Sensitivity Study of the MODIS Cloud Top Property Algorithm to CO_2 Spectral Response Functions

***Hong Zhang*[a*], *Richard Frey*[a] and *Paul Menzel*[b]**

[a] *Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin, Madison, WI USA*

[b] *Office of Research and Applications, NOAA/NESDIS, Madison, WI USA*

Abstract

The algorithm which produces cloud top property products (MOD06/MYD06) from MODIS (MODerate-Resolution Imaging Spectroradiometer) on EOS Terra and Aqua has been developed at University of Wisconsin-Madison. The CO_2 slicing algorithm is used to infer cloud top pressure and effective cloud amount. The accuracy of the cloud retrieval depends critically on the knowledge of instrument spectral response functions (SRF) used in a fast radiative transfer model. Intercalibration with AIRS (Atmospheric Infrared Sounder) has suggested possible SRF shifts between actual and reported values of 1.0 /cm, 0.8/cm, and 0.8/cm for CO_2 band 36 (14.2 μm), 35 (13.9 μm), and 34 (13.6 μm), respectively. These shifted SRFs have been used in Aqua/MODIS granules; early results have shown high thin clouds are very sensitive to the spectral adjustment, introducing a significant improvement of cloud top properties retrieval. Comparisons of cloud top properties between AIRS and MODIS are studied to demonstrate the advantages of the spectral adjustment.

1. Introduction

The CO_2 slicing algorithm (Smith et al. 1974; Menzel et al. 1983; and Zhang and Menzel 2002) has been generally accepted as a useful algorithm for determining cloud top pressure (CTP) and effective cloud amount (ECA) for tropospheric clouds above 600 hPa. The accuracy of the retrievals depends critically on the knowledge of the spectral response function (SRF) used in a fast radiative transfer model. Recently, we found that there are biases between MODIS (MODerate resolution Imaging Spectroradiometer) and AIRS (Atmospheric Infrared Sounder) measurements in certain long wave infrared CO_2 absorption bands that are possibly due to shifts in the MODIS SRF. In this paper, we investigate the sensitivity of MODIS cloud top properties to CO_2 channel spectral response functions. Section 2 shows comparisons of infrared radiances between MODIS and AIRS. The advantages of AIRS high spectral resolution and MODIS high spatial

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* Hong. Zhang@ssec.wisc.edu; Phone (608)263-2348; Fax (608)262-5974.

resolution were used in the intercalibration of MODIS and AIRS. Section 3 shows several case studies of Aqua/MODIS granules in tropical and middle latitude areas where retrieval results from original SRF and shifted SRF are discussed. Results are summarized in Section 4.

2. Comparison of MODIS and AIRS Infrared Radiances

AIRS and MODIS on the EOS Aqua spacecraft measure the upwelling infrared radiance for numerous remote sensing and climate related applications. MODIS (King et al. 2003) provides global observations of Earth's land, ocean, and atmosphere in 36 spectral bands. These include visible (VIS), near infrared (NIR) and infrared (IR) of the spectrum from 0.4 to 14.5 μm, the infrared footprints are 1km in diameter at nadir. AIRS (Auman et al. 2003) is a high spectral resolution infrared sounder which measures the thermal infrared spectrum with 2378 spectral channels covering 3.75 to 15.4 μm with footprints approximately 13.5km in diameter at nadir. Comparisons of AIRS and MODIS observations (Tobin et al., 2005) illustrate the utility of using high spectral resolution observations to create highly accurate comparisons with a broadband sensor. The high spectral resolution AIRS spectra are reduced to MODIS spectral resolution and the high spatial resolution MODIS data are reduced to match AIRS spatial resolution. Figure 1 shows MODIS brightness temperatures (left panels) and AIRS minus MODIS brightness temperature differences (right panels) for band 30 through 36. An example of MODIS band 35 (13.9 μm) brightness temperature differences using original and shifted SRF (shifted +0.8 cm^{-1}) is shown in Figure 2. Red lines in these two figures represent the use of shifted SRFs. AIRS and MODIS differences are much closer to 0 with the use of shifted SRFs. The temperature dependence is also greatly reduced. The right panel shows histograms of the differences. Shifted SRF values (1 cm^{-1} for band 36, 0.8 cm^{-1} for both bands 35 and 34, and –0.15 cm^{-1} for band 33) were used in our study to ascertain the impact on cloud top property retrievals. Figure 3 shows the sensitivity of MODIS from band 34 to band 36 weighting functions to the SRF shifts using the USA standard atmosphere profile. Band 36 is sensitive to high clouds while bands 34 and 35 are sensitive to middle and low clouds, though any of these bands may be used to retrieve transmissive cloud top properties.

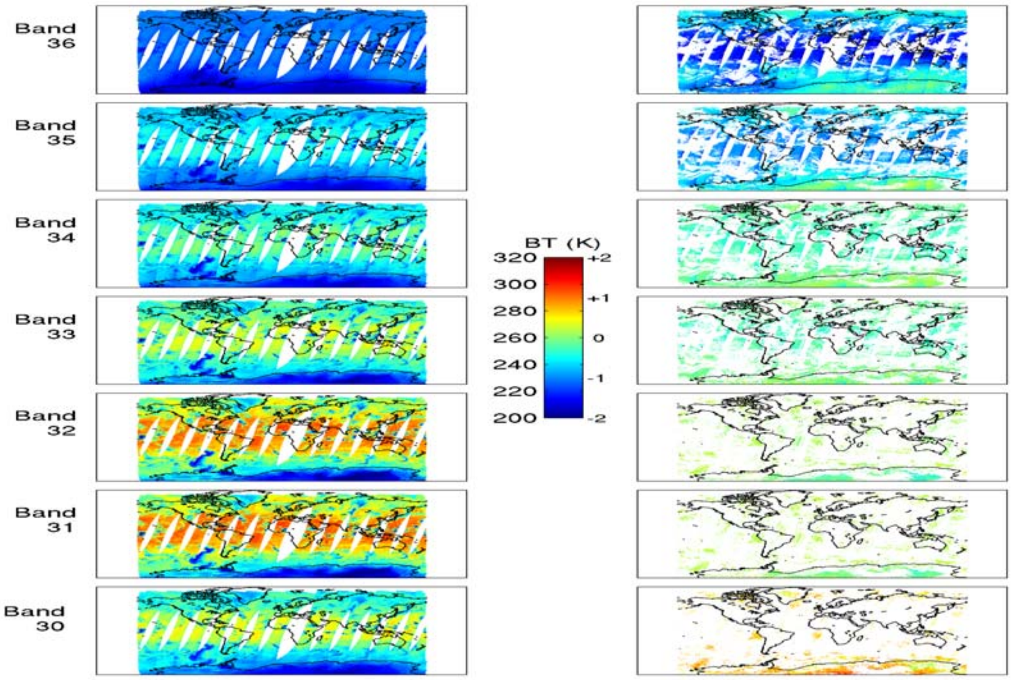

Figure 1: Images of 6 Sep 2002 descending MODIS brightness temperatures (left panels) and AIRS minus MODIS brightness temperature differences (right panels) for bands 36 thru 30. (*Tobin et. al, 2005)*

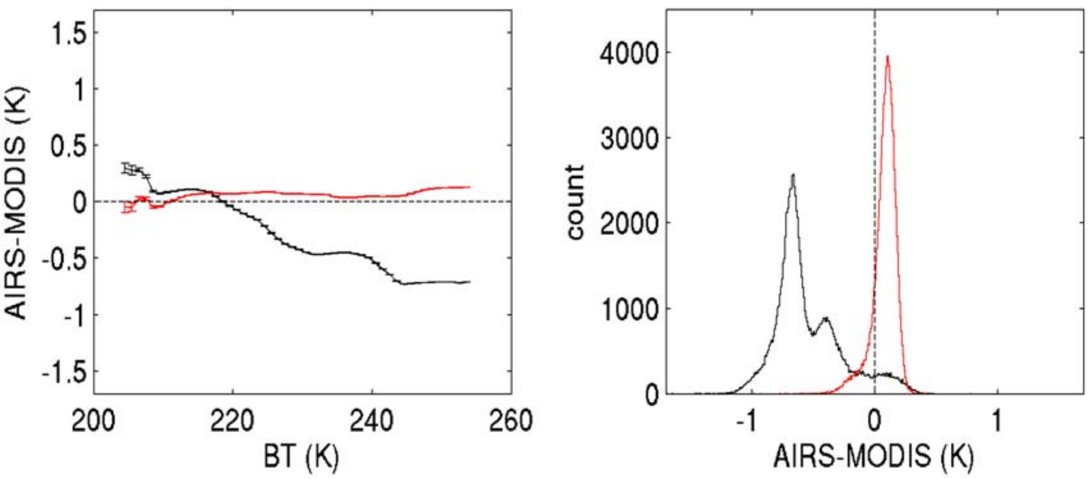

Figure 2: An example of MODIS band 35 (13.9 mm) brightness temperature differences using original SRF (black) and using MODIS SRF shifted +0.8 cm $^{-1}$ (red). (*Tobin et. al, 2005)*

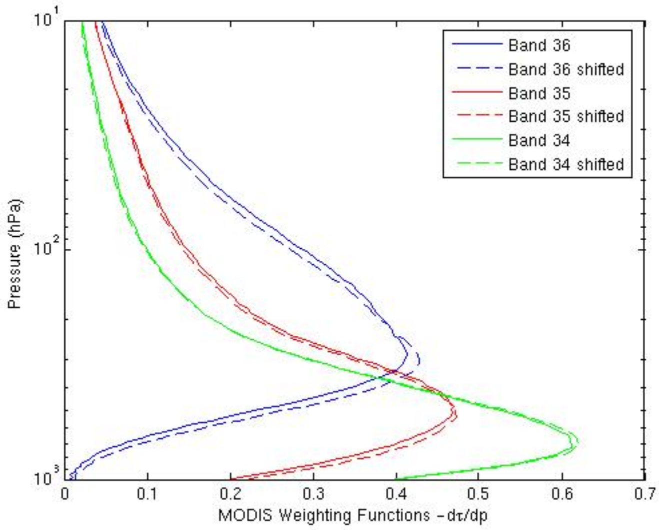

Figure 3: Weighting Function for MODIS from band 34 to 36 with original SRF and shifted SRF using the USA standard atmospheric profile.

3. Results and Discussion

3.1 Study Case 1 – Middle Lat. Area

A MODIS/Aqua granule from middle latitudes is presented for study. The 11 µm image in Figure 4 shows lots of high clouds and thin cirrus. Also shown are high clouds (CTP < 400 hPa in color) retrieved using original and shifted SRFs. There are more high clouds, and especially high thin clouds, retrieved with the use of the shifted SRFs (right).

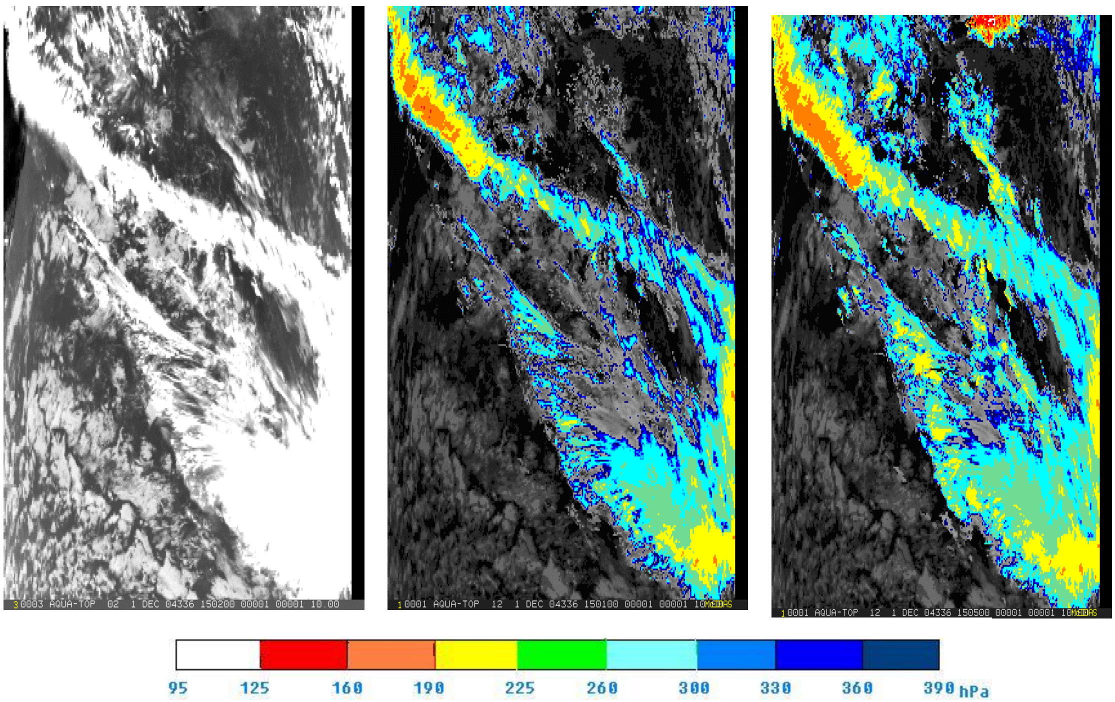

Figure 4: Aqua/MODIS 1500 UTC on day 2004336: (left) Band 31 (11µm); (middle) Hi CTP retrieved from original SRF; (right) Hi CTP retrieved from shifted SRF.

Calculated and observed clear sky radiances using the two SRF sets are analyzed. The upper panel in Figure 5 shows scatterplots of observed vs. calculated clear-sky radiances using original SRFs; the bottom panel is the same but using shifted SRFs. Band 36 shows the most sensitivity to SRF changes. Calculated radiances using the original SRF are smaller than observed values, meaning that the calculated clear is colder than the observed. After applying the shifted SRF, calculated radiances agree well with observed clear radiances. For other bands, there are less dramatic changes.

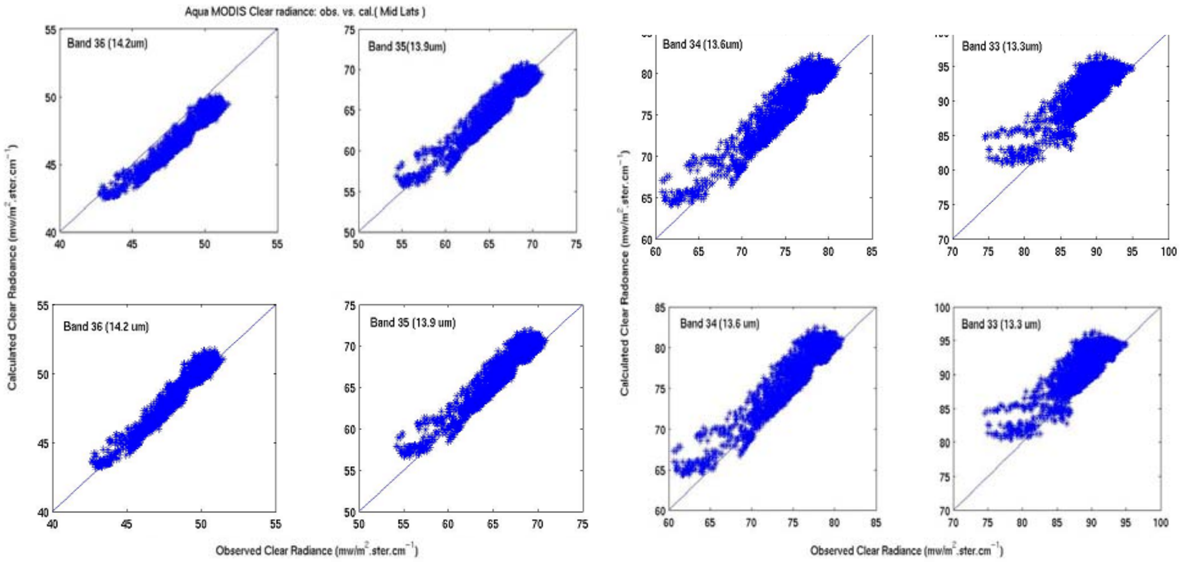

Figure 5: Scatterplots of Calculated Clear Radiance vs. Observed Clear Radiance in Mid-Lat. for band 33, 34, 35, and 36. Upper: using original Spectral Response Function, Bottom: using Tobin's shifted Spectral Response Function.

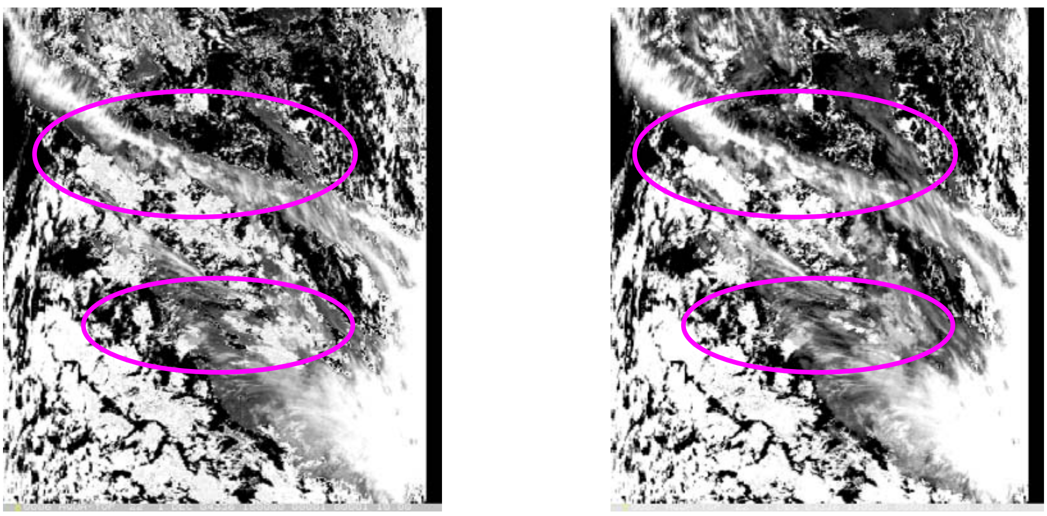

Figure 6: ECA on Aqua/MODIS 1500UTC on day 2004336. Left is from original SRF and the right from shifted SRF.

Figure 6 shows effective cloud amounts (ECA); brighter areas mean larger ECA. The pink circles show thick cloud edges that are not realistic; after the shifted SRFs were applied in the cloud retrieval, the thick cloud edges disappeared. Also, more cirrus CTPs were successfully retrieved using the ratio of band 36/35, which is theoretically more sensitive to high clouds than either the 35/34 or 34/33 ratios. This preliminary result shows the shifted SRFs improve high cloud retrieval in middle latitudes.

3.2 Study Case 2 – Tropical Area

A tropical granule is also studied; Figure 7 shows the Aqua/MODIS 11μm image (left, most clouds have very high tops), high CTP retrieved using original SRF (middle) and shifted SRF (right). After applying the shifted SRFs, more high clouds are identified. However some cloud tops are placed too high and some cirrus clouds are missing. Scatterplots of calculated vs. observed clear radiance for this case is shown in Figure 8. With the SRF shift applied, calculated clear radiances in bands 35 and 36 get much larger than observed values and may have significant errors.

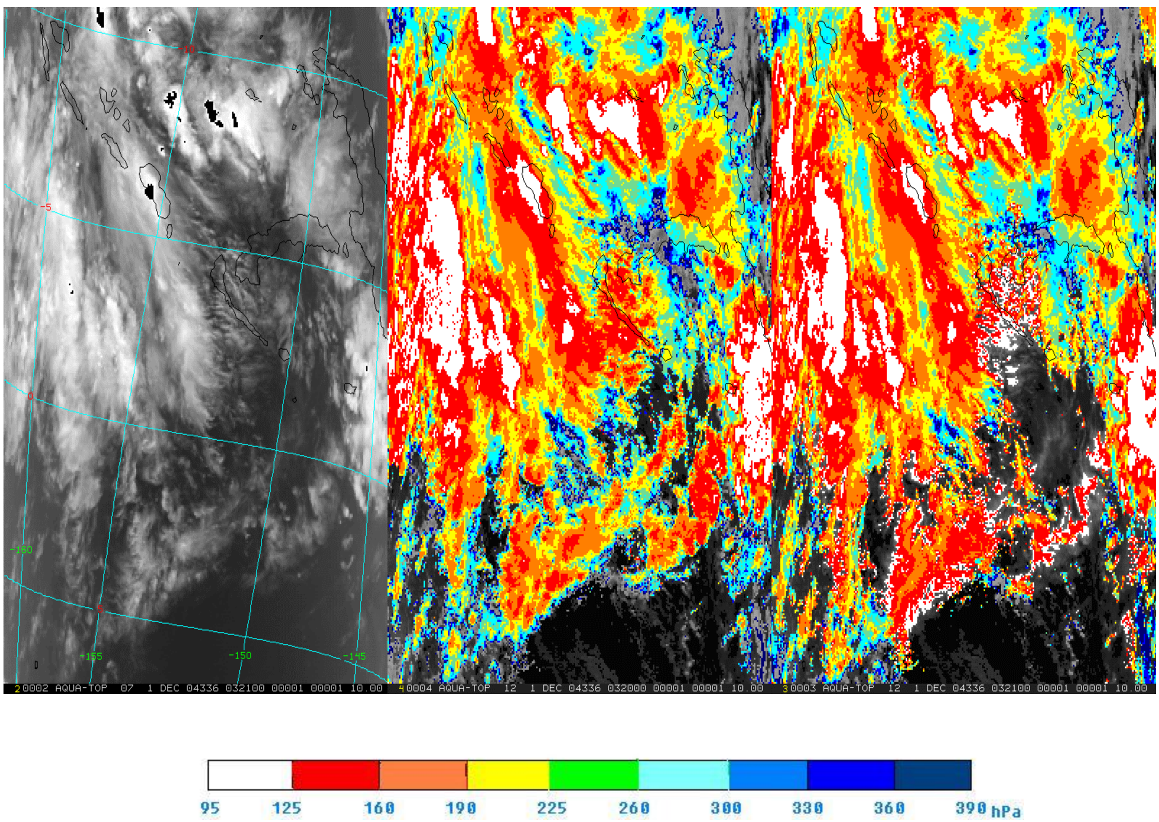

Figure 7: Aqua/MODIS 0320UTC on day 2004336: (left) Band 31 (11μm)(Black spots are due to McIDAS set the limit of temperature less than 200K); (middle) Hi CTP retrieved from original SRF; (right) Hi CTP retrieved from shifted SRF.

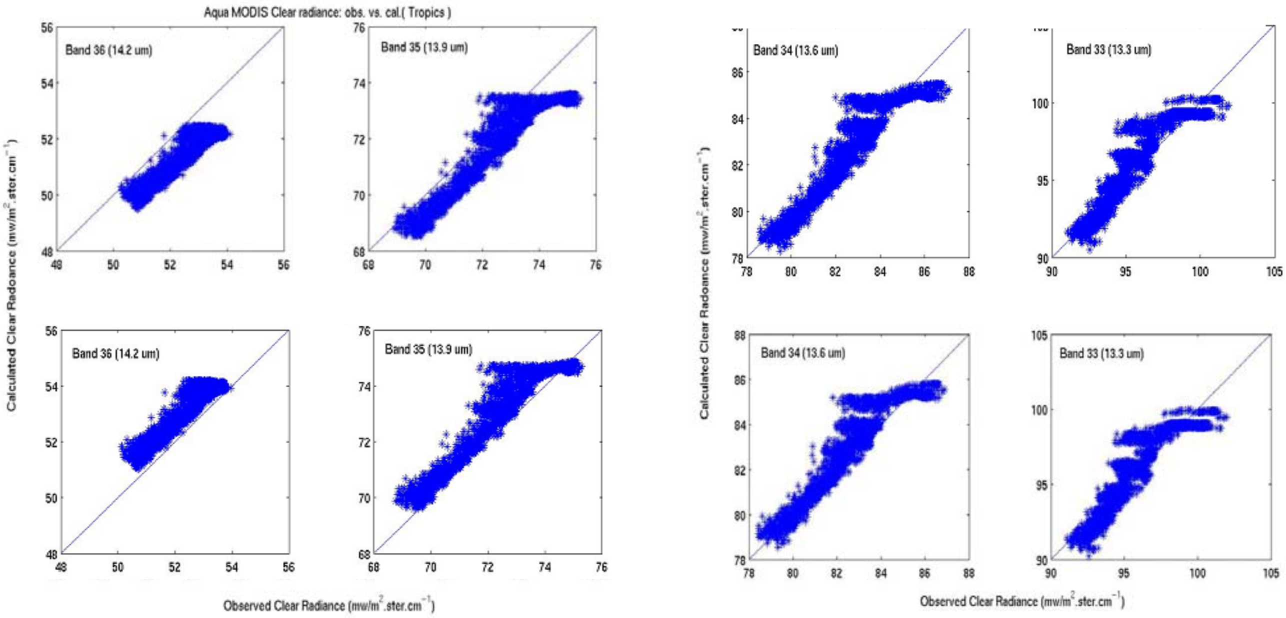

Figure 8: Scatterplots of Calculated Clear Radiance vs. Observed Clear Radiance in Tropical area for Band 33, 34, 35, and 36. Upper: using original Spectral Response Function, Bottom: using Tobin's shifted Spectral Response Function.

From an analysis of ratios selected in producing cloud top pressure retrievals for this granule, some cloud pressures were too high because the calculated clear radiances in bands 35 and 36 were adjusted too much. Some cirrus clouds in this granule are missing due to the IR window method being used instead of the CO_2 slicing algorithm. This occurs when no valid retrieval is possible using any of the CO_2 band ratios. More study is needed to understand this over-correction in tropical atmospheres.

4. Summary

In this study, comparisons of AIRS and MODIS radiance observations are reported and an adjustment to MODIS calculated clear-sky radiances are evaluated for Aqua MODIS cloud property retrievals. Radiance differences in MODIS bands 33 through 36 display clear and significant dependencies on scene temperature. Shifted SRF values are tested in MODIS cloud top properties retrievals, MODIS band 36 shows the most sensitivity to the SRF changes. Detection of high thin cirrus is found to be sensitive to changes in CO_2 channel SRFs. In the mid-latitudes, MODIS CTP retrievals are improved but in the tropics, results are mixed. More study is required to understand the nature of the AIRS/MODIS measurement differences, including a possible MODIS SRF shift.

Acknowledgments

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