P6.8

'ICECAP': A GOES IMAGE PRODUCT DEPICTING AIRCRAFT ICING POTENTIAL AND MAXCIMUM ICING ALTITUDE

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1. INTRODUCTION

Since 1996, derived products that show the potential for aircraft icing have been obtained from Geostationary Operational Environmental Satellite (GOES) data (e.g, Ellrod 1996; Vivekanandan et al 1996). GOES Imagers provide a variety of spectral bands that are useful for measuring or inferring conditions conducive to icing such as: cloud top temperature, visible cloud reflectance, and cloud phase. The use of longwave Infrared (IR) channels can determine cloud top temperature, and help distinguish thin ice clouds from liquid water clouds in order to reduce false detection. Shortwave IR channels also help in assessing cloud phase, especially at night. The frequent sampling intervals (15 min over the Continental United States), and moderate resolution (4-8 km IR, 1 km visible) of GOES Imager data are both favorable for monitoring icing conditions in support of aviation advisories and short range forecasts. The principal weakness of IR remote sensing techniques is the inability to observe supercooled clouds that are obscured by higher cloud layers. Although IR techniques only observe cloud tops, it has been shown however that liquid water tends to accumulate near the tops of stratiform cloud layers (e.g. Rauber and Tokay 1991), thus making GOES techniques effective in many situations. While experimental GOES icing products available from National Environmental Satellite, Data, and Information Service (NESDIS) provide useful information on the spatial coverage of supercooled clouds, there has been to date no information on the vertical extent of icing. This paper describes efforts to utilize the existing Cloud Top Product derived from GOES Sounder data to augment the Imager icing product to estimate the maximum altitude of possible icing conditions.

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2. GOES ICING AND CLOUD TOP PRODUCTS

The NESDIS combined icing and cloud top product is referred to as 'ICECAP' (Icing Enhanced Cloud-top Altitude Product). The product consists of icing risk determined from the GOES five channel Imager (Table 1), combined with cloud top heights extracted from the nineteen channel GOES Sounder (Menzel et al 1998). The procedures used for determining each of these components will be discussed separately in the following sections.

TABLE 1.
GOES Imager Spectral Bands

	GOES 8-11		GOES M-P	
Band	Wave-length (μm)	Res. (km)	Wave-length (μm)	Res. (km)
1	0.6	1	0.6	1
2	3.9	4	3.9	4
3	6.7	8	**6.5**	**4**
4	10.7	4	10.7	4
5	12.0	4	**-**	**-**
6	-	-	**13.3**	**8**

2.1. *Icing Potential Estimated From the GOES Imager*

Conditions favorable for icing have long been established (e.g. World Meteorological Organization 1954; Hansman 1989). The most important ingredients are: (1) liquid phase clouds, (2) temperatures in the 0 to -20°C range, (3) large droplet diameters (>50µm for moderate to severe), (4) weak upward motion to replenish the available supercooled water,

(5) large liquid water contents, and (6) thick, extensive cloud systems resulting in long in-flight exposure to icing conditions. The only parameter that can be directly measured from GOES is the cloud top temperature. While the shortwave IR channel (3.9 μm) reflectivity exhibits some response to cloud droplet diameters, this effect is most pronounced at diameters < 30μm (Kleespies 1995). Other parameters must be inferred by means of empirical techniques.

The cloud top temperature range used in the NESDIS product is 0 to -25 C. The colder limit captures a greater percentage of icing cases, as it accounts for cooling with height typically found in deeper cloud layers. Cloud phase at night is determined by a Band 4 – Band 2 brightness temperature difference (BTD) threshold technique, similar to the nighttime fog product which is used to identify water clouds. Band 1 visible data is corrected for solar zenith angle using a program developed at the National Weather Service (NWS) Aviation Weather Center.

The test for liquid water clouds is then determined using empirical thresholds based on the Band 4- Band 2 BTD. The latter was obtained for a large number of BTD observations for known cloud and surface types (Figure 1), for which Band 4 IR temperatures were between 0C and -25C and icing was reported by aircraft. As seen in Figure 1, this approach works well except for situations where there are thin cirrus clouds over warm stratocumulus or snow cover. In those cases, it is not possible to eliminate false signatures without use of IR techniques.

With GOES-8 through GOES-11, a Band 5-Band 4 (split window) approach was used to minimize the false icing from cirrus (Ellrod 1996), but since GOES-12 does not have the 12 μm channel, the 13.3 μm channel must be used instead. A set of dependant data based on Band 4 and 6 BTD was used to develop a new cirrus screening technique which was implemented during the Summer of 2004 (Figure 2). It is estimated that 70-80% of the false signatures due to cirrus can be eliminated in this manner. A summary of the GOES-12 icing product algorithm is shown by the flow diagram in Figure 3.

2.2 *Cloud Top Heights Obtained From the GOES Sounder*

The GOES Cloud Top Product (CTP) has been generated from the Sounder since the mid 1990's (Menzel et al 1998). The CTP algorithm has internal tests for the presence of (1) clear pixels based on comparisons with surface temperature data, (2) opaque clouds, and (3) semi-transparent clouds. If opaque clouds are determined to be present, an IR Window Technique is used to determine cloud height by matching the IR cloud top temperature (CTT) to a numerical prediction model first guess temperature profile. For low stratus clouds, the associated cloud top height is determined by finding the first CTT match to the first guess by searching from the ground up, whereas middle and high cloud matches are made from the top down. If the cloud is semi-transparent, the cloud top height is estimated using the CO_2 Analysis Technique (COAT). The COAT is a physical relationship based on a special version of the Radiative Transfer Equation that employs radiances from the Sounder IR window band at 11 μm and CO_2 absorption bands from 13-15 μm. The main assumptions are (1) the cloud is opaque but infinitesimally thin (thus allowing application for semi-transparent clouds), and (2) emissivity is the same in both spectral ranges. Details on the CTP generation and scientific approach are found in Schreiner and Schmit 2001 and Schreiner et al 2002. The CTP has since become more widely available to users via the World Wide Web (e.g. http://cimss.ssec.wisc.edu/goes/realtime/grtmain.html#ctop), and the NWS Advanced Weather Interactive Data Analysis System (AWIPS).

3. CREATION OF ICECAP

Imager icing and Sounder CTP programs are normally run separately due to differences in scan strategies, sensor resolutions, and data availability times. Processing to create the ICECAP has been combined into a single script that runs when the availability of all necessary satellite data is assured (see timeline in Figure 4). The CTP is produced hourly via the GOES Sounder processing system for both GOES-East (12) and West (10), and the data is output in ASCII format to an Office of Research and Applications server at the World Weather Building, Camp Springs,

Maryland. The experimental ICECAP program obtains the multi-spectral Imager data for three times, each an hour apart (spanning a two hour period), normalizes the visible image data, performs the icing threshold tests (Figure 3), composites the icing information for the two hour period, and finally blends the cloud top data from the previous hour, resulting in the final product. If icing is likely based on various tests of Imager data, the program searches for co-located Sounder cloud top information using a nearest neighbor approach. Two-hour compositing allows detection of some icing pixels that are obscured by broken higher cloud layers, and to minimize low light conditions near the solar terminator that result in poor detection from either nighttime or daytime methods. Potential icing areas are assigned to an artificial brightness count range, while the non-icing areas use gray scale IR Band 4 data as a background. Colors are assigned to icing pixels corresponding to cloud top height intervals of six thousand feet (1.9 km), although display of three thousand foot (0.9 km) intervals is possible. An example of the ICECAP for the Northeast U. S. on 27 July 2004 at 1400 UTC is shown in Figure 5. The location and altitude of moderate icing reported in Michigan and Indiana was accurately depicted by ICECAP. Experimental ICECAP images became available during the spring, 2004 on the NESDIS Operational Products Development Branch aircraft icing Web page:
http://www.orbit.nesdis.noaa.gov/smcd/opdb/aviation/icg.html

4. PRODUCT VALIDATION

The composite ICECAP product has not yet been validated. However, each component of the product (Imager icing and Sounder CTP) have undergone extensive independent verification. The Imager icing product was incorporated in NOAA Forecast Systems Laboratory's Real-Time Verification System (RTVS) in early 2002. RTVS compares real-time observations from aircraft pilot reports (PIREPs) or surface observations versus experimental or operational algorithms for the diagnosis or forecasting of various aviation parameters (turbulence, icing, convection, etc) derived from numerical model data, satellites or other sensors (Mahoney 2002). In order to perform the verification, the GOES Imager icing product is remapped to correspond to the 40 km resolution Rapid Update Cycle (RUC) model, converted to netCDF format, and copied to FSL via file transfer protocol (ftp). Since there is currently no height information for the satellite product, the icing height is assigned based on information contained in the PIREPs. Statistics are generated on the Probability of Detection (PODy), bias, etc, that can be viewed interactively for periods of time spanning individual days, months, or years in either graphical or tabular formats. Geographical areas are also user-selectable.

A graph showing PODy for the GOES Icing Product from April 2002 through March 2004 is shown in Figure 6. A network outage resulted in loss of data during April-May of 2003 and again from late March through early July 2004. Improvements described in Section 2 related to visible data normalization and modified thresholds for GOES-12 products implemented in late Summer and Fall 2003 resulted in improved POD values (blue line segments). Performance was best below 12,000 ft (3.8 km) (blue dashed lines), reflecting the strength of the GOES product in identifying icing conditions related to cold air stratiform cloudiness events dominant during the cool seasons. During summer, poor statistics were due to the prevalence of convective icing, and abundant cirrus cloud cover. However, mean PODy for July 2004 (not shown) was 64%, with 83% PODy for icing below 12 kft, the best results obtained so far for a summer month. Implementation of the Band 4-6 cirrus filter described in Section 2 (late Summer 2004) is expected to reduce false alarms.

The GOES CTP was compared with data from ground based lidar and radar systems at the Department of Energy's Atmospheric Radiation Measurement (ARM) program's Cloud and Radiation Test-bed (CART) site in Lamont, Oklahoma from April 2000 to March 2002 (Hawkinson 2003). These comparison measurements yielded a mean difference of 1772 meters and a standard deviation of 1733 meters. The difference in GOES cloud top measurements is within ±500 meters for 22% of the retrievals (371 out of 1762) and within ±1500 meters for 56% of the retrievals (981 out of 1762).

5. FUTURE PLANS

Inclusion of ICECAP into the RTVS would help to better determine the usefulness of the GOES icing product by providing additional statistics such as percentage of airspace volume. The use of freezing level heights derived from the GOES Sounder, supplemented by numerical model data, could be used to estimate the depth of potential icing cloud layers as a supplement to ICECAP.

6. SUMMARY AND CONCLUSIONS

A composite satellite product that displays regions of aircraft icing risk along with associated cloud top heights has been created by combining data from the GOES Imager and Sounder. The image product, referred to as 'ICECAP,' is created hourly, and is color-coded to show cloud-top altitudes in six thousand foot intervals. Experimental ICECAP images became available routinely on the Web during the spring of 2004. Validation of ICECAP components (Imager icing and Sounder cloud top heights) indicates that the product is most useful during cool seasons for icing events that occur below 3.8 km (12,000 ft) (PODy of 55%-80%). The standard deviation of the cloud top height error is about 1.7 km.

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8. REFERENCES

Ellrod, G. P., 1996: The use of GOES-8 multi-spectral imagery for the detection of aircraft icing regions. *Preprints, 8th Conf. on Satellite Meteorology and Oceanography*, January 28-February 2, 1996, Atlanta, Georgia, Amer. Meteor. Soc., Boston, 168-171.

Hansman, R. J., 1989: The influence of ice accretion physics on the forecasting of aircraft icing conditions. *Preprint Volume, 3rd Intl. Conf. on the Aviation Weather System*, 30 January – 3 February 1989, Anaheim, California, Amer. Meteor. Soc., Boston, 154-158.

Hawkinson, J., 2003: A comparison study using the GOES cloud top pressure product and cloud lidar and radar. Master's Thesis, University of Wisconsin, Dept. of Atmospheric and Oceanic Science, 35 pp.

Kleespies, T., 1995: The retrieval of marine stratiform cloud properties from multiple observations of varying solar illumination. *J. Appl. Meteor.*, **34**, 1512-1524.

Mahoney, J., J. Henderson, B. Brown, J. Hart, A. Loughe, C. Fischer, and B. Sigren, 2002: The Real-Time Verification System (RTVS) and its application to aviation weather forecasts. *Preprints, 10th Conference on Aviation, Range, and Aerospace Meteorology*, American Meteorological Society, Boston, 323-326.

Menzel, W. P., F. Holt, T. Schmit, R. Aune, A. Schreiner, G. Wade, and D. Gray, (1998) Application of GOES-8/9 soundings to weather forecasting and nowcasting. *Bull. Amer. Meteor. Soc.*, ***79*****(10)**, 2059-2077.

Rauber R., and A. Tokay, 1991: An explanation for the existence of supercooled water at the top of cold clouds. *J. Atmos. Sci.*, **48**, 1005-1023.

Schreiner, A.J., T.J. Schmit, and R.M. Aune, (2002) Maritime inversions and the GOES Sounder cloud product, *National Weather Digest*, ***26***, 27-38.

Schreiner, A.J. and T.J. Schmit, (2001) Derived Cloud Products from the GOES-M Imager, *Preprints, 11th Conference on Satellite Meteorology and Oceanography*, Madison, Wisconsin, Amer. Meteor.Soc., 420-423.

World Meteorological Organization, 1954: Meteorological aspects of aircraft icing. *WMO Tech. Note No. 3*, WMO – No. 30.TP9, Geneva, Switzerland, 18 pp.

Vivekanandan, J., G. Thompson, and T. F. Lee, 1996: Aircraft icing detection using satellite data and weather forecast model results. *FAA Intl. Conf. on Aircraft Icing*, Springfield, VA, May 6-8, 1996.

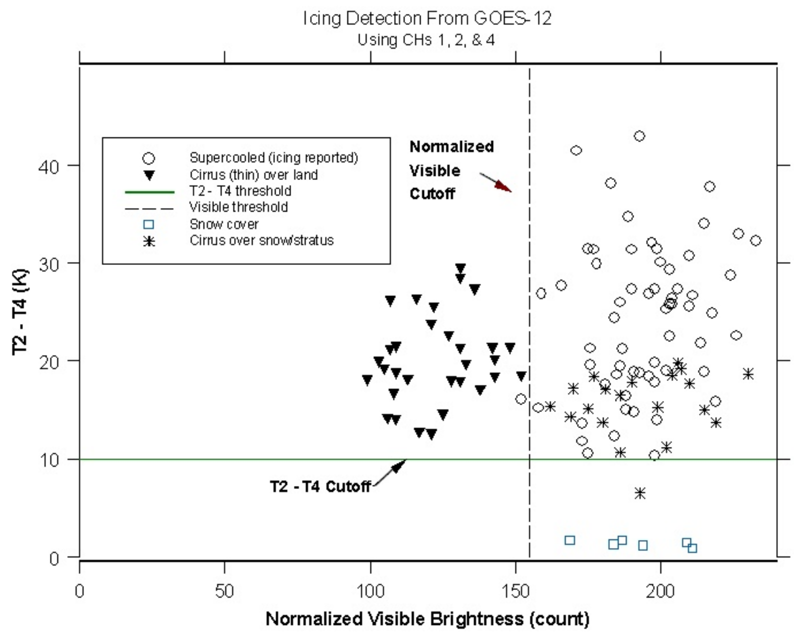

Figure 1. *CH2 minus CH4 temperature (K) versus visible channel brightness count corrected for solar zenith angle for various cloud and surface types with 0 < T4 < -30C. Horizontal and vertical lines are used as thresholds for identifying clouds with icing potential.*

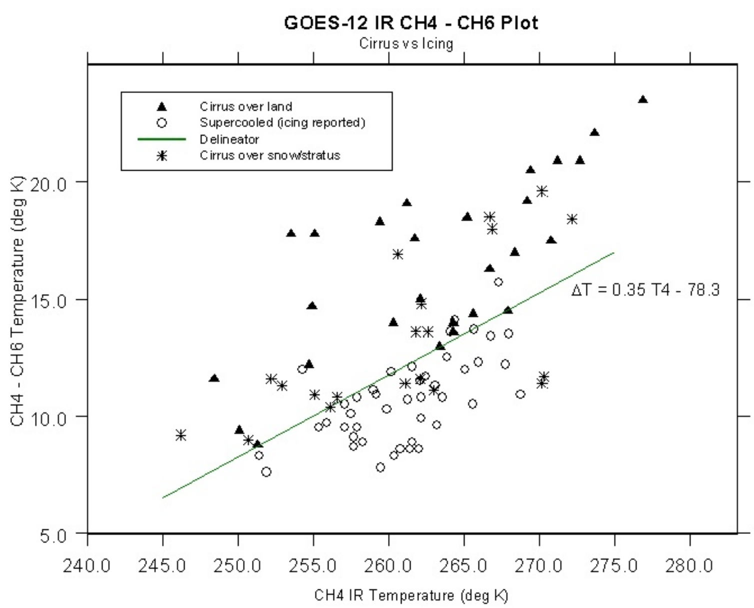

Figure 2. *Channel (CH) 4 minus CH 6 IR brightness temperature difference (K) from GOES-12 for indicated cloud types versus CH 4 temperature (K). Solid line is discriminator for eliminating false icing produced by thin cirrus from icing product.*

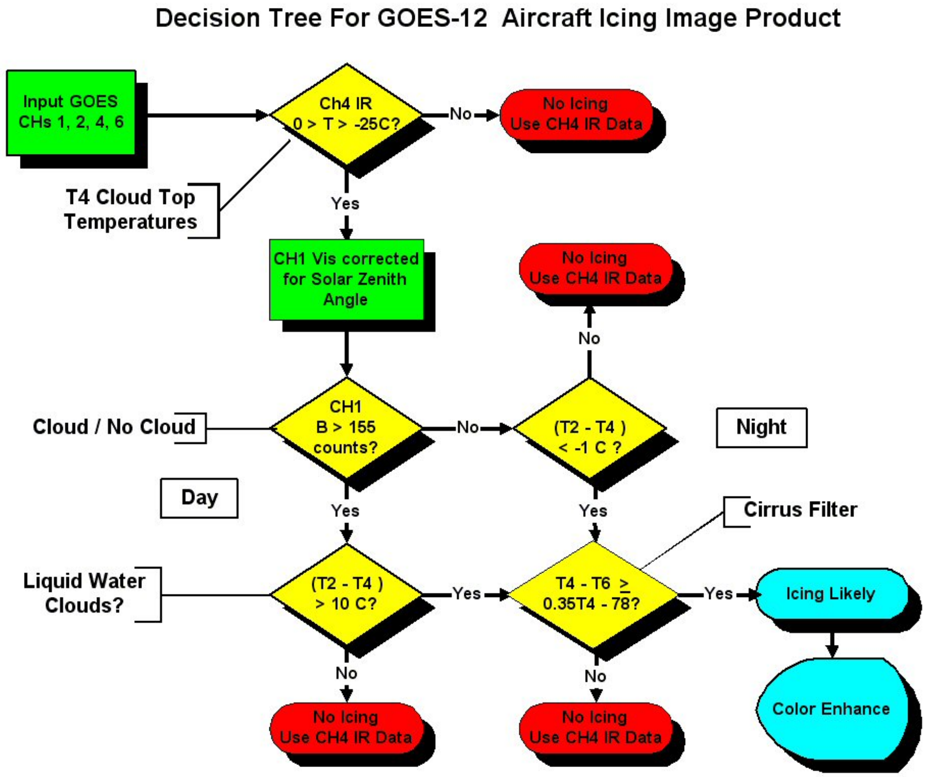

Figure 3. *Logic flow used in the generation of the GOES-12 Imager icing product.*

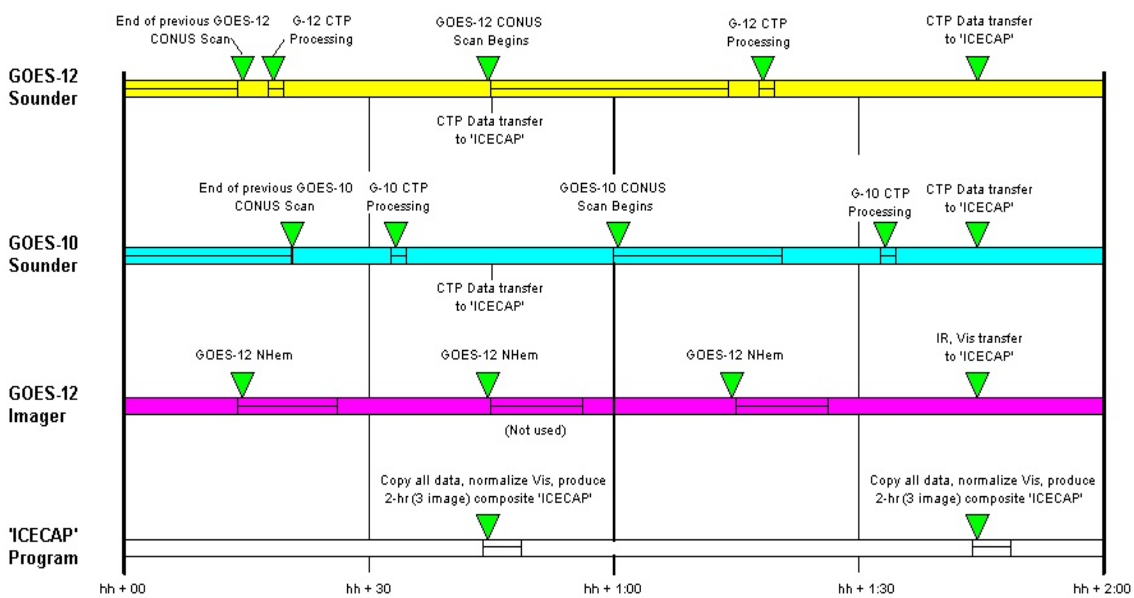

Figure 4. *Timeline showing processing steps involved in the creation of ICECAP.*

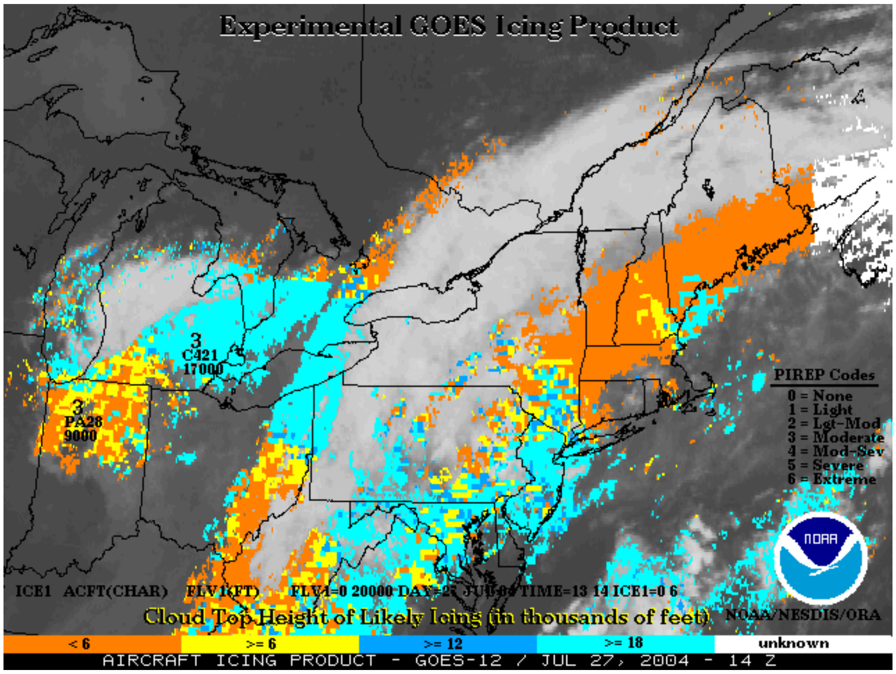

Figure 5. *Regional ICECAP image valid 1400 UTC, 27 July 2004. Legend shows cloud top height color-coded for six thousand ft intervals.*

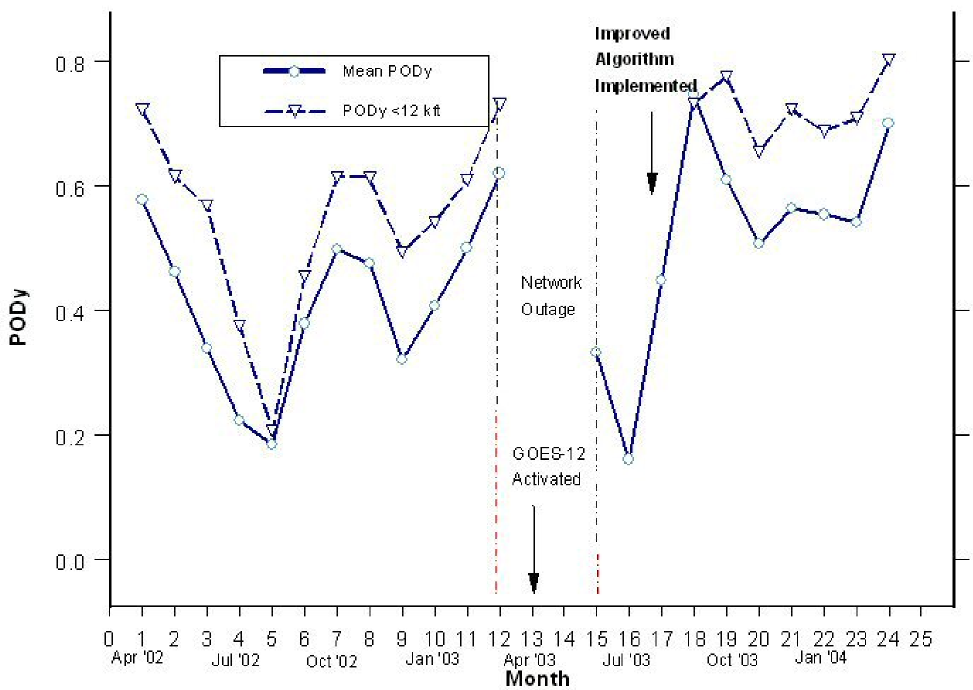

Figure 6. *Mean Probability of Detection of icing occurrence (PODy) for the Imager icing product based on RTVS output for all levels (solid blue line), and for flight levels below 12 thousand feet (dashed line) for the period from April 2002 to March 2004.*