CONTRASTING THE ICE NUCLEATION IN TWO LEE WAVE CLOUDS OBSERVED DURING THE ICE-L CAMPAIGN

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1. Introduction

We present some early observations from the recent NSF funded ICE-L (Ice in Clouds Experiment - Layer clouds) field campaign over Wyoming and Colorado in fall 2007. The long term goal of the project is to show that the number of ice particles formed by nucleation mechanisms can be predicted if the aerosol feeding into the cloud is adequately characterised both physically and chemically.

Airborne observations made with the NCAR C-130 in two isolated lee wave clouds on separate days are compared and contrasted. While both clouds were sampled between -20C and -30C, one cloud contained relatively large amounts of ice while the other was relatively devoid of ice.

The data presented are from flights RF03 and RF04 made on the 16 November 2007 and the 18 November 2007, respectively. Over this period the synoptic situation was characterised by a low pressure system in the Pacific to the northwest of the operating area. This system drifted slowly north over three days but spawned a smaller shorter wavelength low pressure system that remained further south. This situation maintained a slight ridging over the operating region and advected moisture at midlevels into Wyoming on strong westerlies.

2. Instrumentation

Instrumentation for the ICE-L campaign aboard the C-130 for hydrometeor characterisation included a new NCAR developed fast 2D-C (64 elements, 25 micron pixel size), Cloud Droplet Probe (CDP 3-50 μm), Small Ice Detector (SID2H, $\sim$3-50 μm), Cloud Particle Imager (CPI 10-2000 μm). Aerosol characterisation intrumentation included a Condensation Nuclei counter (CN D$>$50nm), Ultra High Sensitivity Aerosol Spectrometer (UHSAS 50nm - 1 μm), Counter Flow Virtual Impactor (CVI), Aerosol Time Of Flight Mass Spectrometer (ATOFMS), Aerodyne compact Time of Flight Aerosol Mass Spectrometer (AMS), Ice Nuclei Counter (INC). Bulk and environmental probes included the Rosemount Icing Detector (RICE), and Buck hygrometer. Other core measurements of winds and temperature were also measured.

3. Cloud passes

We present one straight and level leg through a wave cloud for each of the days considered. Figure 1 shows the data for RF03. The flow of air through the cloud is from right to left (i.e. the aircraft was flying into the wind). For RF03, the aircraft encountered (410 s) an updraft of 2 m s^{-1} close to the leading edge of the cloud (390 s). The CDP and SID2H then show concentrations of $\sim$100 cm^{-3} between 390 and 240s (LWC $\sim$0.15 g m^{-3}). Within the liquid cloud the 2DC registers particles with sizes greater than 100 μm and the CPI imagery shows heavily rimed particles. The radar indicates relatively high reflectivities and cloud extending to between 1000 and 1500 m above the sampling altitude. Downstream (time$<$240s) of the liquid cloud there is an ice tail exhibiting ice concentrations of $\sim$50 L^{-1} on the 2DC (D$>$100μm) and $\sim$0.5 cm^{-3} on the CDP and SID2H. The CPI imagery shows ice crystals less or not affected by riming, perhaps representing aseparatee population to the rimed particles seen within the liquid cloud. The minimum temperature encountered by the aircraft

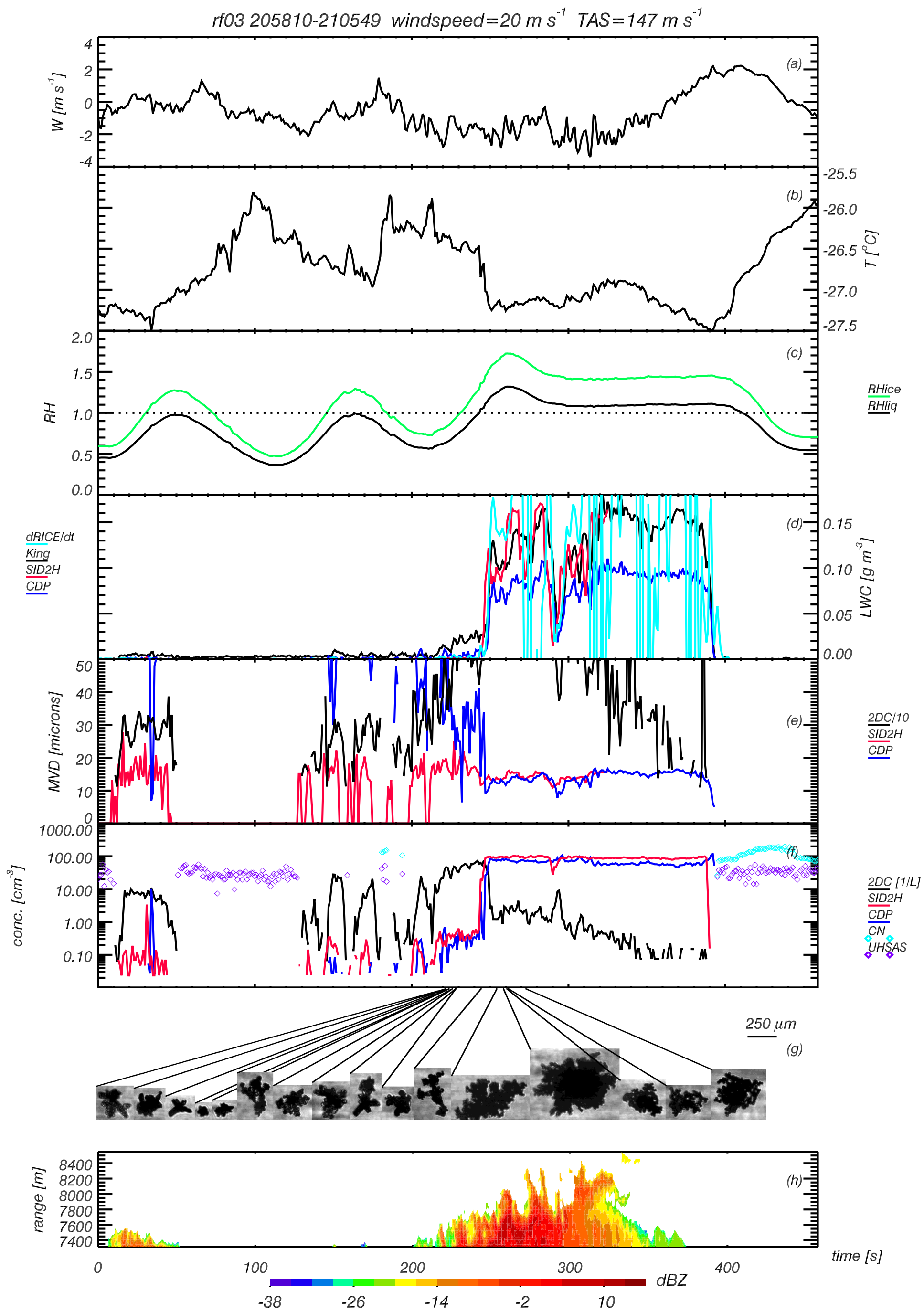

Figure 1: RF03. Various data (1 Hz) versus time along a straight and level run for a) vertical air velocity. b) Air temperature. c) Relative humidity with respect to ice and liquid obtained using the Buck hygrometer. d) Liquid water content (LWC) estimates from the CDP, SID2-H, King hot wire and the time derivative (mV/s) of the Rosemount icing probe (proportional to LWC). e) Mean volume diameter from the CDP, SID2 and ratio of 3rd and 2nd moment of the PSD for the 2DC (D>100μm) - for the 2DC the size has been divided by 10 for plotting purposes. f) Concentrations for the CDP, SID2H, 2DC (D>100μm), also shown are CN (D>50nm) and UHSAS (D>0.1μm) concentrations. g) Example CPI imagery with lines linking to location along the run (250 micron scale bar is shown). h) Radar reflectivity (zenith view) from the Wyoming Cloud Radar.

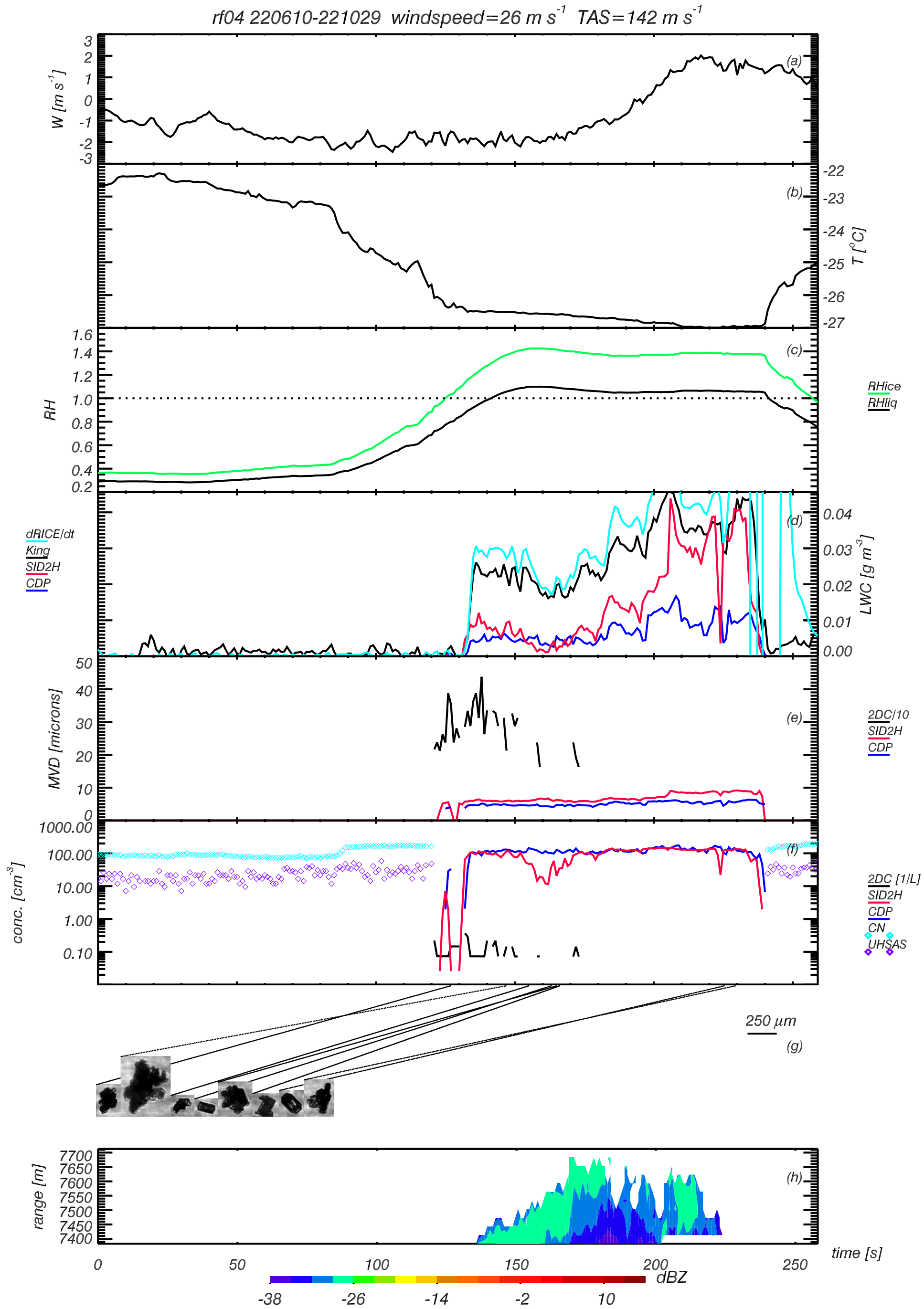

Figure 2: Same as fig. 1, but for RF04

during the run is -27.5C. Figure 2 shows a similar plot for RF04. Again the air flow through the cloud is from right to left. The maximum updraft of 2 m s^{-1} is encountered near the beginning of the liquid cloud and the minimum temperature along the run (-27C). This time the LWC on the King probe is only up to 0.04 g m^{-3} and the liquid cloud is shorter in horizontal extent (240-130s). Again, the CDP and SID2H show droplet concentrations around 100 cm^{-3} but the lower LWC means that the mean droplet size in RF04 is smaller. There is little evidence of an ice tail downwind of the liquid cloud. Ice is present and can be seen on the CPI images as well as the 2DC, but this time the concentrations of particles larger than 100 μm are $\sim$0.1 L^{-1}. The radar image reveals a much thinner cloud than on the previous flight with another thin layer above (500-1000m) that does not appear to be precipitating.

4. Aerosol

Analysis of the UHSAS size distributions on these days at the potential temperatures where clouds were found (fig. 3) indicates that there is a difference in the aerosol concentrations greater than 300 nm in size: there are more larger particles on the day with more ice (RF03). Additionally, X-ray chemical analysis of the CVI residuals larger than 0.5 μm indicate they are composed primarily of salts and show increased industrial, crustal and biomass fractions of the total number analysed in RF03 when compared to RF04, but a reduced fraction of sulphate. The ATOFMS analysis of CVI residuals (larger than 300 nm) showed that salts were the dominant residual in ice and liquid. Residuals collected in ice during RF03 showed increased fractions of silicate material associated with the salts and these salts appeared fresher (decreased presence of nitrate/sulphate) in the ice residuals in comparison to the residuals obtained in the liquid cloud. The AMS showed that ice residuals correlate well with the presence of Chlorine and organic material. The aerosol do appear to exhibit different size distributions and chemical characteristics between the two flights. However, the IN counter operating at water saturation and temperatures close to those measured during the sampling runs only shows concentrations of up to 1 L^{-1} (30s average) for both flights. While this is adequate for explaining the ice concentrations on RF04 (see Eidhammer et al. 2008) and to some extent the concentrations seen in the mixed phase region of the cloud, it is not enough to explain the concentrations seen in the outflow regions downwind of the liquid cloud in RF03.

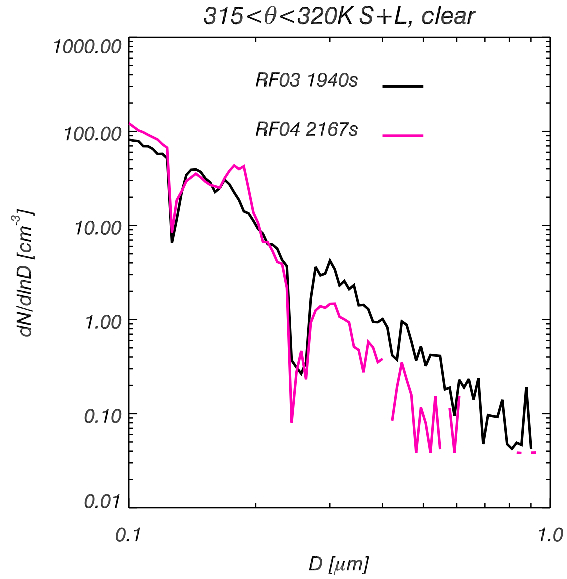

Figure 3: UHSAS aerosol size distributions for RF03 and RF04 averaged over periods when the potential temperature was between 315K and 320K, the range in which the clouds sampled formed.

5. Discussion

The greater concentrations of ice in RF03 when compared to RF04 for similar sampling temperatures, and updraft speeds indicate that the production of ice was different. There are two possibilities: i) A difference in the nature of the aerosol ingested into these wave clouds allowed more condensation/immersion freezing to occur during RF03. ii) The droplets at the top of the cloud in RF03 were exposed to cold enough temperatures ($T<$-35C) to allow homogeneous freezing to occur (or potentially deposition nucleation at these cold temperatures).

Because the difference in aerosol physical and chemical characteristics is not matched by a difference in IN counter measurements, this casts some doubt on the explanation of the difference in ice concentrations between the two flights being due solely to the nature of the aerosol. The second possibility is ice being formed higher up at colder temperatures through homogeneous freezing and then being sampled as the aircraft intercepts trajectories from higher altitudes. Simply assuming a sinusoidal fit to the wave vertical velocity suggests a maximum vertical displacement of 700m from the sampling level allowing parcels to experience temperatures down to perhaps -34C at the coldest along a trajectory. The aircraft would then intercept these trajectories in the ice tail of the run shown for RF03. The cloud does extend higher than 700 m above the sampling level and this higher cloud could be the source of the rimed particles seen in the liquid cloud. We interpret the proposed existence of two populations of ice crystals (rimed and unrimed) as indicating that some homogeneously frozen ice could have become rimed early on and crossed parcel streamlines becoming increasingly rimed as they fell to the aircraft sampling altitude. The character of the ice crystal images in the ice tail of the RF03 run are less affected by riming and may represent crystals formed on parcel trajectories that only reached -34C. This temperature is not cold enough for homogeneous freezing and so these crystals may have formed through heterogeneous freezing.

RF03 is more complex story than RF04, and it will require multi-trajectory parcel model runs to build up a more comprehensive picture of the history of the cloud intercepted by the aircraft at the sampling level. This approach will be required to rule out the hypothesis that the differences seen between RF03 and RF04 are largely due to aerosol differences.

Acknowledgements

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