CLIMATE CHANGE

Snakes tell a torrid tale

Matthew Huber

The discovery in Colombia of a giant species of fossil snake is news in itself. But a wider, more controversial inference to be drawn is that tropical climate in the past was not buffered from global warming.

As the world uneasily eyes a warmer future, a large community of researchers is investigating the past for the insights it might provide into the likely magnitude of climatic and ecological change. Time intervals in Earth's past, such as the early Palaeogene (between 65 million and 40 million years ago), are known to have been much warmer than today. The presence of fossil crocodiles[1] and palm trees[2] ringing the Arctic and in the hinterlands of Wyoming and Siberia, combined with quantitative records of palaeoclimate, indicate[1–5] above-freezing winter conditions and annual average temperatures in these regions that were often at least 15 °C. But if the extratropics were this warm, how hot were the tropics? Head *et al.* (page 715 of this issue) provide tantalizing clues from an unusual source[6].

Establishing the magnitude of past variation in tropical climate is a formidable challenge. Twenty years ago we thought that the tropics cooled as the world warmed (and vice versa)[7]. Ten years ago the consensus became that, compared with modern values, tropical temperatures were at most only slightly warmer during the various hot, 'greenhouse' climates that have occurred over the past 145 million years[8] and that they cooled by at most a couple of degrees during the ice ages. This muted variation in tropical climate is a puzzle: mechanisms that drive climate change at higher latitudes should also substantially affect lower latitudes. In the early Palaeogene, how could the poles be 30 °C or more warmer than they are today if the tropics were only 2 °C warmer?

For their part, climate modellers have concluded that hot tropical temperatures, and the high concentrations of greenhouse gases that cause them, are required to reproduce warm extratropics, because standard models and dynamical theory do not produce Equator-to-pole temperature gradients much weaker than they have been in modern times[9]. Nevertheless, based on the supposition that the models are missing important physics, many hypotheses and novel mechanisms have been proposed that centre on the existence of a 'thermostat' that maintains tropical temperatures at a fixed level[10,11]. These attempts to include new feedbacks have illuminated many dark alleys of climate dynamics, but so far all have been dead ends[10].

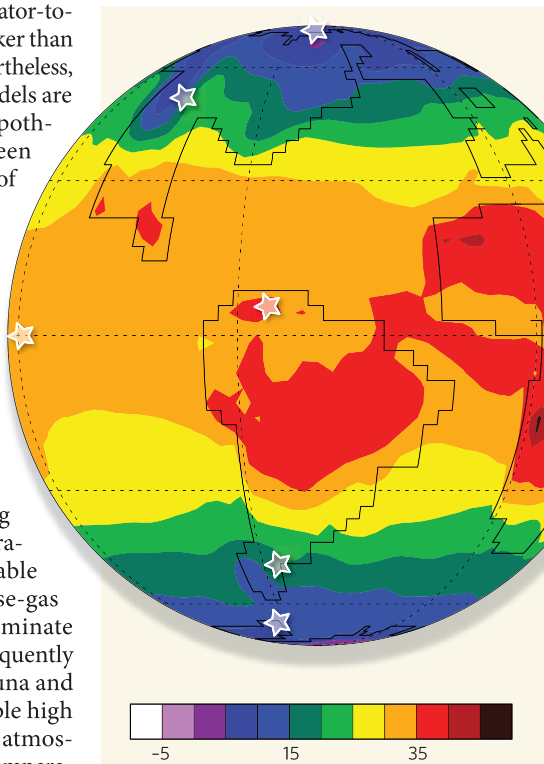

Figure 1 | Simulation of annual average surface temperatures about 58 million years ago. Stars indicate the localities for which temperature estimates exist with ages close to those of Head and colleagues' discoveries[6] in the Cerrejón Formation. In each locality, simulated temperatures match well with those estimated from temperature proxy estimates, suggesting that, with reasonable atmospheric concentrations of greenhouse gases, current models can simulate climate at this time. The simulation was carried out with the National Center for Atmospheric Research Community Climate System model (version 3), with boundary conditions for the early Palaeogene and an atmospheric CO_2 concentration of 2,240 parts per million. Temperature proxy reconstructions are from refs 3–6,12 and 14. Sea surface temperatures derived from oxygen isotopes in planktonic foraminifera that have not been proven to be as well preserved as those reported in refs 12 and 13 have been omitted from the comparison.

Whether a tropical thermostat exists is fundamentally important for three reasons. The tropics, defined broadly (30° N to 30° S), make up half of Earth's surface area and so play an outsized part in determining past variations in global mean temperature and the sensitivity of this variable to forcing factors such as greenhouse-gas concentrations. The tropics also dominate global biodiversity, and have been frequently considered stable, safe havens for fauna and flora compared with the more variable high latitudes. Finally, because the global atmosphere–ocean circulation is driven by temperature gradients, tropical temperatures provide a linchpin on which the rest of the general circulation depends.

In the past few years, studies[12–14] based on new temperature proxy measurements, and on better-preserved records from established proxies, have produced warmer estimates for the tropics (5–10 °C warmer than modern values) than those drawn from previous work. Debate continues about whether earlier estimates were systematically biased to cool values. One independent line of evidence for an unchanging tropical climate comes from terrestrial palaeotemperature proxies derived from leaf shape, which support the idea that tropical temperatures were near modern values (24–26 °C)[7]. Of course, leaf-derived tropical temperatures could be wrong as well. Head and colleagues[6] show that this may be the case.

In the Cerrejón Formation of Colombia, South America, Head *et al.* have discovered fossil vertebrae aged between 58 million and 60 million years old, estimated to be from eight individuals of the largest species of snake ever found. But what makes the study so intriguing is that the authors relate the animal's immense projected size — 13 metres long and more than 1 tonne in weight — to a minimum annual mean temperature. To do this, they use an empirical relationship between temperature and size derived from modern organisms. The method has a biophysical grounding in the metabolism of large, air-breathing, terrestrial poikilotherms (animals whose internal temperature varies with ambient temperature). Essentially, poikilothermic animals must sustain a minimal metabolism to survive and, making the standard assumption that this metabolic rate scales with temperature, larger poikilotherms must live in warmer environments. This is the case with snakes today. Head *et al.* estimate that the giant snake required minimum temperatures of 32–33 °C, which is 6–8 °C warmer than temperatures reconstructed from floras within the same formation, and much warmer than modern values.

If we assume that Head and colleagues' temperature estimates are accurate, and it is a big assumption, there are major implications. First, there is no tropical thermostat: although negative feedbacks may slow or inhibit tropical warming, they do not provide a hard limit, and theories that predict the existence of thermostats[11] are invalid. Second, by comparing their snake-derived estimate with a palaeotemperature estimate from high-latitude Patagonia, Head *et al.* find that temperature gradients did not depart markedly from those of modern times, verifying the results of climate models. Indeed, temperatures reconstructed for this age can now be reproduced by coupled ocean–atmosphere models, provided tropical temperatures are as hot as indicated by the new results[6] (Fig. 1).

Third, although the flora and fauna in the Cerrejón Formation were remarkably resilient, and thrived in apparently hotter and wetter conditions than those of any modern rainforest setting, they may have lived near the limit of their tolerance. As Head *et al.*[6] remark, the span of time between 58 million and 60 million years ago was cooler than subsequent intervals, and further warming during the Palaeocene–Eocene Thermal Maximum, around 55.5 million years ago, could have produced widespread heat-death in terrestrial and marine ecosystems[14]. Finally, new temperature estimates from a multiple proxy approach[6,12–14] suggest that global mean temperatures were at least 10 °C warmer than modern temperatures, much warmer than previously estimated. That implies either that global average temperatures were very sensitive to greenhouse-gas forcing, or that concentrations of greenhouse gases were at the upper end of their reconstructed range[15].

All that said, these implications are based on a new type of proxy: Head and colleagues' findings are the result of probably the first study in 'snake palaeothermometry', and as such must be viewed with caution. Is the empirical link between size and temperature really generalizable and accurate? Could the ability to lose heat be an important limitation for these giant snakes, rendering Head and colleagues' extrapolations moot? Can a few vertebrae truly provide accurate estimates of snake size? Why have similarly giant snakes not been found in other warm intervals?

The findings attest to the resiliency of tropical ecosystems in the face of extreme warming, but more work is clearly necessary. For the moment, however, the burden of proof is on those who argue that the tropics do not warm substantially in a greenhouse world. ■

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