June 2008

Marine Science Review – 257

Climate and climate change

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In this review:

A. Recent publications available online
B. Recent articles with abstracts

O/A denotes an open access article or journal

A. Recent publications available online

NSTC. 2008. ***Scientific Assessment of the Effects of Global Change on the United States.*** A Report of the Committee on Environment and Natural Resources, National Science and Technology Council. 261pp.

Available at: http://www.ostp.gov/galleries/NSTC%20Reports/Scientific%20Assessment%20FULL%20Report.pdf

Notes: This national scientific assessment integrates, evaluates, and interprets the findings of the U.S. Climate Change Science Program (CCSP) and draws from and synthesizes findings from previous assessments of the science, including reports and products by the Intergovernmental Panel on Climate Change (IPCC). It analyzes current trends in global change, both natural and human-induced, and it projects major trends for the future. It analyzes the effects of these changes on the natural environment, agriculture, water resources, social systems, energy production and use, transportation, and human health. It is intended to help inform discussion of the relevant issues by decisionmakers, stakeholders, and the public. As such, this report addresses the requirements for assessment in the Global Change Research Act of 1990. This assessment addresses not only climate change, but also other change in the global environment—including water resources, oceans, atmospheric chemistry, land productivity, and ecological systems—that may alter the capacity of Earth to sustain life. This broader set of changes is referred to as 'global change,' as defined in the Global Change Research Act. Over the past several years, our understanding of climate variability and change and our ability to estimate their future effects has improved significantly. The conclusions in this assessment build on the vast body of observations, modeling, decision support, and other types of activities conducted under the auspices of CCSP and from previous assessments of the science, including reports and products by the IPCC, CCSP, and others.

B. Recent articles with abstracts

Fu, F.X., Zhang, Y.H., Warner, M.E., Feng, Y.Y., Sun, J., and Hutchins, D.A. **A comparison of future increased CO_2 and temperature effects on sympatric *Heterosigma akashiwo* and *Prorocentrum minimum*.** *Harmful Algae* 7(1): 76-90, 2008.

Notes: Very little is known about how global anthropogenic changes will affect major harmful algal bloom groups. Shifts in the growth and physiology of HAB species like the raphidophyte *Heterosigma akashiwo* and the dinoflagellate *Prorocentrum minimum* due to rising CO_2 and temperature could alter their relative abundance and environmental impacts in estuaries where both form blooms, such as the Delaware Inland Bays (DIB). We grew semi-continuous cultures of sympatric DIB isolates of these two species under four conditions: (1) 20ºC and 375 ppm CO_2 (ambient control), (2) 20ºC and 750 ppm CO_2 (high CO_2), (3) 24ºC and 375 ppm CO_2 (high temperature), and (4) 24ºC and 750 ppm CO_2 (combined). Elevated CO_2 alone or in concert with temperature stimulated *Heterosigma* growth, but had no significant effect on *Prorocentrum* growth. P_{Bmax} (the

maximum biomass-normalized light-saturated carbon fixation rate) in *Heterosigma* was increased only by simultaneous CO_2 and temperature increases, whereas P_{Bmax} in *Prorocentrum* responded significantly to CO_2 enrichment, with or without increased temperature. CO_2 and temperature affected photosynthetic parameters α, Φ_{max}, E_k, and $\Delta F/F'_m$ in both species. Increased temperature decreased and increased the Chl *a* content of *Heterosigma* and *Prorocentrum*, respectively. CO_2 availability and temperature had pronounced effects on cellular quotas of C and N in *Heterosigma*, but not in *Prorocentrum*. Ratios of C:P and N:P increased with elevated carbon dioxide in *Heterosigma* but not in *Prorocentrum*. These changes in cellular nutrient quotas and ratios imply that *Heterosigma* could be more vulnerable to N limitation but less vulnerable to P-limitation than *Prorocentrum* under future environmental conditions. In general, *Heterosigma* growth and physiology showed a much greater positive response to elevated CO_2 and temperature compared to *Prorocentrum*, consistent with what is known about their respective carbon acquisition mechanisms. Hence, rising temperature and CO_2 either alone or in combination with other limiting factors could significantly alter the relative dominance of these two co-existing HAB species over the next century.

Crutzen, P.J., Mosier, A.R., Smith, K.A., and Winiwarter, W. **N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels.** *Atmospheric Chemistry and Physics* 8(2): 389-395, 2008. **O/A**

Notes: The relationship, on a global basis, between the amount of N fixed by chemical, biological or atmospheric processes entering the terrestrial biosphere, and the total emission of nitrous oxide (N_2O), has been re-examined, using known global atmospheric removal rates and concentration growth of N_2O as a proxy for overall emissions. For both the pre-industrial period and in recent times, after taking into account the large-scale changes in synthetic N fertiliser production, we find an overall conversion factor of 3-5% from newly fixed N to N_2O-N. We assume the same factor to be valid for biofuel production systems. It is covered only in part by the default conversion factor for "direct" emissions from agricultural crop lands (1%) estimated by IPCC (2006), and the default factors for the "indirect" emissions (following volatilization/deposition and leaching/runoff of N: 0.35-0.45%) cited therein. However, as we show in the paper, when additional emissions included in the IPCC methodology, e.g. those from livestock production, are included, the total may not be inconsistent with that given by our "topdown" method. When the extra N_2O emission from biofuel production is calculated in "CO_2-equivalent" global warming terms, and compared with the quasi-cooling effect of "saving" emissions of fossil fuel derived CO_2, the outcome is that the production of commonly used biofuels, such as biodiesel from rapeseed and bioethanol from corn (maize), depending on N fertilizer uptake efficiency by the plants, can contribute as much or more to global warming by N_2O emissions than cooling by fossil fuel savings. Crops with less N demand, such as grasses and woody coppice species, have more favourable climate impacts. This analysis only considers the conversion of biomass to biofuel. It does not take into account the use of fossil fuel on the farms and for fertilizer and pesticide production, but it also neglects the production of useful co-products. Both factors partially compensate each other. This needs to be analyzed in a full life cycle assessment.

Meier, W.N., Stroeve, J., and Fetterer, F. **Whither Arctic sea ice?: a clear signal regionally, seasonally, and extending beyond the satellite record.** *Annals of Glaciology* 46(1): 428-434, 2007.

Notes: The Arctic sea ice has been pointed to as one of the first and clearest indicators of climate change. Satellite passive microwave observations from 1979 through 2005 now indicate a significant -8.4 ± 1.5% decade^{-1} trend (99% confidence level) in September sea-ice extent, a larger trend than earlier estimates due to acceleration of the decline over the past 41 years. There are differences in regional trends, with some regions more stable than others; not all regional trends are significant. The largest trends tend to occur in months where melt is at or near its peak for a given region. A longer time series of September extents since 1953 was adjusted to correct biases and extended through 2005. The trend from the longer time series is -7.7 ± 0.6% decade^{-1} (99%), slightly less than from the satellite-derived data that begin in 1979, which is expected given the recent acceleration in the decline.

Barreiro, M., Fedorov, A., Pacanowski, R., and Philander, S.G. **Abrupt climate changes: How freshening of the northern Atlantic affects the thermohaline and wind-driven oceanic circulations.** *Annual Review of Earth and Planetary Sciences* 36: 33-58, 2008.

Notes: Leading hypotheses for abrupt climate changes are focused on the ocean response to a freshening of surface waters in the north Atlantic. The degree to which such a freshening affects the deep, slow thermohaline, rather than the shallow, swift,

wind-driven circulations of the ocean, and hence the degree to which that freshening affects climate in high rather than low latitudes, differ from model to model, depending on factors such as the treatment of diffusive processes in the oceans. Many comprehensive climate models are biased and confine the influence mainly to the thermohaline circulation and northern climates. Simulations of paleoclimates can provide valuable tests for the models, but only some of those climates provide sufficiently stringent tests to determine which models are realistic.

Hall, D.K., Williams, R.S., Luthcke, S.B., and Digirolamo, N.E. **Greenland ice sheet surface temperature, melt and mass loss: 2000-06.** *Journal of Glaciology* 54(184): 81-93, 2008.

Notes: A daily time series of 'clear-sky' surface temperature has been compiled of the Greenland ice sheet (GIS) using 1 km resolution moderate-resolution imaging spectroradiometer (MODIS) land-surface temperature (LST) maps from 2000 to 2006. We also used mass-concentration data from the Gravity Recovery and Climate Experiment (GRACE) to study mass change in relationship to surface melt from 2003 to 2006. The mean LST of the GIS increased during the study period by ~0.27°C a^{-1}. The increase was especially notable in the northern half of the ice sheet during the winter months. Melt-season length and timing were also studied in each of the six major drainage basins. Rapid (<15 days) and sustained mass loss below 2000 m elevation was triggered in 2004 and 2005 as recorded by GRACE when surface melt begins. Initiation of large-scale surface melt was followed rapidly by mass loss. This indicates that surface meltwater is flowing rapidly to the base of the ice sheet, causing acceleration of outlet glaciers, thus highlighting the metastability of parts of the GIS and the vulnerability of the ice sheet to air-temperature increases. If air temperatures continue to rise over Greenland, increased surface melt will play a large role in ice-sheet mass loss.

Emanuel, K., Sundararajan, R., and Williams, J. **Hurricanes and global warming: Results from downscaling IPCC AR4 simulations.** *Bulletin of the American Meteorological Society* 89(3): 347-367, 2008. **O/A**

Notes: A new technique for deriving hurricane climatologies from global data, applied to climate models, indicates that global warming should reduce the global frequency of hurricanes, though their intensity may increase in some locations. Changes in tropical cyclone activity are among the more potentially consequential results of global climate change, and it is therefore of considerable interest to understand how anthropogenic climate change may affect such storms. Global climate models are currently used to estimate future climate change, but the current generation of models lacks the horizontal resolution necessary to resolve the intense inner core of tropical cyclones. Here we review a new technique for inferring tropical cyclone climatology from the output of global models, extend it to predict genesis climatologies (rather than relying on historical climatology), and apply it to current and future climate states simulated by a suite of global models developed in support of the most recent Intergovernmental Panel on Climate Change report. This new technique attacks the horizontal resolution problem by using a specialized, coupled ocean-atmosphere hurricane model phrased in angular momentum coordinates, which provide a high resolution of the core at low cost. This model is run along each of 2,000 storm tracks generated using an advection-and-beta model, which is, in turn, driven by large-scale winds derived from the global models. In an extension to this method, tracks are initiated by randomly seeding large areas of the tropics with weak vortices and then allowing the intensity model to determine their survival, based on large-scale environmental conditions. We show that this method is largely successful in reproducing the observed seasonal cycle and interannual variability of tropical cyclones in the present climate, and that it is more modestly successful in simulating their spatial distribution. When applied to simulations of global climate with double the present concentration of carbon dioxide, this method predicts substantial changes and geographic shifts in tropical cyclone activity, but with much variation among the global climate models used. Basinwide power dissipation and storm intensity generally increase with global warming, but the results vary from model to model and from basin to basin. Storm frequency decreases in the Southern Hemisphere and north Indian Ocean, increases in the western North Pacific, and is indeterminate elsewhere. We demonstrate that in these simulations, the change in tropical cyclone activity is greatly influenced by the increasing difference between the moist entropy of the boundary layer and that of the middle troposphere as the climate warms.

Hiddink, J.G. and ter Hofstede, R. **Climate induced increases in species richness of marine fishes.** *Global Change Biology* 14(3): 453-460, 2008.

Notes: Climate change has been predicted to lead to changes in local and regional species richness through species extinctions and latitudinal ranges shifts. Here, we show that species richness of fish in the North Sea, a group of ecological and socio-economical importance, has increased over a 22-year period and that this rise is related to higher water temperatures. Over eight times more fish species displayed increased distribution ranges in the North Sea (mainly small-sized species of southerly origin) compared with those whose range decreased (primarily large and northerly species). This increase in species richness can be explained from the fact that fish species richness in general decreases with latitude. This observation confirms that the interaction between large-scale biogeographical patterns and climate change may lead to increasing species richness at temperate latitudes.

Hare, C.E., Leblanc, K., DiTullio, G.R., Kudela, R.M., Zhang, Y., Lee, P.A., Riseman, S., and Hutchins, D.A. **Consequences of increased temperature and CO_2 for phytoplankton community structure in the Bering Sea.** *Marine Ecology Progress Series* 352: 9-16, 2007.

Notes: Global climate change is predicted to have large effects on the ocean that could cause shifts in current algal community structure, major nutrient cycles, and carbon export. The Bering Sea is already experiencing changes in sea surface temperature (SST), unprecedented algal blooms, and alterations to trophic level dynamics. We incubated phytoplankton communities from 2 Bering Sea regimes under conditions of elevated SST and/or partial pressure of carbon dioxide (pCO_2) similar to predicted values for 2100. In our 'greenhouse ocean' simulations, maximum biomass-normalized photosynthetic rates increased 2.6 to 3.5 times and community composition shifted away from diatoms and towards nanophytoplankton. These changes were driven largely by elevated temperature, with secondary effects from increased pCO_2. If these results are indicative of future climate responses, community shifts towards nanophytoplankton dominance could reduce the ability of the Bering Sea to maintain the productive diatom-based food webs that currently support one of the world's most productive fisheries.

Saunders, M.A. and Lea, A.S. **Large contribution of sea surface warming to recent increase in Atlantic hurricane activity.** *Nature* 451(7178): 557-561, 2008.

Notes: Atlantic hurricane activity has increased significantly since 1995, but the underlying causes of this increase remain uncertain. It is widely thought that rising Atlantic sea surface temperatures have had a role in this, but the magnitude of this contribution is not known. Here we quantify this contribution for storms that formed in the tropical North Atlantic, Caribbean Sea and Gulf of Mexico; these regions together account for most of the hurricanes that make landfall in the United States. We show that a statistical model based on two environmental variables local sea surface temperature and an atmospheric wind field - can replicate a large proportion of the variance in tropical Atlantic hurricane frequency and activity between 1965 and 2005. We then remove the influence of the atmospheric wind field to assess the contribution of sea surface temperature. Our results indicate that the sensitivity of tropical Atlantic hurricane activity to August September sea surface temperature over the period we consider is such that a 0.5ºC increase in sea surface temperature is associated with a ~ 40% increase in hurricane frequency and activity. The results also indicate that local sea surface warming was responsible for ~ 40% of the increase in hurricane activity relative to the 1950-2000 average between 1996 and 2005. Our analysis does not identify whether warming induced by greenhouse gases contributed to the increase in hurricane activity, but the ability of climate models to reproduce the observed relationship between hurricanes and sea surface temperature will serve as a useful means of assessing whether they are likely to provide reliable projections of future changes in Atlantic hurricane activity.

Stott, P.A., Huntingford, C., Jones, C.D., and Kettleborough, J.A. **Observed climate change constrains the likelihood of extreme future global warming.** *Tellus B* 60(1): 76-81, 2008.

Notes: If cooling due to present-day levels of atmospheric aerosol is suppressing global temperatures, future reductions in aerosols emissions would allow the full greenhouse gas induced warming to be realised. The many uncertainties in aerosol physics and chemistry mean that a large range of present-day aerosol cooling is possible which could imply a large climate sensitivity, extremely large future warming and the increased risk of catastrophic consequences. Despite large uncertainties in aerosol physics and chemistry, observed spatial and temporal patterns of past temperature change allow quantitative assessment of the strength of present-day aerosol cooling. Such observational constraints provide a probabilistic framework in which to assess the likelihood of extremely large warming if a very large suppression of global warming by aerosols were to be

removed. The likelihoods of future warming extents are calculated assuming four scenarios of future anthropogenic emissions. While such results are still subject to uncertainty, they indicate that future warming by the end of the 21st century is likely to be between the extremes implied by very strong or very weak present-day aerosol cooling. It is very likely that present-day aerosol cooling is suppressing a major portion of current greenhouse warming.

Auffhammer, M. and Carson, R.T. **Forecasting the path of China's CO_2 emissions using province level information.** *Journal of Environmental Economics and Management* 55(3): 229-247, 2008.

Notes: Our results suggest that the anticipated path of China's carbon dioxide (CO_2) emissions has dramatically increased over the last five years. The magnitude of the projected increase in Chinese emissions out to 2010 is several times larger than reductions embodied in the Kyoto Protocol. Our estimates are based on a unique provincial-level panel data set from the Chinese Environmental Protection Agency. This data set contains considerably more information relevant to the path of likely Chinese greenhouse gas emissions than national level time series models currently in use. Model selection criteria clearly reject the popular static environmental Kuznets curve specification in favor of a class of dynamic models with spatial dependence.

Bradshaw, W.E. and Holzapfel, C.M. **Genetic response to rapid climate change: it's seasonal timing that matters.** *Molecular Ecology* 17(1): 157-166, 2008.

Notes: The primary nonbiological result of recent rapid climate change is warming winter temperatures, particularly at northern latitudes, leading to longer growing seasons and new seasonal exigencies and opportunities. Biological responses reflect selection due to the earlier arrival of spring, the later arrival of fall, or the increasing length of the growing season. Animals from rotifers to rodents use the high reliability of day length to time the seasonal transitions in their life histories that are crucial to fitness in temperate and polar environments: when to begin developing in the spring, when to reproduce, when to enter dormancy or when to migrate, thereby exploiting favourable temperatures and avoiding unfavourable temperatures. In documented cases of evolutionary (genetic) response to recent, rapid climate change, the role of day length (photoperiodism) ranges from causal to inhibitory; in no case has there been demonstrated a genetic shift in thermal optima or thermal tolerance. More effort should be made to explore the role of photoperiodism in genetic responses to climate change and to rule out the role of photoperiod in the timing of seasonal life histories before thermal adaptation is assumed to be the major evolutionary response to climate change.

Gienapp, P., Teplitsky, C., Alho, J.S., Mills, J.A., and Merila, J. **Climate change and evolution: disentangling environmental and genetic responses.** *Molecular Ecology* 17(1): 167-178, 2008.

Notes: Rapid climate change is likely to impose strong selection pressures on traits important for fitness, and therefore, microevolution in response to climate-mediated selection is potentially an important mechanism mitigating negative consequences of climate change. We reviewed the empirical evidence for recent microevolutionary responses to climate change in longitudinal studies emphasizing the following three perspectives emerging from the published data. First, although signatures of climate change are clearly visible in many ecological processes, similar examples of microevolutionary responses in literature are in fact very rare. Second, the quality of evidence for microevolutionary responses to climate change is far from satisfactory as the documented responses are often - if not typically - based on nongenetic data. We reinforce the view that it is as important to make the distinction between genetic (evolutionary) and phenotypic (includes a nongenetic, plastic component) responses clear, as it is to understand the relative roles of plasticity and genetics in adaptation to climate change. Third, in order to illustrate the difficulties and their potential ubiquity in detection of microevolution in response to natural selection, we reviewed the quantitative genetic studies on microevolutionary responses to natural selection in the context of long-term studies of vertebrates. The available evidence points to the overall conclusion that many responses perceived as adaptations to changing environmental conditions could be environmentally induced plastic responses rather than microevolutionary adaptations. Hence, clear-cut evidence indicating a significant role for evolutionary adaptation to ongoing climate warming is conspicuously scarce.

Rohling, E.J., Grant, K., Hemleben, Ch., Siddall, M., Hoogakker, B.A.A., Bolshaw, M., and Kucera, M. **High rates of sea-level rise during the last interglacial period.** *Nature Geoscience* 1(1): 38-42, 2008. O/A

Notes: The last interglacial period, Marine Isotope Stage (MIS) 5e, was characterized by global mean surface temperatures that were at least 2ºC warmer than present. Mean sea level stood 4-6m higher than modern sea level, with an important contribution from a reduction of the Greenland ice sheet. Although some fossil reef data indicate sea-level fluctuations of up to 10m around the mean, so far it has not been possible to constrain the duration and rates of change of these shorter-termvariations. Here, we use a combination of a continuous high-resolution sea level record, based on the stable oxygen isotopes of planktonic foraminifera from the central Red Sea, and age constraints from coral data to estimate rates of sea-level change during MIS-5e. We find average rates of sea-level rise of 1.6m per century. As global mean temperatures during MIS-5e were comparable to projections for future climate change under the influence of anthropogenic greenhouse-gas emissions, these observed rates of sea-level change inform the ongoing debate about high versus low rates of sea-level rise in the coming century.

Rignot, E., Bamber, J.L., van den Broeke, M.R., Davis, C., Li, Y., van de Berg, W.-J., and van Meijgaard, E. **Recent Antarctic ice mass loss from radar interferometry and regional climate modelling.** *Nature Geoscience* 1(2): 106-110, 2008.

Notes: Large uncertainties remain in the current and future contribution to sea level rise from Antarctica. Climate warming may increase snowfall in the continent's interior, but enhance glacier discharge at the coast where warmer air and ocean temperatures erode the buttressing ice shelves. Here, we use satellite interferometric synthetic-aperture radar observations from 1992 to 2006 covering 85% of Antarctica's coastline to estimate the total mass flux into the ocean. We compare the mass fluxes from large drainage basin units with interior snow accumulation calculated from a regional atmospheric climate model for 1980 to 2004. In East Antarctica, small glacier losses in Wilkes Land and glacier gains at the mouths of the Filchner and Ross ice shelves combine to a near-zero loss of 4 ± 61Gtyr^{-1}. In West Antarctica, widespread losses along the Bellingshausen and Amundsen seas increased the ice sheet loss by 59% in 10 years to reach 132 ± 60Gtyr^{-1} in 2006. In the Peninsula, losses increased by 140% to reach 60 ± 46Gtyr^{-1} in 2006. Losses are concentrated along narrow channels occupied by outlet glaciers and are caused by ongoing and past glacier acceleration. Changes in glacier flow therefore have a significant, if not dominant impact on ice sheet mass balance.

Ramanathan, V. and Carmichael, G. **Global and regional climate changes due to black carbon.** *Nature Geoscience* 1(4): 221-227, 2008. O/A

Notes: Black carbon in soot is the dominant absorber of visible solar radiation in the atmosphere. Anthropogenic sources of black carbon, although distributed globally, are most concentrated in the tropics where solar irradiance is highest. Black carbon is often transported over long distances, mixing with other aerosols along the way. The aerosol mix can form transcontinental plumes of atmospheric brown clouds, with vertical extents of 3 to 5 km. Because of the combination of high absorption, a regional distribution roughly aligned with solar irradiance, and the capacity to form widespread atmospheric brown clouds in a mixture with other aerosols, emissions of black carbon are the second strongest contribution to current global warming, after carbon dioxide emissions. In the Himalayan region, solar heating from black carbon at high elevations may be just as important as carbon dioxide in the melting of snowpacks and glaciers. The interception of solar radiation by atmospheric brown clouds leads to dimming at the Earth's surface with important implications for the hydrological cycle, and the deposition of black carbon darkens snow and ice surfaces, which can contribute to melting, in particular of Arctic sea ice.

Fuglestvedt, J., Berntsen, T., Myhre, G., Rypdal, K., and Skeie, R.B. **Climate forcing from the transport sectors.** *Proceedings of the National Academy of Sciences [USA]* 105(2): 454-458, 2008. O/A

Notes: Although the transport sector is responsible for a large and growing share of global emissions affecting climate, its overall contribution has not been quantified. We provide a comprehensive analysis of radiative forcing from the road transport, shipping, aviation, and rail subsectors, using both past- and forward-looking perspectives. We find that, since preindustrial times, transport has contributed 15% and 31% of the total man-made CO_2 and O_3 forcing, respectively. A forward-looking perspective shows that the current emissions from transport are responsible for 16% of the integrated net

forcing over 100 years from all current man-made emissions. The dominating contributor to positive forcing (warming) is CO_2, followed by tropospheric O_3. By subsector, road transport is the largest contributor to warming. The transport sector also exerts cooling through reduced methane lifetime and atmospheric aerosol effects. Shipping causes net cooling, except on future time scales of several centuries. Much of the forcing from transport comes from emissions not covered by the Kyoto Protocol.

Joos, F. and Spahni, R. **Rates of change in natural and anthropogenic radiative forcing over the past 20,000 years.** *Proceedings of the National Academy of Sciences [USA]* 105(5): 1425-1430, 2008.

Notes: The rate of change of climate codetermines the global warming impacts on natural and socioeconomic systems and their capabilities to adapt. Establishing past rates of climate change from temperature proxy data remains difficult given their limited spatiotemporal resolution. In contrast, past greenhouse gas radiative forcing, causing climate to change, is well known from ice cores. We compare rates of change of anthropogenic forcing with rates of natural greenhouse gas forcing since the Last Glacial Maximum and of solar and volcanic forcing of the last millennium. The smoothing of atmospheric variations by the enclosure process of air into ice is computed with a firn diffusion and enclosure model. The 20th century increase in CO_2 and its radiative forcing occurred more than an order of magnitude faster than any sustained change during the past 22,000 years. The average rate of increase in the radiative forcing not just from CO_2 but from the combination of CO_2, CH_4, and N_2O is larger during the Industrial Era than during any comparable period of at least the past 16,000 years. In addition, the decadal-to-century scale rate of change in anthropogenic forcing is unusually high in the context of the natural forcing variations (solar and volcanoes) of the past millennium. Our analysis implies that global climate change, which is anthropogenic in origin, is progressing at a speed that is unprecedented at least during the last 22,000 years.

Yasuhara, M., Cronin, T.M., deMenocal, P.B., Okahashi, H., and Linsley, B.K. **Abrupt climate change and collapse of deep-sea ecosystems.** *Proceedings of the National Academy of Sciences [USA]* 105(5): 1556-1560, 2008.

Notes: We investigated the deep-sea fossil record of benthic ostracodes during periods of rapid climate and oceanographic change over the past 20,000 years in a core from intermediate depth in the northwestern Atlantic. Results show that deep-sea benthic community "collapses" occur with faunal turnover of up to 50% during major climatically driven oceanographic changes. Species diversity as measured by the Shannon–Wiener index falls from 3 to as low as 1.6 during these events. Major disruptions in the benthic communities commenced with Heinrich Event 1, the Inter-Allerød Cold Period (IACP: 13.1 ka), the Younger Dryas (YD: 12.9–11.5 ka), and several Holocene Bond events when changes in deep-water circulation occurred. The largest collapse is associated with the YD/IACP and is characterized by an abrupt two-step decrease in both the upper North Atlantic Deep Water assemblage and species diversity at 13.1 ka and at 12.2 ka. The ostracode fauna at this site did not fully recover until 8 ka, with the establishment of Labrador Sea Water ventilation. Ecologically opportunistic slope species prospered during this community collapse. Other abrupt community collapses during the past 20 ka generally correspond to millennial climate events. These results indicate that deep-sea ecosystems are not immune to the effects of rapid climate changes occurring over centuries or less.

Bracegirdle, T.J., Connolley, W.M., and Turner, J. **Antarctic climate change over the twenty first century.** *Journal of Geophysical Research* 113(3): art. D03103, 2008.

Notes: Here we present a new assessment of Antarctic climate change over the 21st century based on data from the models that were developed as part of the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4). To provide more reliable estimates of future change, a weighting scheme was applied to the model output, which depends on a measure of their ability to reproduce the mean climate of the late 20th century. The results show a seasonal variation of increases in circumpolar westerlies around Antarctica, which show the largest increases of 27% in autumn. This seasonal cycle was found to be consistent with projected changes in the semi-annual oscillation (SAO). In summer and autumn the increases of the westerly wind component migrate sufficiently far south to be manifested as a reduction of the coastal easterlies. The surface warming averaged over the continent is projected to be 0.34°C dec^{-1} with an inter-model standard deviation of 0.10°C dec^{-1}. More rapid warming occurs during the winter over regions of sea ice retreat, e.g., 0.51 ± 0.26°C dec^{-1} around East Antarctica. Projections of total sea-ice area show a decrease of $2.6 \pm 0.73 \times 10^6$ km^2 (33%). There is a projected increase of net

precipitation averaged over the continent of 2.9 ± 1.2 mm a^{-1} dec^{-1}. The weighting gives a larger increase of the autumn SAO peak, up to 30% larger for April. This is consistent with larger weighted autumn increases of circumpolar westerlies, more sea ice reduction and resulting larger skin temperature increases.

Comiso, J.C. and Nishio, F. **Trends in the sea ice cover using enhanced and compatible AMSR-E, SSM/I, and SMMR data.** *Journal of Geophysical Research* 113(2): art. C02S07, 2008.

Notes: Arguably, the most remarkable manifestation of change in the polar regions is the rapid decline in the Arctic perennial ice cover. Changes in the global sea ice cover, however, have been more modest, being only slightly negative in the Northern Hemisphere and even slightly positive in the Southern Hemisphere, the significance of which has not been adequately assessed because of unknown errors in the satellite historical data. Recent Advanced Microwave Scanning Radiometer (AMSR-E) high-resolution data are used as the baseline for generating an enhanced sea ice data set used in this study. Brightness temperature data from historical Special Scanning Microwave Imager (SSM/I) and Scanning Multichannel Microwave Radiometer (SMMR) sensors were normalized to be consistent with those from AMSR-E, and sea ice parameters were derived from all three data sets using the same algorithm for optimum consistency and accuracy. A small bias in sea ice extent is observed between AMSR-E and SSM/I data which, if uncorrected, causes an error of 0.62%/decade in the Arctic and 0.26%/decade in the Antarctic. Similar corrections are not needed in trend estimates of sea ice area. Biases due to seasonal changes in the accuracy of ice edge determinations, especially during melt periods, were also evaluated, and impacts on the trend results appear to be small. When updated to 2006, the trends in ice extent and area in the Arctic are now slightly more negative at -3.4 ± 0.2 and -4.0 ± 0.2% per decade, respectively, while the corresponding trends in the Antarctic remains slight but positive at 0.9 ± 0.2 and 1.7 ± 0.3% per decade.

Shindell, D.T., Levy, H., Schwarzkopf, M.D., Horowitz, L.W., Lamarque, J.-F., and Faluvegi, G. **Multimodel projections of climate change from short-lived emissions due to human activities.** *Journal of Geophysical Research* 113(11): art. D11109, 2008.

Notes: We use the GISS (Goddard Institute for Space Studies), GFDL (Geophysical Fluid Dynamics Laboratory) and NCAR (National Center for Atmospheric Research) climate models to study the climate impact of the future evolution of short-lived radiatively active species (ozone and aerosols). The models used mid-range A1B emission scenarios, independently calculated the resulting composition change, and then performed transient simulations to 2050 examining the response to projected changes in short-lived species and to changes in both long-lived and short-lived species together. By 2050, two models show that the global mean annual average warming due to long-lived GHGs (greenhouse gases) is enhanced by 20-25% due to the radiatively active short-lived species. One model shows virtually no effect from short-lived species. Intermodel differences are largely related to differences in emissions projections for short-lived species, which are substantial even for a particular storyline. For aerosols, these uncertainties are usually dominant, though for sulfate uncertainties in aerosol physics are also substantial. For tropospheric ozone, uncertainties in physical processes are more important than uncertainties in precursor emissions. Differences in future atmospheric burdens and radiative forcing for aerosols are dominated by divergent assumptions about emissions from South and East Asia. In all three models, the spatial distribution of radiative forcing is less important than that of climate sensitivity in predicting climate impact. Both short-lived and long-lived species appear to cause enhanced climate responses in the same regions of high sensitivity rather than short-lived species having an enhanced effect primarily near polluted areas. Since short-lived species can significantly influence climate, regional air quality emission control strategies for short-lived pollutants may substantially impact climate over large (e.g., hemispheric) scales.

Comiso, J.C., Parkinson, C.L., Gersten, R., and Stock, L. **Accelerated decline in the Arctic sea ice cover.** *Geophysical Research Letters* 35(1): art. L01703, 2008.

Notes: Satellite data reveal unusually low Arctic sea ice coverage during the summer of 2007, caused in part by anomalously high temperatures and southerly winds. The extent and area of the ice cover reached minima on 14 September 2007 at 4.1 × 106 km^2 and 3.6 × 106 km^2, respectively. These are 24% and 27% lower than the previous record lows, both reached on 21 September 2005, and 37% and 38% less than the climatological averages. Acceleration in the decline is evident as the extent and area trends of the entire ice cover (seasonal and perennial ice) have shifted from about -2.2 and -3.0% per decade in 1979-

1996 to about -10.1 and -10.7% per decade in the last 10 years. The latter trends are now comparable to the high negative trends of -10.2 and -11.4% per decade for the perennial ice extent and area, 1979-2007.

Matthews, H.D. and Caldeira, K. **Stabilizing climate requires near-zero emissions.** *Geophysical Research Letters* 35(4): art. L04705, 2008.

Notes: Current international climate mitigation efforts aim to stabilize levels of greenhouse gases in the atmosphere. However, human-induced climate warming will continue for many centuries, even after atmospheric CO2 levels are stabilized. In this paper, we assess the CO2 emissions requirements for global temperature stabilization within the next several centuries, using an Earth system model of intermediate complexity. We show first that a single pulse of carbon released into the atmosphere increases globally averaged surface temperature by an amount that remains approximately constant for several centuries, even in the absence of additional emissions. We then show that to hold climate constant at a given global temperature requires near-zero future carbon emissions. Our results suggest that future anthropogenic emissions would need to be eliminated in order to stabilize global-mean temperatures. As a consequence, any future anthropogenic emissions will commit the climate system to warming that is essentially irreversible on centennial timescales.

Tortell, P.D., Payne, C.D., Li, Y., Trimborn, S., Rost, B., Smith, W.O., Riesselman, C., Dunbar, R. B., Sedwick, P., and DiTullio, G.R. **CO[2] sensitivity of Southern Ocean phytoplankton.** *Geophysical Research Letters* 35(4): art. L04605, 2008.

Notes: The Southern Ocean exerts a strong impact on marine biogeochemical cycles and global air-sea CO_2 fluxes. Over the coming century, large increases in surface ocean CO_2 levels, combined with increased upper water column temperatures and stratification, are expected to diminish Southern Ocean CO_2 uptake. These effects could be significantly modulated by concomitant CO_2-dependent changes in the region's biological carbon pump. Here we show that CO_2 concentrations affect the physiology, growth and species composition of phytoplankton assemblages in the Ross Sea, Antarctica. Field results from in situ sampling and ship-board incubation experiments demonstrate that inorganic carbon uptake, steady-state productivity and diatom species composition are sensitive to CO_2 concentrations ranging from 100 to 800 ppm. Elevated CO_2 led to a measurable increase in phytoplankton productivity, promoting the growth of larger chain-forming diatoms. Our results suggest that CO_2 concentrations can influence biological carbon cycling in the Southern Ocean, thereby creating potential climate feedbacks.

Lange, M.A. **Assessing climate change impacts in the European north.** *Climatic Change* 87(1-2): 7-34, 2008.

Notes: Global climate change and its regional manifestation will result in significant impacts in the European North. However, in order to determine the consequences of such impacts, a holistic, integrated assessment is needed. This paper sets the stage for the remainder of this volume by describing an attempt to derive such an assessment for the Barents Sea Region through the EU-funded BALANCE project. The paper explains some of the major methodologies employed in the study. It also provides insight into major results obtained and attempts to answer a number of overarching questions. It will be shown that climate change does present a significant threat to environmental and societal integrity in the study region. However, it will also be shown that stakeholders regard other drivers of future changes (economical, political developments) at least as equally important for their personal lives.

Dankers, R. and Middelkoop, H. **River discharge and freshwater runoff to the Barents Sea under present and future climate conditions.** *Climatic Change* 87(1-2): 131-153, 2008.

Notes: River discharge forms a major freshwater input into the Arctic Ocean, and as such it has the potential to influence the oceanic circulation. As the hydrology of Arctic river basins is dominated by cryospheric processes such as snow accumulation and snowmelt, it may also be highly sensitive to a change in climate. Estimating the water balance of these river basins is therefore important, but it is complicated by the sparseness of observations and the large uncertainties related to the measurement of snowfalls. This study aims at simulating the water balance of the Barents Sea drainage basin in Northern

Europe under present and future climate conditions. We used a regional climate model to drive a large-scale hydrological model of the area. Using simulated precipitation derived from a climate model led to an overestimation of the annual discharge in most river basins, but not in all. Under the B2 scenario of climate change, the model simulated a 25% increase in freshwater runoff, which is proportionally larger than the projected precipitation increase. As the snow season is 30-50 day shorter, the spring discharge peak is shifted by about 2-3 weeks, but the hydrological regime of the rivers remains dominated by snowmelt.

Ellingsen, I.H., Dalpadado, P., Slagstad, D., and Loeng, H. **Impact of climatic change on the biological production in the Barents Sea.** *Climatic Change* 87(1-2): 155-175, 2008.

Notes: The Barents Sea is a high latitude ecosystem and is an important nursery and feeding area for commercial fish stocks such as cod, capelin and herring. There is a large inter-annual variability both in physical and biological conditions in the Barents Sea. Understanding and predicting changes in the system requires insight into the coupled nature of the physical and biological interactions. A coupled physical and biological ocean model is used to study the impact of postulated future atmospheric changes on the physical and biological conditions in the Barents Sea. Results from this simulation not only show that there is a large variability in the physical conditions on a wide range of time scales, but also that the temperature in the Barents Sea is increasing. The corresponding ice cover decrease is most noticeable in the summer months. The changes in physical properties will most likely have an impact on the biotope. On average, the primary production increases slightly over a 65 year long period, about 8%, partly due to an increased production in the northern Barents Sea. The model further simulates that the production of Atlantic zooplankton species increases approximately 20% and becomes more abundant in the east. The Arctic zooplankton biomass decreases significantly (50%) causing the total simulated production to decrease.

Roderfeld, H., Blyth, E., Dankers, R., Huse, G., Slagstad, D., Ellingsen, I., Wolf, A., and Lange, M.A. **Potential impact of climate change on ecosystems of the Barents Sea Region.** *Climatic Change* 87(1-2): 283-303, 2008.

Notes: The EU project BALANCE (Global Change Vulnerabilities in the Barents region: Linking Arctic Natural Resources, Climate Change and Economies) aims to assess vulnerability to climate change in the Barents Sea Region. As a prerequisite the potential impact of climate change on selected ecosystems of the study area has to be quantified, which is the subject of the present paper. A set of ecosystem models was run to generate baseline and future scenarios for 1990, 2020, 2050 and 2080. The models are based on data from the Regional Climate Model (REMO), driven by a GCM which in turn is forced by the IPCC-B2 scenario. The climate change is documented by means of the Koppen climate classification. Since the multitude of models requires the effect of climate change on individual terrestrial and marine systems to be integrated, the paper concentrates on a standardised visualisation of potential impacts by use of a Geographical Information System for the timeslices 2050 and 2080. The resulting maps show that both terrestrial and marine ecosystems of the Barents region will undergo significant changes until both 2050 and 2080.
