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LALINET: The first Latin American-born regional atmospheric observational network

Juan Carlos Antuña-Marrero[(1)], Eduardo Landulfo[(2)], René Estevan[(1)], Boris Barja[(1,3)], Alan Robock[(4)], Elián Wolfram[(5)], Pablo Ristori[(5)], Barclay Clemesha[(6)], Francesco Zaratti[(7)], Ricardo Forno[(7)], Errico Armandillo[(8)], Álvaro E. Bastidas[(9)], Ángel M. de Frutos Baraja[(10)], David N. Whiteman[(11)], Eduardo Quel[(5)], Henrique M. J. Barbosa[(3)], Fabio Lopes[(2)], Elena Montilla-Rosero[(12,13)], and Juan L. Guerrero-Rascado[(2,14,15)]

(1) Grupo de Óptica Atmosférica de Camagüey, Centro Meteorológico de Camagüey, INSMET, Cuba

(2) Centro de Lasers e Aplicações, Instituto de Pesquisas Energéticas e Nucleares (IPEN), Avd. Prof. Lineu Prestes 2242, São Paulo, Brasil

(3) Instituto de Física, Universidade de São Paulo, Rua do Matão, Travessa R, 187, São Paulo, Brasil

(4) Department of Environmental Sciences, Rutgers University, 14 College Farm Road, New Brunswick, NJ 08901-8551, USA

(5) División Lidar, CEILAP (UNIDEF-CONICET), San Juan Bautista de La Salle 4397 (B1603ALO), Villa Martelli, Buenos Aires, Argentina

(6) Upper Atmosphere Research Group, FISAT, INPE, Brazil

(7) Laboratorio de Física de la Atmósfera, Universidad Mayor de San Andrés, Casilla 8635, La Paz, Bolivia

(8) ESTEC, ESA, The Netherlands

(9) Escuela de Física, Universidad Nacional de Colombia Sede Medellín, Calle 59ª Nº 63-20, Medellín Colombia

(10) Grupo de Óptica Atmosférica, Universidad de Valladolid, Valladolid, Spain

(11) GSFC, NASA, United States

(12) Centro de Óptica y Fotónica CEFOP, Universidad de Concepción, Casilla 4016, Concepción, Chile

(13) Escuela de Ciencias, Departamento de Ciencias Físicas, Universidad EAFIT, Medellín, Colombia

(14) Instituto Interuniversitario de Investigación del Sistema Tierra en Andalucía (IISTA-CEAMA), Av. del Mediterráneo, 18006, Granada, España

(15) Universidad de Granada, Dpto. Física Aplicada, Fuentenueva s/n, 18071, Granada, España

Address all correspondence to: J. C. Antuña-Marrero, Grupo de Óptica Atmosférica de Camagüey, Centro Meteorológico de Camagüey, Cuba

E-mail: jcam45@gmail.com

Capsule: A Latin-American community of scientists engaged in atmospheric research using lidar has been built during the last 15 years, and in the process has generated a regional lidar network.

Abstract:

Sustained and coordinated efforts of lidar teams in Latin America at the beginning of the 21st century have built LALINET (Latin American Lidar NETwork), the only observational network in Latin America created by the agreement and commitment of Latin American scientists. They worked with limited funding but an abundance of enthusiasm and commitment toward their joint goal. Before LALINET, there were a few pioneering lidar stations operating in Latin America, described briefly here. Bi-annual Latin American Lidar Workshops, held from 2001 to the present, supported both the development of the regional lidar community and LALINET. At those meetings, lidar researchers from Latin America meet to conduct regular scientific and technical exchanges among themselves and with experts from the rest of the world. Regional and international scientific cooperation has played an important role for the development of both the individual teams and the network. The current LALINET status and activities are described, emphasizing the processes of standardization of the measurements, methodologies, calibration protocols, and retrieval algorithms. Failures and successes achieved in the buildup of LALINET are presented. In addition, the first LALINET joint measurement campaign and a set of aerosol extinction profile measurements obtained from the aerosol plume produced by the Calbuco volcano eruption on April 22, 2015, are described and discussed.

Introduction:

From its establishment, the World Meteorological Organization (WMO) has promoted the development of local, regional, and global atmospheric observational networks, providing standardized, quality-controlled information (WMO, 1947). The role of observational networks has increased and evolved over the last half century. Nowadays, observational networks gather information about the state of the atmosphere with passive and active instruments, both at the surface and in space. Such information is of utmost importance for data assimilation by models forecasting the status of the earth-atmosphere system at multiple spatial and temporal scales. It is also fundamental for climate research and the development of policy responses, becoming a key component of the emerging Global Framework for Climate Services (WMO, 2011).

Networks of ground-based lidar (LIght Detection And Ranging) are now playing an important role at meteorological institutions worldwide for both services and research. That information complements satellite observations, because ground-based lidars can provide regular, high-resolution vertical profiles of atmospheric components like aerosols, clouds, ozone, and water vapor, all of which have been defined as *essential climate variables* (Bojinski et al., 2014). Satellites in contrast provide global observations of the atmospheric components but they are limited by temporal variation at a particular place and also by limited resolution in time and height. However, building a regional network of lidars is probably one of the most challenging of any ground-based atmospheric network-building processes. Among its challenges is the different instrumental design of existing lidars, mainly locally built at scientific and academic institutions. Another important challenge is the standardization of the diverse calibration, measurement, and data processing procedures. Because most of the lidars are built based on local research interests, it is also necessary to reconcile local scientific interests and practices with the ones from the network.

EARLINET (European Aerosol Research Lidar Network), http://www.earlinet.org/, established in 2000, is the pioneer regional lidar network (Bösenberg, et al., 2000; Pappalardo et al., 2014). Its establishment has been supported by funding from the European Community, together with funds from national governments for their local lidar teams. More recently, under the WMO Global Atmospheric Watch (GAW) aerosol program, a global aerosol network has been created. GALION (GAW Aerosol Lidar Observation Network), http://alg.umbc.edu/galion/, is devoted specifically to aerosols and has been organized as a network of lidar networks. It is composed of the existing regional lidar networks EARLINET, AD-NET (Asian Dust Network) http://www-lidar.nies.go.jp/ (Shimizu et al., 2004; Sugimoto et al., 2015), CISLiNet (Community of Independent States Lidar Network) (Chaikovsky et al., 2006), MPLNET (Micro-Pulse Lidar Network) http://mplnet.gsfc.nasa.gov/ (Welton et al., 2001), NDACC (Network for the Detection of Atmospheric Composition Change) http://www.ndsc.ncep.noaa.gov/ (Kurylo, 1991), CREST-CLN (NOAA Cooperative Remote Sensing Science and Technology Lidar Network), formerly REALM (Regional East Aerosol Lidar Mesonet) http://noaacrest.org/about/facilities/crest-lidar-network (Hoff et al., 2002), and LALINET (Latin America Lidar Network) http://lalinet.org/.

LALINET, the youngest GALION affiliate, was created during the First Workshop on Lidar Measurements in Latin America (WLMLA), held March 6-8, 2001, in Camagüey, Cuba. The report of the workshop stated, “A longer-term plan was also discussed to establish a network of LIDARs in Latin America using identical instruments, data processing, and measurement protocols, including taking measurements on the same days, and during satellite overpasses. This

America's LIDAR Network (ALINE) was strongly endorsed by the participants, who agreed to work together toward its establishment." (Robock and Antuña, 2001a).

Here we detail the first 12 years of LALINET, from the first ideas in 2001 to official recognition by WMO in 2013, a history that is intertwined inseparably with the WLMLA history and international cooperation. The present status of the network and future perspectives are also discussed.

Antecedents:

20th Century lidar projects in Latin America:

The first lasers, developed in the early 1960s, found immediate application for measuring atmospheric properties (Fiocco and Grams, 1964). The pioneering lidar project in Latin America (LA), and one of the few in the world at that time, operated in Kingston, Jamaica. It began in April 1964 (AFOSR, 1972) and continued until 1979 (Phillip et al., 1985). Located in Stony Hill, Jamaica (18.0°N, 76.8°W), and operated by the Physics Department of the University of West Indies, its main goal was to study atmospheric density profile using measurements of molecular scattering. However, it also proved useful from the very beginning for measuring stratospheric aerosol layers (Clemesha et al., 1966). Figure 1 shows the Mark 1 lidar system, the first of the two instruments developed by the project. The Mark 1 lidar was the result of a feasibility study, designed to measure Rayleigh scattering up to about 50 km. It was replaced by the Mark 2, which ultimately reached 100 km.

The next lidar was developed at INPE (Instituto Nacional de Pesquisas Espaciais - Brazilian National Space Research Institute), São José dos Campos, Brazil (23°S, 46°W) in 1969 for the study of mesosphere dynamics as its main interest, but stratospheric aerosol measurements were also conducted (Clemesha and Rodrigues, 1971). In 1972, the capability for measuring the sodium layer in the high mesosphere/lower thermosphere was installed (Clemesha and Simonich, 1978). By 2007, the capability for measuring mesopause temperatures between 88 and 100 km was added, using a Sodium Doppler lidar (Clemesha et al., 2010).

A Russian lidar for stratospheric aerosol measurements was installed at Camagüey, Cuba (21.4°N, 77.9°W) late in 1988, originating the Camagüey Lidar Station (CLS) which belongs to the Instituto Nacional de Meteorología (INSMET). The instrument operated irregularly up to 1997, but the team was able to maintain regular measurements of the Mt. Pinatubo stratospheric aerosols between January 1992 and November 1993 (see Figure 1 of Stenchikov et al., 1998). In addition, cirrus cloud measurements were conducted. The project history, including the transition from the CLS to the Grupo de Óptica Atmosférica de Camagüey (GOAC), has been previously described (Antuña et al., 2012a).

The University of Illinois Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) lidar was installed at the Arecibo Observatory, Puerto Rico (18.4°N, 66.8°W) in January 1989. It was operated as a Rayleigh and sodium lidar during the months of January, March and April 1989 (Kane et al., 1993). In April 1990, a Doppler Rayleigh lidar system developed in situ began to operate (Tepley et al., 1991; Tepley and Rojas, 1993). This lidar station, not associated with LALINET, is still operative (http://www.naic.edu/~lidar/lidar_home.html).

The fifth, and the most successful lidar project in LA, was developed by the Centro de Investigaciones en Láseres y Aplicaciones (CEILAP), belonging to the Instituto de Investigaciones Científicas y Técnicas del Ministerio de Defensa and the Consejo Nacional de Investigaciones Científicas y Técnicas, located at Villa Martelli, Buenos Aires, Argentina (34.6°S, 58.5°W). A first attempt to build a lidar and install it at the El Leoncito Astronomical Observatory in the Andes province of San Juan, in cooperation with the Istituto di Fisica dell'Atmosfera, Italy, and the Centre National de la Recherche Scientifique (CNRS), France, was abandoned because of the remote location of the site (Congedutti et al, 1993). The first lidar was built and installed in 1994 and began measurements in September the same year at CEILAP in cooperation with Pierre Flamant from CNRS and the Ecole Polytechnique, France (Giraldez et al., 1995; Quel, 2011).

The sixth lidar project is located at the Centro de Lasers e Aplicações, Instituto de Pesquisas Energéticas e Nucleares (IPEN), São Paulo University, Brazil. During a visit of Alexandros Papayannis from National Technical University of Athens (NTUA) to IPEN on August 27, 1998, an informal agreement was reached with NTUA. After the visit, he and Jacques Porteneuve from CNRS designed the elastic system that was built at IPEN and became operative in 2000 (Landulfo et al., 2001).

By the end of the 20th century, six lidar projects existed in LA, but only four of them were operative. There were almost no contacts or exchanges between them.

The Series of Workshops on Lidar Measurements in Latin America: the Backbone of LALINET:

In 1994, at the North Atlantic Treaty Organization (NATO) Advanced Research Workshop on the effects of the Mount Pinatubo eruption on the atmosphere and climate, held in Rome on September 26-30, 1994, an agreement was reached among several of the attendees to conduct a workshop on lidar measurements in Latin America. The workshop, planned to be held at Camagüey, Cuba the following year did not take place because of local organizational difficulties.

<u>I and II WLMLA:</u>

Working on his Ph.D., Juan Carlos Antuña-Marrero compiled the available stratospheric lidar measurements after the 1991 Mt Pinatubo eruption for comparison with the spatial-temporal coincident Stratospheric Aerosol Gas Experiment II (SAGE II) satellite measurements (Antuña et al., 2002a, 2003). In the process, he learned about the existing worldwide lidar projects at that time and got in contact with most of the teams, including the ones in LA. E-mail exchanges began with Barclay Clemesha, leader of the lidar team in São José dos Campos, Brazil, who provided the backscattering ratio monthly mean profiles from his site during the Mt. Pinatubo eruption. Joint analysis of the collected measurements showed that LA was one the regions with poor coverage of stratospheric lidars at the time of the Mt. Pinatubo eruption. In addition, by 1998 the SAGE II instrument, in orbit from October 1984, had far surpassed its expected lifetime of two years. The expected replacement, the SAGE III instrument, was on board the Russian satellite Meteor-3M in a polar orbit, conducting aerosol profile measurements over mid and high latitudes but not over the tropics. Under those circumstances, the global monitoring of any potential stratospheric aerosol plume from a tropical volcanic eruption would rely on tropical stratospheric lidars.

In July 1998, the lead author and René Estevan (then a technician and 1st year student of electric engineering at Camagüey University, Cuba) attended the 19th International Laser Radar Conference (ILRC). They presented a poster at the meeting, hosted at the US Naval Academy, Annapolis, Maryland. However, the most important issue was learning about the international lidar community and the particulars of organizing such a meeting in further exchanges with the organizers and attendees.

Extensive and fruitful discussions took place between Juan Carlos Antuña-Marrero and Alan Robock about all the former issues. They arrived at a joint commitment to rescue the failed earlier initiative of a WLMLA. A proposal was submitted in 1998 to the Program to Expand

Scientific Capacity in the Americas (PESCA), a call from the Inter-American Institute for Global Change Research (IAI). The project called "Characterization of Stratospheric and Tropospheric Aerosols over Central and South America," was led by Pablo Canziani from the Department of Atmospheric Sciences at the University of Buenos Aires, and with the participation of CLS and the Department of Environmental Sciences of Rutgers University. Among its goals was the improvement of observations of aerosols in this region. It included support for a WLMLA, held in Camagüey, Cuba on March 6-8, 2001 with 23 attendees (Table 1, Figure 2). The World Climate Research Program and the Stratospheric Processes and their Relationship to Climate Program co-sponsored this meeting. It became the first IAI workshop held in Cuba since the beginning of IAI (Robock and Antuña 2001a; 2001b).

The proposal included the first acronym selected for the future lidar network: ALINE (American Lidar NEtwork). It was envisaged as a hemispheric network, taking into account that the Americas are the only continent having land from the North to the South Poles (Antuña et al., 2002b). Pierre Flamant, in further exchanges, suggested the acronym LALINET (Latin American Lidar NETwork), which ended up being used broadly by the lidar community in LA, and is used now for consolidating a LA lidar network. Nevertheless, we have not given up the goal of ALINE as a hemispheric lidar network in the future.

Because of the success of the I WLMLA, the idea for conducting the II WLMLA gained momentum. It was organized also by the CLS team in cooperation with Alan Robock, and conducted in Camagüey, Cuba, February 17-21, 2003. The main financial support came from the European Space Agency (ESA), and additional funding contributed by the IAI, the Department of Environmental Sciences of Rutgers University, and the Cuban Meteorological Institute. The II WLMLA established several of the core practices for the following workshops. One of the most important was a lidar training course for new students and researchers in the field. They continue to be conducted in each workshop held up to this date. The II WLMLA reaffirmed the "gentleman's agreement" reached at the first one, a term selected for defining the way we work by cooperation among members with no formal structure, reaching decisions by consensus. In addition, the rotation of the WLMLA hosted by different lidar teams came into practice, with an offer made by Álvaro Bastidas to host the III WLMLA in Popayán, Colombia, in 2005.

Progress from the III to the VIII WLMLA:

The WLMLA series continues up to the present. Table 1 lists the years they took place and the hosting cities and countries. In addition, it contains information about the number of attendees, their geographical distribution, how many were students, and the number and types of presentations. The total number of attendees and the ones from LA show an increasing trend peaking at both the V and VI WLMLA followed by values at the same levels as IV WLMLA and before. More relevant is the fact that the percentages of LA attendees has remained above 60% from the IV WLMLA to the present, showing the predominantly Latin American character of the meetings and at the same time, the interest of the international scientific community. Regarding the number of students, after the 22% achieved at the I WLMLA, the number of attending students remained over 30%, with an average of 41% for the eight WLMLAs already hosted. The WLMLA has clearly achieved one of its main goals, to facilitate education and scientific capacity-building of students and young scientists related to lidar research in Latin America.

Table 1 shows that scientists from the rest of the world attended all of the eight WLMLAs already held, representing an average of 30% of the attendees, contributing to important exchanges and cooperation discussed in the next section. Oral presentations and posters show the same trends as the number of attendees, with an average of 15 posters and 25 oral presentations. In general, we are pleased with this level of participation, taking into account the size of the lidar community in LA and the number of existing lidars.

A series of presentations and papers at the ILRCs describe the progress, obstacles and challenges over the years building up LALINET (Antuña et al., 2002b, 2006, 2008, 2010, 2012b; Landulfo et al., 2015) http://lalinet.org/index.php/Main/Publications. In addition, each of the WLMLA local organizing committees has prepared a report of each meeting http://lalinet.org/index.php/Aline/Newsletter. In 2010 Eduardo Landulfo assumed the leadership and coordination of LALINET upon agreement of the lidar team leaders, as proposed by Juan Carlos Antuña-Marrero.

The VII WLMLA, held in Pucón, Concepción, Chile in 2013 signaled the end of a first cycle of rotation of the workshop hosting throughout all the existing lidar groups. A new rotation cycle began with the VIII WLMLA hosted at Cayo Coco, Ciego de Ávila, Cuba in 2015. From the time of the first workshop, care was taken to avoid hosting it in the same year as the ILRCs. However, in 2014 the 27th ILRC was postponed until 2015, the same year the VIII workshop took place in Cayo Coco, Cuba. To avoid that situation the IX Workshop was held successfully in Santos, São Paulo, Brazil, July 11-16, 2016, hosted by the IPEN lidar team. The X Workshop will be held in Medellin, Colombia, November 18 to 23, 2018.

LALINET formalized cooperation with GALION-WMO in 2013. The goals for LALINET include the continuation of the process of standardization of the measurements, calibration, and processing algorithms; maintaining regular workshops, with lidar courses; and increasing international cooperation both with individual teams and with the network. The main challenges have been finding funding for the workshops and for network activities and making the network and the individual team's goals compatible.

The Role of International Cooperation:

The support by Alan Robock and Pablo Canziani in the funding search, organization, and execution of the I WLMLA was the first of the many international cooperation contributions that made possible the buildup of LALINET. Right at the I WLMLA, international cooperation began. Under ESA support, promoted by Errico Armandillo, a refurbished lidar from Quanta System was made available for LALINET. The lidar team at the University of La Sapienza under the leadership of the late Giorgio Fiocco tested the instrument. The instrument was installed at the Laboratorio de Física de la Atmósfera, Universidad Mayor de San Andrés, La Paz, Bolivia, in 2006 (Forno et al., 2006). Unfortunately, the lidar had many problems with its electronics due to the altitude of La Paz, 3420 m. However, thanks to the enthusiastic support of David Whiteman at NASA Goddard Space Flight Center (GSFC), a new Nd:YAG laser was installed. In addition, several modifications, mainly to the optical and acquisition systems, were performed. That lidar system has been working properly in La Paz since 2010.

After the I WLMLA a proposal for establishing a lidar station at Quito, Ecuador (0º, 78ºW, 2850 m) was submitted to NASA, but it was not funded (Antuña et al., 2002b). ESA contributed to support the II Workshop, because of the initiative and enthusiasm of Errico Armandillo, who engaged himself in promoting LALINET worldwide. ESA continued providing financial support to each of the following WLMLAs until the present. That regular contribution has played an important role for guaranteeing basic support for the organizing and conducting the WLMLA series.

Beginning with the III WLMLA, the attendees have had the possibility of publishing their presentations as articles in *Óptica Pura y Aplicada* (OPA), a peer-reviewed journal of the Optical

Society of Spain (OPA, 2015). This has been possible thanks to the contribution of the Grupo de Óptica Atmosférica, University of Valladolid (GOA-UVA), Spain, led by Ángel de Frutos Baraja. Seventy papers have been already published in OPA between the III and the VII WLMLA (Antuña et al., 2012b). Two graduate students from Colombia began their Ph.D. studies at GOA-UVA by the end of 2005, under the supervision of Ángel de Frutos Baraja. They were mainly supported by fellowships from the Alban Program of the European Community. Both of them successfully completed their Ph.D.s and one of them, Elena Montilla-Rosero, returned in 2010 to LA. She engaged in the setup of a lidar station at the Center for Optics and Photonics (CEFOP), University of Concepción, Chile, and became the leader of the lidar team until the middle of 2015. The lidar has been operative since 2012 (Montilla-Rosero et al., 2012, 2016). During all the setup process, the collaboration with existing LALINET stations, such as São Paulo, Buenos Aires, and Medellín, was crucial.

In 1998, Differential Absorption Lidar (DIAL) ozone measurements began in Villa Martelli, Buenos Aires, Argentina, in cooperation with Gerard Megie from CNRS (Pazmiño et al., 1999; 2001). In 2002, the system was upgraded and installed in a laboratory-container donated by the CNRS and by 2005 in cooperation with the Japan International Cooperation Agency (JICA), it was moved to Rio Gallegos in Patagonia (Wolfram et al., 2005). This system has been part of NDACC since 2008, and it is being upgraded and prepared to continue operating into the near future in cooperation with JICA. A mobile DIAL lidar was set up at Villa Martelli in 2004 (Wolfram et al., 2004a) as well as a Raman water vapor lidar (Wolfram et al., 2004b).

The eruption of Puyehue-Cordón Caulle volcano in Chile in June 2011 caused the cancellation of many flights to and from Patagonia. The Defense Ministry of the Argentinian Republic instructed CEILAP to develop and install five lidar stations to measure volcanic ash around the country. By February 2015 the instruments were built and installed with funds from the Defense Ministry Special Project 31'554/11. They are located from south to north at the airports of Río Gallegos, Comodoro Rivadavia, Bariloche, Neuquén, and Aeroparque de Buenos Aires. The National Meteorological Service operates the lidars (Quel et al., 2015).

In cooperation with JICA a High Spectral Resolution Lidar, the first in Latin America, developed at CEILAP, became operative by December 2015 (Quel, 2015). For more than 20 years CEILAP has been conducting the lidar project in LA with the highest rate of increase in the number of lidar instruments, the most advanced technology, and measuring the broadest set of atmospheric variables with lidar. Cooperation with France has been very productive, initiated in 1975 by Eduardo Quel together with Gerard Megie, Sophie Godin, and Pierre Flamant from France. JICA has been cooperating with CEILAP from 1998 to the present with periodic international evaluations. The program SATREPS (JST/JICA) is currently supporting a five-year project between Japan, Chile, and Argentina for the development of an atmospheric environmental risk management system in South America (http://www.jst.go.jp/global/english/kadai/h2404_argentine.html).

In 2006 Eduardo Landulfo from the São Paulo lidar station at the Centro de Lasers e Aplicações, IPEN, Brazil, conducted a working visit to the GSFC and Howard University to learn about Raman lidar technology with David Whiteman and Demetrius Venable. It allowed Eduardo Landulfo to work on Water Vapor Raman Lidar calibration (Venable et al., 2011). It also allowed an upgrade of the original system to Raman and buildup of the UV Raman water vapor lidar. Further improvements of the system were conducted in cooperation with Igor Veselovskii and Mikhail Korenskii from the Physics Instrumentation Center, Moscow, Russia in 2010. Cirrus cloud lidar studies at São Paulo, began in cooperation with Phillip Keckhut from CNRS, France, in 2008 (Larroza et al., 2013). In early 2009, a new transportable commercial unit from Raymetrics Ltd. was added to the equipment pool and expanded the lidar measurement capabilities in Brazil. Soon it will be followed by a scanning lidar to be deployed in an industrial area near São Paulo. The newest system will be a 3-channel polarizing system in Natal, nicknamed DUSTER, to be assembled at IPEN with a telescope and detection system designed by Igor Veselovskii. It will perform measurements of aerosol long-range transport into the eastern part of South America.

The setup of the lidar station at Medellín, Colombia, was possible thanks to the cooperation and agreements reached at the workshops and exchanges with LALINET teams and other partners (Nisperuza and Bastidas, 2011). A set of loans and donations provided needed resources: a pulsed Nd:YAG laser donated by Massimo Del Guasta from the Institute of Applied Physics "NelloCarrara," Italy; photomultiplier detectors by Eduardo Landulfo, from IPEN, Brazil. In addition, a large Newtonian telescope optimized to 1064 nm and various optical and electronic elements have been donated through the efforts and willingness of David Whiteman from GSFC, who also supported the initiative and consolidation of a NASA-AERONET sun photometer site in Colombia. The Medellín lidar team has also benefited from its participation in major projects under the leadership of Victoria Cachorro and Ángel M. de Frutos Baraja, GOA-UVA.

The setup of a lidar station in the Amazon forest started in 2010, when the Laboratory of Atmospheric Physics of the University of São Paulo, Brazil, bought a commercial Raman lidar from Raymetrics Ltd. The advice from the lidar group at the Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany was important to determine the system best suited for long-term continuous measurements. The TROPOS team, led by Albert Ansmann, also contributed to solving alignment and thermal stability issues after lidar operation started in July 2011. In addition, Birgit Heese (TROPOS) and Boris Barja (GOAC) contributed to the development of the elastic and Raman algorithms in 2012. Standard quality assurance procedures, as in most LALINET stations, started to be fully applied only in 2014, with the collaboration of Juan Luis Guerrero-Rascado, from the University of Granada in Spain (Barbosa et al, 2014a; Guerrero-Rascado et al., 2016).

Many other colleagues from all over the world have contributed as professors, members of award committees of the workshops, and direct advice to the network and/or individual teams. In addition, many contributions of spare parts and equipment have already taken place. No less important has been the support for attendance at international conferences and meetings, training and fellowships, including for Ph.D. students, several of whom returned to LA.

ICLAS and ILRC's:

In 2006 at the 23rd ILRC, held in Japan, the International Coordination group on Laser Atmospheric Studies (ICLAS) elected Juan Carlos Antuña-Marrero as one of its members, representing LA. He served a 6-year term, proposing Eduardo Landulfo as ICLAS member at the end of his term. Eduardo Landulfo was elected ICLAS member at the 26th ILRC held in Greece, in 2012. He was already coordinating LALINET activities. Having a representative at ICLAS during all those years granted LALINET connection and exchanges with the broad lidar community worldwide. It also allowed publicizing of the activities conducted in LA and searching for international cooperation.

GALION:

In March 2007, the I GALION Workshop took place at the Max Planck Institute in Hamburg, Germany. Juan Carlos Antuña-Marrero was invited and he joined the WMO Panel commissioned for the design and implementation of GALION representing LALINET (Bösenberg et al., 2008). At the II GALION Workshop, held at WMO Headquarters in Geneva in September 2010, both Eduardo Landulfo and Juan Carlos Antuña-Marrero attended to facilitate the transition between the former and new coordinator of LALINET activities. In early 2013, Eduardo Landulfo signed a formal agreement for the official contribution of LALINET to GALION (http://lalinet.org/uploads/Aline/Commitment/Aline_Letter_WMO_GAW.pdf). The goal of formalizing LALINET had been reached, but new challenges emerged for it, required to become a standardized lidar network.

Current LALINET status and activities:

Table 2 lists the existing lidar teams and the main technical features of their 10 operating instruments, also shown on the map in Figure 3. The ten operational stations are distributed from 46°S to 6°N and 75°W to 46°W. They are all located in urban/suburban environments except the one in Manaus, Brazil. Although Raman lidars are located in seven of the 10 stations, they are concentrated in Argentina (4) and Brazil (3). In the rest of the countries, Bolivia, Colombia, and Chile, the systems are elastic lidars. It is expected that new stations will be developed in the region covering a larger area and homogenizing its geographical distribution.

The status of LALINET is characterized by the coordination and execution of several joint actions and activities. The workshops continue as a central mechanism for the coordination of the general and long-lasting actions, with a LALINET executive meeting and the open discussion session. In addition, the workshops continue being an educational tool for capacity building.

There is an overlap between the Argentinian Lidar station operation – since some of them are closely related to an operational volcanic alert network in collaboration with the local weather service and Air Force – and the LALINET operational tasks, which are more devoted to academic/scientific goals. Those stations in the operational network should be included when they have satisfied the LALINET/WMO protocol in measurements and data quality requirements, but which due to manpower and schedule follow up have not yet fully joined LALINET.

Diagnostics and quality control tests of LALINET instrumentation have already been conducted and will be updated regularly. Preliminary actions have already taken place for establishing measurement protocols, data assurance programs, and cross validation and calibration campaigns to reach a better technical status. The first joint measurement campaign and comparison of lidar inversion algorithms has been conducted successfully. Monitoring of the Calbuco eruption aerosols was the most recent combined effort in LALINET. We describe briefly those actions:

First LALINET campaign and comparison of lidar inversion algorithms:

The first LALINET Pilot campaign was conducted September 10-14, 2012, during the South American biomass-burning season. Only four of the eight lidars in the LALINET network that could have participated were able to conduct measurements: Manaus at 355 nm, São Paulo at 355 and 532nm, Buenos Aires at 355, 532 and 1064 nm, and Concepción at 532 nm. Simultaneous measurements coordination was a challenge because seven of the eight lidar stations depended on fair weather and on a local operator for the measurement routine (Barbosa et al., 2014b).

The campaign was followed by the first comparison of the individual teams' algorithms for the elastic retrieval of the aerosol backscatter coefficient. Raw signal profiles from the four stations were manually screened. Then a 1-hour average cloud-free profile was selected from each station dataset. The resulting four elastic profiles were processed by members of each lidar group using their own elastic lidar algorithm. Figure 4 shows the results achieved at 2nd and 4th comparison stages for the four cloud-free profiles produced by the algorithm of each one of the four participating teams. The improvement reached at stage 4 is illustrated by the good agreement between the derived backscatter profiles. Only in the case of the Buenos Aires profile was a fifth stage necessary. This effort was the first step in the standardization of the measurements, calibration, and processing algorithm. It also demonstrated that coordination is one of the main challenges of this type of activity (Barbosa et al., 2014b). Results were encouraging although many difficulties remained to be solved. Thus, it was decided that a new series of workshops was necessary, but this time focused on developing a common set of data analysis algorithms. The I Workshop on Lidar Inversion Algorithms of LALINET took place in March 10-14, 2014 at CEFOP, University of Concepción, Chile, who financially supported it. Its goal was to compare the inversion algorithms for elastic backscatter lidars from the different LALINET teams in order to develop a uniform unified and improved algorithm. This time, simulated lidar datasets, provided by EARLINET colleagues (Böckmann et al., 2004), were used instead of measurements for the algorithm evaluation. Several bugs in the algorithms were fixed and important progress was achieved during the four-day meeting (LALINET, 2014). Lack of funding for LALINET as a network is limiting how often we can hold these algorithm-development workshops, but a second is planned for 2017.

Diagnostics and quality control tests of LALINET instrumentation:

The first step for the standardization of LALINET instruments was conducting an instrument inventory. It consisted of compiling a wide set of technical specifications (covering station information, mode of operation, and emitter/receiver features, among others). This arduous task highlighted the instrumental strengths and weaknesses of LALINET. In particular, it was demonstrated that current LALINET measurements are not appropriate for research on aerosol microphysical properties due to the reduced number of wavelengths available in the network. In addition, some physical and optical aerosol properties cannot be distinguished in LALINET measurements in spite of being relevant in strategic areas where the impact of long-range transport of Saharan dust or volcanic aerosols is possible. Nevertheless, the capabilities for water vapor profiling allow studies to be conducted on one of the important climate issues: aerosol hygroscopic growth. In addition, most of the LALINET lidars are not serially-produced systems and, consequently, a strict quality assurance is required (Guerrero-Rascado et al., 2016).

An inter-comparison of all LALINET systems, performing co-located and simultaneous measurements, is not possible because of current funding limitations and logistical problems. However, instrumental harmonization has been done since 2014 by adapting the instrumental quality assurance protocols routinely applied in EARLINET (Freudenthaler et al., 2016; Wandinger et al., 2016). The aim of such tests is to detect potential anomalies in the performance of the individual lidar systems. Quality control procedures applied by EARLINET including fundamentals, examples and file format were adapted and distributed among LALINET stations. Tests were implemented to characterize the performance in the near range (quadrants and in-out telecover tests), in the far range (Rayleigh fit test), the electronic noise (dark current test), and the synchronization between the pulse-firing mechanism and the recording system (zero-bin and bin-shift tests). In 2014, all these tests were requested to be conducted at each LALINET station and to be submitted by the middle 2014. After evaluation, an individual report for each station was submitted to the station principal investigator. It included evaluation of the tests, assessment, and suggestions to improve the instrumental performance in case it was needed. Six of the nine

LALINET systems had already carried out the instrumental quality assurance tests by the end of 2014.

Deficiencies in some stations were mainly related to optical misalignment or deficient optical design, resulting in an inappropriate performance in the near and/or far range. By means of these tests, it was possible to identify the LALINET stations with high-level performance and the deficiencies to be overcome in some stations for getting a robust, trustable lidar network in the future. It was agreed that the quality assurance protocols would be applied once per year or more frequently if instrumental upgrades are performed. In 2015, similar results were obtained for all stations and these protocols started to be applied on the new lidar system DUSTER (still under implementation) in Natal, Brazil.

Examples of the quality assurance tests conducted are depicted in Figures 5 and 6. Figure 5 shows the quadrant telecover test for the channel 355 analog mode for the system MAO (Manaus, Brazil) on June 9, 2015. The telecover test is used to compare several lidar signals collected using different parts of the telescope. In particular, the procedure for the quadrant telecover test consists in dividing the telescope aperture in four quadrants, defined (clockwise) as North (in reference to the laser beam), East, South and West. Measurements are taken covering three quadrants by a dark sheet and only the remaining quadrant collects the backscattered signal coming from the atmosphere. The instrumental conclusions extracted from data shown in Figure 5 are trustable due to the negligible atmospheric variability (from the comparison of sectors North and North2) during the measurement sequence. The comparison among these signals allows assessing the performance of a lidar system in the near range. Signals shown in Figure 5 reveal that the altitude for the maximum normalized lidar range corrected signal (*RCS*) in the near range was achieved following the expected sequence (North ≈ North2 < East = West < South), indicating good lidar alignment in the near range. In addition, no differences among quadrants were found above ~1 km.

In Figure 6 the Rayleigh fit on September 17, 2015 is shown for the channel 532 photon counting mode of the system MAO installed at Manaus (Brazil). The Rayleigh or molecular fit is a tool that is able to characterize the quality alignment of a lidar system in the far range. To this aim, the *RCS* is compared to the expected molecular range corrected signal (β_{mol}^{att}). β_{mol}^{att} takes into account the molecular backscatter coefficient, the correction with square distance and the attenuation due to atmospheric transmittance. Only photon counting signals are used for this test because they allow us to investigate the far height range. Figure 6 shows a good agreement between the molecular attenuated backscatter signal and the normalized atmospheric backscatter with a similar trend above 6 km up to more than ~18 km. Peaks observed between 12 and 15 km correspond to several cirrus cloud layers. For this case, this height range 6-12 km can be used as reference altitude for Klett-Fernald and Raman inversion methods. Examples of zero-bin, bin-shift and dark current tests can be seen in Guerrero-Rascado et al. (2014) for a non LALINET lidar system installed in Cubatão (Brazil).

Monitoring Calbuco eruption aerosols:

On April 22, 2015, the Calbuco volcano in Chile (41.33°S, 72.62°W) erupted after 43 years of inactivity, followed by a great amount of aerosol and gas injection into the atmosphere. Pyroclastic material dispersed into the atmosphere, posed a threat to aviation traffic and air quality over a large area, from its location to the Patagonian and Pampa regions, reaching the Atlantic and Pacific Oceans and neighboring countries, Argentina, Brazil, Paraguay and Uruguay, transported by the westerly winds at these latitudes. The presence of volcanic aerosol layers could be identified easily near Calbuco and thereafter by satellite remote sensors and ground-based lidars in the path of the dispersed aerosols. CALIPSO and MODIS were the space platforms used to track these layers and lidars from the LALINET network, as well as independent stations in South America, gave us the possibility to get a 4-D distribution of Calbuco aerosols during the eruption event and the following days after its occurrence (April 22-30). Most of the lidar stations had collocated AERONET sun photometers to help in the optical characterization and not all LALINET stations were able to observe this event given the air circulation pattern dominating this part of the globe and their distance from the location of atmospheric injection. A special web page has been setup at the LALINET web site containing information of our measurements http://lalinet.org/index.php/Campaign/CalbucoVolcano2015.

Lidar quick looks in the cited web site show no signal of Calbuco at the La Paz and Medellin lidar stations. From the rest of the lidar quick looks it could be seen that the aerosols from Calbuco eruption were registered at the lidar stations located at Aeroparque (Buenos Aires), Comodoro Rivadavia, Bariloche, Neuquén and Rio Gallegos, all five in Argentina. In addition, the lidars at Concepcion, Chile and Sao Paulo, Brazil also measured the aerosols from the Calbuco eruption. Here we illustrate the Calbuco lidar measurements conducted at three of those LALINET network sites, selected according to their location with respect to Calbuco volcano: CEFOP, University of Concepción, Chile lidar located west of the Calbuco, the nearest station to the volcano, Aeroparque, Buenos Aires, Argentina, lidar located east of Calbuco and São Paulo, Brazil, the northernmost LALINET station that measured Calbuco aerosols. Preliminary results from those stations follow.

The quick look of the lidar range corrected signal at 532 nm from CEFOP, University of Concepción, Chile, for the afternoon of April 23 is shown in Figure 7. The tropospheric aerosols from Calbuco can be seen, ranging between 5 and 9 km. They were observed for the first time around 12:45 LT and lasted until at least 21:00 LT, showing a decrease of its vertical extension, initially between 5 and 9 km to ~~around half a km~~ around 7 km of altitude by 21:00 LT. When the aerosols were registered for the first time, they showed a multilayer structure between 5 and 9 km of altitude. The multilayer structure was present from 14:30-19:00 LT; then the original, clearly defined layers, apparently merged completely. Nevertheless, from that time up to around 19 LT, a layered structure of the aerosols range corrected signal is evident. After near 19:30 LT the layer notably decreased its intensity and narrowed.

Lidar range corrected signal in Figure 7 was averaged and subsequently integrated considering a lidar ratio of 55 (Ansmann et al., 2010; 2011; Grofl et al., 2012) to generate Figure 8. In Figure 8 the resulting profile of the extinction coefficient is shown. The aerosol extinction coefficient maximum appears in a narrow double layer around 8 km of altitude.

The daily mean AOD at 500 nm measured by an AERONET sun photometer, located at the Concepcion University, is shown in Figure 9. The daily mean AOD at 500 nm has a value of 0.26 for April 23. The AOD at 532 nm calculated from the same day integrated profile of aerosols extinction coefficients, both in time and altitude, has a value of 0.28, showing a very good agreement with the AOD at 500 nm measured by the sun-photometer.

Figure 10 shows the quick look of the lidar measurements conducted at Aeroparque, Buenos Aires, Argentina (34.559 °S, 58.417 °W). From 21 LT to 24 LT of April 24 at altitudes ranging between 5 and 7 km the first signals of the aerosol layers are evident, showing a sinking tendency. Around 1:00 LT three narrow layers of tropospheric aerosols are detected by first time below 6 km and above around 4.5 km of altitude, that merged by 3:00 LT. From 1:00 LT to around 7:00 LT the aerosol layer continues to sink down to above the 3 km of altitude. In addition, the vertical size of the layer increases with top above 5 km and base below 4 km between 5:00 LT and

8:00 LT. For the next 13 hours, up to 21:00 LT the aerosol layer remains around 4 km with a slow tendency of its thickness to decrease. Although the Aeroparque lidar, to the east of the Calbuco, measured a tropospheric aerosol layer like the one measured by the CEFOP lidar, to the west of the volcano, the altitude, vertical structure and time variability are different. Only the multilayer structure is present in both aerosol layers when they were detected by first time at both lidar sites. Further studies are required to understand this behavior and explain the individual mechanisms of formation and transport of each one of these volcanic tropospheric aerosol layers. The quick look also shows the nocturnal to diurnal transition and evolution of the boundary layer, reaching up to around 2 km of altitude during the day.

The aerosol extinction profiles were calculated integrating the lidar range corrected signal every 15 minutes, then using the Fernald backwards equation in the intermediate region. A lidar ratio of 55 sr^{-1} was selected to convert the lidar backscattering to lidar extinction, like in the case of the CEFOP lidar described above (Ansmann et al., 2010; 2011; Grofl et al., 2012). The integration of the lidar aerosol extinction to calculate the AOD was only applied to the tropospheric aerosol layer, excluding the aerosols present in the boundary layer. We used AERONET AOD sun photometer observations conducted at CEILAP (34.6°S, 58.5°W), around 8 km from Aeroparque, quality control level 2.0 after verifying that the AERONET cloud-screening algorithm did not discard any of the level 1.5 data for April 25 at Buenos Aires. Sun photometer AOD at 532 nm was derived from the AOD at 500 nm and the Ångstrom exponent derived from the AOD at the wavelengths of 500 and 675 nm. Then sun photometer AOD values at 532 nm every 15 minutes were derived by interpolation to match the lidar wavelength. AOD from the lidar and the sun photometer appears in Figure 11. There is a very good match between Calbuco AOD derived from lidar measurements and the total AOD measured by the AERONET sun photometer. The differences between the lidar AOD and the sun photometer AOD (δAOD) are also plotted, ranging $\pm$ 0.05. The mean value of δAOD is on the order of 10^{-4}, approximately two orders of magnitudes below the magnitudes of the minimum errors of the sun photometer and the lidar AOD. Positive values of δAOD could be caused by boundary layer aerosols, not accounted for in the lidar AOD calculations.

Figure 12 shows the lidar measurements conducted at São Paulo University (SPU) on the afternoon of April 27, 2015. The signal produced by the Calbuco volcano aerosols is located around 19 km, well into the stratosphere. Differently from the lidar quick looks at CEFOP on April 23 and at Buenos Aires on April 25, the aerosol layer from Calbuco, measured at SPU on April 27 was in the stratosphere and remain almost unchanged in altitude and structure for the whole period it was observed. The meteorological sounding conducted at the Campo Marte weather service station (WMO code SBMT) at 00 UTC shows the tropopause located around 16 km, confirming the volcanic aerosol layer is located completely in the stratosphere.

Lidar extinction profiles retrieved at SPU at 532 nm are compared with space and time coincident aerosols extinction profiles measured by the Ozone Mapper and Profiler Suite, Limb Profiler (OMPS/LP) instrument. Ångstrom exponents (α_A) were used to calculate extinction coefficients at 532 nm from the OMPS/LS extinctions coefficients at 674 nm. In one calculation, α_A is kept constant in altitude with a value of 2.31, derived from OMPS/LS simulations (Taha et al., 2011). Another option is to use α_A from the 1991 Mt. Pinatubo volcanic eruption, calculated from the size distributions of the stratospheric sulfuric acid aerosol derived from balloon borne particle counter measurements. Four height intervals from the tropopause to 30 km were defined for α_A with a time resolution of four months from 1991 to 1999 in the spectral range 355 nm to

1064 nm (Jäger and Deshler, 2002). We selected α_A values corresponding to the first four months after the Mt. Pinatubo eruption.

In Figure 13 the OMPS/LP aerosol extinction profiles for 532 nm derived from the aerosol extinction profile at 674 nm are shown with 1 km vertical resolution, derived using both constant-in-altitude α_A and the post-Pinatubo-vertical-layer-defined α_A. The OMPS/LP measurement was conducted at 26°S and 37°W on April 27, 2015 at 16:26:03 UTC, 1019 km from the lidar located at SPU (23.56°S, 46.74°W). The aerosol extinction profile retrieved by the lidar, with a 7.5 m vertical resolution, at this site on April 27 is shown in Figure 13. The lidar ratio of 64 sr used to retrieve the extinction profile was obtained by the applying the two-way transmittance method for the volcanic layer (Platt, 1973; Chen et al., 2002). According to a NASA OMI + GEOS-5 model simulation, the OMPS/LP measurement took place in the thick part of the stratospheric aerosol layer, while a thin part of the stratospheric aerosol layer was located over the SPU lidar (Krotkov, 2016). This explains the differences in the aerosol extinction profiles, wider in the case of the OMPS/LP measurements and narrow in the lidar aerosol extinction profile at SPU. However, the aerosol extinction profiles from OMPS/LP and the SPU lidar show coincidence in the magnitude of the maxima of the aerosol extinction profiles and their vertical location. Further analyses are being conducted by LALINET teams.

Summary:

In this paper, we describe the origin of LALINET, which began as a series of technical meetings and evolved into a coordination of lidar stations together with ancillary instrumentation. The entire process took about 15 years and had many contributions and collaborations from scientists and institutions throughout the globe. The recognition of the network by WMO and GALION was a landmark and started a new era for the network. There are no antecedents of an atmospheric observational regional network built in Latin America by the agreement of Latin American scientists. However, there are many potential future opportunities and scientific goals to grant new insights into the state of the climate in the Caribbean, Central and South America, which will demand much coordination and the need to search for fostering mechanisms to achieve these goals. LALINET serves as an example of creating a new young community in the field and keeping it intact. But maintaining it will require continuing effort to maintain excellence in our activities, sustain the progress reported above, and ensure its continuity into the future.

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Table 1: History of the Workshop on Lidar Measurements in Latin America (WLMLA). Total attendees includes those from Latin America (LA) and those from the Rest of the World (RW). Students (ST) are also listed. For the three categories of attendees, the percent with respect to the total number of attendees appears in parenthesis. Also the number of presentations (Papers) by categories are listed as Posters (PO) and Oral presentations (OR, includes lectures).

WLMLA (Year)	**Location**	**Attendees**				**Papers**	
		LA	**RW**	**Total**	**ST**	**PO**	**OR**
I (2001)	Camagüey, **Cuba**	9 (39%)	14 (61%)	23	5 (22%)	5	14
II (2003)	Camagüey, **Cuba**	13 (52%)	12 (48%)	25	13 (52%)	2	25
III (2005)	Popayán, **Colombia**	41 (79%)	11 (21%)	52	26 (50%)	6	25
IV (2007)	Ilhabela, **Brazil**	30 (71%)	12 (29%)	42	20 (48%)	16	29
V (2009)	Buenos Aires, **Argentina**	42 (65%)	23 (35%)	65	21 (32%)	31	31
VI (2011)	La Paz, **Bolivia**	52 (81%)	12 (19%)	64	32 (50%)	15	21
VII (2013)	Pucón, **Chile**	35 (76%)	11 (24%)	46	19 (41%)	20	24
VIII (2015)	Cayo-Coco, **Cuba**	29 (71%)	12 (29%)	41	15 (37%)	25	19
IX (2016)	Santos, São Paulo, **Brazil**	52 (90%)	6 (6%)	58	22 (40%)	25	23

Table 2: Existing LALINET lidar teams and the main technical features of their operating instruments.

City, Country	Lat, Long Elevation	Lidar system	Start year	Environment type
Medellín, Colombia	6.26ºN, 75.58ºW 1538 m	Elastic, 1064 & 532 nm	2012	urban
Manaus, Brazil	2.89ºS, 59.97ºW 100 m	UV Raman, 355, 387, 408 nm	2011	forest, some land use around
La Paz, Bolivia	16.54ºS, 68.07ºW 3420 m	Elastic, 532nm	2010	urban
São Paulo, Brazil	23.56ºS, 46.74ºW 740 m	Raman; emits 355 & 532; detects 355, 387, 408, 532, 607 & 660 nm	2001	urban
São Paulo, Brazil	23.56ºS, 46.74ºW 740 m	UV Raman; emits 532; detects 532 & 607 nm	2009	urban
Buenos Aires, Argentina	34.56ºS, 58.51ºW 20 m	Raman; emits 1064, 532, 355; detects 1064, 607, 532, 408, 387, 355 nm	2012	suburban
Concepción, Chile	36.84ºS, 73.02ºW 170 m	Elastic, 532nm	2012	urban
Neuquén, Argentina	38.95ºS, 68.14ºW 271 m	Raman; emits 1064, 532, 355; detects 1064, 607, 532 ∥, 532 ⊥, 408 nm	2013	urban/suburban
Bariloche, Argentina	41.15ºS, 71.16ºW 840 m	Raman; emits 1064, 532, 355; detects 1064, 607, 532, 408, 387, 355 nm	2012	urban/suburban
Comodoro Rivadavia, Argentina	45.79ºS, 67.46ºW 49 m	Raman; emits 1064, 532, 355; detects 1064, 607, 532 ∥, 532 ⊥, 408 nm	2012	urban/suburban

Figure Captions:

Figure 1: Mark 1 Lidar, University of West Indies, Kingston, Jamaica. Photo taken between 1965 and 1966. (Photo by Barclay Clemesha.)

Figure 2: Group photo from the 1st Workshop on Lidar Measurements in Latin America, held at Camagüey, Cuba, March 6-8, 2001. In front seated, from left to right: Alan Robock, Barclay Clemesha, Dale Simonich, Reynaldo Victoria, and Errico Armandillo. Back row, standing, from left to right: Juan Carlos Antuña-Marrero, René Estevan, Boris Barja, Arturo Peña, Roberto Naranjo, Roger Rivero Vega, Elian Wolfram, Orlando Rodriguez, Roberto Aroche, Eduardo Palenque, Ruben Delgado, Craig Tepley, Patricia Mothes, Shikha Raizada and Minard Hall. (Photo by Alan Robock.)

Figure 3: Geographical distribution of the LALINET lidar stations listed in Table 2.

Figure 4: Particle backscatter coefficients (Mm^{-1} sr^{-1}) obtained by each participating group at the 2nd and 4th processing stages on top and bottom respectively. From left to right, results from São Paulo, Concepción, Manaus, and Buenos Aires datasets. Groups 1-4 represent the four lidar algorithms (one from each lidar team) that were intercompared.

Figure 5. Example of quadrant telecover test of the channel 355 analog mode for system MAO (Manaus, Brazil) on June 9, 2015. Colors refer to the different quadrants: North (N, black), East

(E, red), South (S, green), West (W, blue) and North 2 (N2, magenta). Curves represent the lidar range corrected signals normalized at the height-range 4-5 km.

Figure 6. Example of Rayleigh fit for the channel 532 photon counting mode for system SPU (São Paulo, Brazil) on September 17, 2015. Molecular signal (in red) represents the theoretical behavior expected under clean conditions (no aerosol particles or clouds). The measured lidar signals, normalized at the height-range 10-12 km is shown in black.

Figure 7: Quick look of the lidar range corrected signal at 532 nm measured at CEFOP, University of Concepción, Chile, the afternoon of April 23, 2015. The signal between 5 and 9 km shows tropospheric aerosols from the Calbuco volcanic eruption.

Figure 8: Profile of the extinction coefficient at 532 nm at CEFOP, University of Concepción, Chile, for the afternoon of April 23, 2015. The lidar range corrected signal has been integrated for the entire time period shown in Figure 7. Vertical resolution is 7.5 m.

Figure 9: Daily mean AOD at 500 nm measured by an AERONET sun photometer at CEFOP, University of Concepción, Chile, for the entire month of April 2015. The quality level of AERONET is 1.5. April 23rd is denoted by the vertical blue dashed line.

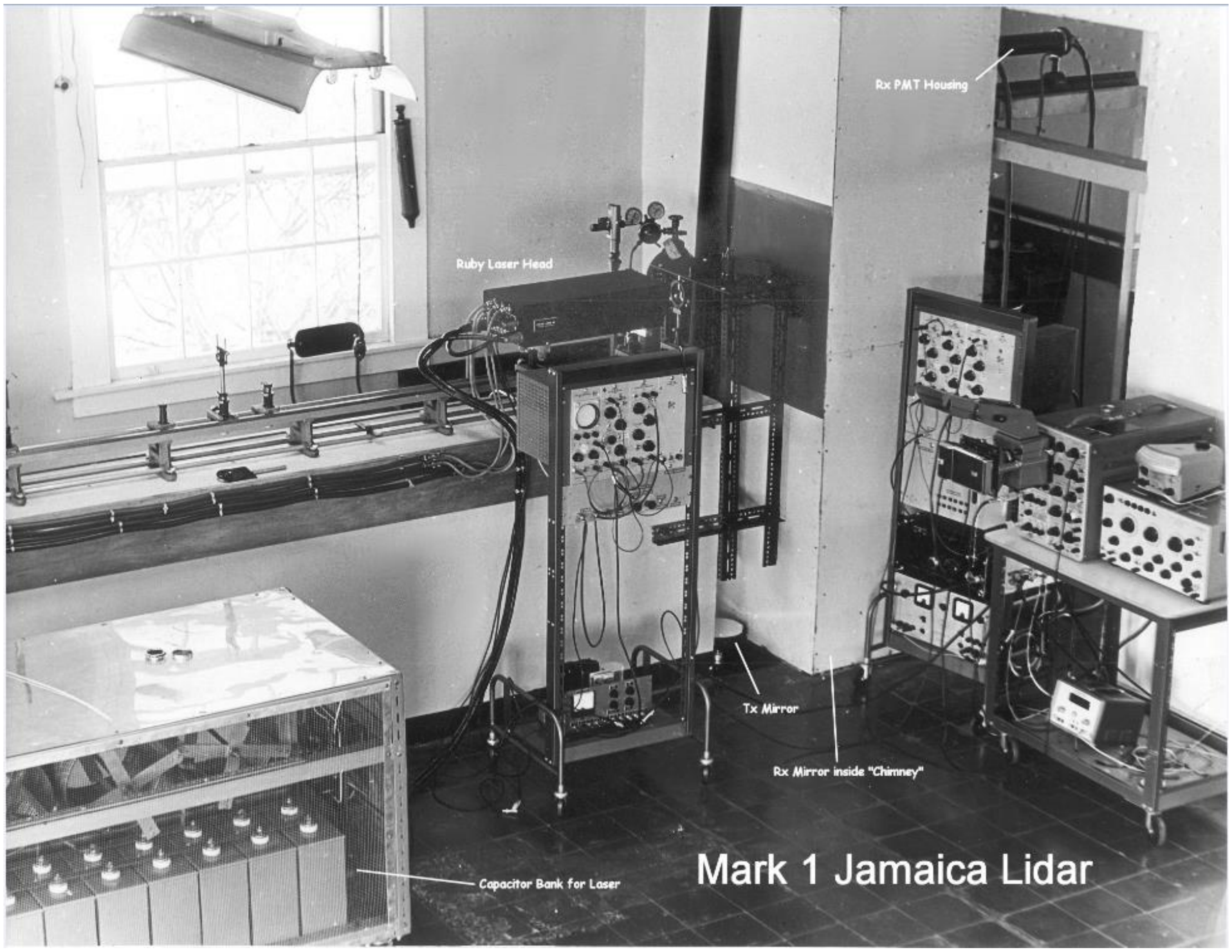
Figure 10: Quick look of the lidar range corrected signal at 532 nm measured at Buenos Aires, Argentina (34.559 °S, 58.417 °W), on April 25, 2015. The signal between 4 and 6 km shows

tropospheric aerosols from the Calbuco volcanic eruption. Vertical resolution is 45 m and temporal resolution 1 minute.

Figure 11: Fifteen minute mean AOD from the lidar measurements at 532 nm (blue stars) and fifteen minute mean AOD at 532 nm from the sun photometer (black circles). δAOD values represent the difference between the sunphotometer AOD and lidar AOD (magenta diamonds). Measurements from both instruments at Buenos Aires, Argentina, on April 25, 2015.

Figure 12: Lidar range corrected signal at 532 nm measured at SPU (São Paulo, Brazil) the afternoon of April 27, 2015. The signal around 19 km is aerosols from the Calbuco volcanic eruption.

Figure 13: Lidar aerosols extinction profile at 532 nm (green) retrieved by the SPU (São Paulo, Brazil). OMPS/LP aerosols extinction profiles at 532 nm derived from OMPS/LP aerosols extinction profiles at 674 nm, using two sets of Ångstrom exponents, indicated here as κe.



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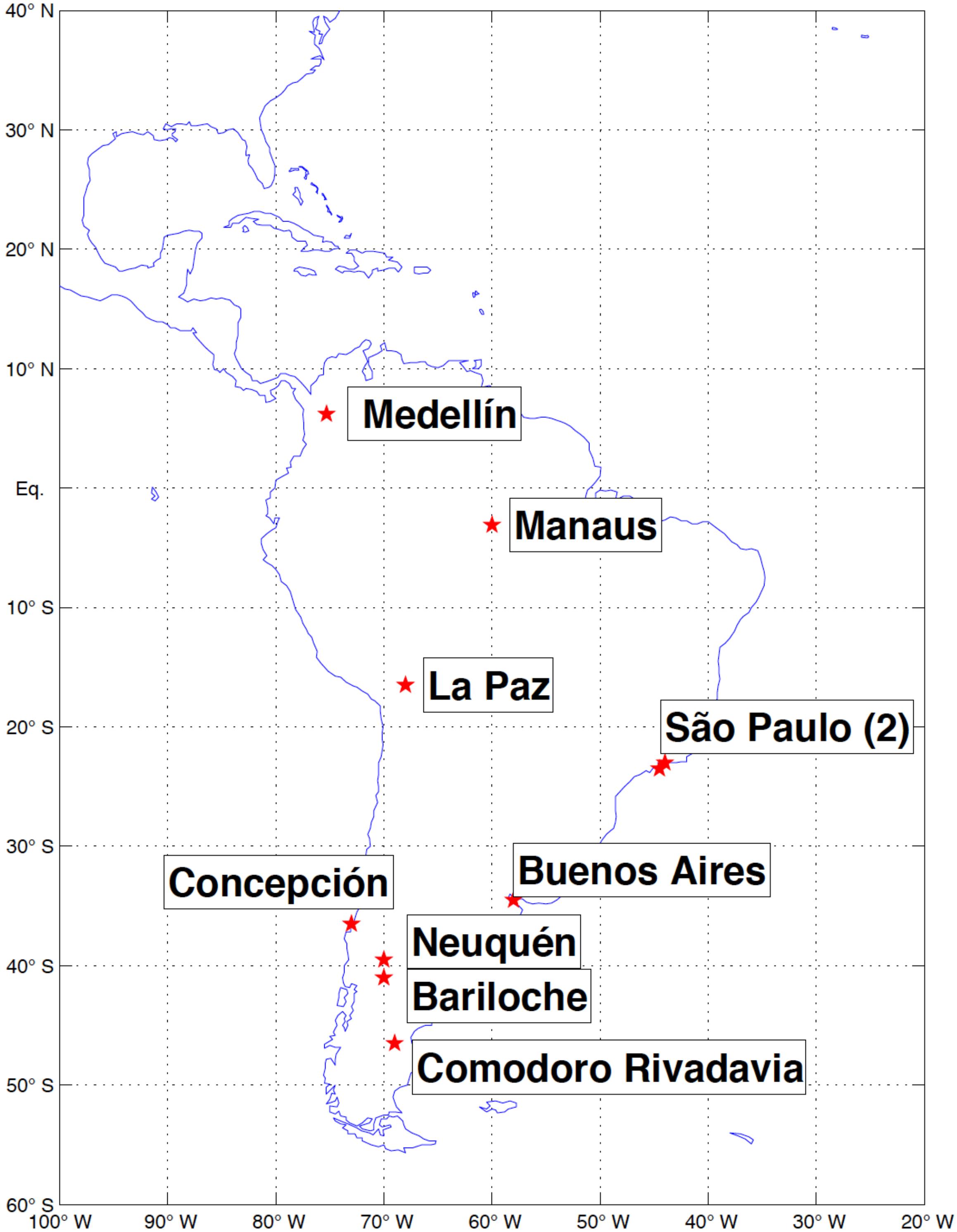

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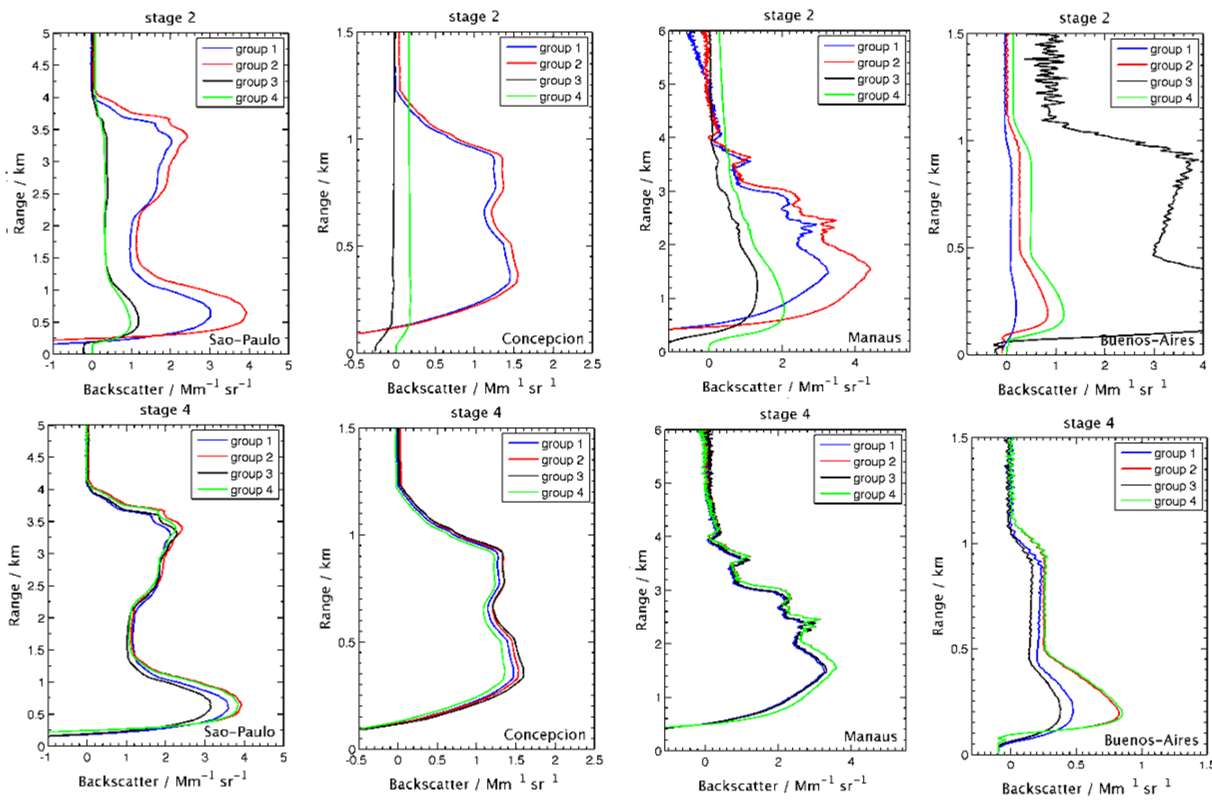

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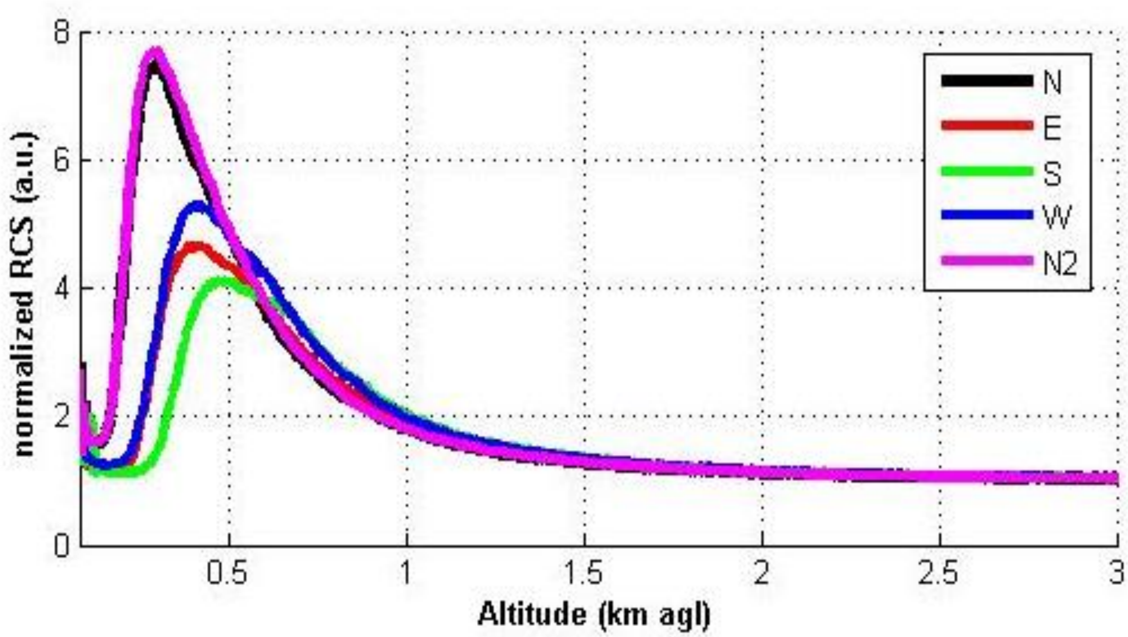

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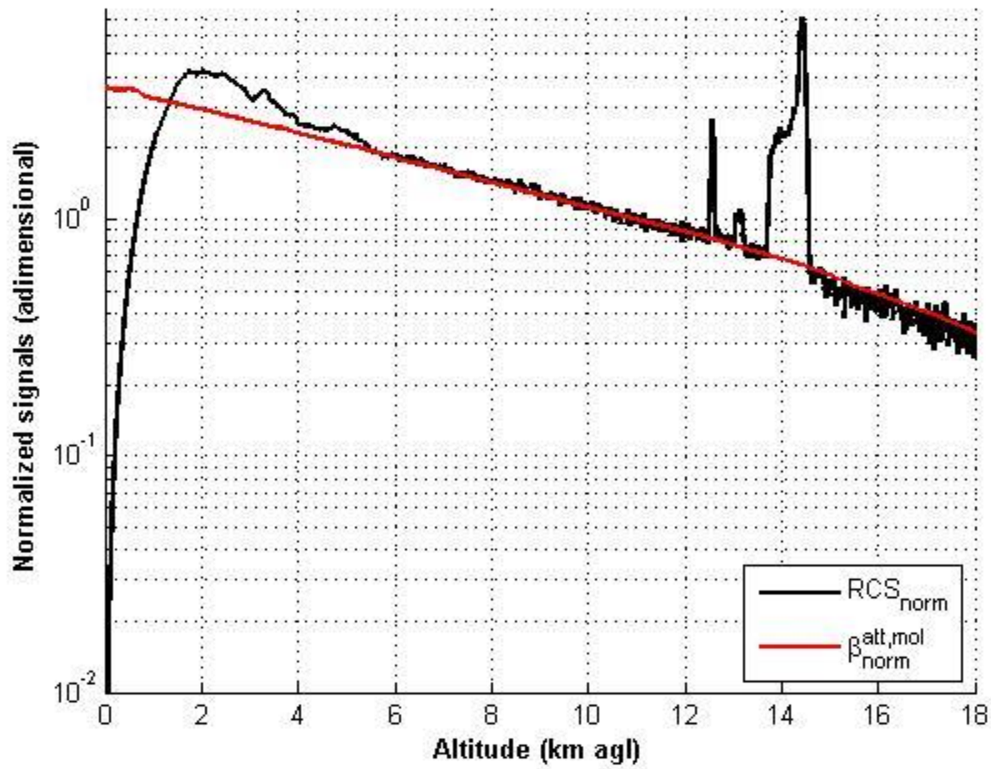

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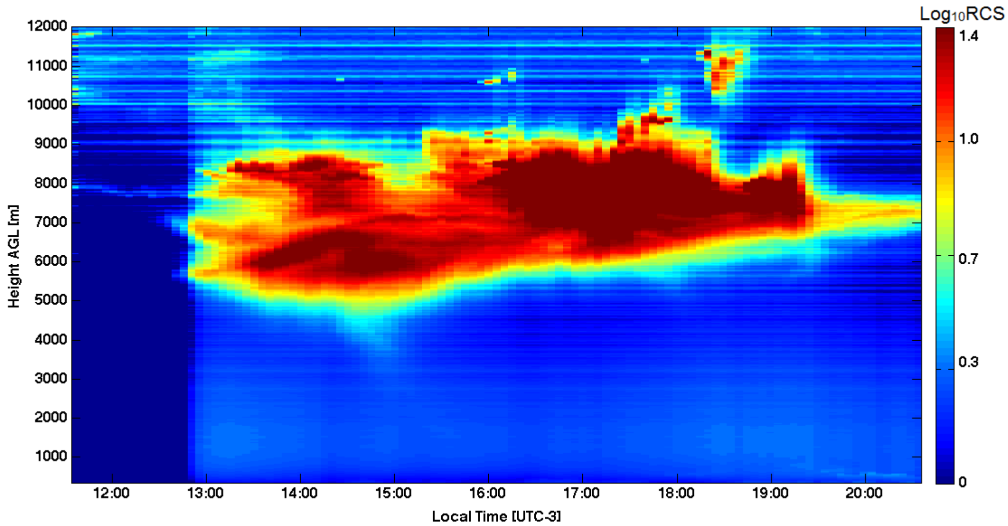

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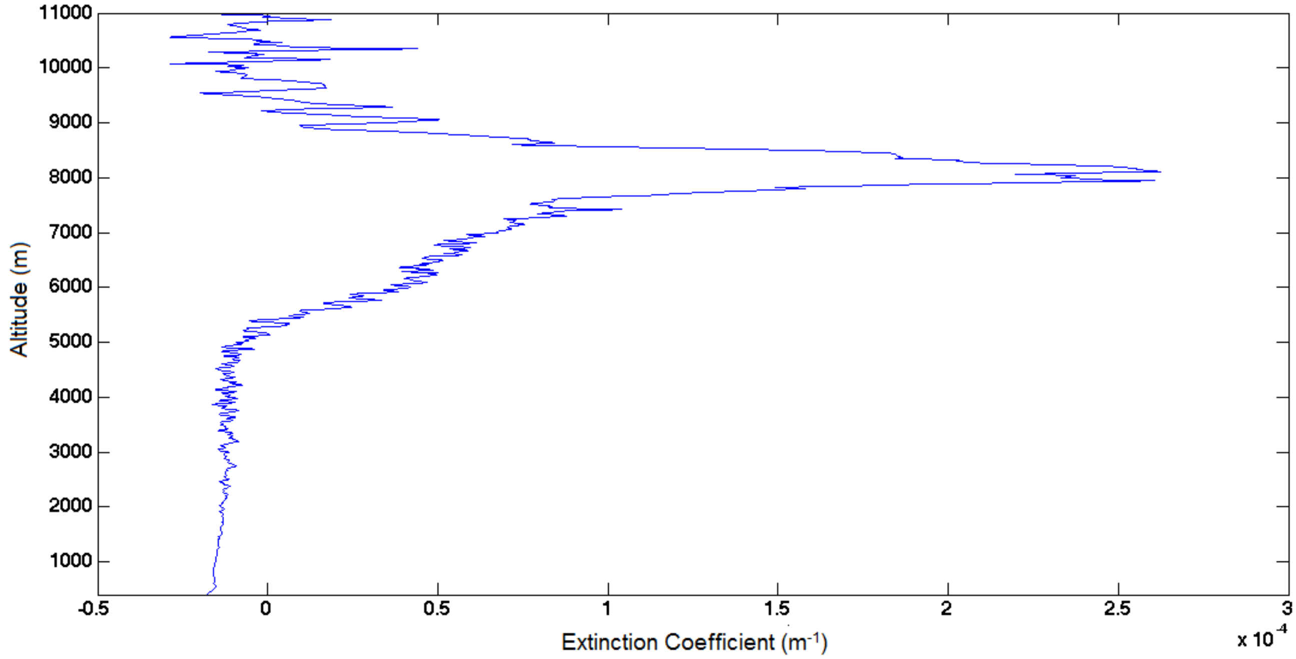

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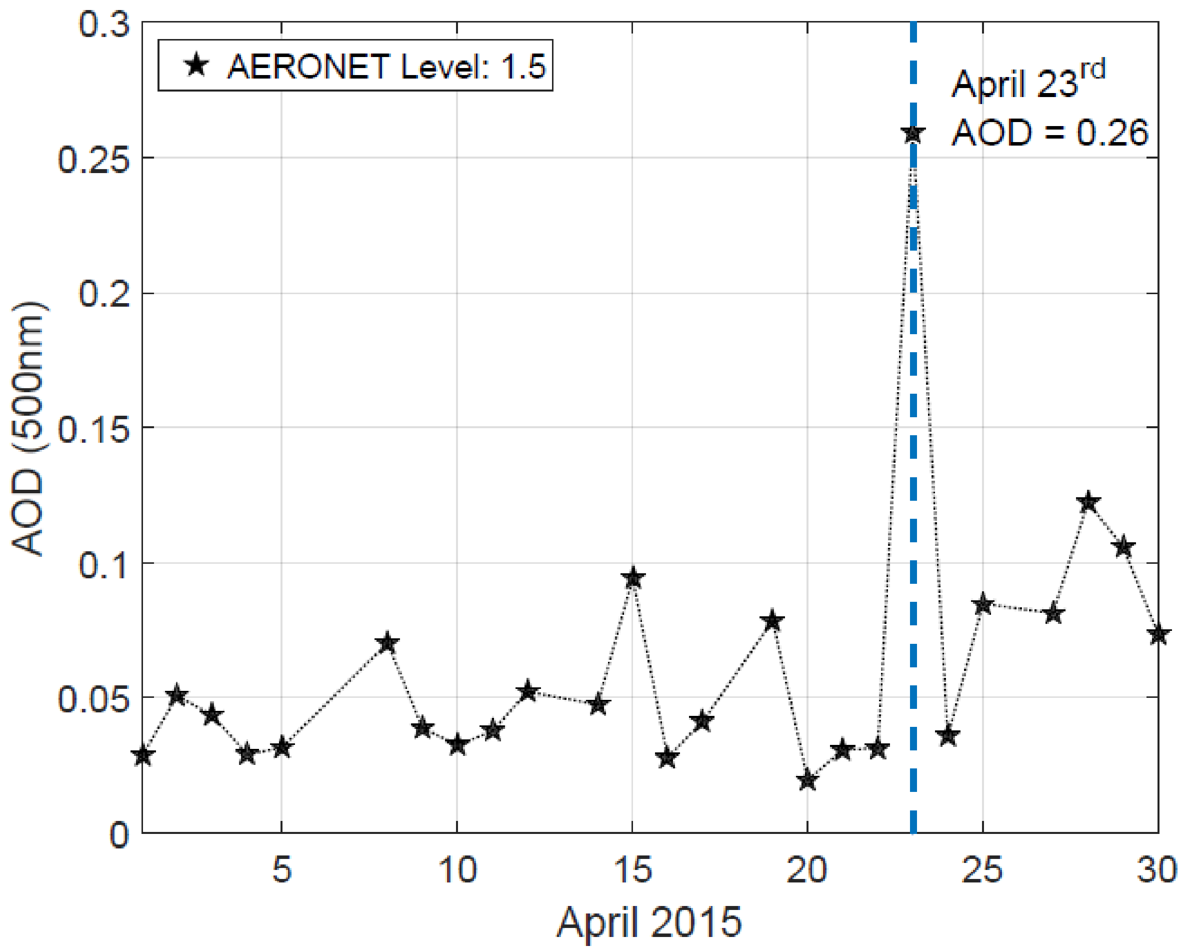

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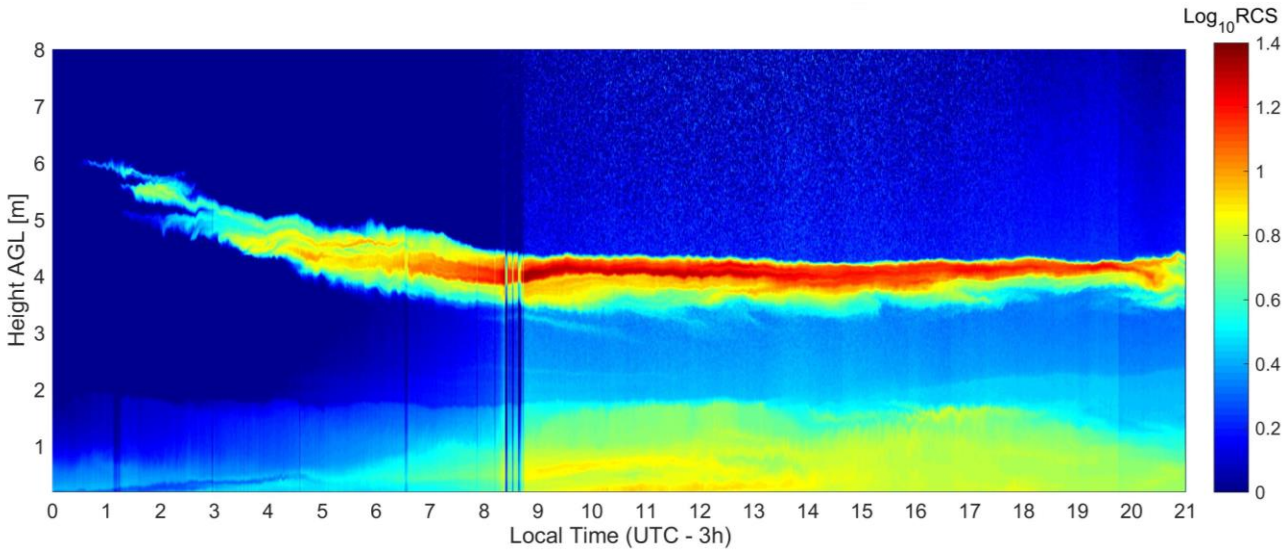

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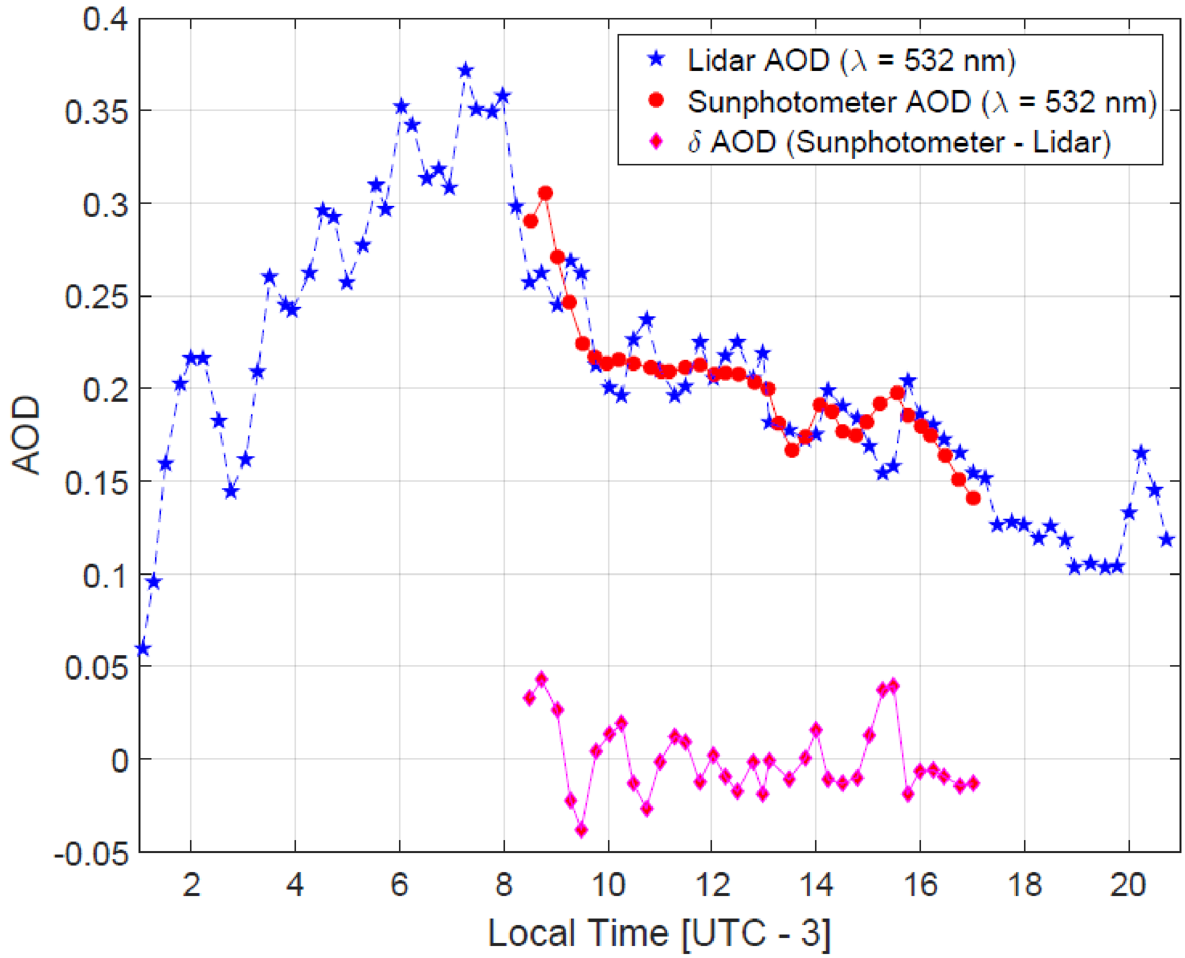

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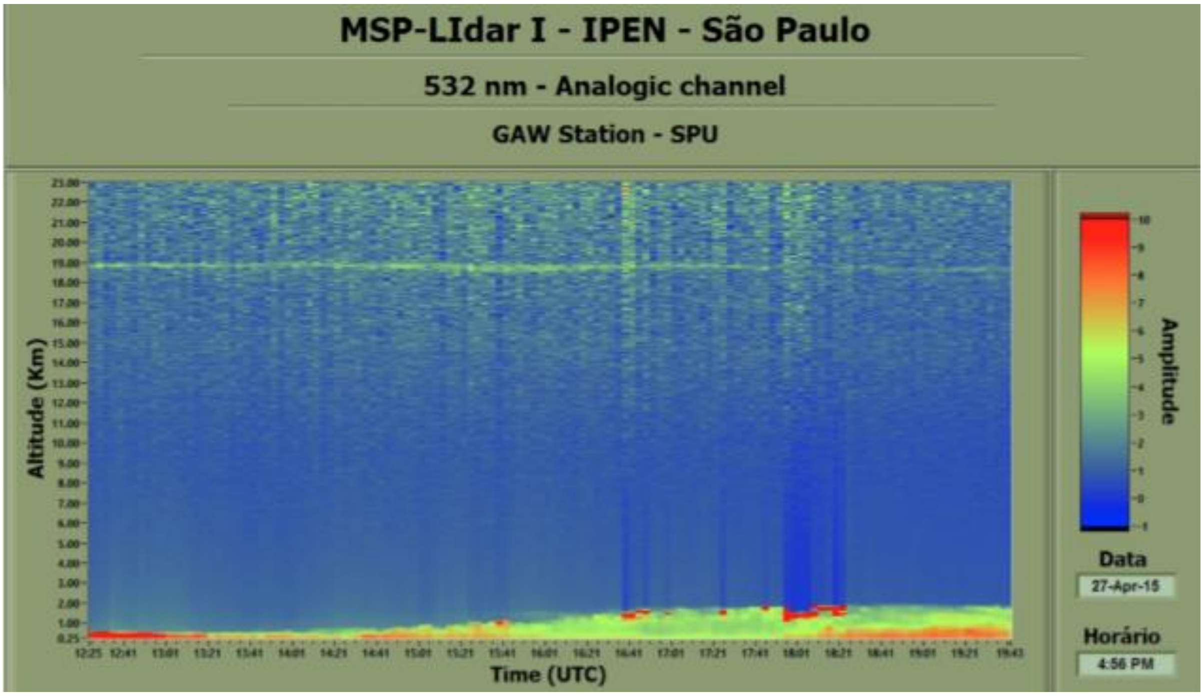

Figure 12: Lidar range corrected signal at 532 nm measured at SPU (São Paulo, Brazil) the afternoon of April 27, 2015. The signal around 19 km is aerosols from the Calbuco volcanic eruption.

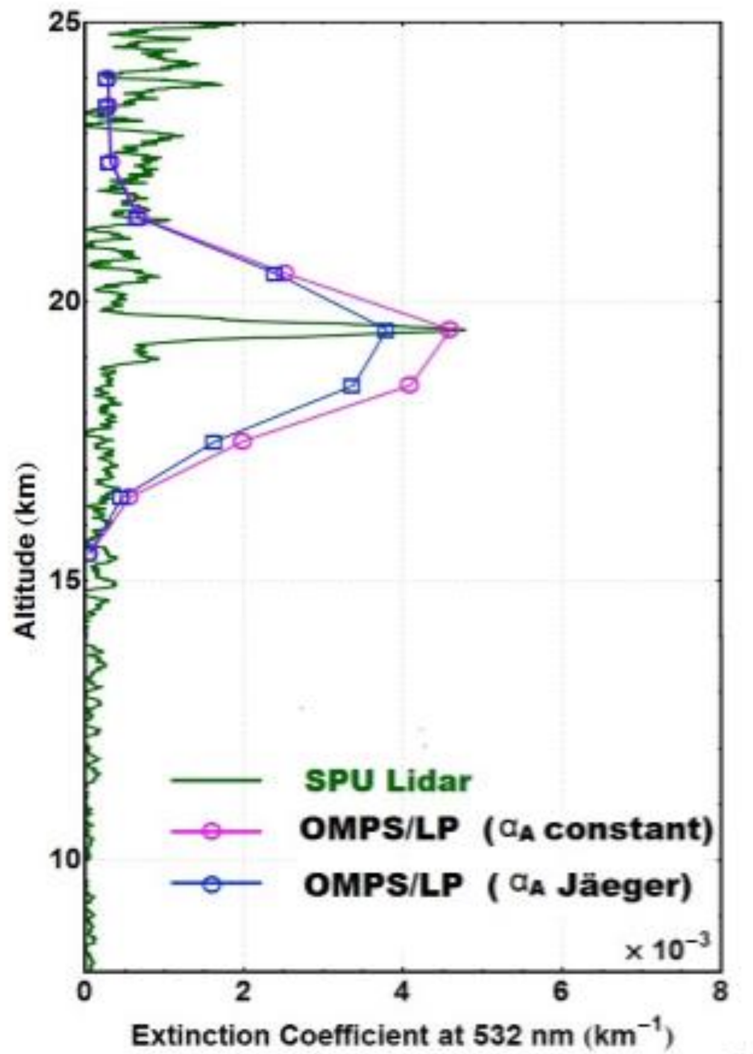

Figure 13: Lidar aerosols extinction profile at 532 nm (green) retrieved by the SPU (São Paulo, Brazil). OMPS/LP aerosols extinction profiles at 532 nm derived from OMPS/LP aerosols extinction profiles at 674 nm, using two sets of Ångstrom exponents, indicated here as α_A.