Evaluating Icing Nowcasts using CloudSat

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1. Abstract

The Current Icing Product (CIP) was developed by the National Center for Atmospheric Research to diagnose aircraft icing conditions over the contiguous United States and southern Canada. CloudSat is an orbiting cloud radar that gives a two dimensional vertical profile of cloud along the orbital track of the satellite. When combined with temperature information from a numerical model, CloudSat can supply important clues about the location of supercooled liquid water, and we compare it to CIP in several cases. We compare the results of CloudSat to CIP and a newer satellite-based icing algorithm.

2. Introduction

The CIP algorithm (Bernstein 2005) combines satellite, radar, surface, lightning, and pilot-report observations with model output to create a detailed three-dimensional hourly diagnosis of the potential for icing and supercooled large drops along with icing severity. These inputs are merged using decision-tree and fuzzy logic.

CloudSat does not detect cloud phase, which is the fundamental ingredient for aircraft icing, but it does give a detailed depiction of cloud layers. However, when combined with temperature information from a numerical model, CloudSat can supply important clues about the location of supercooled liquid water (SLW).

First, we will examine a multilayered system over the Great Lakes, illustrating the ability of CloudSat to resolve cloud layers not analyzed by CIP. Second, we will present a case from the Canadian CloudSat/CALIPSO Validation Project (C3VP) experiment in southern Canada during the winter of 2006/2007 (Kankiewicz et al. 2005). For the second case we will compare CIP data to profiles from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (Calipso) satellite which contains a cloud lidar. This instrument is capable of detecting thinner cloud than CloudSat and also to detect cloud phase, a crucial capability in the analysis of SLW.

3. Current Icing Product (CIP)

CloudSat provides cross-sections of clouds through the weather systems associated with SLW. Low and mid-level clouds are likely to contain SLW and are the topic of field campaigns (Kankiewicz et al. 2005). The three dimensional analysis of clouds is key to the approach by Bernstein et al. (2005) to specify regions of likely icing in near realtime. In the CIP scheme

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satellite and surface data are used to reduce the vertical and areal extent of clouds fields predicted by numerical model estimates (Schultz and Politovich 1992). The diminished extent leads to a reduction of the area warned in subsequent icing nowcasts (Thompson et al. 1997). Using infrared and visible techniques, satellite screening often fails to eliminate many clouds because of cirrus which obscures lower clouds. CloudSat is capable of detecting clouds throughout the vertical column and therefore can operate as an important check to the effectiveness of CIP. Ellrod and Bailey (2007), Minnis et al. (2004) and Minnis et al. (2005) all use GOES data to assess icing potential from satellite.

CIP was developed as a tool for diagnosing in-flight icing conditions from the surface to 30,000 ft. MSL over the CONUS and southern Canada at 20 km horizontal resolution. It was initially developed during the winter of 1997-98 and provides hourly diagnoses of icing probability, icing severity, and supercooled large drop (SLD) potential. CIP is a physically-based algorithm and uses a situational approach to identify the location and severity of icing. Cloud physics principles, along with experiences in sampling and forecasting icing conditions from field programs, form the basis for the derivation of the final products.

We compare CloudSat and CIP profiles to output from the Minnis et al. (2004 and 2005) algorithm which specifies icing intensity and severity. We provide inputs to the algorithm based on the retrievals of Mitrescu et al. 2006. We start by retrieving cloud mask and type, cloud top temperature and effective radius, optical depth and liquid water path. Using the assumption that cloud microphysical properties follow a gamma size distribution, a radiative transfer model is used to pre-compute the radiances at the top of the atmosphere for a wide range of such distributions of phases and cloud optical depths at various solar-cloud-satellite angles. Surface emissivity and/or albedo and atmospheric emission and attenuation (dependent on water vapor) are also accounted for. Spectral channel response functions for all GOES channels are used to modulate these simulated radiances, which are then matched to the observed ones. Thus, by using an optimal estimation method, a corresponding set of cloud thermodynamic, microphysical, and optical properties are assigned to each cloud pixel. We call this scheme the NRL-Minnis algorithm.

4. CloudSat and Calipso

Launched on April 28, 2006, CloudSat (Stephens et al. 2002) is a NASA Earth observation satellite, using a radar to measure the altitude and properties of clouds. CloudSat flies in formation in the "A Train" with several other satellites (Aqua, Aura, CALIPSO, and the French PARASOL). The main instrument on CloudSat is the Cloud Profiling Radar (CPR), a 94-GHz nadir-looking radar that measures the power backscattered by clouds as a function of distance from the radar. CloudSat's primary mission is scheduled to continue for 22 months in order to allow more than one seasonal cycle to be observed. Based on radar lifetime data, NASA expects the radar to operate for three years with a 99 percent probability.

CloudSat has a 240-m vertical range resolution between the surface and 30 km. Due to surface contamination, the three gates nearest the surface are presently unavailable, limiting the usefulness of cloud information below 1.5 km. Future improvements may extend its effectiveness closer to the surface of the earth. CloudSat observes a single row of pixels along its flight path with footprint size of 1.4 x 3.5 km. CloudSat is not a “operational” satellite, but the Naval Research Laboratory (http://www.nrlmry.navy.mil/NEXSAT.html) posts CloudSat products, some shown in this paper compared to corresponding CIP output, in near-realtime, several hours after overpass time.

Primarily launched to observe atmospheric aerosols (Winker et al. 2003; Winker et al. 2004), the Calipso mission was undertaken to complement CloudSat observations. The primary sensor is the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), containing a unique capability to profile the vertical structure of the atmosphere, including the interaction of clouds and aerosols.
5. Case Examples

Fig. 1 shows the Geocolor (Miller et al. 2006) product for January 15 2007. It is difficult to distinguish different cloud regimes from this image alone. The NRL-Minnis algorithm (Fig. 2) shows ice cloud (indeterminate type - gray) over much of the region, but a high potential for icing (red) in some of the northern areas. The CIP algorithm (Fig. 3) shows a broad area of icing even for areas where the NRL-Minnis classification is indeterminate. This is because CIP relies on a variety of data sources for a three-dimensional icing analysis, not just satellite. Overlaid are PIREP observations of icing.

![Figure 1](image1.png)

**Figure 1** Daytime Geocolor Product of north central United States and southern Canada, January 15 2007, 1845 UTC.

![Figure 2](image2.png)

**Figure 2** GOES-based Minnis et al. algorithm showing icing conditions corresponding to the image in Fig. 1. Large red area in the north (high icing potential) is sampled in CloudSat trace (blue line) in Fig. 4. Gray indicates indeterminate icing potential.
Figure 3 Shades of blue: CIP output corresponding to the Figs. 1 and 2. Printed numbers: PIREP observations of icing severity ranging from trace (1) to severe (8).

Figure 4 Top: CloudSat Trace (annotated on Figs. 1, 2, and 3). At about 43° N an asterisk marks the position of a PIREP observation of moderate icing. Bottom: Corresponding CIP trace. Red trace in the bottom right indicates high icing potential according to the Minnis et al. algorithm.

The CloudSat trace (Fig. 4) shows significantly more detail than the other products. Specifically, it shows a transition from a very deep cloud system in the center of the plot to a shallower layered system to the north (right). It is at this transition point that a moderate icing PIREP (asterisk) appears at the top of the lower cloud that was not being seeded by ice crystals from above. Such a seeding effect is likely in the deep cloud system to the south. Thus, the SLW in the vicinity of the PIREP is not being depleted from above and is likely of greater magnitude than the SLW in the deep cloud. The NRL-Minnis algorithm (red trace at the bottom far right of lower diagram) corresponds to lower level clouds which are not obscured by the cirrus deck shown by CloudSat.

A second case highlights the use of CloudSat and Calipso together for a more thorough comparison to CIP icing output. Fig. 5 shows the output from NRL-Minnis algorithm. The red and gold areas correspond to icing areas indicated by the algorithm. Fig. 6 shows three traces corresponding to the blue line in Fig. 5. CloudSat shows a flat, low cloud layer with top at about 4 km. In most places a single layer appears; elsewhere there is another layer below. The CIP
analysis agrees reasonably well with CloudSat except that it does not show the double layer structure. Significantly, the Calipso trace shows a near-horizontal layer of liquid water (red color) at cloud top. Together with the NOGAPS cloud top temperature of about -18 C, the Calipso trace suggests SLW and the potential for aircraft icing. Blues and purples on the CALIPSO trace represent smaller backscatter values, marking cirrus clouds at about 10 km. Notice that Calipso has the ability to detect water cloud features under thin cirrus. However, it does not have the ability to penetrate water clouds in the same way CloudSat can. Thus, only the top of the lower, water cloud top can be observed. Notice that at the southern end of the Calipso trace (at about time 18:28 UTC) there is a mixture of reds and blue at about 4 km, suggesting a mixed phase cloud at about -18 C.

Figure 5 NRL-Minnis Algorithm November 5 2006 1815 UTC. Blue trace indicates position of data shown in Fig. 6.

Figure 6 Top: CloudSat Trace; Middle: CIP Trace; Bottom: Calipso Backscatter. Date/Time corresponding to Fig. 5
6. Summary and Conclusions

1. CloudSat and CIP output must be compared with caution since CIP output is strongly constrained in the vertical by temperature (0 to -25 C levels).
2. CloudSat gives very detailed views of cloud structure that can be used better understand icing environments.
3. CloudSat helps confirm that direct satellite observation of liquid water is restricted to regions where higher, colder clouds are absent.
4. CloudSat reveals low cloud layers which can not be observed with conventional visible and infrared measurements. These cloud systems are detached from seeder/feeder clouds and therefore probably contain elevated SLW.
5. Combining CloudSat and Calipso data can reveal even more information about the icing environment than CloudSat by itself, especially about cloud phase. Even mixed phase environments can be revealed.

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8. References


