Deuterium excess anomaly of precipitation in Svalbard

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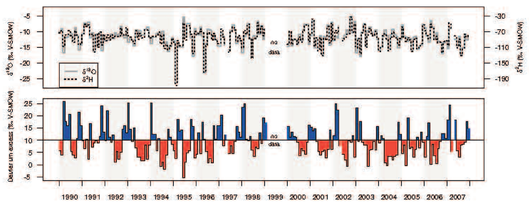
HYDROLOGY

Precipitation

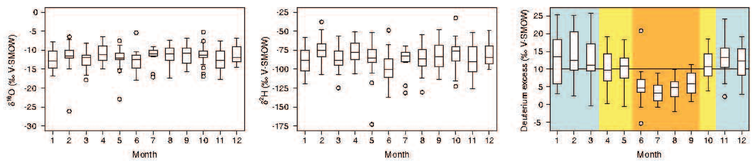
Temporal variation of isotopic composition

Time series of monthly isotope ratios and deuterium excess in precipitation at IAEA GNIP station Ny Alesund (78.15°N, 11.56°E, 7m). Axes of δ^2H and $\delta^{18}O$ are scaled to match for a deuterium excess of 10 (=GMWL).

Deuterium excess values >10 are indicated by blue, <10 by red bars.



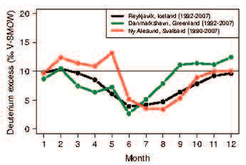
Seasonality of isotopic composition



Isotope ratios δ^2H and $\delta^{18}O$ are influenced by local atmospheric conditions during precipitation formation. Thus they represent single event characteristics and follow no clear seasonal pattern. However, a strong seasonality is obvious for deuterium excess, suggesting a winter (blue), transition (yellow) and summer (orange) period. It reflects differences in the moisture source area, as the isotopic content of lower-tropospheric vapour over Svalbard exhibits the same pattern (Frankenberg et al., 2009) and secondary processes (sub-cloud evaporation, snow formation) seem to be of only minor importance.

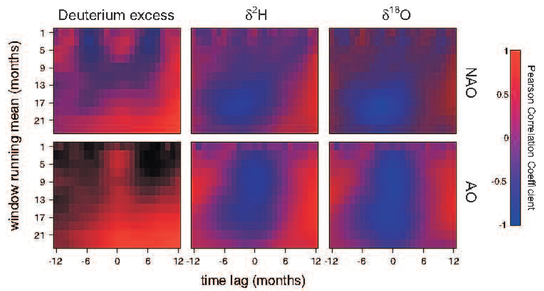
Comparison with other high latitude stations

Other high latitue GNIP stations in Greenland and Iceland also have a pronounced annual pattern in deuterium excess with a smaller amplitude in Iceland. Winter values are related to a strong kinetic effect during evaporation from local source regions with large sea surface - air temperature contrasts.



During the summer period more atmospheric moisture originating from the warmer North Atlantic intrudes into the polar regions. Hence, vapour is formed under conditions that are characterized by less kinetic fractionation. This contributes to the yearly minimum deuterium excesses.

Coupling with atmospheric circulation



Cross correlation analyses with the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) indices show noticeable differences between deuterium excess and the isotope ratios on different time scales.The results highlight the importance of large scale atmospheric circulation controlling moisture fluxes from different regions. As long-term trends in circulation indices are well known, effects on the isotopic composition of precipitation can be expected. However, time series of isotopic precipitation composition in Svalbard do not show visible trends (yet).

Background

Stable water isotopes (^2H, ^{18}O) are a widely used tool for environmental and climate system analyses. During the last years new measurement techniques (Cavity Ring-Down Spectroscopy) facilitated the joint quantification of both δ^2H and $\delta^{18}O$. Consequently, the second-order isotope parameter deuterium excess (δ^2H - 8 $\delta^{18}O$) can be utilized to study environmental questions.

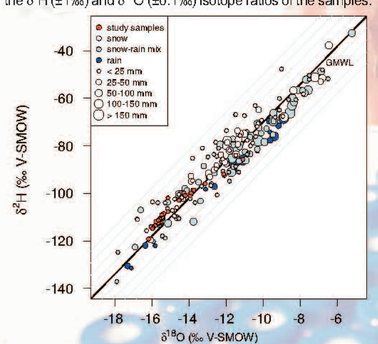
The isotope ratios δ^2H and $\delta^{18}O$ in precipitation mainly depend on temperature conditons during precipitation formation and local characteristics such as latitude, continentality and elevation. Whereas these are controlled by equilibrium fractionation processes, the deuterium excess contains also information about kinetic (non-equilibrium) isotope fractionation. Especially influenced by ocean-atmosphere interactions during evaporation, deuterium excess can be used to delimit spatially and temporally variable moisture source regions. The contrast between sea surface and air temperature and the humidity and wind profile at the evaporation site define the anomaly of deuterium excess.

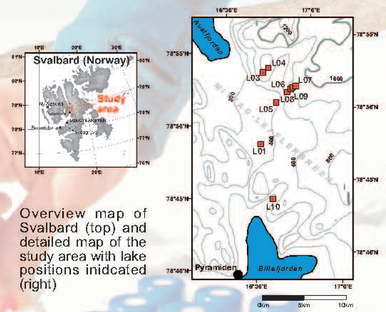
However, there is still no unified theory which explains the generation processes and the spatio-temporal distribution of deuterium excess in atmospheric vapour and precipitation.

Study area and data

During a field campaign in August 2009 water samples from ten high-arctic lakes adjacent to the Mittag-Lefflerbreen glacier on Svalbard were taken. Additionaly, inflowing and outflowing surface waters and the top layer of the surrounding snow pack were sampled. For each lake the outflow rate and surface area (using a handheld GPS unit) were estimated in the field.

Laser spectrometry (Picarro G1102-i) was used to quantify the δ^2H (±1‰) and $\delta^{18}O$ (±0.1‰) isotope ratios of the samples.





Overview map of Svalbard (top) and detailed map of the study area with lake positions inidcated (right)

Most samples plot parallel to the global meteoric water line (GMWL) with deuterium excesses of ~13.5. Smaller deuterium excess values are observed for samples with δ^2H larger than -100‰.

The isotope ratios are within the range of the isotopic composition of precipitation at the coastal IAEA GNIP station located in Ny Alesund (1990-2007).

Conclusions

Deuterium excess of precipitation in Svalbard shows a strong seasonal signal due to different moisture source areas.

The seasonal signal is linked to circulation patterns and provides a possibility to detect changes in vapour sources and atmospheric processes.

Deuterium excess of precipitation is reflected by surface waters and can be traced through the hydrologic cycle.

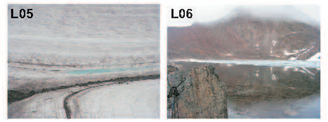
The studied lakes are dominated by direct snow melt water, but diffuse contribution of subsurface water can be substantial.

With the nowadays common combined analysis of both δ^2H and $\delta^{18}O$ the deuterium excess is a useful indicator to characterise hydrological processes and systems, especially in high latitude regions. However, the mechanism of deuterium excess generation must be explored for a complete understanding of its information content.

Lakes

Lake characteristics

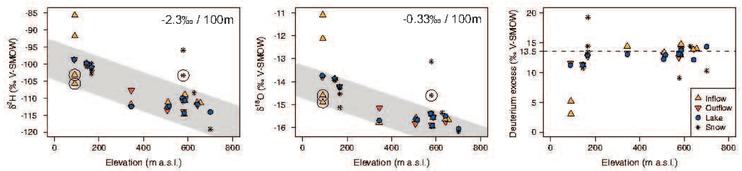
The studied lakes cover an elevation range of 600m and feature differences in mapped water sources. Despite high uncertainties due to unknown mean lake depths, the calculated mean residence times (MRT) indicate a complete turnover of lake water within days to few weeks for most lakes.



Lake	Description	Elevation (m a.s.l.)	Water source	Lake area [a] (m²)	Lake volume [a] (m³)	Outflow [a] (m³/d)	MRT (d)
L01	Franzinitzkin (lower lake)	145	upper lake (L02), snow	560 (±12)	3634 (±3136)	168 (±51)	41 (±39)
L02	Franzinitzkin (upper lake)	166	permafrost, subsurface, snow	3990 (±756)	34960 (±13545)	216 (±45)	222 (±211)
L03	Sedelhöhjellet (lower)	590	upper lake (L04), snow	26900 (±5200)	166400 (±145900)	4500 (±1350)	71 (±68)
L04	Sedelhöhjellet (upper)	701	permafrost, snow	1690 (±320)	10240 (±8960)	no data	no data
L05	Glacier lake Camp	345	glacier	5300 (±1060)	30920 (±25630)	4995 (±1485)	19 (±12)
L06	Bertjellet 1 (lower)	429	upper lake (L07), snow	130000 (±26000)	833000 (±723800)	9874 (±2962)	162 (±154)
L07	Bertjellet 2	576	upper lake (L08), snow	1690 (±320)	10240 (±8960)	1468 (±469)	13 (±12)
L08	Bertjellet 3	587	upper lake (L09), snow	7690 (±1530)	48640 (±42560)	21600 (±6480)	8.3 (±4.1)
L09	Bertjellet 4 (upper)	643	snow, glacier	3700 (±740)	23680 (±20720)	21600 (±6480)	2.1 (±2.0)
L10	Ragnhildmorane felt	89	moraine	4800 (±960)	28160 (±24640)	71 (±21)	766 (±728)

[a] uncertainty ~20% [a] uncertainty mainly from depth (~50%) [a] uncertainty ~30%

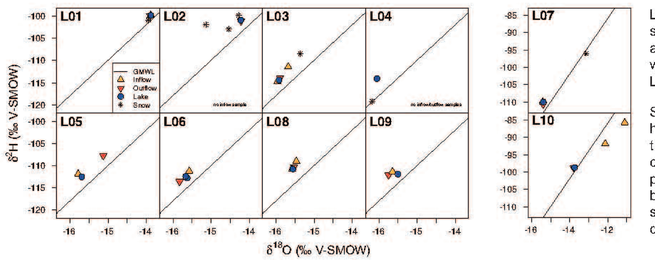
Elevation effect of water samples



Both δ^2H and $\delta^{18}O$ values show a depletion with increasing elevation due to stronger fractionation at lower temperatures. The observed gradient for $\delta^{18}O$ is close to the theoretical value of -0.36‰ / 100m for adiabatic cooling. Enriched samples were corrected to a deuterium excess of 13.5 (indicated by circles).

Deuterium excess is ~13.5 for the high elevation lakes and reflects winter precipitation. It is lower for the water sampled below 200m. This suggests evaporative enrichment at the lowest sites as a consequence of the earlier onset of snow melt and possibly longer flowpaths near the surface or a local contribution of summer precipitation.

Inferring lake water soures



Lake water was sampled bankside and was not always well mixed (L05, L06, L09).

Snow samples are highly variable in their isotope composition and probably influenced by evaporation and sublimation after deposition.

Most liquid water samples plot above the GMWL and contain the signature of winter precipitation (deuterium excess > 10). This demonstrates the dominance of water input from snow melt. The inflows to the lowest lake (L10) are isotopically enriched. To explain lake water isotopic ratios, significant subsurface inflow is necessary. However, this groundwater flow must be sustained by winter precipitation to achieve the lake water composition. Subsurface inflow is also likely for other lakes (L03, L06, L08) and the glacier lake L05 (englacial contribution).

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