DEDICAtE

Development of a dual-channel Depolarization lidar technique for the derivation of CALIPSO/ Aeolus/ EarthCARE-related conversion factors

ESTEC Contract No. 4000112750/14/NL/MV/fk

Executive Summary

Submitted to:

The European Space Research and Technology Centre

Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands

Date of Issue: 02 March 2017

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1 Motivation

DEDICAtE, aims to the development of a dual-channel depolarization lidar technique for the derivation of CALIPSO/ADM-Aeolus/EarthCARE-related conversion factors. CALIPSO is capable of retrieving linear particle depolarization ratio at 532 nm in a global scale, providing this well-calibrated product since 2006. Future ESA missions EarthCARE and ADM-Aeolus are based on the employment of the High Spectral Resolution polarization-sensitive lidar technique at 355 nm. Dual-wavelength polarization observations are needed for relating long-term observations of dust particles of CALIOP at 532 nm with ATLID at 355 nm.

To serve this homogenization concept for the existing and future lidar missions (CALIPSO, ADM-Aeolus and EarthCARE), ESA conducted several studies addressing the wavelength dependence of extinction and backscatter (ESA-CALIPSO, LIVAS), in which multi-wavelength measurements from ground-based networks like EARLINET and AERONET were used. However, none of these studies managed to tackle correctly the depolarization wavelength dependence due to the limited datasets available at that time. Still, only few EARLINET stations provide today polarization observations at more than one wavelength on a regular basis. Sparse multi-wavelength measurements are available from ground-based lidars mainly during experimental campaigns, coming however from different measurement techniques and systems (Groß et al., 2011). Moreover, ground-based lidar systems only measure the linear particle depolarization ratio. DEDICAtE managed to fill this gap by analysing high-quality dual-depolarization measurements collected in three experimental field campaigns (CHARADMExp, Tropical Atlantic Cruise and BACCHUS) and applying conversions to CALIPSO data in order to derive a global climatology of particle linear and circular depolarization ratios at 355 nm.

2 Implementation

In order to fulfil DEDICAtE objectives, the depolarization spectral dependencies of dust and ice particles have been derived from the measurements performed by two dual-depolarization lidars, namely the EMORAL and PollyXT systems (Althausen et al., 2009; Engelmann et al., 2015). The datasets obtained during three experimental field campaigns have been used, namely, ESA-CHARADMExp, BACCHUS and Tropical Atlantic Cruise.

The mean value of the ratio 355 nm to 532 nm particle linear depolarization ratios (PLDR) is calculated by the available measurements and then used as a conversion factor for converting the LIVAS depolarization ratios as derived by CALIPSO at 532 nm, to 355 nm. Moreover, the climatological PLDR values of dust are converted to particle circular depolarization ratio (PCDR), a parameter of paramount importance for the assessment of the future ADM-Aeolus aerosol product. The data processing chain for the derivation of dust PLDR and PCDR climatological values structured in LIVAS database (Amiridis et al., 2015), is illustrated in Figure 2-1.

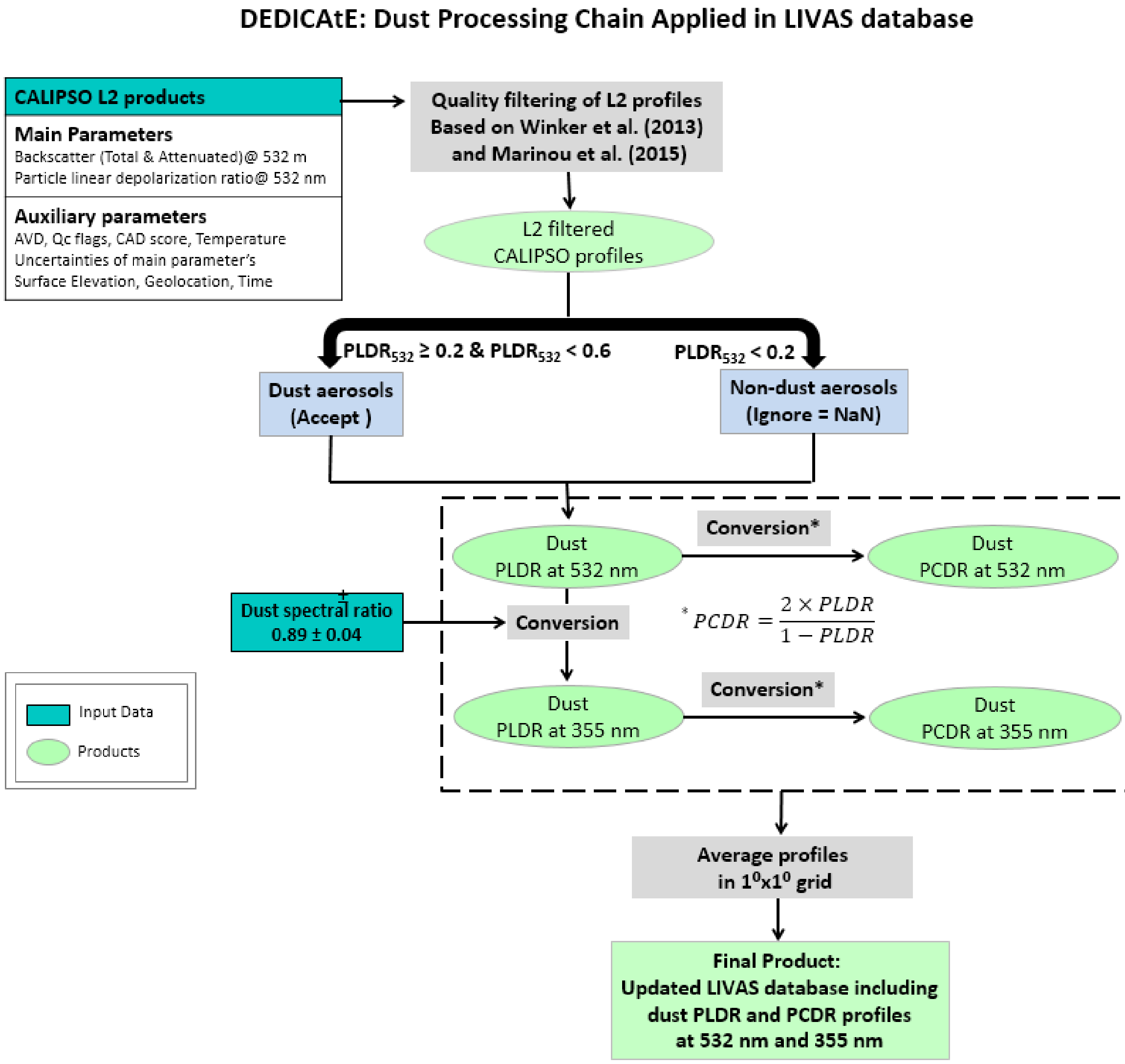

Figure 2-1 A schematic outline of the processing chain applied in LIVAS dust climatology, in the framework of DEDICAtE, for the derivation of $PLDR_{355}$ and $PCDR_{355}$ values.

3 Overview of the results

3.1 Conversion factors

The factors used for the spectral conversion of LIVAS PLDR values from 532 to 355 nm are retrieved per aerosol/cloud type from the datasets obtained during three experimental field campaigns (ESA-CHARAMExp, BACCHUS and Tropical Atlantic Cruise). Each aerosol profile obtained from the lidar measurements, has been analyzed based on its geometrical and optical properties. For each selected layer, FLEXPART transport simulations are performed to determine its origin, transport path and age. The BSC-DREAM8b (e.g. Basart et al., 2012) is also used to identify the dust advection. For the conversion of PLDR to PCDR values, we used the theoretical relation proposed by Mishchenko and Hovenier 1995, valid for random particle orientation (**Eq. 3-1**).

$$PCDR = \frac{2 \cdot PLDR}{1 - PLDR} \quad \textbf{Eq. 3-1}$$

In

Table 3-1, we present the spectral dependence of PLDR and PCDR values for the aerosol types and mixtures detected during ESA-CHARADMExp campaign. The error values presented in

Table 3-1, have been calculated with error propagation formulation, from the estimated PLDR error.

Table 3-1: Spectral dependence of PLDR and PCDR for the aerosol types and mixtures detected during ESA-CHARADMExp campaign.

AEROSOL		
	PLDR 355/532	**PCDR 355/532**
Dust near the sources	0.938 ± 0.180	0.917 ± 0.239
Long-range advected Dust / Polluted Continental	0.739	0.686

Marine	1.045 ± 0.355	1.047 ± 0.367
Marine-Dust	1	1
CIRRUS		
Ice particles	1.079 ± 0.063	1.149 ± 0.122

In order to increase the number of case studies with pure dust observations we used additional datasets obtained from other experimental field campaigns. More precisely, the conversion factor found for dust is shown in Figure 3-1.

The case studies examined during ESA-CHARADMExp campaign revealed a mean spectral dependence ($PLDR_{355/532}$) of dust particles of the order 0.94 ± 0.18 (Figure 3-1). The corresponding values obtained during the Tropical Atlantic Cruise and BACCHUS campaigns found equal to 0.86 ± 0.10 and 0.87 ± 0.16 (Figure 3-1), respectively. The overall mean value of the aforementioned spectral dependency of dust particles is found to be 0.89 ± 0.04 (Figure 3-1). Previous studies reported similar values (0.8-1.2) for 355/532 (SAMUM-1&2) and for 1064/532, around 1.5 for mixtures of dust and 0.9 for pure dust (Burton et al., 2012).

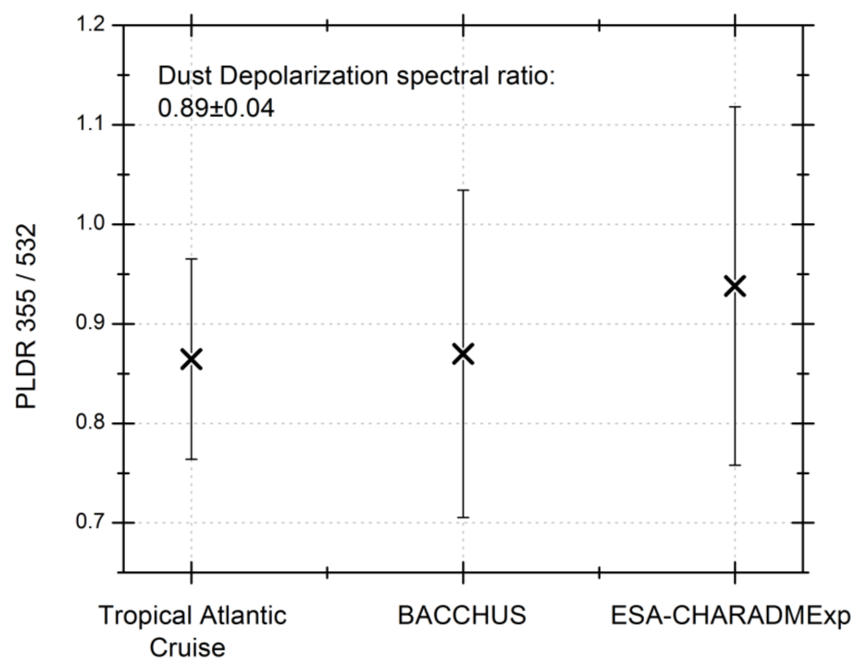

Figure 3-1: Spectral PLDR ratio ($PLDR_{355/532}$) revealed during the experimental campaigns of Tropical Atlantic Cruise, BACCHUS and ESA-CHARADMExp.

During SALTRACE campaign in Barbados, TROPOS operated three depolarization channels at 355, 532 and 1064 nm to measure in cirrus clouds. Their findings were similar to the results reported in TN4 of DEDICAtE for the measurements taken during ESA-CHARADMExp campaign. PLDR values around 50% were found at all three wavelengths. Moreover, their measurements suggest that there is no evidence of spectral dependence in cirrus clouds ($PLDR_{355/532}$=1). In the case of rather thin cirrus clouds the spectral dependence is of the order of a few percent, values that reside well within the limits of measurement accuracy.

3.2 Consolidation in LIVAS DB

In the framework of DEDICAtE, the linear depolarization ratio at 532 nm derived by CALIPSO in LIVAS has been converted to 355 nm for dust and ice particles based on the depolarization conversion factors delivered in the project. The LIVAS global climatological database has been converted to include both the PLDR and PCDR values at 355 nm along with their uncertainties. In the methodology followed within DEDICAtE for deriving dust $PLDR_{355}$ and $PCDR_{355,}$ the CALIPSO L2 particle backscatter β_{532r} and the $PLDR_{532}$ have been used as initial input data. These products have been further quality filtered according to Winker et al. (2012) and Marinou et al. (2016). The data processing chain for the derivation of dust PLDR and PCDR climatological values structured in LIVAS database, has been illustrated in Figure 2-1.

An example of the methodology followed for CALIPSO is given in the following figures. We used a LIVAS dust scene over the south-western Saharan region on 30 June 2008 (Figure 3-2).

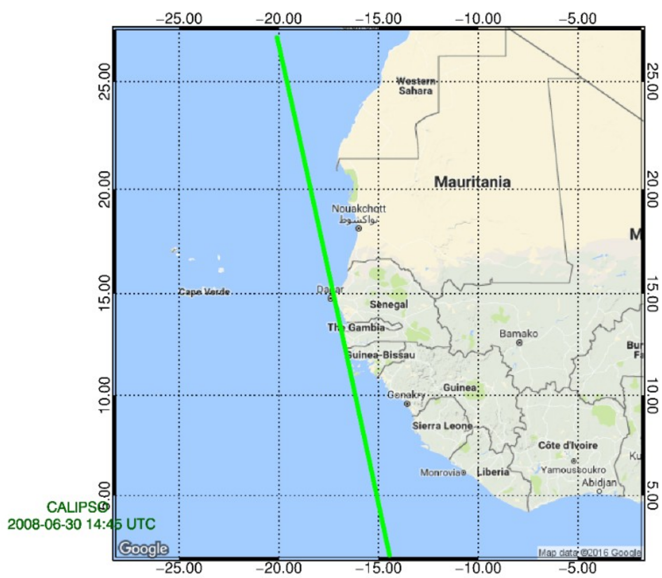

Figure 3-2: CALIPSO ground-track on 30 June 2008, over Capo Verde.

For the latitude range 15 ^{o} - 30^{o}, high aerosol load extended from ground to 5 km, was depicted from CALIPSO measurements (Figure 3-3; top). The aerosol classification scheme of CALIPSO, characterized this aerosol layer as dust (Figure 3-3; bottom), since the retrieved $PLDR_{532}$ values found to be above 0.2 (Figure 3-4; top). Following the methodology presented in Section 4-3, from CALIPSO's $PLDR_{532}$ values of dust, by applying the conversion factor of 0.89±0.04, we estimated the spatio-temporal evolution of the corresponding $PLDR_{355}$ dust values for the aforementioned latitude range (Figure 3-4; middle). Moreover the equation 3.1 was applied for converting the dust $PLDR_{355}$ to $PCDR_{355}$ values (Figure 3-4; bottom).

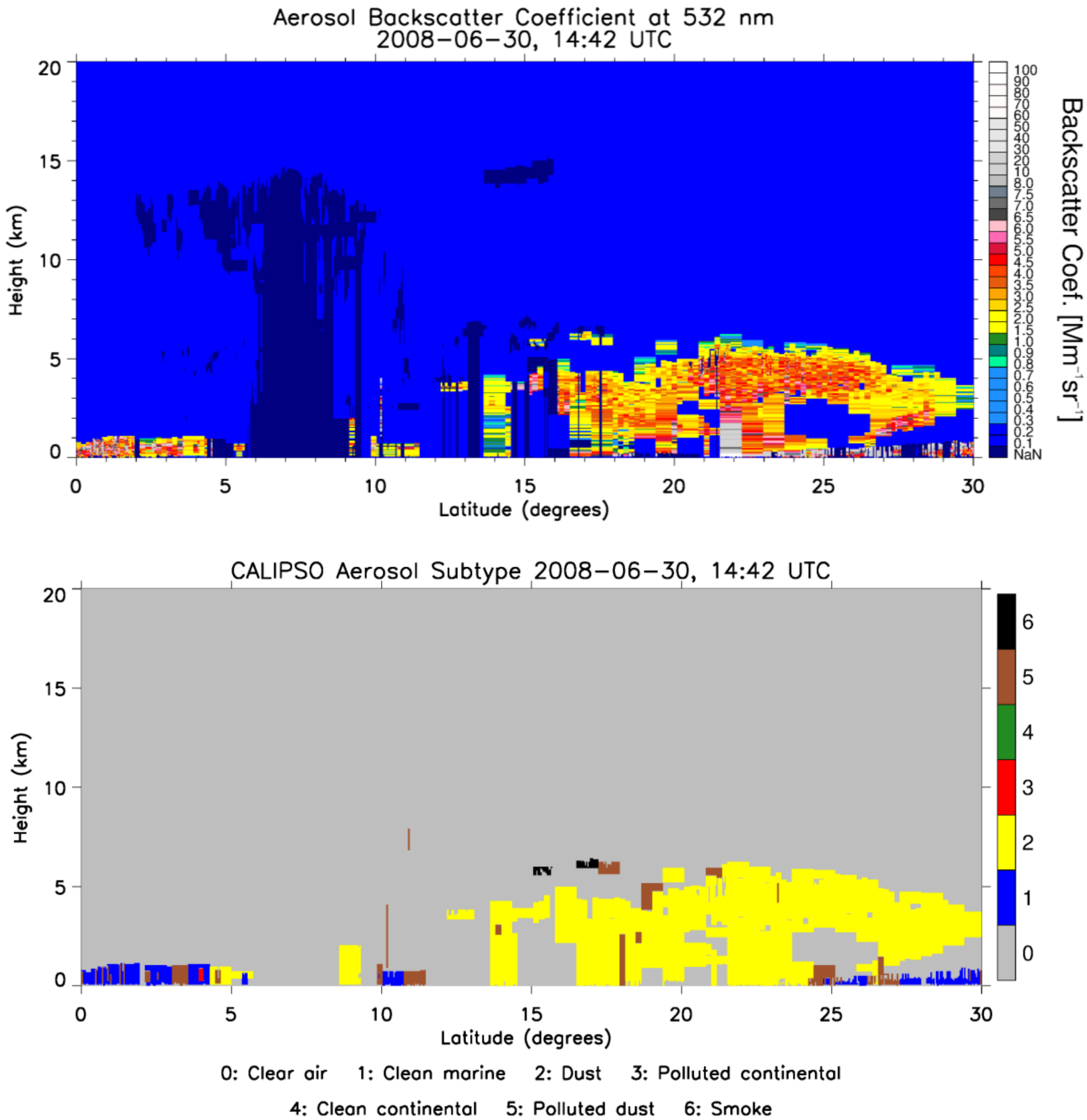

Figure 3-3: CALIPSO cross section of the aerosol backscatter coefficient at 532 nm (top) and aerosol feature mask (bottom) on 30 June 2008, over Capo Verde.

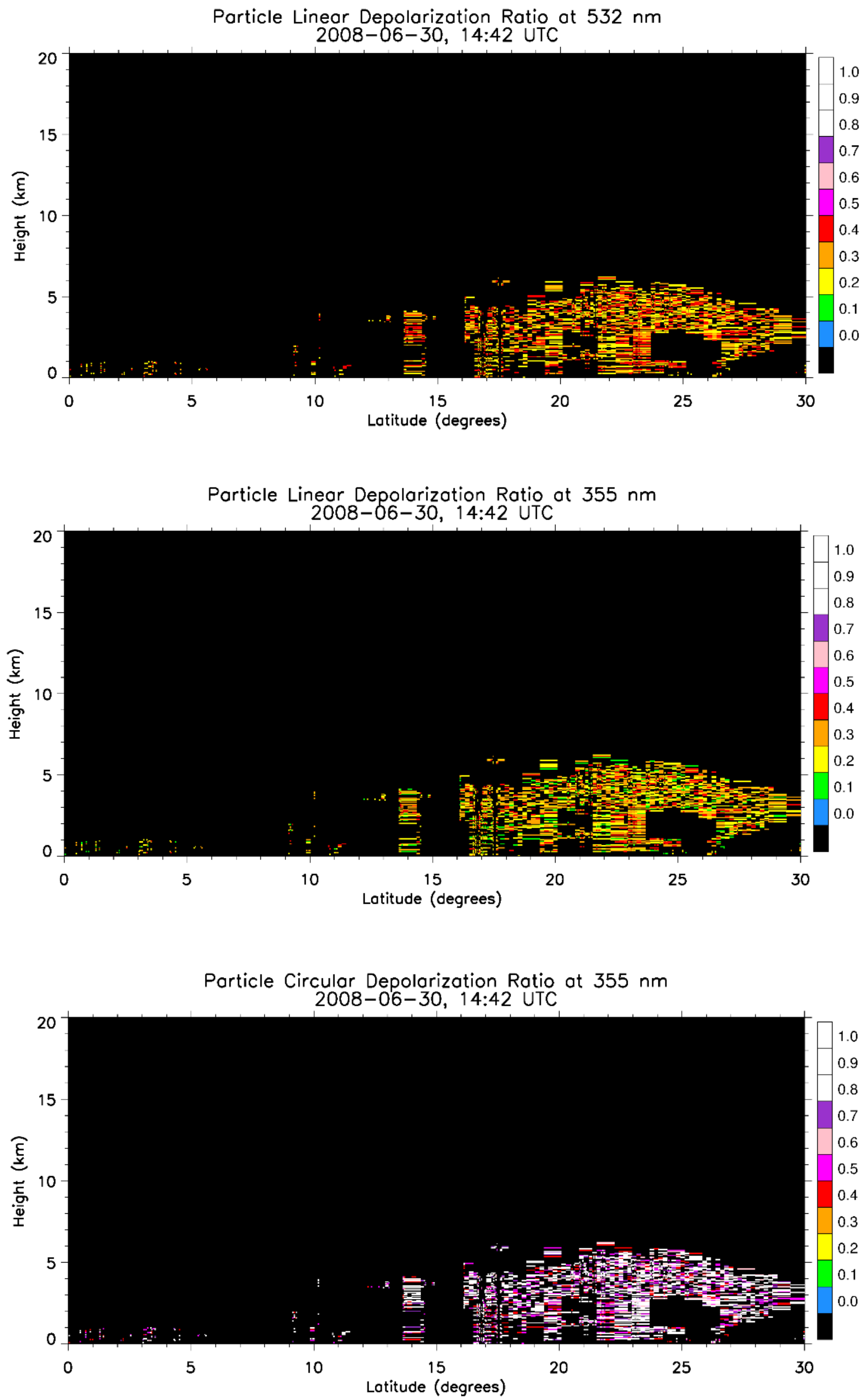

Figure 3-4: CALIPSO cross section of the PLDR at 532 nm (top), dust PLDR values converted at 355 nm using DEDICAtE (middle) and dust PCDR values converted at 355 nm, on 30 June 2008, over Capo Verde.

After the calculation of the new dust polarization profiles on the original CALIPSO analysis of 5 km horizontal resolution, the CALIPSO curtain is divided in cells of $1^{o}x1^{o}$ degree. As an example, in the scene above, the cell with centroids at longitude equals to -18.5 and latitude equals to 22.5 degrees incorporates all the profiles of this overpass with longitudes between -18 and -19 degrees and latitudes between 22 and 23 degrees. These dust profiles are averaged in order to provide the mean dust PLDR and PCDR values for the under study CALIPSO overpass in the cell (Figure 3-5). With this procedure we calculate dust polarization profiles in $1^{o}x1^{o}$ degree cells for every overpass.

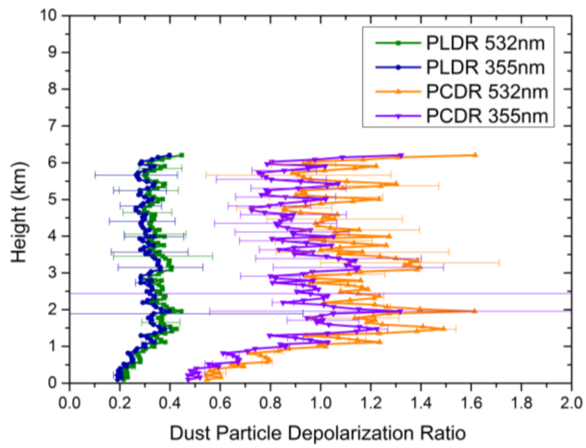

Figure 3-5: CALIPSO dust PLDR and PCDR at 532 nm and 355 nm for the overpass on 30 June 2008, in the 1-degree cell with longitudes between -18 and -19 degrees and latitudes between 22 and 23 degrees.

By averaging all CALIPSO overpasses (during years 2007- 2009) from a 1x1 degree grid, we calculate the mean dust polarization profiles per cell. For the cell in our example, the 9-year mean dust polarization profiles are shown in Figure 3-6. Following this approach for every $1^{o}x1^{o}$ degree cell, the DEDICAtE global database is produced, which consist of 49.968 cells.

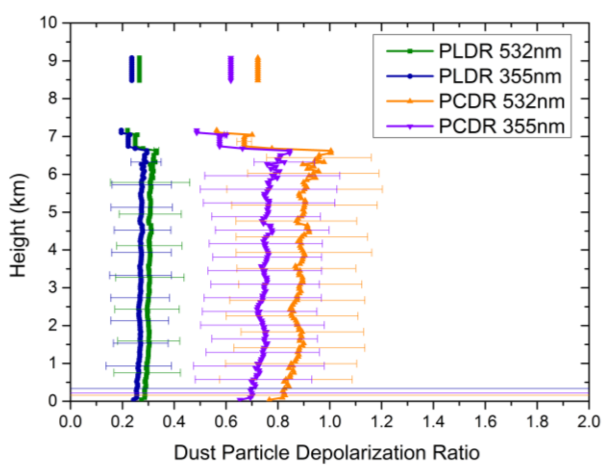

Figure 3-6: 9-year mean of CALIPSO dust PLDR and PCDR at 532 nm and 355, in the 1-degree cell with longitudes between -18 and -19 degrees and latitudes between 22 and 23 degrees.

4 Recommendations and further developments

DEDICAtE delivered dual-depolarization conversion factors for dust and ice particles, based on ground-based EARLINET datasets collected in experimental campaigns. The outcome of the study has been consolidated in the ESA-LIVAS database, in order to provide a global dataset of linear and circular particle depolarization ratios at 355 nm. This unique 9-year dataset will significantly contribute to the interpretation of the products anticipated from the upcoming ESA lidar missions ADM-Aeolus and EarthCARE.

One critical point identified during DEDICAtE concerns the non-negligible variability found on dust particle depolarization conversion factors. This variability cannot be attributed solely to the systematic error of the measurements, since the lidar systems used in DEDICAtE were well-calibrated according to the quality assurance standards followed by the well-established EARLINET network. Possible reasons for the observed dust particle depolarization ratio discrepancies could include (a) the transport path and mixing conditions of dust particles (e.g. Groß et al., 2015) and (b) the mineral composition of the dust sources (e.g. Nickovic et al., 2012).

In order to explain these discrepancies, towards enhancing our knowledge on the dust particle characteristics in terms of fundamental optical and microphysical properties, an increase on the level of information content coming from existing lidar techniques is needed. One promising technique has been recently suggested by Mischenko et al. (2016), which includes the employment of an additional telescope receiver for depolarization detections at the scattering angle of 170°. Such a setup would most probably increase the lidar depolarization information content expected by the existing ground-based and space-borne lidars. The proposed theoretical approach could be further explored for ADM-Aeolus and EarthCARE missions, which can be accompanied by a second telescope in orbit. This bistatic lidar configuration can also be studied in ground-based systems such as EMORAL, PollyXT or WALL-E.

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