MODIS Thermal Emissive Band Crosstalk Workshop

For the MODIS Sensor Working Group (MsWG)
August 1, 2018

Introduction

- The MODIS TEBs (20-25 and 27-30) for both Aqua and Terra show signs of electronic crosstalk. This contamination can have an impact on Earth-view imagery.

- A correction to the contamination can be derived from lunar imagery, and has been applied to Terra bands 27-30 in Collection 6.1.

- The same methodology can be applied across each affected band in both Aqua and Terra MODIS.

- We will assess the impact on Earth-view imagery for each of the remaining bands in Aqua and Terra MODIS.

Outline

- Impact of the contamination on Earth-view imagery.

- Development of the algorithm and derivation of the crosstalk coefficients.

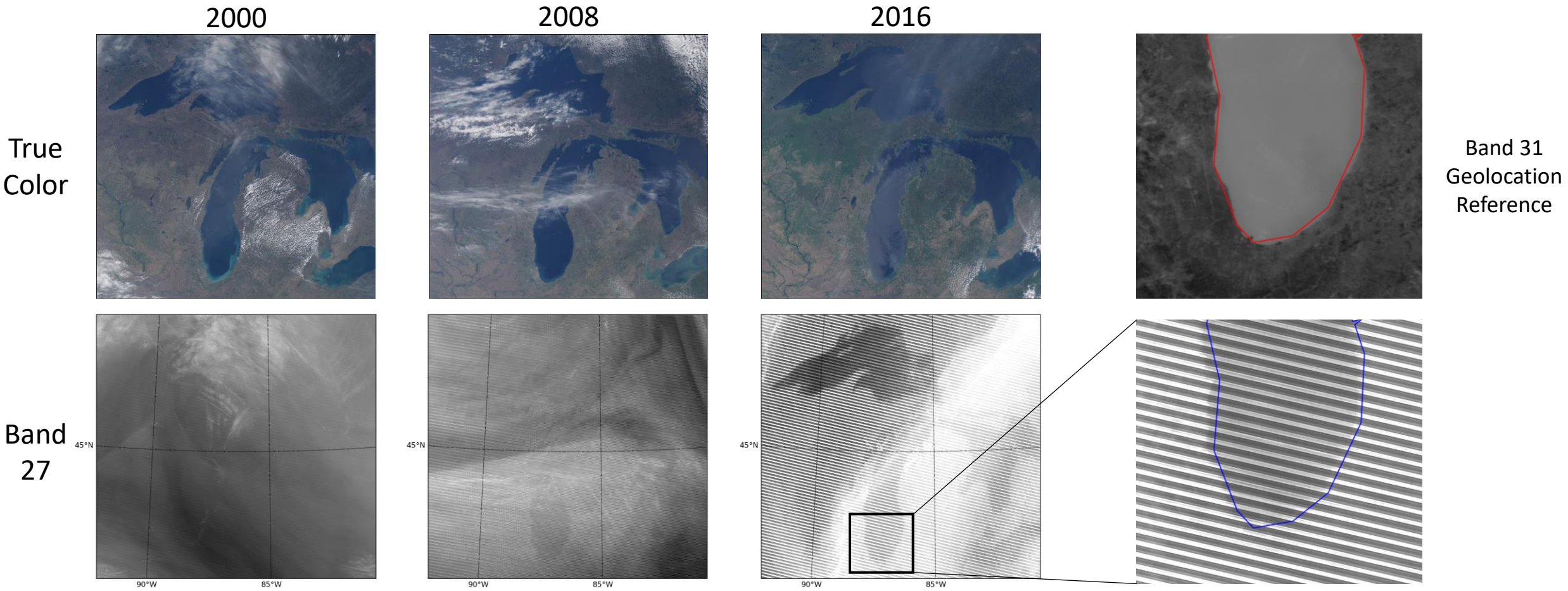
- Sample image corrections
  - A look at corrected/uncorrected images where the contamination is most apparent
  - Brightness temperature retrieval histograms
  - Line profile comparisons

- Correction assessment over warm ocean scenes
  - Use a long-term trending data set over the equatorial Pacific Ocean
  - These scenes are near or slightly above the typical brightness temperature for the TEBs
  - Provides a good opportunity to assess the long-term performance of the correction

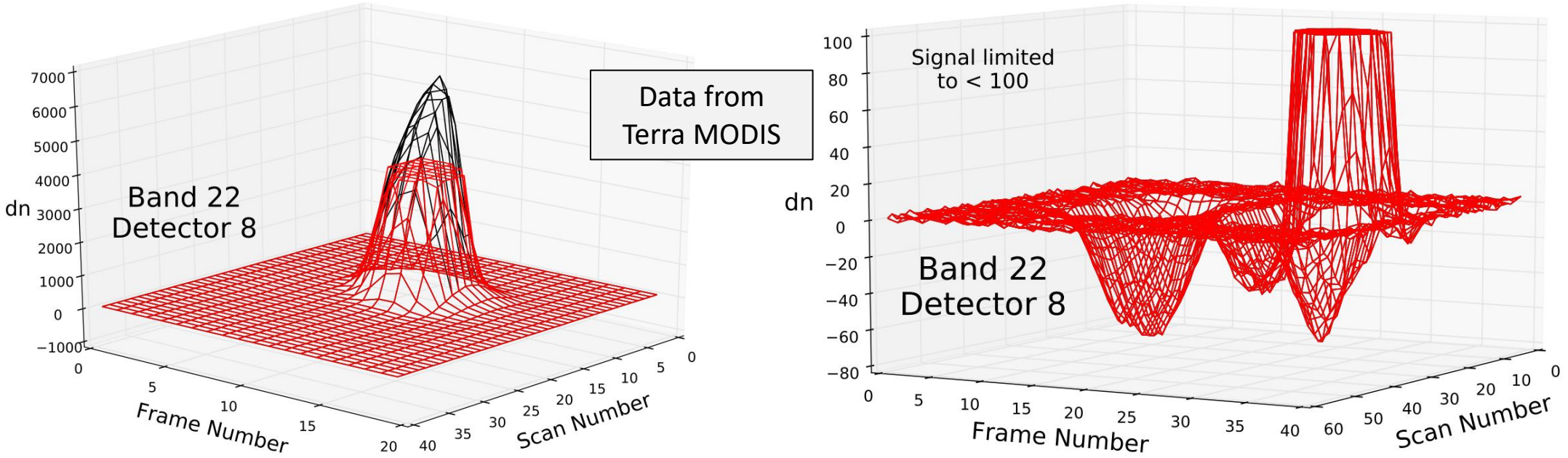
- Magnitude of the impact for 1-orbit of data
  - Some differences observed for day versus night for bands impacted at low brightness temperature

Appearance of the Land/Water Boundary

- As the Terra mission progressed, signal contamination increased, and is seen in the form of striping and the appearance of a land/water boundary in band 27. The boundary appears offset from the expected location of the feature, implying that the contamination comes from another band on the FPA.

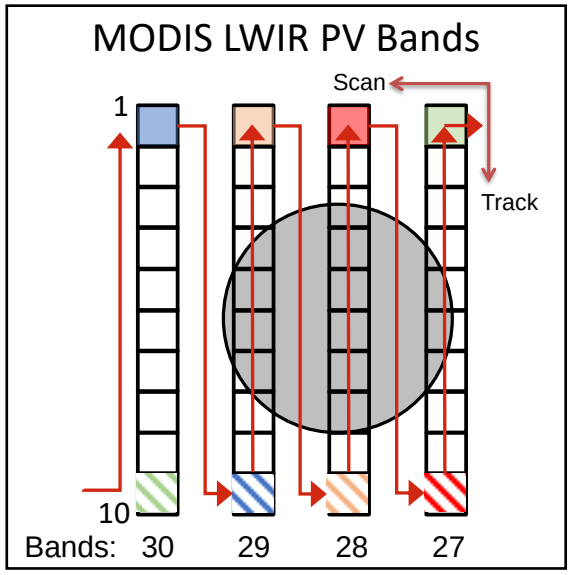


Lunar Images



- The signal during lunar observations saturates at 4095 before background subtraction due to the high scene temperature of the Moon (**red data**).
- The saturation can be corrected using the ratio of the unsaturated pixel values with band 31 (**black data**).
- Outside of the main lunar signal, contamination can be seen in the form of a signal deviation from the background level.

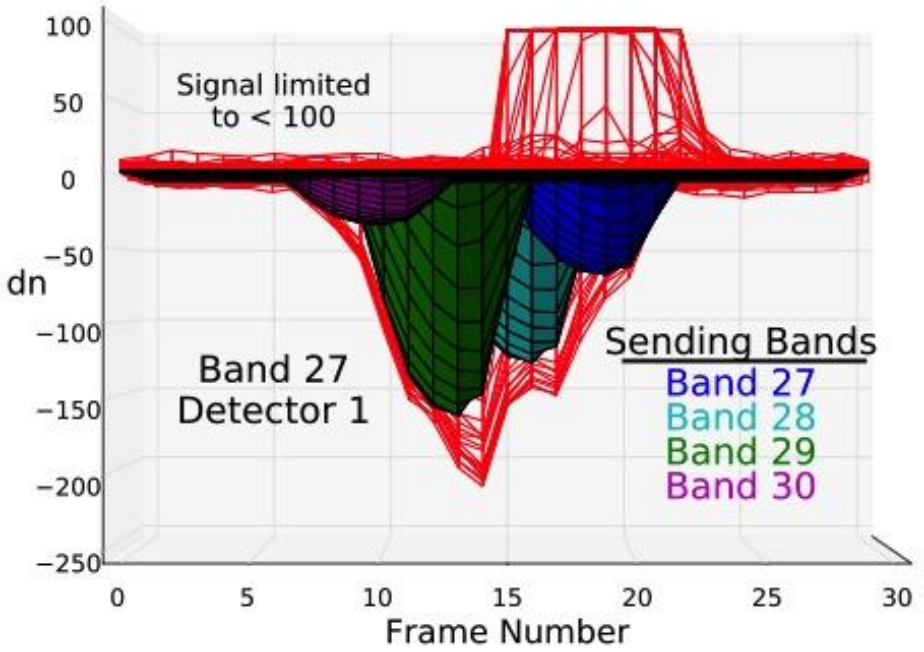
Development of the Algorithm

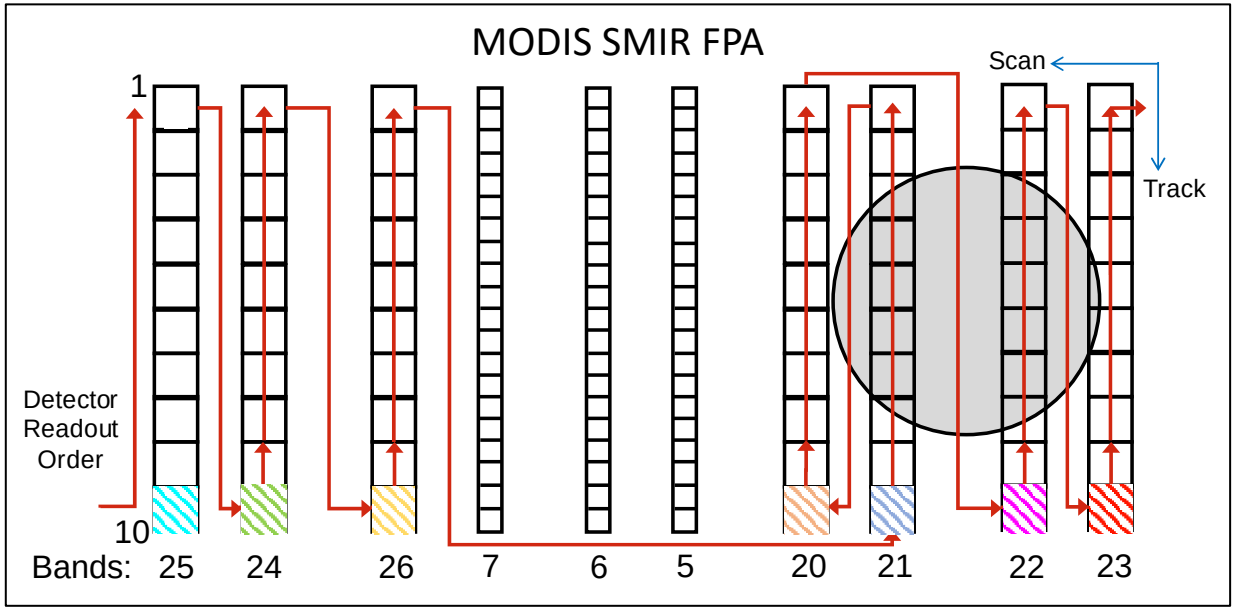


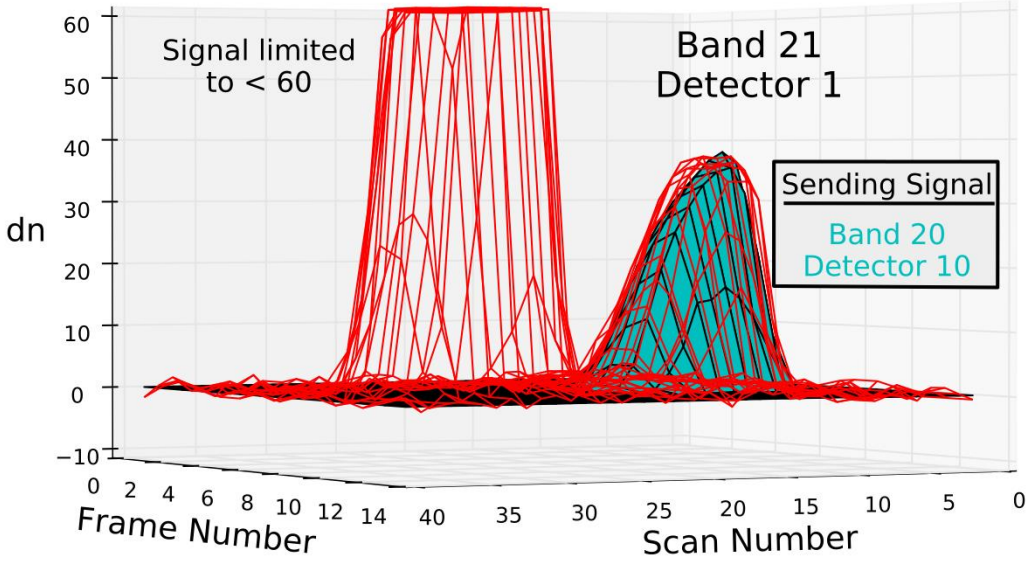
Detector 1 Receiving

Detector 10 Sending

Detector Readout







Deriving the Correction Coefficients

- We linear correction coefficients, $c_{i,j}$, to to correct the background subtracted signal for a given detector, i, in every data sector.

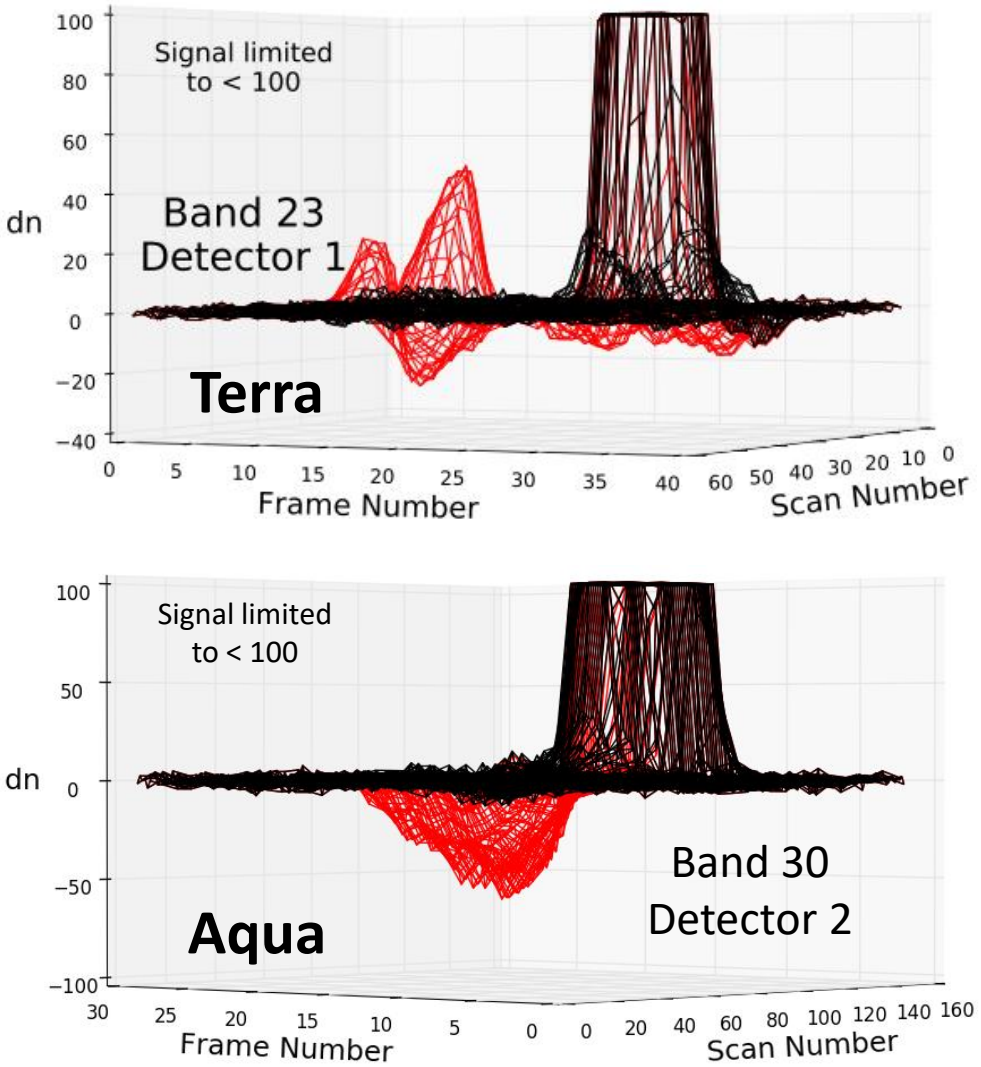
$$dn_i(S,F) = dn_i^* - \sum_j c_{i,j} \cdot dn_j^*(S, F + \Delta F_j)$$

- To derive the coefficients, we minimize the contamination relative to a reference signal by varying the values of $c_{i,j}$.

$$\eta_i^2 = \sum_{S,F} \left(dn_i^*(S,F) - dn_{ref,i}(S,F) - \sum_j c_{i,j} \cdot dn_j^*(S, F + \Delta F_j) \right)^2$$

- The reference signal, dn_{ref}, is band 31 for the LWIR bands. For the MWIR bands, the lunar signal is sharp enough to reference to the background level.

- The first check that we have of the correction coefficients is to reapply them to the lunar signal (right).



Exceptions to the Normal Derivation

- For detector 1 in each band, the detector 10 contamination is treated separately from the band average. Other single sending detectors are also treated this way. (see next slide)

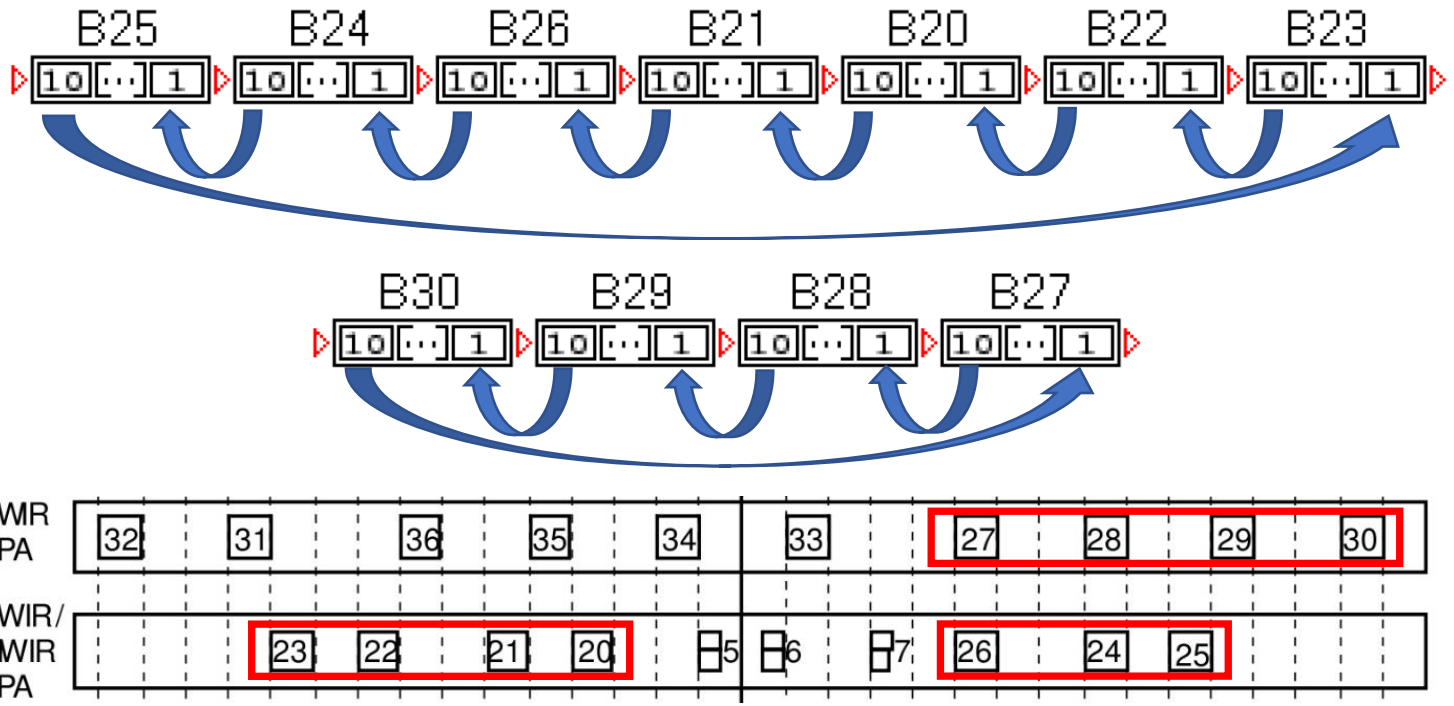
- Contamination that is not properly aligned in frame number is removed from consideration, as it likely arises from a different effect (potentially stray light). **Using these signals in the correction can have a negative impact on EV data** (increased detector spread, for instance).

- The band 26 sending for the **Terra** MWIR bands is derived using EV data from ice cloud scenes where the band 26 signal is high and the TEB signal is low. The signal is difficult to derive from Lunar data where the TEB signal dominates. [2]

- The Terra MWIR bands are only corrected after September 2001. Early mission electronics side changes were numerous and affect the performance of the algorithm.

Detector 10 to Detector 1 Contamination

- Affects detector 1 of bands 20 to 30.
- Contamination from one sending detector of one sending band.



FPA	SMWIR								LWIR				
Receiving Band	20	21	22	23	23	24	25	26	27	27	28	29	30
Receiving Detector	1	1	1	1	1	1	1	1	1	1	1	1	1
Sending Band	22	20	23	25	25	26	24	21	30	30	27	28	29
Sending Detector	10	10	10	10	1	10	10	10	10	1	10	10	10

Application of the Correction

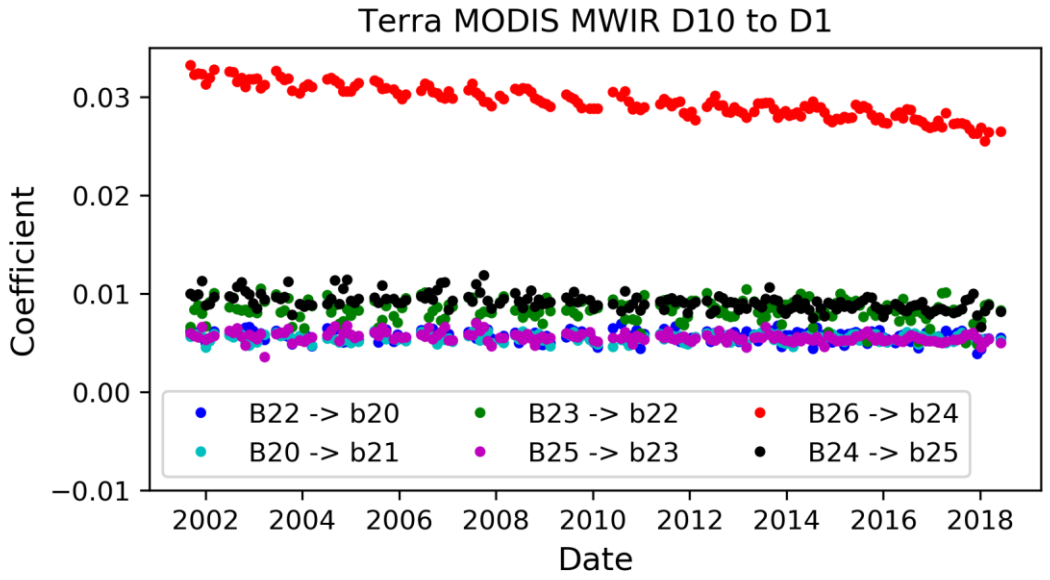
- The correction is applied to each data sector, which includes the Earth-view, space-view and blackbody sectors at the pixel level

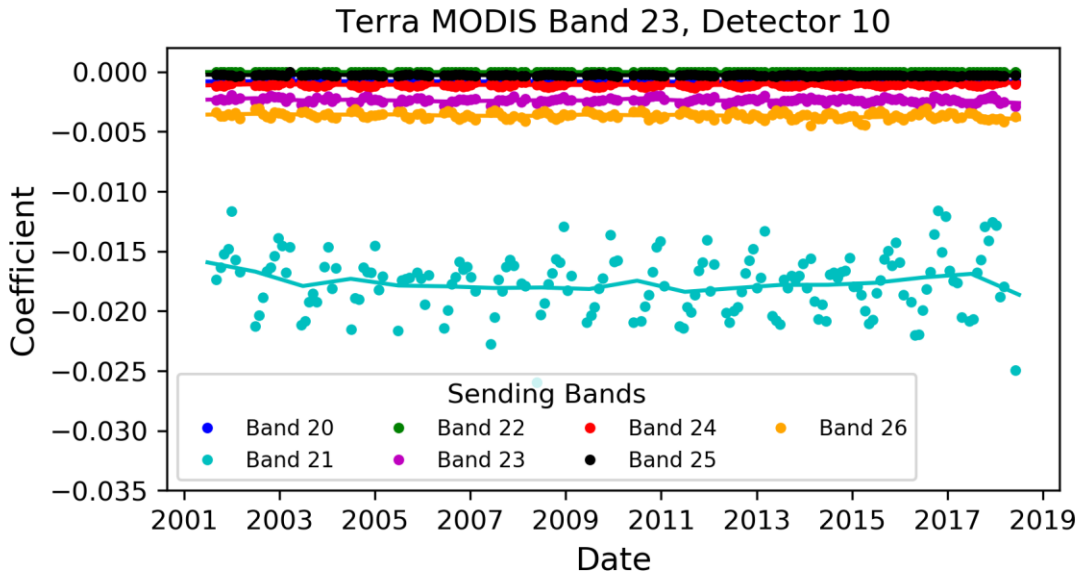
$$dn_i(S,F) = dn_i^* - \sum_j c_{i,j} \cdot dn_j^*(S, F + \Delta F_j)$$

- The linear gain coefficient is corrected on a scan-by-scan basis using the corrected blackbody data. The non-linear terms are only significantly affected for bands 27-30 in Terra MODIS. A correction to these terms is applied in Collection 6.1.

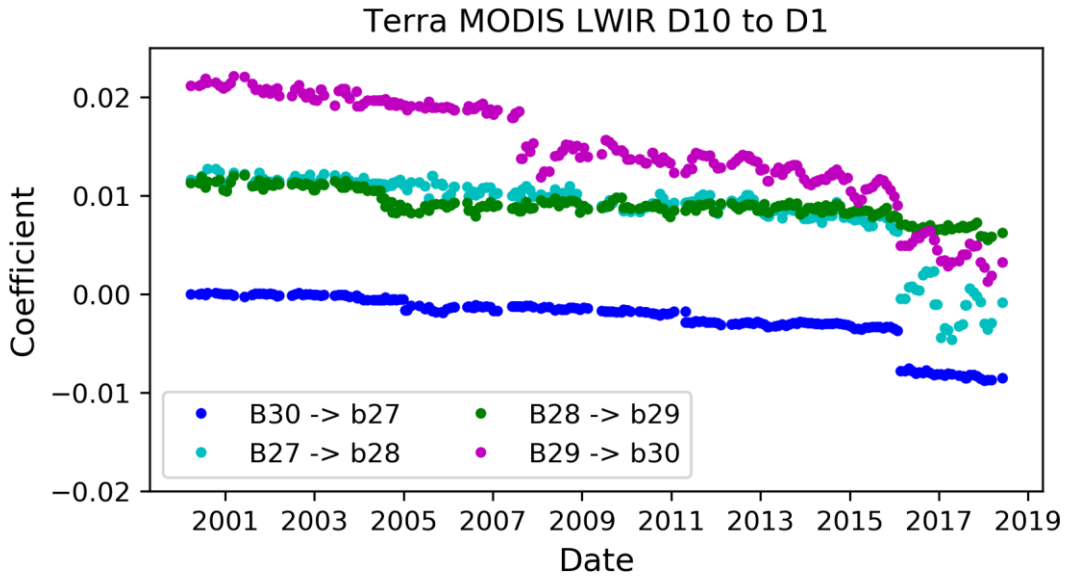
- **We will first show the results as applied to Terra MODIS and then show the results for Aqua MODIS.**

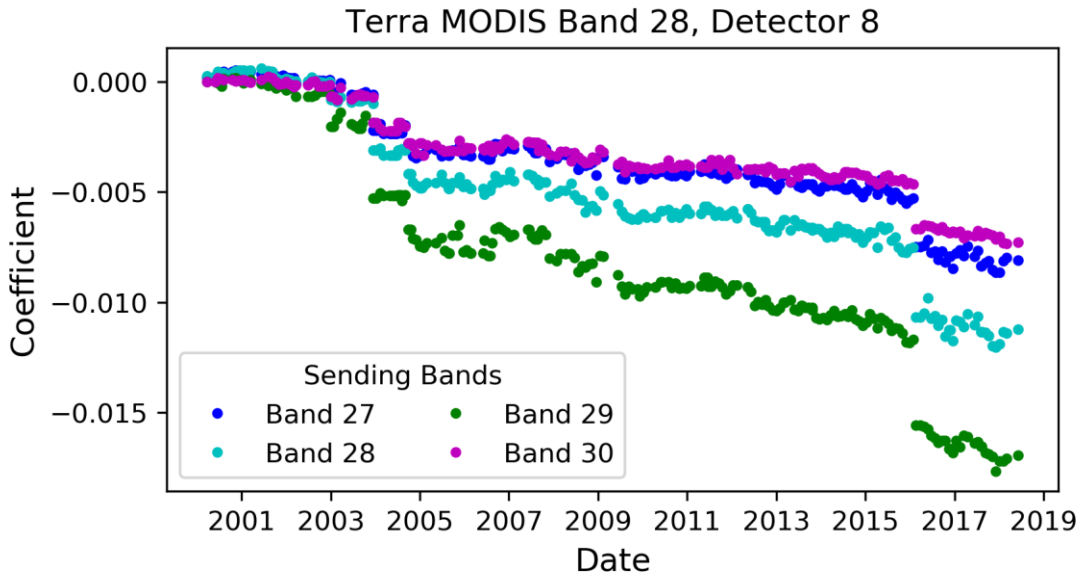
Crosstalk Coefficients for Terra MODIS



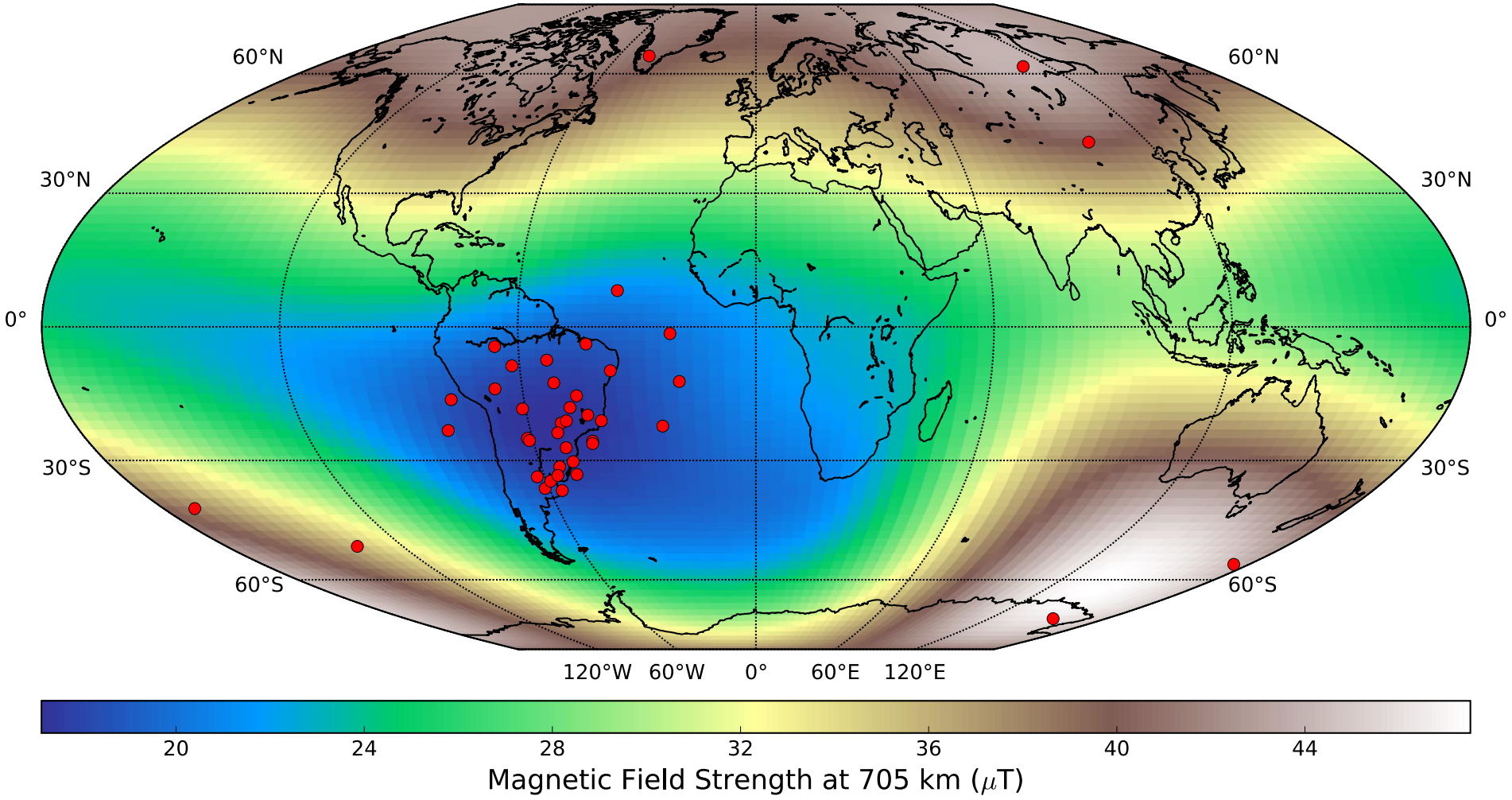


Annual average shown as solid lines to show the effect of the seasonal oscillations.





Geolocation of the Gain Change Events



*See reference 1

Image Correction For Terra MODIS Band 22

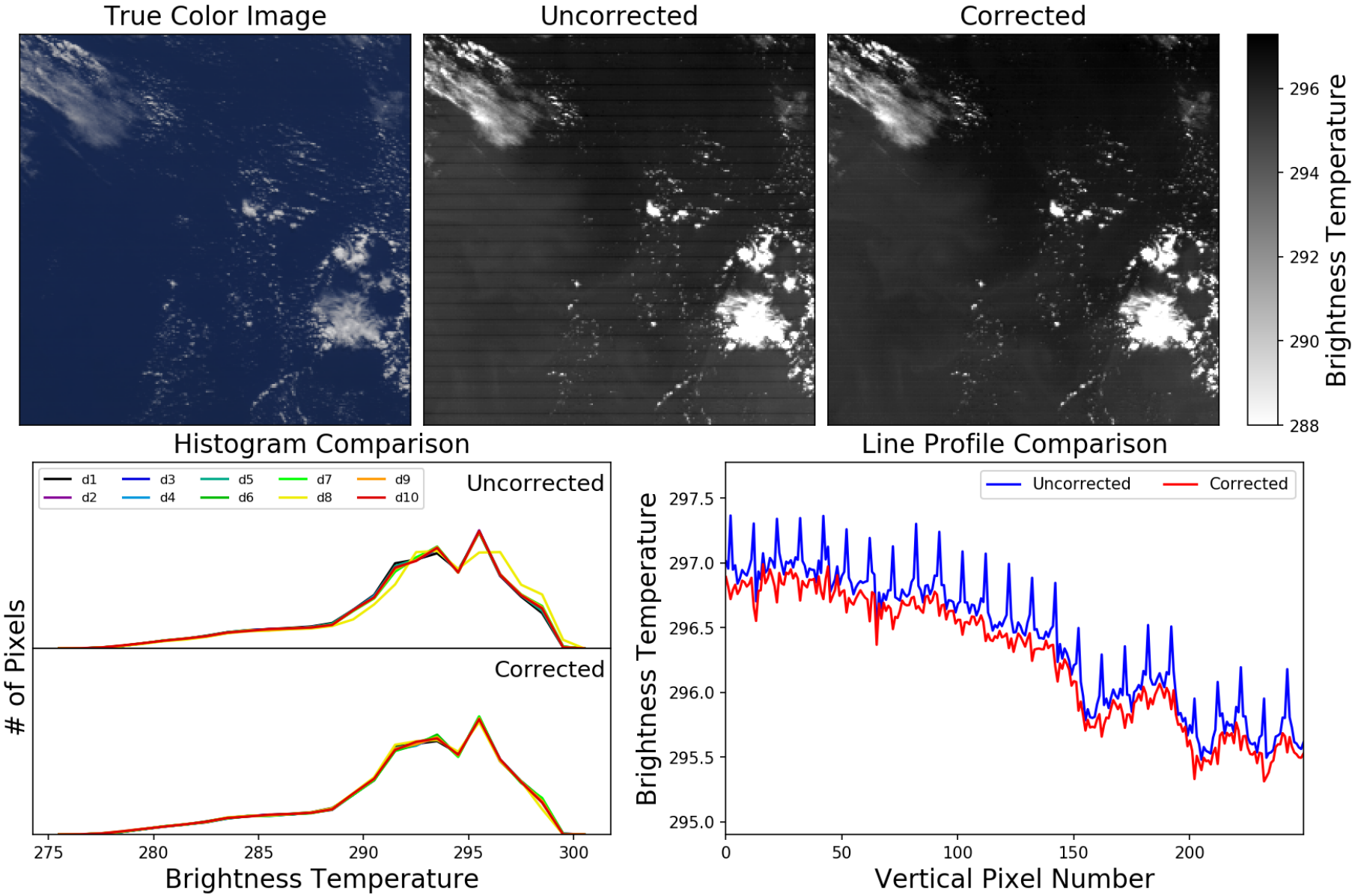


Image Correction For Terra MODIS Band 24

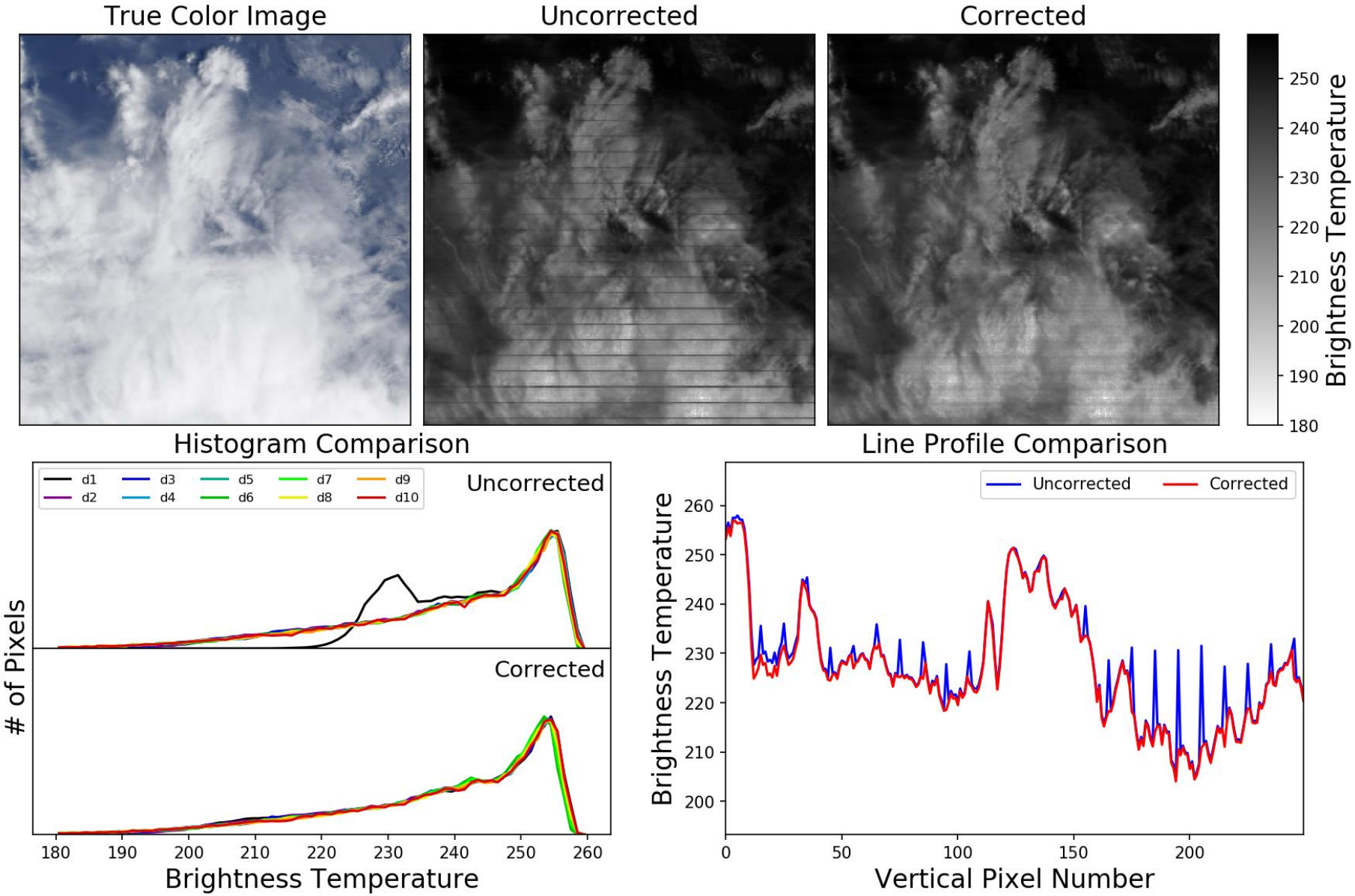


Image Correction For Terra MODIS Band 27

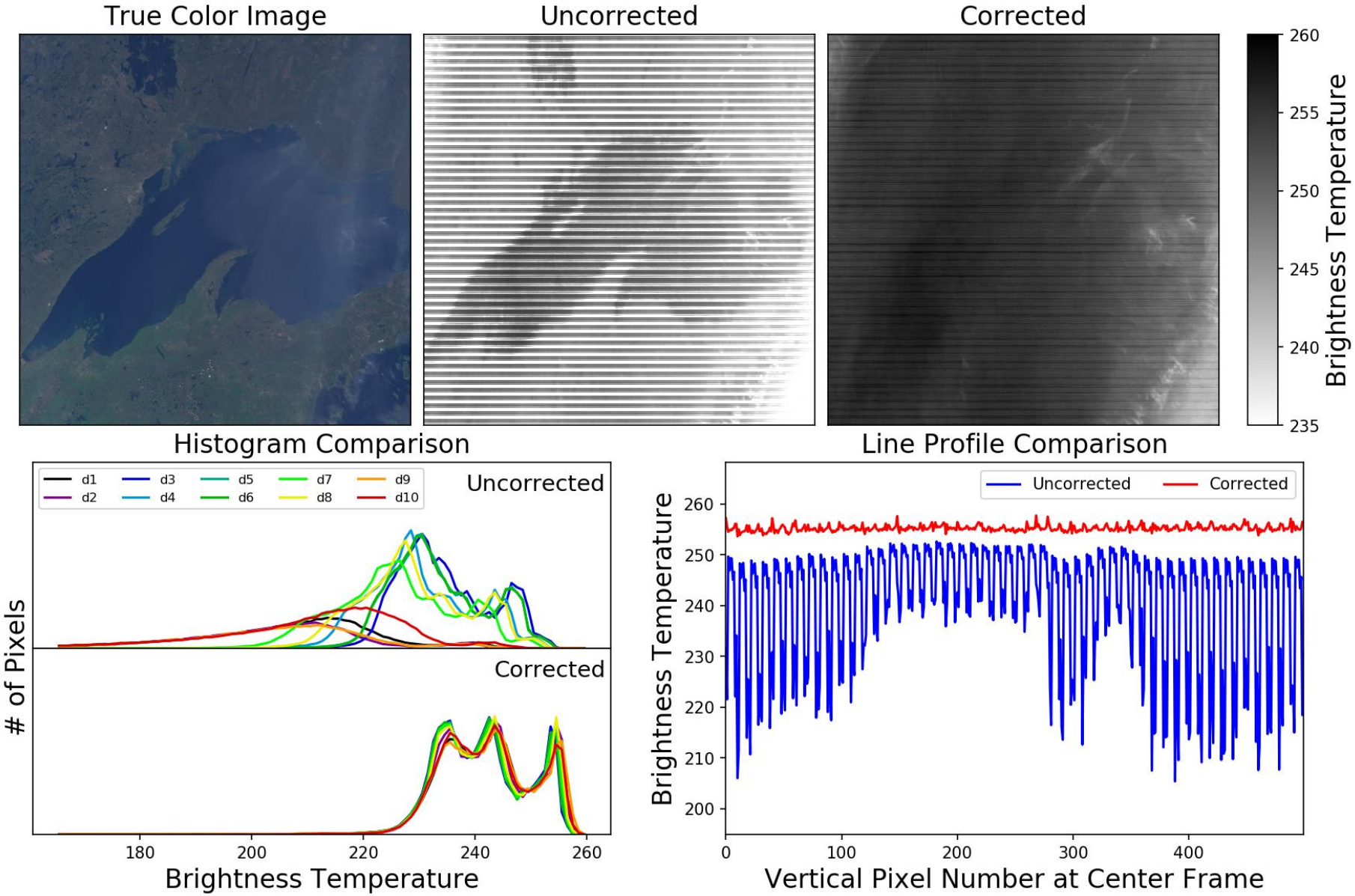
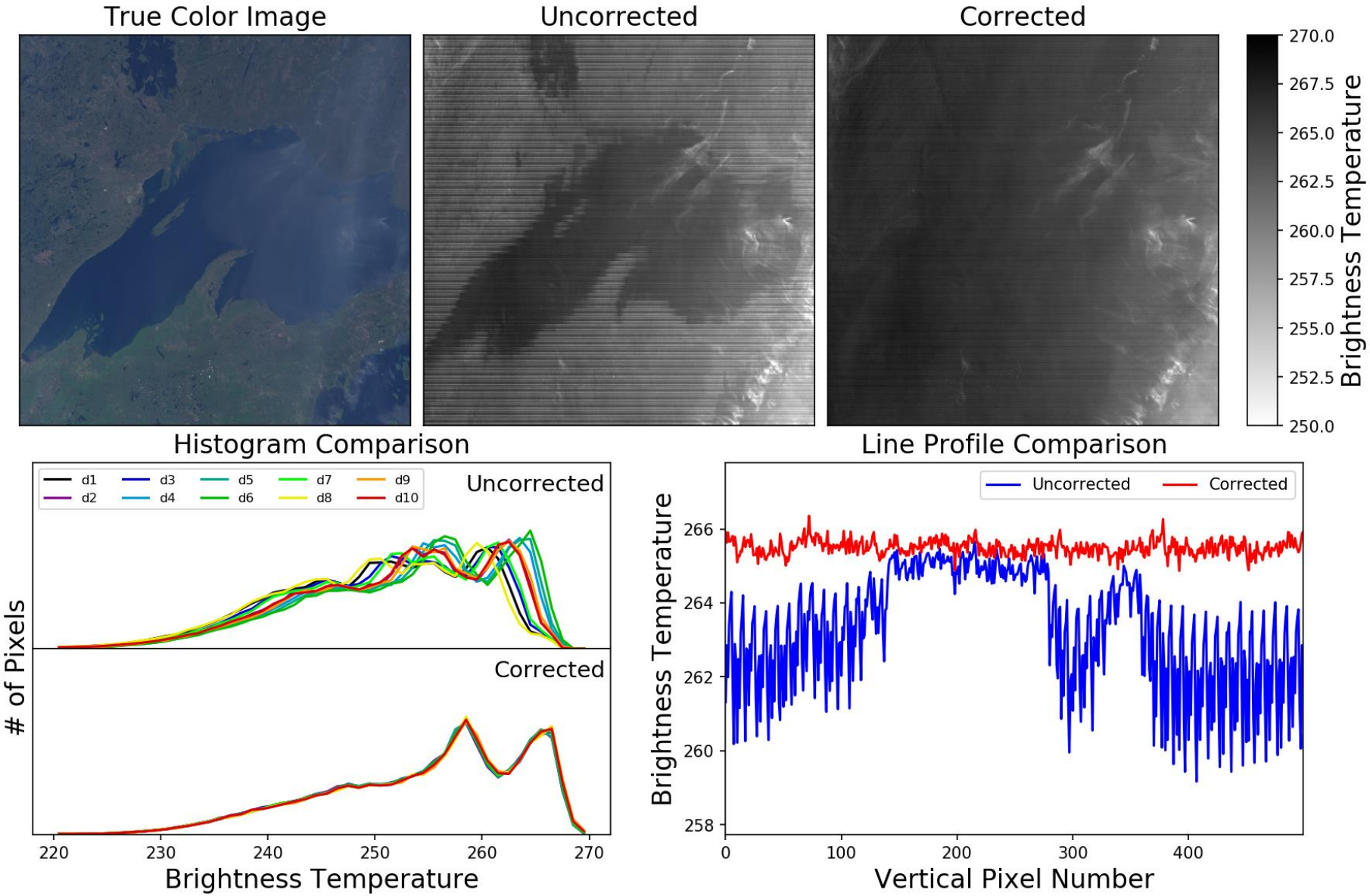
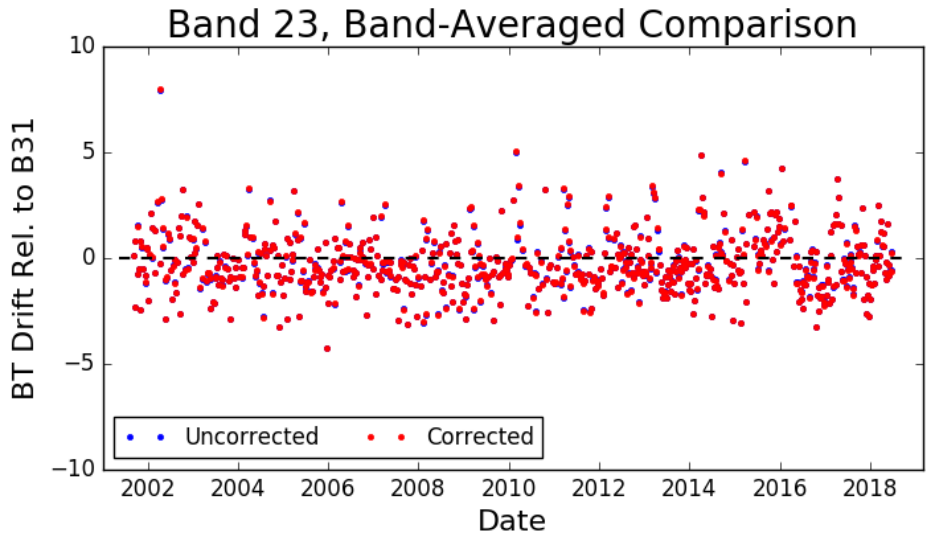
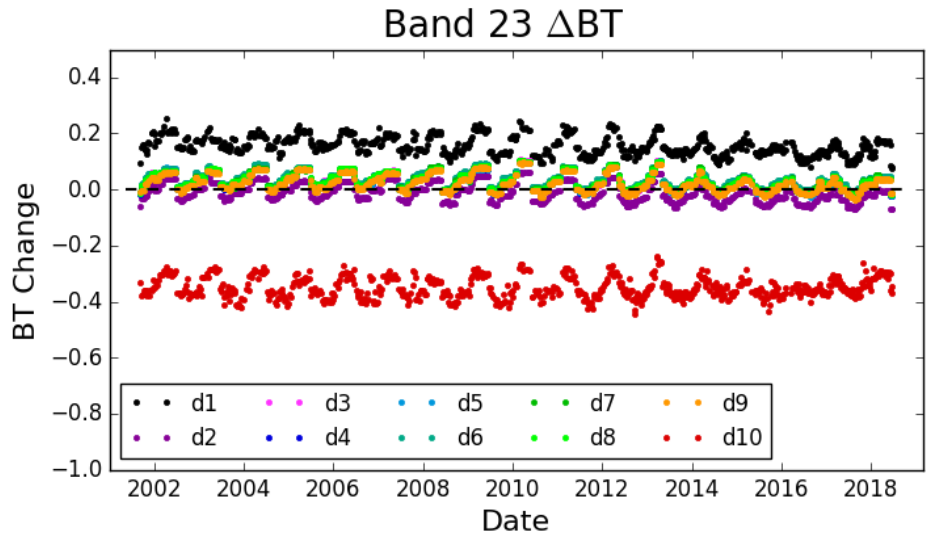


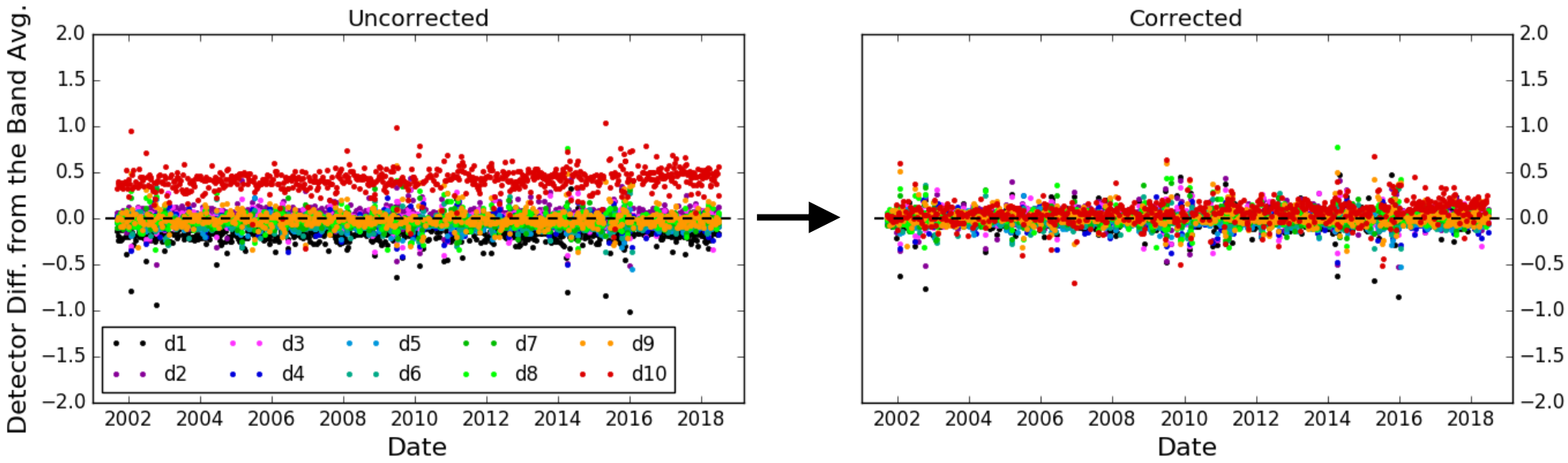
Image Correction For Terra MODIS Band 28



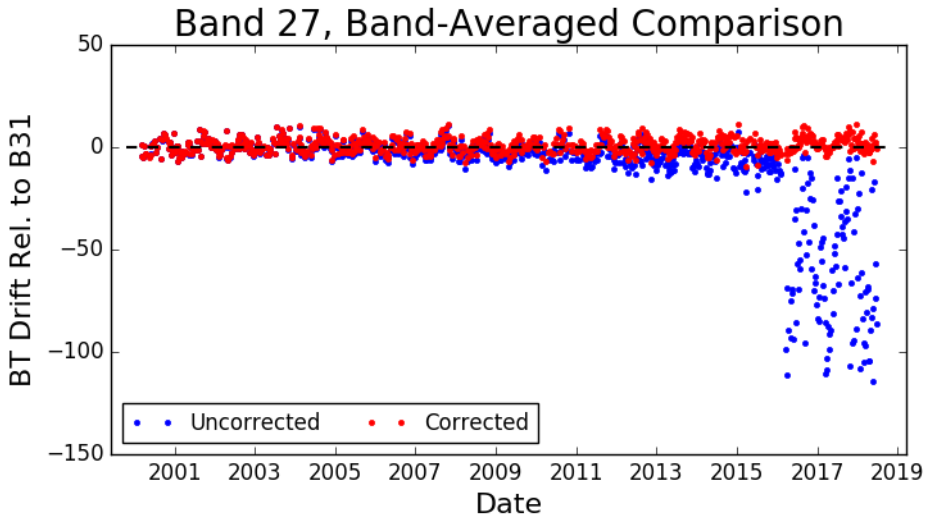
Long-Term Trending Over Warm Ocean - Terra

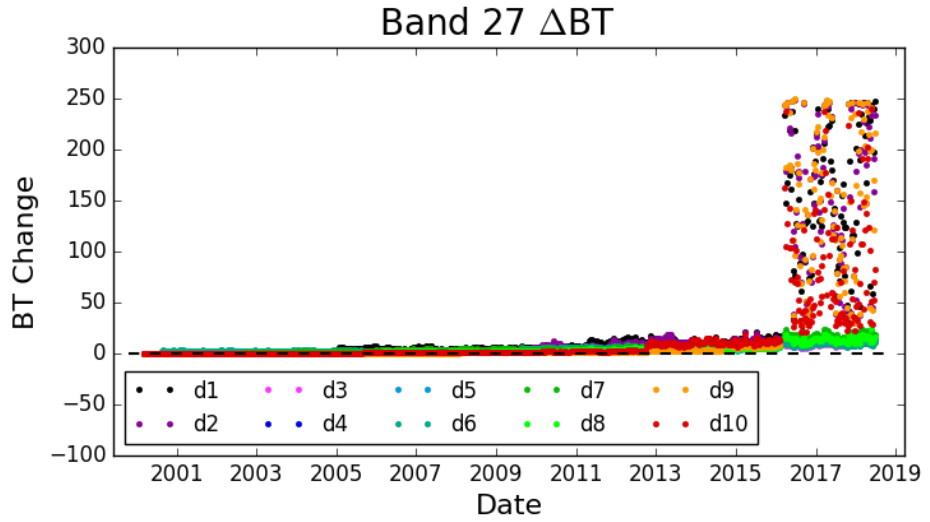


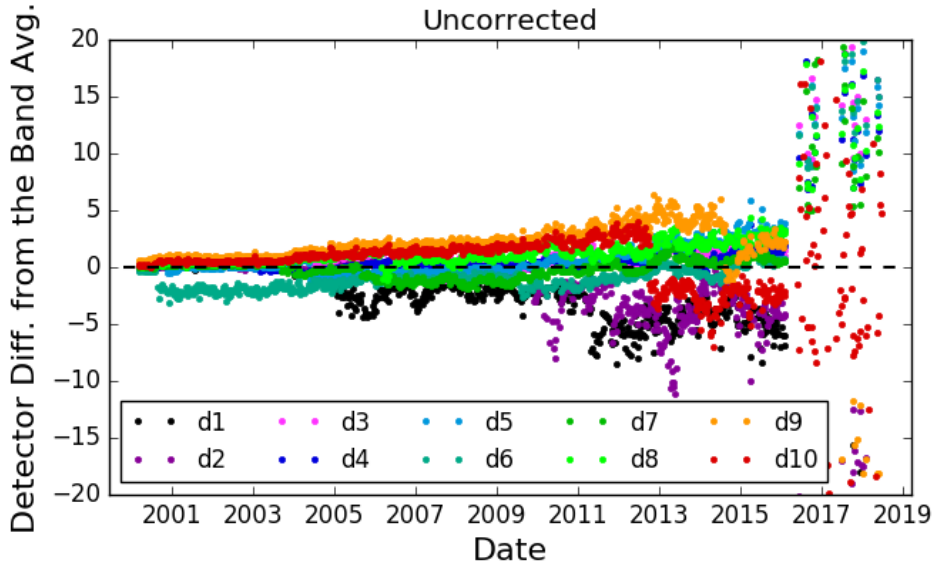


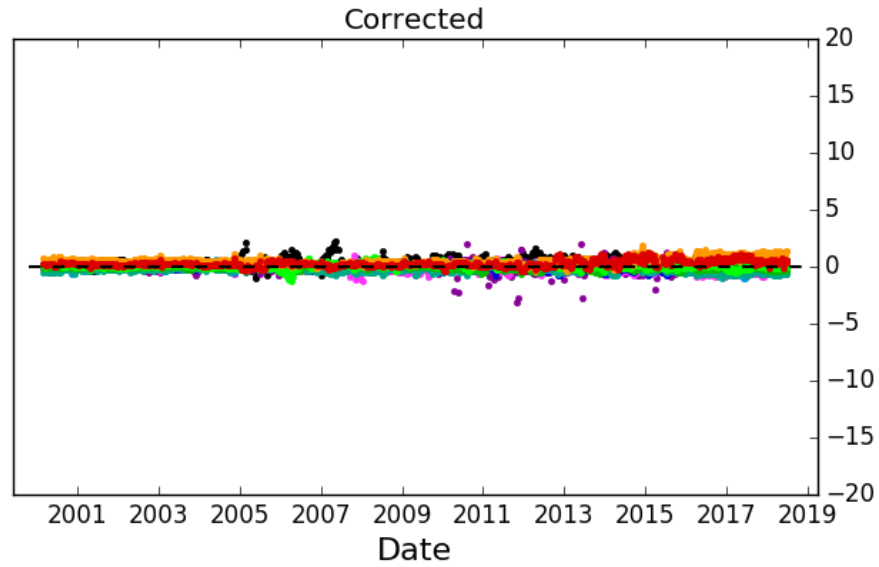


Long-Term Trending Over Warm Ocean - Terra



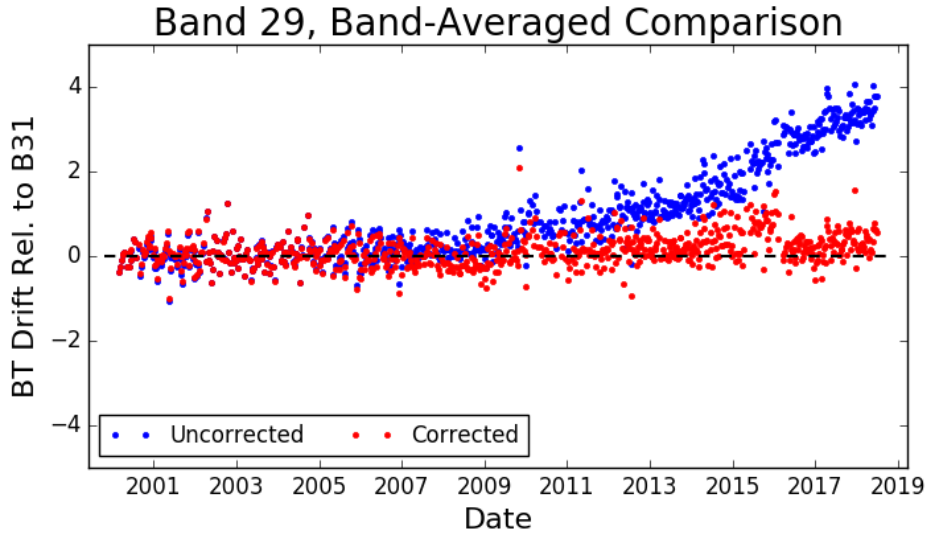


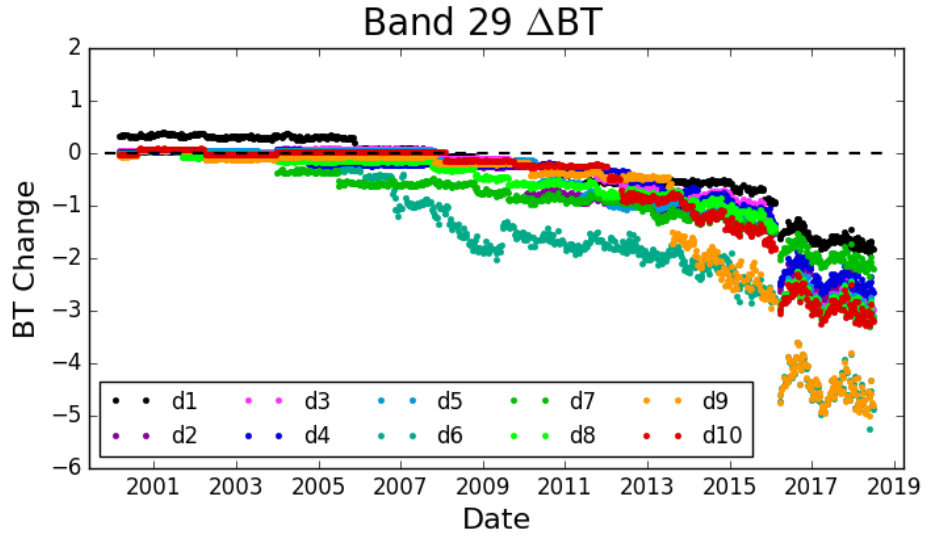


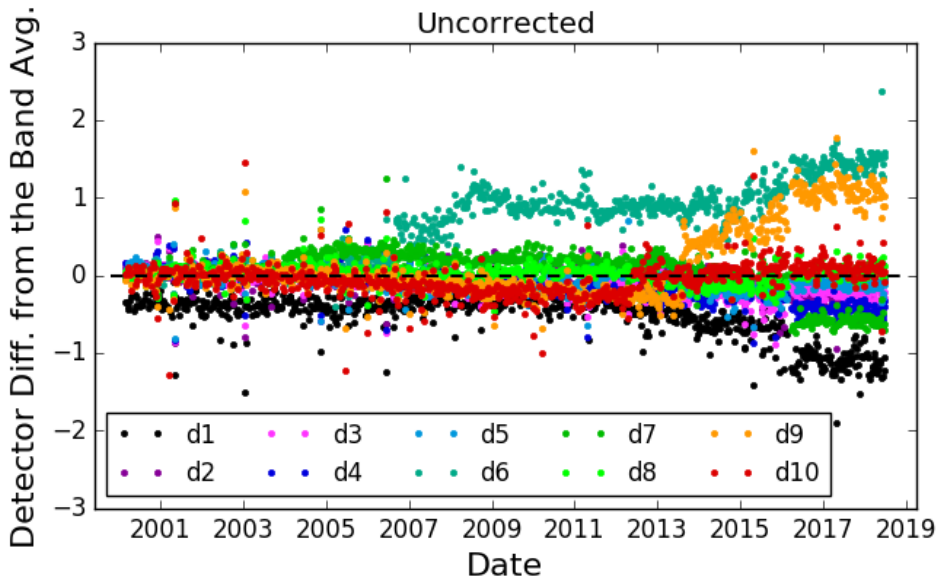


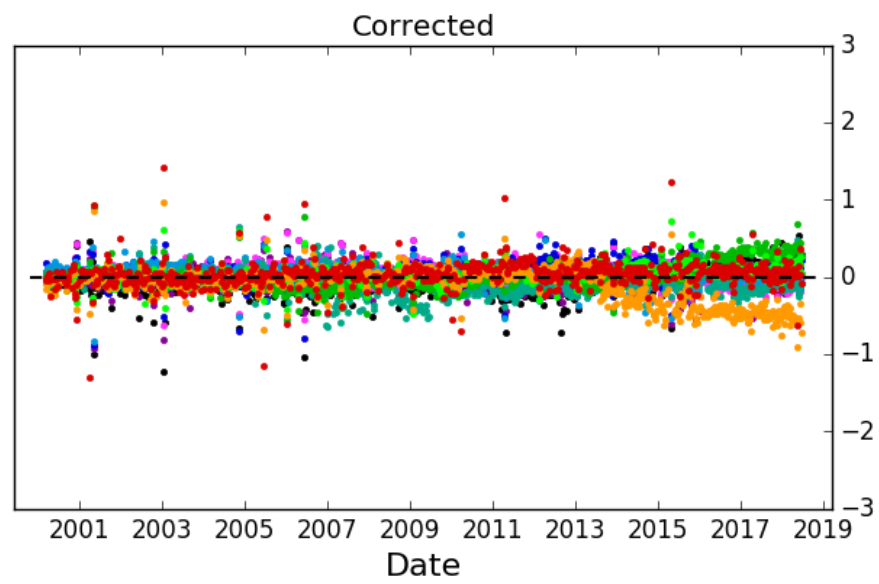
Correction implemented in Collection 6.1

Long-Term Trending Over Warm Ocean - Terra



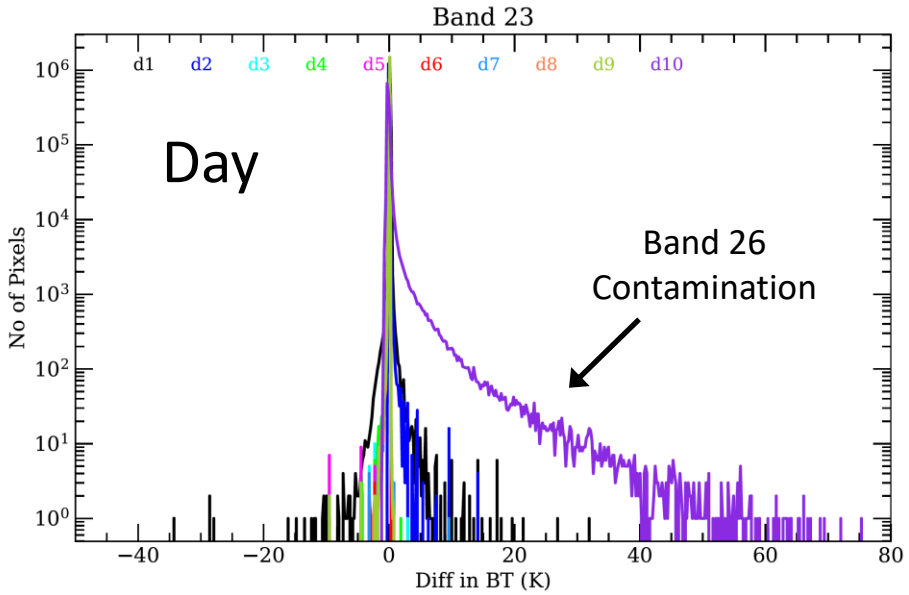


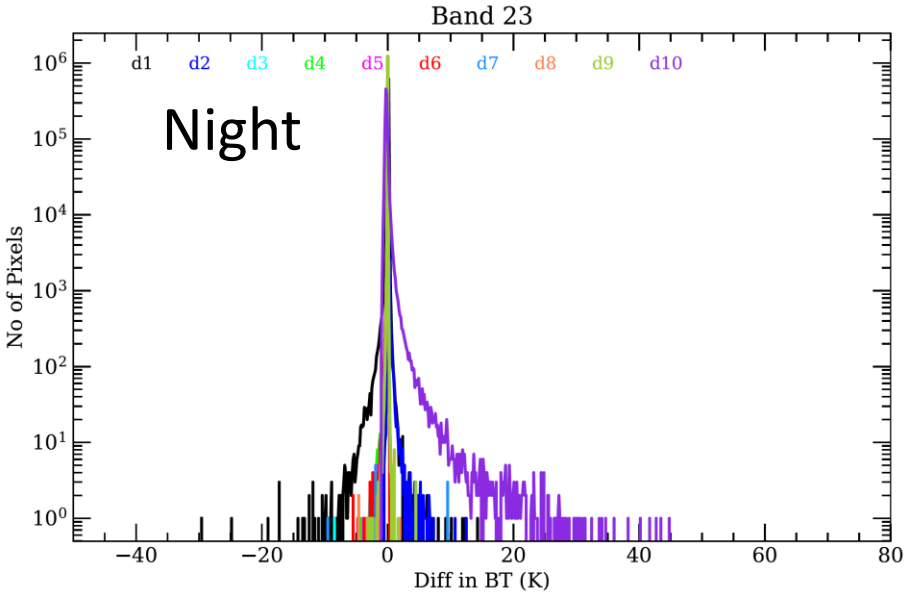




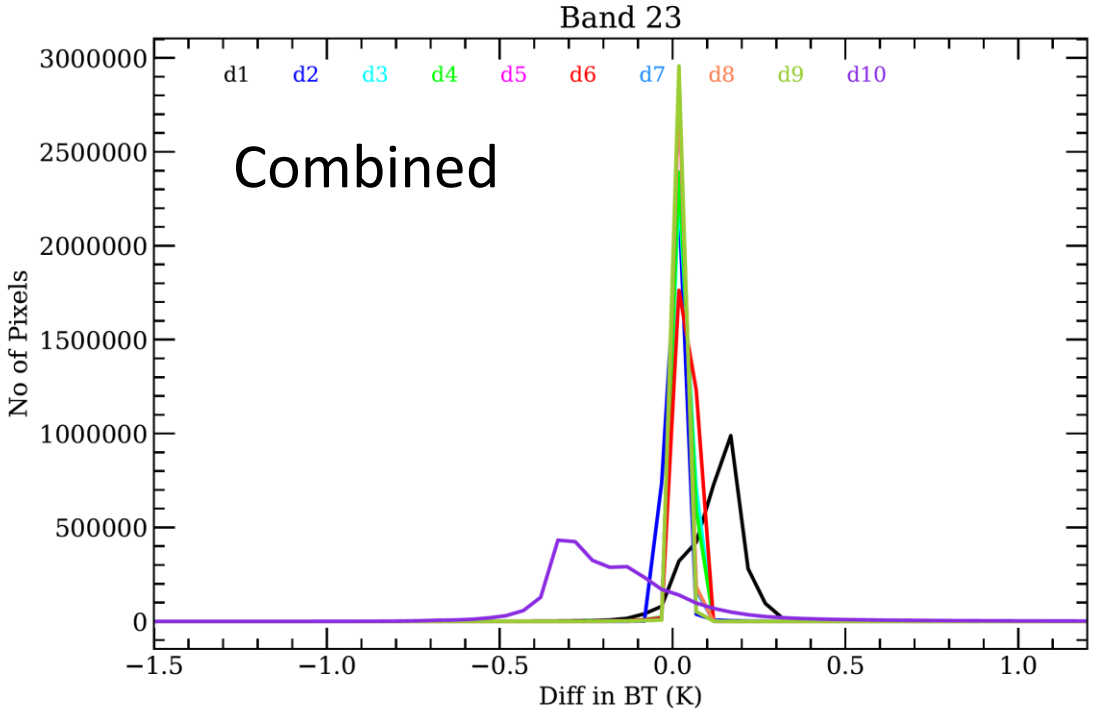
Correction implemented in Collection 6.1

Correction Magnitude Over 1-Orbit



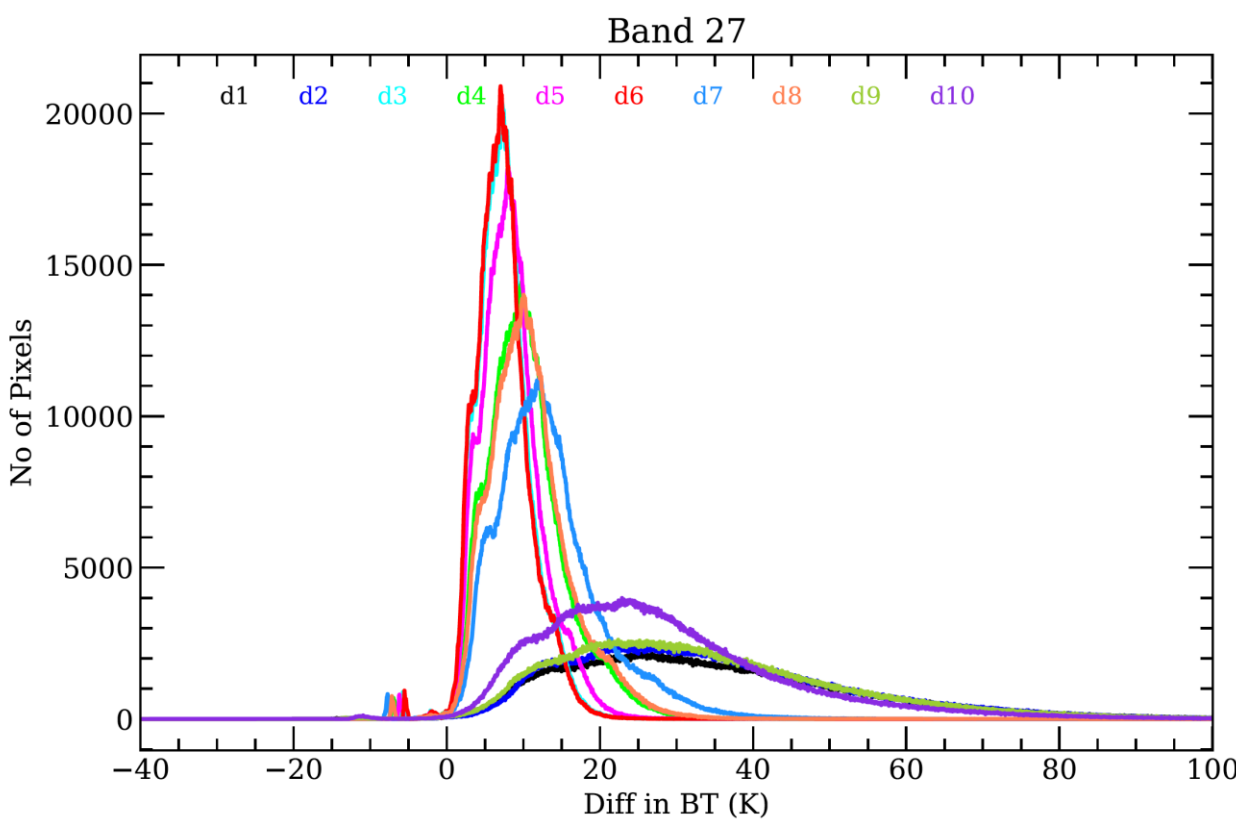


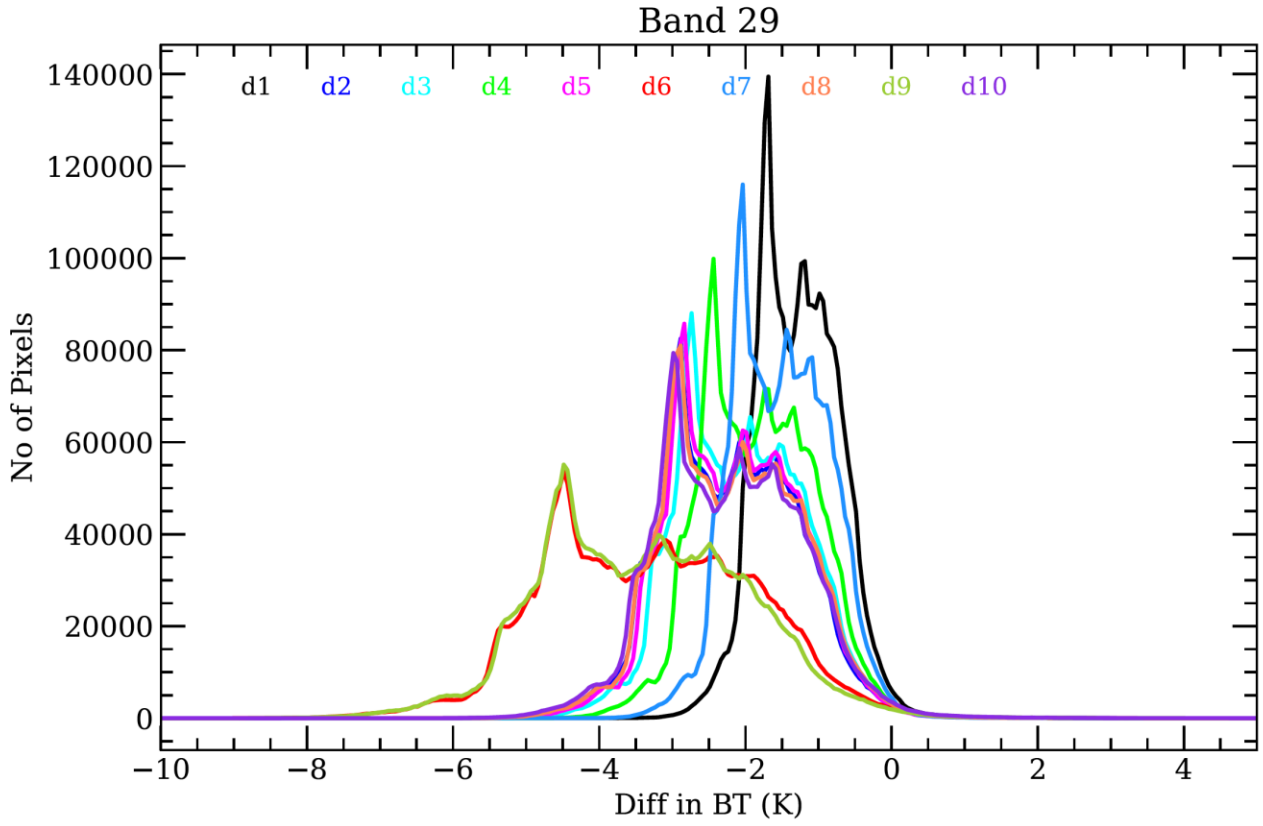
- Band 23 has contamination over ice cloud scenes during the daytime from band 26 (left). The y-scale is on a log scale for these plots.
- On a linear scale (right), detectors 1 and 10 show a correction away from 0, which matches what we see in the ocean trending data from the previous slides.



Correction Magnitude Over 1-Orbit

- The LWIR bands show a significant correction for all of the detectors.
- The magnitude of the correction is greater during the daytime due to the higher signal size of the sending bands, but otherwise has the same nature.





Crosstalk Impact Assessment – Terra MWIR

Band	Contamination Impact	Correction Impact	Recommendation
20	No discernable impact.	No Correction Required	No action recommended
21	D1 and D9 striping over **water scenes**. D1 striping over **desert scenes**. D9 Striping over **ice clouds scenes.**	Some image improvement over water. Limited impact over desert and ice clouds.	No action recommended
22	D8 striping over **ice cloud scenes** (large) and **water scenes** (~0.5K).	Effectively removes contamination	**Apply correction for detector 8**
23	D10 striping over **ice cloud scenes** (large) and **water scenes** (~0.5K)**.**	Effectively removes contamination	**Apply correction for detectors 1 and 10**
24	D1 striping over **ice cloud scenes**. 0.5 – 1 K change over ocean scenes for all detectors.	Effectively removes D1 striping. Slight increase in detector spread over ocean scenes.	**Apply correction for detector 1**
25	No discernable impact	No Correction Required	No action recommended

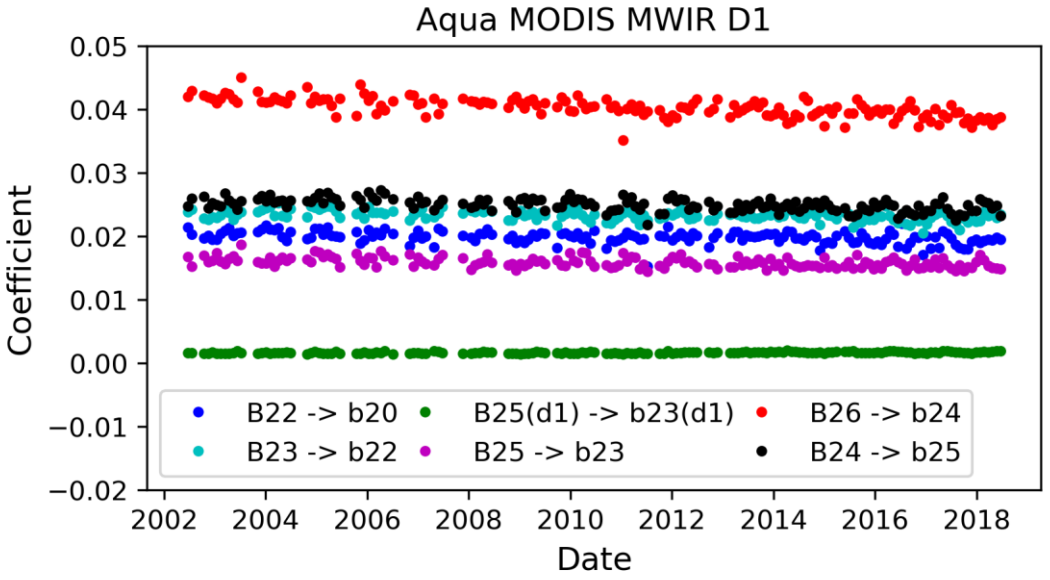
Crosstalk Impact Assessment – Terra LWIR

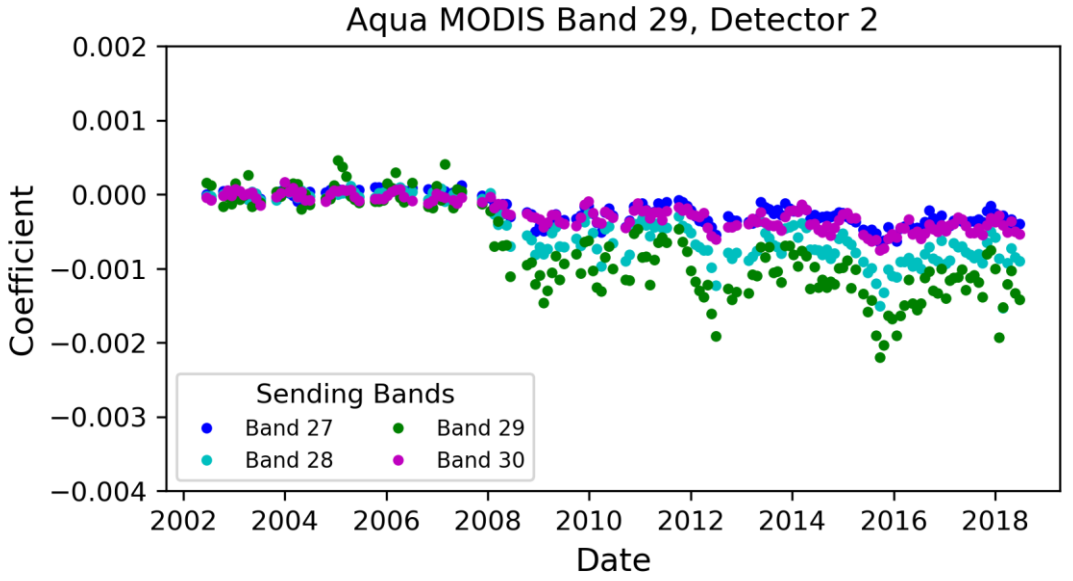
Band	Contamination Impact	Correction Impact	Recommendation
27	Striping and false land/water boundary features. Significant bias that increases throughout the mission, especially after 2016	Effectively removes contamination	A correction is already implemented in Collection 6.1 for all detectors
28	Striping and false land/water boundary features. Significant bias that increases throughout the mission.	Effectively removes contamination	A correction is already implemented in Collection 6.1 for all detectors
29	Increasing bias and striping throughout the mission. Causes false cloud detection in cloud mask tests.	Effectively removes contamination	A correction is already implemented in Collection 6.1 for all detectors
30	Increasing bias and striping throughout the mission.	Effectively removes contamination	A correction is already implemented in Collection 6.1 for all detectors

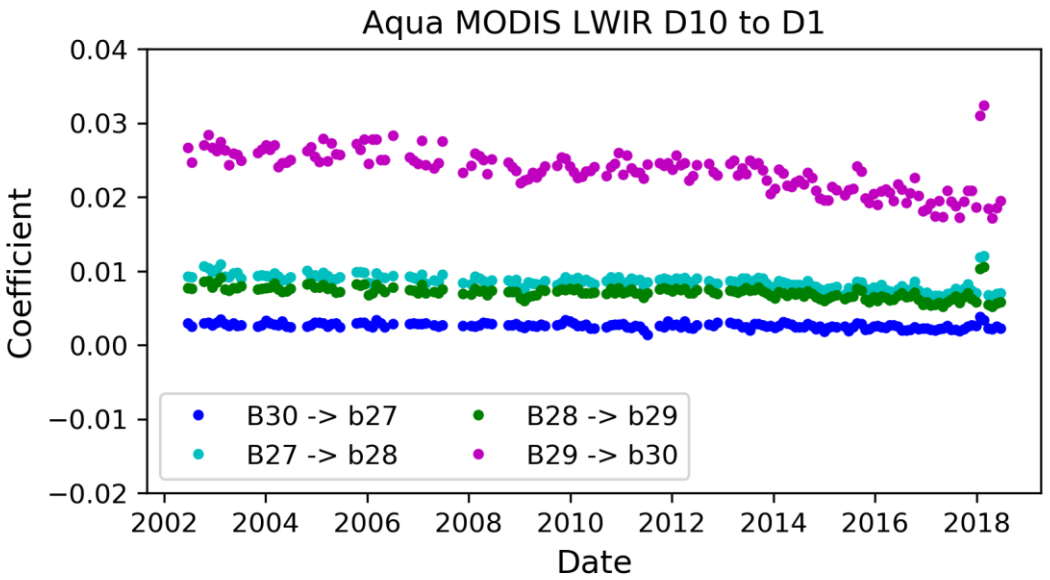
Crosstalk Correction For Aqua MODIS

- For Aqua MODIS, we use a similar methodology for identifying and deriving the crosstalk correction coefficients.
- For the MWIR bands, the contamination is at a consistent level throughout the mission, similar to Terra.
- For the LWIR bands, the contamination level can change like Terra, but the magnitude is much smaller for Aqua bands 27-30.
- For Collection 6.1, no correction is currently applied for Aqua MODIS.

Crosstalk Coefficients for Aqua MODIS







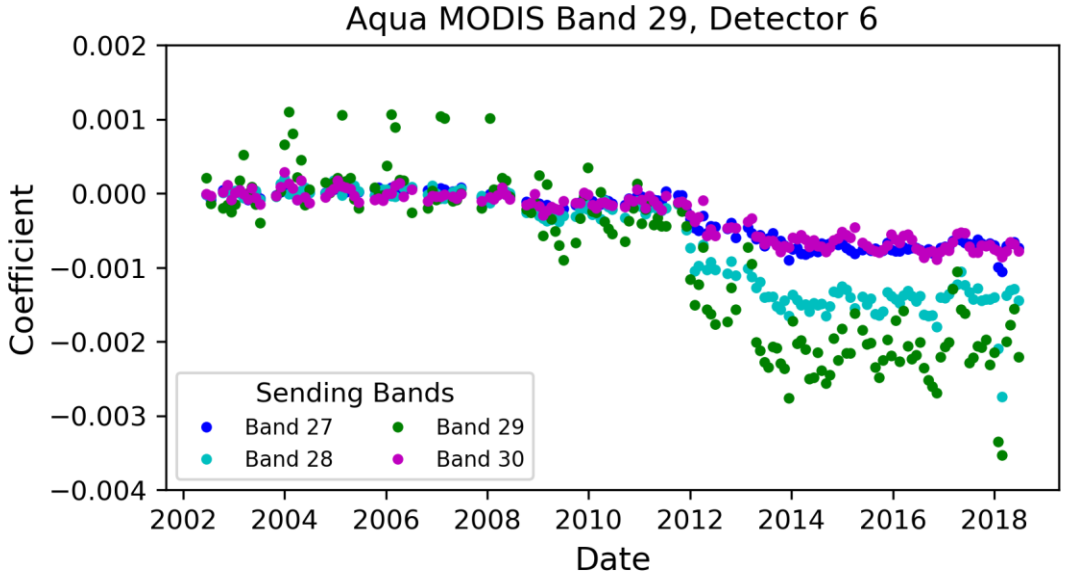
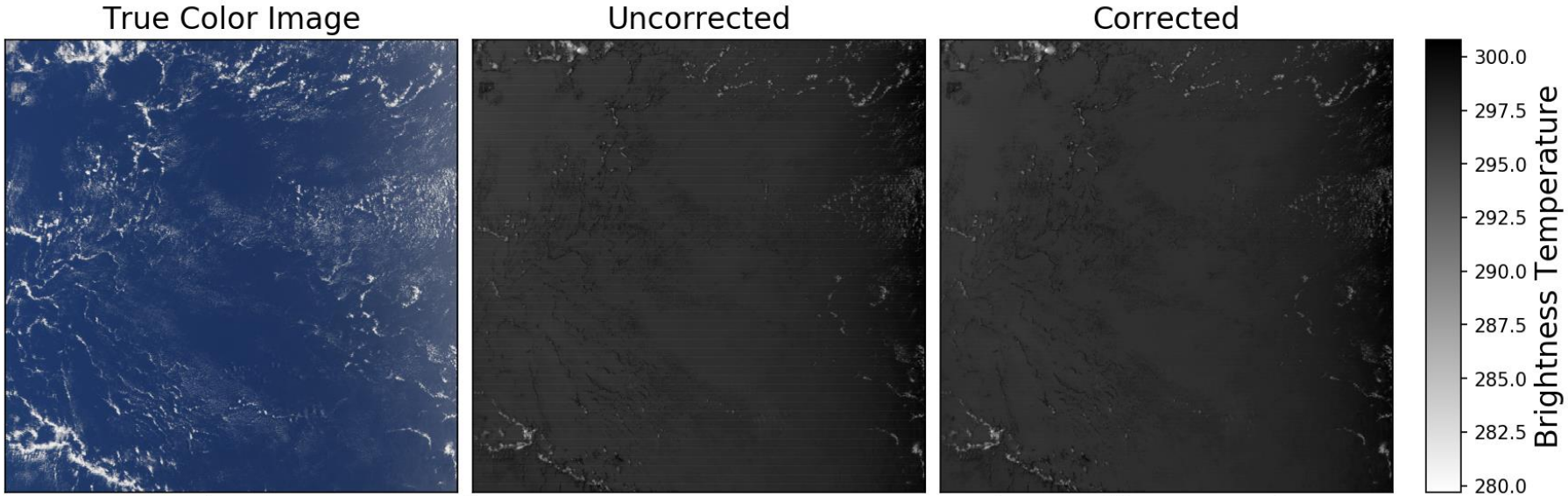
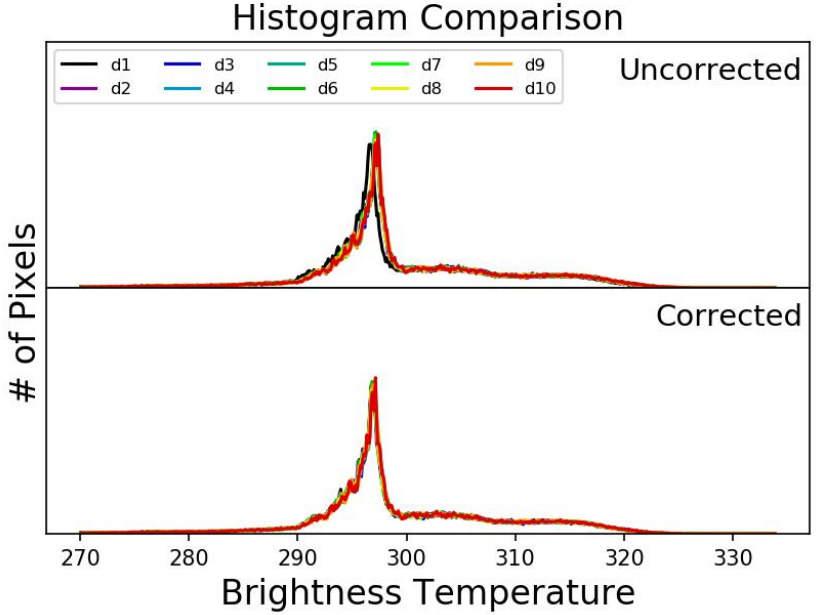


Image Correction For Aqua MODIS Band 23





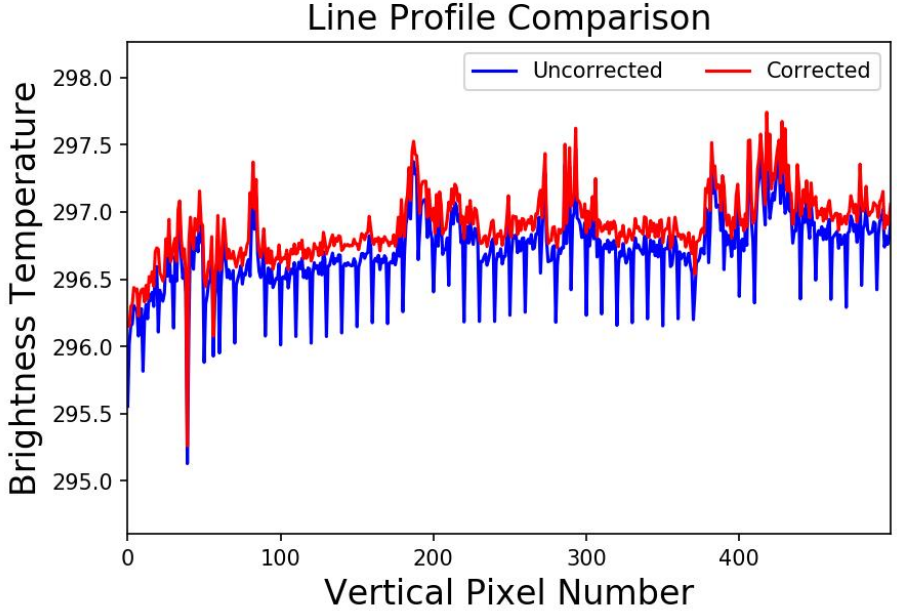
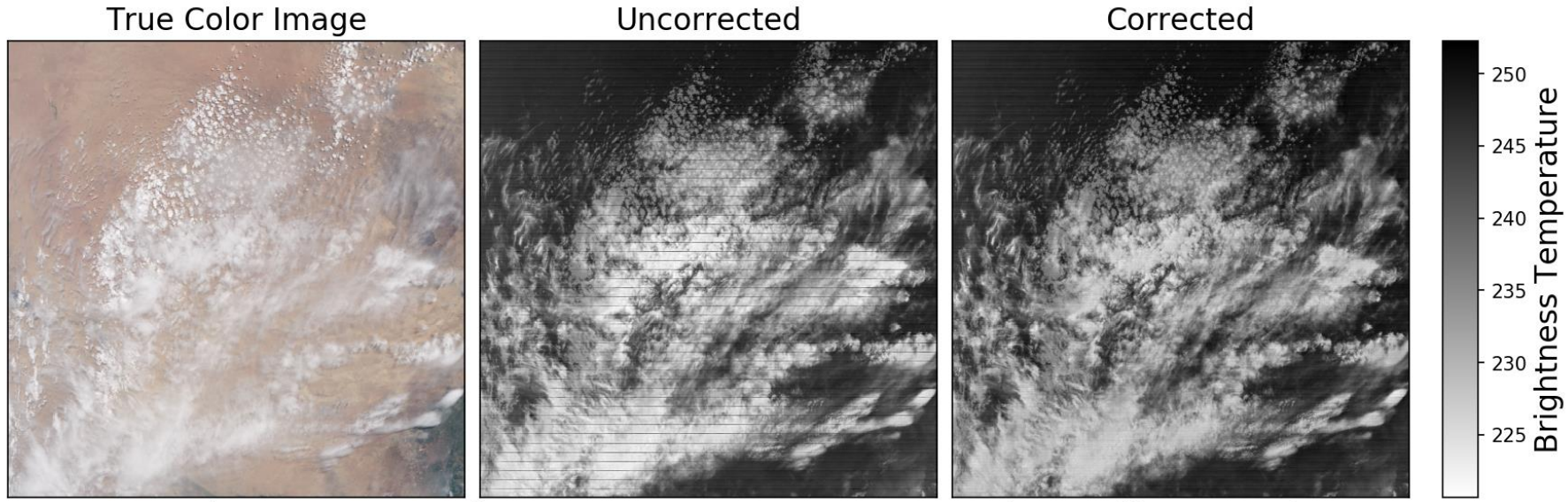
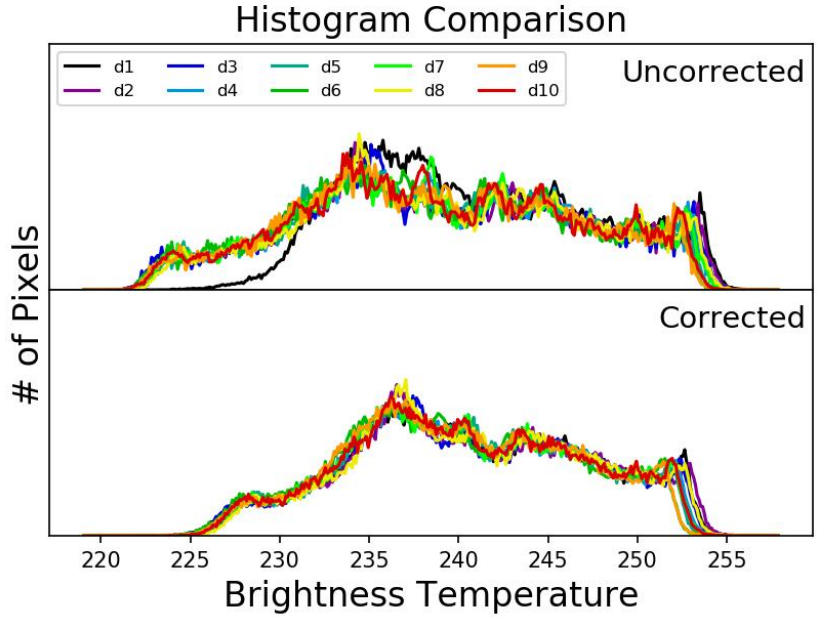


Image Correction For Aqua MODIS Band 24





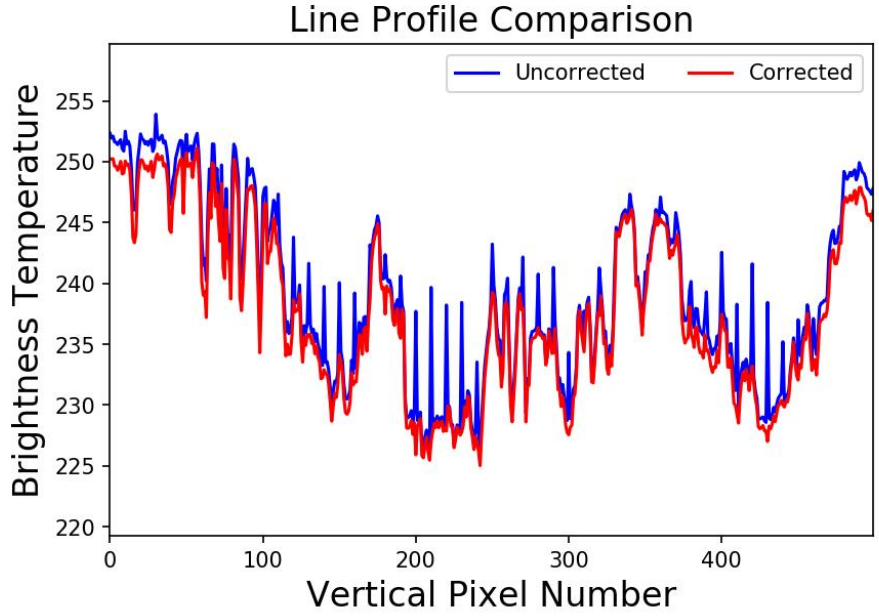
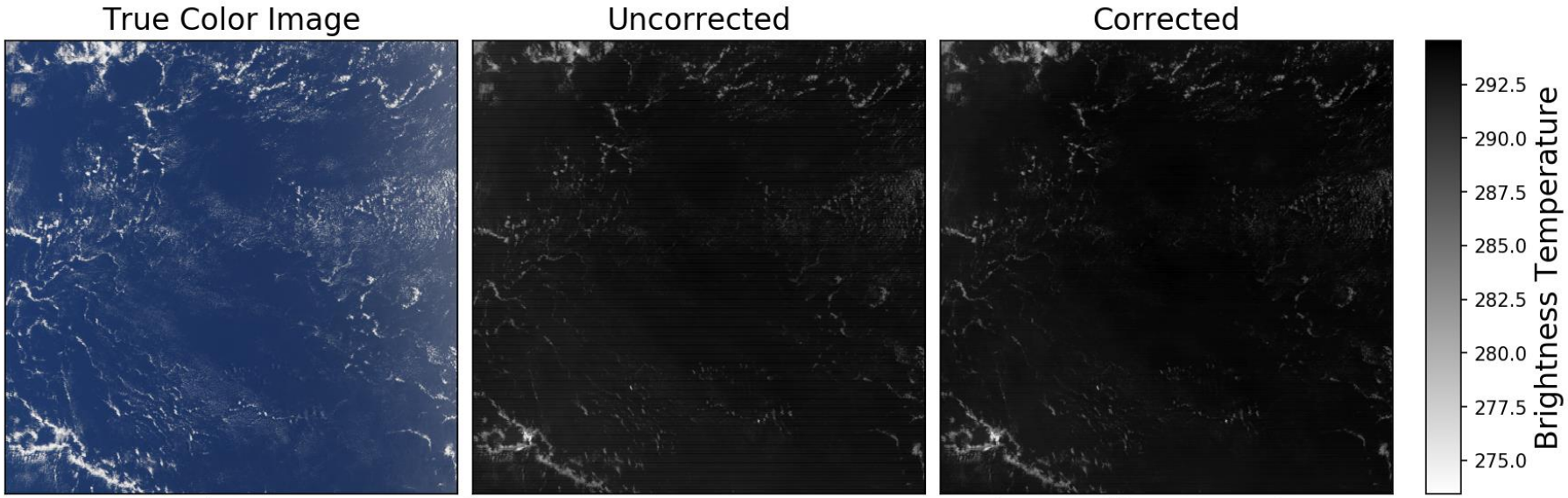
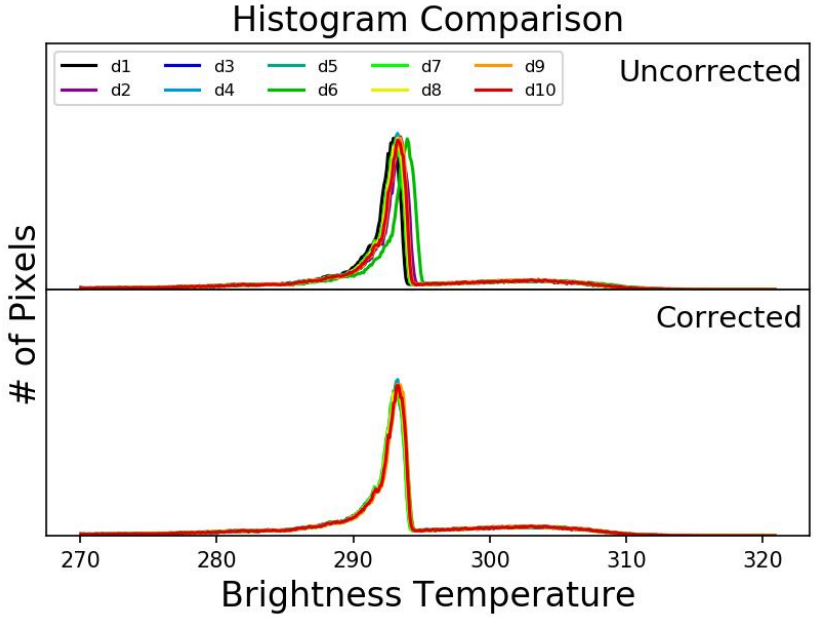


Image Correction For Aqua MODIS Band 29





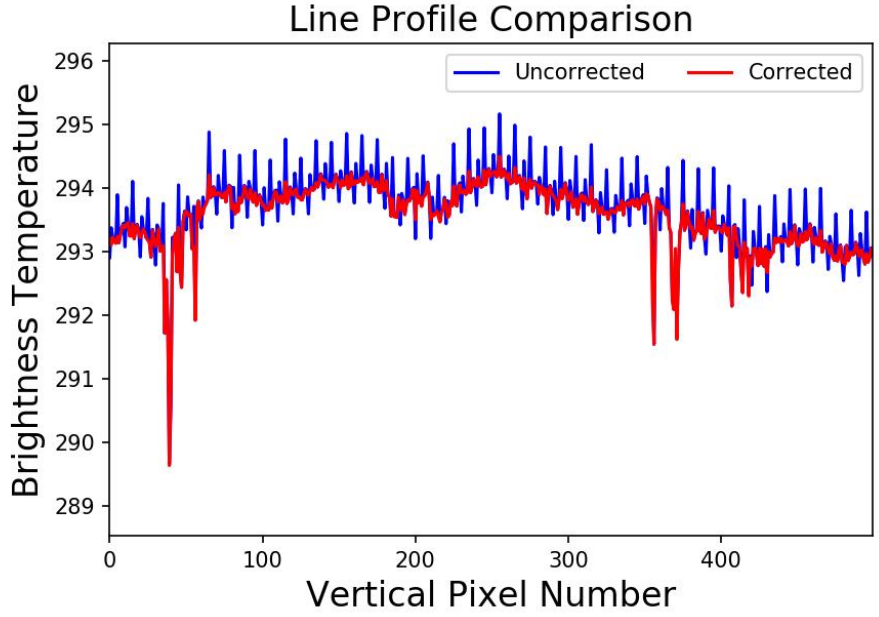
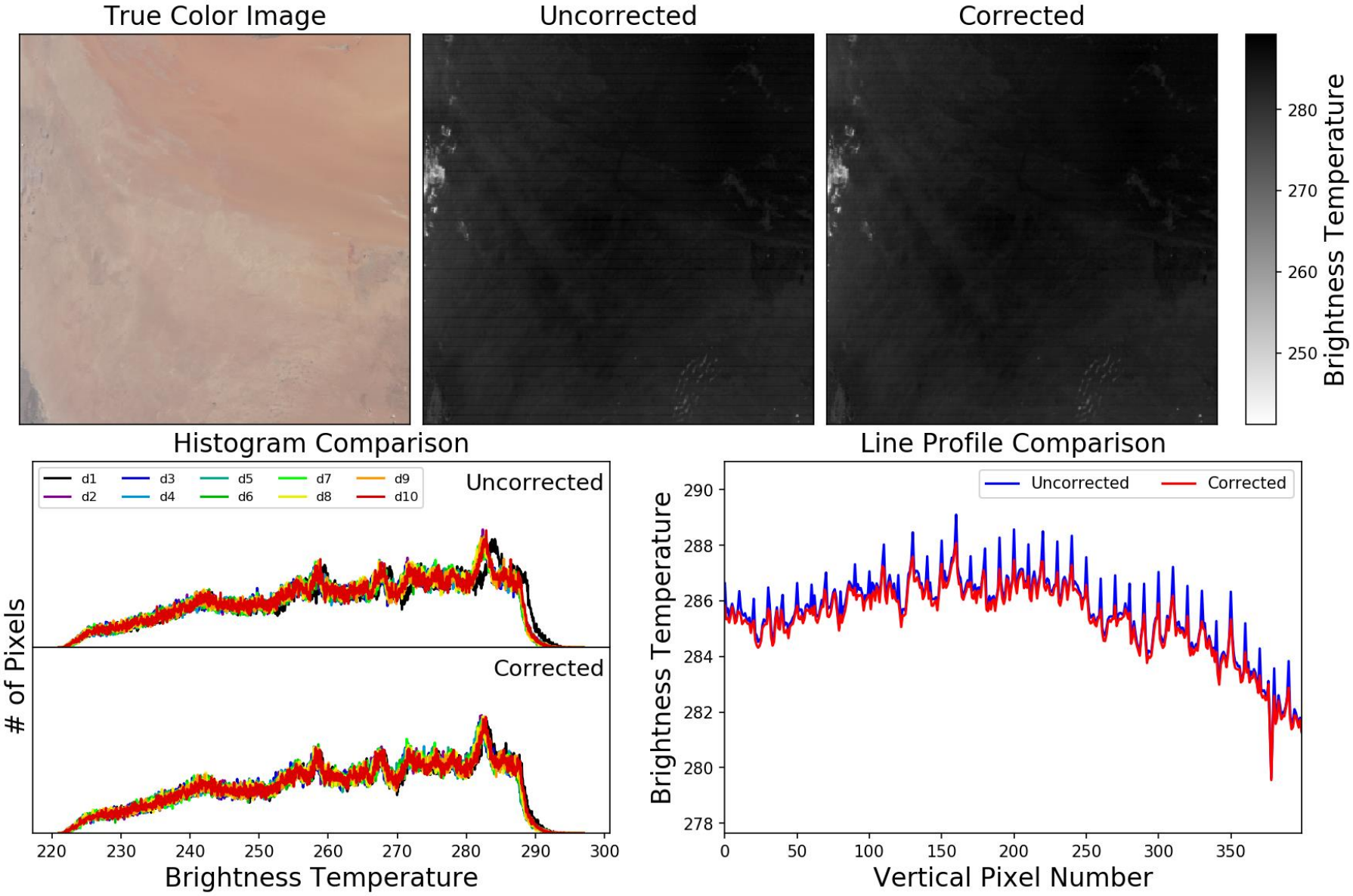
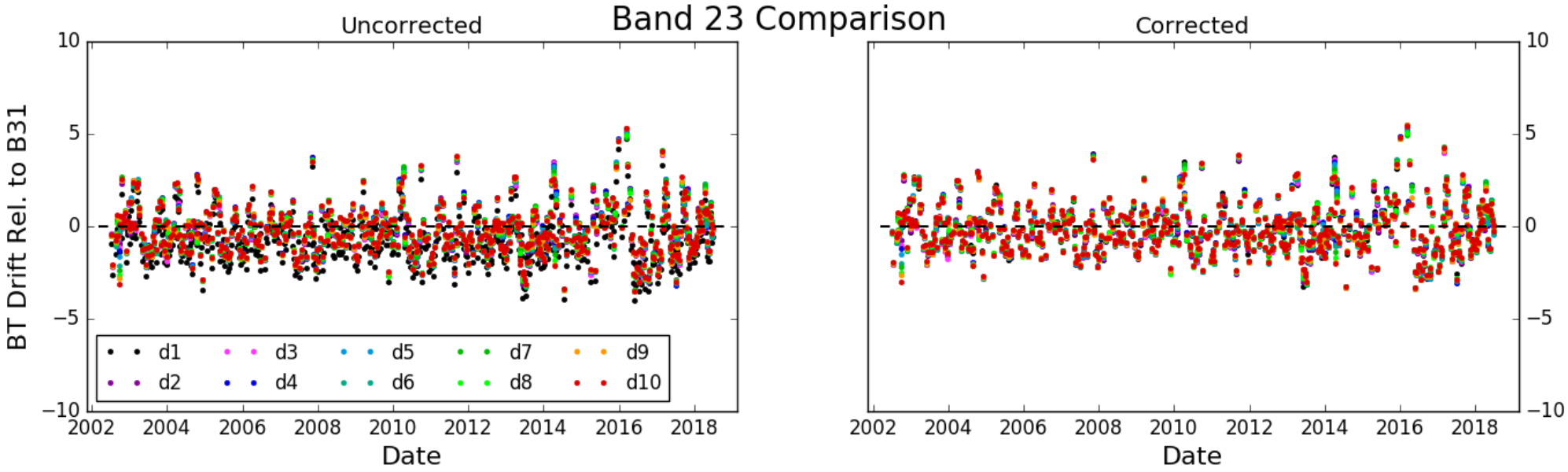
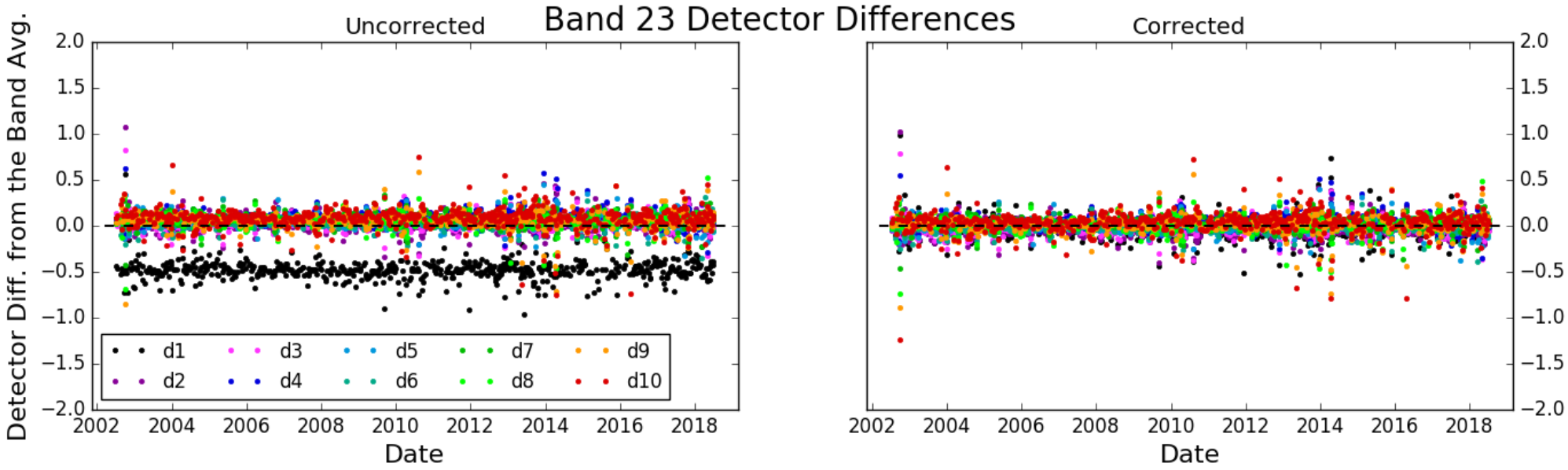


Image Correction For Aqua MODIS Band 30

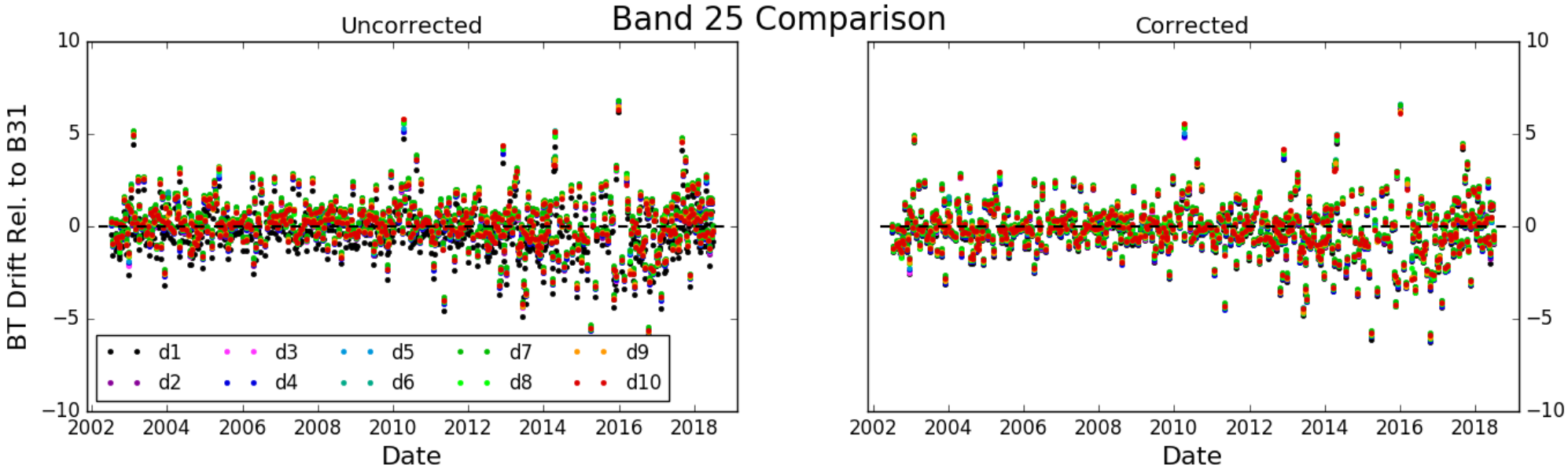


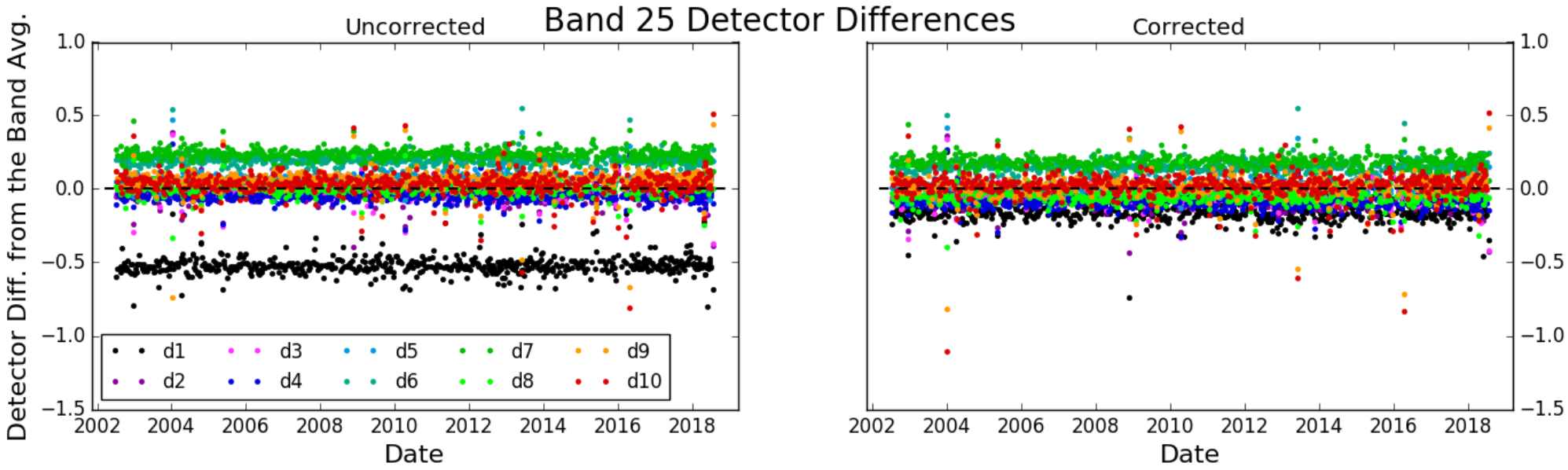
Long-Term Trending Over Warm Ocean - Aqua



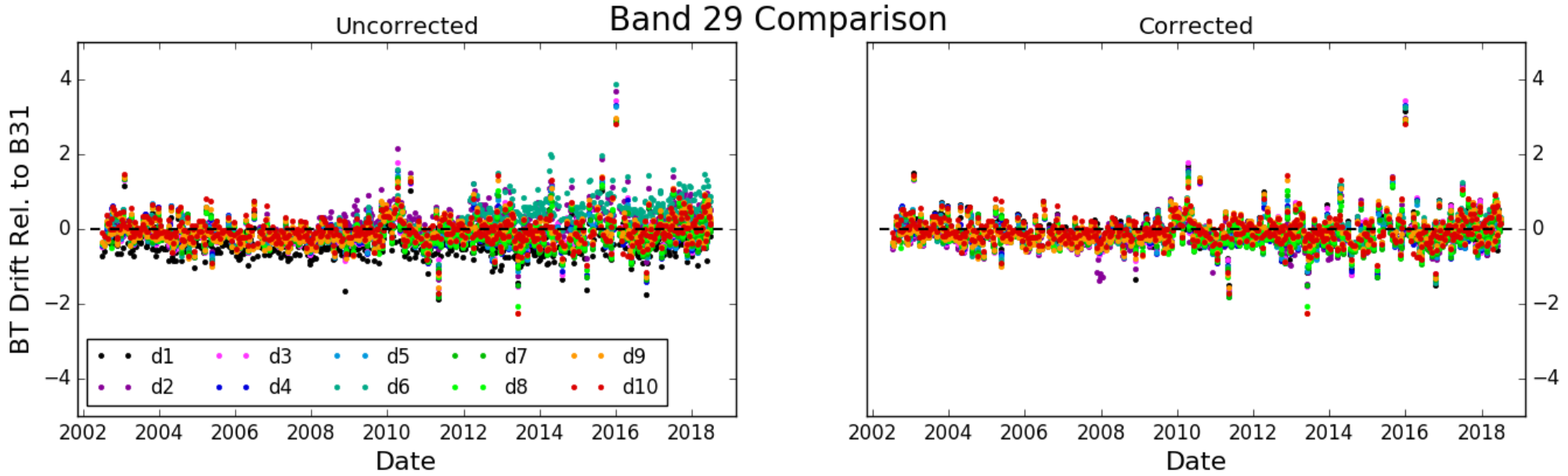


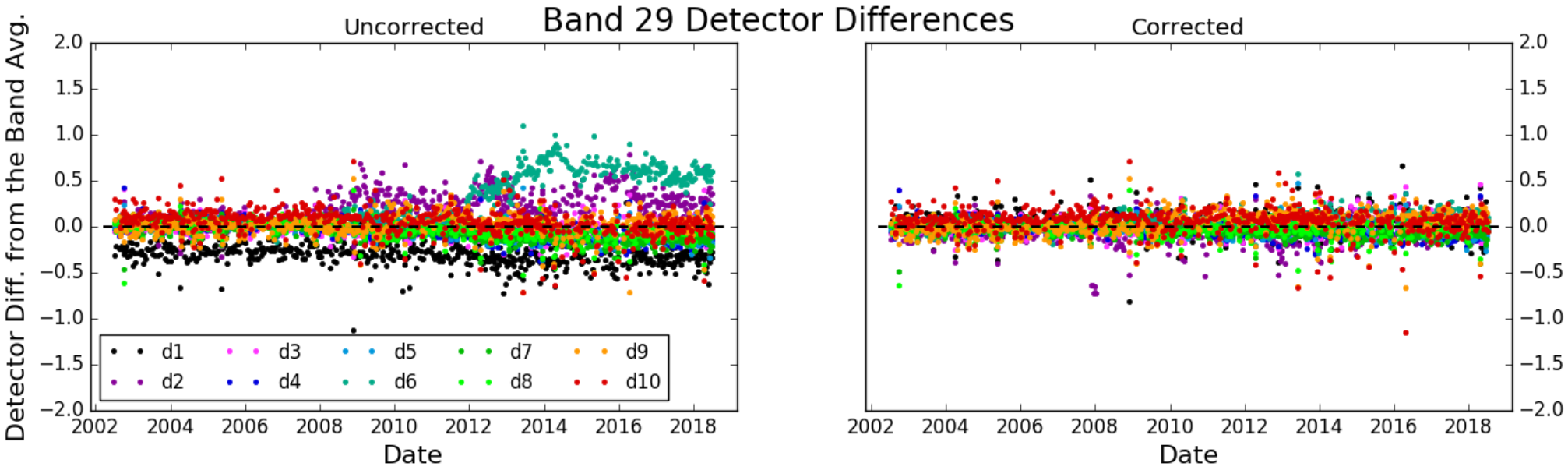
Long-Term Trending Over Warm Ocean - Aqua



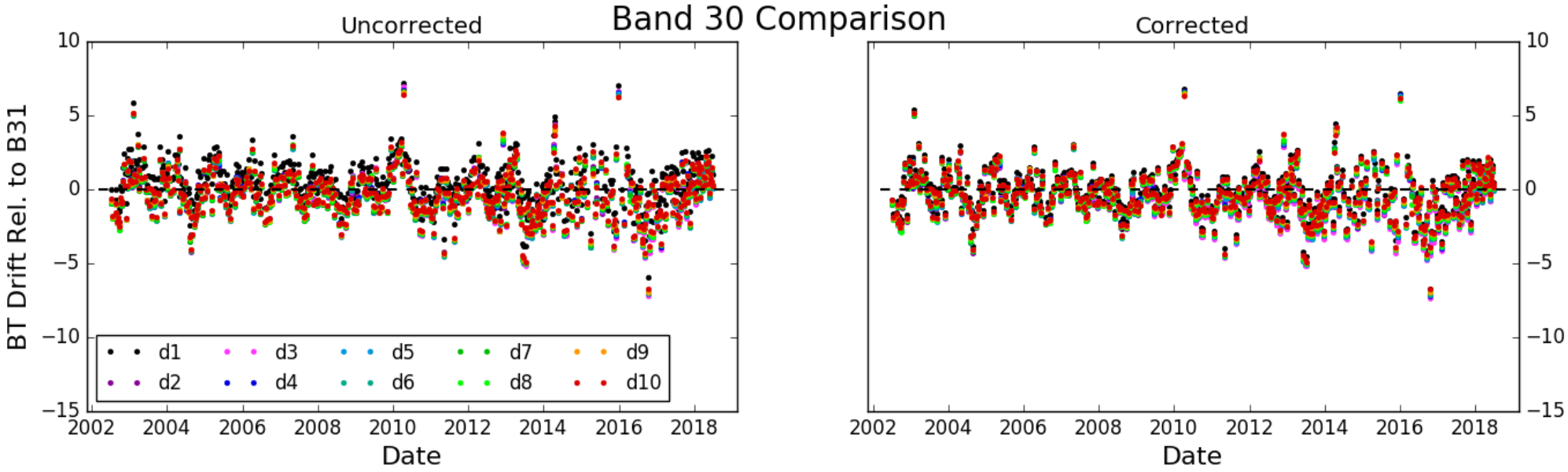


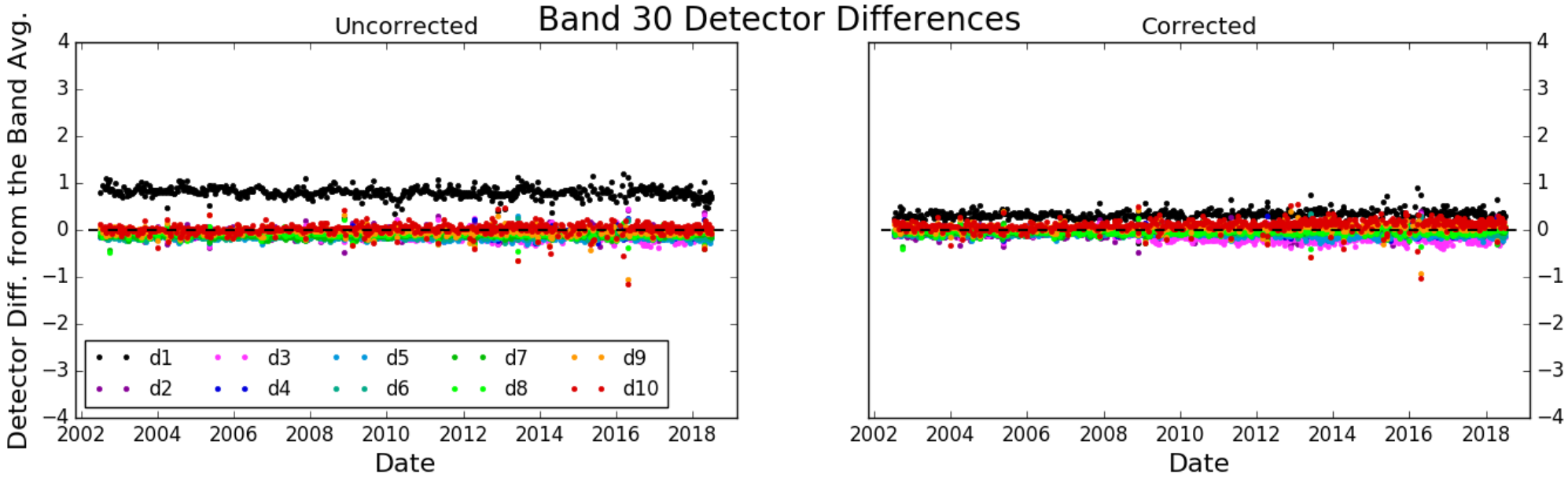
Long-Term Trending Over Warm Ocean - Aqua





Long-Term Trending Over Warm Ocean - Aqua



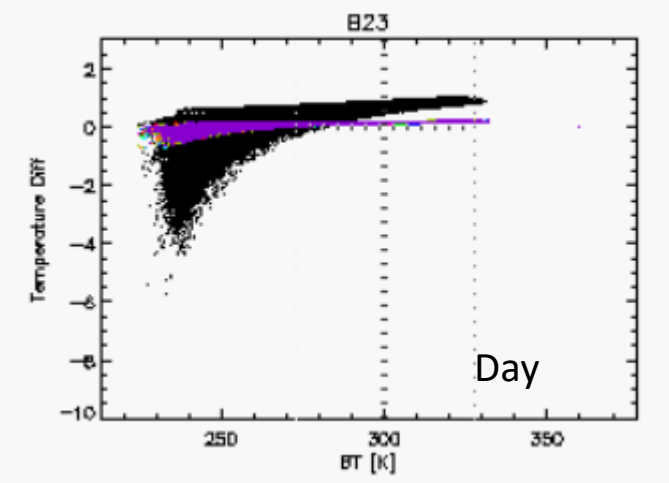


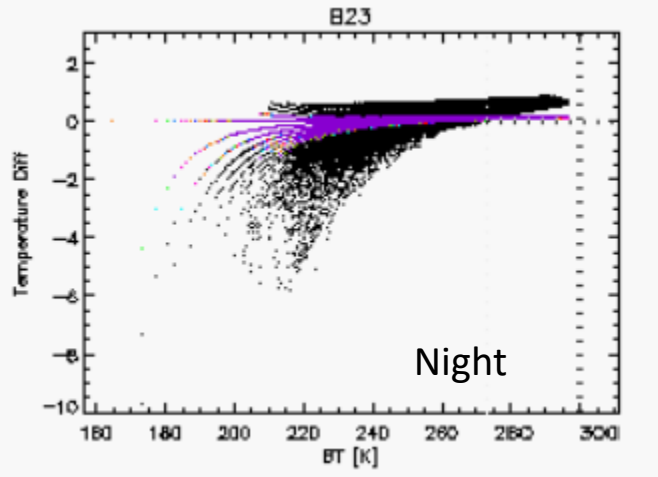
Correction Magnitude Over 1-Orbit

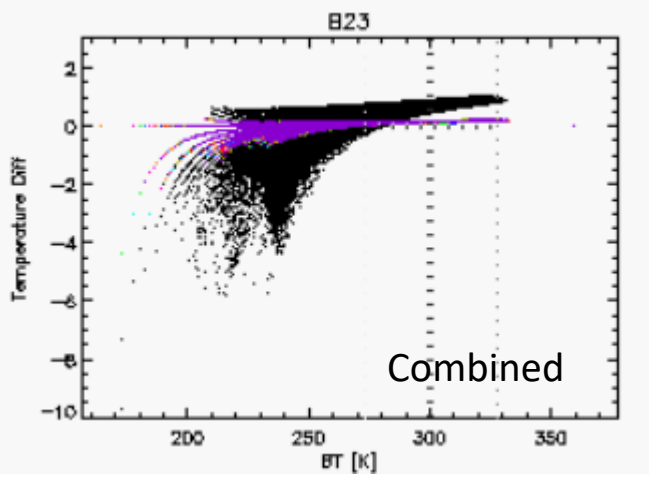
(1) Band 23 detector 1 has contamination from band 25 detector 1 and 10. Band-to-band contamination from bands 24 and 25

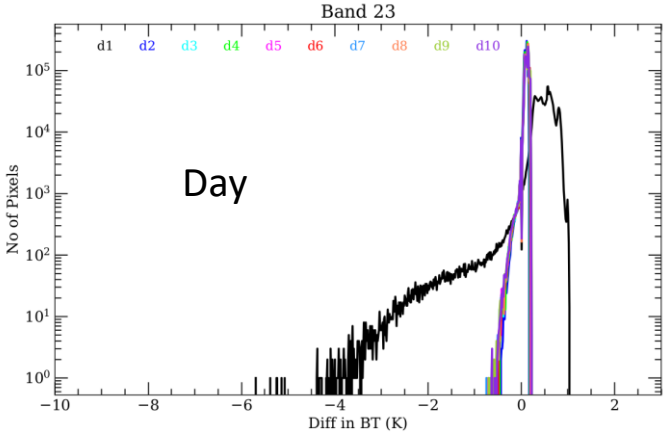
(2) The large contamination is in the low BT range for detector 1. The correction is around 0.5 K.

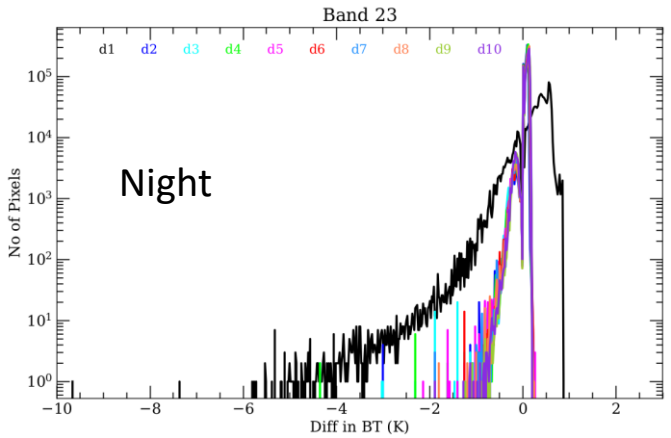
(3) The y-scale is on a log scale for histogram plots for daytime and nighttime . The combined histogram is on a linear scale.

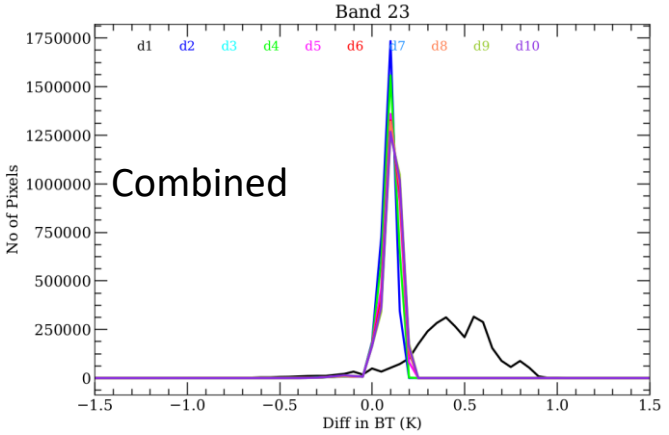






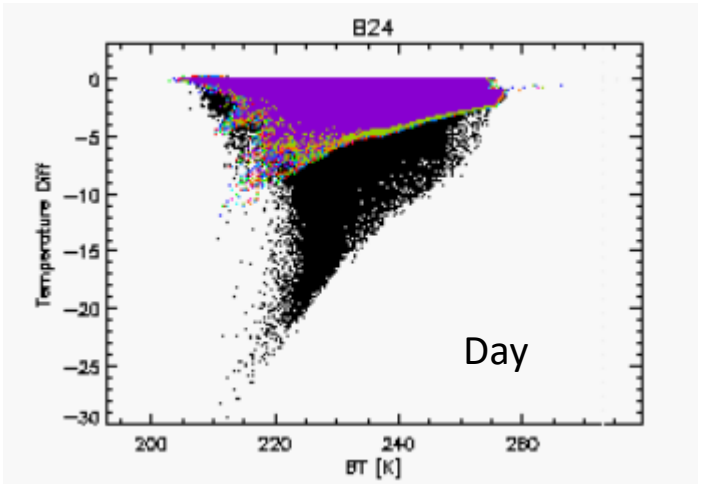


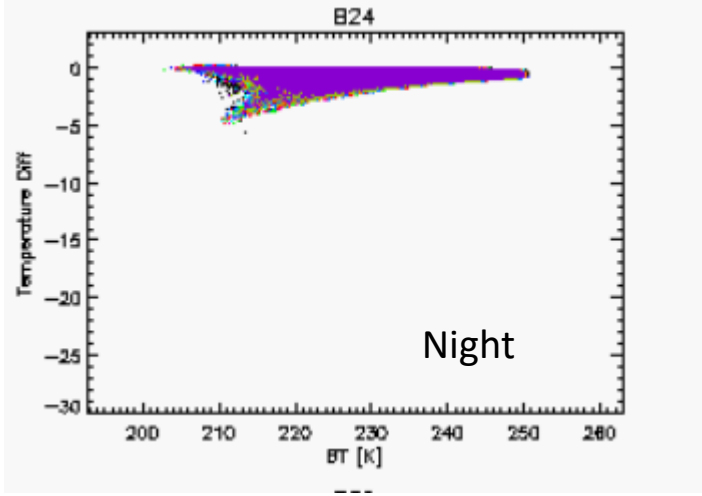


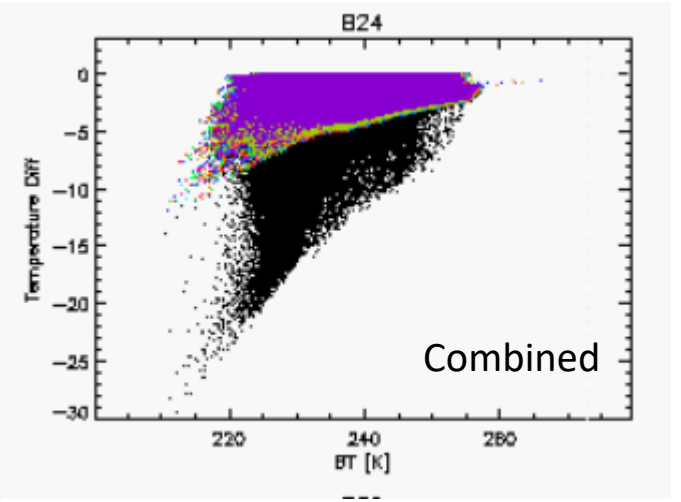


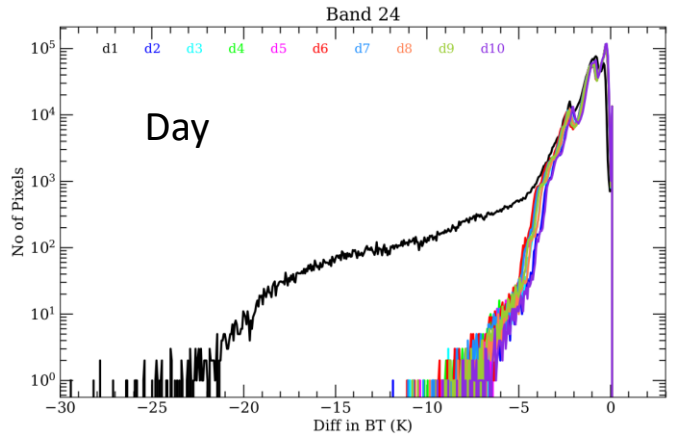
Correction Magnitude Over 1-Orbit

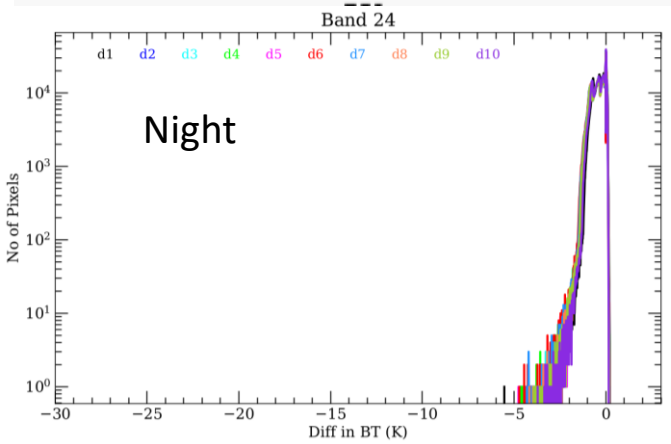
(1) Band 24 detector 1 has contamination from band 26. Band-to-band contamination from bands 20 to 23
(2) The large contamination is in the low BT range. Detector 1 contamination occurs during daytime due to band 26
(3) The y-scale is on a log scale for histogram plots for daytime and nighttime over 1-orbit. The combined histogram is on a linear scale.

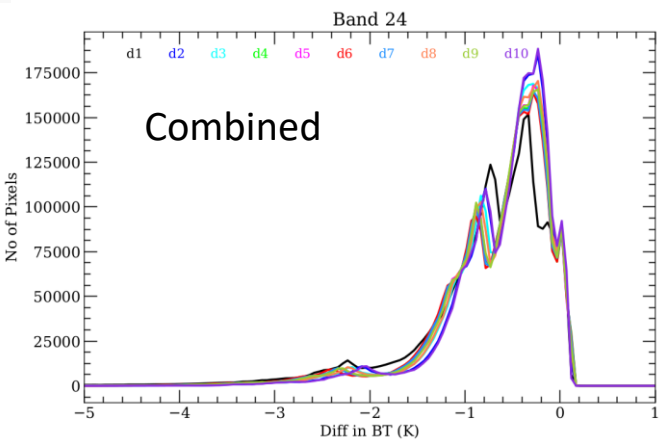






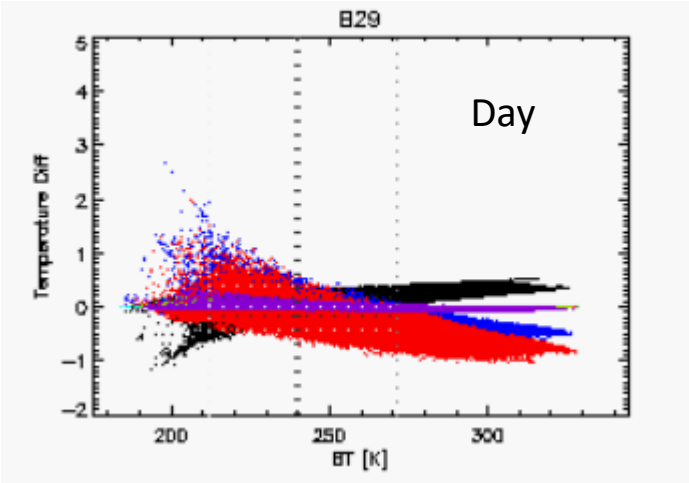


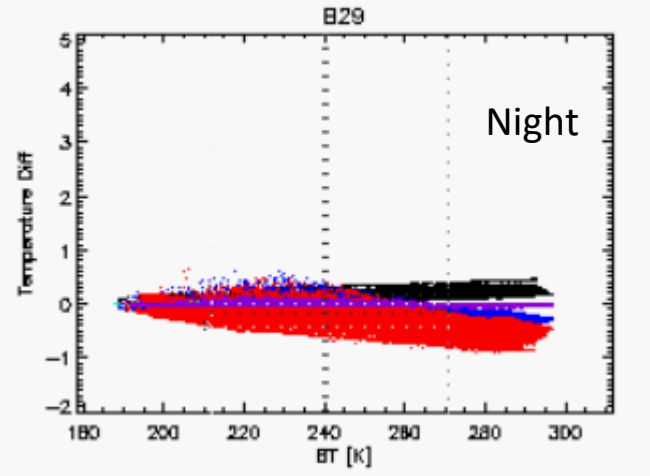


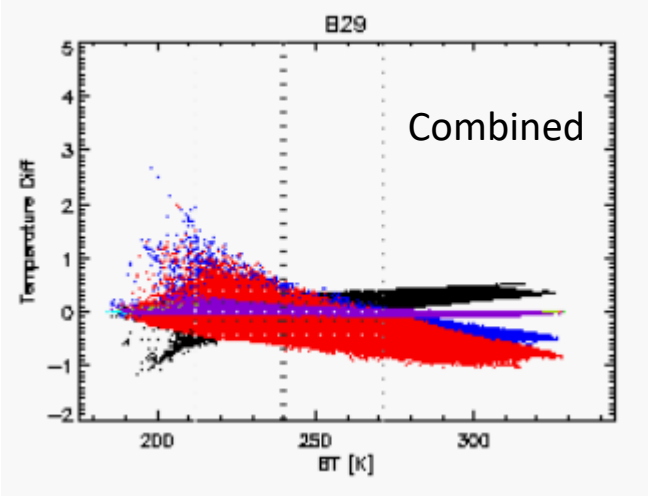


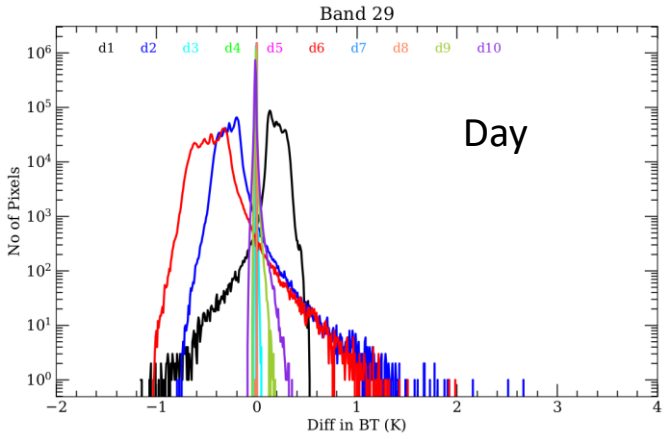
Correction Magnitude Over 1-Orbit

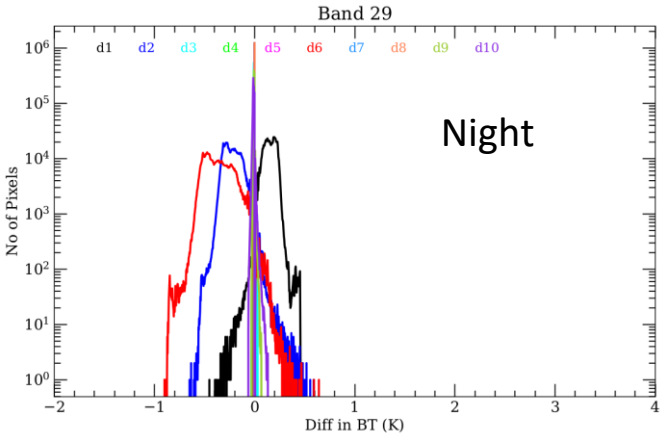
(1) Band 29 detector 1 has contamination from band 28 detector 10. Band-to-band contamination from bands 27 to 30
(2) Large contamination occurs for detectors 1, 2 and 6. The correction is around 0.2K, -0.25 K, and-0.35K respectively.
(3) The y-scale is on a log scale for histogram plots for daytime and nighttime over 1-orbit. The combined histogram is on a linear scale.

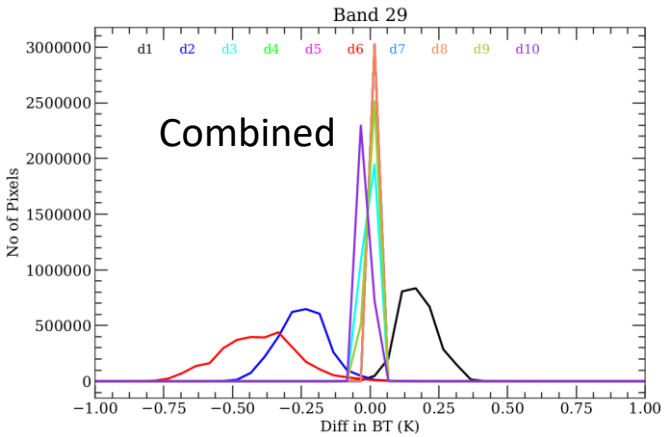






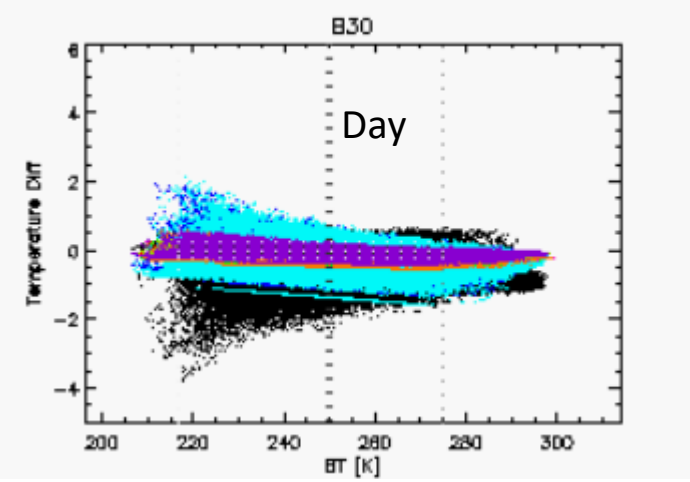


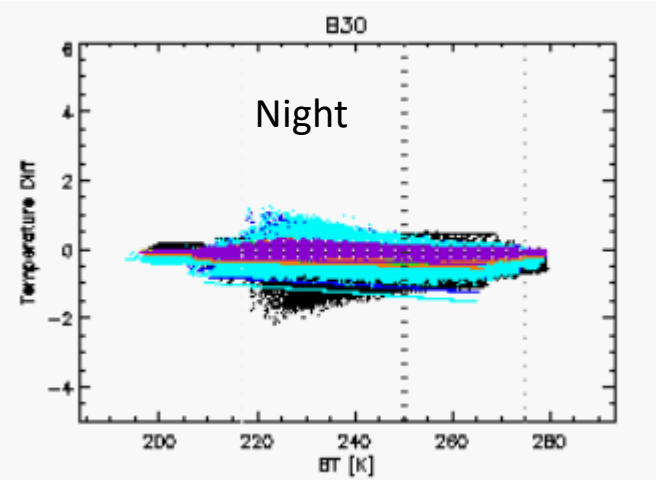


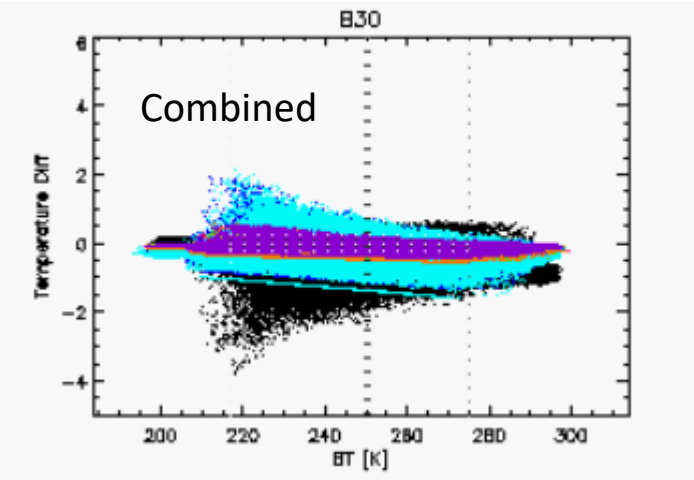


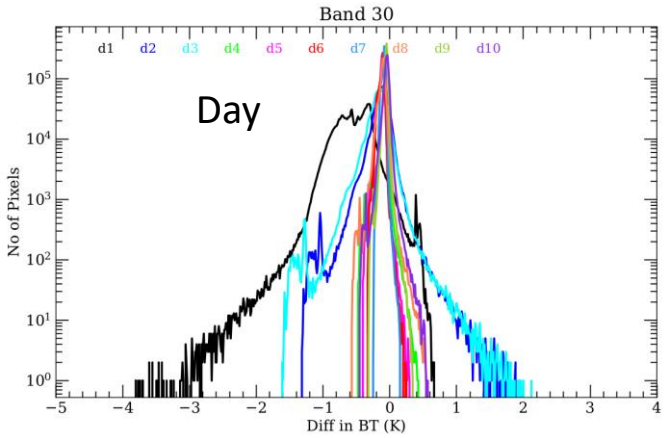
Correction Magnitude Over 1-Orbit

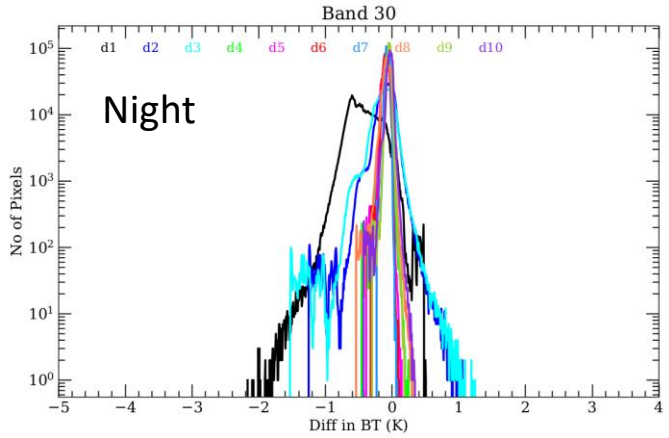
(1) Band 30 detector 1 has contamination from band 29 detector 10. Band-to-band contamination from bands 27 to 30
(2) Large contamination occurs for detector 1. The correction is around -0.5K.
(3) The y-scale is on a log scale for histogram plots for daytime and nighttime over 1-orbit. The combined histogram is on a linear scale.

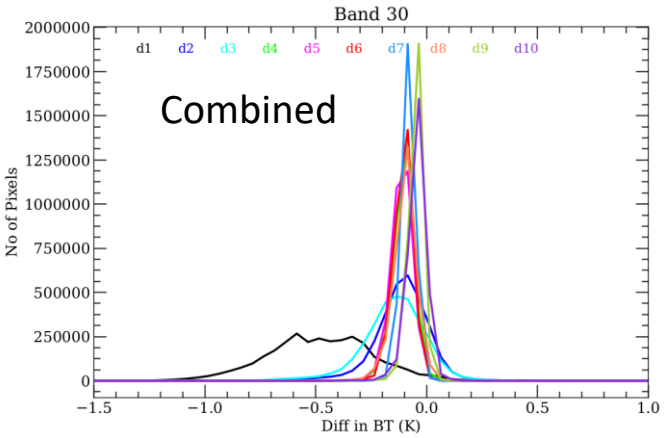












Crosstalk Impact Assessment – Aqua MWIR

Band	Contamination Impact	Correction Impact	Recommendation
20	D1 impact ~0.15K on average Insignificant impact for others.	Effectively removes contamination	**Apply correction for detector 1 (sending from B22 D10)**
21	Contamination is insignificant**.**	No Correction Required	No action recommended
22	D1 impact ~0.2K on average Insignificant impact for others.	Effectively removes contamination	**Apply correction for detector 1 (sending from B23 D10)**
23	D1 striping over **ice cloud scenes** (large) and **water scenes** (~0.5K)**.**	Effectively removes contamination	**Apply correction for detectors 1 (sending from B25 D10&D1)**
24	D1 striping over low BT scenes during daytime.	Effectively removes D1 striping over low BT scenes during daytime	**Apply correction for detector 1 (sending from B26 D10)**
25	D1 impact ~0.2K on average Insignificant impact for others.	Effectively removes contamination	**Apply correction for detector 1 (sending from B24 D10)**

Crosstalk Impact Assessment – Aqua LWIR

Band	Contamination Impact	Correction Impact	Recommendation
27	D1 impact ~0.8K on average	Effectively removes contamination	**Apply correction for detector 1 (sending from B30 D10)**
28	Contamination is insignificant**.**	No Correction Required	No action recommended
29	D1 impact ~0.2K D2 (noisy) ~0.25K since 2008 D6 (noisy) ~ 0.35K since 2008	Effectively removes contaminations	**Apply correction for detectors 1, 2, and 6**
30	D1 impact ~0.45K on average Insignificant impact for others.	Effectively removes contamination	**Apply correction for detector 1 (sending from B29 D10)**

Summary

- By applying the experience gained in the correction of the PV LWIR bands in Terra MODIS to the rest of the TEBs for both Aqua and Terra, we are able to assess the impact of crosstalk contamination and provide a correction to the Earth-view imagery.

- Outside of Terra bands 27-30, only a few detectors are significantly affected and require a correction.

- These corrections will be implemented in the L1B data in a future collection. However, the impact for this new correction on the science products should be minimal, as it mostly involves destriping of the L1B imagery and the Wisconsin destriping algorithm should correct most of these artifacts.

References

1. T. Wilson, A. Wu, A. Shrestha, X. Geng, Z. Wang, C. Moeller, R. Frey, and X. Xiong, "Development and Implementation of an Electronic Crosstalk Correction for Bands 27-30 in Terra MODIS Collection 6," *Remote Sens*., **9**, 569 (2017).

2. T. Wilson, A. Shrestha, and X. Xiong, "Electronic crosstalk impact assessment in the Terra MODIS mid-wave infrared bands," *Proc. SPIE*, **10423**, 104231Z (2017).

3. G. Keller, Z. Wang, A. Wu, and X. Xiong, "Aqua MODIS band 24 crosstalk striping," *IEEE Geoscience and Remote Sensing Letters*, **14**(4), 475 (2017).

4. G. Keller, Z. Wang, A. Wu, and X. Xiong, "Aqua MODIS electronic crosstalk survey from Moon observations," *Proc. SPIE*, **10423**, 1032314 (2017).