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Improvements to Terra MODIS L1B, L2 and L3 science products through using crosstalk corrected L1B radiances

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ABSTRACT

Observations in the Terra MODIS PVLWIR bands 27 – 30 are known to be influenced by electronic crosstalk from those bands as senders and into those same bands as receivers. The magnitude of this crosstalk affecting L1B radiances has been steadily increasing throughout the mission lifetime, and has resulted in several detectors within these bands to be unusable for making L2 and L3 science products. In recent years, the crosstalk contamination has been recognized as compromising the climate quality status of several MODIS L2 and L3 science products that depend on the PVLWIR bands. In response, the MODIS Characterization Support Team (MCST) has undertaken an effort to generate a crosstalk correction algorithm in the operational L1B radiance algorithm. The correction algorithm has been tested and established and crosstalk corrected L1B radiances have been tested in several Terra MODIS L2 science product algorithms, including MOD35 (Cloud Mask), MOD06 (Cloud Fraction, Cloud Particle Phase, Cloud Top Properties), and MOD07 (Water Vapor Profiles). Comparisons of Terra MODIS to Aqua MODIS and Terra MODIS to MetOp-A IASI show that long-term trends in Collection 6 L1B radiances and the associated L2 and L3 science products are greatly improved by the crosstalk correction. The crosstalk correction is slated for implementation into Collect 6.1 of MODIS processing.

Keywords: MODIS, L1B, TEB, L2, crosstalk, validation, Terra

1. INTRODUCTION

The MODerate-resolution Imaging Spectroradiometer (MODIS)[1], the flagship instrument on NASA's Earth Observing System Terra satellite, has been collecting global Earth observations in support of climate research for over 17 years. Terra MODIS has 36 bands. Bands 1-19 and 26 are reflective solar bands (RSB) and are collected at 1 km spatial resolution except for bands 1 and 2 (250 m) and bands 3-7 (500 m). Thermal emissive bands (TEB) 20-25 and 27-36 are all collected at 1 km spatial resolution (Table 1, Figure 1). Each 1 km resolution band has a linear array of 10 detectors that sweeps the Earth scene in the across track direction ("whisk-broom"), using a dual-sided paddlewheel scan mirror, as well as calibration sources that include an onboard blackbody source, a solar diffuser, and a look into deep space[2]; 500 m and 250 m resolution bands have 20 and 40 detectors, respectively. The Terra MODIS L1B radiances support the generation of over 40 native resolution level-2 (L2) and gridded level-3 (L3) science products, a critical contribution to global climate research.

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Table 1. MODIS spectral and radiometric specifications for thermal emissive bands.

MWIR PVLWIR LWIR

MODIS TEB Band No.[1]	CWL (Bandwidth) (μm)	Radiometric Accuracy Specification[2]	Typical Earth Scene Temperature (K)	Saturation Temperature (K)	Primary Science Use
20	3.788 (3.70-3.88)	0.75% (0.18 K)	300	335	Surface/Cloud Temp.
21	3.992 (3.96-4.04)	10.0% (3.0 K)	335	500	Fire detection.
22	3.971 (3.93-4.02)	1.0% (0.25 K)	300	328	Surface/Cloud Temp.
23	4.057 (4.01-4.10)	1.0% (0.25 K)	300	328	Surface/Cloud Temp.
24	4.473(4.43-4.52)	1.0% (0.19 K)	250	315	Atmospheric Temp.
25	4.545 (4.50-4.59)	1.0% (0.24 K)	275	315	Atmospheric Temp.
27	6.765 (6.64-6.89)	1.0% (0.27 K)	240	315	Water Vapor
28	7.337 (7.17-7.50)	1.0% (0.32 K)	250	315	Water Vapor
29	8.524 (8.34-8.71)	1.0% (0.53 K)	300	324	Water Vapor, Cloud
30	9.730 (9.58-9.88)	1.0% (0.42 K)	250	315	Ozone
31	11.014 (10.76-11.27)	0.5% (0.34 K)	300	324	Surface/Cloud Temp.
32	12.018 (11.78-12.27)	0.5% (0.37 K)	300	324	Surface/Cloud Temp.
33	13.361 (13.21-13.51)	1.0% (0.61 K)	260	315	Cloud Top Properties
34	13.679 (13.52-13.84)	1.0% (0.58 K)	250	315	Cloud Top Properties
35	13.911 (13.74-14.08)	1.0% (0.55 K)	240	315	Cloud Top Properties
36	14.194 (14.06-14.33)	1.0% (0.47 K)	220	315	Cloud Top Properties

1. Band 26 is a reflectance band and thus not included in the list of TEB
2. for typical Earth scene radiance of that band

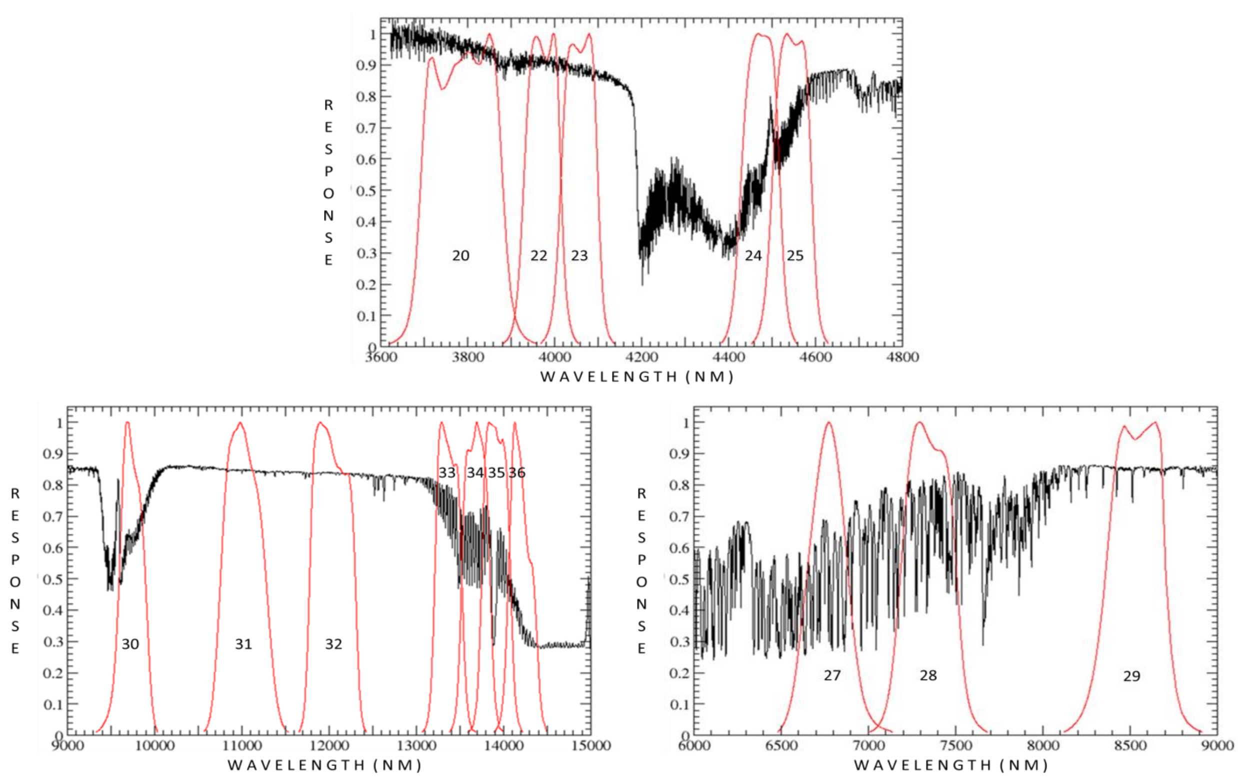

Figure 1. Terra MODIS (w/band numbers) relative spectral response for thermal bands overlain on IASI spectrum.

Sustaining the quality of Terra MODIS L1B radiances and reflectances for climate science application has been the task of the MODIS Characterization Support Team (MCST) in collaboration with the science community. Over the Terra MODIS lifetime, MCST has monitored the instrument behavior and maintained L1B product performance; this includes data analysis, Look-Up Table (LUT) generation, and L1B code modifications. When performance anomalies have been encountered, MCST has led the analysis and testing effort to identify and isolate root causes in support of forming mitigation strategies and implementing correction procedures. The restoration of L1B, L2, and L3 product quality by mitigating the effect of electronic crosstalk within the Collection 6 (C6) Terra MODIS photovoltaic longwave infrared (PVLWIR) bands 27 - 30 is the subject of this paper. These bands support MODIS atmospheric temperature and water vapor retrievals, plus cloud detection and cloud property retrievals. The climate quality of these L2 and L3 products depends heavily upon the quality of the band 27 - 30 radiances.

Electronic crosstalk in the PVLWIR bands 27 - 30 causes signal detected in one PVLWIR band/detector combination (sender) to influence the signal level in another PVLWIR band/detector combination (receiver) by either adding to or subtracting from the signal in the receiving band/detector. This phenomenon was first observed in prelaunch testing of the Terra MODIS instrument and subsequently in on-orbit Terra MODIS imagery[3]. A detector of one PVLWIR band may send to (or receive from) detectors of other PVLWIR bands or other detectors in the same band, e.g. band 29 detector 1 can send to any detector in bands 27, 28, or 30 as well as to detectors 2 - 10 in band 29. An extensive investigation by MCST of Collection 6 (C6) L1B led to a characterization of electronic crosstalk in the PVLWIR bands and a correction algorithm that is planned for implementation into the C6.1 operational MODIS L1B (MOD02) product. The crosstalk correction coefficients are based upon monthly lunar observations by MODIS. Details of the correction algorithm have been previously described[4]; this paper will focus primarily on evidence of improved L1B radiances and L2 and L3 science products resulting from the crosstalk correction for the PVLWIR bands.

2. TERRA MODIS L1B PERFORMANCE IN PVLWIR BANDS

The influence of electronic crosstalk in the Terra MODIS PVLWIR bands has gradually increased over the mission lifetime, causing, for example, Earth surface features to become prominent in atmospheric band 27, increased detector striping, and trends in radiometric biases. These observations, plus MODIS monthly lunar observations showing a correlation in signal between PVLWIR bands viewing the Moon and other PVLWIR bands simultaneously not viewing the Moon, have verified the presence of crosstalk in these bands[3,4]. Figure 2 shows an example of C6 Terra MODIS band 29 – band 31 brightness temperature differences (B29-B31) for Earth scenes before (red data) and after (green data) the crosstalk correction has been applied. The data shown in Figure 2 is for only MODIS detector 5 (product order) to eliminate detector striping that would introduce scatter to the plot. The B29-B31 difference is an important test used to identify ice cloud over water in the MODIS Cloud Mask product (MOD35). Crosstalk-contaminated B29-B31 differences have caused false cloud retrievals in the C6 MOD35 product (see Section 3). The four panels of Figure 2 each show predominantly clear sky ocean data sampled from a tropical granule in July of four separate years during the Terra MODIS mission. The effect of crosstalk on B29 has been found to be largest for tropical Earth scenes. Early in the mission (e.g. 2003, upper left panel), the Terra MODIS B29-B31 uncorrected differences (red) were very similar to those of Aqua MODIS (blue) for the same clear sky ocean scenes (3 hours later) and the crosstalk corrected B29-B31 differences (green) were very similar to the uncorrected

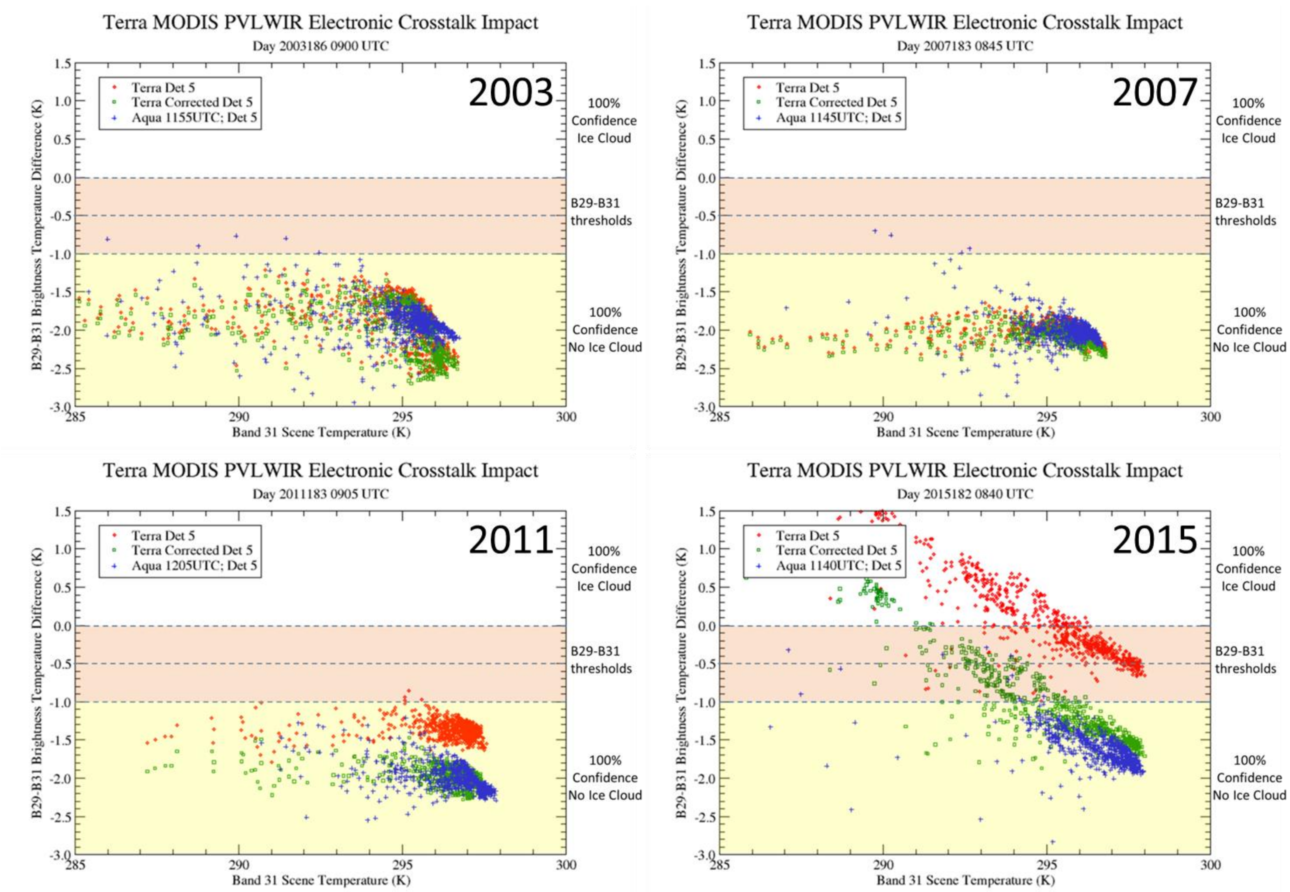

Figure 2. Terra MODIS B29-B31 brightness temperature difference examples for data scenes in four separate years. After correction (green), B29-B31 differences closely match Aqua MODIS B29-B31 differences (blue) for all years. The initially very small correction increases through the mission.

differences. However, it's evident in subsequent years that the influence of electronic crosstalk in Terra MODIS band 29 increased, causing the B29-B31 differences (red) to become more and more positive and out-of-family those of with Aqua MODIS (blue). In the more recent years, the crosstalk correction was effective and necessary in restoring agreement between the Terra MODIS and Aqua MODIS observations. Similar behavior, though of different amplitude, has been found in bands 27, 28, and 30 observations. In all cases, the crosstalk correction has brought the Terra MODIS and Aqua MODIS data into closer agreement, although the efficacy of the correction varies between bands and between detectors within bands.

Additionally, the crosstalk correction significantly reduces detector striping in the L1B radiances of the PVLWIR bands (Figure 3). This is especially true in the B27-B28 differences where striping of about 8 K (peak to valley average) is reduced to less than 1 K (left column). B29-B31 striping (center column) is reduced from about 1 K down to about 0.5 K by the correction, and B30-B31 striping (right column) is reduced from about 3 K down to about 2 K with most of that striping caused by detector 1 behavior. Note that detector striping in B31, which is unaffected by electronic crosstalk, is typically < 0.1 K and thus striping in the B29-B31 (B30-B31) differences is largely due to B29 (B30).

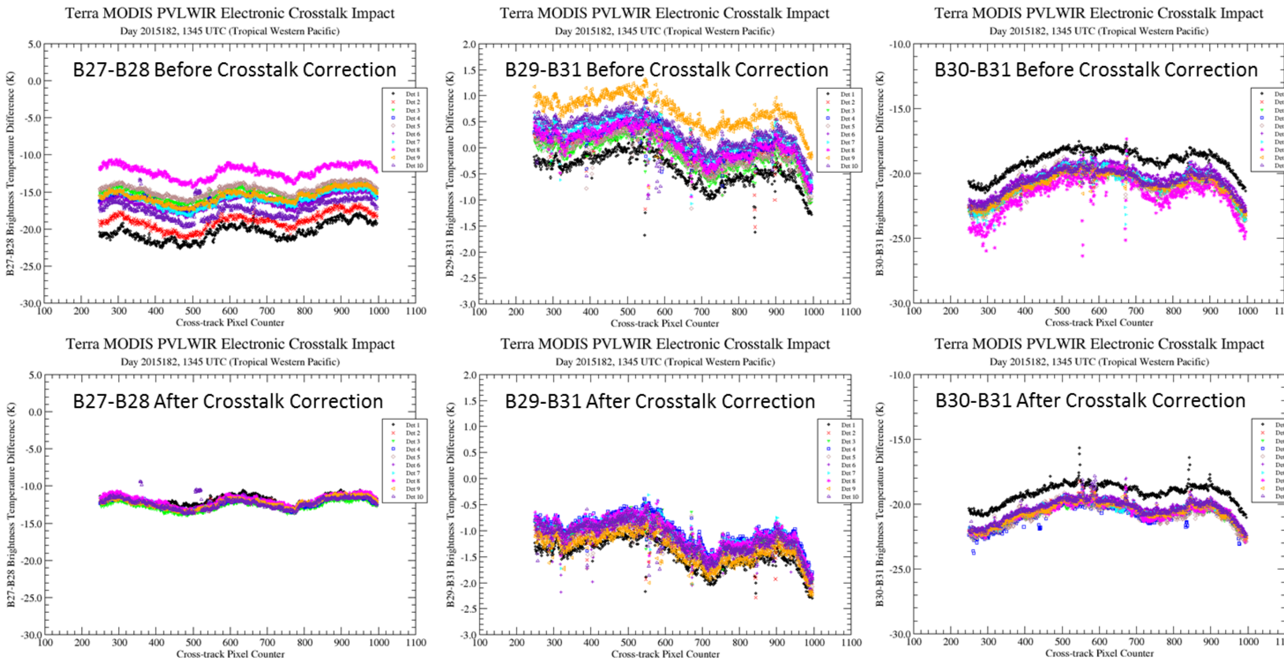

Figure 3. Sample Terra MODIS brightness temperature differences for all detectors before (top row) and after (bottom row) crosstalk correction from a tropical scene on July 1, 2015. Comparing the top row panel to the corresponding bottom row panel demonstrates the reduction in detector striping achieved through applying the crosstalk correction algorithm.

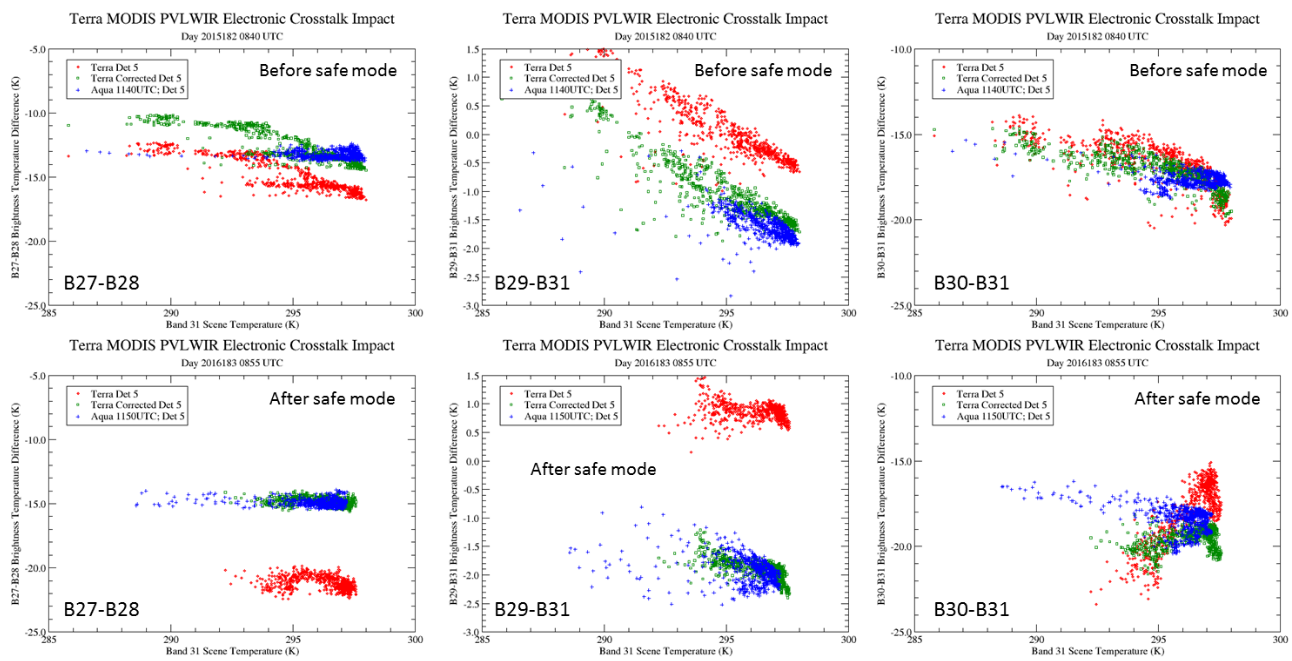

Figure 4. Sample Terra MODIS brightness temperature differences for detector 5 before (top row) and after (bottom row) the February 2016 safe mode event. For all bands, the performance of the crosstalk correction is similar after the safe mode compared to before the safe mode.

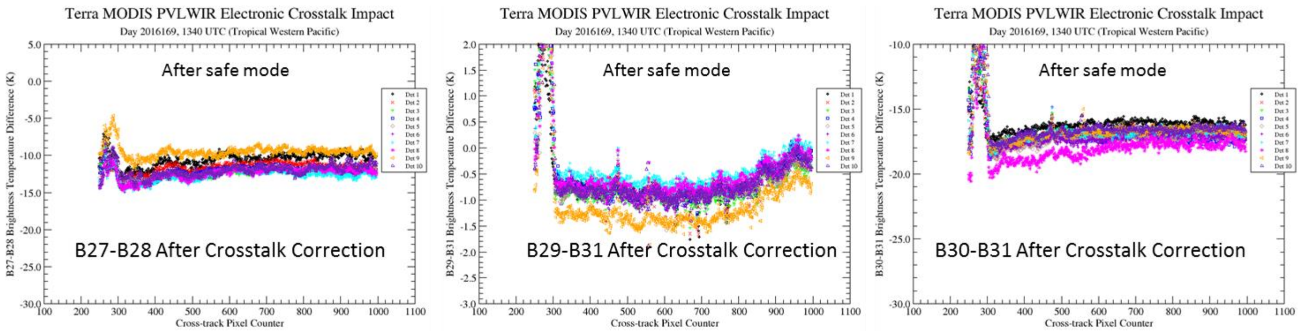

Figure 5. Sample crosstalk corrected brightness temperature differences for all detectors after the February 2016 Terra MODIS safe mode event. Comparing to the bottom row of Figure 3 indicates that detector striping is increased significantly in the B27–B28 difference after the safe mode event, is slightly increased in B29 due to detector 9 behavior, and is about the same in B30 (though more broadly spread among detectors than before).

On February 18, 2016 the Terra MODIS instrument entered a safe mode status when the Terra spacecraft exceeded specified limits on pointing during an inclination adjustment maneuver. MODIS was in safe mode from 18 to 24 February and its focal plane temperatures were uncontrolled. After the safe mode, the electronic crosstalk behavior showed a significant increase in amplitude[4]. The crosstalk correction algorithm, updated with lunar-based crosstalk correction coefficients representative of performance after the safe mode event, was tested and found to be effective in restoring Terra MODIS brightness temperatures to agreement with Aqua (Figure 4). While the detector 5 example of Figure 4 is representative, the detector to detector performance varies, causing an increase in detector striping for B27–B28 to about 3 K whereas detector striping remained about the same for B29 (0.7 K) and B30 (2 K) after the safe mode (Figure 5).

Comparisons of Terra MODIS L1B radiances with those of other well-calibrated instruments provide insight on the MODIS performance. The Terra and MetOp-A satellites both fly in a morning sun-synchronous orbit, crossing the same Earth location at nadir within minutes of each other several hundred times per month. These crossings, known as Simultaneous Nadir Overpasses (SNO), provide an opportunity to assess MODIS calibration against the well-calibrated hyperspectral IASI instrument[5,6,7]. While Terra and MetOp-A SNOs occur only in narrow high latitude belts in the northern and southern hemisphere (Figure 6) and therefore do not sample the full dynamic range of global Earth scene conditions, the comparisons still provide insight on MODIS bias trends and scene temperature dependence. For SNOs within +/-10 minutes, all MODIS 1 km field of view (FOV) radiances were averaged over a 50 km radius from the SNO point and compared to the averaged IASI 13 km FOV radiances falling within that same radius. Before averaging, the IASI radiances were spectrally convolved to the MODIS relative spectral response (RSR) shown in Figure 1. As indicated in Figure 6, the 50 km radius typically includes 14 to 16 IASI FOVs with spatial gaps and over 7000 contiguous MODIS FOVs.

The SNO comparisons for April in the years 2008 – 2016 reveal trends in time as well as bias as a function of scene temperature. The SNOs were screened to remove excessively non-uniform scenes by computing a standard deviation of the MODIS pixels within the 50 km radius of the SNO location. If the MODIS standard deviation exceeded 3 K, the SNO event was discarded. Each April had 150 – 300 SNOs after screening.

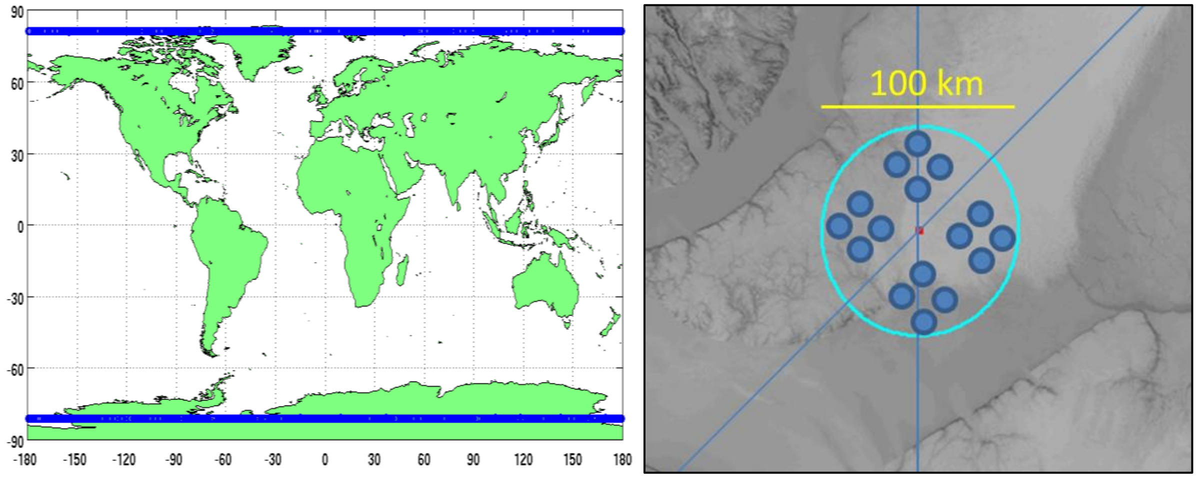

Figure 6. Typical coverage of MetOp-A and Terra SNOs across high latitude belts shown in blue (left panel) and zoomed in showing IASI FOVs (shaded blue circles) over typical MODIS 11um polar image (right panel).

Before applying the crosstalk correction the ensemble bias for all four bands shows varying levels of dependence upon scene temperature, exhibiting slopes and curvature in the plots (Figure 7). By contrast, the ensemble bias for band 31 (which is unaffected by crosstalk) shows essentially no dependence on scene temperature. Bias trends easily exceed 1 K in bands 27 and 30 over the eight year period in the MODIS comparisons with IASI, suggesting that the MODIS L1B radiances of these bands are not useful for climate science. The sharp increase in the B27 bias for April 2016 indicates a significant change in band 27 performance after the February 2016 Terra safe mode event. The safe mode event resulted in a significant increase in electronic crosstalk for all PVLWIR bands[4]. Bands 28 and 29 also show trends that are closer to 0.5 K over the period. Although these trends are smaller, they nevertheless impact L2 and L3 products, as will be seen in Section 3. The trends in all PVLWIR bands depart from those of band 31 and are indicative of the increasing influence of electronic crosstalk over the period. Further, evidence from L2 and L3 products suggests that these trends are significantly larger in warm scenes that prevail in the low latitudes of the tropical zone. Unfortunately, there are no low latitude SNOs between Terra and MetOp-A with which to verify this behavior.

After applying the crosstalk correction in the L1B algorithm, the MODIS biases and trending were significantly reduced (Figure 8). The largest improvements occur at the warmer scene temperatures with less change for cold, low signal, scenes. The scene dependence of MODIS biases is greatly reduced in all bands, most dramatically in B27 where biases of several degrees for warmer scene temperature are reduced to less than 0.5 K. The scene temperature dependence in all the PVLWIR bands after the crosstalk correction is more linear and more closely matches that of band 31. Bias trends over time are also generally reduced, most notably in B27 where the trend reduces from about -2 K for these SNO scenes down to about -0.5 K over the eight year period. The band 30 trend, while significantly reduced by the correction, is still about 1.0 K, suggesting that the crosstalk correction is not as effective for this band. Trends in band 28 and 29 become more closely matched to that of band 31, which exhibits minimal trending in the absence of crosstalk.

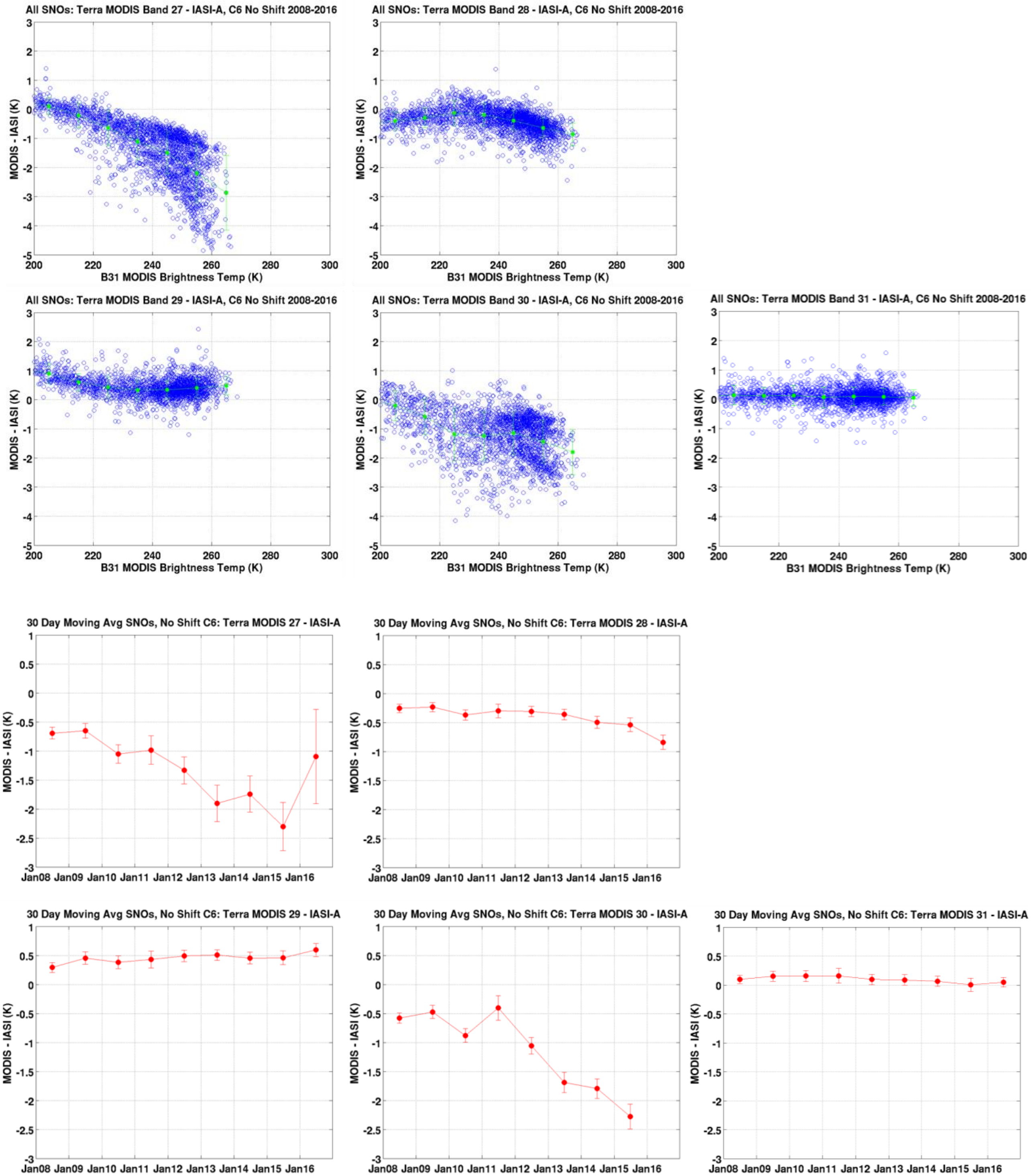

Figure 7. Terra MODIS – MetOp-A IASI SNO comparisons for bands 27 - 30 before crosstalk correction of MODIS L1B radiances. Band 31 plots provided as a band that is not affected by crosstalk.

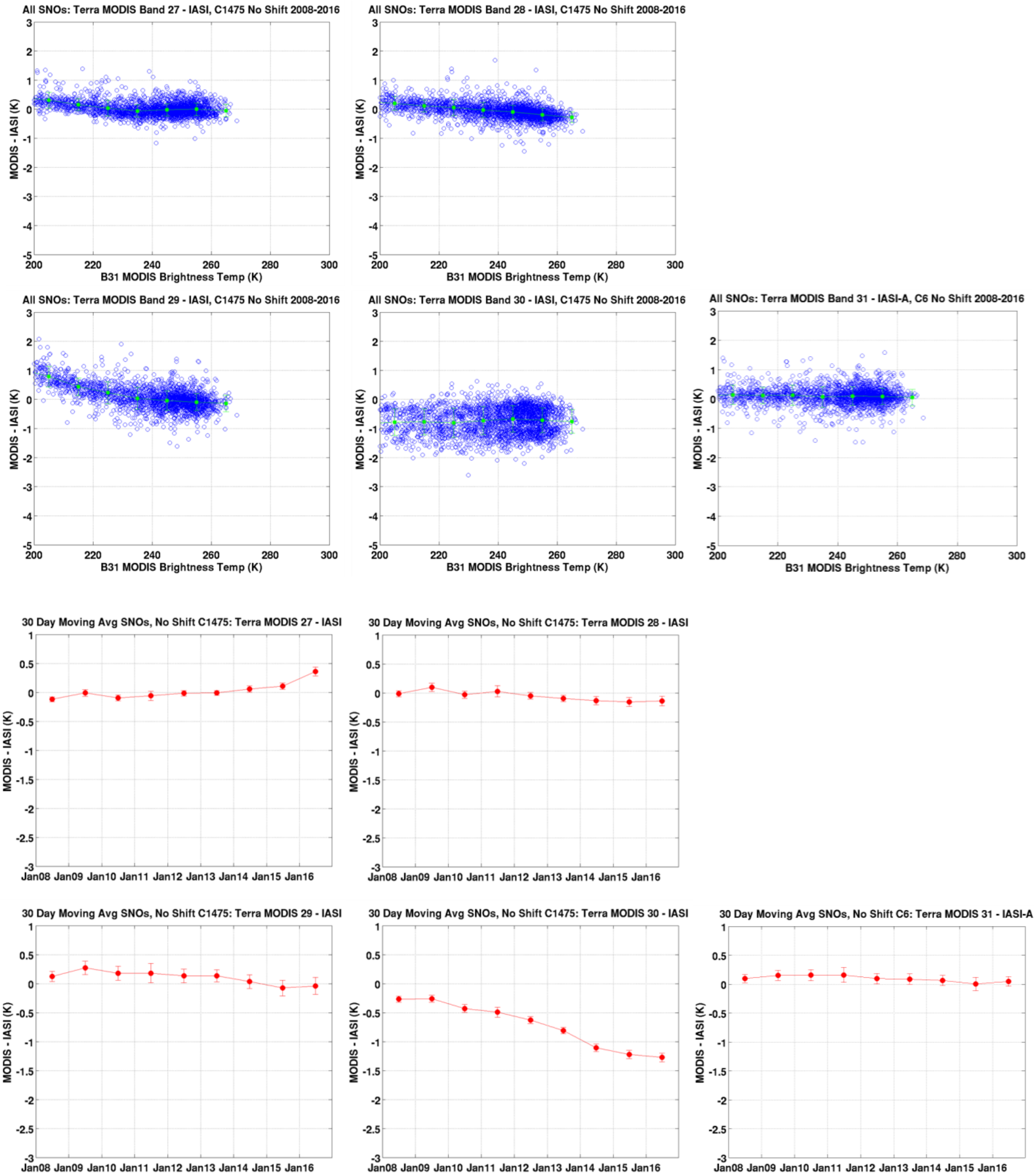

Figure 8. Terra MODIS – MetOp-A IASI SNO comparisons for bands 27 - 30 after crosstalk correction of MODIS L1B radiances. Band 31 plots same as in Figure 7.

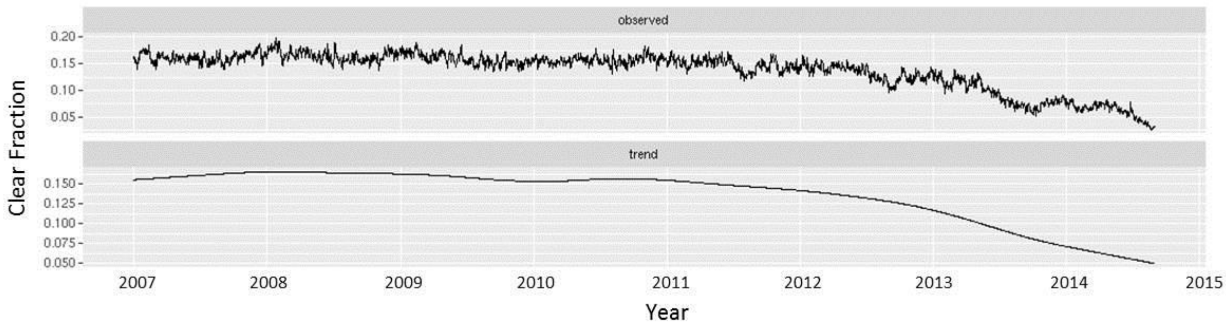

Figure 9. Fraction of confident clear pixels in the MODIS cloud mask (MOD35) as a function of time, from 60S to 60N latitude, water surfaces only.

3. TERRA MODIS L2 AND L3 PRODUCT PERFORMANCE

3.1 TERRA MODIS Cloud Mask (MOD35)

The MODIS cloud mask (MOD35) uses up to 19 spectral bands to indicate a level of confidence that a given 1-km pixel is unobstructed by clouds or aerosols (i.e., clear)[8]. MOD35 performs spectral tests using PVLWIR bands 27, 28, and 29 (see Table 1), both singly and in tandem with other bands, to discriminate between clear and cloudy skies. Band 27 (B27) brightness temperatures (BTs) are used in a high cloud test over most of the globe while B27-B31 brightness temperature differences (BTDs) are used to determine clear sky pixels (strong temperature inversions) in polar night conditions. B28-B31 BTDs are useful for cloud detection in nighttime land scenes and for both cloud and clear sky detection in polar night conditions. B28-B29 BTDs are employed for middle and low cloud detection over nighttime oceans and B29-B31 BTDs detect ice clouds over both day and night oceans.

This latter ice cloud test was particularly problematic as B29 BTs began to warm relative to B31 over time due to the increase of electronic crosstalk. Each cloud test in the MOD35 algorithm has three associated thresholds: confident clear, mid-confidence, and confident cloud. The B29-B31 ice cloud test threshold values are -1.0K, -0.5K, and 0.0K, respectively (see Figure 2 for illustration of these thresholds). Note that a B29-B31 BTD < -1.0K means there is high confidence of no *ice* cloud in the pixel, not necessarily that the pixel is free of *any* cloud. As B29 continued to warm, the BTDs for actual clear pixels began to cross the confident clear (see 2011 case in Figure 2), then the mid-confidence, and finally the confident cloud thresholds (2015 case in Figure 2). MOD35 final results are reported as "confident clear", "probably clear", "probably cloudy", and "confident cloudy". Beginning in about 2011, the B29-B31 test began to result in MOD35 labeling actual clear-sky oceanic pixels as "probably clear". With the passage of more time, clear pixels became increasingly "probably cloudy", and finally, "confident cloudy", i.e. false cloud. (For a discussion of how individual spectral tests are combined to form the four final cloud mask classes, see [9]).

This progression is illustrated in Figure 9, showing the fraction of MOD35 confident clear pixels from 60S-60N over oceans as a function of time (trend). One sees a decrease beginning in about 2011 that accelerates in following years. The variability in the clear fraction (observed) also decreases after this date, indicating that cloudy vs. clear sky discrimination has become severely compromised in oceanic regions of the world.

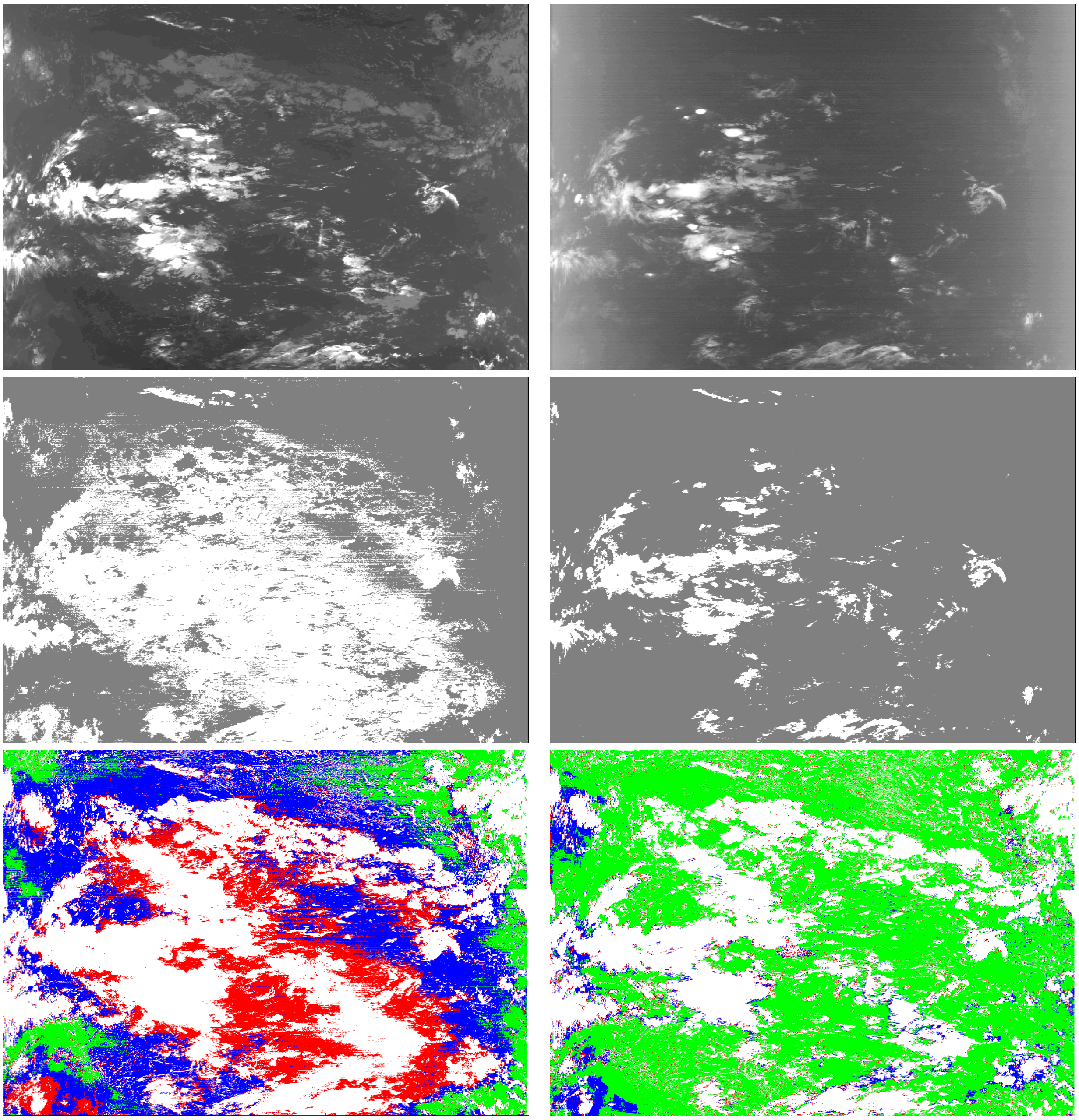

Figure 10. MODIS granule from 31 March 2014 at 05:30 UTC. Parts a, b (top row) are MODIS bands 31, 35 (11.1, 13.9 µm), parts b, c (middle row) show results of 8.6-11.1 µm BTD ice phase cloud test for pre- and post- crosstalk calibration correction, parts e, f (bottom row) are final mask results for pre- and post- crosstalk calibration correction. Green is confident clear, blue is probably clear, red is probably cloud, and white is confident cloud.

The crosstalk corrections made to Terra MODIS L1B greatly improved the performance of the MODIS cloud mask. An example of the change in the B29-B31 BTD test and resulting output cloud mask is shown in Figure 10. Parts a and b (top row, left and right) show 11.1 and 13.9 µm imagery, respectively, from this nighttime scene located in the tropical eastern Pacific. Parts c and d (middle row) are depictions of the B29-B31 BTD test where the white areas indicate confidence of clear sky < 0.5 (cloudy) before and after applying the crosstalk correction to L1B, respectively. The value 0.5 is the mid-confidence threshold mentioned above. Note that the cloudy regions in part d correspond closely to the 13.9 µm imagery that shows mainly high and presumably ice clouds. Parts e and f (bottom row) are similar to c and d but illustrate changes in the final output cloud mask (i.e., changes in the spatial distributions of the four output classes mentioned above). Green is clear, blue is probably clear, red is probably cloudy, and white is confident cloudy. The improvement in discrimination between clear and cloudy pixels is dramatic. The other spectral tests listed at the beginning of this section are also impacted positively by the crosstalk correction but the largest overall improvement to MOD35 is through the B29-B31 BTD test as illustrated in Figure10.

3.2 TERRA MODIS Cloud Top Properties (MOD06CT)

Two other MODIS atmosphere products, found in MOD06 L2 output files, were impacted by the upward drift in B29 (8.6 µm) radiances. The IR cloud phase was severely impacted as far too many clouds were labeled as ice phase or undecided. In the CO_2 slicing cloud top pressure algorithm, too many clouds were determined to be middle or high level (cloud top pressure too low).

Figure 11 shows pre- and post- crosstalk correction examples of these two products for a 5-minute granule located in the southern subtropical Pacific Ocean. Parts a and b (top row, left and right) show B31 (11 µm) and B35 (13.9 µm) imagery. Higher and colder clouds are bright white in the B31 image, while middle and low level clouds are gray and the surface is very dark. Due to atmospheric CO_2 absorption, B35 imagery shows only middle and high level clouds. Parts c and d (middle row) show cloud top pressure (CTP) retrievals using pre- and post- crosstalk L1B input radiances. The colored pixels indicate high clouds (CTP < 440 hPa) where the highest clouds are yellow, orange, and red. The CTPs are very similar between the two except for the scattered high cloud retrievals over the low clouds in the pre-crosstalk correction results (center of left hand image). This was due to a skewed ratio of observed minus calculated 8.6 µm to 11.1 µm radiances ("beta ratio")[10] used to screen out unreliable retrievals over water phase clouds. This screening has returned to its normal effectiveness as seen in part d. Parts e and f (bottom row) show pre- and post-crosstalk IR cloud phase retrievals. Red indicates ice phase, blue is water phase, and yellow is undecided. Previous to the crosstalk correction, there was a large number of undecided phase retrievals which have disappeared with the change to the L1B data. A key spectral test in the IR phase algorithm is the B29-B31 BTD. As crosstalk increased causing B29 to warm relative to B31, that BTD became less negative, eventually coming to the point where actual water phase clouds were yielding BTDs normally associated with mixed phase or multilayer clouds, hence the "undecided" designation.

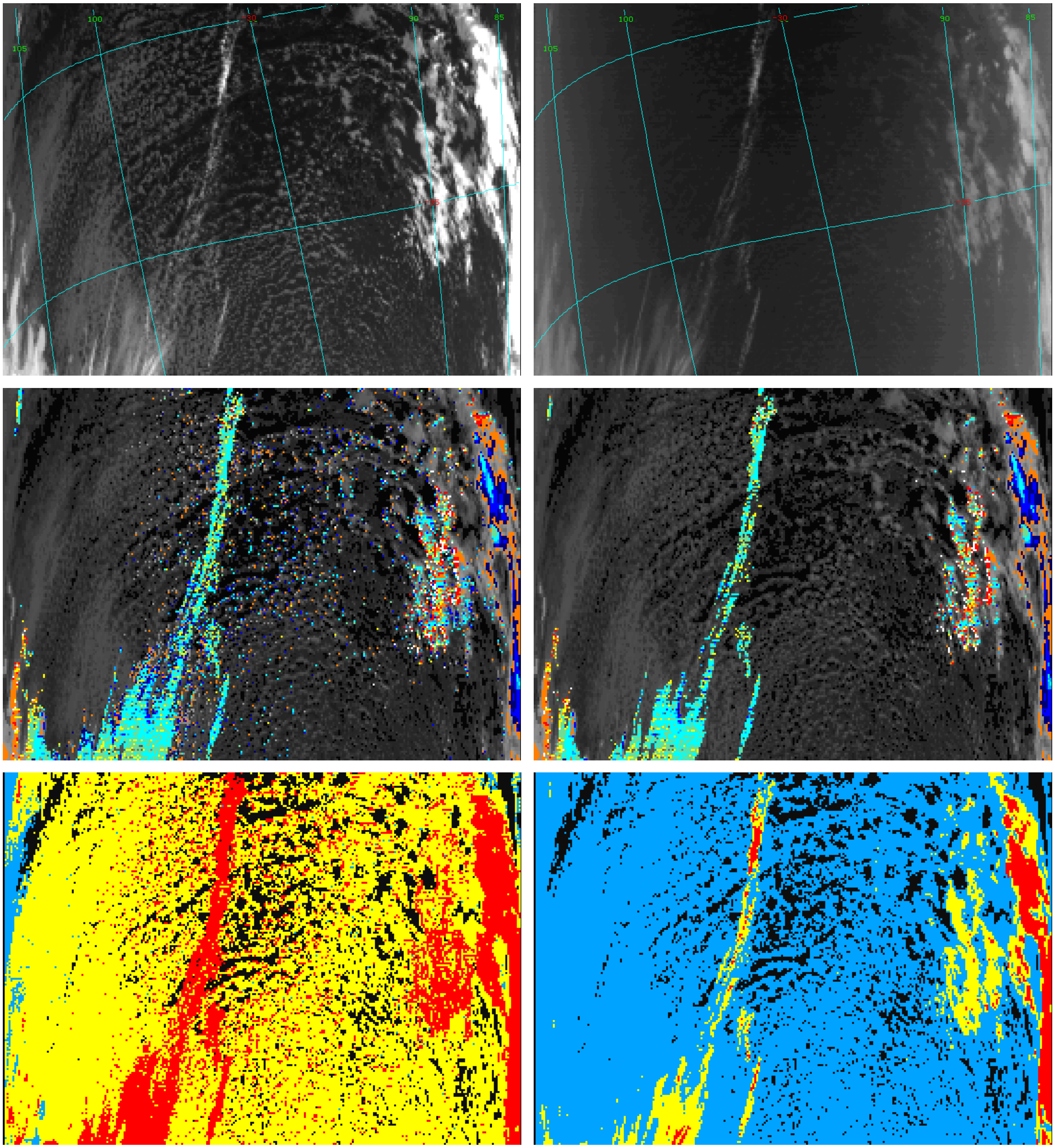

Figure 11. MODIS granule from 1 July 2016 at 16:30 UTC. Parts a, b (top row, left and right) show MODIS B31, B35 (11.1, 13.9 µm) imagery, parts b, c (middle row) detail CO_2 slicing results for pre- and post- crosstalk calibration correction (colored pixels are CTPs < 440 hPa). Parts e, f (bottom row) are IR cloud phase results for pre- and post-crosstalk calibration correction. Red indicates ice phase, blue is water phase, and yellow is undecided.

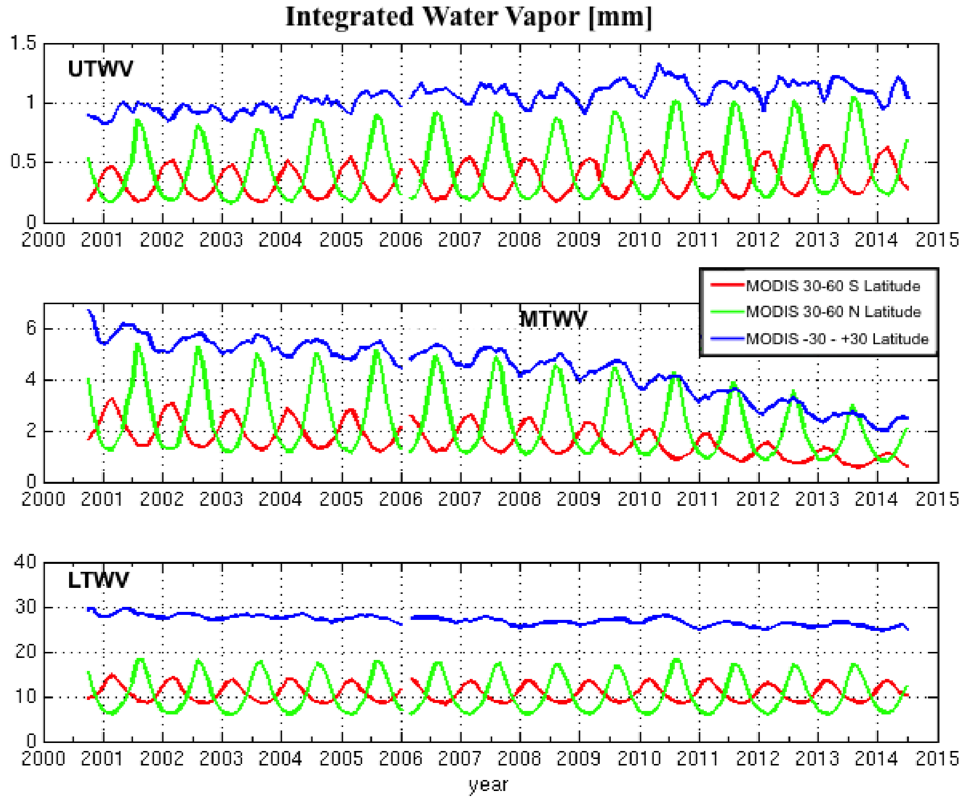

Figure 12. Time series of C6 monthly mean Terra MODIS upper, middle and lower troposphere integrated water vapor (UTWV, MTWV, LTWV, respectively) for the mid-latitude North (30N - 60N, red), mid-latitude South (30S - 60S, green) and tropical latitude (30N - 30S, blue) zones at nighttime.

3.3 TERRA MODIS Atmospheric Profiles (MOD07)

The L2 operational algorithm for retrieving temperature and moisture profiles, total column ozone, total and layer integrated water vapor from infrared (IR) radiances observed by the NASA Terra MODIS instrument is a clear sky synthetic regression retrieval algorithm called MOD07. MOD07 inputs are the clear-sky radiances over land and ocean for both day and night from eleven MODIS infrared channels (25, 27-36) that include the crosstalk affected PVLWIR bands. The operational algorithm consists of several procedures that include cloud filtering (MOD35), averaging clear radiances over 5 by 5 field-of-view (FOV) areas, forward model calculations, and a regression based retrieval. The radiative transfer calculation of the MODIS spectral band radiances is performed using the JCSDA Community Radiative Transfer Model (CRTM)[11] including spectral shifts to some bands (27-28, 30, 34-36) to bring their radiances in line with those of the AIRS[12] and IASI sensors[13].

Trends in the C6 MOD07 upper (UTWV, above 440 hPa), middle (MTWV, between 440 and 640 hPa) and lower (LTWV, below 640 hPa) troposphere water vapor show a noticeable negative trend in the MTWV and a modest positive trend in the UTWV, especially over the tropics (Figure 12). These trends are not found in corresponding Aqua MODIS C6 products and point towards a biasing of the Terra MODIS trends due to crosstalk increasing in the PVLWIR bands.

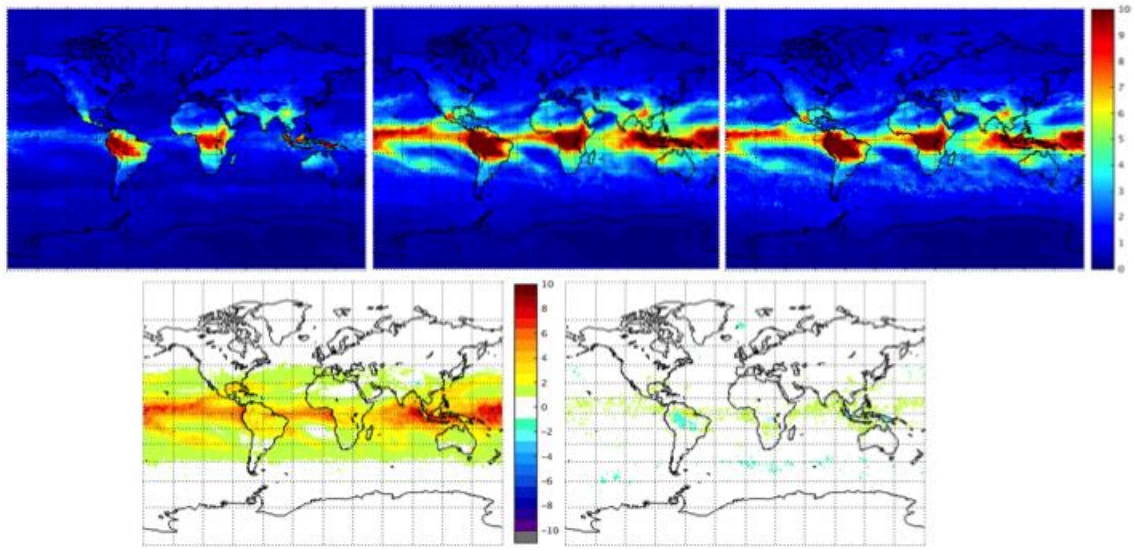

Figure 13: The MOD08 integrated water vapor of the middle troposphere (MTWV) for April 2015 from Terra MODIS C6 (top left), Aqua MODIS C6 (top middle) and crosstalk corrected Terra MODIS (top right). Differences between Terra C6 and Aqua C6 (bottom left) and Terra crosstalk corrected and Aqua C6 (bottom right) are also shown.

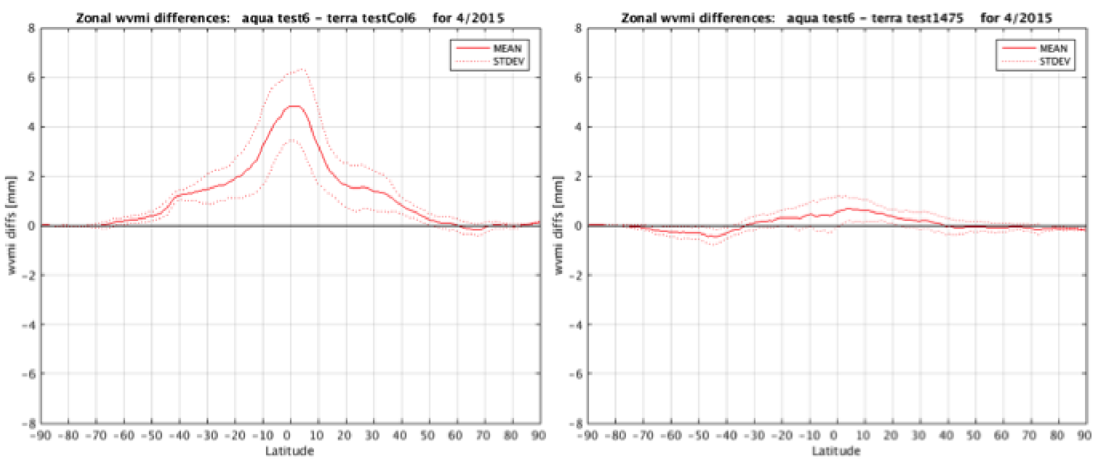

Figure 14: The latitudinal profile of the April 2015 MOD08 MTWV differences between Aqua MODIS C6 and Terra MODIS C6 (left), and between Aqua MODIS C6 and Terra MODIS crosstalk corrected (right).

To investigate this, the NASA DAAC provided Terra MODIS crosstalk corrected L1B plus MOD07 and MOD08 (L3) layer integrated water vapor products for the month of April in every year from 2000 through 2016, plus July 2016. Figure 13 shows three (Terra C6, Aqua C6, and Terra crosstalk corrected) fields of MTWV for April 2015. The bottom panels show the MTWV differences between C6 Terra and C6 Aqua (left) products and between the crosstalk corrected Terra and C6 Aqua (right). The C6 Terra MTWV (top left panel) is artificially reduced by crosstalk errors in band 27 and band 28, especially in the tropics over ocean.

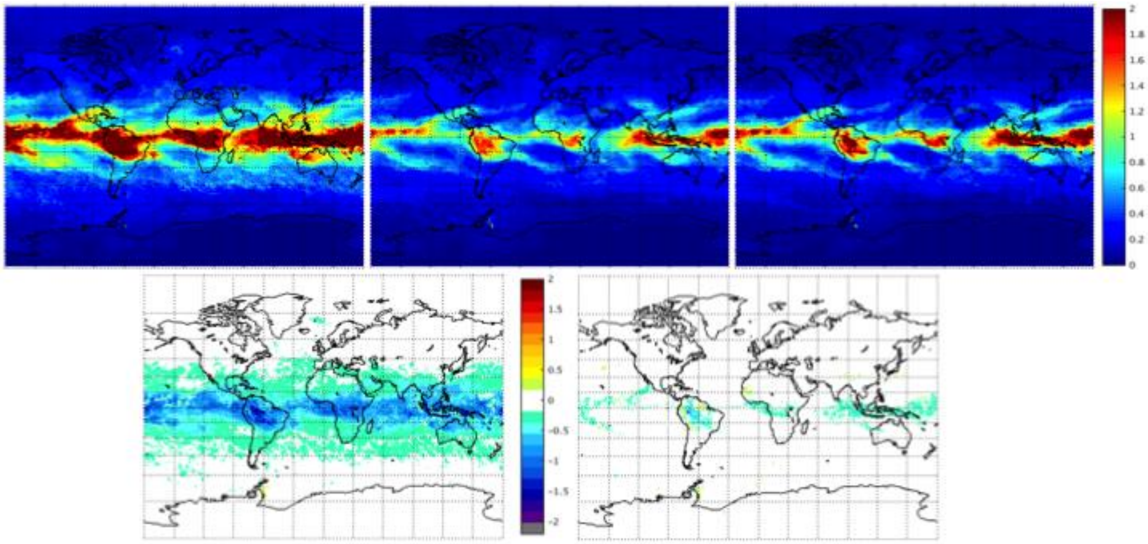

Figure 15. Same as Figure 13, except for upper troposphere (UTWV).

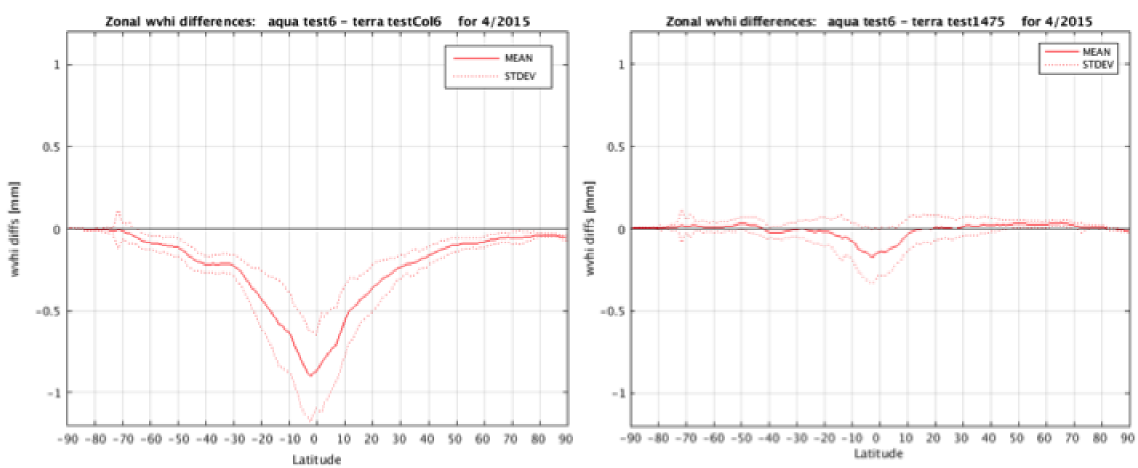

Figure 16. Same as Figure 14, except for upper troposphere (UTWV).

However the crosstalk corrected MTWV (top right panel) much more closely matches that of Aqua MYD07 (top middle panel) with differences falling to less than 2 mm over the entire globe (bottom right panel).

The distribution of the latitudinal mean differences for April 2015 is plotted in Figure 14. The left panel represents the mean and standard deviation of the differences between C6 Terra and Aqua and the right panel shows the same using the Terra crosstalk corrected data. The Terra C6 differences shows a strong latitudinal dependence in the distribution with the maximum occurring in the Equatorial zone (5mm; ~ 50% of the absolute value); after the crosstalk correction, the mean differences are reduced at all latitudes and the latitudinal dependence is largely removed with equatorial zone differences less than 0.8mm (< 10% of absolute value). Standard deviations are also significantly lowered, suggesting that the uncertainty of the MOD08 product is reduced.

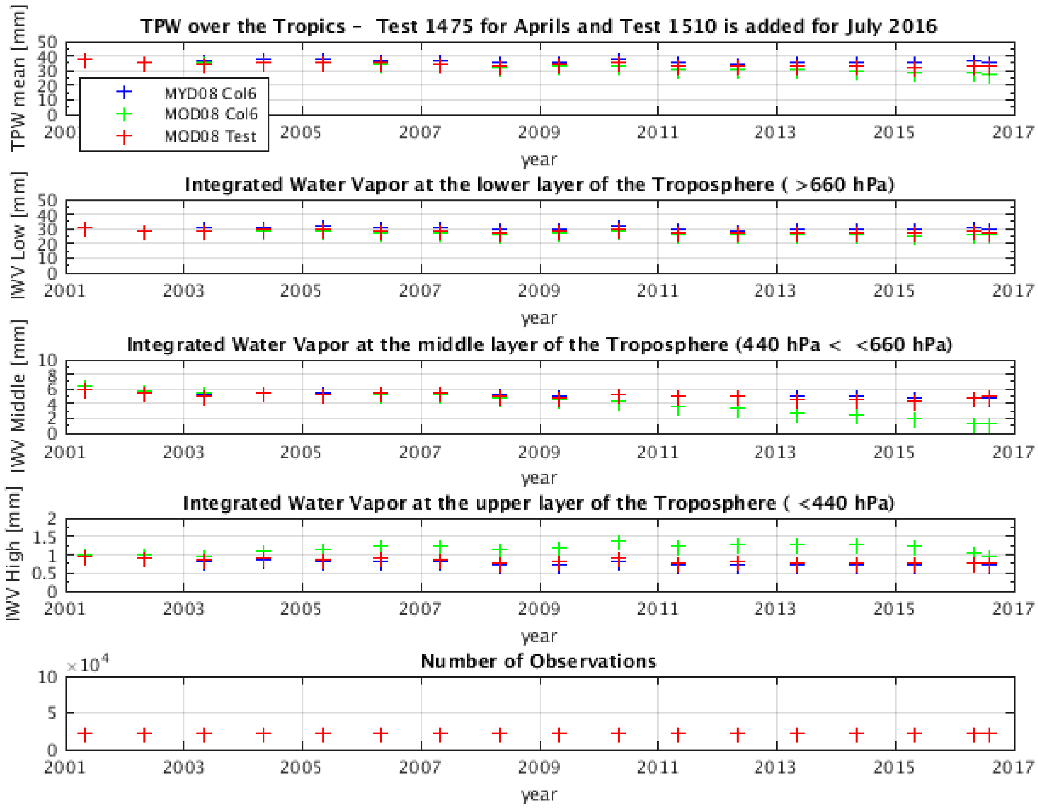

Figure 17: Terra (MOD) and Aqua (MYD) tropical integrated water vapor 16 year trends for total (TPW), lower, middle and upper layers for C6 and for Terra crosstalk corrected ("Test"). The crosstalk correction moves the Terra moisture trends into closer agreement with the Aqua trends in all layers.

Figures 15 and 16 are similar to Figures 13 and 14, except showing UTWV results. The effect of the crosstalk error on the UTWV is to on average increase the water vapor amount (opposite of MTWV). Again, after crosstalk correction, the Terra MODIS UTWV product much more closely matches that of Aqua MODIS. Figure 16 illustrates that the maximum differences occurring in the equatorial zone are also largely eliminated and standard deviations are reduced by the crosstalk correction (right panel of Fig 16).

Figure 17, a time series of the L3 total, LTWV, MTWV and UTWV integrated water vapor in the tropics, indicates that the crosstalk error in C6 radiances caused a moisture deficit in the lower and middle layer of the troposphere and excessive moisture in the upper troposphere. The time series show this becoming more pronounced in about 2010 (see green crosses) for LTWV and MTWV and evident already in 2003 for UTWV (note that the scaling is different for each plot and may be masking behavior of LTWV and MTWV earlier in the mission). The trends from 2001 to the present for crosstalk corrected Terra TPW, UTWV, MTWV and LTWV (red crosses) show that the crosstalk correction is moving the Terra moisture products closer to the Aqua determinations (especially for UTWV and MTWV). The crosstalk corrected Terra trends may be further altered by adjustments to the spectral shifts of bands 27-28 and 30. These shifts will be re-evaluated using crosstalk corrected L1B radiances when the crosstalk correction goes into the operational Terra MODIS L1B product algorithm C6.1, anticipated in the 2nd half of 2017.

4. SUMMARY

A crosstalk correction developed by MCST for Terra MODIS PVLWIR bands 27-30 has been tested in L1B, L2 and L3 science products to address poor performance found in Terra MODIS Collection 6 products that use the PVLWIR bands. The correction has brought Terra MODIS L1B into much closer agreement with that of Aqua MODIS and has largely eliminated calibration bias trends in these bands when compared to MetOp-A IASI. In L2 and L3, the correction has removed abundant false cloud results in the MOD35 Cloud Mask product, especially in tropical regions where the crosstalk correction of Earth scene radiances exceeds 1 K. The improvement to the L1B radiances plus improvements in the MOD35 performance flow down to other L2 products such as MOD06 Cloud Phase and Cloud Top Properties where many "uncertain" retrievals are now correctly retrieved as "water" cloud and many false high cloud retrievals are eliminated. The MOD07/08 integrated water vapor product trends match those from Aqua MODIS much more closely for all atmospheric layers although some departures yet exist which may signal that the spectral shifts applied to bands 27, 28 and 30 for C6 MOD07 processing are not accurate after the crosstalk correction. These shifts will be reviewed and updated. A latitudinal dependence caused by the crosstalk error is also largely eliminated. This work suggests that these Terra MODIS products can be restored to climate quality status by the crosstalk correction. The PVLWIR band crosstalk correction is recommended for implementation into Terra MODIS operational C6.1 processing.

5. ACKNOWLEDGEMENTS

The development of the crosstalk correction by MCST enables the improvements achieved in the L2 and L3 products discussed in this work. Test data sets were generated by the staff at MODAPS. This work has been funded under NASA Grant NNX14AH48G.

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