3.3 High resolution measurement of ice - supercooled water cloud interfaces

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1. Introduction

Mixed phase cloud, as supercooled cloud drops and ice crystals, exists in the atmosphere on a large range of scales and is responsible for a variety of phenomena leading to precipitation, electrification and chemical reactions. Such mixes are also responsible for uncertainties in radiation transfer and questionable interpretation of satellite measurements as well as being potentially responsible for aircraft icing enhancement under specific cloud scales and particle sizes. Such mixed phase cloud arises in several ways and has characteristics dependent on its origins, (Riley and McDowall 1998; Korolev and Isaac 2002; Korolev et al. 2003).

The existence of entirely supercooled cloud is well known to occur, over a range of temperatures between 0°C and -40°C in lenticular and other clouds. Should overriding cirrus be present at lower temperatures, crystals grow and fall out to seed such supercooled cloud below, leading to the growth of individual crystals in a supercooled drop environment over a considerable area. Alternatively, more complex dynamics are involved as in strong convection with supercooled drops forming up shear and ice crystals in induced evaporative downdrafts down shear with an interface of varying proportions of ice and water between the two regions. In this case a horizontal aircraft traverse reveals a changing proportion of ice/water ratio, the details of which change with temperature over the range 0 °C to -40 °C. Such events also take place on a smaller scale in the weaker convection of stratiform cloud, having ice forming processes in the up shear liquid of the convective elements and ice particles first growing and then evaporating in down shear descent but covering a much narrower range of temperature than deep convection.

Frontal situations and other gravity flows provide similar situations in as far as cold air advection to a region of supercooled cloud leads to such discontinuities. Processes taking place in such interface regions range from a proliferation of ice crystals as by Hallett-Mossop processes or by ice evaporation at appropriate temperatures. Charge separation takes place in regions of riming ice particles and collision-bounce of ambient vapor grown ice crystals together with the chemical reactions triggered by separation and concentration of chemical species during the accreted drop freezing processes.

2. The measurements

During AIRS II project Nov 2003, (Isaac et al. 2005), the NCAR C-130 flew missions near the Great Lakes, Cleveland OH to Mirabel, Montreal to observe the microphysical structure of such mixed phase cloud regions over a range of temperatures to assess their importance and to gain insight into their origins and evolution. Such penetrations were mostly along the wind direction while approaching the water–ice cloud interface from the water or ice side and relied primarily on the T probe for measurement of LWC and IWC Fig 1 and 2, (Hallett et al. 2005). The T probe comprises three collocated sensors each maintained at temperatures near 150 °C, the power to maintain temperature being measured at one or 1/10 second intervals. A cylindrical sensor mounted normal to the airflow (right) collects mostly water; a cylindrical sensor with a forward facing re-entrant slot collects ice plus water (left); a cylindrical sensor mounted along the airflow collects no particles and serves as a reference. Data are recorded as water and ice plus water ±0.05g/m^3 concentration utilizing knowledge of latent heat of evaporation. Two T probes having sensors of diameter 3 mm and 1 cm allow

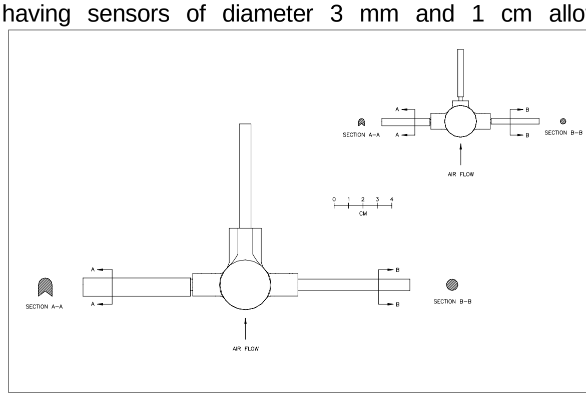

Figure 1: Plan view of large and small T probes showing re-entrant cross section for total (ice plus water) and water only, cylindrical cross section. In practice the cylindrical cross sections responds minimally to ice impact near the stagnation point, to be estimated as required as a second order correction. This requires a comparison between small and large T probe measurements and an estimate of particle density determined from the measurement matrix or independently from Cloudscope measurements.

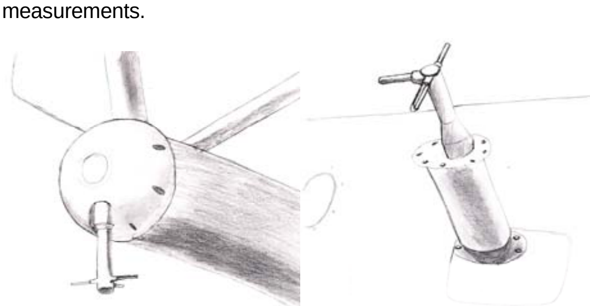

Figure 2: Sketch of T probe mountings on C-130, small T on wing tip with large Cloudscope and large T probe on fuselage.

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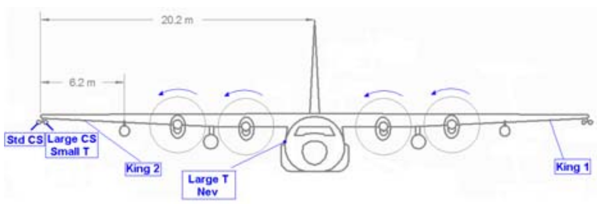

Figure 3: Mounting points of instruments on the NCAR C-130. The large T was mounted on the fuselage for power accessibility; the small probe near the wing tip, some 20m distant and could well be in regions of different cloud particle composition as well as in regions differing slightly in local airflow.

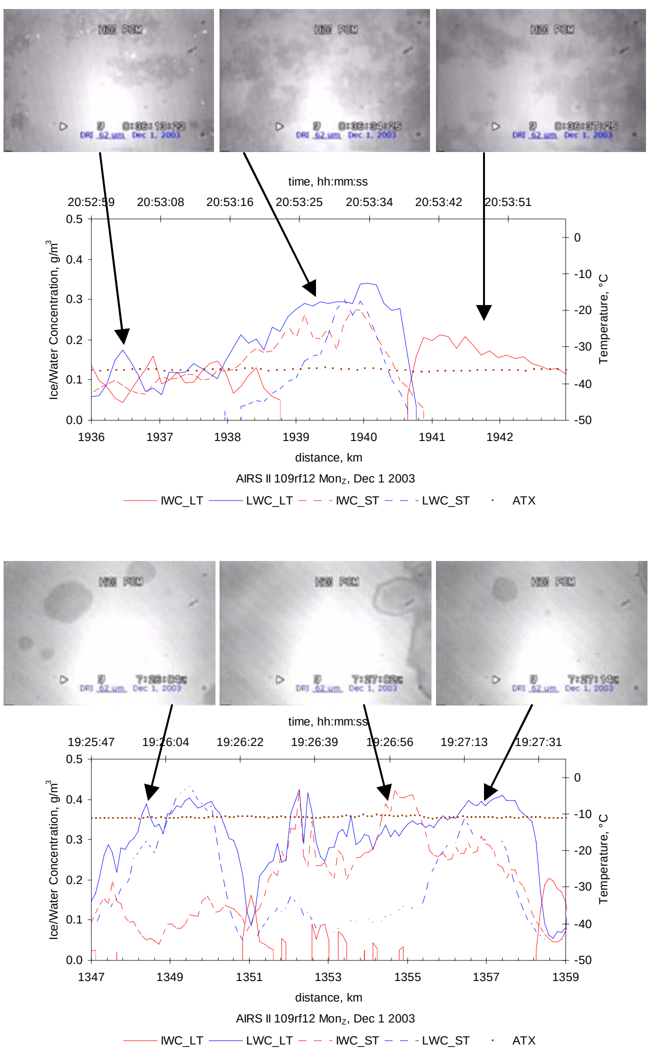

Figure 4: Inverse relationship of large T (full line) and small T (dashed line) illustrates the nature of the gradients for different temperatures for both ice and water. The interpretation of relative T probe measurements is given by collocated video of particles collected by the Cloudscope. 425 µm width image shows ice, water or mixed phase particles. Droplets collected at low temperature may nucleate and freeze on collection, a process deduced from the movie sequence.

collection of different size, shape, and density particles. Cloudscope images provide information on particle size, shape, concentration and particle density through evaporation rate as required.

The large T instrument was mounted on the fuselage for power accessibility; the small probe near the wing tip, some 20m distant and could be located in regions of different cloud particle composition (Fig 3).

3. Observations

The ice-water cloud interfaces selected for analysis showed a lack of ice above flight level as judged from the aircraft lidar data; the penetration direction was made normal to the interface geometry as far as could be judged from the wind field at flight level and radar depiction. Figure 4 shows interfaces sharp over 100 to 200 m near -37 °C and -10 °C respectively as measured by the large T probe (continuous lines). The resolution limit in this case for measurements of water and ice content of the interfaces is less than 200 m; the video resolution is 1/30 s, equivalent to about 3 to 5 m. The interfaces of interest are at Fig. 4a) 1936.5 km and 1940.8 km, and Fig 4b) 1351 km and 1358.5 km. Both large and small T probe are shown in this plot, the differences resulting from different collection of particles for sensors of different diameter. Differences in collection also occur from different density and shape of the particles, to be determined from the 1/30 s cloudscope video images. This data confirms that interfaces are sharp to well below 1 second resolution used in these studies. The small T probe was operated with a longer reading time constant and did not show the sharpness of these interfaces.

Fig 5a) and 5b) show a later section of the penetration of Figure 4. Medium resolution plots 5c) and 5d) show a sharp interface at 1994.8 km and a plot of ice to total water content (ice plus water) ratio. A high resolution plot 5e) and 5f) show the interface at 1994.8 km together with wind data, showing LWC associated with about 5 m/s vertical velocity with a directional shear of 10° at the interface.

The plots in Figure 6a and 6b show the structure of the mixed phase interfaces as well as changing concentration of ice and ice plus water at -10 °C. There is agreement between small T and large T for ice and water probes near 1139 km and 1145 km, and disagreement between 1147 km to 1153 km.

It is clear that the differences of ice and water collection on the two sensors of the probe, corrected for ambient conditions, must depend on the properties of the collected ice and water through the collection efficiency and thence the size, concentration, habit and density of the ice particles. This may be inferred from the Cloudscope or data from other probes and corrections applied individually. Alternatively, the matrix of Ice, Water, small T, and Large T may be derived empirically from individual calibrations to provide a working interpretation in the absence of other data (Figure 7). This approach will work better for larger, more spherical, higher density particles and conversely.

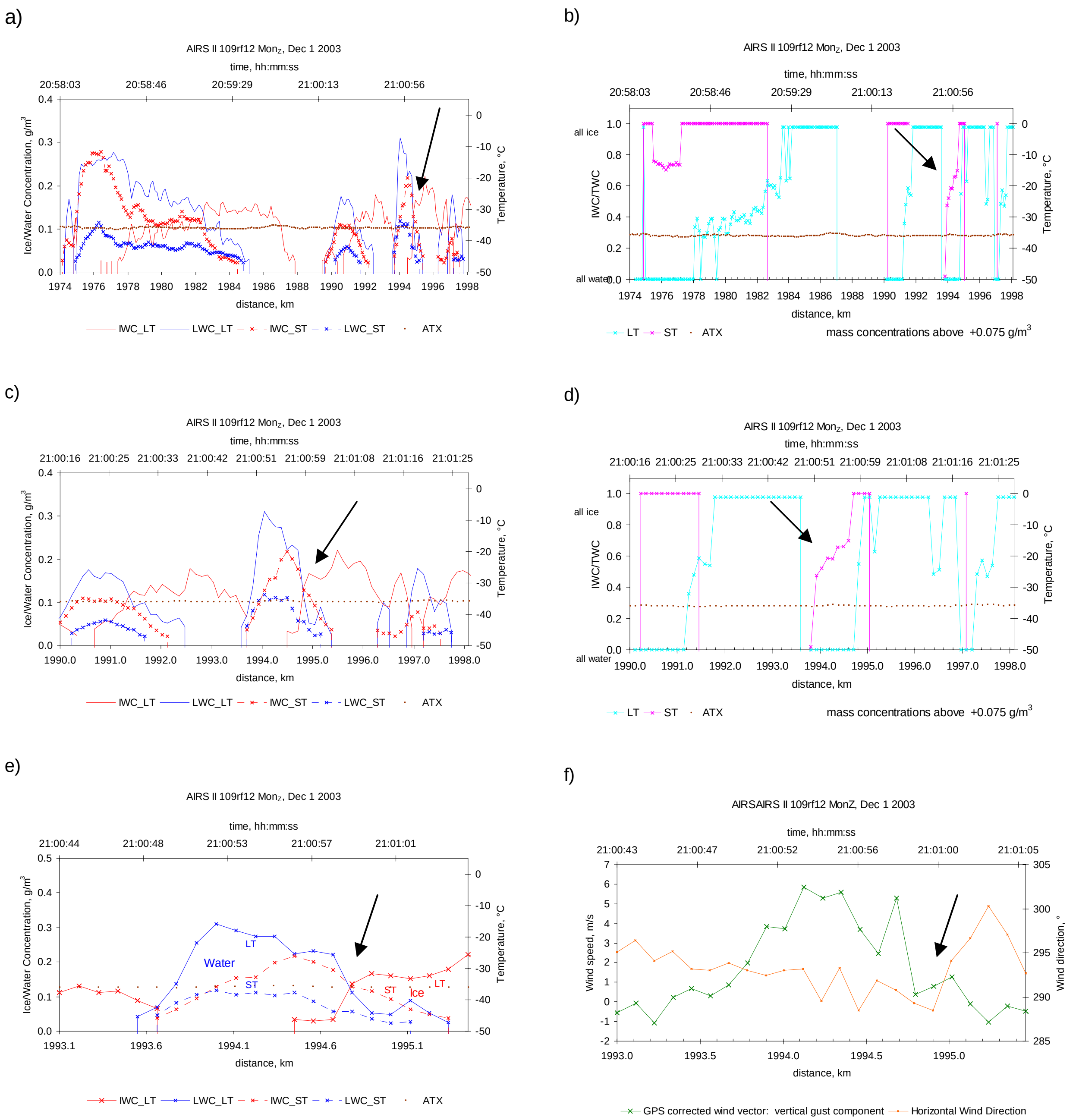

Figure 5: Plot of mixed phase fraction showing different horizontal gradients for sequential penetrations; the interface studied is at 1994.7 km (arrow). 5a) and 5b) show low resolution plots of ice and water content and ice to total water (ice plus water) ratio respectively. 5c) and 5d) show similar plots at medium resolution. 5e) is an expanded plot of T probe data from figure 5a showing ice-water interface well defined by the large T probe and less well defined by the small T probe, having lower resolution. 5f) shows vertical velocity and horizontal wind direction across interface. The horizontal wind speed was almost constant at 25 m/s.

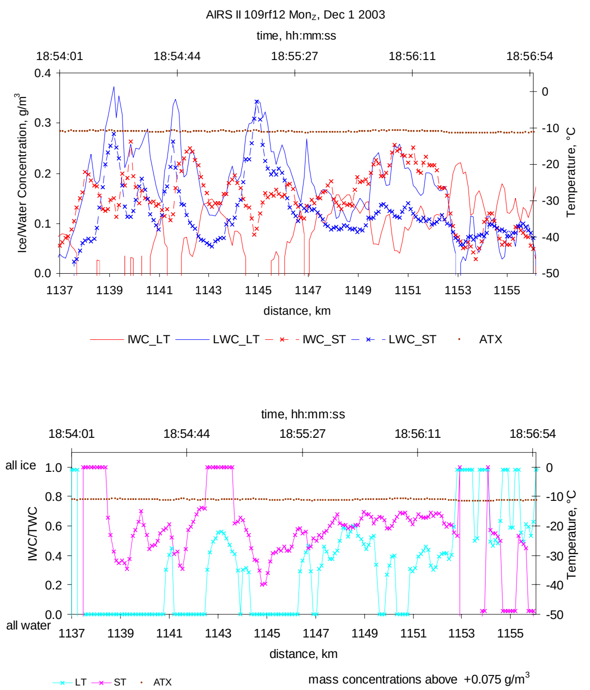

Figure 6: Plots of one second data concentration for -10 °C of ice and supercooled water and ice/total ratio at one second intervals (approx 100m) showing regions of agreement, 1140km 1146km and disagreement 1994.5km between large and small T probes.

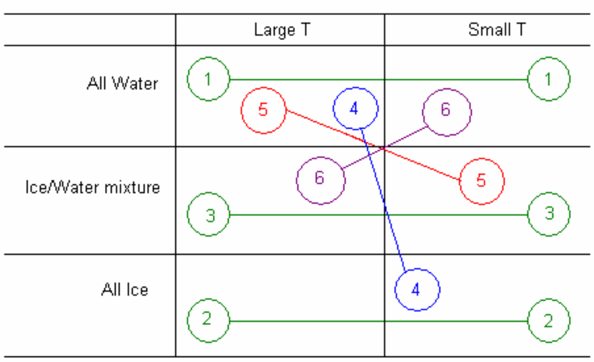

Figure 7: Protocol for interpretation of composite data between Large and Small T probes. Cases 1, 2, and 3 correspond to regions of identical collection; case 4 corresponds to regions with large water droplets and small ice crystals; case 5 to regions with large and small water droplets and small ice crystals; and case 6 to regions with large and small water droplets and large ice crystals.

Measurements can be made from both externally mixed phase cloud (individual particles as ice plus supercooled cloud or rain drops) and internally mixed water-ice particles as melting or freezing snow (Oraltay and Hallett 2005) or graupel as it begins to grow as wet hail. Such resolution may be further improved by use of 1/10 second data; Saturation at high ice/water contents may be avoided by use of probes at higher temperature.

Full interpretation for those regions where there is significant disagreement requires insight into particle size, shape and density and spatial in homogeneity and the likely implication for aircraft collection, bounce and splash. There are parallel implications for accretion of mixed phase on instruments themselves and also on falling hydrometeors.

4. Conclusions

The elegance of the T probe is its ability to provide real time measurements on ice and water liquid content with high resolution.

It is clear that there are measures with comparable sensors of cloud ice and water which show sharp discontinuities, over 100's of meters in dimension and probably much less. There are differences between probes of different size, to be interpreted in terms of ice properties and its accretion, providing new information on how aircraft may ice up in mixed phase.

There are also differences between collection of instruments at different sites for local aerodynamic reasons and also because there really are differences between wing tip and fuselage. There is a realization that our instruments, while still having sensing imperfections, have capability of providing higher resolution data. Improving resolution further is necessary to fully understand particle interactions leading to a variety of cloud processes as referred to in the introduction. A faster response algorithm for the T probe data, resolving 1/10 s, and a higher operating temperature will lead to correspondingly higher spatial resolution over a wider range of operation conditions.

5. References

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6. Acknowledgement

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