Landsat 8 Thermal Infrared Sensor (TIRS) Stray Light Correction Algorithm Update

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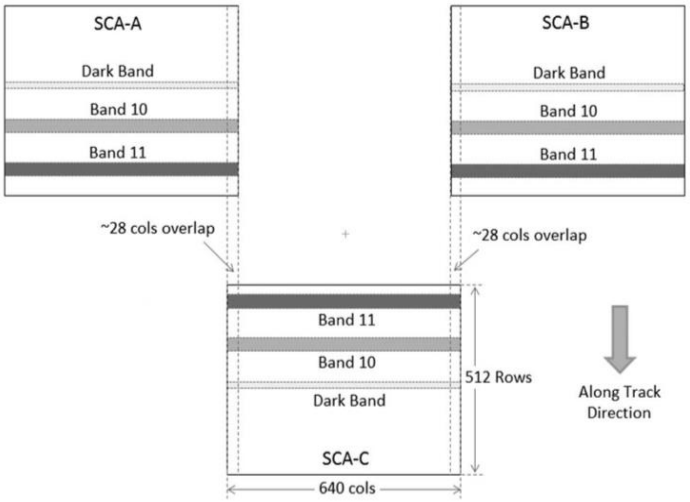
Image artifacts point to possible stray light issue

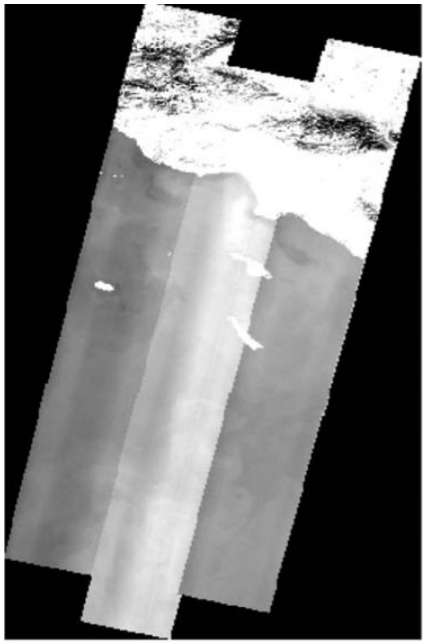
Landsat 8 Thermal Infrared Sensor (TIRS)

- Push-broom architecture
- Three staggered arrays
- Two thermal bands (10.9 & 12.0 micron)
- 185 km swath (15-deg FOV)

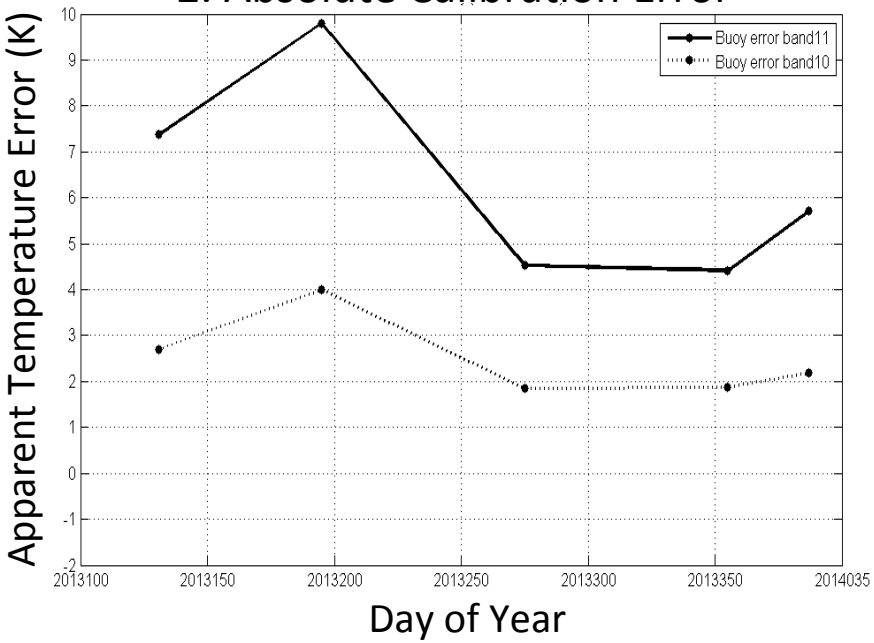


Two major artifacts:

1. Non-Uniform Banding

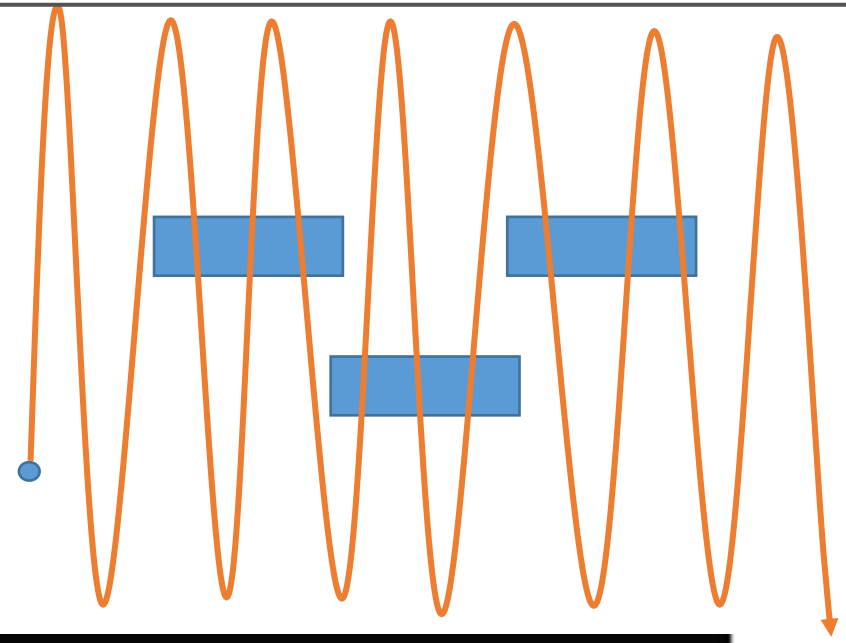


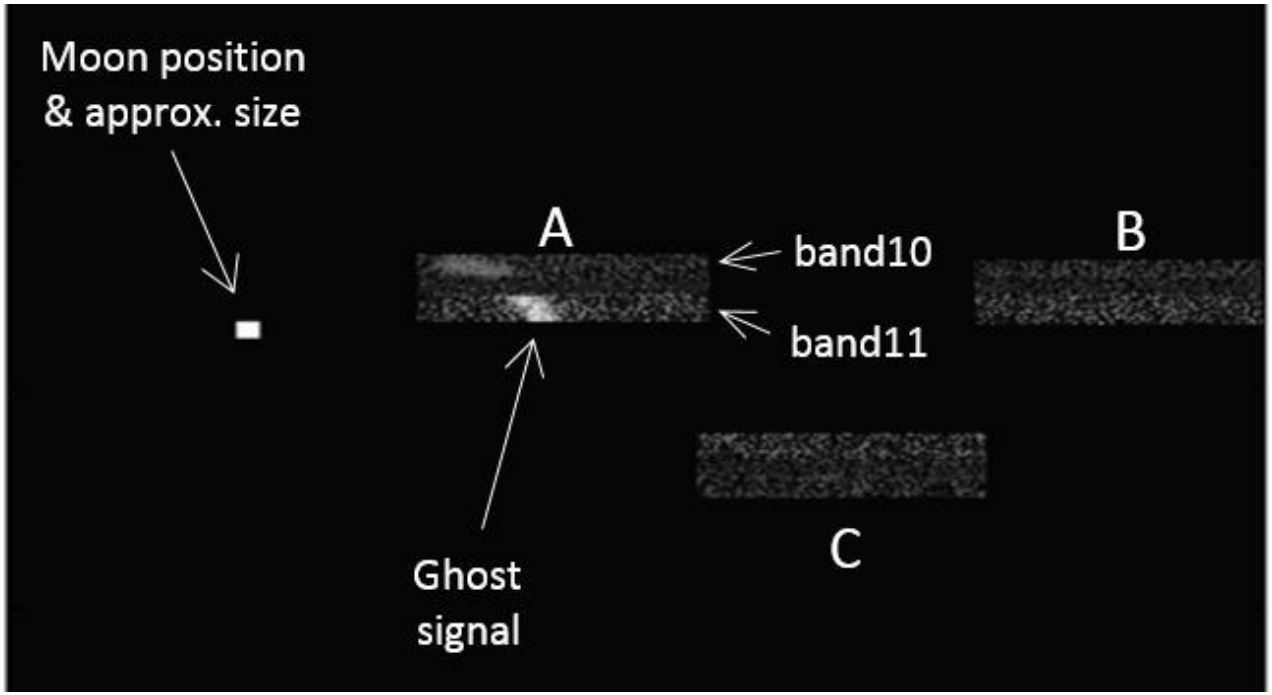
2. Absolute Calibration Error



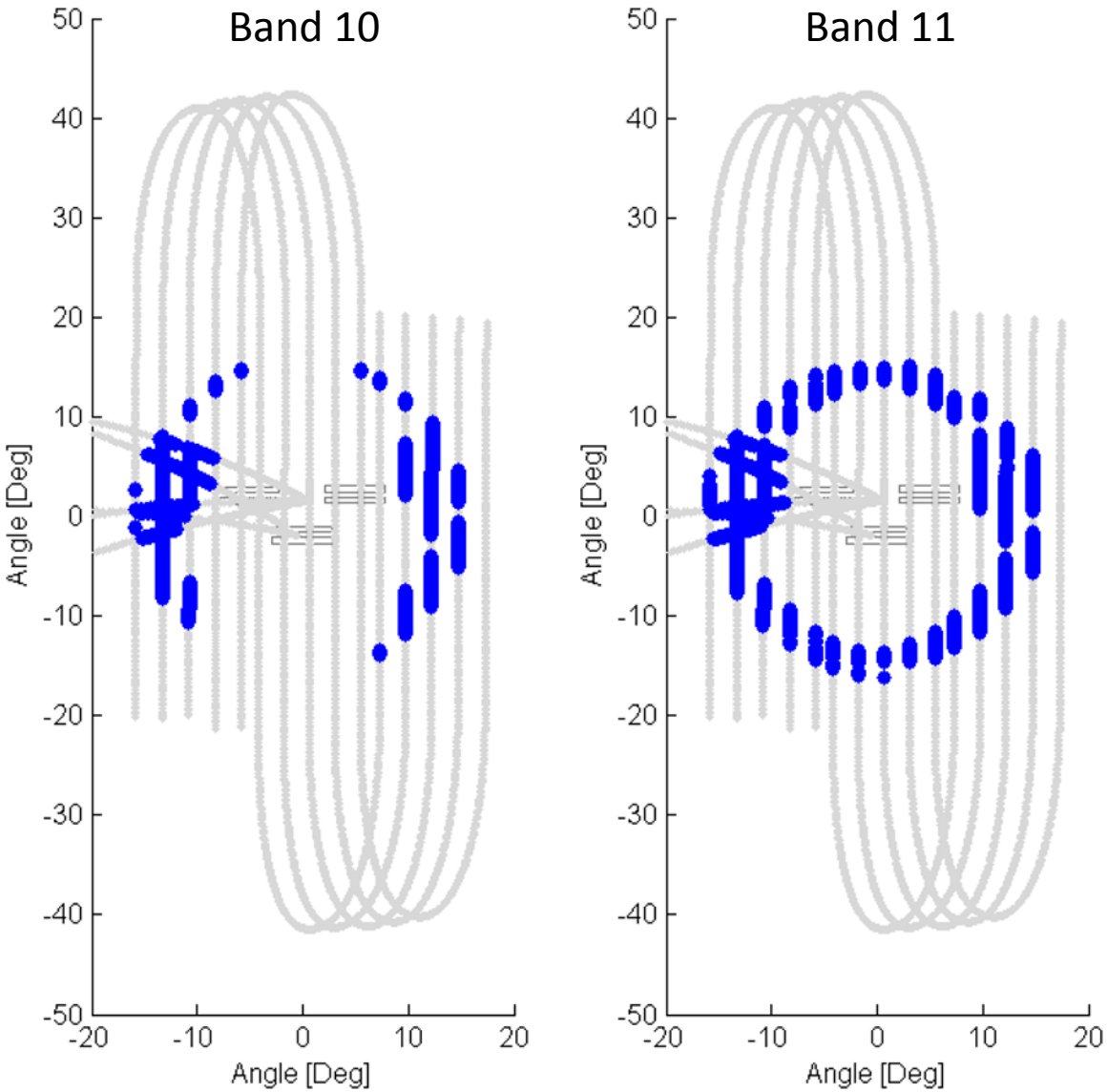
Lunar raster scan definitively showed stray light

- Raster-scan the moon around the out-of-field
- Should see “nothing” when moon is outside field-of-view



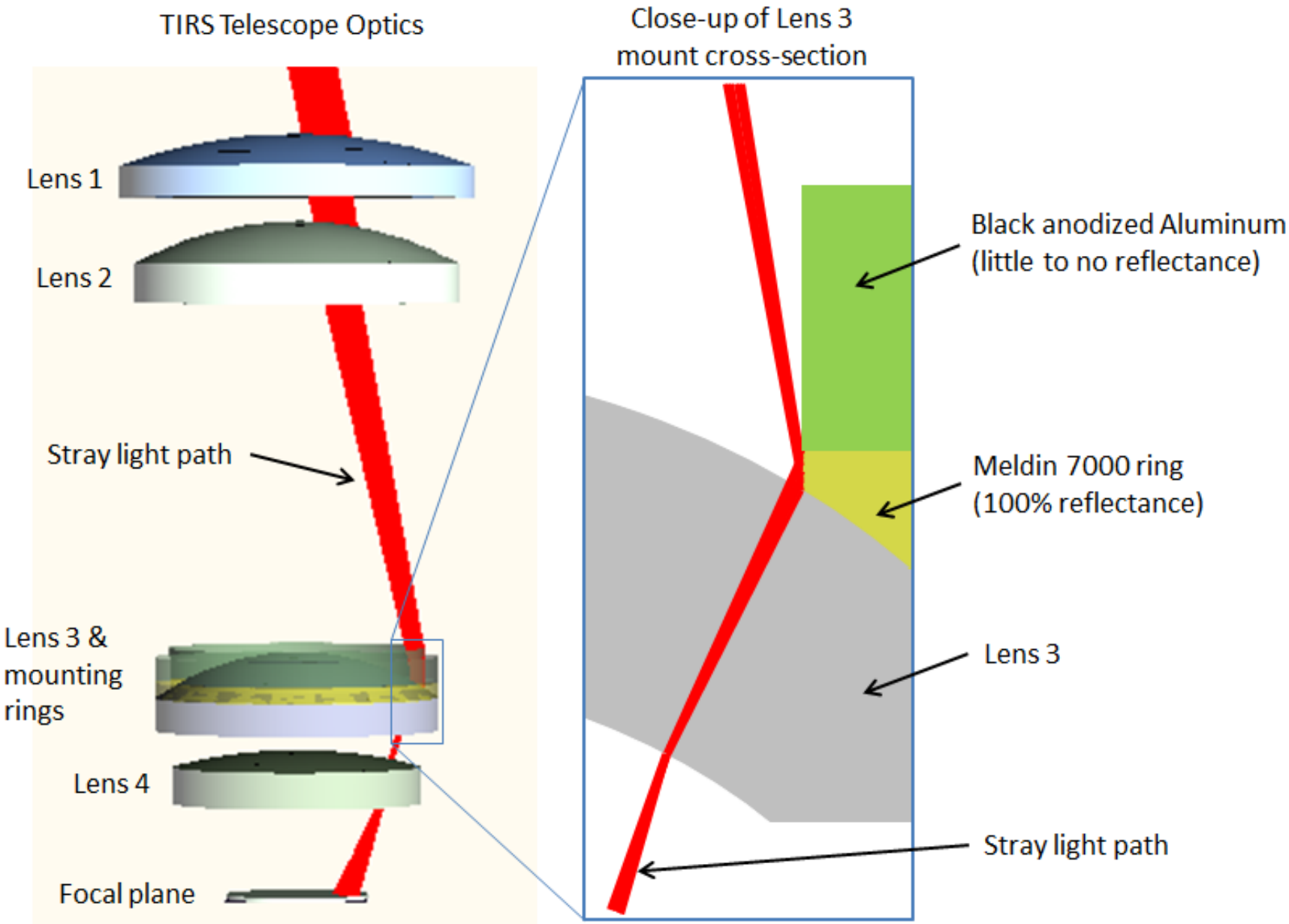


Map of stray light locations from lunar positions



Lunar locations (blue) in which a stray light signal appeared <u>anywhere</u> on the detectors

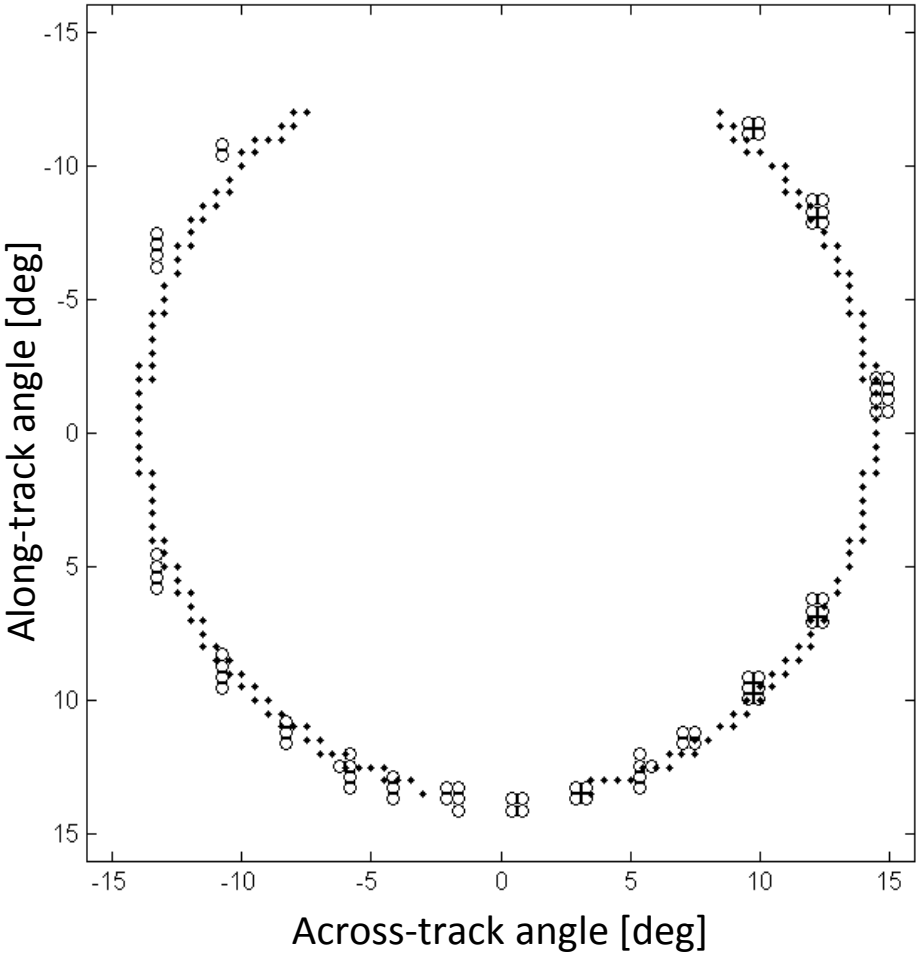
Lunar data used to inform optical stray light model



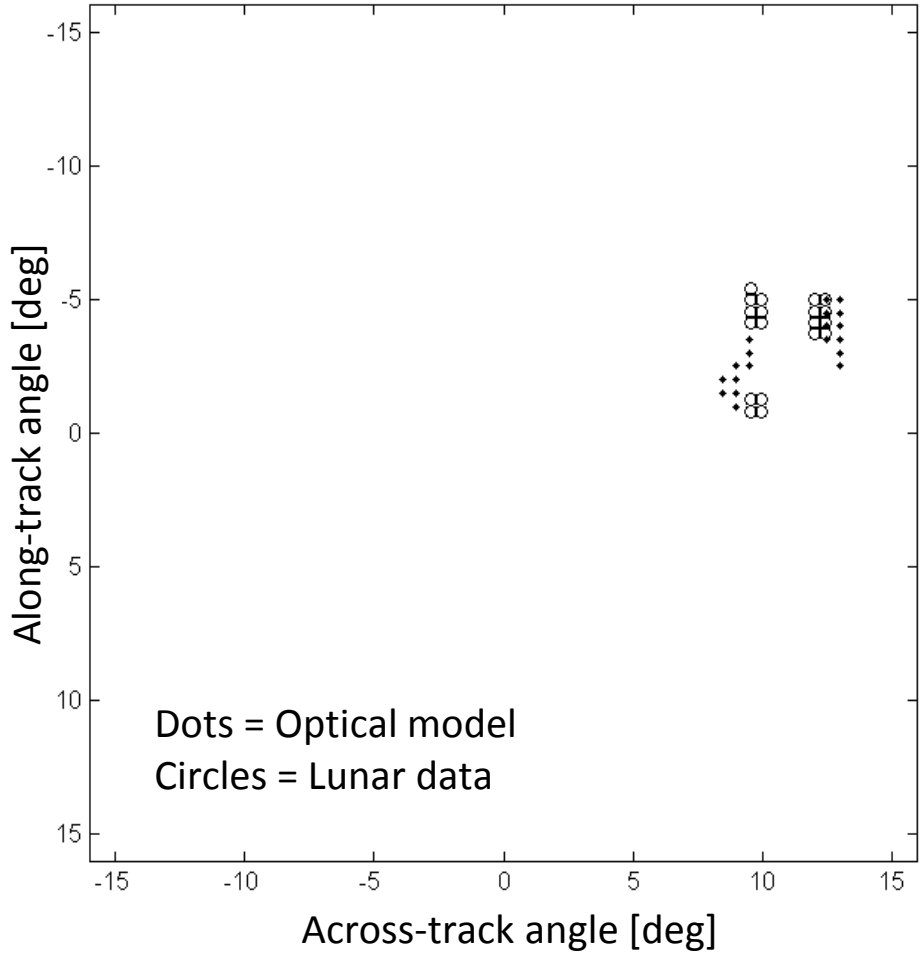
* Scott Rohrbach & Eric Mentzell (NASA/GSFC)

Reverse ray trace produces stray light map for each detector

Stray light map for one detector on array -C

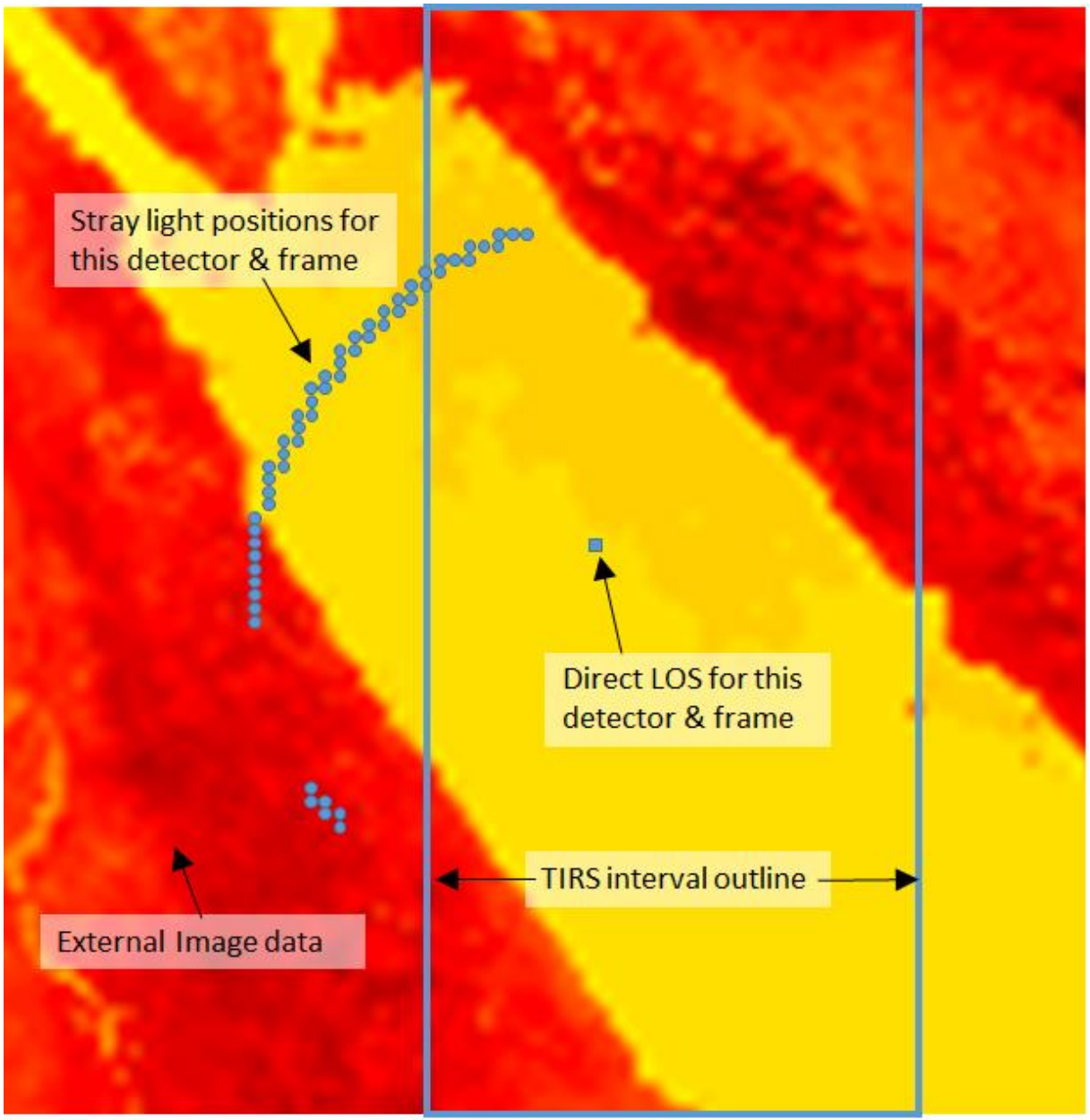


Stray light map for one detector on array -B



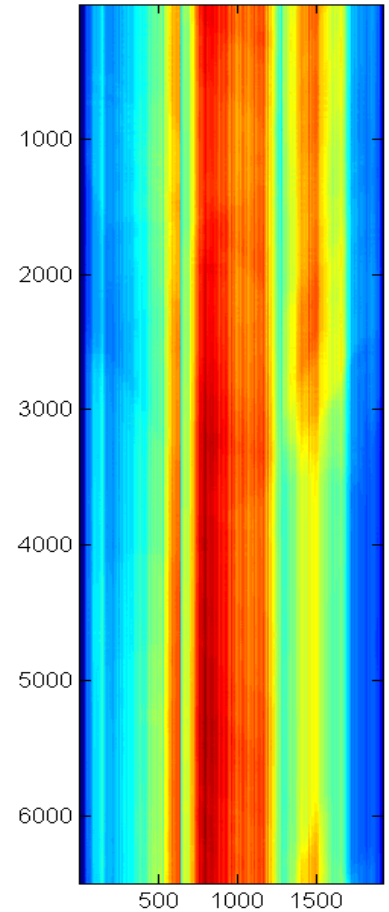
* Unique map for each detector (i.e.- different stray light signal for every detector)

Stray light removal algorithm: Optical model with out-of-field data

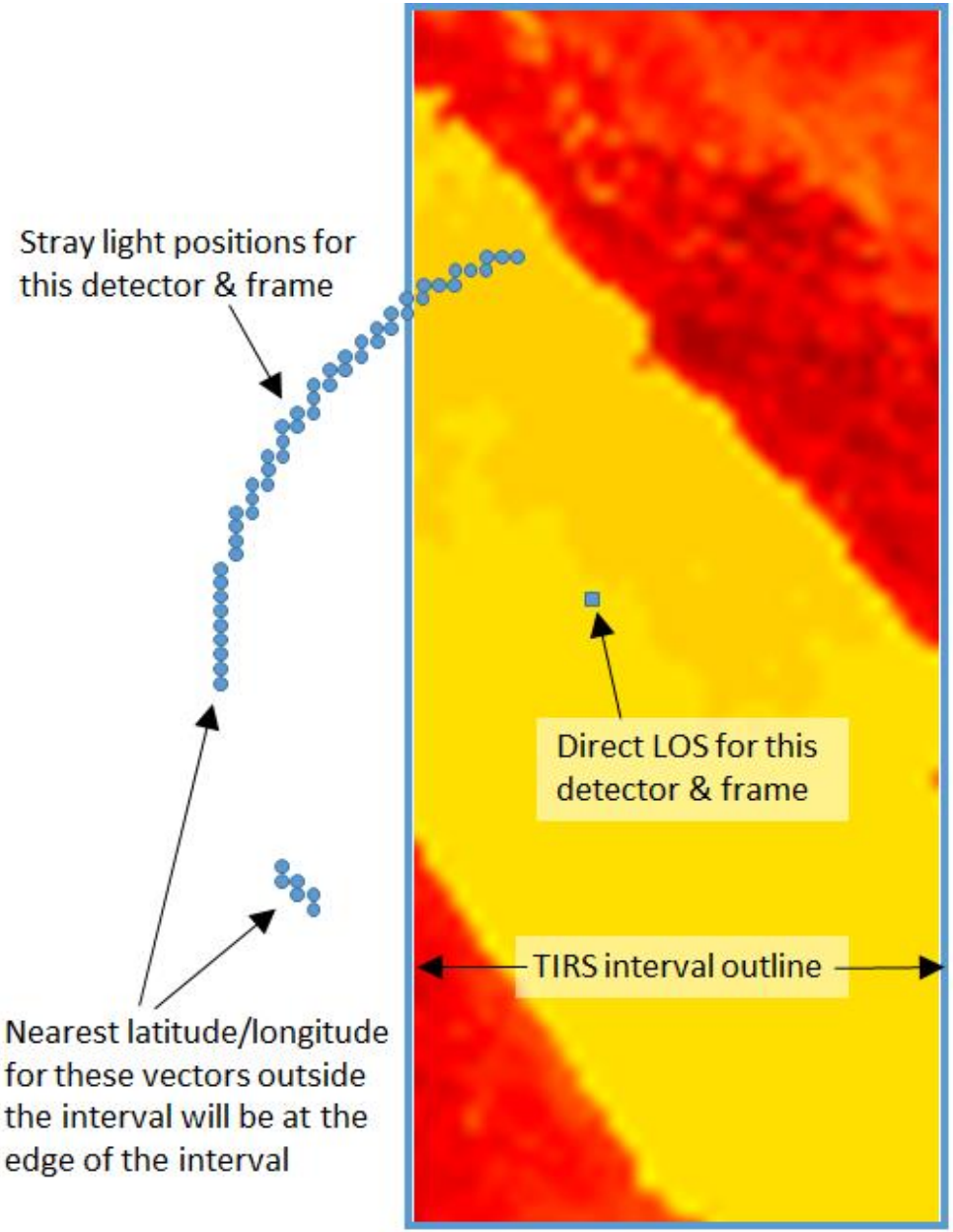


$$StrayLight = a \cdot (Ext.Sampled) + b$$
$$= a \cdot \left(\sum L_{ext_i} \cdot w_i\right) + b$$

Calculated signal to remove from TIRS interval



Stray light removal algorithm: Optical model with TIRS data only



$$StrayLight = a \cdot (Ext.Sampled) + b$$
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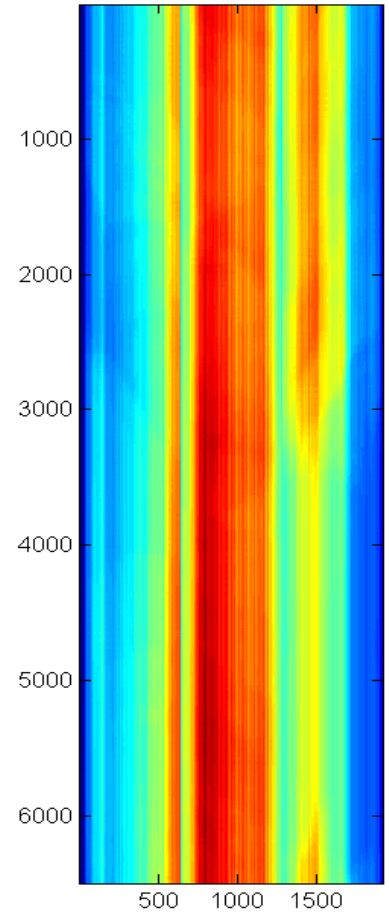
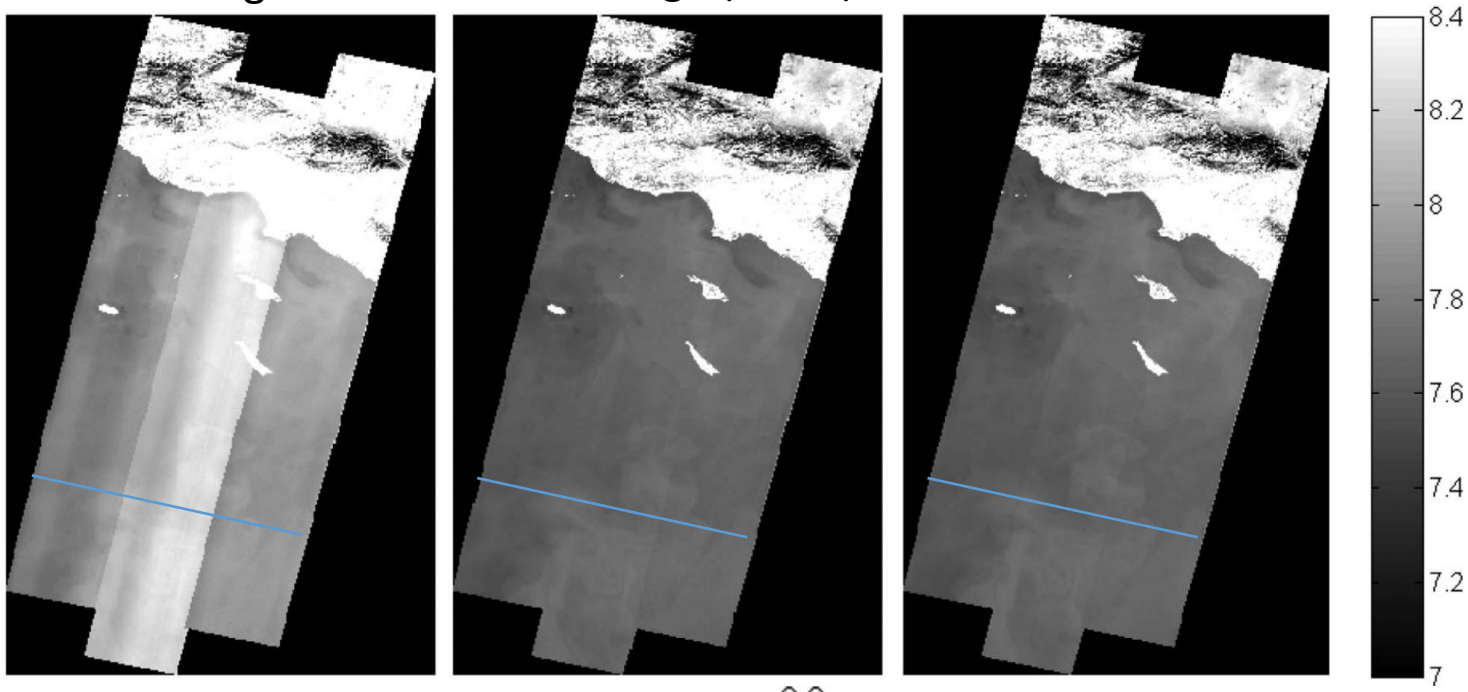
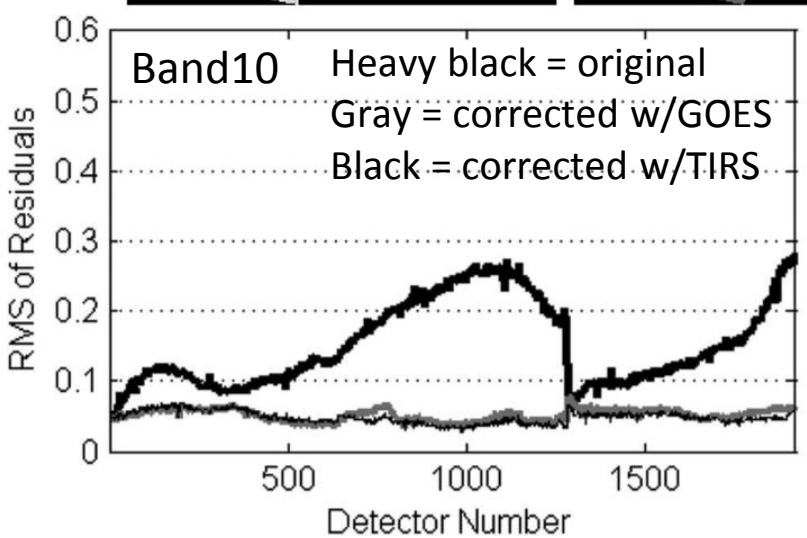
Calculated signal to remove from TIRS interval

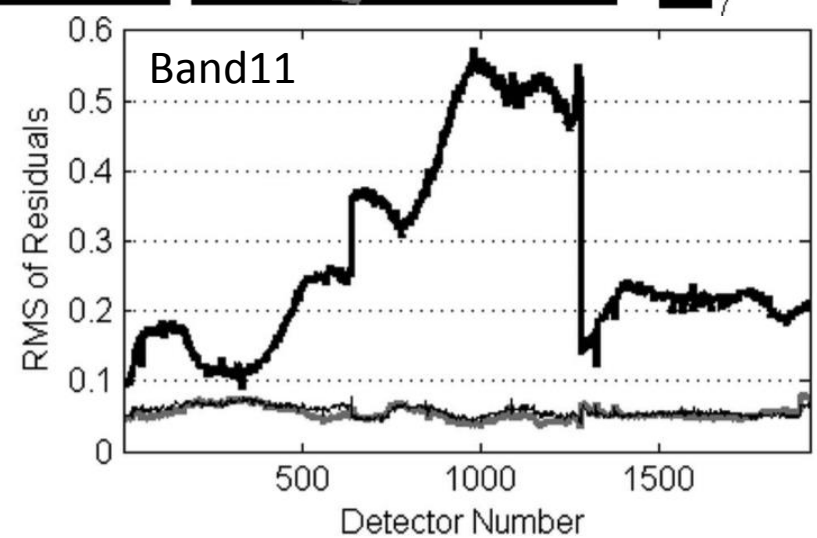


Stray light correction with and without out-of-field knowledge

Original Image | Corrected w/ out-of-field knowledge (GOES) | Corrected w/ only TIRS data







More Background on Stray Light Investigation & Correction Algorithm

Pursued TIRS-on-TIRS correction:

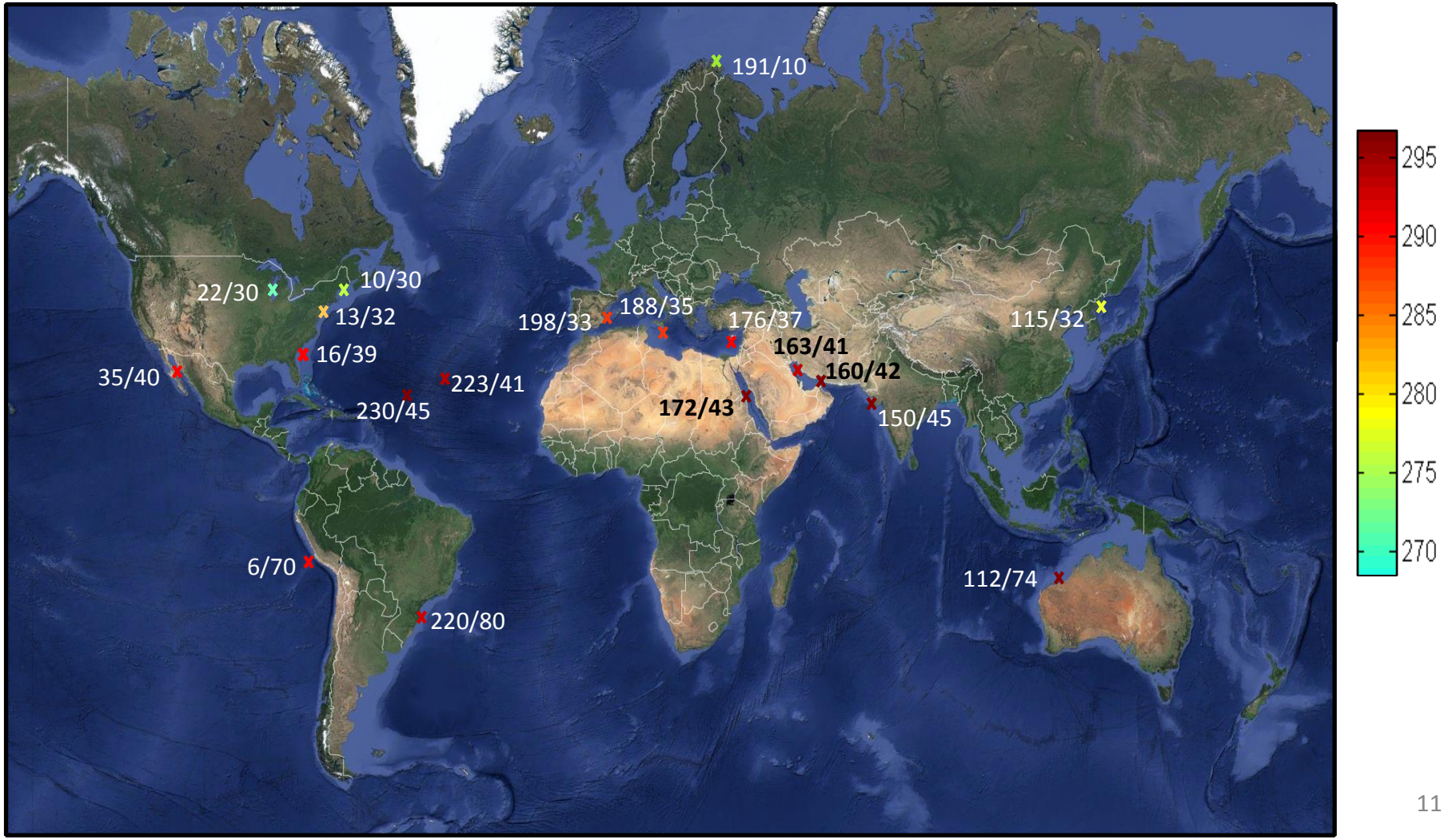
- Algorithm uses only TIRS interval data (no other sensor data) with optical model
- Able to be run in “real time” (i.e.- no significant processing lag) to produce corrected TIRS scenes
- Issues with external sensor (e.g. - GOES) data:
  - Band shape
  - View angle
  - cross-cal between sensors required for global coverage

More information:

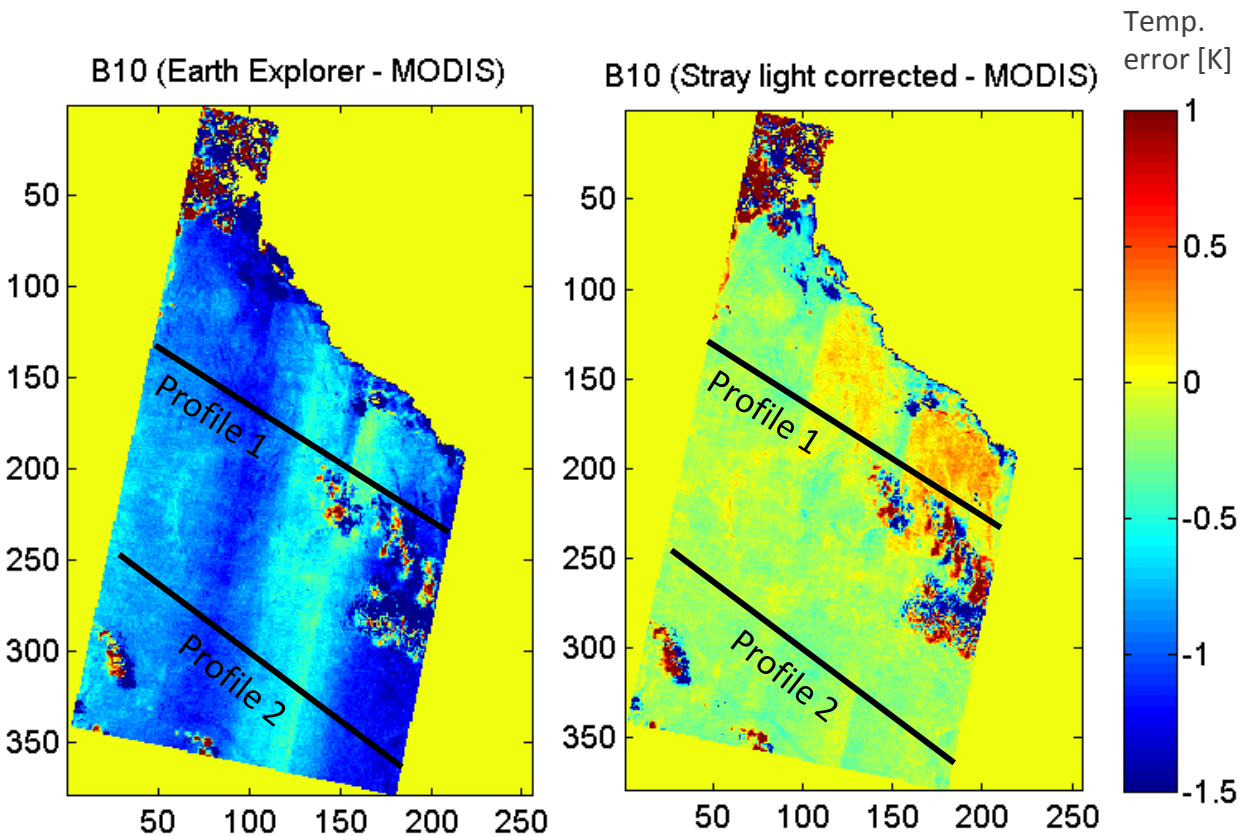
- Montanaro, M., Gerace, A., Lunsford, A., & Reuter, D. "Stray Light Artifacts in Imagery from the Landsat 8 Thermal Infrared Sensor." *Remote Sensing*, 6, 10435-10456 (2014). [doi:10.3390/rs61110435]
- Montanaro, M., Gerace, A., & Rohrbach, S. "Toward an operational stray light correction for the Landsat 8 Thermal Infrared Sensor." *Applied Optics*, 54, 3963-3978 (2015). [doi: 10.1364/AO.54.003963]
- Gerace, A. & Montanaro, M. “Validation of the stray light correction algorithm for the Landsat 8 Thermal Infrared Sensor”. -- IN WORK

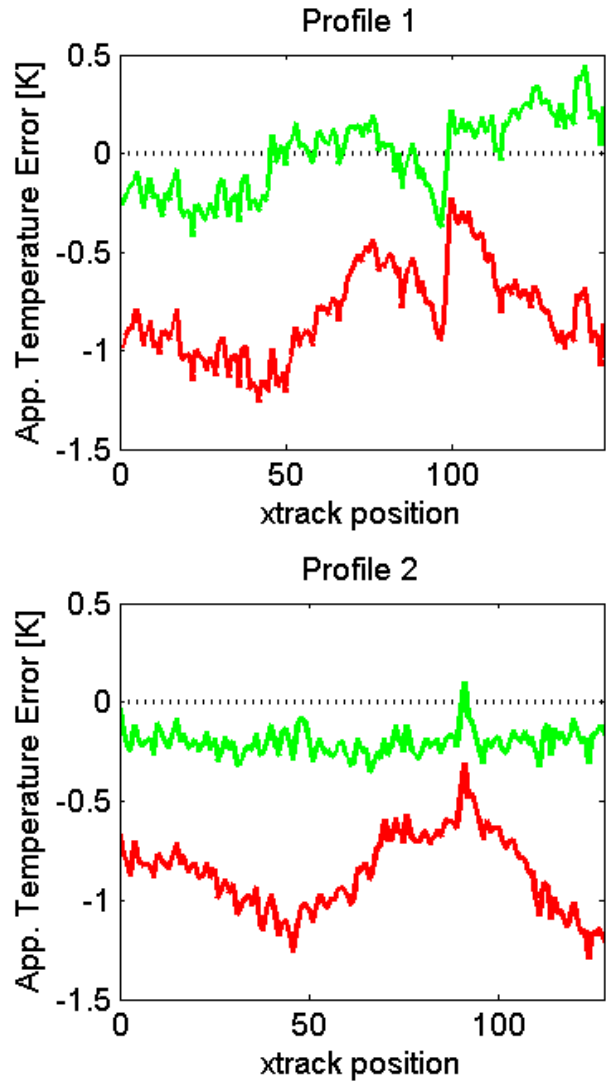
Full Scene Correction Demonstration – Validation Challenges

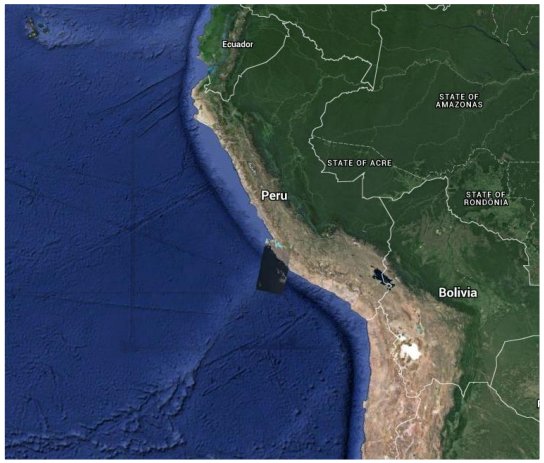
- During L8/Terra underfly period, TIRS centered on MODIS field-of-view
- Compare TIRS current product and corrected product to Terra/MODIS "truth"
- Recall current product (EarthExplorer) has a flat bias subtracted to make absolute cal error for N. hemisphere growing season scenes approximately zero.



Path 006, Row 070: Band 10

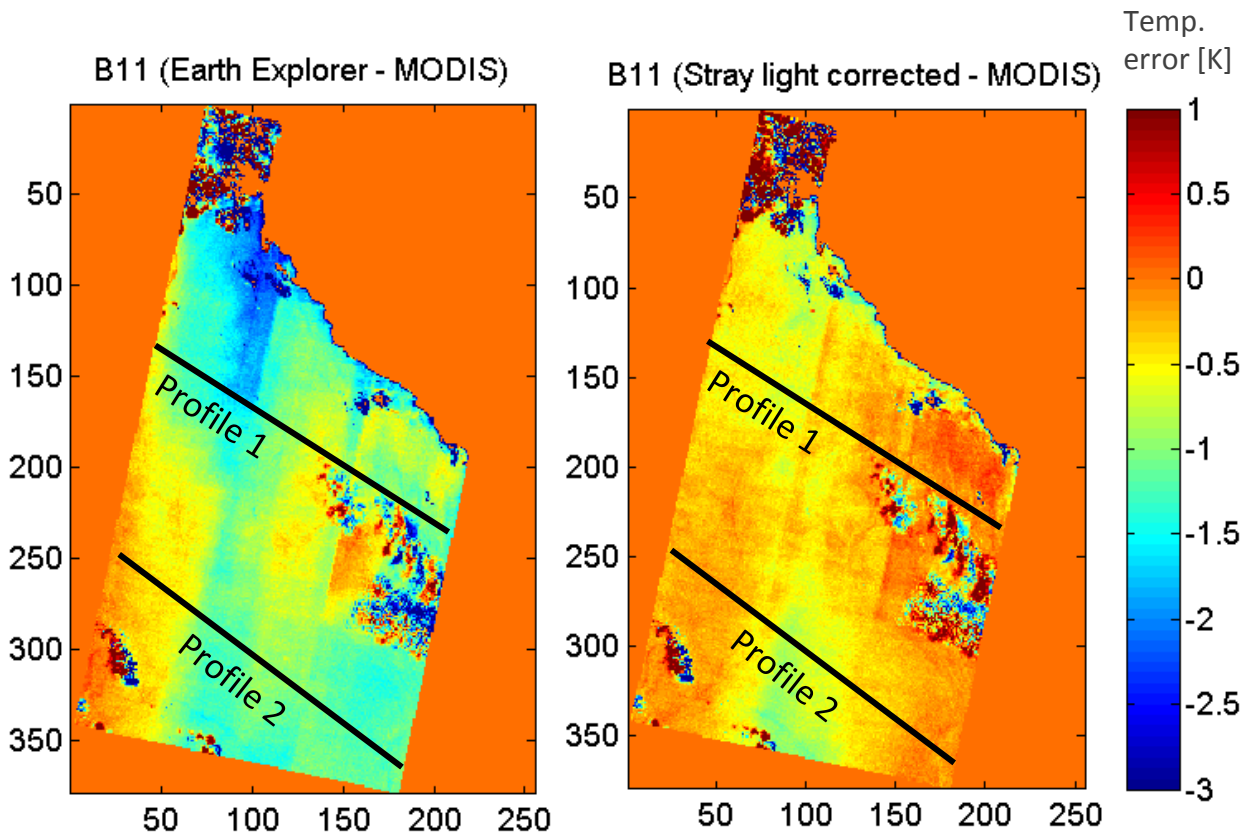


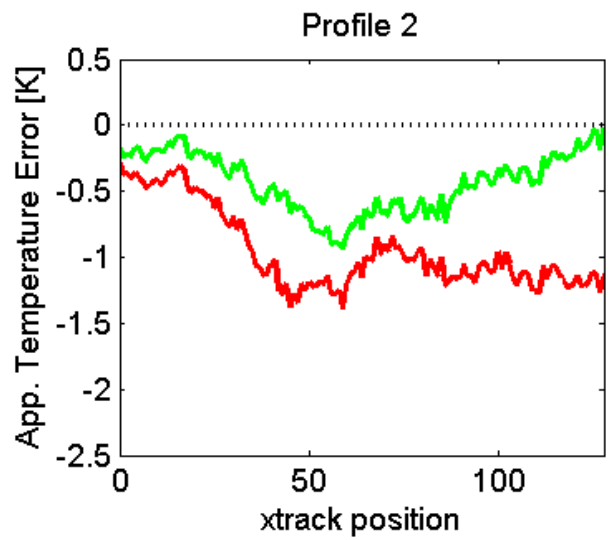


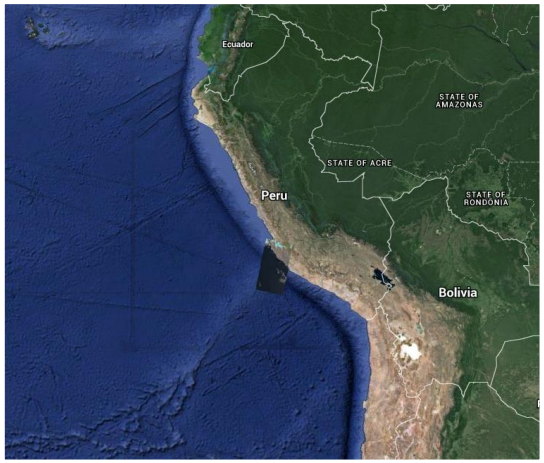


	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.229	0.199	0.850	0.199	-0.818	-0.016
Profile 2	0.195	0.067	0.888	0.213	-0.867	-0.203

Path 006, Row 070: Band 11

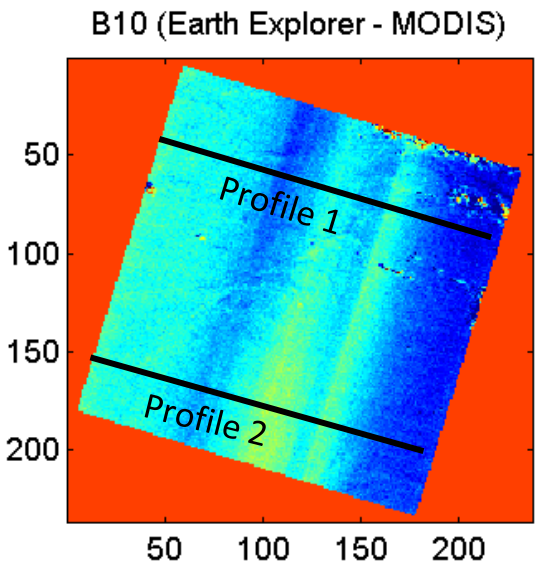


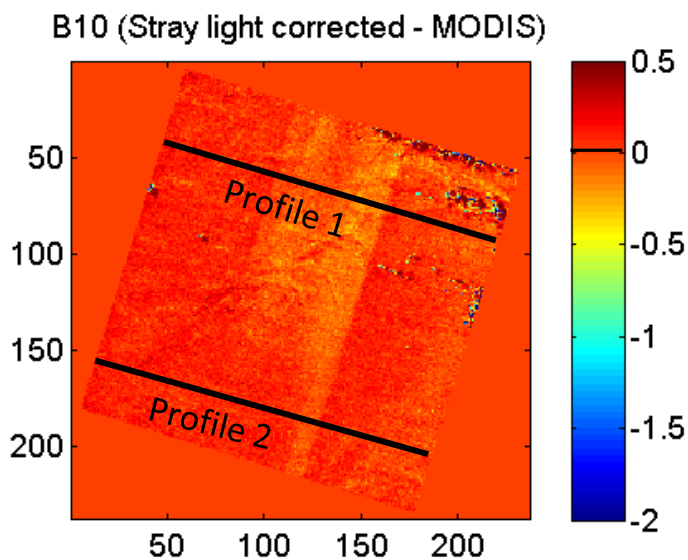


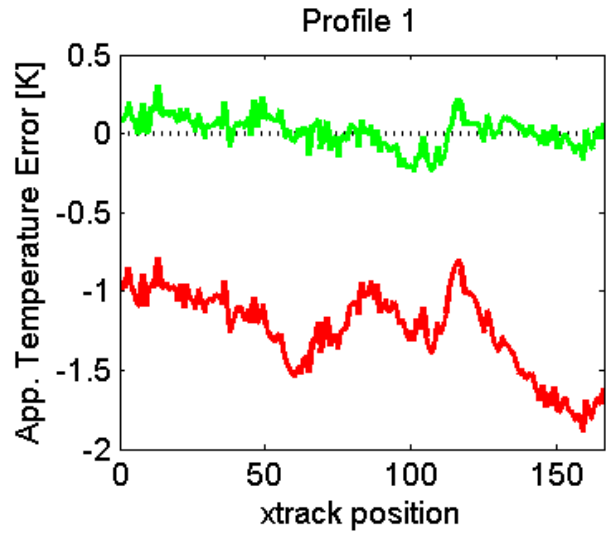


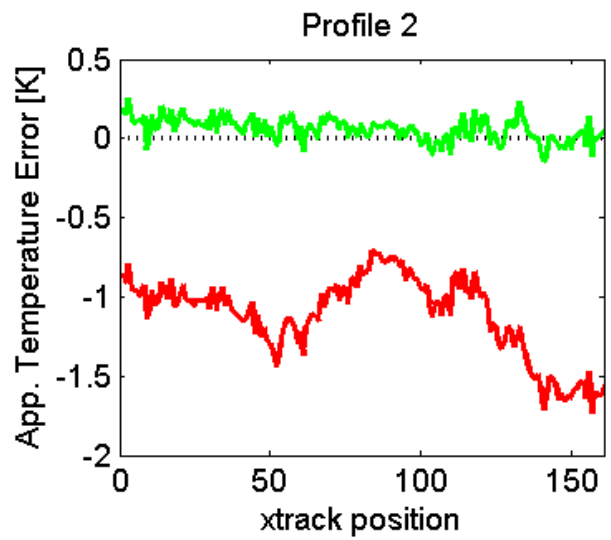
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.365	0.277	1.137	0.366	-1.078	-0.239
Profile 2	0.302	0.227	1.002	0.492	-0.955	-0.438

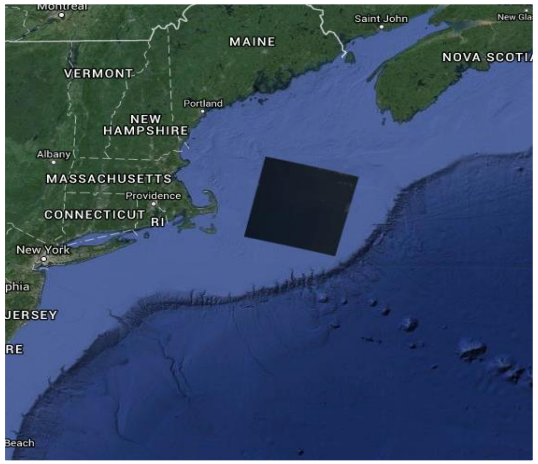
Path 010, Row 030: Band 10





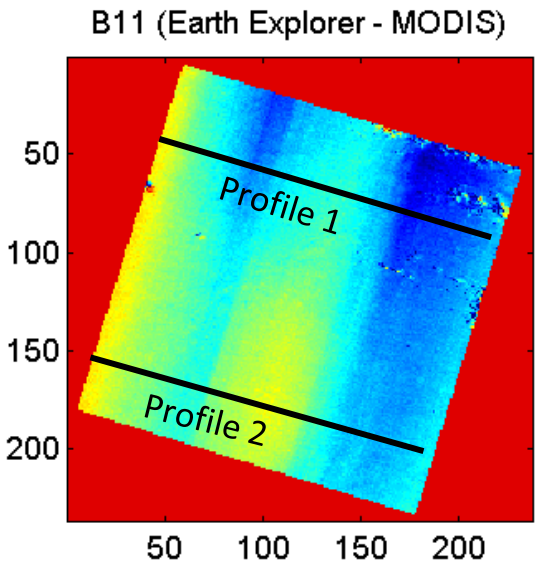


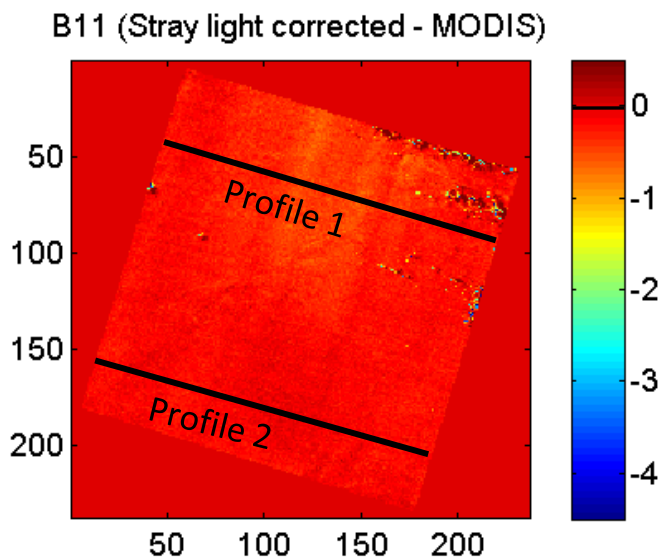


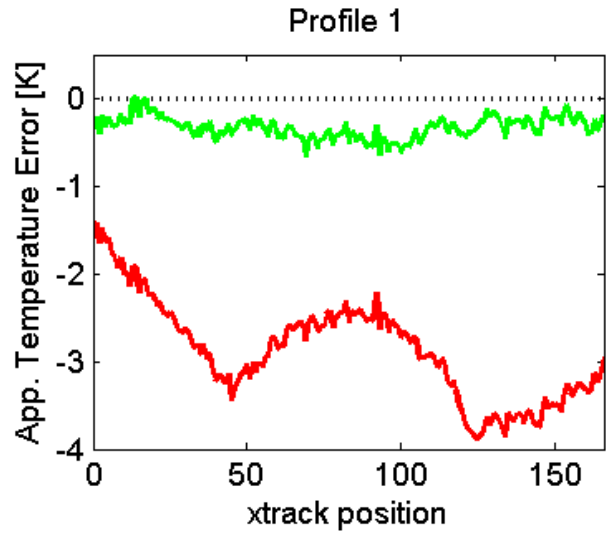


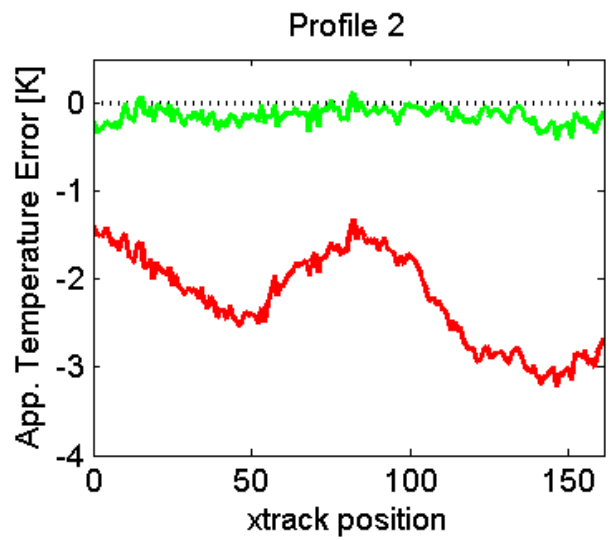
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.258	0.102	1.275	0.103	-1.248	0.013
Profile 2	0.253	0.074	1.145	0.094	-1.117	0.058

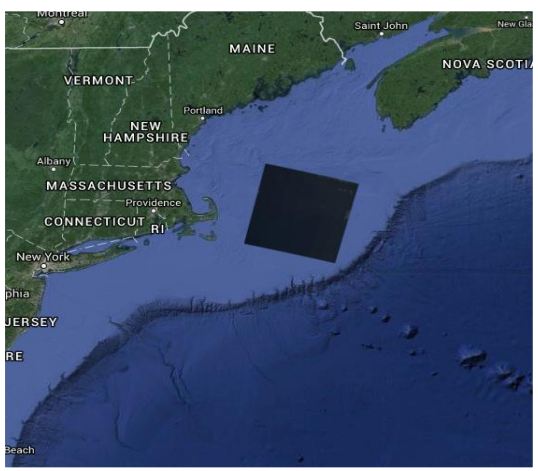
Path 010, Row 030: Band 11





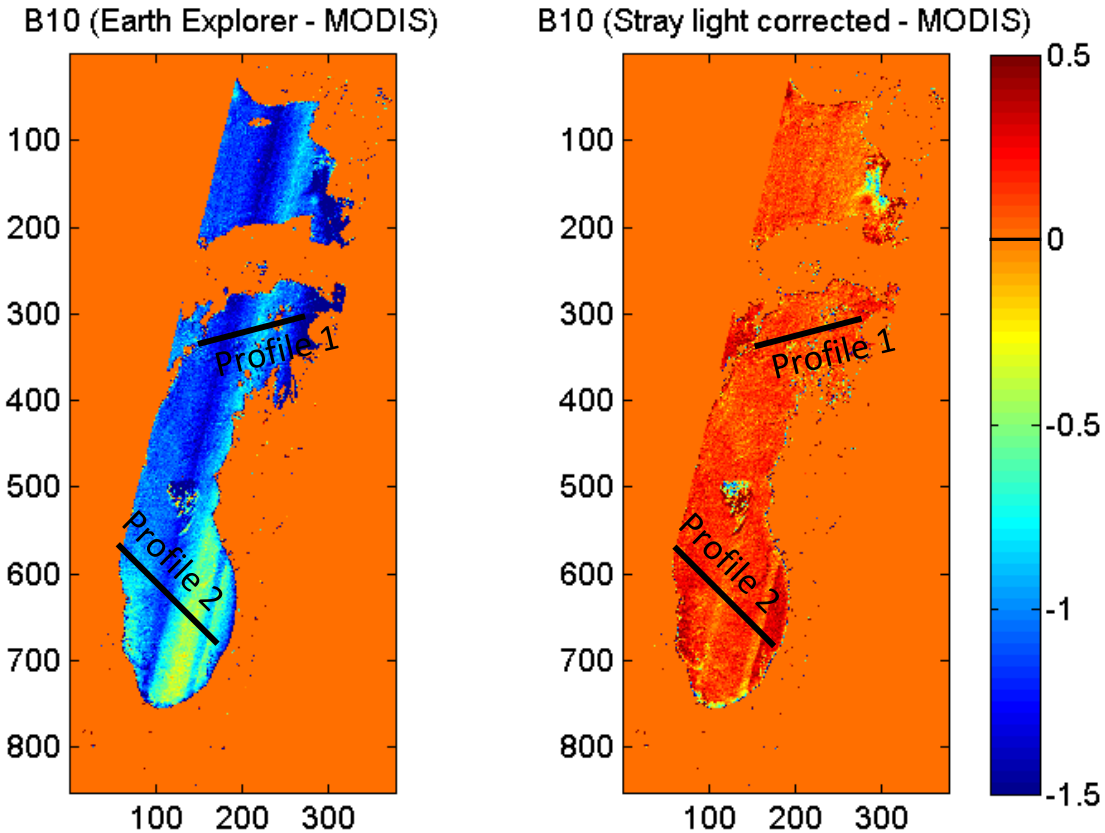


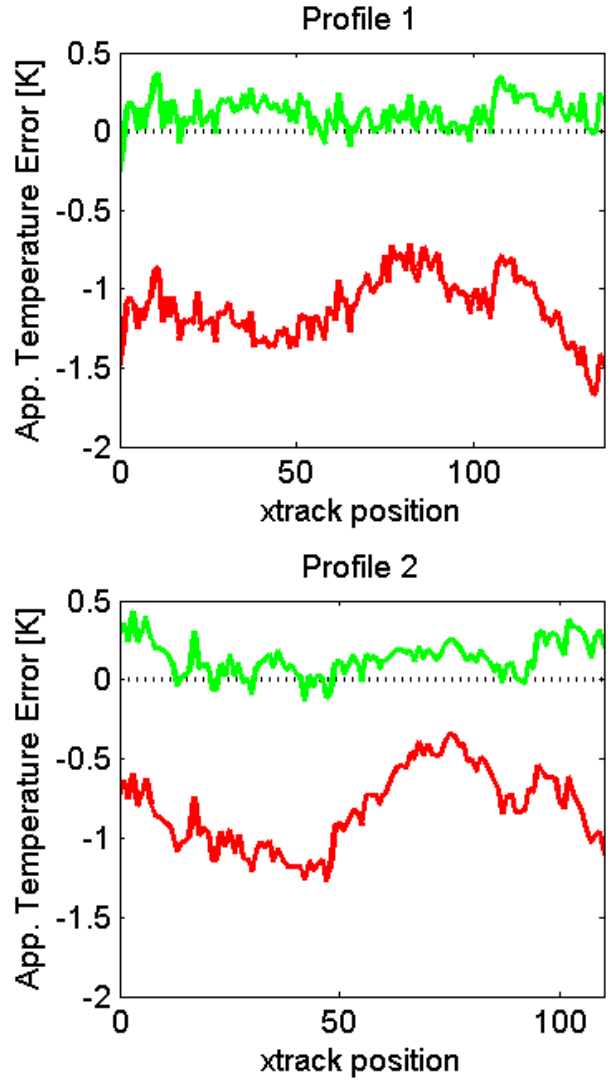




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.573	0.127	2.935	0.357	-2.879	-0.334
Profile 2	0.529	0.093	2.281	0.175	-2.220	-0.149

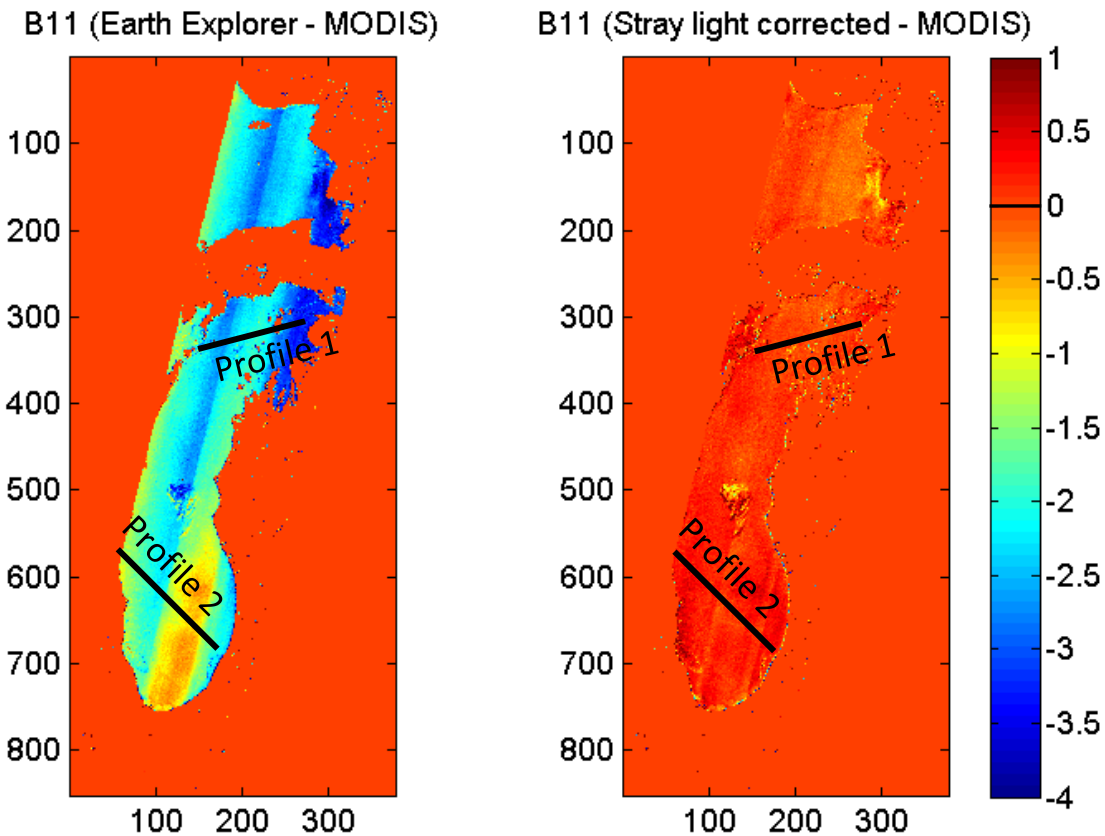
Path 022, Row 030: Band 10

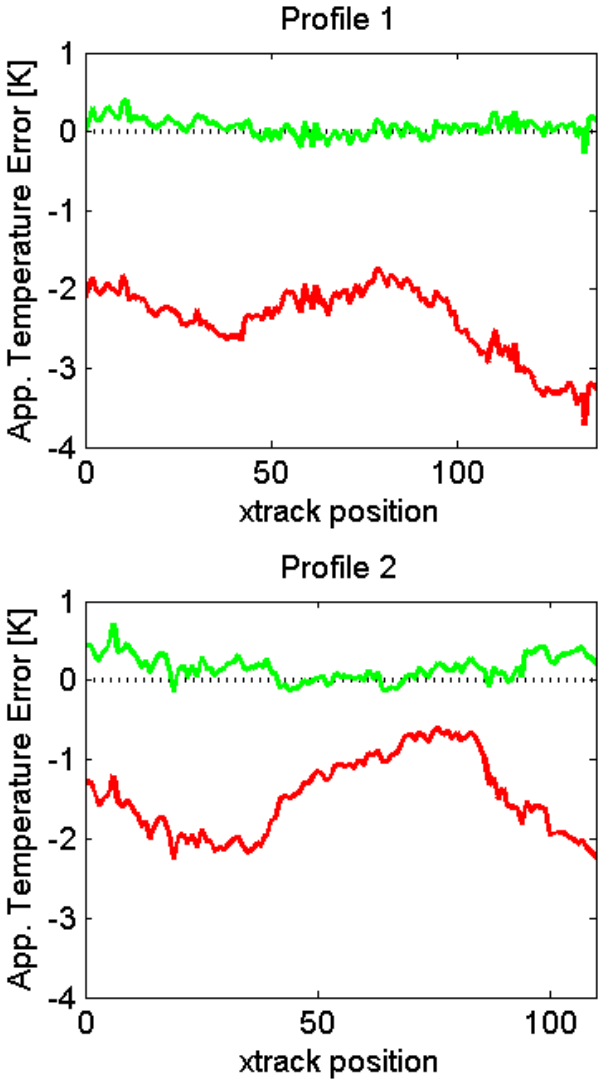




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.201	0.101	1.141	0.151	-1.123	0.113
Profile 2	0.246	0.114	0.856	0.176	-0.820	0.135

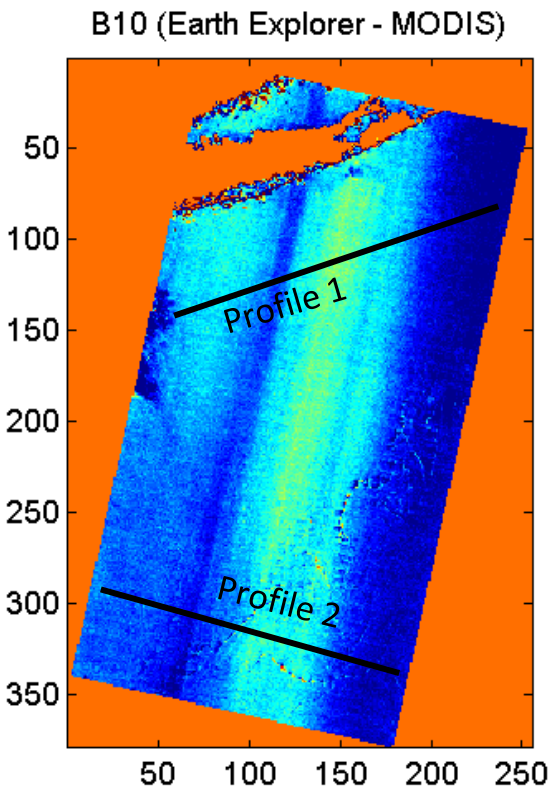
Path 022, Row 030: Band 11

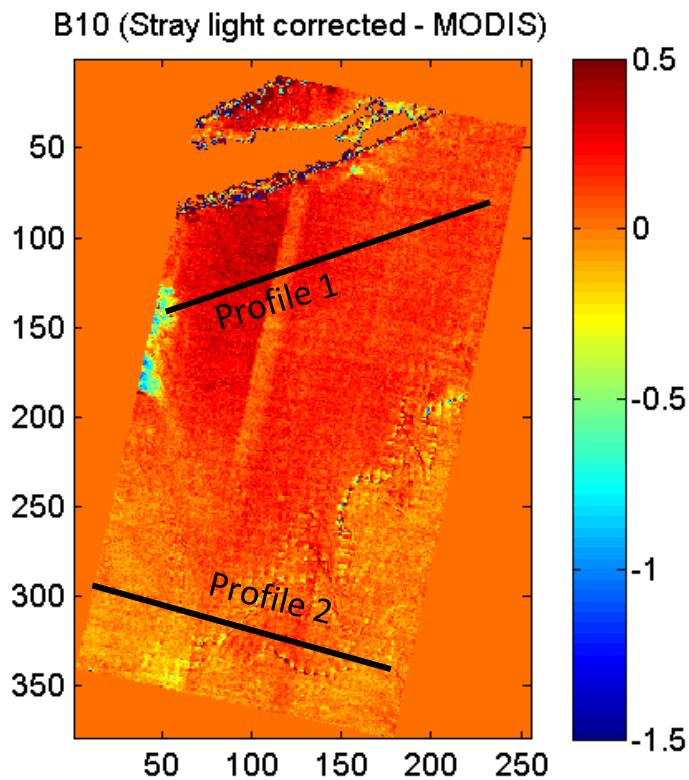


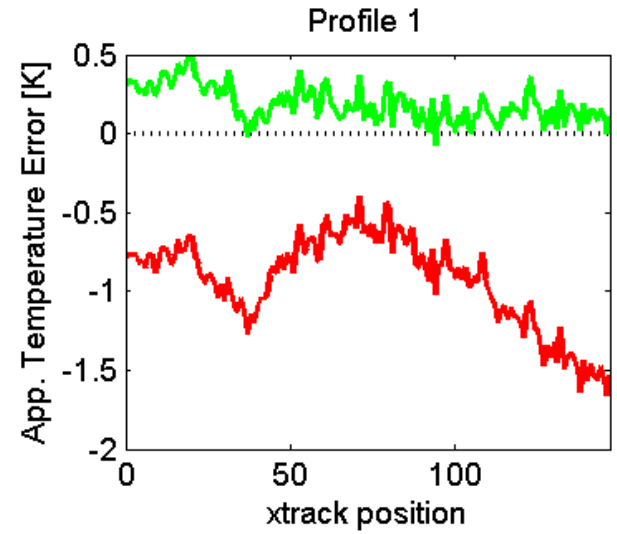


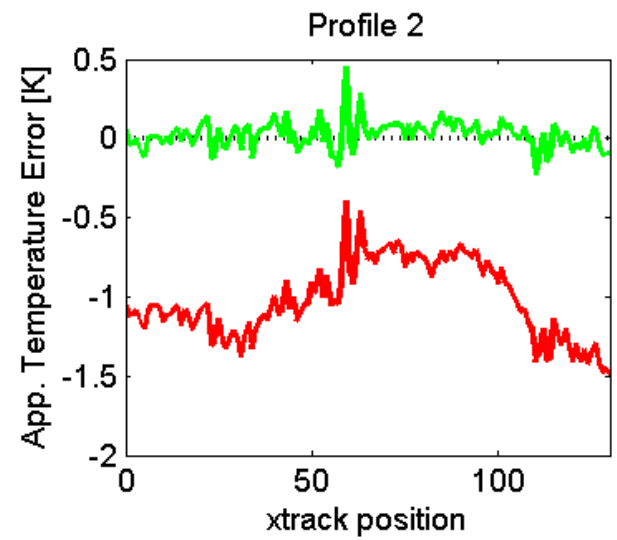
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.451	0.113	2.448	0.124	-2.406	0.054
Profile 2	0.494	0.163	1.552	0.227	-1.472	0.158

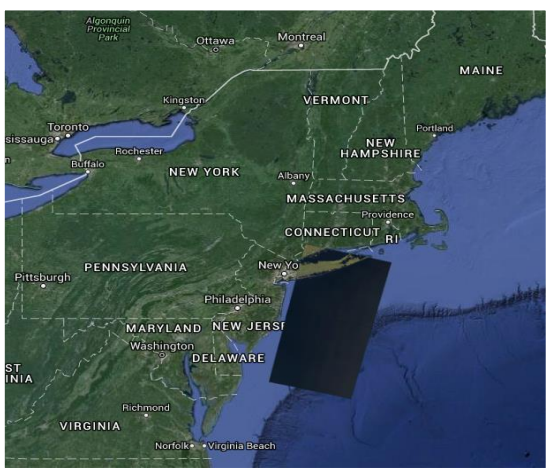
Path 013, Row 032: Band 10





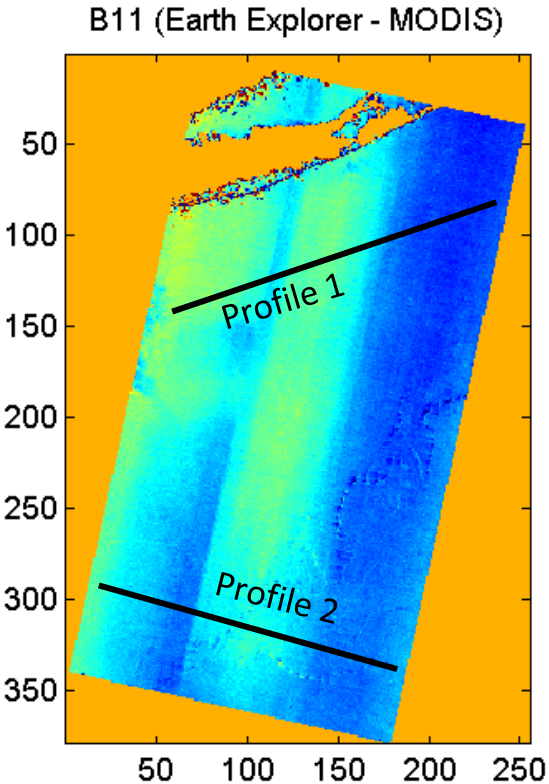


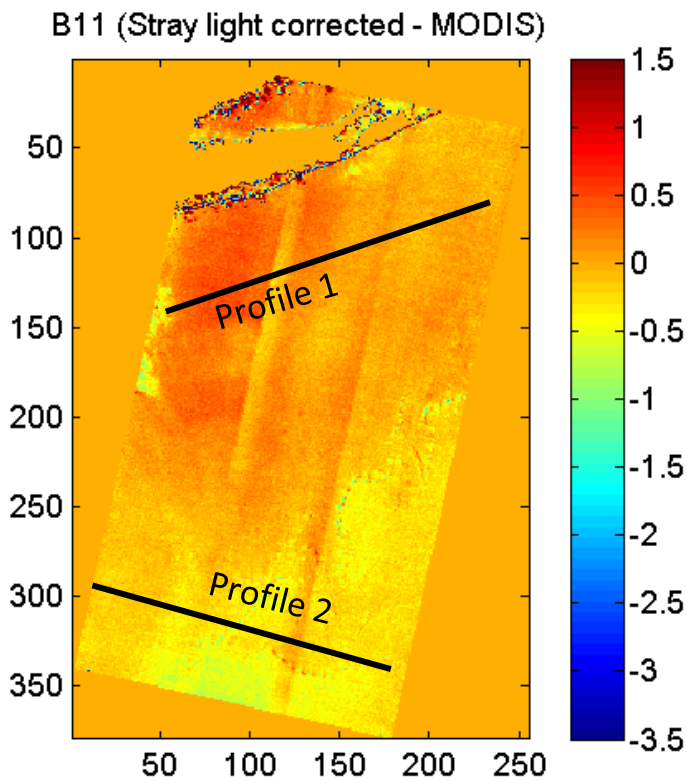


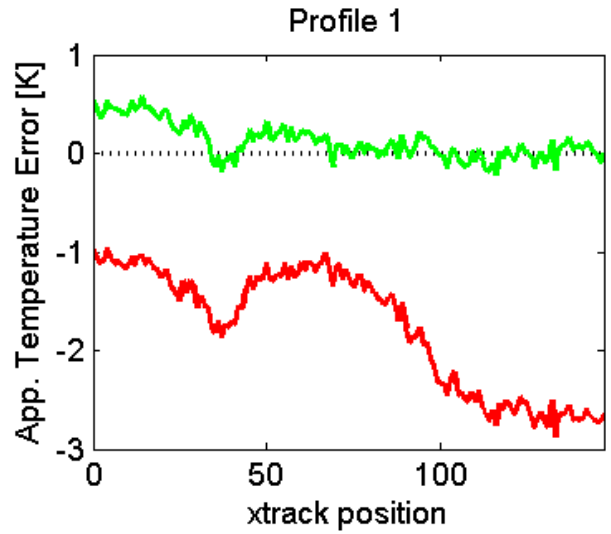


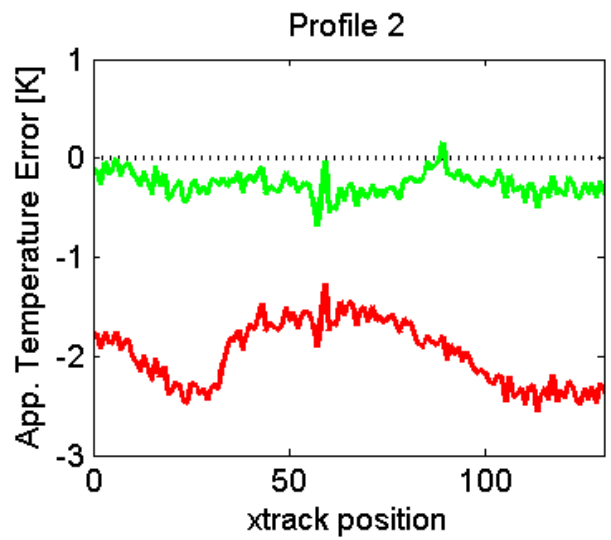
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.290	0.115	0.979	0.217	-0.935	0.185
Profile 2	0.239	0.088	1.052	0.090	-1.024	0.020

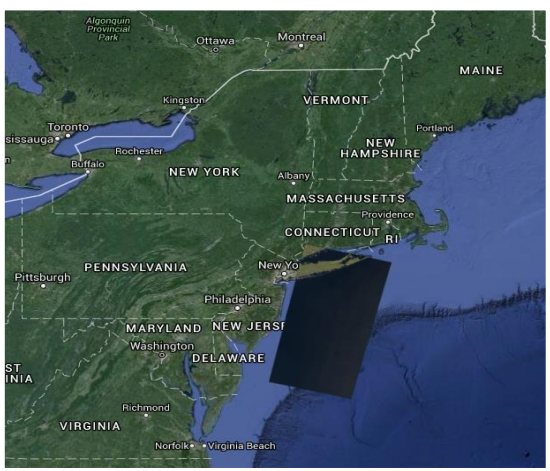
Path 013, Row 032: Band 11





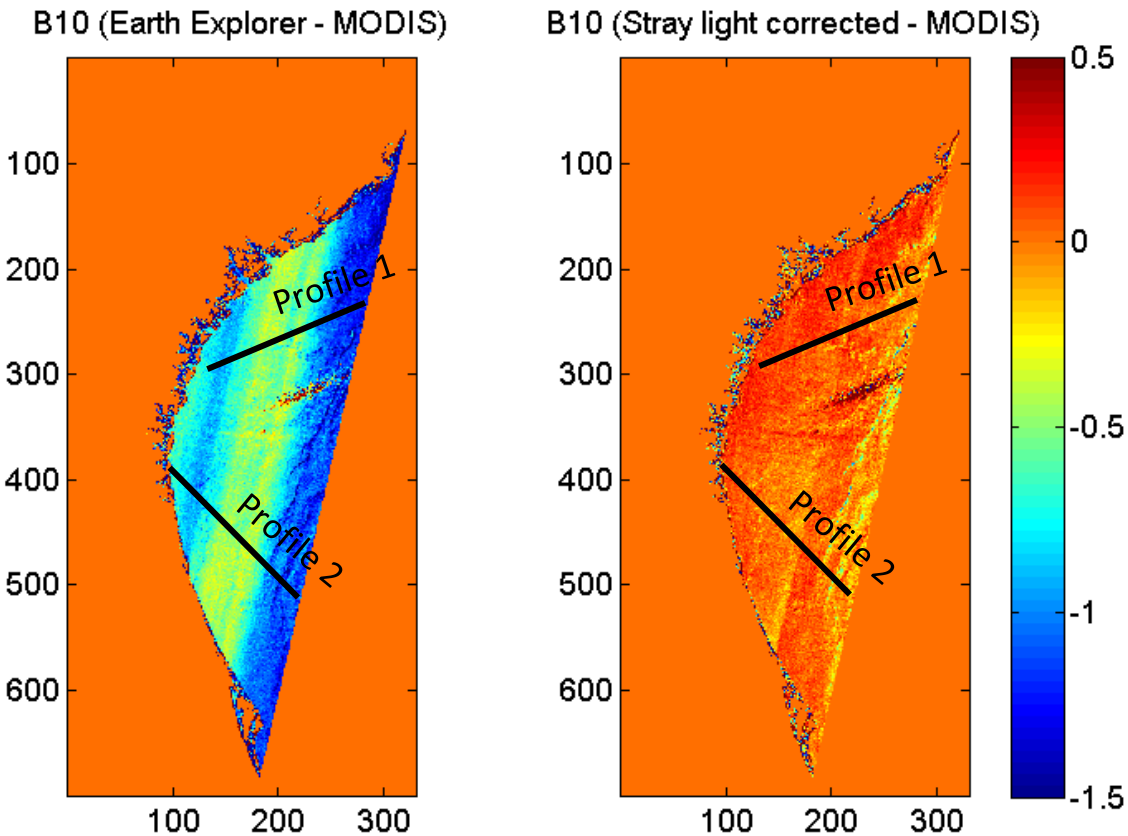


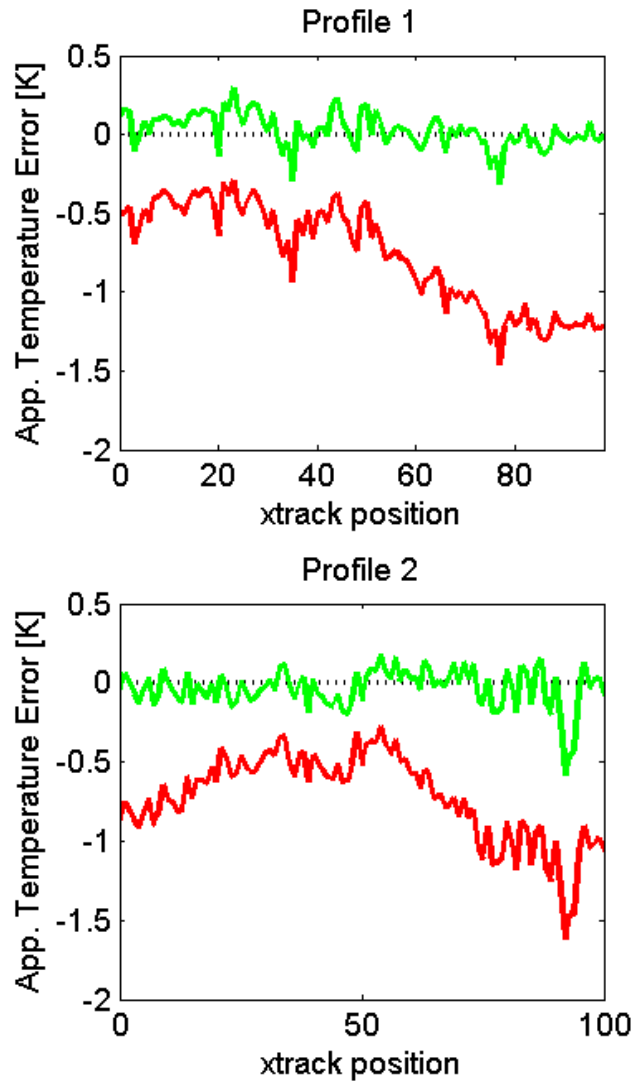




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.622	0.183	1.874	0.216	-1.769	0.115
Profile 2	0.319	0.123	2.006	0.292	-1.980	-0.264

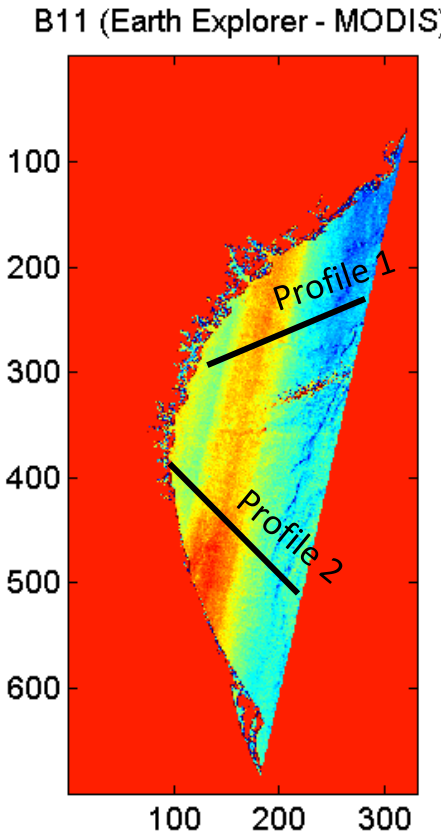
Path 016, Row 039: Band 10

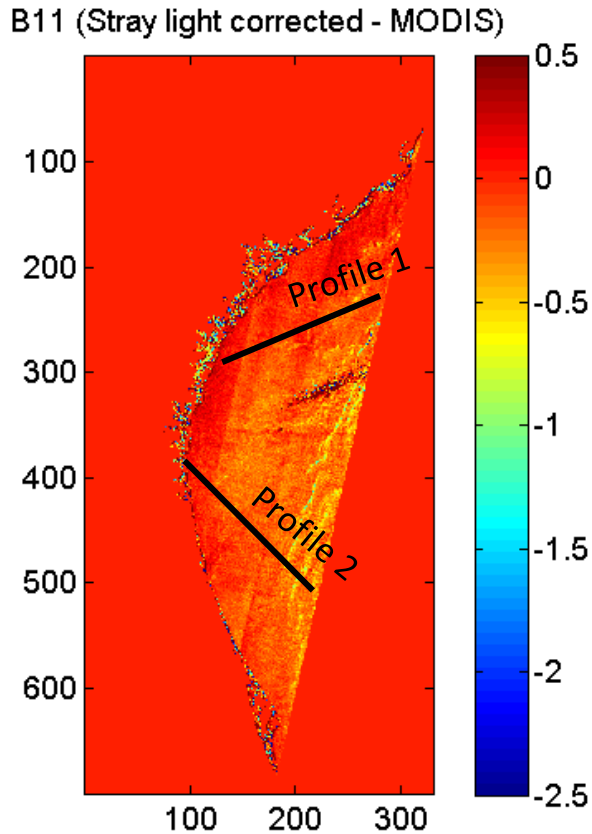


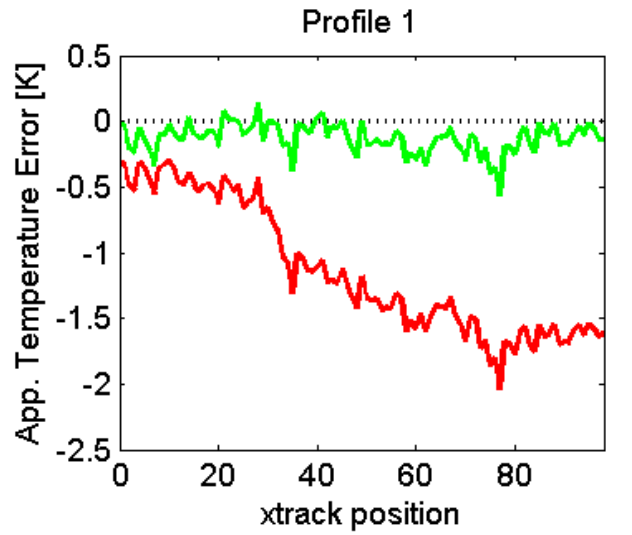


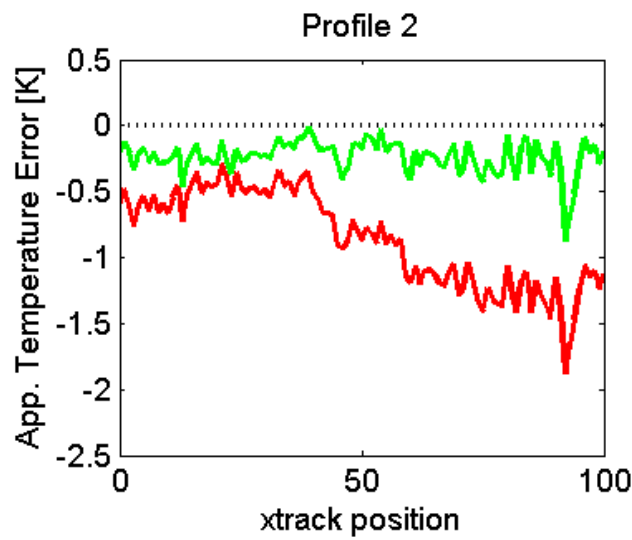
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.329	0.108	0.839	0.110	-0.773	0.025
Profile 2	0.278	0.125	0.782	0.130	-0.732	-0.039

Path 016, Row 039: Band 11



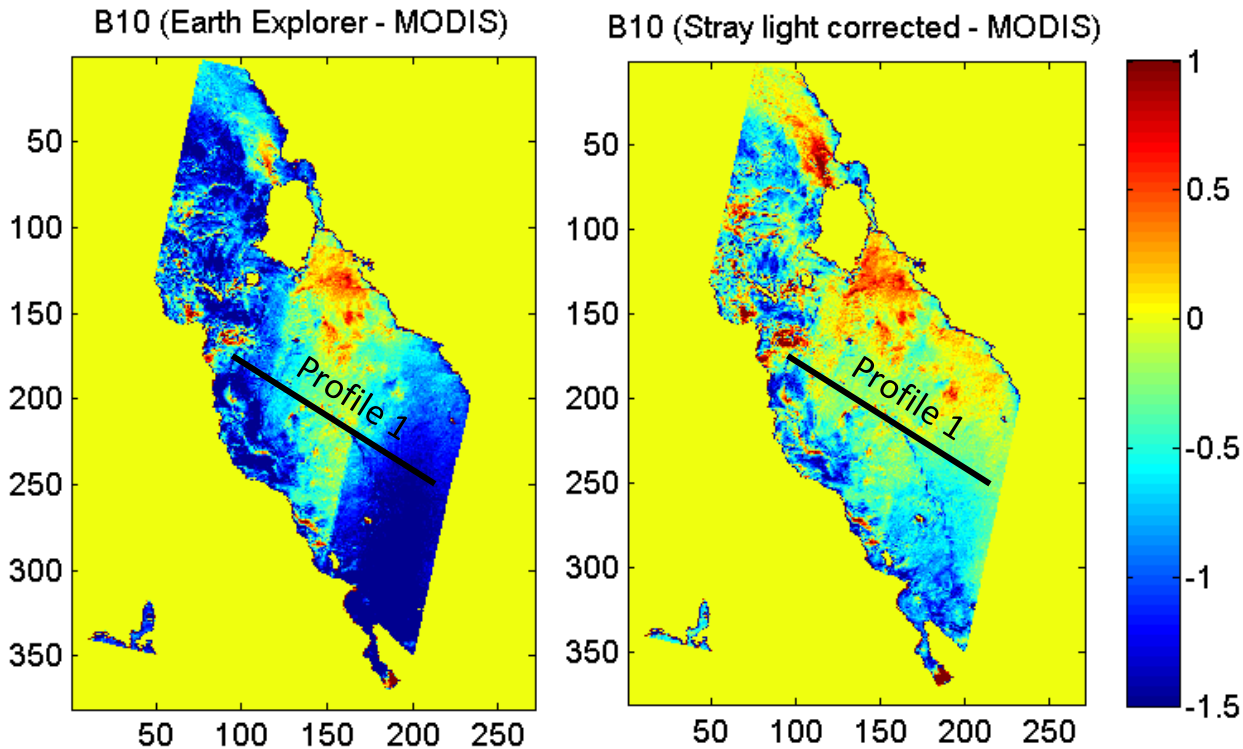


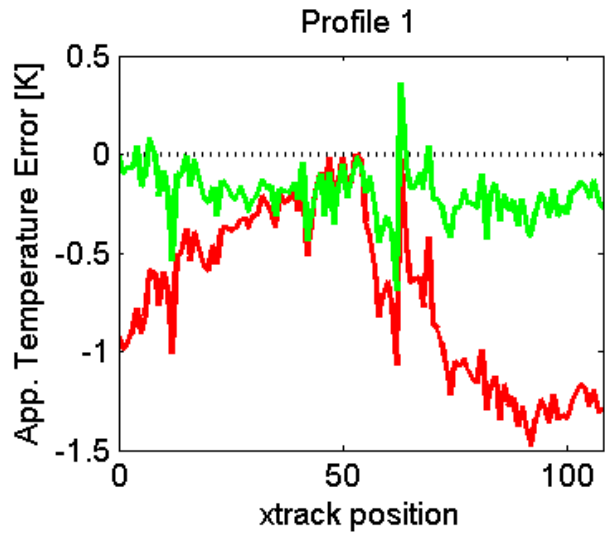


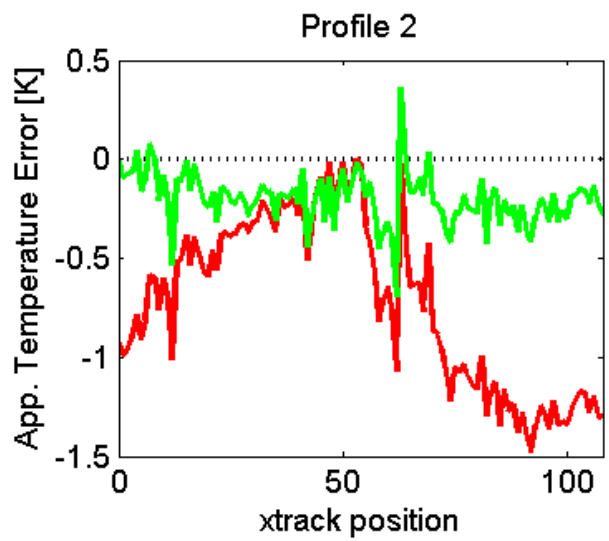


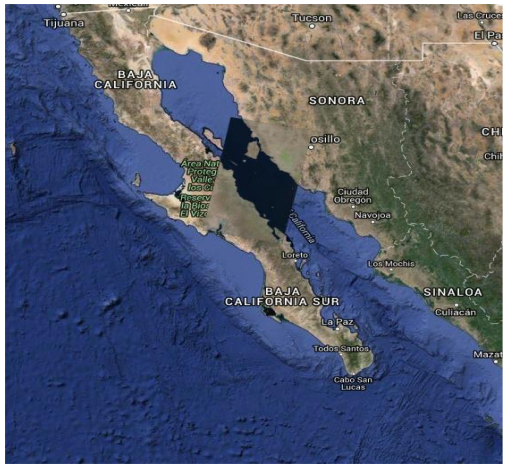
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.503	0.112	1.248	0.171	-1.143	-0.129
Profile 2	0.369	0.127	0.941	0.272	-0.866	-0.240

Path 035, Row 040: Band 10



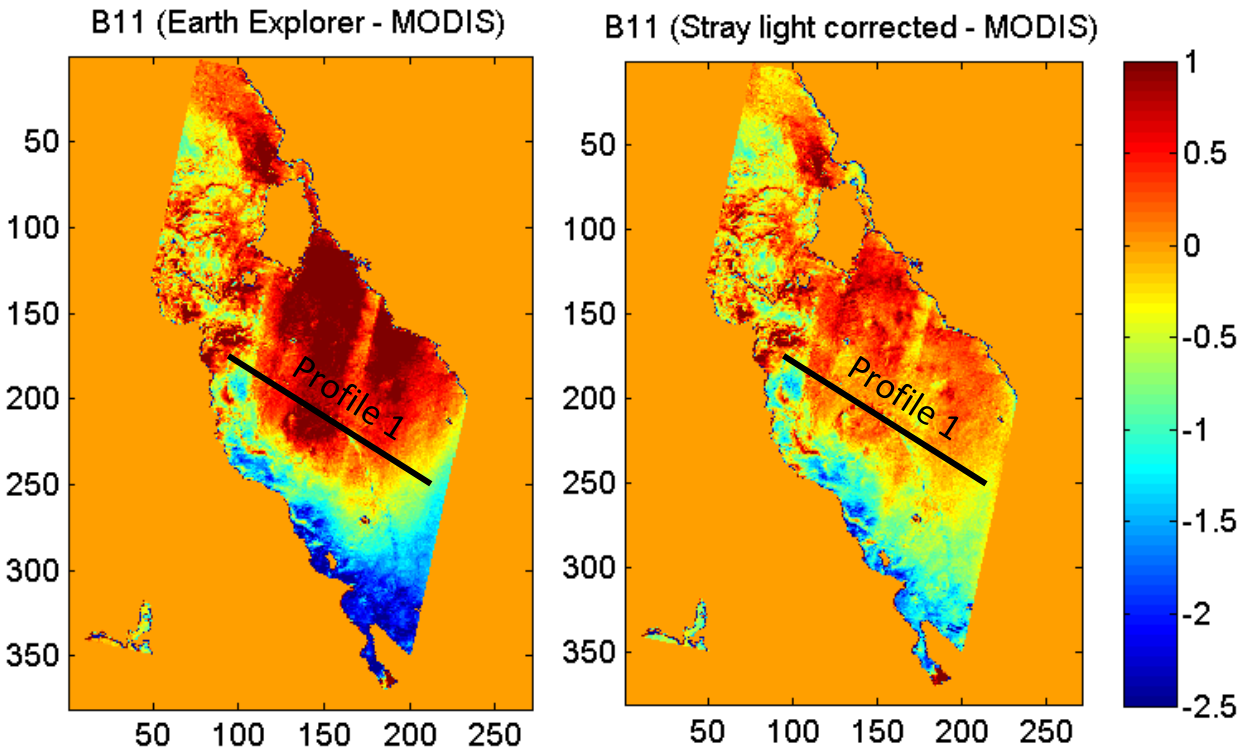


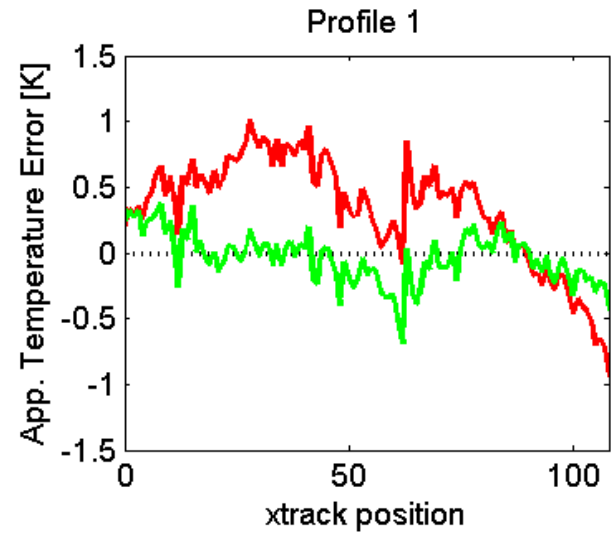


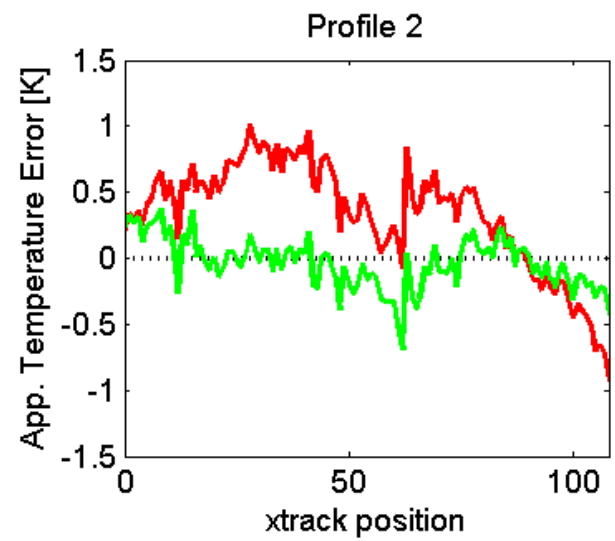


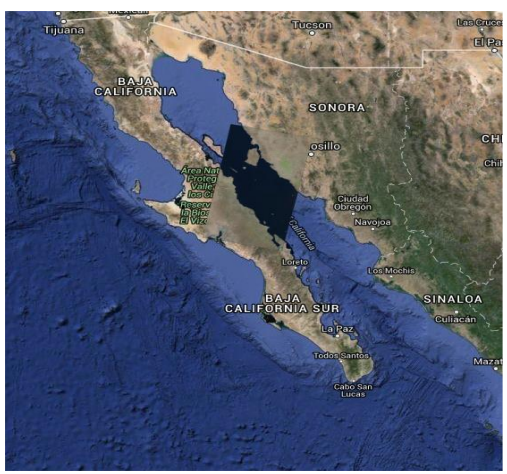
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.428	0.135	0.843	0.242	-0.728	-0.201

Path 035, Row 040: Band 11



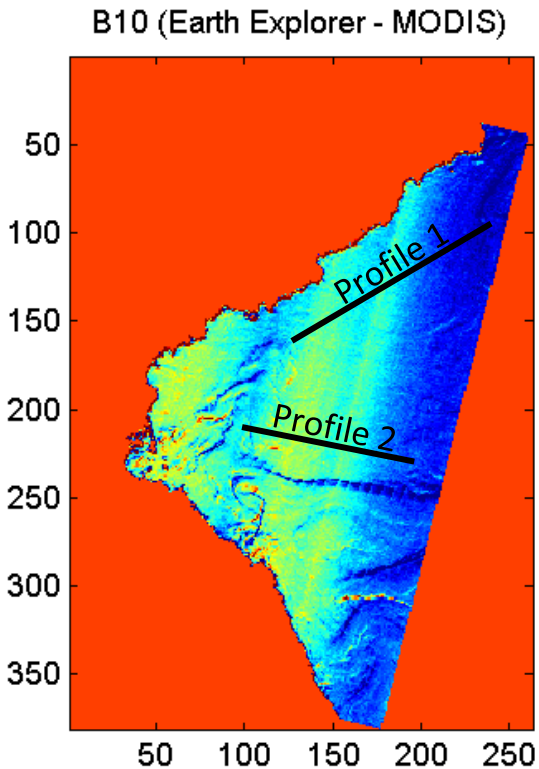


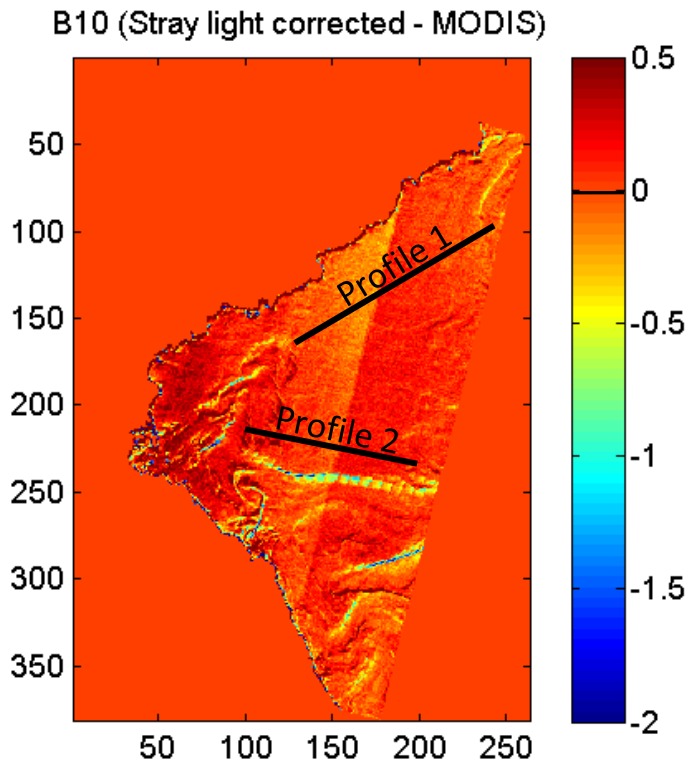


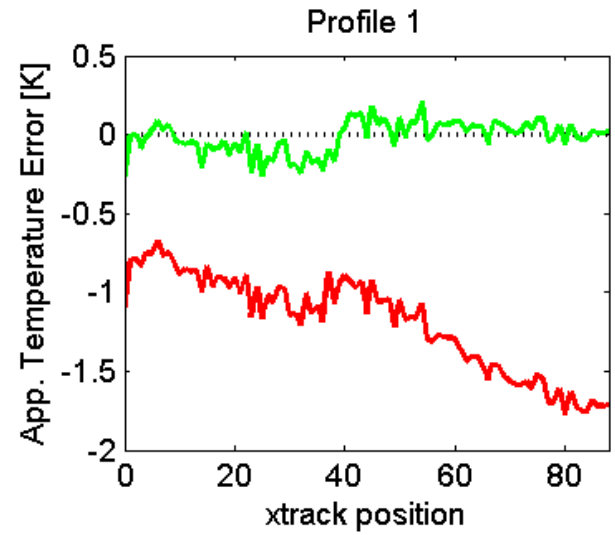


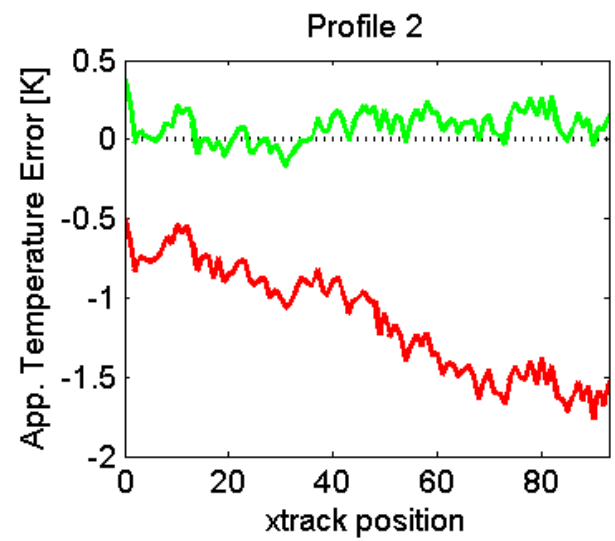
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.408	0.194	0.524	0.197	0.331	-0.040

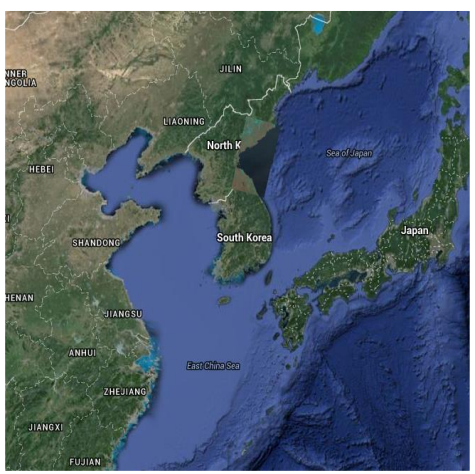
Path 115, Row 032: Band 10





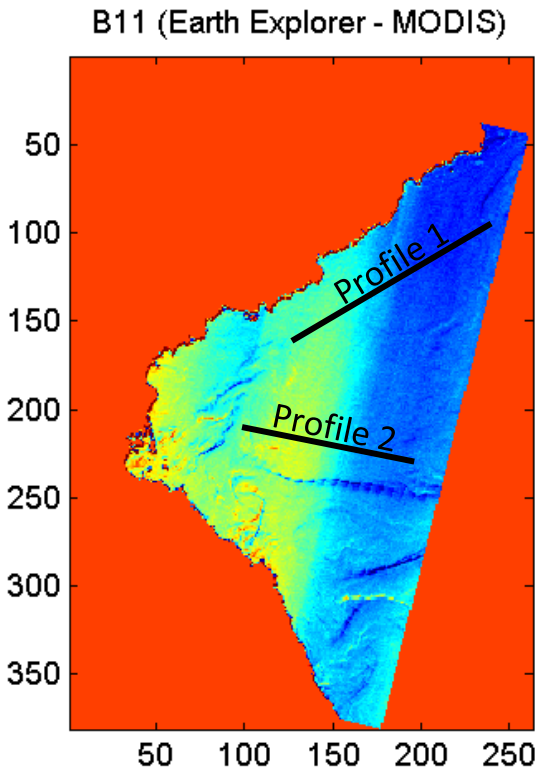


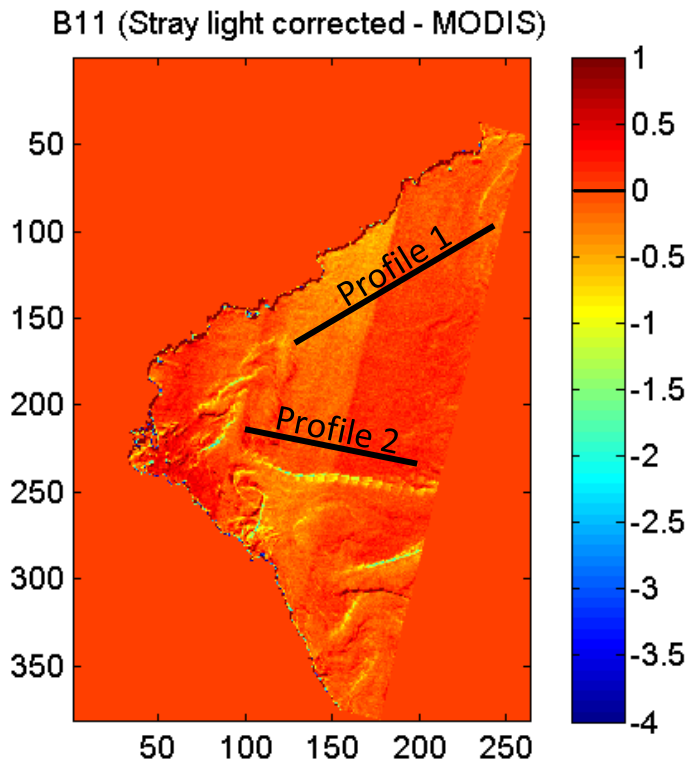


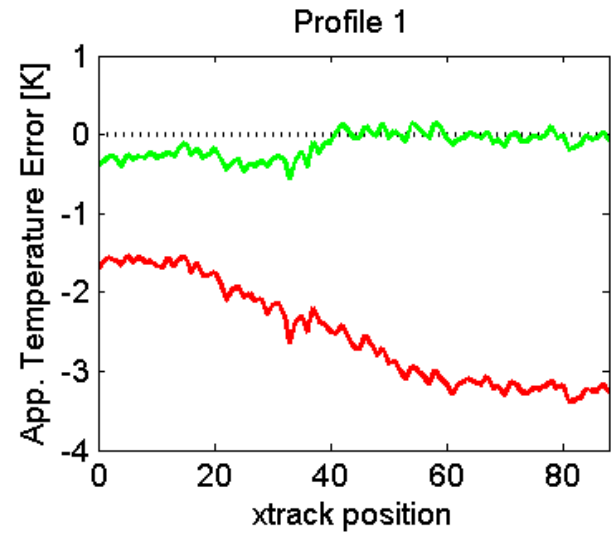


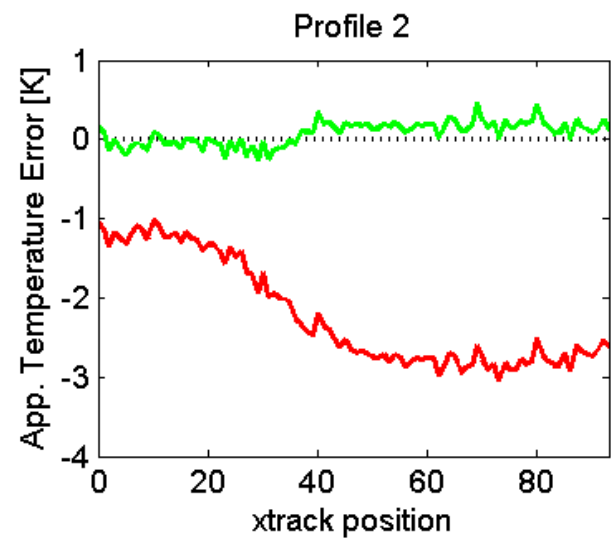
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.310	0.104	1.232	0.105	-1.193	-0.018
Profile 2	0.348	0.102	1.193	0.128	-1.142	0.077

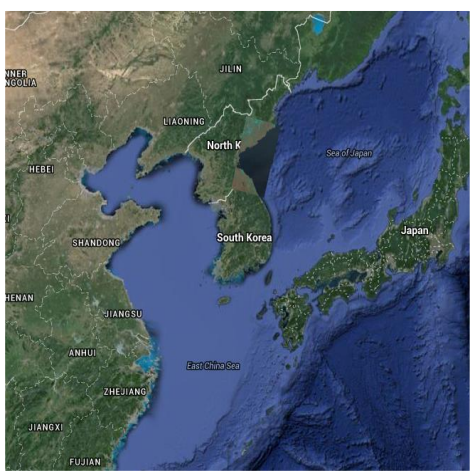
Path 115, Row 032: Band 11





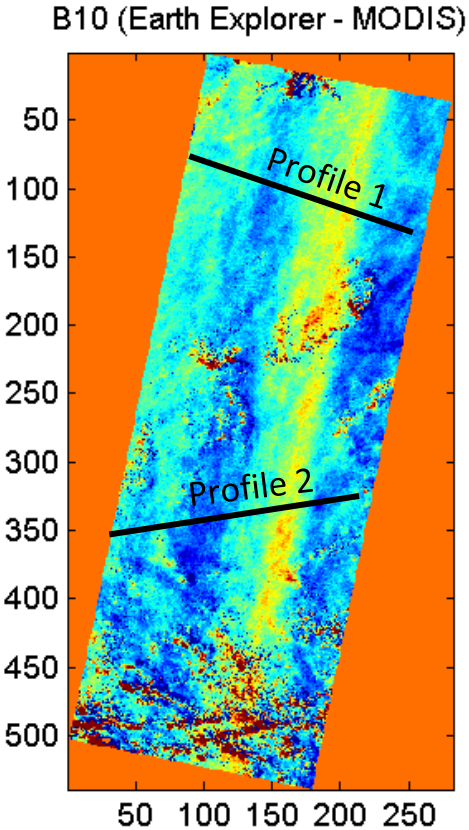


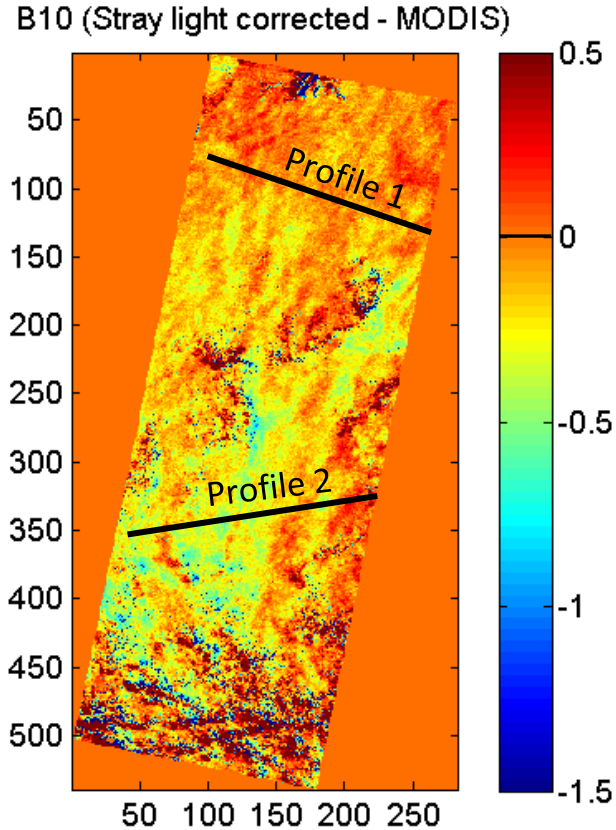


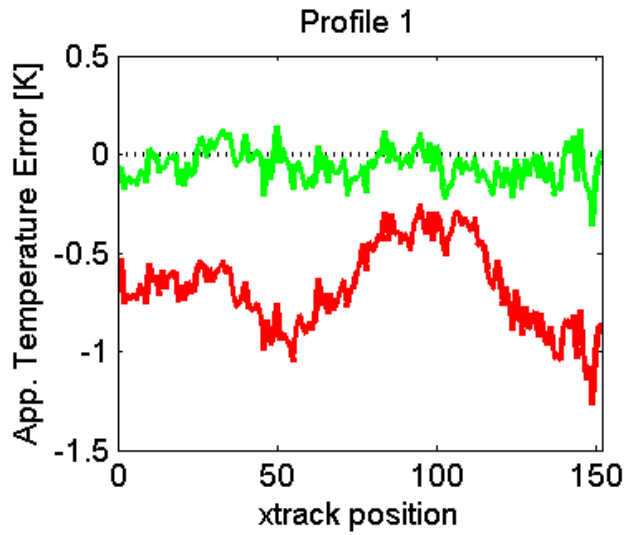


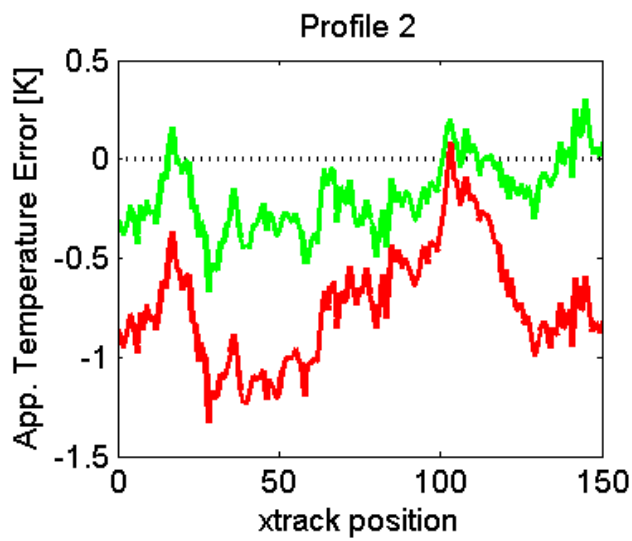
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.639	0.166	2.617	0.219	-2.539	-0.144
Profile 2	0.675	0.149	2.316	0.166	-2.217	0.075

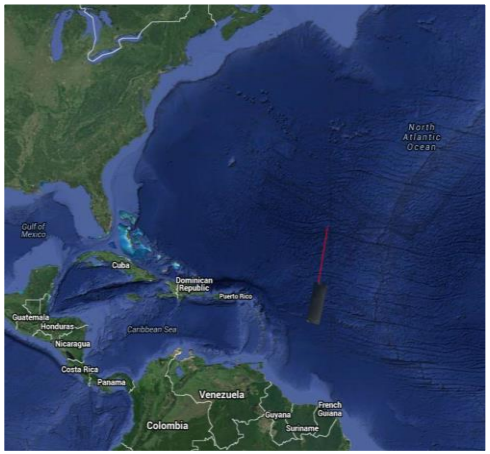
Path 230, Row 045: Band 10





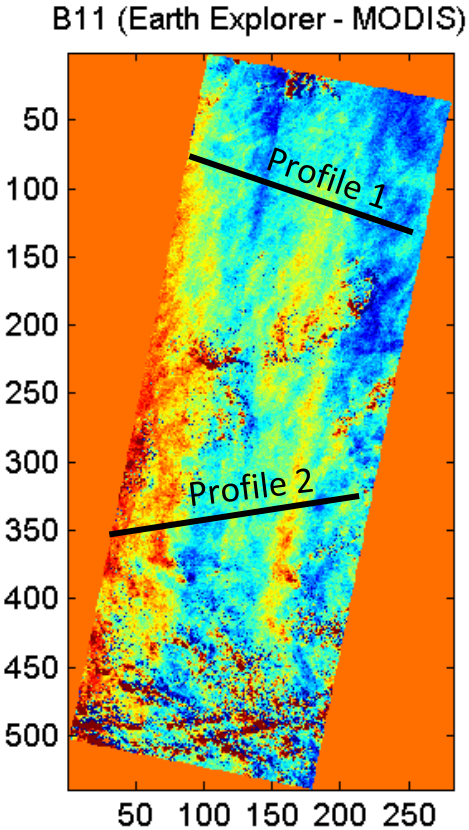


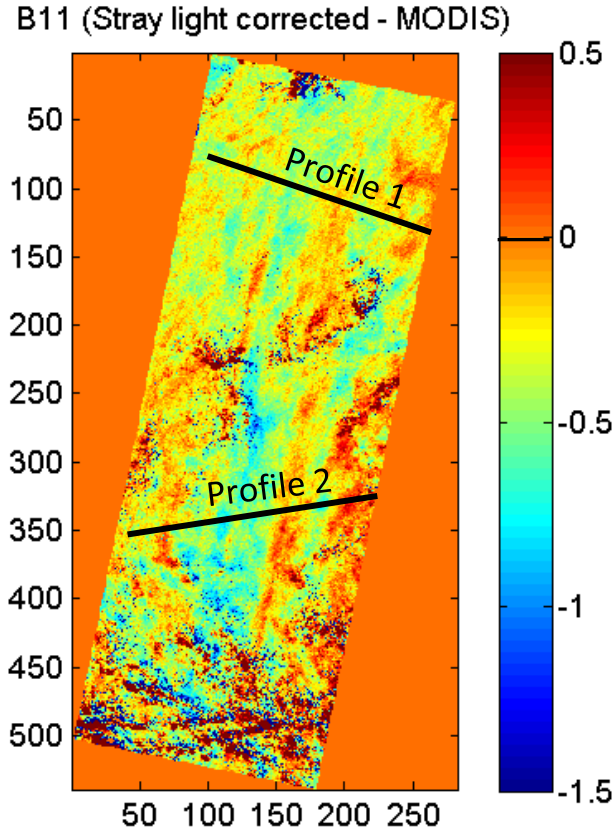


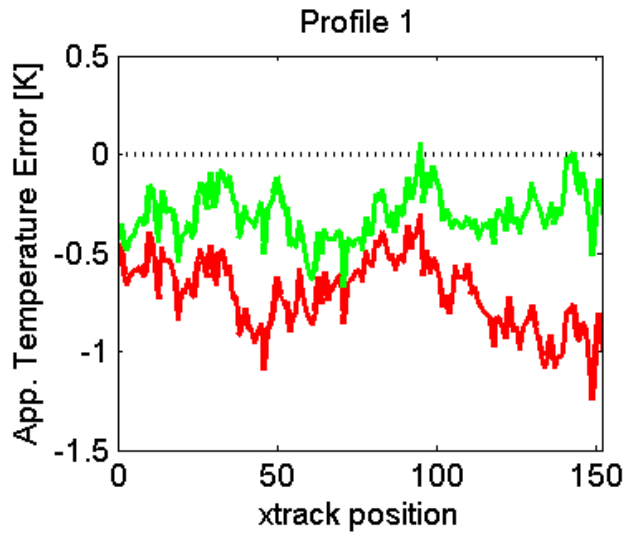


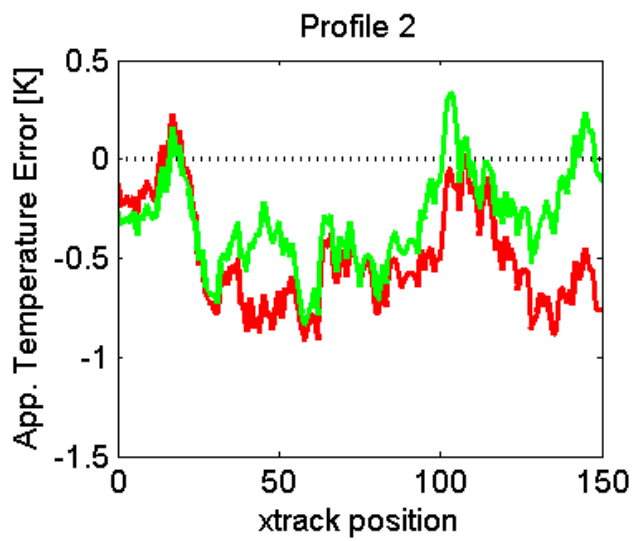
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.212	0.087	0.707	0.106	-0.675	-0.061
Profile 2	0.287	0.184	0.799	0.261	-0.745	-0.186

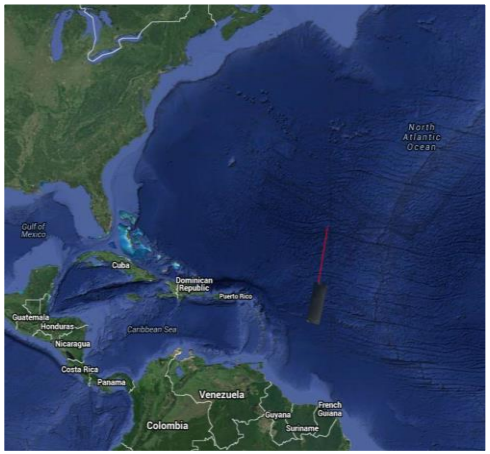
Path 230, Row 045: Band 11





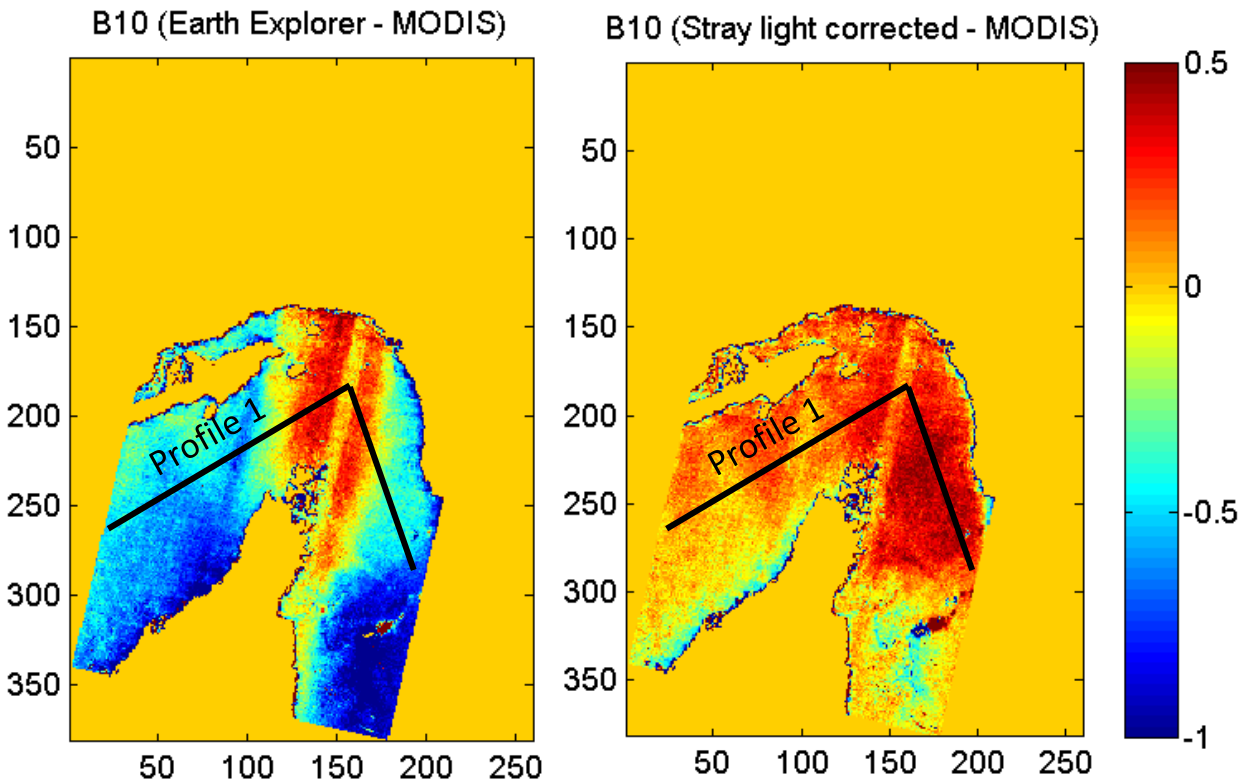


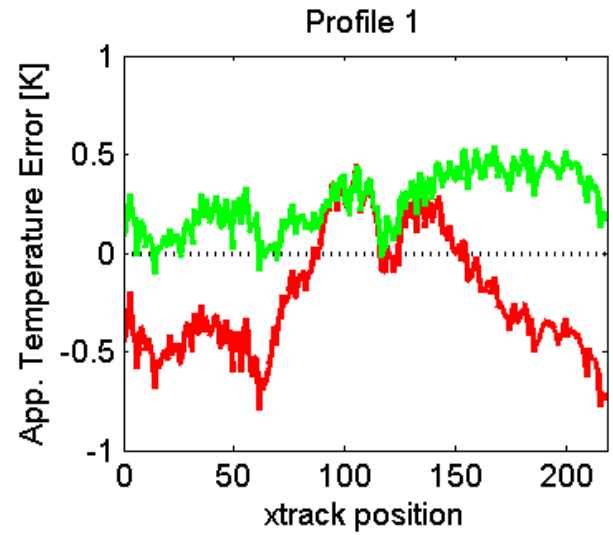




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.181	0.129	0.735	0.337	-0.713	-0.311
Profile 2	0.263	0.242	0.566	0.390	-0.502	-0.307

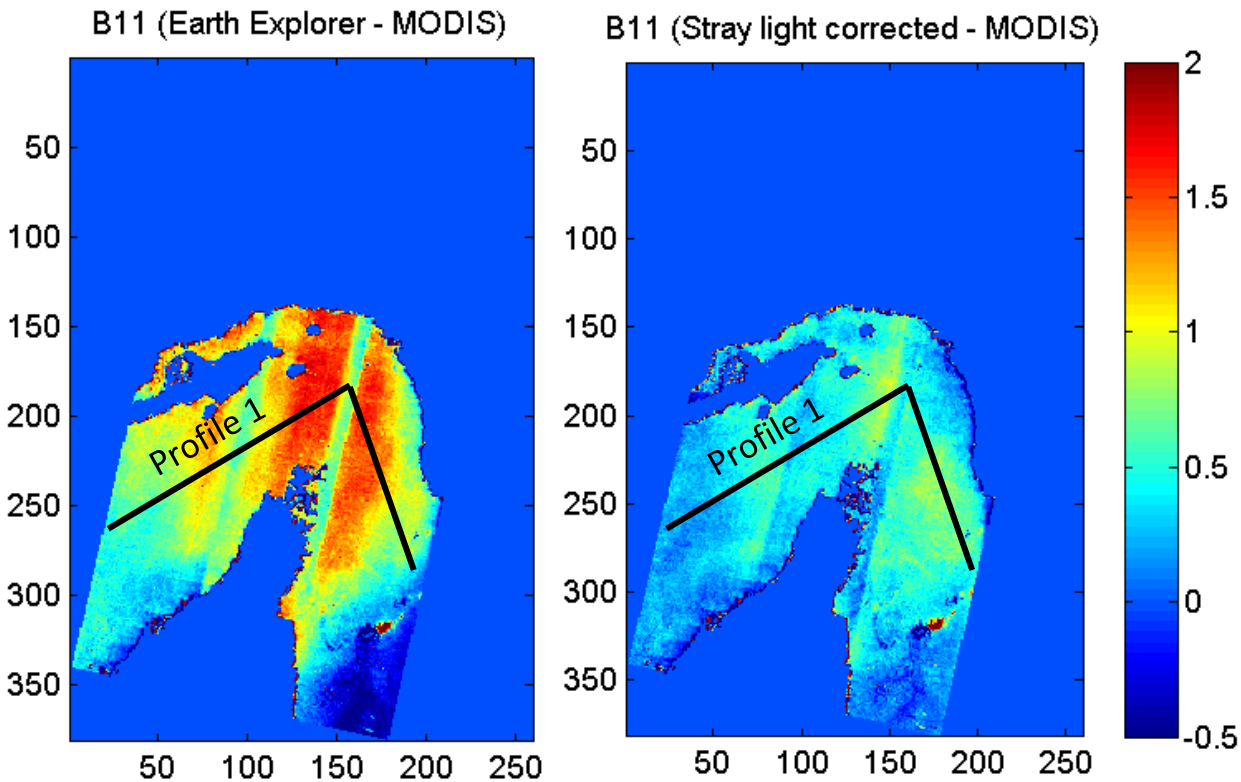
Path 160, Row 042: Band 10

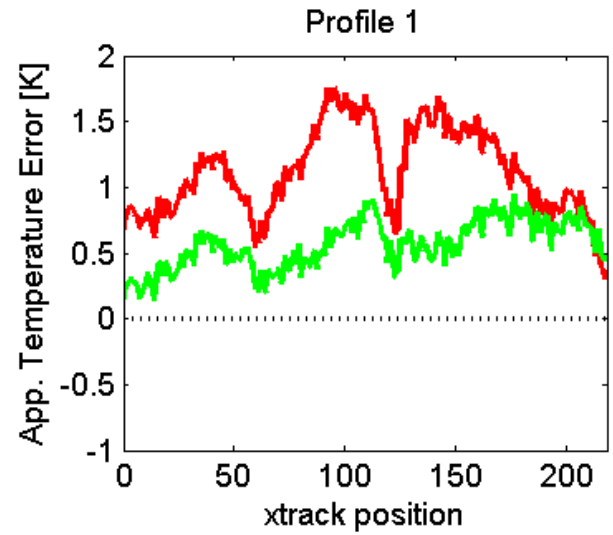




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.301	0.153	0.371	0.297	-0.218	0.255

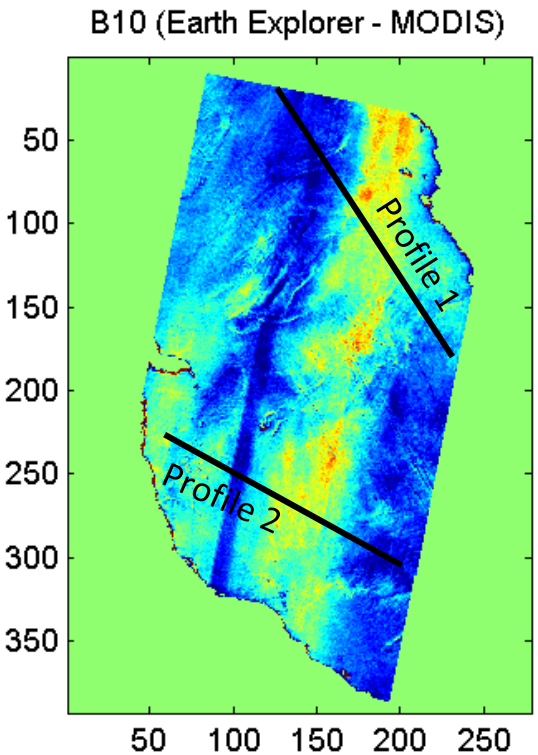
Path 160, Row 042: Band 11

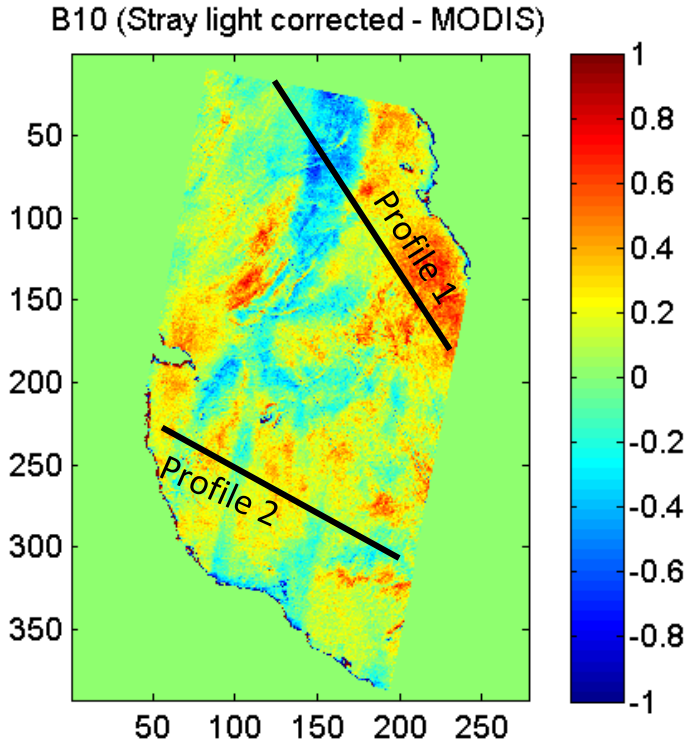


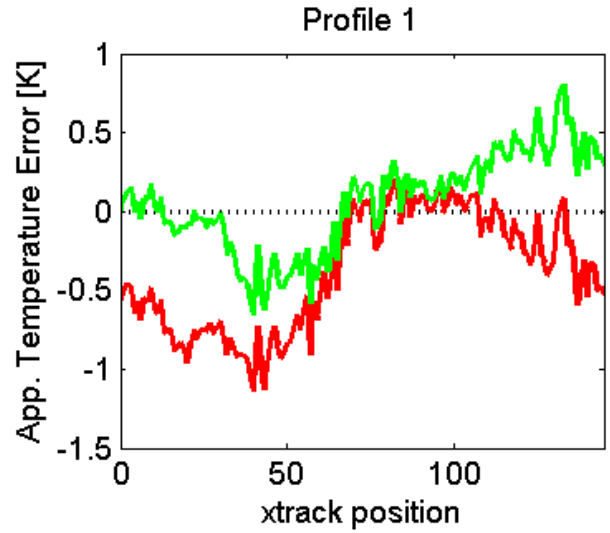


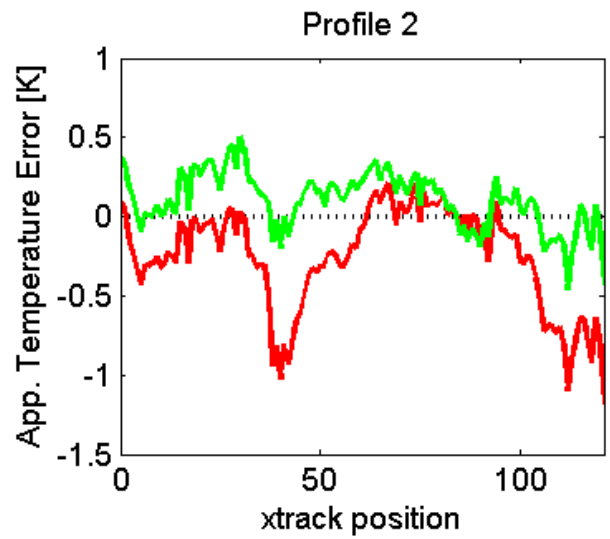
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.333	0.185	1.163	0.588	1.114	0.558

Path 172, Row 043: Band 10



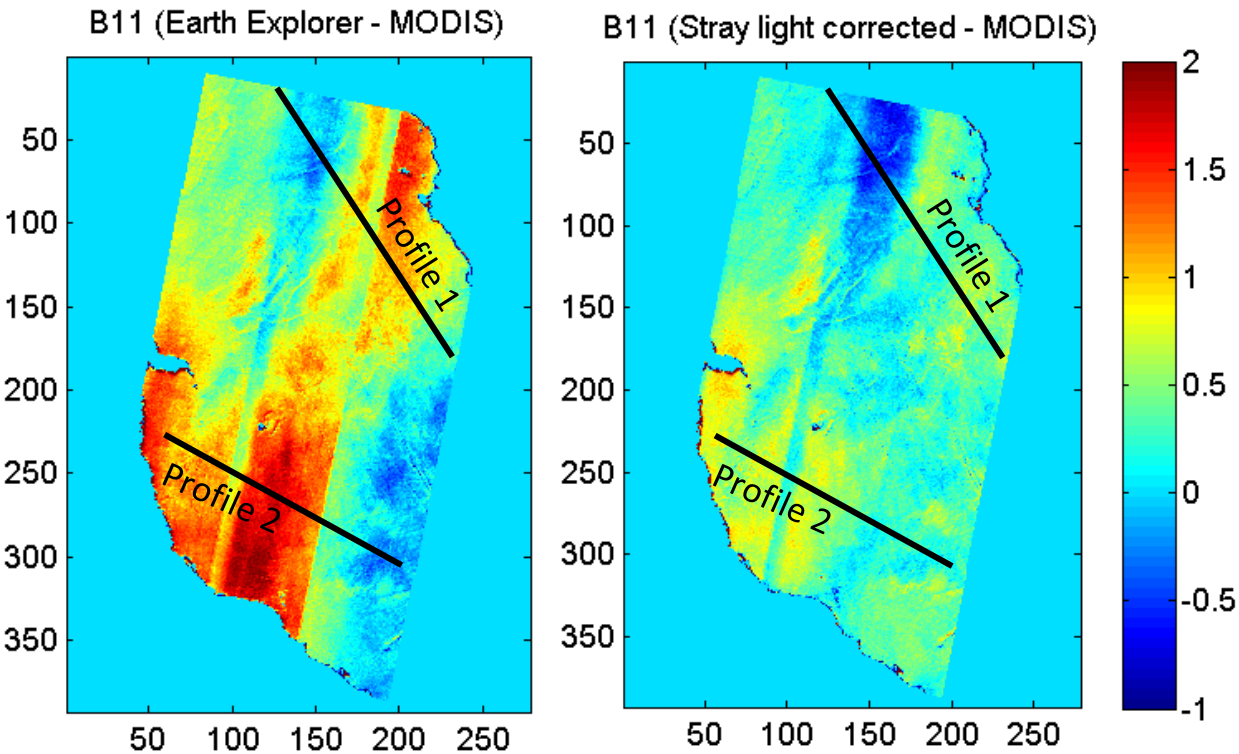


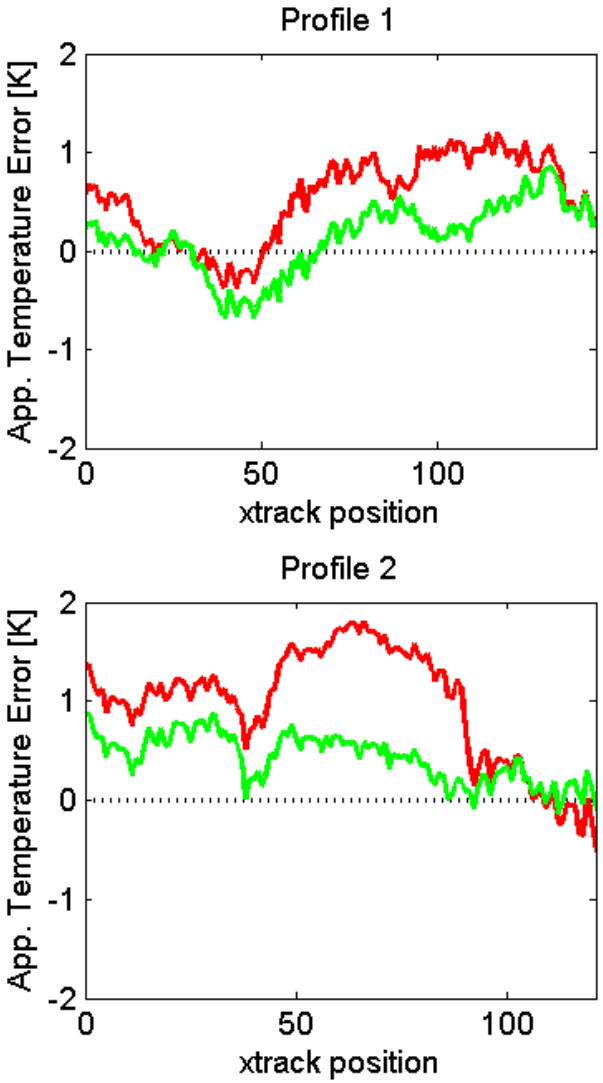




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.372	0.311	0.536	0.315	-0.387	0.057
Profile 2	0.322	0.179	0.412	0.206	-0.258	0.102

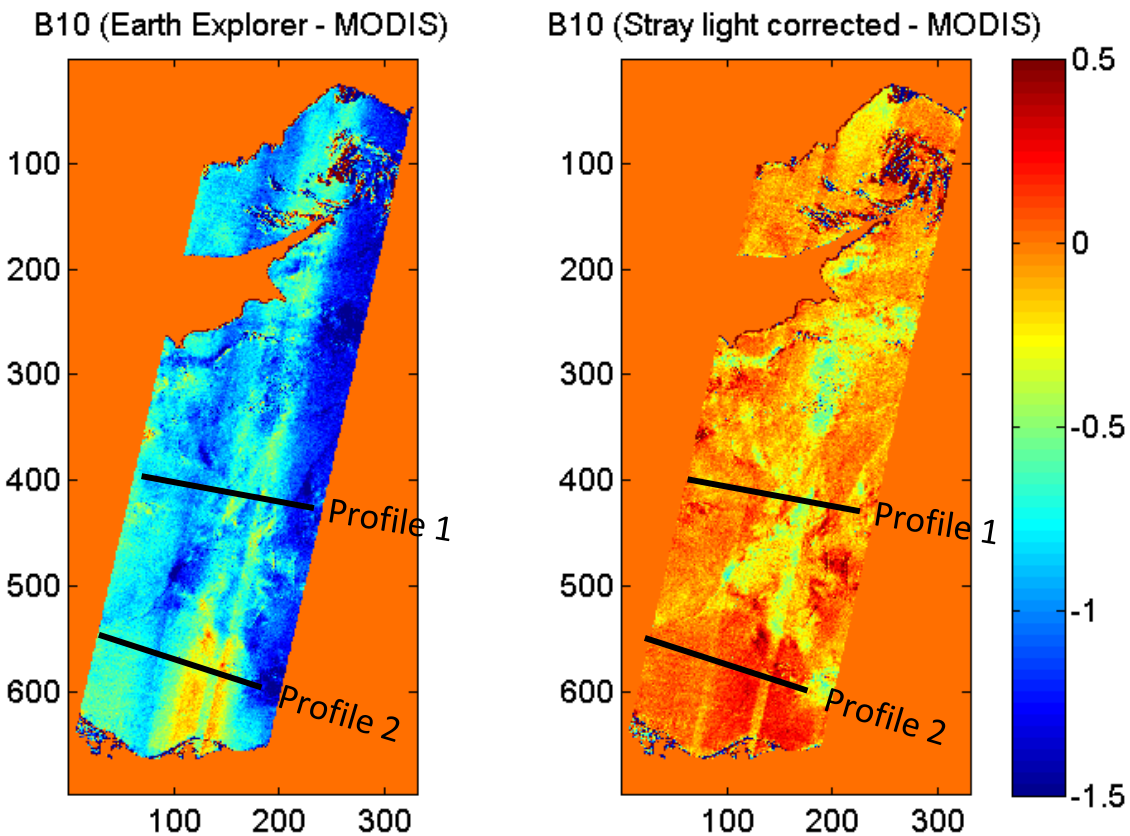
Path 172, Row 043: Band 11

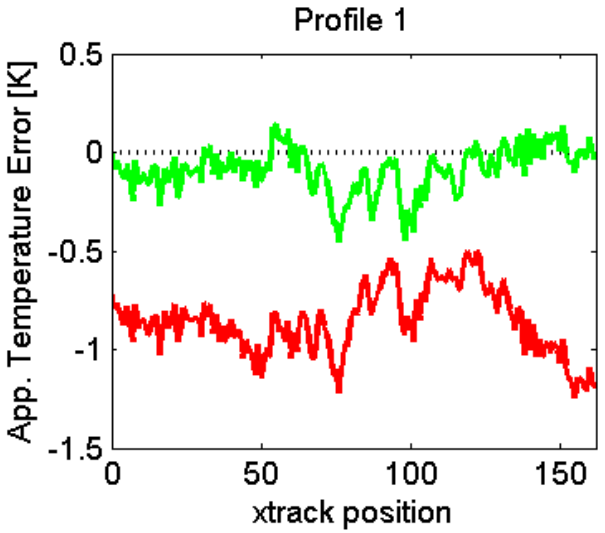


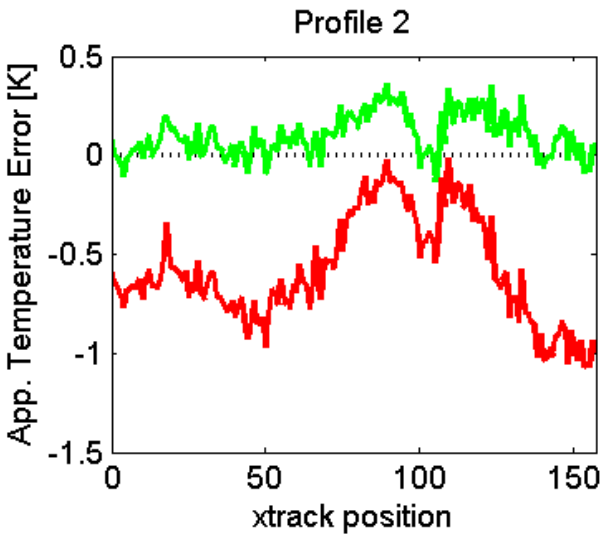


	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.427	0.354	0.683	0.377	0.534	0.131
Profile 2	0.584	0.248	1.126	0.488	0.964	0.421

Path 176, Row 037: Band 10

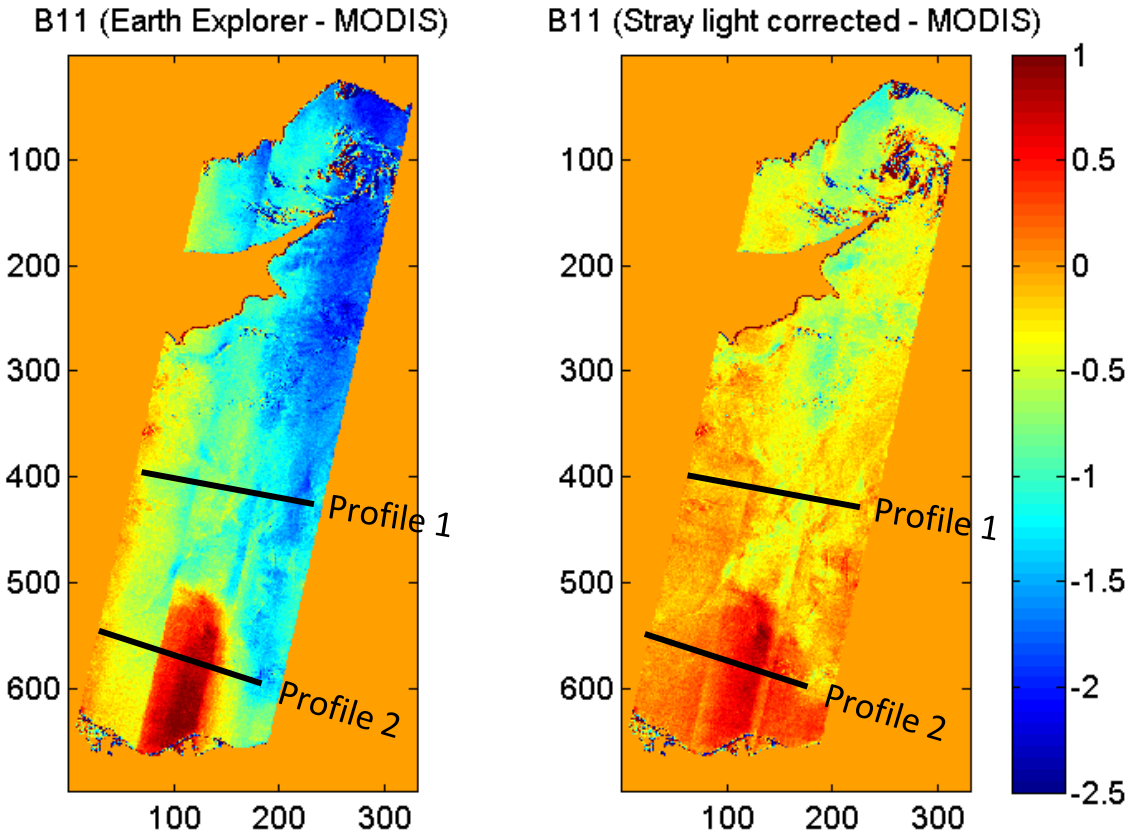


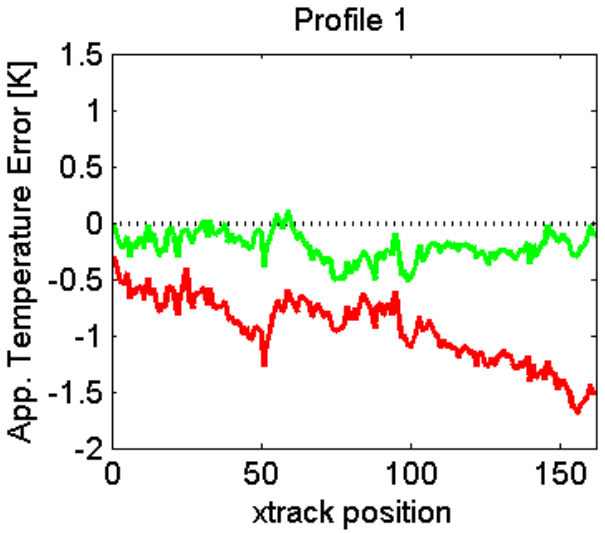


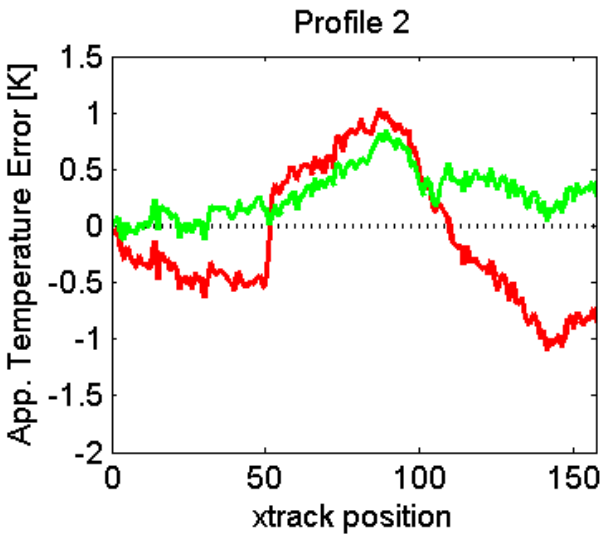


	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.167	0.118	0.878	0.149	-0.862	-0.092
Profile 2	0.266	0.109	0.645	0.145	-0.588	0.097

Path 176, Row 037: Band 11

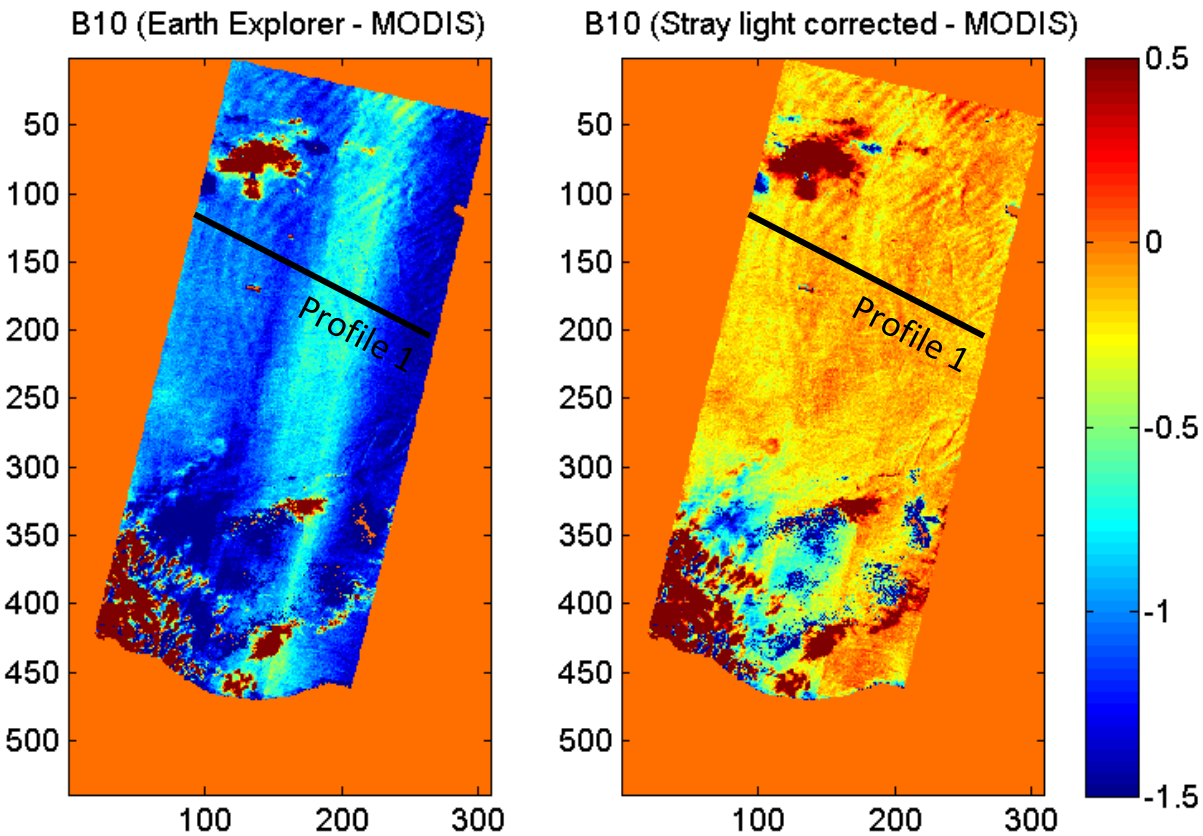


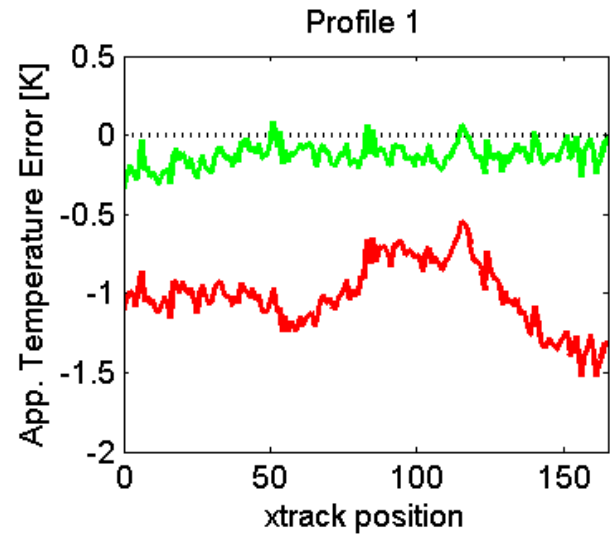




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.301	0.128	0.990	0.248	-0.943	-0.213
Profile 2	0.596	0.218	0.604	0.356	-0.104	0.282

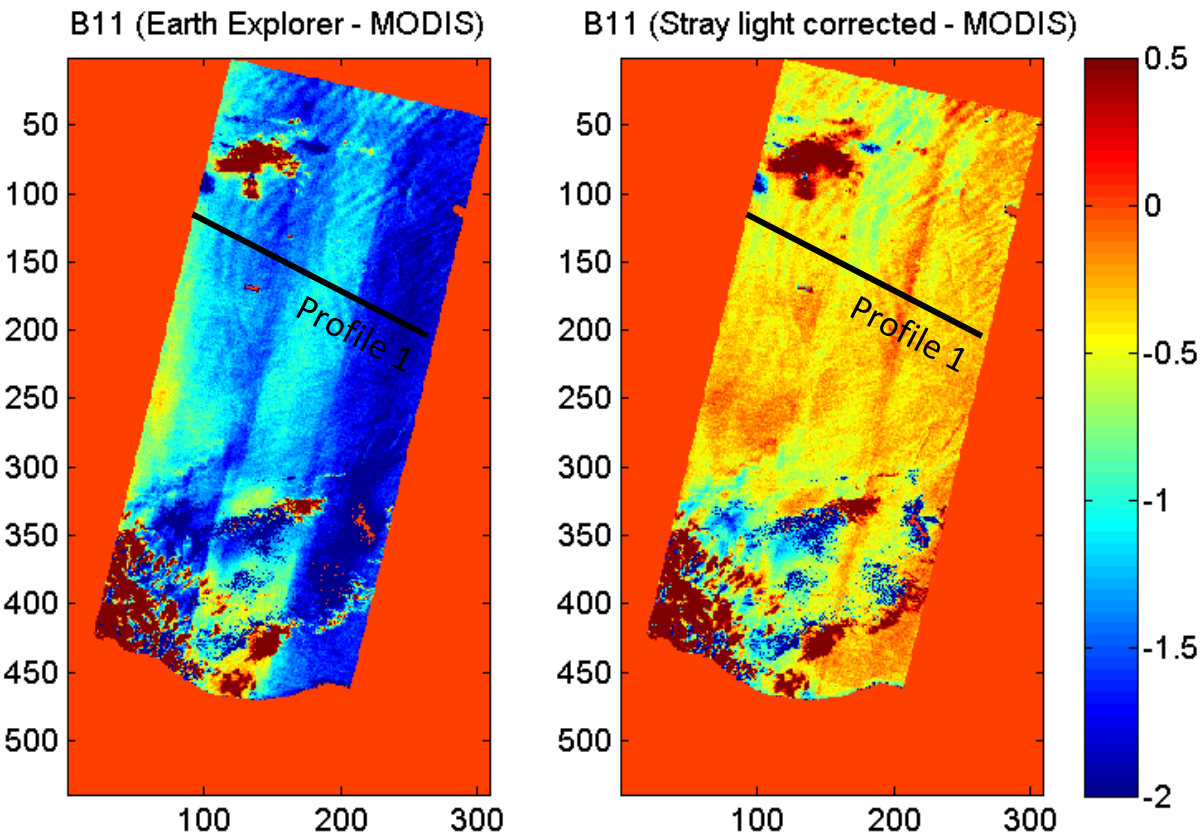
Path 188, Row 035: Band 10

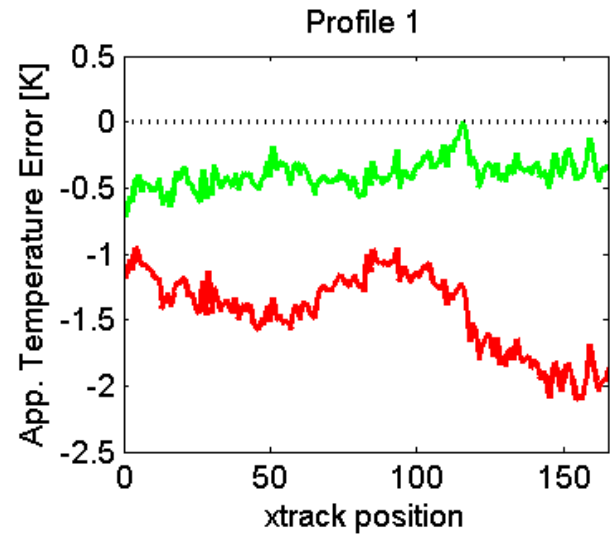




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.208	0.076	1.037	0.152	-1.016	-0.132

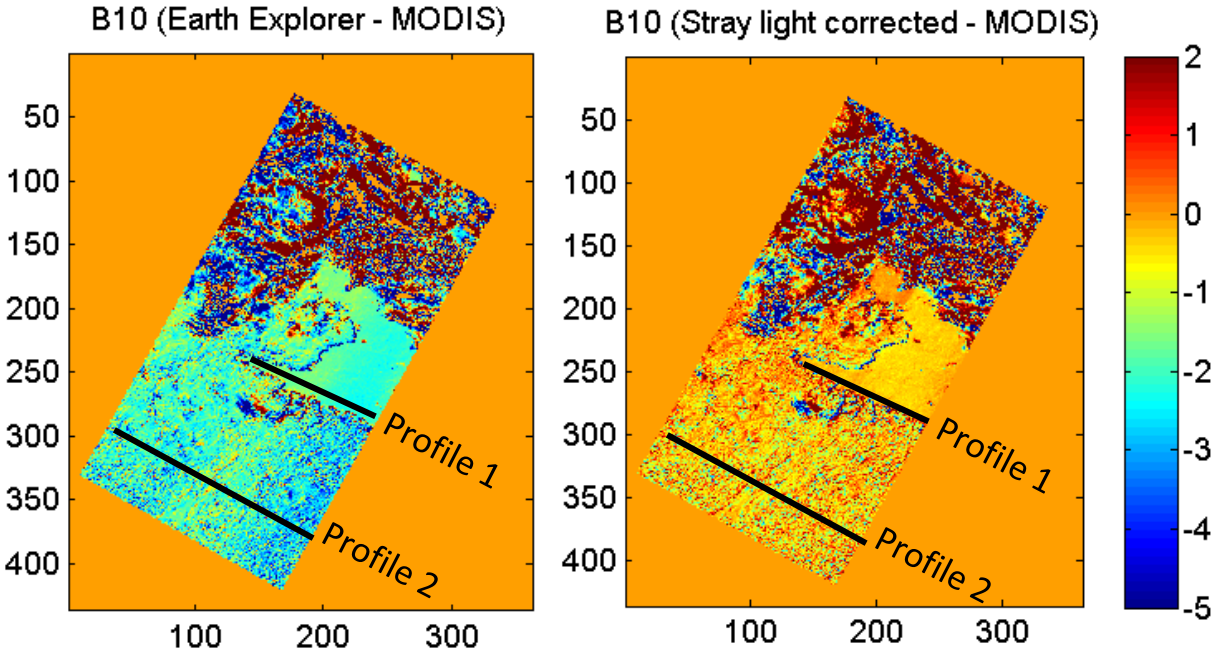
Path 188, Row 035: Band 11

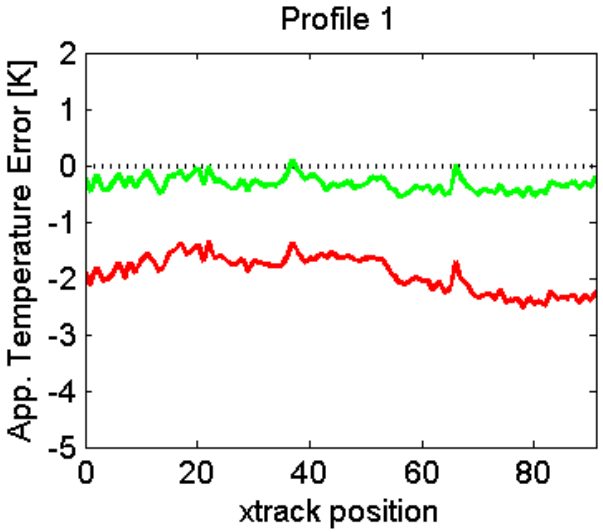


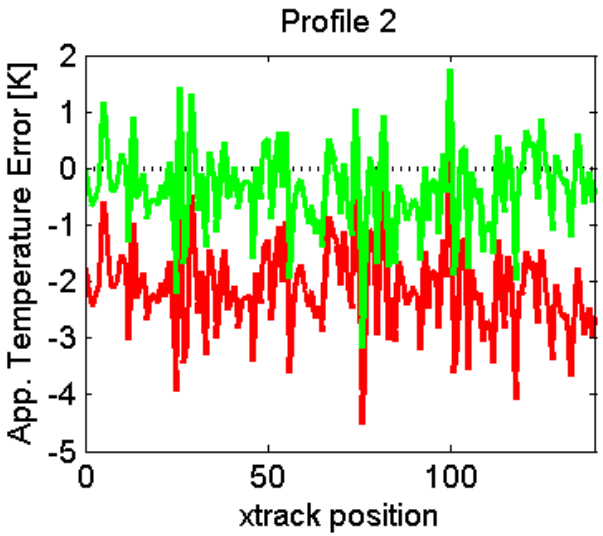


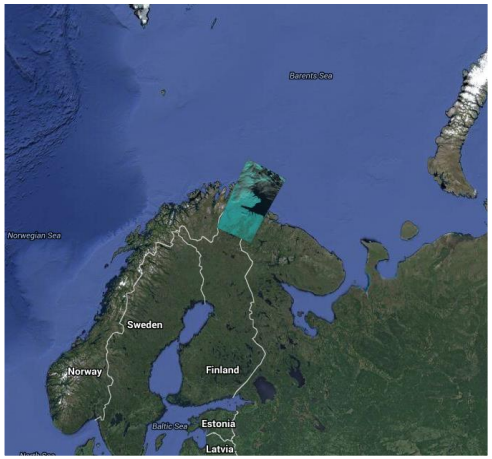
	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.299	0.113	1.469	0.412	-1.439	-0.396

Path 191, Row 010: Band 10



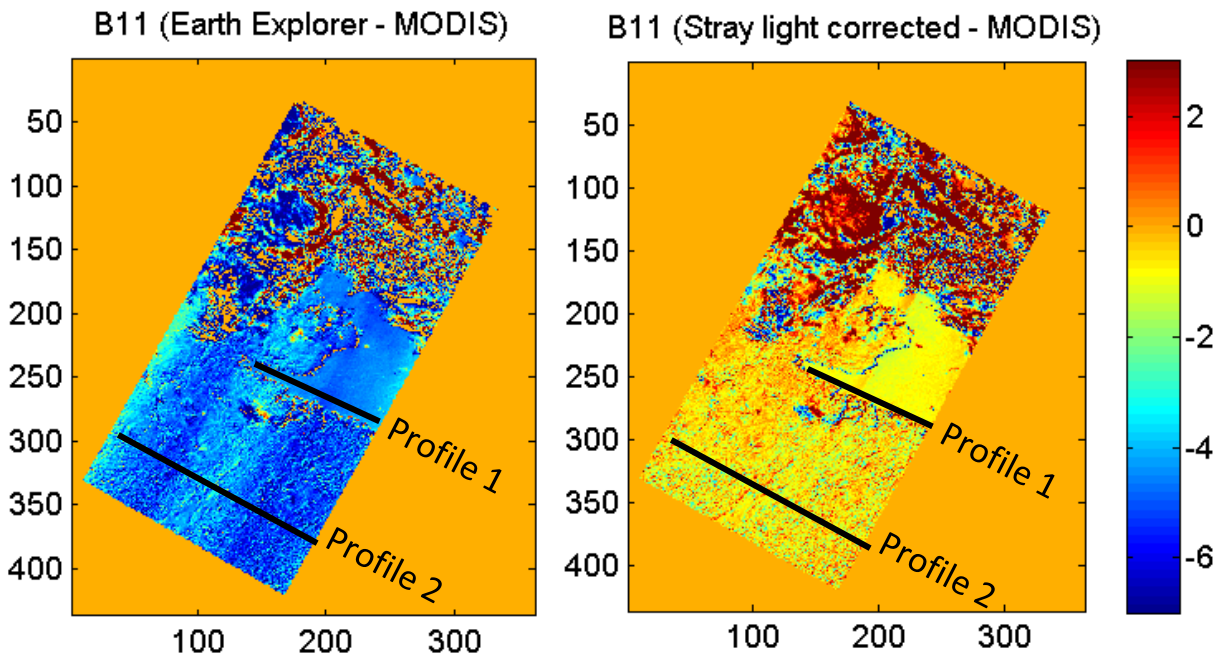


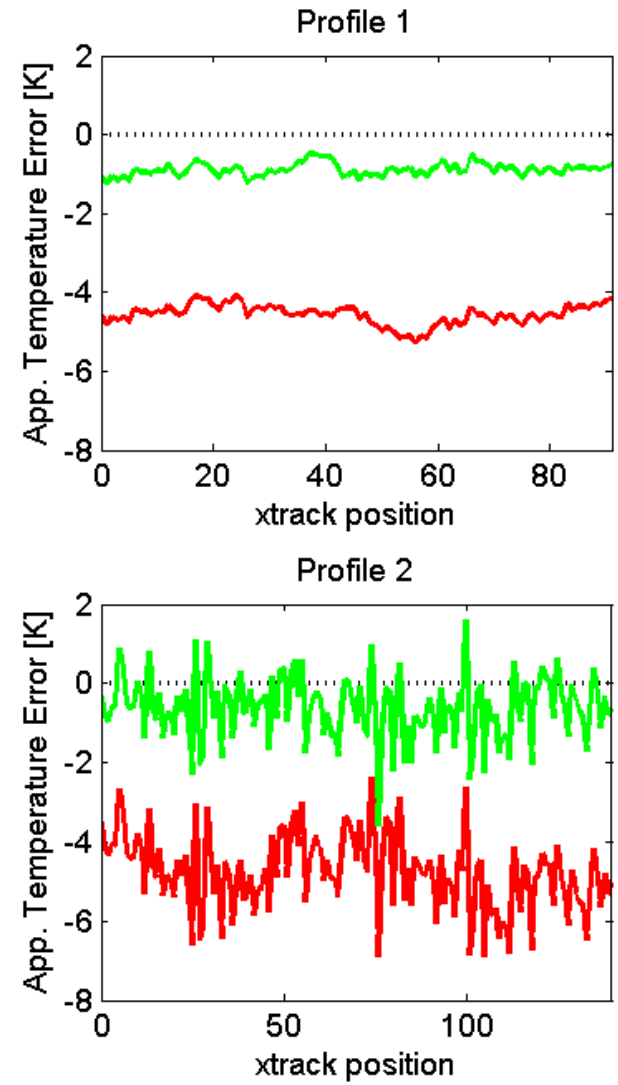




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.316	0.134	1.946	0.358	-1.920	-0.332
Profile 2	0.790	0.769	2.310	0.869	-2.172	-0.410

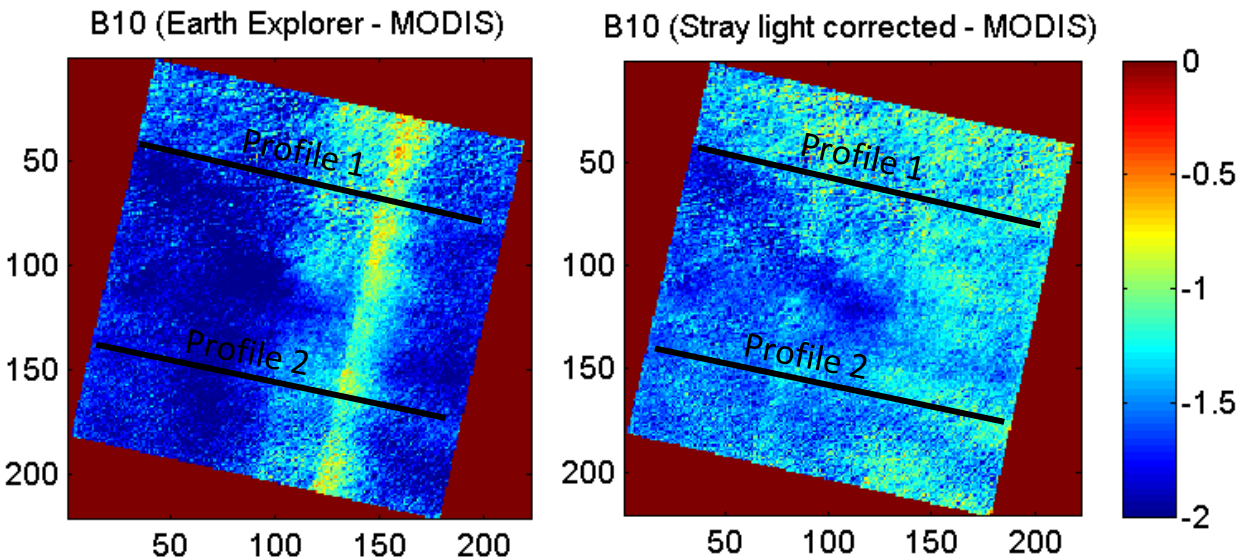
Path 191, Row 010: Band 11

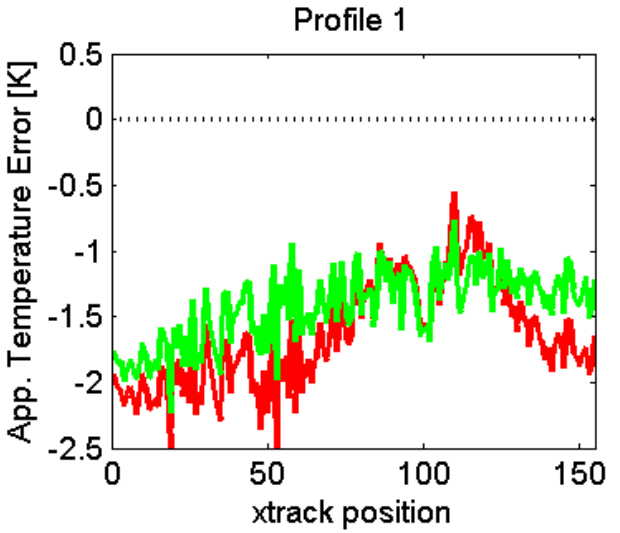


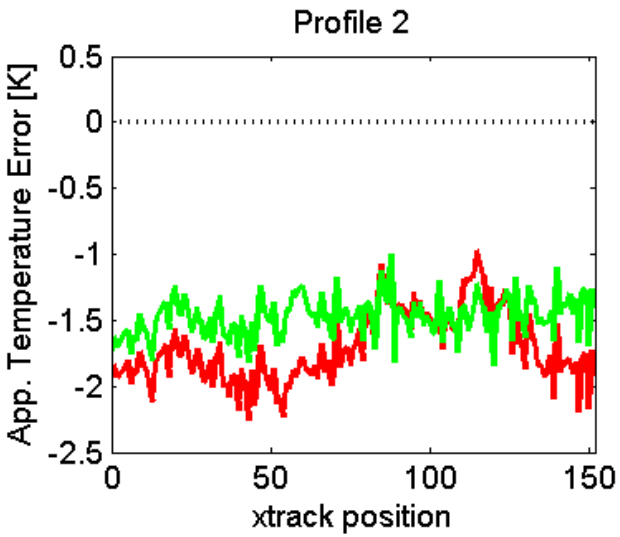


	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.256	0.164	4.580	0.911	-4.573	-0.896
Profile 2	0.954	0.807	4.884	1.037	-4.790	-0.655

Path 198, Row 046: Band 10

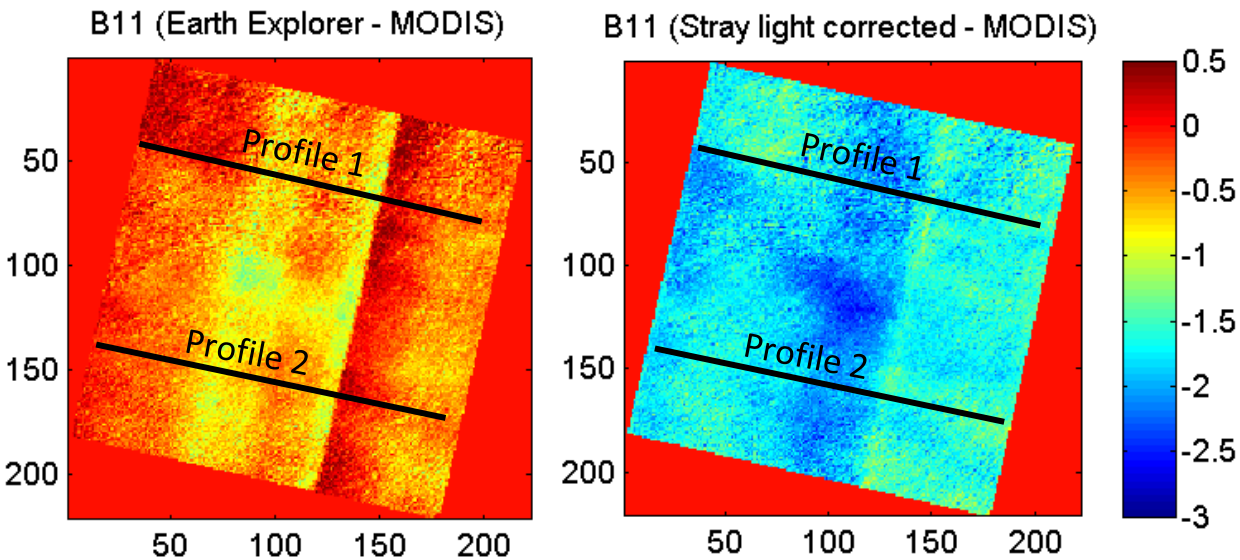


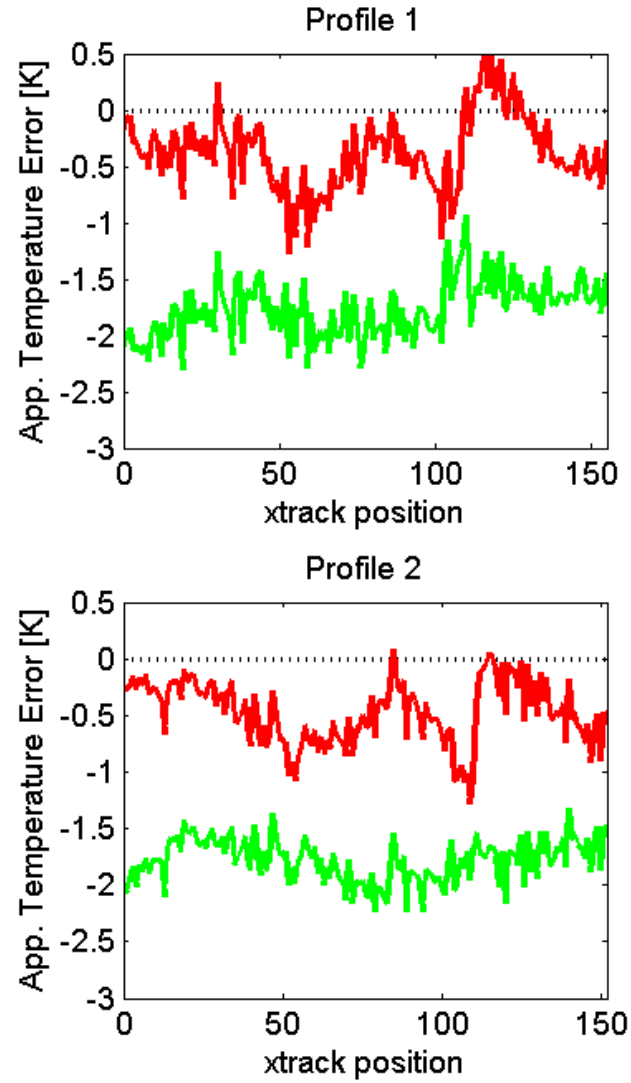




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.405	0.281	1.698	1.463	-1.649	-1.436
Profile 2	0.271	0.156	1.739	1.489	-1.718	-1.481

Path 198, Row 046: Band 11

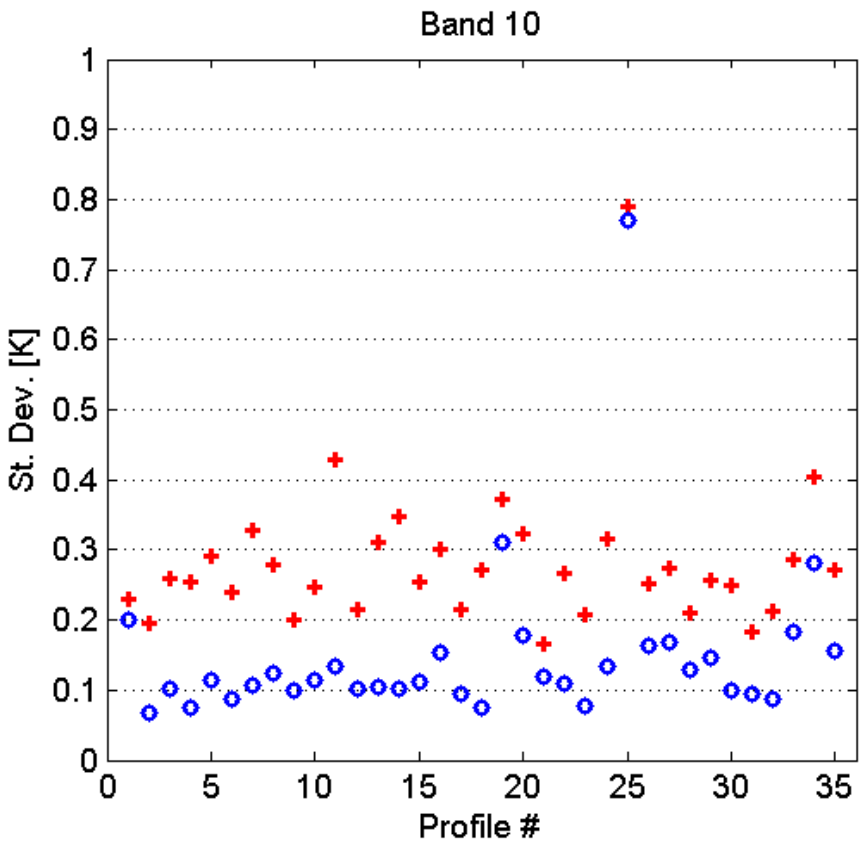


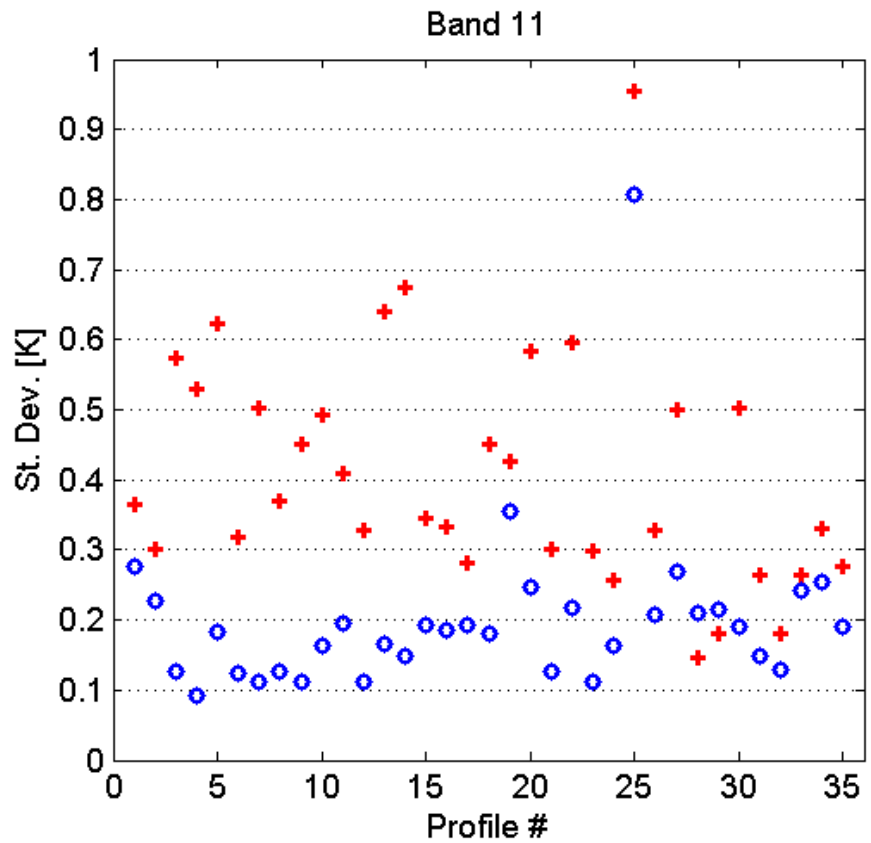


	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.332	0.255	0.504	1.797	-0.380	-1.779
Profile 2	0.277	0.191	0.553	1.796	-0.479	-1.786

St. Dev. summary ("relative calibration"):

In terms of Apparent Temperature error with Terra/MODIS



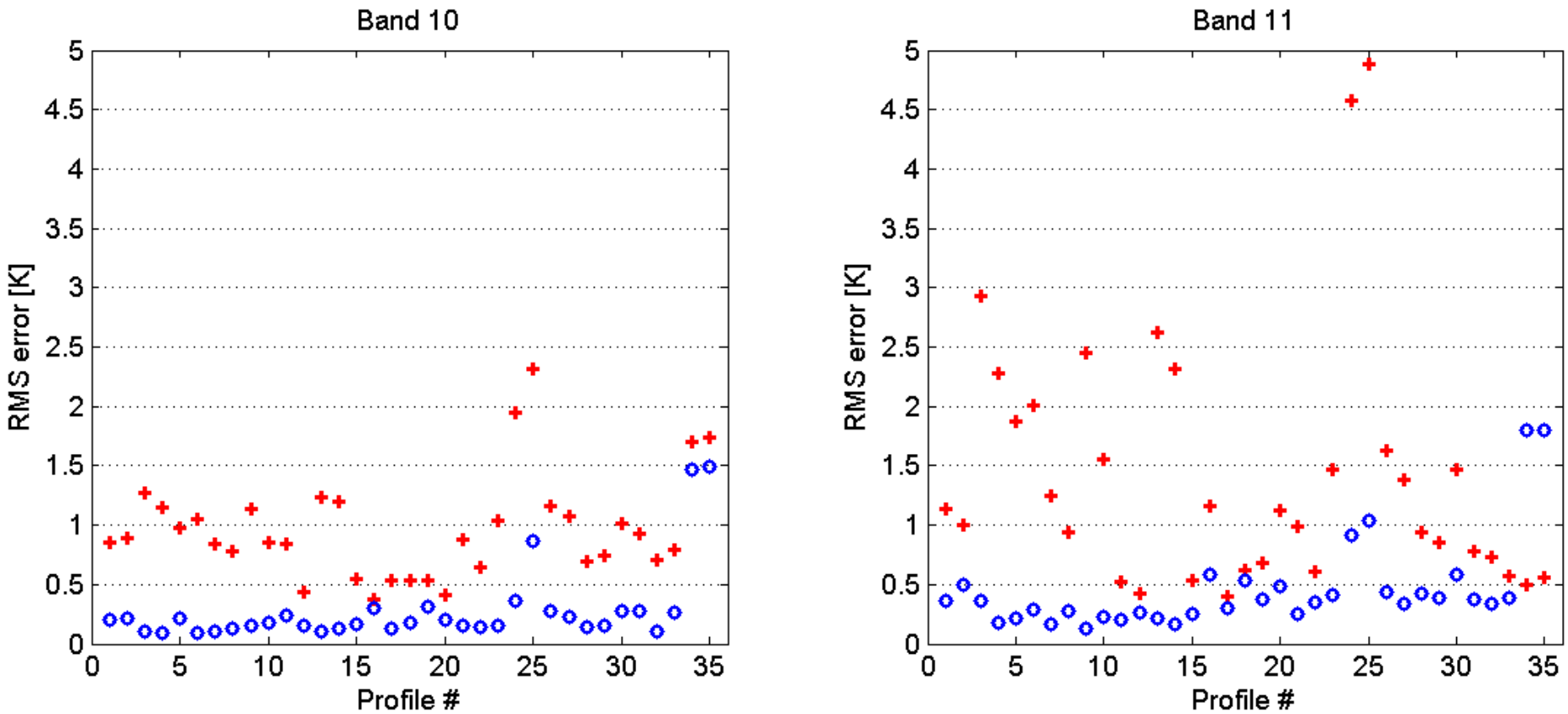


+ Current Product

o Stray Light Corrected

RMSE summary ("absolute calibration"):

In terms of Apparent Temperature error with Terra/MODIS

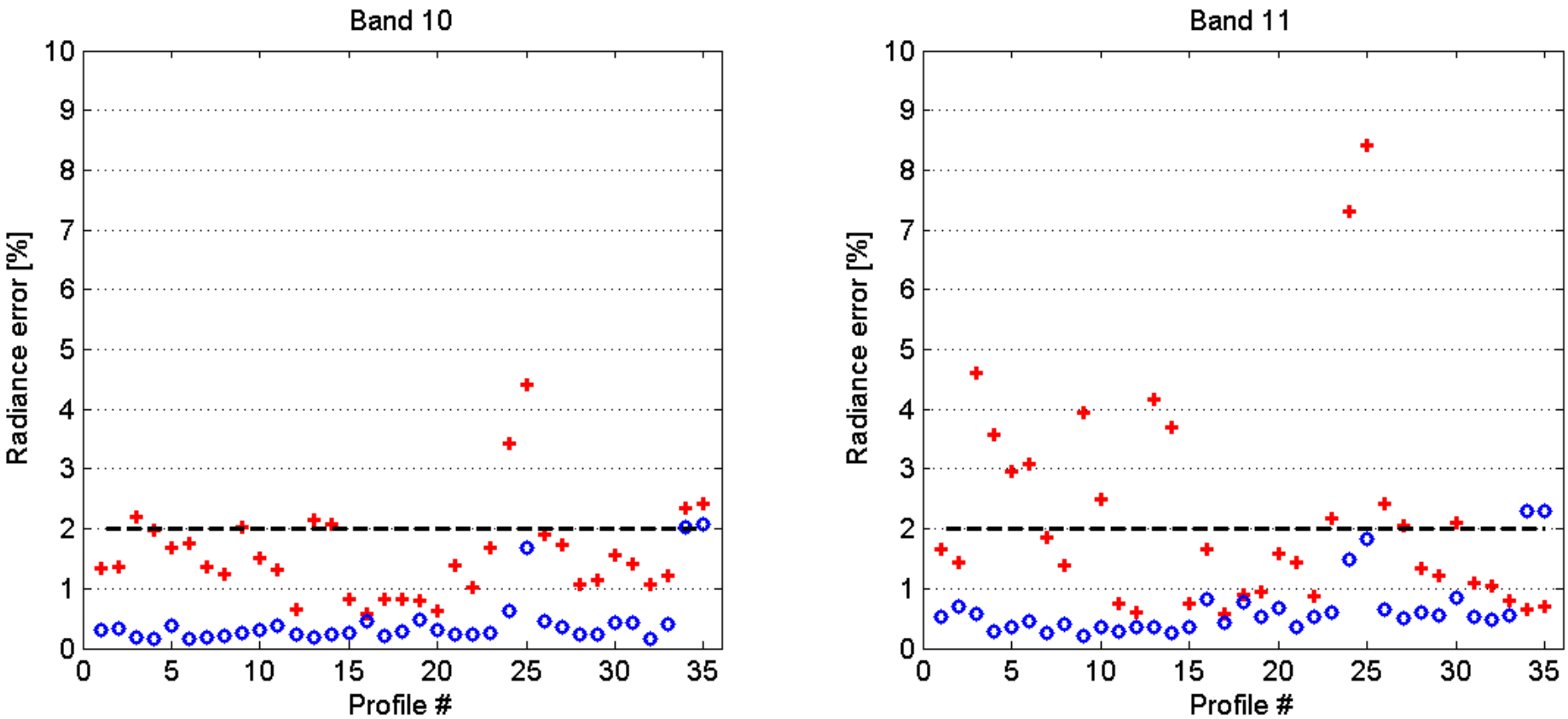


+ Current Product

o Stray Light Corrected

RMSE summary ("absolute calibration"):

In terms of Percent Radiance error with Terra/MODIS



+ Current Product

o Stray Light Corrected

NOTE: TIRS has a 2% absolute radiometric uncertainty requirement for scene temperatures between 260 and 330 K and 4% otherwise

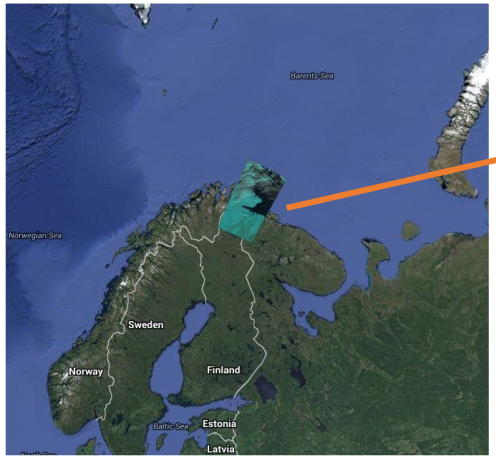
RMSE summary ("absolute calibration"):

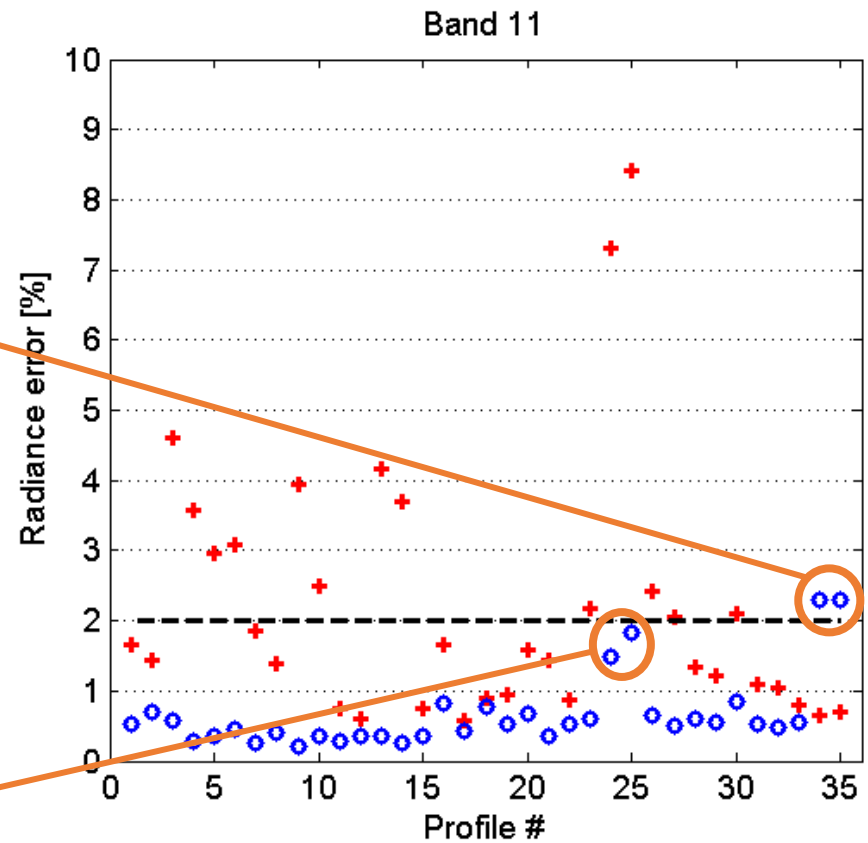
In terms of Percent Radiance error with Terra/MODIS

Large difference between TIRS and MODIS due to the Earth changing between the two overflight times

Path 198 desert

Path 191 land/clouds





+ Current Product

o Stray Light Corrected

TIRS-507 Banding 1:
The root mean square of the deviation from the average radiance across the full FOV for any 100 contiguous pixel column averages of radiometrically corrected TIRS image data within a band shall not exceed 0.5% of that average radiance. This banding requirement is met when for all n:

$$\sqrt{\sum_{i=n}^{n+99} \left(\overline{L_i} - \overline{L'}\right)^2 / 100} \leq 0.005\ \overline{L'}$$

TIRS-514 Banding 2:
The standard deviation of the radiometrically corrected values across any 100 contiguous pixels column averages of TIRS image data within a band shall be less than 0.5% of the average radiance across the full FOV. Note: The average radiance across the FOV is used here merely as a reference for deriving the magnitude of the 0.5%. The mean in the standard deviation calculation is, by definition, the mean of the 100 pixel columns and not the entire FOV mean. This banding requirement is met when for all n:

$$\sqrt{\sum_{i=n}^{n+99} \left(\overline{L_i} - \overline{L}\right)^2 / 99} \leq 0.005\ \overline{L'}$$

Banding requirements

- Run banding metrics on MODIS-subtracted TIRS scene before and after correction (need a uniform scene to calculate banding)

- Take with grain of salt:
  - using MODIS to make a “uniform scene” (susceptible to the changing Earth between Terra and Landsat 8)
  - banding metric intended to be per-detector (all 1920 detectors) not MODIS-resolution pixels
  - No other way we can think of to calculate banding on-orbit

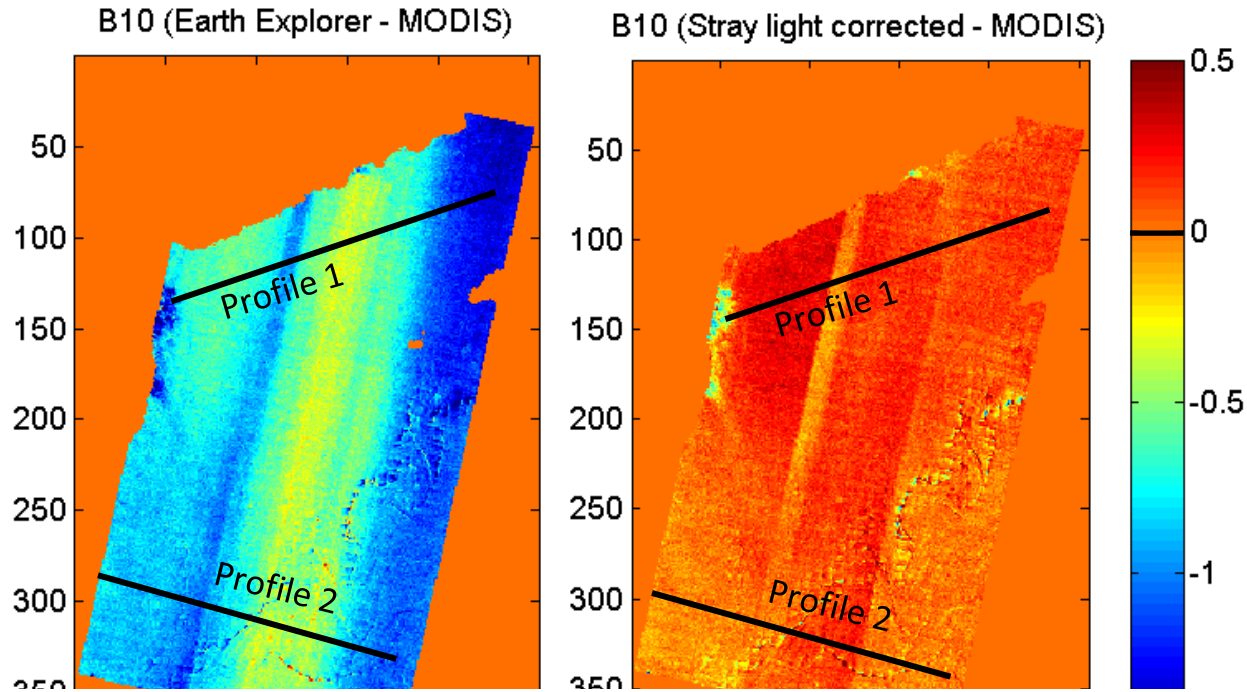
- Banding calculated on every scene profile from the previous slides. Will show a few examples on the following slides

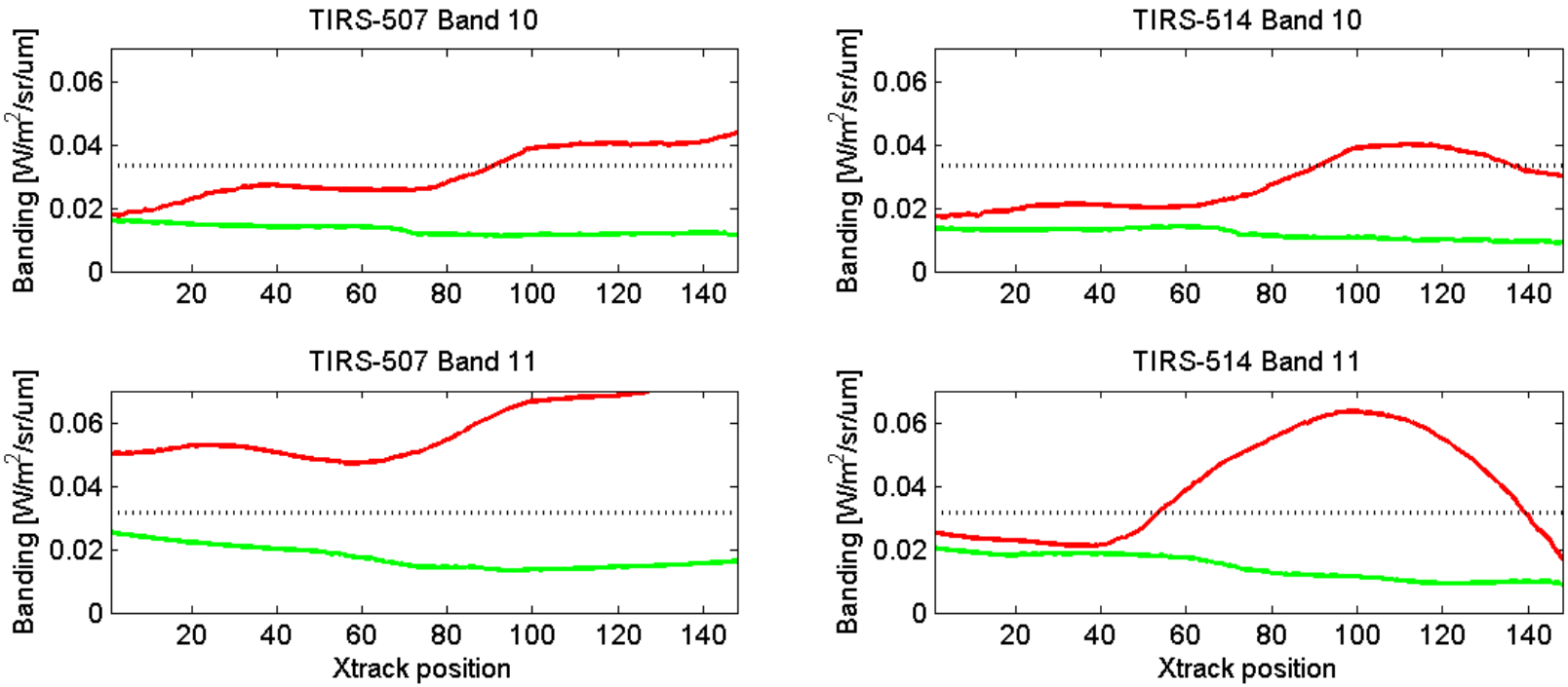
Path 013, Row 032

Long Island, Profile 1

---- Current Product

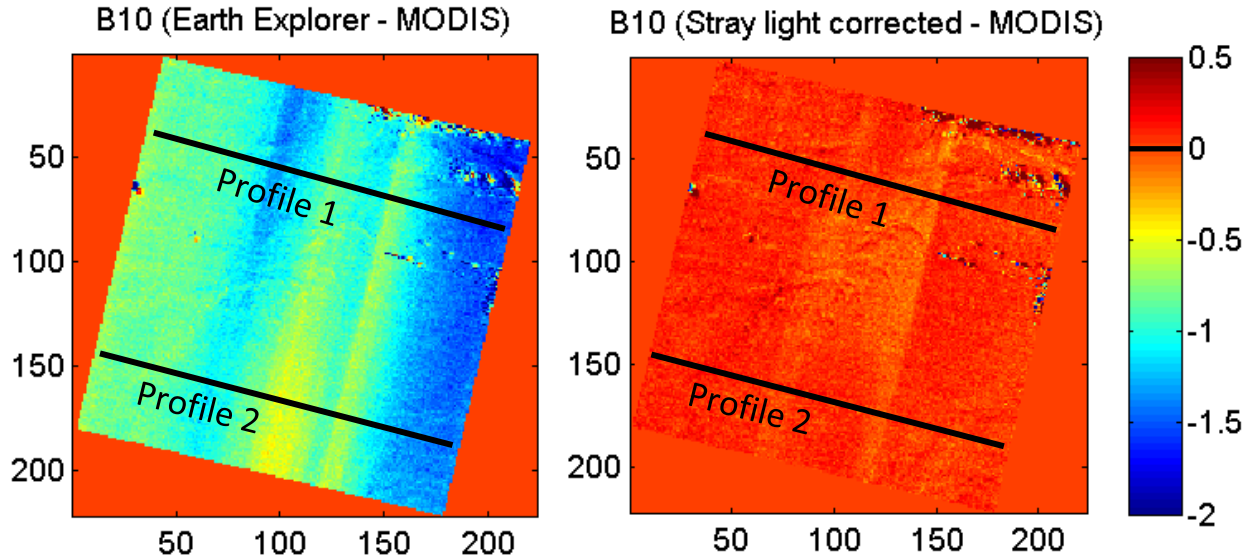
---- Stray Light Corrected





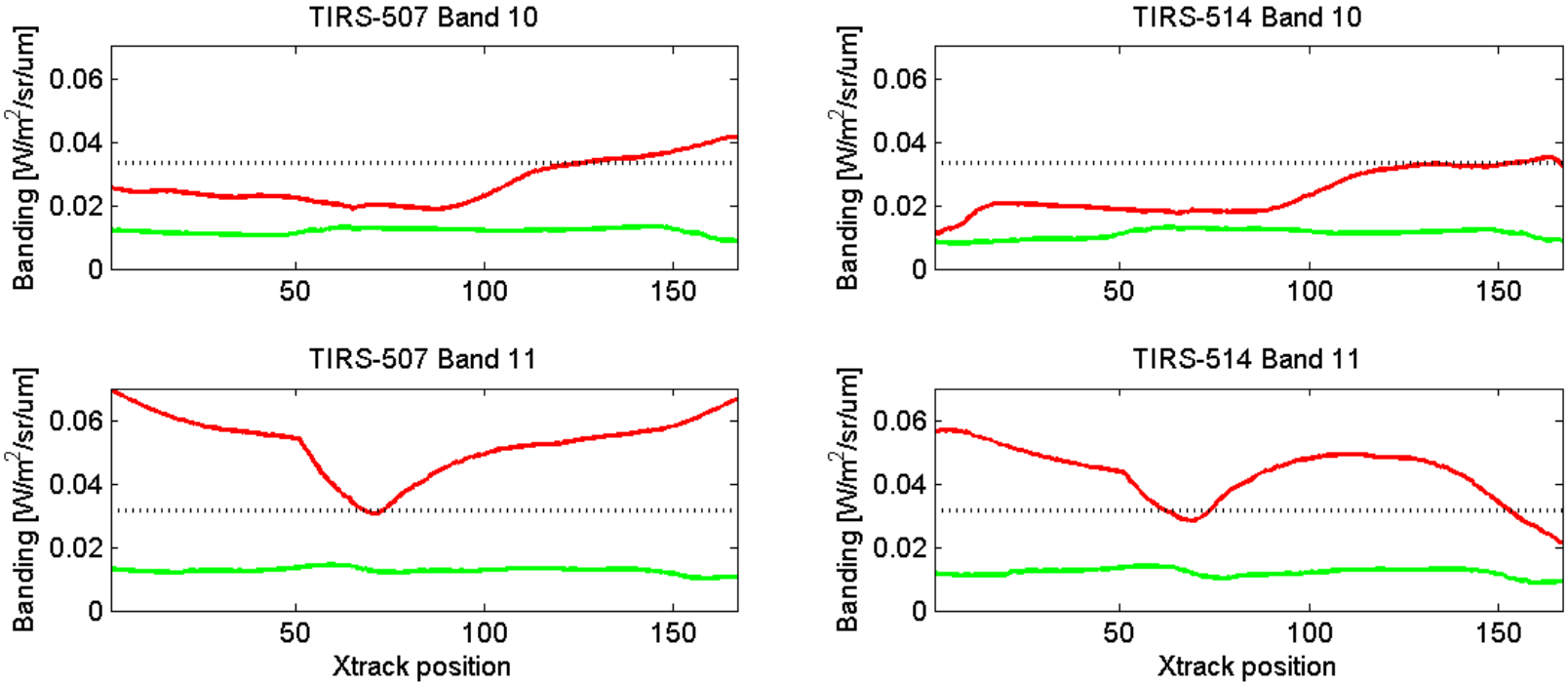
Path 010, Row 030

Atlantic ocean, Profile 1



---- Current Product

---- Stray Light Corrected

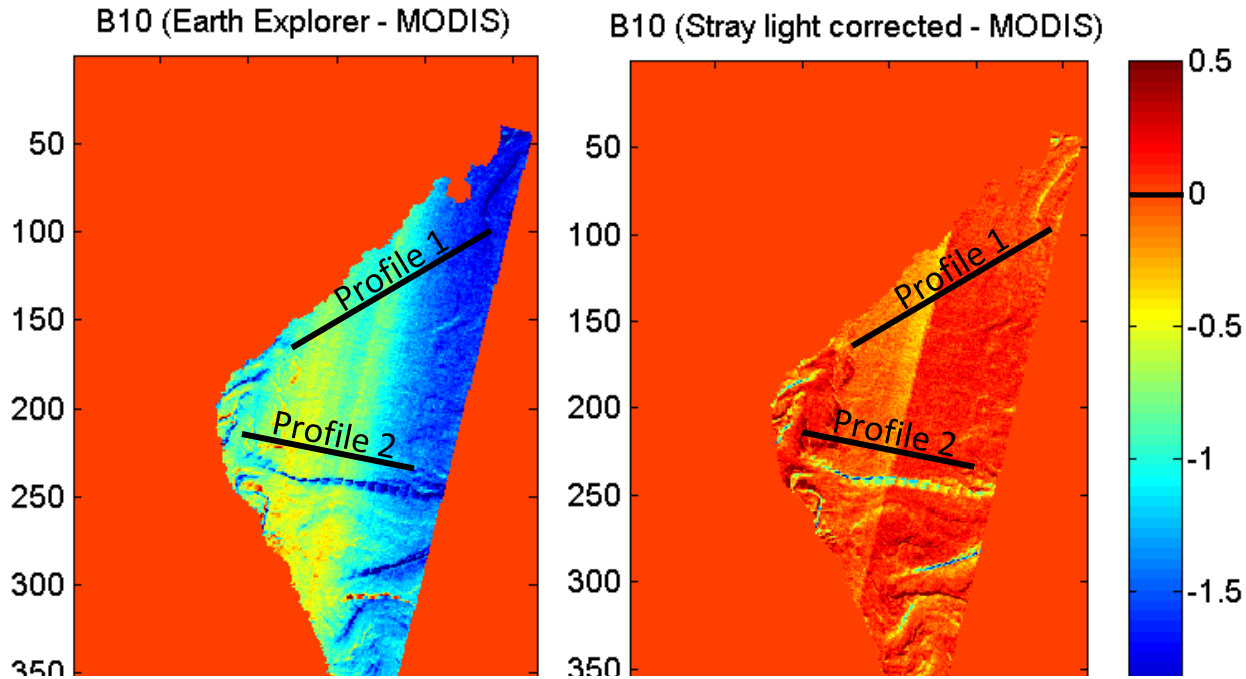


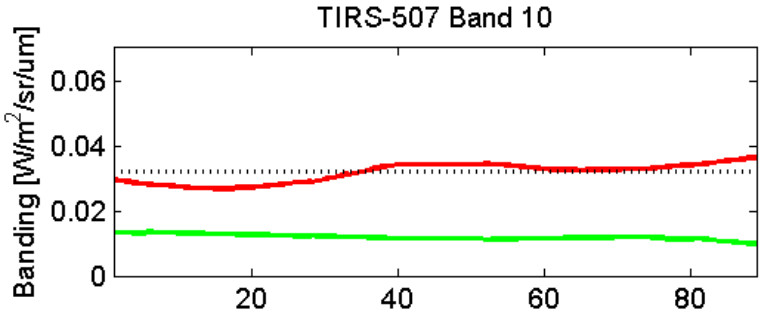
Path 115, Row 032

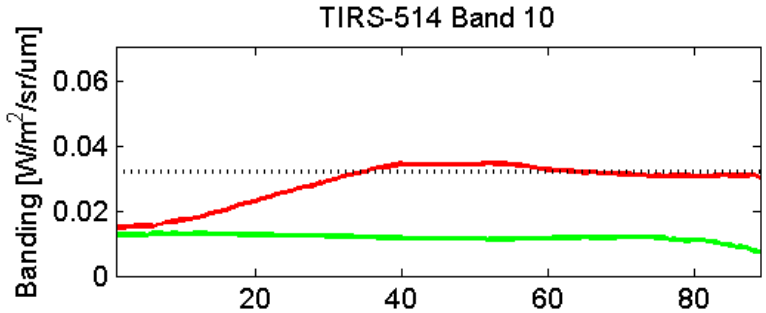
Korea, Profile 1

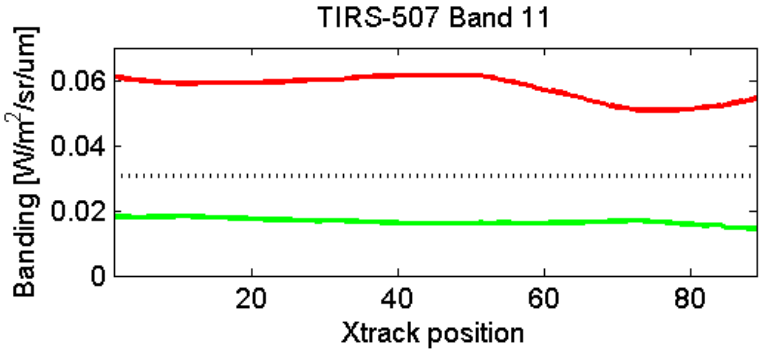
---- Current Product

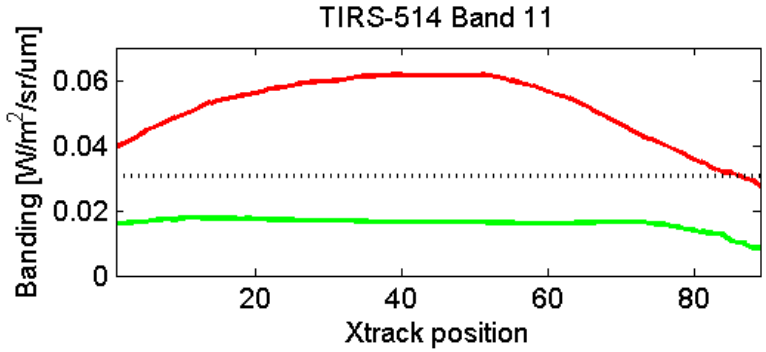
---- Stray Light Corrected









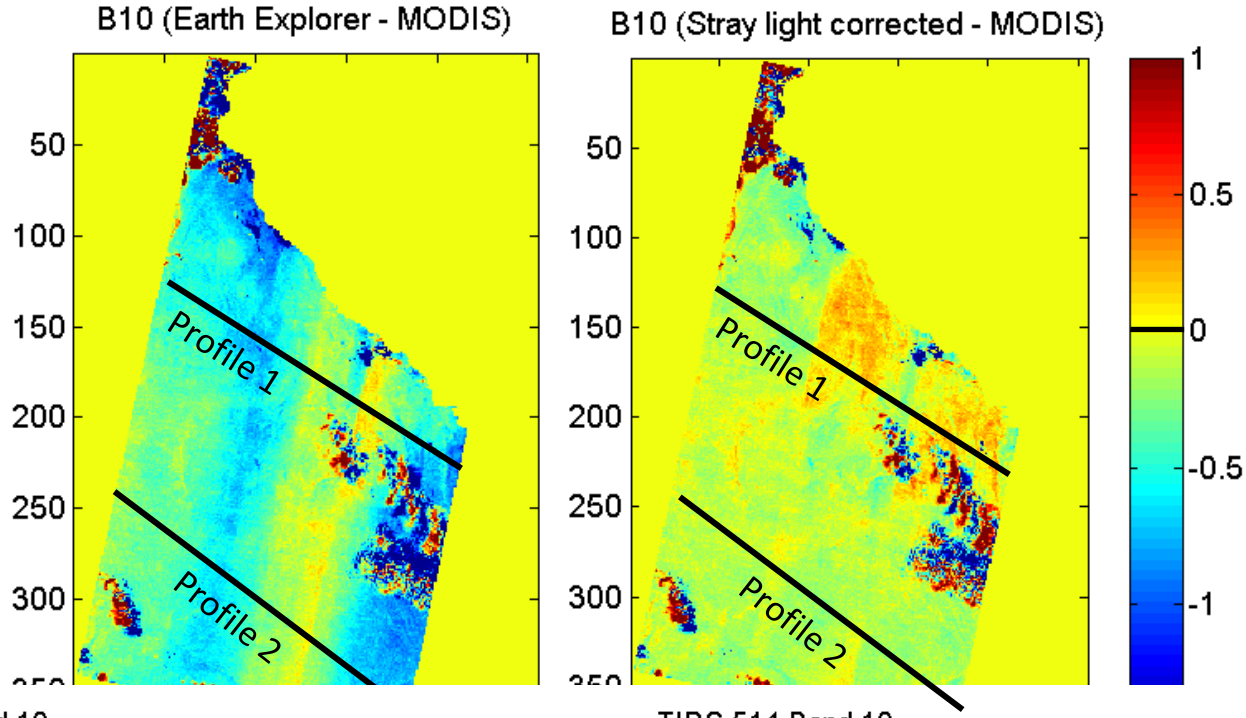


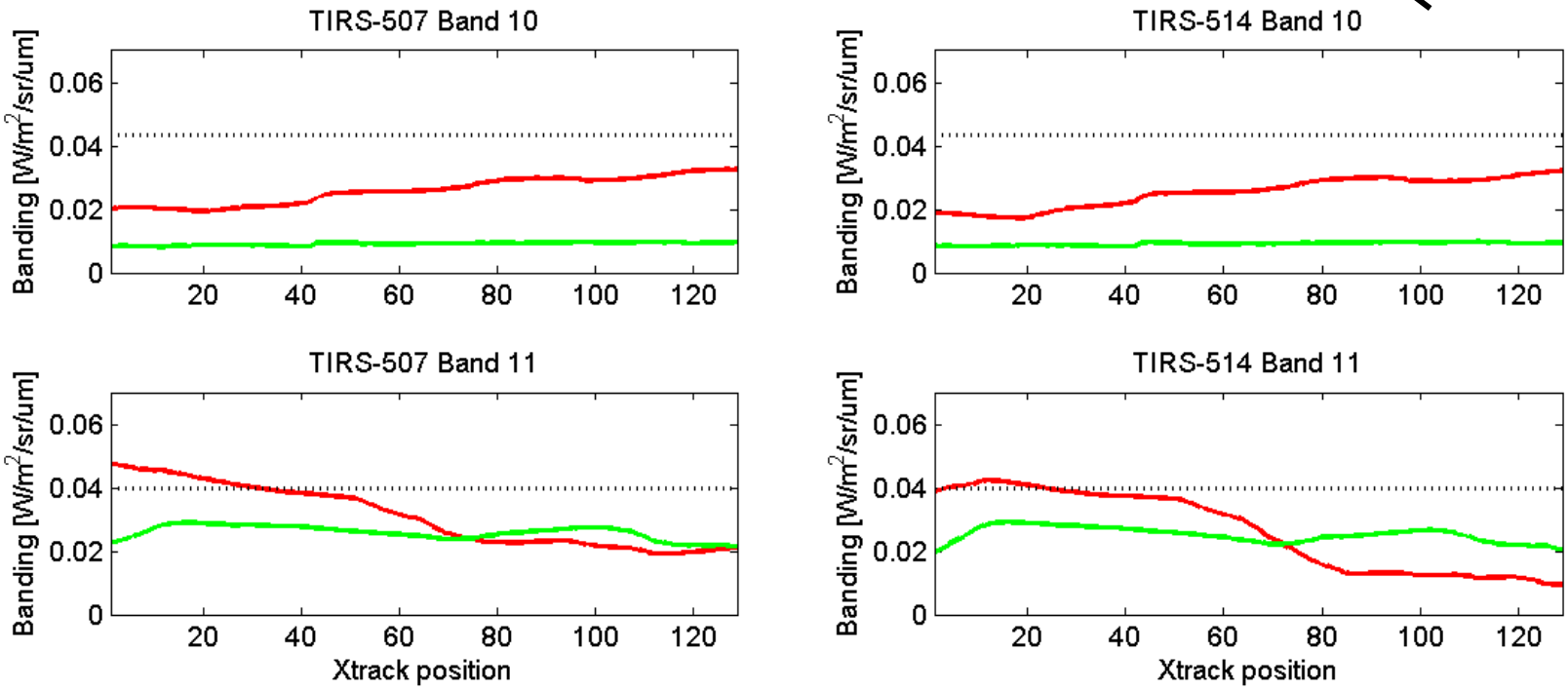
Path 006, Row 070

Peru, Profile 2

---- Current Product

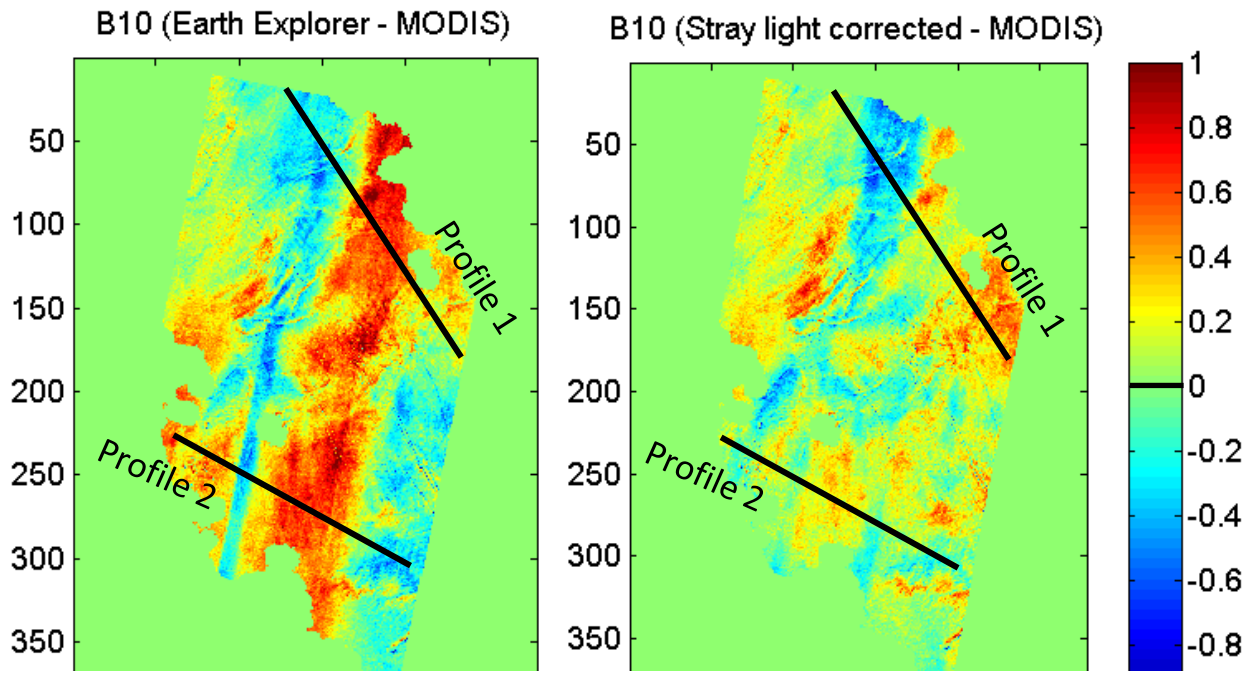
---- Stray Light Corrected





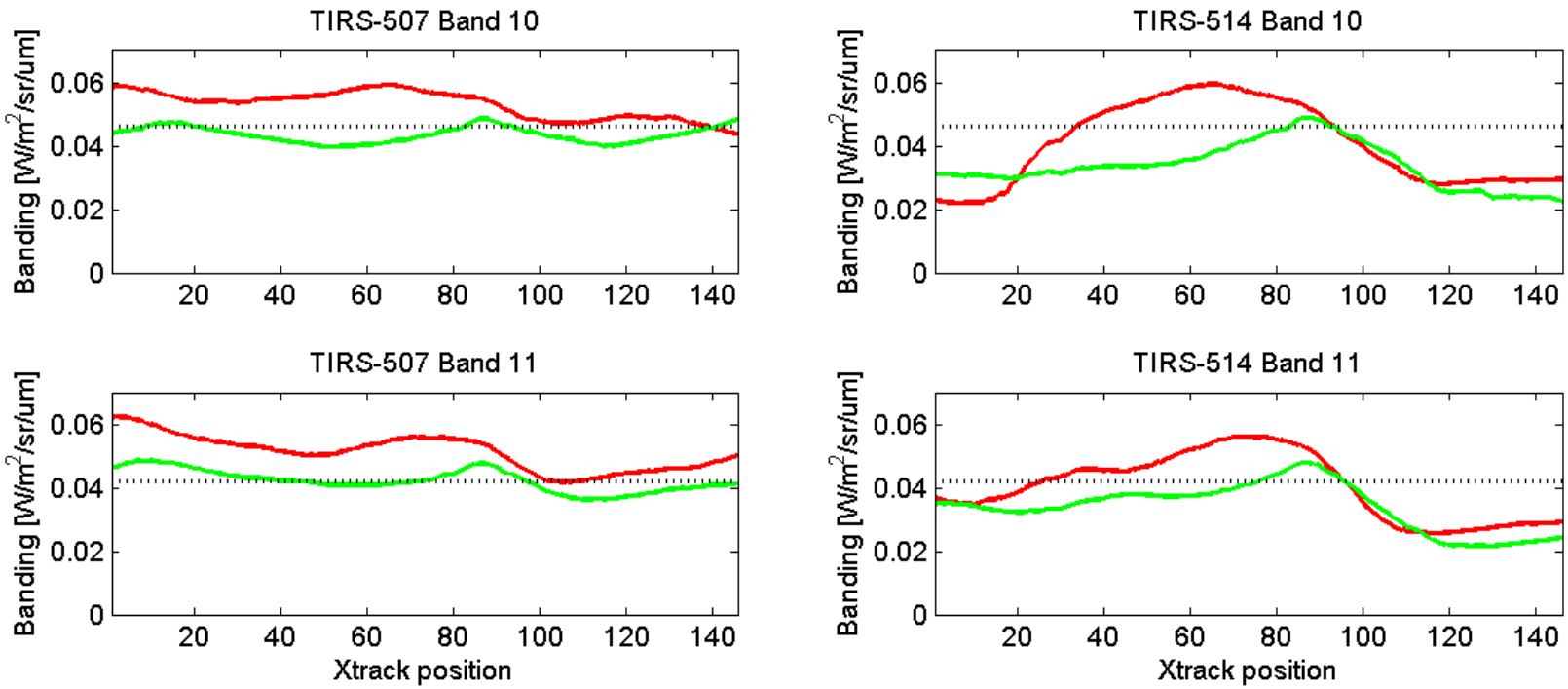
Path 172, Row 043

Red Sea, Profile 1



---- Current Product

---- Stray Light Corrected

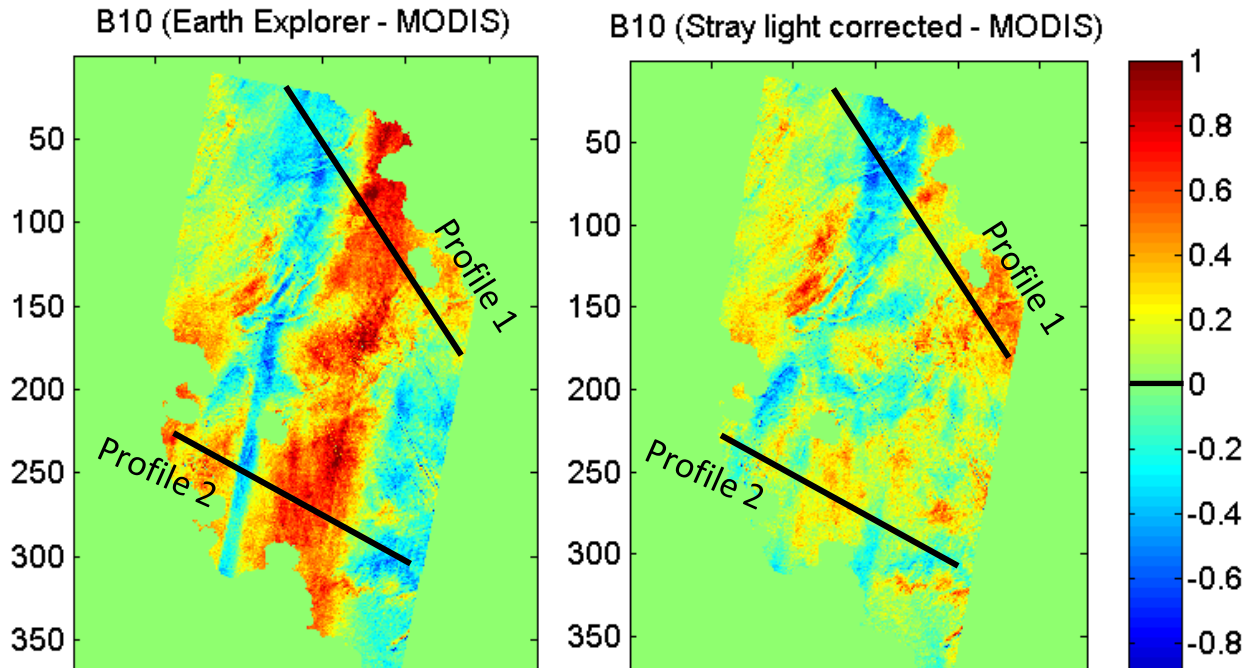


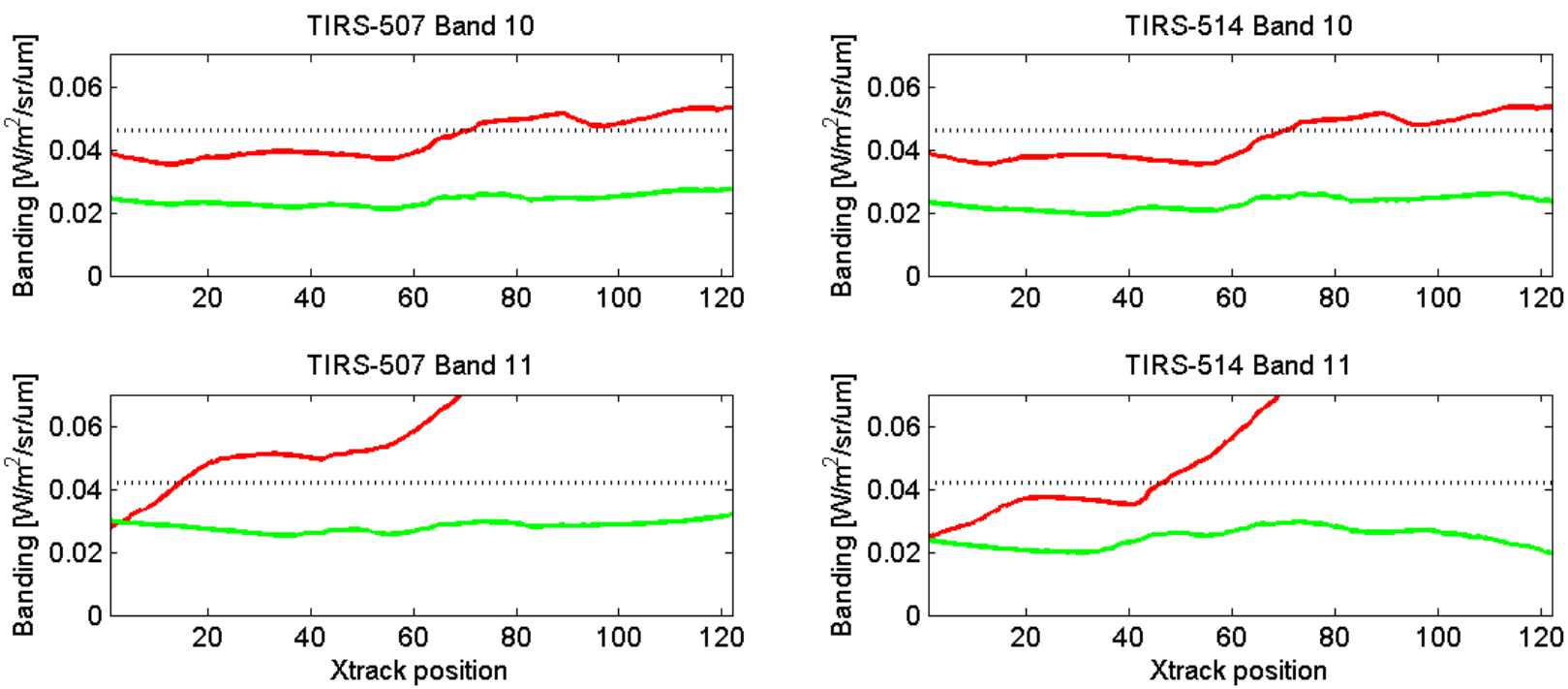
Path 172, Row 043

Red Sea, Profile 2

---- Current Product

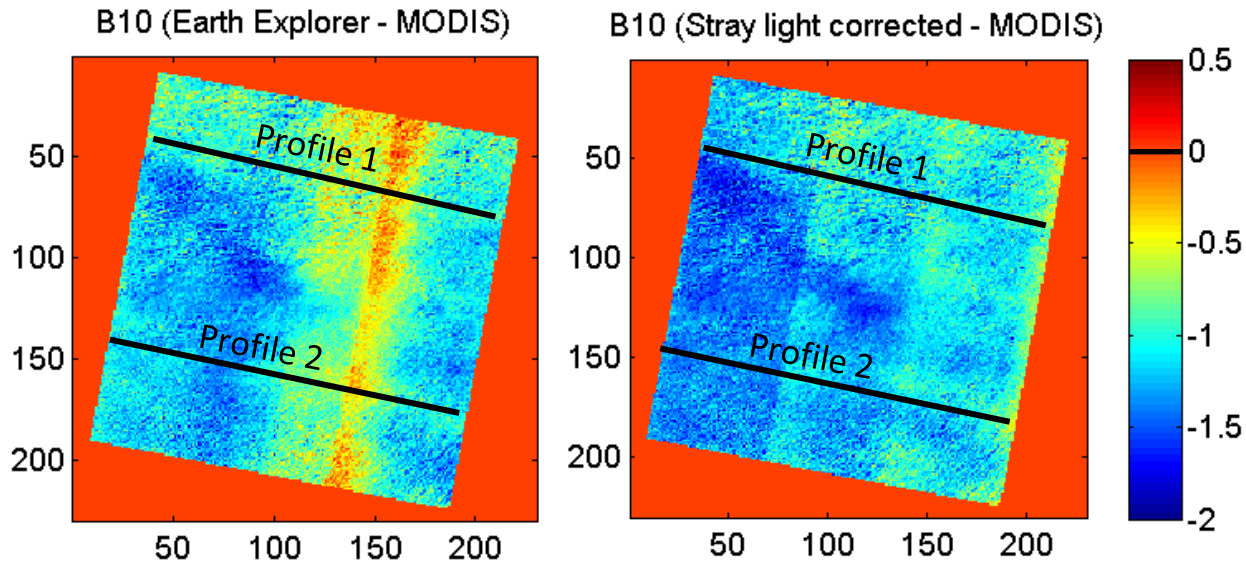
---- Stray Light Corrected





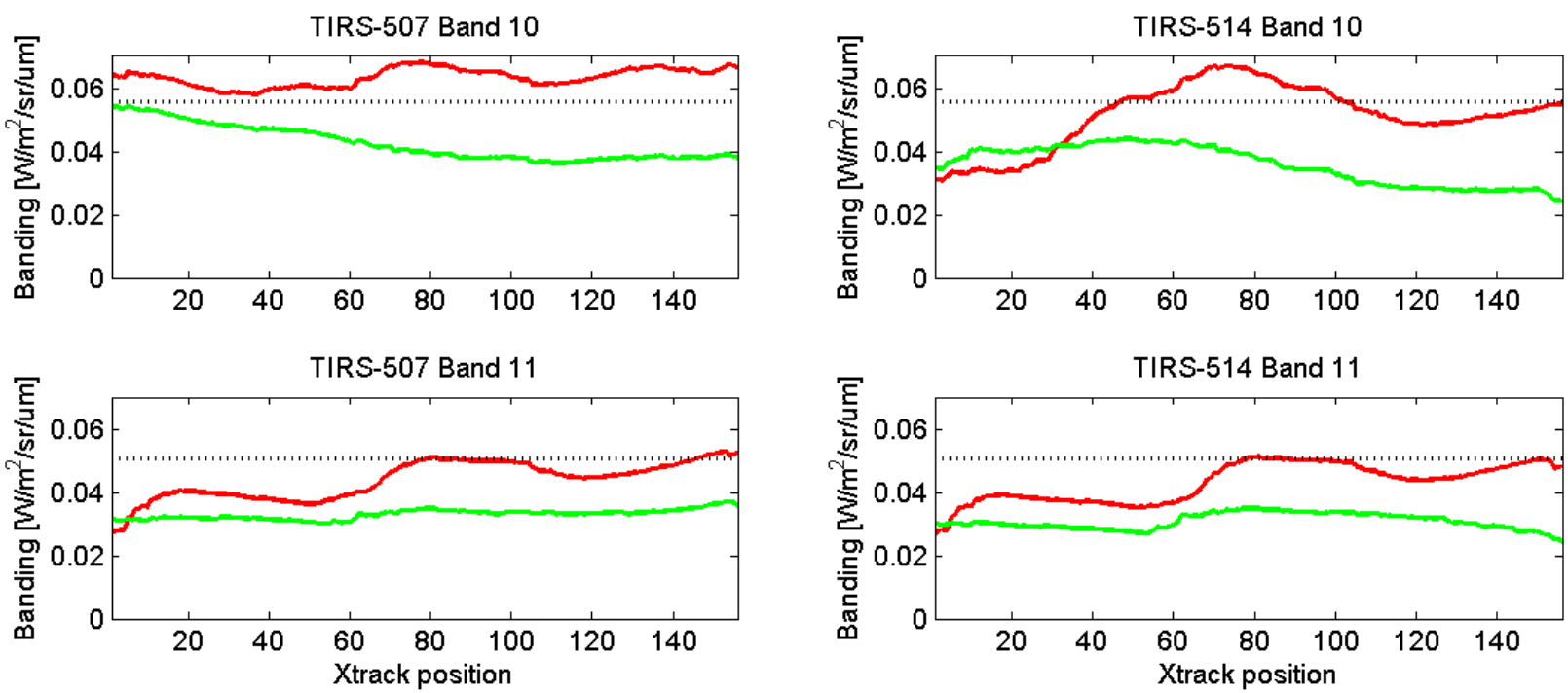
Path 198, Row 046

Sahara, Profile 1



---- Current Product

---- Stray Light Corrected



Current Status

- EROS has this algorithm implemented in off-line test system (Tim Beckmann & Co.)

Pepsi Challenge to the Science Team:

- Do you have a favorite scene you want corrected?

Aaron Gerace (gerace@cis.rit.edu)
Matt Montanaro (montanaro@cis.rit.edu)

Split Window

$$LST = b_0 + (b_1 + b_2 \frac{1-\varepsilon}{\varepsilon} + b_3 \frac{\Delta\varepsilon}{\varepsilon^2}) \frac{T_i + T_j}{2} + (b_4 + b_5 \frac{1-\varepsilon}{\varepsilon} + b_6 \frac{\Delta\varepsilon}{\varepsilon^2}) \frac{T_i - T_j}{2} + b_7 (T_i - T_j)^2 \quad [1]$$

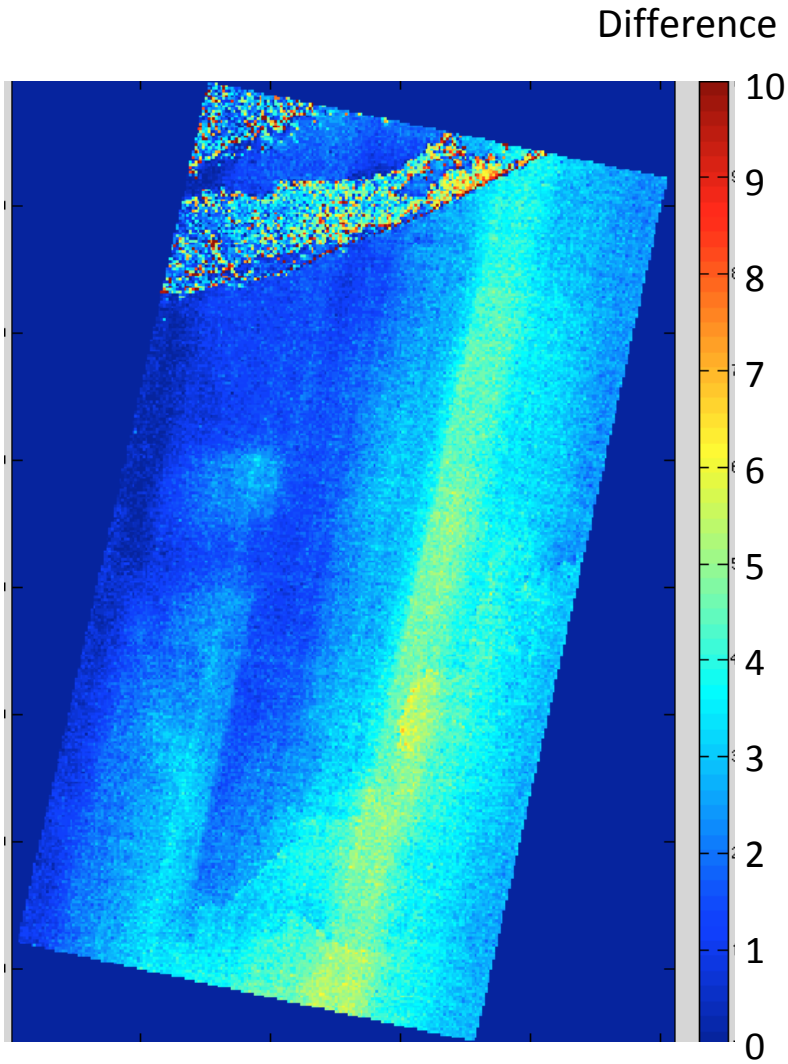
CWV (g/cm^2)	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	RMSE
[0.0, 2.5]	−2.78009	1.01408	0.15833	−0.34991	4.04487	3.55414	−8.88394	0.09152	0.34 K
[2.0, 3.5]	11.00824	0.95995	0.17243	−0.28852	7.11492	0.42684	−6.62025	−0.06381	0.60 K
[3.0, 4.5]	9.62610	0.96202	0.13834	−0.17262	7.87883	5.17910	−13.26611	−0.07603	0.71 K
[4.0, 5.5]	0.61258	0.99124	0.10051	−0.09664	7.85758	6.86626	−15.00742	−0.01185	0.86 K
[5.0, 6.3]	−0.34808	0.98123	0.05599	−0.03518	11.96444	9.06710	−14.74085	−0.20471	0.93 K
[0.0, 6.3]	−0.41165	1.00522	0.14543	−0.27297	4.06655	−6.92512	−18.27461	0.24468	0.87 K

[2]

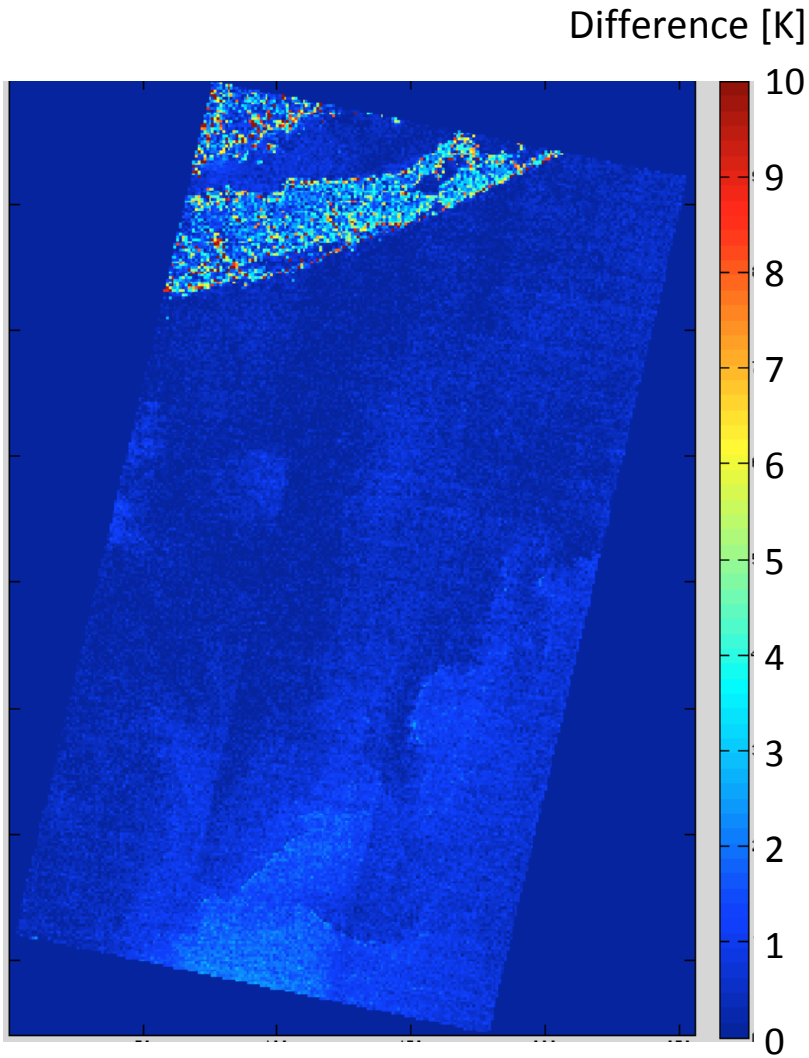
- Used emissivity of water.
- Applied split window to Terra-MODIS, v5 TIRS, SLC TIRS.
- Assuming MODIS is truth, generated difference images.

1. Wan, Z.; New refinements and validation of the collection-6 MODIS land-surface temperature/emissivity product. *Remote Sens. Environ.* **2014**, 140, 36–45.
2. Du, C.; Ren, H.; Qin, Q.; Meng, J.; Zhao, S. A Practical Split-Window Algorithm for Estimating Land Surface Temperature from Landsat 8 Data. *Remote Sens.* **2015**, *7*, 647-665.

Split Window



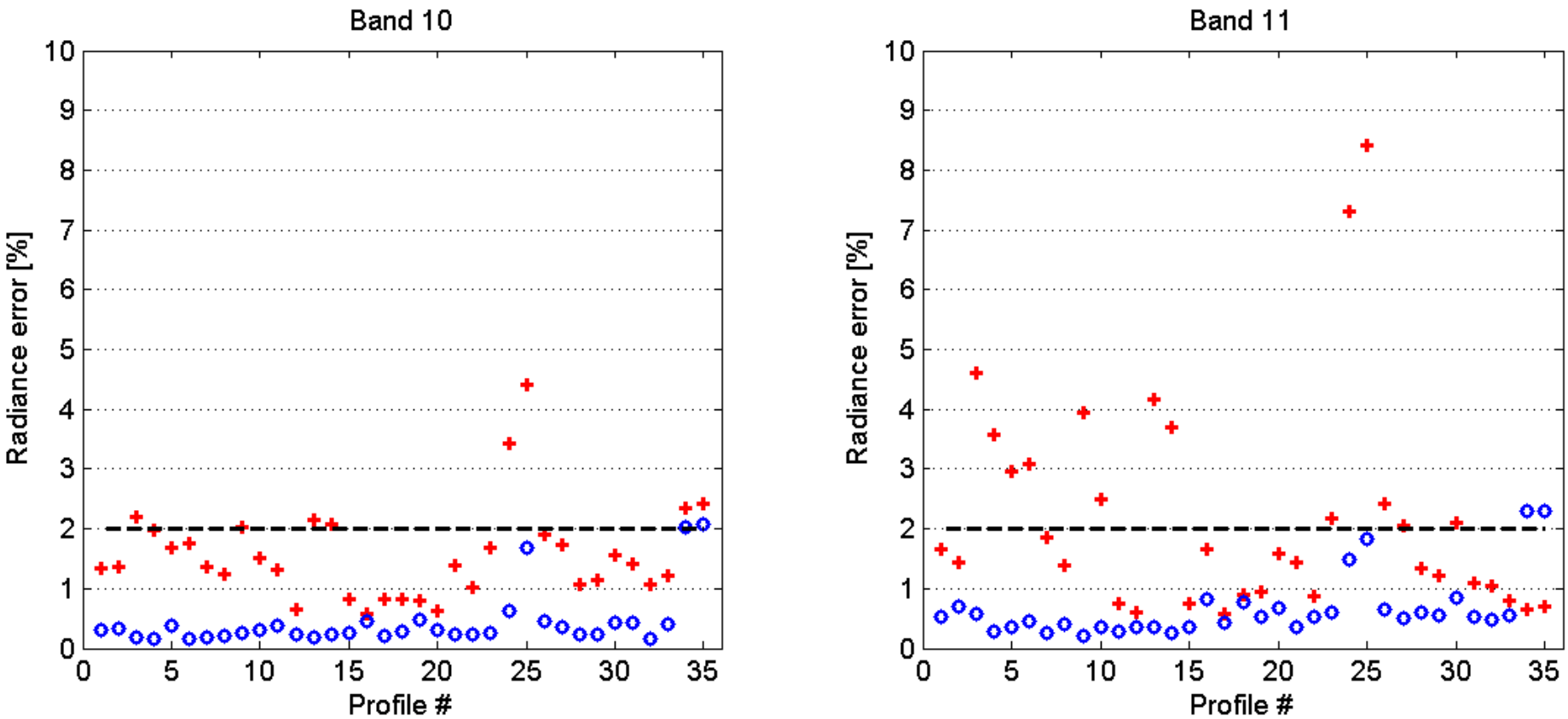
Retrieved (MODIS T_{surf} – TIRS current T_{surf})



Retrieved (MODIS T_{surf} – TIRS corrected T_{surf})

RMSE summary ("absolute calibration"):

In terms of Percent Radiance error with Terra/MODIS



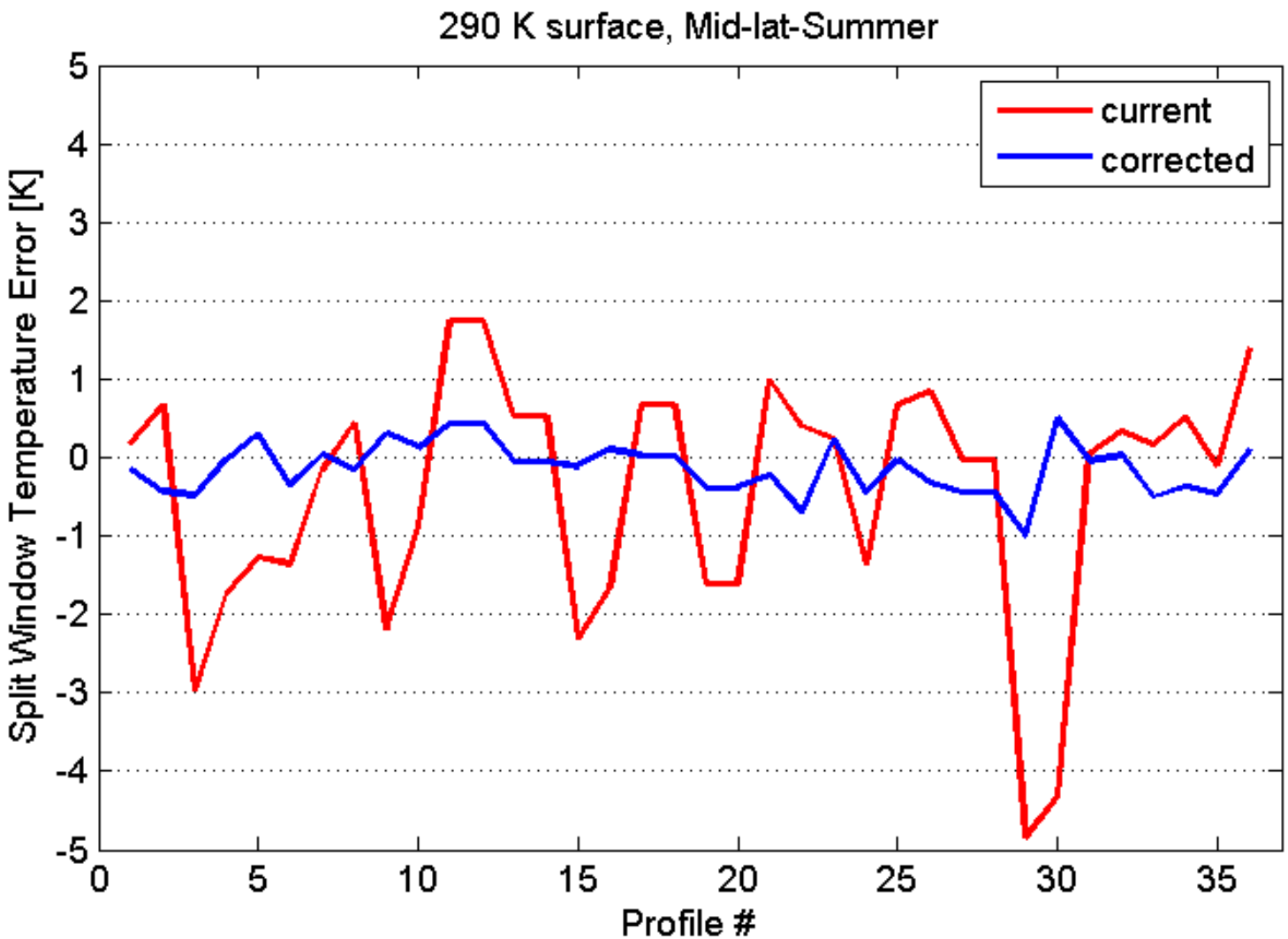
+ Current Product

o Stray Light Corrected

NOTE: TIRS has a 2% absolute radiometric uncertainty requirement for scene temperatures between 260 and 330 K and 4% otherwise

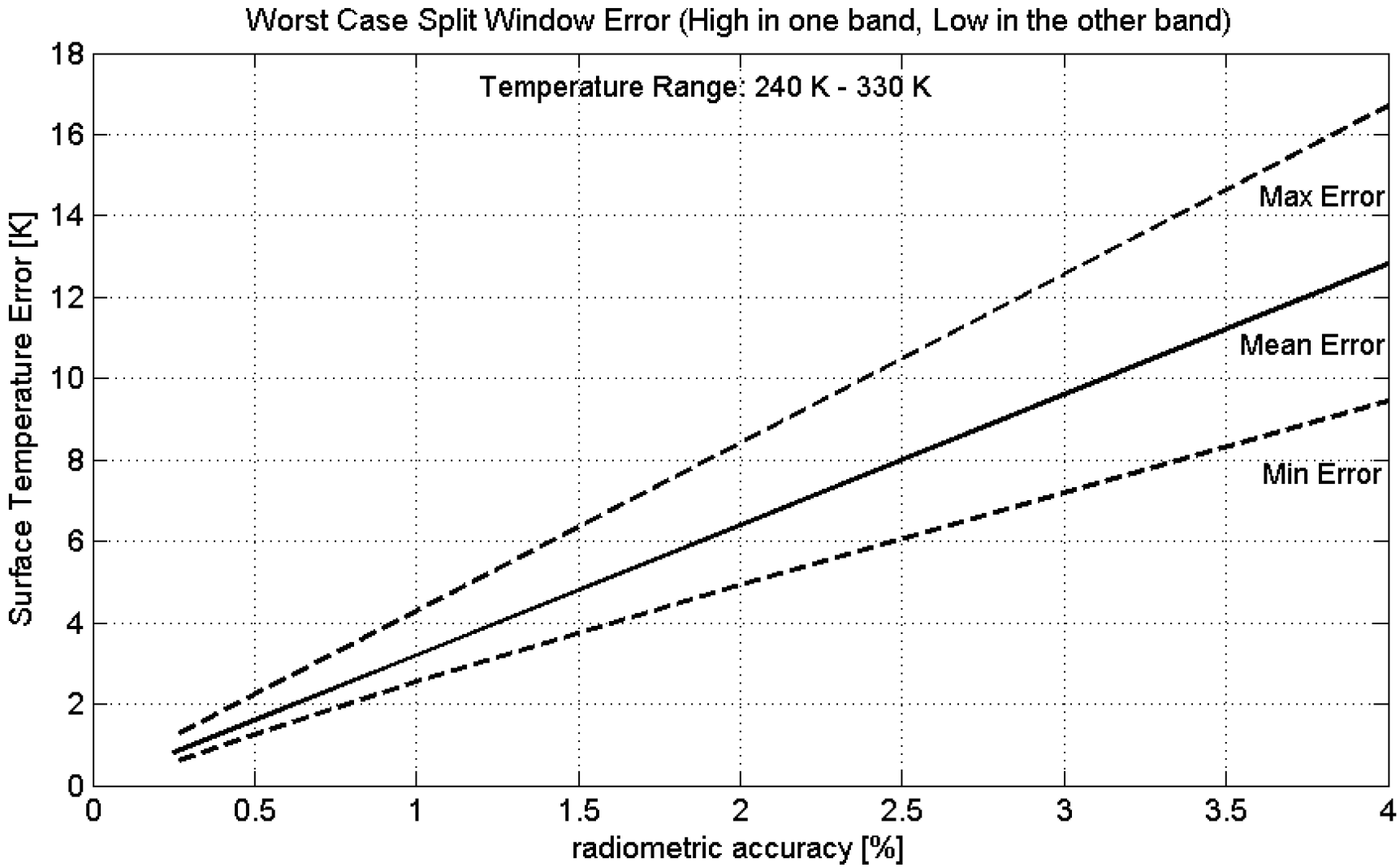
Ballpark split window surface temperature error over water for each profile

- Use residual RMS errors for each scene profile to estimate split window error (i.e.- add RMS error to both bands and determine error in surface temperature)



BACKUP

Ballpark worst case split window error



Becker & Li:
http://www.researchgate.net/publication/248976658_Becker_F_Li_Z._Towards_a_local_split_window_method_over_land_surfaces._International_Journal_of_Remote_Sensing