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COPMARISON OF NASA-LANGLEY SATELLITE-DERIVED CLOUD PROPERTIES WITH PILOT REPORTS IN AIRCRAFT ICING SCENARIOS

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1. INTRODUCTION

Knowledge of a cloud's microphysical-properties, especially clouds containing supercooled large water droplets (SLD), can help to determine hazardous areas of potential in-flight aircraft icing. The NASA Langley Research Center (LaRC) Cloud and Radiation Research Group currently derives cloud top microphysical property products (hereafter referred to as LaRC Cloud Products) from Geostaionary Operational Environmental Satellite (GOES) data over the United States (CONUS) in near real time (Minnis et al., 2004a). The purpose of this study is to evaluate the potential effectiveness of certain NASA-LaRC Cloud Products for refining estimates of an icing severity index. The LaRC Cloud Products that demonstrate a relationship to icing severity will be considered for integration into the Current Icing Product (CIP), an operational in-flight icing nowcasting system (Politivich et al, 2005).

The study compares various LaRC Cloud Products to pilot reports (PIREPs) of icing severity to ascertain where correlations exist. Previous studies have shown that the LaRC Liquid Water Path (LWP) product is positively correlated with icing severity estimates from PIREPs and research aircraft data for a limited data set (Minnis et al., 2004b; Wolff et al., 2005). A larger data set is considered here, and the evaluation process mimics that applied to all other input data sets used by the CIP system. Data are classified by meteorological scenario for the analysis. Cloud phase, liquid water path (LWP), ice water path (IWP), effective radius (Re), effective diameter (De), and optical depth (Tau) products are evaluated against an archived set of PIREPs.

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2. DATA

2.1 *Satellite Derived Cloud Property Data*

The LaRC Cloud Products evaluated in this study, LWP, Re, IWP, and De, are derived from the visible infrared solar-infrared split window technique for daytime and the solar-infrared infrared split window technique for terminator and night times (Minnis et al, 2005). Figure 1 shows an example of the LaRC LWP product. Data from the 64 satellite pixels surrounding each icing PIREP location were used for this comparison.

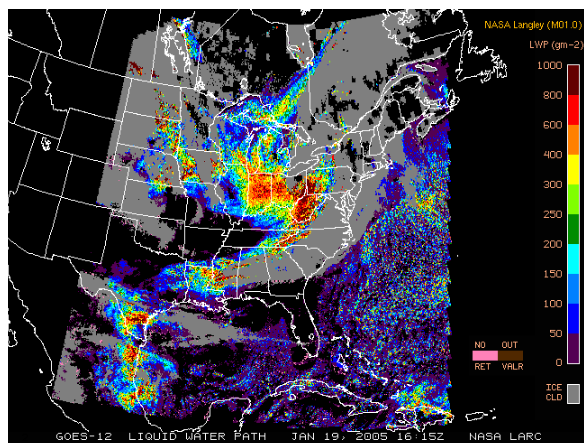

Figure 1 An example LaRC satellite-derived LWP product at 1615 UTC on January 19, 2005.

2.2 *PIREP Data*

PIREPs of icing severity from 5 January to 5 April 2005 over the CONUS were used in this evaluation. Raw PIREP reports are broken down into 9 different categories ranging from -1 (no icing) to 8 (heavy icing). These standard operational categories have been collapsed into 5 categories in an effort to elucidate the correlations. The PIREP icing severity values used in this study are defined in Table 1.

Table 1 Definition of Icing Severity Values used for this study.

Standard PIREP Icing Severity Values	Icing Severity Used in This Study
-1	No Icing
1	Trace
2 and 3	Light
4 and 5	Mod
6, 7, and 8	Heavy

2.3 *CIP Data*

The CIP system uses 8 meteorological scenarios to define the likely microphysical structure of clouds and precipitation (Table 2). Classification of conditions at a specific gridpoint into one of these scenarios is based on model sounding data, radar data, and Meteorological Terminal Air Report (METAR) observations. CIP also uses the model vertical relative humidity (rh) profile to determine how many cloud layers are present. If the model rh drops below 50% for at least 75mb within a model-diagnosed cloud layer, multiple cloud layers are assumed (Politivich et al, 2006). The meteorological scenarios used here all assume a single cloud layer.

2.4 *RUC*

Model sounding data from the 4 grid points surrounding an icing PIREP was used. These data were used to verify that the icing PIREP was actually in cloud, in the vertical.

2.5 *Surface Observations*

METAR precipitation observations were used to verify the CIP scenario associated with the icing PIREP. Radar reflectivity was also used to verify the CIP scenario.

3. METHODLOLGY

The PIREP and NASA LaRC Cloud Products data were sorted by solar zenith angle (sunz) into three time of day categories: day (sunz ≤ 70º); night (sunz ≥ 90º); and terminator (90º > sunz > 70º). Nighttime PIREPs were not evaluated in this study. Only single layer clouds identified by CIP were evaluated. This was done so that the LaRC Cloud Products could be assumed to be identifying the cloud reporting the PIREP.

Table 2 Definitions of CIP single-layer cloud meteorological scenarios (Politivich et al., 2006).

Scenario	Definition
No Precipitation (NP)	No precipitation observed at the surface by METAR or radar.
Below Warm Nose (BWN)	'Classical' FZRA structure with FZRA, PE, RA, FZDZ and/or DZ observed at the surface. The subfreezing layer resides beneath the melting layer (warm nose). Cloud top temperature (CTT) < -12^{o}C
Above Warm Nose (AWN)	'Classical' FZRA structure with FZRA, PE, RA, FZDZ and/or DZ observed at the surface. Cloudy area above melting layer (warm nose). Cloud top temperature (CTT) < -12^{o}C
All Snow (AS)	All sounding levels < 0^{o}C. Snow is the only precipitation observed at the surface.
Cold Rain (CR)	RA is observed at surface and Cloud Top Temp (CTT) ≤ -12 ºC.
Warm Precipitation (WP)	Any non-snow precipitation observed at surface with a CTT > -12 ºC.
Cold Non-Snow/Non-Rain (CNSNR)	FZRA, PE, FZDZ and/or DZ observed at the surface with CTT ≤ -12 ºC.
Convection (CV)	Lightning strikes within 25 km and 15 minutes.

The CIP algorithm assigns each cloudy grid point one of the 8 scenarios shown in Table 2. Sixteen 5-km LaRC pixels are mapped to the 20-km resolution model grid points. In this study the 16 satellite pixels were assigned the CIP scenario associated with the model grid point. Because the CIP scenarios depend on surface observations as part of their definition a distance limit to a METAR observation and radar data associated with the CIP scenario identified was added to help ensure that the scenarios were correctly diagnosed. If the PIREP is not within the distance limit of the surface observation it is discarded. To ensure that the PIREPs being used were in icing conditions, a quality control using RUC temp and rh data was applied. If CTT > 0 ºC or CTT < 30 ºC and/or the rh < 70% the PIREP was removed from the data set because its time or location was likely misidentified.

Boxplots were created from the stratified data set for each CIP scenario for liquid and ice, day and terminator of Re, LWP, De, IWP, and Tau versus PIREP severity. The boxplots display the 75^{th} and 25^{th} percentiles, and median of the values for a given field for each PIREP severity. Outliers, 1.5*(75^{th} -25^{th}), are also shown in these plots.

4. RESULTS

Half of the CIP scenarios (NP, AS, WP, CR) had enough data points to observe valid and robust correlations between the LaRC Cloud Products and PIREP severity. The results of the No Precip (NP) scenario are presented. The other valid scenarios and product correlations are not shown but discussed in the context of the NP scenario.

A boxplot of the LaRC LWP versus PIREP severity for the NP CIP scenario is shown in Figure 2. The LWP senses the liquid water content integrated through the cloud depth. As the PIREP severity increases the LWP would be expected to increase due to the aircraft spending additional time in deeper and/or higher liquid water clouds. The figure shows that the LWP has some ability to predict icing severity. Other CIP scenarios also showed slightly higher LWP associated with heavier icing reports.

Figure 3 displays a boxplot of the LaRC Re versus PIREP severity for the NP CIP scenario. The Re is the effective radius of particles near the cloud top of a cloud determined to be liquid phase cloud by the LaRC phase product. There is a slight correlation between the Re size and the PIREP severity suggesting that when larger drops are present the severity of the icing PIREPs increases. This slight correlation was also seen in the AS CIP scenario. This slight positive correlation did not hold true for the WP and CR scenarios in which the data were much more scattered.

A boxplot of the LaRC IWP verse PIREP severity for the NP CIP scenario is shown in Figure 4. IWP senses the ice water content integrated through the cloud depth. This requires the ice phase to be identified at cloud top. Surprisingly there are large numbers of icing PIREPs within ice phase clouds, suggesting that mixed phase icing is a common occurrence. There is a weak correlation between the IWP values and the PIREP severity, IWP values increase as PIREP severity increases. This result suggests that increased ice mass is associated an increased icing severity. This correlation is not as strong as the LWP correlation but it is still a good correlation which was also seen in the AS CIP scenario. This positive correlation did not hold true for the WP and CR scenarios.

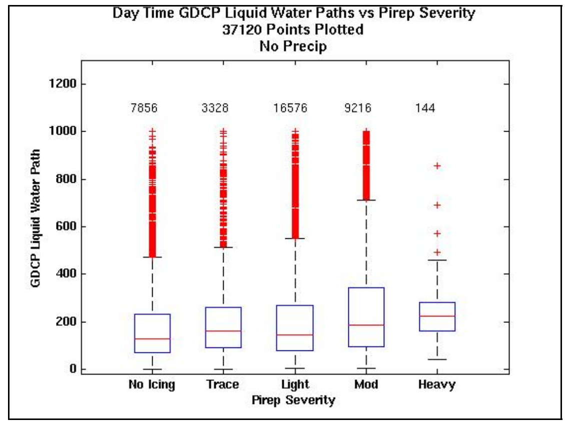

Figure 2 Boxplot of daytime LaRC LWP vs. PIREP severity. Box encloses the 25^{th} – 75^{th} percentiles. Red line indicates median value, while whiskers identify 10^{th}-90^{th} percentiles. The number above each box is the number of data points in each icing severity category.

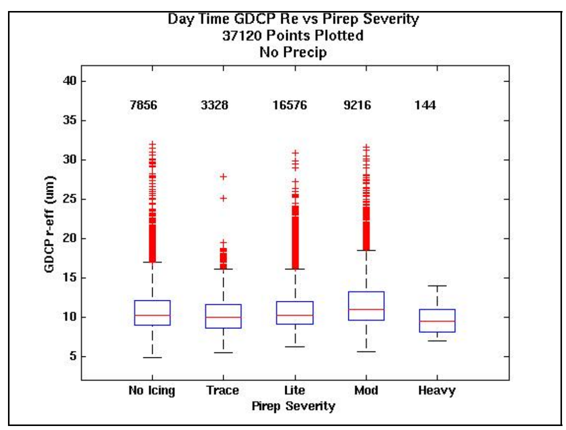

Figure 3 Boxplot of daytime LaRC Re vs. PIREP severity. The number above each box is the number of data points in each Icing severity category.

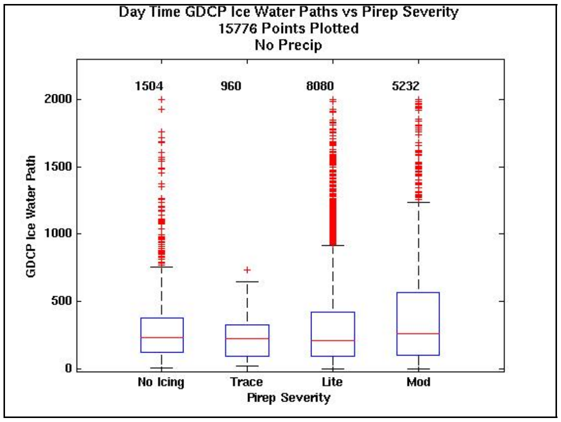

Figure 4 Boxplot of daytime LaRC IWP vs. PIREP severity. The number above each box is the number of data points in each Icing severity category.

Figure 5 displays a boxplot of the LaRC De verse PIREP severity for the NP CIP scenario. De is the effective ice particle diameter at cloud top of an ice phase cloud. There is a very weak negative correlation between the De values and the positive icing PIREP severities, suggesting that smaller ice particles are associated with more severe icing. This negative correlation was also seen in the CR Scenario. The AS showed a slight positive correlation with the De size increasing with PIREP severity. The WP scenario did not show any correlation with severity.

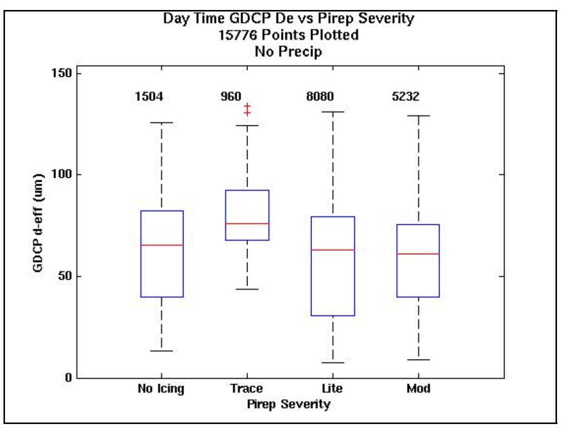

Figure 5 Boxplot of daytime LaRC De vs. PIREP severity. The number above each box is the number of data points in each Icing severity category.

5. SUMMARY AND CONCLUSIONS

Icing PIREPs, filtered by the CIP meteorological scenario, were compared to LaRC cloud products. The LWP and IWP both weakly demonstrated the ability to identify increased icing severity. Significant numbers of positive icing PIREPs were present within clouds identified as ice phase. This suggests that mixed phase icing is common. Slightly larger drops may be associated with increased icing severiy as is smaller ice particles.

These results show the LaRC LWP and IPW used within the added context available from the 3-D CIP algorithm should increase the ability to differentiate icing severity. The LWP is currently being added to the CIP severity algorithm due to its positive correlation with PIREP severity. Additional work is required to determine how Re, De, and IWP can be used by the system. Future important research involves finding ways to differentiate glaciated from mixed phase clouds.

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