# 6.5 Diagnosing icing severity and supercooled large drop regions with an operational aircraft nowcast system using advanced satellite products

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## 1. INTRODUCTION

This is part 2 a the companion paper presented at the 13th Aviation Range and Aerospace Meteorology conference by Haggerty et al., 2008. Products developed at the National Center for Atmospheric Research (NCAR) and disseminated by the U.S. National Weather Service provide nowcast and short-term forecast estimates of icing probability, severity, and the potential for supercooled large droplets (SLD). The Current Icing Product (CIP) combines multiple data sources using fuzzy logic methods to produce a gridded, three-dimensional, hourly depiction of icing-related conditions (Bernstein et al., 2005). The CIP algorithms rely on basic satellite-derived information, such as visible albedo, short-wave infrared temperature and long-wave infrared temperature. The goal of the NASA Advanced Satellite Aviation-weather Products (ASAP) program is to devise methods for incorporating more sophisticated satellite products into aviation weather diagnosis and forecast systems. In this component of the ASAP program, the objective is the continued replacement of the satellite module in the CIP system with satellite-derived cloud products developed by the NASA Langley Research Center (LaRC) Cloud and Radiation Research Group. This paper describes the use of the LaRC cloud products in the CIP severity and SLD algorithms. The hydrometeor phase, effective particle size, cloud effective temperature, and liquid water path products are included in this work.

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## 2. THE CURRENT ICING PRODUCT SYSTEM

The operational CIP algorithm combines information from satellites, radars, surface observations, lightning sensors, and pilot reports with model forecasts of temperature, humidity, supercooled liquid water, and vertical velocity. Fuzzy logic and decision tree logic are applied to combine up to fifty-six interest fields derived from these data sources into a single fused product. The algorithm generates a three-dimensional hourly diagnosis of the probability of icing and supercooled large drops over the continental United States at 20-km horizontal resolution (McDonough and Bernstein, 1999; Bernstein et al., 2005). Results are presented either as a percentage (0-100%) that indicate the probability of icing and for the likelihood of SLD, while the icing severity is presented as a categorical diagnosis within a given volume. Figure 1 depicts the process of combining data from surface observations, models, radar, pilot reports, and satellite sensors to arrive at three-dimensional estimates of icing probability and severity, along with the potential for SLD over the continental United States. Following determination of the cloud structure and classification of conditions into pre-defined meteorological scenarios, fuzzy logic methods and decision-tree techniques are applied to determine the likelihood of icing and SLD at each location, thereby maximizing the strengths of each dataset. Routine CIP output is available on the Aviation Digital Data Service web page at:

http://adds.aviationweather.noaa.gov.

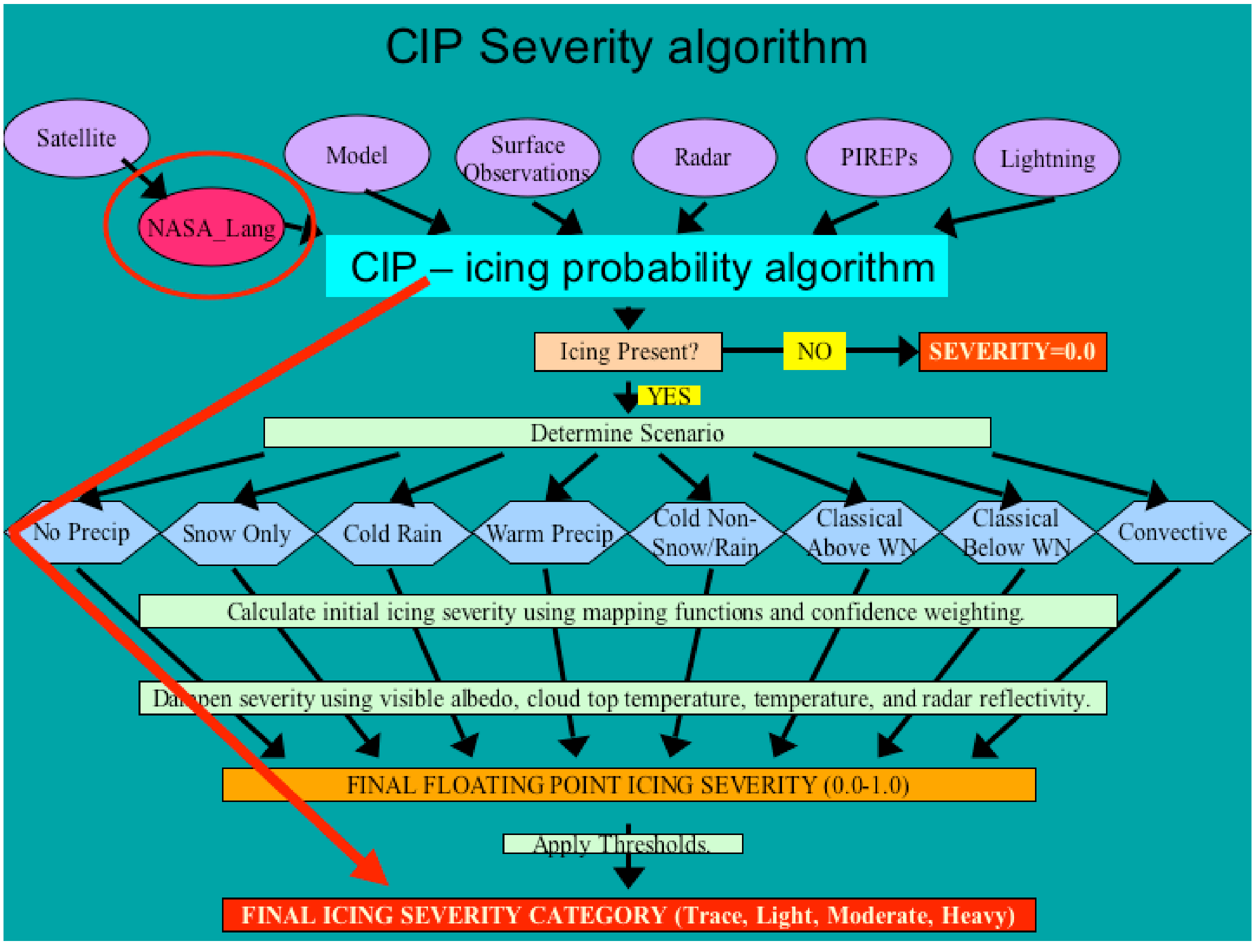


*Figure 1: Diagram showing the Current Icing Product (CIP) system which uses multiple sources of data as input and combines them using fuzzy logic methods and decision tree technology to produce estimates of icing probability, icing severity, and the potential for supercooled large drops. Red arrow shows path through CIP algorithm with clouds and no precipitation was present.*

**3. SATELLITE CLOUD PRODUCTS**

The cloud products under evaluation for inclusion in CIP are derived from the Geostationary Operational Environmental Satellite (GOES). The GOES Imager has channels in the visible, near-infrared, and thermal infrared portions of the spectrum. NASA LaRC algorithms are applied to half-hourly GOES-10 (Western U.S.) and GOES-12 (Eastern U.S.) Imager data. The Visible Infrared Solar-infrared Split-window Technique (VISST) is used during daytime hours. The Solar-infrared Split-window Technique (SIST) uses a subset of the Imager channels to derive products at night (Minnis et al., 2005).

The LaRC system first classifies each 4-km GOES pixel as clear or cloudy using a complex cloud identification scheme (Trepte et al. 1999). VISST/SIST thresholds are then applied to each cloud pixel to determine phase, optical depth, effective particle size, effective temperature, effective height, and ice or liquid water path. These parameters are used to estimate cloud-top and base altitudes and temperatures. The analyses utilize the 0.65, 3.9, 10.8, and 13.3 μm GOES imager channels during daytime hours and the latter three channels at night. An example showing the derived liquid water path over the northeastern United States is shown in Figure 2.

Based on results of multiple validation studies performed on the LaRC cloud products in meteorological conditions associated with icing (Wolff et al., 2005; Haggerty et al., 2005; Khaiyer et al., 2003; Smith et al., 2002; Black et al., 2007), specific fields have been targeted as likely to provide useful information about the location of supercooled liquid clouds. Black et al. (2008) describe an objective verification process that classifies meteorological conditions into one of the CIP-defined scenarios and compares the satellite products to PIREPS. Using results of these studies, methods for integrating specific products into an experimental version of CIP have been developed.

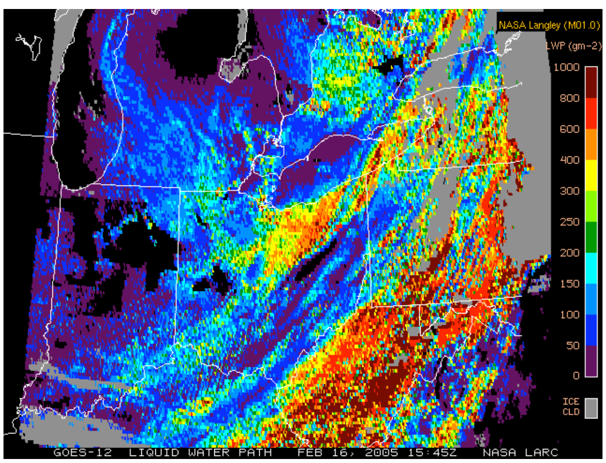


*Figure 2: Liquid water path at 1545 UTC on February 16, 2005 as derived from GOES-12 imagery using the Visible Infrared Solar-infrared Split window Technique (VISST).*

**4. INTEGRATION METHODOLOGY**

Initially the LaRC GOES data was put on the CIP (Rapid Update Cycle) grid. The LaRC satellite pixels were remapped to 5-km and placed on the model's map project projection. Sixteen pixels were assigned to each CIP grid point (Fig 3). Each of the pixels mapped to the grid point were examined and the algorithm then used the 75th percentile value of the pixel distribution.

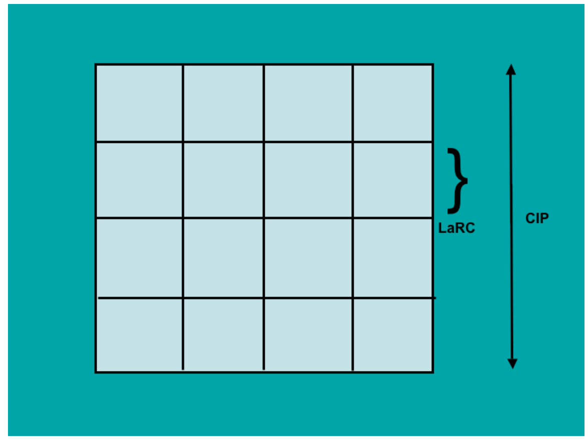


*Figure 3: Diagram showing the mapping of the LaRC 5-km satellite pixels to the 20-km CIP horizontal resolution.*

CIP algorithms apply fuzzy logic methods and decision-tree techniques to determine the probability and severity of icing as well as the SLD potential at each CIP grid box. The fuzzy logic scheme employs interest maps for each data set to quantify the value (on a scale from 0 to 1) of a given variable in specified meteorological conditions. Thus, new interest maps are developed and/or existing interest maps are refined to incorporate new information provided by the LaRC satellite cloud products. This paper describes continuing efforts to incorporate, via fuzzy logic methods, the LaRC products into the CIP icing, severity, and SLD fields.

**4.1 *CIP Severity algorithm***

LaRC data sets that were used in the experimental version of the CIP severity algorithm include the cloud phase product, the liquid (total) water path (LWP), a confidence map which is a function solar angle (SA) - which itself is a function of the time of day and year. Increasingly severe icing would be predicted with a supercooled liquid phase retrieval, along with a large liquid water path retrieval.

Confidence would be increased if the scene was well illuminated by the sun. The entire description of the new algorithm for all meteorological scenarios is beyond the scope of this paper, therefore we use a case study to demonstrate this work. The branch of the algorithm presented in the case study is shown by the red arrow in Fig. 1.

On January 19, 2005 a cyclone crossed the central Appalachians. This cyclone produced severe icing over Clarksburg, WV as reported by aircraft, between the altitudes of 1 and 3-km at 18:01 UTC. The data associated with the CIP grid point closest to the icing report was examined. The CIP cloud scheme was used to determine the grid point to be cloudy and the cloud top to be 4,500-m (Haggerty et al., 2008), while the cloud base was determined to be 300-m (Bernstein et al., 2005). Once the cloud layer was determined the CIP icing probability within the cloud layer is computed.

Next the icing severity is computed using an equation that combines relative weights, and icing-severity specific fuzzy logic membership functions from different data sets and their combinations. Some of these weighted membership functions are then combined with confidence functions. The satellite part of the severity equation is:

sat_interest = (SAT_MAP X SAT_WEIGHT X SAT_CONF).

The first LaRC product analyzed was the cloud-phase. The 16 cloud-phase pixels associated with the icing pilot report (PIREP) had 13 pixels identified as supercooled liquid and 3 identified as ice phase. The 75$^{th}$ percentile of the 16-pixel distribution assigns the CIP grid point as supercooled liquid (Fig. 4). Next the liquid water path (LWP) product is analyzed. The distribution for the pixels mapped to the icing PIREP showed a wide range of values. The 75$^{th}$ percentile value mapped to the CIP grid point was over 1000 g m$^{-2}$ (Fig. 5).

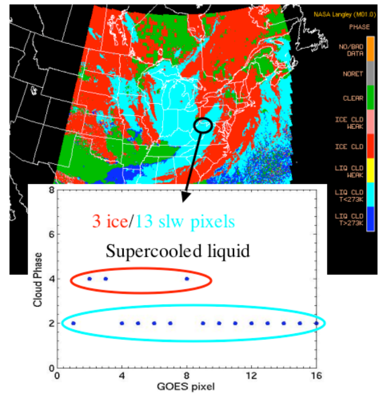


*Figure 4: LaRC cloud-phase at 1745 UTC on January 19, 2005. The pixels mapped to the icing pilot report are plotted with 13 identified as supercooled liquid and 3 identified as ice.*

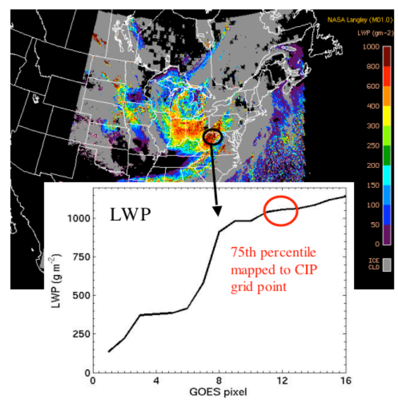


*Figure 5: Liquid water path at 1745 UTC on January 19, 2005. The pixels mapped to the icing pilot report location along with the 75$^{th}$ percentile value are plotted.*

The solar angle interest is computed as a function of the amount of solar energy available to the scene. Interest is maximized when the solar angle is less than 70$^{o}$ (the sun well above the horizon). When the sun is near or below the horizon the 0.67-$\mu$m channel (visible) is not available and an important input of the LWP calculation is missing. Therefore the product is assumed to have lower quality than in the day. The retrievals from 3.9-$\mu$m channel must be used differently at night than in the day and the channel is difficult to interpret at sunset and sunrise. This leads to the solar angle confidence map (Fig. 6).

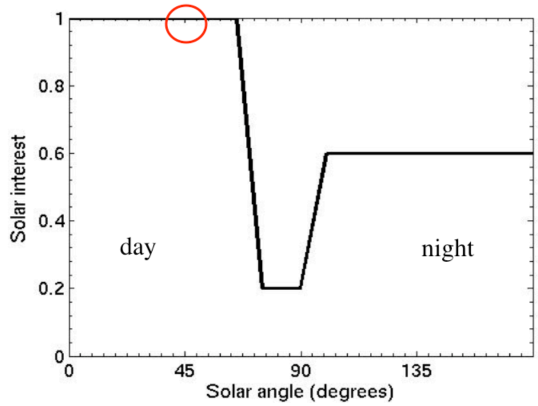


*Figure 5: Solar angle interest map. Maximum confidence occurs when the scene is well illuminated by the sun. The red circle identifies the solar angle and interest associated with the Clarksburg, WV PIREP.*

The LWP membership function was created from the work of Black et al., 2007. The LWP interest is determined from the 75th percentile and is applied to the cloud layer (Fig. 6). The icing location near Clarksburg, WV has a very high LWP so the interest is very high through the layer. A second approach, which allows the LWP interest to decay as the distance below cloud top increases, was also under test.

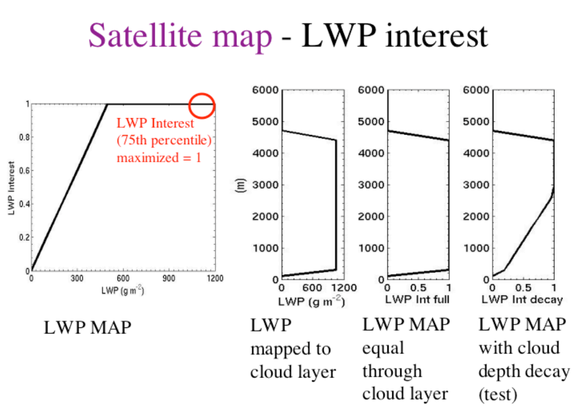


*Figure 6: LWP interest map and its application to the CIP cloud layer. The red circle shows the interest for the PIREP and this maximum interest was applied through the cloud depth. A second test, which decays the interest well below the cloud top level, was also tested.*

The phase membership function was fairly simple in structure with the interest maximized when the phase assigned to the CIP grid point is supercooled liquid and set to 0.25 when the phase is ice. Other predictors in the severity algorithm can also infer the cloud phase.

Finally the satellite severity interest is computed. In this case all the predictors are maximized so the satellite severity interest is maximized (Fig. 8).

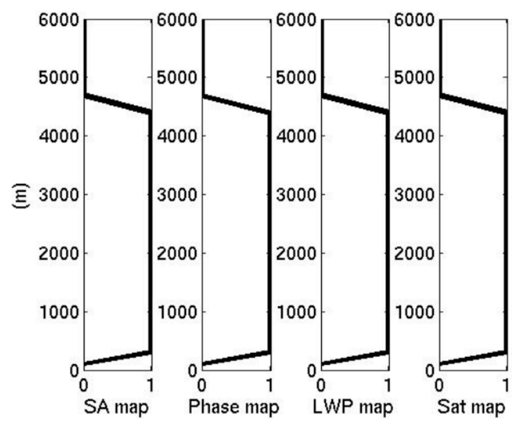


*Figure 8: The solar angle (SA) interest map, phase map and LWP map are multiplied to calculate the Sat map. Since each are maximized the Sat severity interest is also correctly maximized.*

**4.2 *CIP SLD algorithm***

A new version of the CIP SLD algorithm was created using in part the LaRC cloud phase and effective drop size retrievals. The new algorithm combines output from three different predictors. The operational CIP SLD algorithm identifies SLD within cloud layers were supercooled large drops are observed at the surface. This algorithm doesn't identify SLD if the associated surface precipitation is not observed. The model based SLD algorithm in the Forecast Icing Product (FIP) uses the total condensate output from the numerical model and a layer detection scheme (McDonough 2008). The LaRC contribution to this new algorithm is the liquid phase effective radius. This algorithm assumes that when large drops are observed at cloud top they will be also be found lower down in the cloud layer.

The determination of the effective radius value mapped to the CIP grid point follows methods shown above. Thus when the phase is liquid the effective radius pixels are mapped to the CIP grid point. The distribution is analyzed and the 75$^{th}$ percentile of the drop size distribution is assigned to the CIP grid point. The membership function itself is designed to allow drops larger than ~16 μm to have significant interest (Fig. 9.).

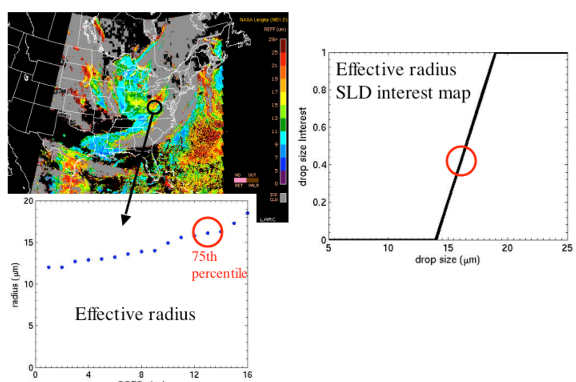


*Figure 9 The LaRC effective radius retrieval at 17:45 UTC on January 19, 2005 is presented. The pixels at the PIREP location were extracted and the 75$^{th}$ percentile (red circle) of the distribution extracted. The effective radius map is shown on the right with the red circle identifying the PIREP effective radius used by the CIP SLD algorithm.*

Finally the output values form the three different algorithms are combined as a weighted sum.

SLD_pot = A*(surface_SLD) + B*(FIP_SLD) + C*(LaRC_SLD)

With A=B=C = 0.333

The CIP SLD calculation for the PIREP location over Clarksburg, WV suggests that the LaRC product may identify SLD conditions when the other predictors fail (Fig 10). SLD was observed at the surface in the region although not at Clarksburg, WV.

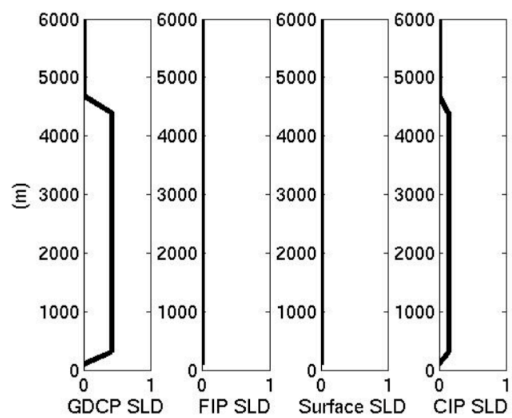


*Figure 10 the updated CIP SLD algorithm including the LaRC effective radius algorithm (GDCP SLD), FIP SLD, and operational surface-precipitation SLD algorithm applied to the Clarksburg, WV PIREP.*

### 5. Future Plans

Verification of the complete experimental CIP with a larger data set is underway and the results will be available in the NCAR-LaRC webpage.

http://www.ral.ucar.edu/icing/cip/gdcp/

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