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Inferring Low Cloud Base Heights at Night for Aviation Using Satellite Infrared and Surface Temperature Data

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Abstract—A nighttime image product that depicts areas of the lowest cloud base heights has been developed by combining brightness temperature data from the Geostationary Operational Environmental Satellite (GOES) Imager InfraRed (IR) bands centered at 3.9 μm and 10.7 μm, with hourly shelter temperatures from surface observing sites and offshore marine buoys. A dependent data sample showed a good correlation between the surface temperature minus IR cloud top temperature differences versus measured cloud base heights. Histogram analysis indicated that a temperature difference of less than 4-C related to a > 50% frequency of ceilings below 1000 ft above ground level, the threshold for Instrument Flight Rules (IFR). Using this result as a model, an experimental Low Cloud Base image product was developed that highlights regions of likely IFR ceilings. Validation of the Low Cloud Base product for two separate periods resulted in Probabilities of Detection of 67% and 72% and False Alarm Rates of 6% and 11%, respectively. Some regional variation observed could be related to the relative frequency of multi-layered overcast conditions. The biggest factor leading to underdetection of IFR ceilings by the GOES Low Cloud Base product is the presence of overlying clouds, including thin cirrus contamination. The GOES Low Cloud Base product shows potential for use as guidance for aviation meteorologists over both continental and marine areas.

Key words: Fog forecasting, satellite applications, aviation operations.

1. Introduction

Detection of fog and low clouds at night with meteorological satellite data can be accomplished using brightness temperature differences (BTD) between the 3.9 μm shortwave (T2) and 10.7 μm window (T4) infrared (IR) channels such as those available from the Geostationary Operational Environmental Satellite (GOES) Imagers (Ellrod, 1995; Lee *et al.*, 1997), and the polar orbiting National Oceanic and Atmospheric Administration (NOAA) series (Eyre *et al.,* 1984). This derived imagery (sometimes referred to as the "fog product") clearly shows low-level water clouds (fog and stratus) that may often go undetected using only a single

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IR channel. Unfortunately, low clouds are only detectable if they are sufficiently thick (> 50–100 m) and not overlain by higher cloud layers. Additionally, the current nighttime low-cloud product cannot easily distinguish clouds that may result in low ceilings[1] and/or reduced surface visibilities from higher-based stratus, stratocumulus, and altostratus that do not represent significant hazards to aviation or marine interests.

The likelihood that fog is present may be assessed by means of empirical rules based on satellite image features such as: brightness, texture, growth or movement. However, these rules require some expertise and experience for proper application. A more objective, easily interpreted product that estimates the likelihood of very low ceilings and/or visibilities is desired.

Efforts to produce an experimental, enhanced GOES fog product began in 1997 with the collection of surface-based ceiling and visibility reports from Meteorological Aviation Reporting (METAR) sites in the United States, along with co-located GOES IR brightness temperature data. Analysis of the data was completed in 1999, and plans for generating an experimental prototype product for ceilings were described (ELLROD, 2000). This paper will discuss: (1) The research, (2) image processing procedures, (3) two examples of the product's capabilities, and (4) verification results.

2. Data Analysis

During the summer of 1997, cloud base ceiling heights (ft), visibilities (nm), and GOES IR cloud top temperatures (°K) were collected for a large number of cases (N = 592) of nighttime low clouds over the Continental United States (CONUS). When the GOES fog product observed low clouds (determined when $T_4 - T_2 > 2$ °K),[2] two hypotheses were tested. The first hypothesis assumed that low ceilings and visibilities were accompanied by relatively smooth appearance in the GOES fog product (consistent with stratiform clouds), resulting in a low standard deviation (more spatial coherence) of observed brightness temperatures near the surface reporting station. The second hypothesis assumed that low ceilings and visibilities were accompanied by a relatively small temperature difference between the 10.7 μm window IR cloud top temperatures (T_4) and the surface temperature (T_{sfc}) obtained from METAR data. The latter is an empirical rule that is often used to check for the presence of very low clouds. This small temperature difference results in poor discrimination of low clouds in single band IR imagery (EYRE *et al.*, 1984; BADER *et al.*, 1995). In many cases, the IR cloud top

[1] A ceiling is reported when there is 5/8 or greater cloud cover.

[2] Brightness temperatures are typically several degrees cooler in IR Channel 2 than in Channel 4 at night for opaque clouds consisting of liquid droplets, due to lower emissivity at 3.9 μm.