Marine Science Review – 175

Climate and climate change

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In this review:

A. Recent articles – no abstract available

Cronin, T.M. and Walker, H.A. **Restoring coastal ecosystems and abrupt climate change.** *Climatic Change* 74(4): 369-376, 2006.

Anthes, R.A., Corell, R.W., Holland, G., Hurrell, J.W., MacCracken, M.C., and Trenberth, K.E. **Hurricanes and global warming—potential linkages and consequences.** *Bulletin of the American Meteorological Society* 87(5): 623-628, 2006.

Pielke, R., Landsea, C., Mayfield, M., Laver, J., and Pasch, R. **Reply to "Hurricanes and global warming—potential linkages and consequences".** *Bulletin of the American Meteorological Society* 87(5): 628-631, 2006.

Schiermeier, Q. **Arctic ecology: On thin ice.** *Nature* 441(7090): 146-147, 2006.

B. Recent publications available online

U.S. Energy Information Administration (EIA). 2006. **International Energy Outlook 2006**. EIA, U.S. Department of Energy, Washington, DC. 192pp.

Available at: www.eia.doe.gov/oiaf/ieo/index.html

Notes: The U.S. Energy Information Administration (EIA) projects a world energy demand that will increase 71 percent between 2003 to 2030 while energy-related carbon dioxide emissions will rise 75 percent. World oil use is projected to grow from 80 million barrels per day in 2003 to 118 million barrels per day in 2030. Annual world coal consumption is projected to increase from 5,440 million short tons in 2003 to 10,561 million short tons by 2030. Annual consumption of electricity generated from nuclear power worldwide is projected to increase from 2,523 billion kilowatt-hours in 2003 to 3,299 billion kilowatt-hours in 2030. The EIA states that the projections in this report are not statements of what will happen, but what might happen given the specific assumptions and methodologies used. These projections provide an objective, policy-neutral reference case that can be used to analyze international energy markets. As a policy-neutral data and analysis organization, EIA does not propose, advocate, or speculate on future legislative and regulatory changes. The projections are based on U.S. and foreign government laws effective as of January 1, 2006. Assuming fixed laws, even knowing that changes will occur, will naturally result in projections that differ from the final data. Models are abstractions of energy production and consumption activities, regulatory activities, and producer and consumer behavior. The forecasts are highly dependent on the data, analytical methodologies, model structures, and specific assumptions used in their development. Trends depicted in the analysis are indicative of tendencies in the real world rather than representations of specific real-world outcomes. Many events that shape energy markets are random and cannot be anticipated, and the content and timing of policy developments, as well as assumptions concerning future technology characteristics, demographics, and resource availability, are inherently uncertain.

US EPA. 2006. **Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990 – 2020**. Office of Atmospheric Programs, Climate Change Division, U.S. Environmental Protection Agency, Washington, DC. 266pp.

Available at: http://www.epa.gov/nonco2/econ-inv/pdfs/GreenhouseGasReport.pdf

Notes: The aim of this report is to provide historical and projected estimates of emissions of non-carbon dioxide (non-CO2) greenhouse gases (GHGs) from anthropogenic sources. The report provides a consistent and comprehensive estimate of non-CO2 greenhouse gases for over ninety individual countries and eight regions. The analysis provides information that can be used to understand national contributions of GHG emissions, historical progress on reductions, and mitigation opportunities. The gases included in this report are the direct GHGs—other than CO2 —covered by the United Nations Framework Convention on Climate Change (UNFCCC): methane (CH4), nitrous oxide (N2O), and the high global warming potential (high GWP) gases. The high GWP gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6). Compounds covered by the Montreal Protocol are not included in this report. Historical estimates are reported for 1990, 1995, and 2000 and projections of emissions are provided for 2005, 2010, 2015, and 2020. Projections reflect the currently achieved impact of sector specific climate policy programs, agreements, and measures that are already in place, but exclude GHG reductions due to additional planned activities whose impacts are less certain. The U.S. Environmental Protection Agency (EPA) collects emission estimates from publicly available nationally-prepared GHG reports that are prepared in a manner consistent with the *Revised 1996Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC Guidelines) (IPCC, 1997) and the IPCC Good Practice Guidance and Uncertainty Management in *National Greenhouse Gas Inventories* (IPCC Good Practice Guidance) (IPCC, 2000). If national estimates are not available, EPA estimates emissions in order to produce a complete inventory for the world. EPA's calculated emissions estimates are prepared in a consistent manner across all countries using IPCC default methodologies, international statistics for activity data, and the IPCC Tier 1 default emission factors.

Kleypas, J.A., Feely, R.A., Fabry, V.J., Langdon, C., Sabine, C.L., and Robbins, L.L. 2006. **Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research.** Report of a workshop held 18–20 April 2005, St. Petersburg, FL, sponsored by NSF, NOAA, and the U.S. Geological Survey. 88 pp.

Available at: http://www.isse.ucar.edu/florida/

Notes: The St. Petersburg Workshop was designed to take the next step toward understanding the response of marine calcification to increasing atmospheric CO2 concentration. The aims of the workshop were to summarize existing knowledge on the topic, reach a consensus on what the most pressing scientific issues are, and identify future research strategies for addressing these issues. Although workshop participants were drawn from a wide range of scientific disciplines, there was a clear convergence on the major scientific issues that should be pursued over the next 5–10 years. These include:
• Determine the calcification response to elevated CO2 in benthic calcifiers such as corals (including cold-water corals), coralline algae, foraminifera, molluscs, and echinoderms; and in planktonic calcifiers such as coccolithophores, foraminifera, and shelled pteropods;
• Discriminate the various mechanisms of calcification within calcifying groups, through physiological experiments, to better understand the cross-taxa range of responses to changing seawater chemistry;
• Determine the interactive effects of multiple variables that affect calcification and dissolution in organisms (saturation state, light, temperature, nutrients) through continued experimental studies on an expanded suite of calcifying groups;
• Establish clear links between laboratory experiments and the natural environment, by combining laboratory experiments with field studies;
• Characterize the diurnal and seasonal cycles of the carbonate system on coral reefs, including commitment to long-term monitoring of the system response to continued increases in CO2;
• In concert with above, monitor in situ calcification and dissolution in planktonic and benthic organisms, with better characterization of the key environmental controls on calcification;
• Incorporate ecological questions into observations and experiments; e.g., How does a change in calcification rate affect the ecology and survivorship of an organism? How will ecosystem functions differ between communities with and without calcifying species?
• Improve the accounting of coral reef and open ocean carbonate budgets through combined measurements of seawater chemistry, CaCO3 production, dissolution and accumulation, and, in near-shore environments, bioerosion and offshelf export of CaCO3;

• Quantify and parameterize the mechanisms that contribute to the carbonate system, through biogeochemical and ecological modeling, and apply such modeling to guide future sampling and experimental efforts;
• Develop protocols for the various methodologies used in seawater chemistry and calcification measurements.
Some of these research objectives require technological development, but others can be addressed immediately. While much work remains toward answering the fundamental question: "How will marine calcification rates respond to increasing atmospheric CO2 concentrations," we need to begin investigations that look forward to answering the question: "What are the consequences of reduced calcification in both planktonic and benthic calcifying communities and ecosystems?" We should not wait until we answer the former question before tackling the latter. This report is intended as a guide to program managers and researchers toward designing research projects that address these important questions. It is written with the detail and references needed to serve as a resource for researchers, including graduate students, who wish to tackle projects within the sometimes confusing topic of marine carbonate chemistry and calcification.

C. Recent articles with abstracts

Melloul, A. and Collin, M. **Hydrogeological changes in coastal aquifers due to sea level rise.** *Ocean and Coastal Management* 49(5-6): 281-297, 2006.

Notes: Global warming and climatic changes can lead to sea level rise (SLR) of dozens of cms over up-coming decades, along with groundwater permanent reserve losses (PRL). This study focuses on understanding the processes and estimating groundwater losses. A case study for such phenomena is Israel's Coastal aquifer. PRL estimation methodology is based upon a simple hydrogeological conceptual model. The results lead to estimation of two main components of an aquifer's PRL, and to key factors that can enhance or mitigate these losses. Such recommended measures as high-resolution topographic mapping and improved monitoring of sea level have been noted.

Chiba, S., Tadokoro, K., Sugisaki, H., and Saino, T. **Effects of decadal climate change on zooplankton over the last 50 years in the western subarctic North Pacific.** *Global Change Biology* 12(5): 907-920, 2006.

Notes: Decadal- to multi-decadal variations have been reported in many regional ecosystems in the North Pacific, resulting in an increasing demand to elucidate the link between long-term climatic forcing and marine ecosystems. We detected phenological and quantitative changes in the copepod community in response to the decadal climatic variation in the western subarctic North Pacific by analyzing the extensive zooplankton collection taken since the 1950s, the Odate Collection. Copepod species were classified into five seasonal groups depending on the timing of the annual peak in abundance. The abundance of the spring community gradually increased for the period 1960-2002. The spring-summer community also showed an increasing trend in May, but a decadal oscillation pattern of quasi-30-year cycles in July. Phenological changes coincided with the climate regime shift in the mid-1970s, indicated by the Pacific decadal oscillation index (PDO). After the regime shift, the timing of the peak abundance was delayed one month, from March-April to April-May, in the spring community, whereas it peaked earlier, from June-July to May-June, in the spring-summer community, resulting in an overlap of the high productivity period for the two communities in May. Wintertime cooling, followed by rapid summertime warming, was considered to be responsible for delayed initiation and early termination of the productive season after the mid-1970s. Another phenological shift, quite different from the previous decade, was observed in the mid-1990s, when warm winters followed by cool summers lengthened the productive season. The results suggest that climatic forcing with different decadal cycles may operate independently during winter-spring and spring-summer to create seasonal and interannual variations in hydrographic conditions; thus, combinations of these seasonal processes may determine the annual biological productivity.

Smith, J.R., Fong, P., and Ambrose, R.F. **Dramatic declines in mussel bed community diversity: Response to climate change?** *Ecology* 87(5): 1153-1161, 2006.

Notes: Mussel beds along the wave-exposed coast of the eastern North Pacific Ocean serve as an important habitat, harboring a high diversity of species. A comparison of California mussel bed community diversity in 2002 to historical data (1960s to 1970s) revealed large declines (mean loss 58.9%), including some declines > 141 species (~ 80% loss). Concurrent work

revealed inconsistent changes in mussel populations (biomass and bed thickness) along the California coast, suggesting that diversity declines may be related to large-scale processes rather than local habitat destruction. Potential factors causing declines in mussel community diversity are discussed, with regional climate change associated with the Pacific Decadal Oscillation and climate change-induced alterations of ecological interactions and biological processes suggested as likely causes. Although extensive literature has predicted the potential effects of climate change on global diversity, this study is one of the few examples of declines attributed to climate change.

Svensson, C.J., Johansson, E., and Aberg, P. **Competing species in a changing climate: effects of recruitment disturbances on two interacting barnacle species.** *Journal of Animal Ecology* 75(3): 765-776, 2006.

Notes: The climate is changing and data-based simulation models can be a valuable tool for predicting population response to such changes and investigate the mechanisms of population change. In this study, a data-based two-species matrix model was constructed to explore the possible effects of elevated sea surface temperature (i.e. climate change) on the interaction between open populations of the south Atlantic barnacle species *Chthamalus montagui* and the boreal species *Semibalanus balanoides* in the north-east Atlantic. First, the model was used to perform an elasticity analysis to determine the relative importance of recruitment and survival in the interaction. Further, three scenarios of changes in recruitment, related to climate change, were investigated with model simulations: (i) increased frequencies of low recruitment for *S. balanoides*; (ii) increased frequencies of high recruitment for *C. montagui*; (iii) a combination of (i) and (ii). Model simulations showed that in present environmental conditions, *S. balanoides* occupied most of the space and dominated the interaction through high recruitment and survival. These results matched independent field observations, which validated the model for further analyses. The elasticity analyses showed that although free space was available there was competition for space during recruitment intervals. It was also shown that both populations were sensitive to changes in recruitment. Introducing the three scenarios of recruitment disturbances led to large changes in species abundance and free space. The most significant changes were found when scenario (i) and (ii) were combined, producing a shift in species dynamics towards *C. montagui* dominance. This demonstrates that recruitment can be an important mechanism in the interaction between populations and that the population response to changes in recruitment depends on the added response of interacting species. In a more general context, this model shows that increased sea surface temperature could rapidly lead to increased competition from southern species at higher latitudes. This might accelerate the effects of climate change on the species distribution at these latitudes and eventually lead to changes in community dynamics on temperate and subarctic shores.

Allan, J.C. and Komar, P.D. **Climate controls on US West Coast erosion processes.** *Journal of Coastal Research* 22(3): 511-529, 2006.

Notes: Erosion along the West Coast of the United States is affected by climate controls that include a trend of increasing wave heights during at least the past 25 years that might be related to global warming and the El Nino Southern Oscillation (ENSO) range between El Ninos and La Ninas that affects both annual wave conditions and monthly mean water levels that raise tidal elevations. These processes are analyzed for sites from Washington to south-central California, revealing a latitude dependence of the individual processes and how their combinations affect total water levels at the shore, which is important to beach and property erosion. Particularly significant on the coast of the Pacific Northwest (Washington and Oregon) has been the progressive decadal increases in deep-water wave heights and periods, which have increased breaker heights and elevated storm wave runup levels on beaches. Along the entire West Coast, the annual variations in wave conditions above and below any progressive decadal increase are controlled by the North Pacific index (NPI), the atmospheric pressure difference between the Hawaiian High and Aleutian Low, and the ENSO range, as demonstrated by a strong correlation with the multivariate ENSO index (MEI), with the highest wave conditions occurring during El Ninos. In addition, the ENSO range is particularly important in controlling mean water levels, causing tides to reach their highest elevations during El Ninos, again shown by correlations with MEIs along the entire West Coast. With El Ninos producing increased deep-water wave heights, runup levels on beaches, and elevated tides, the total water levels at the shore from the combined processes are significantly higher compared with normal or La Nina years, resulting in episodes of major property erosion along the entire US West Coast.

Reiner, D.M., Curry, T.E., DeFigueiredo, M.A., Herzog, H. J., Ansolabehere, S.D., Itaoka, K., Johnsson, F., and Odenberger, M. **American exceptionalism? Similarities and differences in national attitudes toward energy policy and global**

warming. *Environmental Science and Technology* 40(7): 2093-2098, 2006.

Notes: Despite sharp differences in government policy, the views of the U.S. public on energy and global warming are remarkably similar to those in Sweden, Britain, and Japan. Americans do exhibit some differences, placing lower priority on the environment and global warming, and with fewer believing that "global warming has been established as a serious problem and immediate action is necessary". There also remains a small hard core of skeptics (< 10%) who do not believe in the science of climate change and the need for action, a group that is much smaller in the other countries surveyed. The similarities are, however, pervasive. Similar preferences are manifest across a wide range of technology and fuel choices, in support of renewables, in research priorities, in a basic understanding of which technologies produce or reduce carbon dioxide (or misunderstandings in the case of nuclear power), and in willingness to pay for solving global warming.

Sun, J.M. and Ariya, P.A. **Atmospheric organic and bio-aerosols as cloud condensation nuclei (CCN): A review.** *Atmospheric Environment* 40(5): 795-820, 2006.

Notes: Organic substances have been recognized as active cloud condensation and ice formation nuclei for several decades. In some regions of the world, these organic compounds (OC) consist predominantly of suspended matter mass, which can have local (e.g. toxicity, health hazards) and global (e.g. climate change) impacts. However, due to the complexity of their chemical nature, the significance of organic molecules in driving physical and chemical atmospheric processes is still very uncertain and poorly understood. The aim of this review paper is to assess the current state of knowledge regarding the role of organic aerosols (including bioaerosols) as cloud condensation nuclei (CCN), as well as to compare the existing theoretical and experimental data. It seems that classical Kohler theory does not adequately describe the hygroscopic behaviour of predominantly identified organic CCN such as pure dicarboxylic acid particles. Factors such as surface tension, impurities, volatility, morphology, contact angle, deliquescence, and the oxidation process should be considered in the theoretical prediction of the CCN ability of OC and the interpretation of experimental results. Major identified constituents of organic CCN, their main sources and their CCN properties will be herein reviewed. We will also discuss areas of uncertainty and expose key issues deserving of future research.

Dyson, T. **On development, demography and climate change: The end of the world as we know it?** *Population and Environment* 27(2): 117-149, 2005.

Notes: This paper comments on the issue of global warming and climate change, in an attempt to provide fresh perspective. Essentially, five main arguments are made. First, that the process of modern economic development has been based on the burning of fossil fuels, and that this will continue to apply for the foreseeable future. Second, that in large part due to momentum in economic and demographic processes, it is inevitable that there will be a major rise in atmospheric CO2 during the present century. Third, that available data on global temperatures suggest strongly that the coming warming will be appreciably faster than anything that humanity has experienced during historical times. Moreover, especially in a system that is being forced, the chance of an abrupt change in climate happening must be rated as fair. Fourth, that while it is impossible to attach precise probabilities to different scenarios, the range of plausible unpleasant climate outcomes seems at least as great as the range of more manageable ones. The consequences of future climate change may be considerable; indeed, they could be almost inconceivable - with several negative changes occurring simultaneously and to cumulative adverse effect. There is an urgent need to improve ways of thinking about what could happen. Fifth, the paper maintains that the human response to other difficult 'long' threats - such as that posed by HIV/AIDS - reveals a broadly analogous sequence of social reactions (e.g. denial, avoidance, recrimination) to that which is unfolding with respect to carbon emissions and climate change. Therefore the view expressed here is that major behavioral change to limit world carbon emissions is unlikely in the foreseeable future, and that the broad sway of future events is probably now set to run its course.

Haines, A., Kovats, R.S., Campbell-Lendrum, D., and Corvalan, C. **Climate change and human health: impacts, vulnerability, and mitigation.** *The Lancet* 367(9528): 2101-2109, 2006.

Notes: It is now widely accepted that climate change is occurring as a result of the accumulation of greenhouse gases in the atmosphere arising from the combustion of fossil fuels. Climate change may affect health through a range of pathways - e.g.,

as a result of increased frequency and intensity of heat waves, reduction in cold-related deaths, increased floods and droughts, changes in the distribution of vector-borne diseases, and effects on the risk of disasters and malnutrition. The overall balance of effects on health is likely to be negative and populations in low-income countries are likely to be particularly vulnerable to the adverse effects. The experience of the 2003 heat wave in Europe shows that high-income countries might also be adversely affected. Adaptation to climate change requires public-health strategies and improved surveillance. Mitigation of climate change by reducing the use of fossil fuels and increasing the use of a number of renewable energy technologies should improve health in the near term by reducing exposure to air pollution.

Unger, N., Shindell, D.T., Koch, D. M., Amann, M., Cofala, J., and Streets, D.G. **Influences of man-made emissions and climate changes on tropospheric ozone, methane, and sulfate at 2030 from a broad range of possible futures.** *Journal of Geophysical Research* 111(12): art. D12313, 2006.

Notes: We apply the Goddard Institute for Space Studies composition-climate model to an assessment of tropospheric O3, CH4, and sulfate at 2030. We compare four different anthropogenic emissions forecasts: A1B and B1 from the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios and Current Legislation (CLE) and Maximum Feasible Reduction (MFR) from the International Institute for Applied Systems Analysis. The projections encompass a wide range of possible man-made emissions changes. The A1B, B1, and CLE forecasts all suggest large increases in surface O3 and sulfate baseline pollution at tropical and subtropical latitudes, especially over the Indian subcontinent, where the pollution increases may be as large as 100%. The ranges of annual mean regional ground level O3 and sulfate changes across all scenarios are -10 to +30 ppbv and -1200 to +3000 pptv, respectively. Physical climate changes reduce future surface O3, but tend to increase ground level sulfate locally over North Africa because of an enhancement of aqueous-phase SO2 oxidation. For all examined future scenarios the combined sum of the CH4, O3, and sulfate radiative forcings is positive, even for the MFR scenario, because of the large reduction in sulfate. For A1B the forcings are as much as half of that of the preindustrial to present-day forcing for each species. For MFR the sign of the forcing for each species is reversed with respect to the other scenarios. At 2030, global changes in climate-sensitive natural emissions of CH4 from wetlands, NOx from lightning, and dimethyl sulfide from the ocean appear to be small (<5%).

Vecchi, G.A., Soden, B.J., Wittenberg, A.T., Held, I.M., Leetmaa, A., and Harrison, M.J. **Weakening of tropical Pacific atmospheric circulation due to anthropogenic forcing.** *Nature* 441(7089): 73-76, 2006.

Notes: Since the mid-nineteenth century the Earth's surface has warmed, and models indicate that human activities have caused part of the warming by altering the radiative balance of the atmosphere. Simple theories suggest that global warming will reduce the strength of the mean tropical atmospheric circulation. An important aspect of this tropical circulation is a large-scale zonal (east- west) overturning of air across the equatorial Pacific Ocean - driven by convection to the west and subsidence to the east - known as the Walker circulation. Here we explore changes in tropical Pacific circulation since the mid-nineteenth century using observations and a suite of global climate model experiments. Observed Indo-Pacific sea level pressure reveals a weakening of the Walker circulation. The size of this trend is consistent with theoretical predictions, is accurately reproduced by climate model simulations and, within the climate models, is largely due to anthropogenic forcing. The climate model indicates that the weakened surface winds have altered the thermal structure and circulation of the tropical Pacific Ocean. These results support model projections of further weakening of tropical atmospheric circulation during the twenty-first century.

Weatherhead, E.C. and Andersen, S.B. **The search for signs of recovery of the ozone layer.** *Nature* 441(7089): 39-45, 2006.

Notes: Evidence of mid-latitude ozone depletion and proof that the Antarctic ozone hole was caused by humans spurred policy makers from the late 1980s onwards to ratify the Montreal Protocol and subsequent treaties, legislating for reduced production of ozone-depleting substances. The case of anthropogenic ozone loss has often been cited since as a success story of international agreements in the regulation of environmental pollution. Although recent data suggest that total column ozone abundances have at least not decreased over the past eight years for most of the world, it is still uncertain whether this improvement is actually attributable to the observed decline in the amount of ozone-depleting substances in the Earth's

atmosphere. The high natural variability in ozone abundances, due in part to the solar cycle as well as changes in transport and temperature, could override the relatively small changes expected from the recent decrease in ozone-depleting substances. Whatever the benefits of the Montreal agreement, recovery of ozone is likely to occur in a different atmospheric environment, with changes expected in atmospheric transport, temperature and important trace gases. It is therefore unlikely that ozone will stabilize at levels observed before 1980, when a decline in ozone concentrations was first observed.

López-Urrutia, A., San Martin, E., Harris, R.P., and Irigoien, X. **Scaling the metabolic balance of the oceans.** *Proceedings of the National Academy of Sciences [USA]* 103(23): 8739-8744, 2006.

Notes: Oceanic communities are sources or sinks of CO2, depending on the balance between primary production and community respiration. The prediction of how global climate change will modify this metabolic balance of the oceans is limited by the lack of a comprehensive underlying theory. Here, we show that the balance between production and respiration is profoundly affected by environmental temperature. We extend the general metabolic theory of ecology to the production and respiration of oceanic communities and show that ecosystem rates can be reliably scaled from theoretical knowledge of organism physiology and measurement of population abundance. Our theory predicts that the differential temperature-dependence of respiration and photosynthesis at the organism level determines the response of the metabolic balance of the epipelagic ocean to changes in ambient temperature, a prediction that we support with empirical data over the global ocean. Furthermore, our model predicts that there will be a negative feedback of ocean communities to climate warming because they will capture less CO2 with a future increase in ocean temperature. This feedback of marine biota will further aggravate the anthropogenic effects on global warming.

Gilman, S.E., Wethey, D.S., and Helmuth, B. **Variation in the sensitivity of organismal body temperature to climate change over local and geographic scales.** *Proceedings of the National Academy of Sciences [USA]* 103(25): 9560-9565, 2006.

Notes: Global climate change is expected to have broad ecological consequences for species and communities. Attempts to forecast these consequences usually assume that changes in air or water temperature will translate into equivalent changes in a species' organismal body temperature. This simple change is unlikely because an organism's body temperature is determined by a complex series of interactions between the organism and its environment. Using a biophysical model, validated with 5 years of field observations, we examined the relationship between environmental temperature change and body temperature of the intertidal mussel *Mytilus californianus* over 1,600 km of its geographic distribution. We found that at all locations examined simulated changes in air or water temperature always produced less than equivalent changes in the daily maximum mussel body temperature. Moreover, the magnitude of body temperature change was highly variable, both within and among locations. A simulated 1°C increase in air or water temperature raised the maximum monthly average of daily body temperature maxima by 0.07-0.92°C, depending on the geographic location, vertical position, and temperature variable. We combined these sensitivities with predicted climate change for 2100 and calculated increases in monthly average maximum body temperature of 0.97-4.12°C, depending on location and climate change scenario. Thus geographic variation in body temperature sensitivity can modulate species' experiences of climate change and must be considered when predicting the biological consequences of climate change.

Torn, M.S. and Harte, J. **Missing feedbacks, asymmetric uncertainties, and the underestimation of future warming.** *Geophysical Research Letters* 33(10): art. L10703, 2006.

Notes: Historical evidence shows that atmospheric greenhouse gas (GhG) concentrations increase during periods of warming, implying a positive feedback to future climate change. We quantified this feedback for CO2 and CH4 by combining the mathematics of feedback with empirical ice-core information and general circulation model (GCM) climate sensitivity, finding that the warming of 1.5-4.5°C associated with anthropogenic doubling of CO2 is amplified to 1.6-6.0°C warming, with the uncertainty range deriving from GCM simulations and paleo temperature records. Thus, anthropogenic emissions result in higher final GhG concentrations, and therefore more warming, than would be predicted in the absence of this feedback. Moreover, a symmetrical uncertainty in any component of feedback, whether positive or negative, produces an asymmetrical distribution of expected temperatures skewed toward higher temperature. For both reasons, the omission of key positive feedbacks and asymmetrical uncertainty from feedbacks, it is likely that the future will be hotter than we think.

Scheffer, M., Brovkin, V., and Cox, P.M. **Positive feedback between global warming and atmospheric CO2 concentration inferred from past climate change.** *Geophysical Research Letters* 33(10): art. L10702, 2006.

Notes: There is good evidence that higher global temperatures will promote a rise of greenhouse gas levels, implying a positive feedback which will increase the effect of anthropogenic emissions on global temperatures. However, the magnitude of this effect predicted by the available models remains highly uncertain, due to the accumulation of uncertainties in the processes thought to be involved. Here we present an alternative way of estimating the magnitude of the feedback effect based on reconstructed past changes. Linking this information with the mid-range Intergovernmental Panel on Climate Change estimation of the greenhouse gas effect on temperature we suggest that the feedback of global temperature on atmospheric CO2 will promote warming by an extra 15-78% on a century-scale. This estimate may be conservative as we did not account for synergistic effects of likely temperature moderated increase in other greenhouse gases. Our semi-empirical approach independently supports process based simulations suggesting that feedback may cause a considerable boost in warming.

Thomas, R., Frederick, E., Krabill, W., Manizade, S., and Martin, C. **Progressive increase in ice loss from Greenland.** *Geophysical Research Letters* 33(10): art. L10503, 2006.

Notes: Laser altimeter measurements over Greenland show increasing thickening rates above 2000 m, reflecting increasing snowfall in a warming climate. But near-coastal thinning rates have increased substantially since the mid 1990s, and net mass loss more than doubled from an average of 4-50 Gt yr-1 between 1993/4 and 1998/9 to 57-105 Gt yr-1 between 1998/9 and 2004. This increasing trend is very similar to findings from independent mass-budget studies, but differs widely from ERS radar altimeter results. This may result from limitations associated with the large ERS footprint over sloping and undulating surfaces that typify fast, narrow glaciers where thinning is most pronounced.

Loáiciga, H.A. **Modern-age buildup of CO2 and its effects on seawater acidity and salinity.** *Geophysical Research Letters* 33(10): art. L10605, 2006.

Notes: The impacts of increases in atmospheric CO2 since the midst of the 18th century on average seawater salinity and acidity are evaluated. Assuming that the rise in the planetary mean surface temperature continues unabated, and that it eventually causes the melting of terrestrial ice and permanent snow, it is calculated that the average seawater salinity would be lowered not more than 0.61‰ from its current 35‰. It is also calculated -using an equilibrium model of aqueous carbonate species in seawater open to the atmosphere- that the increase in atmospheric CO2 from 280 ppmv (representative of 18th-century conditions) to 380 ppmv (representative of current conditions) raises the average seawater acidity approximately 0.09 pH units across the range of seawater temperature considered (0 to 30°C). A doubling of CO2 from 380 ppmv to 760 ppmv (the 2 × CO2 scenario) increases the seawater acidity approximately 0.19 pH units across the same range of seawater temperature. In the latter case, the predicted increase in acidity results in a pH within the water-quality limits for seawater of 6.5 and 8.5 and a change in pH less than 0.20 pH units. This paper's results concerning average seawater salinity and acidity show that, on a global scale and over the time scales considered (hundreds of years), there would not be accentuated changes in either seawater salinity or acidity from the observed or hypothesized rises in atmospheric CO2 concentrations.

Klotzbach, P.J. **Trends in global tropical cyclone activity over the past twenty years (1986-2005).** *Geophysical Research Letters* 33(10): art. L10805, 2006.

Notes: The recent destructive Atlantic hurricane seasons and several recent publications have sparked debate over whether warming tropical sea surface temperatures (SSTs) are causing more intense, longer-lived tropical cyclones. This paper investigates worldwide tropical cyclone frequency and intensity to determine trends in activity over the past twenty years during which there has been an approximate 0.2°-0.4°C warming of SSTs. The data indicate a large increasing trend in tropical cyclone intensity and longevity for the North Atlantic basin and a considerable decreasing trend for the Northeast Pacific. All other basins showed small trends, and there has been no significant change in global net tropical cyclone activity. There has

been a small increase in global Category 4-5 hurricanes from the period 1986-1995 to the period 1996-2005. Most of this increase is likely due to improved observational technology. These findings indicate that other important factors govern intensity and frequency of tropical cyclones besides SSTs.

Robson, J.I., Gohar, L.K., Hurley, M.D., Shine, K.P., and Wallington, T.J. **Revised IR spectrum, radiative efficiency and global warming potential of nitrogen trifluoride.** *Geophysical Research Letters* 33(10): art. L10817, 2006.

Notes: Nitrogen trifluoride (NF3) is an industrial gas used in the semiconductor industry as a plasma etchant and chamber cleaning gas. NF3 is an alternative to other potent greenhouse gases and its usage has increased markedly over the last decade. In recognition of its increased relevance and to aid planning of future usage we report an updated radiative efficiency and global warming potentials for NF3. Laboratory measurements give an integrated absorption cross section of 7.04 × 10-17 cm2 molecule-1 cm-1 over the spectral region 200-2000 cm-1. The radiative efficiency is calculated to be 0.21 Wm-2 ppbv-1 and the 100 year GWP, relative to carbon dioxide, is 17200. These values are approximately 60% higher than previously published estimates, primarily reflecting the higher infrared absorption cross-sections reported here.

Keith, D.W., Ha-Duong, M., and Stolaroff, J.K. **Climate strategy with CO2 capture from the air.** *Climatic Change* 74(1-3): 17-45, 2006.

Notes: It is physically possible to capture CO2 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.

Azar, C., Lindgren, K., Larson, E., and Mollersten, K. **Carbon capture and storage from fossil fuels and biomass - Costs and potential role in stabilizing the atmosphere.** *Climatic Change* 74(1-3): 47-79, 2006.

Notes: The capture and storage of CO2 from combustion of fossil fuels is gaining attraction as a means to deal with climate change. CO2 emissions from biomass conversion processes can also be captured. If that is done, biomass energy with CO2 capture and storage (BECS) would become a technology that removes CO2 from the atmosphere and at the same time deliver CO2-neutral energy carriers (heat, electricity or hydrogen) to society. Here we present estimates of the costs and conversion efficiency of electricity, hydrogen and heat generation from fossil fuels and biomass with CO2 capture and storage. We then insert these technology characteristics into a global energy and transportation model (GET 5.0), and calculate costs of stabilizing atmospheric CO2 concentration at 350 and 450 ppm. We find that carbon capture and storage technologies applied to fossil fuels have the potential to reduce the cost of meeting the 350 ppm stabilisation targets by 50% compared to a case where these technologies are not available and by 80% when BECS is allowed. For the 450 ppm scenario, the reduction in costs is 40 and 42%, respectively. Thus, the difference in costs between cases where BECS technologies are allowed and where they are not is marginal for the 450 ppm stabilization target. It is for very low stabilization targets that negative emissions become warranted, and this makes BECS more valuable than in cases with higher stabilization targets. Systematic and stochastic sensitivity analysis is performed. Finally, BECS opens up the possibility to remove CO2 from the atmosphere. But this option should not be seen as an argument in favour of doing nothing about the climate problem now and then switching on this technology if climate change turns out to be a significant problem. It is not likely that BECS can be initiated sufficiently rapidly at a sufficient scale to follow this path to avoiding abrupt and serious climate changes if that would happen.

Litynski, J.T., Klara, S.M., McIlvried, H.G., and Srivastava, R.D. **An overview of terrestrial sequestration of carbon dioxide: The United States Department of Energy's fossil energy R&D program.** *Climatic Change* 74(1-3): 81-95, 2006.

Notes: Increasing concentrations of CO2 and other greenhouse gases (GHG) in the Earth's atmosphere have the potential to enhance the natural greenhouse effect, which may result in climatic changes. The main anthropogenic contributors to this increase are fossil fuel combustion, land use conversion, and soil cultivation. It is clear that overcoming the challenge of global climate change will require a combination of approaches, including increased energy efficiency, energy conservation, alternative energy sources, and carbon (C) capture and sequestration. The United States Department of Energy (DOE) is sponsoring the development of new technologies that can provide energy and promote economic prosperity while reducing GHG emissions. One option that can contribute to achieving this goal is the capture and sequestration of CO2 in geologic formations. An alternative approach is C sequestration in terrestrial ecosystems through natural processes. Enhancing such natural pools (known as natural sequestration) can make a significant contribution to CO2 management strategies with the potential to sequester about 290 Tg C/ y in U.S. soils. In addition to soils, there is also a large potential for C sequestration in above and belowground biomass in forest ecosystems. A major area of interest to DOE's fossil energy program is reclaimed mined lands, of which there may be 0.63 x10(6) ha in the U.S. These areas are essentially devoid of soil C; therefore, they provide an excellent opportunity to sequester C in both soils and vegetation. Measurement of C in these ecosystems requires the development of new technology and protocols that are accurate and economically viable. Field demonstrations are needed to accurately determine C sequestration potential and to demonstrate the ecological and aesthetic benefits in improved soil and water quality, increased biodiversity, and restored ecosystems. The DOE's research program in natural sequestration highlights fundamental and applied studies, such as the development of measurement, monitoring, and verification technologies and protocols and field tests aimed at developing techniques for maximizing the productivity of hitherto infertile soils and degraded ecosystems.

Gough, C. and Shackley, S. **Towards a multi-criteria methodology for assessment of geological carbon storage options.** *Climatic Change* 74(1-3): 141-174, 2006.

Notes: Carbon capture and storage (CCS) could achieve drastic cuts in the CO2 emissions associated with fossil fuels in the near to medium term and has been promoted as a significant climate change mitigation option. As the profile of this family of technologies grows rapidly, there remain many uncertainties relating to its viability, effectiveness and desirability. In this paper we begin to map out some of the key issues associated with CCS, using a multi-criteria approach to explore how an (admittedly small) selection of stakeholders perceive alternative storage options and energy scenarios. We present five long-term scenarios describing alternative ways in which the UK energy system could develop and which deploy different levels of carbon storage. The key storage options considered are oil and gas fields (both disused and with enhanced oil recovery), traps in saline aquifers, saline aquifers outside traps and on-shore sites. The relative performance of the scenarios and the storage reservoirs included within them have been assessed against a set of socio-economic, technical and environmental criteria by a small selection of stakeholders to the carbon storage debate. Whilst we cannot make strong conclusions regarding precise stakeholder opinions at this stage due to the small size of the sample, the broad delineation of the arguments for and against CCS are evident. Multi-criteria assessment (MCA) appears to hold much potential as a useful tool for characterising and better understanding differences in stakeholder assessments of CCS and its implications, and for identifying options around which greater consensus on the desirability (or otherwise) of CCS as a mitigation strategy might emerge.

Damen, K., Faaij, A., and Turkenburg, W. **Health, safety and environmental risks of underground CO2 storage - Overview of mechanisms and current knowledge.** *Climatic Change* 74(1-3): 289-318, 2006.

Notes: CO2 capture and storage (CCS) in geological reservoirs may be part of a strategy to reduce global anthropogenic CO2 emissions. Insight in the risks associated with underground CO2 storage is needed to ensure that it can be applied as safe and effective greenhouse mitigation option. This paper aims to give an overview of the current (gaps in) knowledge of risks associated with underground CO2 storage and research areas that need to be addressed to increase our understanding in those risks. Risks caused by a failure in surface installations are understood and can be minimised by risk abatement technologies and safety measures. The risks caused by underground CO2 storage (CO2 and CH4 leakage, seismicity, ground movement and brine displacement) are less well understood. Main R&D objective is to determine the processes controlling leakage

through/along wells, faults and fractures to assess leakage rates and to assess the effects on (marine) ecosystems. Although R&D activities currently being undertaken are working on these issues, it is expected that further demonstration projects and experimental work is needed to provide data for more thorough risk assessment.

Schuiling, R.D. and Krijgsman, P. **Enhanced weathering: An effective and cheap tool to sequester CO2.** *Climatic Change* 74(1-3): 349-354, 2006.

Notes: Weathering and subsequent precipitation of Ca- and Mg-carbonates are the main processes that control the CO2-concentration in the atmosphere. It seems logical, therefore, to use enhanced weathering as a tool to reduce rising CO2-levels. This can be applied as a technology, by reacting captured CO2 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 CO2-levels of the atmosphere will be adopted more readily if they also serve some broader economic goals. An effective strategy for CO2 control will require many parallel approaches simultaneously.

Hare, B. and Meinshausen, M. **How much warming are we committed to and how much can be avoided?** *Climatic Change* 75(1-2): 111-149, 2006.

Notes: This paper examines different concepts of a 'warming commitment' which is often used in various ways to describe or imply that a certain level of warming is irrevocably committed to over time frames such as the next 50 to 100 years, or longer. We review and quantify four different concepts, namely (1) a 'constant emission warming commitment', (2) a 'present forcing warming commitment', (3) a 'zero emission (geophysical) warming commitment' and (4) a 'feasible scenario warming commitment'. While a 'feasible scenario warming commitment' is probably the most relevant one for policy making, it depends centrally on key assumptions as to the technical, economic and political feasibility of future greenhouse gas emission reductions. This issue is of direct policy relevance when one considers that the 2002 global mean temperatures were 0.8 +/- 0.2ºC above the pre-industrial (1861-1890) mean and the European Union has a stated goal of limiting warming to 2ºC above the pre-industrial mean: What is the risk that we are committed to overshoot 2ºC? Using a simple climate model (MAGICC) for probabilistic computations based on the conventional IPCC uncertainty range for climate sensitivity (1.5 to 4.5ºC), we found that (1) a constant emission scenario is virtually certain to overshoot 2ºC with a central estimate of 2.0ºC by 2100 (4.2ºC by 2400). (2) For the present radiative forcing levels it seems unlikely that 2ºC are overshoot. (central warming estimate 1.1ºC by 2100 and 1.2ºC by 2400 with ~ 10% probability of overshooting 2ºC). However, the risk of overshooting is increasing rapidly if radiative forcing is stabilized much above 400 ppm CO2 equivalence (1.95 W/m²) in the long-term. (3) From a geophysical point of view, if all human-induced emissions were ceased tomorrow, it seems 'exceptionally unlikely' that 2ºC will be overshoot (central estimate: 0.7ºC by 2100; 0.4ºC by 2400). (4) Assuming future emissions according to the lower end of published mitigation scenarios (350 ppm CO(2)eq to 450 ppm CO(2)eq) provides the central temperature projections are 1.5 to 2.1ºC by 2100 (1.5 to 2.0ºC by 2400) with a risk of overshooting 2ºC between 10 and 50% by 2100 and 1-32% in equilibrium. Furthermore, we quantify the 'avoidable warming' to be 0.16-0.26ºC for every 100 GtC of avoided CO2 emissions - based on a range of published mitigation scenarios.
