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Comment on “Revised paleoaltimetry data show low Tibetan Plateau elevation during the Eocene”

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Botsyun *et al.* (Research Articles, 1 March 2019, eaaq1436) have suggested that the Tibetan Plateau was low (substantially less than 3000 meters) during the Eocene, based on a comparison of oxygen isotope proxy data with isotope-enabled climate model simulations. However, we contend that their conclusions are flawed as the result of a number of failings of both the modeling and the data comparison.

Botsyun *et al.* (*1*), on the basis of a comparison of oxygen isotope data with a set of isotope-enabled climate model simulations, recently suggested that the Tibetan Plateau was low (substantially less than 3000 m) during the Eocene. Along the windward front of the plateau, this modeling work contradicts proxy-based studies using oxygen isotopes [e.g., (*2*)], thermodynamic paleoaltimetry techniques [e.g., (*3*)], and modern observations (*4*). Botsyun *et al.* argue that warmer worlds have a hydrological cycle dissimilar to that of the modern period. However, we contend that their conclusions are flawed as a result of failings of both the modeling and the data comparison.

Stable isotope paleoaltimetry requires several assumptions about the sources of moisture, recycling, and atmospheric circulation, which are difficult to assess from data alone. Many studies have used isotope-enabled climate models to validate these assumptions and improve the estimates of paleoaltitudes [e.g., (*5*)]. We welcome this approach as a way of refining the reliability and accuracy of isotope paleoaltimetry.

However, Botsyun *et al.* have made several weak or incorrect assumptions. First, they used an incomplete modeling approach. They ran an atmosphere-only climate model with no feedbacks between the atmosphere, vegetation, and ocean. They also failed to consider spatial variations in surface ocean isotopic values, which are ultimately the source of the precipitation. In the modern climate, spatial variation is small. However, with the extreme warmth of the Eocene, the enhanced hydrological cycle results in much stronger horizontal gradients in stable isotopes (*6*), which may have an impact on the isotopic value of precipitation.

To investigate the model failings of Botsyun *et al.*, we repeated their analysis using the HadCM3L model, which is an isotope-enabled coupled atmosphere-ocean-vegetation model (*6*, *7*). We used Lutetian (41 to 48 Ma) paleogeography (*8*), a period similar to that in Botsyun *et al.* Our simulation has extensive Tibetan elevation exceeding 4 km. The resulting isotope precipitation map (Fig. 1) should be compared to figure 2 of Botsyun *et al.*, particularly figure 2F (reproduced here), which has a seaway between India and Asia and hence is closest to our paleogeography.

There are substantial differences due to alternative reconstructions of paleogeographies with almost 10° latitude differences in places. However, on the Asian continent both models have some similarity, with typical values from −1 to −6‰ near the coast dropping to about −11 to −12‰ in the interior, broadly consistent with data. This is despite our model using elevations significantly higher than 4 km and shows clearly that our isotopic modeling is consistent with a high Eocene Tibet. Moreover, our spatial pattern of elevation and isotopes is consistent with the Rayleigh distillation model (*2*) underpinning isotope paleoaltimetry, with lowest isotope values corresponding to highest elevations. Recently, Shen and Poulsen (*9*) suggested that Tibetan isotope paleoaltimetry was poor for low elevations only, and our modeling supports this.

Furthermore, because Botsyun *et al.*’s model was atmosphere-only, their changes in topography did not feed back onto sea surface temperatures (SSTs). These feedbacks are important because stronger monsoons will change

upwelling, SSTs, and hence isotopic composition. There is almost no sign of cooler upwelling regions in their ocean simulation, and their EOC-sea simulation has some unrealistic structures in the seaway itself.

The SSTs prescribed by Botsyun *et al.* (based on a different climate model) are generally higher than data suggest (figure S12) and higher than we predict for the mid-Eocene. They resemble those expected at peak warmth of the early Eocene. These very warm SSTs may further explain the differences, because they will change the balance between convective and large-scale precipitation, which affects the isotopic signature (*5*).

The LMDZiso model used by Botsyun *et al.* fails to represent the isotopic depletion measured in Quaternary tropical ice cores, raising the question of whether processes affecting $\delta^{18}O$ in the tropics are well represented (*10*). Furthermore, Gao *et al.* (*11*) showed that LMDZiso simulated $\delta^{18}O$ values are unrealistic with a modern simulated summer $\delta^{18}O$-altitude relationship of –0.15‰ (100 m)$^{-1}$, half that of the observed relationship [–0.3‰ (100 m)$^{-1}$]. This may well explain the underestimate in Botsyun *et al.*'s predicted plateau height.

A further problem with Botsyun *et al.*'s analysis was the choice of data. The data had a broad time range, spanning the extreme warmth of the Paleocene-Eocene Thermal Maximum (52 Ma) to the Eocene-Oligocene boundary (~34 Ma). During such a long period, changes in uplift, paleogeography, and atmospheric CO_2 will likely result in substantial changes in stable isotope distributions. This is especially true for the Paratethys sea, which had started to retreat from the north of Tibet before 47 Ma (*12*). Yet Botsyun *et al.* cluster the data to the mid-Eocene and claim that altitude is the main driver.

The problem with time averaging is compounded by uncertainties in paleolatitude. This is demonstrated by comparing the coastlines of our Fig. 1 with those in figure 6 of (*1*). Botsyun *et al.* use a simple treatment of paleolatitude, selecting one paleomagnetic data anchor point (the Fenghuoshan Group of the Hoh Xil Basin). However, the age of the Fenghuoshan Group was recently corrected to Cretaceous–Early Eocene [72 to 51 Ma (*13*)]. In addition, their anchor point is from sediments that suffer from compaction-caused inclination shallowing, resulting in paleolatitudes being at least 5° too far south (*14*).

Although Botsyun *et al.* acknowledge many of these problems, they use a simple metric to choose the "best-fit" data-model comparison (sum of squared residuals). They also assume that residuals are all equal and ignore that some residuals may be due to the complex structure of the topography. For instance, there can be substantial valley systems within an overall high topography (*15*). A more appropriate Monte Carlo or Bayesian approach would likely change their conclusions.

Deriving paleoaltitudes from stable isotopes is a complex calculation, and we applaud the use of isotope-enabled modeling. However, Botsyun *et al.* used an incomplete model with known serious deficiencies for the present climate. They therefore arrived at incorrect conclusions. The use of a more complete, fully coupled isotope-enabled model shows that parts of Tibet were high in the Eocene, in full agreement with previous isotopic and other metrics.

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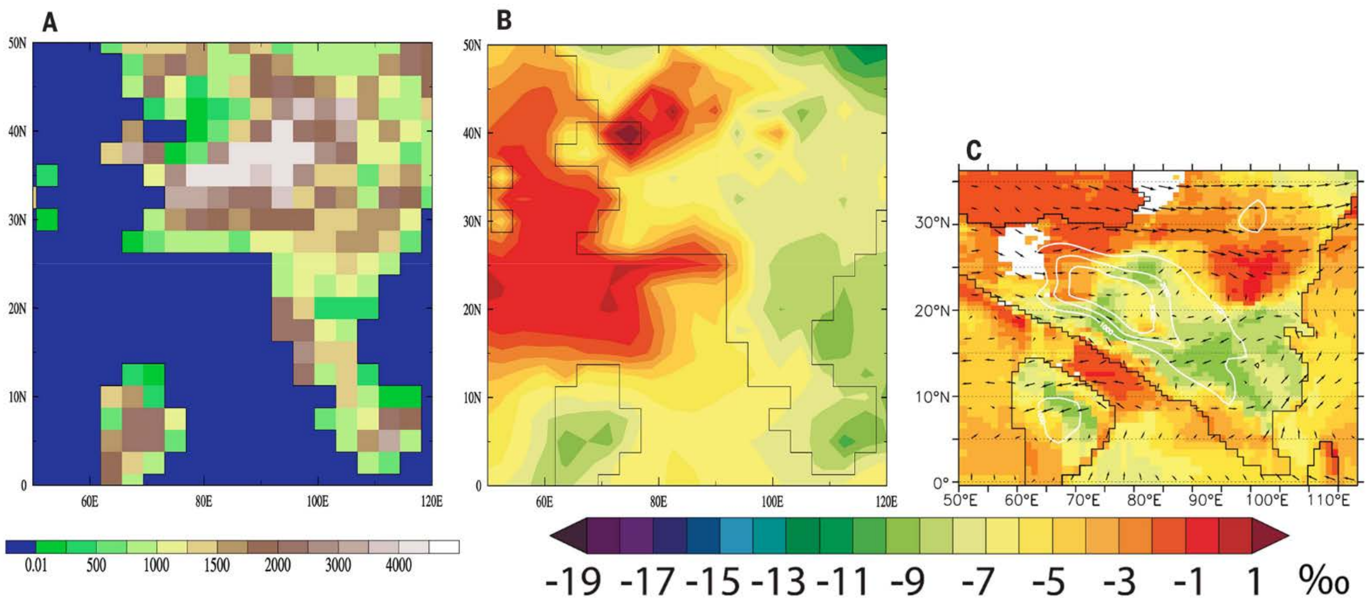

Fig. 1. Maps of geography and calculated δ^{18}O. (**A**) Paleogeographic reconstruction of the Lutetian (*8*). (**B**) June through September (JJAS) precipitation–weighted δ^{18}O using this reconstruction and the isotope-enabled HadCM3L climate model. (**C**) Comparable result from figure 2F of Botsyun *et al*.

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