PNAS LETTER

Reply to Schmittner: Topography affects the ocean circulation but does not fully control it

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The Letter to the Editor (1) suggests that our paper (2) missed a link between topography and ocean circulation and failed to cite the relevant literature. We want to begin by clarifying that we acknowledged the link between topography and ocean circulation and discussed recent relevant literature. In particular, in ref. 2 we noted that "A recent study showed that flattening topography in coupled models leads to a weaker ocean circulation, but the impact on storminess is consistent with our atmospheric model results (storminess asymmetry is still significant with flattened topography)." We were referring to the study by Stouffer et al. (3) who showed the response to flattened topography, in an ensemble of comprehensive coupled climate models, which involves weaker ocean overturning circulation in the Atlantic, equatorward shift of surface zonal wind stress in the Southern Hemisphere, and intensification in the Northern Hemisphere extratropics (figures 7A, 8D–F and 12 in ref. 3). One can infer from figures 7A and 8 in ref. 3 that coupled models with flattened topography exhibit hemispheric asymmetries in extratropical surface zonal wind stress, especially over the ocean. The surface zonal wind stress response to flattened topography in our atmosphere-only simulations is similar to the coupled model responses (compare figures 1–8 D–F in ref. 3). We think that the regional hemispheric differences in coupled models with flattened topography would need to be smaller, cf. figure 2D in ref. 2, to conclude "that topography is likely the dominating factor in controlling the asymmetry of westerly winds and thus storminess between the hemispheres."

Given that PNAS limits the number of references, we chose to focus on ref. 3 since it used an ensemble of comprehensive coupled climate models. We apologize for not citing ref. 4 and other studies that demonstrated an impact of flattened topography on the ocean, e.g., refs. 5 and 6. A comparison of previous results suggests that flattened topography can switch the ocean overturning circulation from the Atlantic to the Pacific basin in some models, e.g., refs. 4–6. However, in other models, it does not switch (3). The impact of topography in the Atlantic basin is sensitive to ocean model details (figure 12 in ref. 3). In all models with flattened topography, the ocean circulation still transports energy across the equator breaking hemispheric symmetry. Thus, previous coupled model results provide evidence that topography affects the ocean circulation but does not fully control it. Previous work has also shown basin geometry affects cross-equatorial ocean energy transport and that realistic cross-equatorial transport can be simulated in models with no topography (7–9).

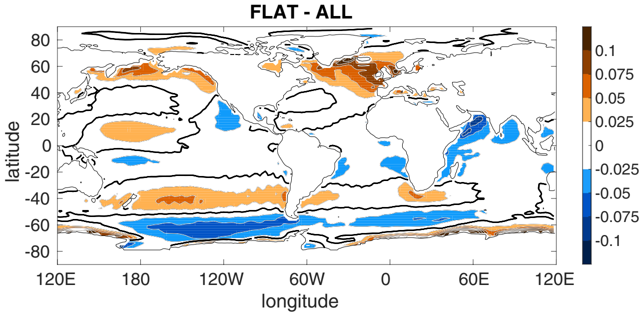

Fig. 1. Difference of annual-mean surface zonal wind stress ($\mathrm{N\,m^{-2}}$) computed as the simulation with flattened topography (FLAT) minus control (ALL) from ref. 2. The contour interval is $0.025\ \mathrm{N\,m^{-2}}$. The thick black contour is zero. Comparable to figure 8 D–F in ref. 3.

Overall, refs. 2 and 3 provide evidence that the hemispheric asymmetry of storminess is still regionally significant with flattened topography. Furthermore, the ocean circulation, and its associated cross-equatorial energy transport, which breaks hemispheric symmetry, is a separate contributing factor to the hemispheric asymmetry of storminess. However, we acknowledge that the "impact of ocean–atmosphere interactions on storminess should be studied further using coupled climate models and observations." Simulations of paleoclimates, involving hosing or changes in basin geometry, could quantify the impact of changes in ocean circulation on the hemispheric asymmetry of storminess in the absence of changes in topography.

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The authors declare no competing interest.

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