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Marine Science Review – 201

Climate and climate change

SeaWeb
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In this review:

A. Recent articles – no abstract available

Shinnar, R. and Citro, F. **A road map to US decarbonization.** *Science* 313(5791): 1243-1244, 2006.

Doney, S.C. **Plankton in a warmer world.** *Nature* 444(7120): 695-696, 2006.

Ruttimann, J. **Sick seas.** *Nature* 442(7106): 978-980, 2006.

B. Recent articles with abstracts

Solomon, S., Portmann, R.W., and Thompson, D.W.J. **Contrasts between Antarctic and Arctic ozone depletion.** *Proceedings of the National Academy of Sciences [USA]* 104(2): 445-449, 2007.

Notes: This work surveys the depth and character of ozone depletion in the Antarctic and Arctic using available long balloon-borne and ground-based records that cover multiple decades from ground-based sites. Such data reveal changes in the range of ozone values including the extremes observed as polar air passes over the stations. Antarctic ozone observations reveal widespread and massive local depletion in the heart of the ozone "hole" region near 18 km, frequently exceeding 90%. Although some ozone losses are apparent in the Arctic during particular years, the depth of the ozone losses in the Arctic are considerably smaller, and their occurrence is far less frequent. Many Antarctic total integrated column ozone observations in spring since approximately the 1980s show values considerably below those ever observed in earlier decades. For the Arctic, there is evidence of some spring season depletion of total ozone at particular stations, but the changes are much less pronounced compared with the range of past data. Thus, the observations demonstrate that the widespread and deep ozone depletion that characterizes the Antarctic ozone hole is a unique feature on the planet.

Clarke, A., Murphy, E.J., Meredith, M.P., King, J.C., Peck, L.S., Barnes, D.K.A., and Smith, R.C. **Climate change and the marine ecosystem of the western Antarctic Peninsula.** *Philosophical Transactions of the Royal Society of London [B]* 362(1477): 149-166, 2007.

Notes: The Antarctic Peninsula is experiencing one of the fastest rates of regional climate change on Earth, resulting in the collapse of ice shelves, the retreat of glaciers and the exposure of new terrestrial habitat. In the nearby oceanic system, winter sea ice in the Bellingshausen and Amundsen seas has decreased in extent by 10% per decade, and shortened in seasonal duration. Surface waters have warmed by more than 1K since the 1950s, and the Circumpolar Deep Water (CDW) of the Antarctic Circumpolar Current has also warmed. Of the changes observed in the marine ecosystem of the western Antarctic Peninsula (WAP) region to date, alterations in winter sea ice dynamics are the most likely to have had a direct impact on the marine fauna, principally through shifts in the extent and timing of habitat for ice-associated biota. Warming of seawater at depths below *ca* 100m has yet to reach the levels that are biologically significant. Continued warming, or a change in the frequency of the flooding of CDW onto the WAP continental shelf may, however, induce sublethal effects that influence

ecological interactions and hence food-web operation. The best evidence for recent changes in the ecosystem may come from organisms which record aspects of their population dynamics in their skeleton (such as molluscs or brachiopods) or where ecological interactions are preserved (such as in encrusting biota of hard substrata). In addition, a southwards shift of marine isotherms may induce a parallel migration of some taxa similar to that observed on land. The complexity of the Southern Ocean food web and the nonlinear nature of many interactions mean that predictions based on short-term studies of a small number of species are likely to be misleading.

Helmuth, B., Broitman, B.R., Blanchette, C.A., Gilman, S., Halpin, P., Harley, C.D.G., O'Donnell, M.J., Hofmann, G.E., Menge, B., and Strickland, D. **Mosaic patterns of thermal stress in the rocky intertidal zone: Implications for climate change.** *Ecological Monographs* 76(4): 461-479, 2006.

Notes: We explicitly quantified spatial and temporal patterns in the body temperature of an ecologically important species of intertidal invertebrate, the mussel *Mytilus californianus*, along the majority of its latitudinal range from Washington to southern California, USA. Using long-term (five years), high-frequency temperature records recorded at multiple sites, we tested the hypothesis that local "modifying factors" such as the timing of low tide in summer can lead to large-scale geographic mosaics of body temperature. Our results show that patterns of body temperature during aerial exposure at low tide vary in physiologically meaningful and often counterintuitive ways over large sections of this species' geographic range. We evaluated the spatial correlations among sites to explore how body temperatures change along the latitudinal gradient, and these analyses show that "hot spots" and "cold spots" exist where temperatures are hotter or colder than expected based on latitude. We identified four major hot spots and four cold spots along the entire geographic gradient with at least one hot spot and one cold spot in each of the three regions examined (Washington-Oregon, Central California, and Southern California). Temporal autocorrelation analysis of year-to-year consistency and temporal predictability in the mussel body temperatures revealed that southern animals experience higher levels of predictability in thermal signals than northern animals. We also explored the role of wave splash at a subset of sites and found that, while average daily temperature extremes varied between sites with different levels of wave splash, yearly extreme temperatures were often similar, as were patterns of predictability. Our results suggest that regional patterns of tidal regime and local pattern of wave splash can overwhelm those of large-scale climate in driving patterns of body temperature, leading to complex thermal mosaics of temperature rather than simple latitudinal gradients. A narrow focus on population changes only at range margins may overlook climatically forced local extinctions and other population changes at sites well within a species range. Our results emphasize the importance of quantitatively examining biogeographic patterns in environmental variables at scales relevant to organisms, and in forecasting the impacts of changes in climate across species ranges.

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di Prisco, G. and Verde, C. **Predicting the impacts of climate change on the evolutionary adaptations of polar fish.** *Reviews in Environmental Science and Biotechnology* 5(2-3): 309-321, 2006.

Notes: The recognition of the important role of the polar habitats in global climate changes has awakened great interest in the evolutionary biology of the organisms that live there, as well as the increasing threat of loss of biological diversity and depletion of marine fisheries. These organisms are exposed to strong environmental constraints, and it is important to understand how they have adapted to cope with these challenges and to what extent adaptations may be upset by current climate changes. Adaptations of the dominant group of Antarctic fish, the suborder Notothenioidei, have been thoroughly investigated by several teams. Considering the amount of information available on cold adaptation, the study of fish adapted to the extreme conditions of the polar seas will allow us to gain invaluable clues on the development, impact and consequences of climate and anthropogenic challenges, with powerful implications for the future of the Earth.

Staehr, P.A. and Birkeland, M.J. **Temperature acclimation of growth, photosynthesis and respiration in two mesophilic phytoplankton species.** *Phycologia* 45(6): 648-656, 2006.

Notes: Temperature acclimation in two mesophilic microalgae, *Microcystis aeruginosa* (Cyanobacteriales) and *Scenedesmus acutus* (Chlorococcales), was studied by measuring growth rate, photosynthesis, respiration, cell size, cellular pigment content and Chl *a*-specific light absorption. Phytoplankton were grown as nutrient-replete semicontinuous cultures for 2 weeks at 5, 15 and 25ºC, during which growth rate was determined from changes in Chl *a*. Gross photosynthesis (*GP*) was measured as ^{14}C

assimilation at saturating light and respiration (*R*) was measured as O-2 uptake along a temperature gradient from 0 to 40ºC. Net photosynthesis (*NP*) was determined as the difference between *GP* and *R*. For both species, acclimation to increasing growth temperatures resulted in increasing growth rate, cellular pigment content and decreasing cell size and Chl *a*-specific light absorption. *Scenedesmus acutus* and *M. aeruginosa* showed the same overall pattern of metabolic acclimation to increasing temperatures: (1) overall higher *GP* and *NP* but lower *R*; (2) increasing optimum temperatures for *GP*, *NP* and *R* and (3) higher metabolic rates at supraoptimal temperatures. *Microcystis aeruginosa* showed several warm-loving traits. It was more sensitive to increasing temperatures (higher Q_{10} values), had higher metabolic rates and optimum temperatures and performed better at high incubation temperatures than *S. acutus* did. This study shows that phytoplankton have a considerable and rapid ability to adjust cellular physiology, metabolism and growth to relatively large changes in growth temperature. This suggests a significant ability to acclimate to increasing temperatures associated with forthcoming climate changes.

Thomas, C.D., Franco, A.M.A., and Hill, J.K. **Range retractions and extinction in the face of climate warming.** *Trends in Ecology and Evolution* 21(8): 415-416, 2006.

Notes: Until recently, published evidence for the responses of species to climate change had revealed more examples of species expanding than retracting their distributions. However, recent papers on butterflies and frogs now show that population-level and species-level extinctions are occurring. The relative lack of previous information about range retractions and extinctions appears to stem, at least partly, from a failure to survey the distributions of species at sufficiently fine resolution to detect declines, and from a failure to attribute such declines to climate change. The new evidence suggests that climate-driven extinctions and range retractions are already widespread.

Sabates, A., Martin, P., Lloret, J., and Raya, V. **Sea warming and fish distribution: the case of the small pelagic fish, *Sardinella aurita*, in the western Mediterranean.** *Global Change Biology* 12(11): 2209-2219, 2006.

Notes: This study analyses the temporal and spatial changes in abundance and distribution of the warm water species round sardinella (*Sardinella aurita*) in the western Mediterranean over the last decades in relation to sea water temperature. In the western Mediterranean basin (1950-2003), a significant positive relationship was found between round sardinella landings and temperature anomalies. Along a latitudinal gradient off the Mediterranean Iberian coast (1989-2004), a gradual increase in species abundance was observed from south to north, with a certain time lag going northwards, associated with the increase in sea water temperature. The abundance of round sardinella in the two warmest and southernmost areas was positively and significantly correlated with sea surface temperature registered during the start of gonad maturation the previous year. In addition, the positive relationship established between water temperature and abundance of round sardinella in the coldest and northernmost study area demonstrates that there is a temperature limit for the distribution of this species in the western Mediterranean. In addition, this study analyses round sardinella larvae distribution and abundance in the summers of 2003 and 2004, and conducts a comparison with the situation 20 years ago (summer 1983). Results show a marked increase in larval abundance during the last decades and the present appearance of larvae in the northernmost study areas, where they did not occur 20 years ago. This indicates the successful reproduction of round sardinella in the northern part of the Mediterranean, where the species has expanded, confirming its establishment in the area.

Bischof, K., Gómez, I., Molis, M., Hanelt, D., Karsten, U., Lüder, U., Roleda, M.Y., Zacher, K., and Wiencke, C. **Ultraviolet radiation shapes seaweed communities.** *Reviews in Environmental Science and Biotechnology* 5(2-3): 141-166, 2006.

Notes: Stratospheric ozone depletion and the concomitant increase in irradiance of ultraviolet-B radiation (UVB) at the earth's surface represent major threats to terrestrial and aquatic ecosystems. In costal rocky shore environments, seaweeds constitute a group of organisms of particular significance to ecosystem function. Thus, impairment of seaweed performance by UVB-exposure may result in severe changes in the functioning of coastal ecosystems. Here we present our view on how UVB radiation affects seaweed physiology and ecology and, thus, shapes the coastal environment by affecting the spatial, species and functional structure of seaweed communities.

Shepherd, J.M. and Knutson, T. **The current debate on the linkage between global warming and hurricanes.** *Geography Compass* 1(1): 1-24, 2007.

Notes: Following Hurricane Katrina and the parade of storms that affected the conterminous United States in 2004-2005, the apparent recent increase in intense hurricane activity in the Atlantic basin, and the reported increases in recent decades in some hurricane intensity and duration measures in several basins have received considerable attention. An important ongoing avenue of investigation in the climate and meteorology research communities is to determine the relative roles of anthropogenic forcing (i.e., global warming) and natural variability in producing the observed recent increases in hurricane frequency in the Atlantic, as well as the reported increases of tropical cyclone activity measures in several other ocean basins. A survey of the existing literature shows that many types of data have been used to describe hurricane intensity, and not all records are of sufficient length to reliably identify historical trends. Additionally, there are concerns among researchers about possible effects of data inhomogeneities on the reported trends. Much of the current debate has focused on the relative roles of sea-surface temperatures or large-scale potential intensity versus the role of other environmental factors such as vertical wind shear in causing observed changes in hurricane statistics. Significantly more research - from observations, theory, and modeling - is needed to resolve the current debate around global warming and hurricanes.

Daniel, J.S., Velders, G.J.M., Solomon, S., McFarland, M., and Montzka, S.A. **Present and future sources and emissions of halocarbons: Toward new constraints.** *Journal of Geophysical Research* 112(D2): art. D02301, 2007.

Notes: Accurate chlorocarbon and bromocarbon mixing ratio projections are necessary to make accurate estimates of future stratospheric ozone depletion. As global production of ozone depleting substances (ODSs) continues to decline in response to the Montreal Protocol, the quantity of ODSs in existing products and equipment, referred to as "banks," has the potential to make an important contribution to future ODS emissions and the associated ozone depletion. Recently, large discrepancies between two approaches to estimating bank sizes have been reported for several ODSs (World Meteorological Organization (WMO), 2003; Intergovernmental Panel on Climate Change/Technology and Economic Assessment Panel (IPCC/TEAP), 2005). We analyze these bank differences for CFC-11 and CFC-12 and find that they are significant in terms of the amount of projected future ozone depletion, a finding that is also relevant to assessing the potential environmental benefits of recovering and destroying banked CFCs. We consider observed trends in atmospheric abundances and past production estimates of these chemicals to gain insight into the bank sizes and their roles as emission sources for the CFCs. If it is assumed that the rates of release from the banks have not increased over the last few years, a lower limit for the CFC-12 bank size in 2002 is approximately 500 kt, consistent with the recent bottom-up estimate of IPCC/TEAP (2005). The larger estimated CFC-11 and CFC-12 banks (IPCC/TEAP, 2005), if accurate, would lead to greater future emissions and, hence, to greater stratospheric chlorine abundances that can affect future ozone as compared to the smaller WMO (2003) banks.

Benedetti-Cecchi, L., Bertocci, I., Vaselli, S., and Maggi, E. **Temporal variance reverses the impact of high mean intensity of stress in climate change experiments.** *Ecology* 87(10): 2489-2499, 2006.

Notes: Extreme climate events produce simultaneous changes to the mean and to the variance of climatic variables over ecological time scales. While several studies have investigated how ecological systems respond to changes in mean values of climate variables, the combined effects of mean and variance are poorly understood. We examined the response of low-shore assemblages of algae and invertebrates of rocky seashores in the northwest Mediterranean to factorial manipulations of mean intensity and temporal variance of aerial exposure, a type of disturbance whose intensity and temporal patterning of occurrence are predicted to change with changing climate conditions. Effects of variance were often in the opposite direction of those elicited by changes in the mean. Increasing aerial exposure at regular intervals had negative effects both on diversity of assemblages and on percent cover of filamentous and coarsely branched algae, but greater temporal variance drastically reduced these effects. The opposite was observed for the abundance of barnacles and encrusting coralline algae, where high temporal variance of aerial exposure either reversed a positive effect of mean intensity (barnacles) or caused a negative effect that did not occur under low temporal variance (encrusting algae). These results provide the first experimental evidence that changes in mean intensity and temporal variance of climatic variables affect natural assemblages of species interactively, suggesting that high temporal variance may mitigate the ecological impacts of ongoing and predicted climate changes.

Litzow, M.A. **Climate regime shifts and community reorganization in the Gulf of Alaska: how do recent shifts compare with 1976/1977?** *ICES Journal of Marine Science* 63(8): 1386-1396, 2006.

Notes: Climate regime shifts have recently occurred in the North Pacific (1998-1999) and the Arctic (2000), but the nature of biological reaction to these events is poorly understood. An index of local climate (1960-2005), and data from commercial fishery catches (1960-2004) and from small-mesh trawl surveys (1972-2005) are used to assess the impacts of these climate events in the Subarctic Gulf of Alaska. Non-linear regression showed that survey catch composition strongly responded to local climate at lags of 2 and 4 years, providing evidence of rapid ecological response to climate change in the system. A sequential regime shift detection method identified rapid change in local climate, and in survey and commercial catches following the well-documented regime shift to a positive state of the Pacific Decadal Oscillation (PDO) in 1976/1977. However, the analysis failed to detect the 1998/1999 regime shift in local climate, or in survey or commercial catches. This result is consistent with the view that the 1998/1999 climate regime shift did not represent a reversion to a negative PDO state. Local temperature increased and local sea level pressure decreased in the Gulf of Alaska during the years 2001- 2005, consistent with anthropogenic warming and recent spatial reorganization in Arctic climate. There was no evidence of community reorganization following this climate event. Further observation will be required to evaluate the persistence of this new climate pattern, and the nature of community reaction to it.

Kirby, R.R., Johns, D.G., and Lindley, J.A. **Fathers in hot water: rising sea temperatures and a Northeastern Atlantic pipefish baby boom.** *Biology Letters* 2(4): 597-600, 2006.

Notes: We report unprecedented numbers of juvenile snake pipefish, *Entelurus aequoreus*, in continuous plankton records of the Northeastern Atlantic since 2002. Increased sea surface temperatures (SSTs) in the Northern Hemisphere, linked to global warming, are a likely cause. Analysis of a long-term time-series of SST data in the North-eastern Atlantic shows a rise in winter, spring and summer sea temperatures (January-September), when the eggs of *E. aqueoreus*, which are brooded by the male, are developing and the larvae are growing in plankton. From what is known of the reproductive biology of closely related species, we suggest that the increased abundance of larval and juvenile *E. aequoreus* in the plankton as far west as the Mid-Atlantic Ridge may reflect the impact of temperature on abundance, through its effects on the operational sex ratio and potential reproductive rate, the onset of the breeding season and juvenile survival in this sex role reversed fish.

Spreng, D., Marland, G., and Weinberg, A.M. **CO_2 capture and storage: Another Faustian Bargain?** *Energy Policy* 35(2): 850-854, 2007.

Notes: A quarter-century ago, one of us termed the use of nuclear energy a Faustian Bargain. In this paper, we discuss what a Faustian Bargain means, how the expression has been used in characterizing other technologies, and in what measure CO_2 capture and storage is a Faustian Bargain. If we are about to enter into another Faustian Bargain, we should understand the contract.

Bange, H.W. **Nitrous oxide and methane in European coastal waters.** *Estuarine, Coastal and Shelf Science* 70(3): 361-374, 2006.

Notes: Coastal areas such as continental shelves, estuaries, deltas, fjords and lagoons can release high amounts of nitrous oxide (N_2O) and methane (CH_4) to the atmosphere. However, estimates of trace gas emissions are often biased by incomplete spatial and temporal coverages. Based on a compilation of literature data, the distributions of N_2O and CH_4 in European coastal areas (i.e. Arctic Ocean, Baltic Sea, North Sea, northeastern Atlantic Ocean, Mediterranean Sea, Black Sea) were reviewed and their emissions to the atmosphere reassessed. Maximum N2O saturations were found in estuarine systems, whereas the shelf waters, which are not influenced by freshwater plumes, are close to equilibrium with the atmosphere. This implies that N_2O is mainly formed in estuarine systems. European coastal waters are a net source of N_2O to the atmosphere (0.33-0.67 Tg N $year^{-1}$) with the major contribution coming from estuarine/river systems and not from open shelf areas. European shelf areas contribute significantly (up to 26%) to the global oceanic N_2O emissions. CH_4 saturations show a high temporal and spatial variability with maximum values in estuarine/fjord systems. European coastal areas are a source of atmospheric CH_4 (0.35-0.75 Tg C $year^{-1}$) and contribute significantly to the overall global CH_4 oceanic emissions. However,

this estimate still seems to be a severe underestimation since CH_4 fluxes from estuaries and shallow seeps are not adequately represented. Future N_2O and CH_4 emissions from coastal areas strongly depend on the degree of eutrophication of coastal waters and might increase in the future.

Borges, A.V., Schiettecatte, L.S., Abril, G., Delille, B., and Gazeau, E. **Carbon dioxide in European coastal waters.** *Estuarine, Coastal and Shelf Science* 70(3): 375-387, 2006.

Notes: We compiled from literature annually integrated air-water fluxes of carbon dioxide (CO_2) computed from field measurements, in 20 coastal European environments that were gathered into 3 main ecosystems: inner estuaries, upwelling continental shelves and non-upwelling continental shelves. The comparison of annual cycles of the partial pressure of CO_2 (pCO_2) in 5 contrasting continental shelves provided insights into the biogeochemical drivers of the CO_2 fluxes. The latter were also investigated by comparing CO2 fluxes to net ecosystem (NEP) and net community production (NCP) in 3 contrasted coastal ecosystems. Air-water CO_2 fluxes were scaled at European regional level and compared to fluxes of atmospheric CO_2 in other aquatic and terrestrial compartments. Continental shelves are significant sinks for atmospheric CO_2 at an average rate of -1.9 molC m^2 yr^1 that scaled at European level corresponds to an absorption of atmospheric CO2 of -68.1 TgC yr^1. This sink is equivalent to the one reported for the terrestrial biosphere of -66.1 TgC yr^1, based on carbon-stock change models. Estuaries are significant sources of CO_2 to the atmosphere at an average rate of 49.9 molC m^2 yr^1 that is higher than the CO_2 emission to the atmosphere from rivers, streams and lakes. The scaled emission of CO_2 to the atmosphere from inner estuaries of about 67.0 TgC yr^1 would almost fully balance the sink of atmospheric CO_2 computed for continental shelves. However, the scaled emission of CO_2 from estuaries to the atmosphere is inconsistent with the potential emission of CO_2 based on the fate of river organic carbon during estuarine transit. This discrepancy is most probably due to the poorly constrained surface area estimate of inner estuaries.

Lund, D.C., Lynch-Stieglitz, J., and Curry, W.B. **Gulf Stream density structure and transport during the past millennium.** *Nature* 444(7119): 601-604, 2006.

Notes: The Gulf Stream transports approximately 31 Sv (1 Sv = 10^6 m^3 s^{-1}) of water and 1.3 x 10^{15} W of heat into the North Atlantic ocean. The possibility of abrupt changes in Gulf Stream heat transport is one of the key uncertainties in predictions of climate change for the coming centuries. Given the limited length of the instrumental record, our knowledge of Gulf Stream behaviour on long timescales must rely heavily on information from geologic archives. Here we use foraminifera from a suite of high-resolution sediment cores in the Florida Straits to show that the cross-current density gradient and vertical current shear of the Gulf Stream were systematically lower during the Little Ice Age (AD 1200 to 1850). We also estimate that Little Ice Age volume transport was ten per cent weaker than today's. The timing of reduced flow is consistent with temperature minima in several palaeoclimate records, implying that diminished oceanic heat transport may have contributed to Little Ice Age cooling in the North Atlantic. The interval of low flow also coincides with anomalously high Gulf Stream surface salinity, suggesting a tight linkage between the Atlantic Ocean circulation and hydrologic cycle during the past millennium.

Behrenfeld, M.J., O'Malley, R.T., Siegel, D.A., McClain, C.R., Sarmiento, J.L., Feldman, G.C., Milligan, A.J., Falkowski, P.G., Letelier, R.M., and Boss, E.S. **Climate-driven trends in contemporary ocean productivity.** *Nature* 444(7120): 752-755, 2006.

Notes: Contributing roughly half of the biosphere's net primary production (NPP), photosynthesis by oceanic phytoplankton is a vital link in the cycling of carbon between living and inorganic stocks. Each day, more than a hundred million tons of carbon in the form of CO_2 are fixed into organic material by these ubiquitous, microscopic plants of the upper ocean, and each day a similar amount of organic carbon is transferred into marine ecosystems by sinking and grazing. The distribution of phytoplankton biomass and NPP is defined by the availability of light and nutrients (nitrogen, phosphate, iron). These growth-limiting factors are in turn regulated by physical processes of ocean circulation, mixed-layer dynamics, upwelling, atmospheric dust deposition, and the solar cycle. Satellite measurements of ocean colour provide a means of quantifying ocean productivity on a global scale and linking its variability to environmental factors. Here we describe global ocean NPP changes detected from space over the past decade. The period is dominated by an initial increase in NPP of 1,930 teragrams of carbon a year (Tg C yr^{-1}), followed by a prolonged decrease averaging 190 Tg C yr^{-1}. These trends are driven by changes occurring in the

expansive stratified low-latitude oceans and are tightly coupled to coincident climate variability. This link between the physical environment and ocean biology functions through changes in upper-ocean temperature and stratification, which influence the availability of nutrients for phytoplankton growth. The observed reductions in ocean productivity during the recent post-1999 warming period provide insight on how future climate change can alter marine food webs

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Schneider, S.H. **Climate change: Do we know enough for policy action?** *Science and Engineering Ethics* 12(4): 607-636, 2006.

Notes: The climate change problem must be thought of in terms of risk, not certainty. There are many well-established elements of the problem that carry considerable confidence whereas some aspects are speculative. Therefore, the climate problem emerges not simply as a normal science research issue, but as a risk management policy debate as well. Descriptive science entails using empirical and theoretical methods to quantify the two factors that go into risk assessment: "What can happen?" and "What are the odds?" (Probability x Consequences). Policymakers should, in turn, take that information and use it to make value judgments about what is safe, what is dangerous, what is fair. To make these judgments, policymakers need to know the probabilities that experts assign to various possible outcomes in order to make risk management decisions to hedge against unsafe, dangerous and unfair outcomes. The climate debate needs to be reframed away from absolute costs - or benefits - into relative delay times to achieve specific caps or to avoid crossing specific agreed "dangerous" climate change thresholds. Even in most optimistic scenarios, CO_2 will stabilize at a much higher concentration than it has reached today, and temperature will rise accordingly. It will take even longer for sea level rise from thermal expansion and the melting of polar ice to occur, but what is most problematic is that how we handle our emissions now and in the next five decades preconditions the sustainability of the next millennium.

Mégie, G. **From stratospheric ozone to climate change: Historical perspective on precaution and scientific responsibility.** *Science and Engineering Ethics* 12(4): 596-606, 2006.

Notes: The issue of the impact of human activities on the stratospheric ozone layer emerged in the early 1970s. But international regulations to mitigate the most serious effects were not adopted until the mid-1980s. This case holds lessons for addressing more complex environmental problems. Concepts that should inform discussion include 'latency,' 'counter-factual scenario based on the Precautionary Principle,' 'inter-generational burden sharing,' and 'estimating global costs under factual and counter-factual regulatory scenarios.' Stringent regulations were adopted when large scientific uncertainty existed, and the environmental problem would have been prevented or more rapidly mitigated, at relatively modest incremental price, but for a time delay before more rigorous Precautionary measures were implemented. Will history repeat itself in the case of climate change?

Rignot, E. **Changes in ice dynamics and mass balance of the Antarctic ice sheet.** *Philosophical Transactions of the Royal Society of London [A]* 364(1844): 1637-1655, 2006.

Notes: The concept that the Antarctic ice sheet changes with eternal slowness has been challenged by recent observations from satellites. Pronounced regional warming in the Antarctic Peninsula triggered ice shelf collapse, which led to a 10-fold increase in glacier flow and rapid ice sheet retreat. This chain of events illustrated the vulnerability of ice shelves to climate warming and their buffering role on the mass balance of Antarctica. In West Antarctica, the Pine Island Bay sector is draining far more ice into the ocean than is stored upstream from snow accumulation. This sector could raise sea level by 1m and trigger widespread retreat of ice in West Antarctica. Pine Island Glacier accelerated 38% since 1975, and most of the speed up took place over the last decade. Its neighbour Thwaites Glacier is widening up and may double its width when its weakened eastern ice shelf breaks up. Widespread acceleration in this sector may be caused by glacier ungrounding from ice shelf melting by an ocean that has recently warmed by 0.3°C. In contrast, glaciers buffered from oceanic change by large ice shelves have only small contributions to sea level. In East Antarctica, many glaciers are close to a state of mass balance, but sectors grounded well below sea level, such as Cook Ice Shelf, Ninnis/Mertz, Frost and Totten glaciers, are thinning and losing mass. Hence, East Antarctica is not immune to changes.

Jacobs, S. **Observations of change in the Southern Ocean.** *Philosophical Transactions of the Royal Society of London [A]* 364(1844): 1657-1681, 2006.

Notes: The Southern Ocean has been in a state of disequilibrium with its atmosphere and cryosphere during recent decades. Ocean station and drifting float observations have revealed rising temperatures in the upper 3000m. Salinity has declined in intermediate waters and more rapidly in the sparsely sampled high latitudes. Dissolved oxygen levels may also have decreased, but measurement accuracy is inconsistent. Sea ice area increased from 1979 to 1998, particularly in the Ross Sea, while a decline in ice extent since the early 1970s has been led by the Amundsen-Bellingshausen sector. Fresher waters with lower oxygen isotope content on the Pacific-Antarctic continental shelf are consistent with increased melting of continental ice. Newly forming bottom water has become colder and less salty downstream from that region, but generally warmer in the Weddell Sea. Many ice shelves have retreated or thinned, but others have grown and no trend is apparent in the large iceberg calving rate. Warming and isotherm shoaling within the polar gyres may result in part from changes in the Southern Annular Mode, which could facilitate deep-water access to the continental shelves. Sea-level rise over the past half century has a strong eustatic component and has recently accelerated. Observations over longer periods and with better spatial coverage are needed to better understand the processes causing these changes and their links to the Antarctic ice sheet.

Gregory, J.M. and Huybrechts, P. **Ice-sheet contributions to future sea-level change.** *Philosophical Transactions of the Royal Society of London [A]* 364(1844): 1709-1731, 2006.

Notes: Accurate simulation of ice-sheet surface mass balance requires higher spatial resolution than is afforded by typical atmosphere-ocean general circulation models (AOGCMs), owing, in particular, to the need to resolve the narrow and steep margins where the majority of precipitation and ablation occurs. We have developed a method for calculating mass-balance changes by combining ice-sheet average time-series from AOGCM projections for future centuries, both with information from high-resolution climate models run for short periods and with a 20km ice-sheet mass-balance model. Antarctica contributes negatively to sea level on account of increased accumulation, while Greenland contributes positively because ablation increases more rapidly. The uncertainty in the results is about 20% for Antarctica and 35% for Greenland. Changes in ice-sheet topography and dynamics are not included, but we discuss their possible effects. For an annual- and area-average warming exceeding 4.5±0.9K in Greenland and 3.1±0.8K in the global average, the net surface mass balance of the Greenland ice sheet becomes negative, in which case it is likely that the ice sheet would eventually be eliminated, raising global-average sea level by 7m.

Mitchell, J.F.B., Lowe, J., Wood, R.A., and Vellinga, M. **Extreme events due to human-induced climate change.** *Philosophical Transactions of the Royal Society of London [A]* 364(1845): 2117-2133, 2006.

Notes: A recent assessment by the Intergovernmental Panel on Climate Change concluded that the Earth's climate would be 2-6°C warmer than in the pre-industrial era by the end of the twenty-first century, due to human-induced increases in greenhouse gases. In the absence of other changes, this would lead to the warmest period on Earth for at least the last 1000 years, and probably the last 100 000 years. The large-scale warming is expected to be accompanied by increased frequency and/or intensity of extreme events, such as heatwaves, heavy rainfall, storms and coastal flooding. There are also several possibilities that this large change could initiate nonlinear climate responses which lead to even more extreme and rapid (on the time-scale of decades) climate change, including the collapse of the ocean 'conveyor belt' circulation, the collapse of major ice sheets or the release of large amounts of methane in high latitudes leading to further global warming. Although these catastrophic events are much more speculative than the direct warming due to increased greenhouse gases, their potential impacts are great and therefore should be included in any risk assessment of the impacts of anthropogenic climate change.

Rennermalm, A.K., Wood, E.F., Déry, S.J., Weaver, A.J., and Eby, M. **Sensitivity of the thermohaline circulation to Arctic Ocean runoff.** *Geophysical Research Letters* 33(12): art. L12703, 2006.

Notes: Arctic Ocean river runoff increases over the 20th century raise concerns of the potential impact it may have on the thermohaline circulation (THC) and thus global climate. This study investigates how changes in Arctic river discharge may

control THC by a series of experiments with an intermediate complexity global climate model. The experiments show an inverse relationship between THC strength and changes to riverine freshwater discharge, similar to the response of THC to surface freshening of the North Atlantic. Arctic Ocean freshwater export and volume were more sensitive to river runoff than sea ice export. A strong linear relationship between the THC strength and the steric height gradient (depth integrated density anomaly and an important driver for the western boundary current) suggests that the Arctic freshwater pools and fluxes are very effective in translating changes in runoff to THC strength by regulating the ocean water density in the North Atlantic.

Fiore, A.M., Horowitz, L.W., Dlugokencky, E.J., and West, J.J. **Impact of meteorology and emissions on methane trends, 1990–2004.** *Geophysical Research Letters* 33(12): art. L12809, 2006.

Notes: Over the past century, atmospheric methane (CH_4) rose dramatically before leveling off in the late 1990s. The processes controlling this trend are poorly understood, limiting confidence in projections of future CH_4. The MOZART-2 global tropospheric chemistry model qualitatively captures the observed CH_4 trend (increasing in the early 1990s and then leveling off) with constant emissions. From 1991-1995 to 2000-2004, the CH_4 lifetime versus tropospheric OH decreases by 1.6%, reflecting increases in OH and temperature. The rise in OH stems from an increase in lightning NOx as parameterized in the model. A simulation including annually varying anthropogenic and wetland CH_4 emissions, as well as the changes in meteorology, best reproduces the observed CH_4 distribution, trend, and seasonal cycles. Projections of future CH_4 abundances should consider climate-driven changes in CH_4 sources and sinks.

Latif, M., Keenlyside, N., and Bader, J. **Tropical sea surface temperature, vertical wind shear, and hurricane development.** *Geophysical Research Letters* 34(1): art. L01710, 2007.

Notes: The anomalously strong hurricane activity in the Atlantic sector during the recent years led to a controversy about the impact of global warming on hurricane activity in the Atlantic sector. Here we show that the temperature difference between the tropical North Atlantic and the tropical Indian and Pacific Oceans (Indo-Pacific) is a key parameter in controlling the vertical wind shear over the Atlantic, an important quantity for hurricane activity. The stronger warming of the tropical North Atlantic relative to that of the Indo-Pacific during the most recent years drove reduced vertical wind shear over the Atlantic and is thus responsible for the strong hurricane activity observed. In 2006, however, the temperature difference between the tropical North Atlantic and the tropical Indian and Pacific Oceans is much reduced, which explains the relatively weak hurricane season.

Gouretski, V. and Koltermann, K.P. **How much is the ocean really warming?** *Geophysical Research Letters* 34(1): art. L01610, 2007.

Notes: We use a global hydrographic dataset to study the effect of instrument related biases on the estimates of long-term temperature changes in the global ocean since the 1950s. The largest discrepancies are found between the expendable bathythermographs (XBT) and bottle and CTD data, with XBT temperatures being positively biased by 0.2-0.4°C on average. Since the XBT data are the largest proportion of the dataset, this bias results in a significant World Ocean warming artefact when time periods before and after introduction of XBT are compared. Using bias-corrected XBT data we argue reduces the ocean heat content change since the 1950s by a factor of 0.62. Our estimate of the ocean heat content increase (0-3000 m) between 1957-66 and 1987-96 is $12.8 \cdot 10^{22}$ J. Because of imperfect sampling this estimate has an uncertainty of at least $8 \cdot 10^{22}$ J.

Portmann, R.W. and Solomon, S. **Indirect radiative forcing of the ozone layer during the 21st century.** *Geophysical Research Letters* 34(2): art. L02813, 2007.

Notes: The response of a coupled two-dimensional radiative-chemical-dynamical model to possible 21st century changes of the greenhouse gasses (GHGs) carbon dioxide, nitrous oxide and methane are explored using a range of IPCC marker scenarios of GHG emissions. The changes to the ozone layer caused by these GHGs are found to be relatively large (e.g., up to 5% global mean column ozone changes and 30% local changes for CO2 using the IPCC A2 scenario between 2000 and

2100) and the mechanisms for these changes are discussed. The ozone changes are compared to the recovery of ozone due to expected decreases in chlorine containing compounds. Since carbon dioxide, nitrous oxide, and methane affect ozone they induce an indirect radiative forcing in addition to their direct radiative forcing. These indirect radiative forcings are computed using a combination of accurate line-by-line and band radiative transfer models and are compared to the radiative forcing of ozone during the 1979-2000 time period. Although the changes in ozone are large at some altitudes over the 2000-2100 time horizon, the range of associated future indirect radiative forcings from ozone over the range of IPCC scenarios are found to be -0.1 to 0.1 W m^{-2}, which is small compared with the corresponding range of total direct radiative forcing of 2.2 to 6.2 W m^{-2} for these GHGs over this time horizon.
