

Marine Science Review – 196

Climate and climate change



In this review:

- A. Recent articles – no abstract available
- B. Recent articles with abstracts

A. Recent articles – no abstract available

Francis, J.A. and Hunter, E. **New insight into the disappearing arctic sea ice.** *Eos Transactions* 87(46): 509-511, 2006.

Oppenheimer, M. and Todorov, A. **Global warming: The psychology of long term risk.** *Climatic Change* 77(1-2): 1-6, 2006.

Kerr, R.A. **Global warming may be homing in on Atlantic hurricanes.** *Science* 314(5801): 910-911, 2006.

Cazenave, A. **How fast are the ice sheets melting?** *Science* 314(5803): 1250-1252, 2006.

Laštovicka, J., Akmaev, R.A., Beig, G., Bremer, J., and Emmert, J.T. **Global change in the upper atmosphere.** *Science* 314(5803): 1253-1254, 2006.

Kerr, R.A. **False alarm: Atlantic conveyor belt hasn't slowed down after all.** *Science* 314(5802): 1064, 2006.

B. Recent articles with abstracts

Sheeran, K.A. **Who should abate carbon emissions? A note.** *Environmental and Resource Economics* 35(2): 89-98, 2006.

Notes: Economists commonly believe that failure to equalize the marginal cost of carbon abatement across countries implies a loss of global efficiency. Chichilnisky and Heal [(1994), *Economic Letters* 44, 444] first challenged this consensus a decade ago, demonstrating that, in general, efficiency does not require equalizing marginal abatement costs. This note revisits that important debate. It provides the missing intuition behind Chichilnisky and Heal's surprising result, explains what critical assumption gives rise to their result, and clarifies the role a social welfare function plays in their model. The implications of Chichilnisky and Heal's result are increasingly important, given international debate over the preferential role given to developing countries in the Kyoto Protocol and the role those countries will play in future climate negotiations.

Langer, G., Geisen, M., Baumann, K.-H., Kläs, J., Riebesell, U., Thoms, S., and Young, J.R. **Species-specific responses of calcifying algae to changing seawater carbonate chemistry.** *Geochemistry Geophysics Geosystems* 7(9): art. Q09006, 2006.

Notes: Uptake of half of the fossil fuel CO₂ into the ocean causes gradual seawater acidification. This has been shown to slow down calcification of major calcifying groups, such as corals, foraminifera, and coccolithophores. Here we show that two of the most productive marine calcifying species, the coccolithophores *Coccolithus pelagicus* and *Calcidiscus leptoporus*, do not follow the CO₂-related calcification response previously found. In batch culture experiments, particulate inorganic carbon (PIC) of *C. leptoporus* changes with increasing CO₂ concentration in a nonlinear relationship. A PIC optimum curve is obtained, with a maximum value at present-day surface ocean pCO₂ levels (~360 ppm CO₂). With particulate organic carbon (POC) remaining constant over the range of CO₂ concentrations, the PIC/POC ratio also shows an optimum curve. In the *C. pelagicus* cultures,

neither PIC nor POC changes significantly over the CO₂ range tested, yielding a stable PIC/POC ratio. Since growth rate in both species did not change with *p*CO₂, POC and PIC production show the same pattern as POC and PIC. The two investigated species respond differently to changes in the seawater carbonate chemistry, highlighting the need to consider species-specific effects when evaluating whole ecosystem responses. Changes of calcification rate (PIC production) were highly correlated to changes in coccolith morphology. Since our experimental results suggest altered coccolith morphology (at least in the case of *C. leptoporus*) in the geological past, coccoliths originating from sedimentary records of periods with different CO₂ levels were analyzed. Analysis of sediment samples was performed on six cores obtained from locations well above the lysocline and covering a range of latitudes throughout the Atlantic Ocean. Scanning electron micrograph analysis of coccolith morphologies did not reveal any evidence for significant numbers of incomplete or malformed coccoliths of *C. pelagicus* and *C. leptoporus* in last glacial maximum and Holocene sediments. The discrepancy between experimental and geological results might be explained by adaptation to changing carbonate chemistry.

Ebi, K.L., Mills, D.M., Smith, J.B., and Grambsch, A. **Climate change and human health impacts in the United States: An update on the results of the US National Assessment.** *Environmental Health Perspectives* 114(9): 1318-1324, 2006.

Notes: The health sector component of the first U.S. National Assessment, published in 2000, synthesized the anticipated health impacts of climate variability and change for five categories of health outcomes: impacts attributable to temperature, extreme weather events (e.g., storms and floods), air pollution, water- and food-borne diseases, and vector- and rodent-borne diseases. The Health Sector Assessment (HSA) concluded that climate variability and change are likely to increase morbidity and mortality risks for several climate-sensitive health outcomes, with the net impact uncertain. The objective of this study was to update the first HSA based on recent publications that address the potential impacts of climate variability and change in the United States for the five health outcome categories. The literature published since the first HSA supports the initial conclusions, with new data refining quantitative exposure-response relationships for several health end points, particularly for extreme heat events and air pollution. The United States continues to have a very high capacity to plan for and respond to climate change, although relatively little progress has been noted in the literature on implementing adaptive strategies and measures. Large knowledge gaps remain, resulting in a substantial need for additional research to improve our understanding of how weather and climate, both directly and indirectly, can influence human health. Filling these knowledge gaps will help better define the potential health impacts of climate change and identify specific public health adaptations to increase resilience.

Frauenfeld, O.W., Zhang, T., and McCreight, J.L. **Northern Hemisphere freezing/thawing index variations over the twentieth century.** *International Journal of Climatology* 27(1): 47-63, 2007.

Notes: Changes in the ground thermal regime in high-latitude cold regions have important consequences for surface and subsurface hydrology, the surface energy and moisture balance, carbon exchange, as well as ecosystem diversity and productivity. However, assessing these changes, particularly in light of significant atmospheric and terrestrial changes in recent decades, remains a challenge owing to data sparseness and discontinuous observations. The annual freezing and thawing index can be useful in evaluating permafrost and seasonally frozen ground distribution, has important engineering applications, and is a useful indicator of high-latitude climate change. The freezing/thawing index is generally defined based on daily observations, which are not readily available for many high-latitude locations. We thus employ monthly air temperatures, and provide an assessment of the validity of this approach. On the basis of a comprehensive relative error (RE) evaluation we find that our methodology introduces errors of less than 5% for most high-latitude land areas, and works well in many midlatitude regions as well. We evaluate a suite of gridded monthly temperature datasets and select the University of East Anglia's Climatic Research Unit (CRU) temperature product, available for 1901-2002. We are thus able to provide a continuous long-term 25 km × 25 km gridded Northern Hemisphere freezing/thawing index. Long-term climatologies of the freezing/thawing index delineate the cold regions of the Northern Hemisphere, as well as areas of seasonally frozen ground and permafrost. Objective trend analysis indicates that in recent decades, no significant changes have occurred in Russian permafrost regions; however, seasonally frozen ground areas are experiencing significant warming trends. Over North America, Canadian and Alaskan permafrost regions are experiencing a decrease in freezing index during the cold season, while coastal areas and eastern Canada are seeing significant increase in warm season thawing index.

Park, G.-H., Lee, K., Tishchenko, P., Min, D.-H., Warner, M.J., Talley, L.D., Kang, D.-J., and Kim, K.-R. **Large accumulation of anthropogenic CO₂ in the East (Japan) Sea and its significant impact on carbonate chemistry.** *Global Biogeochemical Cycles* 20(40): art. GB4013, 2006.

Notes: This paper reports on a basin-wide inventory of anthropogenic CO₂ in the East (Japan) Sea determined from high-quality alkalinity, chlorofluorocarbon, and nutrient data collected during a summertime survey in 1999 and total dissolved inorganic carbon data calculated from pH and alkalinity measurements. The data set comprises measurements from 203 hydrographic stations and covers most of the East Sea with the exception of the northwestern boundary region. Anthropogenic CO₂ concentrations are estimated by separating this value from total dissolved inorganic carbon using a tracer-based (chlorofluorocarbon) separation technique. Wintertime surface CFC-12 data collected in regions of deep water formation off Vladivostok, Russia, improve the accuracy of estimates of anthropogenic CO₂ concentrations by providing improved air-sea CO₂ disequilibrium values for intermediate and deep waters. Our calculation yields a total anthropogenic CO₂ inventory in the East Sea of 0.40 ± 0.06 petagrams of carbon as of 1999. Anthropogenic CO₂ has already reached the bottom of the East Sea, largely owing to the effective transport of anthropogenic CO₂ from the surface to the ocean interior via deep water formation in the waters off Vladivostok. The highest specific column inventory (vertically integrated inventory per square meter) of anthropogenic CO₂ of 80 mol C m^{-2} is found in the Japan Basin (40°N-44°N). Comparison of this inventory with those for other major basins of the same latitude band reveal that the East Sea values are much higher than the inventory for the Pacific Ocean (20-30 mol C m⁻²) and are similar to the inventory for the North Atlantic (66-72 mol C m⁻²). The substantial accumulation of anthropogenic CO₂ in the East Sea during the industrial era has caused the aragonite and calcite saturation horizons to move upward by 80-220 m and 500-700 m, respectively. These upward movements are approximately 5 times greater than those found in the North Pacific. Both the large accumulation of anthropogenic CO₂ and its significant impact on carbonate chemistry in the East Sea suggest that this sea is an important site for monitoring the future impact of the oceanic invasion of anthropogenic CO₂.

Drinkwater, K.F. **The regime shift of the 1920s and 1930s in the North Atlantic.** *Progress in Oceanography* 68(1): 134-151, 2006.

Notes: During the 1920s and 1930s, there was a dramatic warming of the northern North Atlantic Ocean. Warmer-than-normal sea temperatures, reduced sea ice conditions and enhanced Atlantic inflow in northern regions continued through to the 1950s and 1960s, with the timing of the decline to colder temperatures varying with location. Ecosystem changes associated with the warm period included a general northward movement of fish. Boreal species of fish such as cod, haddock and herring expanded farther north while colder-water species such as capelin and polar cod retreated northward. The maximum recorded movement involved cod, which spread approximately 1200 km northward along West Greenland. Migration patterns of "warmer water" species also changed with earlier arrivals and later departures. New spawning sites were observed farther north for several species or stocks while for others the relative contribution from northern spawning sites increased. Some southern species of fish that were unknown in northern areas prior to the warming event became occasional, and in some cases, frequent visitors. Higher recruitment and growth led to increased biomass of important commercial species such as cod and herring in many regions of the northern North Atlantic. Benthos associated with Atlantic waters spread northward off Western Svalbard and eastward into the eastern Barents Sea. Based on increased phytoplankton and zooplankton production in several areas, it is argued that bottom-up processes were the primary cause of these changes. The warming in the 1920s and 1930s is considered to constitute the most significant regime shift experienced in the North Atlantic in the 20th century.

McNeil, B.I. and Matear, R.J. **Projected climate change impact on oceanic acidification.** *Carbon Balance and Management* 1: art. 1:2, 2006.

Notes: *Background:* Anthropogenic CO₂ uptake by the ocean decreases the pH of seawater, leading to an 'acidification' which may have potential detrimental consequences on marine organisms. Ocean warming or circulation alterations induced by climate change has the potential to slowdown the rate of acidification of ocean waters by decreasing the amount of CO₂ uptake by the ocean. However, a recent study showed that climate change affected the decrease in pH insignificantly. Here, we examine the sensitivity of future oceanic acidification to climate change feedbacks within a coupled atmosphere-ocean model and find that ocean warming dominates the climate change feedbacks. ***Results:*** Our results show that the direct decrease in pH due to ocean warming is approximately equal to but opposite in magnitude to the indirect increase in pH

associated with ocean warming (ie reduced DIC concentration of the upper ocean caused by lower solubility of CO₂).

Conclusion: As climate change feedbacks on pH approximately cancel, future oceanic acidification will closely follow future atmospheric CO₂ concentrations. This suggests the only way to slowdown or mitigate the potential biological consequences of future ocean acidification is to significantly reduce fossil-fuel emissions of CO₂ to the atmosphere.

Tribollet, A., Atkinson, M.J., and Langdon, C. **Effects of elevated pCO₂ on epilithic and endolithic metabolism of reef carbonates.** *Global Change Biology* 12(11): 2200-2208, 2006.

Notes: We investigated effects of elevated partial pressure of CO₂ (pCO₂) on the metabolism of epilithic and endolithic phototrophic communities that colonized experimental coral blocks. Blocks of the massive coral *Porites lobata* were exposed to colonization by epilithic and endolithic organisms at an oceanic site in Kaneohe Bay (Hawaii) for 6 months, and then were transported to laboratory tanks. A bubbling system was used to maintain two treatments for 3 months, one at ambient pCO₂ (400 ppm) and the second at elevated pCO₂ (750 ppm). Net photosynthetic rates of epilithic communities in the high pCO₂ treatment, dominated by encrusting coralline algae, decreased by 35% while respiration rates remained constant. In contrast, metabolism of endolithic phototrophs, comprised of cyanobacteria and algae, was not significantly affected by the elevated pCO₂ even though endoliths contributed about 63% to block production.

Roleda, M.Y., Hanelt, D., and Wiencke, C. **Exposure to ultraviolet radiation delays photosynthetic recovery in Arctic kelp zoospores.** *Photosynthesis Research* 88(3): 311-322, 2006.

Notes: Seasonal reproduction in some Arctic Laminariales coincides with increased UV-B radiation due to stratospheric ozone depletion and relatively high water temperatures during polar spring. To find out the capacity to cope with different spectral irradiance, the kinetics of photosynthetic recovery was investigated in zoospores of four Arctic species of the order Laminariales, the kelps *Saccorhiza dermatodea*, *Alaria esculenta*, *Laminaria digitata*, and *Laminaria saccharina*. The physiology of light harvesting, changes in photosynthetic efficiency and kinetics of photosynthetic recovery were measured by in vivo fluorescence changes of Photosystem II (PSII). Saturation irradiance of freshly released spores showed minimal I_k values (photon fluence rate where initial slope intersects horizontal asymptote of the curve) values ranging from 13 to 18 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$ among species collected at different depths, confirming that spores are low-light adapted. Exposure to different radiation spectra consisting of photosynthetically active radiation (PAR; 400-700 nm), PAR+UV-A radiation (UV-A; 320-400 nm), and PAR+UV-A+UV-B radiation (UV-B; 280-320 nm) showed that the cumulative effects of increasing PAR fluence and the additional effect of UV-A and UV-B radiations on photoinhibition of photosynthesis are species specific. After long exposures, *Laminaria saccharina* was more sensitive to the different light treatments than the other three species investigated. Kinetics of recovery in zoospores showed a fast phase in *S. dermatodea*, which indicates a reduction of the photoprotective process while a slow phase in *L. saccharina* indicates recovery from severe photodamage. This first attempt to study photoinhibition and kinetics of recovery in zoospores showed that zoospores are the stage in the life history of seaweeds most susceptible to light stress and that ultraviolet radiation (UVR) effectively delays photosynthetic recovery. The viability of spores is important on the recruitment of the gametophytic and sporophytic life stages. The impact of UVR on the zoospores is related to the vertical depth distribution of the large sporophytes in the field.

Morse, J.W., Andersson, A.J., and Mackenzie, F.T. **Initial responses of carbonate-rich shelf sediments to rising atmospheric pCO₂ and "ocean acidification": Role of high Mg-calcites.** *Geochimica et Cosmochimica Acta* 70(23): 5814-5830, 2006.

Notes: Carbonate-rich sediments at shoal to shelf depths (<200m) represent a major CaCO₃ reservoir that can rapidly react to the decreasing saturation state of seawater with respect to carbonate minerals, produced by the increasing partial pressure of atmospheric carbon dioxide (pCO₂) and "acidification" of ocean waters. Aragonite is usually the most abundant carbonate mineral in these sediments. However, the second most abundant (typically 24wt%) carbonate mineral is high Mg-calcite (Mg-calcite) whose solubility can exceed that of aragonite making it the "first responder" to the decreasing saturation state of seawater. For the naturally occurring biogenic Mg-calcites, dissolution experiments have been used to predict their "stoichiometric solubilities" as a function of mol% MgCO₃. The only valid relationship that one can provisionally use for the metastable stabilities for Mg-calcite based on composition is that for the synthetically produced phases where metastable

equilibrium has been achieved from both under- and over-saturation. Biogenic Mg-calcites exhibit a large offset in solubility from that of abiotic Mg-calcite and can also exhibit a wide range of solubilities for biogenic Mg-calcites of similar Mg content. This indicates that factors other than the Mg content can influence the solubility of these mineral phases. Thus, it is necessary to turn to observations of natural sediments where changes in the saturation state of surrounding waters occur in order to determine their likely responses to the changing saturation state in upper oceanic waters brought on by increasing $p\text{CO}_2$. In the present study, we investigate the responses of Mg-calcites to rising $p\text{CO}_2$ and "ocean acidification" by means of a simple numerical model based on the experimental range of biogenic Mg-calcite solubilities as a function of Mg content in order to bracket the behavior of the most abundant Mg-calcite phases in the natural environment. In addition, observational data from Bermuda and the Great Bahama Bank are also presented in order to project future responses of these minerals. The numerical simulations suggest that Mg-calcite minerals will respond to rising $p\text{CO}_2$ by sequential dissolution according to mineral stability, progressively leading to removal of the more soluble phases until the least soluble phases remain. These results are confirmed by laboratory experiments and observations from Bermuda. As a consequence of continuous increases in atmospheric CO_2 from burning of fossil fuels, the average composition of contemporary carbonate sediments could change, i.e., the average Mg content in the sediments may slowly decrease. Furthermore, evidence from the Great Bahama Bank indicates that the amount of abiotic carbonate production is likely to decline as $p\text{CO}_2$ continues to rise.

Bazerman, M.H. **Climate change as a predictable surprise.** *Climatic Change* 77(1-2): 179-193, 2006.

Notes: In this article, I analyze climate change as a "predictable surprise," an event that leads an organization or nation to react with surprise, despite the fact that the information necessary to anticipate the event and its consequences was available (Bazerman and Watkins, 2004). I then assess the cognitive, organizational, and political reasons why society fails to implement wise strategies to prevent predictable surprises generally and climate change specifically. Finally, I conclude with an outline of a set of response strategies to overcome barriers to change.

Costello, J.H., Sullivan, B.K., and Gifford, D.J. **A physical-biological interaction underlying variable phenological responses to climate change by coastal zooplankton.** *Journal of Plankton Research* 28(11): 1099-1105, 2006.

Notes: Species-specific differential responses to climate warming that alter phenologies can dramatically affect community function. Using time series data from a Northwest Atlantic estuary, we show that the phenology of a top zooplankton predator, the ctenophore *Mnemiopsis leidyi*, has shifted more in response to climate warming over the past ~ 50 years than that of its major prey species, the copepod *Acartia tonsa*. Before climatic warming, *A. tonsa* was the dominant secondary producer in the estuary and its main period of production occurred before the seasonal appearance of *M. leidyi*. However, since 2000, the seasonal peak abundances of the two species have overlapped, intensifying the predator-prey relationship and resulting in the near extirpation of the once-abundant copepod from the estuary. We propose that the physical mechanism driving the different phenological responses of the two species is differential spring warming of the winter refugia of these two species. Substantial amplification of warming patterns in shallow embayments affects overwintering *M. leidyi* but has little influence over seasonal excystment of overwintering *A. tonsa* eggs located in the broader, deeper regions of the Bay. In this way, large-scale climatic changes are expressed as local-scale temperature variations that differentially affect alternate planktonic life histories to produce novel spring population growth dynamics of the two species and, ultimately, a new summer planktonic community dynamic in Narragansett Bay.

Glasby, G.P. **Drastic reductions in utilizable fossil fuel reserves: an environmental imperative.** *Environment Development and Sustainability* 8(1): 197-215, 2006.

Notes: We are living in a period of exponential growth of world population and energy consumption. Forecasts suggest that the atmospheric CO_2 concentration could reach 750 p.p.m. by 2100. At this level, the coral reefs and the West Antarctic Ice Sheet would be lost and thermohaline circulation in the N. Atlantic could possibly shut down. Crippling the ocean conveyor system would have a major impact on world climate and jeopardize our chances of feeding an enlarged world population. Consumption of the total global hydrocarbon reserves would increase the atmospheric CO_2 concentration to about 2200 p.p.m. We can therefore use less than 20% of the global hydrocarbon reserves without an accompanying massive programme

for the sequestration of CO₂ if we do not wish to cross the threshold atmospheric CO₂ concentration of 750 p.p.m. and risk a major environmental catastrophe.

Lombard, A., Cazenave, A., Le Traon, P.Y., Guinehut, S., and Cabanes, C. **Perspectives on present-day sea level change: a tribute to Christian le Provost.** *Ocean Dynamics* 56(5-6): 445-451, 2006.

Notes: In this paper, we first discuss the controversial result of the work by Cabanes *et al.* (Science 294:840-842, 2001), who suggested that the rate of past century sea level rise may have been overestimated, considering the limited and heterogeneous location of historical tide gauges and the high regional variability of thermal expansion which was supposed to dominate the observed sea level. If correct, this conclusion would have solved the problem raised by the IPCC third assessment report [Church *et al.*, Cambridge University Press, Cambridge, pp 881, 2001], namely, the factor two difference between the 20th century observed sea level rise and the computed climatic contributions. However, recent investigations based on new ocean temperature data sets indicate that thermal expansion only explains part (about 0.4mm/year) of the 1.8mm/year observed sea level rise of the past few decades. In fact, the Cabanes *et al.*'s conclusion was incorrect due to a contamination of abnormally high ocean temperature data in the Gulf Stream area that led to an overestimate of thermal expansion in this region. In this paper, we also estimate thermal expansion over the last decade (1993-2003), using a new ocean temperature and salinity database. We compare our result with three other estimates, two being based on global gridded data sets, and one based on an approach similar to that developed here. It is found that the mean rate of thermosteric sea level rise over the past decade is 1.5 ± 0.3 mm/year, i.e. 50% of the observed 3mm/year by satellite altimetry. For both time spans, past few decades and last decade, a contribution of 1.4mm/year is not explained by thermal expansion, thus needs to be of water mass origin. Direct estimates of land ice melt for the recent years account for about 1mm/year sea level rise. Thus, at least for the last decade, we have moved closer to explaining the observed rate of sea level rise than the IPCC third assessment report.

Church, J.A., White, N.J., and Hunter, J.R. **Sea-level rise at tropical Pacific and Indian Ocean islands.** *Global and Planetary Change* 53(3): 155-168, 2006.

Notes: Historical and projected sea-levels for islands in the tropical Pacific and Indian oceans are a subject of considerable interest and some controversy. The large variability (e.g. El Niño) signals and the shortness of many of the individual tide-gauge records contribute to uncertainty of historical rates of sea-level rise. Here, we determine rates of sea-level rise from tide gauges in the region. We also examine sea-level data from the TOPEX/Poseidon satellite altimeter and from a reconstruction of sea level in order to put the sparse (in space and time) tide-gauge data into context. For 1993 to 2001, all the data show large rates of sea-level rise over the western Pacific and eastern Indian Ocean (approaching 30mm yr⁻¹) and sea-level falls in the eastern Pacific and western Indian Ocean (approaching -10mm yr⁻¹). Over the region 40°S to 40°N, 30°E to 120°W, the average rise is about 4mm yr⁻¹. For 1950 to 2001, the average sea-level rise (relative to land) from the six longest tide-gauge records is 1.4mm yr⁻¹. After correcting for glacial isostatic adjustment and atmospheric pressure effects, this rate is 2.0mm yr⁻¹, close to estimates of the global average and regional average rate of rise. The long tide-gauge records in the equatorial Pacific indicate that the variance of monthly averaged sea-level after 1970 is about twice that before 1970. We find no evidence for the fall in sea level at the Maldives as postulated by Mörner *et al.* (2004). Our best estimate of relative sea-level rise at Funafuti, Tuvalu is 2 ± 1 mm yr⁻¹ over the period 1950 to 2001. The analysis clearly indicates that sea-level in this region is rising. We expect that the continued and increasing rate of sea-level rise and any resulting increase in the frequency or intensity of extreme sea-level events will cause serious problems for the inhabitants of some of these islands during the 21st century.

Broecker, W.S. **Abrupt climate change revisited.** *Global and Planetary Change* 54(3-4): 211-215, 2006.

Notes: Taken together, evidence from east Greenland's mountain moraines and results from atmospheric models appear to provide the answer to a question which has long dogged abrupt climate change research: namely, how were impacts of the Younger Dryas (YD), Dansgaard-Oeschger (D-O) and Heinrich (H) events transmitted so quickly and efficiently throughout the northern hemisphere and tropics? The answer appears to lie in extensive winter sea ice formation which created Siberian-like conditions in the regions surrounding the northern Atlantic. Not only would this account for the ultra cold conditions in the north, but, as suggested by models, it would have pushed the tropical rain belt southward and weakened the monsoons.

The requisite abrupt changes in the extent of sea ice cover are of course best explained by the turning on and turning off of the Atlantic's conveyor circulation.

Murray, T. **Greenland's ice on the scales.** *Nature* 443(7109): 277-278, 2006.

Notes: Satellite measurements of changes in Earth's gravity field reveal ice loss from Greenland's ice sheet. Over the past four years, this melt has contributed to global sea-level rise at an accelerating rate.

Bousquet, P., Ciais, P., Miller, J.B., Dlugokencky, E.J., Hauglustaine, D.A., Prigent, C., Van der Werf, G.R., Peylin, P., Brunke, E.-G., Carouge, C., Langenfelds, R.L., Lathiere, J., Papa, F., Ramonet, M., Schmidt, M., Steele, L.P., Tyler, S.C., and White, J. **Contribution of anthropogenic and natural sources to atmospheric methane variability.** *Nature* 443(7110): 439-443, 2006.

Notes: Methane is an important greenhouse gas, and its atmospheric concentration has nearly tripled since pre-industrial times. The growth rate of atmospheric methane is determined by the balance between surface emissions and photochemical destruction by the hydroxyl radical, the major atmospheric oxidant. Remarkably, this growth rate has decreased markedly since the early 1990s, and the level of methane has remained relatively constant since 1999, leading to a downward revision of its projected influence on global temperatures. Large fluctuations in the growth rate of atmospheric methane are also observed from one year to the next, but their causes remain uncertain. Here we quantify the processes that controlled variations in methane emissions between 1984 and 2003 using an inversion model of atmospheric transport and chemistry. Our results indicate that wetland emissions dominated the inter-annual variability of methane sources, whereas fire emissions played a smaller role, except during the 1997 - 1998 El Nino event. These top-down estimates of changes in wetland and fire emissions are in good agreement with independent estimates based on remote sensing information and biogeochemical models. On longer timescales, our results show that the decrease in atmospheric methane growth during the 1990s was caused by a decline in anthropogenic emissions. Since 1999, however, they indicate that anthropogenic emissions of methane have risen again. The effect of this increase on the growth rate of atmospheric methane has been masked by a coincident decrease in wetland emissions, but atmospheric methane levels may increase in the near future if wetland emissions return to their mean 1990s levels.

Wigley, T.M.L. **A combined mitigation/geoengineering approach to climate stabilization.** *Science* 314(5798): 452-454, 2006.

Notes: Projected anthropogenic warming and increases in CO₂ concentration present a twofold threat, both from climate changes and from CO₂ directly through increasing the acidity of the oceans. Future climate change may be reduced through mitigation (reductions in greenhouse gas emissions) or through geoengineering. Most geoengineering approaches, however, do not address the problem of increasing ocean acidity. A combined mitigation/geo-engineering strategy could remove this deficiency. Here we consider the deliberate injection of sulfate aerosol precursors into the stratosphere. This action could substantially offset future warming and provide additional time to reduce human dependence on fossil fuels and stabilize CO₂ concentrations cost-effectively at an acceptable level.

Matear, R.J. and McNeil, B.I. **Comment on "Preindustrial to modern interdecadal variability in coral reef pH".** *Science* 314(5799): 595, 2006.

Notes: Based on the boron isotopic composition of coral from the southwestern Pacific, Pelejero *et al.* (Reports, 30 September 2005, p. 2204) suggested that natural variations in pH can modulate the impact of ocean acidification on coral reef ecosystems. We show that this claim cannot be reconciled with other marine carbon chemistry constraints and highlight problems with the authors' interpretation of the paleontologic data.

Pelejero, C., Calvo, E., McCulloch, M.T., Marshall, J.F., Gagan, M.K., Lough, J.M., and Opdyke, B.N. **Response to comment on "Preindustrial to modern interdecadal variability in coral reef pH"**. *Science* 314(5799): 595, 2006.

Notes: Coral reefs are exceptional environments where changes in calcification, photosynthesis, and respiration induce large temporal variations of pH. We argue that boron isotopic variations in corals provide a robust proxy for paleo-pH which, together with the likely concomitant changes in the reconstructed partial pressure of CO₂ (PCO₂) calculated by Matear and McNeil, fall within ranges that are typical of modern coral reef ecosystems.

Woodworth, P.L. **Some important issues to do with long-term sea level change.** *Philosophical Transactions of the Royal Society of London [A]* 364(1841): 787-803, 2006.

Notes: This paper gives an overview of several important issues concerned with the measurement and understanding of long-term sea level change, which is one of the most important topics in sea level science. The issues discussed span science, technology and our ability to fund and operate the national and global observation networks required for a proper understanding of long-term change and its impacts.

Miller, L. and Douglas, B.C. **On the rate and causes of twentieth century sea-level rise.** *Philosophical Transactions of the Royal Society of London [A]* 364(1841): 805-820, 2006.

Notes: Both the rate and causes of twentieth century global sea-level rise (GSLR) have been controversial. Estimates from tide-gauges range from less than one, to more than two millimetre yr⁻¹. In contrast, values based on the processes mostly responsible for GSLR-mass increase (from mountain glaciers and the great high latitude ice masses) and volume increase (expansion due to ocean warming)-fall below this range. Either the gauge estimates are too high, or one (or both) of the component estimates is too low. Gauge estimates of GSLR have been in dispute for several decades because of vertical land movements, especially due to glacial isostatic adjustment (GIA). More recently, the possibility has been raised that coastal tide-gauges measure exaggerated rates of sea-level rise because of localized ocean warming. Presented here are two approaches to a resolution of these problems. The first is morphological, based on the limiting values of observed trends of twentieth century relative sea-level rise as a function of distance from the centres of the ice loads at last glacial maximum. This observational approach, which does not depend on a geophysical model of GIA, supports values of GSLR near 2mm yr⁻¹. The second approach involves an analysis of long records of tide-gauge and hydrographic (*in situ* temperature and salinity) observations in the Pacific and Atlantic Oceans. It was found that sea-level trends from tide-gauges, which reflect both mass and volume change, are 2-3 times higher than rates based on hydrographic data which reveal only volume change. These results support those studies that put the twentieth century rate near 2mm yr⁻¹, thereby indicating that mass increase plays a much larger role than ocean warming in twentieth century GSLR.

Plag, H.-P. **Recent relative sea-level trends: an attempt to quantify the forcing factors.** *Philosophical Transactions of the Royal Society of London [A]* 364(1841): 821-84, 2006.

Notes: Local sea-level is affected by a number of forcing factors, which all contribute to the trends observed by tide gauges. Here we use the fingerprints of main factors contributing to secular sea-level trends to construct an initial empirical model that explains best the trends in sea-level as recorded by the large number of coastal tide gauges over the last 50 years. The forcing factors considered include steric changes derived from observations, post-glacial rebound as predicted by geophysical models and mass changes in the Greenland and Antarctic ice sheets as predicted by the static sea-level equation. The approximation of the observed spatial pattern of sea-level trends through a model based on the spatial fingerprints of the main forcing factors fully utilizes the information contents of the available observations and models and allows the interpolation of the sea-level trends between the tide gauges. As a result, we obtain the global picture of sea-level trends due to the forcing factors accounted for in the analysis. Moreover, we derive constraints on the mass changes of the large ice sheets. The empirical models explain about 15% of the variance of the sea-level trends. Nevertheless, the models are correlated with the observations on the level of 0.38±0.07, indicating that most of the unexplained variance is due to contributions with small spatial scales. Averaged over the last five decades, the results indicate that the Antarctic and Greenland ice sheets have been

melting with an equivalent contribution to global sea-level rise of 0.39 ± 0.11 and $0.10 \pm 0.05 \text{ mm yr}^{-1}$, respectively. The steric signal derived from observations is clearly identified in the sea-level trends and is found to be at a minimum of 0.2 mm yr^{-1} , with the most likely value being close to 0.35 mm yr^{-1} . The global tide gauge network, which covers only a small fraction of the ocean surface, appears to sense an average sea-level rise larger than the global average. Extrapolating the regression models to the global ocean and taking into account the uncertainties in the extrapolation results in a most likely global average of the order of $1.05 \pm 0.75 \text{ mm yr}^{-1}$.

Nicholls, R.J. and Tol, R.S.J. **Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century.** *Philosophical Transactions of the Royal Society of London [A]* 364(1841): 1073-1095, 2006.

Notes: Taking the Special Report on Emission Scenarios (SRES) climate and socio-economic scenarios (A1FI, A2, B1 and B2 'future worlds'), the potential impacts of sea-level rise through the twenty-first century are explored using complementary impact and economic analysis methods at the global scale. These methods have never been explored together previously. In all scenarios, the exposure and hence the impact potential due to increased flooding by sea-level rise increases significantly compared to the base year (1990). While mitigation reduces impacts, due to the lagged response of sea-level rise to atmospheric temperature rise, impacts cannot be avoided during the twenty-first century by this response alone. Cost-benefit analyses suggest that widespread protection will be an economically rational response to land loss due to sea-level rise in the four SRES futures that are considered. The most vulnerable future worlds to sea-level rise appear to be the A2 and B2 scenarios, which primarily reflects differences in the socio-economic situation (coastal population, Gross Domestic Product (GDP) and GDP/capita), rather than the magnitude of sea-level rise. Small islands and deltaic settings stand out as being more vulnerable as shown in many earlier analyses. Collectively, these results suggest that human societies will have more choice in how they respond to sea-level rise than is often assumed. However, this conclusion needs to be tempered by recognition that we still do not understand these choices and significant impacts remain possible. Future worlds which experience larger rises in sea-level than considered here (above 35cm), more extreme events, a reactive rather than proactive approach to adaptation, and where GDP growth is slower or more unequal than in the SRES futures remain a concern. There is considerable scope for further research to better understand these diverse issues.

Simpson, I.J., Rowland, F.S., Meinardi, S., and Blake, D.R. **Influence of biomass burning during recent fluctuations in the slow growth of global tropospheric methane.** *Geophysical Research Letters* 33(22): art. L22808, 2006.

Notes: During the past 15 years the annual growth rate of tropospheric methane (CH_4) has shown striking changes over 2-3 year periods, varying from $+1\% \text{ yr}^{-1}$ to slightly negative values ($-0.2\% \text{ yr}^{-1}$). These fluctuations are superimposed on an overall slowdown of the CH_4 growth rate since the 1980s. Here we use our complementary measurement of other compounds (ethane, tetrachloroethene) to confirm the influence of biomass burning on large global CH_4 pulses in 1998 and 2002-2003. Methane growth rate fluctuations also track ENSO indices, most likely via the influence of ENSO activity on large-scale biomass burning. We also report the seventh year of near-zero growth of global CH_4 levels (Dec. 1998-Dec. 2005). The global CH_4 mixing ratio was 1772 ± 1 ppbv in 2005, and CH_4 increases of 118-376 ppbv between 2000-2020 (ten scenarios in the 2001 IPCC report, to levels around 1900+ ppbv by 2020, now appear quite unlikely).

Ivchenko, V.O., Wells, N.C., and Aleynik, D.L. **Anomaly of heat content in the northern Atlantic in the last 7 years: Is the ocean warming or cooling?** *Geophysical Research Letters* 33(22): art. L22606, 2006.

Notes: Whether the North Atlantic Ocean is warming or cooling is an important question both in physical oceanography and climate change. The Argo profiling buoys provide an accurate and stable instrument for determining the tendencies in heat content from the surface to 2000 m from 1999 to 2005. To calculate temperature and heat content anomalies two reference climatologies are used. These are the well known WOA2001 climatology (Stephens *et al.*, 2002), and a new WOCE Global Hydrographic climatology (Gouretski and Koltermann, 2004). The former climatology is used for our main results, and the latter is used for evaluating the sensitivity of our results to the climatology. Our scheme allows us to estimate the anomaly of heat content (AHC) in the North Atlantic and its smaller sub-domains (i.e. 10° boxes) for the period 1999-2005. We have found a dipole structure in the time averaged AHC: negative values are concentrated in the southern and middle latitudes of

the North Atlantic whilst positive values are found north of 50°N. The upper 1500 m of the North Atlantic is warming throughout the period 1999 to 2005.

Winton, M. **Does the Arctic sea ice have a tipping point?** *Geophysical Research Letters* 33(23): art. L23504, 2006.

Notes: Two IPCC fourth assessment report climate models have Arctic Ocean simulations that become sea-ice-free year around in 1%/year CO₂ increase to quadrupling experiments. These runs are examined for evidence of accelerated climate change associated with the removal of sea ice, particularly due to increasing surface albedo feedback. Both models become seasonally ice-free at an annual mean polar temperature of -9°C without registering much impact on the surface albedo feedback or disturbing the linear relationship between Arctic Ocean climate change and that of the surrounding region. When the polar temperature rises above -5°C, however, there is a sharp increase in the surface albedo feedback of one of the models, driving an abrupt elimination of Arctic ice and an increase in temperature above that expected from warming of the surrounding region. The transition to ice-free conditions is more linear in the other model, with ocean heat flux playing the primary driving role.

Holland, M.M., Bitz, C.M., and Tremblay, B. **Future abrupt reductions in the summer Arctic sea ice.** *Geophysical Research Letters* 33(23): art. L23503, 2006.

Notes: We examine the trajectory of Arctic summer sea ice in seven projections from the Community Climate System Model and find that abrupt reductions are a common feature of these 21st century simulations. These events have decreasing September ice extent trends that are typically 4 times larger than comparable observed trends. One event exhibits a decrease from 6 million km² to 2 million km² in a decade, reaching near ice-free September conditions by 2040. In the simulations, ice retreat accelerates as thinning increases the open water formation efficiency for a given melt rate and the ice-albedo feedback increases shortwave absorption. The retreat is abrupt when ocean heat transport to the Arctic is rapidly increasing. Analysis from multiple climate models and three forcing scenarios indicates that abrupt reductions occur in simulations from over 50% of the models and suggests that reductions in future greenhouse gas emissions moderate the likelihood of these events.

Fasullo, J. **Assessing tropical cyclone trends in the context of potential sampling biases.** *Geophysical Research Letters* 33(24): art. L24808, 2006.

Notes: Recently observed trends in the tropical cyclone record are assessed in the context of potential sampling biases. Multi-member syntheses of the hurricane record are created and subjected to time-varying sampling rates and intensity-specific biases to assess the biases' ability to induce spurious trends. While simple linear trends in sampling frequency can be imposed that account for the observed trends in major storms, the same biases result in trends in weaker storms that are significantly at odds with observations. Moreover, it is found that intensity specific biases, which must invariably contribute to prolonged storm durations for weaker categories, are inconsistent with observations. It is concluded therefore that the proposed sampling deficiencies are unable to account fully for recently reported trends, either individually or when considered in tandem. The finding of positive trends must therefore either be robust or result from complex, and as of yet unexplained, sampling biases.

Holgate, S.J. **On the decadal rates of sea level change during the twentieth century.** *Geophysical Research Letters* 34(01): art. L01602, 2007.

Notes: Nine long and nearly continuous sea level records were chosen from around the world to explore rates of change in sea level for 1904-2003. These records were found to capture the variability found in a larger number of stations over the last half century studied previously. Extending the sea level record back over the entire century suggests that the high variability in the rates of sea level change observed over the past 20 years were not particularly unusual. The rate of sea level change was found to be larger in the early part of last century (2.03 ± 0.35 mm/yr 1904-1953), in comparison with the latter part (1.45 ± 0.34 mm/yr 1954-2003). The highest decadal rate of rise occurred in the decade centred on 1980 (5.31 mm/yr) with the lowest

rate of rise occurring in the decade centred on 1964 (-1.49 mm/yr). Over the entire century the mean rate of change was 1.74 ± 0.16 mm/yr.
