P9.14 COMPARISON OF TAMDAR GLFE ICING REPORTS WITH NASA ADVANCED SATELLITE AVIATION-WEATHER PRODUCTS (ASAP) IN-FLIGHT ICING PARAMETERS

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1. INTRODUCTION

The Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Great Lakes Fleet Experiment (GLFE) provided an opportunity to significantly build upon initial icing sensor performance comparisons with cloud microphysical retrievals and derivative products developed by the NASA Langley Research Center (LaRC). These products support the NASA Advanced Satellite Aviation-weather Products (ASAP) initiative and were first discussed by Murray et al. (2004, 2005) and Nguyen et al. (2004). Unlike the 6 sorties made by a University of North Dakota Cessna Citation II aircraft during the 2003 Alliance Icing Research Study (AIRS) II, the GLFE provided a significantly larger and more diverse data set from 63 Mesaba Airlines SAAB 340s conducting over 400 passenger flights daily. These flights were made between the Great Lakes region and 75 airports primarily throughout the mid-western United States as depicted in figure 1.

TAMDAR is a low-cost sensor that was developed by AirDat, LLC for NASA. It is designed to measure and report winds, temperature, humidity, turbulence and icing from regional commercial aircraft (Daniels et al., 2004). TAMDAR Icing reports from the GLFE are compared here to half-hourly NASA ASAP retrievals of cloud microphysical products for evaluating in-flight icing conditions. The ASAP parameters include cloud phase, liquid water path, effective cloud height, super-cooled large droplet (SLD) temperature, SLD diameter and a composite icing severity index. The NASA ASAP team has begun integration research for these measurements to be used in operational icing products developed by the FAA Aviation Weather Research Program (Minnis et. al., 2005, Haggerty et. al, 2005) and also to incorporate them into experimental high-resolution numerical weather prediction models run by NOAA.

AirDat equipped the 63 SAAB aircraft and collected meteorological and icing data during a 6-month period from Dec 15, 2004 through July 15, 2005. April – July 2005 data were available from the AirDat GFLE data portal for this study. Due to time constraints, only April 2005 data were studied. The available data were numerous, comprising over 13,000 icing reports from thousands of flights. This has facilitated the first statistically significant analysis of the data showing probabilities of detection and false alarm rates during the GLFE under diverse conditions of use.

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2. DATA & METHODOLOGY

Geostationary Operational Environmental Satellite (GOES-12) data are collected over the GLFE domain from 25°N - 50°N and 65°W - 105°W. The GOES-12, stationed at 75°W, provides half-hourly 4-km imager data with spectral radiances at 0.65, 3.9, 10.8, and 13.3-μm wavelengths. The pixel-level data are analyzed using the visible infrared solar-infrared split-window technique (VISST; Minnis et al., 2001). Cloud properties and aircraft indices are derived every 30-minutes as described by Minnis et al. (2004a, 2004b). The pixel-level icing parameters are averaged using weighted average of the 4 closest pixels to each TAMDAR observation and matched temporally as closely as possible (±15 minutes) to the GOES-12 image.

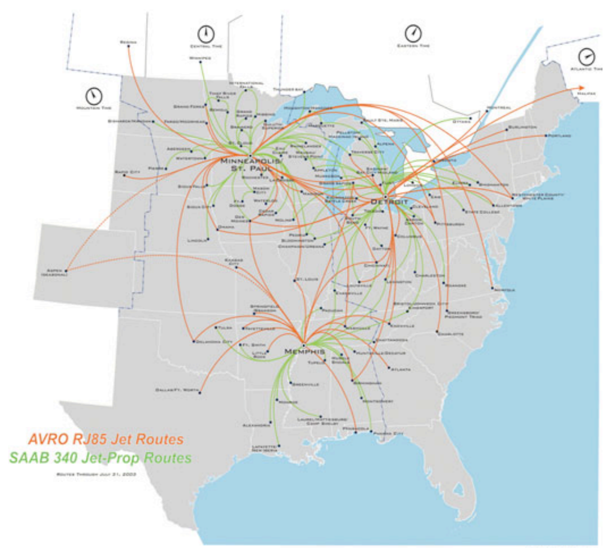

Fig. 1. Mesaba Airlines SAAB 340s regional jet routes throughout the greater Great Lakes region (image courtesy AirDat).

The TAMDAR icing data consist of six indices: “I” signifies that icing is occurring and the probe heater is on; “F” indicates an ice-detector fault; “D” means that no icing is indicated; ”H” signifies no icing and the probe heater is on; “L” indicates that icing is occurring and the heater is about to turn on; and “C” means that the heater has shut-off and the probe is cooling down. The post-processed April 2005 data obtained from AirDat contains only the “I”, “D”, and “H” indicators. There were 440,542 observations of which 13,321 reports indicated icing, 8,951 indicated that the heater was on so icing was not detectable at that time and the rest indicated that no icing was observed. When the TAMDAR probe detects icing, it reports immediately and then at a minimum of every minute thereafter. During aircraft ascent and descent, the probes report more frequently, providing as many as 6 observations per minute to obtain vertical sounding profiles. During level flight, the probes report every 3 minutes. Unlike the few PIREPS reports that are reported (most of which are reported during icing conditions), TAMDAR takes continuous data. Therefore the TAMDAR reports are dominated by 95% no icing indicator. Thus, the GOES and TAMDAR comparison statistics in the results will be biased towards the TAMDAR no-icing category if filters are not properly applied to remove non-significant reports.

3. RESULTS

Figure 2 shows an example of ASAP in-flight icing parameters retrieved over the Eastern US from GOES-12 imager data taken at 16:45 UTC, 2 April 2005. The Multi-channel RGB image (Fig. 2a) combines the 0.65-μm visible band in the red channel, 3.9-μm minus 10.7-μm bands in the green channel, and 10.7-μm infrared band in the blue channel to reveal various types of cloud conditions. The VISST retrieved cloud phase (Fig. 2b) shows clear areas in green, ice clouds in red, warm liquid water clouds in dark blue, and supercooled liquid (SLW) clouds in cyan color. SLW are identified as water clouds with cloud temperatures $T_c < 273$ K. A good concentration of SLW clouds cover much of West Virginia, Ohio, Kentucky, and western North Carolina and Virginia where a low pressure system was located. The derived icing intensity (Fig. 2f) shows most of these areas in generally light icing conditions (blue) except for some moderate-heavy icing conditions (red) in some areas just north of West Virginia. The satellite cloud base (Fig. 2g) was between 0-2 km and cloud top at 1-4 km. The effective water radius and liquid water paths are shown in Figs. 2c and 2d respectively.

A satellite icing classification system using thresholds (Minnis et. al., 2004a) was used to convert icing-related cloud properties to in-flight icing intensity: none, indeterminate, light, moderate-heavy, and no data indices. At the time of this writing, only daytime GOES-12 data from April 1-26, 2005 were analyzed with the exception of 3 missing days (April 19, 20, & 24). In order to compare the TAMDAR data with GOES without biasing the results, only TAMDAR reports at altitudes within the GOES-derived cloud base and top and in a cloudy condition as defined by GOES were compared. The GOES filters reduced the total number of daytime TAMDAR reports from 383,854 to 32,260 cases. Out of the 32,260 cases, TAMDAR reported 13% icing, 6% heater on, and 81% no ice flags while GOES reported 26% icing, 22% no icing, and 52% indeterminate. Because over half of the GOES retrievals are indeterminate, it is desirable to account for potential clouds underneath the ice clouds using a multi-layer technique to retrieve a 3D cloud product. Such a method needs further research.

Figure 3 shows an example of satellite-derived icing indices compared with the TAMDAR icing indicators on a Mesaba flight (with TAMDAR serial number 247) on 22 April 2005 between 18:00-18:30 UTC. This single-layer case shows good agreement between the satellite and TAMDAR. Satellite-derived cloud base and top (small squares) and TAMDAR icing indices (large squares) are plotted as functions of altitude. During the majority of the flight segment, the aircraft was inside the GOES-defined cloud and hence reported icing along with GOES. During the descent below cloud base, the TAMDAR no longer reported icing while GOES still detected icing. This illustrates the need to properly filter out reports that would bias the TAMDAR and GOES statistics.

The results from this study are preliminary. When TAMDAR detects icing, GOES also produced 28% icing. When TAMDAR indicated no icing, the GOES produced 26% no icing. However, if the 52% of the GOES indeterminate cases are ignored, and considering when TAMDAR detected icing compared to GOES, the probability of a positive detection by GOES is 88% of the cases (Fig. 4) and when TAMDAR and GOES both detected no icing, the probability of a null detection is 50%. Thus, of the 13% TAMDAR icing detects, GOES missed icing (false negative) in 4% of these cases. However, the GOES detected icing and TAMDAR detected no icing (false positive) in 75% of the GOES icing cases or 19% of all cases.

4. DISCUSSION AND CONCLUDING REMARKS

The VISST satellite algorithms used in this study are continually being updated. The TAMDAR dataset offers a great opportunity to validate these algorithms to detect icing. As shown in the results, 88% of positive detection from GOES and TAMDAR indicates TAMDAR performs optimally at detecting icing. The high false positive detection (75%) from GOES can be

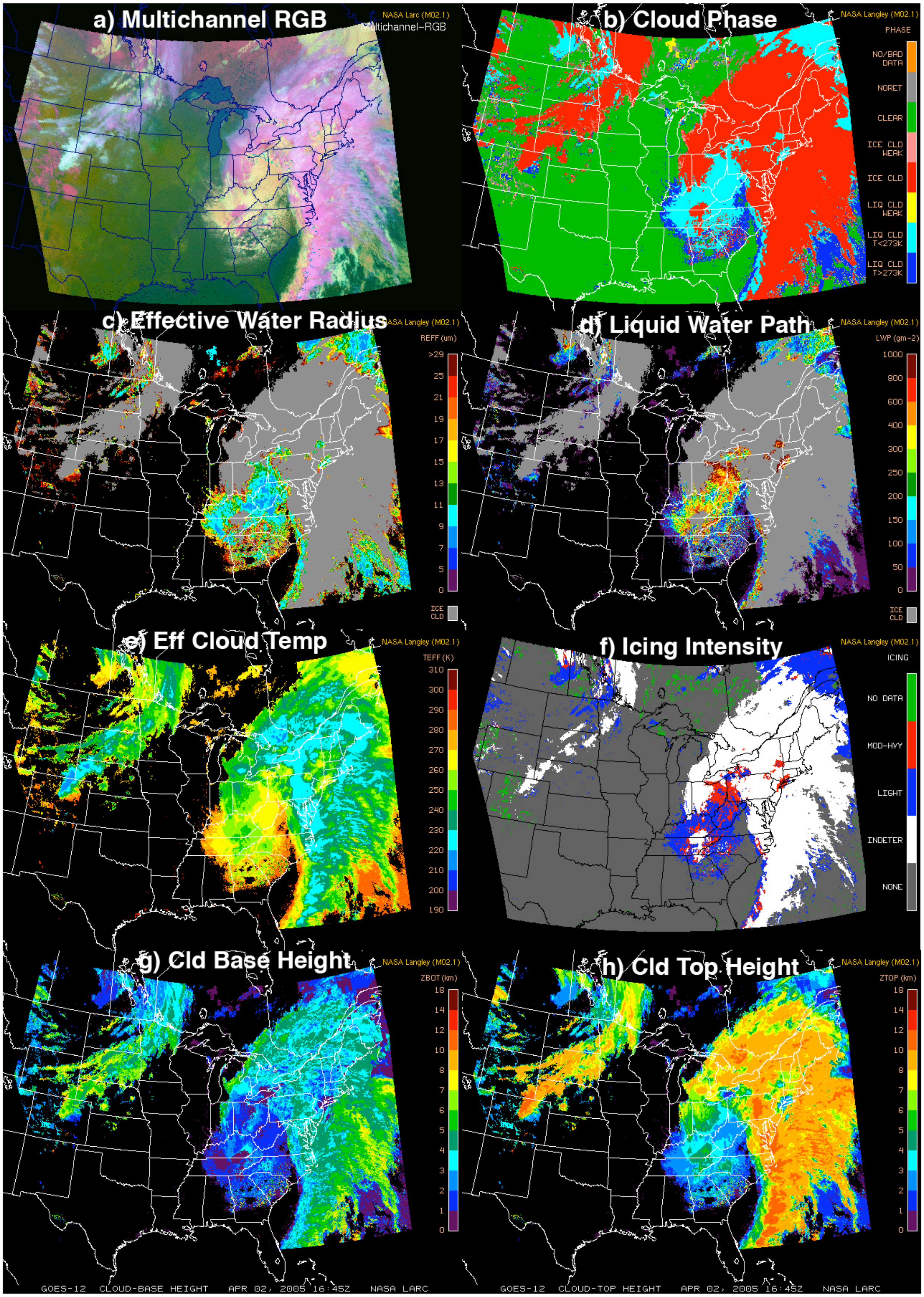

Fig 2. GOES-12 (a) false-color RGB image and (b-h) cloud and icing parameters 16:45 UTC, 02 April 2005

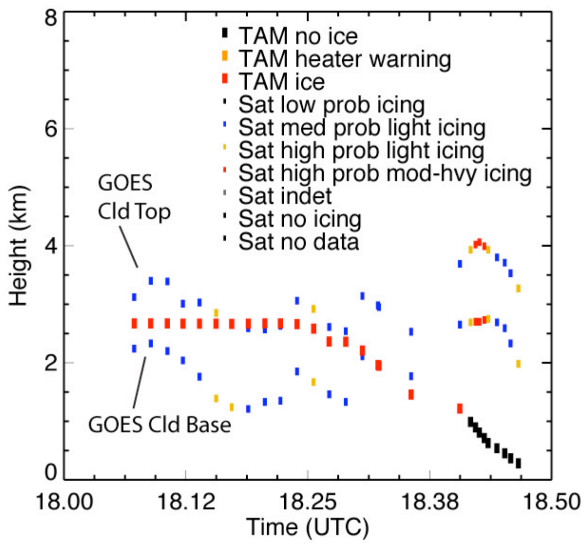

Fig. 3. Comparison of GOES icing probability and TAMDAR icing indicators.

attributed to the errors associated in the calculation of the GOES cloud base and top. With an error standard deviation of 1 km in the cloud base and top heights, many of the TAMDAR no-icing reports not in clouds are being included in the statistics with the GOES icing detects. Another factor to consider is that the VISST produces a horizontally 2-D product. With multi-layered clouds and various cloud thicknessed not being accounted for in the filter, a higher number of TAMDAR no-icing reports are being compared to GOES. Further research is needed to account for cases when the flights are not in clouds. One possibility is to use TAMDAR temperature and relative humidity to include only reports that are significant in producing icing conditions. This will be investigated and presented at the conference.

It would be optimal to produce a 3-D dataset to account for the varying conditions such as multi-layered clouds. The Cloud Icing Potential (CIP) produces such a product (Bernstein et al., 2004) by estimating icing probability at multiple levels using the RUC, PIREPS, and ceilometer datasets. The CIP is currently the operational icing product for the FAA. Collaborative work is being conducted with the NASA, NOAA, and the FAA to integrate the ASAP icing parameters into the CIP products. An added value CIP product will provide a more reliable and robust characterization of icing conditions to warn pilots and improve aviation safety.

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REFERENCES

Bernstein, B. C., F. McDonough, M. K. Politovich and B. G. Brown, 2004: CIP: a physically-based, integrated approach to the diagnosis of in-flight aircraft icing, Part I: Algorithm description. Submitted, *Weather and Forecasting.*

Daniels, T. S., G. Tsoucalas, M. Anderson, D. Mulally, W. Moninger, R. Mamrosh, 2004: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Sensor Development. *Proc. 11th Conf. on Aviation Range, and Aerospace Meteorology*, Hyannis, MA, Amer. Meteor. Soc., Hyannis, MA. October 4-8.

Minnis, P., et al., 2001: A near-real method for deriving cloud and radiation properties from satellites for weather and climate studies. *Proc. AMS 11th Conf. Satellite Meteorology and Oceanography,* Madison, WI, Oct. 15-18, 477-480.

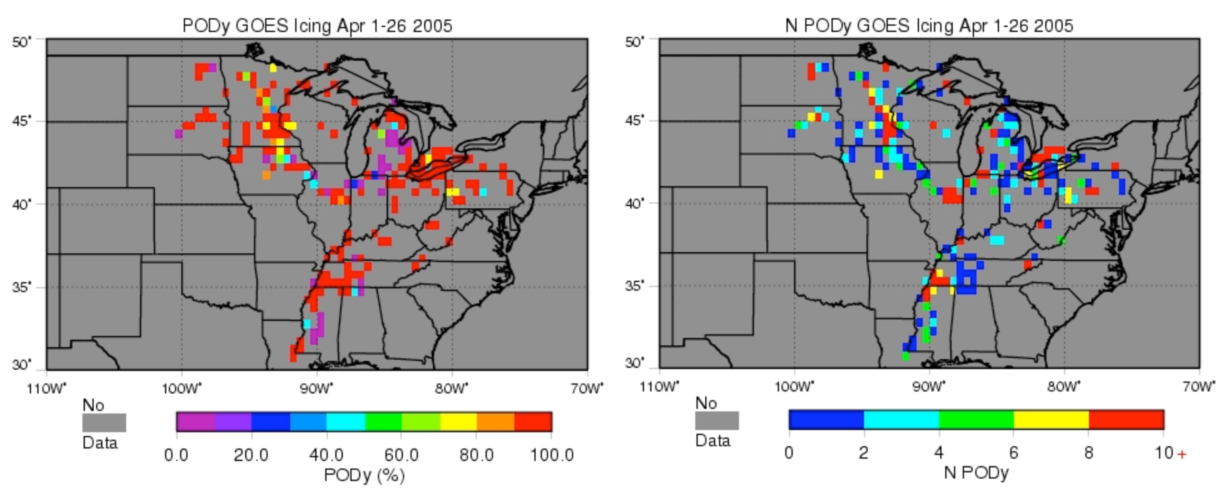

Fig 4. Probability of detecting a positive icing case (PODy) from TAMDAR and GOES (left fig.) and the number of PODy case in each 0.5° grid (right fig.).

Minnis, P., et al., 2004a: Real-time cloud, radiation, and aircraft icing parameters from GOES over the USA. *13th AMS Conf. On Satellite Oceanography and Met.*, Norfolk ,VA, September 20-24.

Minnis, P., W. L. Smith, Jr., L. Nguyen, D. A. Spangenberg, P. W. Heck, R. Palikonda, J. K. Ayers, C. Wolff, and J. J. Murray, 2004b: Near-real time cloud properties and aircraft icing indices from GEO and LEO satellites. *Proc. 49th. SPIE Annual Meeting, Earth Observing Systems IX Conference*, Denver, CO, August 2-6

Minnis, P., L. Nguyen, R. Palikonda, D. A. Spangenberg, J. K. Ayers, Y. Yi, M. L. Nordeen, and C. Wolff, 2004c: Toward a three-dimensional near-real time cloud product for aviationsafety and weather diagnoses. *Proc. 11th Conf. on Aviation Range, and Aerospace Meteorology*, Hyannis, MA, Amer. Meteor. Soc., Hyannis, MA. October 4-8.

Murray, J. J, P. R. Schaffner, P. Minnis, L. Nguyen, V. E. Delnore, and T. S. Daniels, C. A. Grainger, D. Delene, C. A. Wolff, 2004: Troposheric airborne meteorological data reporting (TAMDAR) icing sensor performance during the 2003 Alliance Icing Research Study (AIRS II). *Proc. 11th Conf. on Aviation Range, and Aerospace Meteorology*, Hyannis, MA, Amer. Meteor. Soc., Hyannis, MA. October 4-8.

Murray, J. J, L. Nguyen, T. S. Daniels, P. Minnis, P. R. Schaffner, M. F. Cagle, M. L. Nordeen, C. A. Wolff, M. V. Anderson, D. J. Mulally, K. R. Jensen, C. A. Grainger, and D. Delene, 2005: Tropospheric Airborne Meteorological Data and Reporting (TAMDAR) Icing Sensor Performance during the 2003/2004 Alliance Icing Research Study (AIRS II). *43rd AIAA Aerospace Science Meeting & Exhibit*, Reno, NV, January 10-13.

Nguyen, L., et al., 2004: Comparison of satellite and aircraft measurements of cloud microphysical in icing conditions during ATREC/AIRS-II. *Proc. 11th Conf. on Aviation Range, and Aerospace Meteorology*, Hyannis, MA, Amer. Meteor. Soc., Hyannis, MA. October 4-8.