Accuracy of Water Vapor Observations from in-situ and Remote Sensing Techniques: First Results from the DEMEVAP 2011 Campaign

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ACCURACY OF WATER VAPOR OBSERVATIONS FROM IN-SITU AND REMOTE SENSING TECHNIQUES: FIRST RESULTS FROM THE DEMEVAP 2011 CAMPAIGN AT OHP.

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ABSTRACT

The accuracy of water vapour observations from four different operational radiosonde types (Vaisala RS92, MODEM M2K2-DC and M10, and Meteolabor Snow-White) flows simultaneously on the same ballon are intercompared and compared to GPS and Raman lidar measurements during the DEMEVAP 2011 experiment. The RS92 and Snow-White sondes show a slight moist bias at night-time compared to GPS, while the MODEM sondes show a dry bias. The IGN-LATMOS Raman lidar water vapour measurements are well consistent with RS92. Raman lidar calibration factors determined from RS92 and capacitive humidity sensors achieve stabilities of 2% and 3-5% respectively. They detect a change in the lidar calibration during the experiment which is not explained yet.

1. INTRODUCTION

Measuring water vapour in the atmosphere is still a challenging topic for ever more demanding geophysical applications requiring high absolute accuracy, both at high and low water vapour concentrations, and long term stability. Calibration and validation of satellite sensors and correction of radiosonde biases are major issues both for climate monitoring and weather forecasting. Changes in instruments or sonde types make this task very difficult and require a reference technique for inter-calibration purposes. Scanning Raman lidars have been shown in the past to be a potential candidate technique for transferring absolute calibration from ground-based sensors to other systems such as profilers (e.g. radiosondes and remote-sensing techniques like spectrometers and radiometers) and/or integrated water vapour measurements (e.g. from GPS or dual-channel microwave radiometers).

The DEMEVAP project (MEthodogical DEvelopment for the remote sensing of water VAPor) aims at developing an improved reference humidity sounding system based on the combined used of a scanning Raman lidar, ground-based sensors and GPS. The ultimate goal is to achieve absolute accuracy better than 3% on the total column water vapour. The project is conducted by a consortium of research groups and operational services from Institut National de l'Information Géographique et Forestière (IGN), Institut Pierre Simon Laplace (IPSL), Météo-France and Observatoire Astronomique Marseille-Provence (OAMP). An intensive observing period was conducted in September-October 2011 at Observatoire de Haute Provence (OHP) to assess several Raman lidar calibration methods and evaluate the humidity biases of different operational radiosonde types. This paper reports the first results from the analysis of data collected during DEMEVAP.

2. PROFILE AND IWV INTERCOMPARISON

The DEMEVAP 2011 experiment involved the IGN-LATMOS scanning Raman lidar [1], the OHP Raman lidar [2], four radiosonde systems, five GPS stations, a stellar spectrometer [3], and several ground-based capacitive and dew-point sensors. Observations were collected over 17 nights during which 26 balloons were released which carried a total of 79 radiosondes. Most of the balloons carried 3 or 4 different sonde types simultaneously (Vaisala RS92, MODEM M2K2-DC and M10, and Meteolabor Snow-White).

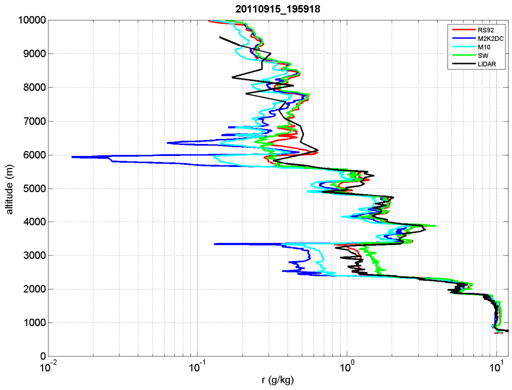

Figure 1. Example of WVMR profile on 15 Sept. 2011 measured by 4 radiosondes launched on the same balloon and IGN-LATMOS Raman lidar.

Figure 1 shows an intercomparison of water vapor mixing ratio (WVMR) profiles measured by the four radiosonde systems and retrieved from the IGN-LATMOS Raman lidar. The agreement between the radiosondes is overall good as long as WVRM remains above 1-2 g/kg. In the dry layer between 2.5 and 3.5 km, the MODEM radiosondes are too dry, while the Snow-White is too wet. In the upper troposphere (above 5.5 km) RS92 and Snow-White agree well. The Raman lidar profile is in good agreement with the RS92 measurements up to 6 km. It confirms namely the biases in MODEM and Snow-White measurements in the dry layer around 3 km.

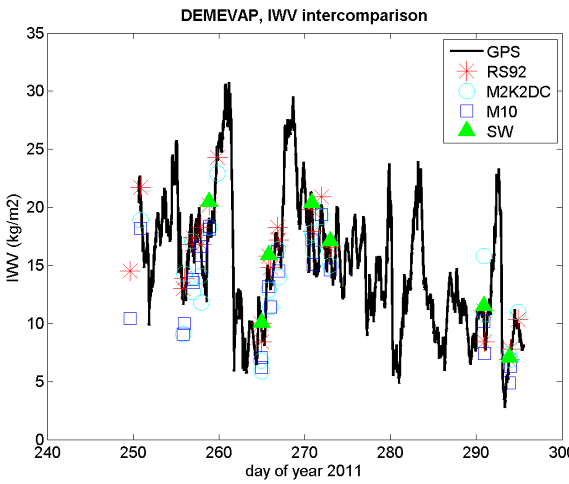

Figure 2. IWV estimates from four radiosonde systems and GPS during the DEMEVAP 2011 experiment.

Integrated Water Vapour (IWV) estimates from the four radiosondes and GPS are compared in Figure 2. The IWV variations during the campaign were very large but well reproduced by the systems. The correlation coefficient with GPS IWV is 0.90 for M2K2DC and above 0.98 for the other systems.

Table 1 reports the results of the comparison of radiosonde IWV to GPS IWV over the whole experiment. The mean difference reveals a slightly humid bias for RS92 and Snow-White (SW) at night-time, which is consistent with [4]. The MODEM sondes show dry biases.

	IWV (kg/m^2)	Bias (%)	Bias (kg/m^2)	Std. Diff. (kg/m^2)	Ratio	NP
RS92	+14.63	+4.4	+0.65	0.69	1.040	24
M2K2DC	+14.63	-6.9	-1.01	2.03	0.938	24
M10	+14.60	-11.8	-1.72	0.97	0.865	23
SW	+13.62	+7.7	+1.05	0.58	1.078	7

Table 1. Comparison of IWV estimates from the four radiosonde system w.r.t GPS. The bias is computed as $IWV_{RS} - IWV_{GPS}$, and the ratio as IWV_{RS} / IWV_{GPS}.

3. RAMAN LIDAR CALIBRATION

The IGN-LATMOS scanning Raman Lidar uses a tripled Nd :YAG laser (355 nm) and narrow (0.4 nm) band-pass interference filters (Barr Associates) for the detection of the Raman signals [1]. Water vapor mixing ratio (WVMR) is determined from the ratio of signals measured in the water vapour and nitrogen channels, according to the following equation [5]:

$$r_{lidar}(z) = C_{lidar} \times \frac{S_{H_2O}(z) - B_{H_2O}}{S_{N_2}(z) - S_{N_2}} \qquad (1)$$

where C_{lidar} is the overall lidar calibration constant, and $S_x(z)$ and $B_x(z)$ are the measured signal and background, respectively, for species x (water vapor or nitrogen) in units number of photons/bin/shot. The lidar calibration constant can be expanded into [1]:

$$C_{lidar} = r_{N_2} \frac{M_{H_2O}}{M_{N_2}} \frac{C_{N_2}}{C_{H_2O}} \frac{T(z,\lambda_{N_2})}{T(z,\lambda_{H_2O})} \frac{\dfrac{d\sigma_{N_2}(z,\lambda_{N_2})}{d\Omega}}{\dfrac{d\sigma_{H_2O}(z,\lambda_{H_2O})}{d\Omega}} \qquad (2)$$

where, r_{N_2} is the mixing ratio of nitrogen, M_x is the molar weight for the given molecules (water vapour or nitrogen) , C_x is the instrumental efficiency (including optical transmission and quantum efficiency of detectors), $T(z,\lambda_x)$ is the atmospheric transmission from ground to distance z at wavelength λ_x, and $\frac{d\sigma_x(z,\lambda_x)}{d\Omega}$ is the given Raman scattering cross section. Only the ratio of these parameters appear need be known. The differential instrumental efficiency is determined from laboratory calibration to within 10%. It may change by a few percent due to mounting/dismounting of optical elements, aging, and thermal effects. The differential atmospheric transmission is computed from standard radiometric models with an accuracy of 2-5 % depending on the aerosol content [6]. The differential Raman scattering cross section is known within 10% from spectroscopic data [7].

Classical Raman lidar calibration methods use radiosondes (RS) or integrated measurements (GPS or microwave radiometers) with an accuracy of 3-5 % [8, 9, 10]. During DEMEVAP, measurements from radiosondes, GPS, and two capacitive humidity sensors (PTU) located on 10-m masts at 90 and 180m from the lidar (evelation angles of 9° and 4°) were collected from which different calibration methods are tested.

Calibration consisted in a least-squares fit of a calibration factor to the lidar constant by minimizing the RMS difference between lidar measurements (WVMR or IWV) and corresponding measurements from RS, PTU or GPS. One calibration factor is determined for each 5 min pointing to the PTU masts or 20 min zenith pointing average during radiosonde ascent. In the case of radiosondes, different layers at different altitudes were tested for the fit.

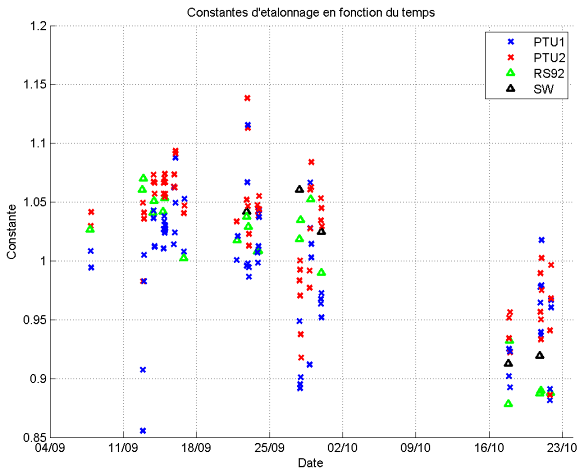

Figure 3. Lidar calibration factor determined from capacitive humidity measurements (PTU1 and PTU2) and radiosonde measurements (RS92 and SW).

Figure 3 compares the lidar calibration factor determined from capacitive humidity measurements (PTU1 and PTU2) and radiosonde measurements (RS92 and SW). The agreement between systems is fair and a consistent offset towards lower values between September and October is observed by all.

Table 1 quantifies the result from these calibration tests where September and October are considered separately. The stability of the calibration factor is around 2% when adjusted onto radiosonde data at short distance (317-1317 m) or over a large layer (200-7000m). At larger distance (1317-2317m), the scatter is around 4% because the lidar WVMR estimates are less precise (the RMSE is larger). The results from PTU are less stable than from radiosondes (3-5%) because they use point measurements (the lidar estimates are taken over a short portion of the profile) and the resulting RMSE is larger. The mean calibration factors from the radiosondes are consistent within 2% between layers, compared to 5% between PTU sensors. Comparing the mean calibration factors between systems yields consistent estimates in September but not in October where the PTU estimates are larger by 6-9%.

	< Clidar >	Std(Clidar)	RMSE (g/kg)
September (17 soundings, 52 PTU measurements)			
317-1317m	1.031	0.022	0.34
1317-2317m	1.013	0.054	0.41
200-7000m	1.027	0.020	0.36
PTU1	1.000	0.052	0.44
PTU2	1.048	0.040	0.46
October (5 soundings, 15 PTU measurements)			
317-1317m	0.895	0.021	0.28
1317-2317m	0.867	0.037	0.29
200-7000m	0.893	0.017	0.27
PTU1	0.940	0.040	0.45
PTU2	0.958	0.031	0.30

Table 2. Comparison of calibration factors from radiosondes (RS92) and capacitive humidity measurements (PTU1 and PTU2).

The difference between lidar calibration factors determined from radiosondes and PTU (mainly in October) is not explained yet. The offset between September and October is actually coincident with a drop in atmospheric temperature of 10°C. A consistent change in the lidar calibration factor is expected due to the temperature dependence of narrowband water vapor and nitrogen Raman measurements, although it is expected to be at the level of 2% rather than 10-15% [8].

4. PERSPECTIVES

A careful investigation is required to understand the reason of the changes in the lidar calibration factor (mainly the offset between September and October). Other calibration methods will also be tested such as GPS IWV calibration [8] and a hybrid method consisting in determining the lidar calibration factor from the GPS data processing procedure [10]. This method provides an original means for calibrating simultaneously total column water vapour from GPS measurements and Raman lidar profiles. Dew-point measurements from ground-based sensors and Snow-White radiosonde will also allow assessing the absolute accuracy of the different methods. In return, calibrated lidar measurements will help assessing the accuracy of operational radiosondes.

5. REFERENCES

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