charge-trapping effects at the crucial interface between a semiconductor and its gate. ■

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CLIMATE CHANGE

Lessons from a distant monsoon

Jonathan T. Overpeck and Julia E. Cole

The burden of global warming falls most heavily on the developing world. A connection forged between the Indian Ocean climate, Asian monsoons and drought in Indonesia makes for an especially bleak outlook for that nation.

As Earth's climate continues to warm, understanding the dimensions of our vulnerability to present and future changes is crucial if we are to plan and adapt. Studies of palaeoclimate have an important role here in helping us to uncover the full range of past climate variability, and so avoid future surprises. On page 299 of this issue, Abram *et al.*[1] present a study of past climate change in Indonesia that expands our view of the pivotal climatological influences in that region to include a geographically distant player: the Asian monsoon.

Indonesia's climate is known to vary significantly from year to year as a result of the El Niño/Southern Oscillation (ENSO) system. This system is associated with changes in sea surface temperature and atmospheric pressure across the tropical Pacific. When the central tropical Pacific to the east of Indonesia is warm (an El Niño phase), the normally abundant rainfall in Indonesia moves eastward, leaving much of the island nation in drought. In the west of the country, drought is also brought about by another coupled oscillation in ocean–atmosphere conditions, the 'Indian Ocean Dipole', as a result of cool sea surface temperatures off Sumatra, the most westerly of Indonesia's principal islands.

Abram and colleagues[1] exploit the fact that climate information is preserved in the geochemistry of huge, rapidly growing corals off Sumatra to study past dipole events in the Indian Ocean. Different aspects of coral geochemistry reflect variations in temperature and in the hydrological balance (the difference between levels of precipitation and evaporation). By analysing several geochemical tracers — oxygen isotopic ratios and the ratio of strontium to calcium — in annually banded coral skeletons, the authors can reconstruct month-by-month changes in temperature and drought. Using fossil corals from the mid-Holocene (between around 6,500 and 4,000 years ago), when the Asian monsoon was stronger and ENSO seemingly weaker than today, they demonstrate that the cool ocean temperatures persisted longer — for five months, instead of three — and were accompanied by longer droughts than has been the case in modern times.

Results of climate simulations for 6,000 years ago agree with these observations and suggest a mechanism for the change. First, a stronger Asian monsoon generates anomalies in the easterly winds that would cool the eastern Indian Ocean, predisposing cooler, deep-ocean water in this area to move upward earlier during dipole events. Cooler sea surface temperatures would lead to anomalous downward movement and outflow of air from the region. The resultant weakening of the degree to which moist air converges, together with the atmospheric vertical motion, would result in reduced precipitation, and drought over adjoining land areas.

But what about ENSO? During El Niño conditions, the eastward migration of rainfall and warm ocean temperatures in the tropical Pacific lead to drought in Indonesia. But it has been suggested[2,3] that the mid-Holocene experienced background conditions that may have more closely resembled La Niña conditions. La Niña brings cooler temperatures to the central tropical Pacific, and Indonesia generally receives enhanced rainfall during these periods. So why were droughts more prominent during the mid-Holocene? The implication of Abram and colleagues' work[1] is that the Asian monsoon trumps ENSO and generates prolonged droughts in Indonesia through its influence on the Indian Ocean Dipole. Whether the more frequent droughts associated with interannual variations in ENSO are similarly affected by a stronger monsoon remains unexplored.

The implications of this study for future climate conditions are sobering. If the consensus holds true that the Asian monsoon will intensify with climate warming, Indonesia can expect more frequent and longer droughts in the future through the coupling of the monsoon with sea temperatures in the eastern Indian Ocean. Rural livelihoods and natural resources will thus be at greater risk as drought undercuts regional food supplies and stokes wildfires that also generate exceedingly poor air quality in the region (Fig. 1). Longer droughts will have many additional social and economic consequences, for example on food supply, health and hydropower. Indonesia is also a pivotal

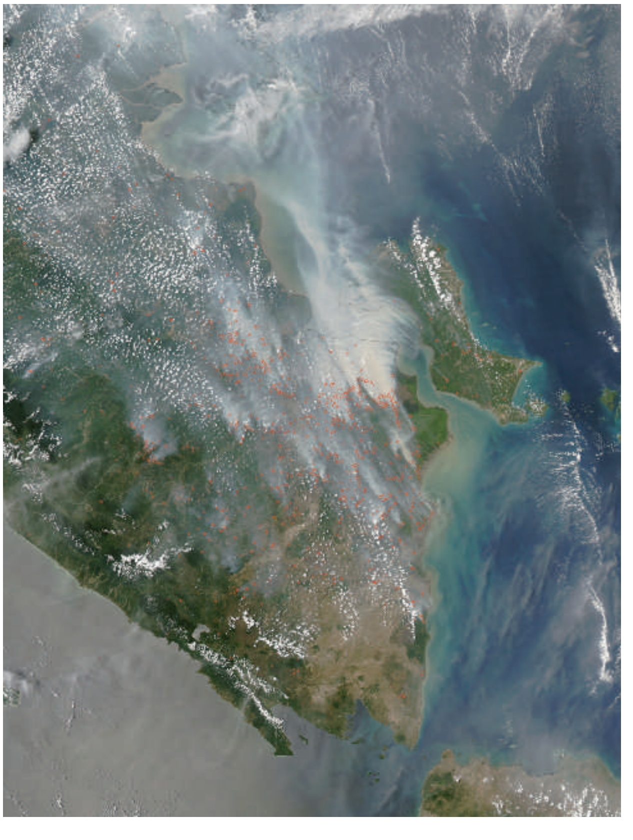

Figure 1 | Indonesian summer. Smoke from wildfires on Sumatra, Indonesia, captured on 27 September 2005 by the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument aboard NASA's Aqua satellite. The extent of such fires is likely to increase if climate warming causes the Asian monsoon to intensify.

MODIS/NASA/GSFC

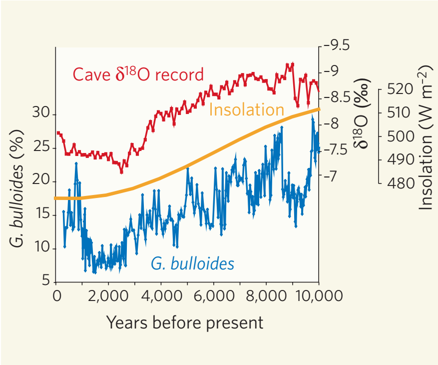

Figure 2 | Abrupt changes in monsoon climate. The weakening of the monsoon during the Holocene period is shown here by the relative abundance of the planktonic foraminiferan *Globigerina bulloides* in the Arabian Sea[11] (blue line), which reflects the intensity of the upwelling of sea water and the strength of monsoon winds. Monsoon weakening is also indicated by records of the oxygen isotopic ratio $\delta^{18}O$ (red line, average of three records) from Dongge Cave in southern China, reflecting the relative amount of summer rainfall[12–14]. At both sites, monsoon weakening is forced primarily by slow changes in summer sunlight[15] ('insolation', yellow; calculated for June at 30° N latitude), but apparently can occur abruptly as a series of steps. Abrupt changes in the Asian monsoon could impinge directly on Indonesia's climate, as Abram *et al.*[1] show.

biodiversity hotspot[4], and drought intensification could bring significant challenges to conservation management.

The troubling consequences do not end there. The palaeoclimate record seems to indicate that the Asian monsoon does not always respond linearly to climate change. The main driver of large-scale monsoon change over the past 10,000 years has been a slow decrease in summer-time solar radiation (insolation) owing to changes in Earth's orbit. Even so, monsoon records show abundant evidence of abrupt, stepwise changes on timescales of a century and shorter (Fig. 2). The mechanisms behind this behaviour are poorly understood, and research is continuing in an attempt to document the degree to which abrupt monsoon changes are spatially and temporally coherent[5].

Nevertheless, palaeoclimate observations caution us to expect similarly abrupt changes as Earth's climate warms. As predictive models do not yet simulate the past abrupt changes in the Asian monsoon, they cannot be trusted to project such abrupt changes realistically into the future. Future monsoon behaviour will also depend on how such natural variations interact with the combined anthropogenic effect from aerosols (thought to weaken monsoon intensity) and greenhouse gases (thought to strengthen it). For example, reductions in air pollution in Asia could, by reducing the damping effects of aerosols on the monsoon, result in sudden monsoon strengthening[1,6].

Indonesia faces the possibility of climate surprises on many fronts. As a nation of islands, it is particularly vulnerable to the rises in sea level of a few metres that are possible if climate warming reaches the 'tipping point' for Earth's ice sheets[7]. Evidence is mounting that a warmer world will experience tropical storms of greater intensity[8,9]. The future behaviour of ENSO is uncertain[10], but also critical for regional climate projections, nowhere more so than in Indonesia. As the regional nuances of future environmental change come into better focus, the dimensions of Indonesia's, and other nations', vulnerability will become slowly clearer. ■

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POLYMER CHEMISTRY

Sacrificial synthesis

Sébastien Perrier and Xiaosong Wang

The size and uniformity of polymer molecules makes it difficult to modify them at just one selected site. But a single chemical group can be attached at the end of a polymer if part of the starting material is forfeited.

Chemists are remarkably proficient at directing the synthesis of small molecules, but fine-tuning the structures of large molecules, such as polymers, is far more taxing. Despite many years of research, the field of macromolecular engineering — the preparation of large molecules with strict control over their size and chemical groups — has many mountainous challenges yet to overcome. But Kilbinger and colleagues[1] have just conquered a particularly troublesome peak. Reporting in *Angewandte Chemie*, they describe an innovative approach for preparing polymer chains with just one chemical group attached at the end, with excellent control over the chain length. Such molecules are much sought-after for potential applications in nanotechnology.

Nature provides endless examples of precisely engineered macromolecules — proteins, for instance, which contain amino-acid side-chains that are accurately positioned, often in a way that determines the proteins' roles. Synthetic chemists have tried to recreate nature's exceptional control over macromolecules, and in so doing they have designed several catalytic reactions that occur only at specific chemical groups.

One such reaction is known as ring-opening metathesis polymerization (ROMP). In this process, an organometallic catalyst breaks the carbon–carbon double bond in a cyclic molecule, to form a ring-opened structure that has a carbon–carbon double bond at one end and a metal–carbon double bond (known as a metal carbene) at the other. The metal carbene can react in the same way as the catalyst, so that a long chain propagates as more ring-opened molecules are added, much as a daisy chain is formed from individual flowers. Eventually, very long polymer chains are formed that contain carbon–carbon double bonds in their 'backbones' and that have a metal carbene at one end. The metathesis reaction that underpins this process is astonishingly versatile, and its pioneers won the Nobel Prize in Chemistry for their work in this area[2–4].

As ROMP leads to a polymer with an active metal carbene at one end, many researchers have attempted to convert this reactive terminus into other useful chemical groups. The product of this reaction is highly desirable: a polymer with just one reactive group attached. Such structures are of interest in molecular engineering because they are potential building blocks for nanocomposite materials, or for biological–synthetic macromolecules (for example, hybrids of proteins and polymers). However, all the attempted reactions with metal carbenes at polymer terminals were plagued by low levels of conversion into the desired product, mainly due to side reactions. For instance, the metal carbene can easily react with double bonds in the polymer chains, causing unwanted chain transfers[5].

Historically, the method of choice for generating mono-derivatized polymers has been anion-initiated polymerization (rather than the metal-carbene-initiated ROMP process). In this process, the active chain-ends of the polymers can be reacted with chemical