all terrestrial carbon is equally reactive. For example, very fresh vegetative debris transported during storms may be rapidly degraded on reaching the ocean, with CO_2 escaping back to the atmosphere. The variability in the composition and ultimate fate of organic carbon (for example, burial versus remineralization) needs to be assessed. These uncertainties will affect the significance of cyclone-induced sequestration of carbon from the terrestrial biosphere in deep sea sediments.

Nevertheless, Hilton and colleagues have made an interesting and potentially important observation that illustrates the complexity of the interactions between the carbon cycle and climate, and provides yet another example of the significance of extreme events in dictating longer-term Earth system behaviour. Indeed, the authors suggest that their observations may be common in humid mountain belts. However, land-to-ocean transfer of terrestrial carbon in a much broader range of river systems may be affected by tropical cyclones.

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CLIMATE SCIENCE

Global warming at the poles

Natural climate variability and limited observational records have made identifying human-influenced climate change at the poles difficult. But a human signature is now emerging in rising Arctic and Antarctic temperatures.

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In the past decade, new observational platforms and improved modelling of the polar climate systems have led to a quantification of recent Arctic and Antarctic climate changes and to a tentative suggestion of causality. A mounting body of literature indicates that the changes in Arctic and Antarctic climate are consistent with the human-induced warming that is occurring globally. On page 750 of this issue, Gillett and colleagues[1] use an innovative attribution technique and simulations from several state-of-the-art global climate models to disentangle the internal and external forcing mechanisms that have contributed to the recently observed variability in near-surface air temperature near the poles.

Arctic near-surface air temperatures have warmed at about twice the global rate over the past 50 years[2]. One of the most dramatic consequences has been the steady decline of sea ice coverage, punctuated by the shocking record minimum in sea ice extent in September 2007 — about 20% below the previous record[3]. The 2007 loss, nearly equalled in 2008, was attributed to anomalous atmospheric conditions but was exacerbated by declining sea ice thickness and extent over the past two decades[4]. Other consequences of Arctic warming include increased river runoff, decreased snow cover, permafrost degradation, and a shrinking Greenland ice sheet that is contributing to the rise in sea level[2] (Fig. 1).


SANDY BRIGGS

Figure 1 A melting iceberg in Home Bay, Baffin Island, in the Canadian Arctic. The analyses by Gillett and colleagues show that increases in temperature in the Arctic and Antarctic regions, along with the attendant thinning of the polar ice sheets, can be attributed to carbon emissions resulting from human activities.

Arctic warming during recent decades has been due partly to atmospheric circulation changes that have not been fully explained by either natural or anthropogenic forcing. The amplified nature of the Arctic warming compared with the global mean rate has been attributed to feedback mechanisms that accelerate climate change, some of which are triggered by the melting of sea ice, snow and permafrost.

Climate changes over Antarctica have been less homogeneous than those in the Arctic region. Antarctic sea ice cover has in general not undergone the marked decline seen for Arctic sea ice[5], and there has been relatively little change in near-surface air temperatures over the vast East Antarctic ice sheet during the past half century[6]. By contrast, recent evidence from ice cores suggests that the sparsely instrumented West Antarctic ice sheet has undergone strong warming with substantial superimposed variability during the past 50–100 years[7]. Several large glaciers that constitute the West Antarctic ice sheet have accelerated and are contributing to rising global sea level[8], owing in part to relatively warm ocean waters now in contact with the base of the ice sheet. Temperature increases on the Antarctic Peninsula of up to 3 °C since the 1950s are among the largest on Earth for that period[9].

The pattern of Antarctic near-surface temperature trends has been attributed primarily to strengthening circumpolar westerly winds, referred to as the Southern Annular Mode. Modelling studies suggest that the upward trend in the Southern Annular Mode is due partly to human activities, including increases in greenhouse gases and the depletion of ozone high above Antarctica (the 'ozone hole'). Others argue that internal climate variability linked to the tropics also has a first-order role in driving the variability of the Southern Annular Mode. Whether the Southern Annular Mode will continue to strengthen in forthcoming decades is still unknown because the relative importance of each of these factors, and how they could change, is uncertain. However, an attribution of the causality of polar climate variability is critical for understanding how the ice sheets will evolve in the twenty-first century.

Gillett and colleagues have analysed the results from several models used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report[10] to examine the mechanisms underlying the observed polar climate changes. Their work demonstrates convincingly what previous studies have suggested — that humans have indeed contributed to warming in both the Arctic and Antarctic regions. The work by Gillett and colleagues is unique in comparison with previous studies that have assessed polar climate variability with the help of global climate models, because it focuses only on the grid points where observational temperature records exist, rather than on the entire Arctic and Antarctic regions.

By this restriction, the group is able to perform an 'apples with apples' comparison of model simulations and polar near-surface temperature records during the twentieth century. Their analysis implies that the models can simulate trends better than previous studies had suggested. Gillett and colleagues were also able to isolate the factors controlling the observed temperature variability. Model simulations that used only natural forcing were unable to recreate the temperature records: observed twentieth-century temperature increases in the Antarctic and Arctic regions could be simulated only when the impacts of industrial greenhouse gas emissions and stratospheric ozone depletion were included in the models.

Because the authors focus only on the grid points for which there are observations, caution must be used in extrapolating the results to the entire polar regions. This is especially true for much of the vast interior of Antarctica, for which there are few observations, and for which other studies suggest that no statistically significant temperature changes exist[6]. Indeed, the distribution of observational records along the coastal margins, and especially on the rapidly warming Antarctic Peninsula, may be biased towards a limited region of Antarctica for which warming has been more pronounced. Gillett and colleagues argue that Antarctic warming would be more widespread if the influence of the Southern Annular Mode trends on temperatures were removed from the signal. In contrast, some of the IPCC models may simulate too much warming over the data-sparse interior of Antarctica[11].

The results of Gillett and colleagues show that efforts to improve polar simulations in the IPCC models are starting to pay off. Their confirmation that humans are contributing to polar changes adds urgency to continuing efforts to simulate more realistic changes in these environments. The coupling of ice sheet processes to the climatic changes in the next generation of global climate models will be an especially important step towards constraining the potentially nonlinear anthropogenic contribution of thinning polar ice sheets to global sea level rise.

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CLIMATE SCIENCE

The other greenhouse effect

Greenhouse agriculture has undergone a massive expansion in southeastern Spain in recent years in order to provide regions of Europe that receive less natural sunlight with fruit and vegetables. In fact, the extremely dry landscape of Almeria, once a backdrop to numerous 'spaghetti westerns', is now home to the world's largest collection of greenhouses.

This horticultural explosion, which has overidden the semi-arid pasture that characterized the region, has had its own regional climatic impact: Pablo Campra of the University of Almeria, Spain and colleagues (*J. Geophys. Res.* **113,** D18109; 2008) found that greenhouses in the coastal regions of Almeria bounce significantly more radiation back into the atmosphere compared with the vegetation in neighbouring communities. The increase in surface reflectance is greatest in summer, when farmers whitewash their greenhouses to stop the plants getting too much sun.

ALEX BRACKE

In an effort to determine the climatic significance of this agricultural development, the team trawled through satellite records of surface reflectivity and regional temperature records. They calculated the net change in solar radiation absorbed due to this particular land-use change, and estimated a reduction by an enormous 19.8 Wm^{-2}, much higher than earlier computations of the radiative effects associated with a variety of land-use changes.

Apparently as a result of this increase in surface reflectivity, the local temperature fell by 0.3 °C per year between 1983 and 2006 — whereas the rest of Spain warmed by 0.5 °C per year over the same period. The development of greenhouse farming in southeastern Spain therefore seems to have generated a microclimate that has provided local relief from global warming.

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