LONG-TERM SERIES OF TROPOSPHERIC WATER VAPOUR AMOUNTS AND HDO/H_2O RATIO PROFILES above JUNGFRAUJOCH

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INTRODUCTION

Water vapour is a crucial climate variable involved in many processes which widely determine the energy budget of our planet. In particular, water vapour is the dominant greenhouse gas in the earth's atmosphere and its radiative forcing is maximum in the middle and upper troposphere. Because of the extremely high variability of water vapour concentration in time and space, it is challenging for the availiable relevant measurement techniques to provide a consistent data set useful for trend trend analyses and climate studies.

Schneider et al. [1] showed that ground-based Fourier Transform Infrared (FTIR) spectroscopy, performed from mountain observatories, allows for the detection of H_2O variabilities up to the tropopause. The errors of the FTIR H_2O profiles (see [1], [2] and [3] for more details) are smaller than 15% throughout the troposphere.

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New strategy (developed and optimized by M. Schneider and F. Hase) to consistenly retrieve tropospheric H_2O profiles :

- using the PROFFIT algorithm;
- retrieval of 4 water isotopologues ($H_2{}^{16}O$, $H_2{}^{18}O$, $H_2{}^{17}O$ and $HD^{16}O$) performed on a logarithmic scale;
- 14 micro-windows located in the 2600-3100 cm^{-1} region;
- speed dependant Voigt ligne shape model;
- joint temperature profile retrieval;
- interspecies constraint for the $HD^{16}O/H_2{}^{16}O$ profiles.

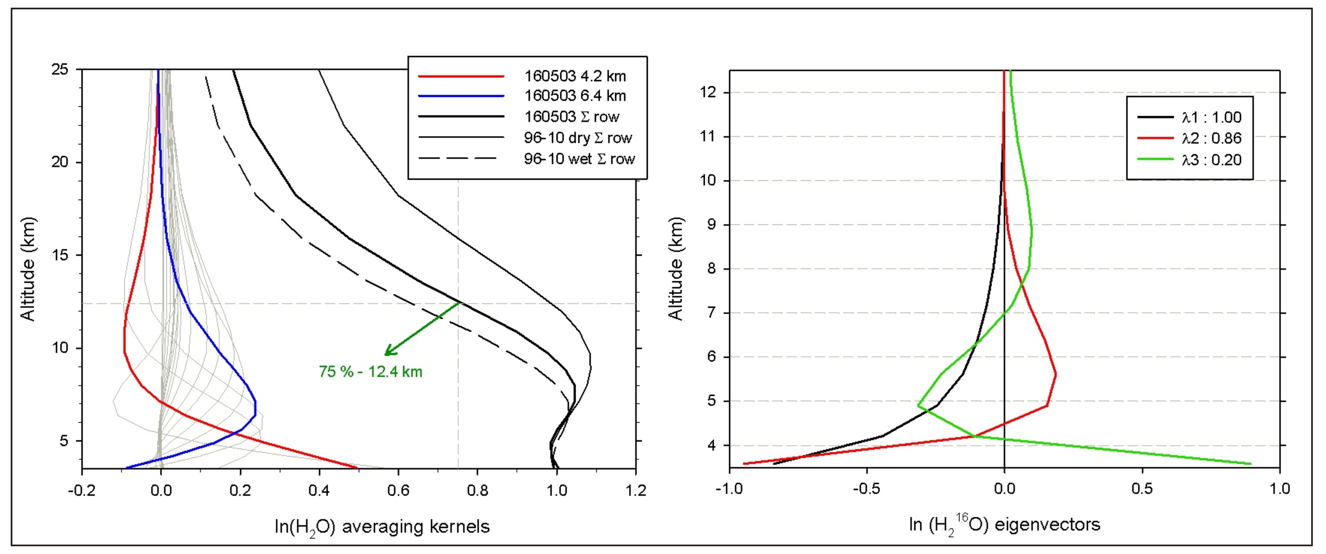

Figure 1 - Left: typical averaging kernels for ground-based FTIR remote sensing of water vapour for the Jungfraujcoh (16.05.2003 6:25 UT). The kernels for the selected heights as given in the legend are highlighted. The total sensitivity (Σrow) is as a thick black line. For comparison, mean total sensitivity is also illustrated for the 1996-2010 period in fonction of humidity conditions (dry: under 0.6 mm and wet: above 3.5 mm) - Right: typical eigenvectors (09.10.2005 14:42 UT).

DATABASE

Observations recorded on a regular basis with FTIR spectrometers, under clear-sky conditions, at the NDACC site of the Jungfraujoch International Scientific Station (Swiss Alps, 46.5°N, 8.0°E, 3580m asl).

Data screening :

- airmass factor (AMF) < 10.0;
- signal to noise ratio > mean+2std;
- sum of water isotopologues degrees of freedom (DOFS) > 4.0;
- quality of the fit (RMS difference between measured and simulated spectra): reject of outliers residuals when fitting RMS in function of AMF;
- instrumental instabilities: reject of outliers in the CO_2 time series (obtained by a specifc fit in the 2610-2630 cm^{-1} region).

Total of selected spectra for the 1996-2011 period : 6247

In the following we express $H_2{}^{16}O$ and $HD^{16}O$ as H_2O and HDO respectively.

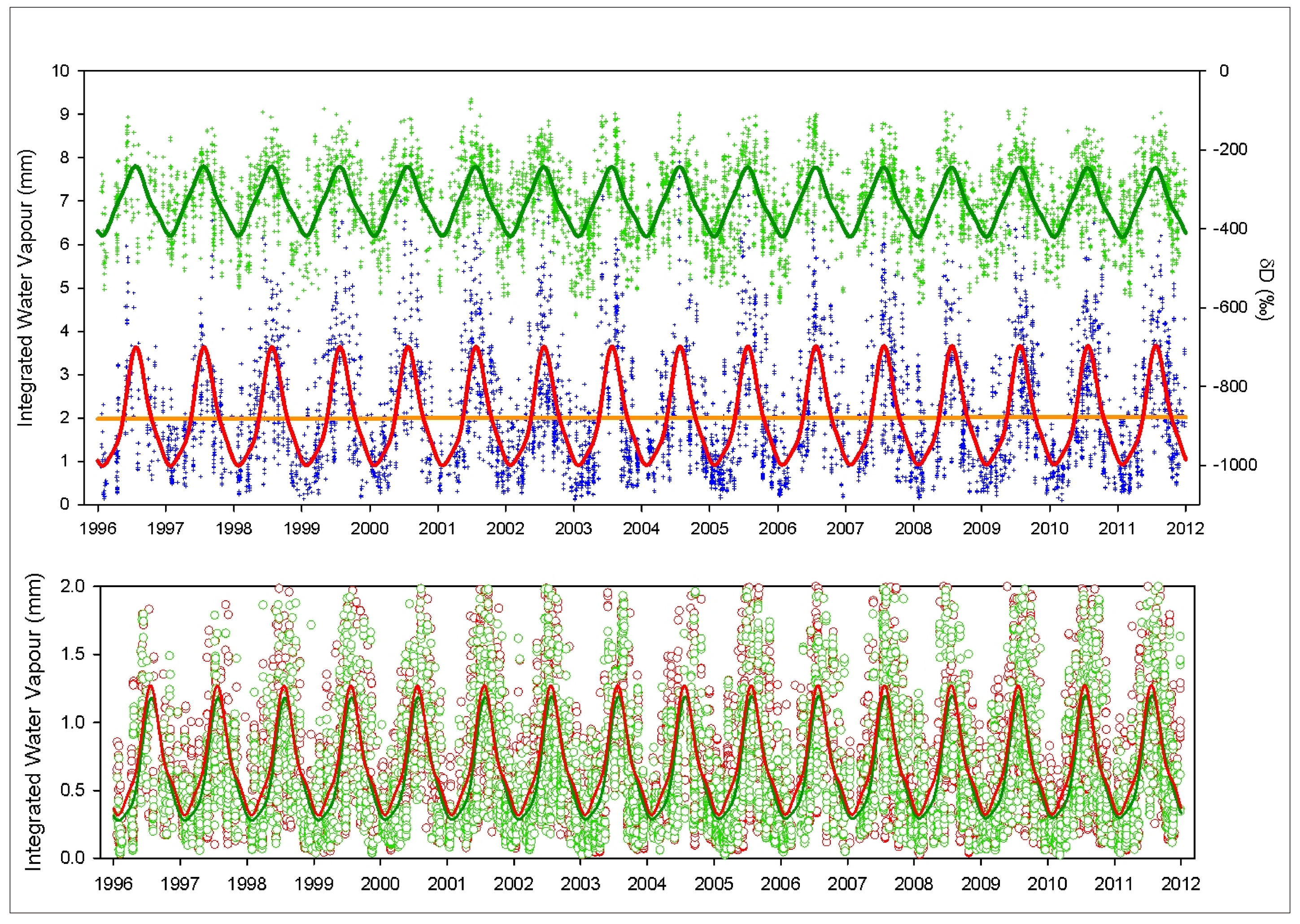

Figure 2 - Top: long-term time series of integrated water vapour (IWV) and δD above Jungfraujoch. Trends have been determined using the bootstrap resampling tool developed by Gardiner et al.[4]. The mathematical function (red and green curves, respectively for IWV and δD) fitted to the individual measurements (reproduced as blue and green crosses, respectively for IWV and δD) is a combination of a Fourier series (seasonal variation) and of a linear function (reproduced here as a thick orange ligne for IWV) - Bottom : long-term time series of IWV for lower (3.58-4.21 km) and middle (4.90-7.18 km) troposphere above Jungfraucoch. Individual measurements are reproduced as red and green circles, respectively. Red and green curves represent the correspondant fitted function.

DISCUSSION - TRENDS

Figure 1 shows that FTIR system is sensitive up to an altitude of 12 km (more than 75% of the atmospheric H_2O is detected by FTIR) in typical Jungfraujoch humidity conditions. The mean DOFS for main isotopologue $H_2{}^{16}O$ (2.06) allows us to distinguish between the lower (3.58-4.21 km) and middle (4.90-7.18 km) tropospheric partial column contribution.

Long-term time series (see fig.2) provide a trend of (0.03±0.06) mm/decade computed for the whole dataset, i.e. not statistically significant at the 95% uncertainty level. The same conclusion is deduced when considering:

- only the summer or winter months, respectively;
- only the lower or middle tropospheric partial columns, respectively.

However, we have to keep in mind that these results are strongly influenced by the time period amplitude. Another retrieval strategy developed by Sussmann et al. [5] for harmonized retrieval of IWV trends, and currently used for Jungfraujoch spectra on a longer time period, provides a trend result of (0.00±0.06) mm/decade for the 1996-2011 period. But considering the 1987-2011 period, this trend becomes statistically significant with a value of (0.05±0.03) mm/decade (+0.37±0.10 for summer months and -0.09±0.04 for winter months). We can expect the same evolution with the MUSICA strategy.

References

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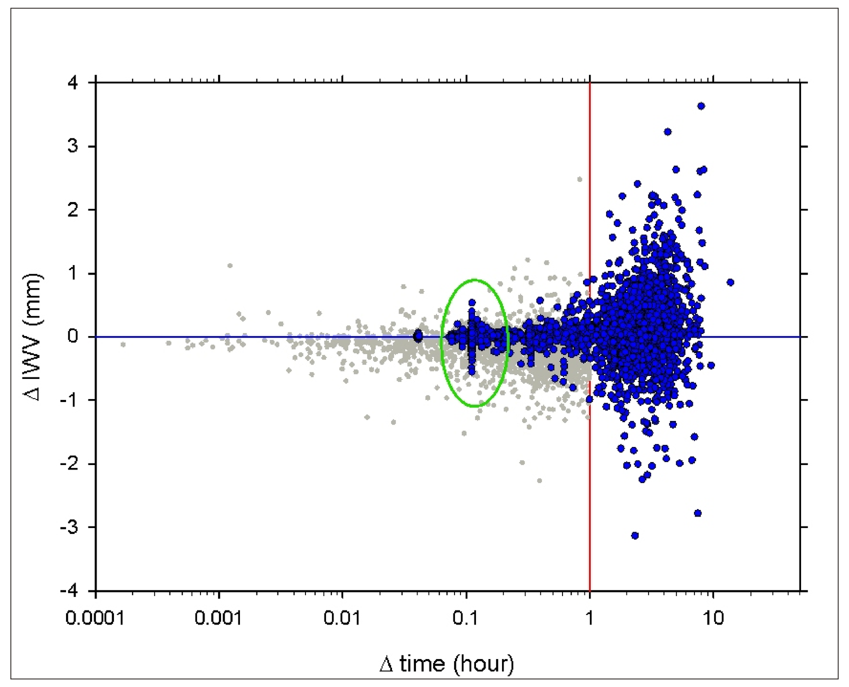
DISCUSSION - PROFILES

To evaluate the shape consistency of our retrieved water vapour profiles, we compare the VMR values obtained for the Jungfraujoch altitude (3.58 km) with coincident temperature and humidity values coming from the MeteoSwiss Jungfraujoch station. Temperature and relative humidity are measured every 10 minutes at 2 meters from the ground. Figure 3 shows (quite logically) that temperature seasonal variation seems to control the one of water vapour concentration. This link between retieved and meteorological values is even more obvious when we estimate the water vapour pressure from measured relative humidity and calculated equilibrium vapour pressure (assuming that it only depends on temperature). Correlation between estimated water vapour pressure and H_2O VMR values presents a coefficient of determination R^2 of 67%.

Figure 4 (top left panel) illustrates the retrieved profiles for 2011. We focused on some particular cases (unexpected IWV values - see top right panel) to see how evaluote the shape of the profiles when humidity conditions seems to be instable. The responses of our retrieved profiles are quite relevant for the two examples considered (bottom panels).

DISCUSSION - TIME LIMIT FOR INTER-COMPARISON

About 4500 couples of successive IWV measurements allows us to plot the diurnal variability of water vapour in function of time. Figure 5 indicates a relative constant variability for interval time under 30 minutes. The expanantial increase of water vapour variability appears clearly beyond a one hour interval time. Some specific time periods (in relation with the length of the FTIR scan) occur very often (see green circle). For example, about 1250 values are included in the 10 seconds interval centered on 6 minutes and 40 secondes. The resulting standard deviation value of 0.054 mm can therefore be considered as a reference value when an iner-comparison of different water vapour measurement techniques is carried out.



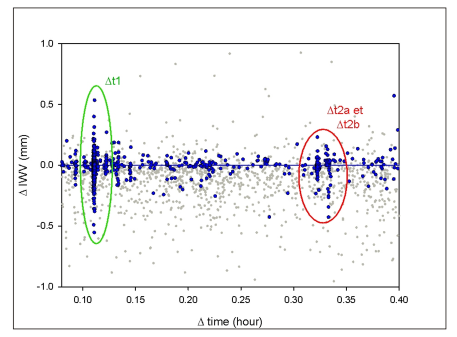


Figure 5 - Left: difference of retrieved IWV between 2 succesive measurements using MUSICA strategy (blue circles) or between 2 measurements using MUSICA and Sussmann strategy (grey crosses) with a limit fixed at 1 hour (red ligne)- Top: focus on specific interval times linked to the instrument (Δt1: 3 scans low resolution, Δt2a: 5 scans high resolution and Δt2b: 3x3 scans low resolution).

DISCUSSION - ANNUAL CYCLE OF δD

- FTIR measurements allow the retrieval of HDO amounts and therefore the monitoring of HDO/$H_2$0 ratio profiles whose variations act as markers for the source and history of the atmospheric water vapour [6].
- δD is the relative difference of the actual HDO/H_2O ratio to a standard HDO/H_2O ratio (SMOW - Standard Mean Ocean Water) in per mil;
- Figure 6 shows δD seasonal variation for 3 different sites;
- A summer maximum value appears for each site, but not at exactly the same time;
- Izaña seems to present a second maximum in March/April (see [7] for more details);
- Jungfraujoch values are systematically lower (altitude effect).

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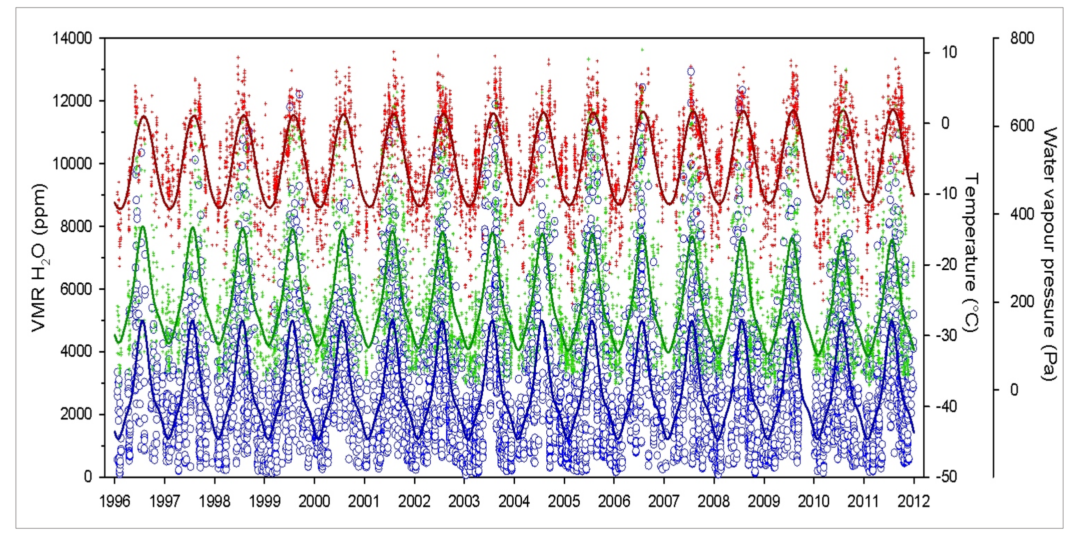

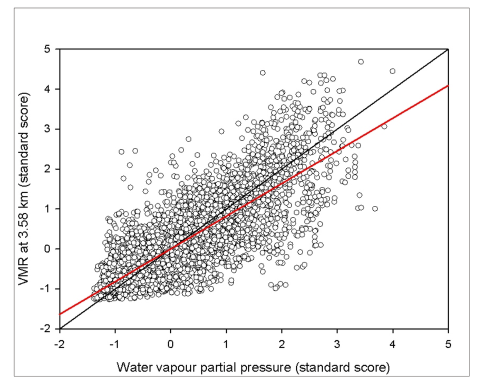

Figure 3 - Top: long-term time series of H_2O volume mixing ratio (VMR) at 3.58 km with coincident temperature and water vapour pressure at Jungfraujoch (2 meters from the ground). Individual data for VMR, temperature and water vapour pressure are reproduced as blue, red and green circles, respectively. The same color code is used for curves illustrating the fitted function - Right: correlation between coincident water vapour pressure and VMR H_2O values.

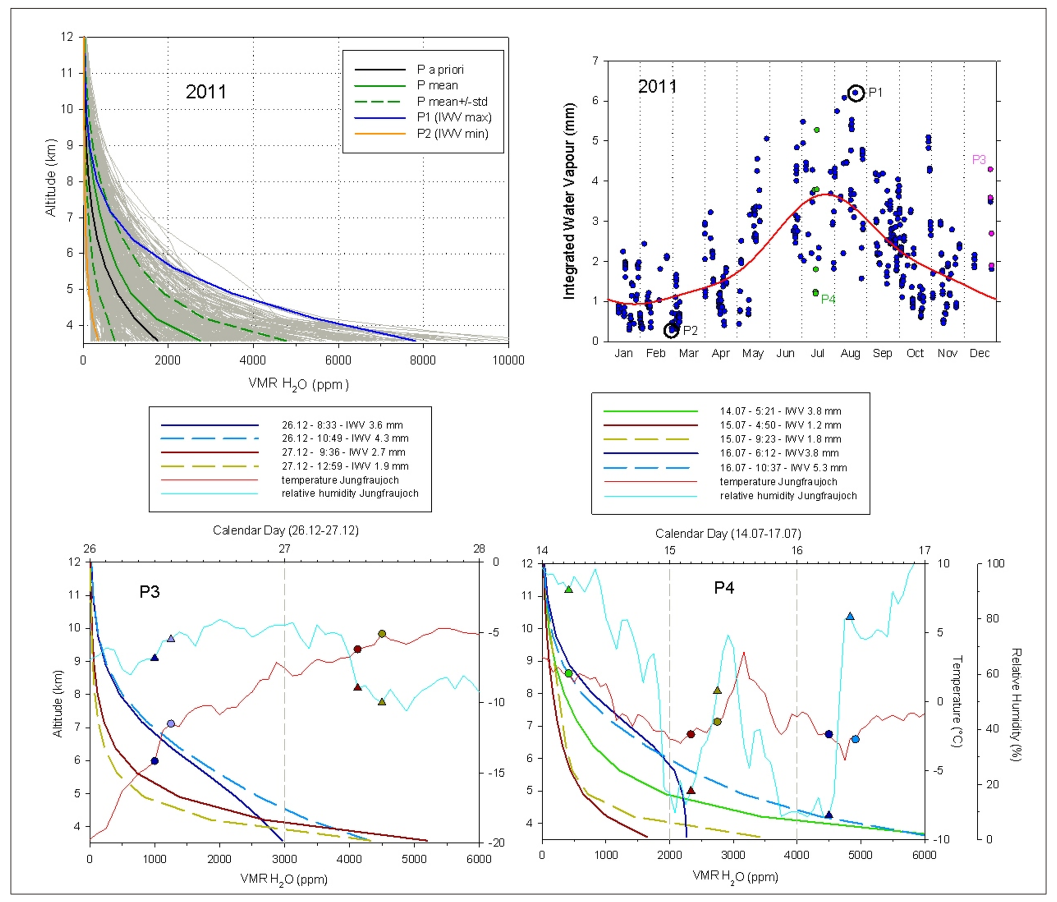

Figure 4 - Top right: focus on the year 2011 from fig.2. Some specific cases are marked (named P1-P2-P3-P4) - Top left: retrieved H_2O profiles for 2011 (in gray lines). Specific profiles as given in the legend are highlihted - Bottom left and right: retrieved H_2O profiles for specific cases (P3 and P4, respectively). See the legend on the top of each panel. Temperature and relative humidity (hourly mean) are coming from Meteoswiss Jungfraujoch station. Circles (or triangles) illustrate the position of the considered profile (see color code in the legend) on the temperature (or relative humidity) time series.

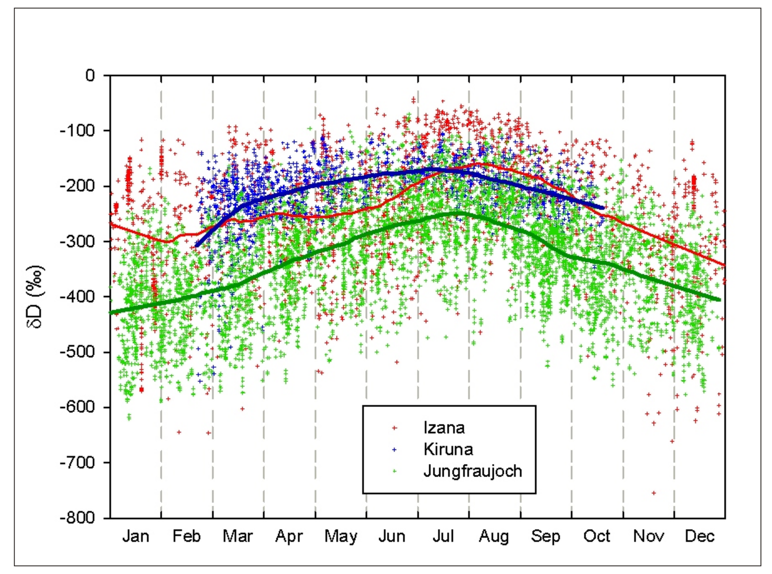

Figure 6 - δD seasonal variation for 3 different sites (Kiruna in Sweden: 67.8°N-20.4°E-419m asl, Izaña on Tenerife island: 28.3°N-16.5°W-2367m asl, and Jungfraujoch) for the 1996-2011 period (except for Kiruna: 1999-2011).