OCEANOGRAPHY

Centennial warming of ocean jets

Identification of an enhanced centennial warming trend in ocean subtropical boundary currents has important implications for our understanding of how climate change is happening.

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A central question in climate science is how the ocean is responding to the slight increase in radiative warming from increasing concentrations of greenhouse gases. Although there is a clear signal of more heat being stored in the global ocean since 1955 (refs 1,2), the associated pattern of ocean warming is less clear. Drawing on previous reconstructions of sea surface temperature trends over the twentieth century[3], Lixin Wu and colleagues present a new view of ocean warming in *Nature Climate Change*[4]. They identify enhanced subtropical warming of the western boundary currents, namely the Kuroshio Current, the Gulf Stream, the Brazil Current, the East Australian Current and the Agulhas Current. The centennial warming trend over these boundary currents is twice as large as the global average. This localized warming is important for the climate system, because the boundary currents redistribute heat within the ocean (Fig. 1), and provide heat and moisture to the overlying atmospheric storm tracks.

It is necessary to consider the difficulties in constructing reliable and representative centennial trends before interpreting this result. Historical ocean data are sparse and restricted to seafaring and trade routes at the start of the twentieth century[5]. Although there is this inherent difficulty, Wu and colleagues analyse the sea-surface-temperature trends based on six different reconstructions from 1900 onwards: two sets based solely on the available historical data and four sets based on different optimal interpolations. There are similar enhanced warming signals in the subtropical boundary currents in all of these reconstructions, implying that their result is independent of the analysis method. As an independent check, they also compare their result with two reconstructions of marine air temperature and again find enhanced warming trends over the western boundary currents.

Assuming that these centennial warming trends are reliable, there is still a concern as to how representative they are compared with shorter-term variability, particularly decadal changes[5]. This aspect is not fully addressed, but the authors do split their post-1900 record into two separate parts. Although the trends differ slightly over each separate period, they find a broadly similar response — enhanced warming of the subtropical western boundary currents.

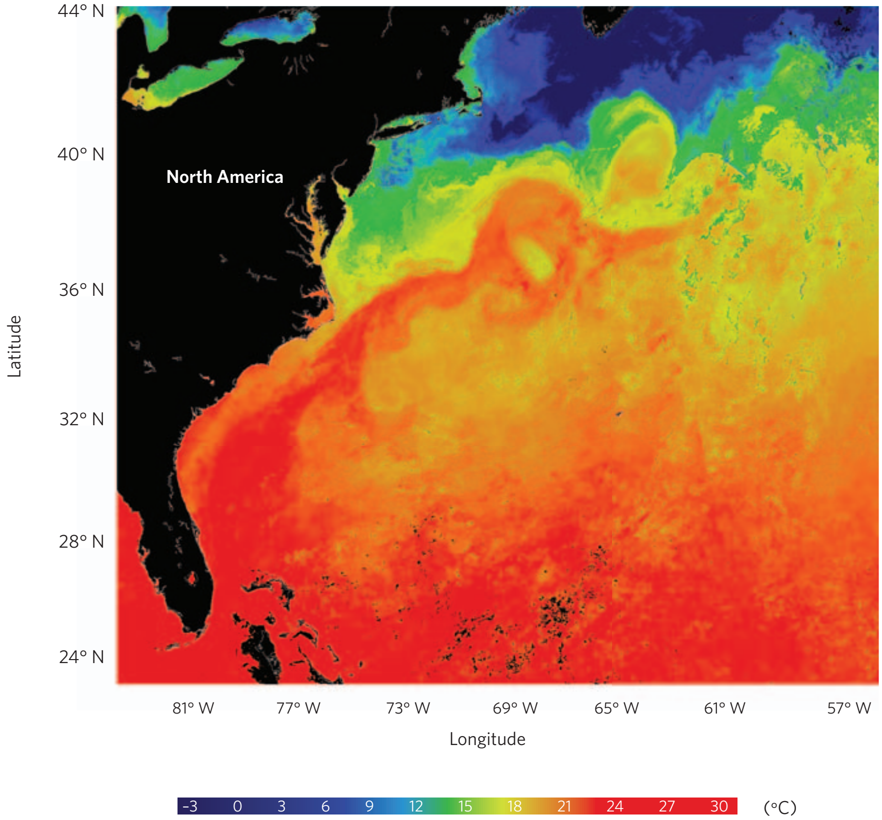

Figure 1 | The western boundary current, the Gulf stream, in the North Atlantic Ocean. A remote-sensing image of sea surface temperature (°C) revealing the subtropical western boundary current in the North Atlantic Ocean — the Gulf Stream — as a plume of warm water leaving the coast and spreading into the interior. The Gulf Stream redistributes heat from the tropics to the mid latitudes, and provides heat and moisture to the overlying atmospheric storm track. The image is formed from NASA MODIS data from a composite of cloud-free data from 13 to 21 May 2006 with any remaining missing data replaced from a monthly composite; data processing by the Natural Environment Research Council Earth Observation Data Acquisition and Analysis Service at Plymouth Marine Laboratory. Figure replotted from ref. 12.

How might these enhanced subtropical warming trends for western boundary currents be achieved? Local warming from the atmosphere is perhaps unlikely to provide this spatial imprint and might instead possibly dampen sea-surface-temperature anomalies over many decades. Changes in basin-scale overturning are also unlikely to be the explanation, because overturning provides enhanced warming in one basin at the expense of another basin, and the warming trends for the boundary currents are seen in each basin.

Instead the enhanced warming of the boundary currents is more likely to be connected to changes in the winds. A poleward shift of the atmospheric winds might similarly displace the subtropical boundary currents and lead to a local warming. The winds also apply a torque to the surface ocean — a twisting force from the contrast in wind stress between the mid-latitude westerlies and easterly trade winds. An increase in this torque can then strengthen the heat transfer in the western boundary currents from the tropics to the mid latitudes.

The authors investigate the effects of the winds by analysing new reanalysis products for the atmosphere and ocean for the twentieth century. They suggest that changes in the wind forcing might play a controlling role, although the uncertainties of these reanalysis products is still unclear. The centennial trends reveal a poleward shift in the extension of the Gulf Stream and the Kuroshio and Brazil currents, in concert with larger poleward shifts in the maximum wind stress line over the North Atlantic, North Pacific and South Atlantic oceans. However, these poleward shifts in boundary currents are not always replicated when the record is split into two separate periods; instead these shifts can reverse in sign or not be significant. Over the Southern Hemisphere, they find that there is an intensification of the surface torque from the winds, consistent with increased ocean heat transfer within the western boundary currents. However, over the Northern Hemisphere, the surface torque from the winds instead seems to have weakened or changed little over the subtropical Pacific and Atlantic oceans, respectively.

The lack of a single explanation of why the western boundary currents seem to be warming is not surprising. The dynamics of how western boundary currents separate from the coast is still under debate[6]: the winds, the shape of the coastline, the bathymetry and the presence of deep boundary currents are all thought to play a role. There has also probably been a complicated response to greenhouse forcing in the atmosphere over the past few decades, an inflation of the tropical Hadley cell[7] and a general poleward migration of jet streams, but also sometimes a weakening of the jets[8,9]. Furthermore, these long-term trends in the boundary currents can easily be masked by the effects of shorter-term variability, such as changes in winds that lead to reversing gyre-scale anomalies in ocean heat storage[10] and variations in the meridional heat transport[11].

In summary, Wu *et al.*[4] have identified an enhanced centennial warming trend over the subtropical ocean boundary currents by drawing on reconstructions of historical data for sea surface and air temperature. Although this trend can easily be masked by decadal variability, this signal is potentially important for climate change in affecting the redistribution of heat within the ocean and the heat supplied to the atmospheric storm tracks. Further work is needed to monitor the warming in these boundary currents and confirm the controlling role of the wind forcing. ❒

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