

Marine Science Review – 183

Climate and climate change



In this review:

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

A. Recent articles – no abstract available

Bradshaw, W.E. and Holzapfel, C.M. **Evolutionary response to rapid climate change.** *Science* 312(5779): 1477-1478, 2006.

Kerr, R.A. **Yes, it's been getting warmer in here since the CO₂ began to rise.** *Science* 312(5782): 1854, 2006.

Martinot, E. **Renewable energy gains momentum: Global markets and policies in the spotlight.** *Environment* 48(6): 26-43, 2006.

Breon, F.-M. **How do aerosols affect cloudiness and climate?** *Science* 313(5787): 623-624, 2006.

B. Recent publications available online

WMO/UNEP. 2006. **Scientific Assessment of Ozone Depletion: 2006** [Executive Summary]. 24pp.

Available at:

http://ozone.unep.org/Publications/Assessment_Reports/2006/Scientific_Assessment_2006_Exec_Summary.pdf

Notes: This assessment, a product of a subsidiary body of the Montreal Protocol, reports that while ozone layer continues to recover, it will not be fully restored over Antarctica until 2060-2075, an extension of 10-25 years over previous estimates. The report's more technical findings include that: controls implemented under the Montreal Protocol appear to be decreasing the atmospheric concentrations of ozone-depleting substances (ODS); in the stratosphere, the decline in concentrations is due primarily to chlorofluorocarbon and methyl bromide reductions; polar ozone fluctuations have been driven by meteorological variations; and, stratospheric ozone depletion has not continued in the non-polar regions largely because stratospheric ODS are no longer increasing. In addition, the report finds that the effects of emissions of methyl bromide from humans appear to be greater than previously thought, as decreases in anthropogenic emissions of methyl bromide appear to lead to greater decreases in atmospheric abundance of methyl bromide than expected. These findings suggest that fumigation-related emissions accounted for 30%, rather than the previously estimated 20%, of atmospheric methyl bromide prior to 1998. As a result, the report estimates the methyl bromide results in 60 times more ozone depletion than an equivalent amount of chlorofluorocarbons, over 30% higher than the previous estimate. The report further discusses the relationship between ozone depletion and global warming, finding that: ODS decreases will drive ozone recovery, but climate change will influence the timing, speed and extent of that recovery; as the ozone layer is repaired, surface UV radiation levels will be driven largely by factors related to climate change; and, stratospheric cooling is predominantly driven by ozone depletion but greenhouse gas increases will contribute to stratospheric cooling in the future.

C. Recent articles with abstracts

Rowland, F.S. **Stratospheric ozone depletion.** *Philosophical Transactions of the Royal Society of London [B]* 361(1469): 769-790, 2006.

Notes: Solar ultraviolet radiation creates an ozone layer in the atmosphere which in turn completely absorbs the most energetic fraction of this radiation. This process both warms the air, creating the stratosphere between 15 and 50 km altitude, and protects the biological activities at the Earth's surface from this damaging radiation. In the last half-century, the chemical mechanisms operating within the ozone layer have been shown to include very efficient catalytic chain reactions involving the chemical species HO, HO₂, NO, NO₂, Cl and ClO. The NO_x and ClO_x chains involve the emission at Earth's surface of stable molecules in very low concentration (N₂O, CCl₂F₂, CCl₃F, etc.) which wander in the atmosphere for as long as a century before absorbing ultraviolet radiation and decomposing to create NO and Cl in the middle of the stratospheric ozone layer. The growing emissions of synthetic chlorofluorocarbon molecules cause a significant diminution in the ozone content of the stratosphere, with the result that more solar ultraviolet-B radiation (290-320 nm wavelength) reaches the surface. This ozone loss occurs in the temperate zone latitudes in all seasons, and especially drastically since the early 1980s in the south polar springtime -- the 'Antarctic ozone hole'. The chemical reactions causing this ozone depletion are primarily based on atomic Cl and ClO, the product of its reaction with ozone. The further manufacture of chlorofluorocarbons has been banned by the 1992 revisions of the 1987 Montreal Protocol of the United Nations. Atmospheric measurements have confirmed that the Protocol has been very successful in reducing further emissions of these molecules. Recovery of the stratosphere to the ozone conditions of the 1950s will occur slowly over the rest of the twenty-first century because of the long lifetime of the precursor molecules.

Dyurgerov, M. and McCabe, G.J. **Associations between accelerated glacier mass wastage and increased summer temperature in coastal regions.** *Arctic, Antarctic and Alpine Research* 38(2): 190-197, 2006.

Notes: Low-elevation glaciers in coastal regions of Alaska, the Canadian Arctic, individual ice caps around the Greenland ice sheet, and the Patagonia Ice Fields have an aggregate glacier area of about 332×10^3 km² and account for approximately 42% of all the glacier area outside the Greenland and Antarctic ice sheets. They have shown volume loss, especially since the end of the 1980s, increasing from about 45% in the 1960s to nearly 67% in 2003 of the total wastage from all glaciers on Earth outside those two largest ice sheets. Thus, a disproportionately large contribution of coastal glacier ablation to sea level rise is evident. We examine cumulative standardized departures (1961-2000 reference period) of glacier mass balances and air temperature data in these four coastal regions. Analyses indicate a strong association between increases in glacier volume losses and summer air temperature at regional and global scales. Increases in glacier volume losses in the coastal regions also coincide with an accelerated rate of ice discharge from outlet glaciers draining the Greenland and West Antarctic ice sheets. These processes imply further increases in sea level rise.

Mitrovica, J.X., Wahr, J., Matsuyama, I., Paulson, A., and Tamisiea, M.E. **Reanalysis of ancient eclipse, astronomic and geodetic data: A possible route to resolving the enigma of global sea-level rise.** *Earth and Planetary Science Letters* 243(3-4): 390-399, 2006.

Notes: Predictions of the Earth's response to the ice age appear to simultaneously reconcile a set of astronomical, geodetic and ancient eclipse observations related to changes in rotation, thus ruling out ice melting as a major contributor to 20th century sea-level rise. We demonstrate that the reconciliation disappears when an improved theory of rotational stability is applied. Furthermore, our reanalysis of longer satellite records renders previous estimates of the secular change in rotation rate suspect. The updated ice-age predictions and observations permit an anomalous 20th century ice flux of ~1 mm/yr equivalent sea-level rise. Thus, the full suite of Earth rotation observations are consistent with a connection between climatic warming and recent melting of ice reservoirs.

Lenton, T.M. **Climate change to the end of the millennium.** *Climatic Change* 76(1-2): 7-29, 2006.

Notes: Anthropogenic climate change will continue long after anthropogenic CO₂ emissions cease. Atmospheric CO₂, global warming and ocean circulation will approach equilibrium on the millennial timescale, whereas thermal expansion of the ocean, ice sheet melt and their contributions to sea level rise are unlikely to be complete. Atmospheric CO₂ in year 3000 depends non-linearly on the total amount of CO₂ emitted and is very likely to exceed the present level of ~ 380 ppmv. CO₂ is doubled for ~ 2500 GtC emitted, quadrupled if all similar to 5000 GtC of conventional fossil fuel resources are emitted, and increases by a factor of ~ 32 if a further 20,000 GtC of exotic fossil fuel resources are emitted. Global warming in year 3000 will also depend on climate sensitivity to doubling CO₂, which is most probably ~ 3°C but highly uncertain. Thermal expansion will contribute 0.5-2 m to millennial sea level rise for each doubling of CO₂. The Greenland ice sheet could melt completely within the millennium under > 8 x CO₂, adding a further ~ 7 m to sea level. The rate of melt depends on the magnitude of forcing above a regional warming threshold of 1-3°C. The West Antarctic ice sheet could be threatened by 4-10°C local warming, and its potential contribution to millennial sea level rise exceeds current maximum estimates of ~ 1 m. The fate of the ocean thermohaline circulation may depend on the rate as well as the magnitude of forcing.

Dentener, F. and et al. **The global atmospheric environment for the next generation.** *Environmental Science and Technology* 40(11): 3586-3594, 2006.

Notes: Air quality, ecosystem exposure to nitrogen deposition, and climate change are intimately coupled problems: we assess changes in the global atmospheric environment between 2000 and 2030 using 26 state-of-the-art global atmospheric chemistry models and three different emissions scenarios. The first (CLE) scenario reflects implementation of current air quality legislation around the world, while the second (MFR) represents a more optimistic case in which all currently feasible technologies are applied to achieve maximum emission reductions. We contrast these scenarios with the more pessimistic IPCC SRES A2 scenario. Ensemble simulations for the year 2000 are consistent among models and show a reasonable agreement with surface ozone, wet deposition, and NO₂ satellite observations. Large parts of the world are currently exposed to high ozone concentrations and high deposition of nitrogen to ecosystems. By 2030, global surface ozone is calculated to increase globally by 1.5 +/- 1.2 ppb (CLE) and 4.3 +/- 2.2 ppb (A2), using the ensemble mean model results and associated +/- 1 sigma standard deviations. Only the progressive MFR scenario will reduce ozone, by -2.3 +/- 1.1 ppb. Climate change is expected to modify surface ozone by -0.8 +/- 0.6 ppb, with larger decreases over sea than over land. Radiative forcing by ozone increases by 63 +/- 15 and 155 +/- 37 mW m² for CLE and A2, respectively, and decreases by -45 +/- 15 mW m² for MFR. We compute that at present 10.1% of the global natural terrestrial ecosystems are exposed to nitrogen deposition above a critical load of 1 g N m⁻² yr⁻¹. These percentages increase by 2030 to 15.8% (CLE), 10.5% (MFR), and 25% (A2). This study shows the importance of enforcing current worldwide air quality legislation and the major benefits of going further. Nonattainment of these air quality policy objectives, such as expressed by the SRES-A2 scenario, would further degrade the global atmospheric environment.

Eshel, G. and Martin, P.A. **Diet, energy, and global warming.** *Earth Interactions* 10: art. 9, 2006.

Notes: The energy consumption of animal- and plant-based diets and, more broadly, the range of energetic planetary footprints spanned by reasonable dietary choices are compared. It is demonstrated that the greenhouse gas emissions of various diets vary by as much as the difference between owning an average sedan versus a sport-utility vehicle under typical driving conditions. The authors conclude with a brief review of the safety of plant-based diets, and find no reasons for concern.

Moreno, A.R. **Climate change and human health in Latin America: drivers, effects, and policies.** *Regional Environmental Change* 6(3): 157-164, 2006.

Notes: Many people would be increasingly affected by living under critical conditions in Latin America if, as expected, global warming aggravates disease and pest transmission processes. Heat waves and air pollution would increase heat-related diseases and illness episodes in large cities. Fire smoke has been associated with irritation of the throat, lung and eyes, and respiratory problems. Climate extreme increases associated with climate change would cause physical damage, population displacement,

and adverse effects on food production, freshwater availability and quality. It would also increase the risks of infectious and vector-borne diseases. Climate change impacts the geographical range, seasonality, and the incidence rate of vector-borne diseases, such as malaria. Climate-related ecological changes may expand cholera transmission, particularly populations in low-laying tropical coastal areas. El Nino conditions may affect the incidence of infectious diseases, such as malaria. Ocean warming would increase temperature-sensitive toxins produced by phytoplankton, which could cause more frequent contamination of seafood. A clearer understanding on the current role of climate change in disease patterns will be able to improve forecasts of potential future impacts of projected climate change and support action to reduce such impacts.

Kikkawa, T., Sato, T., Kita, J., and Ishimatsu, A. **Acute toxicity of temporally varying seawater CO₂ conditions on juveniles of Japanese sillago (*Sillago japonica*).** *Marine Pollution Bulletin* 52(6): 621-625, 2006.

Notes: CO₂ ocean storage by which liquefied CO₂ is injected into the deep-sea to mitigate the climate change would increase the CO₂ concentrations of the surrounding seawater. The biological impacts of such dynamic CO₂ environments are, however, unknown. We examined the acute toxicity of temporally changing seawater CO₂ concentrations on juveniles of *Sillago japonica*. Step-wise increases in ambient CO₂ to *f*CO₂ (fractional CO₂ concentration of the gas mixture bubbled into seawater) levels of 7% and 9% resulted in mortalities of 0.15 and 0.40-0.67 after 18 h, respectively. In contrast, one-step increases to these CO₂ levels killed all fish within 15 min. Further, a sudden drop of *f*CO₂ from 9-10% CO₂ to normocapnia (0.038%) killed all the surviving fish within a few minutes. These results demonstrate that impacts of ocean CO₂ storage need to be examined under conditions mimicking the dynamic changes in CO₂, levels expected to occur by the CO₂ injection procedure.

Leifer, I., Luyendyk, B.P., Boles, J., and Clark, J.F. **Natural marine seepage blowout: Contribution to atmospheric methane.** *Global Biogeochemical Cycles* 20(3): art. GB3008, 2006.

Notes: The release of methane sequestered within deep-sea methane hydrates is postulated as a mechanism for abrupt climate change; however, whether emitted seabed methane reaches the atmosphere is debatable. We observed methane emissions for a blowout from a shallow (22 m) hydrocarbon seep. The emission from the blowout was determined from atmospheric plume measurements. Simulations suggest a 1.1% gas loss to dissolution compared to ~10% loss for a typical low-flux bubble plume. Transfer to the atmosphere primarily was enhanced by the rapid upwelling flows induced by the massive discharge. This mechanism could allow methane suddenly released from deeper (>250 m) waters to contribute significantly to atmospheric methane budgets.

Oldenburg, C.M. and Lewicki, J.L. **On leakage and seepage of CO₂ from geologic storage sites into surface water.** *Environmental Geology* 50(5): 691-705, 2006.

Notes: Geologic carbon sequestration is the capture of anthropogenic carbon dioxide (CO₂) and its storage in deep geologic formations. The processes of CO₂ seepage into surface water after migration through water-saturated sediments are reviewed. Natural CO₂ and CH₄ fluxes are pervasive in surface-water environments and are good analogues to potential leakage and seepage of CO₂. Buoyancy-driven bubble rise in surface water reaches a maximum velocity of approximately 30 cm s⁻¹. CO₂ rise in saturated porous media tends to occur as channel flow rather than bubble flow. A comparison of ebullition versus dispersive gas transport for CO₂ and CH₄ shows that bubble flow will dominate over dispersion in surface water. Gaseous CO₂ solubility in variable-salinity waters decreases as pressure decreases leading to greater likelihood of ebullition and bubble flow in surface water as CO₂ migrates upward.

Huesemann, M.H. **Can advances in science and technology prevent global warming?** *Mitigation and Adaptation Strategies for Global Change* 11(3): 539-77, 2006.

Notes: The most stringent emission scenarios published by the Intergovernmental Panel on Climate Change (IPCC) would result in the stabilization of atmospheric carbon dioxide (CO₂) at concentrations of approximately 550 ppm which would

produce a global temperature increase of at least 2°C by 2100. Given the large uncertainties regarding the potential risks associated with this degree of global warming, it would be more prudent to stabilize atmospheric CO₂ concentrations at or below current levels which, in turn, would require more than 20-fold reduction (i.e., $\geq 95\%$) in per capita carbon emissions in industrialized nations within the next 50-100 years. Using the Kaya equation as a conceptual framework, this paper examines whether CO₂ mitigation approaches such as energy efficiency improvements, carbon sequestration, and the development of carbon-free energy sources would be sufficient to bring about the required reduction in per capita carbon emissions without creating unforeseen negative impacts elsewhere. In terms of energy efficiency, large improvements (≥ 5 -fold) are in principle possible through aggressive investments in R&D and the removal of market imperfections such as corporate subsidies. However, energy efficiency improvements per se will not result in a reduction in carbon emissions if, as predicted by the IPCC, the size of the global economy expands 12-26-fold by 2100. Terrestrial carbon sequestration via reforestation and improved agricultural soil management has many environmental advantages, but has only limited CO₂ mitigation potential because the global terrestrial carbon sink (ca. 200 Gt C) is small relative to the size of fossil fuel deposits (≥ 4000 Gt C). By contrast, very large amounts of CO₂ can potentially be removed from the atmosphere via sequestration in geologic formations and oceans, but carbon storage is not permanent and is likely to create many unpredictable environmental consequences. Renewable energy can in theory provide large amounts of carbon-free power. However, biomass and hydroelectric energy can only be marginally expanded, and large-scale solar energy installations (i.e., wind, photovoltaics, and direct thermal) are likely to have significant negative environmental impacts. Expansion of nuclear energy is highly unlikely due to concerns over reactor safety, radioactive waste management, weapons proliferation, and cost. In view of the serious limitations and liabilities of many proposed CO₂ mitigation approaches, it appears that there remain only few no-regrets options such as drastic energy efficiency improvements, extensive terrestrial carbon sequestration, and cautious expansion of renewable energy generation. These promising CO₂ mitigation technologies have the potential to bring about the required 20-fold reduction in per capita carbon emission only if population and economic growth are halted without delay. Therefore, addressing the problem of global warming requires not only technological research and development but also a reexamination of core values that equate material consumption and economic growth with happiness and well-being.

Kharaka, Y.K., Cole, D.R., Hovorka, S.D., Gunter, W.D., Knauss, K.G., and Freifeld, B.M. **Gas-water-rock interactions in Frio Formation following CO₂ injection: Implications for the storage of greenhouse gases in sedimentary basins.** *Geology* 34(7): 577-580, 2006.

Notes: To investigate the potential for the geologic storage of CO₂ in saline sedimentary aquifers, 1600 t of CO₂ were injected at 1500 m depth into a 24-m-thick sandstone section of the Frio Formation, a regional brine and oil reservoir in the U.S. Gulf Coast. Fluid samples obtained from the injection and observation wells before CO₂ injection showed a Na-Ca-Cl-type brine with 93,000 mg/L total dissolved solids (TDS) at near saturation with CH₄ at reservoir conditions. Following CO₂ breakthrough, samples showed sharp drops in pH (6.5-5.7), pronounced increases in alkalinity (100-3000 mg/L as HCO₃) and Fe (30-1100 mg/L), and significant shifts in the isotopic compositions of H₂O, dissolved inorganic carbon (DIC), and CH₄. Geochemical modeling indicates that brine pH would have dropped lower but for the buffering by dissolution of carbonate and iron oxyhydroxides. This rapid dissolution of carbonate and other minerals could ultimately create pathways in the rock seals or well cements for CO₂ and brine leakage. Dissolution of minerals, especially iron oxyhydroxides, could mobilize toxic trace metals and, where residual oil or suitable organics are present, the injected CO₂ could also mobilize toxic organic compounds. Environmental impacts could be major if large brine volumes with mobilized toxic metals and organics migrated into potable groundwater. The $\delta^{18}\text{O}$ values for brine and CO₂ samples indicate that supercritical CO₂ comprises $\sim 50\%$ of pore-fluid volume ~ 6 mo after the end of injection. Postinjection sampling, coupled with geochemical modeling, indicates that the brine gradually will return to its preinjection composition.

Rand, P.S., Hinch, S.G., Morrison, J., Foreman, M.G.G., MacNutt, M.J., Macdonald, J.S., Healey, M.C., Farrell, A.P., and Higgs, D.A. **Effects of river discharge, temperature, and future climates on energetics and mortality of adult migrating Fraser River sockeye salmon.** *Transactions of the American Fisheries Society* 135(3): 655-667, 2006.

Notes: We evaluated the effects of past and future trends in temperature and discharge in the Fraser River on the migratory performance of the early Stuart population of sockeye salmon *Oncorhynchus nerka*. Fish of lower condition exhibited disproportionately higher mortality during the spawning run, elucidating a critical link between energetic condition and a fish's ability to reach the spawning grounds. We simulated spawning migrations by accounting for energetic demands for an average individual in the population from the time of entry into the Fraser River estuary to arrival on the spawning grounds (about

1,200 km upstream) and estimated energy expenditures for the average migrant during 1950-2001. The model output indicates relatively high interannual variability in migration energy use and a marked increase in energy demands in recent years related to unusually high discharges (e.g., 1997) and warmer than average water temperature (e.g., 1998). We examined how global climate change might effect discharge, water temperature, and the energy used by sockeye salmon during their spawning migration. Expected future reductions in peak flows during freshets markedly reduced transit time to the spawning ground, representing a substantial energy savings that compensated for the effect of the increased metabolic rate resulting from exposure to warmer river temperatures. We suggest that such watershed-scale compensatory mechanisms may be critical to the long-term sustainability of Pacific salmon, given expected changes in climate. However, such compensation will probably only be applicable to some stocks and may be limited under extremely high temperatures where nonenergetic factors such as disease and stress may play a more dominant role in defining mortality. Our results further indicate that a long-term decline in the mean mass of adult sockeye salmon completing their marine residency could erode their migratory fitness during the river migration and hence jeopardize the sustainability of sockeye salmon and the fishery that targets them.

Denny, M.W., Miller, L.P., and Harley, C.D.G. **Thermal stress on intertidal limpets: long-term hindcasts and lethal limits.** *Journal of Experimental Biology* 209(13): 2420-2431, 2006.

Notes: When coupled with long-term meteorological records, a heat-budget model for the limpet, *Lottia gigantea*, provides a wealth of information regarding environmental and topographic controls of body temperature in this ecologically important species. (1) The maximum body temperature predicted for any site (37.5°C) is insufficient to kill all limpets, suggesting that acute thermal stress does not set an absolute upper limit to the elevation of *L. gigantea* on the shore. Therefore, the upper limit must be set by behavioral responses, sublethal effects or ecological interactions. (2) Temperatures sufficient to kill limpets are reached at only a small fraction of substratum orientations and elevations and on only three occasions in 5 years. These rare predicted lethal temperatures could easily be missed in field measurements, thereby influencing the interpretation of thermal stress. (3) Body temperature is typically higher than air temperature, but maximum air temperature can nonetheless be used as an accurate predictor of maximum body temperature. Warmer air temperatures in the future may thus cause increased mortality in this intertidal species. Interpretation of the ecological effects of elevated body temperature depends strongly on laboratory measurements of thermal stress, highlighting the need for additional research on the temporal and spatial variability of thermal limits and sublethal stress. The lengthy time series of body temperatures calculated from the heat-budget model provides insight into how these physiological measurements should be conducted.

Nyenzi, B. and Lefale, P.F. **El Nino Southern Oscillation (ENSO) and global warming.** *Advances in Geosciences* 6: 95-101, 2006.

Notes: It is widely accepted by the international scientific community that human activities have increased atmospheric concentrations of greenhouse gases (GHG) and aerosols since the pre-industrial era. This increase has contributed to most of the warming ($0.6 \pm 0.2^\circ\text{C}$) observed over the 20th century, land areas warming more than the oceans, with the 1990s very likely to be the warmest decade of the 20th century (IPCC, 2001). How this warming influences the occurrence, severity and frequency of ENSO episodes remains highly uncertain. The IPCC (2001) assessment of the scientific literature found insufficient evidence to suggest any direct attribution between increase in ENSO events that occurred in the last 20 to 30 years of the 20th century and global warming (IPCC, 2001). However, assessments carried out since then (e.g. IPCC Fourth Assessment Report (AR4), in preparations) suggest El Nino events have become more frequent, persistent and intense during the last 20 to 30 years compared to the previous 100 years. Attribution to global warming, however, remains highly uncertain. Efforts to simulate and model past, present and future behaviour of ENSO under a warming world due to enhanced GHG concentrations produce conflicting results. Since substantial internally-generated variability of ENSO behaviour on multi-decadal to century timescales occurs in long, unforced atmospheric-oceanic general circulation model (AOGCM) simulations, the attribution of past and future changes in ENSO amplitude and frequency to external forcing like GHG concentrations cannot be made with certainty. Such attribution would require extensive use of ensemble climate experiments or long experiments with stabilised GHG forcing. Although there are now better ENSO simulations in AOGCM, further model improvements are needed to simulate a more realistic Pacific climatology and seasonal cycle of the key modes influencing the climate of the region, as well as more realistic ENSO variability. More research is needed to further enhance scientific understanding of possible teleconnections between ENSO and global warming. It is worth noting the IPCC AR4 due to be release in September 2007, would provide a more detailed assessment of ENSO and global warming than what is being covered in this paper.

Gergis, J.L. and Fowler, A.M. **How unusual was late 20th century El Niño-Southern Oscillation (ENSO)? Assessing evidence from tree-ring, coral, ice-core and documentary palaeoarchives, A.D. 1525-2002.** *Advances in Geosciences* 6: 173-179, 2006.

Notes: Multiple proxy records (tree-ring, coral, ice and documentary) were examined to isolate ENSO signals associated with both phases of the phenomenon for the period A.D. 1525-2002. To avoid making large-scale inferences from single proxy analysis, regional signals were aggregated into a network of high-resolution records, revealing large-scale trends in the frequency, magnitude and duration of pre-instrumental ENSO using novel applications of percentile analysis. Here we use the newly introduced coupled ocean-atmosphere ENSO index (CEI) as a baseline for the calibration of proxy records. The reconstruction revealed 83 extreme or very strong ENSO episodes since A.D. 1525, expanding considerably on existing ENSO event chronologies. Significantly, excerpts of the most comprehensive list of La Niña events compiled to date are presented, indicating peak activity during the 16th to mid 17th and 20th centuries. Although extreme events are seen throughout the 478-year reconstruction, 43% of the extreme ENSO events noted since A.D. 1525 occur during the 20th century, with an obvious bias towards enhanced El Niño conditions in recent decades. Of the total number of extreme event years reconstructed, 30% of all reconstructed ENSO event years occur post-1940 alone suggesting that recent ENSO variability appears anomalous in the context of the past five centuries.

Rive, N., Torvanger, A., and Fuglestedt, J.S. **Climate agreements based on responsibility for global warming: Periodic updating, policy choices, and regional costs.** *Global Environmental Change* 16(2): 182-194, 2006.

Notes: It has been suggested that calculations of historical responsibility for global warming should be used to distribute mitigation requirements in future climate agreements. For a medium-term mitigation scenario, we calculate regional mitigation costs resulting from global allocation schemes based on the Brazilian Proposal that solely incorporate historical responsibility as a burden sharing criterion. We find that they are likely to violate ability-to-pay principles. In spite of less stringent abatement requirements, developing country regions experience cost burdens (as a percentage of GDP) in the same range as those of developed countries. We also assess the policy options available for calculating historical responsibility. The periodic updating of responsibility calculations over time, concerns over the robustness and availability of emissions data, and the question of whether past emissions were knowingly harmful, may lead to policy choices that increase the relative historical responsibility attributed to developing countries. This, in turn, would increase their mitigation cost burden.

Stern, D.I. **Reversal of the trend in global anthropogenic sulfur emissions.** *Global Environmental Change* 16(2): 207-220, 2006.

Notes: Global anthropogenic sulfur emissions increased until the late 1980s. Existing estimates for 1995 and 2000 show a moderate decline from 1990 to 1995 or relative stability throughout the decade. This paper combines previously published data and new econometric estimates to show a 22% decline over the decade to a level not seen since the mid-1960s. The decline is evident in North America, Western and Eastern Europe, and in the last few years in East and South Asia. If this new trend is maintained, local air pollution problems will be ameliorated but global warming may be somewhat exacerbated.

Zweng, M.M. and Münchow, A. **Warming and freshening of Baffin Bay, 1916-2003.** *Journal of Geophysical Research* 111(7): art. C07016, 2006.

Notes: Regression analysis of historical hydrographic data is used to determine changes in temperature and salinity in Baffin Bay for the time period from 1916 to 2003. We find two distinct sets of changes in the Baffin: First, areas affected by the Atlantic inflow to Baffin Bay show substantial and statistically significant warming trends. In the more than 2000 m deep basin the warming peaks at $0.11 \pm 0.06^\circ\text{C}/\text{decade}$ at 700 m depth below the 640 m sill depth of Davis Strait connecting Baffin Bay to the North Atlantic Ocean. A vertical heat flux divergence of $0.25 \text{ W}/\text{m}^2$ is required to warm Baffin Bay below 900 m by the amount observed. The required heat appears to be advected from the shelf and slope regions of the eastern Labrador Sea

via Davis Strait along the west Greenland shelf break and diffuses vertically and horizontally into the deep central basin. The North Atlantic Oscillation index accounts for about 30% of the interannual variance of temperature fluctuations below the Davis Strait sill depth. Second, areas affected by Arctic inflow to Baffin Bay show a marginally significant freshening of up to about 0.086 ± 0.039 psu/decade. This freshening trend extends along the western margin of Baffin Island to Davis Strait and into the Labrador Sea. The freshening in the northern reaches of Baffin Bay is similar in size to that at its southern reaches. Temporal variability of annual composites between these locations appears to be in phase, suggesting a swift transition of Arctic waters at 76°N to Labrador Sea waters at 62°N.

Hurst, D.F., Lin, J.C., Romashkin, P.A., Daube, B.C., Gerbig, C., Matross, D.M., Wofsy, S.C., Hall, B.D., and Elkins, J.W. **Continuing global significance of emissions of Montreal Protocol-restricted halocarbons in the United States and Canada.** *Journal of Geophysical Research* 111(15): art. D15302, 2006.

Notes: Contemporary emissions of six restricted, ozone-depleting halocarbons, chlorofluoro-carbon-11 (CFC-11, CCl₃F), CFC-12 (CCl₂F₂), CFC-113 (CCl₂FCClF₂), methyl chloroform (CH₃CCl₃), carbon tetrachloride (CCl₄), and Halon-1211 (CBrClF₂), and two nonregulated trace gases, chloroform (CHCl₃) and sulfur hexafluoride (SF₆), are estimated for the United States and Canada. The estimates derive from 900 to 2900 in situ measurements of each of these gases within and above the planetary boundary layer over the United States and Canada as part of the 2003 CO₂ Budget and Regional Airborne-North America (COBRA-NA) study. Air masses polluted by anthropogenic sources, identified by concurrently elevated levels of carbon monoxide (CO), SF₆, and CHCl₃, were sampled over a wide geographical range of these two countries. For each polluted air mass, we calculated emission ratios of halocarbons to CO and employed the Stochastic Time-Inverted Lagrangian Transport (STILT) model to determine the footprint associated with the air mass. Gridded CO emission estimates were then mapped onto the footprints and combined with measured emission ratios to generate footprint-weighted halocarbon flux estimates. We present statistically significant linear relationships between halocarbon fluxes (excluding CCl₄) and footprint-weighted population densities, with slopes representative of per capita emission rates. These rates indicate that contemporary emissions of five restricted halocarbons (excluding CCl₄) in the United States and Canada continue to account for significant fractions (7-40%) of global emissions.

Thompson, L.G., Mosley-Thompson, E., Brecher, H., Davis, M., Leon, B., Les, D., Lin, P.-N., Mashiotta, T., and Mountain, K. **Abrupt tropical climate change: Past and present.** *Proceedings of the National Academy of Sciences [USA]* 103(28): 10536-10543, 2006.

Notes: Three lines of evidence for abrupt tropical climate change, both past and present, are presented. First, annually and decadal averaged $\delta^{18}\text{O}$ and net mass-balance histories for the last 400 and 2,000 yr, respectively, demonstrate that the current warming at high elevations in the mid- to low latitudes is unprecedented for at least the last 2 millennia. Second, the continuing retreat of most mid- to low-latitude glaciers, many having persisted for thousands of years, signals a recent and abrupt change in the Earth's climate system. Finally, rooted, soft-bodied wetland plants, now exposed along the margins as the Quelccaya ice cap (Peru) retreats, have been radiocarbon dated and, when coupled with other widespread proxy evidence, provide strong evidence for an abrupt mid-Holocene climate event that marked the transition from early Holocene (pre-5,000-yr-B.P.) conditions to cooler, late Holocene (post-5,000-yr-B.P.) conditions. This abrupt event, ~ 5,200 yr ago, was widespread and spatially coherent through much of the tropics and was coincident with structural changes in several civilizations. These three lines of evidence argue that the present warming and associated glacier retreat are unprecedented in some areas for at least 5,200 yr. The ongoing global-scale, rapid retreat of mountain glaciers is not only contributing to global sea-level rise but also threatening freshwater supplies in many of the world's most populous regions.

Hill, J., Nelson, E., Tilman, D., Polasky, S., and Tiffany, D. **Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels.** *Proceedings of the National Academy of Sciences [USA]* 103(30): 11206-11210, 2006.

Notes: Negative environmental consequences of fossil fuels and concerns about petroleum supplies have spurred the search for renewable transportation biofuels. To be a viable alternative, a biofuel should provide a net energy gain, have environmental benefits, be economically competitive, and be producible in large quantities without reducing food supplies. We use these criteria to evaluate, through life-cycle accounting, ethanol from corn grain and biodiesel from soybeans. Ethanol

yields 25% more energy than the energy invested in its production, whereas biodiesel yields 93% more. Compared with ethanol, biodiesel releases just 1.0%, 8.3%, and 13% of the agricultural nitrogen, phosphorus, and pesticide pollutants, respectively, per net energy gain. Relative to the fossil fuels they displace, greenhouse gas emissions are reduced 12% by the production and combustion of ethanol and 41% by biodiesel. Biodiesel also releases less air pollutants per net energy gain than ethanol. These advantages of biodiesel over ethanol come from lower agricultural inputs and more efficient conversion of feedstocks to fuel. Neither biofuel can replace much petroleum without impacting food supplies. Even dedicating all U.S. corn and soybean production to biofuels would meet only 12% of gasoline demand and 6% of diesel demand. Until recent increases in petroleum prices, high production costs made biofuels unprofitable without subsidies. Biodiesel provides sufficient environmental advantages to merit subsidy. Transportation biofuels such as synfuel hydrocarbons or cellulosic ethanol, if produced from low-input biomass grown on agriculturally marginal land or from waste biomass, could provide much greater supplies and environmental benefits than food-based biofuels.

Zenz House, K., Schrag, D.P., Harvey, C.F., and Lackner, K.S. **Permanent carbon dioxide storage in deep-sea sediments.** *Proceedings of the National Academy of Sciences [USA]* 103(33): 12291-12295, 2006.

Notes: Stabilizing the concentration of atmospheric CO₂ may require storing enormous quantities of captured anthropogenic CO₂ in near-permanent geologic reservoirs. Because of the subsurface temperature profile of terrestrial storage sites, CO₂ stored in these reservoirs is buoyant. As a result, a portion of the injected CO₂ can escape if the reservoir is not appropriately sealed. We show that injecting CO₂ into deep-sea sediments <3,000-m water depth and a few hundred meters of sediment provides permanent geologic storage even with large geomechanical perturbations. At the high pressures and low temperatures common in deep-sea sediments, CO₂ resides in its liquid phase and can be denser than the overlying pore fluid, causing the injected CO₂ to be gravitationally stable. Additionally, CO₂ hydrate formation will impede the flow of CO₂(l) and serve as a second cap on the system. The evolution of the CO₂ plume is described qualitatively from the injection to the formation of CO₂ hydrates and finally to the dilution of the CO₂(aq) solution by diffusion. If calcareous sediments are chosen, then the dissolution of carbonate host rock by the CO₂(aq) solution will slightly increase porosity, which may cause large increases in permeability. Karst formation, however, is unlikely because total dissolution is limited to only a few percent of the rock volume. The total CO₂ storage capacity within the 200-mile economic zone of the U.S. coastline is enormous, capable of storing thousands of years of current U.S. CO₂ emissions.

Hoyos, C.D., Agudelo, P.A., Webster, P.J., and Curry, J.A. **Deconvolution of the factors contributing to the increase in global hurricane intensity.** *Science* 312(5770): 94-97, 2006.

Notes: To better understand the change in global hurricane intensity since 1970, we examined the joint distribution of hurricane intensity with variables identified in the literature as contributing to the intensification of hurricanes. We used a methodology based on information theory, isolating the trend from the shorter-term natural modes of variability. The results show that the trend of increasing numbers of category 4 and 5 hurricanes for the period 1970-2004 is directly linked to the trend in sea-surface temperature; other aspects of the tropical environment, although they influence shorter-term variations in hurricane intensity, do not contribute substantially to the observed global trend.

Fedorov, A.V., Dekens, P.S., McCarthy, M., Ravelo, A.C., de Menocal, P.B., Barreiro, M., Pacanowski, R.C., and Philander, S.G. **The Pliocene paradox (Mechanisms for a permanent El Nino).** *Science* 312(5779): 1485-1489, 2006.

Notes: During the early Pliocene, 5 to 3 million years ago, globally averaged temperatures were substantially higher than they are today, even though the external factors that determine climate were essentially the same. In the tropics, El Nino was continual (or "permanent") rather than intermittent. The appearance of northern continental glaciers, and of cold surface waters in oceanic upwelling zones in low latitudes (both coastal and equatorial), signaled the termination of those warm climate conditions and the end of permanent El Nino. This led to the amplification of obliquity (but not precession) cycles in equatorial sea surface temperatures and in global ice volume, with the former leading the latter by several thousand years. A possible explanation is that the gradual shoaling of the oceanic thermocline reached a threshold around 3 million years ago, when the winds started bringing cold waters to the surface in low latitudes. This introduced feedbacks involving ocean-

atmosphere interactions that, along with ice-albedo feedbacks, amplified obliquity cycles. A future melting of glaciers, changes in the hydrological cycle, and a deepening of the thermocline could restore the warm conditions of the early Pliocene.

Landsea, C.W., Harper, B.A., Hoarau, K., and Knaff, J.A. **Can we detect trends in extreme tropical cyclones?** *Science* 313(5786): 452-454, 2006.

Notes: Subjective measurements and variable procedures make existing tropical cyclone databases insufficiently reliable to detect trends in the frequency of extreme cyclones.

Elsner, J.B., Jagger, T.H., and Tsonis, A.A. **Estimated return periods for Hurricane Katrina.** *Geophysical Research Letters* 33(8): art. L08704, 2006.

Notes: Hurricane Katrina is one of the most destructive natural disaster in U.S. history. The infrequency of severe coastal hurricanes implies that empirical probability estimates of the next big one will be unreliable. Here we use an extreme-value model together with interpolated best-track (HURDAT) records to show that a hurricane of Katrina's intensity or stronger can be expected to occur, on average, once every 21 years somewhere along the Gulf coast from Texas through Alabama and once every 14 years somewhere along the entire coast from Texas through Maine. The model predicts a 100-year return level of 83 ms⁻¹ (186 mph) during globally warm years and 75 ms⁻¹ (168 mph) during globally cool years. This difference is consistent with models predicting an increase in hurricane intensity with increasing greenhouse warming.

Newman, P.A., Nash, E.R., Kawa, S.R., Montzka, S.A., and Schauffler, S.M. **When will the Antarctic ozone hole recover?** *Geophysical Research Letters* 33(12): art. L12814, 2006.

Notes: The Antarctic ozone hole demonstrates large-scale, man-made affects on our atmosphere. Surface observations now show that human produced ozone-depleting substances (ODSs) are declining. The ozone hole should soon start to diminish because of this decline. We demonstrate a parametric model of ozone hole area that is based upon a new algorithm for estimating chlorine and bromine levels over Antarctica and late spring Antarctic stratospheric temperatures. This model explains 95% of the ozone hole area's variance. We then use future ODS levels to predict ozone hole recovery. Full recovery to 1980 levels will occur around 2068 and the area will very slowly decline between 2001 and 2017. Detection of a statistically significant decrease of area will not occur until about 2024. We further show that nominal Antarctic stratospheric greenhouse gas forced temperature change should have a small impact on the ozone hole.

Trenberth, K.E. and Shea, D.J. **Atlantic hurricanes and natural variability in 2005.** *Geophysical Research Letters* 33(12), 2006.

Notes: The 2005 North Atlantic hurricane season (1 June to 30 November) was the most active on record by several measures, surpassing the very active season of 2004 and causing an unprecedented level of damage. Sea surface temperatures (SSTs) in the tropical North Atlantic (TNA) region critical for hurricanes (10° to 20°N) were at record high levels in the extended summer (June to October) of 2005 at 0.9°C above the 1901-70 normal and were a major reason for the record hurricane season. Changes in TNA SSTs are associated with a pattern of natural variation known as the Atlantic Multi-decadal Oscillation (AMO). However, previous AMO indices are conflated with linear trends and a revised AMO index accounts for between 0 and 0.1°C of the 2005 SST anomaly. About 0.45°C of the SST anomaly is common to global SST and is thus linked to global warming and, based on regression, about 0.2°C stemmed from after-effects of the 2004-05 El Niño.

Johnson, G.C. and Doney, S.C. **Recent western South Atlantic bottom water warming.** *Geophysical Research Letters* 33(14): art. L14614, 2006.

Notes: Potential temperature differences are computed from hydrographic sections transiting the western basins of the South Atlantic Ocean from 60°S to the equator in 2005/2003 and 1989/1995. While warming is observed throughout much of the water column, the most statistically significant warming is about +0.04°C in the bottom 1500 dbar of the Brazil Basin, with similar (but less statistically significant) warming signals in the abyssal Argentine Basin and Scotia Sea. These abyssal waters of Antarctic origin spread northward in the South Atlantic. The observed abyssal Argentine Basin warming is of a similar magnitude to that previously reported between 1980 and 1989. The Brazil Basin abyssal warming is similar in size to and consistent in timing with previously reported changes in abyssal southern inflow and northern outflow. The temperature changes reported here, if they were to hold throughout the abyssal world ocean, would contribute substantially to global ocean heat budgets.

Jin, J.J., Semeniuk, K., Manney, G.L., Jonsson, A.I., Beagley, S.R., McConnell, J.C., Dufour, G., Nassar, R., Boone, C.D., Walker, K.A., Bernath, P.F., and Rinsland, C.P. **Severe Arctic ozone loss in the winter 2004/2005: observations from ACE-FTS.** *Geophysical Research Letters* 33(15): art. L15801, 2006.

Notes: The severe Arctic ozone reduction in the winter 2004/2005 is analyzed using ACE-FTS observations and four different analysis techniques: correlations between ozone and long-lived tracers (adjusted to account for mixing), an artificial tracer correlation method, a profile-descent technique, and the empirical relationship between ozone loss and potential PSC volume. The average maximum ozone loss was about 2.1 ppmv at 475 K-500 K (~18 km-20 km). Over 60% of the ozone between 425 K-475 K (~16 km-18 km) was destroyed. The average total column ozone loss was 119 DU, ~20-30 DU larger than the largest previously observed Arctic ozone loss in the winter 1999/2000.

Elsner, J.B. **Evidence in support of the climate change-Atlantic hurricane hypothesis.** *Geophysical Research Letters* 33(16): art. L16705, 2006.

Notes: The power of Atlantic tropical cyclones is rising rather dramatically and the increase is correlated with an increase in the late summer/early fall sea surface temperature over the North Atlantic. A debate concerns the nature of these increases with some studies attributing them to a natural climate fluctuation, known as the Atlantic Multidecadal Oscillation (AMO), and others suggesting climate change related to anthropogenic increases in radiative forcing from greenhouse-gases. Here tests for causality using the global mean near-surface air temperature (GT) and Atlantic sea surface temperature (SST) records during the Atlantic hurricane season are applied. Results show that GT is useful in predicting Atlantic SST, but not the other way around. Thus GT "causes" SST providing additional evidence in support of the climate change hypothesis. Results have serious implications for life and property throughout the Caribbean, Mexico, and portions of the United States.

Royer, T.C. and Grosch, C.E. **Ocean warming and freshening in the northern Gulf of Alaska.** *Geophysical Research Letters* 33(16): art. L16605, 2006.

Notes: Water column temperatures on the shelf in the northern Gulf of Alaska have increased more than 0.8°C and vertical density stratification has increased since 1970 near Seward, Alaska throughout the 250 m depth. This high latitude marine system has low water temperatures, high rates of precipitation, glacial melting, high wind speeds and high rates of biological productivity. A more than 300 km alongshore shift (locally westward) of isotherms is suggested. The observations are consistent with a conceptual ocean-atmosphere circulation model that employs coastal freshwater discharge, glacial ablation and wind forcing. Positive regional feedback mechanisms accelerate the discharge and poleward heat flux, leading to even higher temperatures, increased ocean stratification and increased storminess. This warming and ocean freshening will have significant impacts on the atmosphere and marine ecosystems of the Northeast Pacific, Bering Sea, Arctic Ocean and quite possibly global ocean circulation.
