5A.3 COMPARISON OF NASA-LANGLEY SATELLITE-DERIVED CLOUD TOP MICROPHYICAL PROPERTIES WITH RESEARCH AIRCRAFT DATA

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1. INTRODUCTION

Detection of cloud drop size from satellite data can be useful in determining areas of potential aircraft icing. Being able to remotely identify large liquid droplets at cloud top can help diagnose areas of supercooled large droplets (SLD). Cloud droplet effective radii (r-eff) and liquid water path (LWP) are currently being derived in near-real time from Geostationary Operational Environmental Satellite (GOES) data over the continental United States (CONUS) at NASA Langley Research Center (LaRC; Minnis et al., 2004a). Comparisons with pilot reports showed that the satellite-derived r-eff and LWP were related to aircraft icing conditions and could help estimate the potential icing severity (Minnis et al., 2004b). Although there have been some more quantitative validations of these products using active remote sensors (e.g., Dong et al., 2002), there have been few comparisons with in situ measurements from research aircraft. Although direct comparison between these two data types is difficult due to a variety of factors including variability of cloud top microphysical properties (Young, 1997) and scale differences, information about the quality of the satellite particle size retrievals can be gleaned from examining coincident aircraft data. To continue the quantitative validation of the retrievals, this paper analyzes two different cases where in situ particle size measurements were collected in supercooled liquid clouds.

2. DATA AND METHODOLOGY

2.1 *Satellite Derived Cloud Property Data*

Pixel-level NASA-LaRC cloud phase and cloud top r-eff products were used in this evaluation. These cloud properties are derived from multispectral GOES data using the visible, solar infrared (3.9 µm), and 10.8-µm radiances to estimate cloud optical depth, particle size, and cloud temperature, respectively. Cloud phase is determined from a variety of factors including the cloud temperature and the best fits to the ice and water reflectance models. The LaRC satellite-derived cloud properties are produced twice an hour, at 15 and 45 minutes past the hour. The pixel resolution is approximately 5 km over the Ohio area, where the research aircraft collected in-situ data. Seventeen satellite pixel values surrounding the aircraft's latitude and longitude were used for a broad comparison window.

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2.2 *Aircraft Data*

The NASA Glenn Icing Research Aircraft is a modified DeHavilland 6 Twin Otter with an onboard Forward Scattering Spectrometry Probe (FSSP) that collected particle size data. The FSSP measures particle diameters from 2 µm to 47 µm (McDonough, 2004). A Rosemount Outside Air Temperature probe (OAT) was used to compare cloud top temperatures with satellite IR temperatures to ensure the aircraft penetrated the cloud top. Two research flights from the 2005 NASA Glenn data set are used as case studies to compare measured r-eff and satellite-derived r-eff. One-second data from each flight were used to calculate the r-eff from the FSSP size distributions as

$$\text{r-eff} = \frac{\int n(r)\, r^3\, dr}{\int n(r)\, r^2\, dr}, \qquad (1)$$

where r is the radius of the particle, n(r) is the number of particles in the bin with a radius of size r, and dr is the difference in radius bin sizes with dr = 1.5 (Stephens, 1994). Averages of the r-eff over different time and depth intervals, depending on limitations of each case study, are compared to the NASA LaRC satellite-derived r-eff.

2.3 *Evaluation*

The drop sizes are split into 3 different categories:

Large: r-eff ≥ 15 µm
Medium: 15 µm > r-eff ≥ 12 µm
Small: r-eff < 12µm

These category names are relative to this study and are not meant to have other interpretations.

3. CASE STUDIES

3.1 *25 Jan 2005*

The flight occurred between 1902 UTC and 2045 UTC over eastern Ohio. Figure 1 plots the vertical profiles of total temperature (Tt, static temperature plus friction), dewpoint temperature (Tdew), air temperature (Ts), and icing. Figure 2 shows the vertical profiles of liquid water content These soundings from the aircraft's first ascent clearly shows two cloud layers, the first from about 4500 to 5500 ft and the second from about 9500 ft and up. The flight notes approximate the cloud top to be at 15000 ft. This flight did not break cloud top, but the aircraft was in the upper cloud layer for most of the flight. According to the flight notes drizzle was occurring in the upper cloud layer, suggesting that particles at cloud top were of sufficient size to fall back through the layer and were sampled by the aircraft. Because cloud top was not penetrated, the research aircraft data were selected to coincide with time periods when satellite data were available to optimize the comparison. One minute of nearly constant-altitude FSSP particle size concentration data were compared to the satellite-derived data. Satellite data from ± 30 minutes of the flight times were used for the comparison.

From 19:14:30 to 19:15:30 UTC, the average altitude of the flight was 11400 ft, or about 3600 ft below cloud top. The measured r-eff from the FSSP was 14.02 µm and considered to be in the Medium category. The NASA LaRC cloud phase product determined that all of the surrounding pixels were supercooled liquid water. Averages of the satellite-derived r-eff values at 19:15 UTC from the 17 pixels surrounding the aircraft flight path are listed in Table 1. The average difference between the aircraft-measured and GOES-derived r-eff is ± 3.28 µm at 19:15 UTC. To show the temporal variability of r-eff, the mean satellite-retrieved values of r-eff from data taken at 19:45 UTC (half an hour after the aircraft measurements) are given in Table 2. The average difference between the measured r-eff at 19:15 UTC and the 19:45 UTC satellite derived r-eff is ± 1.59 µm.

The next evaluated time period was 19:39:30 - 19:40:30 UTC. The aircraft flew at an average altitude of 11500 ft, or about 3500 ft below cloud top. The measured r-eff was 10.90 µm. Cloud phase values from the satellite data were again all supercooled liquid water for the associated times and satellite pixels. The satellite-derived r-eff from 19:45 UTC for the 17 pixels surrounding the aircraft are presented in Table 3. The average difference between the measured r-eff at 19:40 UTC and the 19:45 UTC satellite derived r-eff is ± 1.81 µm. For this time period, satellite data from 19:15 UTC (half an hour before the time of the measured r-eff) were available and show the cloud top value of r-eff before the aircraft flew below it as seen in Table 4. The average difference between the measured r-eff at 19:40 UTC and the 19:15

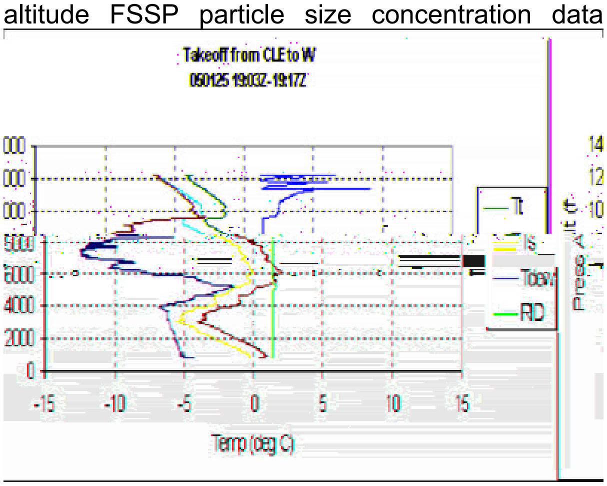

Fig. 1. Sounding from first ascent into cloud, 19:03 - 19:17 UTC, 25 Jan. 2005. Tt = total temp* Ts = air temp, Td = dew point temp, and RID = icing detector.

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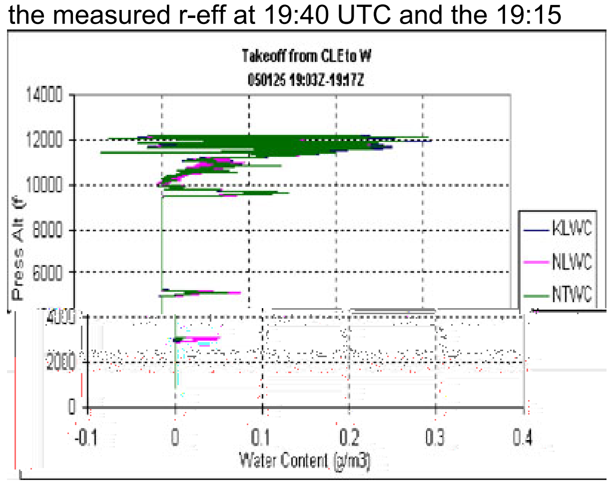

Fig. 2. Vertical water content profiles from flight's first ascent, 19:03 to 19:17 UTC, 25 Jan. 2005.

Table 1. Size distribution of r-eff for the seventeen19:15 UTC satellite pixels surrounding the aircraft at 19:15 UTC and 40.41°N and 82.25°W.

Measured r-eff = 14.02 μm		
Size Category	# of Satellite Pixels in the Same Size Category out of 17	Average r-eff of Satellite Pixel Values in Size Category (μm)
Large	3	20.10
Medium	2	13.40
Small	12	11.10

Table 2. Size distribution of r-eff for the seventeen 19:45 UTC satellite pixels surrounding the aircraft at 19:15 UTC, 40.41°N and 82.25°W.

Measured r-eff = 14.02 μm		
Size Category	# of Satellite Pixels in the Same Size Category out of 17	Average r-eff of Satellite Pixel Values in Size Category (μm)
Large	2	16.70
Medium	13	13.02
Small	2	11.20

Table 3. Size distribution of r-eff for the seventeen 19:45 UTC GOES pixels surrounding the aircraft at 19:40 UTC and 41.48°N and -82.78°W.

Measured r-eff = 10.90 μm		
Size Category	# of Satellite Pixels in the Same Size Category out of 17	Average r-eff of Satellite Pixel Values in Size Category (μm)
Large	2	15.30
Medium	8	12.95
Small	7	10.99

UTC satellite derived r-eff is ± 3.82 μm. The 20:15 UTC GOES-derived r-eff data are given in Table 5. The average difference between the FSSP r-eff at 19:40 UTC and the 19:15 UTC satellite derived r-eff is ± 2.11 μm.

This cloud appears to be transitioning from having larger drops at cloud top to smaller drops as seen with the satellite data. The satellite product imagery shows a gradient in r-eff in the flight area as the clouds move through the flight area. This change is also apparent from the FSSP data, which show the r-eff dropping from 14.02 μm at 19:15 UTC to 10.90 μm at 19:45 UTC. The difference between the aircraft measurements and satellite retrievals did not exceed 4 μm.

3.2 *16 Feb 2005*

This flight began at 15:09 UTC and lasted until 17:15 UTC during 16 Feb. 2005 over eastern Ohio. As seen in the soundings from the aircraft's

Table 4. Size distribution of r-eff for the seventeen 19:15 UTC GOES pixels surrounding the aircraft at 19:40 UTC, 41.48°N and 82.78°W.

Measured r-eff = 10.90 μm		
Size Category	# of Satellite Pixels in the Same Size Category out of 17	Average r-eff of Satellite Pixel Values in Size Category (μm)
Large	8	17.35
Medium	7	12.64
Small	2	11.50

Table 5. Size distribution of r-eff for the seventeen 20:15 UTC GOES pixels surrounding the aircraft at 19:40 UTC, 41.48°N and 82.78°W.

Measured r-eff = 10.90 μm		
Size Category	# of Satellite Pixels in the Same Size Category out of 17	Average r-eff of Satellite Pixel Values in Size Category (μm)
Large	2	15.70
Medium	9	13.27
Small	6	10.37

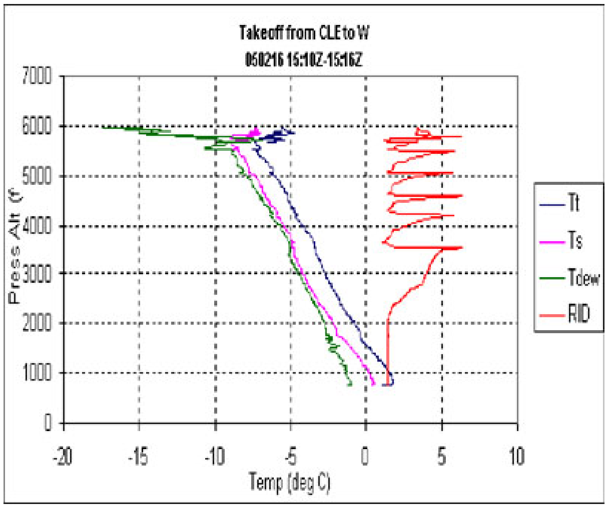

Fig. 3. Same as Fig.1, except sounding from first ascent into cloud, 15:10 - 15:16 UTC, 16 Feb. 2005.

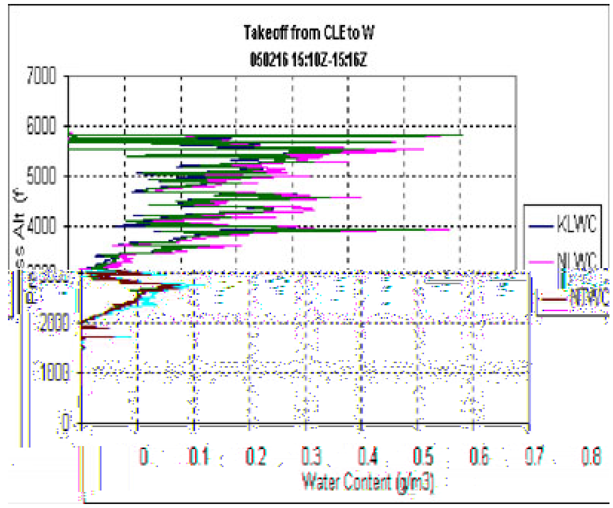

Fig. 4. Same as Fig. 2, except for 15:10 - 15:16 UTC, 16 Feb. 2005.

first ascent up to cloud top (Figs. 3 and 4), there was a single-layer cloud present at the time of the flight. The aircraft sampled cloud top, at approximately 6000 ft, several times. The r-eff values for six of these cloud top penetrations were evaluated for this flight. The LaRC cloud phase product indicated that the cloud was liquid for the entire flight, an assessment that appears to be confirmed by the near equality between the total (NTWC) and liquid (NLWC) water contents in Fig. 4. Due to slight mismatches between the cloud-top samples and the satellite image times, satellite data taken within 20 minutes of the aircraft times were used for comparison. This results in two sets of satellite-derived data values for the measured aircraft r-eff values from one cloud top penetration. The r-eff calculated from the aircraft FSSP size concentration data were averaged 100 ft from cloud top. Examination of the r-eff profiles for several cases indicated that r-eff at the top typically differed from the values at other altitudes by less than 1 μm. Thus, this top layer sample should be representative of the cloud microphysics in the layers just below cloud top also.

Figure 5 compares the maximum, minimum, and average satellite r-eff values with the aircraft r-eff values for the six cloud top penetrations. It can be seen that when larger drops, with sizes in the Medium category, are present the maximum of the 17 pixel satellite values reflect higher values, and the minimum values are also larger. These comparisons were repeated with an averaging depth of 200 ft into the cloud from cloud top. Results were similar to the previous comparison, as expected.

The aircraft values indicate considerable small-scale variability in r-eff with an overall range of 7 μm. The product imagery (http://www-angler.larc.nasa.gov/satimage/products.html) indicate that the scene was relatively uniform. However, if the minima and maxima are considered the results in Fig. 5 have a range of 7 μm also, but the values are higher by 2 μm. The mean values have a range of only 2 μm. The cause of the differences in the absolute values is not immediately apparent, but the 2-μm difference is similar to that found by Dong et al. (2002) using radar and radiometer data. For optically thin clouds, the presence of snow at the surface could result in extra large values of r-eff in the satellite retrieval. There appears to have been some snow cover in the area, however, the LWP computed from the in situ liquid water content profiles is between 200 and 300 gm^{-2}. Thus, the presence of snow should have no effect on the GOES r-eff retrievals.

These results are similar to the cases for 25 Janaury 2005. In tables 1, 2, and 5, the aircraft measured r-eff falls within the range derived by the satellite algorithm, and in two cases, tables 3 and 4, the aircraft measurement r-eff is lower.

4. DISCUSSION AND CONCLUSION

There is evidence that the NASA LaRC satellite-derived r-eff product has some ability to diagnose the presence of Large drops at cloud top. It appears that when Medium drop sizes are measured by the aircraft, the NASA LaRC r-eff product also detects Medium-sized drops in the area. As seen in Fig. 6 for cloud tops 5 and 7, the satellite-derived r-eff values are within 1 μm of the measured r-eff values. Even for cloud tops 2, 3,

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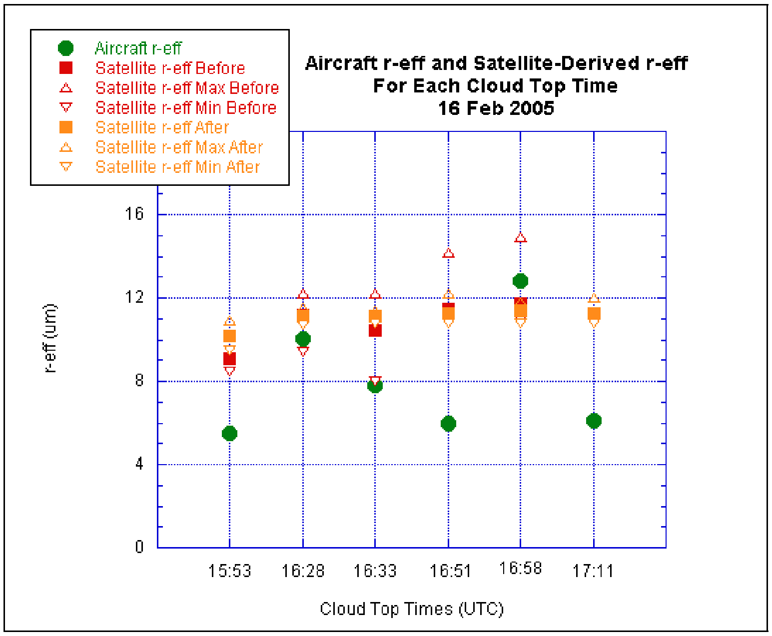

Fig. 5. Summary of results for 16 February 2005 cases. Green circles are the calculated r-eff from aircraft data. Red squares are r-eff averages of 17 satellite pixels for up to 20 min before cloud top penetration. Red up/down triangle denotes max/min from before the cloud top time. Orange squares are r-eff averages of the 17 satellite pixels for up to 20 min after cloud top penetration. Orange up/down triangle denotes the max/min before cloud top penetration.

and 8 (all fall into the Small category), the in-situ r-eff values are within the spread of the satellite-derived r-eff data. There is an issue, though, with the smaller drop sizes: even though the range of r-eff values from the satellite-derived data show that there are drops in the Small size category for cloud tops 1, 4, and 6, the difference between the measured and satellite r-eff seems to be significant. For measured r-eff values less than 7 μm, the minimum r-eff from the corresponding satellite value is at least 3 μm greater. Even though this result is discouraging, the error is small considering the spatial scale differences (i.e., a point measurement by the aircraft vs. a 5 km^2 satellite pixel), and the variability of microphysical cloud top properties (Young, 1997).

The preliminary results from these two case studies weakly suggest that the LaRC r-eff can be used to estimate water droplet sizes at cloud top. Additional results will be presented at the conference.

5. ACKNOWLEDGEMENTS

This project is supported by the NASA Applied Sciences Program through the NASA Advanced Satellite Aviation-weather Products (ASAP) project. NCAR is sponsored by the National Science Foundation. The authors would like to thank Tom Ratvasky and the Icing Branch at the NASA Glenn Research Center for the Twin Otter research aircraft data.

6. REFERENCES

Dong, X., P. Minnis, G. G. Mace, W. L. Smith Jr, M. Poellot, R. T. Marchand, and A. D. Rapp, 2002: Comparison of Stratus Cloud Properties Deduced from Surface, GOES, and Aircraft Data during the March 2000 ARM Cloud IOP. *J. Atmo. Sciences*, 59, 3265 – 3284.

McDonough, F., and B. C. Bernstein, 2004: A Case Study of Great Lakes Supercooled Large Drop Icing Cloud. 11th Conference on Aviation, Range, and Aerospace, Amer. Meteor. Soc. P.615.

Minnis, P., L. Nguyen, W. L. Smith, Jr., M. M. Khaiyer, R. Palikonda, D. A. Spangenberg, D. R. Doelling, D. Phan, G. D. Nowicki, P. W. Heck, and C. Wolff, 2004a: Real-time cloud, radiation, and aircraft icing parameters from GOES over the USA. *Proc. 13th AMS Conf. Satellite Oceanogr. and Meteorol.*, Norfolk, VA, Sept. 20-24, CD-ROM, P7.1.

Minnis, P., W. L. Smith, Jr., L. Nguyen, M. M. Khaiyer, D. A. Spangenberg, P. W. Heck, R. Palikonda, B. C. Bernstein, and F. McDonough,

2004b: A real-time satellite-based icing detection system. *Proc. 14th Intl. Conf. Clouds and*

Precipitation, Bologna, Italy, 18-23 July.
Stephens, G. L., 1994: 1.6.2 Cloud Microphysics *Remote Sensing of the Lower Atmosphere An Introduction.* 21 – 24.

Young, D. F., P. Minnis, D. Baumgardner, and H. Gerber, 1997: Comparison of In Situ and Satellite-Derived Cloud Properties During Success. *Geophysical Research Letters.* 25, 1125 - 1128.

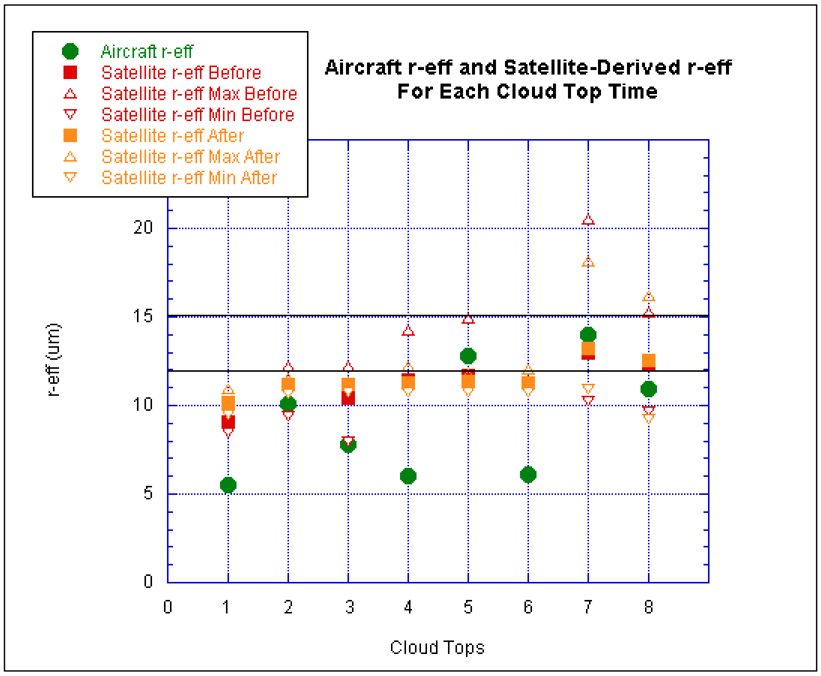

Fig. 6 All cases evaluated in this study are summarized here. The black lines break the graph into the size categories, Small, Medium, and Large, described at the beginning of this document. The green circles are the calculated r-eff from the aircraft data. The red squares are the average r-eff value of the 17 satellite pixels for up to 20 min before the cloud top penetration. The red up/down arrow is for the max/min from before the cloud top time. The orange squares are the average r-eff value of the 17 satellite pixels for up to 20 min after the cloud top penetration. The orange up/down arrow is for the max/min from before the cloud top time.