LAPBIAT ATMOSPHERIC SOUNDING CAMPAIGN IN 2010: UPPER AIR AND REMOTE SENSING OBSERVATIONS OF WATER VAPOR

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ABSTRACT

Accurate measurements of water vapor in the upper troposphere and lower stratosphere (UTLS) are needed for the climate studies. In January-June 2010 the LAPBIAT atmospheric sounding campaign took place in Sodankylä, northern Finland (67.4º N, 26.6º E) to perform profile measurements of water vapor and aerosols in the troposphere and stratosphere by different in situ and remote sensing instruments. The campaign involved balloon borne research grade water vapor instruments such as the Cryogenic Frostpoint Hygrometer (CFH) and the Lyman- alpha fluorescence hygrometer FLASH-B. The climate research radiosonde Vaisala RR01, which is currently under development, was flown in the same payload with the cryogenic frost point hygrometer and the fluorescence hygrometer. The remote sensing instruments participating in the campaign included the microwave radiometer for water vapor measurements MIAWARA-C. This instrument was operated for a six month period, until mid-June 2010. The aerosol in situ profile measurements were made by the new COBALD instrument and by a well established balloon borne aerosol backscatter sonde. The particle measurements in the stratosphere were made simultaneously with the water vapor measurements. Here we provide an overview of the LAPBIAT campaign activities in Sodankylä, including the upper air and remote sensing instrument descriptions and first results of the measurements of water vapor and stratospheric aerosols in the Arctic vortex in early 2010.

Campaign site

Sodankylä site (67.4 °N, 26.6 °E, 179 m above mean sea level) is operated by the Finnish Meteorological Institute Arctic Research Centre. The site is representative of high latitude conditions in the northern Europe. During winter and spring the upper air soundings are frequently sampling air inside the stratospheric vortex. Several measurement programs are running on the long term basis, for example Sodankylä has one of the longest records of upper air measurements of temperature and ozone in the European sector of Arctic. The site has also been active in instrument comparison (e.g. LAUTLOS-WAVVAP in 2004 (Deuber et al., 2005; Vömel et al., 2007; Suortti et al., 2008)) and satellite (e.g. ENVISAT, Aura, MetOp) validation campaigns. Sodankylä is also among the initial stations of the GRUAN network. The Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) was established in year 2008 to meet climate requirements and to improve the current global observing system (Seidel et al., 2009). Upper air observations within the network are expected to provide long-term high-quality climate records, they will be used to validate space based sensors, and will provide data for the study of atmospheric processes.

LAPBIAT Atmospheric Sounding Campaign

The campaign took place in Sodankylä from mid-January 2010 until mid-June 2010. The balloon soundings were made during two time periods. First from January 17 until February 6 altogether 18 balloon payloads were launched with different combination of in situ instruments, total number of sensors flown was 119. In January 2010 very low temperatures were measured in the polar vortex, during this time a series of water vapor and aerosol sonde flights were performed under night-time conditions. From March 10 to March 24 altogether 15 sonde payloads were launched, mostly under day-time conditions, in total 53 different sensors were flown.

The campaign included research grade light-weight balloon borne water vapor instruments such as FLASH-B (Lyman- alpha fluorescence hygrometer) and the Cryogenic Frostpoint Hygrometer (CFH). The prototype of the operational reference radiosonde Vaisala RR01 was flown in the same payload with the cryogenic frost point hygrometer and the fluorescence hygrometer (Lehtola et al., 2010). The radiosondes included RS92 and RS80 by Vaisala, and radiosondes developed by Intermet and Graw. Ozone profiles were measured by ECC type ozone sensors.

The Cryogenic Frost-point Hygrometer (CFH) is a research grade instrument of atmospheric humidity measurements up to the altitude of 25-28 km (Vömel et al., 2007). The instrument measures temperature of a mirror, which maintains a small and constant layer of frost coverage. The cryogenic cooling of the mirror ensures that the frost-point temperatures are achieved even in the coldest and driest layers. Relative humidity and mixing ratio can be calculated based on the frost-point temperature measurement. CFH is a relatively new instrument, some of the first flights of the CFH instrument were made in Sodankylä during the LAUTLOS campaign (Vömel et al., 2007). During the LAPBIAT campaign the CFH instrument was flown with Vaisala RS80 sondes (5 flights) and with Intermet radiosondes (14 flights), 13 CFH flights were combined with the COBALD backscatter sonde and all 19 CFH payloads had an ECC ozone sensor included.

The FLuorescence Advanced Stratospheric Hygrometer for Balloon (FLASH-B) instrument is the Lyman-alpha hygrometer developed at the Central Aerological Observatory. The instrument is based on the fluorescent method, which uses the photodissociation of H2O molecules at a wavelength <137 nm followed by the measurement of the fluorescence of excited OH radicals. The source of Lyman-alpha radiation (at 121.6 nm) is a hydrogen discharge lamp. The detector of OH fluorescence at 308–316 nm is a Hamamatsu R647-P photomultiplier. The intensity of the fluorescent light sensed by the photomultiplier is directly proportional to the water vapor mixing ratio under stratospheric conditions (10–150 hPa) with small oxygen absorption (3% at 50 hPa). The H2O measurement range is limited to pressures lower than 300–400 hPa due to strong

Lyman-alpha absorption in the lower troposphere. In Sodankylä during the campaign the instrument was interfaced to the Vaisala RS92 radiosonde. In total 12 flight of FLASH-B instrument were made during the campaign, 4 flights involved the new experimental version of the instrument.

RS92 radiosonde humidity sensor is a thin-film capacitor that directly measures relative humidity. It consists of two sensors, which are alternately measuring and being heated, thus eliminating coating of the sensor by ice or liquid inside clouds. The RS92 sonde has been manufactured since 2004 and the development of the sensor has been documented by Vaisala (2010). One of the important improvements was the new coating of humidity sensor contacts in late 2006 (Vaisala 2010). In total 47 RS92 sensors were flown during the LAPBIAT campaign.

RR01 is the prototype of the operational reference radiosonde (Lehtola et al., 2010; Vaisala, 2010). The RR01 sonde consists of RS92 radiosonde and Vaisala DRYCAP® sensor. The latter is a new capacitive sensor capable of measuring very low humidity values in upper troposphere and lower stratosphere. During the LAPBIAT campaign we performed 21 RR01 measurements, combined with the CFH frost point hygrometer observations, the results are reported by Lehtola et al. (2010).

Tropospheric water vapor profiles measured by different instruments on January 20 at 15:25 UT are shown as an example of the water vapor sensor comparison flights (Figure 1). This represents a night-time sounding under typical high relative humidity conditions in the lower troposphere, very dry layers in the middle troposphere and cirrus clouds in the higher troposphere. Good agreement between RS92 and CFH humidity measurements can be seen, while the Intermet sonde humidity sensor seems to show larger differences relative to the CFH. Two separate RS92 sensors were flown in this payload showing almost identical humidity readings.

Aerosol profile measurements were made by a well established aerosol backscatter sonde (Rosen and Kjome, 1991) and by the newly developed light-weight aerosol backscatter sonde COBALD (Compact Optical Backscatter Aerosol Detector).

The COBALD instrument is a lightweight backscatter sonde designed by Institute for Atmospheric and Climate Science of the Swiss Federal Institute of Technology Zürich. The instrument uses two high power LEDs in the blue and near infrared spectral range (455 nm and 870 nm) and detects the backscattered light from air molecules, aerosol or cloud droplets. This allows retrieving information of aerosol (or cloud) particle size and number density. In the LAPBIAT campaign configuration it was flown together with an Intermet radiosonde and CFH water vapor sonde. During the campaign 11 COBALD sonde flights were performed in January-Febraury and two flights in March 2010.

The backscatter sonde (BKS), constructed at the University of Wyoming (Rosen and Kjome, 1991), is equipped with a xenon flash lamp, giving a light pulse about once every 7 s. The backscattered light from aerosol and cloud particles is detected by photodiodes on the sonde, each equipped with filters transmitting in two wavelengths around 490 nm and 940 nm. The sonde detects the backscattered signal, at an angle about 173° with respect to the beam forward direction, from an air volume of approximately 1m3 within a few meters from the instrument. Backscatter ratio, i.e. the ratio between the total (particulate and molecular) to the molecular volume backscattering coefficients is the basic measurement of the sonde. During LAPBIAT one of the goals was to perform COBALD versus backscatter sonde comparison flights. These comparison flights were made in January 23 and 24 in the presence of polar stratospheric clouds (PSCs).

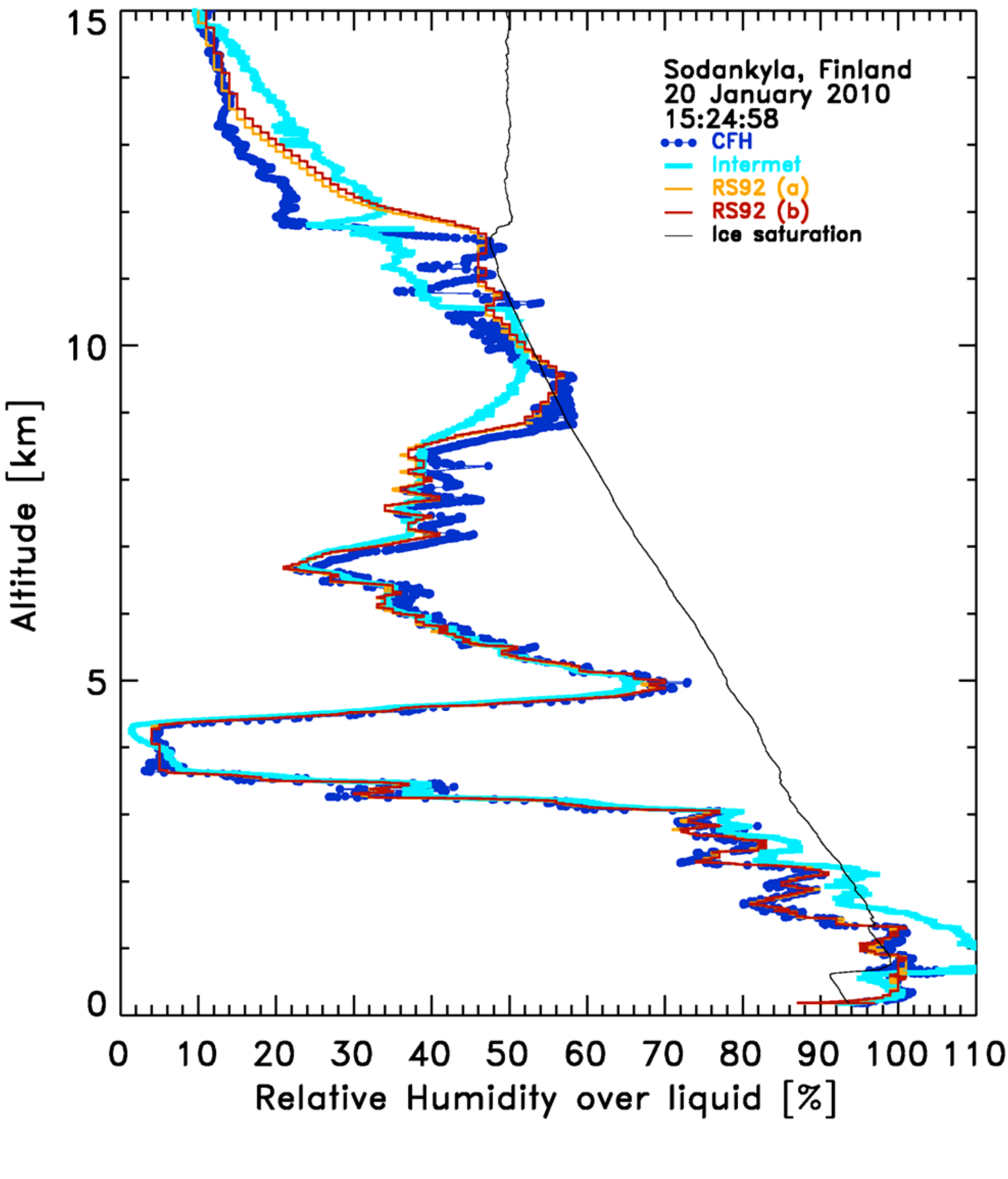

Figure 1. Tropospheric humidity measurements on 20 January 2010 at 15:25 UT over Sodankylä, Finland, using the CFH cryogenic frost point hygrometer, two Vaisala RS92 sensors (marked as sensor "a" and "b") and the Intermet radiosonde.

Figure 2 presents COBALD measurement of very strong PSC layers on January 17, 2010 together with the stratospheric water vapor measurements by two sensors: FLASH-B and CFH. Both sensors show decrease in water vapor mixing ratio above 22 km of altitude. This reduction of water vapor can be attributed to the formation of ice PSCs. Indeed, ice PSC particles were detected in the layer of 22-24 km by COBALD and BKS sondes.

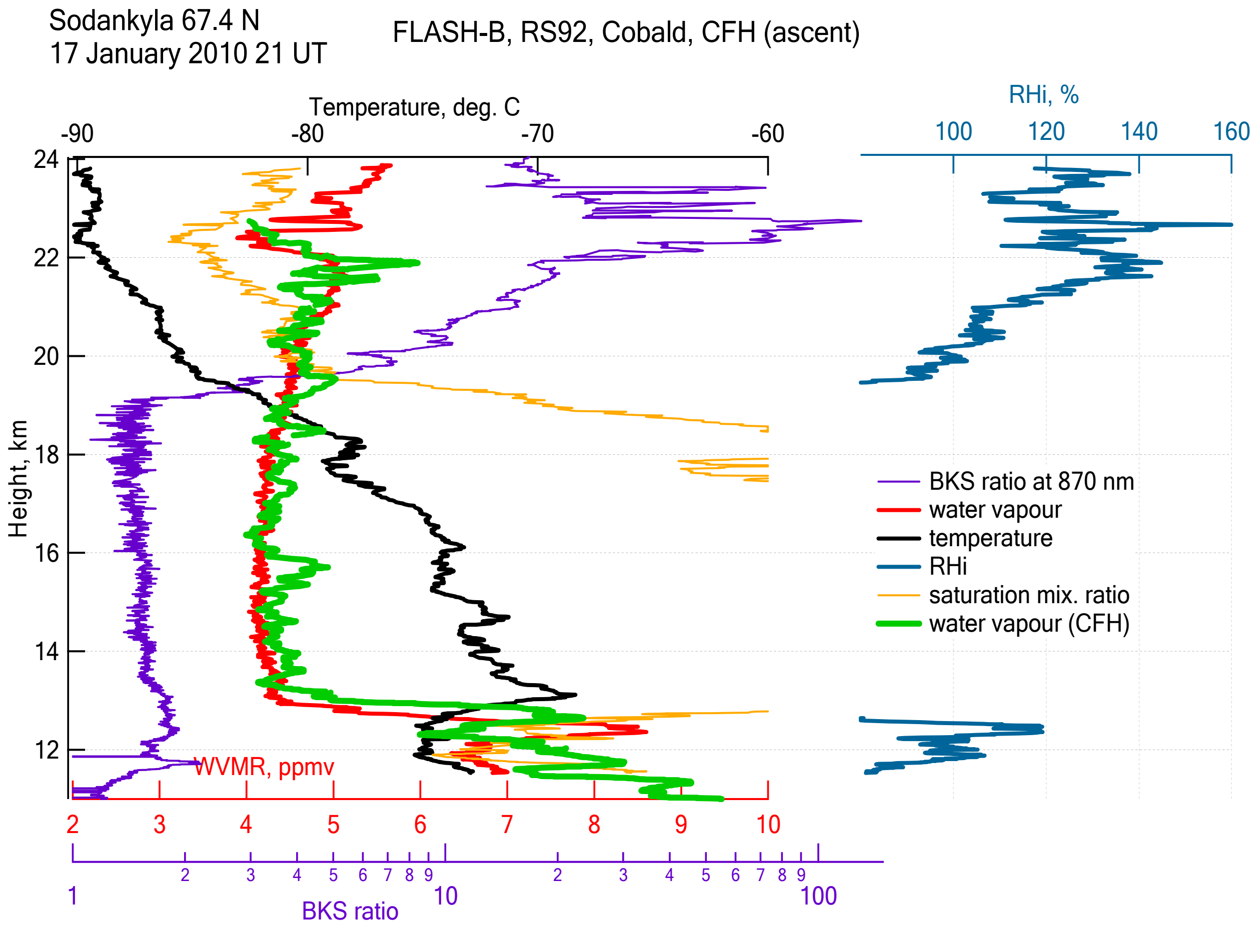

Figure 2. Stratospheric humidity measurements on 17 January 2010 over Sodankylä, Finland, using a CFH cryogenic frost point hygrometer and a FLASH-B hygrometer. Aerosol backscatter ratio at 870 nm was measured by COBALD and temperature profile by Vaisala RS92 radiosonde.

The sequence of stratospheric water vapor measurements by FLASH-B and CFH hygrometers is shown in Figure 3. The extremely low temperatures in the Arctic vortex led to the formation of PSC and thus formation of dehydrated layers in the stratosphere. In the dehydrated layer at 20-24 km water vapor reduction of up to 1.2 ppmv was observed and a rehydration layer below at 18-21 with water vapor enhancements up to 1.1 ppmv. Ice particle sedimentation of about 2 km led to redistribution of stratospheric water vapor within 18-24 km layer in the lower stratosphere.

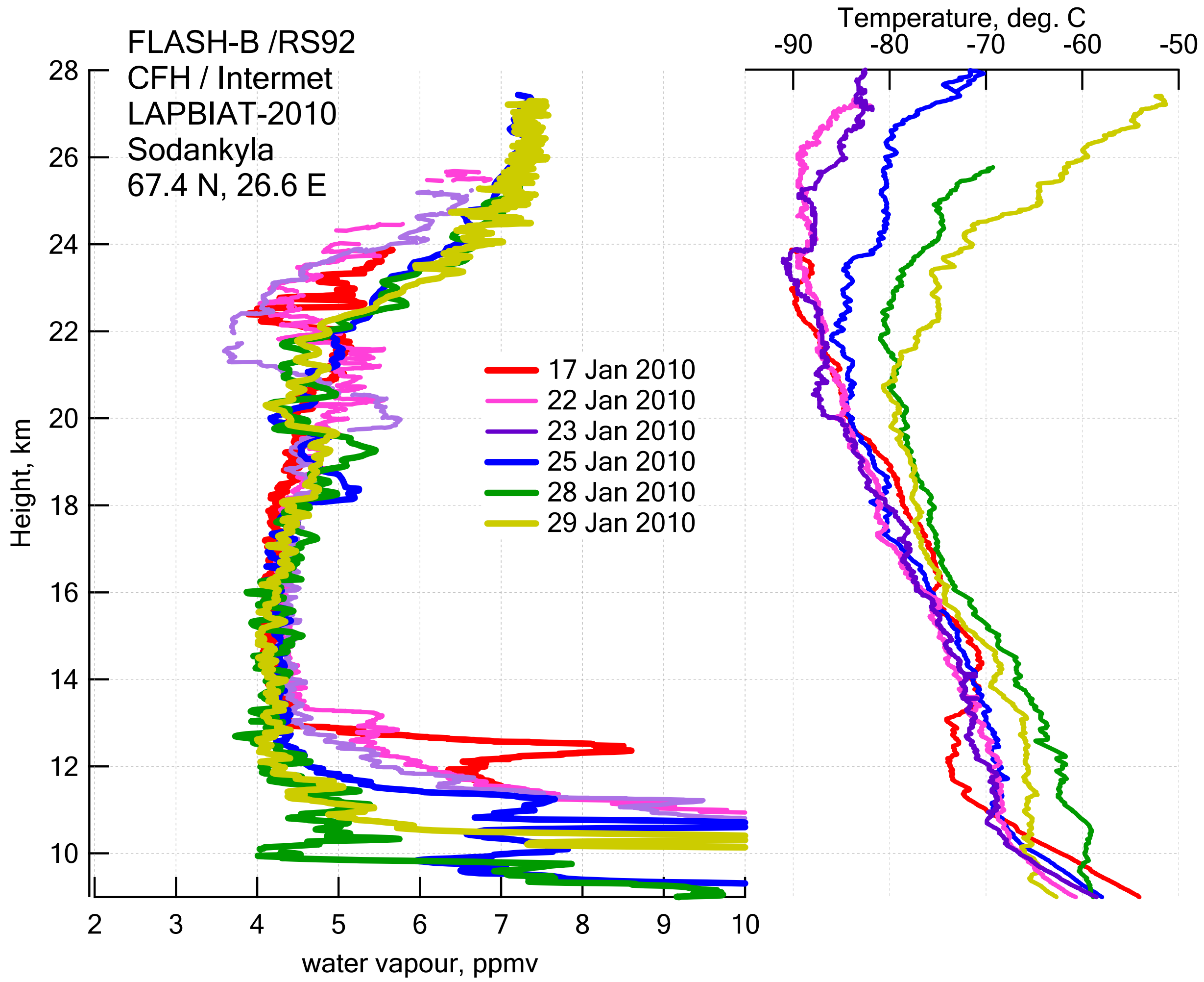

Figure 3. Stratospheric water vapor measurements from 17 to 29 January 2010 over Sodankylä, Finland, using the CFH cryogenic frost point hygrometers and the FLASH-B hygrometers. The corresponding temperature profiles are also shown (right panel).

Comparison of the sonde water vapor measurements with the spaceborne observations from the Microwave Limb Sounder (MLS) on board the Aura satellite are shown in Figure 4: January 21 and January 28 individual profiles and average difference between the measurements. The two cases were chosen to represent the days, when the CFH sonde sampled the dehydrated and rehydrated water vapor layers in the Arctic vortex.

The ground based remote sensing instruments participating in the campaign included the new microwave radiometer for water vapor measurements MIAWARA-C developed by the University of Bern (Straub et al., 2010). MIAWARA-C is a 22GHz water vapor spectro-radiometer which has been designed for profile measurement campaigns of the middle atmosphere. The instrument can be operated as a standalone instrument. The optical system combines a choked gaussian horn antenna with a parabolic mirror, which reduces the size of the instrument. Calibration is done through a balancing scheme with the sky used as the cold load and the tropospheric properties are determined by performing regular tipping curves. The instrument was operated in Sodankylä from January to June 2010 and the first results are reported by Straub et al. (2010).

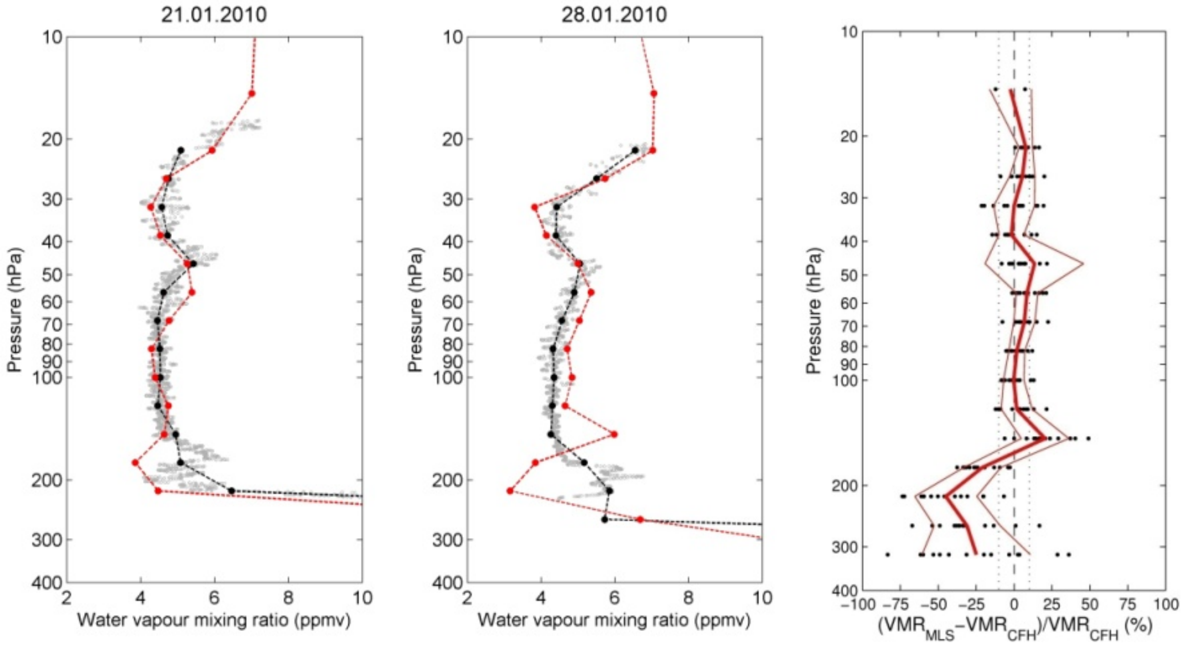

Figure 4. Left: Water vapor measurements by Cryogenic Frost point Hygrometer (CFH, black dots) and Aura MLS instrument (red dots) on January 21 and 28, 2010. The grey dots in the background represent the high vertical resolution data measured by the CFH instrument. Right: average relative difference for all January-February 2010 comparisons.

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