CLIMATE CHANGE

Patterns of tropical warming

The effect of rising greenhouse-gas emissions on climate is not uniform across the globe. An analysis of the mechanisms behind model-projected changes in ocean temperature gives greater confidence in the pattern of tropical warming and its potential impacts.

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Decades of research on climate change have shown that human activity is responsible, at least in part, for the increase in the global mean temperature over the past half century[1]. However, because no one actually experiences global mean temperature, most individuals are instead concerned with what will happen in their local region. This question is far more difficult to address because the climate response varies significantly with location. The largest differences are found between high and low latitudes, and between land and ocean warming. Writing in *Journal of Climate*, Xie and colleagues[2] argue that subtle patterns are also emerging in the evolution of temperature and precipitation across the tropical and subtropical oceans that could have a disproportionate effect on the climate in many regions of the world.

The pattern of tropical and subtropical ocean warming can influence regional climate locally as well as remotely. Warming can have an immediate impact on local ecosystems, and coral reef ecosystems provide a poignant example of this. Rising temperatures result in coral bleaching, a process by which corals expel their symbiotic algae, often leading to widespread coral mortality. As human-induced warming accelerates over the twenty-first century, bleaching episodes have been predicted to become more frequent and severe. Together with ocean acidification, coral bleaching threatens the future of reef ecosystems[3]. However, regional differences in both the rate of warming[4] and the underlying seasonal variability[5] are likely to significantly influence corals' survival trajectories. Combined model simulations reveal that some coral reef regions might be expected to warm nearly twice as much as other reef regions by the end of the twenty-first century (Fig. 1). Knowing how variability at the regional scale interacts with seasonal variability and biological responses, such as adaptation, is critical to understanding the likely trajectories of coral reef decline in different parts of the world[6].

The pattern of tropical-ocean warming can also affect regional climate in distant parts of the globe. Here we consider the example of tropical cyclones. Storm development is influenced by the local environment, such as ocean temperature and atmospheric humidity, but there are also strong remote influences. For instance, warm waters in the central and eastern equatorial Pacific Ocean during El Niño events increase the wind shear over the Atlantic Ocean, which leads to a reduction in the number of hurricanes in the Atlantic region during El Niño years. Moreover, the stability of the atmosphere, which also inhibits storm development, is not tied to local temperature. Instead, atmospheric stability varies with the difference between the local temperature and the tropical mean temperature[7]. In this way, regional changes in the patterns of sea surface temperature in the eastern equatorial Pacific Ocean could affect the number of hurricanes hitting the east coast of the US. To understand how reefs and tropical storms (among other things) are going to be influenced by the effects of greenhouse gases in the future, it is important to have confidence in the projected patterns of warming.

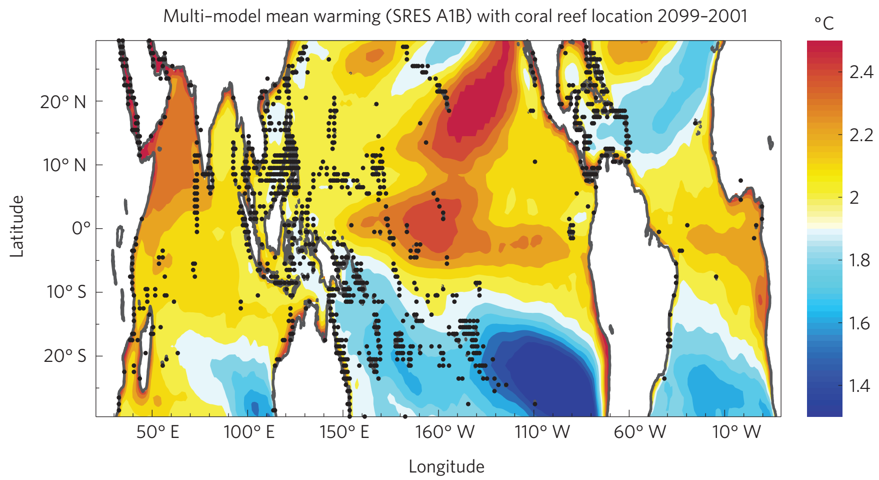

Figure 1 | Sea surface temperature change over the twenty-first century, averaged over 22 climate models for a mid-range emissions scenario (IPCC Special Report on Emissions Scenarios (SRES) A1B (ref. 1); data are available from the Program for Climate Model Diagnosis and Intercomparison). Xie and colleagues[2] suggest that the spatial differences in the warming patterns arise from relatively simple physics of surface evaporation. These regional patterns could be important for the survival of coral reefs in a warming world (reef locations are indicated by black circles; data from www.reefbase.org).

Some confidence comes from the fact that most of the models that were used to compile the Intergovernmental Panel on Climate Change (IPCC) report[1] agree on the main features of the tropical warming pattern (Fig. 1). The central Pacific Ocean is projected to experience the greatest amount of warming, whereas the subtropics, and in particular the southeast Pacific Ocean, are expected to warm less.

However, even if these models agree with one another, how confident can we be that these patterns will emerge in the real world? Xie and colleagues[2] address this concern by focusing on the physical mechanisms that cause these patterns. They propose that spatial patterns of warming arise through the relatively simple physics of surface evaporation. Greenhouse gases heat the ocean surface, and this heating is primarily balanced by an increase in evaporation. However, the ability of the ocean to lose heat by evaporation varies regionally. In regions of high evaporation such as the subtropics, which are typically characterized by strong trade winds and low humidity, a small increase in surface temperature can greatly increase evaporative heat loss[8,9]. Consequently the ocean responds to greenhouse-gas forcing by warming relatively modestly. In contrast, regions of low evaporation, such as the Equator where winds are weak and humidity is high, require substantially higher temperatures to produce the same amount of evaporation. Xie and colleagues point out that changes in wind speed are also part of the picture. For example, in the southeast Pacific Ocean, the trade winds strengthen in most models, for reasons as yet unknown. Increased wind speed increases evaporative heat loss, allowing the ocean to 'let off steam' with relatively little temperature rise.

These hypotheses are elegant in their simplicity — it takes only a paragraph to describe what amounts to many trillions of calculations with computer models. But are we any closer to answering the question of whether the models are right? Will this pattern of warming actually occur in the real world in the twenty-first century, and what will be the impacts on hurricanes, reefs, and regional climates? These answers must come from observations. Surface ocean temperature has been measured on ships and reported in a systematic way since the mid-nineteenth century, and satellite observations fill in the gaps from 1979 onwards. One could examine these datasets to detect the expected pattern of warming over the twentieth century. Unfortunately, there are artefacts in these datasets related to improvements in the measurement technique, which mean that observed trends are not necessarily robust[10]. Moreover, the amplitude of natural variability, that is, variability unrelated to greenhouse-gas forcing, varies greatly from region to region, making quantitative differences between trends in different regions extremely difficult to detect.

Like the Roman god Janus, whose two faces looked to both the future and the past, scientists studying tropical warming must continue to make sustained observations as warming unfolds. At the same time, improved use of palaeoclimate records specific to the tropics, such as geochemical records from coral skeletons, will help to understand regional differences in natural variability and to extract the anthropogenic signal.

The study by Xie and colleagues[2] lays the groundwork for increasing confidence in the pattern of projected tropical and subtropical ocean warming over the twenty-first century. Their findings should embolden us to delve into the available datasets and look for patterns in tropical warming, as there are simple and robust arguments for why they should be present. If we are to understand regional patterns of climate change around the globe, we must recognize that tropical warming is neither uniform nor local in its impacts. ❒

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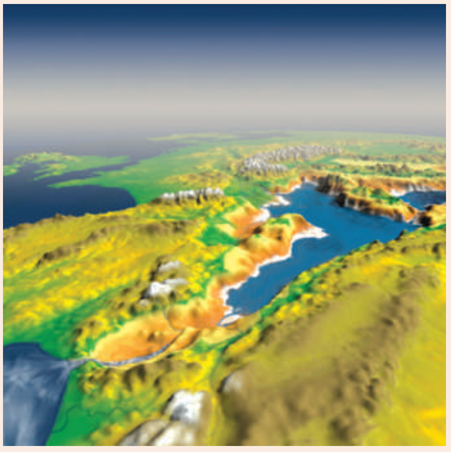
GEOMORPHOLOGY

Flooding fast and furious

About 5.6 million years ago, as Europe and Africa came closer together, the Mediterranean Sea was disconnected from the Atlantic Ocean. With the main source of water to the Mediterranean Sea cut off, it shrank and dried — an event known as the Messinian salinity crisis. Massive deposits of minerals, formed from the salts of brines and sea water, were left behind by the drying ocean, and formed an impressive record of the scale of the evaporation. The desiccation was finally halted about 5.3 million years ago, when further tectonic activity allowed the basin to refill.

Now Daniel Garcia-Castellanos, of the Institut de Ciències de la Terra Juame Almera in Spain, and colleagues have found that the crisis ended rather abruptly: most of the Mediterranean basin seems to have been refilled in no more than two years (*Nature* **462,** 778–781; 2009). The key to their argument lies at the bottom of the Strait of Gibraltar, in the form of a deep channel that cuts across most of the sea floor. This erosional feature is well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known, but had previously been interpreted as a channel formed from fluvial erosion when the sea floor was exposed. Recent observations, however, have cast doubts on this explanation.

Garcia-Castellanos and colleagues suggest that the channel was formed by a megaflood that ended the Messinian salinity crisis. From simulations with a model of rock incision, the authors conclude that the water flow must have been rapid and voluminous — so much so that 90% of the Mediterranean basin would have been filled in a period of a few months up to two years — to incise such a deep, wide channel.

It had previously been assumed that the Mediterranean took thousands of years to refill. But the new estimates, with rates of sea-level rise of up to ten metres per day, are more consistent with evidence of rapid changes in sea level: sediment cores from the Mediterranean show a rapid onset of deep-sea conditions in the basin.

The inflow was so strong that the resulting erosion shifted the eastern edge of the sill westwards by 30 to 80 km, conclude Garcia-Castellanos and colleagues. Thus this catastrophic flood more than five million years ago shaped much of the current sea floor of the Strait of Gibraltar.

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