Greenland Ice Sheet surface melt captured by high frequency water vapor isotope measurements at Thule

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US CLIVAR
2019 Water Isotopes and Climate Workshop
Boulder, CO

Scientific Objectives:

At Thule, Greenland:

- **Identify the signal of melt events in water vapor isotope measurements**
- **Examine fluxes of moisture from sublimation of snow/ice and evaporation of meltwater from the Greenland Ice Sheet**

Background:

Water vapor flux from Greenland Ice Sheet:

- Recent studies of the isotopic composition of precipitation and water vapor have revealed a significant flux of water vapor off the Greenland Ice Sheet (GIS)[1,2] (Figure 1)
- This is coupled with the increasing extent of surface melt of the ice sheet, marked by record melt events this summer (Figures 3 and 5)

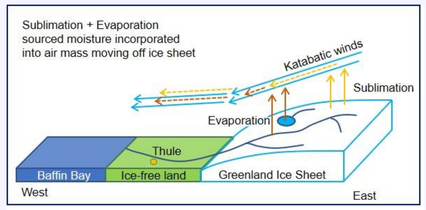

Figure 1. Illustration of mechanism where water vapor sourced from sublimation of snow/ice and evaporation from meltwater is incorporated in air mass transported away from GIS

- To best understand the mass balance of the GIS, the water vapor flux away from the ice sheet merits investigation and quantification
- Measuring the deuterium excess of water vapor offers an effective approach to study evaporation and sublimation, as this parameter is controlled by changes in moisture sources[3,4]
- Water vapor sourced from sublimation of snow and ice and/or evaporation of meltwater has relatively high d-excess[1,4]

Methods:

Water vapor isotope measurements:

- Picarro L2130-i measured hydrogen (δD) and oxygen ($\delta^{18}O$) isotopic ratios and deuterium excess (d-excess or d; $d = \delta D - 8\delta^{18}O$) of water vapor from Thule, NW Greenland from Oct 2016 to present
- Water vapor monitored from top of 1971 building on South Mountain, ~ 1 km south of Thule Air Base airport (Figure 2)

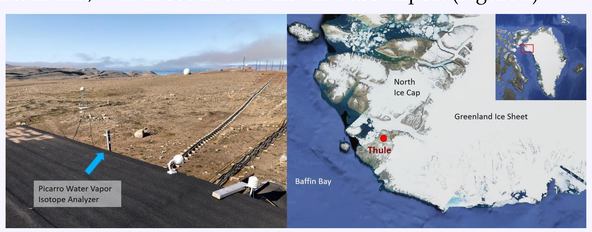

Figure 2. Picarro L2130-i measurement location on roof of 1971 building on South Mountain near Thule Air Base.

Climatological data:

- GIS melt extent: NSIDC daily melt data[5]
- Weather: Wind speed and direction – Thule airport

Conditions for data used in this study:

- Wind direction off ice sheet (North to Southeast, or 0° – 140°)
- Melt season: melt extent of GIS continuously above 100,000 km^2

Results and Discussion:

Greenland Ice Sheet melt:

Figure 3. Photos of melt at edge of GIS around the Thule region during major melt event Jul 28th to Aug 4th, 2019

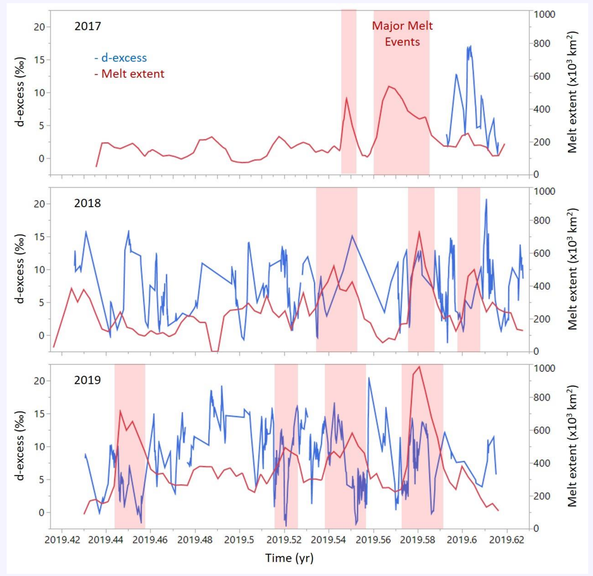

Figure 5. Time series of d-excess (blue) and GIS melt extent (red) over the summer melt seasons in 2017-2019. Major melt events (peak melt extent exceeds 400,000 km^2) highlighted in red. D-excess measurements meet the criteria laid out in Methods.

Water vapor isotope observations:

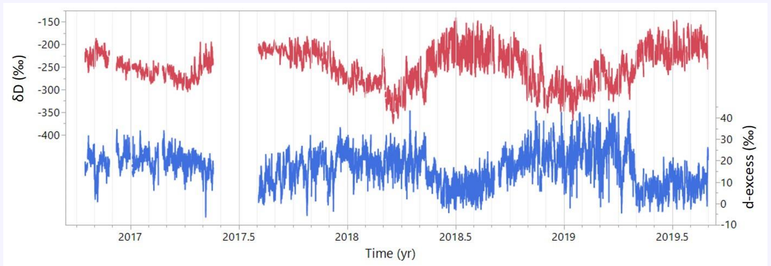

Figure 4. Time series of δD and d-excess for all measurements at Thule, Greenland

Melt and water vapor relationships:

- In general, d-excess increases with melt extent (Figure 6) → this is consistent with the hypothesis that conditions causing increased melt cause more sublimation/evaporation (high d-excess moisture)
  - Water vapor concentrations also generally increase with increasing melt extent
- However, during major melt events, d-excess increases at a lower rate per melt extent than during the rest of the melt season, while water vapor concentrations do not increase at all (Figure 6)
- Conditions that cause large melt events suppress sublimation/evaporation and/or reduce transport away from the ice → flux of water vapor away from the ice sheet is lower than would be expected with the large melt event
  - This is demonstrated by the generally lower rate of increase of d-excess with melt extent, where it is expected that more melt = more sublimation/evaporation = high d-excess

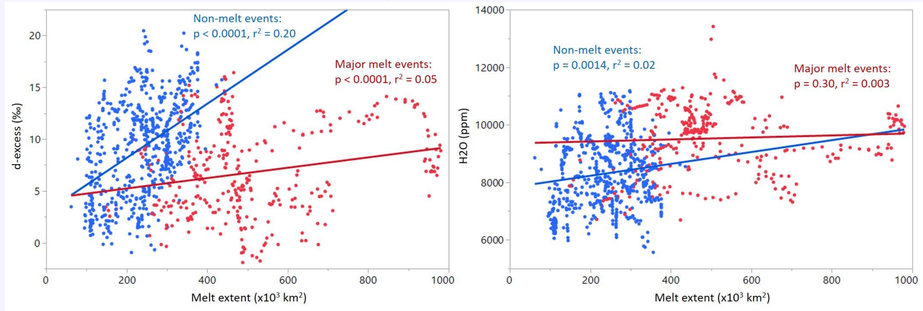

Figure 6. Relationships between d-excess and H_2O vapor concentration vs the GIS melt extent. Data during major melt events (red) show significantly different pattern than data during rest of melt season (blue)

Moisture source partitioning – what is the Greenland Ice Sheet Flux (GISf):

Assumed moisture source d-excess end members: Local marine = 4‰ (Figure 6); Sublimation = 30‰[1]; Meltwater evap = 20‰

Melt season (non-events):

- At avg d-excess = 15‰ (~peak melt extent = 200,000 km^2), if sublimated vapor mixes with marine vapor → GISf = 42%; if 50/50 mix sub/evap → GISf = 52%

Major melt events:

- At avg d-excess = 10‰ (~peak melt extent = 1,000,000 km^2), if sublimated vapor mixes with marine vapor → GISf = 23%; if 50/50 mix sub/evap → GISf = 29%
- If marine source contains H_2O concentration = 8000 ppm, a 23% increase in moisture by GISf = 9840 ppm; 29% increase by GISf → H_2O = 10320 ppm (consistent with Figure 6)

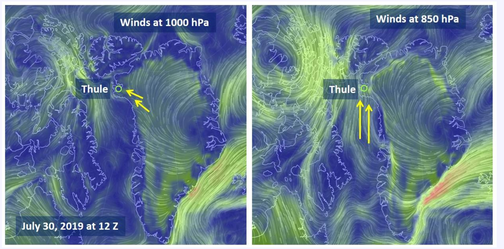

Figure 7. Wind patterns on July 30, 2019 at 12Z during melt event with dominant high pressure system over GIS. Winds at 1000 hPa (left) show katabatics from east, while at 850 hPa (right), winds are predominantly from the south, bringing air from over Baffin Bay to Thule

Why are the large melt events so different? (One possible explanation):

- During big events, high pressure helps lead to significant melt, but in NW Greenland, sets up different scenario (Figure 7)
- While winds at surface are katabatics coming down of the ice, up above, major flow off Baffin Bay which is likely contributing air/moisture to the katabatic flow
- This air has low d-excess, and is already moist, so little sublimation/evaporation incorporation off ice sheet

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Acknowledgements:

1. Work supported by NSF under grants 1852614 for EAGER MOSAiC based Arctic water isotope cycle project
2. US Air Force for providing logistical support and providing weather data
3. Polar Field Services for providing logistical support
4. Picarro for continued technical support for the upkeep of our water vapor analyzer

Conclusions:

- **Influence of sublimation and meltwater evaporation from the Greenland Ice Sheet (GIS) observed in water vapor measurements at Thule, where more melt → more sub/evap → higher d-excess**
- **During large melt events (> 400,000 km^2), water vapor concentration and its isotopic composition respond differently to increases in melt area than at other times**
- **Sublimation/Evaporation may account for upwards of 50% of water vapor in air sourced from over the GIS, however, during large melt events, the conditions responsible for the event suppress sublimation/evaporation rates**