Comparison of in–situ and remote sensing measurements of water vapor made within the frame of the SHOMING project over Switzerland.

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Research Report No. 2009-07-MW
June 26, 2009

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1 Introduction

Water vapor is chemically and radiatively very active in the atmosphere and has thus a huge impact on its composition and radiative balance. Water evaporates from the surface and the combined effect of the temperature lapse rate and the strong temperature dependence of the saturation vapor pressure leads to an exponential decrease of water vapor with altitude with a scale height of approximately 2 km. The upper troposphere and the stratosphere is typically a thousand times dryer than the lower troposphere. Furthermore, the spatial and temporal variability of water vapor is very large. These circumstances make the measurement of water vapor a difficult task and there exists no single technique that can cover altitudes from the surface up to 100 km.
The key to measure water vapor in the whole atmosphere is thus the combination of several measurement techniques. This, however, requires that the different measurements are consistent or are made consistent, for example with the approach proposed by [4] or with the method suggested by [6] (integrated profiling technique).
SHOMING (Stratospheric Humidity Observations and Monitoring) is a project within the Global Atmospheric Watch (GAW) program with the following aims:

- Improvement of existing measurements by optimization of the calibration concept
- Comparison with other sensors in campaigns and complementing data from different techniques in an optimal way
- Long term validation of satellites and combining the ground based measurements with satellite data
- Investigation of temporal variability in stratospheric water vapor and its relation to ozone
- Strengthen the NDACC alpine station Jungfraujoch/Bern

Within the SHOMING project a variety of sensors were available as described below. Deployed from different platforms these sensors cover different altitude ranges and provide the possibility to characterize the water vapor profile from the ground up to 80 km. Within this initiative five balloon soundings have been performed so far. These balloon soundings were coordinated with the activities of a microwave system for stratospheric and mesospheric water vapor and with the activities of a lidar system for tropospheric water vapor. In this work we present an intercomparison of the data of the different measurement techniques in their overlapping region. Knowing the performance or the "information content" of the individual measurements is an important precondition for the next step which is the combination of the various measurements.
After a short description of the different water vapor sensors and measurement techniques in Section 2 the results are presented in Section 3. In Section 4 a summary is given and conclusions drawn.

Sensor	Platform	Technique	Approx. Altitude Range
RS92	Balloon	Thin–film capacitor	0 - 10
Snow White	Balloon	Frost point	0 - 10
FLASH-B	Balloon	Lyman-α	8 - 35
Ralmo	Ground based	Lidar	0 - 10
Miawara	Ground based	Microwave spectrometer	25 - 75

Table 1: Available instruments for the FLASH campaign.

2 Data

2.1 Balloon Soundings

The balloon soundings are performed by MeteoSwiss from the aerological site Payerne (46.82°N, 6.95°E, 491 m amsl), Switzerland. For each sounding the balloon payload was equipped with the sensors given in Table 1. Until the time of writing five soundings could be realized at the following days: February 8, 2008; April 29, 2008; June 24, 2008; October 7, 2008; May 6, 2009. The Soundings are exclusively performed during night and 4 of them were successfully recovered and can be refurbished to some extent.

RS92

The Vaisala RS92 is a thin–film capacitance sensor that directly measures relative humidity. The accuracy of the RS92 measurements is assessed in detail in [7] and is reported as ±4 % for nighttime soundings. For this study no correction was applied to the RS92 data.

Snow White

The Snow White hygrometer manufactured by Meteo Labor AG, Switzerland, is a low cost chilled–mirror humidity sensor. The performance of Snow White is assessed in [3, 9] and is found to be good up to the tropopause. The uncertainty is as good as 2 % RH. The Snow White version MRS–SRS–C34/04–night was used in this project.

FLASH-B

The Fluorescent Advanced Stratospheric Hygrometer for balloon born application is a high end Lyman–α humidity sensor for stratospheric conditions [10]. This instrument took part in the LAUTLOS campaign and has been compared to the CMDL frost point hygrometer [8], which is considered as a reference instrument for water vapor in the troposphere and stratosphere. FLASH–B typically provides good data between the mid troposphere up to the burst altitude of the balloon (typically 35 km) with an uncertainty of 8 % in volume mixing ratio. More reliable measurements are obtained during the descent after the balloon burst.

2.2 Remote Sensing Instruments

Ralmo

Ralmo is a ground based raman lidar system providing water vapor profiles at very high temporal and vertical resolution. It is deployed at the aerological station in Payerne (46.82°N, 6.95°E, 491 m asl). Under good conditions and with longer integration times the lidar system reach the lower stratosphere but it is most reliable in the lower and mid troposphere.

Miawara

The Middle Atmospheric Water Vapor Radiometer, Miawara, is a ground based microwave spectro–radiometer dedicated to stratospheric and mesospheric water vapor (approx. 25 – 75 km) [2]. This instrument has been validated in [1, 5]. The uncertainty of single profiles is 10 % below the 1 hPa level and increases to 30 % at 75 km. Miawara is deployed at Zimmerwald (46.88° N / 7.46° E, 907 m amsl) which is 40 km East of Payerne.

3 Results

3.1 Troposphere

The measurements obtained in the troposphere are shown in Figure 1. The balloon borne measurements are taken during the ascent in the case of RS92 and Snow White and during the descent in the case of Flash. Note that RS92/Snow White and Flash are thus not perfectly collocated. No RS92 was onboard of the first balloon sonde in February 2008 and no lidar data are available for the third flight in June 2008. The upper limit of the lidar measurements lies between 6 and 12 km for dry and wet conditions, respectively. It has to be noted also, that the profiles of the ground based lidar system are not perfectly collocated with the balloon borne measurements. The Flash measurements in June 2008 and May 2009 were not successful because of a failure of the photo multiplier.
The profiles of the relative difference in relative humidity between Snow White and RS92 are shown in Figure 1. Snow White shows a lot of variations that are not present in RS92 data and might be related to difficulties with the temperature control of the mirror. However, on average Snow White shows no bias compared to RS92 in the lower and mid troposphere (< 6 km). Between 6 and 12 km the difference profiles reveal a large spread and indicate on average a wet bias of $10 - 20$ % compared to RS92. Despite the larger spread of the differences at these altitudes the agreement is good enough for the data to be considered as reliable. Above 12 km the differences between Snow White and RS92 get very large and no systematic bias can be determined.
The measurements of Snow White, RS92 and Flash did not reveal considerable agreement above the tropopause and stratospheric measurements of Snow White and RS92 are not presented.

3.2 Stratosphere

The stratospheric measurements taken by the balloon borne Flash hygrometer and by the ground based microwave radiometer Miawara are complemented by observations made by the Microwave Limb Sounder (MLS) onboard the Aura satellite. Figure 2 shows the data of the three successful Flash soundings together with collocated MLS and Miawara profiles. As single profiles of Miawara have a considerable uncertainty of 30 % Figure 2 shows the mean and the standard deviation derived from individual profiles within ± 12 h around the balloon sounding (2–3 profiles). MLS profiles are taken within ± 200 km in latitude and ± 400 km in longitude and within ± 24 h in time. Neither the Flash nor the MLS data have been convolved with the averaging kernels of Miawara. The contribution of the a priori profile is less than 35 % above the 30 hPa level (≈ 24 km).

Figure 3 shows the temporal evolution of water vapor at the 10 hPa level as measured by Miawara and in comparison with MLS and Flash measurements. The data gap during the months June to August is due to baseline problems. Nevertheless, the stability of the Miawara measurements at 10 hPa is remarkable as the retrieval of mid and lower stratospheric water vapor is extremely sensitive to instrumental instabilities like baselines, that arise from internal reflections.

4 Summary and Conclusions

In the frame of the SHOMING project coordinated efforts have been made to measure atmospheric water vapor from the surface up to the mesosphere. In this report an intercomparison of the data collected by the various in situ and remote sensing techniques is presented.

The RH measurements of RS92, Snow White and the lidar system are in good agreement. In particular, no systematic difference could be found between Snow White and RS92 in the lower and mid troposphere. In the upper troposphere the uncertainty of the Snow White and RS92 measurements increases but the agreement is considerably good up to an altitude of 12 km. Based on the data taken within this project, 12 km is found to be the upper limit for the Snow White and RS92 hygrometers.

Three successful Flash measurements are available for intercomparisons in the stratosphere. The burst altitude of the balloon was between 35 adn 37 km. On the other hand, an arbitrary threshold of 35 % a priori contribution has been chosen for the microwave system which allows the retrieved profile to be extended downward to an altitude of 30 km. The agreement between Flash and Miawara in this overlap region is good. Stable long term measurements in the mid stratosphere down to 25 – 30 km by ground based microwave radiometry is a major challenge and requires a very high level of instrumental stability. Any change in the baseline structure, that emerges from internal reflections, affects the retrieval mostly below 40 km. The performance of Miawara in the mid stratosphere is good as revealed by this intercomparison but so far the timeseries at 10 hPa is not continuous and further efforts are required to achieve stable measurements at this altitude level throughout the year.

Generally, the data collected within the SHOMING project are in good agreement and are a good basis to study the synergistic use of these data to retrieve water vapor profiles of high quality from the ground up to the mesosphere using the best combination of information sources at every altitude.

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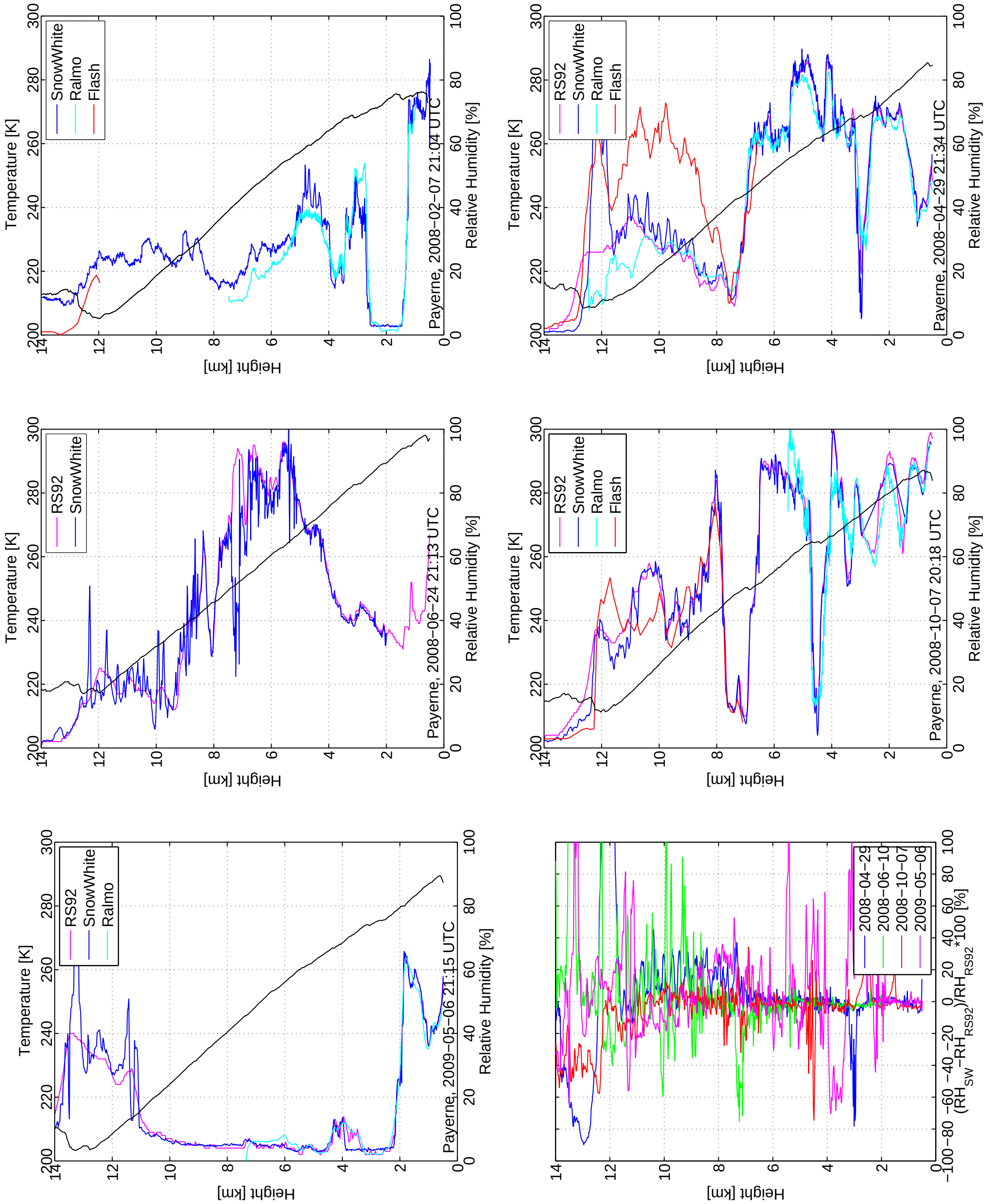

Figure 1: Water vapor profiles measured by the different sensors between 0 and 12 km. No corrections have been made to the data. Temperature is also shown (black). Note, that RS92/Snow White measurements are made during ascend and Flash measurements are made during descent of the balloon flight. These measurements are hence not perfectly collocated. The bottom right plot shows the relative difference in relative humidity between Snow White and RS92.

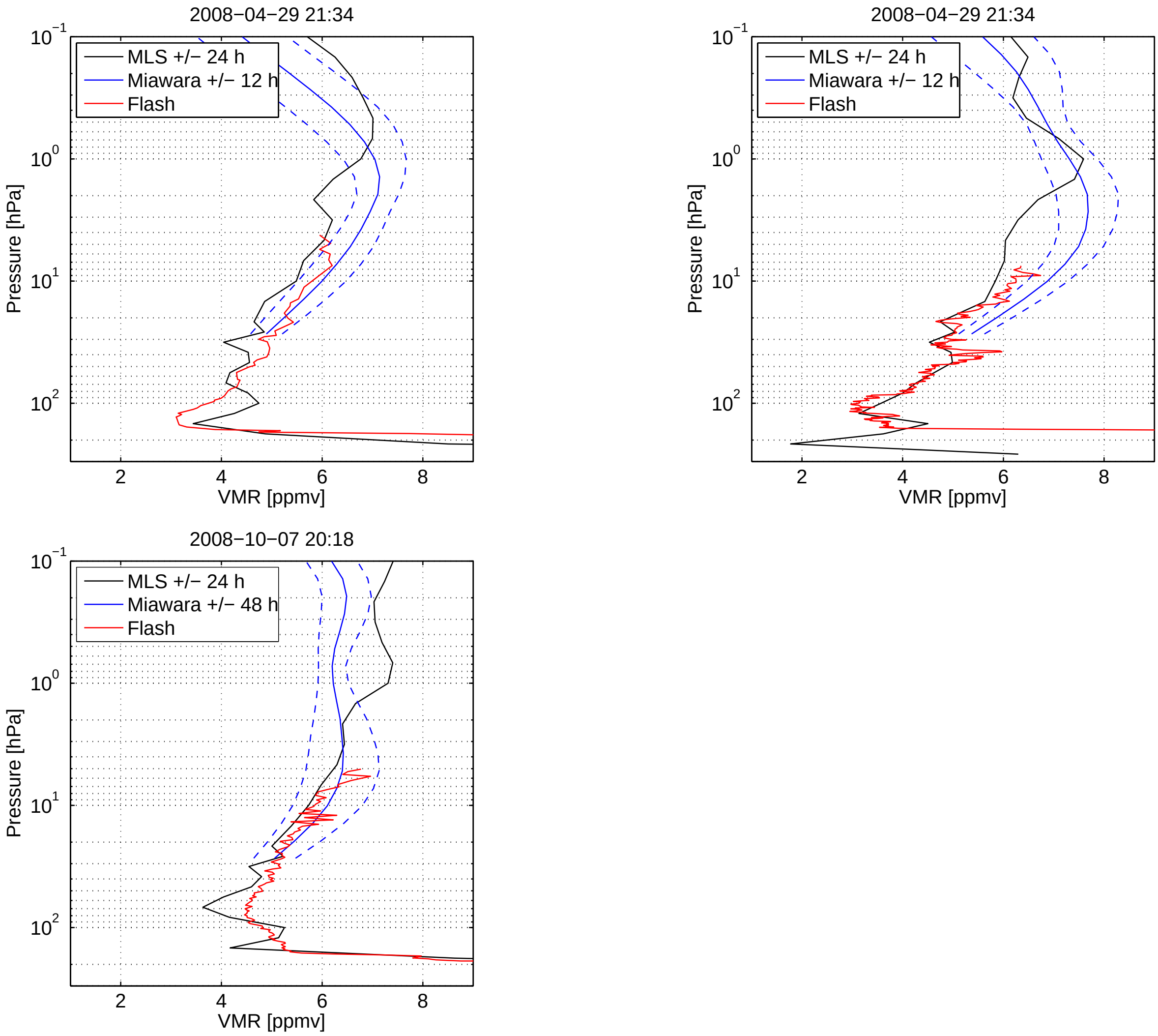

Figure 2: Water vapor profiles measured by the balloon borne Flash hygrometer (red), by the ground based microwave system Miawara (blue) and by the space borne Microwave Limb Sounder (black). Averaging kernels have not been considered and the contribution of the a priori profile to the Miawara retrievals is less than 35 %.

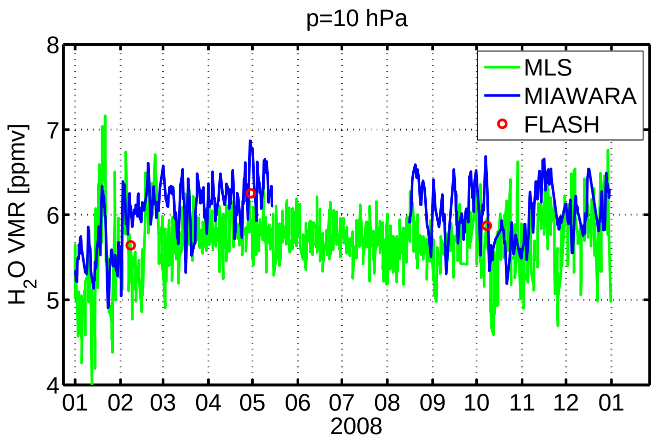

Figure 3: Timeserie of water vapor at 10 hPa as measured by Miawara (blue), MLS (green) and Flash (red circles). Averaging kernels have not been considered and the contribution of the a priori profile to the Miawara retrievals is less than 35 % at this level.