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ILRC 27

WATER VAPOR PROFILES UP TO THE UT/LS FROM RAMAN LIDAR AT REUNION ISLAND (21°S, 55°E) : TECHNICAL DESCRIPTION, DATA PROCESSING AND COMPARISON WITH SONDES

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ABSTRACT

The Maïdo high-altitude observatory located in Reunion Island (21°S, 55°E) is equipped with an innovative lidar designed to monitor the water vapor in the whole troposphere up to the lower stratosphere with a Raman system and to monitor, simultaneously, the temperature in the stratosphere and in the mesosphere based on a Rayleigh scattering technique. Several improvements have been performed on the new instrument to optimize the water vapor mixing ratio measurements thanks to the experience of the previous system. The choice of the operational configuration of the system and the calibration methodology were realized during the campaign MALICCA-1 (MAïdo LIdar Calibration CAmpaign) which provided simultaneous measurements of water vapor and ozone in April 2013. The lidar water vapor profiles are calibrated with water vapor columns obtained from a collocated GNSS receiver. By comparing CFH and Vaisala radiosondes and satellites water vapor mixing ratio profiles with the Raman lidar profiles, the performances of the lidar are shown to be good in the troposphere. With a suitable integration time period, the ability of measuring quantities of a few ppmv in the lower stratosphere is demonstrated. This Raman lidar will provide regular measurements to international networks with high vertical resolution profiles of water vapor in order to document various studies and to insure a long-term survey of the troposphere and of the lower stratosphere.

1. INTRODUCTION

A Raman water vapor lidar has been designed, upgrading a former system running in Reunion Island, in order to measure the water vapor up to the (sub)tropical UT/LS (Upper Troposphere / Lower Stratosphere). This system is located at the Maïdo observatory (2160 m asl) and is operating since October 2012 [1]. The main goal of the MALICCA campaign in April 2013 (Maïdo facility) was to test the potential configurations and to determine the best one for routine measurements. Choices have also been consequently made for the routine data processing code. The present paper will introduce the configuration of the system and of the retrieval code, the first pieces of information on the vertical resolution and the evaluation of the performances, and finally a brief overview of the scientific studies initiated around the first two years data supplied by this lidar.

2. THE MAIDO RAMAN WATER VAPOR LIDAR

Similarly to the ozone DIAL system, the Raman water vapor system operated at Saint-Denis (Reunion Island) before being transferred to the Maïdo observatory [2], enhancing very significantly the reception and emission parts. The new Raman lidar has been designed to monitor water vapor until the lower stratosphere and, simultaneously, the temperature in the stratosphere and in the mesosphere. The system is conceived to work at two wavelengths, 532 and 355 nm, generated by two Quanta Ray Nd:Yag

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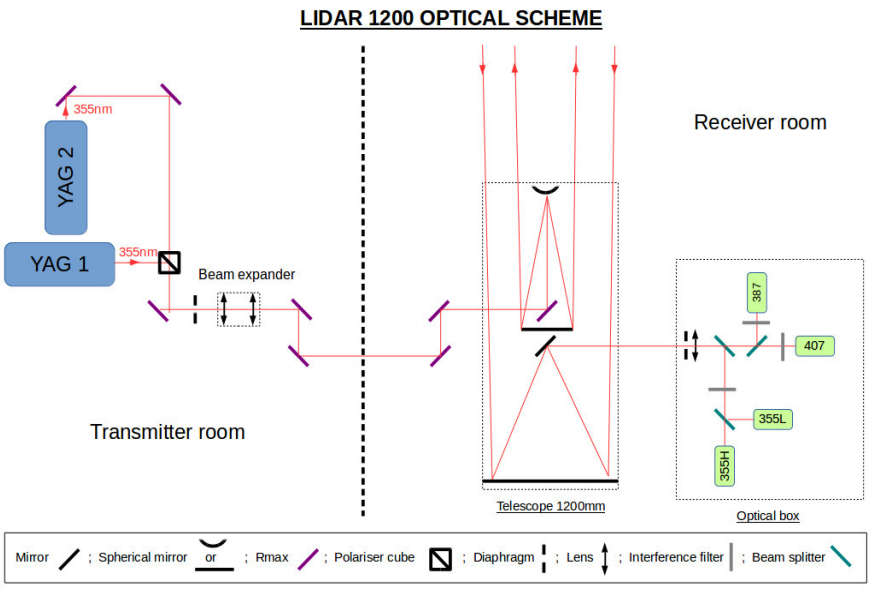

Figure 1. Optical scheme of the Maïdo Raman lidar on a routine basis

lasers, in order to double the power, with a repetition rate of 30 Hz. The emitting pulse of each laser, 532 and 355 nm (that can be synchronized and coupled through polarization cubes), has an energy of, respectively, about 800 and 375 mJ.pulse^{-1}, and a duration pulse of 9 ns. A coaxial geometry for emission and reception has been designed to avoid parallax effects, to extend measurements down to the ground and to facilitate the alignment. The backscattered signal (collected by a 1.2 m diameter telescope) is transferred to the optical ensemble by a set of lenses and mirrors instead of fiber-optic cables. Indeed, the fluorescence in fiber-optic cables has been shown to cause systematic biases. This is an important issue when collecting small Raman scattering by water vapor compared with the large elastic scattering able to generate fluorescence. The light coming from the primary mirror is reflected by a secondary flat mirror, tilted at 45°, directing the light in the optical box unit used to separate the backscattered Raman and Rayleigh signals (figure 1). The field of view (FOV) of the system can be adjusted from 3.0 to 0.5 mrad thanks to a diaphragm field stop at the entrance of this box. The spectral separation of the light is realized by dichroic beam splitters and interference filters (band pass or high pass). Regarding the photon detection and data acquisition, Hamamatsu miniature photomultiplier tubes (PMT) and Licel transient recorders are used.

In April 2013, the different configurations of the system have been tested and the configuration chosen for operational use is : two lasers, the 355 nm wavelength and a 2 mm (0.5 mrad) FOV (figure 1). Such FOV induces a geometrical obturation that is similar for both channels and allows to reduce PMT saturation and to retrieve water vapor mixing ratio down to the ground. Details on the different tests and the final choice of the optical configuration are given in [3].

3. WATER VAPOR PROFILES RETRIEVAL

Uncalibrated profiles are retrieved with a vertical resolution whose values increase with the altitude to compensate the decrease of the signal to noise ratio, with a time selection depending on the water vapor variability at several levels and with the calibration coefficient (calculated afterward from ancillary data column of water vapor).

The vertical resolution of the initial data is 15 m. For retrieving the profiles on a routine basis, data are smoothed with a Blackman filter whose number of points changes with the altitude. The vertical resolution of the profiles with this filter has been calculated by using the cutoff frequency of the transfer function of the filter. The vertical resolution in the lowest layers, in the mid-troposphere, in the upper troposphere and in the lower stratosphere is around 200-400 m, 1, 1.2-1.3 and 1.5 km, respectively.

Profiles are calibrated using integrated water vapor (IWV) columns obtained from GNSS measurements. The recovering altitude of the lidar is very low, and thus, the use of collocated GNSS total columns for the calibration of its profile is appropriate. The receiver is able to collect raw data from GPS and GLONASS satellites constellations. One of the basic GPS atmospheric products is the tropospheric delay which is a

measurement of the GPS signal delay that has traveled between a GPS satellite and a ground-based receiver with respect to propagation in a vacuum. The GPS network used in our typical differential simulation includes twenty one other local stations mainly located around the Reunion volcano massif and about fifteen overseas stations to ensure efficiently high numbers of baselines.

The total absolute error (ΔWVMR) on the calibrated profiles (WVMR) is calculated by :

$$\frac{\Delta \mathrm{WVMR}}{\mathrm{WVMR}} = \sqrt{\underset{(a)}{\left(\frac{\mathrm{d}w}{w}\right)^2} + \underset{(b)}{\left(\frac{\mathrm{d}C}{C}\right)^2} + \underset{(c)}{\left(\frac{\mathrm{d}\Gamma_\Delta}{\Gamma_\Delta}\right)^2}},$$

where (*a*) is the relative error associated to the statistical error of the detectors (PMT), (*b*) is the error linked to the calibration coefficient and (*c*) linked to the extinction coefficient term.

$$\frac{\mathrm{d}w}{w} = \frac{\sqrt{S_N^2 \times \left(N_H + \sigma_{BH}^2\right) + S_H^2 \times \left(N_N + \sigma_{BN}^2\right)}}{S_N S_H}$$

where dw is the lidar statistical error and w the uncalibrated water vapor mixing ratio, N=S-B with S the number of photons counted by the PMT per shot, B the associated background and σ_B the error on B. *N* and *H* subscripts stand for N_2 and H_2O Raman wavelengths.

4. DATA VALIDATION PROCEDURE

The calibration coefficient is supposed to be almost constant if no instrumental change occurs. In order to determine this coefficient, ratios between integrated lidar measurements and GNSS IWV on same temporal extents are checked on the whole dataset. Periods with a constant ratio have been identified on the 2013 and 2014 databases. The average ratio of each period can be considered as the calibration coefficient of the associated profiles. For the operational data processing, the former validated coefficient will be applied to the profile but it will be necessary to identify instrumental changes on a few month overview in order to check possible alteration of the calibration coefficient and thus to recalculate it if necessary. In addition to the known changes, systematic lamp measurements are made at the beginning of each night of measurements in order to survey and quickly identify potential sudden instrumental changes. Once the coefficients are validated, data can be calibrated and used for geophysical purposes.

5. PERFORMANCE EVALUATION

The MALICCA-1 campaign data set shows a good agreement between water vapor lidar measurements and other almost simultaneous and collocated measurements (Vaisala RS92, MLS satellite) [3]. The relative difference between lidar profiles and fifteen radiosoundings was lower than 10% for the low and mid-troposphere and between 10 and 20% for the upper troposphere. Two integration methods has been tested : 240 minutes for an absolute error of approximately 2 ppmv from 17 to 20 km, and 1 ppmv at 20 km for a monthly integration, which demonstrates the ability of the lidar to measure quantities of only few ppm in the UT/LS [3]. The monthly water vapor average profile measured by MLS matches well in the lower stratosphere with the lidar average profile of MALICCA-1 [3].

In November 2014, a first CFH sonde was launched during a 120 minutes water vapor lidar operation. The lidar signal was workable up to

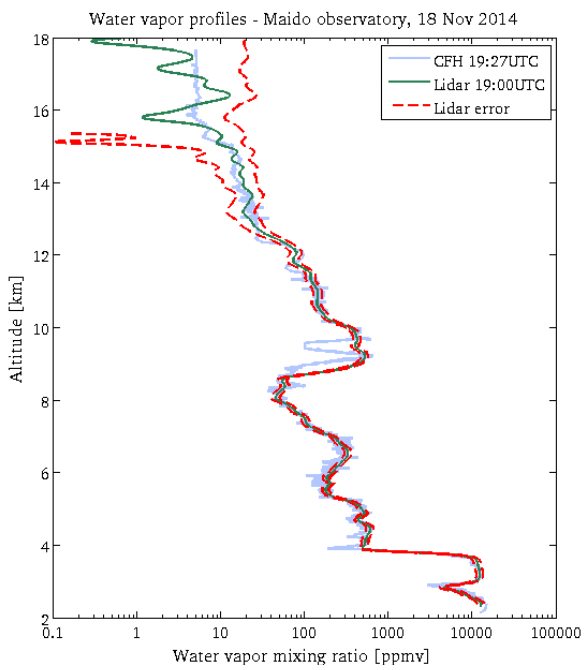

Figure 2. Water vapor mixing ratio profiles on 18 November 2014, in blue : CFH measurement (19:27UTC), and in green : lidar measurement (19:00UTC). Red dotted lines represent the lidar total absolute error on the profile.

approximately 15 km. The CFH profile reached 18 km. The comparison between both profiles shows a good agreement up to the upper troposphere (tropopause at 17 km) considering the lidar total error (figure 2). A non negligible difference occurs in the 10 km wet layer sampled by the sonde and has to be investigated. The instrumental conditions on November 18th allowed the lidar to work with only one laser. This result opens good perspectives for future lidar-CFH comparisons, especially those of the MORGANE (Maïdo ObseRvatory Gas and Aerosols Ndacc Experiment) campaign in May 2015.

6. CAMPAIGN AND ROUTINE MODES

Some intensive measurement campaigns provided a detailed data set of water vapor profiles on short periods in April 2013, November 2013 and November 2014. These campaigns allowed scientific studies on various topics : stratosphere-troposphere exchanges, moistening of the lower stratosphere, cirrus clouds… [4]. Besides, measurements are performed once or twice a week. 58 night measurements were made in 2013, 81 in 2014. With the specific subtropical location of the Maïdo observatory, this instrument will participate to a long-term survey of climate changes.

7. CONCLUSIONS AND PERSPECTIVES

The optimal routine system configuration and data processing code have been determined for the Raman water vapor lidar of the Maïdo facility. The first evaluation of the performances of this lidar shows a good accuracy in the troposphere. Its ability of measuring quantity of few ppm in the lower stratosphere has also been demonstrated, but requires adapted integration time periods. The MORGANE campaign will supply suitable data sets (lidars and lidar-CFH sondes comparisons) to go further in this investigation and to make the Raman lidar granted for the NDACC network label. Future data sets of this lidar will represent opportunities to validate some satellites water vapor measurements [4]. The Maïdo observatory offers a large panel of data thanks to the diversity of its remote sensing instruments. The profiles of collocated and simultaneous lidar measurements of water vapor and ozone will offer opportunities to further investigate tropical UT/LS transport and chemical processes.

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