



Interactive comment on “Modelling oxygen isotopes in the University of Victoria Earth System Climate Model” by C. E. Brennan et al.

C. E. Brennan et al.

cbrennan@ocean.seos.uvic.ca

Received and published: 18 November 2011

We would like to thank the reviewer for assessing the implementation of oxygen isotopes in the UVic model. The reviewer writes that the “simulated d18O favorably compares with present-day data” but has “no skill in predicting d18O in precipitation for the LGM”. We respectfully disagree with the latter. We regret if the reviewer may have misunderstood several aspects of the model’s atmospheric component, including atmospheric moisture transport. Below we consider each issue raised by the reviewer. We specifically address LGM model performance in our response to the reviewer’s second general comment. The reviewer first requests the demonstration of four points. The points are listed (numbered 1-4) and addressed in turn.

1. The model is able to compute a prognostic water transport in the atmosphere that
C1095

could bring some information to the precipitation and its fractionation.

Response: The UVic ESCM is an intermediate complexity climate model due to its simplified atmosphere. This includes specified winds with an additional surface-pressure-dependent wind feedback term, vertically integrated heat and moisture balance equations, and moisture transport parameterized as a function of Fickian diffusion and wind advection. The model computes a prognostic water transport for the bulk vertically integrated column of atmospheric moisture. The model water transport results in reasonable fields of precipitation and evaporation. Due to the importance of Fickian diffusion in moisture transport, atmospheric results are considered to be relevant on decadal and longer timescales. The goal is not to convert the atmospheric model into an Atmospheric General Circulation Model (AGCM), but to produce a sufficiently reasonable distribution of d18O in precipitation.

As to what information is carried to the precipitation and its fractionation, the isotopic signature of the moisture source, moisture transport, and history of condensation are all contributing, albeit in a bulk, vertically integrated signal, to the final isotopic content in precipitation in this model. Also, fractionation during condensation depends on surface air temperature. Therefore, the model does compute a prognostic water transport in the atmosphere that determines precipitation isotopic content.

2. The model has some skills in predicting the deuterium excess, a secondary parameter of the water isotope cycle that is tightly linked to the fractionation of water vapor at evaporative regions and to water transport.

Response: While we recognize that the distribution of deuterium isotopes in atmospheric moisture is tightly linked to that of oxygen isotopes, and provides more information about atmospheric processes and the conditions under which stable water isotope fractionation occurs, we did not choose to include these in this model. We are mainly interested in using the model to assess paleoclimatic interpretations based on oxygen isotope variability in ocean sediment cores. In this regard, deuterium isotopes

are extraneous. We have represented H₂¹⁸O and H₂¹⁶O in the model, and believe that the manuscript should be assessed based on these isotopes.

3. Modeled water and isotopic species are treated in the same way, that is without tuning of the diffusivity of one specie with respect to the other.

Response: This is a philosophical position with which we disagree. Treating the isotopes identically is certainly ideal, and this can be achieved in an AGCM with good results. In a simplified atmosphere model that does not account for vertical isotopic exchange, we introduced an elevation-dependent reduction in the diffusivity of H₂¹⁸O to compensate. With the goal of producing a more realistic distribution of isotopes in model precipitation over mountainous regions, we developed this parameterization, which we view as an acceptable approach for a reduced complexity atmosphere model. Other reduced complexity models listed in Table 3, GENIE-1 and CLIMBER-2, either specify isotope moisture fluxes at ocean grid cells (that is, isotopes are not explicitly represented in atmospheric moisture) (Eqn. 1 and 2 in Marsh et al., 2006), or determine precipitation d¹⁸O as a function of surface temperature and precipitation amount (Eqn. 3 in Roche et al., 2004). Our approach is a significant improvement over these. Without the elevation dependent parameterization, the model precipitation isotopic content is in fact quite similar except in important mountainous regions (Himalayas and the high elevation regions of Greenland and Antarctica).

4. The model has some skills in reproducing paleo-evidences for the LGM, in a prognostic manner, including d¹⁸O of seawater as derived from the MARGO database.

Response: We welcome suggestions for further model-data comparison, however the Multiproxy Approach for the Reconstruction of the Glacial Ocean Surface (MARGO) Project the reviewer requests does not include seawater d¹⁸O data, but rather planktic foraminiferal calcite d¹⁸O (among other proxies). In theory one could combine the foraminiferal calcite d¹⁸O data with the reconstructed SST field to estimate surface seawater d¹⁸O, using the paleotemperature equation (Shackleton, 1974). Unfortu-

C1097

nately, the MARGO Project compilation of foraminiferal calcite d¹⁸O data is not published, and it is currently not available to non-project members (even upon request). For this reason no other isotope-enabled ocean model has compared model output to MARGO d¹⁸O data.

Here we address the reviewer's three general comments, and show that several aspects of the model have been misunderstood.

1. The use of a slightly reduced diffusivity introduces additional fractionation for H₂¹⁸O relative to H₂¹⁶O. This is in fact the goal of introducing this elevation-dependent parameterization, such that the model now forms slightly more depleted precipitation over high-altitude regions (essentially, the "altitude effect"). Without the parameterization, precipitation in these regions is too enriched, since the model cannot capture vertical processes in the atmosphere. The reviewer's statement that the parameterization is "without physical sense" is mistaken: it is a function of elevation, representing vertical effects not captured in the moisture transport occurring in the model's 2-dimensional, vertically-integrated atmospheric grid.

2. The reviewer is mistaken in stating that the LGM simulation contains "identical water transport as for today, but in a globally colder climate". In fact, one component of moisture transport is based on Fickian diffusion, the other by advection by winds, with an additional dynamical wind-feedback term that depends on surface pressure gradients. The wind feedback parameterization is fully described by Weaver et al. (2001) (Equations 13-20). The UVic model LGM simulation contains a LGM-specific set of conditions that together create a very different field of vapor d¹⁸O from present day (see Fig. 9), including an isotopically enriched surface ocean, different atmospheric moisture content, different atmosphere-ocean moisture fluxes, and different isotopic content of those fluxes. The different spatial pattern of LGM H₂¹⁸O moisture leads to a different diffusion-based component of moisture transport. The other change in

C1098

LGM moisture transport originates in the dynamical wind-feedback term. In an LGM simulation, different surface pressure gradients lead to different wind stress anomalies, changing the advection by winds component of moisture transport. LGM moisture transport therefore is different from present day.

For mid and low latitudes, we would not expect to well capture an isotopic shift at a high altitude ice core site (for example, those originating in the Andes of South America), as these would be dominated by the enriched LGM sea surface evaporate in the model. When comparing only to low/mid-latitude cave deposit and aquifer data (6 values), half of the model LGM-PI difference values do not take on the opposite sign (namely, England, Stampriet aquifer, and Sanboa and Hulu caves). At high latitude, model LGM precipitation d18O is more depleted relative to present almost everywhere except the East Antarctic region where most observations are clustered. We were interested to note significant differences in the AGCM LMDZ-iso LGM precipitation d18O when using CLIMAP SSTs versus coupled model SSTs, including a change in sign (LGM – present day d18O) in Greenland and parts of Antarctica (see Figs. 12c and 13c in Risi et al., 2010).

To assess the LGM distribution of d18O in the UVic model, and considering how few observational points exist, the most useful comparison may be between the UVic model precipitation d18O field and the d18O in LGM precipitation simulated by AGCMs. The UVic model LGM distribution of precipitation d18O shares the global pattern produced by the LMDZ-iso model (e.g. Figure 13c, Risi et al., 2010). This pattern consists of depletion (relative to present day) at high latitudes and slight enrichment at low to mid latitudes, with maximum depletion simulated in the same regions in both models (Canadian Archipelago region in the UVic model vs north-central Canada in LMDZ-iso, and northeast of Scandinavia in the UVic model vs northeast of and across Scandinavia in LMDZ-iso). The similarities in global patterns of d18O in LGM precipitation suggest that the UVic model may be able to reproduce the large-scale changes. Hence we find the reviewer's conclusion of "no skill in predicting d18O in precipitation for the LGM" to

C1099

be overly harsh and without merit.

3. The model distribution of d18O in LGM seawater is certainly dependent on the modeled isotopic fluxes (e.g. in evaporation, precipitation, river runoff) at the sea surface. The reviewer is not correct in stating the "model is unable to reproduce the d18O in precipitation for different climate but the present-day one to which it is tuned", as explained in our response to #2 above.

References cited:

MARGO Project Members: Constraints on the magnitude and patterns of ocean cooling at the Last Glacial Maximum, *Nature Geoscience*, 2, 127-132, 2009.

Marsh, R., M. P. L. M. Smith, E. J. Rohling, D. J. Lunt, T. M. Lenton, M. S. Williamson, and A. Yool, Modelling ocean circulation, climate and oxygen isotopes in the ocean over the last 120,000 years, *Clim. Past Discuss.*, 2, 657-709, 2006.

Risi, C., Bony, S., Vimeux, F., and Jouzel, J.: Water-stable isotopes in the LMDZ4 general circulation model: Model evaluation for present-day and past climates and applications to climatic interpretations of tropical isotopic records, *J. Geophys. Res.*, 115, D12118, doi:10.1029/2009JD013255, 2010.

Roche, D., D. Paillard, A. Ganopolski, and G. Hoffmann, Oceanic oxygen-18 at the present day and LGM: equilibrium simulations with a coupled climate model of intermediate complexity, *Earth and Planetary Sci. Lett.*, 218, 317-330, 2004.

Shackleton, N. J., Attainment of isotopic equilibrium between ocean water and the benthic foraminifera genus *Uvigerina*: Isotopic changes in the ocean during the last glacial. In: Labeyrie, J. (Ed.), *Methodes quantitatives d'etude des variations du climat au cours du Pleistocene*. Editions du C.N.R.S., France, pp. 203-209, 1974.

Weaver, A. J., M. Eby, E. C. Wiebe, C. M. Bitz, P. B. Duffy, T. L. Ewen, A. F. Fanning, M.

C1100

M. Holland, A. MacFadyen, H. D. Matthews, K. J. Meissner, O. Saenko, A. Schmittner, H. Wang and M. Yoshimori, The UVic Earth System Climate Model: Model description, climatology, and applications to past, present and future climates, *Atmosphere-Ocean*, 39, 361-428, 2001.

Interactive comment on *Geosci. Model Dev. Discuss.*, 4, 2545, 2011.

C1101