P6.10 COMPARISON OF SATELLITE AND AIRCRAFT MEASUREMENTS OF CLOUD MICROPHYSICAL PROPERTIES IN ICING CONDITIONS DURING ATREC/AIRS-II

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1. INTRODUCTION

Satellites are ideal for continuous monitoring of aircraft icing conditions in many situations over extensive areas. The satellite imager data are used to diagnose a number of cloud properties that can be used to develop icing intensity indices. Developing and validating these indices requires comparison with objective "cloud truth" data in addition to conventional pilot reports (PIREPS) of icing conditions. Minnis et al. (2004a,b) examined the relationships between PIREPS icing and satellite-derived cloud properties. The Atlantic-THORPEX Regional Campaign (ATReC) and the second Alliance Icing Research Study (AIRS-II) field programs were conducted over the northeastern USA and southeastern Canada during late 2003 and early 2004. The aircraft and surface measurements are concerned primarily with the icing characteristics of clouds and, thus, are ideal for providing some validation information for the satellite remote sensing product. This paper starts the process of comparing cloud properties and icing indices derived from the Geostationary Operational Environmental Satellite (GOES) with the aircraft in situ measurements of several cloud properties during campaigns and some of the The comparisons include cloud phase, particle size, icing intensity, base and top altitudes, temperatures, and liquid water path. The results of this study are crucial for developing a more reliable and objective icing product from satellite data. This icing product, currently being derived from GOES data over the USA, is an important complement to more conventional products based on forecasts, and PIREPS.

2. DATA

The satellite data consist of 4-km GOES-12 pixels with associated spectral radiances and cloud properties as described by Minnis et al. (2004a). The data of interest include cloud-top height, phase, base height, temperature, effective droplet radius, liquid water path, and icing potential or risk derived every 15 or 30 minutes. These pixel-level data are averaged along the aircraft flight tracks and matched as closely as possible.

Three aircraft, the NASA Glenn Twin Otter, the Canadian National Research Council (NRC) Convair-580, and the University of North Dakota (UND) Citation-II, carried a variety of in situ sensors and flew a number of icing missions. The Citation-II sensor complement included a set of FSSP and 2-DC probes as Rosemount and TAMDAR icing probes. The TAMDAR is a low cost sensor developed by AirDat for NASA and is designed to measure and report winds, temperature, humidity, turbulence and icing from regional commercial aircraft (Daniels et. al., 2004). The TAMDAR icing data consist of three indices: no ice, heater warning, and ice. These indices are compared with the GOES icing products. Figure 1 shows the Citation-II flight track over and into the clouds over Montreal, Quebec from Bangor, Maine. The flight track is overlaid on the GOES-12 infrared image, which shows little variation in brightness temperature over Montreal.

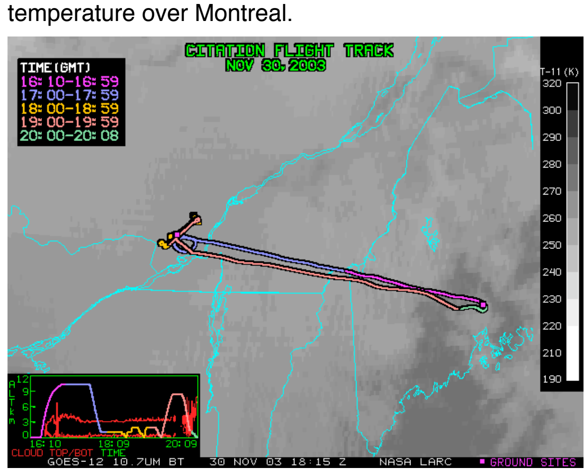

Fig. 1. UND Citation flight track on on GOES-12 infrared image, 1815 UTC, Nov. 30, 2003. Magenta squares indicate Mirabel and Bangor airport.

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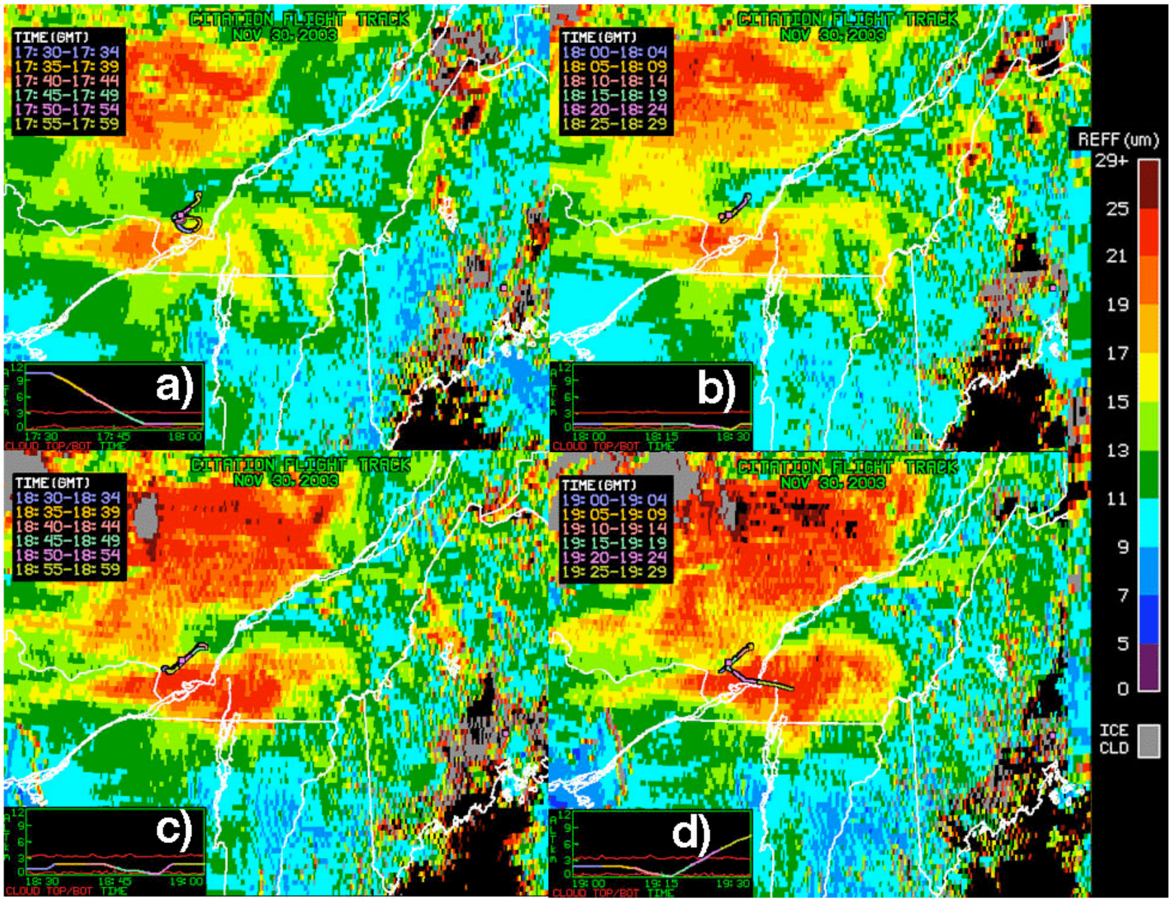

Fig. 2. Effective droplet radius from GOES-12 with flight tracks of UND Citation, 30 November 2003. (a) 1745 UTC, (b) 1815 UTC, (c) 1845 UTC, (d) 1915 UTC.

The NASA Glenn Research Center Twin Otter and Canadian NRC Convair-580 also carried a variety of probes including the King liquid water content and Rosemount icing probes.

3. RESULTS

3.1 Citation Flight, 30 November, 2003

The 30 November 2003 icing mission presents a unique opportunity to validate the NASA Langley's Icing Products. Murray et al. (2004) provide a brief discussion of the flight, which is examined in more detail here. The Citation flight track is plotted over the most closely matched images of the derived effective droplet radii *re* given in μm. In Fig. 2a, the Citation spirals down into the cloud deck passing through clouds with relatively large values of *re* (> 15 μm) then proceeds into an area with smaller values as it begins to fly back and forth over Mirabel Airport in Montreal. The clouds with large values of *re* move northeastward during the Citation passes over Mirabel (Figs. 2b-d). The cycling of the aircraft through different cloud regimes is more readily apparent in Fig. 3, which shows the detected cloud phase averaged over 4 pixels around the pixel corresponding to the aircraft location. The cloud phase determined from the satellite (top of Fig. 3) indicate that the area is clear at the beginning of the flight while supercooled liquid clouds occur either at or below flight level for most of the flight. The icing risk (panel 2, Fig. 3) is also relatively high for much of the flight. The passes over Mirabel are evident in the variation of *re* (third panel of Fig. 3) from 9 μm up to 19 μm or greater and back again several times between 1730 and 1920 UTC. The effective cloud height appears to be relatively constant around 3 km during most of the flight. This lack of variability is consistent with the nearly uniform appearance of the clouds in Fig. 1.

Figures 4 and 5 show the satellite derived icing potential compared with the Citation Rosemount and TAMDAR icing indicators, respectively. The Rosemount data are flagged as icing if the change in the voltage is greater than 1.5 over a 2.6 min interval. The satellite retrievals clearly show high icing probability was detected during the first hour of flight where the Citation climbed and maintained an altitude of over 9 km during the transit from Bangor to Mirabel. Satellite-derived cloud base and top were calculated at around 0.5 and 3

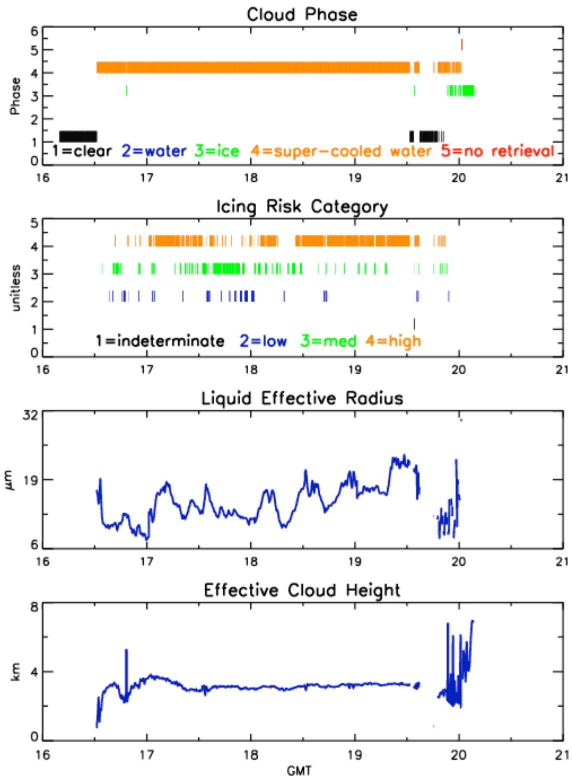

Fig. 3. GOES-12 derived cloud products matched along UND Citation flight track, 30 November 2003.

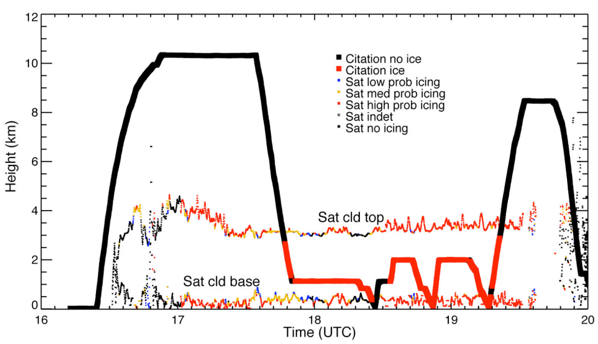

Fig. 4. Comparison of GOES icing probability and Rosemount icing probe, 30 November 30, 2003. Thick red line indicates icing from the Rosemount probe; two thin lines denote boundaries of cloud estimated for GOES.

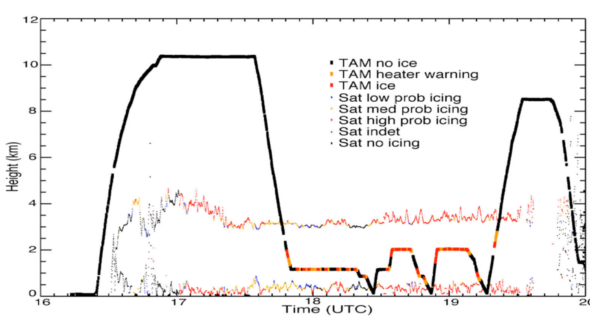

Fig. 5. Same as Fig. 4, except for TAMDAR.

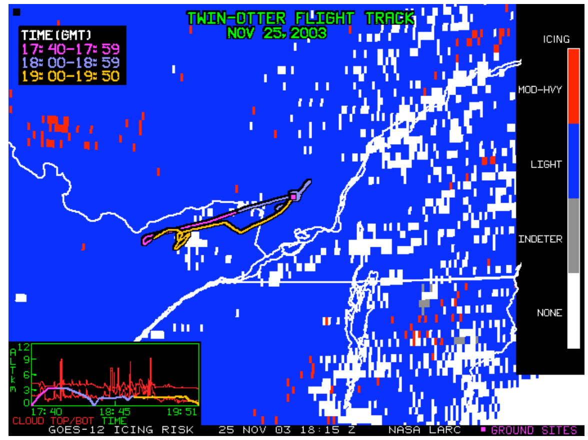

Fig. 7. NASA Glenn Twin Otter flight on Nov 25, 2003 over Mirabel, Canada. Blue and red color denotes light and med-high icing probability from GOES respectively.

km, respectively. As the Citation made a spiral descent over the Mirabel runway, the Rosemount started detecting icing at 3 km while the TAMDAR picked up icing at ~2 km during the descent. Both sensors performed optimally and agree well with satellite measurement for most of the flight. However, at about 1818 UTC, the satellite shows a small gap where no icing was detected for a period of 15-20 min of flight. Both the TAMDAR and Rosemount detected this gap but 10-15 minutes later. This lag needs further analysis.

3.2 Twin Otter Flight, 25 November 2003

The Twin Otter flew a coordinated icing mission with the UND Citation during 25 November 2003. The Twin Otter flew below 3 km in conditions with light-medium icing probability as determined from the satellite observations (Fig. 6). Figure 7 shows the GOES-derived icing probability compared with the Twin Otter Rosemount probe. For most of the flight where the Twin Otter flew below 2 km, the Rosemount detected icing whereas the satellite detected icing for the entire flight. Satellite cloud base and top appear to be a little too high. Ceilometer measurements from weather stations in the vicinity of the flight track revealed that the cloud bases were in the 1-2 km range (figure not shown), a

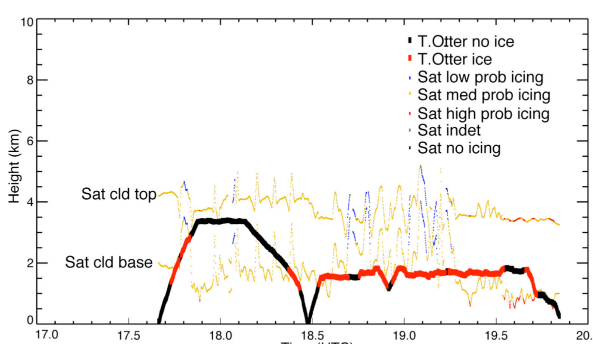

Fig. 7. Same as Fig. 4, except for Twin Otter Rosemount probe, 25 November 2003.

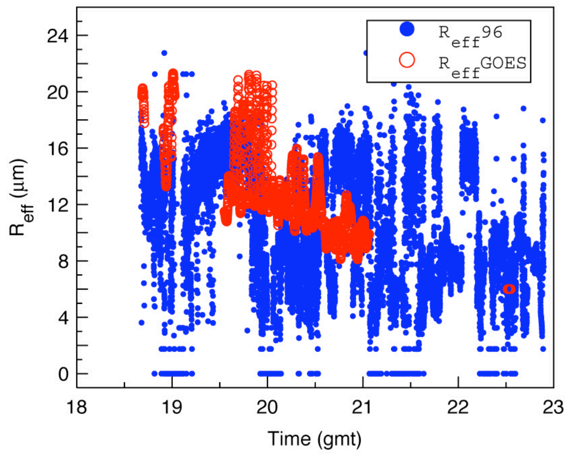

Fig. 8. Comparison of GOES-12 and NRC Convair-580 FSSP effective radius (in µm), 6 February 2004.

finding consistent with the results between 1730 and 1850 UTC. The rise in the GOES cloud heights around 1900 UTC needs further investigation. Overall, the icing from the GOES is located in the correct location horizontally although there is some apparent vertical error.

3.3 Convair-580 Flight, 6 February 2004
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The Convair-580 FSSP-derived effective droplet radii are compared in Fig. 8 with the matched GOES values during the Convair flight during 6 February 2004. The GOES *re* values are slightly larger than their FSSP counterparts near the beginning of the flight and decreased throughout the flight. They appear to be in good agreement with the FSSP data after 1800 UTC. The differences early in the flight could be due to the presence of ice in the otherwise supercooled cloud. Ice particles cause an overestimate of *re* in the GOES retrieval. The icing from GOES (Fig. 9) is coincident with much of icing indicated by the Rosemount icing detector except near the end of the flight. Again there are some discrepancies in the cloud top heights.

4. CONCLUDING REMARKS

These preliminary results indicate that the GOES icing detection is generally consistent with the objective icing detection probes on three different aircraft. GOES only "sees" the tops of the clouds directly, so the occurrence of icing below cloud top must be inferred. Additional analyses using a three-dimensional estimate of aircraft icing from the satellites (Minnis et al. 2004c) should provide for a more direct comparison between the satellite and the aircraft, which samples at different altitudes. The satellites are sometimes too high or low.

Acknowledgments

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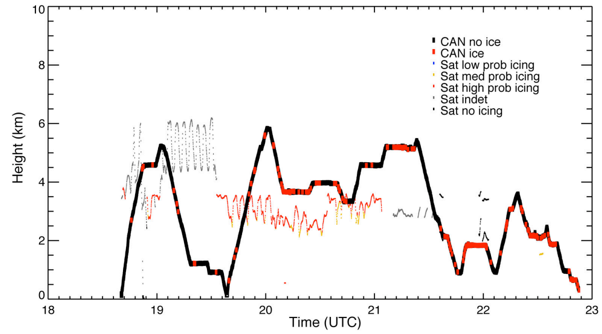

Fig. 9. Same as Fig. 4, except for Canadian NRC Convair-580 Rosemount probe, 6 February 2004.

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