Temperature lidar retrieval using a Rayleigh lidar in Río Gallegos, Argentina

Cálculo de la temperatura lidar usando un lidar Rayleigh en Río Gallegos, Argentina

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ABSTRACT:

The determination of temperature measurements from the Rayleigh scattering is an important remote sensing technique for obtaining stratospheric profiles, particularly in the height stratosphere between 30 and 60 km high. This technique is applied to signals acquired by a lidar (Light Detection and Ranging) called DIAL (Differential Absorption Lidar) for determination of stratospheric ozone profiles installed since 2005 in the Patagonian city of Río Gallegos, Santa Cruz, Argentina. Currently the site is part of the UVO3Patagonia in conjunction with the laboratory of Ozone and UV Radiation in the city of Punta Arenas, Chile distant 200 km (for more information, see www.uvo3patagonia.com). In this paper we showed the technique to measure temperature profiles in the stratosphere between 15-60 km altitude, including the presence of aerosols region located between 15-30 km altitude. The inversion temperature from photoncounting is detected from light scattered by the Rayleigh line at 355 nm generated from a laser Quantel YG-980. The results presented in this paper are validated through intercomparisons with NCEP data.

Keywords: Stratospheric Aerosol, Aerosol Backscatter, Stratospheric Ozone.

RESUMEN:

La determinación de temperatura a partir de mediciones de la retrodispersión Rayleigh es una técnica importante de teledetección para la obtención de perfiles en la estratosfera, sobre todo en alturas entre 30 y 60 km. Esta técnica se aplica a las señales adquiridas mediante un lidar (Light Detection and Ranging) denominado DIAL (Differential Absorption Lidar) para la determinación de perfiles de ozono estratosférico, instalado desde 2005 en la ciudad patagónica de Río Gallegos, Santa Cruz, Argentina. Actualmente este lugar es parte de la red UVO3Patagonia, junto al laboratorio de Ozono y la Radiación UV en la ciudad de Punta Arenas, Chile, distante a 200 km (para más información consultar www.uvo3patagonia.com). En este trabajo mostramos la técnica para medir perfiles de temperatura en la estratosfera, entre 15 y 60 km de altitud, incluyendo la presencia de aerosoles región situada entre 15 a 30 km de altitud. La temperatura de inversión de fotocontaje se detecta a partir de la luz dispersada por la línea de Rayleigh a 355 nm generada por un láser de Quantel YG-980. Los resultados presentados en este documento se validan a través de inter-comparación con los datos del NCEP.

Palabras clave: Aerosoles Estratosféricos, Retrodispersión de Aerosoles, Ozono Estratosférico.

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1. Introduction

The lidar emerged as a powerful technique for the remote sensing of the atmosphere. The Rayleigh scattering due to air molecules has been widely used over the past 20 years to determine the temperature profile of the atmosphere between 30 and 90 km altitude. This method allows to study the dynamics of the middle atmosphere with high vertical resolution and temporal evolution. The extension of this technique to the lower atmosphere below 30 km is limited by aerosol scattering, ozone absorption, and dense atmospheric attenuation. To overcome these difficulties, the wavelength dependent non-elastic Raman scattering technique has been employed recently [1-3]. However, Raman lidar requires a high-power laser transmitter to improve the low-level signal conditions because the Raman scattering cross section is about 3 orders of magnitude smaller than that of the Rayleigh scattering. Ballon-borne instruments, rocket sounding, and satellite observations have been the main sources of information of this region. However, these datasets show many discrepancies and contain deficiencies due to poor vertical resolution and discontinuities. In this respect, the use of lidar, complements the other techniques, since the unique feature of lidar is its capability to make measurements of a number of important atmospheric parameters with excellent space and time resolution.

In this paper we show the temperature profiles between 15 and 60 km altitude derived from a simple Rayleigh lidar. The third harmonic of a Nd:YAG Quantel YG-980 laser at 355 nm was used. The signals obtained at 355 nm were corrected taking into account the presence of stratospheric aerosols, given that they are a major source of uncertainties in the temperature profile.

2. Instrument

In this section the description of different subsystems of the instrument is given. The following sections provide a detailed description of the lidar system which is still in operation at Río Gallegos – Argentina and they were part of SOLAR Campaign held during 2005-2006 south springs [4,5].

2.1. Laser transmitter

The DIAL instrument requires two emitter lasers: for the wavelength absorbed by ozone, an excimer (XeCl) laser emitting at 308 nm with a repetition rate in the range 1-100 Hz, maximum energy per pulse of 300 mJ is utilized. The reference wavelength is produced by a third harmonic of a Nd-YAG laser at 355 nm, 30 Hz repetition rate and 130 mJ maximum energy.

2.2. Optical and electronic receiving systems

The back-scattered photons are collected by four Newtonian telescopes f/2 of 50 cm diameter with parabolic aluminized surfaces of 48 cm diameter. This produces a total reception area of ~7238 cm2.

At the focus of each telescope an optical fiber of 0.94 mm effective diameter, 0.22 ± 0.02 numerical aperture, 0.27 dB/km attenuation (@308 nm), is placed. The other end of the fibers is positioned at the focus of a quartz lens placed inside a spectrometric box. A mechanical chopper is in the optic path of the signal recollected by the telescopes. It has a frequency of 150 Hz and is placed to avoid a rather strong level signal from the lower part of the atmosphere.

The wavelength separation is performed by a holographic diffraction grating of 3600 lines/mm with 40% transmittance at 300 nm. Six channels are detected simultaneously. Four of them correspond to the elastic backscattering photons at two laser wavelengths in high and low energy. Additionally the Raman scattering produced by nitrogen molecules excited with 308 nm and 355 nm are detected. In all the channels Hamamatsu photomultipliers type H6780-03 and R7400U adapted for photon counting for the signal detections are used. The signals are increased by six discriminators of 300 MHz bandwidth with amplification factor of 10 and 5 for high and low level channels respectively. The acquisition of the signals is made by a system developed at Service d'Aeronomie, Institute Pierre Simon Laplace, Paris, France, in six photo counting modules of 300 MHz bandwidth each one, which are operated with 1024 time gates of 1 µs corresponding to a sampling vertical resolution of 300 m. For each channel, two counters work in parallel to avoid dead time between two memory bins. Despite the quality of the counters, overlapping pulses of finite duration limit the linearity of the counting system. The maximum count rate that can be used without modifying the signal linearity by more than 10% is in fact limited to 40-60 count per µs.

3. Methodolgy

Lidar temperature measurements require that only molecular Rayleigh scattering contributes to the return signal and Mie scattering from aerosols is negligible. This is usually the case above 30 km, even after a volcanic eruption such as Mt. Pinatubo. When the Mie scattering is not negligible which occurs typically below 30 km, the temperature value is lower than the real one due to the effects of aerosols.

In this section the temperature retrieval algorithm is described. Fig. 1 presents a flow chart of the data processing. In this algorithm only Rayleigh-scattered light signals produced by the atmosphere from the third harmonic of Nd-YAG laser at 355 nm were used. During the lidar measurements, the output of the multi-channel counters (MCS) provides the raw data as single ASCII files, with an integration time of 1 minute. The retrieval algorithm reads two raw data sets at 355 nm (high and low sensitivity),

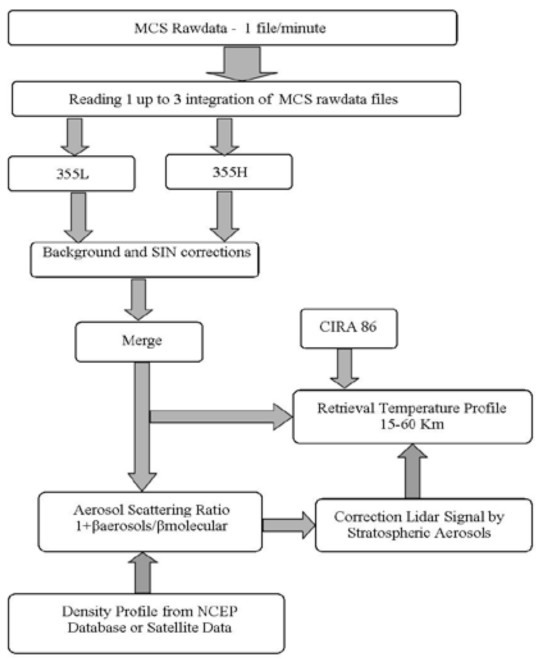

Fig. 1: Flow chart of signal processing. Different corrections are implemented to eliminate uncertainties. Temperature profile below 30 km is corrected using the ASR.

then performs a data integration variable from 1 to 3 hours. In the next step, two corrections are applied to remove systematic errors in the signals: background signals, Signal-Induced Noise (SIN). The objective of these corrections is to obtain a pure lidar backscattering signal. Then both corrected signals are merged by means of linear fitting in the 20-25 km range [6].

The aerosols scattering ratio (ASR) represents the ratio of the backscatter due to aerosols and molecules. The former is derived using the equation Klett-Fernald [7].

4. Retrieval vertical profile of temperature

In regions of the atmosphere where particulates are not present or are in low concentration, changes in the range-corrected signal of an elastic lidar are indicative of changes in the molecular density. If the temperature or molecular density is known then can be extended over a larger region using the lidar signal. The technique works best at stratospheric altitudes and for short wavelengths to maximize the return from molecular scattering and minimize the relative contribution from particular scattering.

The temperature profile is computed from density profile assuming that the atmosphere obeys the perfect gas law and it is in hydrostatic equilibrium. We derived the temperature profile using an equivalent algorithm of Chanin and Hauchecorne [8] in (Eq. 1).

$$T(z)=T(z_0)\frac{z_0^2P(z_0)}{z^2P(z)}+\frac{M}{\kappa z^2P(z)}\int_{z_0}^{z} z'^2\,P(z')g(z')dz' , \quad (1)$$

where $P(z)$ is the number of photons corrected, z the altitude, $g(z)$ is the acceleration of gravity, M is the molecular mass of air, κ is the Boltzmann constant, and $T(z_0)$ is the temperature at a reference altitude z_0. The influence of the chosen reference value is negligible at altitudes about 15 km below the reference altitude. Atmospheric model based on COSPAR (Committee on Space Research) Internacional Reference Atmosphere (CIRA86) is used to give the reference altitude.

As the lidar signal is influenced by aerosols typically below 30 km it is possible from the knowledge of the ASR to perform the ratio between the lidar signal and the ASR, which enables to remove the influence of aerosols on the lidar signal [9]. For each measurement the algorithm calculates two temperature profiles, one with aerosol correction and another one without any correction.

Figure 2 shows two examples of temperature profiles for the same day on September 14, 2005, retrieved with (solid grey line) and without (dotted line) aerosol correction.

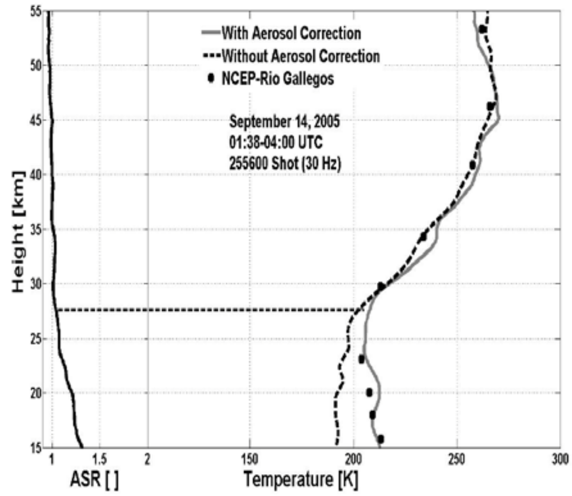

Fig. 2: (Right) Temperature profile on September 14, 2005 corrected for aerosols (grey line) compared to NCEP (black square) data above Río Gallegos. The dotted line shows temperature profile affected by aerosols. The aerosol scattering ratio profile is displayed on the left. The horizontal line separates the region of aerosol influence on lidar temperature profiles.

5. Cases of study and discussion

During the austral spring, the southern part of Argentina is affected by the crossing of the ozone hole which is contained by the polar vortex. In this section two measurements separated by a few days put in evidence the impact that the ozone hole has on the temperature profile. In Fig. 3 are represented the temperature profiles on October 17, 2005 compared with the NCEP data and seasonal average which is obtained using all lidar measurements in the spring from 2005 to 2007.

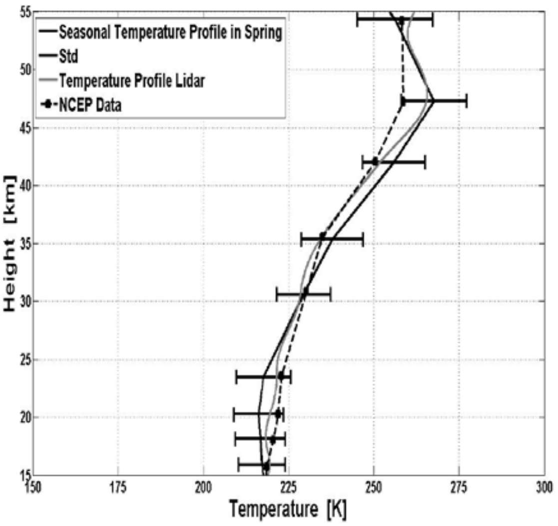

Fig. 3: Mean temperature profile computed from 40 lidar measurements in spring (black solid line) with error bars corresponding to one sigma standard deviation. Grey solid line: lidar temperature profile obtained on October 17, 2005. NCEP temperature profile above Río Gallegos on October 17, 2005 (black square).

Fig. 4: Total ozone from OMI/AURA satellite image on October 17, 2005. Dark zone correspond to depleted ozone region.

The measured temperature profile on October 17, 2005 has good agreement with the seasonal average. It is possible to see from satellite image corresponding to this day, there isn't a really impact of the ozone hole over the temperature profile because the polar vortex is over the Antarctic, far away from Río Gallegos (Fig. 4).

In Fig. 5 shows the temperature profile measured on October 9, 2005 corresponding to the passage of the ozone hole with total column value of 190 Dobson Units above Río Gallegos. A total of 40 measurements were obtained during spring time during 2005-2007 period time.

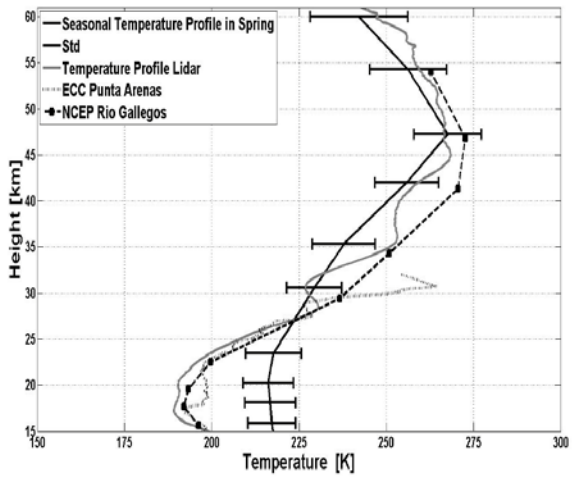

Fig. 5: Mean temperature profile computed from 40 lidar measurements in spring (black solid line) with error bars corresponding to one sigma standard deviation. Grey solid line: lidar temperature profile obtained on October 9, 2005. NCEP temperature profile above Río Gallegos on October 9, 2005 (black square) and temperature profile from ozonesonde launched in Punta Arenas-Chile (dotted grey line) are also shown.

Fig. 6: OMI/AURA satellite image on October 9, 2005.

The measurement of October 9, 2005 was compared to the average lidar temperature profile obtained in spring, in order to evaluate the effect of ozone hole crossing on temperature vertical distribution (see Fig. 6). The black zone represent a depression in the total ozone column which is over the south part of Argentina. It was also compared to the temperature data provided by an ECC ballon sonde launched in coincidence with the lidar measurement by the Laboratory of Ultraviolet Radiation and Ozone RUVO3 located in the University of Magallanes in Punta Arenas city, in Chile, 200 km away from the site of Río Gallegos. Both profiles are in very good agreement and show significant lower temperatures in the 15 – 25 km range. NCEP temperature retrieved above Río Gallegos is also in very good agreement with temperature lidar profile.

6. Conclusions

Systematic monitoring of temperature vertical distribution is performed by a Rayleigh lidar in the range between 15 and 60 km altitude at the Patagonian station of Río Gallegos. Comparisons with NCEP dataset show a very good agreement with the lidar data. Two study cases are evaluated in different conditions of proximity of the polar vortex.

On October 17, 2005 the ozone hole is away from Río Gallegos (Fig. 4). This situation produces that the lidar temperature profile measured on this day has good agreement with the seasonal average. This last profile is the mean of the all lidar temperature dataset.

A second case of study on October 9, 2005 evaluates the impact of ozone hole (Fig. 6) crossing on the temperature vertical distribution. Around 20 km a deviation of -12% with respect to the seasonal average is computed for that day. The lidar temperature profile obtained on October 9, 2005 shows a very good agreement with NCEP data above Río Gallegos and temperature measurements from an ECC ballon sonde, launched in Punta Arenas, Chile.

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