Comment on "Climate Sensitivity Estimated from Temperature Reconstructions of the Last Glacial Maximum"

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Science **337**, 1294 (2012);
DOI: 10.1126/science.1221371

Comment on "Climate Sensitivity Estimated from Temperature Reconstructions of the Last Glacial Maximum"

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Schmittner *et al*. (Reports, 9 December 2011, p. 1385) report a new, low estimate of equilibrium climate sensitivity based on a comparison of Last Glacial Maximum climate model simulations and paleoproxy data. Here, we show that exclusion of questionable comparison points and constructive changes to model design are both likely capable of altering the most probable value of equilibrium climate sensitivity suggested in Schmittner *et al*.

Schmittner *et al*. (*1*) estimate equilibrium climate sensitivity (ECS) by comparing University of Victoria Earth System Climate Model (UVic ESCM) simulations with a range of ECS values to a composite of paleoclimate proxy records of Last Glacial Maximum (LGM) climate, surface air temperature (SAT), and sea surface temperature (SST). The UVic ESCM is an Earth system model of intermediate complexity, and here we highlight some structural uncertainties that, in our opinion, were not accounted for sufficiently in (*1*). Using a simple sensitivity analysis, we show that these uncertainties are likely capable of notably influencing their most likely ECS value.

We first regridded the model output from (*1*) and related land and ocean proxy data onto a common, high-resolution grid (0.2° by 0.2°) to facilitate direct comparison without introducing interpolation artifacts. Low-resolution grid quantities are applied as a single value over the equivalent area on the high-resolution grid. Comparison of model and observation data on this common grid highlights coastal model/observation data mismatches due to land-mask inconsistencies; these points were removed from model/observation comparison.

Over the land component, we found that the analysis in (*1*) erroneously compared model SAT over ice sheets to bare land pollen data (*2*) for several proxy SAT grid points. We excluded these data points from further analysis. Several high-latitude 2° by 2° proxy SAT grid points in Alaska describe remarkably strong gradients and temperatures, including high-latitude LGM temperatures up to 13.4°C warmer than present. For our sensitivity analysis, we excluded these data points because the simple, diffusive, coarse resolution UVic ESCM atmosphere would not be capable of capturing the high-gradient climatic signal that the data suggests, introducing an error in any model-data comparison there.

The Multiproxy Approach for the Reconstruction of the Glacial Ocean Surface (MARGO) reconstruction suggests SSTs of up to 6.2°C warmer than present-day in the LGM high-latitude North Atlantic and Nordic Seas (*3*), with warm values due largely to dinoflagellate cyst data (*4*). Given discrepancies in North Atlantic paleo-SST data, members of the MARGO community note that "the average LGM SST in the Nordic Seas cannot at present be assessed with confidence" (*4*). More importantly, it is not clear that these warm MARGO-derived SST values can be directly compared with equivalent model output, given the presence of a strong North Atlantic cold bias of up to –10°C (*5*) in this model. This cold bias is structural and strongly linked to anomalous sea-ice growth. In addition, we believe that the coarse vertical nature of the UVic ESCM ocean model makes any under-ice SST comparisons dubious. The presence of clear model weaknesses in this region overlaid on uncertain MARGO data led us to exclude oceanic data north of 50°N in the Atlantic, largely removing Arctic sea-ice–covered regions from model/observation comparisons.

The mask of included and excluded points is shown in Fig. 1. We note that excluding certain land and ocean data contributes to the very poor representation of the zonal mean at several latitudes.

Pointwise intermediate-complexity climate model (EMIC)–observation comparisons can generate residual error or "noise" related to the difference between overly smooth climate model output and observational data with strong spatial structure. For this reason, we believe that comparison of latitude-weighted zonal averages instead of analyses based on point-wise comparison is a more discriminating metric of large-spatial-scale EMIC performance, even when the zonal mean is not completely represented. Thus, to explore the first-order influence of comparison point removal on relative model ranking, we zonally averaged data-model differences and performed a relative ranking based on root mean square error (RMSE) of both the data-limited and original data sets (Fig. 2). We found that exclusion of questionable comparisons altered our version of the "best fit" model in (*1*). Although our statistical

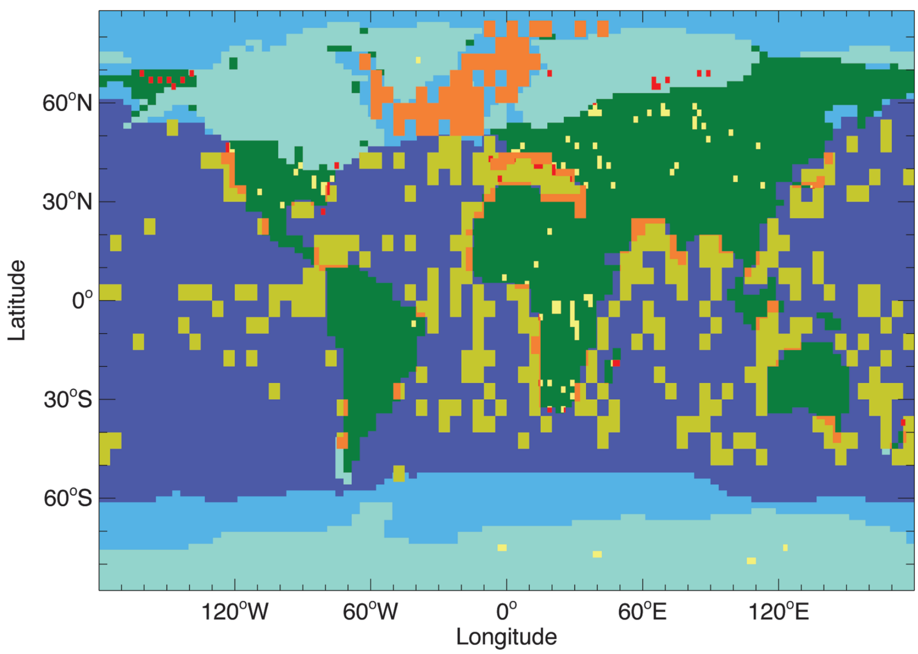

Fig. 1. Spatial map of included/excluded data. Yellow, included land data points; red, excluded land data points; olive, included MARGO data points; orange, excluded MARGO data points; turquoise, land ice; light blue, sea ice in medium-ECS simulation; dark green, model land; dark blue, model ocean. Removal of high northern latitude land and ocean points results in poor zonal coverage above 60°N.

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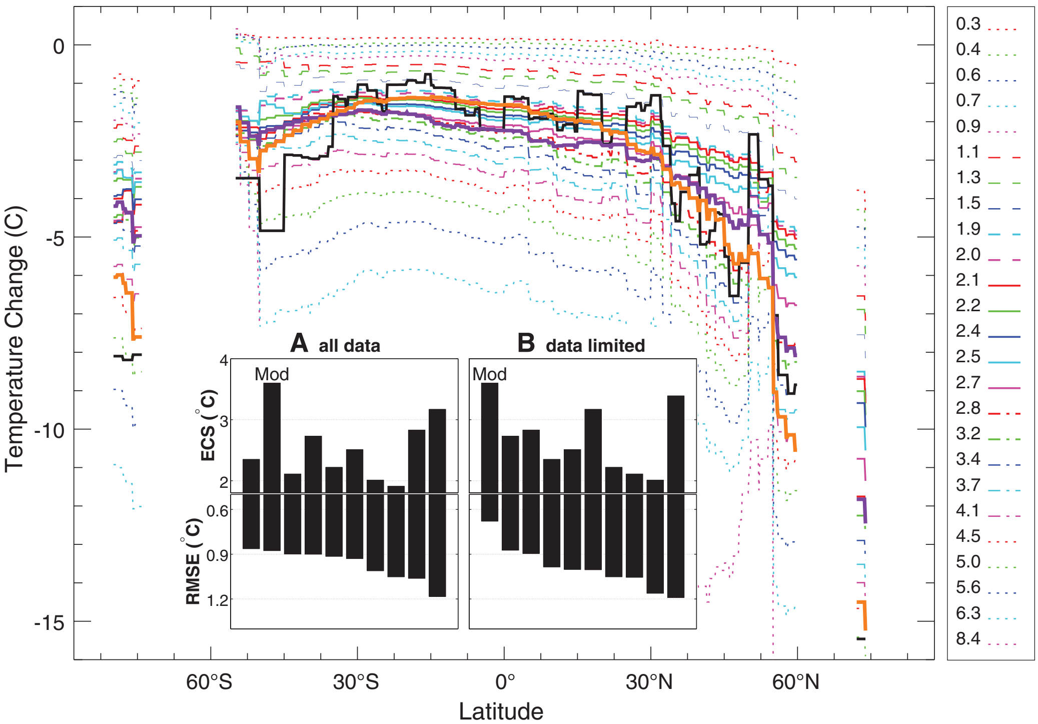

Fig. 2. Latitudinal average LGM-modern SAT/SST difference, with locations of questionable data-model comparisons removed. Black line, composite observations; thick orange line, simulation using a new version of the UVic ESCM with variable latitudinal atmospheric diffusion of heat (Mod); thick purple line, original default UVic ESCM LGM simulation; remaining thin lines, simulations from (*1*). (**Inset**) Latitude-weighted zonal average RMS-based comparison of top-ranking central model simulations from (*1*) and Mod, with (A) all data and (B) limited data. Top bars represent ECS; lower bars show RMSE for each simulation. (A) corresponds to the original analysis in (*1*), whereas (B) corresponds to the updated zonal average differences plotted here. The Mod simulation does notably better than the simulations in (*1*) at simultaneously matching both low-latitude observations and the few robust high-latitude observations when data are limited. With questionable model/data comparisons excluded, the high-ECS Mod simulation performs notably better than the nearest competitor in (*1*). The positions of the simulations in (*1*) also shift, with higher-ECS models moving up in ranking.

processing is simple compared with the analysis in (*1*), it suffices to demonstrate that model performance metrics are strongly dependent on the comparison points used in the analysis. While Schmittner *et al.* also note that removal of particular regions of the data affects their results, their final product results from point-wise comparison using all available locations, which we suggest is not optimal.

Finally, to explore the potentially large dependence of Schmittner *et al.*'s results on the choice of climate model, we carried out a new model simulation with the most recent version of the UVic ESCM in which the atmospheric latitudinal profile of heat diffusion varies in response to the global average atmospheric temperature anomaly (the "Mod" simulation in Fig. 2). This functionality gives a new model with much-improved fit to both Antarctic and Arctic LGM temperatures as recorded by ice cores, yet still retains an excellent fit to low-latitude temperatures. Notably, and most importantly, we found that this model ranks very well with respect to the relative RMSE test, but with a much higher ECS (3.6°C) than similarly ranked models in (*1*). As suggested in (*1*), the lack of dust forcing in our LGM model may lower the equivalent ECS by ~0.3°C, but this is still well above the median ECS estimate of 2.3°C in (*1*).

In summary, we argue that structural model error limits the ability of the model to recreate some aspects of the LGM climate as reconstructed from available proxy data, and this results in nonphysical biases in any model/observation comparison. We also find that reasonable and constructive changes to model design change our best estimate of ECS dramatically. This implies to us that use of more robustly selected comparison points or a different model would likely change the results of (*1*); this puts into question the robustness of their main conclusions (namely, the low and well-constrained ECS value).

Thus, while the overall method is in principle an excellent way of constraining ECS, we suggest that inadequacies in the EMIC that limit it from capturing important aspects of the paleodata and the high dependence of "best-guess" ECS estimates on the choice of climate model preclude the conclusion by Schmittner *et al.* of a low and constrained ECS value.

References and Notes

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Acknowledgments: We thank Schmittner *et al.* for making all model output and paleodata (*2*, *3*) freely available online.

2 March 2012; accepted 24 July 2012
10.1126/science.1221371