Validation of MODIS-Retrieved Cloud Fractions Using Whole Sky Imager Measurements at the Three ARM Sites

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Introduction

Given the importance of clouds in modulating the surface energy budget, it is critical to obtain accurate estimates of their fractional amount in the atmospheric column for use in modeling studies. Satellite remote sensing of cloud properties such as cloud amount has the advantage of providing global coverage on a regular basis. Ground-based surveys of cloud fraction offer a practical database for use in determining the accuracy of these remotely sensed estimates of cloud fraction on a regional scale. Satellite remote sensing of cloud cover suffers from various uncertainties due to surface brightness and variability, pixel resolution, cloud inhomogeneity, etc. In this study, validation of the moderate-resolution imaging spectroradiometer (MODIS) retrievals of day-time cloud fraction using whole sky imager (WSI) retrievals of day-time cloud fraction was made at the three Atmospheric Radiation Measurement (ARM) locales for the year 2002. Statistics concerning the frequency of cloud fraction from the ground-based and satellite platforms will be presented and issues in retrieval discrepancies, especially apparent in the arctic environment, will be shown and a preliminary attempt at diagnosing the problem will be made.

Calculation of Cloud Fraction from WSI Data

The WSI is an automated zenith-viewing imager used for documenting cloud fields. It measures radiances in three spectral bands (450, 650, and 800 nm) in ~1/3° increments 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), dark (C5), or indeterminate (C6). 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%). Note that only those pixels with minor or no quality problems were used in this study.

WSI data for the year 2002 at the Northern Slope of Alaska (NSA) sites (Atqasuk and Barrow), the Tropical Western Pacific (TWP) sites (Manus and Nauru) and the Southern Great Plains central facility (CF) site was downloaded and analyzed for cases where the quality for the classification retrieval was deemed good (little or no quality problems). A database of pixel classifications and the ensuing derived instantaneous cloud fraction amount at each site was developed for the year.

Calculation of Cloud Fraction from MODIS Data

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 the MODIS cloud fraction. First, the cloud mask is determined from applying appropriate single field of view (FOV) spectral tests to each pixel. These tests generally rely on thresholds and there are different algorithms for ocean, desert, land, etc. 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 5 x 5-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 FOV 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 sites from the three ARM locales. At the NSA (top two panels), the WSI captures more instances of clear sky than the MODIS. An inkling of the problem of MODIS cloud misidentification over snow/ice-covered surfaces is indicated, given the relative dearth of clear-sky instances from this instrument over the arctic environment. In the TWP (middle two panels), there is a tendency for the MODIS to identify more overcast scenes while the WSI observes a more broken sky cover. Regardless of the general distribution of cloud cover over these tropical oceanic sites, both instruments capture the prevalent cloudiness of the region. At the CF (bottom panel), more clear-sky to broken-sky instances are seen by the WSI and more overcast scenes are identified by the MODIS. Again, given the greater number of overcast scenes obtained from the MODIS compared to that measured by the WSI, there may be some false identification of cloud during seasons when there is snow cover at the CF. With the exception of the NSA where the cloud regime

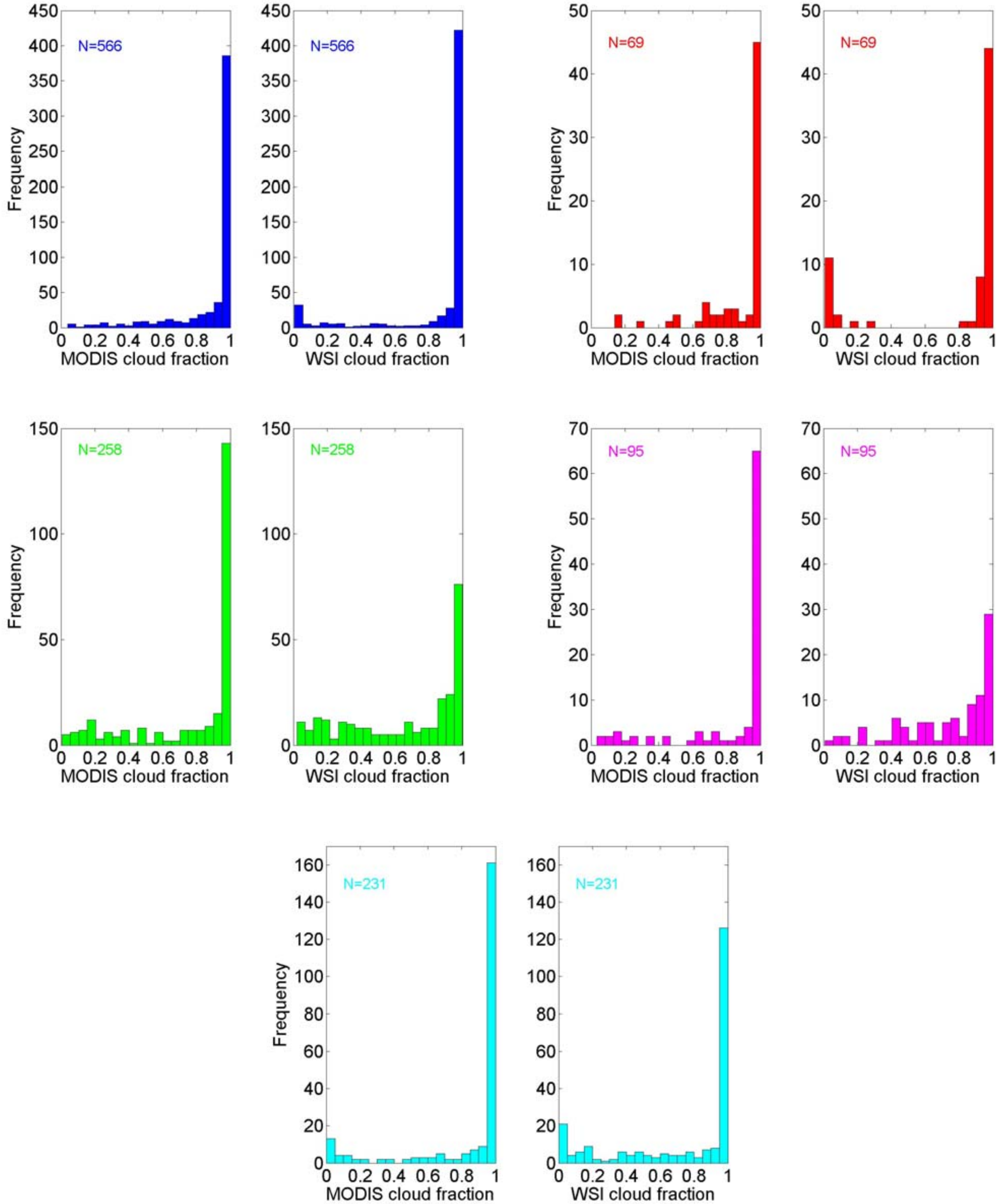

Figure 1. Histograms of MODIS and WSI cloud fractions at the three ARM sites: NSA (Atqasuk and Barrow – top panels), TWP (Manus and Nauru – middle panels), and the CF (bottom panel).

consists primarily of overcast or almost clear/clear-sky conditions, details such as breaks in the cloud cover (if cloudy) over the other locales are more evident when looking up from the ground than when looking down from an altitude of several hundred kilometers so the WSI instrument picks up more cases of partly to mostly cloudy skies. Given the vantage point of each instrument, this is not surprising.

There is reasonable agreement between the MODIS and WSI cloud fractions for the majority of cases, as shown in the seasonally differentiated scatter plots of Figure 2. For all seasons and at all sites (Barrow, Manus, and CF only shown here), the bulk of the cases have absolute magnitudes of differences between the two cloud fractions <0.1. At the NSA (upper left plots with red points) during the winter and spring months (December-January-February and March-April-May), overestimation of MODIS cloud fraction when the WSI shows clear to partly cloudy sky conditions is apparent. This is a known problem with the MODIS cloud mask product. This feature is also seen at the CF during the winter/spring and fall months (bottom plot with cyan points). Figure 3 illustrates more obviously such a case (Atqasuk, March 12, 22h40 Universal Time Coordinates [UTC]), one where the MODIS cloud fraction was calculated as 0.96 and the WSI showed a clear-sky (left image). The MODIS granule (right image) clearly shows a snow-covered surface under clear-sky conditions. There are also some similar gross mismatches over the TWP locale (upper right plots with green points in Figure 2); they may be associated with sun glint although a brief analysis of the spectral tests for sun glint were negative for some of these cases at the TWP. In general, there is a tendency for the MODIS to overestimate the cloud fraction under partially to mostly cloudy sky conditions.

Summary

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 FOV as the WSI.

The majority of cases at all sites show cloud fractions from the MODIS and the WSI that are in reasonable agreement (absolute magnitude of differences between the two cloud fractions <0.1): NSA (78%), TWP (55%), and SGP (69%). There is some tendency for the MODIS to overestimate the cloud fraction under partially to mostly cloudy sky conditions at all sites in all seasons. At the NSA, under clear-sky conditions in the presence of ground snow cover, the MODIS grossly overestimates the cloud fraction. Instances of MODIS overestimation of cloud cover when clear-sky is evident from the WSI also occur at the other sites. MODIS cloud mask pixel-level spectral tests for those instances of large cloud fraction mismatch show contradictory results, i.e., results of different cloud tests performed on each pixel are not consistent. There is some uncertainty in how adequate the spectral tests are in determining the final confidence level of the cloudiness of the MODIS pixel.

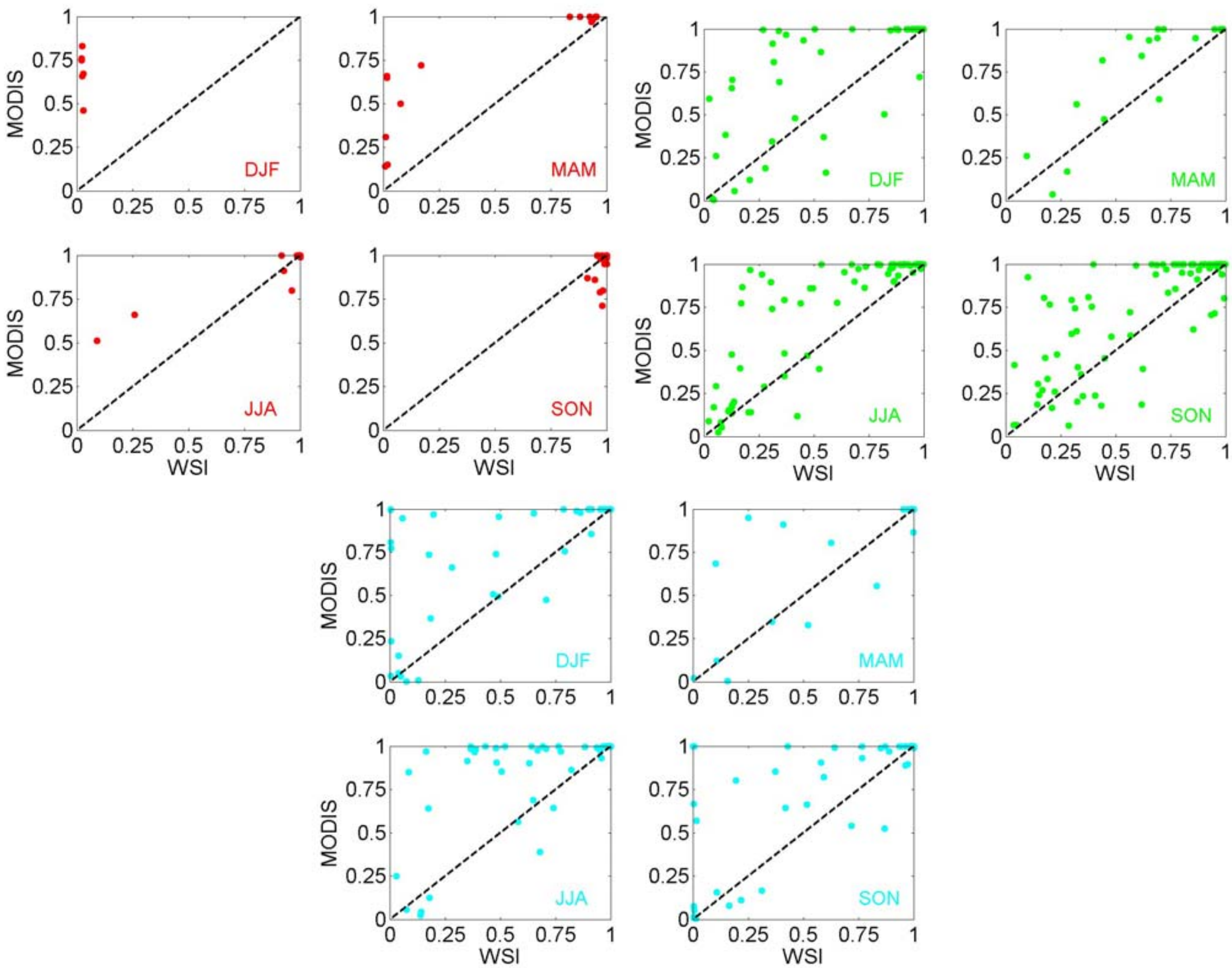

Figure 2. MODIS cloud fraction as a function of WSI cloud fraction at three ARM sites (red – Barrow, green – Manus, cyan – CF. Data separated according to season: Dec-Jan-Feb (DJF), Mar-Apr-May (MAM), Jun-Jul-Aug (JJA), and Sep-Oct-Nov (SON)

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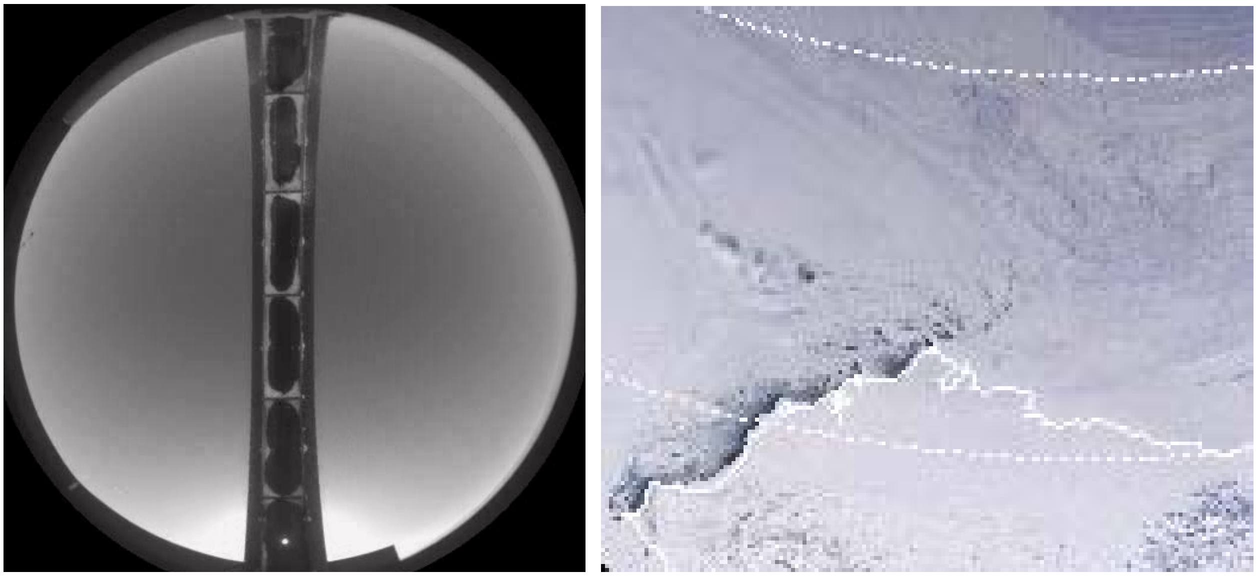

Figure 3. Example of extreme mismatch between MODIS cloud fraction (0.96) and WSI cloud fraction (clear) for Atqasuk, March 12, 22h40 UTC. WSI snapshot at left; MODIS granule snapshot at right.