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LIDAR ICE NUCLEI ESTIMATES AND HOW THEY RELATE WITH AIRBORNE IN-SITU MEASUREMENTS

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ABSTRACT

By means of available ice nucleating particle (INP) parameterization schemes we compute profiles of dust INP number concentration utilizing Polly-XT and CALIPSO lidar observations during the INUIT-BACCHUS-ACTRIS 2016 campaign. The polarization-lidar photometer networking (POLIPHON) method is used to separate dust and non-dust aerosol backscatter, extinction, mass concentration, particle number concentration (for particles with radius > 250 nm) and surface area concentration. The INP final products are compared with aerosol samples collected from unmanned aircraft systems (UAS) and analyzed using the ice nucleus counter FRIDGE.

1 INTRODUCTION

Despite their low concentration in the atmosphere, ice nucleating particles (INP) are crucial for the evolution of ice in clouds, as they act as seed-surfaces for water in order to enable the development and growth of ice. Mineral dust is one of the most important IN aerosol types and has been identified in liquid-water, mixed phase and cirrus clouds in field and laboratory studies [1]. Nevertheless, there are several questions on ice nucleation processes such as the abundance and vertical profile of INP as a function of cloud nucleation conditions (temperature and supersaturation) and the aerosol particle spectrum. Furthermore, field data of INP are limited and the number of observations is still relatively small. Gaps in our knowledge of the detailed impact of aerosols on the evolution of liquid-water, mixed phase and cirrus clouds drive atmospheric research towards field studies of aerosol-cloud-dynamics interaction.

During April 2016, a joint field campaign of INUIT (Ice Nuclei Research Unit), BACCHUS (Impact of Biogenic versus Anthropogenic emissions on Clouds and Climate: towards a Holistic UnderStanding) and ACTRIS (Aerosols, Clouds, and Trace gases Research InfraStructure) projects took place at Cyprus, focusing on aerosol, clouds and ice nucleation in the Eastern

Mediterranean. We use the data from this field campaign to compare remote sensing with airborne in-situ retrievals of INP concentrations (INPC).

2 DATA AND METHODOLOGY

2.1 CAMPAIGN MEASUREMENTS

During the campaign, continuous lidar observations were performed at Nicosia (35°08’26"N, 33°22’52"E, 181m a.s.l.) with the Polly-XT lidar of National Observatory of Athens. The system is a 12 channel system with near-range capabilities (3 elastic, 2 Raman, 2 depolarization, 1 water-vapor, 2 near-range elastic, and 2 near-range Raman signals) [2]. Since the middle of the campaign, lidar observations were complemented by a SUN/SKY/LUNAR AERONET photometer, used to evaluate the horizontal variability of the atmosphere between Nicosia and 2 additional monitoring sites located 30 km westerly, where additional in-situ INP measurements were performed. UAS, operating from the Cyprus institute airfield (Orounda, 35°05’42"N, 33°04’53"E, 327 m a.s.l.) performed observations with the aim to measure the abundance of ice nucleating particles in the lower troposphere [3]. Seven km further west than the airfield, at the Cyprus Atmospheric Observatory (Agia Marina Xyliatou, 35°02’19"N, 33°03’28"E, 532m a.s.l.), an AERONET sun photometer, along with a suite of aerosol and INP in-situ instruments were located.

2.2 POLLY-XT OBSERVATIONS

A first snapshot of the aerosol time-height variability is given in Figure 1 (30/3/2016 - 27/4/2016). During that period, the Eastern Mediterranean was affected by air mass advection from Europe, northern Africa and the Atlantic as indicated by the backward trajectories and DREAM8b dust model [4]. During April 4 to 7 several elevated structures were observed reaching heights up to 10km. The sun photometer observed aerosol optical depths (AOD, 550 nm) values up to 0.3 and Angström exponents (AE, 380 - 870 nm) between 0.5 – 1.0. Atmospheric conditions favored the transport of dust from the west parts of North Africa over the Continental Europe and towards Cyprus. Following this period, we observed five Saharan dust events. The first event (April 8 to 11) was very intense with AOD values of 0.6 to 1.0 and AE less than 0.2. The events of April 15 - 16, 21, and 26 reach AOD values of 0.5 and AE of 0.1 - 0.4. On April 24 minor dust event reached AODs of 0.3 and AE of 0.3 – 0.5. During four out of the five events, ice nucleation was observed in the top of the dust plums, and we observed volume depolarization ratio values (at 532 nm) greater than 32%.

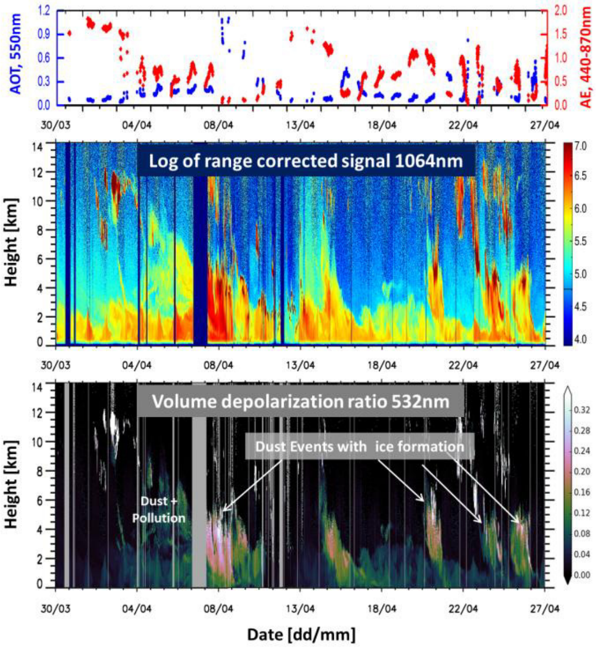

Figure 1: AERONET optical thickness and Ångström exponent, Range-corrected lidar signal and volume linear depolarization ratio measured with Polly-XT at Nicosia from 30 March -27 April 2016.

In order to retrieve INPC profiles from the lidar measurements we follow the methodology described in [5]. In brief, we separate the backscatter profile in dust and non-dust component using POLYPHON technique assuming particle depolarization ratio for dust of 0.31. Then, we calculate the extinction coefficient for the dust and non-dust components from which we estimate mass concentration, particle number concentration (for particles with radius >250nm) and surface area concentration profiles using AERONET parameterizations. Finally, we estimate INP concentrations using the well-known parameterizations of DeMott et al. 2015 (D15), Niemand et al. 2012 (N12) and Steinke et al. 2015 (S15) [5]. Figure 2 provides an example of the estimated products during 21/4/2016 at 1-2 UTC.

INP concentrations start above 5 km a.g.l., where the temperature is less than -10 °C (N12) and above 6 km a.g.l. where the temperature is less than -20 °C (D15, S15). There are a number of distinct pathways of dust ice nucleation: contact freezing, immersion freezing, condensation freezing and deposition nucleation. N12 and D15 quantifies the immersion freezing at or above water saturation.

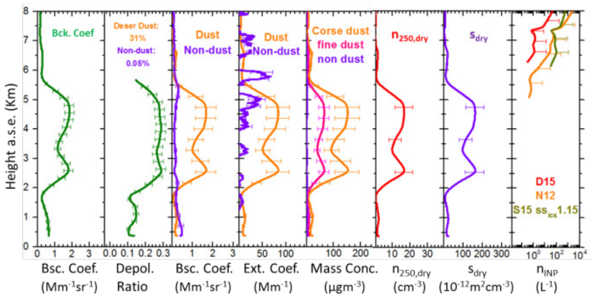

Figure 2: From left to right Polly-XT profiles of: (i) backscatter coefficient, (ii) particle depolarization ratio, (iii) separated backscatter coefficient of dust and non-dust aerosols, (iv) extinction coefficient of dust and non-dust aerosol, (v) mass concentration of coarse dust, fine dust and non-dust aerosol, (vi) large particle number concentration (vii) surface area concentration, (viii) INPC computed with different parameterization schemes. Case of 21/4/2016, 1-2 UTC.

2.3 UAS MEASUREMENTS

Two different types of UAS were used for INP sampling, namely Cruiser and Skywalker X8, able to carry a payload of up to 10 kg and 2 kg respectively. 42 flights were performed in total, which generated a total of 52 samples over 19 days. INPC were measured by electrostatic precipitation of aerosol particles onto silicon wafers onboard the UAS, followed by laboratory analysis of the samples in the ice nucleus counter FRIDGE [2]. FRIDGE usually addresses the deposition / condensation freezing mode(s). During the campaign, the UAS reached maximum altitudes of 2.5 km a.g.l. (2.85 km a.s.l), making these measurements ideal for comparison with the lidar data.

2.4 CALIPSO

In this work we use CALIPSO (The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) [8] for INPC monitoring. During the campaign period, CALIPSO satellite overpassed Nicosia site within 5 km distance two times at 5 and 21 April 2016. From these two cases, we use the case of the 21^{st} of April that coincided with one of the dust events, and CALIPSO L2 product gave quality assured retrievals. The atmospheric curtain of CALIPSO is shown in Figure 3. In this plot, the green dotted line highlights Nicosia station and the box shows the part we use for the INPC retrievals (±80 km for the station). The curtain shows the elevated dust plume and cloud formation at 80 km away from the station, on the top of the dust plume and in heights greater than 5km.

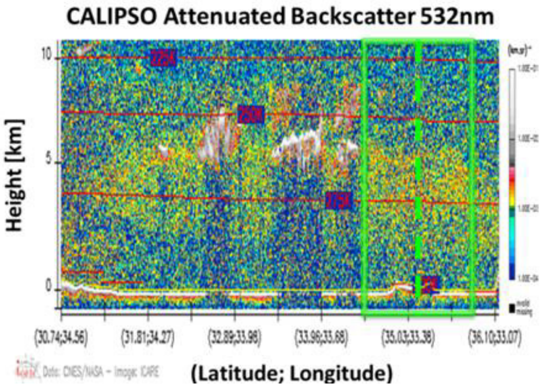

Figure 3: CALIPSO Attenuated Backscatter at 532nm above Nicosia on 21/4/2016, 10:34 UTC. Green dotted line: Polly-XT location. Green box: ±80 km track used for the comparison.

3 CASE OF 21 APRIL 2016

On that day, atmospheric conditions favored the transport of dust from both Sahara Desert and the Arabian Peninsula. The two plums merged over Cyprus during the time of the event, with the major contribution coming from Sahara (DREAM8b dust model). Figure 4 (top) shows the 24hr Polly-XT measurements of that day. Above the station there was formation of ice clouds between 2 and 10 UTC. We were able to derive level 2 cloud-free optical profiles and estimate INPC close to the cloud. These profiles are shown in Figure 4 (bottom). From left to right: Raman retrievals with Polly-XT during 0-1 UTC (fig 4i) and 1-2 UTC (fig 4ii), CALIPSO retrievals at 10:34 UTC (fig 4ii) and Klett retrievals with Polly-XT between 14-15 and 15-16 UTC. INPC estimates are ~ 0.4 L^{-1} at 5 km (-10 ºC) and ~ 4 L^{-1} at 6 km (-20 ºC) before the cloud formation (Polly-XT) and right next to the clouds (CALIPSO). After 14 UTC, and while the dust plume was descending, INPC values lower than 0.2 L^{-1} were observed at heights between 5 and 6 km. The results show a very good agreement between the Polly-XT and CALIPSO INPC retrievals.

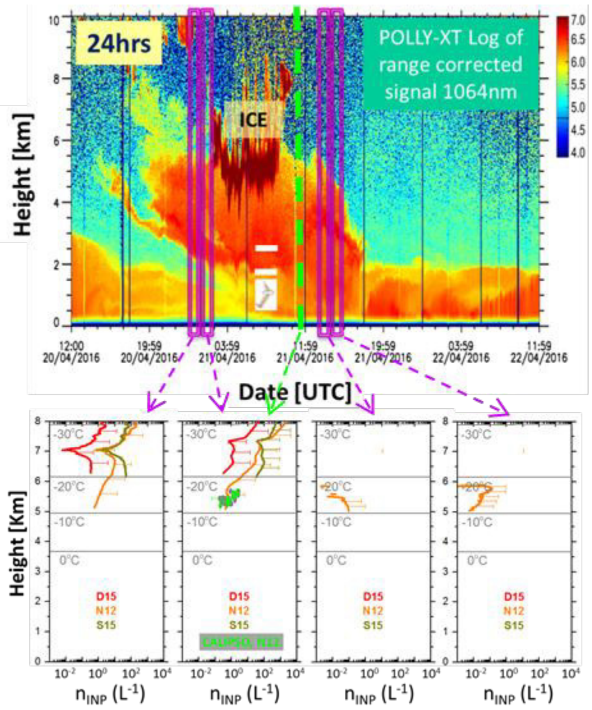

Figure 4: Top: Polly-XT 24hr range-corrected signal at Nicosia during the event of 20-21 April. Purple boxes periods used for INP conc .estimations. Green line: CALIPSO overpass time. White lines: UAS flights period and altitudes. Bottom: INPC for the time periods (from left to right):0-1 UTC, 1-2UTC (Polly-XT) & 10:34 UTC (CALIPSO), 14-15, 15-16UTC.

4 CONCLUSIONS

In Figure 5 the in-situ (UAS) and lidar INPC estimations are compared for three different temperatures (-20°C, -25°C and -30°C). When we apply the N12 and D15 parameterizations for the same height as the UAS flight (2.55 km a.g.l) we get between one to two orders of magnitude higher values compared to the FRIDGE measurements. When we compare the UAS measurements with the lidar INPC values in the actual height of -20°C, -25°C and -30°C (6 km, 6.5 km and 7 km a.g.l.), the N12 parameterization provide INP concentration values closer to the measurements while D15 gives one order of magnitude lower values. We will investigate this topic more intensively in the next time.

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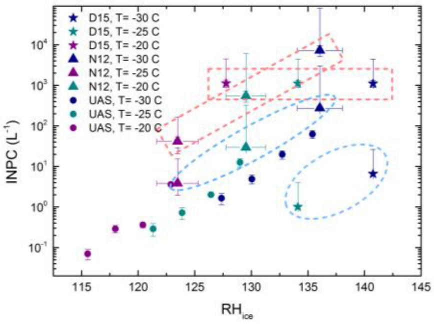

Figure 5: INP concentrations during the event. Dots: UAS measurements. Triangles and stars: lidar estimations based on N12 and D15 respectively. Peach dotted squares correspond to N12 and D15 INPC values for the air mass at the height of UAS flight (2.55 km a.g.l.). Blue dotted circles correspond to INP estimates at the actual heights of Temps -20, -25 and -30 °C during the time window 1-2 UTC.

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