environmental sciences proceedings

MDPI

Proceeding Paper

Development and Validation of an Enhanced Aerosol Product for Aeolus (L2A+) [†]

Konstantinos Rizos [1,2,*], Antonis Gkikas [1,3], Emmanouil Proestakis [1], Thanasis Georgiou [1], Vassilis Amiridis [1], Eleni Marinou [1], David Donovan [4], Nikos Benas [4], Martin Stengel [5], Christian Retscher [6], Holger Baars [7] and Athena Augusta Floutsi [7]

1 Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, 11810 Athens, Greece; agkikas@noa.gr or agkikas@academyofathens.gr (A.G.); proestakis@noa.gr (E.P.); ageorgiou@noa.gr (T.G.); vamoir@noa.gr (V.A.); elmarinou@noa.gr (E.M.)
2 Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, 54636 Thessaloniki, Greece
3 Research Centre for Atmospheric Physics and Climatology, Academy of Athens, 10680 Athens, Greece
4 Royal Netherlands Meteorological Institute (KNMI), 3731 De Bilt, The Netherlands; donovan@knmi.nl (D.D.); benas@knmi.nl (N.B.)
5 Deutscher Wetterdienst (DWD), 63067 Offenbach, Germany; martin.stengel@dwd.de
6 European Space Agency, 00044 Frascati, Italy; christian.retscher@esa.int
7 Leibniz Institute for Tropospheric Research (TROPOS), 04318 Leipzig, Germany; baars@tropos.de (H.B.); floutsi@tropos.de (A.A.F.)
* Correspondence: k.rizos@noa.gr or krizos@physics.auth.gr
† Presented at the 16th International Conference on Meteorology, Climatology and Atmospheric Physics—COMECAP 2023, Athens, Greece, 25–29 September 2023.

Abstract: The missing cross-channel of the lidar system aboard Aeolus (Atmospheric Laser Doppler Instrument; ALADIN) makes it impossible to obtain realistic optical products when the depolarizing atmospheric layers are probed (non-spherical particles). Additionally, it cannot provide retrievals separately for aerosol and cloud targets. To overcome these inherent deficiencies, this study aims to deliver an enhanced Aeolus aerosol product (focusing on dust), which will be utilized on aerosol data assimilation schemes coupled with dust transport models to improve Numerical Weather Prediction (NWP). For the derivation of the improved aerosol product, a series of processing steps were designed, involving the use of spaceborne retrievals/products from multi-sensors in conjunction with reanalysis numerical outputs and reference ground-based measurements.

Keywords: Aeolus; enhanced Aeolus product; cloud filtering; aerosol typing

Citation: Rizos, K.; Gkikas, A.; Proestakis, E.; Georgiou, T.; Amiridis, V.; Marinou, E.; Donovan, D.; Benas, N.; Stengel, M.; Retscher, C.; et al. Development and Validation of an Enhanced Aerosol Product for Aeolus (L2A+). *Environ. Sci. Proc.* **2023**, *26*, 91. https://doi.org/10.3390/environsciproc2023026091

Academic Editors: Konstantinos Moustris and Panagiotis Nastos

Published: 28 August 2023

1. Introduction

The European Space Agency's (ESA) satellite wind mission, Aeolus, launched on 22 August 2018. Aeolus carries the Atmospheric Laser Doppler Instrument (ALADIN), the first space-based high-spectral-resolution lidar [1]. ALADIN emits short laser pulses of a circular polarized light at 354.8 nm and receives the co-polarized backscatter from molecules and particles or hydrometeors in two separate channels, referred to as the Mie and Rayleigh channels [1,2]. The emitted laser pulses are integrated along the satellite orbit direction to obtain measurements of ~3 km resolution (a total number of ~20 laser pulses yield 1 measurement). Then, a total number of 30 measurements are further accumulated to yield an observation (named as BRC, Basic Repeat Cycle) of around 90 km horizontal integration. On the vertical scale, the backscattered signal is integrated over 24-time intervals corresponding to 24 range bins of variable thicknesses (from 0.25 to 2 km). The main scientific objectives of Aeolus are to improve Numerical Weather Predictions (NWPs) and to enhance our understanding of atmospheric dynamics and their associated impact on climate [3,4]. The primary Aeolus product is profiles of the horizontally projected line-of-sight winds and spin-off products (Level-2A; L2A) are profiles of backscatter and extinction coefficients from particles and hydrometeors, respectively [3], derived by the Standard Correct Algorithm (SCA) [1,5]. Evaluation studies have demonstrated that the Aeolus aerosol product (L2A) has a reasonable quality. However, a degradation of its performance is evident when depolarizing features (e.g., dust) are recorded, thus imposing limitations on the exploitation of Aeolus L2A products in aerosol studies. This inherent weakness is attributed to the configuration of ALADIN measuring only the co-polar component of the atmospheric backscattered returns of the circularly polarized emitted beam [6]. Such a deficiency also prohibits discrimination between aerosols and clouds. Aimed towards overcoming the aforementioned inherent restrictions, the present study proposes a methodology to deliver an improved Aeolus product (with a focus on dust), which will be utilized for aerosol data assimilation schemes coupled with dust transport models to improve Numerical Weather Prediction (NWP). For the development of the enhanced Aeolus product, a series of processes is applied, involving the use of multiple data sources in conjunction with reanalysis numerical outputs and reference ground-based measurements. The study period spans September 2021 when the JATAC campaign took place in Cabo Verde. The region of interest refers to an extended domain including the Sahara Desert and the Tropical Atlantic Ocean up to the Caribbean Sea.

2. Materials and Methods

For the derivation of the enhanced Aeolus product (L2A+), a series of processing steps was designed. First, rigorous filtering of the raw Aeolus L2A backscatter coefficients retrievals was performed for the elimination of cloud-contaminated bins. The cloud-filtering methodology relies on the AEL-FM (Aeolus Feature Mask) product from the L2A processors II (originated from the developments for the forthcoming EarthCARE mission but adapted to Aeolus). It is worth mentioning that the mask does not distinguish between different particle types but instead detects areas of strong and weak returns or those associated with clear-sky conditions [7]. Based on the AEL-FM retrievals, the features of the probed atmospheric scene are classified either as clouds or aerosols or as molecular (Rayleigh) atmosphere. These referenced categories of scatterers, as well as their respective sub-types, are defined via image processing techniques, and their availability along the Aeolus track facilitates the selection of cloud-free Aeolus bins on the raw L2A profiles. In Table 1, the features that are categorized in the AEL-FM feature mask product are listed. In the first column, the main output of the AEL-FM feature mask product is given, which corresponds to a feature detection probability index with values ranging from −3 to 10 and the second column presents how these indexes are defined. According to the definitions, clear-sky conditions labeled with feature index value 0 are associated with very low signals that likely originate from clear air while stronger signals with values between 6 and 10 are most likely to have originated from liquid or optically thick ice clouds. Additionally, feature retrievals labeled with an index value of −3 are associated with signals directly affected by the surface.

Since the AEL-FM product is provided at the measurement level (~3 km), for the implementation of the cloud-screening procedure, a conversion was required in order to match Aeolus's SCA horizontal and vertical resolution. The conversion process started by using the flag "cloud" to label AEL-FM index values between 6 and 10 since, according to the definitions given in Table 1, the associated returned signals are most likely to have been affected by clouds. Then, for each BRC bin comprising a given number of measurements each (depending on the processor version), the total percentage of cloud-flagged measurements was computed. Based on the derived "cloud-flag" percentage values (at Aeolus's observation scale), the observations with values exceeding a threshold value (0% in this case) were considered as cloud-contaminated observations and the associated Aeolus SCA optical properties observations were eliminated. Following the aforementioned cloud-filtering process, the Aeolus L2A cloud-free backscatter profiles were derived. Accordingly, the altitude ranges of the dust aerosol layers were defined on the derived cloud-free Aeolus L2A+ backscatter coefficient profiles. Due to the absence of an aerosol classification scheme for the raw Aeolus L2A data, numerical outputs from the Copernicus Atmosphere Monitoring Service (CAMS) reanalysis [8] were implemented for the assignment of aerosol typing. The CAMS aerosol model component includes twelve prognostic tracers, consisting of three bins for sea salt grains of different sizes (0.03–0.5, 0.5–5 and 5–20 µm); three bins for dust (0.03–0.55, 0.55–0.9 and 0.9–20 µm); hydrophilic and hydrophobic organic matter and black carbon; and sulfate aerosols plus its precursor trace gas of sulfur dioxide (SO_2) [9]. From the aforementioned tracers, the dust component as well as the total aerosol mass concentration will be defined. Then, by defining an appropriate threshold value, the strong presence of dust will be determined (the referenced dust-screening method is still under investigation). At this point, only the cross-polar component of the backscatter coefficient, under dust conditions, has been considered. The following working steps include evaluation against the eVe and PollyXT ground-based lidars, operated in the framework of the JATAC campaign in Cabo Verde, based on which the undetected portion of the aerosol load attributed to the absence of a cross-channel on ALADIN will be quantified. Then, the total backscatter (co-polar plus cross-polar) will be calculated and after defining a representative circular dust lidar ratio, the Aeolus L2A+ dust extinction profiles will be derived. The final step corresponds to the conversion of the dust extinction to dust mass concentration, via the POLIPHON method [10], which will be assimilated in the WRF model.

Table 1. Aeolus feature mask indices' definition. The first column provides the feature detection probability index ranging from −3 to 10. The second column shows the definition of each index.

Index	Definition
10	Clouds
9	Most likely clouds
8	Very likely clouds or aerosols
7	More likely clouds or aerosols
6	Likely clouds or aerosols
5	Likely low-altitude aerosol
4	Unlikely clouds or aerosol
3	Likely only molecules
2	Very likely only molecules
1	Most likely only molecules
0	Clear sky
−1	Fully Rayleigh attenuated
−2	No retrievals
−3	Surface data

3. Results

In this section, some preliminary results are presented for the study case on 17 September 2021. Figure 1 shows the region of interest and the Aeolus satellite orbit path for the given case with the thick blue line indicating the ALADIN's measurement track.

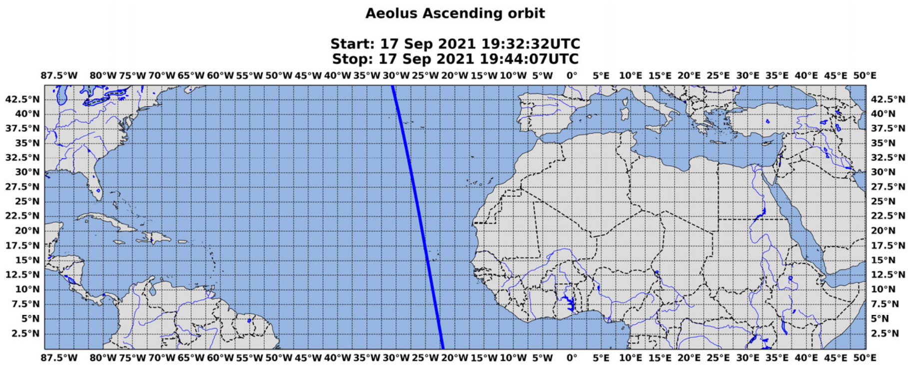

Figure 1. Region of interest and the Aeolus overpass (orbit id: 017790) on 17 September 2021.

The cloud-filtering results for this specific Aeolus orbit are presented in Figure 2. In Figure 2a, the AEL-FM feature mask output along the Aeolus measurement track is shown, where the classified features of the probed atmospheric scene can be observed. It can be seen that features associated with "strong" returns mainly attributed to clouds or high optically thick aerosol layers are brown and red, respectively, while those associated with the molecular atmosphere or clear-sky conditions are green and cyan, respectively. Figure 2b presents the raw Aeolus L2A profiles of the backscatter coefficient retrieved with the SCA algorithm. Accordingly, based on the AEL-FM dataset provided at the measurement level, the cloud-covered BRC bins of the primary L2A Aeolus retrievals (Figure 2b) were detected and eliminated (Figure 2c).

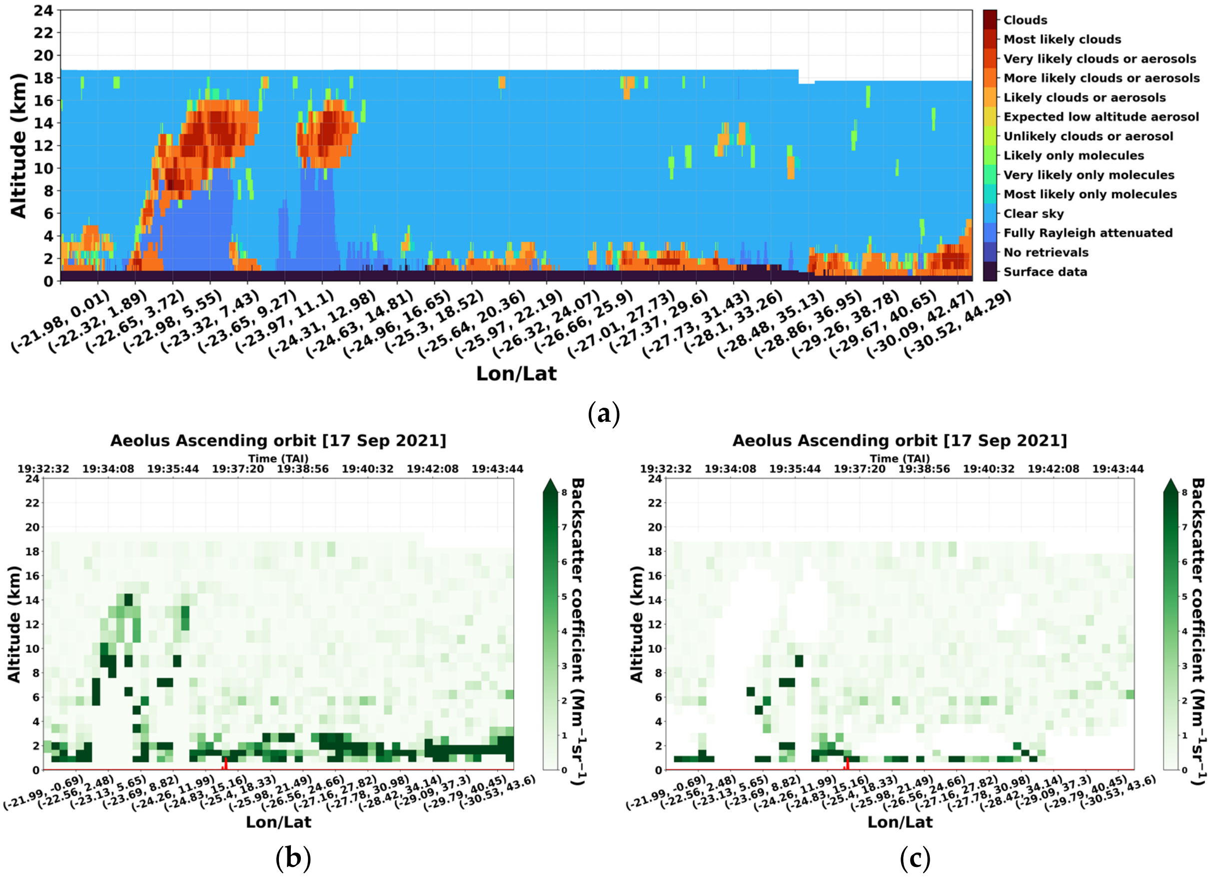

Figure 2. (**a**) AEL-FM feature mask product; (**b**) Raw profiles of L2A SCA backscatter coefficient; and (**c**) cloud-filtered profiles of SCA backscatter coefficient for the Aeolus overpass of orbit id: 017790 on 17 September 2021.

Once the Aeolus L2A+ cloud-free backscatter profiles have been derived, the CAMS reanalysis aerosol outputs will be jointly processed for the identification of atmospheric dust cases to account for the non-detected cross-polar component in the case of strongly depolarizing targets (i.e., dust particles). An indicative study case is illustrated in Figure 3, presenting a Saharan dust outbreak on the 17 September 2021, when dust-abundant air masses originating from N. Africa were crossing the Tropical Atlantic Ocean.

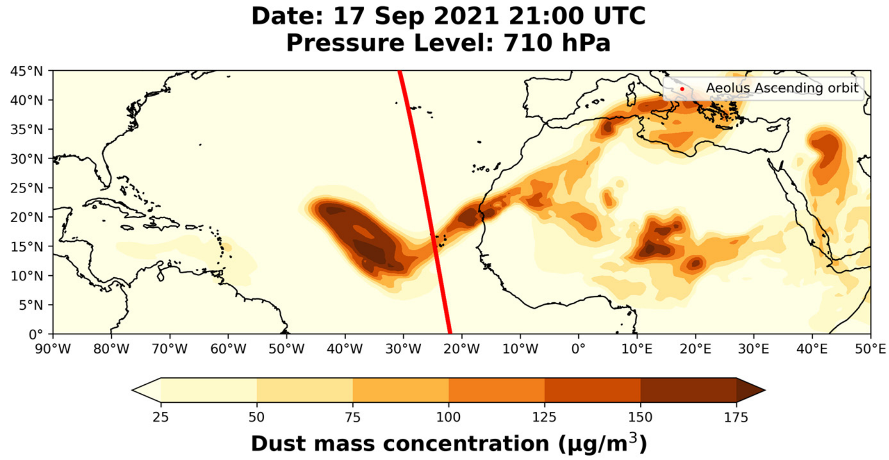

Figure 3. CAMS dust mass concentration over L2A+ RoI for an indicative study case on the 17 September 2021. The red-colored line presents the closest Aeolus orbit for the referenced time.

4. Summary

Aiming to overcome the inherent weakness of Aeolus's lidar system (ALADIN) attributed to the missing cross-polar component of the atmospheric backscattered returns of the circularly polarized emitted beam, this study aimed to deliver an improved Aeolus product (L2A+), which will be utilized on aerosol data assimilation schemes coupled with dust transport models to improve Numerical Weather Prediction (NWP). For the development of the new product, a synergy of processing tools will be used involving the Aeolus feature mask product (AEL-FM) for cloud screening as well as reanalysis numerical outputs (CAMS) and referenced ground-based measurements. Currently, the development analysis is focused on three indicative Aeolus–Cabo Verde overpasses, identified in the framework of the ESA-ASKOS experiment, and more specifically on the 10th, 17th and 24th of September 2021. Once the development analysis focused on these indicative study cases is completed, the methodology will be implemented for all the Aeolus orbits within the region of interest for the whole study period (Figure 4).

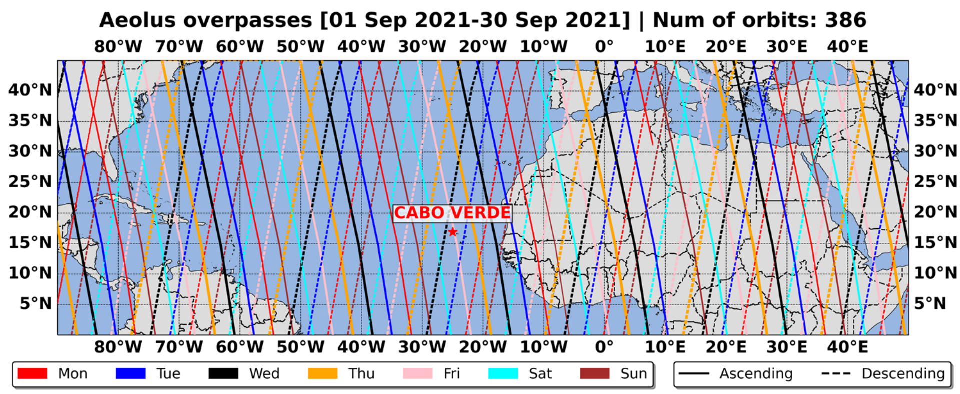

Figure 4. All Aeolus overpasses for the L2A+ region of interest (RoI).

Author Contributions: Conceptualization, V.A. and A.G.; methodology, A.G. and V.A.; software, A.G., K.R. and T.G.; validation, K.R., A.G. and E.P.; formal analysis, K.R.; investigation, V.A.; resources, D.D., N.B., H.B., A.A.F., M.S. and E.M.; writing—original draft preparation, K.R.; writing—review and editing, A.G., E.P. and V.A.; visualization, K.R.; supervision, V.A.; project administration, E.P.; funding acquisition, C.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the European Space Agency (ESA) for the L2A+ project (Contract No. 4000139424/22/I-NS).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: No new data were created.

Acknowledgments: The authors affiliated to the National Observatory of Athens acknowledge the support provided by the following research projects: the NEWTON ESA study, supported by ESA under Contract No. 4000133130/20/I-BG//Aeolus+ Innovation (Aeolus+I); the PANGEA4CalVal project funded by the European Union (Grant Agreement 101079201); the ACTRIS Research Infrastructure; data and services obtained from the PANhellenic GEophysical Observatory of Antikythera (PANGEA) of NOA. EP acknowledges the support provided by the AXA Research Fund for postdoctoral researchers under the project entitled "Earth Observation for Air-Quality—Dust Fine-Mode—EO4AQ-DustFM".

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Flament, T.; Trapon, D.; Lacour, A.; Dabas, A.; Ehlers, F.; Huber, D. Aeolus L2A Aerosol Optical Properties Product: Standard Correct Algorithm and Mie Correct Algorithm. *Atmos. Meas. Tech.* **2021**, *14*, 7851–7871. [CrossRef]
2. Flamant, P.; Cuesta, J.; Denneulin, M.-L.; Dabas, A.; Huber, D. ADM-Aeolus Retrieval Algorithms for Aerosol and Cloud Products. *Tellus A Dyn. Meteorol. Oceanogr.* **2008**, *60*, 273. [CrossRef]
3. Gkikas, A.; Gialitaki, A.; Binietoglou, I.; Marinou, E.; Tsichla, M.; Siomos, N.; Paschou, P.; Kampouri, A.; Voudouri, K.A.; Proestakis, E.; et al. First Assessment of Aeolus Standard Correct Algorithm Particle Backscatter Coefficient Retrievals in the Eastern Mediterranean. *Atmos. Meas. Tech.* **2023**, *16*, 1017–1042. [CrossRef]
4. Stoffelen, A.; Pailleux, J.; Källén, E.; Vaughan, J.M.; Isaksen, L.; Flamant, P.; Wergen, W.; Andersson, E.; Schyberg, H.; Culoma, A.; et al. The Atmospheric Dynamics Mission for Global Wind Field Measurement. *Bull. Am. Meteorol. Soc.* **2005**, *86*, 73–88. [CrossRef]
5. Ehlers, F.; Flament, T.; Dabas, A.; Trapon, D.; Lacour, A.; Baars, H.; Straume-Lindner, A.G. Optimization of Aeolus' Aerosol Optical Properties by Maximum-Likelihood Estimation. *Atmos. Meas. Tech.* **2022**, *15*, 185–203. [CrossRef]
6. Paschou, P.; Siomos, N.; Tsekeri, A.; Louridas, A.; Georgoussis, G.; Freudenthaler, V.; Binietoglou, I.; Tsaknakis, G.; Tavernarakis, A.; Evangelatos, C.; et al. The EVe Reference Polarisation Lidar System for the Calibration and Validation of the Aeolus L2A Product. *Atmos. Meas. Tech.* **2022**, *15*, 2299–2323. [CrossRef]
7. van Zadelhoff, G.-J.; Donovan, D.P.; Wang, P. Detection of Aerosol and Cloud Features for the EarthCARE Lidar ATLID: The A-FM Product. *EGUsphere* **2023**, *2023*, 1–29.
8. Inness, A.; Ades, M.; Agustí-Panareda, A.; Barré, J.; Benedictow, A.; Blechschmidt, A.-M.; Dominguez, J.J.; Engelen, R.; Eskes, H.; Flemming, J.; et al. The CAMS Reanalysis of Atmospheric Composition. *Atmos. Chem. Phys.* **2019**, *19*, 3515–3556. [CrossRef]
9. Morcrette, J.-J.; Boucher, O.; Jones, L.; Salmond, D.; Bechtold, P.; Beljaars, A.; Benedetti, A.; Bonet, A.; Kaiser, J.W.; Razinger, M.; et al. Aerosol Analysis and Forecast in the European Centre for Medium-Range Weather Forecasts Integrated Forecast System: Forward Modeling. *J. Geophys. Res.* **2009**, *114*, D06206. [CrossRef]
10. Ansmann, A.; Mamouri, R.-E.; Hofer, J.; Baars, H.; Althausen, D.; Abdullaev, S.F. Dust Mass, Cloud Condensation Nuclei, and Ice-Nucleating Particle Profiling with Polarization Lidar: Updated POLIPHON Conversion Factors from Global AERONET Analysis. *Atmos. Meas. Tech.* **2019**, *12*, 4849–4865. [CrossRef]