

VALIDATION OF ENVISAT MEASUREMENTS BY GROUND BASED, NIGHTTIME LIDAR SOUNDINGS

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ABSTRACT

A Rayleigh/Mie/Raman lidar system located in the Rome Tor Vergata site participates in the Atmospheric Chemistry Validation Team of ENVISAT for the validation of the MIPAS GOMOS and SCIAMACHY measurements [1]. During the commissioning phase, first set of inter-comparisons has been performed with the measurements available at the present status of the lidar system setup. The lidar system and the data features are briefly reviewed and the lidar error budget is described. Preliminary inter-comparisons between the lidar and ENVISAT temperature and water vapor profiles during commissioning phase are presented.

1. SYSTEM OVERVIEW

The lidar utilizes two laser beams from a Nd:YAG pulsed laser (second and third harmonics: 532 nm, VIS, and 355 nm, UV, respectively) that are vertically sent into the atmosphere. The VIS radiation is used to detect the elastic backscattering signal from air molecules and aerosol. The UV is used to generate Raman backscattering signals from nitrogen and water vapor separately.

Three orders of collectors of different size are utilized to collect the backscattered radiation from the atmosphere. This scheme is necessary to record signals from three separate altitude ranges and to get useful measurements from the boundary layer to the mesosphere, overcoming the problem of the high dynamical range of the signal (about 13 orders of magnitude in the interesting range).

At present the largest collector is working with two 50 cm-diameter telescopes that are used to collect UV returns from the upper atmospheric layers; while for the VIS radiation, a single similar telescope is used. Simultaneously, a medium telescope (30 cm diameter) is employed to collect the VIS and UV returns from the lower atmospheric layers and a smaller telescope (15 cm diameter) is utilized to collect the VIS from the PBL. In the definitive configuration, which should be working by the next month, an array of nine 50 cm-diameter telescopes will be employed as largest collector for both UV and VIS echoes.

The separation of the various interesting wavelength is made in two steps: a dichroic mirror, near the focus of each telescope, divides the VIS from the UV radiation, in the whole. Thereafter all signals from the telescopes are brought to different channels of photodetection through optical fibers. Then, in each UV channel, a second dichroic system separates the N₂ Raman signal (386.7 nm) and the water vapor Raman signal (407.5 nm), and transmits them toward different photomultipliers. The UV elastic backscattering is also separated in a different channel, but still not detected.

Narrow band (2–4 nm) interference filters are used to limit the contribution due to the sky background. Photomultipliers are used for the signal detection. The signal from the photomultipliers is acquired, both by A-D conversion and by photon-counting techniques, by means of a multiple-input transient recorder. This records the signal variation as a function of time delay from the laser pulse and performs a time integration of the various profiles acquired, before transferring the resulting ones to a PC where they are stored. The system is assembled in two standard containers that can be transported by truck. Detailed description of the system can be found in [2, 3]

2. OBSERVABLE QUANTITIES

The profile of the water vapor mixing ratio is obtained by the ratio between the Raman signals of H₂O and N₂, in a range from 75 m altitude to the upper troposphere [4]. The Raman water vapor profiles have been validated during field campaigns since 1999 and are the most reliable products [3].

The temperature profile is obtained by means of the Rayleigh technique in the upper stratosphere and mesosphere. Tests are in progress to assess whether the N₂ Raman signal can be inverted, with a similar procedure, to extend the temperature profile down to the layers where aerosols are present. The Rayleigh inversion algorithm of the upper stratosphere-lower mesosphere temperature is in phase of validation in the frame of the NDSC network [www.ndsc.org].

At the moment, only a qualitative sketch of the aerosol profile is obtained by calculating the range-corrected Rayleigh-Mie signal at 532 nm. However, this allows a detailed depiction of thin clouds (e.g. cirrus), or the location of the base of heavy clouds.

3. ERROR ANALYSIS

3.1 Water Vapor Profiles

The water vapor mixing ratio W_H is defined as the mass of the water vapor divided by the mass of dry air in a given volume. In the Raman lidar technique, the measurement of W_H is obtained by the ratio of the H₂O Raman signal ($\lambda_H = 407.5$ nm) to the N₂ Raman signal ($\lambda_N = 386.7$ nm)[4].

$$W_h(z) = C \frac{S_H(z)}{S_N(z)} \quad (1)$$

Where z is the altitude, $S(z)$ are the lidar signals corresponding to the altitude z , the suffixes H and N stand respectively for water vapor and nitrogen, and C is the system calibration constant for the water vapor mixing ratio measurement. This constant includes all instrumental and atmospheric parameters constant with the altitude. Because of the very large uncertainties in the estimation of these parameters the C value must be calculated by using a value of W_H independently measured (e.g. by radiosonde) at a specific altitude. Actually, the procedure to estimate C consists in: i) comparing the profile of ratio between the Raman signals S_H/S_N with a close (in time and space) water vapor profile measured by radiosonde, ii) finding a sub-interval of best fit between the two profiles and iii) compute the linear regression between the two data set in that sub-interval. The found value for C can be utilized for all the lidar measurements with no changes in the instrumental conditions.

The standard deviation of W_H , computed by means of the error propagation formula, is:

$$\frac{\Delta W_H}{W_H} = \sqrt{\frac{\Delta C^2}{C^2} + \frac{\Delta S_H^2}{S_H^2} + \frac{\Delta S_N^2}{S_N^2}} \quad (2)$$

Where the uncertainty ΔC is given by the regression procedure for the calculation of C and both the uncertainties ΔS are the statistical errors affecting the counting data. For one-hour integration time, the relative uncertainty on the water vapor mixing ratio are 6-7% at 8000 m height, 20% at 10000 m, and more than 60% at 12 km with vertical resolution of 75 m. These values can be improved by decreasing the vertical resolution and/or increasing the averaging time.

3.2 Temperature Profiles

The Rayleigh methodology to retrieve the temperature profile is based on the assumption of hydrostatic equilibrium. Under this condition, the perfect gas law can be reduced in a reversible, one-to-one relationship between air density and

temperature [5]. Owing to the direct proportionality between the range-corrected lidar signal and the air density, the temperature profile is finally obtained by the following equation:

$$T(z_i) = \frac{1}{s(z_i)} \left[T(z_n) s(z_n) + \frac{M}{R_g} \int_{z_i}^{z_n} s(z) g(z) dz \right] \quad (1)$$

Where $T(z)$ is the air temperature at the height z ; z_i is the altitude corresponding to i^{th} data point in the lidar record; z_n is the uppermost utilizable altitude of the lidar sounding; s is the range-corrected lidar signal (i.e. $s(z_i) = z_i^2 S(z_i)$, with $S(z_i)$ the lidar signal corresponding to the altitude z_i); M is the mean molecular weight of the air; R_g is the constant of the perfect gas and $g(z)$ is the gravity acceleration at the altitude z . The application of the error propagation to the last equation (the integral being numerically computed by using the trapezoidal rule) leads to the following equation (see also [6]):

$$\Delta T(z_i) = \frac{1}{s(z_i)} \left\{ s^2(z_n) \Delta^2 T(z_n) + \left[T(z_n) + \frac{Mg(z_n)\delta z}{2R_g} \right]^2 \Delta s^2(z_n) + \left[T(z_i) - \frac{Mg(z_i)\delta z}{2R_g} \right]^2 \Delta s^2(z_i) + \left[\frac{M\delta z}{R_g} \right]^2 \sum_{j=i+1}^{n-1} g^2(z_j) \Delta s^2(z_j) \right\}^{1/2} \quad (2)$$

Where the symbol Δ refers to the absolute uncertainty on the quantity which it refers to, and δz is the height integration interval used in the trapezoidal rule. Owing to the lidar data are acquired by the photon-counting technique, the statistical uncertainty in the range corrected signal is $\Delta s(z_i) = z_i^2 \sqrt{S(z_i)}$.

The estimate of the Rayleigh temperature error is 1 K at 40 km and 3 K at 50 for 2 hours of integration and 3 km of vertical resolution. The technical improvements of the system will allow both drastically decreasing the statistical uncertainty and improving the accuracy.

4. INTERCOMPARISONS

Since lidar water vapor measurements can be performed with satisfactory accuracy in the troposphere, the validation of the lowermost part of the MIPAS vertical profile is addressed. The MIPAS retrieval in the upper troposphere is sensitive to the presence of the clouds and aerosols. So it is of the uppermost importance to validate the capability of MIPAS to provide data in the whole UTLS region. Due to the lack of accuracy of the radio soundings in the upper troposphere, lidar systems could be the key measurement to fulfil such task.

Lidar temperature allows the validation of vertical profiles from GOMOS and MIPAS. In particular, the vertical resolution and accuracy of the lidar sounding in the middle stratosphere led possible an accurate validation of the GOMOS high resolution temperature profile (HRTP or Turbulence product). In order to identify the coincidences, the time difference between the median time of lidar data and the MIPAS/GOMOS measurement should be less than 12 hours for the temperature and 6 hours for the water vapor. The distance between lidar site and the satellite tangent point at the most representative altitude should be less than 600 km.

Table 1 reports the overview of the data acquired by the RMR lidar during the ENVISAT validation phase. The sparse lidar database and the partial availability of ENVISAT data led available few inter-comparisons of water vapor and temperature. Moreover since MIPAS H₂O profiles are not yet provided for the lowermost part of the profile, due to the above difficulties, at the moment it is not possible to perform a direct comparison of water vapor profiles.

Year	Month	Day	Start	End	H ₂ O Data	T Data
2002	05	20	21h06	01h27	X	X
2002	05	29	00h04	01h09	X	
2002	05	30	21h10	01h32	X	X
2002	08	01	02h40	04h05	X	
2002	08	07	23h18	01h25	X	X
2002	09	05	20h58	23h06	X	
2002	09	11	22h09	00h16	X	
2002	11	10	20h50	22h55	X	
2002	12	01	21h23	1h36	X	

Table 1: Date of the measurement, water vapor and temperature profile availability for the Rome lidar measurements carried out during the ENVISAT commissioning phase. Times are given in UT. The available data are uploaded in the validation database

4.1 Water Vapor

As example it is shown on Figure 1 the coincident MIPAS and lidar H₂O vertical profiles, on 2002 December 1st at 21h28 UT. The distance between measurements is 220 km and the time difference between the MIPAS scan and the median time of the lidar profile is 2h21. Lidar data were averaged for two hours (see Table 1)

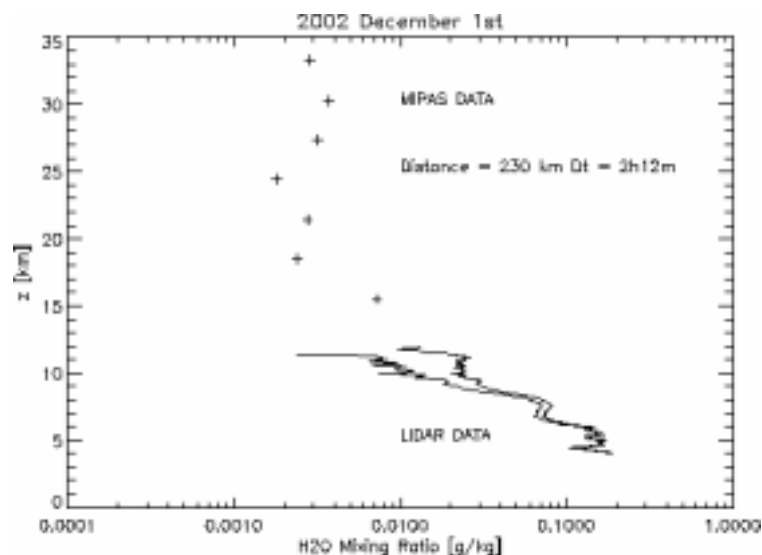


Fig. 1. Comparison between lidar and MIPAS water vapor profiles on December 1, 2002. Two curves indicates the lidar water vapor statistical error

4.2 Temperature

Preliminary results of the inter-comparison are presented in Figure 2. GOMOS temperature and HRTP profiles for May 30th 2002, 20h03 (left panel) are compared with the lidar measurement for the same night. The geographical distance between the lidar site and the GOMOS tangent point at 50 km height is 280 km and the time difference is 3 hours 20 min. The analysis show a bias of 3 to 4 K between the lidar data and the GOMOS low resolution temperature data, and of 4.5 K between Lidar data and GOMOS HRTP data, while a good agreement is found between lidar data and MSIS 90 atmospheric model in the whole stratosphere.

Bias is found for the August 8th 2002 measurement (Figure 2, right panel). Lidar site and GOMOS tangent point are 250 km far and the time difference is 8 hours. HRTP is not available for this date since GOMOS occultation was made in bright limb conditions

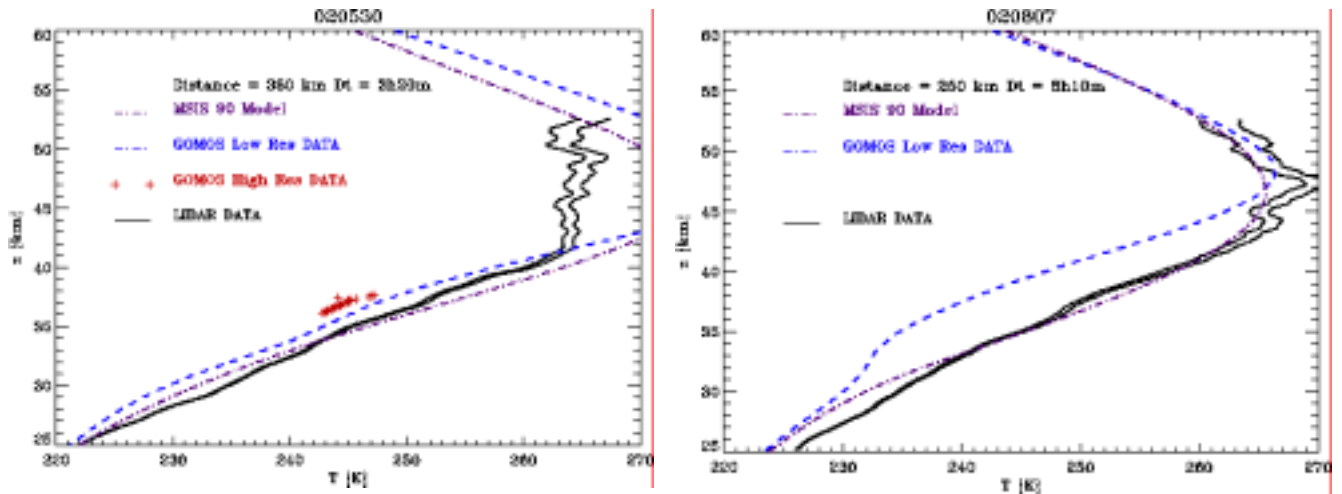


Fig. 2. Temperature vertical profile of Lidar, GOMOS data, and MSIS 90 atmospheric model for May 30, 2002 (left panel) and August 07, 2002 (Right panel). Two curves indicates the statistical error of the lidar temperature measurement

5. CONCLUSIONS

The technical upgrade work of the lidar system and the rainy weather reduced the effective measurement time, allowing the Rome lidar to provide 9 profiles in coincidence with GOMOS or MIPAS measurements. Moreover the limited and partial availability of GOMOS and MIPAS reduced at this moment the possibility of inter-comparison to three coincidences.

Preliminary results of Temperature comparison indicate a systematic bias between GOMOS and lidar data. Nevertheless the database is sparse to provide statistical significance and the lidar temperature estimate is still under improvement. Water vapor lidar data could provide an important dataset for validation once the MIPAS data will be reprocessed in the upper troposphere.

Moreover, if a larger database of coincidences will be available, it is expected to apply quantitative statistical analysis as covariance matrix to compare lidar and satellite data [7].

6. REFERENCES

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