction in plant water demand lowers the risk of die-back and can lead to possible niche expansion in many regions. The analysis presented here focuses primarily on hydrological determinants of HTF extent. We conclude by discussing the role of other factors, notably the physiological effect of higher temperature.

Zepp, R. G., T. V. Callaghan, et al. (2003). "Interactive effects of ozone depletion and climate change on biogeochemical cycles" Photochemical & Photobiological Sciences **2**: 51-51 DOI: 10.1039/b211154n

Open Access Article* Available at: http://xlink.rsc.org/?DOI=b211154n

The effects of ozone depletion on global biogeochemical cycles, via increased UV-B radiation at the Earth's surface, have continued to be documented over the past 4 years. In this report we also document various effects of UV-B that interact with global climate change because the detailed interactions between ozone depletion and climate change are central to the prediction and evaluation of future Earth environmental conditions. There is increasing evidence that elevated UV-B has significant effects on the terrestrial biosphere with important implications for the cycling of carbon, nitrogen and other elements. Increased UV has been shown to induce carbon monoxide production from dead plant matter in terrestrial ecosystems, nitrogen oxide production from Arctic and Antarctic snowpacks, and halogenated substances from several terrestrial ecosystems. New studies on UV effects on the decomposition of dead leaf material confirm that these effects are complex and species-specific. Decomposition can be retarded, accelerated or remain unchanged. It has been difficult to relate effects of UV on decomposition rates to leaf litter chemistry, as this is very variable. However, new evidence shows UV effects on some fungi, bacterial communities and soil fauna that could play roles in decomposition and nutrient cycling. An important new result is that not only is nitrogen cycling in soils perturbed significantly by increased UV-B, but that these effects persist for over a decade. As nitrogen cycling is temperature dependent, this finding clearly links the impacts of ozone depletion to the ability of plants to use nitrogen in a warming global environment. There are many other potential interactions between UV and climate change impacts on terrestrial biogeochemical cycles that remain to be quantified. There is also new evidence that UV-B strongly influences aquatic carbon, nitrogen, sulfur, and metals cycling that affect a wide range of life processes. UV-B accelerates the decomposition of colored dissolved organic matter (CDOM) entering the sea via terrestrial runoff, thus having important effects on oceanic carbon cycle dynamics. Since UV-B influences the distribution of CDOM, there is an impact of UV-B on estimates of oceanic productivity based on remote sensing of ocean color. Thus, oceanic productivity estimates based on remote sensing require estimates of CDOM distributions. Recent research shows that UV-B transforms dissolved organic matter to dissolved inorganic carbon and nitrogen, including carbon dioxide and ammonium and to organic substances that are either more or less readily available to micro-organisms. The extent of these transformations is correlated with loss of UV absorbance by the organic matter. Changes in aquatic primary productivity and decomposition due to climate-related changes in circulation and nutrient supply, which occur concurrently with increased UV-B exposure, have synergistic influences on the penetration of light into aquatic ecosystems. New research has confirmed that UV affects the biological availability of iron, copper and other trace metals in aquatic environments thus potentially affecting the growth of phytoplankton and other microorganisms that are involved in carbon and nitrogen cycling. There are several instances where UV-B modifies the air–sea exchange of trace gases that in turn alter atmospheric chemistry, including the carbon cycle.

Zhou, S. and P. C. Flynn (2005). "Geoengineering Downwelling Ocean Currents: A Cost Assessment." Climatic Change **71**: 203-220 DOI: 10.1007/s10584-005-5933-0

Available at: http://www.springerlink.com/index/10.1007/s10584-005-5933-0

Downwelling ocean currents carry carbon into the deep ocean (the solubility pump), and play a role in controlling the level of atmospheric carbon. The formation of North Atlantic Deep Water (NADW) also releases heat to the atmosphere, which is a contributor to a mild climate in Europe. One possible response to the increase in anthropogenic carbon in the atmosphere and to the possible weakening of the NADW is modification of downwelling ocean currents, by an increase in carbon concentration or volume. This study assesses the costs of seven possible methods of modifying downwelling currents, including using existing industrial techniques for exchange of heat between water and air. Increasing carbon concentration in downwelling currents is not practical due to the high degree of saturation of high latitude surface water. Two of the methods for increasing the volume of downwelling currents were found to be impractical, and four were too expensive to warrant further consideration. Formation of thicker sea ice by pumping ocean water onto the surface of ice sheets is the least expensive of the methods identified for enhancing downwelling ocean currents. Modifying downwelling ocean currents is highly unlikely to ever be a competitive method of sequestering carbon in the deep ocean, but may find future application for climate modification.