Analysis of MODIS cloud masking algorithm using direct broadcast data over Korea and its improvement

H. J. Lee
Remote Sensing Research Laboratory/Meteorological Research Institute,KMA
460-18 Shindaebang-dong, Dongjak-gu, Seoul 156-720, Korea
hjpose@metri.re.kr

C. Y. Chung, M. H. Ahn, and J. C. Nam
Remote Sensing Research Laboratory/Meteorological Research Institute,KMA
460-18 Shindaebang-dong, Dongjak-gu, Seoul 156-720, Korea
cychung@metri.re.kr, mhahn@metri.re.kr, jcnam@metri.re.kr

Abstract: The information on the cloud presence within a instantaneous field of view is the first step toward the derivation of many other geophysical parameters. Here, we first applied the current MODIS cloud detection algorithm developed by University of Wisconsin and compared the results to a visual interpretation of composite data, especially during the daytime. Most of cases, the detection algorithm performs very well, except a few cases with over-detection. One of the reasons for the false detection is due to the time independent use of land information which affects the threshold values of visible channel test. In the presentation, we show detailed analysis of the current cloud detection algorithm and suggest possible way to overcome the current shortfall.

Keywords: MODIS, cloud detection.

1. Introduction

Moderate Resolution Imaging Spectroradiometer (MODIS) is the important instrument onboard the NASA's Earth Observing System (EOS) Terra and Aqua platforms. It monitors continuously our earth and atmospheric science data at high spatial and spectral resolution. This information will provide scientific evidence needed to understand earth/atmospheric changes. The Korea Meteorological Administration (KMA) has processed the data from MODIS onboard Terra and Aqua satellite since Feb. 2001 and May 2003, respectively.

MODIS measures radiances in two visible bands at 250 m spatial resolution, in five more visible bands at 500 m resolution, and the remaining 29 visible and infrared bands at 1000 m resolution. MODIS cloud mask algorithm used radiances and reflectances from 14 spectral bands (Ackerman *et el.*, 1997). Many of the atmospheric and surface parameters require cloud free measurements. The MODIS cloud mask provides an estimate that a given MODIS field of view (FOV) is cloud free.

The current study performs detailed analysis of the operational MODIS cloud mask algorithm in KMA developed by the University of Wisconsin, and exemplifies some problems in the current algorithm, and suggests possible way to improve the current shortfalls.

2. Cloud mask algorithm

The 36 channels of MODIS offer the opportunity for multispectal approaches to global cloud detection. The MODIS cloud mask algorithm determines if a given pixel is clear by combining the results of several spectral thresholds tests. All of the spectral cloud detection tests rely on threshold values. Each test assign a value between 0 and 1, where zero represents high confidence cloudy condition, and 1 represents high confidence clear conditions, and the numbers in between represent increasingly less confidence in cloudy or clear conditions as 0.5 is approached.

The MODIS cloud mask output includes the results from each individual test in binary form. The initial determination of cloud or clear within a MODIS FOV is an amalgamation of the confidence values for all of the single-pixel tests. This initial determination dictates whether additional testing (e.g., spatial uniformity test) is warranted to improve the confidence. The final determination assigns one of four levels: confident clear, probably clear, undecided, and cloudy.

In the MODIS cloud mask algorithm, each spectral test is placed in one of five groups. The confidence for a group is the smallest of the confidence indicators for the individual tests within that group, and the cloud mask Q is then determined from the product of the minimum confidences of each group (Saunders and Kriebel, 1998). This approach is conservative in the estimation of clear sky. The cloud mask reports four levels of confidence that the FOV has a nonobstructed view of the surface: confident clear ($Q > 0.99$), probably clear ($Q > 0.95$), undecided ($Q > 0.66$), and cloudy or obstructed ($Q \leq 0.66$) (Ackerman *et el.*, 1997).

3. Results of Cloud Mask

The MODIS cloud mask product consists of a 6 byte output array at 1 km resolution. This 48 bits per pixel of information includes 4 levels of confidence that a given view of the earth is obstructed by clouds or aerosols, along with ancillary data information (background ecosystem, sunglint, etc) and results of individual tests. The product also contains a 10 byte per 1 km pixel array containing information on quality assurance (Strabala, 1997).

To evaluate the performance of current cloud masking algorithm, we will use one pass data of direct broadcasted MODIS data received at KMA. Figure 1 shows the RGB composite image for Aqua/MODIS on September 12, 2003. The 14th typhoon of 2003 Maemi located near the Cheju island is clearly visible. General performance of cloud mask on this data appears to be very good (not shown here). However, there is some false detection, which will be discussed in detail. Four interesting parts are focused on; (A) the area that looks like clear in RGB composite image, is turned out undecided from cloud mask; (B) the area that may appear to be low cloud in RGB, becomes under-detective; (C) the clear region where the ocean turbidity is extremely high, comes out undecided partially; (D) the small cloud stretch behind Maemi undergoes over-detection.

First of all, for the area (A) which is over the Mongolia desert, Figure 2 shows the results of some cloud masking test, (a) land water flag [bit 6-7], (b) cloud flag-visible reflectance ratio test [bit 21], and (c) cloud mask confidence flag [bit 1-2]. As shown in Figure 1, this area does not contain any cloudiness, although the final result is undecided. This is due to the fact that ancillary background ecosystem used in the cloud mask algorithm falsely assign the land characteristics. Reflectance ratio test [bit 21] of $R_{0.87}/R_{0.65}$ that cannot be used in desert due to its high albedo, detects cloud falsely [Figure 2-(b)]. Therefore, as a result of cloud mask, the A area appears undecided [Figure 2-(c)].

While the information of snow/ice cover is provided by NSIDC (National Snow and Ice Data Center) and NOAA every day, ecosystems that has affected the decision of cloud mask procedure and changed seasonally isn't updated. The cloud mask algorithm has used global 1 km map of ecosystem based on the Olson classification system (Strabala *et el.*, 2002). The area of B seems to be low cloud partially in RGB. Cloud mask tests show that they cannot detect the cloud in this area except smoke test [bit 8] that uses $R_{2.1}$ and $BT_{3.75}$ (not shown here). Smoke doesn't affect the result of cloud mask. Maybe, there are threshold value problems, and further investigations are needed.

Figure 3 shows images of (a) cloud flag-Visible reflectance test [bit 20], (b) cloud flag-Clear sky Restoral test [bit 22], (c) cloud flag-Spatial Consistency [bit 25], and (d) cloud mask confidence flag [bit 1-2] in the C area, respectively. The area of C is shallow ocean where the ocean turbidity is very high. As a result of cloud mask, undecided appears in this area, especially coastal area [Figure 3-(d)]. Reflectance threshold test of $R_{0.87}$ [bit 20] shows there is cloudy [Figure 3-(a)]. But the clear-sky restoral test [bit 22] and the spatial consistency test [bit25], which use NDVI in coastal area and BT_{11} in ocean respectively, show that C area is clear except coastal area [Figure 3-(b), (c)]. Restoral test checks extreme values of NDVI in shallow water conditions, and sets confidence level to "confident clear" if very low or very high values are found. Spatial consistency test computes brightness temperature difference between the (center) pixel of interest and the surrounding eight pixel values, and also outputs the input data for all 9 pixel positions. This test can be performed, if confidence level is between 0.05 and 0.95. Also, increasing the confidence level, if spatial variability test showed uniform conditions (undecided will be probably clear, cloudy will be undecided). There is small cloud stretch behind the typhoon Maemi in the D area. It looks like clear sky during the partial clouds in RGB, but many of the cloud test show that it is cloudy or probably clear. Especially, BT

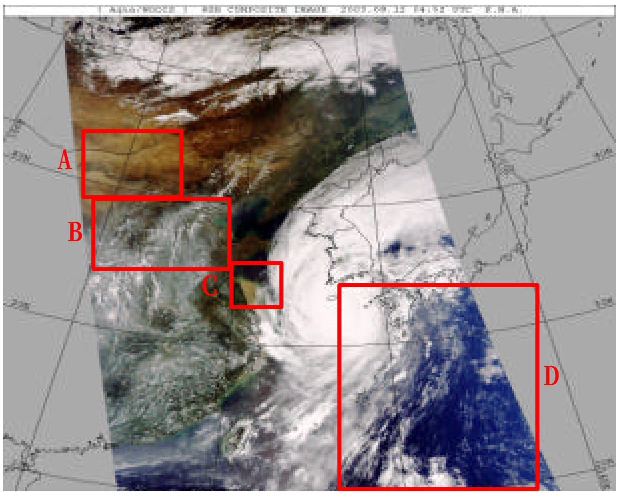

Fig. 1. RGB composite Image for MODIS Aqua on September 12, 0452 UTC, 2003.

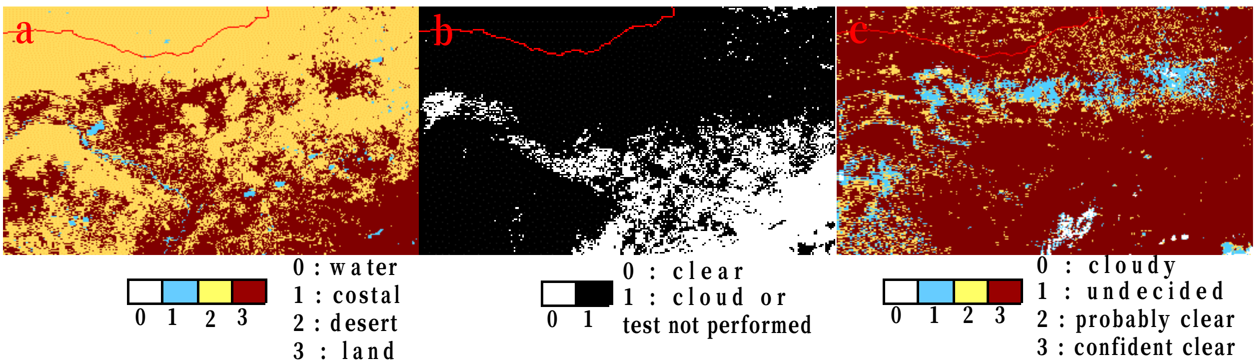

Fig. 2. Images of (a) land water flag [bit 6-7], (b) cloud flag [bit 21], and (c) cloud mask result for MODIS Aqua in the A area on September 12, 0452 UTC, 2003.

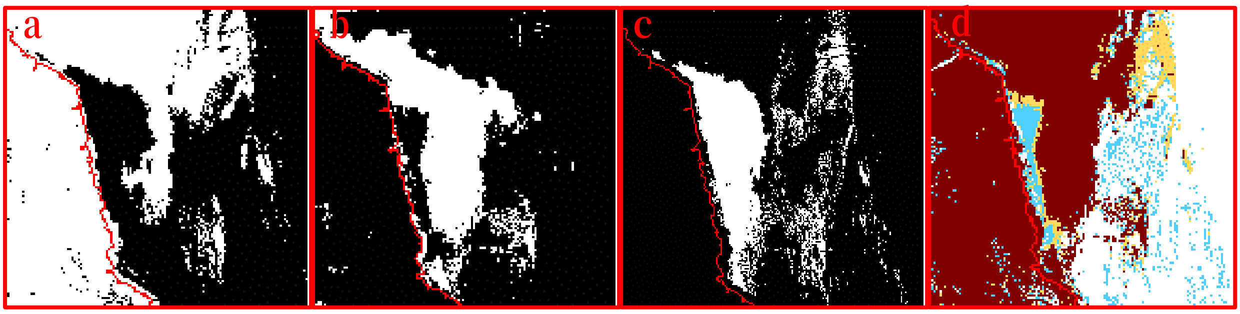

Fig. 3. The same as Fig. 2 except for (a) cloud flag-Visible reflectance test [bit 20], (b) cloud flag-Clear sky Restoral test [bit 22], (c) cloud flag-Spatial Consistency [bit 25], and (d) cloud mask confidence flag [bit 1-2] in the C area, respectively.

different test of BT_{11}-$BT_{3.9}$ [bit 19] detects more clouds than others do in this area (not shown here), and informs us that they are low-level water clouds.

4. Conclusions

MODIS atmospheric and surface parameter retrievals require the precise result of cloud mask algorithm used to identify pixels that are cloud free. The operational retrieval algorithm requires at least 5 of the 25 pixels in a 5 **x** 5 FOV area to have been assigned a 95% or greater confidence of clear by the cloud mask. The retrieval is performed using the average radiance of those pixels that are considered clear (Menzel *et el.*, 2002). Because a retrieval depends on the result of the cloud mask algorithm, cloud contamination may occur if the cloud mask fails to detect a cloud, or the retrieval may not be run if the cloud mask falsely detects a cloud. The cloud mask includes not only four levels of confidence, but also the results from different spectral tests. The MODIS cloud mask algorithm depends on surface type and solar illumination. Therefore, each processing path in the algorithm performs the associated spectral tests.

In this study, the operational cloud mask algorithm in KMA developed by the University of Wisconsin, and the assessment of it is attempted by comparison with the visual interpretation of composite data, especially during the daytime. Most of cases, the cloud mask algorithm performs very well, except a few cases. One of the reasons for the false detection is due to the time independent use of land information which affects the threshold values of visible channel test. The albedo of some area changes seasonally. To mitigate this problem, ecosystems will be needed to improved and updated by using the NDVI frequently. Another may be due to threshold values of the cloud mask tests. It is possible for threshold value of a cloud mask test to vary in different localities. It is anticipated that future study will be necessary.

References

[1] Ackerman, S. A., K. I. Strabala, W. P. Menzel, R. A. Frey, C. C. Moller, L. E. Gumley, B. A. Baum, C. Schaaf, and G. Riggs, 1997. Discriminating clear sky from cloud with MODIS algorithm theoretical basis document (MOD35). Available at: http://modis-atmos.gsfc.nasa.gov/index.html.

[2] Ackerman, S. A., K. I. Strabala, W. P. Menzel, R. A. Frey, C. C. Moeller, and L. E. Gumley, 1997. Discriminating clear sky from cloud with MODIS, *Jour. Geophys. Res.,* 103, pp. 32,141-32,157.

[3] Menzel, W. P., S. W. Seemann, J. Li, and L. E. Gumley, 2002. MODIS atmospheric profile retrieval algorithm theoretical basis document (MOD07). Available at: http://modis-atmos.gsfc.nasa.gov/index.html.

[4] Strabala, K. I., 1997. MODIS Cloud Mask User's Guide. Available at: http://modis-atmos.gsfc.nasa.gov/index.html.

[5] Strabala, K. I., L. E. Gumley, T. Rink, H.-L. Huang, and R. Dengel. 2002. MODIS/AIRS instrument direct broadcast products and applications. Available at: http://modis-atmos.gsfc.nasa.gov/index.html.

[6] Saunders, R. W. and K. T. Kriebel. 1998. An improved method for detecting clear sky and cloudy radiance from AVHRR data. *Int. J. of Remote Sens.,* 9, pp. 123-150.