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AIRCRAFT MEASUREMENTS OF DROP CHARGES IN STRATOCUMULUS CLOUDS: OBSERVATIONS AND MODEL COMPARISONS

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1. INTRODUCTION

Coalescence growth and freezing of supercooled drops by contact ice nuclei (IN) are important cloud microphysical processes that can be enhanced by cloud drop charge. Although cloud drop charges have been obtained from mountain tops and balloons, the origin and spatial distribution of cloud drop charge remains speculative because existing data lacks measurements of other cloud properties. The purpose of the measurements in the 1997-98 Lake-ICE was to obtain drop charges using the NCAR Electra throughout the Sc layer clouds over Lake Michigan for analysis with measurements of drop and ice particle spectra.

2. MEASUREMENTS

The average charge on cloud drops was measured using the counterflow virtual impactor (CVI) system. In the CVI input stream, drops of about 5-25 µm radius were evaporated before entrance into the aircraft (Twohy et al. 1997). The drop residue was collected by an absolute filter electrometer having a sensitivity of 1 femtoamp (10^{-15} A). The mean charges on cloud drops were determined from the electrometer current, sample flow rates and CVI CN concentrations. Mean drop sizes were calculated from the CVI condensed water contents and CN concentrations, as well as FSSP spectra.

2.1 Drop charges at the top of an altostratus layer

The first cloud measurements on January 18, 1998 occurred at 1034 UTC just after the Electra reached level flight at 3.0 km. Figure 1 shows a vertical profile through an As layer obtained by the SABL nadir lidar at IR wavelength onboard the Electra. At this time the Electra was on a westerly heading as it crossed the eastern shoreline of Lake Michigan near Manistee, MI.

The upper dark line in Fig. 1 represents the decent of the aircraft to level flight at 3.0 km elevation. The strongest backscatter power is the bright layer from the upper portion of the cloud layer. Cloud base is at the bottom of the adjacent gray layer at about 2.7 km. Thus, the cloud layer beneath the aircraft is about 300 m thick and rises to slightly above 3 km at the shoreline. Just below the cloud, the backscatter is reduced but increases again below about 2.0 km, perhaps, from increase scattering by aerosol in the surface boundary layer.

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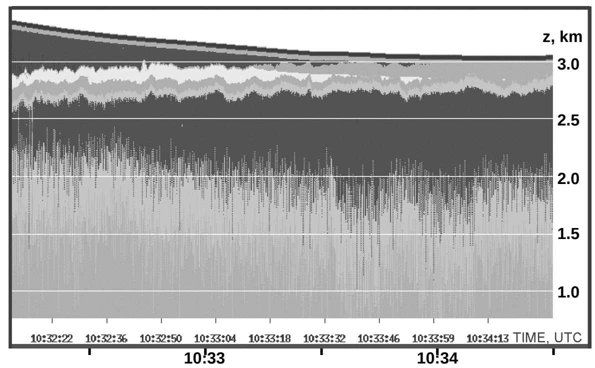

Fig. 1. Profile of altostratus layer over Lake Michigan on January 18, 1998 for 10:32 to 10:34 UTC obtained by SABL nadir lidar at IR wavelength onboard the NCAR Electra RF09 during Lake-ICE.

Figure 2 shows measurements obtained during the first two minutes in the cloud layer with higher tops in the direction of flight. At this time the Electra was in level flight with an elevation that varied by less than ±10 m in response to vertical air motions between +0.8 and –1.2 m/s. There are ten cloud elements indicated by peaks in the FSSP cloud drop concentrations (N_{FP}). Unfortunately, the CVI inlet was switched to the whole air mode (counterflow off) at about 15 seconds after 1036 UTC, so that drop charges could no longer be measured.

A series of four positive current peaks was observed during penetration of cloud elements in the first minute on Fig. 2. The corresponding average drop charges for these cloud elements were 81, 86, 88 and 90e. The positive polarity of drop charge is consistent with a positive screening layer at cloud top. With further penetration into the cloud layer, the positive currents gave way to negative currents with average drop charges of –42 and –24e. The change in polarity indicates negative drop charges within the cloud layer.

The space charge density carried by cloud drops is obtained from the electrometer trace on Fig. 2 after dividing the ordinate by 64. The maximum current peaks of each polarity correspond to ρ_D = +1.9 pC/L and –0.8 pC/L. The 260X and 2DC indicated that ice particles were not a significant factor in the CVI concentration or electrometer current.

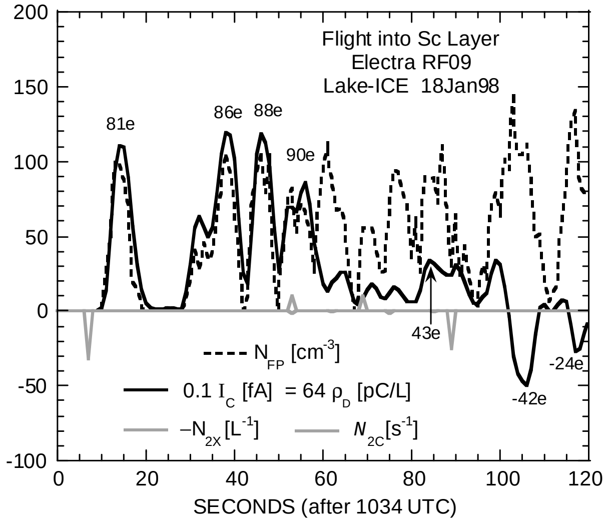

Fig. 2. CVI and aircraft measurements for level flight into the top of a rising altostratus layer on January 18, 1998, beginning at 1034 UTC. Shown are the FSSP concentration (N_{FP}), the cloud particle current (I_C) from the electrometer and associate drop charge density (ρ_D), as well as the ice particle concentration from the 260X (N_{2X}) for diameters above 55 μm and ice particle counts from the 2DC (N_{2C}). The average drop charge is given for the cloud elements in units of electronic charge, e = +1.6 $\times 10^{-19}$ C.

2.2 Drop charges in a stratocumulus layer

The data shown in Fig. 3 were obtained on January 20, 1998 during an ascent through a 600 meter stratocumulus layer near the Michigan shoreline. Upon entering the cloud, the FSSP concentration rose to over 150 cm^{-3} within 5 seconds. The CVI CN concentrations increased gradually, attaining 150 cm^{-3} after 35 second. Initially most of the cloud drops were below the mean CVI cut radius of 4.6 µm. As the drops sizes increase higher in the Sc layer, the CVI concentration approaches the FSSP (N_{FP}).

Ice particle concentrations were largest about 40 seconds before entering the Sc layer where the 260X ice particle concentration peaked at 18 L^{-1}. Inside the Sc layer, ice particles were detected by the 260X during just 3 seconds with values 0.4. 2.6 and 1.3 L^{-1} for sizes 270, 100 and 130 µm. The 2DC registered only 14 ice particles while inside the Sc layer.

At about 25 seconds prior to entering the cloud layer the electrometer current reached its largest positive values of 27 and 28 fA in snow. The current was negative throughout the Sc layer with a maximum of –975 fA. No positive excursions occurred in the cloud although some of wiggles in the current trace may have been caused by positive charges on snow. The negative electrometer current in the cloud layer is consistent with the typical polarity that we found on cloud drops in absence of significant ice particle charges of opposite polarity.

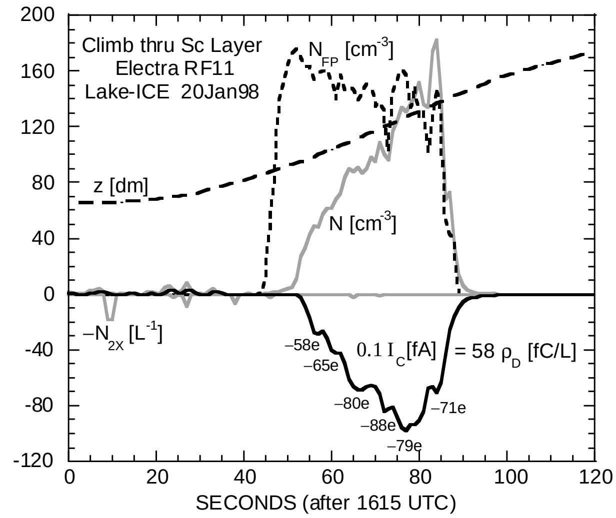

Fig. 3. CVI and aircraft measurements for the climb through Sc layer on January 20, 1998, beginning at 1615 UTC. Shown are the FSSP concentration (N_{FP}), the CVN CN concentration (N) the cloud particle current (I_C) from the electrometer with the associate drop charge density (ρ_D), as well as the ice particle concentration from the 260X (N_{2X}) for diameters above 55 μm. The average cloud drop charge is given in units of electronic charge, e = +1.6 $\times 10^{-19}$ C.

The drop charges on Fig. 3. are averages over the correspond peaks. The charge reached –58e at about 100 m above cloud base. At this early stage of cloud drop growth, only about 30% of the cloud drops were large enough to enter the CVI. Another 200 m higher, the cloud drop charge reached its maximum negative value of –88e, where about 80% of the cloud drops entered the CVI. The average drop charge magnitude then decreased with the last peak of –71e at about 100 m below the apparent top of the Sc layer.

The space charge density carried by particles is obtained from the electrometer trace on Fig. 3 after dividing the ordinate by 58. Thus, the space charge density ρ_D peaked at –1.7 pC/L for drops in the cloud, whereas the maximum positive ρ_D was about 0.04 pC/L associated with small positive currents from ice particles prior to entering the cloud.

The apparent absence of a positive screening layer can be explained if the aircraft emerged from the side of a cloud turret, rather than the top. Unfortunately, we were unable to locate the videos for this Electra flight (RF11) or the Electra flight shown in Fig. 2 (RF09).

3. DISCUSSION

Our most complete observation of a Sc layer indicates that drop charges reach their maximum values well within the cloud layer, in contrast to simple layer models showing charge maximums in the screening layers at cloud base and top. However, the large fields documented within layer clouds (see MacGorman and

Rust, p 46) and the resulting conduction of excess negative ions (Gunn 1956, Phillips 1967, Griffiths et al. 1974, Pruppacher and Klett 1997) may explain the observed drop charge densities of several picocoulombs per liter.

At the conference we will summarize our charge measurements for cloud drops, ice particles and snow. In addition, we will present preliminary calculations using a steady state one-dimensional layer cloud model with cloud conductivity based on the measured drop size distributions from the ascent through the Sc layer (Fig. 3). Iterative calculations will be used to solve for the drop charges in response to the model electric field and polar ion ratios at each model level, and results will be compared to our measurements of drop charge density.

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