Towards an instrumental harmonization in the framework of LALINET: Dataset of technical specifications

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Towards an instrumental harmonization in the framework of LALINET: dataset of technical specifications

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ABSTRACT

The Latin American Lidar Network (LALINET) is the aerosol lidar network operating over South America. LALINET is now an operative network performing a schedule of routine measurements and, currently, is composed by 9 stations distributed over South America. The main objective of LALINET is to generate a consistent and statistically relevant database to enhance the understanding of the particle distribution over the continent and its direct and indirect influence on climate. The creation of an un-biased spatiotemporal database requires a throughout review of the network on two pillars: instrumentation and data processing. Because most of the LALINET systems are not series-produced instruments and, therefore, present large differences in configuration and capabilities, attempts for network harmonization and, consequently, optimization are mandatory. In this study a review of the current instrumental status of all LALINET systems is done and analyzed in detail in order to assess the potential performance of the network and to detect networking weaknesses.

Keywords: harmonization, instrumentation, LALINET, lidar, networking activities, technical specifications

1. INTRODUCTION

Earth's atmosphere is composed of gases, atmospheric aerosol particles, cloud particles and falling hydrometeors. Despite their small mass (and/or volume) fraction, particles strongly influence the weather and climate because they influence the transfer of radiant energy and the spatial distribution of latent heating through the atmosphere [1]. Cloud and aerosol particle features (including amount, optical and microphysical properties) are extremely variable in space and time. As summarized in the Fifth Assessment Report of the Intergovernmental Panel on Change Climate, a multi-regional analysis for 1973–2007 [2] shows that prior to the 1990s visibility-derived

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AOD was relatively constant in most regions analyzed, but after 1990 positive AOD trends were observed over several regions of the planet, including parts of South America [3]. At present, clouds and aerosol particles continue to contribute the largest uncertainty to estimates and interpretations of the Earth's changing energy budget [1].

Advanced aerosol measurements in South America are demanding and are constrained by the lack of infrastructure in this wide area. Until now the long-term aerosol monitoring has been performed by means of AERONET (Aerosol Robotic Network) [4]. However, the reduced number of South-American stations (less than 1% of the total number of level 1.5 AERONET stations) difficult the comprehensive knowledge of the aerosol's role over this part of the world. Moreover, these difficulties are enhanced since routinely information on vertical distribution of aerosol is almost missing. Only short-term studies at different locations (e.g. [5]) and a medium-term analysis of systematic (1 year) multiwavelength polarization Raman lidar observations of particle optical and microphysical properties over the Amazon Basin [6] have been reported. The synergetic combination of thorough, robust and well-established observation systems as AERONET and LALINET (Latin American Lidar Network) are needed to properly quantify the effect of different aerosol types over South America.

LALINET (http://lalinet.org) is a Latin American coordinated lidar network focused on the vertically-resolved monitoring of the particle optical properties distribution (i.e. particle backscatter and extinction profiles) over Latin America, as well as other atmospheric species such as ozone and water vapor. On voluntary basis, this federative lidar network, started in 2001, aims to establish a consistent and statistically relevant database to enhance the understanding of the particle distribution over the continent and its direct and indirect influence on climate. However, the creation of an un-biased spatiotemporal database requires a throughout review of the network on two pillars: instrumentation and data processing. Regarding instrumental aspects, two networking activities have been recently launched, namely (i) collection of information to generate a dataset of technical specifications, and (ii) application of quality tests to improve the characterization of LALINET systems. In this study we present results concerning the first task.

At present, this lidar network consists of 11 lidars operated by 7 groups in 9 stations distributed over South America, covering from Cuba to Argentina and from Chile to Brazil (Figure 1). Most of them are not series-produced instruments and, therefore, present large differences in configuration and capabilities. Thus, the performance of each non-standardized instrument may be different and attempts for network harmonization and, consequently, optimization is mandatory. To this aim, an instrumental inventory was distributed, structured to accommodate a wide variety of lidar configurations. The objective of this work is to provide a review of the current instrumental state of LALINET.

Figure 1. Lidar stations belonging to LALINET. Camagüey station is marked in grey because currently no lidar is operating at this site.

2. METHODOLOGY

Because of the inhomogeneity of LALINET stations, attempts for network harmonization and, consequently, optimization is mandatory. To this aim, an instrumental inventory was distributed, structured to accommodate a wide variety of lidar configurations. The information to be fulfilled for each instrument, with around 80 different entries, is organized as follows:

- *category 1: station information*. Characteristics such as station's and system's name, geographical coordinates and date of system upgrade are included here.

- *category 2: mode of operation*. Zenithal pointing versus scanning capabilities and automatic operation functions are detailed in this section.

- *category 3: emitter*. Information regarding the technical specifications of the laser (as wavelengths, energy per pulse, polarization, beam diameter and divergence) together with descriptors of the beam laser after expansion and alignment are considered here.

- *category 4: receiver optics*. The type of telescope together with its instrumental parameters (as diameter of primary/secondary mirrors, focal length or field of view) and the distance between laser and telescope axes are included in this section.

- *category 5: wavelength detection*. This section involves information regarding the different wavelengths detected, and filters and detectors used.

- *category 6: data acquisition*. Information concerning the data acquisition system and spatial and temporal resolutions are detailed here.

- *category 7: auxiliary information*. This comprises ancillary information as availability of routinely radiosounding launches and sun-photometric information together with additional instrumentation.

The compiled information is stored in an incremental database representing the network metadata repository. It is envisaged that the database will be updated every time that one of the parameters recorded will change at one of the instruments. It will allow to have the updated instrumental information from the whole network and at the same to keep tracking of all the changes occurring in time.

3. RESULTS AND DISCUSSION

The instrumental inventory was distributed in all LALINET stations. After collecting and analyzing all available information, it was possible to perform a detailed report of technical specifications grouped in seven categories. The main results extracted from this networking activity are described in this section.

The information regarding the stations is the first collected category. Table 1 lists the LALINET lidar systems with their official names, locations and geographical coordinates. At present, no lidar system is available in the Camagüey station in Cuba.

Figure 2 shows the main features regarding the mode of operation. The type of pointing in lidar systems is one crucial parameter to determine their applications. Traditionally, lidars are zenith-pointing systems allowing the retrieval of particle optical properties profiles as the particle backscatter [7-10] and extinction coefficients [11], particle lidar ratio [11], particle depolarization ratio [12,13] and similar optical properties for water clouds [14]. Most of the LALINET systems (around 80%) are zenith-pointing lidar. Moreover, those off-zenith systems allow to monitor optical properties of additional atmospheric targets. As it is well-known, the tendency of certain ice crystal shapes (such as plate-like ice crystals) to orient uniformly in space with their maximum dimensions parallel to the ground can result in ambiguous determination of depolarization ratios (leading unexpected low values) and also affecting the determination of backscatter coefficients, due to most commonly horizontally-oriented plate-like ice crystals produce non-depolarizing specular reflections in zenith-pointing direction [15-17]. However, this issue can be easily solve to ensure unambiguous determination of ice clouds using a lidar system pointing a few degrees off the zenithal direction [18,19]. In particular, the LALINET system ma-MA located in Manaus (Brazil) operates regularly at 5º off-zenith, enabling to monitor cirrus clouds in the core of Amazon, although currently without depolarization capabilities [20]. Lidar systems, which offer full scanning capabilities, are typically used for the particle and cloud (water and ice) applications and also for research of industrial flare stacks [21-23].

Table 1. List of lidar systems belonging to LALINET and information regarding the stations.

Lidar system	City/Country	Coordinates
ba-BA-AR	Bariloche / Argentina	41.15ºS 71.16ºW
not applicable	Camagüey / Cuba	21.4ºN 77.8ºW
co-CEFOP-UDEC	Concepción / Chile	36.84ºS 73.02ºW
cr-CR-AR	Comodoro Rivadavia / Argentina	43.24ºS 65.33ºW
ma-MA	Manaus / Brazil	2.89ºS 59.97ºW
me-LOA-UNAL	Medellin / Colombia	6.26ºN 75.58ºW
ne-NE-AR	Neuquén / Argentina	38.59ºS 68.15ºW
pa-LIPAZ	La Paz / Bolivia	16.54ºS 68.07ºW
sp-CLA-IPEN-MSP-LIDAR-I	São Paulo / Brazil	23.56ºS 46.74ºW
sp-CLA-IPEN-MSP-LIDAR-II	São Paulo / Brazil	23.56ºS 46.74ºW

Almost all LALINET systems (up to around 90%) needed attended operation, therefore making the performance dependent from individual operators. Only the system ma-MA in Manaus, placed inside Amazon, is completely an unattended one. Due to the extremely low number of unattended systems (around 10%), efforts must be done on LALINET's systems automation in order to reduce the manpower needed and to improve temporal coverage. Therefore, large part of the LALINET's efforts should be addressed to get as much as possible unattended instruments, which in turn will have repercussions on the manpower devoted on data analysis.

Transportability of systems is also a key feature for a lidar network composed by non-standardized systems because they allow to check the performance and reliability of the individual lidar systems and to detect instrumental problems of the systems [24]. Almost 80% of LALINET systems are transportable, what enables potential intercomparison field campaigns with as much as possible systems measuring at the same time at one place. This study and this inventory of technical specification are hugely useful for contributing to the design of such intercomparison field campaigns, showing the systems and channels that can be compared. At the current state of LALINET, three laboratory-fixed lidar systems (namely co-CEFOP-UDEC, me-LOA-UNAL, and sp-CLA-IPEN-MSP-LIDAR-I) prevent an overall intercomparison campaign; however, instrumental intercomparison campaigns performed in several strategic cores could be carried out. The main core is composed by the systems ba-BA-AR, cr-CR-AR, ma-MA , ne-NE-AR , pa-LIPAZ , sp-CLA-IPEN-MSP-LIDAR-I and sp-CLA-IPEN-MSP-LIDAR-II, and the campaign should take place at the Instituto de Pesquisas Energéticas e Nucleares (IPEN) where the system sp-CLA-IPEN-MSP-LIDAR-I is installed. After this first campaign, one of the Argentinean systems (ba-BA-AR, cr-CR-AR or ne-NE-AR) acting as reference system should be moved to Medellín in Colombia and to La Concepción in Chile for the intercomparison with the systems me-LOA-UNAL and co-CEFOP-UDEC, respectively. It is recommended to increase the Raman capabilities of the Argentinean reference system before carrying out the intercomparison campaigns.

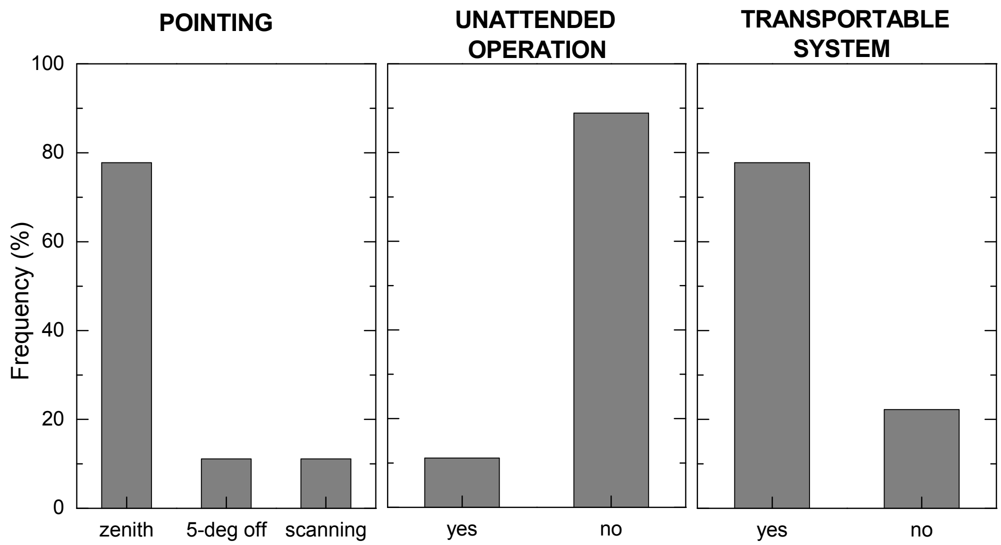

Figure 2. Frequency of some technical specifications regarding the mode of operation for the LALINET lidar stations.

Figure 3 shows the main features regarding the emitter subsystem. The laser head is the cornerstone of a lidar system because its multispectral capabilities determine the final atmospheric products that the lidar can derive. At present, the Nd:YAG laser is the workhorse for the lidar community but there is no preference in the laser model (almost any LALINET lidar is based on a different laser model. The preferred frequency repetition rate is 10 Hz without a large predominance (only around 35%) and the largest repetition rates are used by the systems cr-CR-AR, me-LOA-UNAL and ne-NE-AR (30-50 Hz). The fundamental wavelength of the Nd:YAG laser is 1064 nm but additional emissions at 532 and 355 nm are achieved using generators of second and third harmonic, respectively. Because almost 90% of LALINET systems emit laser radiation at 355 nm, almost 90% at 532 nm and 80% at 1064 nm, only 80% of LALINET systems emit simultaneously at these three wavelengths therefore limiting the number final products that can be derived from part of the lidar systems. Thus, it is recommended to increase the number of emitted wavelengths in whose LALINET systems where the triad of wavelengths is not fulfilled.

Although laser beams are already highly collimated, their diverge is often further reduced by beam expansion result in several benefits: (i) the background light from the atmosphere is efficiently reduced due to a larger surface is illuminated by laser radiation in the probed volume; (ii) fewer photons that could undergo multiple scattering effect in layers with high concentration of scatterers, such as clouds or very loaded aerosol layers, are detected and, therefore, complex multiple scattering corrections [25, 26] do not have to be applied; and (iii) small laser divergence is necessary because the lidar performance could depend on the small acceptance angles of some optical devices for wavelength selection. In spite of the well-known benefits of using a beam expander, alarmingly almost 40% of the emission channels on LALINET systems operate without expansion. This practice is concentrated in the Argentinean systems (ba-BA-AR, cr-CR-AR or ne-NE-AR) and should be corrected in the future. In overall terms, beam divergence before expansion is > 0.4 mrad for almost all the LALINET channels, but after beam expansion around 50% of the channels are configured to values $\leq$ 0.4 mrad.

Figure 4 shows the main features regarding the receiver subsystem. From its inspection, it is clear that the most frequent telescope type used in LALINET is the Newtonian one with almost 70% of the systems. Diameter for the primary mirror ranges between 200 and 400 mm, with around 70% of them $\leq$ 250 mm. However, due to the secondary mirrors, the telescope effective area is reduced by the obscuration area. Diameter for the secondary mirror ranges between 47 and 90 mm, with around 70% of them $\leq$ 70 mm, which reduces the detection are between 21% and 34% depending on the system.

A field stop in the focal point of the receiving telescope determines the lidar field-of-view (FOV). A compromise must be found between a small FOV necessary for high background suppression and a large FOV for an appropriate adjustment of the laser beam within the FOV and for enough signal intensity in the near range. The FOV is a factor of

1.8-3.2 larger than the laser beam divergence for almost 70% of the LALINET system but others like pa-LIPAZ and sp-CLA-IPEN-MSP-LIDAR-I present low values as less as 0.2. In addition, the system me-LOA-UNAL is configured to have a very large FOV of 19 mrad (FOV to laser beam divergence ratio of 38) due to it is a lidar system mostly applied to lower troposphere research and, thus, a very large FOV is request to obtain good benefits in the near range. Adversely, this could start to cause lower signal-to-noise ratio in relatively low altitudes (typically the middle and upper troposphere) and, consequently, it is recommended not to perform the background correction above the lower stratosphere. Moreover, almost 60% of the LALINET systems are usually operated with FOV ≤ 1 mrad, therefore unaffected by multiple scattering effect [26]. Those systems with larger FOVs, namely co-CEFOP-UDEC, ma-MA, me-LOA-UNAL and sp-CLA-IPEN-MSP-LIDAR-II, should consider the application of multiple scattering corrections for clouds studies and under scenarios of very high loads of aerosol particles.

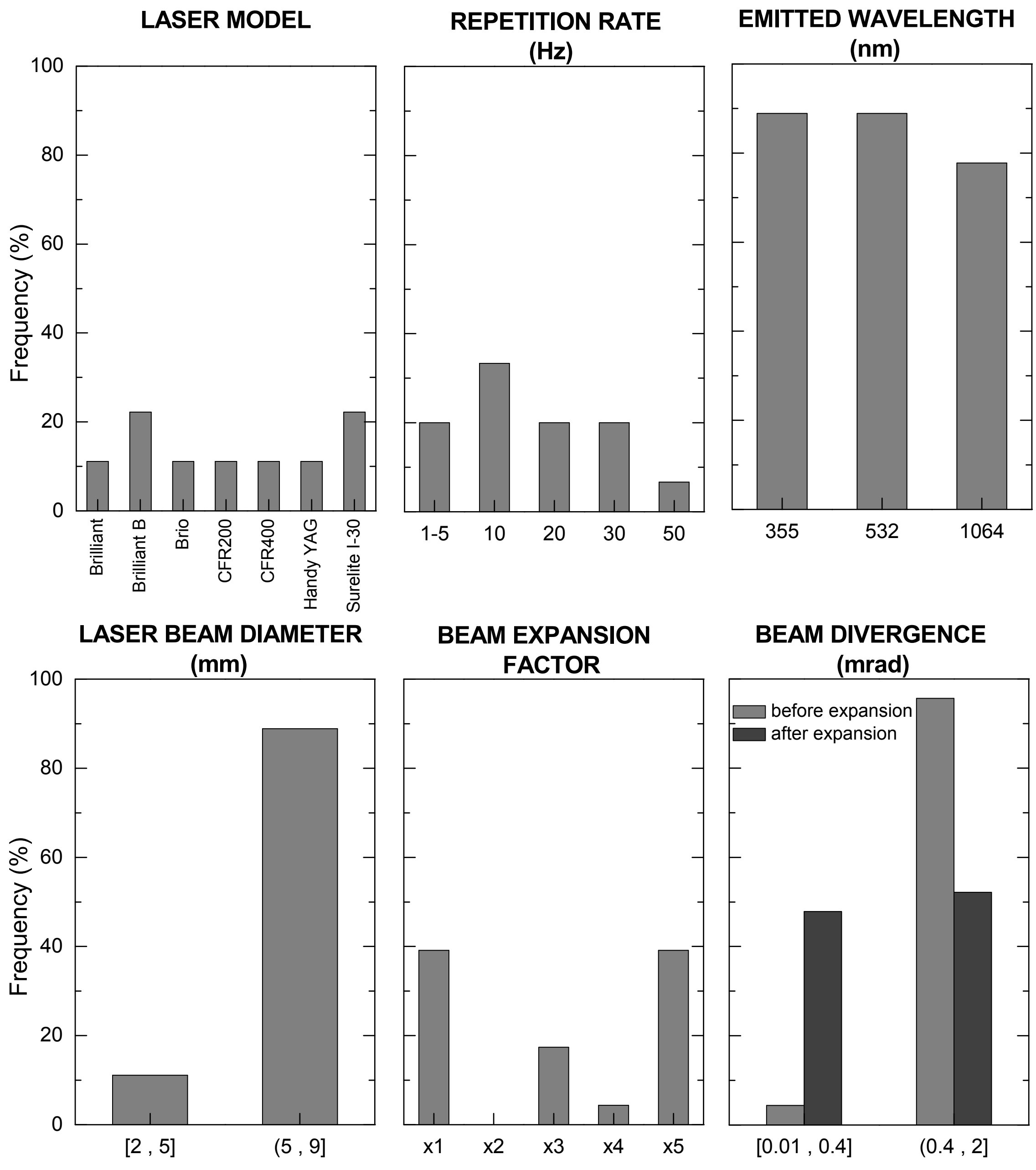

Figure 3. Frequency of some technical specifications regarding the emitter subsystem for the LALINET lidar stations.

Both coaxial (laser beam is on the telescope optical axis) and biaxial configurations (laser beam is off the telescope optical axis, slightly tilted against it) are used but coaxial design is predominant (around 70%). This is a feature that makes LALINET different from other lidar network such as EARLINET [27] where most of the lidars are Cassegrain-design based. Depending on the telescope design, the lidar performance in the near range is different and influences the overlap function, which describes the incomplete overlap between the field of view of the receiver telescope and the emitted laser beam, among other factors [28]. Thus, different procedures depending on the telescope design have to be applied in order to completely characterize the lidar performance in the near range.

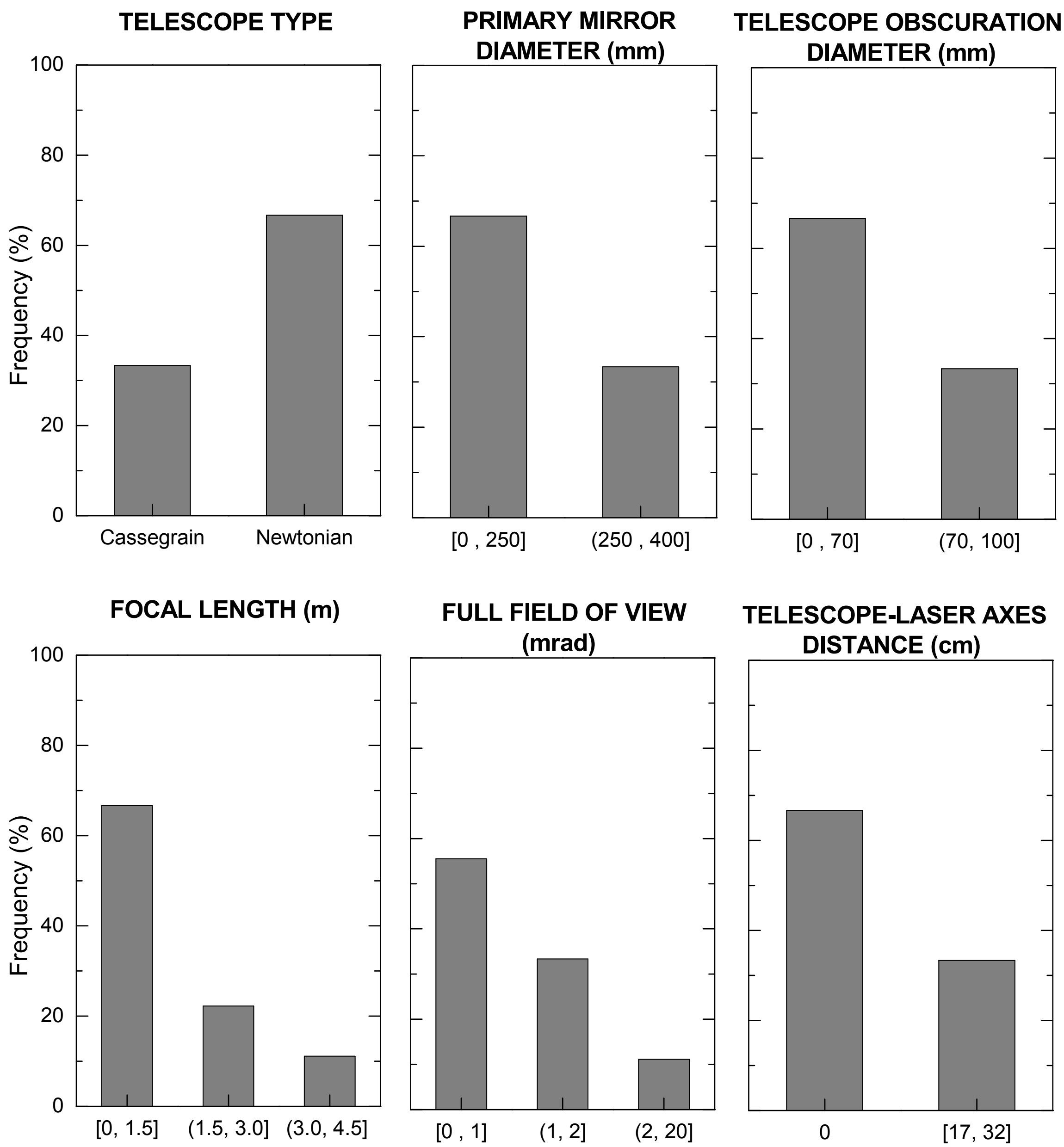

Figure 4. Frequency of some technical specifications regarding the receiver optics subsystem for the LALINET lidar stations.

Figure 5 shows the main features regarding the detection subsystem. We will focus mainly on the detected channel in this functional block because it determines the final atmospheric products that the lidar system is able to provide. As it is typical in lidar systems, elastic channels operate both at day- and nighttime. However, alarmingly, the number of LALINET systems detecting the elastic signal at 1064 nm is really low without exceeding 35%, and not all systems measure signals at 355 (around 80%) and 532 nm (around 90%). The number of systems able to detect the triad of elastic lidar signals drastically decreases up to 33%, corresponding to the Argentinean systems (ba-BA-AR, cr-CR-AR and ne-NE-AR). This limits the spectral capabilities of LALINET preventing, for example, the determination of the Angström exponent profiles to assess qualitatively the particle size [29] linked to the aerosol typing (e.g. [30]). At present, the new algorithms to derive vertically-resolved particle microphysical properties from lidar data together with sunphotometric data, i.e. LIRIC (Lidar-Radiometer Inversion Code) [31] and GARRLIC (Generalized Aerosol Retrieval From Radiometer and Lidar Combined) [32], require at least elastic lidar signals at 355, 532 and 1064 nm (together with sunphotometric data). Thus, if LALINET wants to contribute to the overall understanding of the role of aerosol particles in the climate Earth's system, it is recommended to quickly increase the number of systems detecting simultaneously these three elastic. Together with Angström exponents, the so-called particle linear depolarization ratio is a variable leading to establish an aerosol typing. However, at present only the system cr-CR-AR is able to provide depolarization-related variables. Depolarization capabilities are desirable not only due to they allow to assess the particle sphericity but also they can improve the microphysical retrievals from LIRIC and GARRLIC and they allow the application of POLIPHON (Polarizing Lidar Photometer Networking) [33], which is a technique to retrieve the mass concentration of each component of an external mixture of two aerosol types. Depolarization channels should be included in the current systems and LALINET should extend its coverage in strategic locations where the long-range transport of Saharan dust is expected as the Caribbean region and the northernmost part of South America.

On the other hand, most of the Raman shifted channels operate at nighttime, when the sky background is enough low to obtain good signal-to-noise ratio. Despite of this traditional limitation for Raman lidars, some of the LALINET systems also operate routinely detecting Raman lidar signals during daytime. However, the high noise and background do not allow to derive trustable particle optical properties using Raman signals as desirable. The reduced number of N_2-Raman channels (slightly above 30% and 20% at 387 and 607 nm, respectively), limits the capabilities of LALINET to derive trustable profiles of particle extinction and, subsequently, particle lidar ratio profiles [11], which in turns limits the aerosol typing over South America. Moreover, only the combination of backscatter and extinction coefficients provides trustworthy particle microphysical properties [34], being the systems providing three backscatters and two extinctions, the so-called 3+2 systems, the optimum choice for particle microphysical characterization. Because there is no a LALINET system simultaneous performing Raman shifted measurements at 387 and 607 nm, together with the elastic channel at 1064 nm, at present the retrieval of particle microphysical properties by algorithms of inversion with regularization [34-36] is not possible in LALINET.

Furthermore, other Raman channels are routinely operated in LALINET. Because water vapour is a Raman-active gas with high enough atmospheric concentration, the determination of water vapour mixing ratio is a variable to be profiled using Raman lidars [37, 38]. The method is based on the simultaneous measurement of the N_2-Raman shifted signal used as a reference (387 or 607 nm) and the H_2O-Raman shifted signal (408 or 660 nm). It is surprisingly the relative high number of systems simultaneously measuring the couple of signals 387/408 nm (more than 30%) and 607/660 nm (more than 10%). Besides the derivation of water vapour mixing ratio profile, that is a relevant meteorological variable itself, the water vapour capability allows to perform hygroscopic growth studies over South America [39-41].

Figure 6 shows the main features regarding the data acquisition subsystem. The signal detection is carried out with photomultipliers tubes (PMTs) and avalanche photodiodes (APD), performing the detection in analog and photon-counting modes. The analog mode is preferred for strong backscattered signals, typically in the near range. The photon-counting mode is very sensitive and used when the backscattered signal is weak, typically when it results from a weak scattering process or when the probed atmospheric region is in the far range. A combination of both modes, the so-called glued mode, is the optimum choice to increase the dynamic range of detection in atmospheric applications. All LALINET systems operate in analog mode for all elastic channels but less than 50% of the elastic channels also operate in photon-counting mode. This could limit the detection range of backscattered lidar signals and could reduce the signal-to-noise ratio in the far range. Besides, the whole profile could be affected due to the background correction will have to be computed in relatively low heights that could contain aerosol traces, therefore underestimating the measured signal. In order to increase the quality of the LALINET retrievals, it is recommended to operate simultaneously in analog and photon-counting mode in the elastic channels. Due to the low intensity of the Raman signals, photon-counting mode is typically used for these channels. In the near range, PMTs could saturate and prevent the computation of optical profiles.

To partially correct this fact (incomplete overlap still remains), between 35% and 65% of Raman channels (depending on the wavelength) in LALINET are also detected in analog mode. An exception is the wavelength 660 nm, measured both in analog and photon-counting mode for the unique system containing this channel (system sp-CLA-IPEN-MSP-LIDAR-I). Most of the LALINET systems (approximately 90%) operate with a spatial resolution of 7.5 m and, therefore, this value can be considered as a standard for this network. Only one system performs detections at a poorer vertical resolution (15 m). Anyway most of the systems offer capabilities of selecting different vertical resolutions (3.75, 7.5, 15 and 30 m). Data altitude range is highly variable: around 55% of the LALINET systems permit probing until very high altitudes (around 120 km), leading to a determination of background component free from aerosol particles (both tropospheric particles and stratospheric particles originated by volcanoes). Only the system pa-LIPAZ has a prettigger system to collect data before firing pulses and, therefore, enables the background subtraction using pretrigger data.

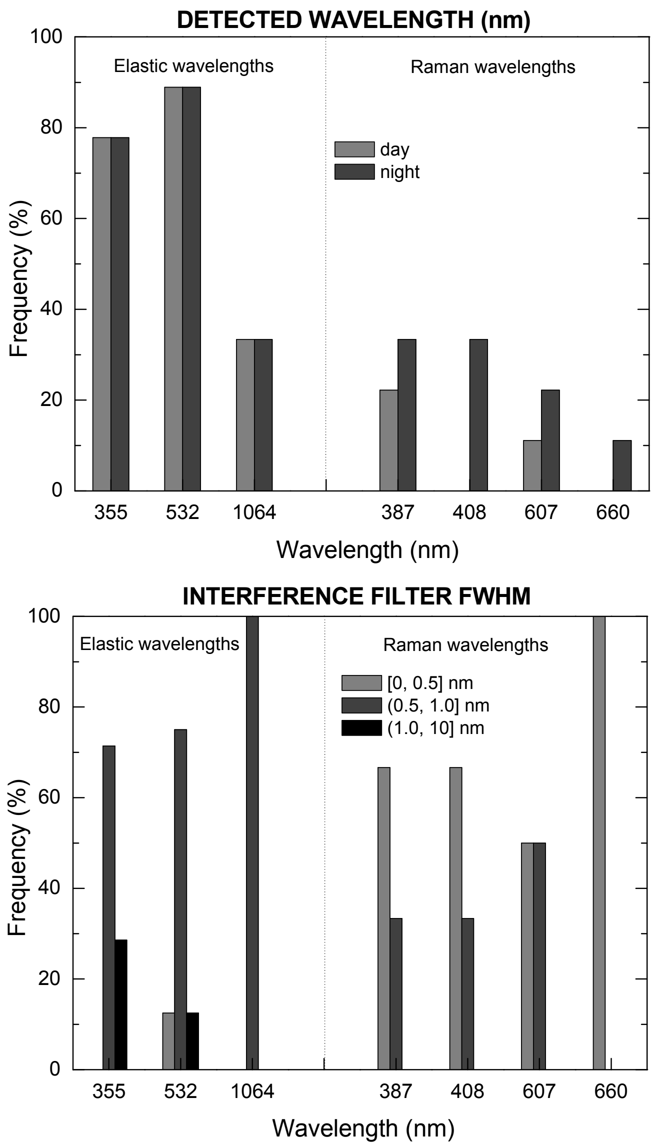

Figure 5. Frequency of some technical specifications regarding the wavelength separation unit for the LALINET lidar stations.

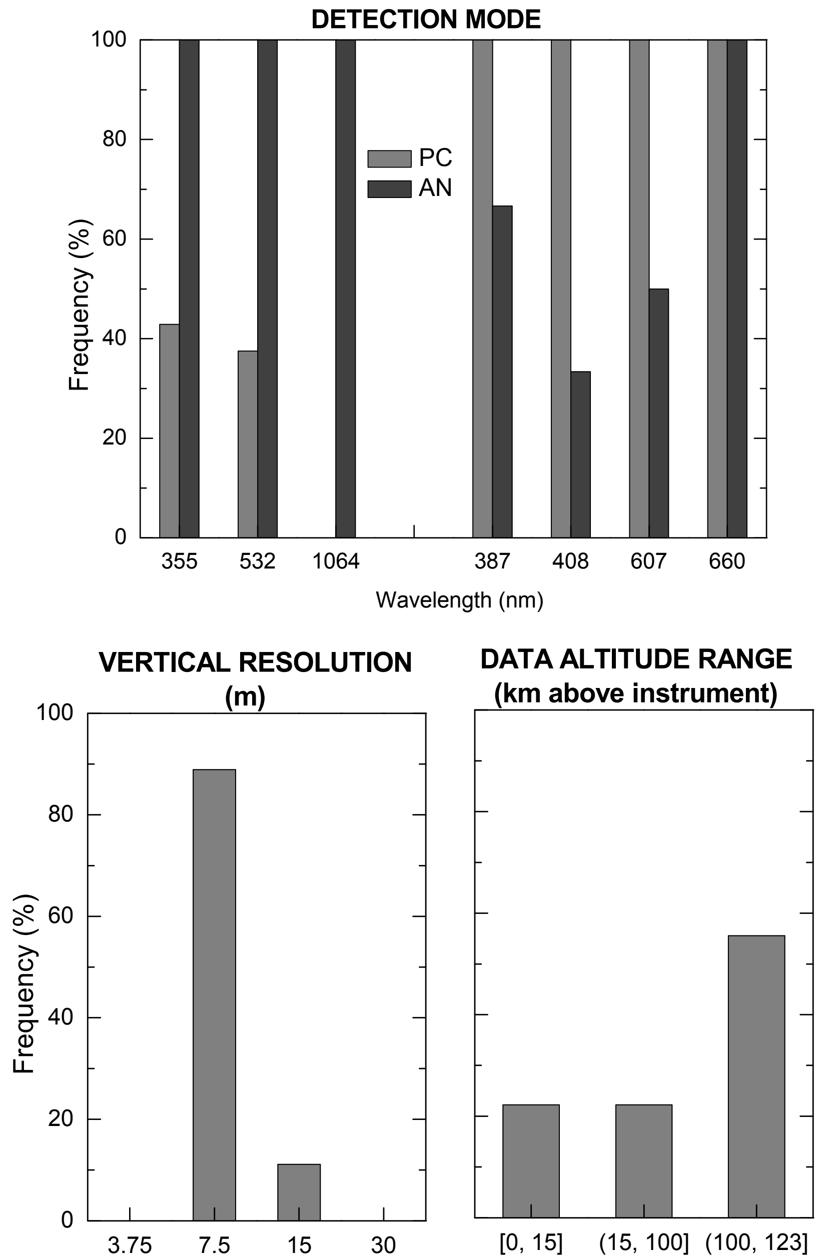

Figure 6. Frequency of some technical specifications regarding the acquisition subsystem for the LALINET lidar stations.

4. CONCLUSIONS

By means of this networking study, which must not be underestimated due the huge number of instrumental characteristics considered, a twofold objective was achieved, that was not only to provide an exhaustive overview of the individual LALINET systems but also to find common instrumental solutions to state-of-the-art common problems. After this diagnostic of the LALINET instrumentation, the main extracted conclusions are:

- efforts must be done to achieve as much as possible unattended systems to improve temporal coverage and to reduce the manpower needed, which in turn will have repercussions on the manpower devoted on data analysis.

- this inventory was hugely useful to design the first LALINET intercomparison exercise through several field campaigns. It is recommended to increase the Raman capabilities of the Argentinean instrument used a reference system before performing the exercise.
- the number of emitted wavelengths should increase in order to achieve the triad 355+532+1064 nm, with the aim of improving the spectral capabilities of LALINET and be able to detect these channels that are the minimum lidar wavelengths to derive particle microphysical properties by combination with sun-photometer data. Besides, no 3+2 systems are available to extract microphysical properties by inversion method with regularization.
- the Argentinean systems (ba-BA-AR, cr-CR-AR or ne-NE-AR) should modify their designs in order to operate using a beam expander
- systems with large FOVs (co-CEFOP-UDEC, ma-MA, me-LOA-UNAL and sp-CLA-IPEN-MSP-LIDAR-II) should consider the application of multiple scattering corrections for clouds studies and under scenarios of very high loads of aerosol particles.
- depolarization capabilities are almost missing in LALINET and this should be improved in the future, especially in strategic locations where long-range transported Saharan dust is expected, such as the Caribbean region and the northernmost part of South America
- the quality of raw lidar profiles should increase incorporating photon-counting mode in the elastic channels.

It is expected that the results of this diagnostic will bring benefits to both the existing stations and to the new groups, and will help the improvement of the overall quality of the aerosol data products derived from LALINET for contributing to the scientific knowledge.

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