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SATELLITE DERIVED CLOUD PRODUCTS FOR USE IN AVIATION SAFETY APPLICATIONS

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1. INTRODUCTION

The Advanced Satellite Aviation weather Products (ASAP) initiative represents a collaboration between NASA, the FAA Aviation Weather Research Program (AWRP) Product Development Teams (PDTs), the University of Wisconsin-Madison Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS), and the University of Alabama in Huntsville (UAH). This initiative has sought to make satellite derived cloud and weather products available to the AWRP PDTs for integration into forecasting algorithms for the aviation community. This paper will describe, specifically, the satellite derived cloud products currently being produced by CIMSS for this purpose. Effective cloud amount, cloud top pressure, and clear-sky surface temperature are available over the CONtinental United States (CONUS) at high temporal resolution. These are derived using geostationary data from the Geostationary Operational Environmental Satellite (GOES) 10 (Western United States) and 12 (Eastern United States) Imager and Sounder instruments. The products are derived using a multi-spectral approach, utilizing the specific spectral information provided by each instrument. A validation study will be presented that compares these satellite-derived products to aircraft data from the Atlantic THORPEX Observing Systems Test (ATOST).

In addition to the CONUS cloud products, cloud amount and cloud top pressure are also available globally, and are derived using data from a suite of geostationary and polar-orbiting meteorological satellites. Cloud/no cloud classification is made using a single wavelength, while cloud top height is derived by comparing to a model profile. While simple in its derived approach, this product provides information over the data sparse oceanic regions, which may aid greatly in the development of more efficient flight tracks over the oceans.

Finally, the ASAP initiative includes efforts to assign a cloud type to clouds detected within a given image. This research is focused on the development of a daytime cloud typing algorithm for use with the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) data. The AVHRR algorithm is currently operational as a part of the CLouds from AVHRR (CLAVR-x) processing system. The MODIS algorithm utilizes several additional spectral bands that will be available on the future Visible/Infrared Imager/Radiometer Suite (VIIRS) instrument, which is scheduled to replace the AVHRR in 2008.

The following sections will describe each of the aforementioned cloud products in detail, and present examples for each.

2. CONUS CLOUD PRODUCTS

The ASAP CONUS cloud products are derived using GOES-10 and GOES-12 Imager and Sounder data. The GOES Sounder retrieved cloud products are described by Schreiner *et al*. (2001). A clear/cloudy classification is made using the four infrared (IR) "window" bands (12.7 μm, 12.1 μm, 11.0 μm, and 3.98 μm), a CO2 absorption band (13.4 μm), the visible band (0.65 μm), as well as a predetermined skin temperature (taken from hourly surface observation data). A series of threshold tests are performed using this information, to determine whether or not a cloud is present. Secondary tests are also performed to separate cases in which a strong temperature inversion is present. Cloud top pressure and effective cloud amount are determined using the CO_2 ratio technique (Chahine 1974; Menzel *et al*. 1983; Wylie and Menzel 1989) in cases where high, thin clouds are present. In cases where the clouds are lower, the cloud top pressure is determined by matching the IR window channel (11 μm) brightness temperature to an *in-situ* temperature profile. This is referred to as the IR window technique, and is documented in Schreiner *et al.* (1993). In cases where the IR window technique is used, the emissivity of the cloud (and thus the effective cloud amount) is assumed to be 1 (e.g. the cloud is opaque and non-transmissive).

Cloud products are also derived using GOES-12 Imager data, using a technique similar to the GOES Sounder cloud products. An example of the GOES 12 Imager derived cloud top height product is shown in Figure 1. This is the full disk GOES imager product, which is produced every 3 hours. A similar, Northern Hemisphere only product is produced hourly. Effective cloud amount and cloud top pressure are not derived

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using GOES-10 Imager data, because the necessary bands are not present. On GOES-12 Imager, the 12.0 µm channel was replaced by a 13.3 µm channel, allowing for a 13.3/11 CO_2 ratio technique to be used. Cloud products derived using Imager data have an improved spatial resolution (4 km) over those derived using Sounder data (10 km). This product is expected to have the most utility in determining where airport visibility may be limited, either currently or in the future due to the advection of clouds and/or fog.

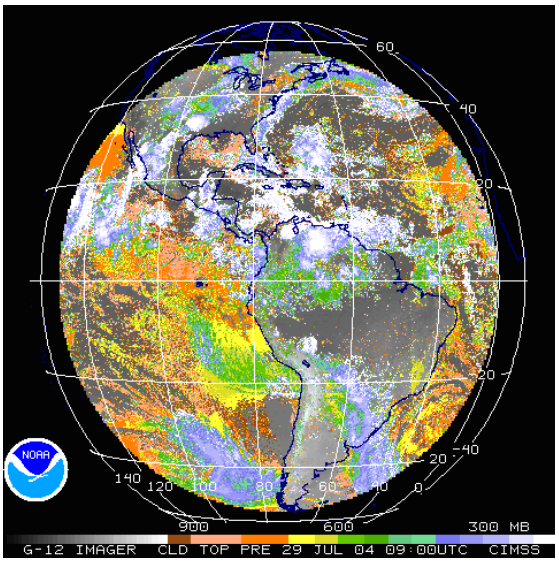


Figure 1. Sample image of cloud top pressure, derived using GOES-12 Imager data.

Validation studies have been performed using the ASAP CONUS cloud products. Specifically, the GOES-12 Imager and Sounder cloud top heights were compared to Cloud Physics Lidar (CPL) measurements from the Atlantic-THORPEX Regional Campaign (ATReC). This experiment was conducted in the winter of 2003 from Bangor, ME, and the CPL flew aboard the NASA ER-2 aircraft. Figure 2 shows a comparison of cloud top heights from 05 Dec 2003. GOES-12 Imager (Sounder) data are shown in red (blue) and CPL data are shown in black. Breaks in the CPL data are times when the aircraft was turning, and thus the CPL was not pointed directly at the cloud. These data were not included in this study. The Imager heights show better agreement with the CPL than the Sounder heights due to the increased spatial resolution of the Imager. The best agreement for both satellite instruments is for mid-level clouds, while both the Sounder and Imager underestimate the CPL cloud top height for both semi-transparent high clouds and warm low-level clouds. The histogram in Figure 2 confirms that the Imager cloud top height is closer to the CPL cloud top height than is the Sounder. However, it also indicates that for both instruments, roughly the same percentage (about 8%) of the data points had absolute errors greater than 5 km (outside the histogram range). This suggests that the cloud types for which height assignments are most difficult (for instance, optically thin cloud or broken cloud) are consistent for both instruments.

Figure 3 shows a similar comparison, for 28 Nov 2003. This particular case contained a fairly uniform layer of optically thick, mid-level clouds. Agreement with the CPL is improved over the previous case for both the Imager and the Sounder. A greater percentage of data points fall within 1 km of the CPL then for the previous case, and nearly all of the points fall within the histogram range.

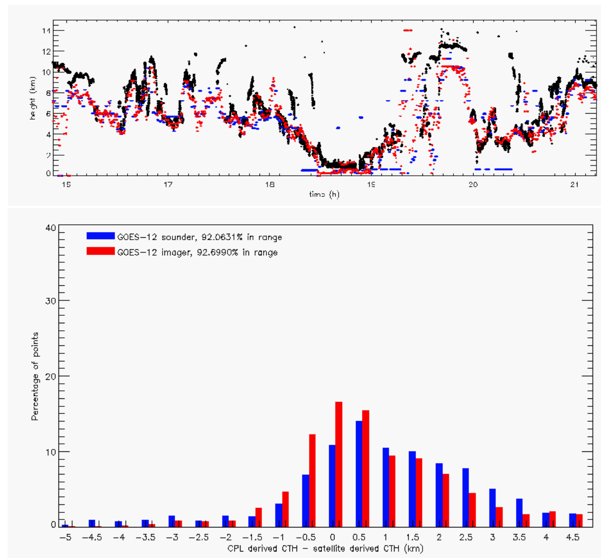


Figure 2. GOES-12 Imager (red) and Sounder (blue) cloud top height with CPL (black) cloud top height from 05 Dec 2003.

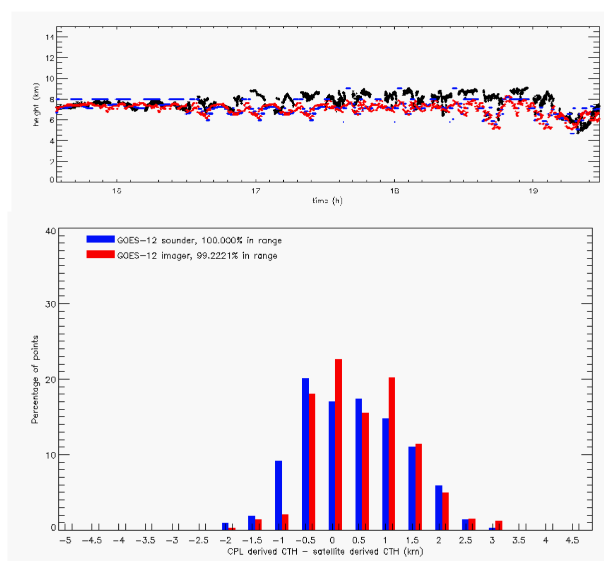


Figure 3. GOES-12 Imager (red) and Sounder (blue) cloud top height with CPL (black) cloud top height from 28 Nov 2003.

Further validation of this product is an ongoing effort at CIMSS. However, preliminary studies such as the ones shown here suggest that both the GOES Imager and Sounder cloud top heights are reliable for mid-level, optically thick clouds. These algorithms may also perform well for high or low clouds, depending on cloud temperature and optical thickness.

3. GLOBAL CLOUD PRODUCTS

In addition to the CONUS cloud products, cloud amount and cloud top pressure are also available globally, and are derived using data from a suite of meteorological satellites including GOES, MODIS, AVHRR, and Meteosat. This product has a .1 degree lat/lon spatial resolution. High temporal resolution geostationary data are used in the tropics and mid-latitudes, while AVHRR and MODIS are used to complete the coverage over the polar regions. An example of the global cloud top height product is shown in Figure 4. This product uses a single wavelength (11 μm) brightness temperature threshold to determine cloud/no cloud classifications globally. This technique is particularly useful for detecting clouds at high and mid-levels, however, may miss low clouds and fog. Cloud top height is determined by comparing the 11 μm brightness temperature to a numerical weather prediction model temperature profile. These data are expected to have the greatest utility over oceanic regions, where the lack of ground-based data is prohibitive to aviation forecasting.

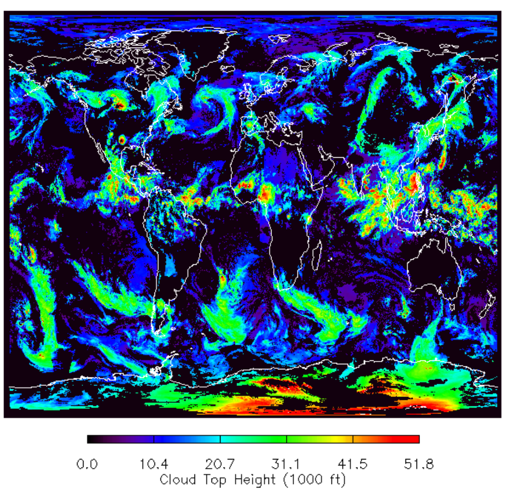


Figure 4. Sample image of cloud top height from the ASAP global cloud product.

4. CLOUD TYPE PRODUCT

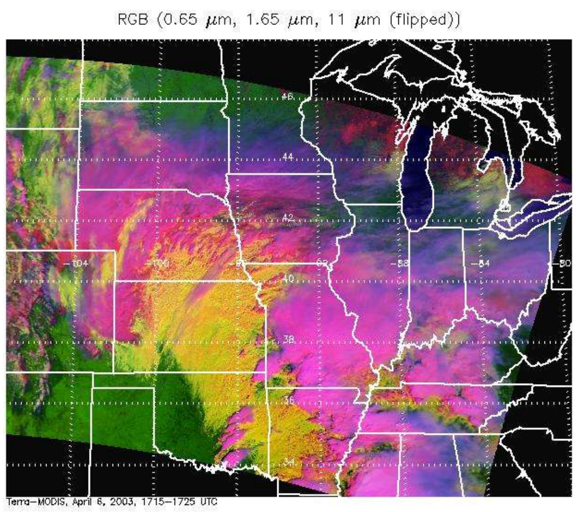
Pavolonis and Heidinger (2004) and Pavolonis *et al.* (2004) describe the development of cloud typing algorithms for use with AVHRR and MODIS data. The AVHRR algorithm is currently operational as a part of the CLAVR-x processing system. The AVHRR has 5 spectral bands: 0.63 μm, 0.86 μm, 1.6 μm or 3.75 μm, 10.8 μm, and 12.0 μm. The MODIS algorithm has been developed largely for the purpose of examining improvements over the current AVHRR product that may be made with the inception of VIIRS. The VIIRS will contain 16 spectral bands, a subset of the 36 spectral bands available on the MODIS instrument. All of the channels that are available on the AVHRR are available on MODIS and will be available on VIIRS. The VIIRS instrument will replace the AVHRR on the National Polar-orbiting Operational Environmental Satellite System (NPOESS), which is scheduled for launch in 2008.

Both the MODIS and AVHRR algorithms are applied only to pixels that are predetermined to be fully cloudy, by either the MODIS or AVHRR operational cloud mask. Each cloudy pixel is then separated into one of five categories: warm liquid water (> 273.16 K), supercooled water or mixed phase, opaque ice (optical depth greater than about 5), semi-transmissive ice (most cirrus), and cloud overlap (multiple cloud layers present). The AVHRR algorithm employs a series of threshold tests that use of all of the 5 spectral bands currently on this instrument. Separate algorithms have been developed that use either channel 3a (1.6 μm) or channel 3b (3.75 μm). The MODIS algorithm uses all the bands that are used by the AVHRR algorithm. Additionally, the 1.38 μm channel and the 8.5 μm channel are used. The 1.38 μm channel improves the detection of high cirrus, while the 8.5 μm channel (in conjunction with the 11 μm channel) improves the assessment of cloud top phase. For a complete and detailed description of each algorithm, please see Pavolonis *et al.* (2004).

Figure 5 shows an example of the MODIS cloud typing product, as will be available through ASAP. Figure 5 (top) is a false color MODIS image from 06 April 2003 (1715 UTC – 1725 UTC). This image was produced using 0.65 μm in red, 1.64 μm in green, and 11.0 μm in blue. Pink areas indicate optically thick ice clouds, blue areas indicate optically thin ice clouds, yellow areas indicate water clouds, and green areas indicate vegetated land surfaces. Figure 5 (bottom) shows the corresponding cloud type as derived using the aforementioned MODIS algorithm. From a simple visual inspection of these images, the MODIS cloud typing algorithm appears to accurately capture the features present in the satellite image. For a full validation study, please see Pavolonis *et al.* (2004) and Pavolonis and Heidinger (2004).

Both the MODIS and AVHRR cloud typing products identify features that are of interest to aviation safety. Possible applications of this product include, but are not limited to, the following:

- The knowledge of the location of optically thick ice clouds often associated with deep convection may be useful in the planning of more efficient flight tracks.
- The detection of supercooled water may help to target areas where aircraft icing is a concern.
- The identification of low water clouds and/or fog may bring attention to areas where airport visibility may be reduced, either currently or in the future due to the advection of low clouds or fog.



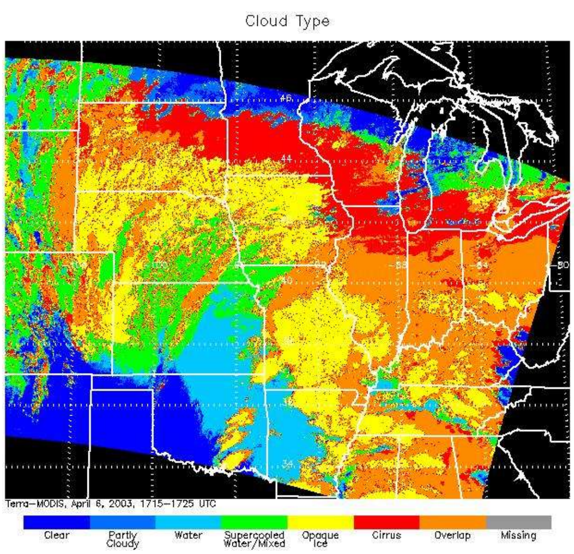


Figure 5: (top) 1 km resolution MODIS false color image from 1715-1725 UTC on 3 April 2003. (bottom) Corresponding cloud type, using the Pavolonis et. al (2004) technique.

5. REFERENCES

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