Evaluating the Moderate Resolution Imaging Spectroradiometer Cloud Detection Algorithm Using Whole-Sky Imager Cloud Cover Data at the Three Atmospheric Radiation Measurement Sites

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Introduction

Satellite remote sensing offers a unique and useful tool in determining cloud cover on a global and local basis. Given the crucial role clouds play in modulating the earth's atmospheric radiative budget, it is important to obtain accurate estimates of cloud fraction for any climate modeling effort. Ground-based retrievals of cloud fraction at particular locales around the world provide a means of establishing the accuracy of satellite-derived cloud cover estimates and can help identify problems with the satellite algorithms used in determining pixel cloudiness. From whole-sky imager (WSI) cloud fraction data obtained at the six major Atmospheric Radiation Measurement (ARM) Climate Research Facility sites (the Central Facility [CF], Nauru, Manus, Darwin, Barrow, and Atqasuk) and Moderate Resolution Imaging Spectroradiometer (MODIS) retrievals of cloud fraction over these facilities, cases where the WSI indicates a clear sky while MODIS retrievals show substantial cloudiness are identified. For these cases, the results from the spectral tests used in the MODIS cloud mask retrieval algorithm are investigated in hopes of gleaning insight into which of the bevy of tests is the source of discordance in the two cloud cover estimates. Preliminary analyses indicate that the set of problematic spectral tests depends on the climatic region (land, ocean, ice/snow). Statistics illustrating this will be presented.

The Instruments and Calculation of Cloud Fractions

The WSI is an automated zenith-viewing imager used for recording sky cover conditions. It measures radiances in three spectral bands (450, 650, and 800 nm) and in ~ 1/3° increment over the entire sky dome and final images are collected every six minutes during the day and night. To put together each image, a cloud decision algorithm is applied and consists of taking the ratio of red to blue images. A site-dependent library of clear-sky ratio images for all solar zenith angles is on hand and spectral ratio comparisons are made to determine whether a particular pixel in the image is clear (C1), laden with aerosol (C2), a mixture of aerosol and cloud (C3), bright (C4, where the spectral ratio is more than three times that of the clear-sky ratio), dark (C5, where the ratio is less than the clear-sky ratio), or intermediate (C6, where the spectral ratio is between one to three times that of the clear-sky ratio). Only those WSI pixels found within a circum-solar angle of 45° (following Kassianov et al. 2005) and with minor or no quality problems were used in the study. The percentage of pixels for each classification type is compiled and for a given image, the cloud fraction is calculated as (C4%+C5%+C6%)/(C1%+C2%+ C3% + C4%+C5%+C6%). WSI data for the year 2002 at the Northern Slope of Alaska (NSA) sites (Atqasuk and Barrow), the Tropical Western Pacific (TWP) sites (Manus, Nauru and Darwin) and the Southern Great Plains CF site was analyzed in this manner and the derived instantaneous cloud fraction amount at each site was developed for the year.

The MODIS is an instrument aboard the Terra and Aqua satellites, scanning radiances in 36 spectral bands (ranging in wavelength from 0.4 µm to 14.4 µm) from an orbital altitude of 705 km.

The cloud mask is one of the many cloud products retrieved from the radiances observed by this space-borne instrument. This 1-km-pixel resolution cloud mask product forms the basis of the derivation of MODIS cloud fraction. First, the cloud mask is determined from applying appropriate single field-of-view spectral tests to each pixel. These tests generally rely on thresholds and brightness temperature differences and include tests specific for identification of high cloud and thin cirrus cloud. An individual confidence flag is assigned to each pixel test and these flags are combined to produce the final cloud mask flag. A group confidence value is assigned to the pixel and is based on this final flag, ranging from less than 0.66 (low confidence of an unobstructed view of the surface) to greater than 0.95 (high confidence that the pixel is clear). For values between 0.66 and 0.95, spatial and temporal continuity tests are further applied in order to determine whether the pixel is confident clear or confident cloudy. The cloud fraction is then calculated from 5x5-km cloud mask pixel groupings, i.e. given the 25 pixels in the group, the cloud fraction for the group equals the number of cloudy pixels divided by 25. This derived cloud fraction is a dataset in the MODIS cloud product (MOD06).

The dates and time intervals in the WSI database were noted for each site and MODIS granules on the date and within the time interval and containing the location of each site were selected. Pixels falling within a 30-km radius around the site in question were chosen and the cloud fractions associated with each of these pixels was averaged to obtain a final cloud fraction within approximately the same field of view as the WSI. For comparison purposes, the WSI cloud fractions were interpolated in time to the time point of the MODIS granule for which a satellite-retrieved cloud fraction was obtained.

Results

Figure 1 shows histograms of MODIS and WSI cloud fractions at the three ARM sites: the NSA (Atqasuk and Barrow combined), the Southern Great Plains CF, and the TWP (Darwin, Manus, and Nauru). At the NSA, the WSI captures more instances of clear sky than the MODIS. At the CF, more broken-sky to clear-sky instances are seen by the WSI and more overcast scenes are identified by the MODIS. In the TWP, there is a tendency for the MODIS to identify more overcast scenes while the WSI observes a more broken sky cover. At the Darwin facility, both instruments capture the wide range of sky conditions. The scatter plots of MODIS cloud fraction as a function of WSI cloud fraction at the six facilities reveals that agreement between the two cloud fractions varies considerably. There is a

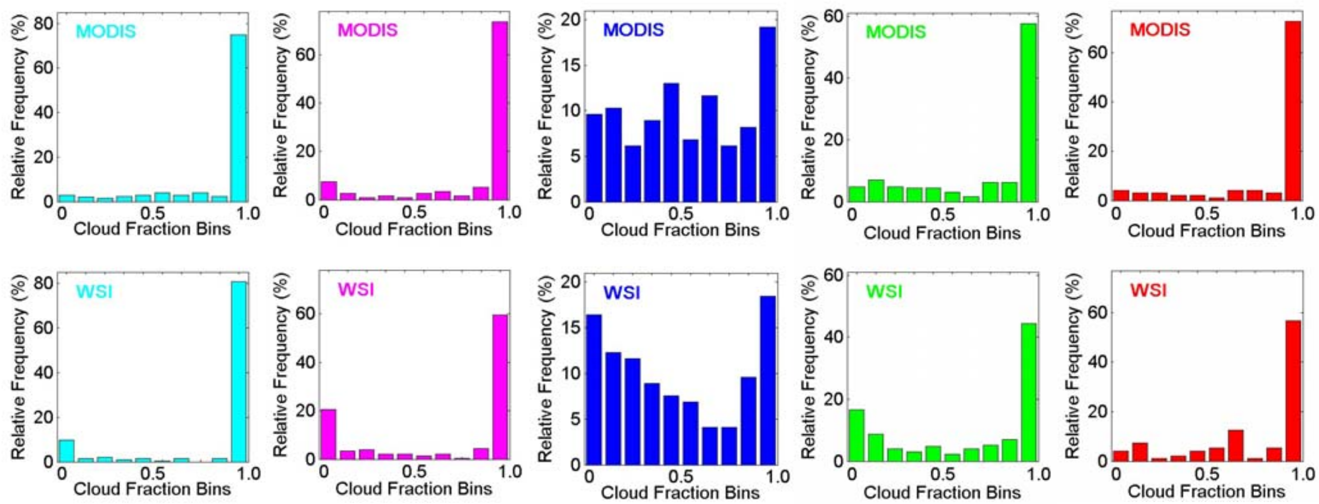

Figure 1. Histograms of MODIS and WSI cloud fractions at the three ARM sites, from left to right: the North Slope of Alaska (Atqasuk and Barrow combined - cyan), the Southern Great Plains (Central Facility – magenta), and the Tropical West Pacific (Darwin - blue, Manus - green, Nauru - red). Cloud fraction bins: 0 to 1 in 0.1 increments.

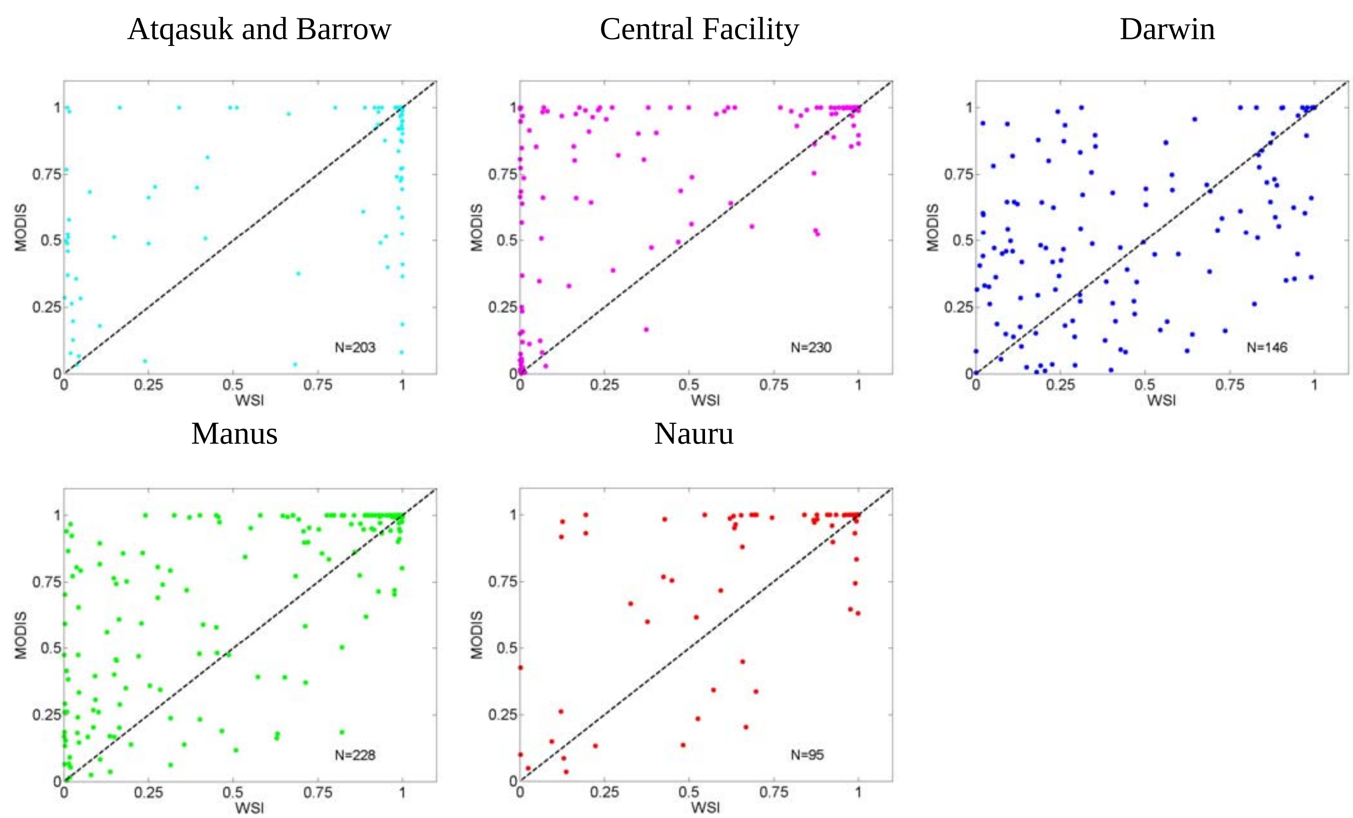

Figure 2. MODIS cloud fraction as a function of WSI cloud fraction at the five ARM facilities.

tendency for the MODIS to overestimate the cloud fraction under partially to mostly cloudy sky conditions. Several cases of complete mismatching are evident.

An extreme scenario of mismatch occurs when the MODIS observes a very cloudy/overcast sky and the WSI observes a clear sky. Several such cases occurred at each facility and were noted. The spectral test results contained in the MODIS cloud mask product (MOD35) were analyzed for these cases. These tests involve (1) a 1.38 µm reflectance threshold test in the solar spectrum and brightness temperature differences in the infrared spectrum to identify thin cirrus, (2) tests using the C02 13.9 µm channel and reflectance (1.38 µm) and brightness temperature (6.7 µm) threshold tests to identify high cloud, and (3) brightness temperature (11 µm) threshold tests, differences between the 11 µm and the 12 µm brightness temperatures, differences between the 11 µm and the 3.7 µm brightness temperatures, 0.66 µm reflectance threshold tests over land and 0.87 µm reflectance threshold tests over ocean, and visible reflectance tests (R0.87/R0.66). A test confident for cloud is equal to 0; a test confident for clear sky is equal to 1. For each pixel falling within the specified radius around each facility, the results from these ten spectral tests were compiled. The average of individual pixel results for a particular test is taken so for each case, a mean value for each of the ten tests is output. If all pixels within the area tested positive for clear sky, the mean value would equal 1 and if all pixels within the area tested positive for cloud, the mean value would equal 0. Generally, there is a mix of clear and cloudy pixels within the area so the average value for a particular test would fall somewhere between 0 and 1. An average value for a test that is greater than 0.9 means that the test identified a mainly clear sky. For each site, the percentage of cases where the average value for each spectral test is greater than 0.9 was determined and these results are presented in Table 1. This shows the tendency of a particular test to correctly indicate the clear-sky condition (as verified by the WSI). In this way, spectral tests that are erroneously indicating cloud can be identified. At the NSA, there is a tendency for the visible reflectance and infrared (IR) threshold tests to mistakenly detect cloud in the presence of snow cover. At the SGP, there's a tendency for the IR threshold test to erroneously indicate presence of cloud due to the complicated surface emissivities. At the TWP, there's a tendency for the 3.7-11 µm test to incorrectly indicate presence of cloud.

Table 1. The tendency of each spectral test (in terms of percentage of cases) to indicate clear sky.

Spectral Test	NSA	SGP CF	TWP
For thin cirrus:			
solar	100.0	80.0	50.0
infrared	90.9	93.3	100.0
For high cloud:			
CO2	n/a	100.0	90.0
1.38 um	100.0	100.0	90.0
6.70 um	100.0	86.7	80.0
For cloud:			
IR threshold	0.0	0.0	10.0
IR temp. diff.	54.5	86.7	35.0
3.7 um – 11 um	72.7	60.0	0.0
VIS reflectance	9.1	33.3	20.0
VIS refl. ratio	0.0	73.3	5.0

Summary

This study attempts to use the ARM WSI cloud cover data to evaluate the performance of the MODIS cloud detection algorithm and identify erroneous tests used in the algorithm. A database of cloud fractions based on WSI pixel classifications of good quality was generated at all sites located within the three ARM regions for the year 2002. At dates and times in the databases for each site, the MODIS cloud fraction product was extracted and pixels within a 30-km radius of each site were selected. The cloud fractions associated with each pixel were then averaged to obtain a total cloud amount within approximately the same field of view as the WSI.

The overall statistics of the frequencies of different cloud cover obtained by MODIS match closely with those from the WSI at almost all ARM locales. However, poor agreement is found for individual cases. Cases where the WSI observed a clear sky and the MODIS identified a very cloudy/overcast sky condition were compiled. The spectral test results from the MODIS cloud mask product were analyzed for these cases with the hope of gaining insight into what tests were failing to indicate a clear sky. At the NSA, there is a tendency for the visible reflectance tests to erroneously detect cloud in the presence of snow cover. At the SGP, there's a tendency for the IR threshold tests to erroneously indicate presence of cloud due to the complicated surface emissivity. At the TWP, there's a tendency for the 3.7-11 µm test to incorrectly indicate presence of cloud.

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