spatially and temporally. At the heart of this debate is whether non-linear climate feedback processes act to accelerate climate change, or whether a more simple linear theory linking climate and the Earth's orbit is sufficient.

Shanahan and co-authors[7] generated a record of palaeo-precipitation during the African Humid Period from Lake Bosumtwi, located at about 6° N. They measured the hydrogen isotope composition of leaf waxes preserved in the lake sediments over the past 20,000 years, which reflects the overall amount of precipitation in the lake's catchment region, and compared these data with the dating of the ancient shorelines that record the expansion and contraction of this lake.

In this area, the onset of humid conditions occurred just under 15,000 years ago, as seen elsewhere in Africa[6,9,10,13]. By 10,000 years ago the lake level had risen by nearly 100 metres. Lake levels and the leaf-wax isotopes indicate that humid conditions persisted until about 3,000 years ago. After that, both proxies gradually fell to modern values. In this tropical region, the termination occurred much later than in sites located further to the north, where the humid conditions generally ended 5,000 to 6,000 years ago[6].

Suspecting a latitudinal trend, Shanahan and co-authors then compiled available North African palaeoclimate records from 9° S to 32° N to constrain the timing of the end of the humid phase (Fig. 1a). The conclusion from this analysis is clear: the end of the African Humid Period progressed from north to south, and closely matches what would be expected from orbital forcing[8]. Specifically, the monsoon rains were reduced first in the north, and then progressively later with decreasing latitude.

However, the end of the African Humid Period was locally abrupt at many sites, transitioning from wet to dry conditions much faster than expected from this simple linear theory. Hence some additional, nonlinear mechanism must have been active at these specific sites. Shanahan *et al.* propose that these locally abrupt transitions were the result of soil moisture and vegetation responses to the gradually retreating monsoon: with diminishing rain, soils rapidly become desiccated and barren, and the loose, sandy soils are subject to rapid wind deflation and transport.

Radiocarbon dating of over 1,000 archaeological sites across North Africa reveals how profoundly the end of the humid phase affected human populations[14]. These dates, which record human occupation at these sites, indicate that North Africa was rapidly depopulated between 6,300 and 5,200 years ago as dry conditions set in (Fig. 1b). Within centuries, sedentary populations appeared along the Nile, marking the emergence of urban and socially stratified Pharaonic culture and construction of the first pyramids[12,14].

Shanahan and co-authors[7] show that the end of the African Humid Period occurred gradually with latitude but changes were quite abrupt locally in many places. It is noteworthy that most of the North African population decline occurred in less than a millennium, suggesting that people, like local climate, can respond nonlinearly to climate change. ❐

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CLIMATE SCIENCE

Pacemakers of warming

In the first decades of the twentieth century, the Earth warmed rapidly. A coral-based climate proxy record of westerly winds over the equatorial Pacific suggests that wind strength and warming rate were linked, as they are today.

Stefan Brönnimann

Whenever climate takes an unexpected turn, a look at the past is warranted. The slowdown of global warming since around 2000 thus prompts analyses of previous episodes of slow or accelerated warming. Among these phases is the early twentieth-century warming, a poorly understood period of relatively rapid warming of global average temperatures between about 1900 and 1945. Writing in *Nature Geoscience*, Thompson *et al.*[1] suggest that this early phase of fast warming was closely linked to frequent strong bursts of westerly winds over the equatorial Pacific, a pattern opposite in sign to that diagnosed for the early 2000s when global warming slowed down unexpectedly.

The warming during the early twentieth century was larger than can be explained solely by changes in incoming radiation as a result of increasing greenhouse-gas concentrations, increasing solar irradiance, or a muting of volcanic activity. An "unusually large realization of internal variability" is additionally required[2]. Traditionally, scientists have searched for this unusual variability in the North Atlantic Ocean[3,4], whose surface temperature increased steeply in the 1920s, accompanied by rapid warming in the European sector of the Arctic. This Atlantic warming is often seen as part of a multidecadal mode of the Atlantic Ocean circulation. However, warming was pronounced over the North American continent, too, as well as in the tropical oceans. Therefore, a broader view of concurrent warming mechanisms is required[5].

Thompson and co-authors[1] suggest instead that the tropical Pacific may have played an important role in the early twentieth-century warming. The authors base their claim on the study of corals from Tarawa, Kiribati, a v-shaped coral atoll in the central equatorial Pacific that opens to the west. Through physical mixing, westerly winds at Tarawa remobilize manganese (Mn) from

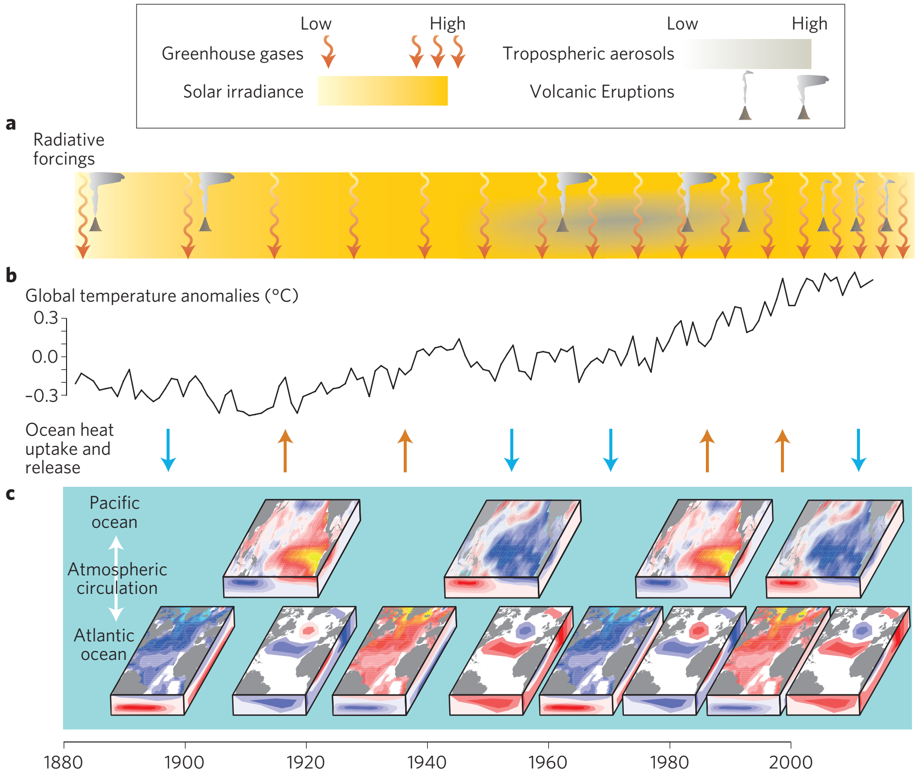

Figure 1 | Variable warming rates. **a–c**, Radiative forcings (**a**) alone are insufficient to explain phases of accelerated or slowed warming of annual mean global surface air temperature (**b**, ref. 12, anomalies with respect to 1951–1980), although they play a dominant role. Rather, energy is stored in (blue arrows) or released by (red arrows) the oceans (**c**, schematic ocean surface and subsurface temperature anomalies). Atmospheric circulation transports the heat surplus or deficit and connects the different ocean basins. An oscillatory mode of the Atlantic Ocean has been suggested previously to have caused the early twentieth-century warming; Thompson *et al.*[1] find a contribution from westerly wind bursts over the tropical Pacific Ocean.

the Mn-enriched lagoonal sediments into the water, which ultimately ends up incorporated into the coral skeletons. The Mn/Ca ratio derived from coral cores is therefore interpreted as a proxy for the frequency of westerly winds. The twentieth-century record of Mn/Ca ratios indicates that the highest frequencies of westerly winds occurred in the 1910s, during the first phase of the early twentieth-century warming, but a decade before the rapid warming of the Atlantic. Conversely, the lowest frequency was found in the 1950s, during a phase of plateauing global temperatures.

Westerly winds are associated with El Niño conditions, during which the tropical Pacific loses heat to the atmosphere and the subsurface ocean subsequently cools. More frequent westerly winds indicate that more heat may have been released from the Pacific Ocean, in line with increasing atmospheric temperatures (Fig. 1). The opposite — infrequent westerly winds and arguably increased heat uptake in the Pacific Ocean — occurred in the 1950s, at the heart of a prolonged period during which global temperatures remained almost stable.

The latter period also serves as an analogue for the present-day slowdown of global warming. Several studies have attributed the slow warming since about 1998 to a cool eastern equatorial Pacific and increased heat storage in the subsurface Pacific Ocean. This is due to strong easterly trade winds and associated with a predominance of La Niña conditions[6,7]. Global temperatures have been shown to follow not only radiative forcings, but also temperature changes in the eastern equatorial Pacific: an altered atmospheric circulation and atmospheric heat transport promote the global spread of anomalous Pacific temperature[8].

The Pacific wind reconstruction by Thompson and co-authors adds another piece of evidence to this mechanism. Other studies, however, have proposed that the Atlantic and Southern Oceans are the main heat sinks responsible for the slowed warming[9], by storing heat at a greater depth and for a longer time than the tropical Pacific. In this scenario, the Atlantic heat sink is related to deep oceanic convection in the subpolar North Atlantic. The basin-wide Atlantic sea surface temperatures then lag behind the increased heat uptake by several years, during which the heat deficit is exported to the Pacific Ocean via the atmosphere. This thread leads back to the early twentieth-century warming, where the relative roles of the tropical Pacific and the Atlantic Ocean must be further analysed, and discussed in the context of the current slowdown of global warming.

One surprising aspect of the study by Thompson and co-authors is that it relies on a climate proxy. Tarawa is a location that is highly relevant for global climate, but poorly observed in the early twentieth century. A wind proxy from this spot is particularly valuable for climate research. It is supported by a temperature proxy from the same location. However, existing alternative data sets of wind or sea-surface temperature in the broader central Pacific region based on instrumental observations[10,11] are inconclusive with respect to changes in the early twentieth century. These different sources of information need to be reconciled.

Increasingly, the realms of palaeoclimatology (which is largely based on proxy reconstruction) and the backward extension of the methods used in modern climatology have started to overlap. Innovative ideas can develop at such an interface, but with this comes the challenge of combining two different perspectives. Collaboration at this particular boundary is not just about reconciling different data sets, but also about the meeting of different scientific cultures. In palaeoclimatology a single proxy can weigh heavily; in dynamical climatology on the other hand, trends are often not trusted even if well-replicated in half a dozen reanalysis data sets. Dynamical climatologists can learn from the former to think more boldly. Conversely, paleoclimatologists might benefit from a more critical stance towards their data, as taken by dynamical climatologists. Working in tandem gives both groups the best chance to exchange not only results but also perspectives.

The suggestion by Thompson and colleagues[1] of a close relationship between western equatorial Pacific winds and warming rate links early twentieth-century climate to the unexpectedly slow warming rates in the beginning of the twenty-first century. With fast progress at the interface of the worlds of palaeo- and modern climate science, taking the long view will become more common. ❐

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MARTIN BRASIER

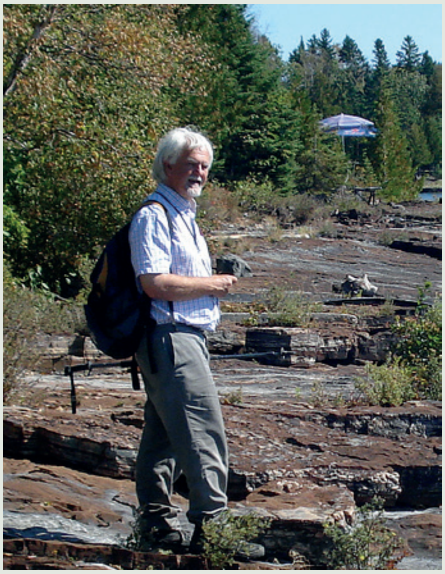
A journey in palaeobiology

Martin Brasier's work lay at the heart of our understanding of the biosphere at key junctures in Earth history. He may be best known for his study of the early biosphere from the origins of life itself to the Cambrian explosion of animals, but the scope of his research was vast, encompassing the entire geological timescale.

Martin's research career began in 1969, when he served as the ship's naturalist on board the Royal Navy hydrographic survey ships *HMS Fawn* and *HMS Fox*. During this time he mapped the microhabitat of foraminifera, algae, seagrasses and mangroves in the Caribbean. After the award of his PhD from University College London in 1973, this early work transitioned to the study of the evolution of symbiosis and seagrass community structure. Later, Martin made unique inroads into understanding how cells interacted in the reef communities of the early Cambrian, also revealing the sponge-like biology of archaeocyathids. By the late 1970s, he was exploring a data-based ecological and taphonomic assessment of the Cambrian explosion of skeletal fossils.

The early 1980s saw the publication of the first edition of Martin's seminal book *Microfossils*, used to this day as a core textbook by students around the world. Relocation to Oxford in 1988 allowed him to explore new technologies, bringing innovative techniques to the study of Ediacaran and Cambrian evolutionary radiations, the origins of the major invertebrate groups, and Snowball Earth. During this time Martin took a leading role in the International Geoscience Programme (IGCP) committees established to discuss the stratotype sections and the formal definition of the Cambrian and Ediacaran time periods.

Over the last 20 years Martin has helped to revolutionize the study of the earliest biosphere, pioneering a critical approach to the assessment of the biogenicity of the most ancient microfossils and trace fossils. Those present will never forget his clear reasoning and good humour during the intense debate over the controversial identification of 3.5-billion-year-old microfossils in the Apex chert at the NASA Ames conference of 2002, describing his opponent's performance as 'truly hydrothermal, with more heat than light' as he took over at the podium, before convincing the majority of the audience that the 'microfossils' were no more than fortuitously-arranged blobs of carbon. He was always open to new interpretations, quick to embrace new ideas and new technology, and remained at the very forefront of this field right up to his death.



DAVID WACEY

Martin had a wonderful ability for storytelling, whether during student tutorials over the occasional glass of port, or through his notebooks, which were often works of art. He put this talent to great effect in his popular science books *Darwin's Lost World* and *Secret Chambers*, bringing the Precambrian to life for a diverse audience. Martin strongly believed in sharing good ideas and widening access to scientific education. He was rightly proud of the impact his books had; this impact will undoubtedly continue for years to come.

In early 2014 Martin's scientific contributions were formally recognized by the award of the prestigious Lyell Medal from the Geological Society of London. On the occasion of his retirement in September 2014, the diversity of attendees showed the huge influence that Martin has had across the geological community, and the warmth with which he was regarded.

Given the huge amount of research Martin produced, and continued with renewed vigour after his retirement, it would be easy to overlook his many other talents and interests. Martin was a skilled jazz pianist, even building some of his own keyboard instruments. He could recite large passages of Monty Python's *The Life of Brian* (providing much entertainment when on fieldwork). He had a love of archaeology, and amassed an impressive collection of Roman seal stamps and coins. His fascination with the history of science led him to collect a variety of notable objects and books, ranging from Robert Hooke and Charles Darwin up to the NASA moon landings — all of which he delighted in showing to students and visitors.

Martin was a great family man and condolences go to his wife Cecilia and children Matthew, Alexander and Zoe at this very difficult time. Martin had a remarkable talent for reconciling family holidays with geological fieldwork, so it is no surprise to find his son Alexander following in the family tradition as a lecturer in geology at the University of Aberdeen. Martin's nurturing and kind nature extended to the hundreds of students he tutored during his time as tutorial fellow at St Edmund Hall, Oxford, as well as the many PhD students and young postdoctoral researchers he mentored. He leaves a huge scientific legacy, and Martin's intellectual spirit will live on in the research his protégés conduct, and in the students they in turn inspire.

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