P3.57

OPERATIONAL CLOUD DETECTION IN GOES IMAGERY

Gary J. Jedlovec*
Global Hydrology and Climate Center
NASA/Marshall Space Flight Center, Huntsville, Alabama

and

Kevin Laws
Global Hydrology and Climate Center
University of Alabama - Huntsville, Huntsville, Alabama

1. INTRODUCTION

The accurate detection of clouds in satellite imagery is important in research and operational applications. Cloud cover influences the distribution of solar radiation reaching the ground where it is absorbed. Resulting fluxes of sensible and latent heat are critical to the accurate characterization of boundary layer behavior and mesoscale circulations that often lead to convective development. Therefore the spatial and temporal variation in cloud cover can greatly affect regional and localized weather processes.

NOAA's geostationary satellites play a key role in observing the spatial and temporal variations in cloud cover over much of North America and surrounding ocean regions. The nearly continuous viewing of the Imager and Sounder on the *GOES-East* and *West* satellites allows for the rapid temporal sampling of changes in cloud cover not captured by higher spatial resolution polar orbit instruments. While limited to 1km and 4km (or 8km from the Sounder) in the visible and infrared channels, respectively, the *GOES* Imager and Sounder are used by NOAA to generate real-time cloud products in support of their operational data requirements. Their cloud detection approach uses time and space dependent threshold tests involving inter-band comparisons, and comparisons to satellite-derived estimates of skin temperature and albedo (Hayden et al. 1996).

* *Corresponding author address: Gary J. Jedlovec, NASA/MSFC Global Hydrology and Climate Center, 320 Sparkman Drive, Huntsville, Alabama 35805; e-mail: gary.jedlovec@msfc.nasa.gov.*

Guillory et al. (1998) presented a new method for cloud detection using the shortwave and longwave window channels on the *GOES* Imager. The bi-spectral spatial coherence (BSC) method uses two spatial tests and one spectral threshold to identify clouds in *GOES* Imager or Sounder imagery. The BSC technique has been used operationally over the last several years at the Global Hydrology and Climate Center (GHCC) to support numerous climate research and modeling activities (Lapenta et al. 2001). The performance of the BSC method has been adequate during the day, however continued poor performance of the algorithm near sunrise / sunset and at night has prompted further research into the cloud detect problem. The focus of this conference paper and companion poster is to present some preliminary results of a modification to the BSC technique to improve the "round-the-clock" performance of the operational cloud detection algorithm used at GHCC. The paper describes the new algorithm and compares the results with the previous BSC approach and with the NOAA/NESDIS operational cloud product.

2. METHODOLOGY

The underlying principle of the original BSC approach is that the emissivity difference of clouds at 11 and 3.7 micrometers varies from that of the surface (land or ocean) and can be detected from channel differences. While the emissivity of clouds at 3.7 micrometers is considerably less than at 11 micrometers, reflected solar radiation at 3.7 micrometers makes the effective brightness temperatures (sum of emission and reflective components) quite large. The emissivity difference can be detected in the *GOES* 11 minus the 3.7 micrometer channel brightness temperature difference. During the day, this difference is a large (negative) number in the presence of clouds and a small (positive or negative) number in non-cloudy regions. Thus, the transition region from a clear to a cloudy region is manifested in the 11 – 3.7-micrometer difference image as a discontinuity or edge. The BSC technique applies several spatial filters (standard deviation and adjacent pixel tests) to the difference image to first detect the cloud boundaries (edges) and then fill in the cloudy regions (Lecue 1997). This approach works pretty well from mid-morning through late afternoon, but its performance is reduced near sunrise and sunset.

2.1 ***Bi-spectral ThresHold Approach***

Over the last year, considerable time was spent tuning the spatial filters in the BSC method to more effectively detect clouds under low sun angles without much success. However, analysis of the difference images in these cases (low sun angle) indicated that a subtle distinction existed between the cloudy and non-cloudy regions. The key was how to objectively detect these differences. The new Bi-spectral ThresHold (BTH) method was developed to do this.

The 11 – 3.7 micrometer brightness temperature differences under low solar angles are spatially and temporally variant. To capture this variation, a sequence of difference images for each time corresponding to the last 20 days is maintained. The historical difference images are used to determine two threshold images, one for positive differences and the other for negative differences, which represent the “expected” minimum difference value corresponding to clear regions. These minimum difference threshold images are used as an additional cloud check in the BSC algorithm. Therefore, the new bi-spectral threshold (BTH) approach uses the following methodology:

1) create 11 – 3.7 micrometer difference image
2) apply standard deviation test on difference image to detect clouds edges,
3) apply adjacent pixel test to fill in around cloud boundaries, and
4) use minimum difference threshold images as a final cloud check.

2.2 ***Intercomparison***

To demonstrate the improvement of the new bi-spectral threshold (BTH) approach over its predecessor, the bi-spectral spatial coherence (BSC) method, a two-week period from July 2001 was selected for comparison. Each method was applied to hourly *GOES-8* Imager data on each day between 1100 and 2300 UTC. The resultant cloud images were inter-compared and differences were monitored. The NOAA/NESDIS operational cloud product from the *GOES-8* Imager was obtained for each day and time and used in the comparison as well.

2.3 ***Validation***

To quantify the performance of the three different cloud detection methods (BTH, BSC, NOAA/NESDIS), fifteen eastern U.S. sites were selected for validation purposes based on unique topography including coastline, lakeshore, mountain range, urban/rural areas, and over open water. A trained meteorologist / satellite specialist used a time sequence of *GOES* visible and infrared images to subjectively determine the presence of clouds over a 32 km x 32 km area. If the area was partly cloudy, then the entire area was labeled as cloudy. This approach allowed for the overall cloud patterns and signatures from frontal structures, daytime cumulus fields and cirrus clouds to be identified. To further aid in the subjective cloud determination, eight of the fifteen sites selected were augmented Automated Surface Observing System (ASOS) stations (Unger 1992). The ASOS data not only provide the amount of cloud coverage, but also include cloud height, which has important implications when looking at reflective properties from different cloud regimes. A cloud – no cloud determination at each site, for each time on each day, provided the “ground truth” for the cloud validation. Each of the three satellite-derived cloud products were compared to this ground truth data and labeled in one of four ways: clear-correct (CLC), clear-incorrect (CLI), cloudy-correct (CDC), or cloudy-incorrect (CDI).

3. PRELIMINARY RESULTS

The dates for this initial study were 12 July through 26 July 2001. During this fifteen-day period, several days were not analyzed due to the loss of data, but there were several hundred verified points for each hour. The following results demonstrate the performance of the techniques for two representative times, namely, 1145 UTC and 1845 UTC. Performance at other times was similar and will be presented in the companion poster presentation. The results below are presented as the percentage correct and incorrect

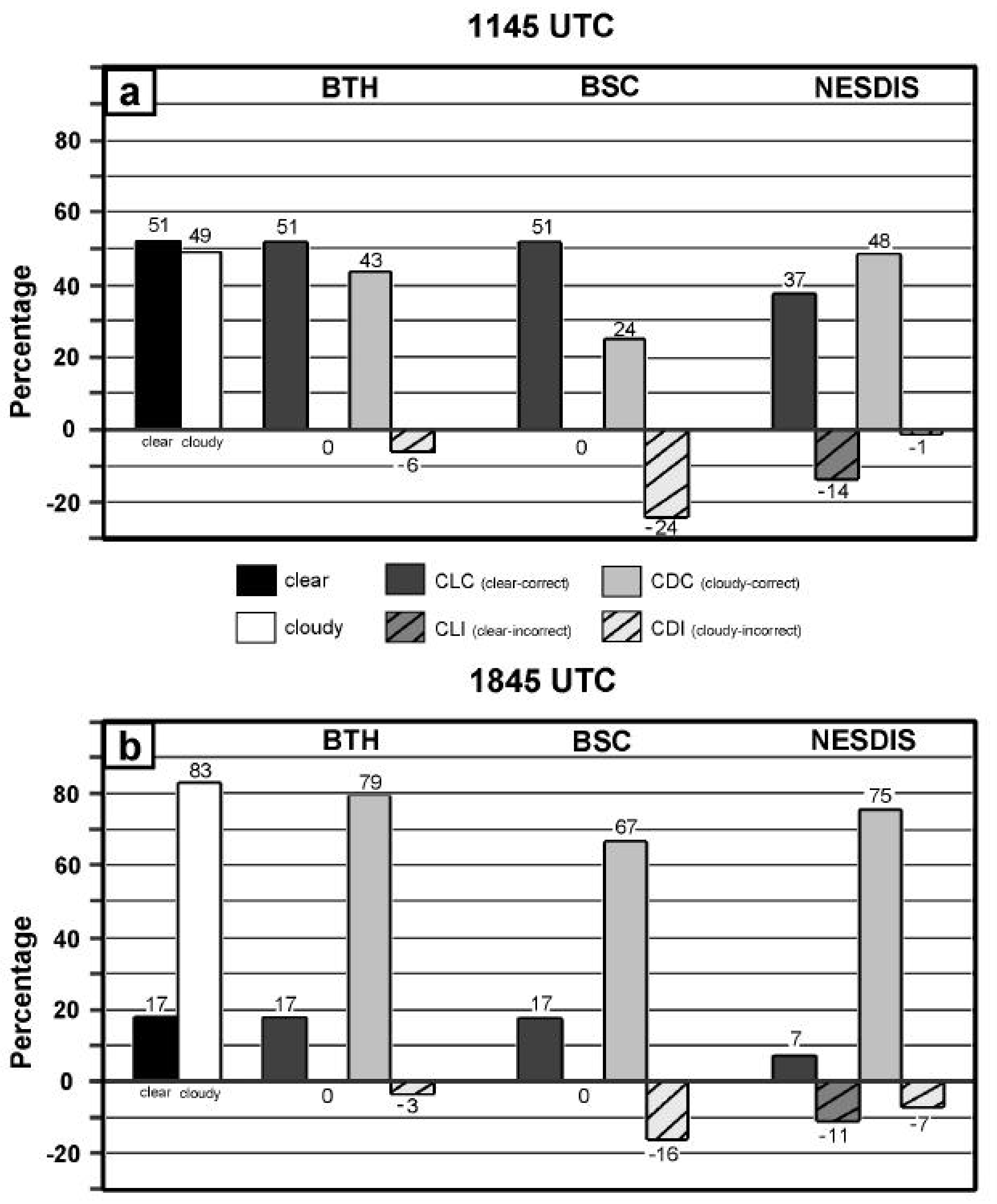

Figure 1. Statistical analysis comparing the three different cloud detection methods: Bi-spectral ThresHold (BTH), Bi-spectral Spatial Coherence (BSC), and NOAA/NESDIS. These results are based upon the initial study from 12-26 July 2001 for a) 1145 UTC and b) 1845 UTC.

for the clear and cloudy regions for all days combined. Each cloud mask technique is shown separately with the corresponding percentages. At 1145 UTC, nearly 50% of the validation points for these days were cloudy, while at 1845 UTC over 80% of the points contained some type of cloud.

Figure 1 presents the results for 1145 and 1845 UTC, respectively. The performance of the original BSC technique (currently used operationally at the Global Hydrology and Climate Center) is typical of the algorithm's performance during the warm season. It can be seen that the algorithm tends to under-determine the clouds. While nearly all of the clear points are properly detected, 24% of the clouds go undetected at 1145 UTC. The BSC algorithm's performance improves at 1845 UTC as the amount of undetected cloudy points falls to about 16%. This is significant because most of the ground truth points are cloudy at this time. The NESDIS operational product from the *GOES-8* Imager is used as a reference in this study. In contrast with the BSC technique, the NESDIS cloud algorithm seems to over determine clouds at both times. At 1145 UTC nearly all of the clouds are properly determined but about one-fourth (14%/51%) of the clear points are also improperly determined as clouds. This characteristic pattern exists at 1845 UTC as well although the amount of undetected cloudy points goes up a fair bit. Overall, the original BSC and NESDIS cloud products perform equally well in some regions but fail in others for their own separate reasons.

The results for the new BTH technique are also shown in the figures. Significant improvement over both the BSC and NESDIS techniques occurred for all times, including both times presented here. At 1145 UTC the BTH method detects the clear regions very well and only misses (under-determines) the clouds by about 6%. This is reduced down to just a few percent at 1845 UTC without degradation (over determination of clouds) in the clear regions.

4. DISCUSSION

The results of the new bi-spectral threshold (BTH) technique have been shown to offer improvements over existing techniques applied to *GOES* imagery for the detection of clouds. The running 20-day minimum difference threshold images used as part of the algorithm incorporate knowledge of the spatial and temporal changes in thermal characteristics of the surface which are important for cloud detection. In image form, these thresholds capture the spatially varying affects of solar illumination (as a function of time of day) and land use. The 20-day influence on the threshold images captures the seasonal variation in the solar illumination and land cover changes. Although it has only been tested on a limited number of days in one season, the new BTH method should perform quite well in other seasons as well.

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