Water vapor isotope measurements above the Greenland Ice Sheet and importance for interpretation of surface-atmosphere interactions

H. C. Steen-Larsen¹, V. Masson-Delmotte¹, E. Brun², R. Winkler¹, F. Prie¹, A. Landais¹, C. Risi³, B. Stenni⁴

¹ Laboratoire des Sciences du Climat et de l’Environnement, CEA-CNRS/IPSL Gif-Sur-Yvette
² Meteo-France/CNRM, Toulouse
³ Laboratoire Meteorologie Dynamic, Paris
⁴ Department of Mathematics and Geosciences, University of Trieste
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- Introduction to stable water isotopes
- The diurnal water vapor cycle above the Greenland Ice Sheet
- Tracing Arctic moisture using isotopes

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Isotope hydrology

*Isotopologues* are molecules with an isotope exchanged in

\[
\delta^{18}O = \frac{\left( \frac{H_2^{18}O}{H_2^{16}O} \right)_{\text{sample}}}{\left( \frac{H_2^{18}O}{H_2^{16}O} \right)_{\text{ocean}}} - 1 \times 1000
\]

\[
\delta D = \frac{\left( \frac{HDO}{H_2O} \right)_{\text{sample}}}{\left( \frac{HDO}{H_2O} \right)_{\text{ocean}}} - 1 \times 1000
\]

Nomenclature:

- **Regular water**
- **Heavy water**
- **Even heavier water**
FRACTIONATION is temperature-dependent
-Larger at low temperature

Water Vapor

- Hot

Liquid Water

- Cold
Setup of the NEEM isotopic surface campaign 2009 - 2012

- Subsurface temperature Measurements 0-150cm With 10 mK resolution
- Air temperatures 1, 3, 7, 10, 13 m above snow surface
- d18O and dD of vapor Continuously from 1, 3, 7, 10, 13 m above snow surface
- Precipitation samples Collected as often as possible
- Surface snow samples every 12 hours
Water vapor isotopes on top of the Greenland Ice Sheet
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Vertical diurnal structure of the atmospheric water vapor close to the surface

Hourly time slices of diurnal cycle

Height above surface [m] vs. Humidity [PPM] with mean value removed

Warming and Cooling

~2h local, ~6h local, ~10h local, ~14h local, ~18h local, ~22h local
The structure of the isotopic profile with height

- Gradient with height in both humidity and isotopes

- Free troposphere and boundary layer interaction

- Snow-Air interaction

- Snow-pack fluxes

- Humidity and isotopes are linked
Still work in progress

Model output (Mass flux and snow surface temperature) from CROCUS

ERA-40 re-analysis → CROCUS Snow pack scheme → Validate against observation

Snow surface isotopes → Interstitial fluxes Snow-air fluxes

Free troposphere isotopes → Boundary layer model → Compare with atmospheric water vapor isotopes

Time [UTC]
Humidity at ~1 meter
Humidity at ~13 meter
SO at ~2 meter
SO at ~13 meter
Temperature at ~1 meter

3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-10000
5
10
15
20
Time (UTC)
Humidity [ppm]
Water vapor isotopes as means of tracking origin of the vapor

Introducing the second order parameter: $d_{\text{excess}} = \delta D - 8 \bullet \delta^{18}O$

Captures kinetic fractionation occurring when a humidity gradient is present because of different molecular diffusivity of the isotopes.
Water vapor isotopes as means of tracking origin of the vapor

Introducing the second order parameter: $d_{excess} = \delta D - 8 \cdot \delta^{18}O$

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Using back trajectories to find the moisture source
Using back trajectories to find the moisture source

Sea Ice

Very dry air

Vapor with high d-excess

Strong evaporation
Comparing the observations with isotope enabled GCM

Bad agreement between observed and modeled d-excess

Good agreement between observed and modeled humidity.

OK agreement between observed and modeled dD isotopic composition
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\texttt{hanschr@gfy.ku.dk}

\textsuperscript{1} Laboratoire des Sciences du Climat et de l’Environnement, CEA-CNRS/IPSL Gif-Sur-Yvette
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