the Eocene, attributing the discrepancy between these and previous tropical SST estimates to the effects of diagenetic overprinting of the latter. Here we note some potential flaws in their interpretation of the new oxygen-isotope data.

Although dissolution and incipient secondary calcification of tropical, deep-sea fossil planktonic foraminifera bias shell $\delta^{18}O$ ratios towards higher values[2–4], we consider it unlikely that all tropical planktonic foraminifera tests are overprinted to the extent claimed by Pearson *et al*. Their estimate of up to 50% secondary calcite is based on a comparison of multi-species carbon and oxygen isotope values from planktonic foraminifera of "similar age" from Tanzanian outcrops and the Deep Sea Drilling Project Site 523 in the eastern South Atlantic Ocean, and their key assumption is that initial conditions are identical for both sets of samples.

However, given the differences in latitude, and the likely proximity of Tanzania and Site 523 to warm western and to cool eastern boundary currents, respectively, SST could have differed by as much as 6–8 °C between the two localities in the Eocene, just as it does today. This alone could account for 80% of the $\delta^{18}O$ difference between the two data sets. Moreover, as implied by the clay-rich depositional facies from which the Tanzanian fossils were extracted, it is likely that regional sea-surface salinities and seawater $\delta^{18}O$ were lower, possibly by as much as 3.0 p.p.t. and 1.0 p.p.t, respectively, than at Site 523. This local salinity difference would further bias the Tanzanian SST estimates towards higher values. These biases are compounded by the fact that the chronostratigraphic constraints on the Tanzanian sediment sequences are relatively coarse, a point that is reflected in the reported age errors of the Tanzanian samples, which is ±1–2 Myr.

As a result of these and other potential biases, it may prove difficult to constrain absolute estimates of SST in tropical coastal oceans to better than ±3.0 °C for Eocene or Cretaceous 'greenhouse' intervals. This raises the issue of whether this is the most effective approach to resolving the enigma of greenhouse-gas tropical SSTs. We think not, and favour a more practical strategy that focuses on relative changes in temperature that were associated with episodes of rapid, short-lived climate change[5–7].

Why? One reason is that it is easier to quantify relative changes in temperature on short timescales (about 10^2–10^4 yr), even in sediments that have been slightly to moderately overprinted. Because secondary calcification in sediments of uniform lithology is constant over short length scales, primary offsets in fossil-shell chemistry tend to be preserved, although slightly attenuated[3,6].

Second, by focusing on rapid, transient events, the number of climate-forcing parameters can be reduced to greenhouse-gas levels, as all other non-astronomical parameters, such as changes in continental geography and elevation, operate on much longer timescales. However, this strategy will be most effective when dealing with well-dated, stratigraphically continuous (over millions of years) and lithologically uniform sedimentary sequences, such as those typically recovered from the deep sea.

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Pearson et al. *reply* — We agree with Zachos and colleagues that much can be learned about transient climate events from well-dated carbonate sediments from the deep ocean, and that the problem of recrystallization of such sediments (when tens of millions of years old) means that constraining relative temperature changes from oxygen-isotope data is more appropriate than attempting to measure absolute values.

We note, however, that this marks a shift of emphasis from studies spanning several decades, in which attempts have been made to determine actual temperatures from the deep-sea record and to compare them with the output of climate-model simulations (for example, see refs 1–3). We also warn against assuming that "primary offsets in fossil shell chemistry tend to be preserved", as diagenetic overprinting will tend markedly to reduce such offsets, as well as attenuating stratigraphic patterns.

We have suggested that recrystallization could account for as much as 50% of the mass of planktonic foraminifera in typical deep-sea samples, which would reduce estimated SSTs in the tropics by 10–15 °C. Zachos *et al*. have questioned our comparison of isotope data from well-preserved, middle-Eocene foraminifera from Tanzania and a recrystallized deep-sea assemblage. But we did not assume that initial conditions were identical for the two sites — indeed, we were careful to point out the likely original difference in temperature. When this is taken into account, we calculate that the oxygen-isotope data suggest a 55% diagenetic overprint of the deep-sea sample towards an ocean bottom-water temperature of about 10 °C (ref. 4). A similar overprint is also implied by the greatly reduced inter-species carbon-isotope differentials.

We also discussed the question of $\delta^{18}O_{sw}$ on the Tanzanian margin. For several reasons (the narrow open shelf, probable onshore current, normal stratification, full plankton assemblages and results of palaeosalinity modelling), we think it unlikely that the salinity was as much as 3.0 p.p.t. lower than in the deep ocean. But even if it were, the probable relationship between $\delta^{18}O_{sw}$ and salinity at this latitude would imply a $\delta^{18}O_{sw}$ value that is only about 0.5 p.p.t. more negative, which corresponds to an estimated temperature increase of about 2 °C. This is a small effect when compared with the apparent difference of nearly 15 °C in estimated SST between the East African shelf and coeval open-ocean sites such as ODP Site 865 (ref. 2). We stress that our Tanzanian data are also supported by similar results from Mexico, Alabama and the Adriatic Sea.

Study of both deep-sea carbonates and hemipelagic clays is crucial to ensure that sampling is as spatially distributed as possible. But there is no reason why hemipelagic mudstones should not be as accurately dated as deep-sea carbonates, thereby combining the advantages of high-resolution stratigraphy and good microfossil preservation. Recent Ocean Drilling Program (ODP) coring in New Jersey has already demonstrated this potential[5], and we anticipate further well-dated Cretaceous and Palaeogene mudstones from a forthcoming ODP leg to Demerara Rise (in the equatorial Atlantic Ocean) and from our own drilling in Tanzania. Such investigations will help to elucidate past variation in absolute palaeotemperatures and meridional temperature gradients, which remains critical for testing the greenhouse theory for past warm climates.

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