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Systematic Ozone and Solar UV Measurements in the Observatorio Atmosférico de la Patagonia Austral, Argentina

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SUMMARY

The depletion of the polar ozone layer is one of the strongest anthropogenic signals in the Earth system. Subpolar regions in the southern part of South America are affected by this phenomenon, covered sometimes by air masses with less ozone than normal with the corresponding UV enhancements at ground surface. Motivated by these atmospheric events, Argentina and Chile with the financial support of JICA has joined scientific efforts to develop UVO_3 Patagonia project. It has as main objectives monitoring ozone and UV radiation in Southern Patagonia. The Ozone and RUV laboratory (Chile) and the Lidar Division of CEILAP (Argentina) are the execute laboratories of this project. The Observatorio Atmosférico de la Patagonia Austral (Atmospheric Observatory of Southern Patagonia) is located in South Patagonia (51º 55'S, 69º 14'W), in subpolar region and it is a convenient monitoring site of the atmosphere in the Southern Hemisphere. In this experimental site is operative a differential absorption lidar instrument (DIAL) for the measurement of ozone vertical distribution. This instrument belongs of Network Data for Atmospheric Composition Change (NDACC). The altitude range of the ozone measurement is 14-45 km, which provides the opportunity to monitor the perturbations due to the passage of stratospheric polar air over Río Gallegos. Systematic stratospheric ozone profile measurement has been carried on in this experimental site since 2005. We identified three mayor perturbation of ozone hole over the stratospheric ozone profile in Río Gallegos. Approach of polar vortex during late winter, overpass of ozone hole in middle spring and dilution process during late spring change the shape and content of stratospheric ozone profile and by consequences the solar UV. Solar surface irradiance and total ozone content were measured with a Brewer spectraphotometer and moderate narrow band radiometer GUV-541 deployed in the Río Gallegos experimental site. Depleted ozone columns were measured during ozone hole overpass, and the analysis of unique extreme ozone depletion event in November 2009 is reported and compared with Multisensor Data Reanalysis of TOMS/OMI satellite data.

Key words: Lidar, Ozone, UV radiation, Polar Vortex

INTRODUCTION

Now a day we have strong evidence that human activities link to industrialized process have perturbed the natural balance of atmosphere composition (WMO, 2011). This fact has produced global scale issues like ozone depletion around the globe. The stronger manifestation of this phenomenon is the Antarctic ozone depletion today well known as ozone hole (Farman, 1985). Subpolar regions as the Patagonia in Argentina and Chile, in the southern part of South America are affected by this phenomenon covered sometimes by air masses with less ozone than normal with the corresponding UV enhancements at ground surface.

During the past twenty years, this phenomenon has varied in size and with respect to the minimum total ozone value within the Polar Regions. Dynamical processes into the stratosphere cause changes in the size and shape of the polar vortex, which elongates together with the ozone hole that is contained within the vortex. The daily movement of the vortex combined with this particular shape induces overpasses of the ozone hole over the continental part of South America. In these situations large inhabitant cities like Río Gallegos (51º 55'S, 69º 14'W) are under the influence of the ozone hole or near its border, causing an increase of solar UV radiation at these places [Pazmiño et al, 2005; Wolfram, 2009].

Motivated by these atmospheric events, Argentine, Chilean Japanese and French researchers cooperated to conduct atmospheric studies using remote sensing instrument. These instruments were installed in the Observatorio Atmosférico de la Patagonia Austral, OAPA, (Atmospheric Observatory of Southern Patagonia). In this work, we made a brief introduction to the measurement techniques of ozone and UV radiation held in this remote sensing site, and present, as example, same typical measurement.

METHOD AND RESULTS

Site description

The Observatorio Atmosférico de la Patagonia Austral, OAPA, (Atmospheric Observatory of Southern Patagonia) is part of Lidar Division of CEILAP (CITEDEF-CONICET). It is located in Río Gallegos city in South Patagonia (51º 55'S, 69º 14'W). Since June 2005, a shelter with several lidar instruments developed in collaboration with Service d'Aéronomie (CNRS) was deployed in this Patagonian city, 2600 km far away from Buenos Aires. During 2005 and 2007, with the financial support of JICA (Japanese International Cooperation Agency), was held the SOLAR campaign (www.division-lidar.com.ar) (Wolfram, et al., 2006). The principal objective of this campaign was study the ozone layer when the polar vortex crosses over the continental part of Argentina, in South America.

After SOLAR campaign, different projects were developed with financial support of JICA (Japan International Cooperation Agency) in partnership with researchers from Chile, France and Japan. The main objectives of these projects are focused in the observation of atmospheric parameter with lidar remote sensing techniques, specially the measurement of stratospheric ozone profiles using differential absorption lidar technique. Río Gallegos is located in the surf zone of polar vortex, making very interesting place to observe the evolution and perturbation that ozone hole produces on the stratospheric ozone profile.

The OAPA has currently different instrument devoted with the observation of gases (O_3 and NO_2) and particles (i.e aerosols) in the atmosphere, as much as the solar radiation (UV and visible). Several kinds of techniques are used to monitor ozone, like differential absorption lidar (DIAL) for determination of stratospheric ozone profiles and different radiometers, as SAOZ and Brewer for total ozone column measurements. In this paper we only focused in DIAL ozone products and solar UV index measured with GUV radiometer.

DIAL Instrument

The DIAL technique is a well-established technique for the ozone profile measurement, as is demonstrated by the large number of publications about the subject. The DIAL technique uses XeCl excimer laser emission at 308 nm for absorbed wavelength and the 355 nm third harmonic radiation of Nd-YAG laser for the reference wavelength. Both laser pulses are sending sequentially to the atmosphere. Six channels are used for the signal acquisition, four of them for the detection of elastically backscattered signal of the emitted wavelengths (high energy mode for the higher altitude ranges, attenuated energy for the lower ranges) and two corresponding to the first Stokes nitrogen Raman of the emitted wavelengths. The optical receiving system consists of four parabolic telescopes (f/2) 50 cm diameter. Four quartz optical fibers are placed at the focal points of the telescopes and come together vertically to form the entrance slit of the spectrometer. These transmit the backscatter radiation from the atmosphere to an optical analyzer device, which includes optics for image formation, a chopper to prevent the saturation of the photomultipliers and a spectrometer designed to separate/split the different wavelengths to be detected. A fundamental part of the spectrometer is a Jobin Yvon holographic grating with 3600 lines per millimeter characterized by 40% efficiency in the 150-450 nm spectral range. It separates 5 wavelengths, 4 of which are used for obtaining ozone profiles and the combination of the fifth wavelength (347 nm) with one of the previous ones (332 nm) for obtaining profiles of water vapor in the troposphere. A full description of this DIAL system can be found in Wolfram et al (2008).

GUV radiometer

The multi-channel moderate-bandwidth GUV-541 have proven to be an acceptable solution for monitoring solar UV irradiance, between UV spectroradiometer very expensive and high maintenance, and broadband radiometers that provide only partial information because they cannot distinguish between changes in UV radiation caused by alterations in cloud cover and variations caused by changes in ozone amount. GUV filter radiometers, designed and manufactured by Biospherical Instruments Inc. The instruments provide measurements in five approximately 10 nm wide UV bands centered at 305, 313, 320, 340, and 380 nm.

The synergy of UV irradiance measured with this instrument and radiative transfer model permits to obtain UV related products, like UV index or erythemal irradiance, and cloud optical depth, between other. In this work we present UV index measurement derived from GUV radiometer.

Measurements

The ozone observation with lidar in OAPA are conducted within two different measurements protocols: an intensive period between August and November each year, (later winter - spring time at South Hemisphere), and routine measurement period for the rest of the year. During intensive measurement period which is coincident with the ozone hole development, the stratospheric ozone layer is monitored during 4 hours average time each available clear night.

Total ozone column in Río Gallegos follows a seasonal variation over the year with minimum values around autumn (March-April) and maximum values during spring (September-October). Over this annual variability total ozone column presents great day to day variation. These rapid changes are caused by the approximation and overpass on Río Gallegos of polar air masses that air isolated from middle latitude air by polar vortex.

The fluctuations on total ozone column are clearly appreciated in Figure 1, where total ozone column measured by OMI/AURA instrument (blue line) are plotted from 2005 to 2009. White line is the climatologic monthly mean ozone column using multi sensor reanalysis (MSR) total ozone column from 1987- 2008 time period**.**

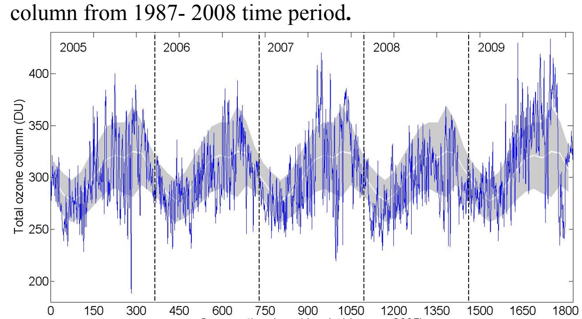

Figure 1. Time evolution of total ozone column over OAPA measured with OMI/NASA instrument (Blue Line). White line is the climatologic monthly mean ozone column using multisensor reanalysis (MSR) total ozone column from

1987- 2008 time period. Gray shadow area corresponds to +/- 1 standard deviation.

Stratospheric ozone profiles are measured with a Differential Absorption Lidar (DIAL). This instrument belongs to NDACC (Network for the Detection of Atmospheric Composition Change). Since 2005 this instrument has been monitoring ozone profiles in the stratosphere. Extreme ozone depletion has been measured as consequence of ozone hole passing over. Also, vortex dilution processes were measured in late spring-early summer.

The 2009 spring was a very special moment, because the polar vortex overpass several time during October, and it was stagnant over continent on November, producing strong perturbation of ozone profile as consequence of ozone hole located over Southern Patagonia. Figure 2 shows the DIAL ozone profile measured for middle November. The strong reduction over 20 km is clearly appreciated in comparison with the climatological profile of Fortuin & Kelder (Fortuin and Kelder, 1998) for this month and this latitude.

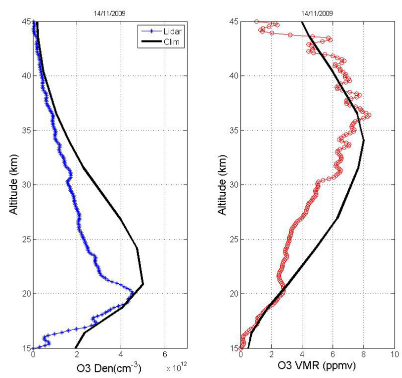

Figure 2. DIAL ozone profile on November 14, 2009. Blue line is the ozone number density (cm-3) (left panel, blue line) and ozone volume mixing ratio (ppmv) (right panel, red circles). For comparison of vertical ozone profile shape change, November climatologic Fortuin & Kelder ozone profile is included (black line).

These events produce strong impact in the solar UV radiation that reach ground surface (UVI). UVI is measured with different radiometers and Brewer spectra photometer (SN 124) of INPE. Particularly on November 15 the UV index reach values as high as 13 despite the cloud cover present in Río Gallegos for this day. It produces an extreme solar sunbathing.

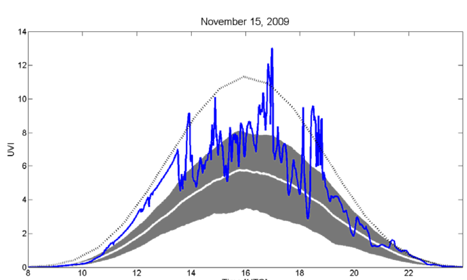

Figure 3. Time evolution of UV Index in Río Gallegos on November 15, 2009. The measurements were obtained with a GUV 541 and they are plotted in blue line. November monthly mean of UVI is showed in white line and the shadow grey area correspond to +/- 1SD. Modeled UVI for Nov. 15 is showed in dotted black line.

CONCLUSIONS

The OAPA is an atmospheric laboratory that performs several kinds of atmospheric measurements in Río Gallegos, Southern Partagonia. Since June 2005 stratospheric ozone profiles and solar UV radiation have been measured between other atmospheric parameters. In this paper we reported one example of differential absorption lidar measurement of stratosphere ozone number density in the 15 - 45 km range for a situation of ozone anomaly. Ozone hole overpass and vortex dilution are identified as examples of reduction and change in stratospheric ozone profiles. Also an extreme solar sunbathing occurred on November 2009 is reported. We identified three mayor perturbation of ozone hole over the stratospheric ozone profile in Río Gallegos. Approach of polar vortex during late winter, overpass of ozone hole in middle spring and dilution process during late spring change the shape and content of stratospheric ozone profile and by consequences the solar UV radiation that reach the surface.

ACKNOWLEDGMENTS

The authors would like to thank JICA (Japan International Cooperation Agency) by financial support of UVO_3 Patagonia Project; the CNRS in France for their collaboration in facilitating the shelter and part of the electronic instruments of DIAL.

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Evaluation of inversion algorithm sensitivity in stratospheric ozone DIAL profile.

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SUMMARY

The DIAL system belonging to Observatorio Atmosférico de la Patagonia Austral, Río Gallegos, Argentina has been included in the NDACC since December 2008. One caveat of large networks such as NDACC is the difficulty to report information of similar nature consistently from one research group (or instrument) to another. The inversion algorithm used in the stratospheric ozone DIAL measurements involves different source of systematic and statistic errors. Due to the rapid decrease of the signal-to-noise ratio in the high stratosphere, it is necessary to degrade the vertical resolution of the measurement in order to limit the statistical error at this altitude range, to reasonable values. The final statistical error on the measurement is the result of a compromise between the experimental system characteristics such as the duration of the measurement and the final vertical resolution. The aim of this study is test the DIAL algorithm resolution used to retrieve the ozone profile comparing with the synthetic ozone profile. This synthetic ozone profile is calculated by mean of lidar equation using an ECC sonde profile as input parameter. This ozone profile was measured with an ozonesonde launched in Río Gallegos in March 2011 as part of intercomparison campaign.

Key words: DIAL, vertical resolution, ozone profile.

INTRODUCTION

Use of Differential Absorption Lidar (DIAL) systems is becoming more widespread for monitoring the ozone vertical distribution throughout the world (Sophie Godin et. al., 1999).
In Observatorio Atmosférico de la Patagonia Austral (OAPA) was installed a Lidar system which retrieve ozone profiles in the stratosphere since 2005. In 2008 this lidar joined to the Network for the Detection Composition Change (NDACC) for the long-term monitoring of stratospheric ozone.
To achieve the goals of the NDACC, the ozone profile supplied to the NDACC archive have been extensively checked in intercomparison campaigns. However, uncertainty exists with respect to the interpretation of altitude resolutions reported by various ozone DIAL instruments (Georg Beyerle et.al., 1999).
For a DIAL system, ozone number densities $n_{O3}(z)$ are calculates by

$$n_{O_3}(z) = \frac{1}{\sigma_{on} - \sigma_{off}} \left[\frac{1}{2} \left(\frac{d}{dz} \ln \frac{P_{off}(z)}{P_{on}(z)} \right) \right] - \left[\alpha_{on}(z) - \alpha_{off}(z) \right]$$

where the contribution from aerosols has been neglected; σ_{on} and σ_{off} are the ozone absorption cross section for wavelength λ_{on} and λ_{off} respectively; α_{on} and α_{off} are the extinction coefficient for molecular scattering for the mentioned wavelength; and P_{on} and P_{off} are the lidar signals.
The evaluation of the term d/dz ln $[P_{off}(z)/P_{on}(z)]$ is an essential element of the analysis. Generally, differentiation has the effect of applying a high-pass filter to a signal. In DIAL analysis this fact represents a problem, as the signal counts P at stratospheric altitudes contain high-wave-number noise contributions
Typically, the altitude resolution $\Delta z(z_i)$ of ozone profiles is defined in terms of the derivative filter. Because various filters are used, values of $\Delta z(z_i)$ from different data analyses are generally not comparable.
Here we test the algorithm used in the DIAL system of OAPA to retrieve the vertical ozone variation. To that end we use the synthetic ozone profile measured by ozonesonde like an input to calculate the lidar signal for then obtain the ozone profile from the DIAL algorithm. This profile calculated is compared with the ozonesonde. The lidar signals are calculated without noise.

METHOD AND RESULTS

In a pure molecular atmosphere (i.e. neglected the aerosols) the lidar signal for an altitude z of the atmosphere and for a wavelength can be written like

$$P(z) = k \frac{\beta_{molec}}{z^2} e^{-2\left[\int_{z=0}^{z} \beta_{molec} \cdot \frac{8\pi}{3} dz + \int_{z=0}^{z} \sigma_{O_3} . n_{O_3} dz \right]}$$

where $\beta_{moléc}$ is the Rayleigh backscatter coefficient; $8\pi/3$ is the ratio between extinction and molecular backscatter; σ_{O3} is the

ozone cross section and n_{O3} is the ozone number density. The value of 2 before the exponent indicate that the laser bin pass through the atmosphere two times between z_0 (site altitude) and z. The first term of the exponent counts the extinction of the atmosphere due to scattering of molecules only for a given wavelength while the second term take in account the absorption of ozone at this emitted wavelength. To obtain the synthetic lidar signal for λ_{on} and λ_{off} we need to calculate the backscatter coefficient and the second term of the exponent for both wavelengths. The backscatter coefficient β was calculated from the density of the atmosphere using the pressure and temperature profile measured by a sonde launched in Punta Arenas, Chile, near of OAPA. Knowing the ozone cross section for two interest wavelengths, we can calculate the second term of the exponent from the ozone profile measured by the ozonesonde between 0 and 32 km as input of the DIAL algorithm. This profile was completed with the Fortuin & Kelder(1998) climatology profile.

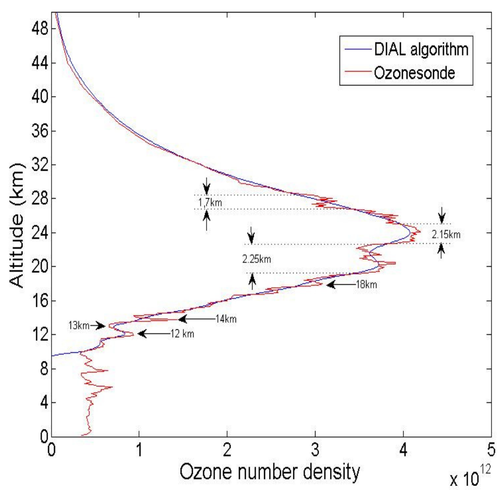

Figure 1. Comparison of both calculated ozone profile from the DIAL algorithm in the OAPA (blue) and the synthetic ozone profile obtained from measured by ozonesonde (red).

Figure 1 shows a comparison between the ozone profile calculated (DIAL algorithm) and ozone profile measured by the ozonesonde which was used as an input to calculate the lidar signals. Although the lidar signals in λ_{on} and λ_{off} (308nm and 355nm respectively) was calculated without noise, the algorithm has an intrinsic resolution. The calculate profile is like the measured one but more smoothed. The highlighted zones show the altitudes where the variations of ozone number density are greater. Around the 12 and 13 km have two local peaks where the resolution (figure 2) is 0.8km. The calculated profile follows the behavior of measured but not reaches the local maximum and minimum of the peak. At 14 km there is other local peak but more narrow. The resolution at this altitude is 0.8km and the wide of the peak is 0.4 km. For this reason is probably that the calculated profile can't "see" this layering. Around 20 km the ozone profile measured by the sonde shows a large variation. The measured profile presents four peaks.

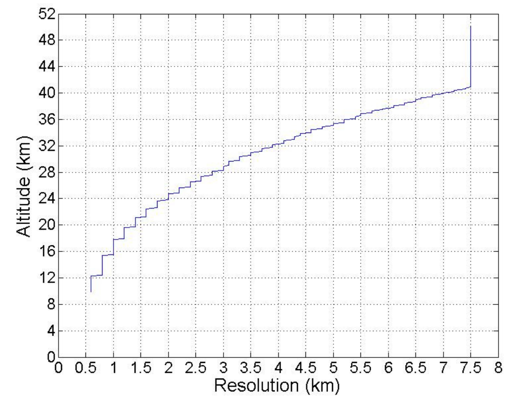

Figure 2. Vertical resolution used in the DIAL algorithm.

The calculate profile follows the ozonesonde but very smooth. Figure 2 shows the resolution increase with the altitude and in that altitude (around 20 km) the calculated profile doesn't follow the thin peaks. Around the 28 km where the resolution is of 3km, the measured profile presents a variation similar to 12 and 13 km. We observe that the DIAL algorithm profile don't follow this trend due that the resolution in this altitude is greater than the resolution at lower altitude.

CONCLUSIONS

We presented a descriptive study of a vertical ozone profile obtained by the DIAL algorithm used in Río Gallegos. This study shows how act the DIAL algorithm smoothing the ozone profile calculated respect of the measured and variations in the shape of ozone profile in same layer is lost. It is important to note that the calculated profile was obtained without noise. In future studies we try to introduce a modeled noise to obtain lidar signals more real.

ACKNOWLEDGMENTS

The authors would like to thank JICA (Japan International Cooperation Agency) by financial support of UVO_3 Patagonia Project; the CNRS in France for their collaboration in facilitating the shelter and part of the electronic instruments of DIAL.

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Remote control and telescope auto-alignment system for multiangle lidar under development at CEILAP, Argentina

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SUMMARY

At CEILAP (CITEDEF-CONICET), a multiangle Raman lidar is under development to monitor aerosol extinction in the frame of the CTA (Cherenkov Telescope Array) Project. This is an initiative to build the next generation of ground-based instruments to collect very high energy gamma-ray radiation. It will serve as an open observatory for a wide astrophysics community and will explore the Universe in depth in Very High Energy (> 10 GeV) gamma-rays. The atmospheric conditions are is a major interest for CTA, and this instrument plays a major role measuring the atmospheric optical depth.
The reception system is made by six 40 cm in diameter Newtonian telescopes, totally exposed to the hard environmental condition during the shifts. These working conditions could produce misalignments between laser and telescopes, losing the required overlap. To avoid that, a telescope controlled by a self-alignment system is under development to solve this problem. This is performed by PC software running from the acquisition module which is connected via ethernet to a microcontroller. This paper, describes the self-alignment method and hardware work in progress.

Key words: multiangle lidar, Raman, CTA observatory, aerosols.

INTRODUCTION

The Cherenkov Telescope Array Consortium (CTA) contemplates the design, construction and the operation of two observatories for the detection of gamma-ray produced by extraterrestrial sources at energies range between 10^{10} eV to 10^{14} eV. These observatories will be deployed at each hemisphere for full sky-map coverage. Each Observatory will consist of a telescope array sensitive to the atmospheric generated Cherenkov radiation that will improve the performance of the actual detectors. The objectives proposed for CTA will be attained using an array of multiple telescopes distributed over a surface of 1 km^2, located at sites with excellent optical and atmospheric conditions at a height of 2000 to 3500 mts above the sea level. The comprehension of the atmospheric conditions during the measurements is extremely important for the CTA Observatory. In fact, the atmosphere acts as the first detector at which the air showers are developed. The array of detectors observe the gamma ray induced cascades by measuring the Cherenkov light produced by their charged particles moving above the speed of light of the surrounding atmosphere. The emitted light is attenuated from the source to the telescope due to molecular, aerosol and cloud extinction. Lidars play a leading role in monitoring of sky conditions, by both detecting the overall cloud coverage and measuring the atmospheric opacity due to aerosol and clouds over the Observatory. The location of this astronomical facility will be selected after a careful study of the preselected zones, regarding the latitude, altitude, the atmospheric conditions, and the available local infrastructure. At the Southern hemisphere, Argentina is one of the candidate countries for the installation of the CTA Observatory. The places proposed are "El Leoncito", located in San Juan state and "El CASLEO", in Salta.

LIDAR HARDWARE

LIDAR telescope is planned to be mounted on a steerable frame, and moved using two DC servomotors, reading its position by two relative encoders.

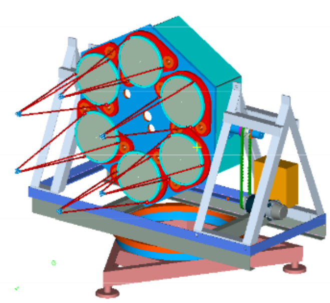

Figure 1. A preliminary sketch of the multiangle lidar under construction.

Movements are handled by a microcontroller that communicates with the lidar PC through an ethernet connection. Each LIDAR is equipped with a Nd:Yag laser, that generates laser pulses at 355, 532 and 1064 nm at a repetition rate of 50 Hz and a pulse energy of ~20 mJ @ 355 nm. The backscattered light is collected by six Newtonian telescopes with 40 cm diameter, 1 m focal length. A

multiwavelength spectrometer separates the backscattered wavelengths and concentrates the light into several Hamamatsu H6780 photomultipliers. A Licel TR20-160 module is used to digitalize and store the lidar profiles

This lidar has special requirements:

- It has to be able to be operated remotely. The lidar operator may not have an a priori knowledge on lidar techniques.
- Telescopes, mechanics and electronics, will be exposed during nighttime to extreme environmental conditions (wind burst, temperature span, etc.), which could produce lidar misalignments

These are the main reasons that encourage the development of a fully automatic alignment system is to keep the telescopes aligned during the acquisition period.

LIDAR COMUNICATIONS

The lidar system under development has two operational modes: *local mode* and *remote mode*. *Local mode* was developed for maintenance procedures. The presence of a lidar technician is required on site to perform hardware improvements and specific tests. *Remote mode* was programmed to perform shift operations. In this case the lidar will be remotely operated and monitored from the control center. The lidar computer was designed to communicate with control center server wirelessly via a WiFi link, creating a local lidar network under the TCP/IP protocol.

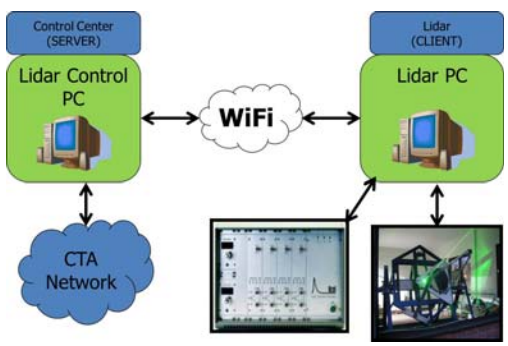

Figure 2. A general schematic layout of the lidar communication system. If remote mode is set, the shifter can monitor and control all the operations.

At the link endpoints, several processes communicate with each other to send/receive control and monitoring messages.

LIDAR SOFTWARE

A more detailed view of the process at each lidar PC can be seen on Figure 3. Each computer works under Linux operating system and all the software was developed in C/C++. A socket-based IPC (Inter Process Communication) was programed to communicate the local with the remote process. To increase their efficiency, each process is totally independent, and communicates to the other via control messages.

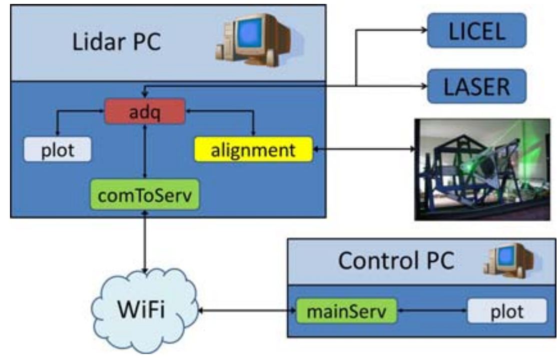

Figure 3. A general diagram about connections in both sides of the lidar system.

A brief description of each process at both sides of the link is described below:

Lidar PC side (client):
adq: Is the main process at the client (lidar) side. It controls the acquisition timing, it communicates with the laser, it triggers the Licel, it sends the acquired new file to the *plot* process, and, if necessary, to the *alignment* process.
plot: Waits messages from the *adq* process, conformed mainly by the new acquired file path and shows it on the display.
comToServ: This process handle all the messages from/to the client/server side.
alignment: This process receive the path to the acquired file from *adq* and process this signal to obtain the alignment parameters to determine the telescope position.
Control PC side (server):
mainServ: Handle the communication between the shifter and the client PC.
plot: Shows the lidar signal from the last saved file.

MICROCONTROLLER-CONTROLLED TELESCOPES

The tilt angle of the telescopes is driven by a set of stepper motors, handled by a RCM2200 Rabbit System microcontroller. This is Z80 family-based high-performance 8 bit microcontroller. It has a built-in Ethernet interface with an integrated TCP/IP stack, making it a good choice for interconnectivity. This interface is used to link the microcontroller with the lidar PC. The instruction set is based on the original Z80 microprocessor, with some additional instructions.
The aims of the Rabbit microcontroller algorithm is to decode the Ethernet information received from the lidar PC *alignment* process, and to handle the signals to correct the stepper motor drivers. The message from the lidar PC to the Rabbit microcontroller has 3 parameters: motor to be controlled, direction and number of steps. Therefore, the firmware of the Rabbit microcontroller is a “dummy terminal” that only receives message and drives the motor. After that, it sends an acknowledge message back to the *alignment* process.

ALIGNMENT ALGORITHM

The alignment algorithm is a cooperative procedure between the *adq* and the *alignment* processes, both running on the lidar PC, and a firmware recorded in the Rabbit microcontroller.
When the alignment mode is set at the *adq* process, each path of the acquired file is sent to *alignment*. Moreover, after

saving a new file at the lidar PC, this file is transferred to the control PC for a backup. A summarized procedure flowchart can be seen on Figure 5.

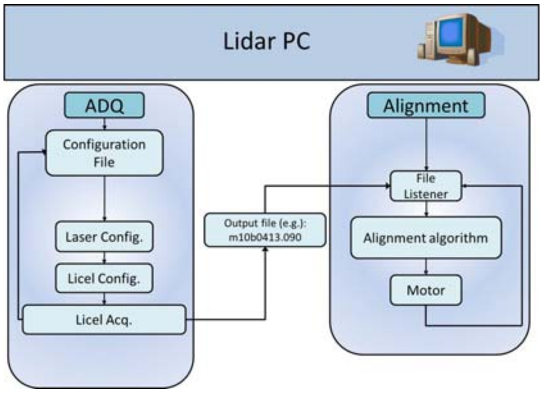

Figure 4. Communication Diagram between the *acquisition* and the *alignment* processes. Both are fully independent, and they communicate via the IPC socket, implemented under C/C++.

The aim of the alignment algorithm is to quantify the alignment state of the recently acquired file and to save it with its tilt position in a table. After that, *alignment* tilts the telescope to a new position and sends an acknowledge message to *acq*, to trigger new acquisition.
The alignment state quantification is obtained by accumulating the lidar signal over certain range, as it seen on the next figure:

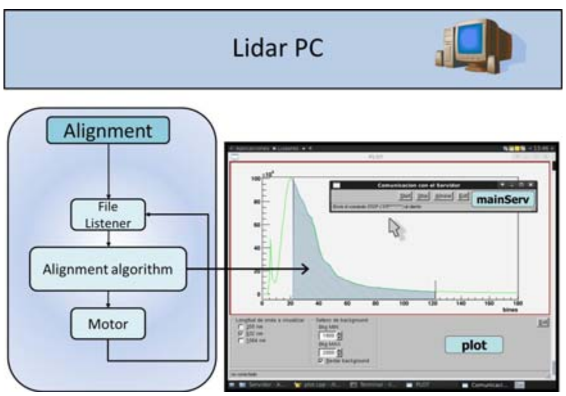

Figure 5.

After finishing the scanning process, the microcontroller sets the telescope position to the one at wich the maximum value was attained. This procedure tends to increase the lidar signal in a wide dynamic range.

FIRST RESULTS

This algorithm was successfully tested, comparing the vertical lidar signals obtained with the ones obtained by the MWRL lidar at CEILAP (CITEDEF-CONICET). The test was done for a vertical fixed position, as can be seen on Figure 4.
The CEILAP's telescope was manually aligned to provide the reference signal. The tested telescope was left intentionally misaligned to test the optimization algorithm.

Figure 4. Picture of the setup of lidar intercomparison.

After turning on the alignment mode, the algorithm exhibited good results, approaching the telescope's signal under test to the reference lidar signal. The next figure shows the lidar signals after the alignment process.

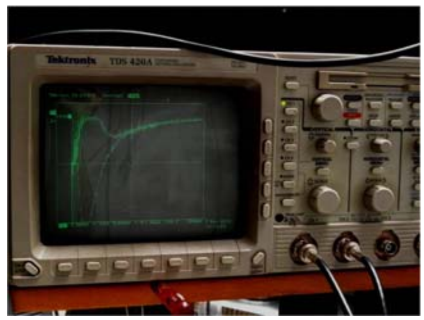

Figure 5. Picture of the lidar signals intercomparison after alignment algorithm success.

The differences seen on the last figure are due to the different distance to the laser source of the systems. Figure 5 shows the long range agreement of the signals.

CONCLUSIONS

The system is ready to be tested in a slant path fixed angle. The lidar is actually being installed inside a container to perform this new test. A new enhanced version of the controlled telescope actuators is under construction. First measurements indicate that it will be possible to achieve the expected auto-optimizations goals during the scanning procedure. The new software for a multiangle lidar prototype is fully operational.

ACKNOWLEDGMENTS

Authors wish to thank JICA, ANCyPT, the CITEFA main workshop's technicians and José Luis Luque from the CEILAP workshop for their support on this development.

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Rayleigh lidar temperature profiles between 15 - 60 km during OZITOS campaign in Río Gallegos (51° 55'S, 69° 14'W), Argentina

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SUMMARY

The determination of temperature measurements from the Rayleigh scattering is an important remote sensing technique for obtaining stratospheric profiles. This technique is applied to signals acquired by a Rayleigh lidar (Light Detection and Ranging). Currently the Observatorio Atmosférico de la Patagonia Austral (51° 55'S, 69° 14'W) in Río Gallegos, Argentina is part of the UVO3Patagonia project in collaboration with the laboratory of Ozone and UV Radiation in the city of Punta Arenas, Chile distant 200 km, for more information www.uvo3patagonia.com. In this paper we showed the technique to measure temperature profiles in the stratosphere between 15-60 km altitude. We compared the temperature profiles obtained of the second ozone sounding campaign called OZITOS (**OZ**one profi**l**e a**T** Rí**O** Galleg**OS**) carried out in March 2011 in Río Gallegos with the temperature profile retrieved by the Rayleigh lidar using the line of 355 nm, in the same period. The results presented in this paper are validated through intercomparisons with measurements made by MLS instrument (Microwave Limb Sounder) onboard the NASA AURA satellite platform and NCEP data.

Key words: Rayleigh lidar, temperature profile, radiosounding measurements

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 (Gross *et al.,* 1997) (Gu *et al.,* 1997) (Nedeljkovic *et al.,* 1993). 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. Balloon 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.
Since 2007, CEILAP group has installed the Observatorio Atmosférico de la Patagonia Austral. Actually we have a binational project with the laboratory of ozone and UV radiation (LabO_3RUV) from Magallanes's University called UVO3 Patagonia, supported by Japanese Cooperation Agency (JICA). Both groups are specialized in measured the depletion ozone using differents techniques. In CEILAP group basically can obtain ozone profile using a DIAL system described (Wolfram *et al.,* 2008). The LabO_3RUV measured using ECC balloon sonde (Electrochemical Concentration Cell), developed by Komhyr (Komhyr 1969, 1971).
The final objective of this paper is to do an introduction to temperature profiles using a Rayleigh lidar which will be describe below. Also a campaign of ozonesounding made in Río Gallegos in March 2011, called OZITOS II (OZone profile aT RíO GallegOS) will be used to compare temperature profiles between 10 up to 32 km.
The analysis that we will make below is important to know since the campaign OZITOS II was principally designed for the validation of ozone profile. This paper try to use the temperature from radiosounding aboard the balloon sonde to compare the temperature profile obtained by the Rayleigh lidar temperature, and this way increase the capability of the instrument. Also we use the data from the National Centers for Environmental Prediction (NCEP) and the MLS instrument aboard satellite AURA-NASA (Acker and Leptoukh, 2007).

METHODOLOGY

The methodologies described in this section were separated in two parts: the first one describe how obtain a temperature profile from a Rayleigh lidar as a part of the DIAL system. The second one, tried describe the sensor used for the validation of temperature profile from Rayleigh lidar.

Rayleigh lidar temperature profiles

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 (Steinbrecht and Carswell, 1995). 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.
The temperature 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), 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.
After this corrections, we retrieved the temperature profile from the lidar signal.

ECC sondes

The balloon sondes used during OZITOS II campaign are configured by a radiosounding and an ECC which is the responsible for the detection of ozone concentration. In our experiment the ECC sonde launched has also a radiosounding which can measure temperature, humidity and pressure.
The radio receptor is a Lockheed Martin LMG6. It was used for store all data emitted by the sonde. As sensor we used a meteorological radiosounding LMS6. An ECC model EN-SCI Corporation was used for measure the ozone concentration.

OZITOS II CAMPAIGN

In December 2008, the instrument DIAL for the measurements of stratospheric ozone profile deployed in the Patagonian city of Río Gallegos was accepted as part NDACC (Network for the Detection Atmospheric Composition Change). This new stage of the instrument must satisfy new requirements as intercomparisons with other kind of sensor to check the stability and guarantee a quality in the measurements. Very often different groups around the world used ECC balloon sondes for measured ozone concentration in a region between the surface up to 30 km aprox.
Though the principal objective was to make validations between DIAL and ECC balloon sondes, this paper showed the comparison between temperature profile derived with the 355 nm line as described above and the temperature profile measured with the radiosounding, during OZITOS II campaign.

Experimental design

The night March 17, 2011 both groups decided to lunch in a same night three balloon sonde in coincidence with the DIAL operation. The aim was study the minimum time of integration in the data files acquired by DIAL systems. The schedule of the experimental design is showed in Figure 1.

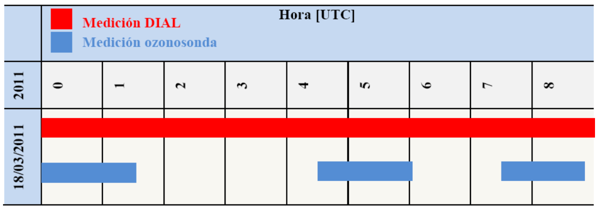
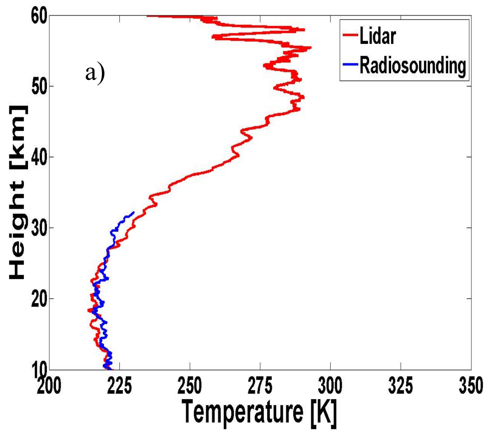


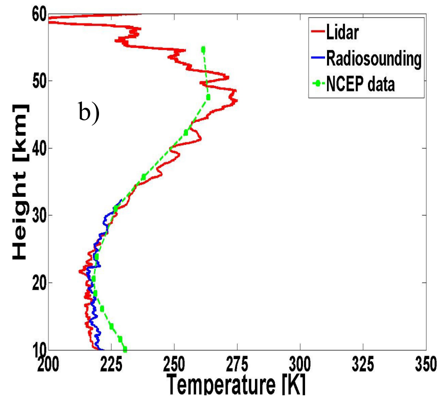
Figure 1. Schedule of measurement made in the OAPA during OZITOS II campaign in March 17, 2011. The red bar is the time that the lidar were measuring and blue bar the period of flight of each ozonesounding.

Where the horizontal red bar indicate the total time of measurement of the DIAL system and the blue bar indicate the time of flight of the ozonesounding. Can you show that the DIAL systems was operating more than nine hours. If we select a time of integration of three hours we can obtain three independent measurements that each one can be compared with each balloon sonde launched (same period time of flight). Now we can decrease the time of integration, and we can derivate for example more profiles.
The advantage using signals obtained by a DIAL system, is that we can use the signals in 355 nm from the Nd:YAG laser for retrieved a temperature profile without produced any interference on the ozone measurements.

Results and discussion

We have taken from the total measurement about nine hours from Rayleigh, three independent period of time which we calculated the temperature profile using a time of 180 minutes of integration. This time is quasi-coincident with the time of flight of the ozonesounding launched beside, 1 km away of the DIAL system in Río Gallegos. This means that we can compare temperature derived from both instruments.
In Figure 2, we showed the comparison of the temperature profile between the Rayleigh lidar temperature and the radiosounding.





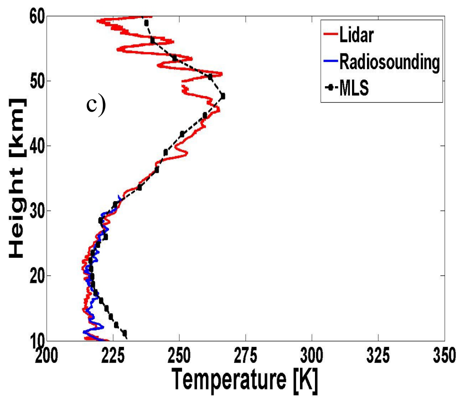


Figure 2. Comparison of the temperature profiles; a), b), c) are the temperature profile by the Rayleigh lidar (red line) compared with radiosounding (blue line). b) show the comparison with NCEP data (dashed green line with square) for March 17, 2011 in Río Gallegos and c) show the comparison with a MLS sensor(dashed black line with square) aboard AURA-NASA in March 17, 2011 lat=-51.74 °, lon= -75.23 °, time: 06:03:09 (UTC).

The region of comparison between both instruments is a disvantage due they have different heights of cover.
In the case of the Rayleigh lidar we can obtain temperature profile from aprox. 10 km up to 60 km. While in the balloon sonde only we can measured temperature profile between the surface up to 32 km. The effective zone where both instruments can be compared, cover the range 10 to 32 km, aprox, limited in the lower part for the lidar and in the higher part for the balloon burst altitude.
The Figure 2 has shown the good agreement between the diferent profiles, having a relative error lidar - radiosounding lower than 4 %. Additional in b) we superposed the NCEP data for the same day of measurement, and c) show the comparison with the data provided by the MLS instrument aboard the plataform AURA-NASA.

CONCLUSION

This paper has shown three independent temperature profiles derivated with a Rayleigh temperature lidar for one day (March 17, 2011). These profiles were obtained as a part of the OZITOS II Campaign described above. In each measurement the Rayleigh temperature profiles were compared with the radiosounding aboard the balloon sonde. The effective region for the comparison can be established due figure 2 in the region between 10 up to 30 km aprox. Both instruments have shown good agreement in this region, with a typical relative error lower than 4 %. We have observed also that in this night the three lidar profiles are similar, indicating that the atmospheric conditions were stable. As a comparison with other instrument as the NCEP data and MLS instrument aboard the AURA-NASA satellite has been to do it. It measurements were superposed in the profiles b) and c) (figure 2) showing very good agreement in the region above 20 km. For the region below both measurements (NCEP data and MLS) indicate a discrepancy very similar when are compared with the radiosounding and temperature lidar profiles.

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Analyses used in this paper were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC.

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Determination of the seasonal variation of the nitrogen dioxide and ozone vertical column density at Río Gallegos, Santa Cruz province, Argentina, using a zenith-sky DOAS system

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SUMMARY

Stratospheric ozone (O_3) plays a critical role in the atmosphere by absorbing most of the biologically damaging solar UV radiation before it reaches the Earth's surface. Nitrogen dioxide (NO_2) is a key trace gas in the ozone photochemical. The systematic sensing of NO_2 and other minority gases is essential in order to understand the stratospheric O_3 destruction and formation processes. We present the study carried out on the seasonal variation of the O_3 and NO_2 vertical column density (VCD), using a zenith-sky DOAS (Differential Optical Absorption Spectroscopy). This system is composed of a spectral analyzer (portable spectrometer HR4000, Ocean Optics), two optical fibers (400 µm of core, 25 cm and 6 m of longitude) and an automatic mechanical shutter. NO_2 and O_3 VCD are derived from solar spectra acquired during twilights (87° - 91° zenithal angles). The data retrieved by our instrument are compared with those coming from the SAOZ spectrometer (Systeme d'Analyse par Observation Zenithale, Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS), France). Both systems are located in Rio Gallegos, Santa Cruz province, Argentine (51° 36' S; 69° 19' W, 15 m asl), in the CEILAP-RG remote sensing station.

Key words: zenith-sky DOAS, NO2, O3, OMI, SAOZ

INTRODUCTION

Stratospheric ozone (O_3) plays a critical role in the atmosphere by absorbing most of the biologically damaging solar UV radiation before it reaches the Earth's surface. The most important nitrogen species emitted to the atmosphere are nitrous oxide (N_2O), nitrogen oxides ($NO_x = NO{+}NO_2$) and ammonium (NH_3). N_2O is an important greenhouse gas which is naturally emitted by earth and sea bacteria, and also produced by human activities, mainly agriculture. It is a very stable molecule which is transported to the stratosphere. In the middle and upper stratosphere N_2O is converted to NO by reaction with excited oxygen atoms O (^{1}D) produced mainly by UV photolysis of O_3 (Fish and Jones, 1995).

During daylight a balance between NO and NO_2 concentrations is established through the reaction of the former with O_3 and the rapid photolysis and reaction with atomic oxygen of the latter. At night, NO_2 is converted first to NO_3 and via a three-body reaction to the N_2O_5 reservoir. This causes a build-up of N_2O_5 during the night followed by a slow release during the following day through photolysis. The diurnal variation of NO_2 therefore comprises a maximum immediately after sunset, followed by a slow decrease throughout the night and a sharp drop to minimum at sunrise.

As well as the diurnal variation there is a seasonal variation in stratospheric NO_2 at mid-latitudes due to the combined effects of photochemistry and atmospheric transport (Gil et al., 2007).

The development of remote sensing systems for monitoring of trace gases is fundamental to understand the dynamic processes that occur in the stratosphere. The LIDAR Division (CEILAP-CITEDEF) has in Río Gallegos, Santa Cruz province (51° 36' S; 69º 19' W; 15 m asl) a remote sensing station (CEILAP-RG) where systematically are carry out measurements of several atmospheric parameter (www.division-lidar.com.ar), as for example: the concentration in vertical column O_3 and of NO_2, the O_3 concentration discriminated in height (O_3 profile obtained by LIDAR, between 15 and 45 km), aerosol optical thickness, solar irradiance (UV-A, UV-B, NIR), etc. It is necessary to highlight that Río Gallegos city is affected every spring by a significant decrease of the stratospheric O_3 that produces an increment of the UV solar radiations that arrive to the surface.

MATERIALS AND METHOD

We present the development of a compact atmospheric remote sensing system, able to determine the VCD (Vertical Column

Density) of multiple trace gases. It is a low-cost and portable zenith-sky DOAS system (Figure 1) - hereafter referred to as ERO-DOAS - composed of a mini-spectrometer (HR4000, Ocean Optics), two optical fibers (400 µm of core, 6 m and 25 cm of longitude) and a home-made external shutter (Raponi et al., 2011).

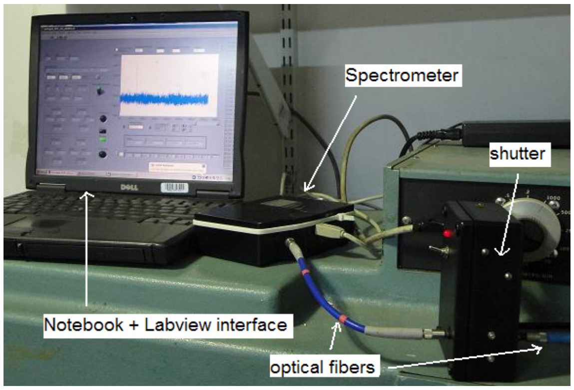

Figure 1. The zenith-sky DOAS system's components: a notebook, the software designed using Labview®, the spectrometer (HR4000), an automatic shutter and the optical fibers.

HR4000 allow us to+ measure solar spectral irradiance in the UV-visible range (290-650 nm). It is a simple spectrograph equipped with a fixed diffraction grating (600 grooves/mm blazed at 400 nm) and a 3648-pixel lineal array CCD. We developed an automatic shutter to determine the dark current of each measurement, and to remove this noise to the twilight spectra. A software development using Labview® controls the start and the end of spectral measurements, the retrieval of acquired spectra and the shutter. The computer internal clock is daily updated to avoid possible time shifts and to maintain accuracy on zenithal and azimuth angles calculations.

The software sets the CCD integration time to maximize signal/noise ratio. The dark (current) spectra are measured with the same integration time than the twilight spectra measured immediately before. This ensures that the subtracted dark noise is similar to the one actually measured over the illuminated period.

The instrumental function and the system resolution were determined using low pressure lamps spectra provided by the Physics Laboratory of Instituto Tecnológico de Buenos Aires (ITBA). We retrieved the spectrometer instrument function from a helium lamp. The full width at half maximum (FWHM) of the Voigt profile fitted to the He line was 1.03 nm at ~447 nm. The lamp spectra were also used to recalibrate ERO's wavelength mapping. This recalibration shows a shift of about -1.55 nm from the original (nominal) manufacturer calibration.

The analysis of visible spectra based on the DOAS concept presents the advantage of allowing for simultaneous retrieval of VCDs of different species, over a wide range of meteorological conditions. NO_2 and O_3 VCDs are retrieved from zenithal solar spectra (in the visible range) acquired on "twilight" conditions (zenithal angle between 87° and 91°) applying the DOAS (Differential Optical Absorption Spectroscopy) technique.

RESULTS

We present a study on the O_3 and NO_2 VCDs seasonal variation at Río Gallegos. In Figure 2 we can observe the NO_2 VCD seasonal variation at Río Gallegos during 2004-2011, retrieved by OMI/AURA. The concentration ranging from $6x10^{15}$ molec/cm^2 in summer to $1.6x10^{15}$ molec/cm^2 in winter and early spring.

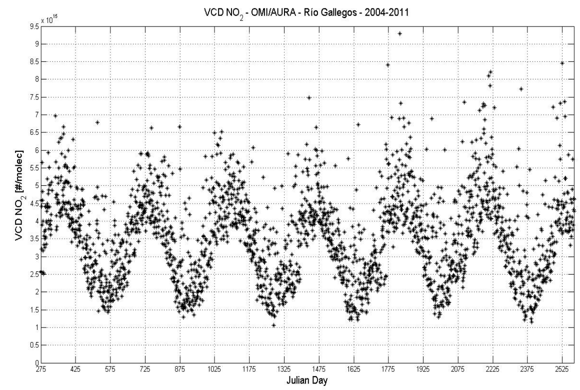

Figure 2. NO_2 VCD variability at Río Gallegos, Santa Cruz province, Argentina, retrieved by OMI-AURA, from 2004 to 2011.

Figure 3 show the NO_2 and O_3 vertical column densities obtained with a SAOZ spectrometer (Système d'Analyse par Observation Zenithale), LATMOS (Laboratoire Atmosphères, Milieux, Observations Spatiales), France, located in the CEILAP-RG station, during 2009.

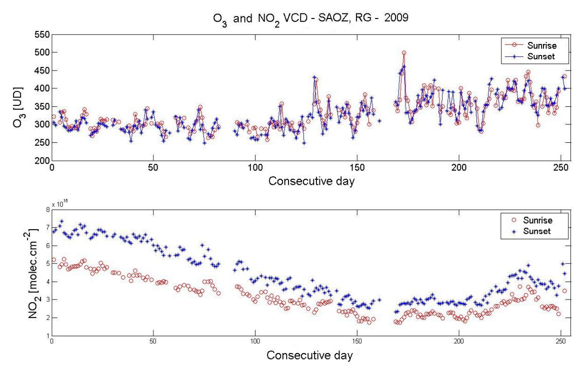

Figure 3: NO_2 and O_3 VCD seasonal variation during 2009, retrieved by SAOZ spectrometer at Río Gallegos.

In the case of the O_3 VCD significant differences are not observed among the concentrations at sunrise and at sunset, as us we waited. In the case of NO_2, to be a gas with a comparatively short photochemical time of life, it presents a significant variability during the day. For that reason, an important difference among the concentrations measured during the twilights, exist.

In Figure 4 we compare the O_3 and NO_2 VCD retrieved by ERO-DOAS and SAOZ spectrometer (both of them located in CEILAP-RG station), during September/December 2009.

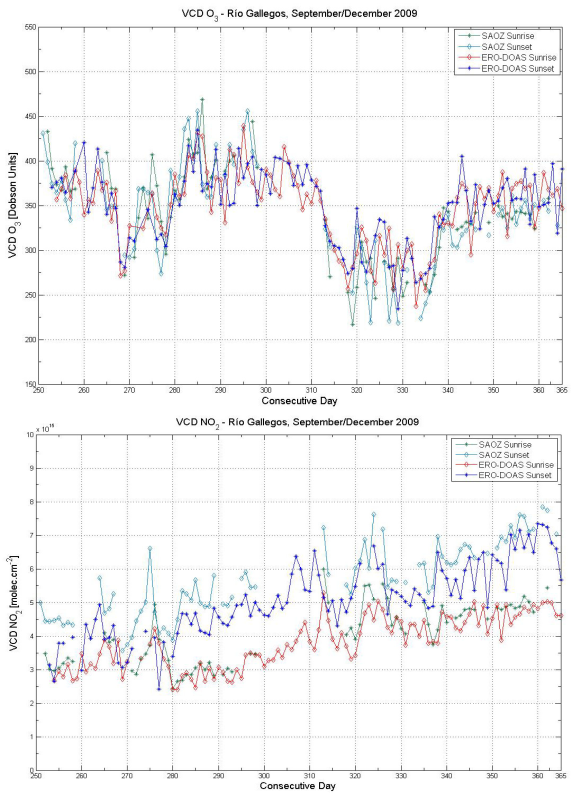

Figure 4. O_3 and NO_2 VCD retrieved by ERO-DOAS and SAOZ instruments at Río Gallegos, during September/December 2009.

For the ozone there is a good agreement among the instruments with an average relative difference about 13%. In the case of NO_2, we observe a better agreement among results at sunrise than at sunset between SAOZ and ERO-DOAS data.

CONCLUSIONS

Our zenith-sky DOAS system has the capability of sensing automatically several chemical species and the advantage of being portable (which offers the possibility to move the instrument to carry out measurements campaigns). We observe in both ground-based instruments a strong daily variability of the NO_2 VCD (sunrise vs. sunset). This variability is probably associated with the NO_x vertical distribution, the temperature in the high layers of the atmosphere and maybe the variability of other active species. In the case of the O_3 the daily variability of the gas is low, reason why the comparison between the sunrise and sunset data is very good.

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NÚMERO ESPECIAL DEDICADO A
LAS PRESENTACIONES Y POSTERS DEL
"VI WORKSHOP ON LIDAR MEASUREMENTS IN LATIN AMERICA"

Secciones

Los artículos en este número especial se distribuyen en las siguientes secciones:

I. **Presentaciones**: Estos trabajos muestran, en resumen, las presentaciones mostradas por los expositores del workshop.

II. **Posters**: En esta sección se presentan los posters presentados por los expositores, en la sessión de posters en el workshop.

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