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POINT COMPARISONS OF RESEARCH AIRCRAFT DATA TO GOES-DERIVED CLOUD PRODUCTS

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1. BACKGROUND

GOES-derived cloud products (GDCP) developed at the NASA Langley Research Center (LaRC) are being examined as a possible ingredient/data source to the Current Icing Potential (CIP; Bernstein et al. 2005, Haggerty et al. 2005). These cloud products provide information about the microphysical properties of the cloud tops and are created by combining standard satellite information with model output (Minnis et al. 1995, 2004a, 2004b). They have proven useful for identifying areas of icing, both in nowcasting icing conditions (Wolff et al. 2005) and when compared to other icing algorithms (Chapman et al. 2005). Part of the examination process has involved comparing the GDCP to research aircraft measurements of supercooled liquid water content (SLWC). These data provide the best information about the actual atmospheric conditions since measured SLWC is an important indicator of the potential for and severity of icing. Correlations between the GDCP and measured SLWC will aid in determining which fields should be incorporated into CIP and how to combine them with existing information to improve icing diagnoses.

The GDCP are most useful at cloud top and previous studies have focused on this area. However, because CIP is a three dimensional product it must be determined whether it is reasonable to relate GDCP fields to properties of the entire cloud layer. This study will compare research aircraft data to the GDCP, regardless of the aircraft position in the cloud, in order to help make that decision.

2. DATA AND METHODOLOGY

Aircraft data were obtained from field programs and flight tests that occurred in the fall of 2003 and the winters of 2004 and 2005 over the eastern United States and Canada. Each aircraft was equipped with a CSIRO liquid water content probe (King et. al 1978). CSIRO probe observations were corrected for any biases and combined with subfreezing temperature measurements to determine when and how much SLW was present.

The aircraft data were then averaged over 4 km segments in order to match the horizontal resolution of the satellite products. The midpoint time of the 4 km aircraft segment was used to find the satellite data that was nearest to it in time. The GDCP were available at 15 and 45 minutes past the hour, so all of the aircraft data points were within 15 minutes of the satellite data. Because of the small length of the aircraft segments almost all of the satellite data files had multiple segments from the same aircraft matched to them.

Software from NASA LaRC was used to extract the GDCP at the point nearest to the midpoint of the 4 km aircraft segment. The GDCP fields tested were the cloud phase, water path (liquid or ice), particle size (radius for liquid and diameter for ice), optical depth, cloud top height, and cloud base height (see Minnis et al. 2004b for a description). These parameters were only extracted when the aircraft point was determined to occur in the daytime (solar zenith angle less than 78°). This was done because most of the flights occurred during the day, and different retrieval algorithms are applied in the solar terminator and at night. Consistency in the comparisons was desired for this study. This paper will focus on results from comparisons with the cloud phase, liquid water path (LWP), and liquid particle size (effective radius [REFF]).

3. CLOUD PHASE

The GDCP cloud base and top height fields were used to define the depth of the cloud. Aircraft data points were only compared to satellite products if they were determined to be within the satellite defined cloud layer or if the point matched to a pixel was identified as "clear" in the phase product. The dataset contained 6400 combined points. Of these, 5526 were inside the GDCP defined cloud and 874 were diagnosed to occur in clear areas. Of the cloudy matches, 2644 (48%)

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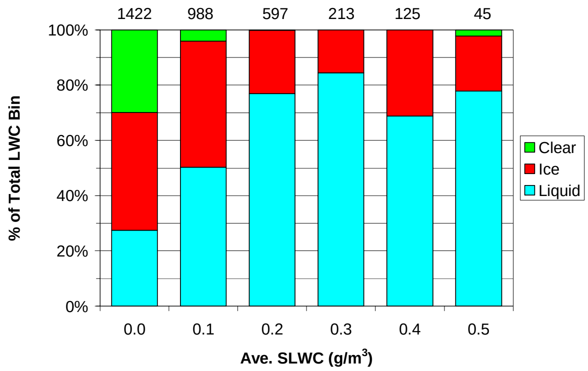

Figure 1. Percentage of the SLWC bins associated with each GDCP diagnosed phase (liquid, ice, clear). The numbers at the top represent the total number of observations in each SLWC bin.

were in a liquid cloud and 2882 (52%) were in an ice cloud, as diagnosed by the GDCP.

Figure 1 shows the distribution of GDCP cloud phase diagnoses compared with the average SLWC measured by the aircraft. The SLWC values along the x-axis represent the midpoints of each bin so that the 0.1 g/m^3 bin contains 0.05 ≤ SLWC < 0.15 g/m^3. All values between 0.01 and 0.05 g/m^3 were removed from the analysis because of noise in the data and because portions of the 4 km segments may have been outside of cloud. The total number of observations in each SLWC bin is shown at the top of the respective columns.

About 70% of locations where SLWC = 0.0 g/m^3 were associated with diagnoses of clear skies or ice tops. As the average aircraft measured SLWC increased, the percentage of points classified as having liquid tops by the satellite also increased, with liquid clouds diagnosed the majority of the time for the SLWC bins of 0.2 g/m^3 and higher. These results are expected, but this is not to imply that all of the liquid diagnoses for the low SLWC bins and the ice diagnoses for the high SLWC bins are incorrect. A variety of factors may contribute to some of these apparent errors in the phase product. This study assumed that the GDCP defined cloud consisted of a single layer because no other information was available. Multi-layer clouds are quite common and they would cause a discrepancy since the aircraft may be flying in a dry layer below cloud top or in a lower cloud layer of different microphysical makeup than the upper cloud layer that is visible to satellite.

It is known that the cloud top height field in the GDCP is often too high. This becomes important because of the nature of some of the aircraft data used. For many of the flight programs, the

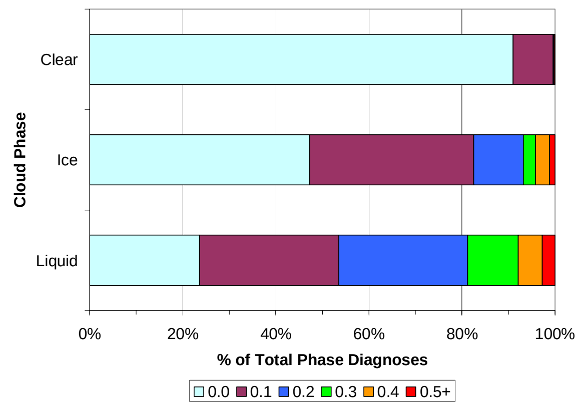

Figure 2. Percentage of the GDCP diagnosed cloud phase associated with each SLWC bin (shown in the color bar below the chart).

purpose of the tests was to accrete ice on the aircraft and then go out of cloud to do performance tests and document the icing. Usually, this was done only a few hundred feet above cloud top. If the GDCP cloud top height was too high then the aircraft would still be in the GDCP defined cloud, even though it was actually just above the real cloud top. This would cause an aircraft point with no SLWC to be matched with a pixel classified as having liquid or ice phase.

Examining the percentage of the GDCP phase diagnoses associated with each SLWC bin shows similar trends (Fig. 2). Over 90% of the clear diagnoses were matched to SLWC of 0.0 g/m^3. The percentage of ice cloud diagnoses was also largest at zero SLWC and decreased with increasing SLWC. Only 22% of the liquid diagnoses were in that bin, which means that some SLW was observed within 78% of all clouds classified as liquid in this dataset. The highest percentages of SLWC > 0.15 g/m^3 (0.2 and higher bins) were in liquid diagnosed clouds.

As discussed above, the GDCP were allowed to define the vertical extent of the cloud and the aircraft data were then determined to be inside or outside of it. Another comparison method is to use the average SLWC from the research aircraft to determine whether or not a point is cloudy, using an SLWC threshold of 0.05 g/m^3. This changed the percentage of total aircraft segments that fell into each phase category (Table 1). The percentage of liquid diagnosed clouds increased dramatically while the pixels diagnosed as clear decreased for the aircraft defined clouds. This shows that there are very few errors in the diagnosis of clear pixels for this dataset. It had very little effect on the percentage of clouds misclassified as ice phase clouds.

Cloud Phase	GDCP Defined Cloud	Aircraft Defined Cloud
Liquid	48%	62%
Ice	38%	36%
Clear (No cloud)	14%	2%

Table 1. Percentage of aircraft points in each cloud phase for GDCP and aircraft defined clouds.

4. LIQUID WATER PATH AND EFFECTIVE RADIUS

The liquid water path (LWP) product provides an estimate of the total water in a column through the cloud while the effective radius (REFF) estimates the particle sizes at cloud top. All of the comparisons of these products to aircraft SLWC were done only for clouds that were diagnosed as liquid by the GDCP (2644 points).

A direct comparison of these fields to SLWC does not show much of a trend. High LWP does not appear to correspond with higher SLWC for these cases (Fig. 3a). This is likely because the aircraft data points used in this study were used regardless of their location in the cloud. Forecaster experience has indicated that a better trend is expected if only points at or near the cloud top are used. The REFF field (Fig. 3b) had most of its values between 7 and 13 µm regardless of SLWC bin. The highest SLWC values were associated with 8 < REFF < 15 µm, and SLWC values slope downward beyond REFF = 13 µm. This is also expected since the relationship between particle size and SLWC is not a direct one across all cases. It depends more on the number concentration of the particles. It may also be associated with a decrease in the measured SLWC by the CSIRO probe as portions of the drop spectra exceed ~50 µm (Biter, 1987). Supercooled large drops (SLD) have been observed in some of these situations.

While these fields do not show much trend, individually, there are some combinations that may be of some use. Figure 4 is a plot of SLWC vs. LWP (as in Fig. 3a) but with the markers colored to represent REFF. As shown in Fig. 3 the higher SLWC points tend to be associated with a variety of LWP values with fairly small REFF (< 13 µm; blue and green markers). Most of the points with large REFF (> 13 µm; orange and red markers) are associated with low SLWC (< 0.2 g/m^3). These points also show a wide range of LWP. Many of the biggest particles appear to be clustered near the lowest LWP values as well. A

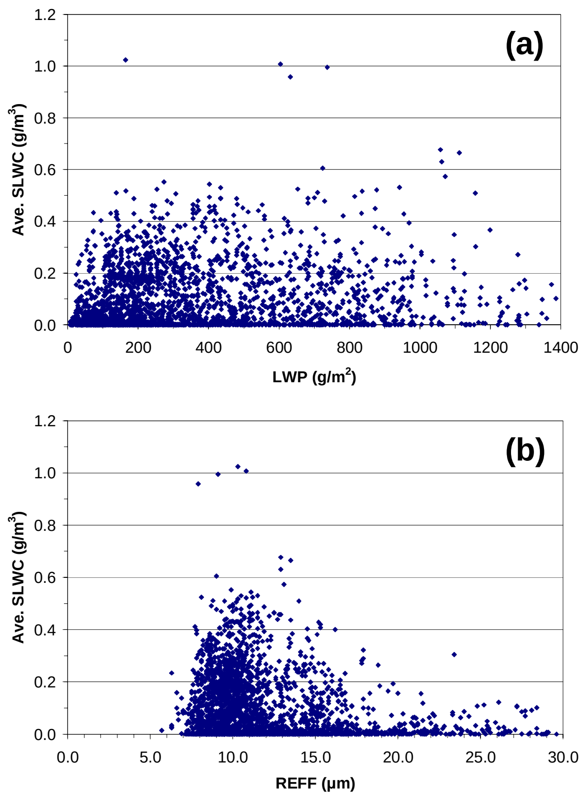

Figure 3. Average SLWC vs. (a) LWP and (b) REFF.

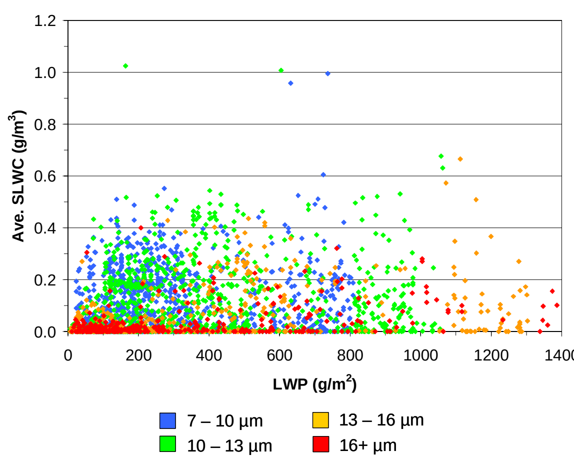

Figure 4. As in Fig. 3a, but with the markers colored to represent REFF.

possible explanation for this is mixed phase conditions at cloud top resulting in large ice particles (high REFF) and small amounts of liquid water (low LWP). The average cloud top temperature (CTT) for the largest particles (16+ µm) is -15.5°C as compared with a CTT of -12.9°C for the particles between 7 and 10 µm. CTT is not a direct indicator of phase, but a mixed phase cloud becomes more likely with colder CTT. Some of these data points will need to be examined more closely in order to verify whether such conditions were present.

Figure 4 also hints at the relationship between LWP and REFF. The 7-10 µm (blue) particles seem to all have LWP below 800 g/m^2. For the 10-13 (green) and 13-16 µm (orange) ranges the maxima are near 1100 and 1300 g/m^2, respectively. A plot of LWP vs. REFF (Fig. 5) shows an upper bound to the LWP as a function of REFF. The LWP is never more than 85 times the REFF (black diagonal line). It appears that an all liquid cloud with small particles will never show extremely high values of LWP. These small drop clouds can have high SLWC, though, if they also have a large number concentration (Bernstein et al. 2004).

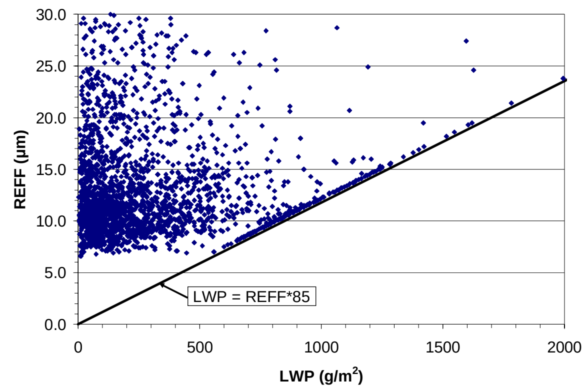

Figure 5. REFF vs. LWP for the aircraft dataset. The diagonal line represents REFF*85.

5. CONCLUSIONS AND FUTURE WORK

Comparing the GDCP to the aircraft data did not reveal direct correlations between them and the amount of SLWC measured in cloud. Like any dataset used to diagnose or forecast icing they must be used in context with other observations. For example, the phase product could be used to give more confidence that a given cloud contains liquid. Using combinations of the GDCP may also be of use. High REFF and low LWP in a liquid cloud may help identify a mixed phase cloud, while a combination of high REFF and high LWP might help with the identification of areas of potential SLD growth. Fields like the ice water path (IWP) and effective diameter (DEFF) may also prove effective in clouds diagnosed as ice phase. All of these combinations may be useful in the diagnosis of icing probability and severity.

This study only compared the nearest point from the GDCP to the aircraft data. Including some of the surrounding satellite points and using a consensus of the phase or an average LWP may have some advantages. Some of the points were undoubtedly at the edge of the cloud or in a transition zone between liquid and ice clouds. Examination of the surrounding pixels would help identify these areas and may allow for the use of some of the SLWC values between 0.01 and 0.05 g/m^3 because more certainty about the presence of a solid cloud would be obtained, which may allow for a better filter for noise in the probe.

Future work may focus on comparing the GDCP only to aircraft data points that are determined to be at or near the top of the highest cloud. Individual case studies using this method have been promising. Time constraints and the large volume of aircraft data did not allow for such analysis to be completed for this paper. Determining how to apply these products throughout a cloud layer may still prove difficult, even with improved correlations.

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