P9.3 SATELLITE CLOUD PRODUCTS FOR AIR WEATHER SAFETY APPLICATIONS IN REMOTE AREAS

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1. INTRODUCTION

In remote areas like Alaska and northern Canada, low altitude flights are common forms of transportation, but the temporal and spatial density of surface and aircraft observations relevant to air weather in those areas is minimal. With the continuous availability of well-calibrated research satellites and the advent of more spectral channels and higher resolution on geostationary satellite imagers such as the GOES-I (Geostationary Operational Environmental Satellite) series or the Moderate Resolution Imaging Spectroradiometer (MODIS) on *Terra* and *Aqua*, it has become possible to provide better quantification of cloud properties that are useful for diagnosing conditions such as aircraft icing potential and ceiling height or for providing other information such as surface radiation, cloud water content, or other parameters that would be useful for energy, agriculture, or weather forecast assimilation. Currently, GOES data are being analyzed in near-real-time over southern Canada and the contiguous United States to provide estimates of cloud-top and base heights and cloud liquid water path (LWP) that are used for determining icing conditions and ceiling height. In this paper, the same analysis methods applied over those more southern areas are used to analyze GOES, MODIS, and NOAA Advanced Very High Resolution Radiometer (AVHRR) data over Alaska and northwestern Canada to test their ability to provide useful information about icing potential and ceiling heights in those more remote regions.

The high temporal resolution data from GOES are valuable for the southern portion of the analysis domain, while the MODIS and AVHRR data provide less frequent but higher resolution data for the entire domain. This initial study anticipates the development of a high-latitude Current Icing Potential product based on numerical weather prediction for the Alaska region and the availability of MODIS-like sensors on the future NOAA Polar Orbiting Environmental Satellite Series (NPOESS). The use of satellite data for diagnosing icing potential and ceiling heights should be valuable for future flight safety systems in remote areas.

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2. DATA & METHODOLOGY

The imager on GOES-10 at 135°W measures radiances at 0.65 (VIS), 3.9, 10.8 (IR), and 12 μm while the 12-μm channel on GOES-12 at 75°W was replaced with a 13.3-μm channel. Currently, GOES-12 data are analyzed over an area between 65°W and 105°W, while the GOES-10 data cover 90°W to 125°W. The analysis of the GOES and other data over the North America uses USA domain nominally extends from 25°N to 50°N and from 65°W to 125°W (Minnis et al., 2005). To cover all of North America, the GOES-10 and 12 analysis domains will be extended to 72°N and 66°N, respectively, as shown in the composite GOES-10/12 10.8-μm image taken at 1715 UTC, 25 October 2005. The analysis procedures and output products are described by Minnis et al. (2004). Analysis of the data with the Visible Infrared Solar-infrared Split-window Technique (VISST) requires vertical profiles of temperature and humidity at each time step. Currently, the 20-km Rapid Update Cycle (RUC) analyses (Benjamin et al., 2004) provide hourly profiles of temperature and humidity. The RUC data are used to convert the VISST-retrieved cloud temperature Tc to cloud height z_c and to correct radiances for atmospheric attenuation. The proposed expansion of the RUC to include all of North America at 13-km resolution permits

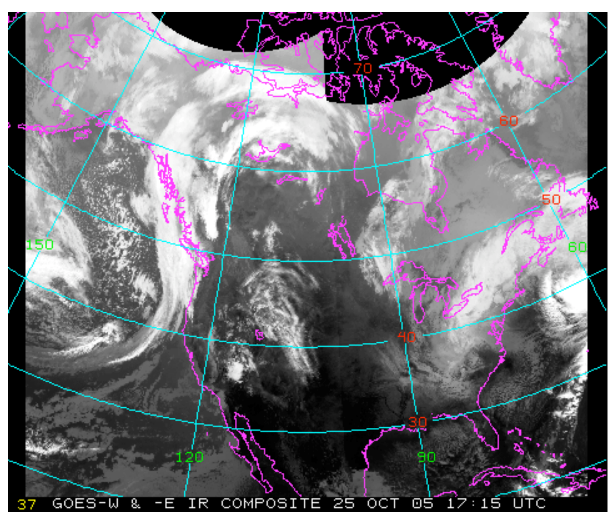

Fig. 1. *Composite GOES-10/12 IR image showing northern extent of coverage, 1715 UTC, 25 October 2005.*

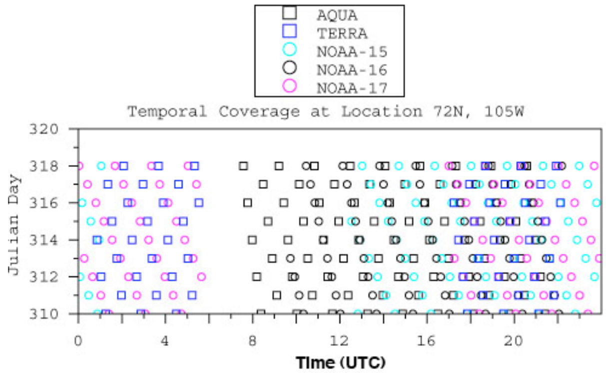

Fig. 2. *Temporal coverage of a location at 72°N and 105°W by polar-orbiting satellites at VZA < 70°.*

the expansion of the near-real time analyses to include Alaska and northern Canada.

The GOES viewing zenith angle (VZA) at 72°N approaches 90° rendering much of the data at those latitudes nearly unusable. Additionally, the coverage by GOES-12 does not extend as far north as GOES-10 requiring the use of additional satellite resources. Polar-orbiting satellites (POES) provide views of the Earth at high latitudes with increasing frequency at high latitudes. Instead of the twice-per-day coverage at the Equator, a given cross-track scanning imager on a POES can observe a given polar location as many as 10-12 times per day. While that type of sampling does not provide the half-hourly resolution of GOES, the temporal resolution and coverage can be enhanced by using multiple POES. To determine the potential coverage at high latitudes, orbital prediction routines were used to calculate the times when the *NOAA*-15, 16, and 17 AVHRR's and the *Aqua* and *Terra* MODIS would view a given latitude with VZA < 70°. The results are summarized in Fig. 2, which shows color- and shape-coded samples for each imager as a function of UTC for a series of 19 days in November 2005. Nearly half-hourly coverage is obtained before 0500 UTC and after 1100 UTC. Sparser sampling, mainly from Aqua is obtained between those hours. Such sampling potential should continue in the future with new operational satellites, NPOESS. Thus, by combining GOES and POES imagery, it should be possible to obtain high temporal and spatial coverage of the high latitudes up to at least 72°N at reasonable VZAs.

3. CURRENT ANALYSES

As a prelude to future expansion of the near-real time analyses, the GOES-10 and AVHRR data are being analyzed over Alaska to test the algorithms in this extreme environment. Figure 3 shows the GOES-10 and NOAA-16 AVHRR RGB images and the VISST phase classification for data taken 1 hour apart near 0000 UTC, 28 September 2005 over Alaska. The image shows a high cloud system over the southern half of Alaska with a clear stripe above it, snow over the Brooks Range, and a low cloud deck extending from the Arctic Ocean far inland up to the mountains. A clear area of sea ice surrounded by open water is evident in the top half of the imagery, especially in the NOAA-16 picture (Fig. 3b). The effects of foreshortening on the GOES image, where the VZA ranges from 60 to almost 90°, are most evident in the wider cirrus strands and the greatly reduced gap between the low clouds in the north and the edge of the high clouds. The GOES resolution is much poorer at these latitudes as seen in the definition of the snow over the mountain range.

This case is a good example of the types of conditions that will be encountered over the Arctic: low solar zenith angles (SZA), complex backgrounds, and highly variable cloud types. These images were taken in the early morning when SZA < 82° over the Arctic Ocean in the northern part of the domain. When the VISST was applied to these images, only pixels with VZA < 82.5° were used. Normally, only pixels with VZA < 70° are analyzed. The result of the limit is that upper left corner of the GOES image is eliminated. The analysis becomes more risky because of the high VZA of the remaining pixels. The GOES retrieval classifies much of the southern two thirds of the domain as ice cloud with some strange rectangular clear areas appearing where ice clouds are evident. There are fewer of these bogus clear areas in the AVHRR results. These are related to the low-resolution model soundings (RUC was not available here) that were used in the analysis. The algorithms have not yet been optimized for high latitude applications. The foreshortening and, probably, some advection eliminated much of the clear area detected in the AVHRR data over central Alaska. Most of the low-level cloud deck over northern Alaska and the ocean is classified as supercooled liquid. However, clouds in the extreme north are classified as clear because they are in the near-twilight status when the VIS and 3.9-μm channels are compromised because of the low light. Likewise, most of the snowy areas are classified as ice clouds. Despite the obvious and significant errors, the two retrievals are remarkably similar. Further refinement of the algorithms to account for these extreme angles and poor soundings should yield much better and probably more consistent results.

The retrieved cloud effective droplet radii (r_e), were derived for the liquid water cloud pixels. The results are shown in Fig. 4 along with the liquid water path (LWP), and icing potential index. Except for the extreme north where the GOES detection fails, the general patterns of the r_e values (Fig. 4a, b) are similar although the magnitudes differ by 2-3 μm or more. This difference is most likely a VZA effect that is poorly accounted for in the plane-parallel retrieval models. The LWP (Fig. 4c, d) is based on the product of r_e and the cloud optical depth. Again, the patterns are similar for the two retrievals, but they differ considerably in magnitude. The greater magnitude of LWP in Fig. 4c yields icing potential values (Fig. 4e) that are more intense than expected based on the AVHRR retrieval (Fig. 4f).

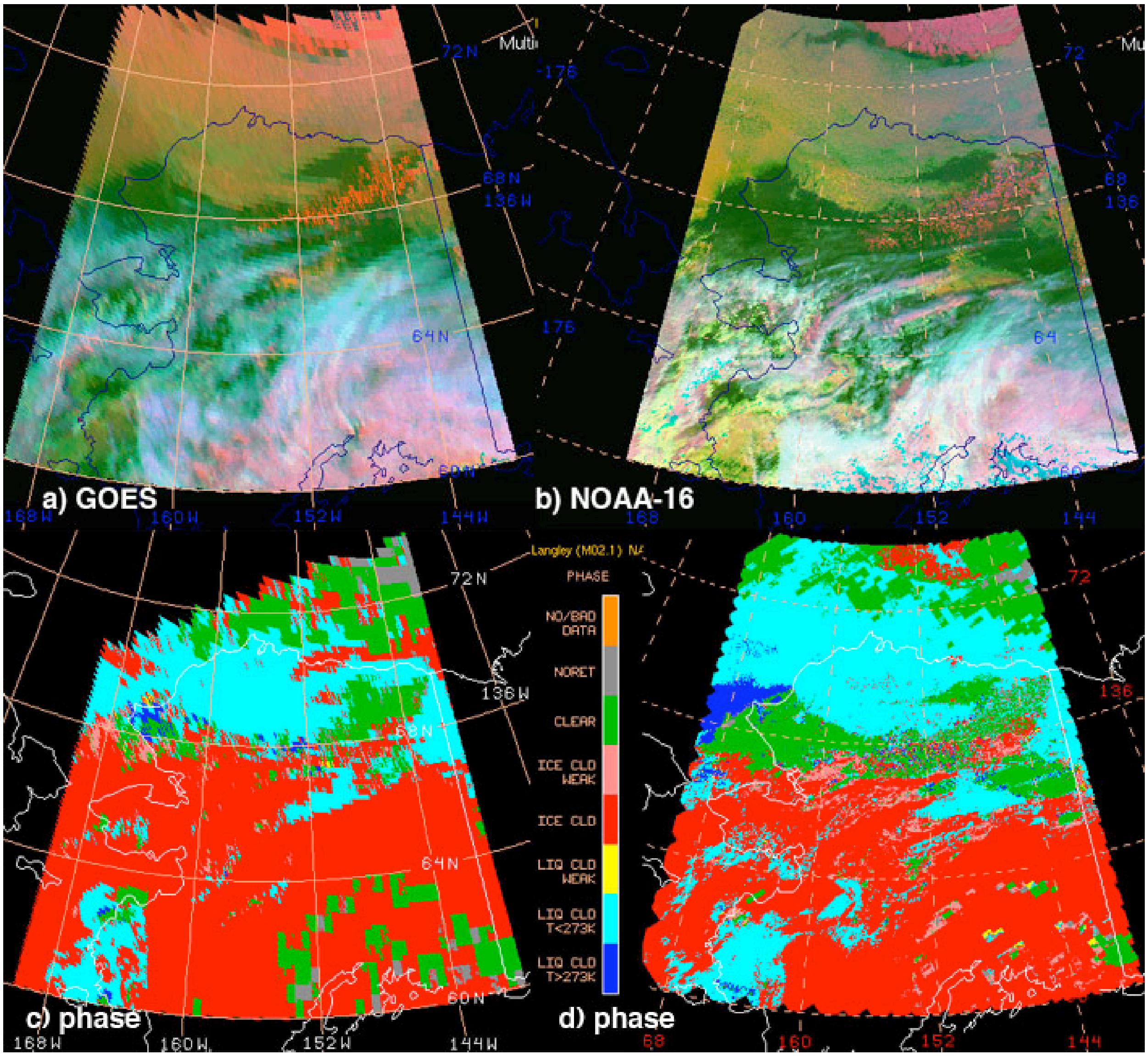

Fig. 3. Imagery and cloud phase mask over Alaska from (left side) GOES-10, 0000 UTC, 28 September 2005 and from (right side) NOAA-16 AVHRR, 2301 UTC, 27 September 2005. In the RGB images (a & b), the faint white and magenta areas correspond to ice clouds, the green areas to clear land and water, yellowish-peach areas to low clouds and the bright magenta or orange to clear snow scenes. In the phase images, gray indicates no retrieval, red and pink are ice clouds, green is clear, dark blue is warm water clouds, and light blue is supercooled water clouds.

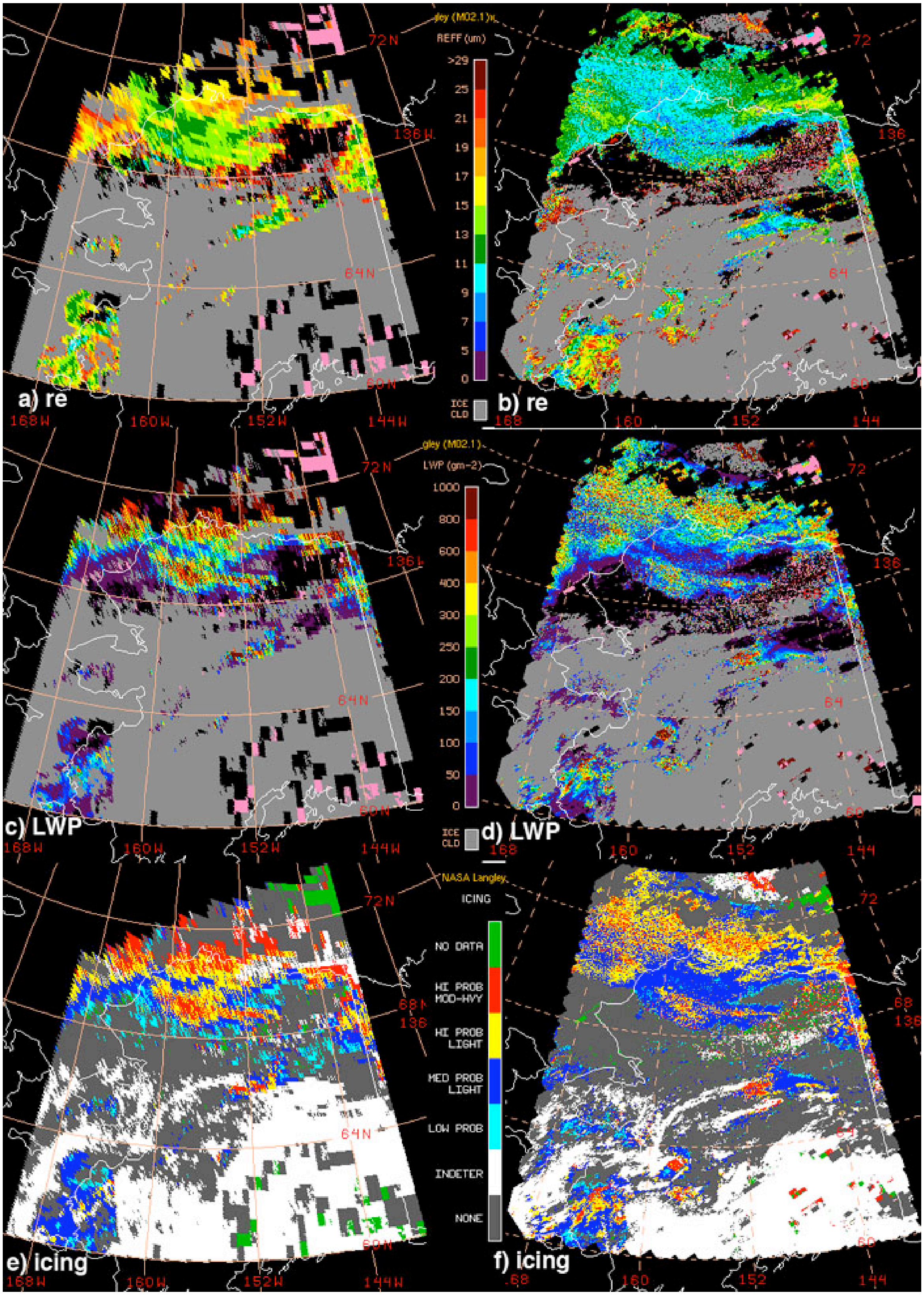

Fig. 4. Same as Fig. 3, except for top (a & b) is effective droplet radiuswhere 5 (blue) to 21 µm (red), > 21 clouds; middle (c & d) is LWP in 0-1000 gm^{-2} (nonlinear); and bottom (e and f) icing where gray is indeterminate icing, low – blue, medium – yellow, high – red; (h) low – blue, moderate/severe - red.

4. INITIAL VALIDATION

The example results presented above serve as samples of the products being generated since 22 September 2005. No attempt has been made yet to optimize the analyses as they were for the southern domain (Minnis et al., 2005). Nevertheless, it is instructive to find some objective "cloud truth" sources to find out how well the untuned algorithm is working and determine where it needs to be altered.

Pilot reports (PIREPS) of icing taken over Alaska between 22 September and 22 October 2005 were compared with the GOES-based estimates of icing like those shown in Fig. 4e. Only 294 reports were available. Of those, the VISST produced 32% indeterminate because of obscuration by a high ice cloud. Of the remaining reports, 87% were positive icing PIREPS. The VISST classified only 56% of the positive icing reports as potential icing cases. This is not surprising given the current state of the retrievals.

5. CONCLUDING REMARKS

The structure for analyzing GOES and POES data over the Arctic has been developed using low-resolution weather analyses and cloud detection methods optimized for mid-latitudes. The initial applications of those algorithms produce similar results from different satellites but much additional work is needed before reliable and accurate output is generated. Having the processing structure in place will facilitate improvement of the retrievals. Accurate, up-to-date snow ice maps will be ingested and more refined estimates of clear-sky albedo and temperature will be developed. When the initial North American RUC becomes available, it should be incorporated to provide better temporal and spatial resolution for the retrievals. Retrievals at high SZA and VZA need to be investigated further to reduce the biases and eliminate missed cloud conditions. A decision tree for combining POES and GOES data in a timely fashion must be developed along with parallax corrections to properly locate clouds observed at large VZAs.

The satellite icing algorithms are just one part of a comprehensive aircraft icing program being developed by NASA, NOAA, and the FAA. The icing index reported here is simply a measure of how the objectively derived cloud parameters can be used to diagnose aircraft icing conditions. Ultimately, the results will be combined with PIREPS, model forecasts, and other data within the Cloud Icing Potential (CIP) product (Bernstein et al., 2004; Haggerty et al., 2005) to provide a near-real time optimized characterization of icing conditions for pilots and flight controllers. The CIP is being expanded to match the North American RUC domain. Thus, development of accurate satellite cloud parameters for the same domain is imperative to maintain the level of accuracy and reliability expected from the CIP.

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