Linking evapotranspiration, boundary-layer processes and atmospheric moisture using isotope tracer modeling and data

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Abstract

Large-scale synoptic weather cycles are a major control of the day-to-day variation in the isotopic composition of atmospheric water vapor at continental sites. The sub-grid convection, atmospheric mixing and land processes (via evapotranspiration (ET) feedback) further modify the isotopic variation. This study uses high-quality spectroscopy measurements to place local constraints on the isotopic composition of near-surface water vapor in an isotope-incorporated land surface model (Iso-MATSIRO). A full-year, near continuous observation of hourly oxygen-18 and deuterium isotope ratios in atmospheric water vapor at Wind River field station, WA, USA, reveals times of strong influence from surface ET versus times when convective mixing dominates. These surface isotope measurements provide a robust foundation to improve the representation of the kinetic isotopic effects arising from ET and source water partitioning. Nudged, isotope-enabled GCM (IsoGSM) simulations reproduce isotopic variations influenced by large-scale, synoptic weather cycles, but are less successful in capturing variations associated with sub-grid processes. Specifically, the model is unable to produce the large and consistent variability in the deuterium excess (*dx*) values of near-surface water vapor. This 'terrestrial feedback' to the atmosphere is poorly parameterized in the IsoGSM. Future effort requires improved land surface parameterization to accurately describe the kinetic (evaporative) effect, which in turn, providing powerful constraints to assess processes that control atmospheric moisture variability in climate models.

Calibration protocol and data quality

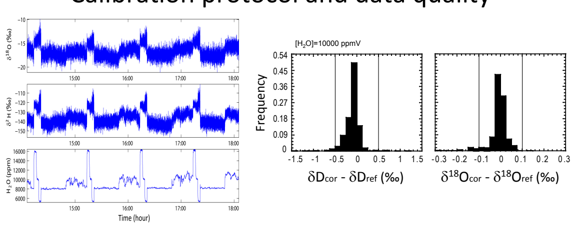


Figure 1. An example of spectroscopy water vapor isotope sampling with reference vapor introduced at 3 levels of H_2O mixing ratios hourly (Rambo et al. 2011). We calibrate the ambient air with a source water of known isotopic composition that produces hourly $\delta^{18}O$ and δ^2H (or δD) measurements of water vapor with an overall accuracy of ±0.1‰ for $\delta^{18}O$, ±0.5‰ for δ^2H (Farlin et al. 2013) .

Vapor isotope variation during spring soil thawing

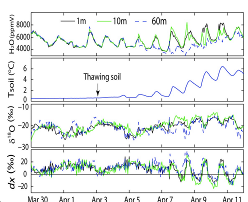


Figure 2. A two-week period in spring showing water vapor isotope variation in canopy air before and after top soil thawing. We observed pronounced and consistent diel fluctuations in $\delta^{18}O$ and deuterium excess ($dx = \delta^2H - 8\times\delta^{18}O$, Dansgaard 1964) after spring thawing of top soils, which results in soil moisture readily available to support plant photosynthetic activity, evapotranspiration and alter energy balance. Water vapor isotope variations are tied to these surface activities.

Model-data comparison of vapor isotopes

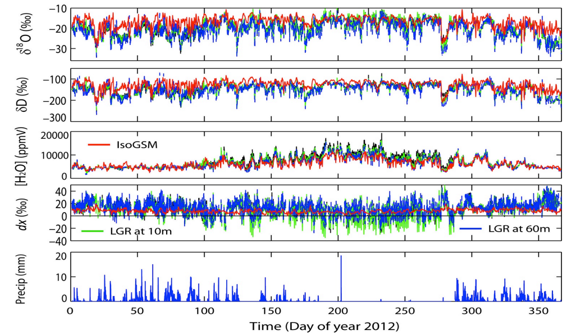


Figure 3. Comparison between nudged IsoGSM simulations and observations made at 2 canopy heights (10m and 60m) in the Wind River Experimental Forest, Carson, WA. The agreement suggests large-scale synoptic weather cycles as the primary control of the day-to-day variation in the isotopic composition of near-surface water vapor. The disagreement in *dx* suggests poor realization of the kinetic process in the model, which is notoriously difficult to resolve until now because isotope models have not adequately considered subgrid atmospheric and hydrologic processes and terrestrial feedbacks via surface ET fluxes.

Vapor isotope variation following a snowfall event

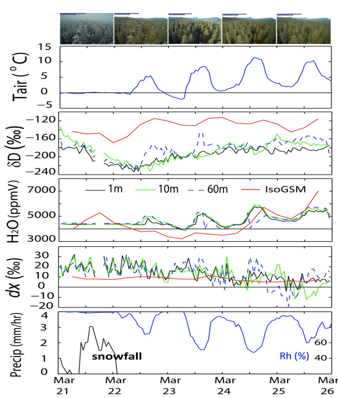
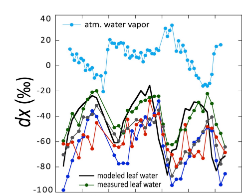


Figure 4. This example illustrates how a snowstorm event can strongly affect the mixing ratio and isotopic composition of near-surface atmospheric moisture. During the snowfall on March 21, air temperature (Tair) stayed near freezing and relative humidity (Rh) was close to 100%. This precipitation event caused a rapid decrease in the δD of water vapor while *dx* values stayed relatively constant. The next few days following the snowmelt, which started on March 22, δD began to increase and *dx* began to decrease. In this case, the nudged IsoGSM simulation did not reproduce the isotopic variation very well.

Measured *d* excess in vapor and leaf water

Figure 5. Measured *dx* values show a strong coupling between leaf water and atmospheric water vapor. We observed more positive *dx* values during nighttime and more negative *dx* values during daytime in bulk leaf water, while the opposite was true for canopy water vapor. The two sets of *dx* values approach each other at predawn hours when Rh is close to 100%.



Seasonal patterns of vapor isotope variation

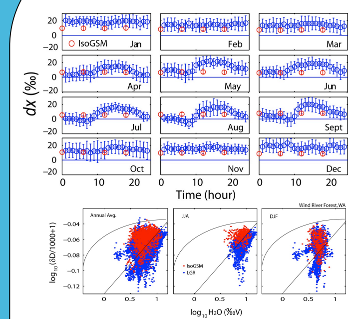


Figure 6. (Top panel) The ensemble-averaged diel variation in the *dx* observation presented by months. Winter months see higher and more constant *dx* values ranging between 10-20‰. Diel *dx* fluctuation is most pronounced in the summer. (Lower panel) Comparison between modeled and measured δ-q relationship separated by season.

An offline experiment with land surface model (Iso-MATSIRO) and its preliminary results

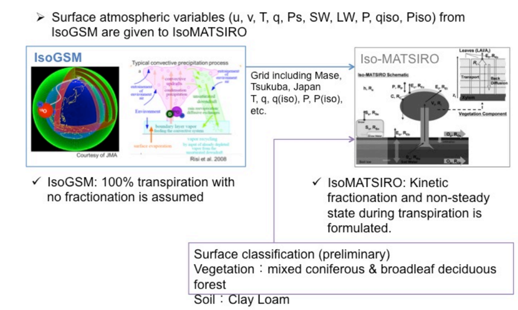


Figure 7. Schematics showing the coupling between an improved isotope land surface model (IsoMATSIRO) and the nudged IsoGSM. This framework aims to account for the interaction between boundary-layer dynamics and feedbacks from surface ET fluxes. These sub-grid processes are currently under-represented in the GCMs.

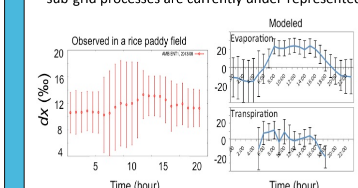


Figure 8. Comparison between modeled and measured *dx* of water vapor in a rice paddy field in Japan. IsoMATSIRO successfully simulated the diel variation, which mainly came from evaporation. Transpiration appears to have little impact on the diurnal course of *dx*.

Acknowledgements

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