

**Supercooled liquid water cloud properties derived from GOES:
Comparisons with in-situ aircraft measurements**

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4.2 SUPERCOOLED LIQUID WATER CLOUD PROPERTIES DERIVED FROM GOES: COMPARISONS WITH IN-SITU AIRCRAFT MEASUREMENTS

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1. INTRODUCTION

The existence of super-cooled liquid water (SLW) in clouds is of concern to the general aviation community since it can freeze on contact with aircraft and adversely affect the aircraft's performance. Icing on the airframe can increase drag, decrease lift and cause control problems. Several factors determine the degree with which SLW will freeze and affect an aircraft's performance including the type and weight of the aircraft, the duration of exposure to SLW and the accretion rate of ice on the airframe. The severity of ice accretion is sensitive to temperature, the liquid water content and the drop size distribution (Rasmussen et al., 1992). Much attention has been given to improving the detection and forecasting of aircraft icing over the past decade. A number of temperature and humidity based diagnostic algorithms have been incorporated with numerical weather prediction models to produce icing forecast products over the United States (Schultz and Politovitch, 1992; Forbes et al. 1993). An intercomparison of in-flight icing algorithms was recently conducted by Thompson et al., (1997a) and Brown et al., (1997). Those studies revealed that temperature and humidity based algorithms significantly over-predict the area coverage of SLW clouds. Thompson et al., (1997b), showed that satellite data can be used to reduce the predicted spatial extent of SLW by excluding areas that are cloud-free or where the satellite-derived cloud top temperature is above freezing. Satellite data can also be used to detect SLW directly since it is often found to accumulate in

the top several hundred meters of cloud layers (Rauber and Tokay, 1991). Recent advances in geostationary satellite sensors now permit us to derive cloud optical depth, particle size, phase and water path in near real-time. Ellrod and Nelson (1996) have shown the potential for using geostationary satellite data to detect SLW clouds. Smith et al., (2000) demonstrated a favorable comparison of this technique to positive pilot reports of icing. In this paper, we apply a technique to identify SLW clouds and derive the cloud optical properties from geostationary satellite data. The satellite retrievals are co-located and compared with in-situ aircraft measurements of cloud microphysical properties made over a three month period from the NASA Glenn Twin Otter (Miller et al., (1998) This work is being done in an effort to further validate the satellite retrievals and to explore the potential for determining icing severity from real-time operational satellite data based on the extent to which the aircraft data are able to indicate icing severity.

2. DATA AND METHODOLOGY

A suite of algorithms have been developed to derive pixel level cloud properties for the Clouds and Earth's Radiant Energy System (CERES) project (Minnis et al. 1995, 1998, 1999). These algorithms have been adapted and are being applied to Geostationary Operational Environment Satellite (GOES-8) data over the United States for the Atmospheric Radiation Measurement (ARM) program. Cloud properties are determined by matching radiance observations at 0.63, 3.9, 10.8 and 12.0 μm at a nominal 4-km resolution to parameterizations of model calculations of cloud emittance and

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reflectance for a wide range of water droplet and ice particle sizes (Minnis et al, 1998). Additionally, a robust cloud mask has been developed to exploit the multi-spectral information now available on operational satellites. Accurate maps of clear-sky surface albedo and emissivity have been developed (Smith et al. 1999, Sun-Mack et al, 1999) and are crucial to both the cloud identification and the cloud retrievals. The atmospheric contribution to the satellite radiances is separated from the cloud contribution. Atmospheric optical depths are calculated for the GOES-8 wavelengths following the method of Kratz (1995) and utilizing temperature and humidity profiles obtained from 3-hourly Rapid Update Cycle (RUC) operational analyses. Calibration of the 0.63- μm channel is performed and follows the method of Nguyen et al. (2001). Nominal calibrations for the other channels are employed. These algorithms are running operationally at 30-minute resolution to derive cloud and radiation parameters from GOES-8 data taken over the Southern Great Plains (SGP) of the USA for the ARM program (see <http://angler.larc.nasa.gov/armsgp> for examples of the cloud products). In this study we apply the technique to GOES data over the Ohio Valley at times coincident with NASA Glenn Twin Otter flights.

2.1 Determination of SLW

In the satellite analyses presented here, clouds determined to be composed of water droplets with temperatures below 273K are denoted as SLW and indicate the potential for aircraft icing. The method is described in more detail in Smith et al., (2000).

3. RESULTS

There were at least 17 Twin Otter flights that penetrated SLW clouds during the period of January 17 through March 30, 2001. Satellite analyses have been performed for eight of these flights at the time of this writing. Figure 1 depicts cloud phase derived from the GOES data over a large region encompassing the location of the aircraft flights which generally occurred over north-central Ohio in the vicinity of Cleveland. Large areas of SLW were identified in the satellite retrievals for all the days. On a few of the days, higher cloud decks were present above the aircraft. Table 1 lists the mean SLW cloud microphysical properties and

cloud temperature derived from the satellite data in a region approximately 3600 square miles encompassing the aircraft flights. Cloud optical depths ranged from about 10 to 40. Liquid water paths were found to range from 70 to 260 g/m^2 and the water droplet effective radii generally ranged from 8 to 12 μm . The cloud temperatures were generally 260 to 266 K. The regions analyzed on March 7 and 21 were dominated by higher clouds with a small percentage of SLW pixels found near their edges. The higher clouds appear to have contaminated the satellite retrieval of SLW droplet radius on March 21 and cloud temperature on March 7, with values of 16.9 and 252K found respectively. It's unlikely these days will yield meaningful comparisons with the aircraft data collected in the lower SLW clouds but nevertheless are shown here and indicate the nature of the uncertainties in the satellite retrievals in the relatively small fraction of pixels found near cloud edges due to sub-pixel scale inhomogeneities.

4. CONCLUDING REMARKS

A technique for deriving cloud optical properties and, in particular, SLW, from high spatial and temporal resolution satellite data has been applied to GOES data over the Ohio Valley. The results are being compared to aircraft measurements of SLW cloud microphysics. The analysis reported here is just the beginning. For the conference, we plan to have analyzed the aircraft microphysics data and plan to do a more thorough comparison of cloud properties derived from the satellite data along the flight track of the Twin Otter. Those data will be compared to the aircraft microphysics measurements as they have just recently become available. There were also about a half dozen flight days in January 2001 that will also be analyzed. The aircraft data are valuable to validating the satellite retrievals of SLW cloud properties. Of particular interest will be the comparison between the cloud microphysical properties derived from the aircraft data collected in-cloud and those properties derived from space.

References

Brown, B. G., G. Thompson, R. T. Bruintjes, R. Bullock, and T. Kane, 1997: Intercomparison of in-flight icing algorithms. Part II: Statistical verification results. *Wea. Forecasting*, **12**, 890-914.

- Ellrod, G. and J. P. Nelson, 1996: Remote Sensing of Aircraft Icing Regions Using GOES Multispectral Imager Data, Preprints 15th Conf. on Weather Analysis and Forecasting, 19-23 August, 1996 Norfolk, Virginia, Amer. Meteor. Soc., Boston, 9-12
- Forbes, G. S., Y. Hu, B. G. Brown, B. C. Bernstein, and M. K. Politovitch, 1993: Examination of conditions in the proximity of pilot reports of icing during STORM- FEST. Preprints, *Fifth Int. Conf. On Aviation Weather Systems*, Vienna, VA., Amer. Meteor. Soc., 282-286.
- Kratz, D. P., 1995: The correlated k-distribution technique as applied to the AVHRR channels. *J. Quant. Spectrosc. Radiat. Transfer*, **53**, 501-507
- Miller, D., T. Ratvasky, B. Bernstein, F. McDonough and J.W. Strapp, 1998: NASA/FAA/NCAR supercooled large droplet icing flight research: summary of winter 96-97 flight operations. 36th Aerospace Science Meeting and Exhibit, AIAA, Reno NV, 12-15 January.
- Minnis, P.; Kratz, D. P.; Coakley, J. A., Jr.; King, M. D.; Garber, D.; Heck, P.; Mayor, S.; Young, D. F. and Arduini, R., 1995: Cloud Optical Property Retrieval (Subsystem 4.3). "Clouds and the Earth's Radiant Energy System (CERES) Algorithm Theoretical Basis Document, Volume III: Cloud Analyses and Radiance Inversions (Subsystem 4)", *NASA RP 1376 Vol. 3*, edited by CERES Science Team, 135-176.
- Minnis, P.; Garber, D. P.; Young, D. F.; Arduini, R. F.; and Takano, Y., 1998: Parameterization of reflectance and effective emittance for satellite remote sensing of cloud properties. *Journal of Atmospheric Sciences*, **55**, 3313-3339. .
- Minnis, P., D. F. Young, B. A. Wielicki, P. W. Heck, S. Sun-Mack, and T. D. Murray, 1999: Cloud Properties Derived From VIRS For CERES. Proceedings of the 10th AMS Conference on Atmospheric Radiation, Madison, WI., June 28-July 2
- Nguyen, L., P. Minnis, J.K. Ayers, D.R. Doelling, Intercalibration of Meteorological Satellite Imagers Using VIRS, ATSR-2 and MODIS, 2001: Proc. AMS 11th Conf. on Satellite Meteorology and Oceanography, 442-445.
- Rasmussen, R., and Coauthors, 1992: Winter Icing and Storms Project (WISP). *Bull. Amer. Meteor. Soc.*, **73**, 951-974.
- 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
- Schultz, P., and M. K. Politovitch, 1992: Toward the improvement of aircraft icing forecasts for the continental United States. *Wea Forecasting*, **7**, 493-500.
- Smith, W. L., Jr., P. Minnis, D. F. Young, and Y. Chen, 1999: Satellite-derived surface emissivity for ARM and CERES. *Proc. AMS 10th Conf. Atmos. Rad.*, Madison, WI, June 28 – July 2, 410-413.
- Smith, W.L., Patrick Minnis and D.F. Young, An Icing Product Derived from Geostationary Satellite Data. Preprints, *AMS 9th Conference on Aviation, Range and Aerospace Meteorology*, 11-15 Sept, 2000, Orlando, FL.
- Sun-Mack, S., Y. Chen, T. D. Murray, P. Minnis, and D. F. Young, 1999: Visible clear-sky and near-infrared surface albedos derived from VIRS data for CERES . *Proc. AMS10th Conf. Atmos. Rad.*, 28 June – 2 July, Madison, WI.
- Thompson, G., R. T. Brientjes, B. G. Brown, and F. Hage, 1997a: Intercomparison of in-flight icing algorithms. Part I: WISP94 real-time icing prediction and evaluation program. *Wea. Forecasting*, **12**, 878-889.
- Thompson, G., T. F. Lee, and R. Bullock, 1997b: Using satellite data to reduce spatial extent of diagnosed icing. *Wea. Forecasting*, **12**, 185-190.

	Optical Depth	LWP (g/m**2)	Droplet Radius (µm)	Temperature (K)
Feb 23, 2001 (1445 UTC)	22	118	8.6	261
Feb 26, 2001 (1445 UTC)	38	182	7.7	263
Mar 02, 2001 (1445 UTC)	33	260	11.7	266
Mar 02, 2001 (1845 UTC)	24	135	9.1	267
Mar 07, 2001 (1445 UTC)	28	213	11.7	252
Mar 21, 2001 (1815 UTC)	10	102	16.9	262
Mar 27, 2001 (1815 UTC)	15	69	7.7	260
Mar 29, 2001 (1715 UTC)	26	204	11.6	261

Table 1. Cloud properties derived from GOES in the vicinity of the NASA Glenn Twin Otter for select cases

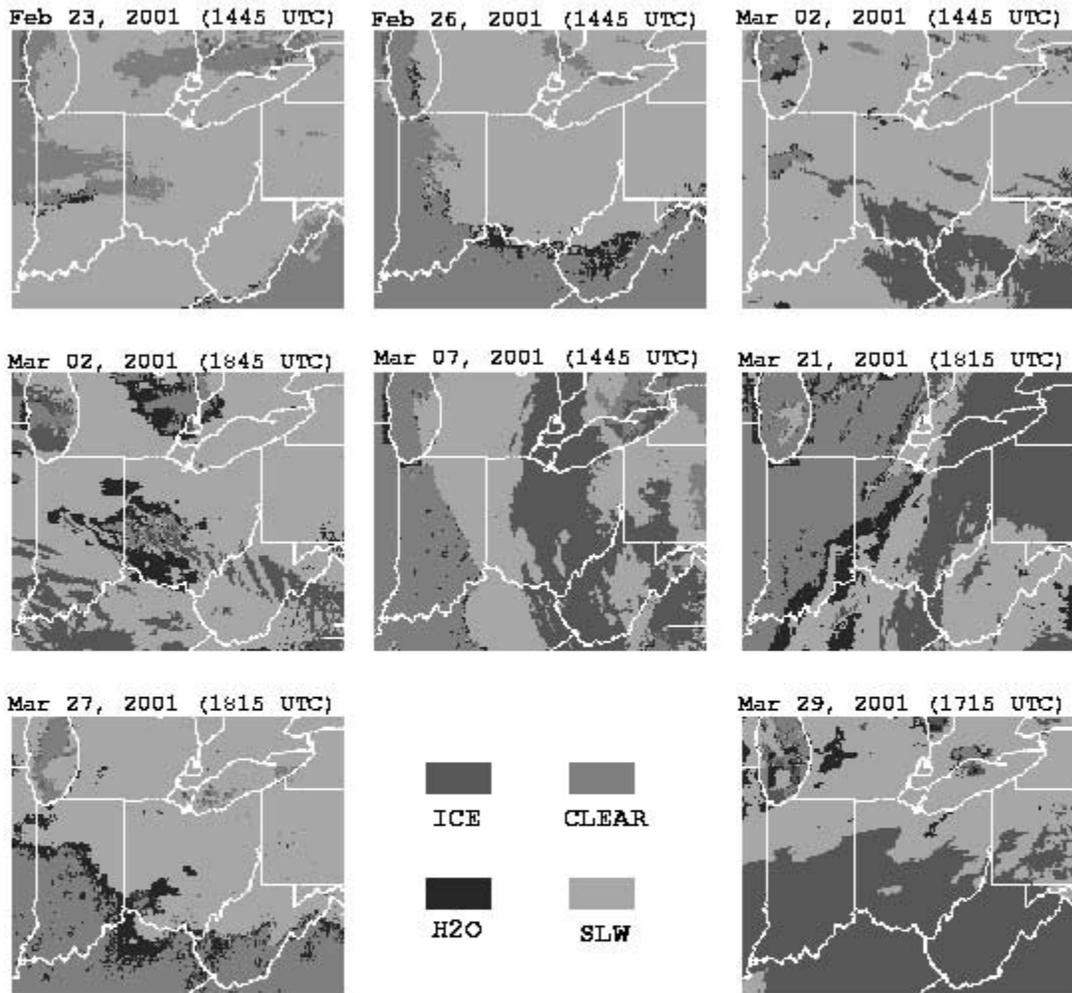


Figure 1. Cloud phase derived from GOES-8 coincident with NASA Glenn Twin Otter penetrations through SLW clouds near Cleveland, Ohio.