COMPARISON OF LWC MEASUREMENTS ON THE NCAR C-130 IN AIRS-2

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1. INTRODUCTION

The Alliance Icing Research Study (AIRS) is a collaborative effort involving several Canadian and U.S. research agencies and Universities. The second field study (AIRS-2) occurred from November 2003 to February 2004 and had ground-based remote sensing and several instrumented research aircraft. More information about the AIRS program can be found at http://www.airs-icing.org/index.htm

The focus of this paper is in-situ observations of liquid water that were made by the NSF/NCAR C-130 during AIRS-2. This aircraft was equipped with a variety of instruments to measure cloud particles and liquid water content (LWC). It made fifteen research flights through stratiform and stratocumulus clouds over the Great Lakes region from Ohio to Montreal, Quebec. The clouds included liquid, ice, and mixed-phase types.

This paper describes the instrumentation and shows examples of the measurements from segments of two flights. The goal of this research is to use the measurements to characterize the microphysical properties of these clouds, to improve the instrumentation, and to identify conditions when there are systematic differences in LWC measurements. These differences can arise from the range of drop sizes, the affects of probe location on the aircraft (fuselage, under-wing, wing-tip, pod), time response, and sub-cloud scale structure (Korolev et al., 2003).

2. INSTRUMENTATION

LWC instruments on the NCAR C-130 included four hot-wire type devices (PMS King, Nevzorov, DRI large and small T-probes), optical scattering probes (FSSP-100), optical array probes (PMS 2D-C, 2D-P, 260-X), HVPS (High Volume Precipitation Spectrometer), Cloud Particle Imaging probe (CPI), and a counter-flow virtual impactor (CVI). The Nevzorov, DRI T-probes, and CVI also measure ice water content (IWC). A Rosemount icing detector (RICE) detected supercooled liquid water. These instruments were on the fuselage and under-wing locations as shown in the top of Figure 1.

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The hot-wire devices measure the electrical power required to maintain a heated element at a constant temperature, typically 100 to 150°C. The PMS-King device is sensitive primarily to liquid water (King et al. 1978). The Nevzorov probe has three hot elements, one of which is shadowed from cloud particles and measures dry heat transfer to the air flow (Korolev et al. 1998). The other two elements are exposed to cloud particles and need additional power to account for latent heat. They measure both the liquid phase and the total condensate (ice plus liquid).

The DRI T-probes operate on the same principle as the King and Nevzorov probes, but the T-probes have a different geometry -- they are shaped like the letter “T”, and their heater wires are internal, not on the surface. This makes them more robust, i.e., less likely to be damaged by hitting cloud particles at (100+ $m\ s^{-1}$). The thermal response time of the T-probes is approximately 0.1 and 1.0 s for the small and large versions, respectively. Two T-probe units were operated on the C-130. A small one was mounted in a PMS pod under the wing, and a large one was mounted on the fuselage. This made it more susceptible to particle shadowing and size-sorting (King, 1984).

In order to calculate condensate mass from the PMS optical array probe data, an assumption is made about the mass density of the particles. For liquid, the density is 1.0 $g\ m^{-3}$, and for graupel or snow we assume 0.5. This leads to large uncertainty because actual values may range from ~0.05 to 0.9.

The CVI samples cloud particles larger than ~5 µm diameter into a dry nitrogen stream and measures the vapor content of their evaporated residuals (Twohy et al., 1997). It provides an independent measure of mass concentration.

All of these measurements are affected by the specific location of the probe on the aircraft because of issues related to the local airflow, such as speed and inertial shadowing or concentrating by aircraft structures. We expect there may be some variation in measurements because some of the probes are widely separated. For example, the two hot-wire King probes are ~34 m apart, cf., Figure 1.

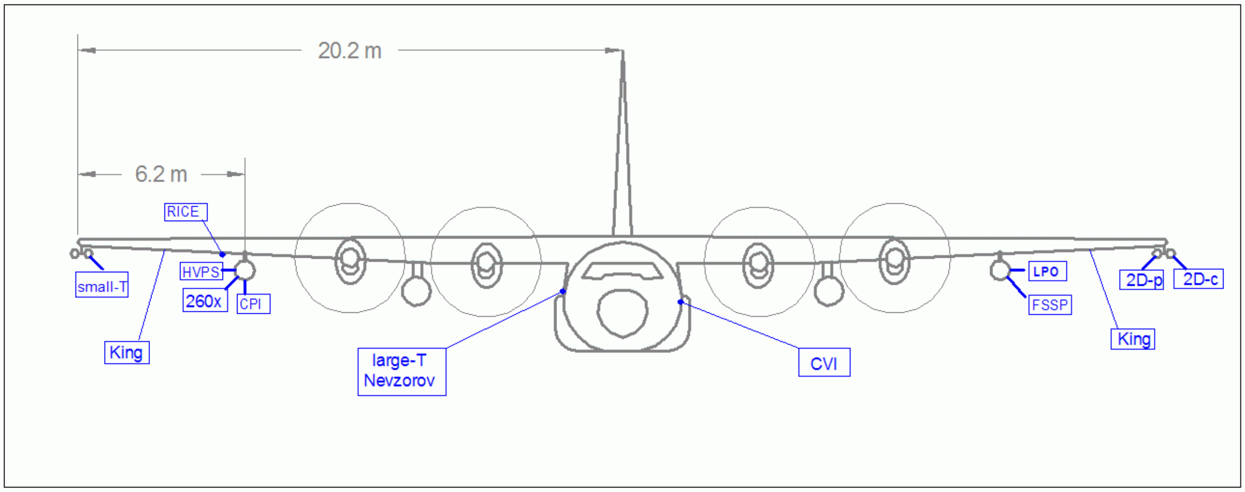

Figure 1. LWC instrumentation on NCAR C-130 during AIRS-2 project.

3. OBSERVATIONS

AIRS-2 flights were based out of Cleveland, Ohio, and most proceeded north across Lake Erie. Weather during this project presented a wide range of sampling conditions in stratiform and stratocumulus clouds, with some deep precipitating systems. Segments from two flights were selected for presentation in this paper.

3.1 Research Flight 9, 19-Nov-2003

This segment illustrates the relative agreement and the discrepancies among LWC measurements. The C-130 made a spiral ascent from 1200 to 7100 m through a deep precipitating system.

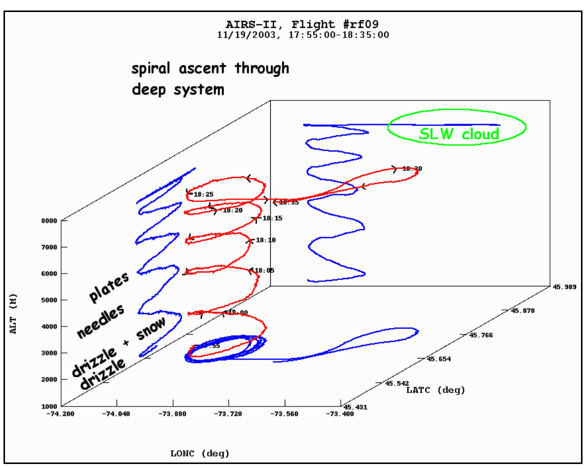

Figure 2. Sprial ascent in deep precipitating cloud system. Blue traces are projections onto horizontal and vertical planes.

A variety of cloud particle types were encountered, as shown in Figure 2. The lowest altitude had drizzle at +9°C. At higher altitudes, there was a progression of snow particles and sections of mixed-phase cloud.

A time history microphysics data during this ascent is shown in Figure 3. There was significant amount of small scale structure. Areas of embedded cloud water were supercooled in the upper regions (after 18:03). The water content is plotted with a logarithmic scale in order to show the large range of values measured by these instruments.

Traces from the LWC probes (bottom panel) follow similar traces, although differences are apparent. Measurements of ice water content (second panel) also parallel each other. The CVI and FSSP data (third panel) show yet more differences in water content. These differences are attributable to the size of particles measured by the instrument, by cloud structure, and by probe sites and local airflow on the C-130.

LWC values in water content from the 2D array probes (fourth panel from bottom) are significantly overestimated because of incorrect assumptions about particle density being 1.0 g m^{-3}. The CVI can be used to estimate the actual density. Its cut size was 7 µm diameter, and it is likely that most of the condensate mass was in larger sizes. If the mass density of the snow is ~0.1, then the water content from the 2D array probes will match that from the CVI. A density of 0.1 is a reasonable value for snow.

In Figure 2, the period 18:28 to 18:35 was an excursion through supercooled water cloud. Data from this period are plotted in Figure 4. The hot-wire probes showed consistent and parallel responses during this period, and none of the 2D probes detected snow particles. Variations between the measurements could be due to probe sensitivities.

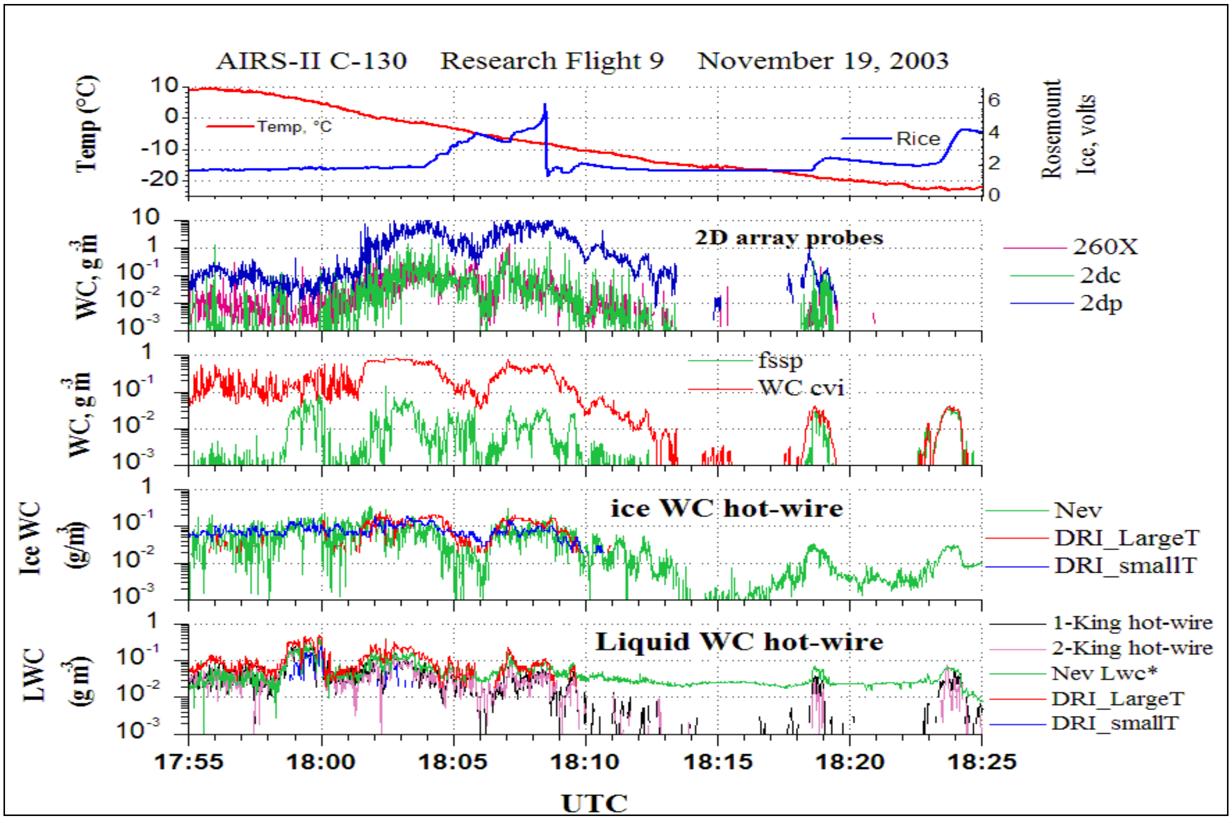

Figure 3. Time history of microphysics data during spiral ascent.

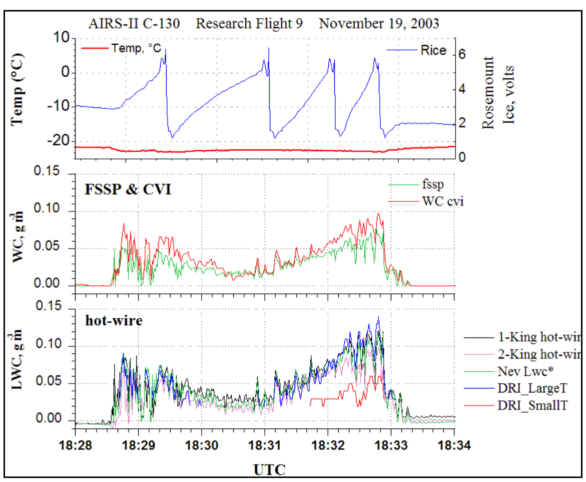

Figure 4. Six minute pass through supercooled water cloud.

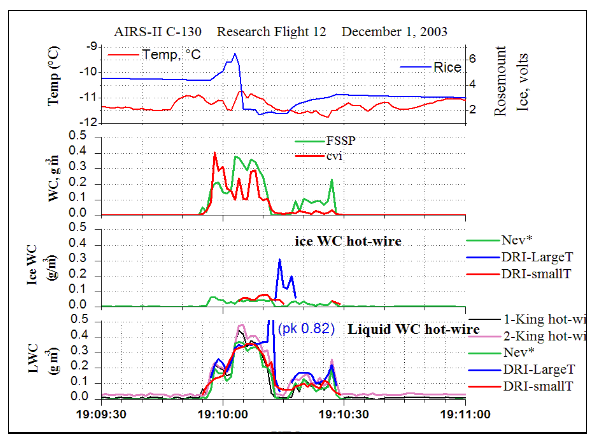

Figure 5. Ninety seconds of data with pass through one small convective cloud.

3.2 Research Flight 12, 1-Dec-2003

During part of Research Flight 12, the C-130 criss-crossed repeatedly through a field of small, separated stratocumulus clouds. The passes were at constant altitude of 1600 m and temperature -11°C. The clouds had up and down drafts ~2 m s^{-1} and contained both liquid water and snow. Each cloud pass was ~1-2 km in length.

A particular segment in Figure 5 shows a pass through one cloud. Measurements from the LWC probes are in general agreement, although there is some variation. During this period, the CVI cut size was 14 µm, above which was ~50% of cloud condensate mass. There was an abrupt transition LWC that occurs at 19:10:12. In order to examine the small scale variations, we used high rate data (25 Hz) that were available for some of the measurements. Voltage conversions of analog measurements from the hot-wire probes are made at fast data rates (>100 Hz), then averaged down to 1-Hz for analysis. Figure 6 shows the same small cloud as in Figure 5, but 25-Hz data are substituted for the Nevzorov and #2 King hot-wire probe. While the 1-Hz data accurately portray the general trends, there is clearly structure at finer scales, as revealed by the high rate data. The large value of LWC measured by the DRI large T-probe may seem out of bounds, but cloudscope evidence (right wing tip) suggests it is valid. Video images 19:10:10 to 19:10:12 show clearly the presence of liquid water and a small amount of ice impacting at ~19:10:12 (Figure 6 lower panel). The later peak (19:10:14 on upper panel) was a mix of a little water and mostly ice, 2-3 mm diameter. Note also the rapid fluctuations of #2 King hot-wire. Do these fine scale events reflect singular impacts of snow particles?

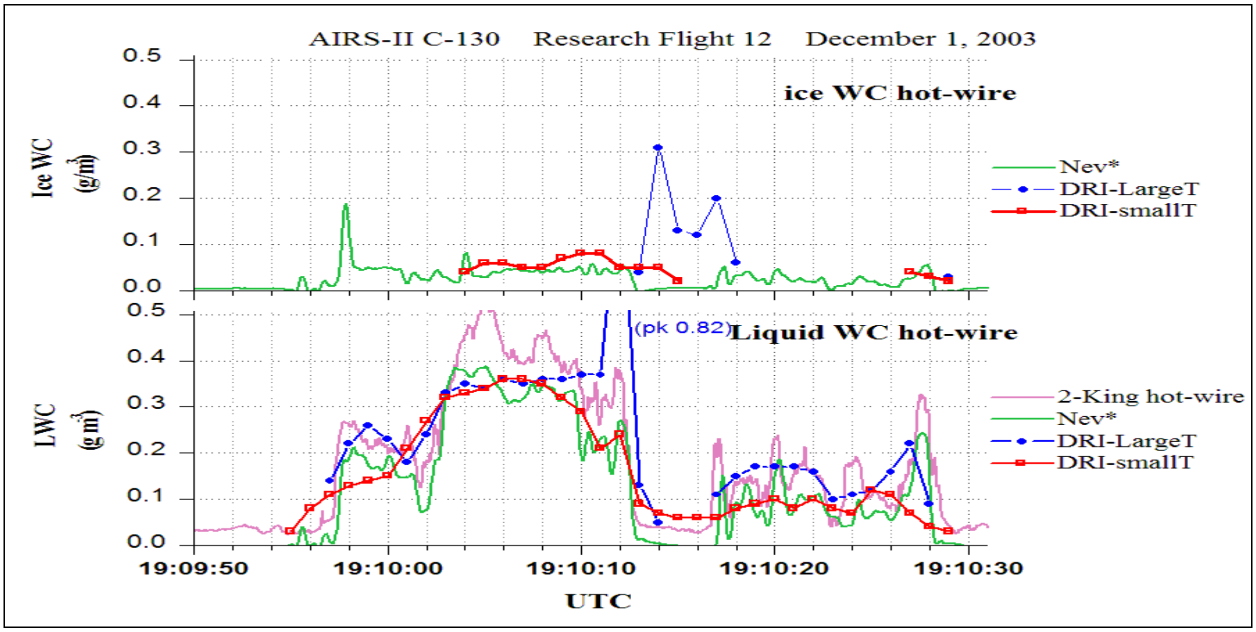

Figure 6. Zooms in on same cloud as Figure 5. Dots mark 1-Hz data, and continuous lines are for high rate (25 Hz) data.

3.3 Discussion

Measurements of LWC were made on the NSF/NCAR C-130 using a variety of instruments. In the liquid regions of AIRS-2 clouds, they show general agreement. Fine scale structure is revealed by high rate data and shows that some transition regions are significantly less than 100 m wide.

Further studies are planned. Correlations between the different probes will be examined and grouped according to particle size and single or mixed phase conditions.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

Hallett, J., R. Purcell, Roberts, M., Vidaurre, G., Wermers, D., 2005: Measurement for Characterization of Mixed Phase Clouds. *American Institute of Aeronautics and Astronautics.* AIAA-2005-862 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, Jan. 10-13, 2005.

King, W.D., 1984: Air flow and particle trajectories around aircraft fuselages. I: Theory. *J. Atmos. Ocean. Tech.*, 1, 5-13.

King, W.D., D.A. Parkin and R.J. Handsworth, 1978: A hot-wire liquid water device having fully calculable response characteristics. *J. Appl. Meteor.*, 17, 1809-1813.

Korolev, A. V., Strapp, J. W., Isaac, G. A. and Nevzorov, A. N., 1998: The Nevzorov airborne hot-wire LWC-TWC probe: principle of operation and performance characteristics. *J. Atmos. Oceanic Technol.*, 15, 1495–1510

Korolev, A.V., G.A. Isaac, S.G. Cober, J.W. Strapp, and J. Hallett, 2003 Part A: Microphysical Characterization of Mixed Phase Clouds. *Q.J.R. Meteorol. Soc.,* 129, 39-66.

Twohy, C. H., Schanot, A. J. and Cooper, W. A., 1997: Measurement of condensed water content and ice clouds using an airborne counter-flow virtual impactor. *J. Atmos. Oceanic Techn.*, 14, 197–202.