Climate change and palaeoclimatology

Neoproterozoic climate modelling supports a 'slushball' Earth (*January 2008*)

Following its first discovery, evidence for low-latitude glacial action at several times during the Neoproterozoic has fuelled one of the most publicised controversies in the geosciences. Was the Earth totally frozen over during these episodes, or was ice confined only to parts of the surface? Whatever, the last part of the Precambrian witnessed huge fluctuations of many kinds, and after the cold epochs the first large animals made a sudden appearance. The most dramatic geochemical ups and downs in Earth history took place, in the form of sudden extreme shifts in the relative proportions of the stable isotopes of carbon in seawater, as recorded by marine carbonate rocks. These fluctuations correlate closely with the evidence for low-latitude glaciations: large negative excursions of $\delta^{13}C$ with glacial epochs, and positive values developing between them. The first can be interpreted as the result of massive declines in photosynthetic fixation of organic carbon. The second suggests repeated recoveries of such biological productivity, which favours the extraction of ^{12}C from seawater and an increase in the relative proportion of the heavier ^{13}C as organic carbon becomes buried in seafloor sediments.

Since organic carbon is ultimately extracted photosynthetically from carbon dioxide in the atmosphere, a link between climate and living processes (and those that bury dead organisms) can be the basis for models attempting to explain the extraordinary events of Neoproterozoic times. If large amounts of organic carbon are buried or remain suspended in the oceans, the drawdown of atmospheric CO_2 reduces the greenhouse effect and leads to cooling. Conceivably, the effect could be to so reduce global mean surface temperature that freezing conditions grip even the lowest latitudes. Once glacial and sea ice becomes established, its high reflectivity reduces the amount of incoming solar radiation that is absorbed to warm the Earth. The two processes combined would tend to lock frigid conditions in place until such time as gradual release of volcanic CO_2 increased the atmospheric greenhouse effect. That is the theoretical essence of the Snowball Earth hypothesis in which complete ice cover sterilised surface biology for long periods. However, it leaves out two important factors: as water cools it is able to dissolve more gases from the atmosphere; organic carbon in ocean water can be transformed to dissolved CO_2 if it is oxidised, thereby reducing the amount of carbon being buried. Modelling the carbon-climate link in the Neoproterozoic requires that both factors are accounted for (Peltier *et al*. 2007. Snowball Earth prevention by dissolved organic carbon remineralization. *Nature*, v. **450**, p. 813-818; DOI: 10.1038/nature06354).

The model devised by Richard Peltier and colleagues from the University of Toronto also incorporates the distribution of land at the time. Results from it show a looping behaviour, with recovery from frigidity as increases in dissolved oxygen convert organic carbon to dissolved carbon dioxide, whose increasing concentration in turn leads to more escape of the gas to the atmosphere. The model also suggests how glacial and sea ice might have developed during such a cycle, and with the late Precambrian configuration of drifting continents it allows for low-latitude continental glaciation, but not for all-enveloping sea ice. The implication is indeed glacial events vastly greater than those of the late Palaeozoic and during the present Ice Age, but less effect on marine photosynthesis than from Snowball conditions – a 'Slushball' Peltier *et al*. explain why the cyclical processes suggested by the model stopped before the start of the Phanerozoic, from carbon-isotope evidence for a massive oxidation of suspended marine organic carbon around 550 Ma. Thereafter, abundant oxygen and large animals ensured most dead organic carbon was oxidised in the oceans.

Unsurprisingly, one of the authors of the Snowball hypothesis finds flaws in the geochemical argument for its impossibility (Kaufman, A.J. 2007. Slush find. *Nature*, v. **450**, p. 807-808; DOI: 10.1038/450807a). Not only was oxygen likely to have been at far lower atmospheric concentrations than it became in the Phanerozoic, the glacial epochs provide evidence that its concentration in seawater was very low. The marine diamictites associated with each contain both ironstones and iron-oxide cements. For them to have formed demands high concentrations of dissolved iron in sea water, in the form of reduced Fe^{2+} ions; incompatible with widespread oxidizing conditions that would favour Fe^{3+} whose compounds are insoluble.

Some good news about carbon burial (*January 2008*)

The second largest 'sink' for atmospheric CO_2, after silicate weathering and formation of carbonate sediments, is the burial of organic carbon. Derived from photosynthesis of carbon dioxide in the air or dissolved in water, organic carbon descends from the photic zone of the oceans or is carried from the land by rivers. In the second case it is often believed that more than 70% of the carbon load of rivers is oxidised back to CO_2 before having a chance of being buried in marine sediments. To estimate the proportion that does contribute to carbon sequestration is a complicated matter, involving measurement of the carbon budgeting for an entire river basin and its offshore sediments. This has been done by a team of French geochemists for the huge Ganges-Brahmaputra system that drains the northern Indian subcontinent and much of the Himalaya (Galy, V. *et al*. 2007. Efficient carbon burial in the Bengal fan sustained by the Himalayan erosional system. *Nature*, v. **450**, p. 407-410; DOI: 10.1038/nature06273). This system carries a stupendous load of sediment, especially during the monsoon season. At 1 to 2 billion t of sediment deposited from suspension in the Bay of Bengal each year, this is the largest single flux of sediment from land to the ocean floor. Even more is delivered as bed load (rolling and bouncing sand particles) to build up the Ganges-Brahmaputra delta of Bangladesh and West Bengal, India. The authors found that recently produced organic carbon is about 4 to 5 times more abundant in the suspended sediment load than is reworked fossil carbon derived by erosion of ancient sedimentary rocks, which itself is predominant in the bed load. Fossil carbon makes no difference to the modern carbon cycle, provided it does not get oxidised, which is less likely than for recent organic carbon in a form that can be metabolised.

By comparing the recent organic carbon load suspended in the rivers' flow with that in the fine sediments of the Bengal Fan, Galy *et al*. have been able to show that most of that carbon is conserved without oxidation. As a result, the Bengal Fan accounts annually for about 15% of global carbon burial. There are two reasons for this remarkable efficiency: the low oxygen availability in deep waters of the Bay of Bengal; the very high sediment load from erosion of the Himalaya that buries carbon before oxidation is possible. Orogenic belts in humid areas are therefore key factors in exerting negative feedback on climate, whereas drainages of flat areas, such as the Amazon and especially its main tributary the Rio Negro, encourage oxidation in their lower reaches and offshore and are less important.

A Cretaceous Ice Age? (*March 2008*)

Accepted geoscientific 'wisdom' is that the Cretaceous Period was so warm that forests reached polar latitudes and so too did cold-blooded reptiles. Planktonic forams' oxygen isotopes indicate that the Cretaceous 'hothouse' in the Turonian (93.5-89.3 Ma) produced tropical sea-surface temperatures up to 37°C; about human blood temperature. It also saw sea level reach an all time high. Both features have been attributed to the rate of ocean-floor volcanism being at its highest. It has, however, been difficult to model the warmth at high latitudes without fudging the input to climate models.

Measuring $\delta^{18}O$ in both planktonic and benthonic (ocean-floor) forams at centimetre spacings in Turonian ocean-floor sediments seems to have truly bamboozled specialists in the Cretaceous. They reveal a period of ~200 ka at around 91.2 Ma where both show a sharp increase (Bornemann, A. and 8 others 2008. Isotopic evidence for glaciation during the Cretaceous supergreenhouse. *Science*, v. **319**, p. 189-192; DOI: 10.1126/science.1148777). Respectively, the peaks reflect decreased sea-surface temperature (but only down to 32°C in the tropics) and an increase in the extraction of light ^{16}O from the oceans; only likely when ice caps build up on land. The size of the benthonic $\delta^{18}O$ increase suggests ice caps about half the size of that now blanketing Antarctica. Other evidence includes rapid decreases in Turonian sea level in Europe, North America and Russia; only likely on such a scale as a result of glacio-eustasy. However, direct evidence in the form of tillites, striated pavements and glacio-marine sediments has yet to turn up

Until these convincing data emerged, it seemed that sufficient post-Permian frigidity for large-scale glaciation had not developed until the Oligocene (~34 Ma). However, the paradox of high-latitude ice caps and low-latitude balmy seas is resolvable. Evaporation from the tropical sea surface would have been much greater than nowadays. Transport of moisture to cooler areas may have resulted in such immense winter snowfall at high latitudes that sufficient remained unmelted after winter darkness for its albedo to further cool the polar region. Almost certainly the site for the ice cap would have been Antarctica, which in the Cretaceous, as now, sat over the South Pole. Remove the present ice, and that continent would have had an average surface height of between 1 and 2 km that would have encouraged snow to build up, were sufficient to have fallen during the Turonian. Yet without the direct evidence for glaciation in sediments – much would be buried by the present Antarctic ice cap, if not eroded away - the scenario is difficult for some to believe.

Holocene cold spell and glacial lake burst (*March 2008*)

The most startling event during the gradual warming after the last glacial maximum was the millennium of icy conditions between 12.59 and 11.7 ka; the Younger Dryas. Long after Holocene warmth seemed well established and agriculture had been underway for two millennia, with perhaps increased human population, a smaller cold 'snap' took place, between 8.21 and 8.17 ka; i.e. for about 70 years. Its main effect was around the North Atlantic, but it was felt over the whole hemisphere. It must have been devastating for early farmers and new migrants into lands at higher latitude. High-resolution records of many kinds are possible for such a young event, from both ice and marine cores, and also terrestrial pollen records from mires. Norwegian, French and Dutch climate researchers have gleaned a great deal from a sea-floor core drilled between southern Greenland and Labrador (Kleiven, H.F. *et al*. 2008. Reduced North Atlantic deep water and the glacial Lake Agassiz outburst. *Science*, v. **319**, p. 60-64; DOI: 10.1126/science.1148924). Their combined fossil, oxygen-isotope and mineralogical study shows anomalies from about 170 years before to 100 years after the drop in regional temperatures. These include signs of decreased saltiness of the water in the Labrador Basin and a reduction in production of deep water in the North Atlantic. This is exactly the predicted signature for a shut-down of the Gulf Stream, similar to those implicated in Dansgaard-Oeschger events through the last Ice Age and the Younger Dryas itself.

The Younger Dryas has been linked to sudden drainage of huge glacially dammed lakes that once surrounded the ice cap of the Canadian Shield. One scenario for that is a huge, protracted flood down the St Lawrence River into the North Atlantic, another being one down the MacKenzie River into the Arctic Ocean. Freshening of surface waters by such means would have reduced the formation of the dense cold brines that sink to form North Atlantic Deep Water today. In so doing these down-wellings drag surface waters northwards from low latitudes to form the Gulf Stream that makes the western side of the North Atlantic unusually warm. If they stop or slow significantly regional air temperatures fall, as they did again around 8.2 ka. In this case the likely cause was escape of water melted from the last dregs of the North American ice sheet that had been held in a glacial lake south of Hudson Bay: Lake Agassiz.

Impact cause for Younger Dryas draws flak (*May 2008*)

Almost a year ago two dozen scientists presented evidence to suggest that onset of the Younger Dryas at 12.9 ka followed upper atmosphere explosions of cometary material (see *Whizz-bang view of Younger Dryas* July 2007). Their view was based on: excess iridium; tiny spherules; fullerenes containing extraterrestrial helium; nanodiamonds and evidence for huge wildfires. Not quite the Full Monty, as neither crater nor shocked mineral grains were claimed, hence the teams' opting for a cometary airburst. In North America such signs were said to overly the last known occurrences of Clovis tools at 7 archaeological sites (see *Clovis First hypothesis dumped* Human evolution and migrations March 2007). It was pretty clear that the suggestion for a hitherto unnoticed event with a widespread signature – 26 sites either side of the Atlantic were cited – was going to be challenged, and so it has proved (Kerr, R.A. 2008. Experts find no evidence for a mammoth-killer impact. *Science*, v. **319**, p. 1331-1332; DOI: 10.1126/science.319.5868.1331), perhaps not unconnected with the blaze of publicity surrounding the paper's appearance, including several TV documentaries.

Well, say experts, sooty layers do suggest large-scale fires, but forest fires occur every year, especially when humans are around. Fullerenes or 'buckyballs' equally can form terrestrially, except those containing ET helium. The last is regarded by many critics as 'inventive'; they have never been isolated since such combinations were first reported in 2001 (see *Extinctions by impacts: smoking artillery* March 2002). The accepted methodology for detection of tiny diamonds seems to have been ignored, and that claimed to have found them misused. The iridium 'spike' – crucial in identifying the global nature of the K-T event – by itself is not enough for claims of impacts. Astonishingly, the authors cited such a Younger

Dryas iridium spike in a Greenland ice core, yet the originator of those data says his paper does not report abnormal iridium at 12.9 ka or anywhere during the YD. Microspherules rain down all the time with interplanetary dust, and do not constitute sound evidence either.

So, what on Earth is going on? A collaboration between 26 authors, who willingly supply other workers with materials for checking surely cannot be conspiring at a hoax. Impact experts are hinting at 'over-enthusiasm' by a team outside the 'impact community'. It all sounds oddly similar to the furore that in 1980 greeted first suggestions by Alvarez *pere et fils* for the K-T impact…

A 0.8 Ma history of changing greenhouse gases (*July 2008*)

Polar ice cores have presented us with the most exquisite records of how high-latitude climate has changed in the recent past. They provide indirect clues, or proxies, presented by variations in stable isotopes of oxygen and deuterium (temperature change), dust and sulfate content (aridity and volcanicity respectively) in successive layers of ice. That record extends back to 800 ka in the Dome C core from Antarctica, and shows in great detail the course of the last nine glacial-interglacial cycles. This includes the effect of a changeover from a 40 ka astronomical pacing to one of around 100 ka and many intricacies on millennial time scales. The most tangible archive of information resides in the air bubbles trapped by the original snow that eventually turned into ice. That reveals how the intricate pacing of climate change has been almost perfectly tracked by the global carbon cycle as shown by changes in the concentrations of carbon dioxide and methane. This was first demonstrated by cores through the Greenland ice cap, which penetrate just the last glacial episode and the warm interglacials before and after. After several years of painstaking bubble analyses at many collaborating labs, the full 800 ka greenhouse-gas records from Antarctica have now appeared (Luthi, D. and 10 others 2008. High resolution carbon dioxide concentration record 650,000-800,000 years before present. *Nature*, v. **453**, p. 379-382; DOI: 10.1038/nature06949. Lulergue, L. and 9 others 2008. Orbital and millennial-scale features of atmospheric CH_4 over the past 800,000 years. *Nature*, v. **453**, p. 383-386; DOI: 10.1038/nature06950).

These long records demonstrate the close connection between climate and greenhouse gases that must have been maintained by complex (and not fully understood) feedback mechanisms. Different Earth processes affect the two principal gases, methane probably being controlled by effects of varying temperature and rainfall on peat-rich swamps in the tropics, whereas carbon dioxide's main driver is capture and release of carbon by the oceans. The central feature remains that of astronomical forces, with perhaps some sign of a signal from the 413 ka component of orbital eccentricity from a shift in the range of temperatures and greenhouse gases in 100 ka cycles around 450 ka ago, and a broad change in methane concentrations. Yet, despite being a pole away from high northern latitudes where comparison of the Greenland ice record with North Atlantic sea-floor sediment data revealed a northern cause for dramatic short term shifts, much the same millennial cycles characterise the whole Antarctic record. It could be that these rapid changes are proxies for the course of northern climate vagaries – there are about 75 of them in the Antarctic methane record. So stunning are the new data that they are sure to spur attempts to go back even further by more drilling in Antarctica, probably in the eastern ice cap where current air temperature and snow fall are extremely low and a greater length of time may be preserved in a smaller thickness of ice. That is because the faster snow and ice accumulate the more rapidly flow removes the record: the reason why the thick Greenland ice, although capable of yielding time resolution of as little as individual years, cannot retain records much beyond 200 ka.

See also: Brook, E. 2008. Windows on the greenhouse. *Nature*, v. **453**, p. 291-292, DOI: 10.1038/453291a.

The yellowing of the Sahara (*July 2008*)

As Earth emerged steadily from the last glacial maximum, around 14.8 ka, when temperatures were close to those of the Holocene yet sea level still had a way to rise before reaching its current level, the Sahara became a land of wetlands, lakes and grassland. Many caves within its modern arid confines contain superb artwork depicting its fauna and the forager-hunters that preyed on it. Around the time of the earliest Pharaonic civilisation on the Nile floodplain (~3000 BCE) the humid episode ended, forcing inhabitants of the Sahara either to the Nile valley or the Mediterranean coast. Having spanned the millennium-long climatic upheaval of the Younger Dryas and the relative stability and warmth of the early Holocene, why it ended is something of a mystery. A small, amazingly beautiful lake in northern Chad seems to hold the key, as it has existed and gathered sediment for at least 6 thousand years (Kröpelin, S and 14 others 2008. Climate-driven ecosystem succession in the Sahara: the past 6000 years. *Science*, v. **320**, p. 765-768; DOI: 10.1126/science.1154913). Lake Yoa is one of several permanent lakes fed by ancient groundwater from the vast Nubian Sandstone aquifer, yet receives negligible rainfall. The uppermost lake sediments are laminated in an annual fashion so that each layer and its contents of aquatic organisms, pollen and dust can be precisely dated.

Lake Yoa, Chad. (Credit: S. Kröpelin)

Between 4200 and 3900 years ago the lake changed from a freshwater habitat to a salt lake when evaporation overcame recharge by rain. However, the environment as a whole did not change suddenly, but progressively. The sudden change in salinity resulted from Lake Yoa losing any outflow, which previously had removed salts accumulated by evaporation of the inflowing groundwater. The lake would then no longer have had any use for humans and their livestock, but conditions did not drive people out of the Sahara suddenly.

See also: Gramling, C. 2008. Un-greening the Sahara. *Geotimes* (July 2008)

Testing hypotheses for the onset of Northern Hemisphere glaciation (*September 2008*)

Whereas Antarctica began to develop significant ice caps by the early Oligocene, those of the Northern Hemisphere, principally on Greenland, did not arise until about 3 Ma ago. There are several hypotheses for that onset of the Great Ice Age: closure of the Panama seaway and increased poleward heat transport in the North Atlantic; perhaps related development of the El Niño cycle in the East Pacific; uplift of the Himalaya and Rocky Mountains to change atmospheric circulation; lowered atmospheric CO_2, and a combination of all four that allowed the Milankovich astronomical forcing to get a grip on Earth's climate 'machine'. Testing the hypotheses is somewhat more difficult than find empirical support for them; i.e. coincidences in timing. Climate scientists from Bristol, Cambridge and Leeds universities in the UK have attempted such a test, using a complex climate model involving coupled atmosphere-ocean circulation and ice-sheet models (Lunt, D.J. *et al*. 2008. Late Pliocene Greenland glaciation controlled by a decline in atmospheric CO_2 levels. *Nature*, v. **454**, p. 1102-1105; DOI: 10.1038/nature07223). Only a decrease in the greenhouse effect could have transformed climate over Greenland sufficiently to equip it with a large ice sheet, the other three main hypotheses falling a long way short, although each could have led to small ice volumes. Significantly, the study failed to find support for any of the terrestrial processes having been capable of 'priming' orbital and rotational forcing to such an extent that they triggered glaciation. Despite the claims by the authors, as computing power goes up and the resolution of feasible climate modelling comes down it is quite likely that within a few years there will be another view 'supported' by models.

Climate shock of the Younger Dryas (*September 2008*)

Between 12,900-11,500 years before the present, high northern latitudes returned to almost full glacial conditions, after about 6000 years of warming since the Last Glacial Maximum. Just prior to the Younger Dryas cooling event, conditions had warmed to an extent that European people had migrated northwards, some to occupy what are now the British Isles. Temperate grasslands teeming with game were the probable attraction, and still-low sea levels permitted crossing of what became the North Sea. Although it is possible that some people remained in Britain through the thousand-year mini glaciation, conditions would have been at the extremes of winter cold and year-long windiness, judging from the Greenland ice-core records of air temperature and dust. Those records have shown for some time that the transition from warmth to frigidity was rapid, but not *how* rapid. The cold spell had much in common with sudden, millennial-scale coolings repeated several times during the run-up to the last glacial maximum. Each such event has been linked with interruptions in the shallow and deep circulation of North Atlantic ocean waters, a likely trigger having been reduction in the salinity of surface waters as a result of floods of fresh water, either through collapses of ice caps and melting of icebergs or, in the case of the Younger Dryas, release of massive amounts of fresh water from glacially-blocked lakes in North America. One result would have been failure of cold, dense surface water to sink at high latitudes, thereby shutting down the suction effect that drags warm water northwards to raise temperatures, especially in NW Europe.

There are concerns that unsuspected climate shifts that stem from the Earth System rather than astronomical influences – the Milankovich effect – may characterise the period of global warming caused by human activities. Increased precipitation at high northern latitudes or melting of ice on Greenland could result in falling ocean salinity and slowing or shutdown of the North Atlantic heat conveyor. Two sets of data published in August 2008 highlight potential climate shifts that may arise with virtually no warning. Both rely on the potentially high resolution of cores through ice caps and stagnant lakes that are annually layered, which has hitherto not been fully exploited by climate scientists. European and North American researchers have focussed on the upper part of the latest core through the Greenland ice cap, using two or three samples from each annual layer (Steffensen, J.P. and 19 others 2008. High-resolution Greenland ice core data show abrupt climate change happens in few years. *Science*, v. **321**, p. 680-684; DOI: 10.1126/science.1157707). Deuterium and oxygen isotopes during the onset of the Younger Dryas show a marked cooling at the source of moisture precipitated as snow within 1 to 3 years, which the authors ascribe to the Intertropical Convergence Zone migrating northwards through a major change in atmospheric circulation. Temperature over the Greenland ice cap also changed, but over about 50 years [note however, that the sharp warming of the Bölling episode took less than a decade].

The second study uses annually varved lake sediments that accumulated in an isolated lake in central Germany that filled a circular depression formed by explosive volcanism (Brauer, A. *et al*. 2008. An abrupt wind shift in western Europe at the onset of the Younger Dryas cold period. *Nature Geoscience*, v. **1**, 520-523; DOI: 10.1038/ngeo263). The seasonal sediment layers change in thickness, colour and mineralogy as warmth gave way to the frigidity of the Younger Dryas. One of the proxies, the iron content of the sediments deposited under anoxic conditions during winters fell significantly within a year at 12679 BP, along with a 4-5 fold increase in the rate of sediment deposition. Together with shifts in the lake biota, these features suggest to the authors that within a year wind strength increased greatly, probably due to a greater incidence of storm-force westerlies brought on by a change in the position of the jet stream. Today, westerly winds add to warming in northern Europe, around 12.7 ka they added to cooling, which can only be explained by global cooling or a southward excursion of sea ice in the North Atlantic.

Neither abrupt climate shift can be produced by validation of today's climate models using actual data from the time just before they took place. It follows therefore that similar shifts in the near future could make themselves felt with no warning.

Opinion has drifted back and forth regarding the global effects of the Younger Dryas, evidence for its effects in the Southern Hemisphere being scanty. The best place to look for direct evidence would be in mid-latitude glaciers, especially where they are abundant in South America and New Zealand. A study of the largest of these, the Southern Patagonian Icefield (Ackert, R.P *et al*. 2008. Patagonian glacier response during the late glacial-Holocene transition. *Science*, v. **321**, p. 392-395; DOI: 10.1126/science.1157215) indicates that the ice there advanced around the time of the YD. However, its dating indicates that the advance lay outside the 1300 year span of the cold period in the Northern Hemisphere. It was more likely due to a local response to increased precipitation from air moving from the east.

See also: Flückiger, J. 2008. Did you say "fast"? *Science*, v. **321**, p. 650-651; DOI: 10.1126/science.1159821.

East African evidence for Late Pleistocene climate change (*November 2008*)

The most interesting times in human prehistory were those when African hominins set off from their home continent for new habitats. The earliest seems to have been the migration of *Homo ergaster* some 1.8 Ma ago, and the most riveting, of course, was that of modern humans who set out to colonise the entire habitable planet sometime around 80 to 60 ka ago. It is pretty certain that the population movements were driven by environmental changes that provided a driving pressure to seek survivable conditions beyond Africa, such as episodes of drying in East Africa, and passable exits from the continent, such as sea-level falls to produce land bridges like that of the Straits of Bab el Mandab. One of the glaring gaps in knowledge about those circumstances is evidence for climate change from Africa itself. The problem has been that many of the Great Lakes did not fill until the last 12 ka or so, so provide no sediment cores and proxy climate records for the crucial period in human history. Lake Tanganyika is an exception, being so enormously deep that it survived much of the last glacial episode when Africa was probably a lot drier than now. Cores of Lake Tanganyika sediment reach back at least to 60 ka (more might be had if coring was done using drilling rather than piston coring) and a surprising record has emerged from that time (Tierney, J.E. *et al*. 2008. Northern Hemisphere controls on tropical southeast African climate during the last 60,000 years. *Science*, v. **322**, p. 252-255; DOI: 10.1126/science.1160485).

Deuterium and organic geochemical data from the cores are proxies for water temperature and precipitation in the lake's catchment, and show fluctuations that clearly match the familiar patterns of climate change from Greenland ice cores, and the intensity of the Asian monsoon recorded in Chinese cave deposits. This match shows clearly that the East African climate followed closely the orbitally-induced changes in solar input at high northern latitudes. But the cause of the linkage is not clear. One candidate is the varying position of the Intertropical Convergence Zone (ITCZ). Yet it seems that known shifts in the ITCZ are not linked to East African fluctuations. So the connection with the Asian monsoon hints at controls by the changes in Indian Ocean sea-surface temperature. The 'teleconnection' is characterised by very abrupt shifts from humidity to aridity, and profound aridity around 57, 47.5 and 38 ka. These may have resulted in extreme ecological shifts in the southern East African Rift System, resulting in considerable stresses on human groups. Sadly, data from the most probable first period of migration out of Africa by modern humans (70-80 ka) have not been reached by the piston coring method – maybe they will eventually be accessed by rotary drilling. However, the close linkage with the Greenland record does suggest that cool/arid conditions occurred in the modern human heartland around 70 and 74 ka, when sea level was beginning to fall to 80 m below that at present.

Younger Dryas and the Bat Cave (*November 2008*)

It seems that bats have a remarkable loyalty to their chosen cave, whatever the weather. Thick guano deposits coat the floors of most caves that are now popular with bats. While the deposits are bioturbated by a narrow range of unwholesome insects, sufficient stratigraphy remains intact for more intrepid scientists to chance their hand at proxy records of climate in the caves' vicinity; but data are, unsurprisingly, rather scanty. Arid conditions enhance preservation of such cave-floor deposits, and Bat Cave in the Grand

Canyon of Arizona has attracted attention (Wurtster, C.M. *et al*. 2008. Stable carbon and hydrogen isotopes from bat guano in the Grand Canyon, USA, reveal Younger Dryas and 8.2 ka events. *Geology*, v. **36**, p. 683-688; DOI: 10.1130/G24938A.1). The team from Scotland, Canada, the USA and New Zealand show that both the Younger Dryas and a lesser global cold spell at 8.2 ka are discernible in the guano core from Bat Cave, but the signals arise from a rather circuitous cause. Bat guano is largely made up of the chitinous remains of the insects eaten by the bats, and it is the isotopic variation in the insects' diet that the chitin preserves. That in turn stems from local vegetation, in some cases pollen or nectar consumed by the bugs, or even the blood of mammals or birds taken by bloodsucking insects – itself several metabolic steps from the local vegetation. These complexities may account for the rather 'noisy' guano data, yet it seems likely that other caves will be probed in arid areas where speleothem (from stalactites) has not developed continually through the caves' lifetimes.