Sublimation origin of negative deuterium excess observed in snow and ice samples from McMurdo Dry Valleys and Allan Hills Blue Ice Areas, East Antarctica

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Motivation

- The use of stable isotopes of oxygen and hydrogen in polar ice to infer past temperature is built upon the assumption that post-deposition processes do not alter the isotopic composition of snow (Friedman et al., 1991; Petit et al., 1999).
- This assumption has been increasingly challenged by observations of vapor-snow exchange (Steen-Larsen et al., 2014; Ritter et al., 2016; Madsen et al., 2019; Hughes et al, in press), but it is not clear if sublimation alone is capable of causing isotopic fractionation. However, if it does, deuterium excess (d-excess = δD - 8*δ[18]O) should decrease.
- While most of the d-excess values observed in present-day Antarctic surface snow are positive (Masson-Delmotte et al., 2008), a notable exception can be found in the McMurdo Dry Valleys and the nearby (~100 km away) Allan Hills Blue BIAs where conditions are persistently dry and windy. Surface snow samples consistently show negative d-excess values (Dadic et al., 2015; Gooseff et al., 2006; Masson-Delmotte et al., 2008). These sites provide an opportunity to investigate whether ice sublimation causes isotopic fractionation in the field.

Figure 1. Allan Hills Blue Ice Area. Taken on Dec 27, 2015 by Y.Y. The glacial ice (blue) is in clear contrast to snow/firn (white). The ice "bumps" seen to the left of the picture reflects bedrock relief.

Model setup

- Isotope-enabled Community Earth System Model (**iCESM**) was used to simulate snowfall d-excess values at Allan Hills and Dry Valleys, using prescribed sea-surface temperature and sea-ice observations from 1977–2012 with 25 regions tagged.
- Mixed-Cloud Isotope Model (**MCIM**), a component of the iCESM, was used independently to evaluate under what conditions negative d-excess in precipitation can occur.

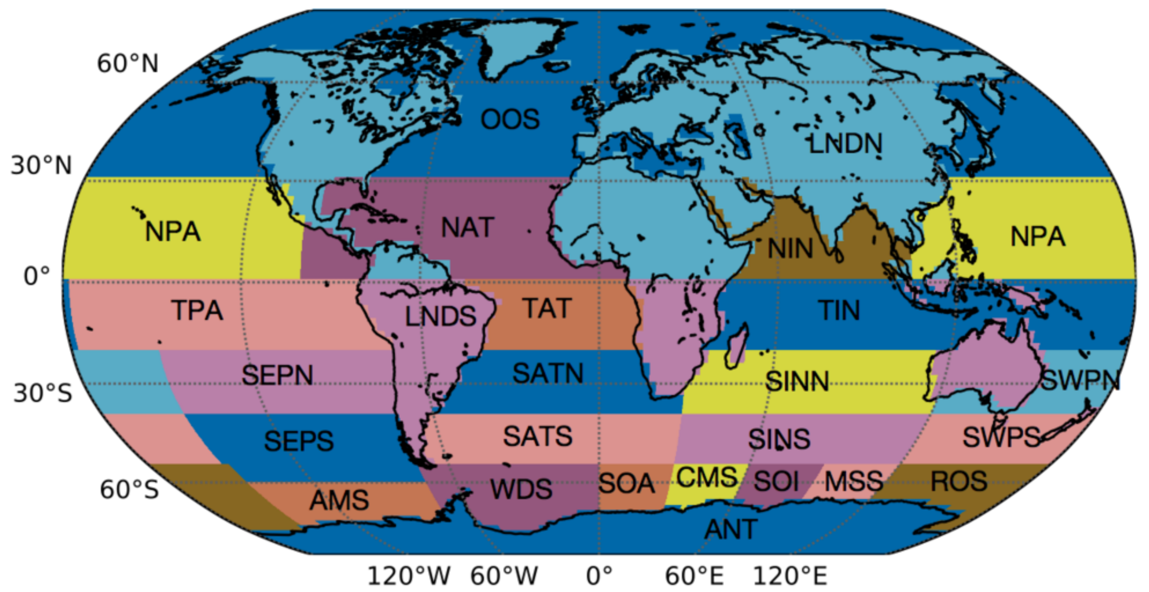

Figure 2. Moisture source regions tagged in the numerical experiment.

Results and Discussion

1. iCESM

- Modeled d-excess is systematic lower than observations.
- In Taylor Dome near the Dry Valleys region, the model underestimates d-excess by 6‰.
- Adding this 6‰ offset to d-excess precipitation over Allan Hills yields 4.8‰ d-excess.
- Measured d-excess, however, is -2.9‰.

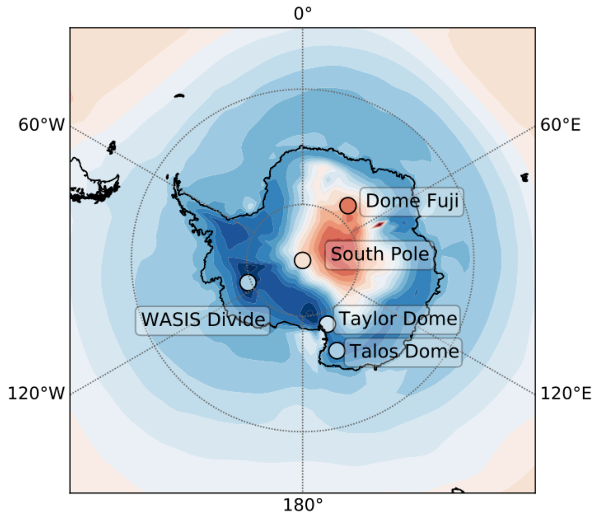

Figure 3. Climatological precipitation d-excess simulated by iCESM (1977-2012 CE) and ice core measurements (post 1840 CE).

2. MCIM

- Negative d-excess can only occur if the majority of moisture comes from Southern Ocean, which however only accounts for <50% of precipitation in Dry Valleys/Allan Hills simulated by iCESM.

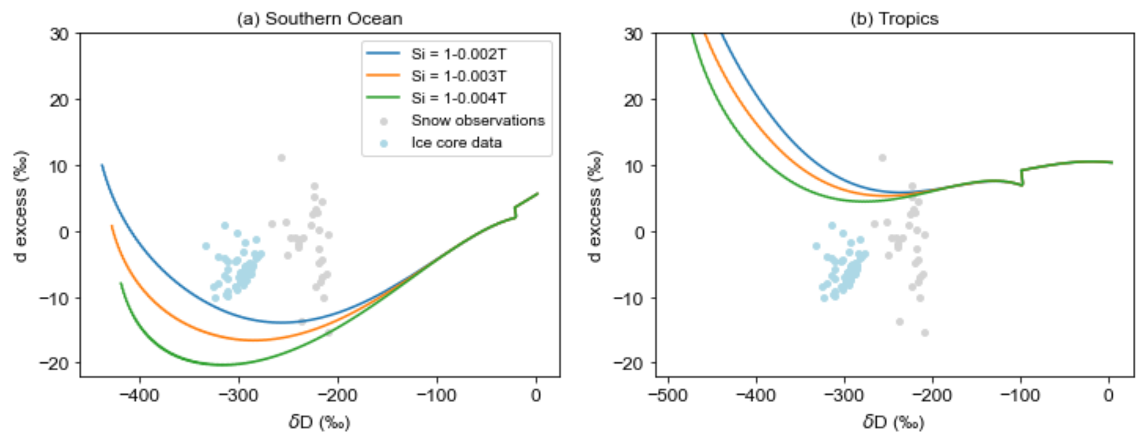

Figure 4. Modeled d-excess in precipitation along moisture trajectories if moisture solely originates from (a) the Southern Ocean and (b) the Tropical ocean for three different supersaturated parameter S_i as a function of condensation temperature, with the maximum values of relative humidity and minimum values of SST from 1977 to 2012 over the regions using the Mixed-Cloud Isotope Model.

3. Rayleigh*-distillation model (* homogenization occurs through solid-state-diffusion)

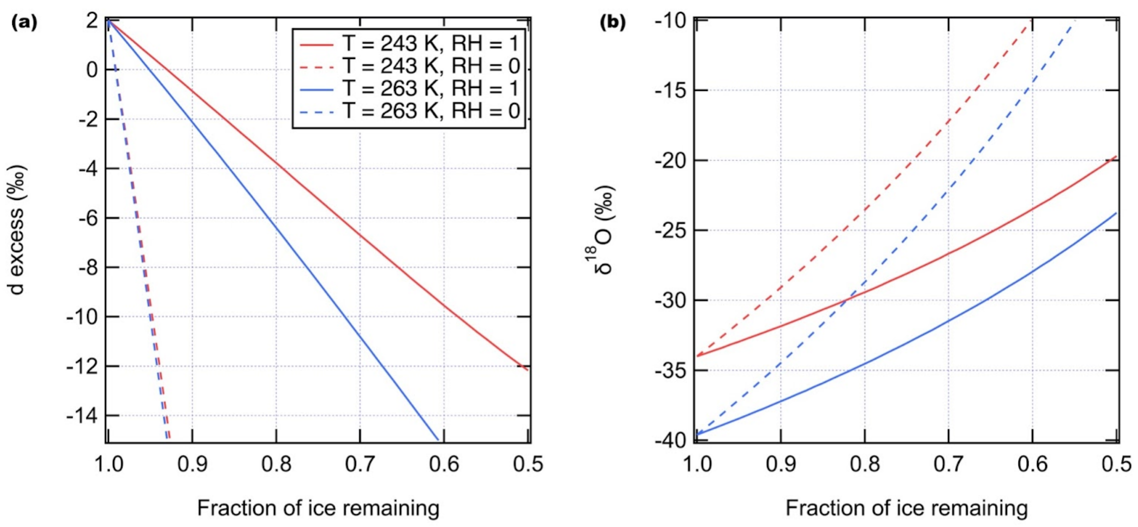

Figure 5. Quantifying the effect of sublimation on d-excess (a) and δ[18]O (b) in the remaining snow using a Rayleigh-distillation model under interglacial (red) and glacial (blue) conditions. Depending on RH, 3 to 24% of the surface snow is lost due to sublimation to yield a negative d-excess of -5‰.

Summary

- Negative d-excess in precipitation over Allan Hills and the Dry Valleys cannot be realistically reproduced by current-generation climate models.
- To yield negative deuterium excess in Antarctic precipitation, unrealistically high moisture contribution from high-latitude oceans is required.
- Sublimation fractionation must contribute to negative deuterium excess.

References

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