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Climate and climate change

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In this review:

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A. Recent articles with abstracts

Bromwich, D.H. and Nicolas, J.P. Sea-level rise: Ice-sheet uncertainty. *Nature Geoscience* 3(9): 596-597, 2010.

Notes: Gravity measurements of the ice-mass loss in Greenland and Antarctica are complicated by glacial isostatic adjustment. Simultaneous estimates of both signals confirm the negative trends in ice-sheet mass balance, but not their magnitude.

Kern, S., Kaleschke, L., and Spreen, G. Climatology of the Nordic (Irminger, Greenland, Barents, Kara and White/Pechora) Seas ice cover based on 85 GHz satellite microwave radiometry: 1992–2008. *Tellus A* 62(4): 411-434, 2010.

Notes: The ice cover of the Arctic peripheral seas bordering the Northern North Atlantic is examined for 1992-2008 using the ARTIST Sea Ice (ASI) algorithm applied to derive the sea ice concentration from 85 GHz SSM/I measurements. Our analysis reveals a 2 months longer ice-free season in the Irminger Sea (IS), and reductions in ice area and extent between 1992-1999 and 2000-2008 by 10-20% during winter and 30-55% in summer. Barents Sea (BS) ice-cover anomalies (ICA) persist twice as long as ICA in the other regions. Early winter ICA in region IS are correlated to late summer/fall Greenland Sea (GS) ICA. Summertime GS and wintertime IS ICA are correlated to winter Fram Strait ice-area flux anomalies. The wintertime GS ice-cover decrease is associated with less IS Odden events. Our analysis suggests a large-scale, interregional ocean-ice-atmosphere feedback mechanism involving regions BS, Kara (KS) and White/Pechora Sea (WPS). To understand this mechanism the current and preceding general atmospheric circulation, associated variations in Arctic Ocean ice export and oceanic heat advection are needed. However, our results suggest (1) BS ICA could play a key role to predict subsequent KS ICA and (2) anomalous Arctic Ocean ice export into BS could trigger long-lasting BS ICA.

Fu, F.-X., Place, A.R., Garcia, N.S., and Hutchins, D.A. CO_2 and phosphate availability control the toxicity of the harmful bloom dinoflagellate *Karlodinium veneficum*. *Aquatic Microbial Ecology* 59(1): 55-65, 2010.

Notes: We demonstrated that the toxicity of the harmful bloom dinoflagellate *Karlodinium veneficum* is regulated by both CO_2 concentrations and phosphate availability. Semi-continuous cultures were grown in a factorial experiment under all combinations of 3 CO_2 levels (230, 430 and 745 ppm) and 2 phosphate conditions (0.5 and 20 uM). After steady-state acclimation was achieved, karlotoxin cellular quotas and growth rates were determined in all 6 treatments. This strain produced both types of karlotoxin, Km Tx-1 and Km Tx-2. Chlorophyll *a*-normalized production of the 2 types of karlotoxins was much higher in P-limited cultures compared with P-replete ones under the same CO_2 conditions. Increasing CO_2 strongly stimulated production of Km Tx-1 and decreased production of Km Tx-2 in both treatments, but especially in P-limited cultures. Because the Km Tx-1 toxin is an order of magnitude more potent than Km Tx-2, total cellular toxicity was increased dramatically at high pCO_2, particularly in P-limited cultures. Specific growth rates were accelerated by enriched CO_2 in P-replete cultures, but not in P-limited treatments. Growth rates or toxicity of *K. veneficum* could increase substantially in the

future with high CO_2 levels in the ocean, depending on P availability, and so interactions between rising CO_2 and eutrophication could cause major shifts in present clay patterns of harmful algal toxin production. These results suggest that over the coming decades, rising CO_2 could substantially increase karlotoxin damage to food webs in the often P-limited estuaries where *Karlodinium* blooms occur.

Sorte, C.J.B., Williams, S.L., and Carlton, J.T. Marine range shifts and species introductions: comparative spread rates and community impacts. *Global Ecology and Biogeography* 19(3): 303-316, 2010.

Notes: *Aim* Shifts in species ranges are a predicted and realized effect of global climate change; however, few studies have addressed the rates and consequence of such shifts, particularly in marine systems. Given ecological similarities between shifting and introduced species, we examined how our understanding of range shifts may be informed by the more established study of non-native species introductions. *Location* Marine systems world-wide. *Methods* Database and citation searches were used to identify 129 marine species experiencing range shifts and to determine spread rates and impacts on recipient communities. Analyses of spread rates were based on studies for which post-establishment spread was reported in linear distance. The sizes of the effects of community impacts of shifting species were compared with those of functionally similar introduced species having ecologically similar impacts. *Results* Our review and meta-analyses revealed that: (1) 75% of the range shifts found through the database search were in the poleward direction, consistent with climate change scenarios, (2) spread rates of range shifts were lower than those of introductions, (3) shifting species spread over an order of magnitude faster in marine than in terrestrial systems, and (4) directions of community effects were largely negative and magnitudes were often similar for shifters and introduced species; however, this comparison was limited by few data for range-shifting species. *Main conclusions* Although marine range shifts are likely to proceed more slowly than marine introductions, the community-level effects could be as great, and in the same direction, as those of introduced species. Because it is well-established that introduced species are a primary threat to global biodiversity, it follows that, just like introductions, range shifts have the potential to seriously affect biological systems. In addition, given that ranges shift faster in marine than terrestrial environments, marine communities might be affected faster than terrestrial ones as species shift with climate change. Regardless of habitat, consideration of range shifts in the context of invasion biology can improve our understanding of what to expect from climate change-driven shifts as well as provide tools for formal assessment of risks to community structure and function.

Banks, S.C., Ling, S.D., Johnson, C.R., Piggott, M.P., Williamson, J.E., and Beheregaray, L.B. Genetic structure of a recent climate change-driven range extension. *Molecular Ecology* 19(10): 2011-2024, 2010.

Notes: The life-history strategies of some species make them strong candidates for rapid exploitation of novel habitat under new climate regimes. Some early-responding species may be considered invasive, and negatively impact on 'naive' ecosystems. The barrens-forming sea urchin *Centrostephanus rodgersii* is one such species, having a high dispersal capability and a high-latitude range margin limited only by a developmental temperature threshold. Within this species' range in eastern Australian waters, sea temperatures have increased at greater than double the global average rate. The coinciding poleward range extension of *C. rodgersii* has caused major ecological changes, threatening reef biodiversity and fisheries productivity. We investigated microsatellite diversity and population structure associated with range expansion by this species. Generalized linear model analyses revealed no reduction in genetic diversity in the newly colonized region. A 'seascape genetics' analysis of genetic distances found no spatial genetic structure associated with the range extension. The distinctive genetic characteristic of the extension zone populations was reduced population-specific F_{ST}, consistent with very rapid population expansion. Demographic and genetic simulations support our inference of high connectivity between pre- and post-extension zones. Thus, the range shift appears to be a poleward extension of the highly-connected rangewide population of *C. rodgersii*. This is consistent with advection of larvae by the intensified warm water East Australian current, which has also increased Tasmanian Sea temperatures above the species' lower developmental threshold. Thus, ocean circulation changes have improved the climatic suitability of novel habitat for *C. rodgersii* and provided the supply of recruits necessary for colonization.

Willis, K.J., Bennett, K.D., Bhagwat, S.A., and Birks, H.J.B. 4 ºC and beyond: What did this mean for biodiversity in the past? *Systematics and Biodiversity* 8(1): 3-9, 2010. O / A

Notes: How do the predicted climatic changes (IPCC, 2007) for the next century compare in magnitude and rate to those that Earth has previously encountered? Are there comparable intervals of rapid rates of temperature change, sea-level rise and levels of atmospheric CO_2 that can be used as analogues to assess possible biotic responses to future change? Or are we stepping into the great unknown? This perspective article focuses on intervals in time in the fossil record when atmospheric CO_2 concentrations increased up to 1200 ppmv, temperatures in mid-to high-latitudes increased by greater than 4 ºC within 60 years, and sea levels rose by up to 3 m higher than present. For these intervals in time, case studies of past biotic responses are presented to demonstrate the scale and impact of the magnitude and rate of such climate changes on biodiversity. We argue that although the underlying mechanisms responsible for these past changes in climate were very different (i.e. natural processes rather than anthropogenic), the rates and magnitude of climate change are similar to those predicted for the future and therefore potentially relevant to understanding future biotic response. What emerges from these past records is evidence for rapid community turnover, migrations, development of novel ecosystems and thresholds from one stable ecosystem state to another, but there is very little evidence for broad-scale extinctions due to a warming world. Based on this evidence from the fossil record, we make four recommendations for future climate-change integrated conservation strategies.

Stauder, M., Vezzulli, L., Pezzati, E., Repetto, B., and Pruzzo, C. Temperature affects *Vibrio cholerae* O1 El Tor persistence in the aquatic environment via an enhanced expression of GbpA and MSHA adhesins. *Environmental Microbiology Reports* 2(1): 140-144, 2010. O / A

Notes: *Vibrio cholerae* O1 El Tor attachment to chitin and biofilm formation on polyvinylchloride surfaces via the N-acetylglucosamine-binding protein A (GbpA) and the mannose-sensitive haemagglutinin (MSHA) were investigated under different temperature and salinity conditions simulating those found in the aquatic environment. *In vitro* tests showed that *mshA* and *gbpA* defective *V. cholerae* N16961 strains displayed a significant reduction ($P < 0.05$) in attachment to chitin in comparison with the parent in all the environmental conditions tested. The lack of *mshA*, but not *gbpA*, resulted in a significant decrease ($P < 0.05$) of *V. cholerae* N16961 strain ability to form biofilm. Wild-type attachment to chitin and biofilm formation increased from 15 ºC to 25 ºC as did *gbpA* and *mshA* expression. *In situ* data obtained analysing zooplankton and water samples collected in coastal waters of NW Mediterranean Sea over an annual cycle showed that the percentage of plankton-associated *V. cholerae* was positive correlated with sea surface temperature, and increased dramatically at temperature values above 22 ºC. It is suggested that temperature plays a major role in affecting persistence of *V. cholerae* in the aquatic environment by promoting colonization of environmental surfaces, via an enhanced expression of both *mshA* and *gbpA*.

Marbà, N. and Duarte, C.M. Mediterranean warming triggers seagrass (*Posidonia oceanica*) shoot mortality. *Global Change Biology* 16(8): 2366-2375, 2010.

Notes: Rapid warming of the Mediterranean Sea threatens marine biodiversity, particularly key ecosystems already stressed by other impacts such as *Posidonia oceanica* meadows. A 6-year monitoring of seawater temperature and annual *P. oceanica* shoot demography at Cabrera Archipelago National Park (Balearic Islands, Western Mediterranean) allowed us to determine if warming influenced shoot mortality and recruitment rates of seagrasses growing in relative pristine environments. The average annual maximum temperature for 2002-2006 was 1 ºC above temperatures recorded in 1988-1999 (26.6 ºC), two heat waves impacted the region (with seawater warming up to 28.83 ºC in 2003 and to 28.54 ºC in 2006) and the cumulative temperature anomaly, above the 1988-1999 mean annual maximum temperature, during the growing season (i.e. degree-days) ranged between 0 ºC in 2002 and 70 ºC in 2003. Median annual *P. oceanica* shoot mortality rates varied from 0.067 $year^{-1}$ in 2002 to 0.123 $year^{-1}$ in 2003, and exceeded recruitment rates in all stations and years except in shallow stations for year 2004. Interannual fluctuations in shoot recruitment were independent of seawater warming ($P > 0.05$). *P. oceanica* meadows experienced a decline throughout the study period at an average rate of -0.050 ± 0.020 $year^{-1}$. Interannual variability in *P. oceanica* shoot mortality was coupled ($R_2 > 0.40$) to seawater warming variability and increasing water depth: shoot mortality rates increased by 0.022 $year^{-1}$ (i.e. an additional 2% $year^{-1}$) for each additional degree of annual maximum temperature and by 0.001 $year^{-1}$ (i.e. 0.1% $year^{-1}$) for each accumulated degree water temperature remained above 26.6 ºC during the growing season. These results demonstrate that *P. oceanica* meadows are highly vulnerable to warming, which can induce steep declines in shoot abundance as well indicating that climate change poses a significant threat to this important habitat.

Gray, L.J. *et al.* Solar influences on climate. *Reviews of Geophysics* 48: art. RG4001, 2010.

Notes: Understanding the influence of solar variability on the Earth's climate requires knowledge of solar variability, solar-terrestrial interactions, and the mechanisms determining the response of the Earth's climate system. We provide a summary of our current understanding in each of these three areas. Observations and mechanisms for the Sun's variability are described, including solar irradiance variations on both decadal and centennial time scales and their relation to galactic cosmic rays. Corresponding observations of variations of the Earth's climate on associated time scales are described, including variations in ozone, temperatures, winds, clouds, precipitation, and regional modes of variability such as the monsoons and the North Atlantic Oscillation. A discussion of the available solar and climate proxies is provided. Mechanisms proposed to explain these climate observations are described, including the effects of variations in solar irradiance and of charged particles. Finally, the contributions of solar variations to recent observations of global climate change are discussed.

Naqvi, S.W.A., Bange, H.W., Farias, L., Monteiro, P. M. S., Scranton, M. I., and Zhang, J. Marine hypoxia/anoxia as a source of CH_4 and N_2O. *Biogeosciences* 7(7): 2159-2190, 2010. O/A

Notes: We review here the available information on methane (CH_4) and nitrous oxide (N_2O) from major marine, mostly coastal, oxygen (O_2)-deficient zones formed both naturally and as a result of human activities (mainly eutrophication). Concentrations of both gases in subsurface waters are affected by ambient O_2 levels to varying degrees. Organic matter supply to seafloor appears to be the primary factor controlling CH_4 production in sediments and its supply to (and concentration in) overlying waters, with bottom-water O_2-deficiency exerting only a modulating effect. High (micromolar level) CH_4 accumulation occurs in anoxic (sulphidic) waters of silled basins, such as the Black Sea and Cariaco Basin, and over the highly productive Namibian shelf. In other regions experiencing various degrees of O_2-deficiency (hypoxia to anoxia), CH_4 concentrations vary from a few to hundreds of nanomolar levels. Since coastal O_2-deficient zones are generally very productive and are sometimes located close to river mouths and submarine hydrocarbon seeps, it is difficult to differentiate any O_2-deficiency-induced enhancement from in situ production of CH_4 in the water column and its inputs through freshwater runoff or seepage from sediments. While the role of bottom-water O_2-deficiency in CH_4 formation appears to be secondary, even when CH_4 accumulates in O_2-deficient subsurface waters, methanotrophic activity severely restricts its diffusive efflux to the atmosphere. As a result, an intensification or expansion of coastal O_2-deficient zones will probably not drastically change the present status where emission from the ocean as a whole forms an insignificant term in the atmospheric CH_4 budget. The situation is different for N_2O, the production of which is greatly enhanced in low-O_2 waters, and although it is lost through denitrification in most suboxic and anoxic environments, the peripheries of such environments offer most suitable conditions for its production, with the exception of enclosed anoxic basins. Most O_2-deficient systems serve as strong net sources of N_2O to the atmosphere. This is especially true for coastal upwelling regions with shallow O_2-deficient zones where a dramatic increase in N_2O production often occurs in rapidly denitrifying waters. Nitrous oxide emissions from these zones are globally significant, and so their ongoing intensification and expansion is likely to lead to a significant increase in N_2O emission from the ocean. However, a meaningful quantitative prediction of this increase is not possible at present because of continuing uncertainties concerning the formative pathways to N_2O as well as insufficient data from key coastal regions.

Schmalenbach, I. and Franke, H.D. Potential impact of climate warming on the recruitment of an economically and ecologically important species, the European lobster (*Homarus gammarus*) at Helgoland, North Sea. *Marine Biology* 157(5): 1127-1135, 2010.

Notes: A laboratory-based study was performed to assess the impact of climate warming on the recruitment of the endangered population of the European lobster (*Homarus gammarus*) at Helgoland (North Sea, German Bight). Egg-bearing females collected in situ just after spawning in late summer were subjected to various seasonal temperature regimes. Regimes with elevated temperatures (mild winters) resulted in a strong seasonal forward shift of larval hatching. Hatching took place at significantly lower temperatures than under regimes with normal winters. Experiments on larval development across a range of constant temperatures showed that no successful larval development occurred at temperatures below 14 ºC. Larval survival increased from 9% at 14 ºC to 80% at 22 ºC, while duration of larval development decreased correspondingly from 26 to 13 days. We hypothesize that an ongoing warming of the North Sea will strongly affect the recruitment success of the Helgoland

lobster, mainly resulting from a decoupling of the seasonal peak appearance of larvae from optimal external conditions (temperature, food availability) for larval development.

Peck, L.S., Morley, S.A., and Clark, M.S. Poor acclimation capacities in Antarctic marine ectotherms. *Marine Biology* 157(9): 2051-2059, 2010.

Notes: Animals can respond to temperature change by the following means: using physiological flexibility (including acclimation); or adapting; or migrating, with acclimation proposed as the major mechanism dictating prospects for survival in marine groups. In this study, 6 species of Antarctic invertebrate covering 4 phyla, Echinodermata, Mollusca, Brachiopoda and Crustacea were subjected to acclimation trials at 3 ºC for 60 days. Using acute upper lethal temperatures as a metric of ability to acclimate, only one species (*Marseniopsis mollis*) increased its acute upper limit. Furthermore, analysis of oxygen consumption on the urchin *Sterechinus neumayeri* and the amphipod *Paraceradocus gibber* showed their metabolic rates were also not compensated over the 60-day exposure period. Thus, 5 out of 6 species failed to acclimate to temperatures only 3.5 ºC above the annual average and 1-2 ºC above current summer maximum values. We discuss the proposal that the abilities of Antarctic marine species to adjust to elevated environmental temperatures are as limited, if not more so, than tropical species.

Screen, J.A. and Simmonds, I. The central role of diminishing sea ice in recent Arctic temperature amplification. *Nature* 464(7293): 1334-1337, 2010.

Notes: The rise in Arctic near-surface air temperatures has been almost twice as large as the global average in recent decades – a feature known as 'Arctic amplification'. Increased concentrations of atmospheric greenhouse gases have driven Arctic and global average warming; however, the underlying causes of Arctic amplification remain uncertain. The roles of reductions in snow and sea ice cover and changes in atmospheric and oceanic circulation, cloud cover and water vapour are still matters of debate. A better understanding of the processes responsible for the recent amplified warming is essential for assessing the likelihood, and impacts, of future rapid Arctic warming and sea ice loss. Here we show that the Arctic warming is strongest at the surface during most of the year and is primarily consistent with reductions in sea ice cover. Changes in cloud cover, in contrast, have not contributed strongly to recent warming. Increases in atmospheric water vapour content, partly in response to reduced sea ice cover, may have enhanced warming in the lower part of the atmosphere during summer and early autumn. We conclude that diminishing sea ice has had a leading role in recent Arctic temperature amplification. The findings reinforce suggestions that strong positive ice-temperature feedbacks have emerged in the Arctic, increasing the chances of further rapid warming and sea ice loss, and will probably affect polar ecosystems, ice-sheet mass balance and human activities in the Arctic.

Boyce, D.G., Lewis, M.R., and Worm, B. Global phytoplankton decline over the past century. *Nature* 466(7306): 591-596, 2010.

Notes: In the oceans, ubiquitous microscopic phototrophs (phytoplankton) account for approximately half the production of organic matter on Earth. Analyses of satellite-derived phytoplankton concentration (available since 1979) have suggested decadal-scale fluctuations linked to climate forcing, but the length of this record is insufficient to resolve longer-term trends. Here we combine available ocean transparency measurements and in situ chlorophyll observations to estimate the time dependence of phytoplankton biomass at local, regional and global scales since 1899. We observe declines in eight out of ten ocean regions, and estimate a global rate of decline of ~1% of the global median per year. Our analyses further reveal interannual to decadal phytoplankton fluctuations superimposed on long-term trends. These fluctuations are strongly correlated with basin-scale climate indices, whereas long-term declining trends are related to increasing sea surface temperatures. We conclude that global phytoplankton concentration has declined over the past century; this decline will need to be considered in future studies of marine ecosystems, geochemical cycling, ocean circulation and fisheries.

Schmidt, G.A., Ruedy, R.A., Miller, R.L., and Lacis, A.A. Attribution of the present-day total greenhouse effect. *Journal of Geophysical Research – Atmospheres* 115(20): art. D20106, 2010.

Notes: The relative contributions of atmospheric long-wave absorbers to the present-day global greenhouse effect are among the most misquoted statistics in public discussions of climate change. Much of the interest in these values is however due to an implicit assumption that these contributions are directly relevant for the question of climate sensitivity. Motivated by the need for a clear reference for this issue, we review the existing literature and use the Goddard Institute for Space Studies ModelE radiation module to provide an overview of the role of each absorber at the present-day and under doubled CO_2. With a straightforward scheme for allocating overlaps, we find that water vapor is the dominant contributor (~50% of the effect), followed by clouds (~25%) and then CO_2 with ~20%. All other absorbers play only minor roles. In a doubled CO2 scenario, this allocation is essentially unchanged, even though the magnitude of the total greenhouse effect is significantly larger than the initial radiative forcing, underscoring the importance of feedbacks from water vapor and clouds to climate sensitivity.

Palm, S.P., Strey, S.T., Spinhirne, J., and Markus, T. Influence of Arctic sea ice extent on polar cloud fraction and vertical structure and implications for regional climate. *Journal of Geophysical Research – Atmospheres* 115(21): art. D21209, 2010.

Notes: Recent satellite lidar measurements of cloud properties spanning a period of 5 years are used to examine a possible connection between Arctic sea ice amount and polar cloud fraction and vertical distribution. We find an anticorrelation between sea ice extent and cloud fraction with maximum cloudiness occurring over areas with little or no sea ice. We also find that over ice-free regions, there is greater low cloud frequency and average optical depth. Most of the optical depth increase is due to the presence of geometrically thicker clouds over water. In addition, our analysis indicates that over the last 5 years, October and March average polar cloud fraction has increased by about 7% and 10%, respectively, as year average sea ice extent has decreased by 5%-7%. The observed cloud changes are likely due to a number of effects including, but not limited to, the observed decrease in sea ice extent and thickness. Increasing cloud amount and changes in vertical distribution and optical properties have the potential to affect the radiative balance of the Arctic region by decreasing both the upwelling terrestrial longwave radiation and the downward shortwave solar radiation. Because longwave radiation dominates in the long polar winter, the overall effect of increasing low cloud cover is likely a warming of the Arctic and thus a positive climate feedback, possibly accelerating the melting of Arctic sea ice.

Cantin, N.E., Cohen, A.L., Karnauskas, K.B., Tarrant, A.M., and McCorkle, D.C. Ocean warming slows coral growth in the central Red Sea. *Science* 329(5989): 322-325, 2010.

Notes: Sea surface temperature (SST) across much of the tropics has increased by 0.4 º to 1 ºC since the mid-1970s. A parallel increase in the frequency and extent of coral bleaching and mortality has fueled concern that climate change poses a major threat to the survival of coral reef ecosystems worldwide. Here we show that steadily rising SSTs, not ocean acidification, are already driving dramatic changes in the growth of an important reef-building coral in the central Red Sea. Three-dimensional computed tomography analyses of the massive coral *Diploastrea heliopora* reveal that skeletal growth of apparently healthy colonies has declined by 30% since 1998. The same corals responded to a short-lived warm event in 1941/1942, but recovered within 3 years as the ocean cooled. Combining our data with climate model simulations by the Intergovernmental Panel on Climate Change, we predict that should the current warming trend continue, this coral could cease growing altogether by 2070.

Cai, W.J., Chen, L.Q., Chen, B.S., Gao, Z.Y., Lee, S.H., Chen, J.F., Pierrot, D., Sullivan, K., Wang, Y.C., Hu, X.P., Huang, W.J., Zhang, Y.H., Xu, S.Q., Murata, A., Grebmeier, J.M., Jones, E.P., and Zhang, H.S. Decrease in the CO_2 uptake capacity in an ice-free Arctic Ocean basin. *Science* 329(5991): 556-559, 2010.

Notes: It has been predicted that the Arctic Ocean will sequester much greater amounts of carbon dioxide (CO_2) from the atmosphere as a result of sea ice melt and increasing primary productivity. However, this prediction was made on the basis of observations from either highly productive ocean margins or ice-covered basins before the recent major ice retreat. We report here a high-resolution survey of sea-surface CO_2 concentration across the Canada Basin, showing a great increase relative to

earlier observations. Rapid CO_2 invasion from the atmosphere and low biological CO_2 drawdown are the main causes for the higher CO_2, which also acts as a barrier to further CO_2 invasion. Contrary to the current view, we predict that the Arctic Ocean basin will not become a large atmospheric CO_2 sink under ice-free conditions.

Le Quéré, C., Takahashi, T., Buitenhuis, E.T., Rödenbeck, C., and Sutherland, S.C. Impact of climate change and variability on the global oceanic sink of CO_2. *Global Biogeochemical Cycles* 24(40): art. GB4007, 2010.

Notes: About one quarter of the CO_2 emitted to the atmosphere by human activities is absorbed annually by the ocean. All the processes that influence the oceanic uptake of CO_2 are controlled by climate. Hence changes in climate (both natural and human-induced) are expected to alter the uptake of CO_2 by the ocean. However, available information that constrains the direction, magnitude, or rapidity of the response of ocean CO_2 to changes in climate is limited. We present an analysis of oceanic CO_2 trends for 1981 to 2007 from data and a model. Our analysis suggests that the global ocean responded to recent changes in climate by outgassing some preindustrial carbon, in part compensating the oceanic uptake of anthropogenic CO_2. Using a model, we estimate that climate change and variability reduced the CO_2 uptake by 12% compared to a simulation where constant climate is imposed, and offset 63% of the trend in response to increasing atmospheric CO_2 alone. The response is caused by changes in wind patterns and ocean warming, with important nonlinear effects that amplify the response of oceanic CO_2 to changes in climate by >30%.

Metzl, N. et al. Recent acceleration of the sea surface fCO_2 growth rate in the North Atlantic subpolar gyre (1993-2008) revealed by winter observations. *Global Biogeochemical Cycles* 24(40): art. GB4004, 2010.

Notes: Recent studies based on ocean and atmospheric carbon dioxide (CO_2) observations, suggesting that the ocean carbon uptake has been reduced, may help explain the increase in the fraction of anthropogenic CO_2 emissions that remain in the atmosphere. Is it a response to climate change or a signal of ocean natural variability or both? Regional process analyses are needed to follow the ocean carbon uptake and to enable better attributions of the observed changes. Here, we describe the evolution of the surface ocean CO_2 fugacity (fCO_2^{oc}) over the period 1993-2008 in the North Atlantic subpolar gyre (NASPG). This analysis is based primarily on observations of dissolved inorganic carbon (DIC) and total alkalinity (TA) conducted at different seasons in the NASPG between Iceland and Canada. The fCO_2^{oc} trends based on DIC and TA data are also compared with direct fCO_2 measurements obtained between 2003 and 2007 in the same region. During winters 1993-2003, the fCO_2^{oc} growth rate was 3.7 (±0.6) μatm yr^{-1}, higher than in the atmosphere, 1.8 (±0.1) μatm yr^{-1}. This translates to a reduction of the ocean carbon uptake primarily explained by sea surface warming, up to 0.24 (±0.04) °C yr^{-1}. This warming is a consequence of advection of warm water northward from the North Atlantic into the Irminger basin, which occurred as the North Atlantic Oscillation (NAO) index moved into a negative phase in winter 1995/1996. In winter 2001-2008, the fCO_2^{oc} rise was particularly fast, between 5.8 (±1.1) and 7.2 (±1.3) μatm yr^{-1} depending on the region, more than twice the atmospheric growth rate of 2.1 (±0.2) μatm yr^{-1}, and in the winter of 2007-2008 the area was supersaturated with CO_2. As opposed to the 1990s, this appears to be almost entirely due to changes in seawater carbonate chemistry, the combination of increasing DIC and decreasing of TA. The rapid fCO_2^{oc} increase was not only driven by regional uptake of anthropogenic CO_2 but was also likely controlled by a recent increase in convective processes-vertical mixing in the NASPG and cannot be directly associated with NAO variability. The fCO_2^{oc} increase observed in 2001-2008 leads to a significant drop in pH of -0.069 (±0.007) $decade^{-1}$.

Polyak, L., Alley, R.B., Andrews, J.T., Brigham-Grette, J., Cronin, T.M., Darby, D.A., Dyke, A.S., Fitzpatrick, J.J., Funder, S., Holland, M., Jennings, A.E., Miller, G.H., O'Regan, M., Savelle, J., Serreze, M., St. John, K., White, J.W.C., and Wolff, E. History of sea ice in the Arctic. *Quaternary Science Reviews* 29(15-16): 1757-1778, 2010.

Notes: Arctic sea-ice extent and volume are declining rapidly. Several studies project that the Arctic Ocean may become seasonally ice-free by the year 2040 or even earlier. Putting this into perspective requires information on the history of Arctic sea-ice conditions through the geologic past. This information can be provided by proxy records from the Arctic Ocean floor and from the surrounding coasts. Although existing records are far from complete, they indicate that sea ice became a feature

of the Arctic by 47Ma, following a pronounced decline in atmospheric pCO_2 after the Paleocene–Eocene Thermal Optimum, and consistently covered at least part of the Arctic Ocean for no less than the last 13–14 million years. Ice was apparently most widespread during the last 2–3 million years, in accordance with Earth's overall cooler climate. Nevertheless, episodes of considerably reduced sea ice or even seasonally ice-free conditions occurred during warmer periods linked to orbital variations. The last low-ice event related to orbital forcing (high insolation) was in the early Holocene, after which the northern high latitudes cooled overall, with some superimposed shorter-term (multidecadal to millennial-scale) and lower-magnitude variability. The current reduction in Arctic ice cover started in the late 19th century, consistent with the rapidly warming climate, and became very pronounced over the last three decades. This ice loss appears to be unmatched over at least the last few thousand years and unexplainable by any of the known natural variabilities.

Miller, G.H., Alley, R.B., Brigham-Grette, J., Fitzpatrick, J.J., Polyak, L., Serreze, M.C., and White, J.W.C. Arctic amplification: Can the past constrain the future? *Quaternary Science Reviews* 29(15-16): 1779-1790, 2010.

Notes: Arctic amplification, the observation that surface air temperature changes in the Arctic exceed those of the Northern Hemisphere as a whole, is a pervasive feature of climate models, and has recently emerged in observational data relative to the warming trend of the past century. The magnitude of Arctic amplification is an important, but poorly constrained variable necessary to estimate global average temperature change over the next century. Here we evaluate the mechanisms responsible for Arctic amplification on Quaternary timescales, and review evidence from four intervals in the past 3Ma for which sufficient paleoclimate data and model simulations are available to estimate the magnitude of Arctic amplification under climate states both warmer and colder than present. Despite differences in forcings and feedbacks for these reconstructions compared to today, the Arctic temperature change consistently exceeds the Northern Hemisphere average by a factor of 3-4, suggesting that Arctic warming will continue to greatly exceed the global average over the coming century, with concomitant reductions in terrestrial ice masses and, consequently, an increasing rate of sea level rise.

Kug, J.-S., Choi, D.-H., Jin, F.-F., Kwon, W.-T., and Ren, H.-L. Role of synoptic eddy feedback on polar climate responses to the anthropogenic forcing. *Geophysical Research Letters* 37(14): art. L14704, 2010.

Notes: Amplified polar warming and moistening under global warming are critical issues for the climate changes. The authors find that a poleward shift of the westerly jet stream and associated synoptic eddy feedback play a critical role in enhancing polar warming and moistening. Namely, the mean circulation changes due to anthropogenic forcing lead to the changes in storm feedbacks, which reinforce again climate responses, particularly the polar responses such as the enhanced polar warming and moistening. It is demonstrated here that the storm feedback can be explained by a simple rule based on the mean circulation change. This rule can be used for understanding other regional climate responses to the anthropogenic forcing.

Kolker, A.S., Kirwan, M.L., Goodbred, S.L., and Cochran, J.K. Global climate changes recorded in coastal wetland sediments: Empirical observations linked to theoretical predictions. *Geophysical Research Letters* 37(14): art. L14706, 2010.

Notes: Whether coastal areas are experiencing, and responding to, an accelerated rate of global sea-level rise (GSLR) is critically important for the ~2 billion people living near Earth's oceans. Accretion rates from a suite of physiographically diverse coastal wetlands surrounding Long Island, NY accelerated during the 20th century at $2.3 \pm 0.2 \times 10^{-2}$ mm yr^{-2}, which is comparable to reported rates of GSLR acceleration and global temperature changes. Wetlands varied in tidal range, salinity and geomorphic setting, and were located in embayments with limited human impacts in a region with limited and constant rates of subsidence. From geochronologies with temporal resolutions of 2-5 yr, we constructed new composite histories of sediment accretion and mineral deposition. Wetland dynamics are consistent with predictions from sedimentology and a numerical model of ecogeomorphic response, suggesting that these systems, and likely others worldwide, are responding to accelerated GSLR and related climatic changes.

Sigmond, M. and Fyfe, J.C. Has the ozone hole contributed to increased Antarctic sea ice extent? *Geophysical Research Letters* 37(18): art. L18502, 2010.

Notes: Since the 1970s sea ice extent has decreased dramatically in the Northern Hemisphere and increased slightly in the Southern Hemisphere, a difference that is potentially explained by ozone depletion in the Southern Hemisphere stratosphere. In this study we consider the impact of stratospheric ozone depletion on Antarctic sea ice extent using a climate model forced with observed stratospheric ozone depletion from 1979 to 2005. Contrary to expectations, our model simulates a year-round decrease in Antarctic sea ice due to stratospheric ozone depletion. The largest percentage sea ice decrease in our model occurs in the austral summer near the coast of Antarctica, due to a mechanism involving offshore Ekman sea ice transport. The largest absolute decrease is simulated in the austral winter away from the coast of Antarctica, in response to an ocean warming that is consistent with a poleward shift of the large-scale pattern of sea surface temperature. Our model results strongly suggest that processes not linked to stratospheric ozone depletion must be invoked to explain the observed increase in Antarctic sea ice extent.

Irvine, P.J., Ridgwell, A., and Lunt, D.J. Assessing the regional disparities in geoengineering impacts. *Geophysical Research Letters* 37(18): art. L18702, 2010.

Notes: Solar Radiation Management (SRM) Geoengineering may ameliorate many consequences of global warming but also has the potential to drive regional climates outside the envelope of greenhouse-gas induced warming, creating 'novel' conditions, and could affect precipitation in some regions disproportionably. Here, using a fully coupled climate model we explore some new methodologies for assessing regional disparities in geoengineering impacts. Taking a $4 \times CO_2$ climate and an idealized 'sunshade' SRM strategy, we consider different fractions of the maximum theoretical, $4 \times CO_2$-cancelling global mean cooling. Whilst regional predictions in particularly relatively low resolution global climate models must be treated with caution, our simulations indicate that it might be possible to identify a level of SRM geoengineering capable of meeting multiple targets, such as maintaining a stable mass balance of the Greenland ice sheet and cooling global climate, but without reducing global precipitation below pre-industrial or exposing significant fractions of the Earth to 'novel' climate conditions.

Helm, K.P., Bindoff, N.L., and Church, J.A. Changes in the global hydrological-cycle inferred from ocean salinity. *Geophysical Research Letters* 37(18): art. L18701, 2010.

Notes: Using global datasets of in situ observations, we calculate salinity changes on ocean-density surfaces between 1970 and 2005. This reveals a global pattern of increased salinities near the upper-ocean salinity-maximum layer (average depth of ~100 m) and decreased salinities near the intermediate salinity minimum (average depth of ~700 m). The salinity changes imply a 3 ± 2% decrease in precipitation-minus evaporation (P-E) over the mid and low latitude oceans in both hemispheres, a 7 ± 4% increase in the Northern Hemisphere high latitudes, and a 16 ± 6% increase in the Southern Ocean since 1970. This pattern of increased precipitation at high latitudes and decreased precipitation in the subtropics is reflected in both land records and in the short satellite records. The quantification of the atmospheric signal of climate change on ocean salinity supports model projections, and extends the growing evidence for an acceleration of the Earth's water cycle.

Ditlevsen, P.D. and Johnsen, S.J. Tipping points: Early warning and wishful thinking. *Geophysical Research Letters* 37(19): art. L19703, 2010.

Notes: The causes for and possible predictions of rapid climate changes are poorly understood. The most pronounced changes observed, beside the glacial terminations, are the Dansgaard-Oeschger events. Present day general circulation climate models simulating glacial conditions are not capable of reproducing these rapid shifts. It is thus not known if they are due to bifurcations in the structural stability of the climate or if they are induced by stochastic fluctuations. By analyzing a high resolution ice core record we exclude the bifurcation scenario, which strongly suggests that they are noise induced and thus have very limited predictability.

Zhang, J., Steele, M., and Schweiger, A. Arctic sea ice response to atmospheric forcings with varying levels of anthropogenic warming and climate variability. *Geophysical Research Letters* 37(20): art. L20505, 2010.

Notes: Numerical experiments are conducted to project arctic sea ice responses to varying levels of future anthropogenic warming and climate variability over 2010-2050. A summer ice-free Arctic Ocean is likely by the mid-2040s if arctic surface air temperature (SAT) increases 4 °C by 2050 and climate variability is similar to the past relatively warm two decades. If such a SAT increase is reduced by one-half or if a future Arctic experiences a range of SAT fluctuation similar to the past five decades, a summer ice-free Arctic Ocean would be unlikely before 2050. If SAT increases 4 °C by 2050, summer ice volume decreases to very low levels (10-37% of the 1978-2009 summer mean) as early as 2025 and remains low in the following years, while summer ice extent continues to fluctuate annually. Summer ice volume may be more sensitive to warming while summer ice extent more sensitive to climate variability. The rate of annual mean ice volume decrease relaxes approaching 2050. This is because, while increasing SAT increases summer ice melt, a thinner ice cover increases winter ice growth. A thinner ice cover also results in a reduced ice export, which helps to further slow ice volume loss. Because of enhanced winter ice growth, arctic winter ice extent remains nearly stable and therefore appears to be a less sensitive climate indicator.

Kwok, R. and Cunningham, G.F. Contribution of melt in the Beaufort Sea to the decline in Arctic multiyear sea ice coverage: 1993-2009. *Geophysical Research Letters* 37(20): art. L20501, 2010.

Notes: For the summers of 1993 through 2009, we estimate the loss of multiyear sea ice (MYI) area in the Beaufort Sea due to melt. Parcels of MYI in April are traced into the Beaufort Sea where they melt as the ice edge retreats. Net loss of area (with fractional MYI coverage >50%) over the 17-year period is ~900 × 10^3 km^2. Three-quarters of that area, ~10% of the area of the Arctic Ocean, was lost after 2000. There is a clear positive trend in the record, with a distinct peak of 213 × 10^3 km^2 in 2008; this is twice the summer outflow at the Fram Strait that year. The net melt area of 490 × 10^3 km^2 between 2005 and 2008 accounts for nearly 32% of the net loss of 1.54 × 10^6 km^2 of Arctic Ocean MYI coverage over the same period. Volume loss, for the years with ICESat thickness (2004-2009), is highest at 473 km^3 in 2008 followed by 320 km^3 in 2007. Net loss in MYI volume for the six summers is ~1400 km^3. This is ~20% of the loss in MYI volume of 6300 km^3 during 2004-2008. This adds to the freshwater content of the Arctic Ocean and locally to the freshening of the Beaufort Gyre.

Phillips, T., Rajaram, H., and Steffen, K. Cryo-hydrologic warming: A potential mechanism for rapid thermal response of ice sheets. *Geophysical Research Letters* 37(20): art. L20503, 2010.

Notes: Cryo-Hydrologic (CH) warming is proposed as a potential mechanism for rapid thermal response of glaciers and ice sheets to climate warming. We present a simple parameterization to incorporate CH warming in thermal models of ice sheets using a dual-continuum concept, which treats ice and the cryo-hydrologic system (CHS) as overlapping continua with heat exchange between them. The presence of liquid water in the CHS due to surface melt leads to warming of the ice. The magnitude and time-scale of CH warming is controlled by the average spacing between elements of the CHS, which is often of the order of just 10's of meters. The corresponding time-scale of thermal response is of the order of years-decades, in contrast to conventional estimates of thermal response time-scales based on vertical conduction through ice (~10^{2-3} m thick), which are of the order of centuries to millennia. We show that CH warming is already occurring along the west coast of Greenland. Increased temperatures resulting from CH warming will reduce ice viscosity and thus contribute to faster ice flow.

Kumar, A., Perlwitz, J., Eischeid, J., Quan, X., Xu, T., Zhang, T., Hoerling, M., Jha, B., and Wang, W. Contribution of sea ice loss to Arctic amplification. *Geophysical Research Letters* 37(21): art. L21701, 2010.

Notes: Atmospheric climate models are subjected to the observed sea ice conditions during 2007 to estimate the regionality, seasonality, and vertical pattern of temperature responses to recent Arctic sea ice loss. It is shown that anomalous sea ice conditions accounted for virtually all of the estimated Arctic amplification in *surface-based* warming over the Arctic Ocean, and furthermore they accounted for a large fraction of Arctic amplification occurring over the high-latitude land between 60°N and the Arctic Ocean. Sea ice loss did not appreciably contribute to observed 2007 land temperature warmth equatorward of 60°N. Likewise, the observed warming of the *free atmosphere* attributable to sea ice loss is confined to Arctic latitudes, and is

vertically confined to the lowest 1000 m. The results further highlight a strong seasonality of the temperature response to the 2007 sea ice loss. A weak signal of Arctic amplification in surface based warming is found during boreal summer, whereas a dramatically stronger signal is shown to develop during early autumn that persisted through December even as sea ice coverage approached its climatological values in response to the polar night.

Rykaczewski, R.R. and Dunne, J.P. Enhanced nutrient supply to the California Current Ecosystem with global warming and increased stratification in an earth system model. *Geophysical Research Letters* 37(21): art. L21606, 2010.

Notes: A leading hypothesis relating productivity with climate variability in the California Current Ecosystem (CCE) describes an alternation between warmer, well-stratified periods of low productivity and cooler periods of high productivity. This empirical relationship suggests that productivity will decline with global warming. Here, we explore the response of productivity to future climate change in the CCE using an earth system model. This model projects increases in nitrate supply and productivity in the CCE during the 21st century despite increases in stratification and limited change in wind-driven upwelling. We attribute the increased nitrate supply to enrichment of deep source waters entering the CCE resulting from decreased ventilation of the North Pacific. Decreases in dissolved-oxygen concentration and increasing acidification accompany projected increases in nitrate. This analysis illustrates that anthropogenic climate change may be unlike past variability; empirical relationships based on historical observations may be inappropriate for projecting ecosystem responses to future climate change.