P1.21 GOES CLOUD DETECTION AT THE GLOBAL HYDROLOGY AND CLIMATE CENTER

Gary J. Jedlovec*
NASA/MSFC/Global Hydrology and Climate Center
National Space Science and Technology Center
Huntsville, Alabama

and

Kevin Laws
UAH/Global Hydrology and Climate Center
National Space Science and Technology Center
Huntsville, Alabama

1. INTRODUCTION

NOAA's geostationary satellites play a key role in observing the spatial and temporal variations in surface and atmospheric features over much of North America and surrounding ocean regions. The nearly continuous viewing of the *GOES-East* and *West* satellites allows for the rapid temporal sampling of changes in land surface temperature, atmospheric stability, and clouds which are important for monitoring short-term weather. While limited in spatial resolution compared to low-earth orbiting satellites, the *GOES* Imager and Sounder data and products are heavily used by NOAA, DOD, NASA, and other agencies and private companies to support their operational requirements.

The Global Hydrology and Climate Center (GHCC) in Huntsville, Alabama receives GOES East and West satellite data in real-time from their GVAR ground stations and produces a number of products from the Imager and Sounder in support of their research and operational activities. One new focus area in which they support is the Short-term Prediction and Research Transition (SPoRT) Center. The mission of the SPoRT Center is to accelerate the infusion of NOAA and NASA ESE observations, data assimilation and modeling research into NWS forecast operations and decision-making at regional and local levels. The principal focus is on the regional scale and emphasizes forecast improvements on a time scale of 0-12 hours. Real-time products from GOES not routinely available to the NWS through AWIPS, can provide value-added capabilities to the forecaster. A critical element in providing useful products to the operational community is the ability to detect and monitor cloud cover and on a 24h basis. The successful detection of clouds in day and night imagery eliminates cloud contamination in products such as land surface temperature, surface insolation and albedo, precipitable water and stability and provides a robust description of the clouds themselves. However, the day and nighttime detection of clouds is not trivial task and is the focus of this paper.

Guillory et al. (1998) presented a new method for cloud detection using the shortwave and longwave window channels on the *GOES* Imager. A modified version of this approach called the bi-spectral spatial coherence (BSC) method used two spatial tests and one spectral threshold to identify clouds in the *GOES* Imager or Sounder imagery (Jedlovec and Laws 2001). The BSC technique was used operationally over the last several years at the GHCC to support numerous climate research and modeling activities. The performance of the BSC method was adequate during the day, however poor performance of the algorithm near sunrise / sunset and at night prompted further research into the cloud detect problem. The focus of this conference paper and companion poster is to present the new cloud detection algorithm now in use at GHCC with GOES Imager and Sounder data. The new technique, called the Bi-spectral Threshold and Height (BTH) method, builds on

* *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.

the previous BSC method but adds spatially and temporally varying thresholds to the procedure. In this paper, the new approach is validated with comparison to subjectively determine cloud cover at a number of points for a two week period during each season. The BTH method is also compared to the BSC method to show relative improvement in its performance. An additional advantage of the new technique is that cloud top pressure information is routinely provided with the cloud mask. A comparison of the BTH cloud pressures to other height assignment approaches is included in this paper.

2. METHODOLOGY

An underlying principle of cloud detection with GOES imagery is that the emissivity difference of clouds at 10.7 and 3.9 micrometers varies from that of the surface (land or ocean) and can be detected from channel brightness temperature differences. While the emissivity of clouds at 3.9 micrometers is considerably less than at 10.7 micrometers, reflected solar radiation at 3.9 micrometers makes the effective brightness temperatures (sum of emission and reflective components) quite large. During the day, the $T_{bb3.9} >> T_{bb10.7}$, but at night, because the emissivity is lower at 3.9 micrometers, the $T_{bb3.9} < T_{bb10.7}$. The emissivity difference can be detected in the *GOES* 10.7 minus the 3.9-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 10.7 – 3.9-micrometer difference image as a discontinuity or edge. However, emissivity varies with cloud type and the effect of varying solar input at the surface or cloud makes this a challenging problem.

2.1 *Bi-spectral ThresHold and Height (BTH Approach) at GHCC*

The key to cloud detection in the BTH technique is the use of multispectral channel differences to contrast clear and cloudy regions. The 10.7 and 3.9-micrometer channels on the Imager and similar channels on the Sounder are used to produce a hourly difference image (longwave minus shortwave) for this purpose. Both positive differences, which occur at low sun angles and at night, and negative differences that occur during the day, are preserved in the difference image. Two composite images are also created for each hour, which represent the smallest negative and smallest positive difference image values (values closest to zero) from the preceding 20 day period (for each time). These composite images serve to provide spatially and temporally varying thresholds for the BTH method. An additional 20 day composite image is generated for each hour using the warmest longwave (10.7 micrometers) brightness temperature for each location (pixel) from the 20 day period. This composite image is assumed to represent a warm cloud-free thermal image for each time period.

The BTH method uses the above images in a four step procedure cloud detection procedure. This procedure is schematically described in Figure 1. In the first step, each pixel in the difference image (longwave–shortwave) corresponding to the current observation time is subjected to an ***adjacent pixel test***. Each pixel (i) along the scan line in the difference image (DI(i)) is compared to the previous one (i-1). If the difference in adjacent pixels (in the difference image) is greater than 27.4K (difference/2 > 13.7K in Figure 1), a cloud (edge) is detected. This procedure is more successful in identifying the edges of many clouds during the day than at night. The second step attempts to "fill-in" between the cloud edges by analyzing the ***one-dimensional spatial variability*** of the pixels. To do this, two separate tests are used. The difference between the current difference image value (DI(i)) and the one corresponding to the preceding pixel (DI(i-1)) is calculated. For a cloud to be detected, this calculated difference value must be less than 3.1K if the preceding image location (I-1) was clear or it must negative (<0.0K) if it the preceding image location was cloudy. In this way the spatial variability in the difference image corresponding to a cloud free surface versus a cloud shield are considered.

The last two steps in the BTH method detect clouds in regions where the first two steps fail. The third step of the BTH method utilizes the two composite images derived for each hour, which represent the largest negative and smallest positive difference image values from the preceding 20 day period. This ***minimum difference test*** compares the current difference image value to these composite images. If the current difference image value is negative (high sun angles), then a difference image value less than the composite image value minus 5.1K is deemed to be cloudy.

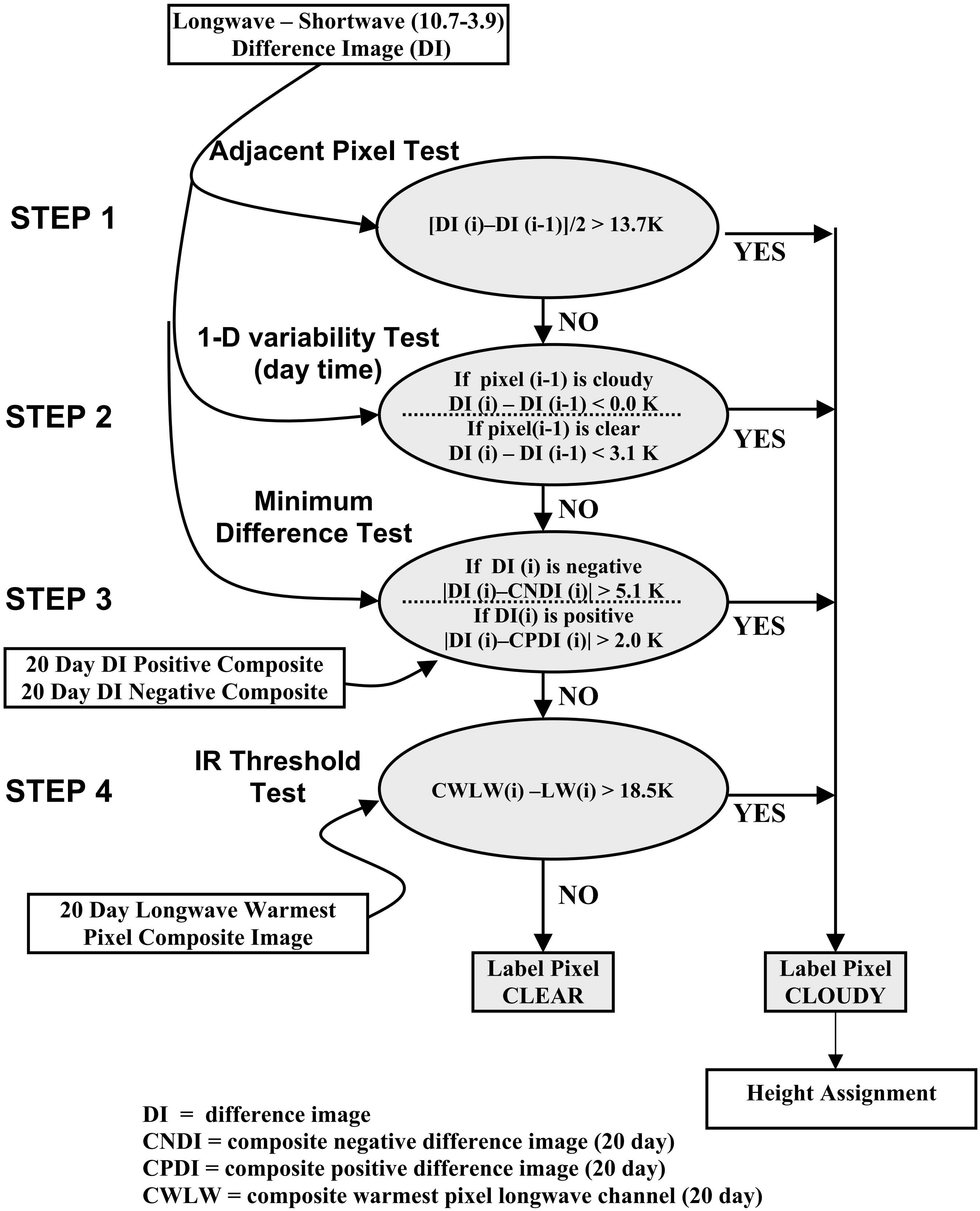

Figure 1. Flow diagram of the Bi-spectral Threshold and Height (BTH) Cloud Algorithm.

A positive difference image value must be greater than the composite image value plus 2.0K to be deemed cloudy. The 20-day composite positive and negative difference images incorporate spatially varying information for night-time and day-time cloud determinations separately. This is a significant change from the previous BSC method that did not separate out positive and negative differences.

The fourth and final test in the BTH method involves the longwave (10.7 micrometer channel) information and catches a few clouds missed by the previous three tests. This **IR threshold test** uses an hourly 20-day composite of the warmest 10.7-micrometer channel values at each pixel location. This product is essentially a "warm" cloud free 10.7-micrometer channel image. A pixel in the current 10.7 micrometer image is deemed cloudy if its 18.5K colder than the warm 10.7 micrometer channel composite image for that location and time period.

The results from each step of the BTH cloud detection procedure for the GOES-8 Imager are shown in Figure 2 for 0645 and 1845UTC on March 11, 2002. The corresponding 10.7-micrometer and 10.7 – 3.9-micrometer difference images are also presented. The 10.7-micrometer images (top left and right) show weak thermal surface temperature gradients both at night (0645UTC) and during the day (1845UTC). Low (warm clouds) are difficult to discern in both the night and day images. The difference images (middle pair of images) provide additional contrast in these regions. The difference images have been scaled so that negative difference image values are dark and positive are bright. The bottom left and right panels show the resulting cloud map using the BTH procedures for night and day time data. The map is color coded to distinguish which step of the algorithm is detecting the cloud. At 0645UTC, the minimum difference test (step 3) and the IR temperature threshold (step 4) significantly contribute to the cloud map. Note that the negative and positive thresholds detect clouds in distinctively difference regions. The positive threshold test detects the lower clouds (warmer in the infrared image) and the negative test detects the clod high clouds (probably cirrus). The infrared threshold test (step 4) also detects a large cloud shield. In contrast, the day time cloud map at 1845UTC is dominated by the negative difference threshold test. This is because the reflected solar radiation during the day makes the 3.9-micrometer brightness temperatures considerably warmer than the 10.7 micrometer values. The utility of each detection step in the BTH technique varies with time of day and spatial location as it is heavily influenced by the solar zenith angle.

2.2 *Cloud top pressure assignment*

A cloud top pressure is assigned to each pixel that is determined to be cloudy in the GOES satellite imagery. The pressure assignment is similar to that used by Fritz and Winston (1962) and applied by Jedlovec et al. (2000). A forecast temperature field valid at the cloud observation time from the MM5 regional model run in real time at GHCC is used. The GOES 10.7 micrometer channel brightness temperature corresponding to each cloudy pixel is referenced to the closest thermodynamic profile corresponding in the model grid point data. Log-linear interpolation is used between model vertical pressure levels to assign a precise pressure corresponding the cloud top temperature. An example of this cloud top pressure product is shown in Figure 3 along with the MODIS cloud product for the corresponding time. The MODIS cloud product was produced using a sophisticated mulitspectral algorithm (Ackerman et al. 1998) and was obtained from the EOS DAAC. The figure shows excellent agreement in cloud coverage between the GOES and MODIS cloud products. The color bar indicates the cloud top pressures assigned by each method. There is good agreement in these cloud top pressures in most areas. Discrepancies occur between some of the colder cloud regions over Tennessee, Alabama, and Georgia. This cloud top temperature discrepancy will be address later in the paper.

3. **RESULTS**

To quantify the performance of the BTH cloud detection method, 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

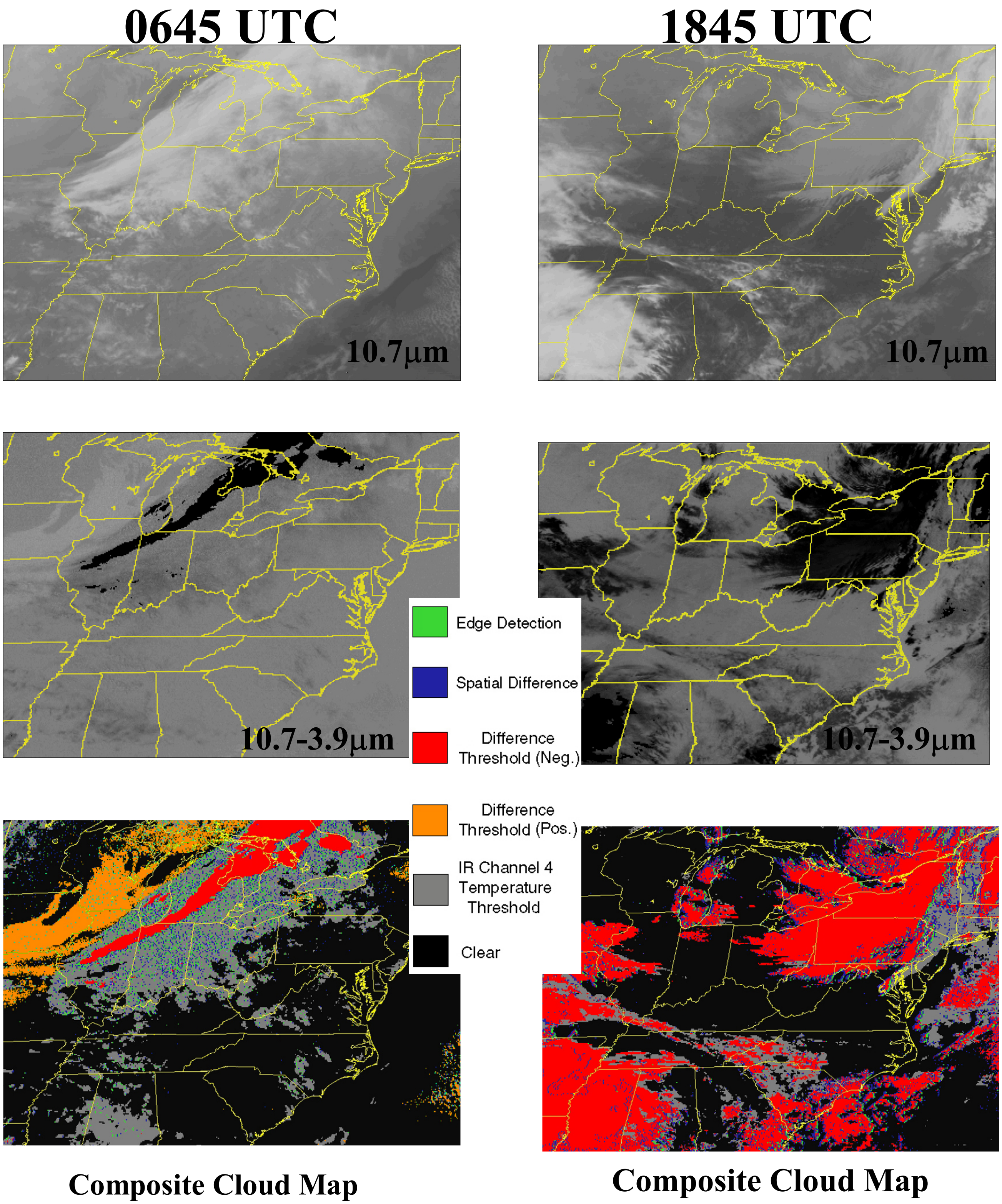

Figure 2. Components of the BTH cloud detection algorithm. The left-hand images correspond to 0645 UTC and the right hand images correspond to 1845 UTC (day). The top images are the 10.7 micrometer window chanel values, the middle images the difference image, and the bottom images the composite cloud mask. The colors in the cloud mask correspond to the each step in the BTH algorithm.

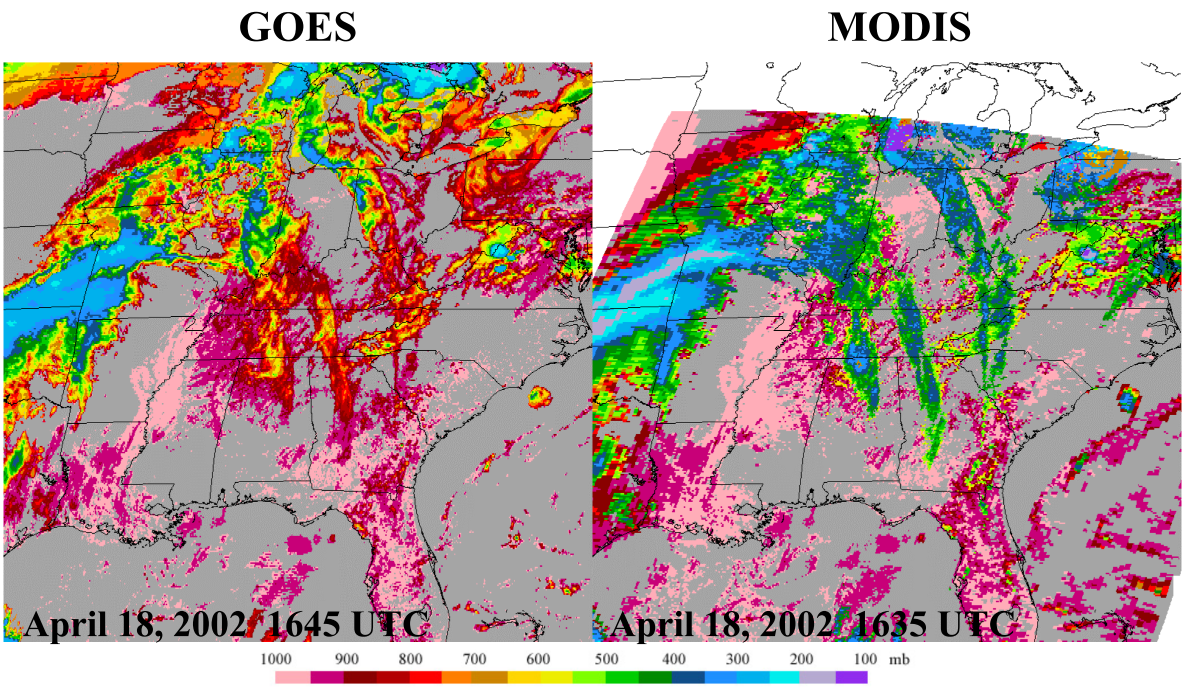

Figure 3. Cloud products from GOES (left) and MODIS (right) for April 18, 2002 at approximately the same observation time.

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).

The validation results were performed for a two-week period from each season to study the performance variation of the algorithm with season. The results presented in Figure 4 represent only the springtime period from March 8-21, 2002. The percentage of cloudy points in the validation data varies with time of day and the largest values occurred during mid-day (green and white bars on each chart). The performance of the BSC and BTH methods is shown for 0045, 0645, 1245, and 1845 UTC in each panel. The blue bars compare the performance for the cloudy points and the red bars for the clear regions. At 0045, 0645, and 1245 UTC, the BSC method severely under determines the clouds (hashed blue bars below the zero line). Jedlovec and Laws (2001) found a similar under determination of cl8uds in their previous BSC evaluation. The BTH method substantially improves on this poor performance and under determines only a few percent of the clouds at these times. Both algorithms perform quite well during the day (1845 UTC) with only a slight under determination of clouds by the BSC method. Both algorithms are shown to properly detect virtually all of the clear regions correctly throughout this spring case study. Performance in other seasons (not shown) varies a bit from these results. In fall and summer, BSC actually performs better than in the springtime case. The performance of the BTH algorithm degrades a bit during the summertime case study at 1245 and 1845 UTC when about 10% of the clouds go undetected (under determined). This is still less than for the BSC technique at these times.

To evaluate the pressure-height assignment method used in this version of the BTH technique, cloud top pressures are compared to those derived from the University of Wisconsin / NESDIS algorithm (Schreiner et al. 2001). Figure 5 presents a scatterplot of collocated results for a two-week period from July 3-16, 2002 with all times combined. The points have been color-coded to highlight particular aspects of the comparison. The yellow points indicate

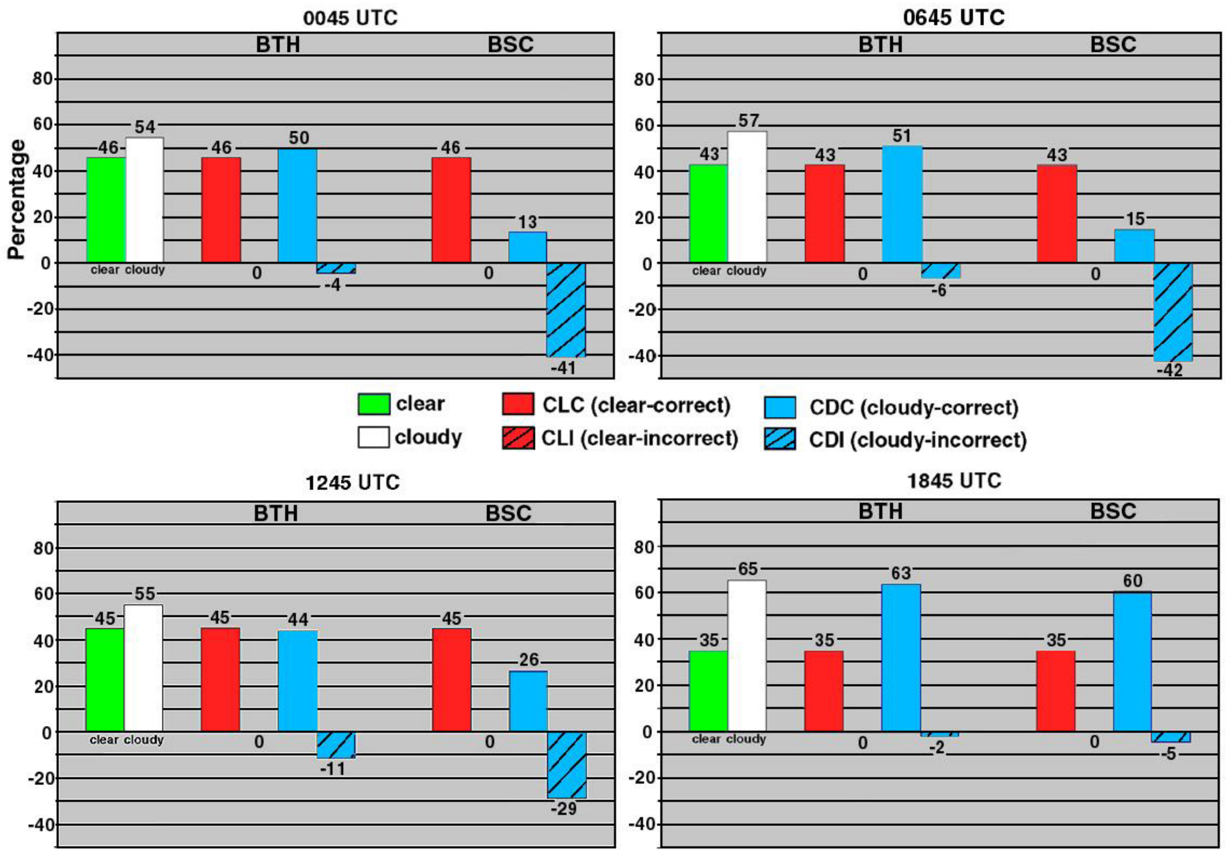

Figure 4. Validation results for the BSC and BTH cloud detection algorithms during the springtime case study at four different observation times. Values are expressed as percent of the total number of validation points.

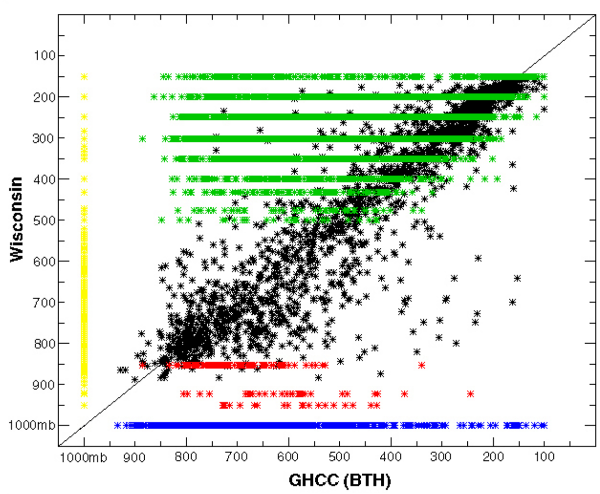

Figure 5. Scatterplot of BTH and UW/NESDIS cloud top pressures for July 3-16, 2002.

regions where the UW method determines clouds and the BTH does not while blue points indicate where the BTH has detected clouds and the UW algorithm does not. The UW method uses a combined infrared look-up and CO_2 slicing method for its height assignment. The CO_2 procedure is used when thin clouds are detected above 500mb. These points are indicated in green. It is obvious that the BTH heights significantly depart from the UW heights for these points with a bias of over 100mb. However, the accuracy of the UW CO_2 heights is limited to fixed pressure levels above 500 mb. For opaque clouds corresponding to the black points, the correlation of the two datasets is quite good (0.89) with a bias of about 25 mb. The red points correspond to clouds where the UW method uses a slightly different reference method because of the presence of low-level inversions in the data.

The results above demonstrate the BTH algorithm now in use at the GHCC is substantially better than its predecessor the BSC method. This new algorithm greatly improves cloud detection near sunrise and sunset and at night. The BTH algorithm now provides 24h cloud detection capabilities for subsequent product generation. Although the cloud detection result presented above are for the OES Imager, similar performance has been documented using the GOES Sounder. The courser spatial resolution of the sounder only slightly degrades the performance of the BTH method. The GOES Sounder cloud product was compared to a NESDIS cloud detection method used at the University of Wisconsin for an evaluation of the BTH pressure assignment method. The cloud top pressures assigned by the BTH algorithm were shown to be limited in the presence of non-opaque clouds. Improvements to the BTH pressure assignment method to use the CO2 channel on the Sounder will improve these results.

Acknowledgments

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