File Revision Date
September 2nd, 2022

Data Set Description
PI: Dr. Sophie Godin-Beekmann
Instrument: Stratospheric ozone DIAL lidar
Site(s): Observatoire de Haute-Provence
Measurement Quantities: Stratospheric ozone vertical profile

DOI : https://doi.org/10.25326/292

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Instrument Description
Ozone measurements are performed using the DIAL (Differential Absorption Lidar) technique, which requires the simultaneous emission of two laser beams characterized by a different ozone absorption cross-section. The absorbed laser radiation is emitted by an IPEX-746 LightMachinery XeCl excimer laser at 308 nm and the reference line is provided by the third harmonic of a Continuum Nd:Yag laser at 355 nm. The XeCl operates at 100 HZ, while the Nd:Yag laser operates at 50 HZ. Output energies are 200 mJ at 308 nm and 60 mJ at 355 nm. Beam expanders are used to reduce the divergence of the excimer laser to 0.2 mrad and of the Nd:Yag laser to 0.1 mrad.

The optical receiving system consists of four similar F/3 mirrors of 53 cm diameter, which correspond to an equivalent receiving surface of 1m diameter. Both laser beams are emitted in the center of the collecting area so that each mirror acts as the receiver of an elementary lidar but the whole system is quasi-coaxial. The light is collected by four optical fibers of 1 mm diameter mounted in the focal plane of each mirror. The fiber mounts can be moved manually in the vertical direction for focalization adjustment. They are motorized in the X-Y directions to position the fibers exactly on the image of the scattered light.

After detection, the optical fibers transmit the backscattered light to the optical analyzing device which includes imaging optics, a mechanical chopper and a multichannel monochromator designed for the wavelength separation. The chopper consists of a 40 Watts cooled motor that drives a blade of 140 mm diameter and 20 mm width, rotating at 24000 rpm in primary vacuum. The 1 mm fibers are assembled together on a line in a specially designed mount which enables a sharp desobturation of the laser signal in 5.7 µs. The monochromator uses a 3600 grooves/mm holographic grating characterized by a dispersion of 0.3 nm/mm and a bandwith of 1.5 nm. The global transmission for each wavelength is about 0.45. The detected wavelengths are 308 nm, 355 nm and the corresponding 1st Stokes wavelengths in the Nitrogen vibrational Raman spectrum (332nm and 387 nm). The backscattered signals related to these wavelengths are used to reduce the volcanic aerosol inference on the measured ozone number density. At the output of the monochromator, the elastically backscattered signal at 308 nm and 355 nm are separated into a low and a high-altitude channel in order to account for the dynamic of the lidar signals in the measurement altitude range, so that in total the lidar set up includes 6 optical channels.

Optical signal detection is made by Hamamatsu photomultiplier tubes running on a counting mode. Counting gating is 1 microsecond providing a 150m vertical resolution. The signals are recorded on a 1024 µs time range that corresponds to roughly 150 km. In addition to the use of mechanical chopper, electronic gating is used on the high-energy Rayleigh channels, in order to suppress signal induced noise resulting from the initial burst of light at lower altitudes. The whole experiment is run by a PC. Lidar signals are stored in 10000 shots files providing a temporal resolution of 200 seconds. For each file, the raw signals are displayed during the experiment and a signal pre-processing is made every 30000 shots in order to display the slopes of the signals and the corresponding ozone profile (Godin-Beekmann et al., 2003).

Algorithm Description

The lidar signals are time averaged over the whole measurement period (3 to 4 hours in general) in order to increase the signal-to-noise ratio. Averaged signals are then corrected from the background light which is estimated using a linear regression in the altitude range where the lidar signal is negligible (80 - 150 km). Another correction is applied on the lidar signals in order to account for the dead time effect in the photon counters mode.

The ozone number density is retrieved from the derivation of the logarithm of the corrected lidar signals.

It is necessary in the DIAL technique to use a low-pass filter in order to account for the rapid decrease of the signal-to-noise ratio in the high-altitude range. In our case, the logarithm of each signal is fitted to a 2nd order polynomial and the ozone number density is computed from the difference of the derivative of the fitted polynomial. The smoothing is achieved by varying the number of points on which the signals are fitted.

The ozone number density is derived from the three lidar signal pairs detected by the experimental system: Rayleigh high energy, Rayleigh low energy and Raman, which optimize the precision of the retrieved ozone profile in the high stratosphere, the middle-low stratosphere and the lower stratosphere respectively. The Raman wavelengths provide an ozone profile much less perturbed by the presence of volcanic aerosols than the Rayleigh ones but due to the smaller Raman scattering efficiency, the Raman signals are less energetic and the vertical resolution of the Raman ozone profile has to be reduced as compared to the Rayleigh one. In condition of low stratospheric background aerosol, it is thus preferable to use the low energy Rayleigh signals. In order to check the linearity of these signals in the lower stratosphere and correct the photon counting dead time effect, the following procedure is applied: the Raman signals and the corresponding Raman ozone profile are used to compute a ‘reference Rayleigh’ slope at each wavelength. The parameter used for the dead time correction of the Rayleigh signals is then adjusted to obtain the best fit with the ‘reference Rayleigh’ slope. The same procedure is applied to check the linearity of the high energy Rayleigh channels but this time against the low energy Rayleigh slopes. The dead time correction is adjusted in order to obtain the best agreement between the low energy and the high energy Rayleigh slopes. The ozone profile is retrieved first by combining for each wavelength the slopes of the low energy and high energy Rayleigh signals and then by combining the Raman and the composite Rayleigh ozone profiles. The altitude range where the Raman and the Rayleigh profiles are combined depends on the aerosol content in the low stratosphere. Finally, the ozone number density is corrected from the Rayleigh extinction using composite pressure-temperature profiles computed from nearby radiosoundings performed in Nimes, and operational NCEP data (Godin-Beekmann et al., 2003). These pressure-temperature profiles are provided in the data file and can be used for ozone/altitude unit conversion.

In addition to making measurements of ozone, the offline of a DIAL system (355 nm) can be used to calculate aerosol extinction coefficient at 355nm (Khaykin et al., 2017) and Rayleigh temperature (Wing et al., 2020). The LAVANDE campaign represented the first attempt to validate LiO_3S temperature profiles within the framework of NDACC.

Expected Precision/Accuracy of Instrument

The accuracy of the ozone lidar measurement depends on the correction of the differential molecular and aerosol scattering, the differential absorption by other constituents and on the temperature dependence of the ozone absorption cross-sections (Godin et al., 1989). The maximum residual random error after correction is estimated to 3 % in the case of background aerosols. Additional error is due to the smoothing of lidar signals especially in the upper stratosphere (Godin et al., 1999). The precision of the measurement corresponds to the statistical error of the signal due to the random character of the detection process which follows basically the Poisson statistics. Among other parameters such as the power of the lasers and the telescope detection area, it depends on the duration of the measurements and the vertical resolution chosen to process the data. The total accuracy varies from about 3 % to 20 % in the 15-50 km altitude range, for a corresponding vertical resolution ranging from 0.4 to 6 km and a typical temporal resolution of 4 hours.

Instrument History

1985 – 1993

Systematic stratospheric DIAL ozone measurements began at OHP in 1986. Campaign ozone profiles from July and December 1985 are also available in the NDACC database. The main features of the lidar set-up were 2 laser sources (a XeCl excimer laser and a Nd:Yag laser) providing the absorbed (308 nm) and the reference (355 nm) wavelengths respectively, a 80 cm diameter cassegrain telescope, detecting optics including photomultiplier tubes to record the laser light and 2 counting channels linked to a PC microcomputer for the acquisition (Godin et al., 1989). At the output of the telescope, a 308 nm Rmax mirror was used to separate the laser radiations which were further selected by interferential filters. Due to the large dynamic of the lidar signals, 2 measurements had to be made sequentially in order to cover the 18-45 km altitude range. A first measurement with the full laser energy and the second one using a glass window at the output of the telescope in order to attenuate the lidar signal at both wavelengths.

1994 - Present

The change of the lidar experimental system to the present configuration was made in December 1993.
A first intercomparison with the GSFC mobile lidar was made in July 1992, one year after the eruption of Mount Pinatubo. At that time the OHP lidar did not detect the Raman wavelength so the ozone profile were obtained from 25 km only. A second intercomparison campaign was organized in 1997. Results show in general a very good agreement between the OHP and GSFC lidars except for a small positive bias of 3 - 5 % around the altitude of the ozone maximum, of the OHP lidar as compared to the GSFC one (Braathen et al., 2004). A third NDACC intercomparison took place in July 2017 and March 2018 (Wing et al., 2020).

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