Tropospheric δD profile measurements by ground-based FTIR

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Water participates in many processes that are crucial for the Earth's climate. By distribution of heat (vertically and horizontally), regulating surface temperature, formation of clouds, radiative forcing due to water vapour, etc., it widely determines the energy budget and thus the climate of our planet. The isotopologue ratios of water (e.g. $HD^{16}O/H_2{}^{16}O$) are a powerful tool for investigating the different water cycle processes. In the following we express $H_2{}^{16}O$ and $HD^{16}O$ as H_2O and HDO, respectively, and $HD^{16}O/H_2{}^{16}O$ as
$\delta D = 1000‰ \bullet \{([HD^{16}O]/[H_2{}^{16}O]) / SMOW\} -1$, where $SMOW=3.1152 \bullet 10^{-4}$ (SMOW: Standard Mean Ocean Water).

In the framework of NDACC ground-based FTIR experiments have been performed at about 25 globally distributed sites since many years and allow the generation of an unprecedented long-term data set of tropospheric δD with some global representativeness. Figure 1 shows column integrated δD retrieved from ship-borne FTIR measurements. These measurements reveal the "latitudinal effect", i.e., decreasing δD towards the poles.

Ground-based FTIR δD profiles

In Schneider et al. (2006) it is demonstrated that NDACC's high quality ground-based FTIR (Fourier Transform Infrared) spectrometer measurements can be used to retrieve δD profiles between the surface and the middle/upper troposphere.

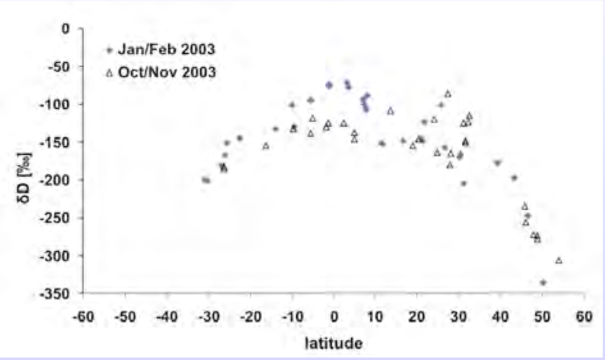

Figure 1: Latitudinal variation of δD obtained during two ship cruises on the Atlantic with the research vessel Polarstern.

The vertical resolution of these FTIR δD profiles is indicated by the averaging kernels shown in Fig. 2 for typical Kiruna and Izaña measurements. It is about 3 km in the lower troposphere and 6 km in the middle troposphere, with typical degrees of freedom of 1.6. Figure 2 also depicts the sum of all averaging kernels (thick solid black line), which indicates the total sensitivity of the FTIR system with respect to δD. For Kiruna the FTIR system is sensitive up to an altitude of 7 km (more than 75% of the atmospheric δD variability is detected by FTIR, see curve δ_{row}). For Izaña this sensitivity range is extended up to 10-11 km.

Theoretically, most errors cancel out by taking the ratio between HDO and H_2O. As leading δD error sources remain inconsistencies between the spectroscopic line parameters of H_2O and HDO. For instance, an inconsistency of 1% between the pressure broadening parameters causes significant errors in the δD profile shape, whereby positive errors in the lower troposphere are correlated to negative errors in the middle/upper troposphere. For more details about the theoretical error estimation please refer to the extensive discussion in Schneider et al. (2006).

Figure 3 shows an example of time series of lower and middle tropospheric δD retrieved from Kiruna FTIR measurements of the 1996 to 2008 period.

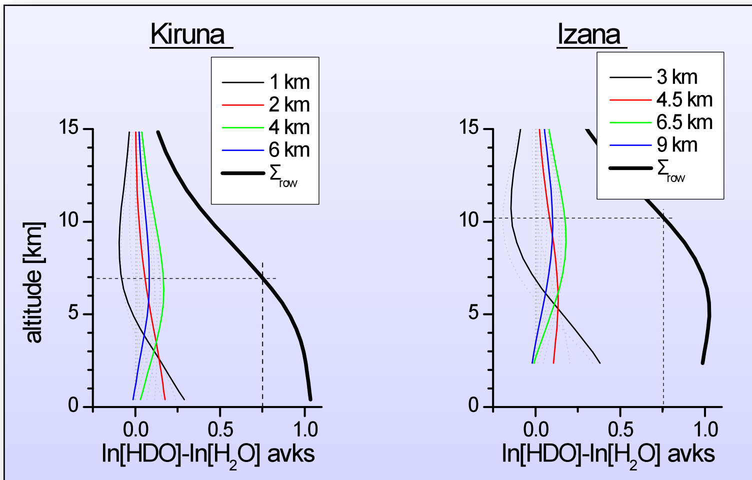

Figure 2: FTIR Averaging kernels for δD (expressed as ln [HDO]-ln[H_2O]). Left panels for Kiruna and right panels for Izaña.

Ground-based δD profile measurements for validating satellite data

Recently there has been large progress in observing tropospheric δD in vapour from space. The sensors TES (Tropospheric Emission Spectrometer, Worden et al., 2007) and SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography, Frankenberg et al., 2009) have provided first global pictures of tropospheric δD, although for limited time periods of a few years only.

The vertical sensitivity of space-based tropospheric δD measurements is limited to the lower troposphere (for nadir sounders working in the near infrared, like SCIAMACHY) or to the middle troposphere (for nadir sounders working in the middle infrared, like TES). As a consequence the validation of the space-based observations requires δD profiles as a reference. The ground-based FTIR technique is the only technique that

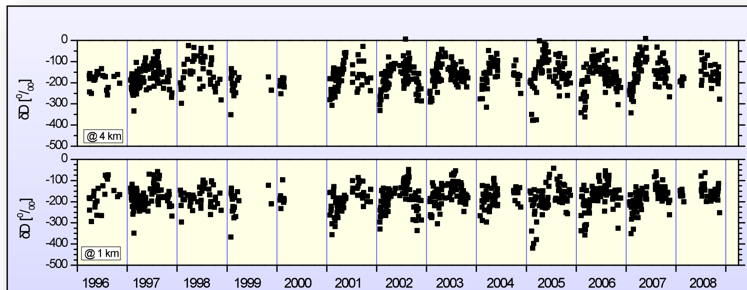

Figure 3. Time series of lower and middle tropospheric (altitude of 1 and 4 km, respectively) δD measured by the ground-based FTIR system at Kiruna.

can provide tropospheric δD profiles on a continuous basis. It is thus the only technique able to comprehensively validate the space-based measurements.

Long-term δD profile time series for constraining climate models

Long-term δD profile observations offer novel opportunities for investigating the atmospheric water cycle. An example is shown in Fig. 4, where the North Atlantic Oscillation index is plotted versus the middle tropospheric δD anomalies measured at the subtropical site of Izaña. The strong correlation indicates that the middle tropospheric water balance in the northern subtropics is significantly affected by pressure anomalies over the extra tropical northern Atlantic. The right panel shows the correlation for an atmospheric circulation model driven by prescribed sea surface temperature. The model does not well understand the subtropical water balance, which is of ultimate importance for climate on a global scale (the subtropics are the key region for the Earth's radiative cooling).

Without progress in modelling the water cycle, climate predictions will remain doubtful. The long-term δD time series produced from the ground-based FTIR measurements promise unprecedented opportunities for improving climate prediction models. For more details please refer to Schneider et al. (2010).

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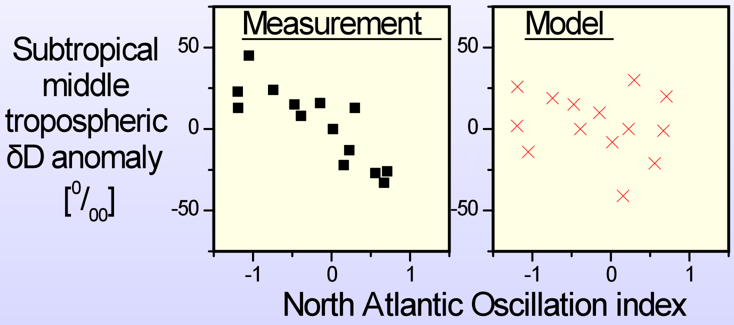

Figure 4: Correlation between the Northern Atlantic Oscillation index and subtropical middle tropospheric δD anomalies (shown are quarterly mean data). Left panel: FTIR measurements; Right panel: model simulations.