Last Glacial Maximum Data Assimilation (`lgmDA`) version 2.0

Jessica E. Tierney

August 8, 2021

Overview: `lgmDA` v2.0 is an update to the data assimilation product published in Tierney et al., (2020). It uses the same proxies and DA parameters as v1.0 but incorporates a wider range of priors, drawn from the model simulations described in Osman et al. (2021). Output now includes monthly SST, sea ice, and SAT as well as mean annual precipitation. I encourage caution in the interpretation of monthly quantities as they have not been validated with independent, monthly-resolved proxies.

Description of model priors: As in Tierney et al., (2020), all model prior states are 50-yr average values. For the LGM timeslice, model priors ($N = 66$) include:

- iCESM1.2 21ka (included in v1)
- iCESM1.3 21ka (included in v1)
- iCESM1.2 18ka (included in v1)
- iCESM1.2 16ka (new for v2)

For the Late Holocene timeslice, model priors ($N = 92$) include:

- iCESM1.2 PI (included in v1)
- iCESM1.3 PI (included in v1)
- iCESM1.2 3ka (included in v1)
- iCESM1.2 PI with prognostic phenology (new for v2)
- iCESM1.2 PI with prognostic phenology (new for v2)
- iCESM1.2 Last Millennium Ensemble with prognostic phenology (new for v2)

Description of proxy data and forward models: Proxy data and forward models used are identical to Tierney et al. (2020) ($N = 956$ proxies for the LGM, $N = 879$ proxies for the Late Holocene).

Description of data assimilation parameters: Data assimilation parameters are identical to Tierney et al. (2020), with localization set at 12,000 km, proxy R set at $R_g/5$. 25 iterations were conducted, withholding 25% of the proxies in each iteration for validation. Non-linear variables (precipitation and sea ice) were transformed prior to assimilation to ensure that the posterior was properly bounded. Annual precipitation was transformed using the natural log, and sea ice fraction was transformed using the logit function.

Validation: Validation with independent ice core and speleothem proxies for δ^{18}O of precipitation is $R^2 = 0.61$, which is generally comparable to v1.0 ($R^2 = 0.67$). However, there is slightly worse performance with the speleothem δ^{18}O in v2.0 versus v1.0. v1.0 maintains a better match to the speleothems and ice cores and thus might be the best product to use for investigation of the isotopes of precipitation.

LGM cooling: The change in global mean surface temperature (GMST; LGM − Late Holocene) in `lgmDA` v2.0 is −5.4°C (−5.9 to −4.9°C, 95% CI). The magnitude of cooling is smaller than v1 (−6.1°C, −6.5 to −5.7°C, 95% CI). The difference comes from the Late Holocene slice, which is 0.8°C colder than the v1 (v2 = 12.8°C, v1 = 13.6°C). In contrast, the GMST of the LGM is similar to v1.0 (v2 = 7.4°C, v1 = 7.5°C). The colder Late Holocene posterior is a consequence of including priors with prognostic phenology in the land model (which have a colder GMST), rather than only including simulations with a prescribed phenology, as was done in v1. The Late Holocene proxies apparently favor a colder solution, a finding supported by the rank histogram analysis in ED Figure 2 of Tierney et al., 2020, which shows that more proxies lie below the prior (i.e. are colder) than above it.

Patterns in LGM cooling: The figure below shows changes in SST and SAT for version 1.0 and 2.0 of the `lgmDA`, respectively. Patterns of change are generally similar although version 2 has less cooling in the central Pacific, the eastern Pacific cold tongue, and the southern Indian Ocean. v2.0 has elevated cooling off of Baja California.

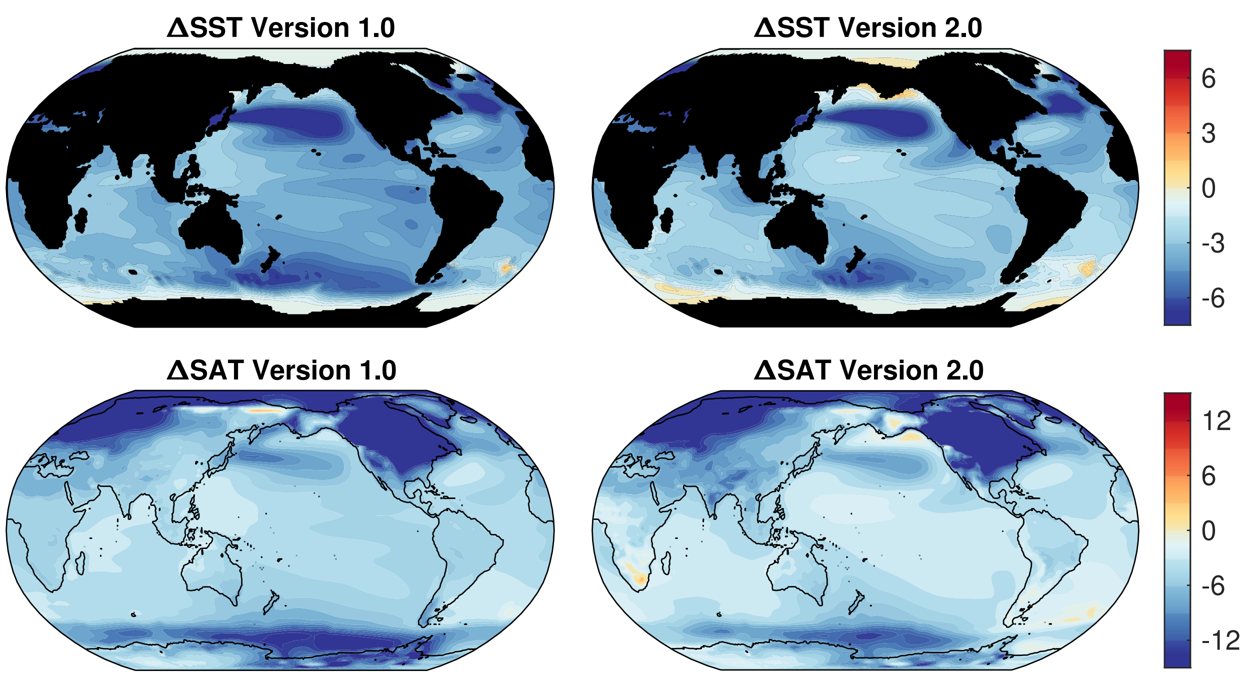

Figure 1: Comparison of changes in SST and SAT (LGM − Late Holocene) between versions 1.0 and 2.0 of `lgmDA`.

Consequences for Equilibrium Climate Sensitivity: Recalculation of ECS ranges with the `lgmDA` v2.0 results in median ECS values that fall between 3–4°C, similar to v1.0. Median ECS with greenhouse gas, ice sheet, and aerosol forcing is 3.0°C (v1 = 3.4°C). It remains highly unlikely that ECS is below 2°C (less than 1% probability) or above 5°C (0% probability).

Monthly Output: v2.0 includes monthly climatologies for SAT, SST, and sea ice fraction. The annual mean of the posterior monthly SST and SAT values matches the posterior annual mean within machine precision. This is not the case for sea ice fraction, however, because this variable was transformed with a logit function prior to data assimilation to preserve the $0-1$ fractional scale, then converted back after the assimilation. Hence, updates to the annual mean sea ice cover and monthly sea cover scale in transformed units but not in the untransformed units, and the mean of monthly sea ice will not match the posterior annual mean.

Citation: When using v2.0, please cite the original `lgmDA` paper:

Tierney, J.E., Zhu, J., King, J., Malevich, S.B., Hakim, G.J., Poulsen, C.J. (2020). Glacial cooling and climate sensitivity revisited. *Nature*, 584, 569–573. `https://doi.org/10.1038/s41586-020-2617-x`.

And ALSO reference the Zenodo data doi for `lgmDA`, which covers v2.0:

`https://doi.org/10.5281/zenodo.5171432`