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Title: Comment on "Revised paleoaltimetry data show low Tibetan Plateau elevation during the Eocene"

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Abstract: Botsyun et al. (Research Articles, 1 March 2019, 10.1126/science.aaq1436) recently suggested that the Tibetan Plateau was low (substantially less than 3000m) during the Eocene, based on comparing oxygen isotope proxy data with isotope-enabled climate model simulations. However, we contend that their conclusions are flawed due to a number of failings of both the modelling and data comparison.

One Sentence Summary: The modelling of stable water isotopes for palaeoaltimetry requires fully integrated earth system modelling to ensure correct conclusions about past uplift history.

Main Text:

Botsyun et al. (*1*) recently suggested that the Tibetan Plateau was low (substantially less than 3000m) during the Eocene, based on comparing oxygen isotope data with a set of isotope-enabled climate model simulations. Along the windward front of the plateau this modelling 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 dissimilar hydrological cycle to that of the modern. However, we contend that their conclusions are unsafe due to failings of both the modelling and 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. made several weak or incorrect assumptions. Firstly, they used an incomplete modelling approach. They ran an atmosphere-only climate model with no feedbacks between the atmosphere, vegetation and ocean. They also fail 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 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 (41-48 Ma) paleogeography (*8*), a similar period 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 fig. 2 of Botsyun et al., particularly fig. 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 -11-12 ‰ 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 modelling 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 palaeoaltimetry, with lowest isotope values corresponding to highest elevations. Recently (*9*) suggested that Tibetan isotope palaeoaltimetry was poor for low elevations only, and our modelling supports this.

Furthermore, since Botsyun et al. model was atmosphere-only, their changes in topography did not feedback onto sea surface temperatures (SST). These feedbacks are important as stronger monsoons will change upwelling, SSTs and hence isotopic composition. There is almost no sign of cooler upwelling regions in their ocean simulation (see S1), 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 impacts the isotopic signature (*5*).

The LMDZiso model used by Botsyun et al. fails to represent the isotopic depletion measured in Quaternary tropical ice cores, questioning whether processes affecting $\delta^{18}O$ in the tropics are well represented (*10*). Furthermore, (*11*) show that LMDZiso simulated δ^{18}O values are unrealistic with modern simulated summer δ^{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. By comparison, our modern simulation well reproduces the observed δ^{18}O lapse rates (unpublished).

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 PETM (52 Ma) to the Eocene-Oligocene boundary (~34Ma). 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 paleo-latitude. This is demonstrated by comparing the coastlines of our fig.1 with those in fig.6. 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 (72-51 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 residuals are all equal and ignore that some residuals may be due to the complex structure of the topography. For instance, (*15*) show that there can be substantial valley systems within an overall high topography. A more appropriate Monte-Carlo or Bayesian approach would likely change their conclusions.

In summary, deriving paleoaltitudes from stable isotopes is a complex calculation and we applaud the use of isotope enabled modelling. 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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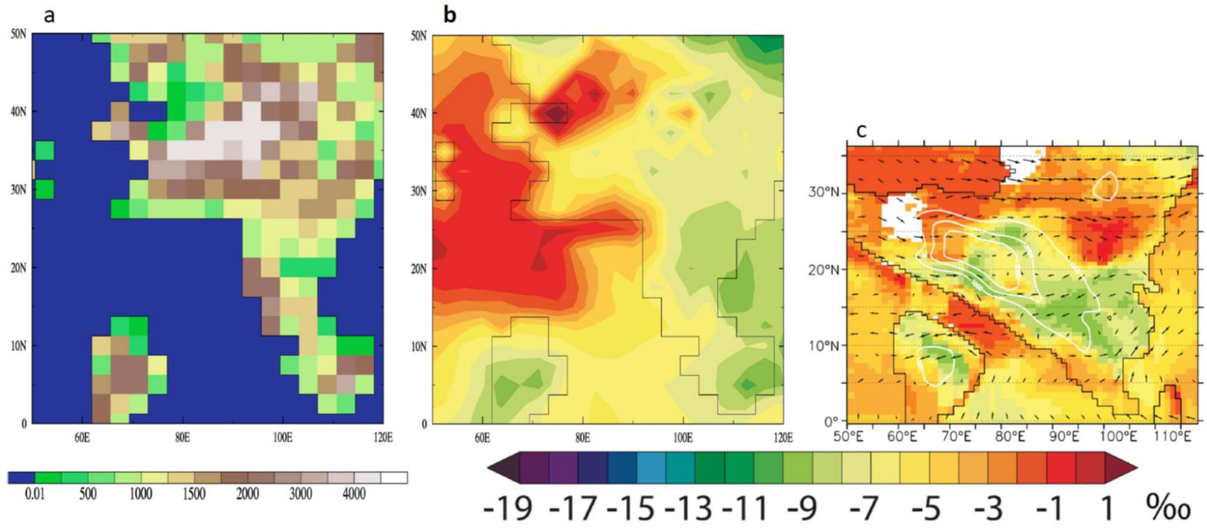
Fig. 1. (a) Paleogeographic reconstruction of the Lutetian (*8*), (b): JJAS precipitation weighted $\delta^{18}O$ using this reconstruction and the isotope enabled HadCM3L climate model, and (c): comparable result from Botsyun et al. (figure 2F).



(Note: Higher quality image in attached pdf).

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