Landsat 8 Thermal Infrared Sensor (TIRS) Stray Light Correction Algorithm Development and Assessment

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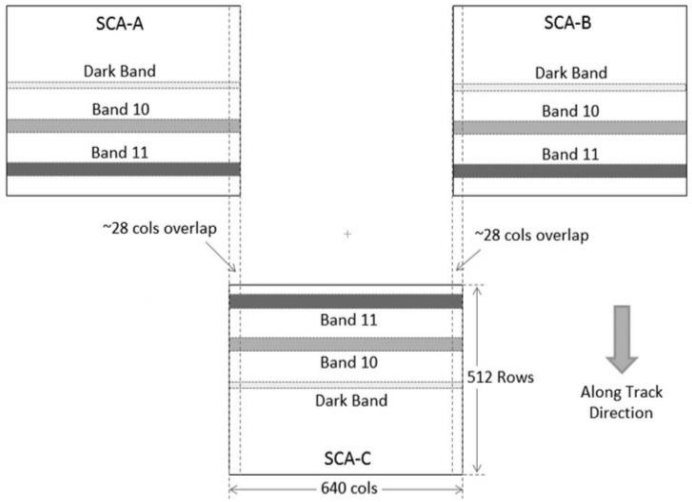
Image artifacts point to possible stray light issue

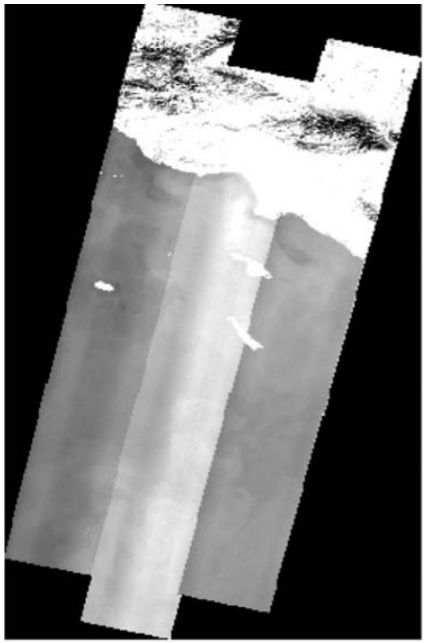
Landsat 8 Thermal Infrared Sensor (TIRS)

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

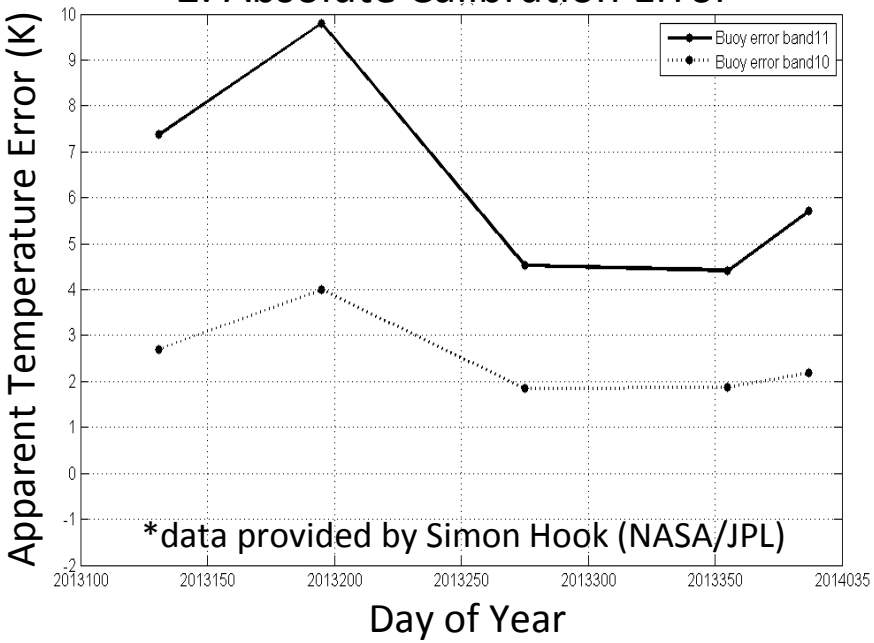


Two major artifacts:

1. Non-Uniform Banding

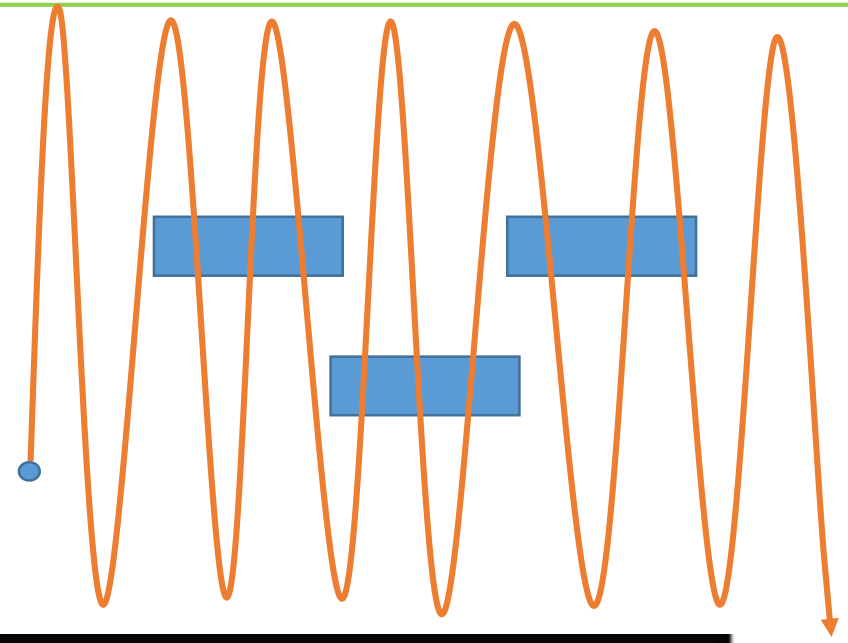


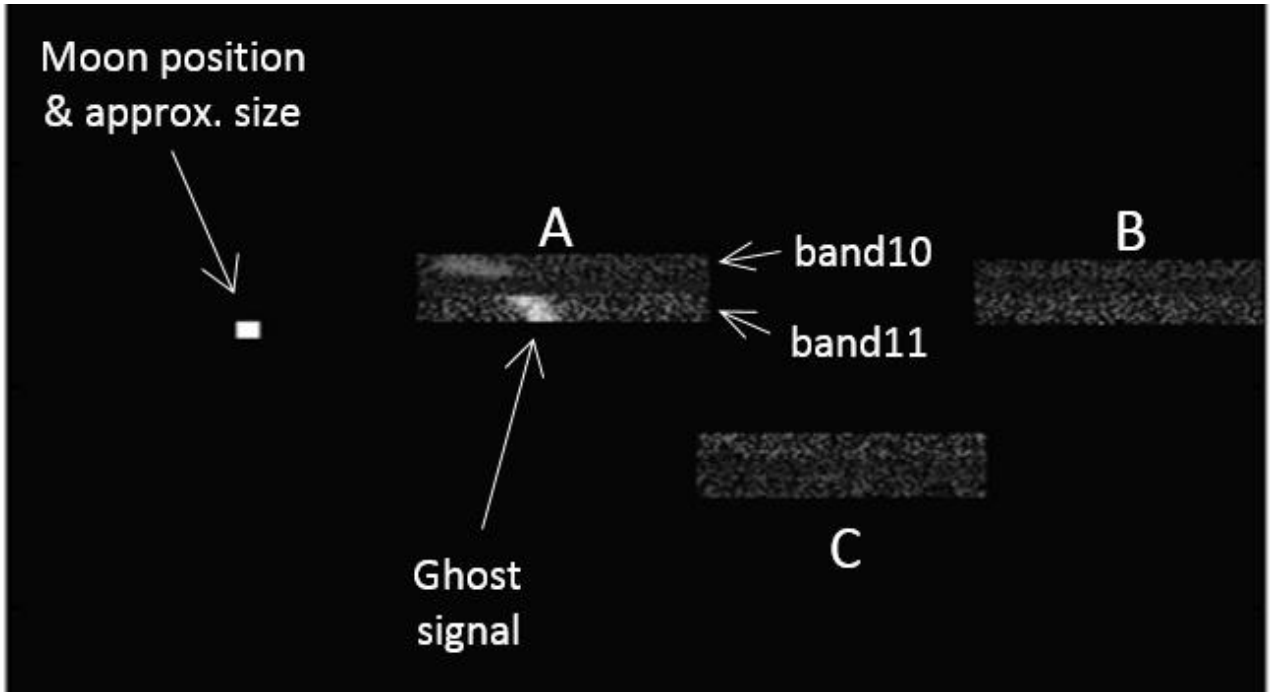
2. Absolute Calibration Error



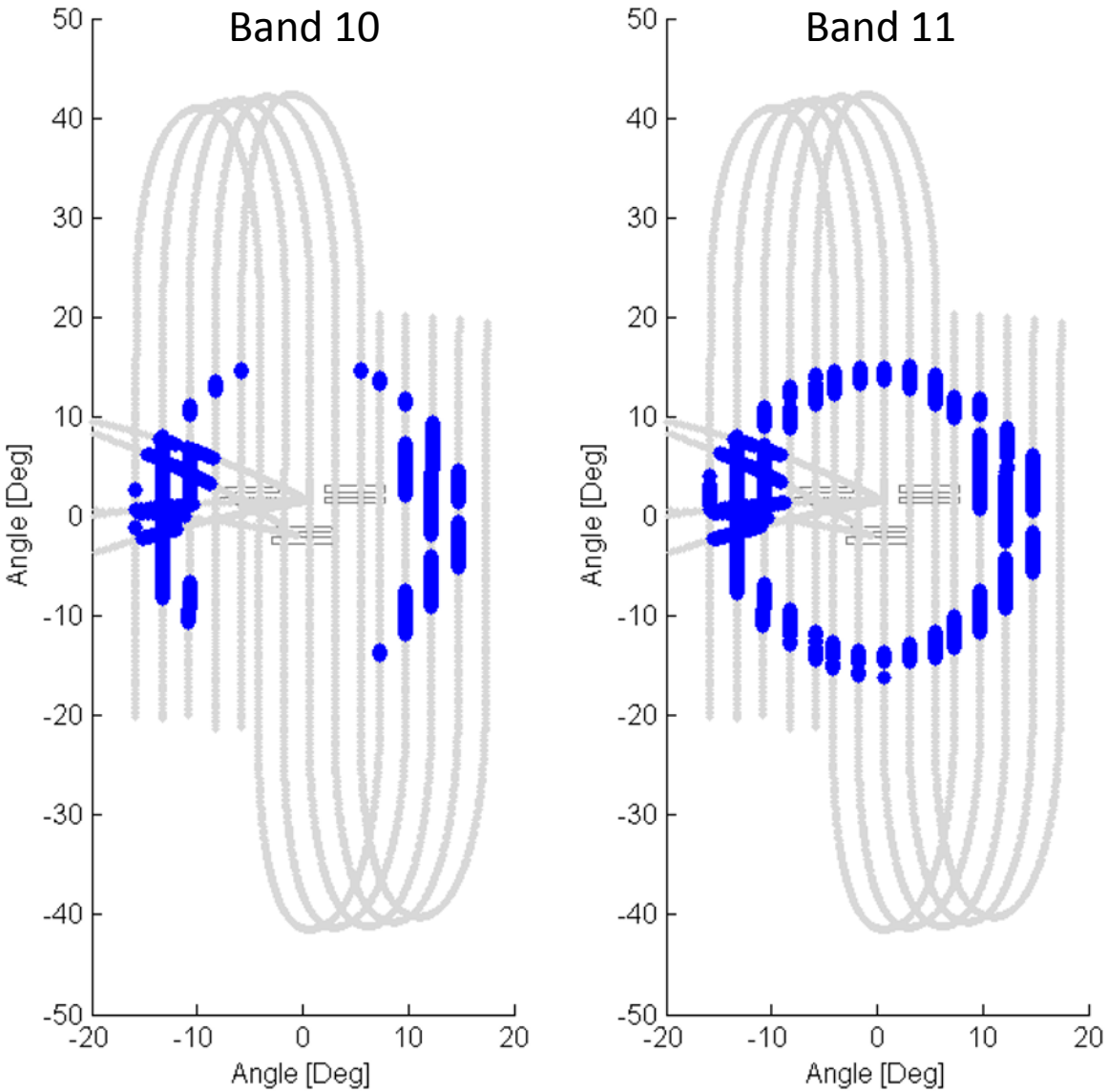
Lunar raster scan definitively showed stray light

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



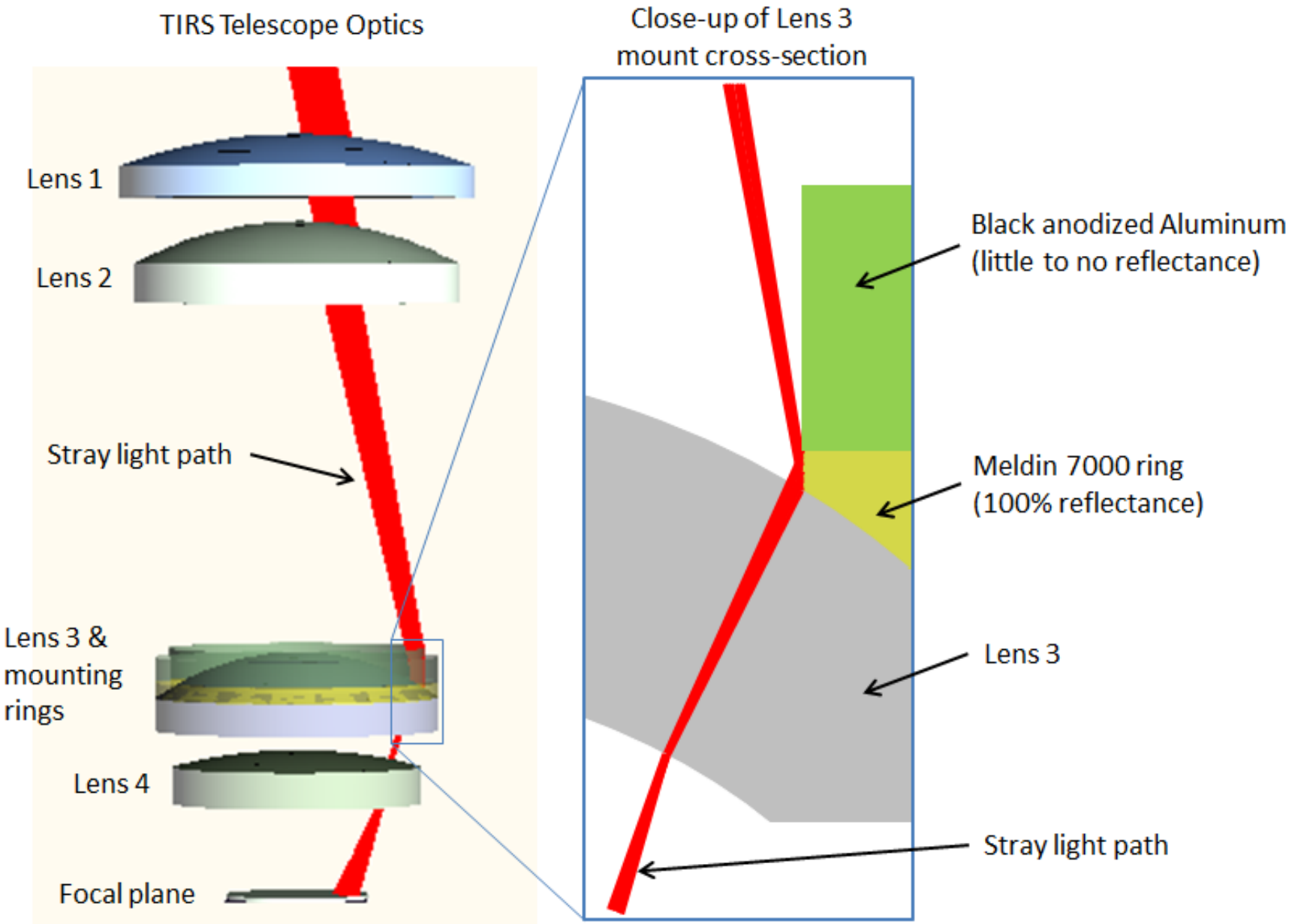


Map of stray light locations from lunar positions



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

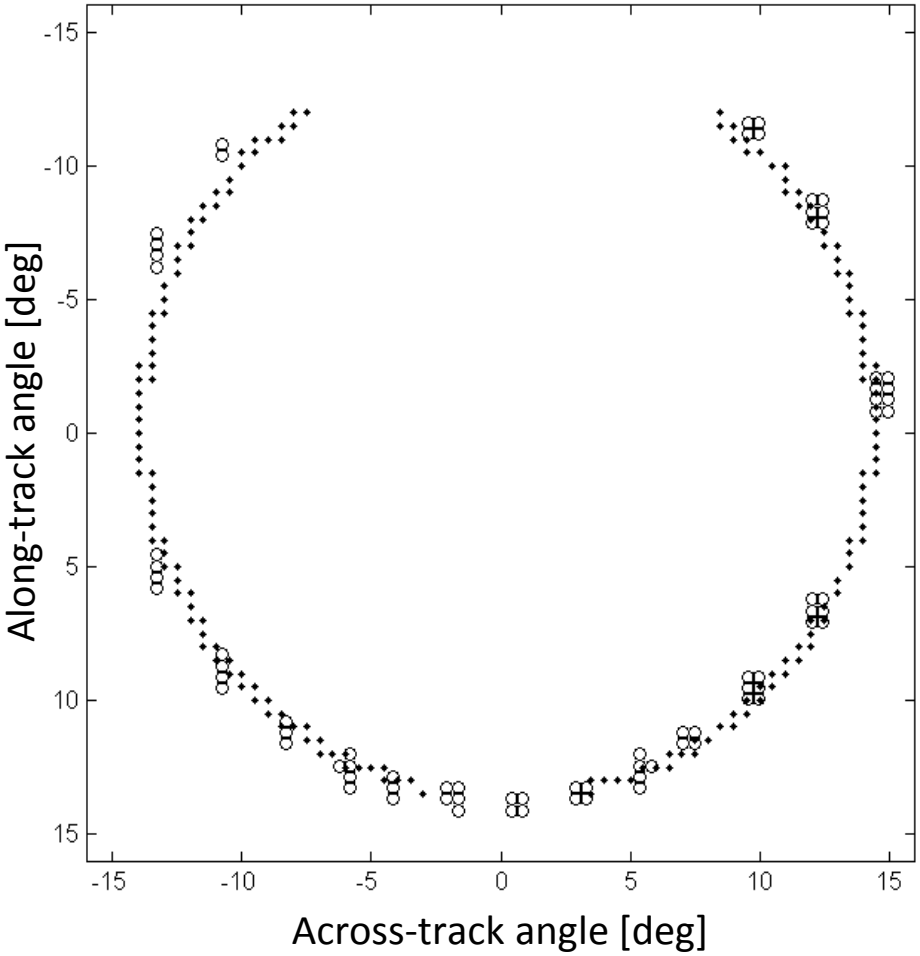
Lunar data used to inform optical stray light model



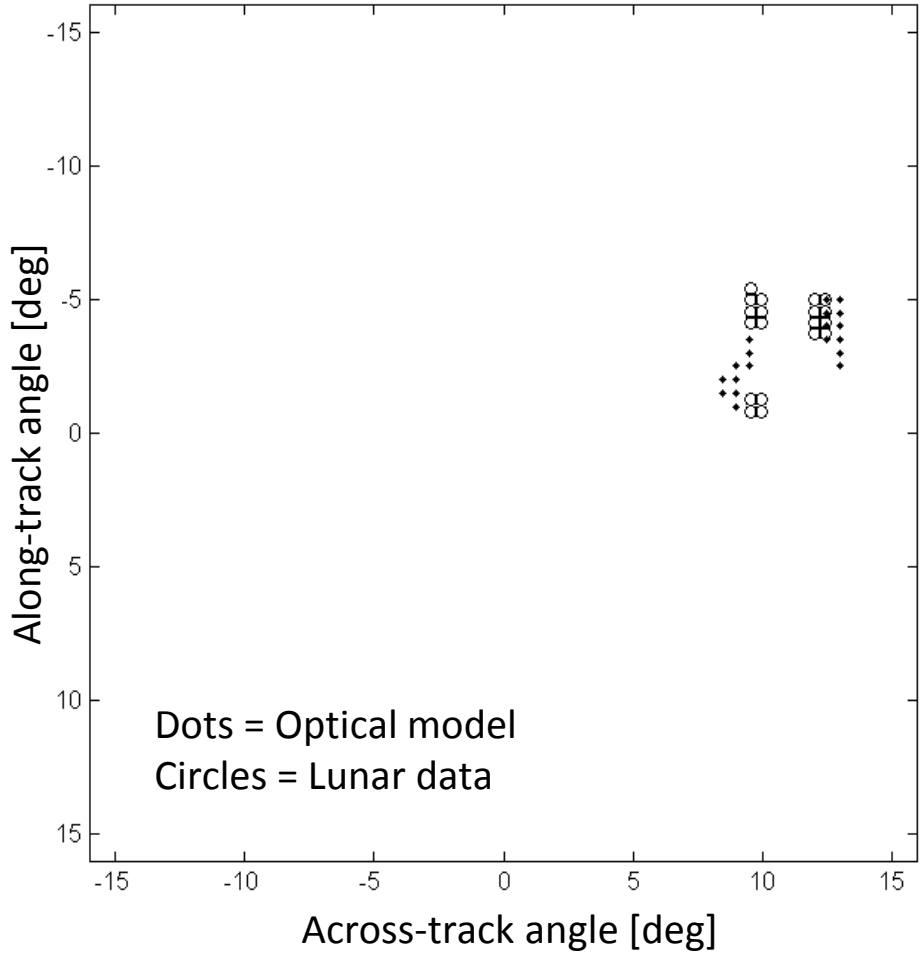
* Scott Rohrbach & Eric Mentzell (NASA/GSFC)

Reverse ray trace produces stray light map for each detector

Stray light map for one detector on array -C

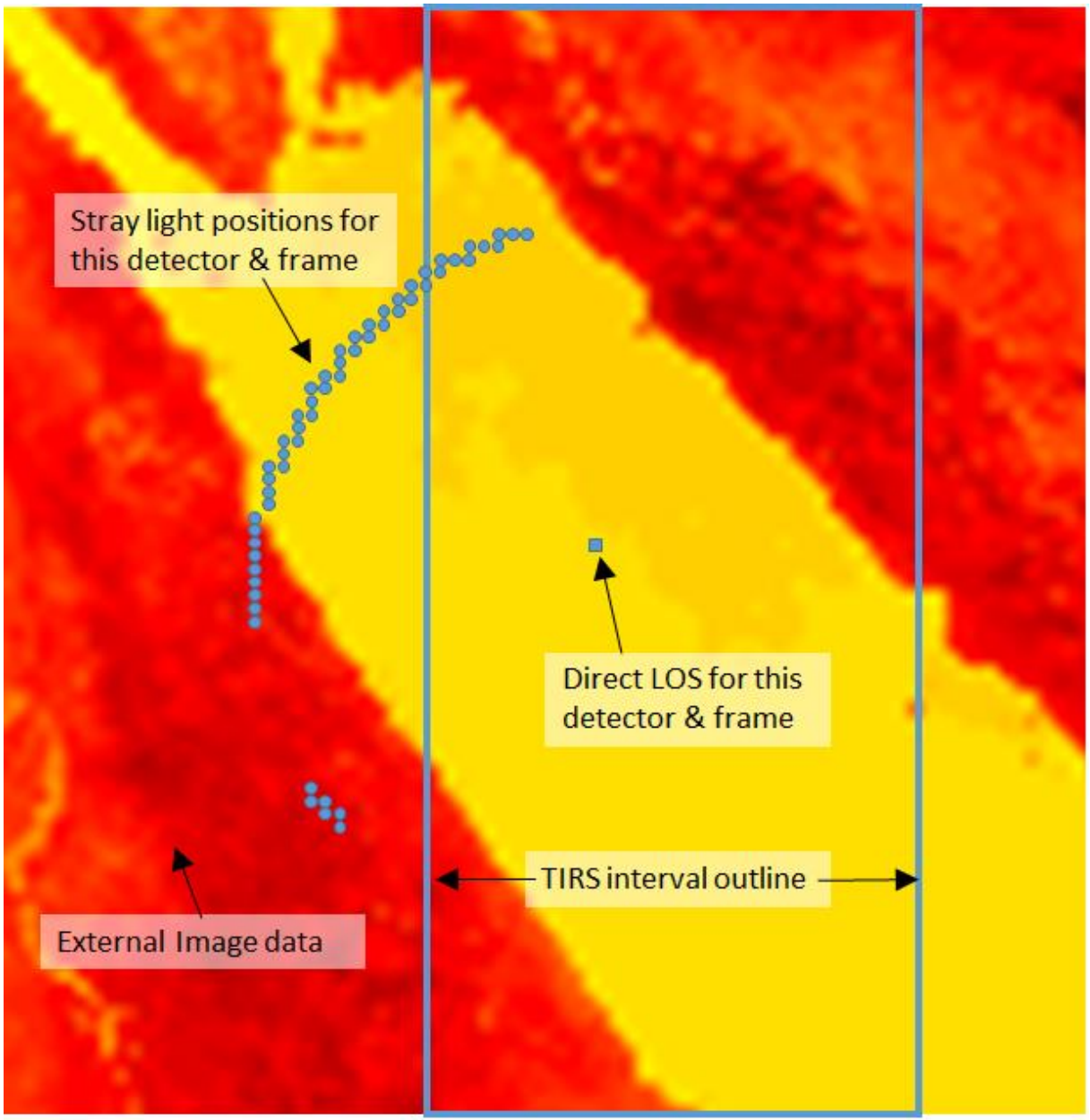


Stray light map for one detector on array -B



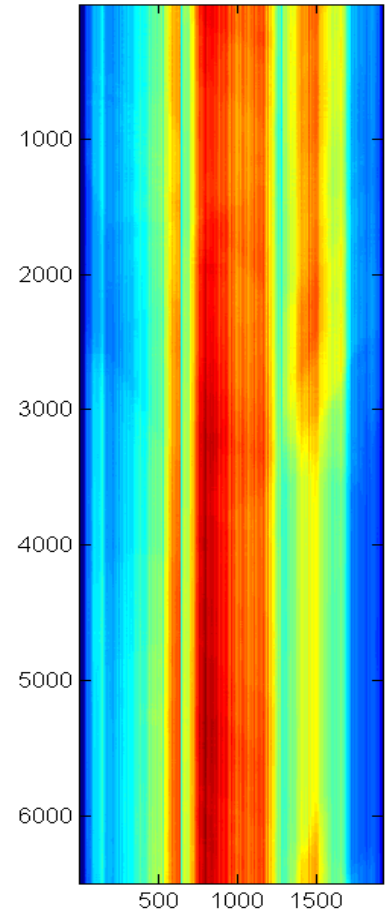
* Unique map for each detector (i.e.- different stray light signal for every detector)

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

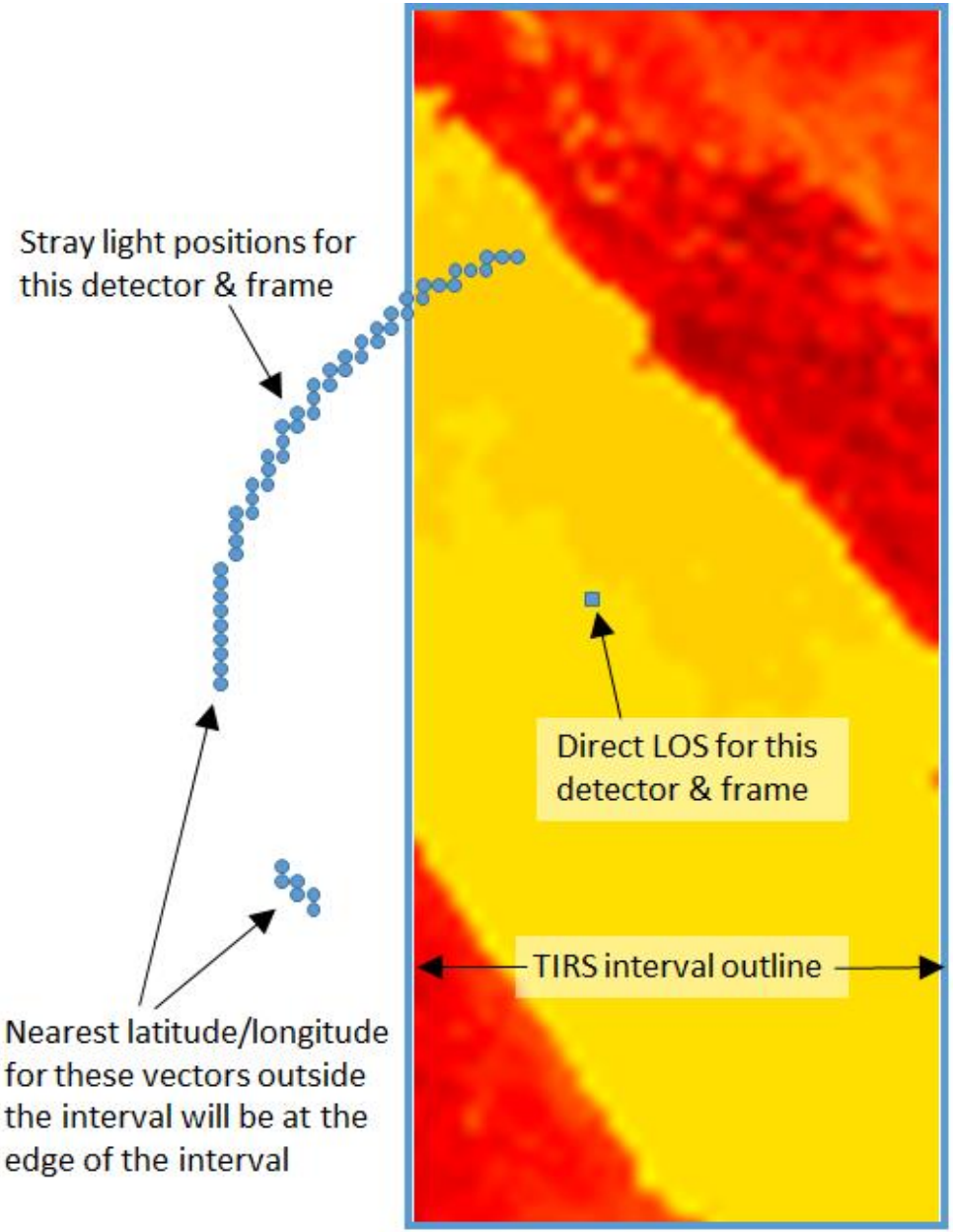


$$StrayLight = a \cdot (Ext.Sampled) + b$$
$$= a \cdot \left(\sum L_{ext_i} \cdot w_i\right) + b$$

Calculated signal to remove from TIRS interval



Stray light removal algorithm: Optical model with TIRS data only



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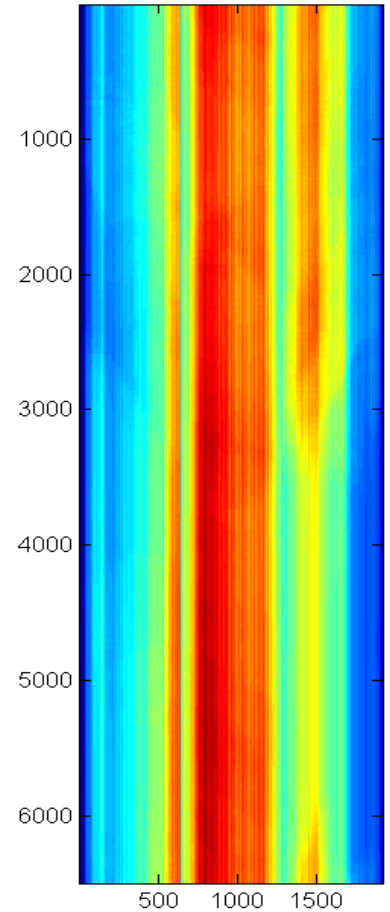
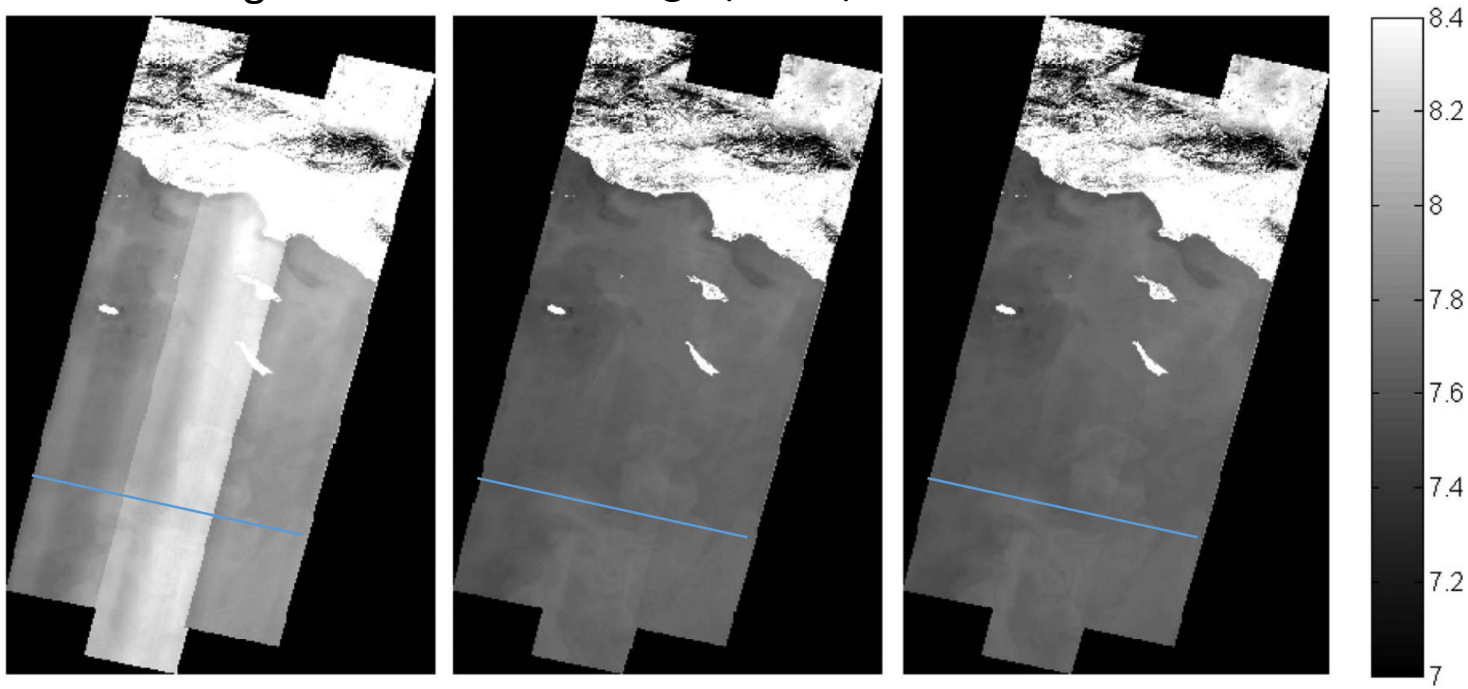
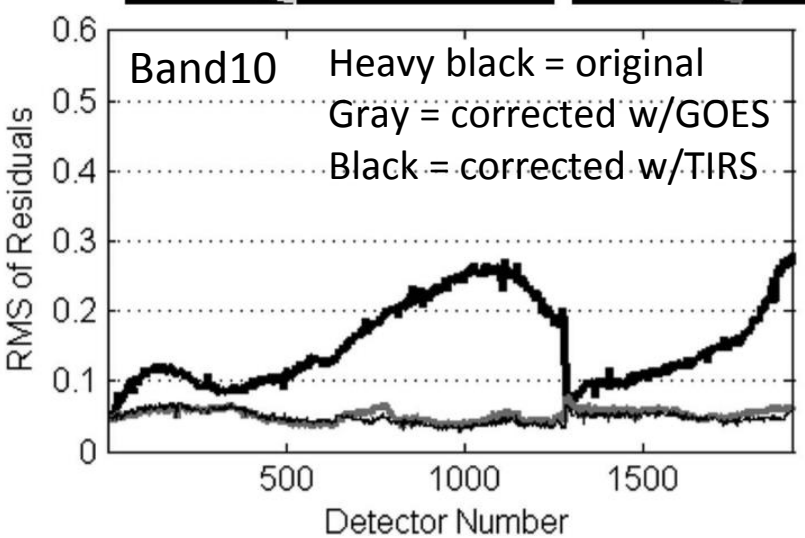
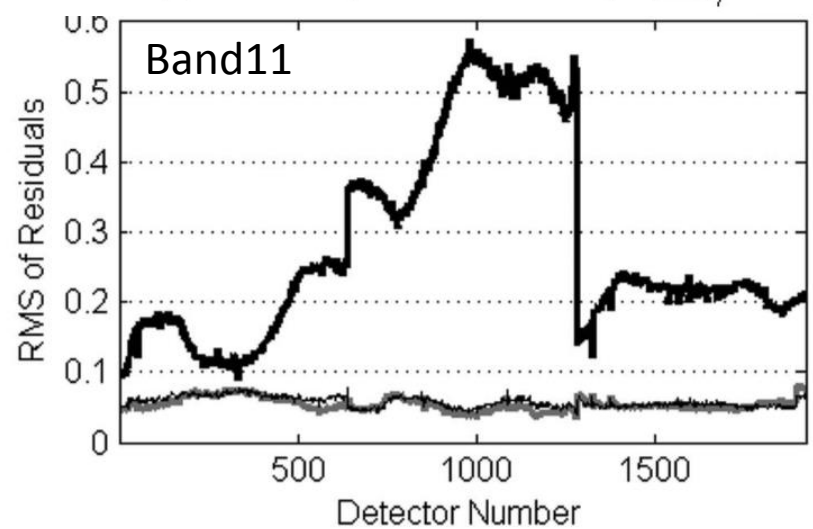


Stray light correction with and without out-of-field knowledge

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







More Background on Stray Light Investigation & Correction Algorithm

Summary:

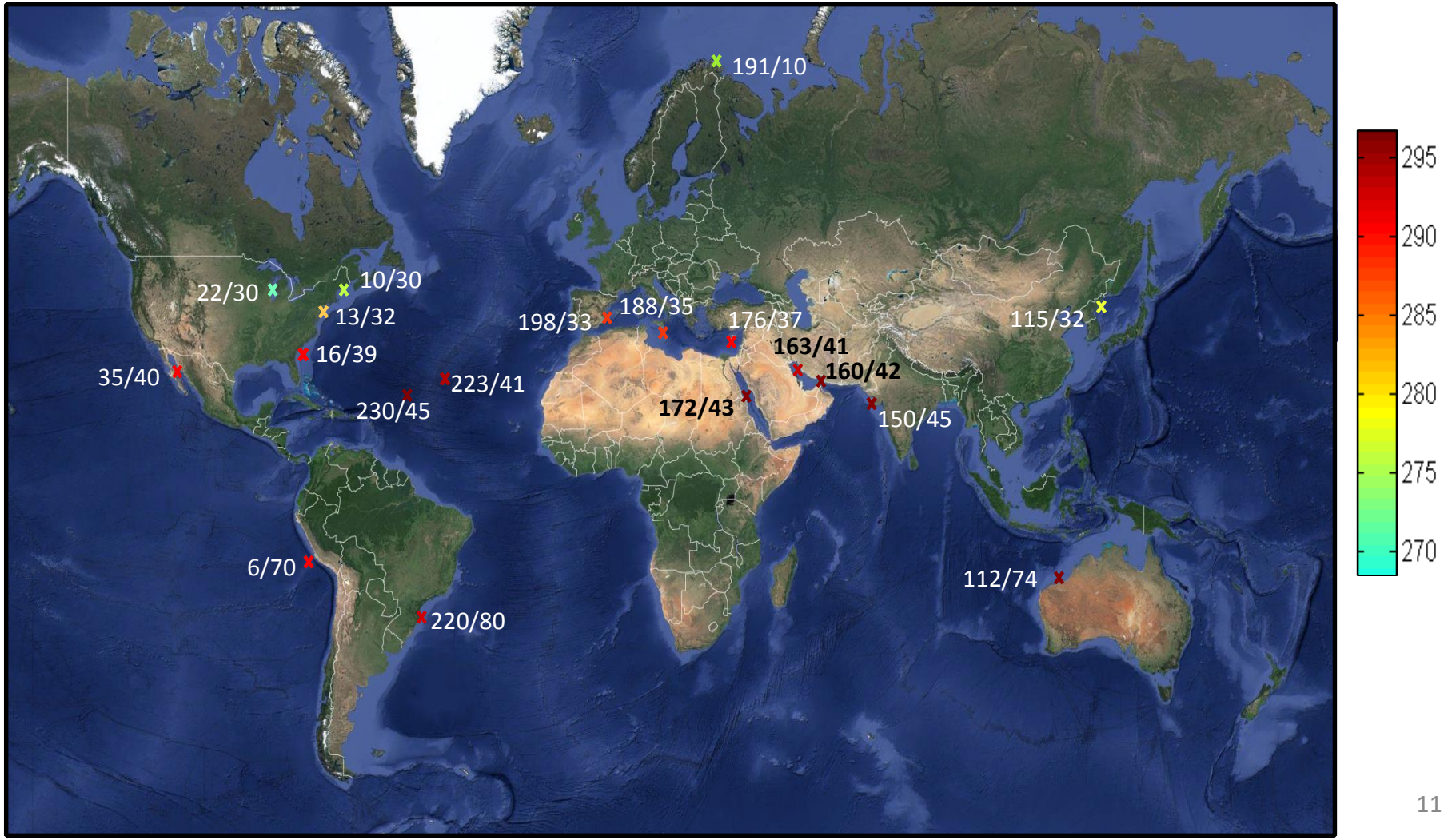
- Algorithm uses only TIRS interval data (no other sensor data) with optical model
- Implemented at EROS in off-line test machine
  - able to generate standard TIRS L1 products
- Able to be run in “real time” (i.e.- no significant processing lag) to produce corrected TIRS scenes

More information:

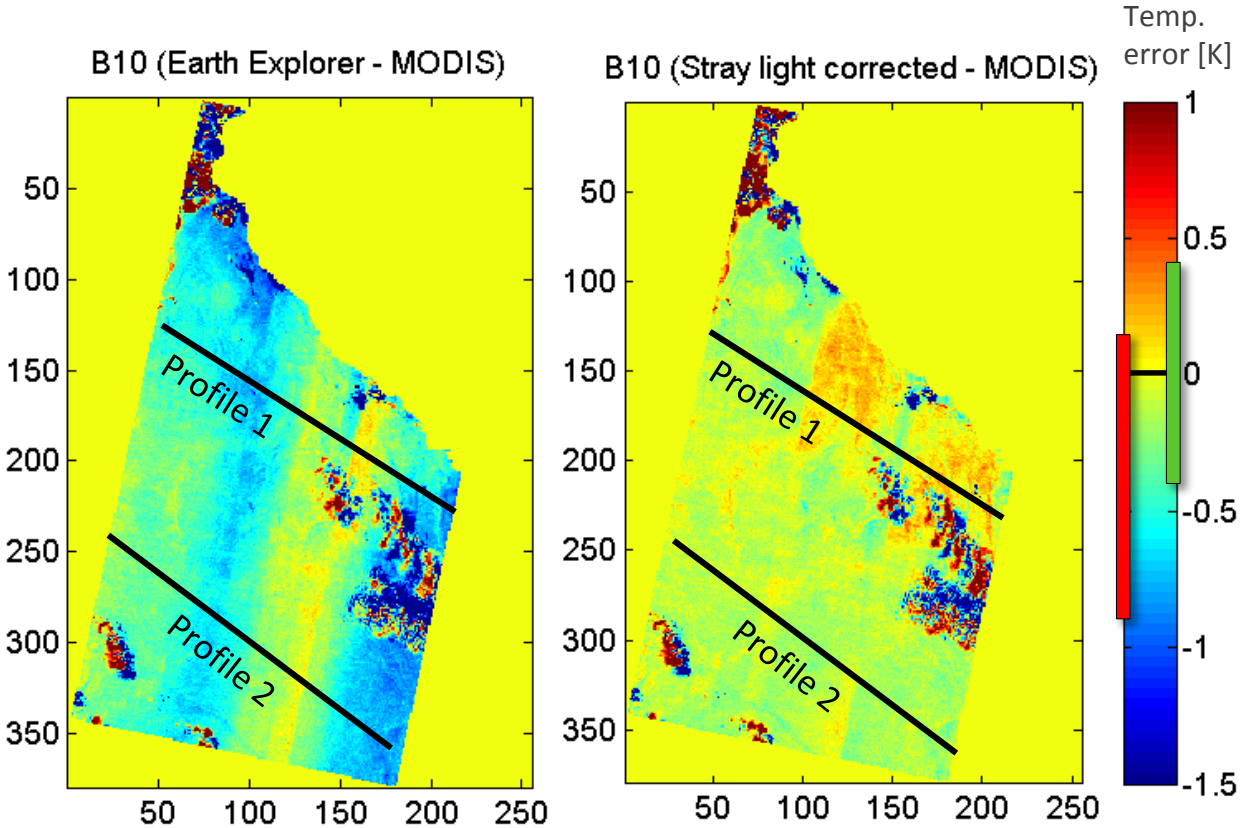
- Montanaro, M., Gerace, A., Lunsford, A., & Reuter, D. "Stray light artifacts in imagery from the Landsat 8 Thermal Infrared Sensor." *Remote Sensing*, 6, 10435-10456 (2014). [doi:10.3390/rs61110435]
- Montanaro, M., Gerace, A., & Rohrbach, S. "Toward an operational stray light correction for the Landsat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

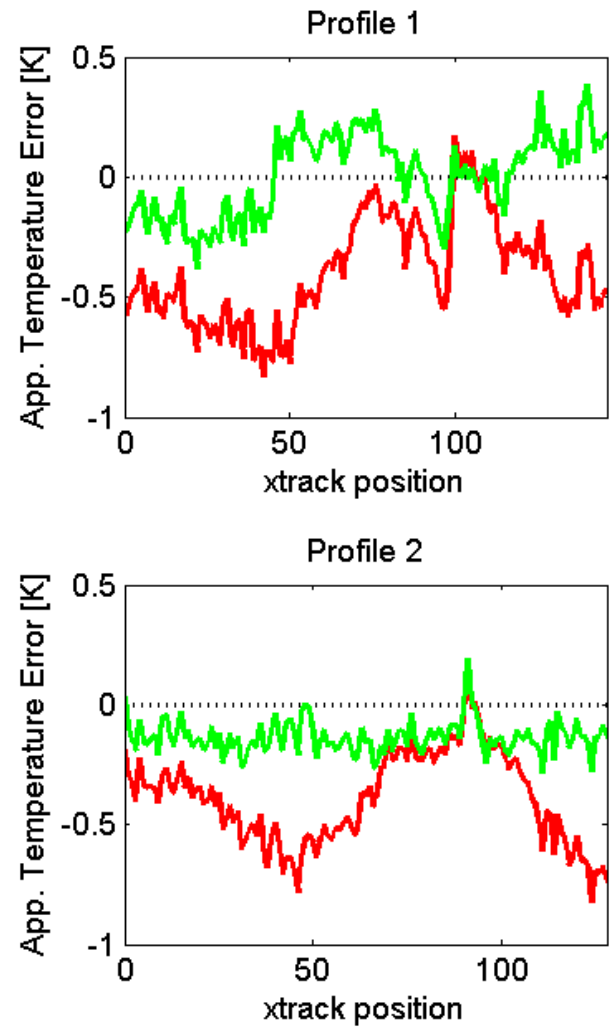
Full Scene Correction Demonstration – Validation Challenges

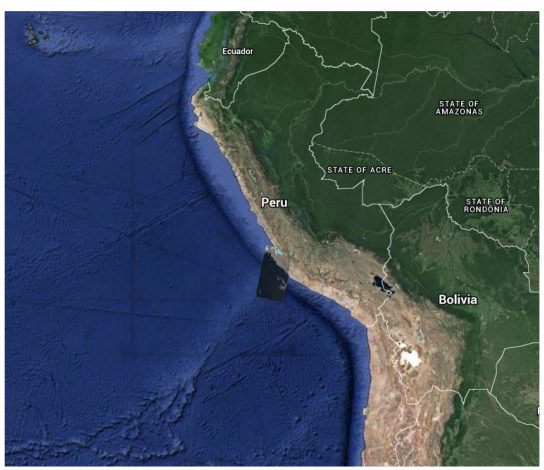
- During L8/Terra underfly period, TIRS centered on MODIS field-of-view
- Compare TIRS current product and corrected product to Terra/MODIS
- Recall current product (EarthExplorer) has a flat bias subtracted to make absolute cal error for N. hemisphere growing season scenes approximately zero.



Path 006, Row 070: Band 10

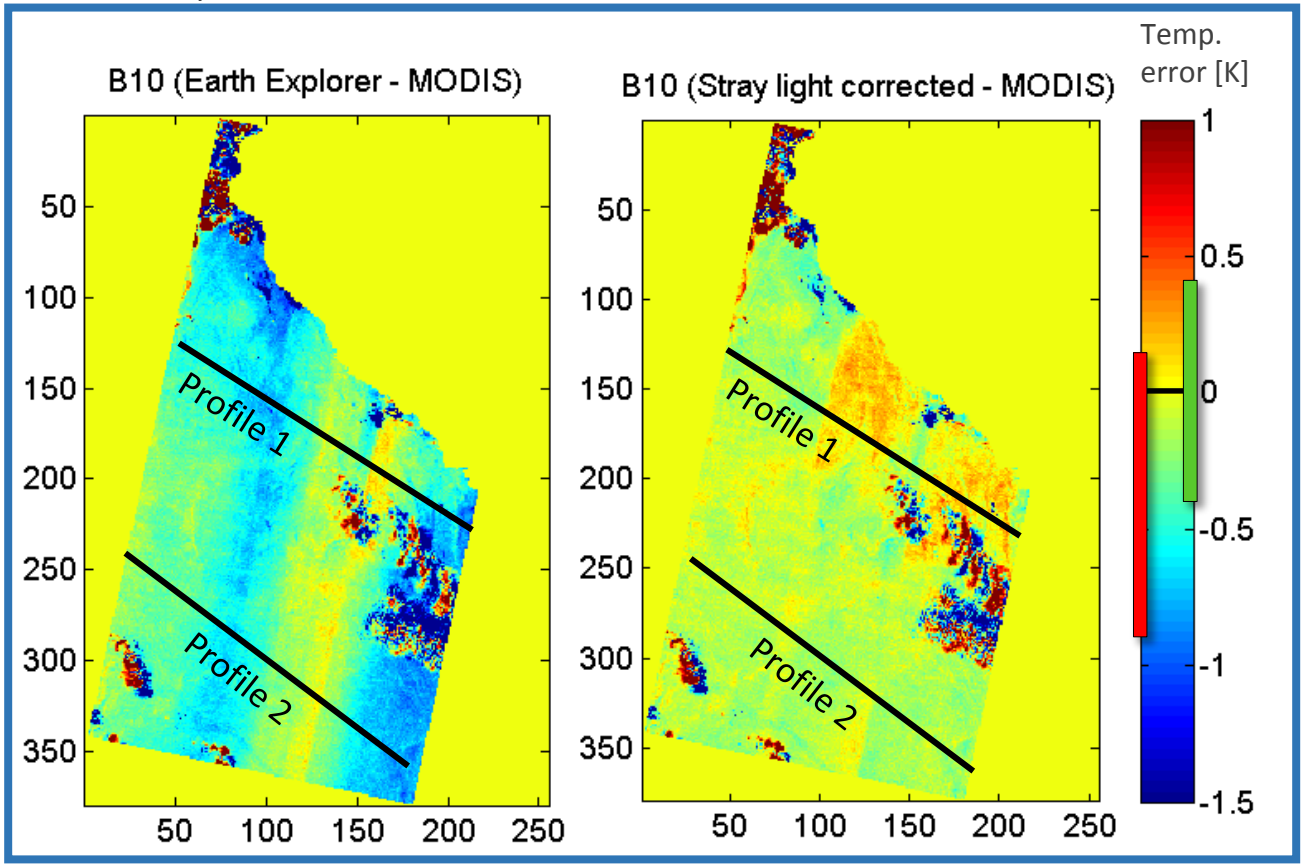


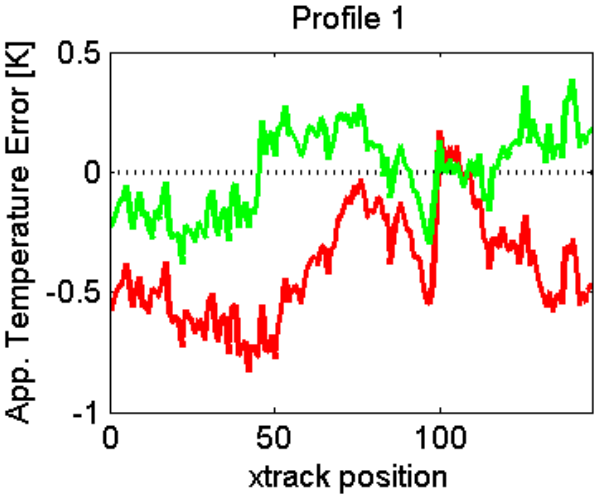


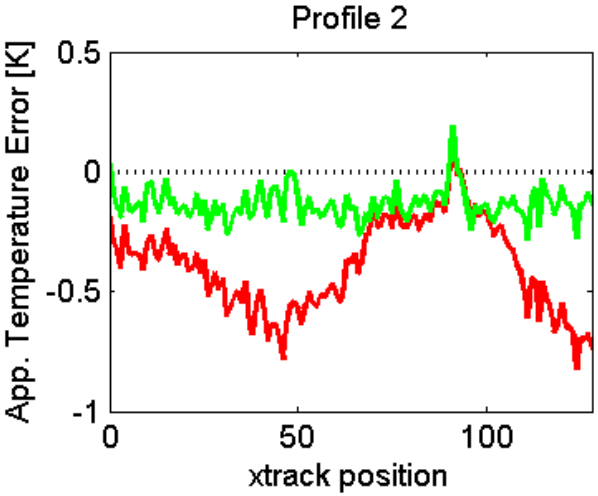


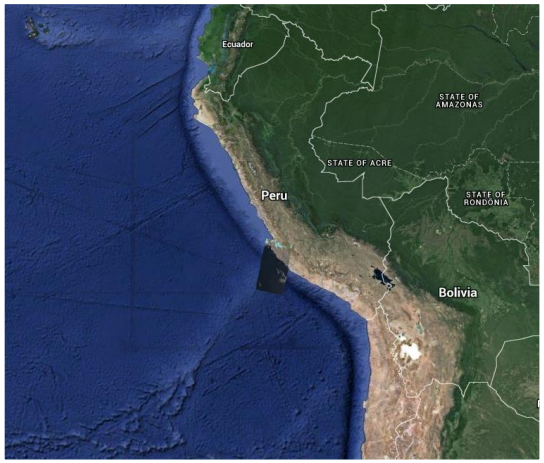
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.221	0.172	0.458	0.172	-0.401	0.003
Profile 2	0.193	0.068	0.439	0.153	-0.394	-0.137

Path 006, Row 070: Band 10









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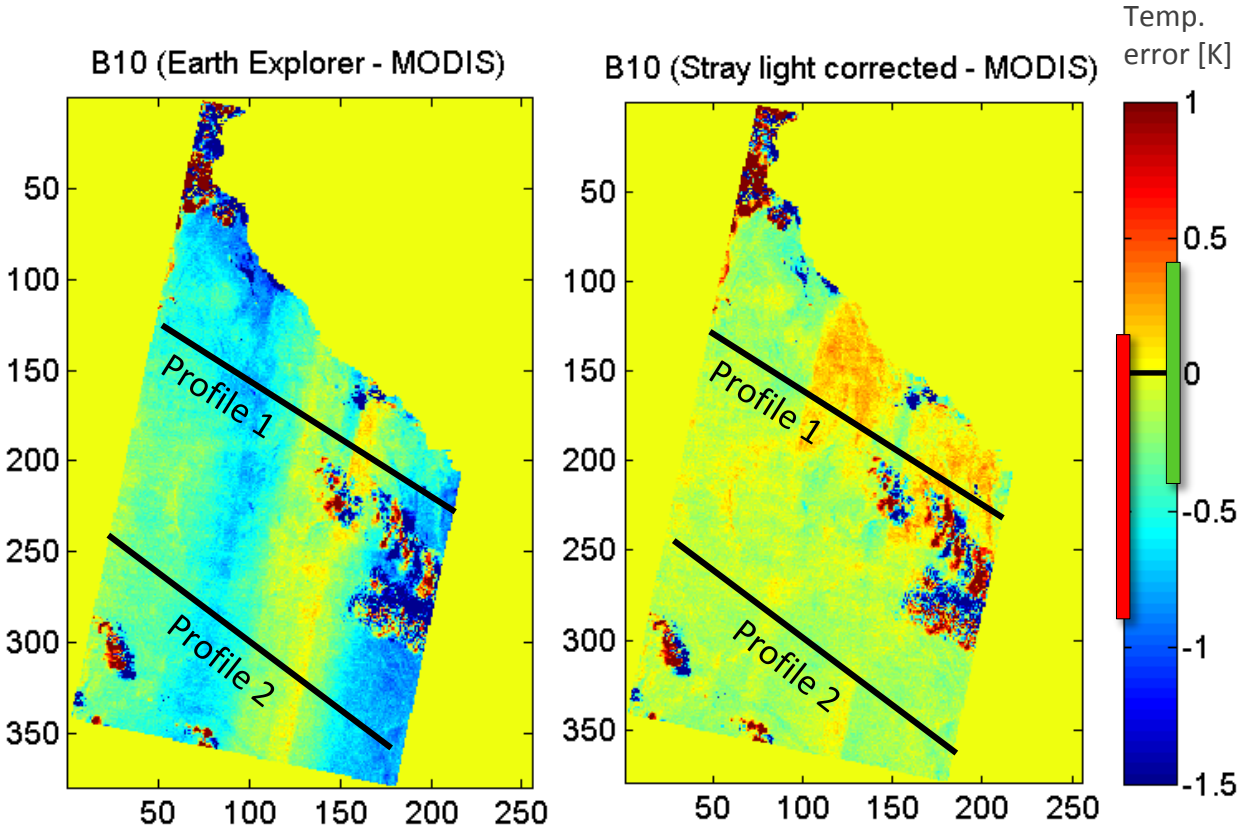

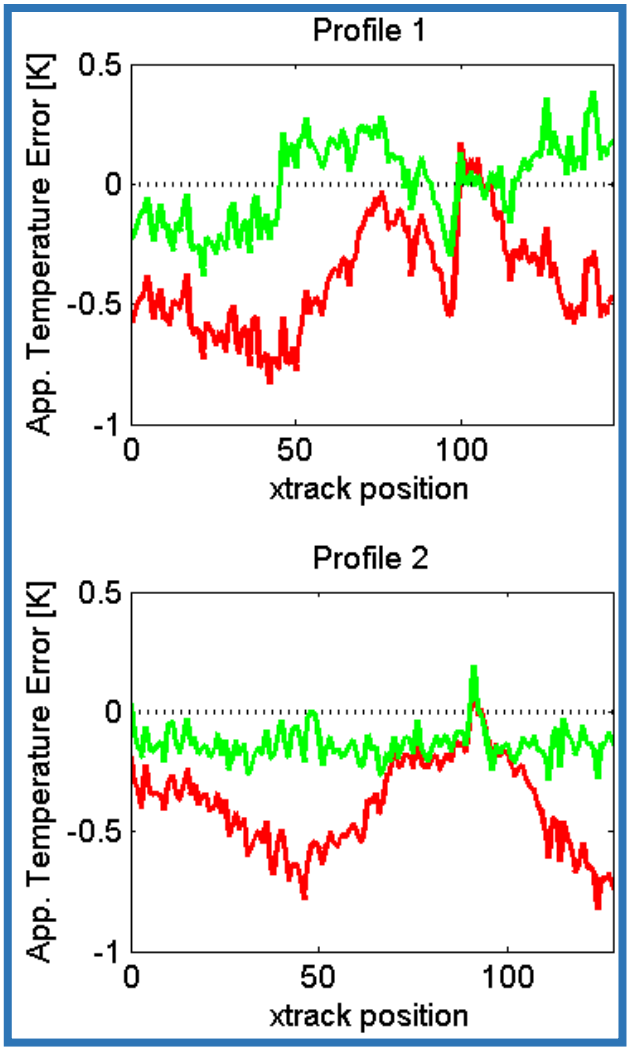

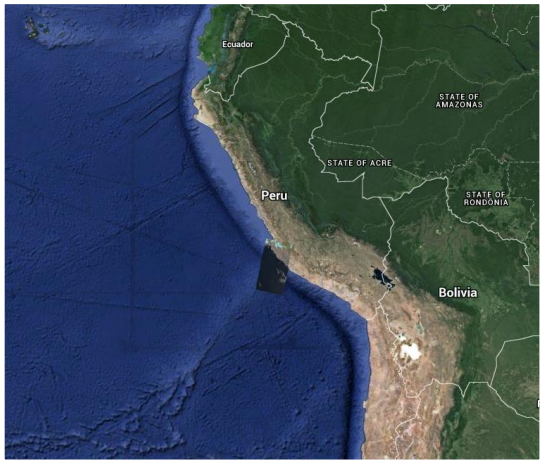

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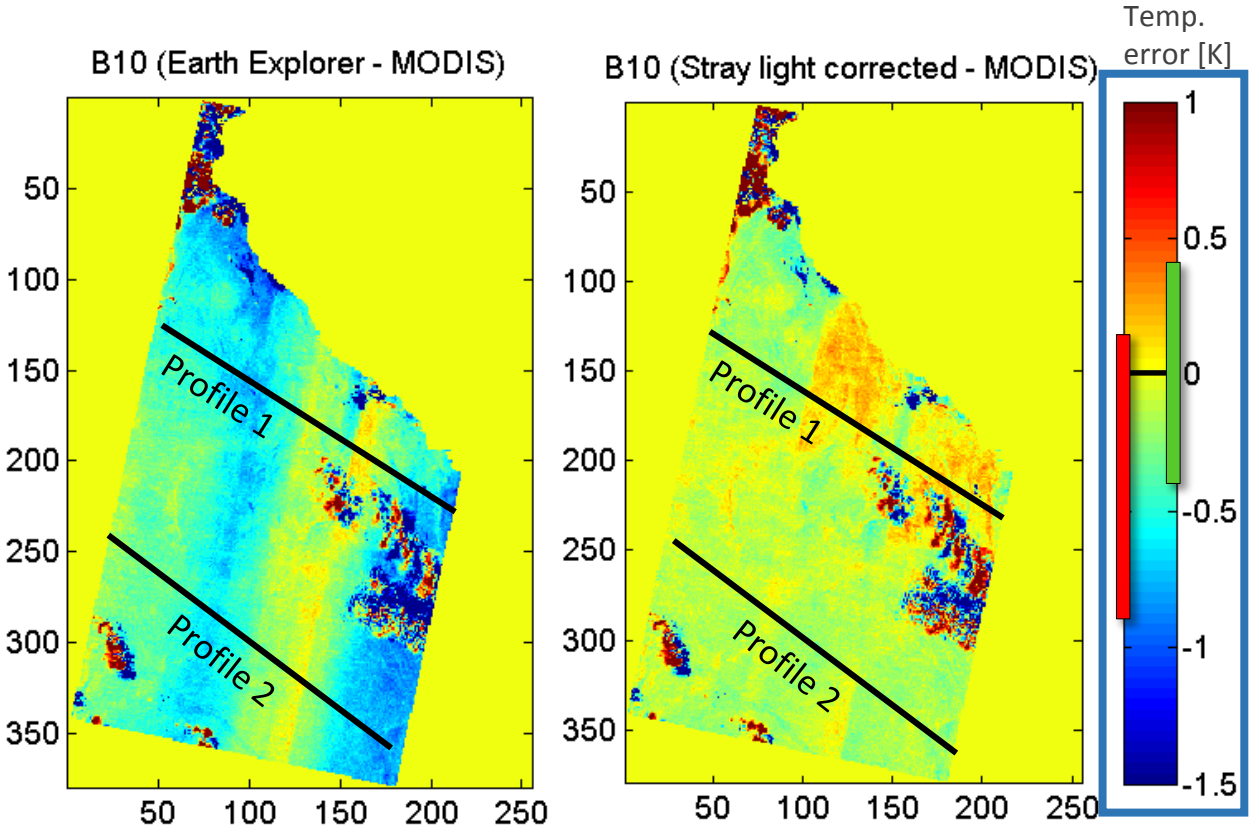

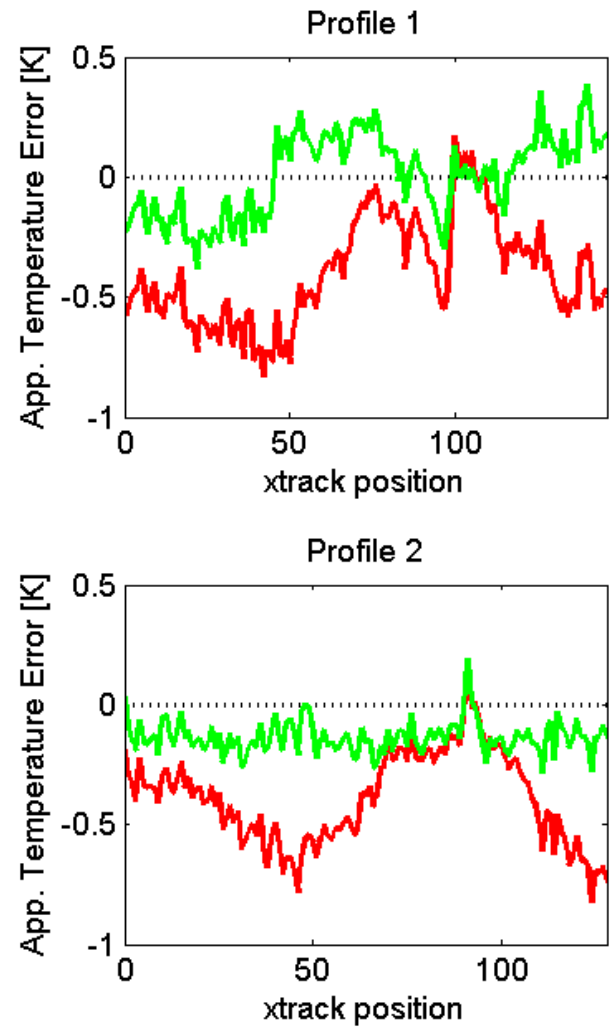

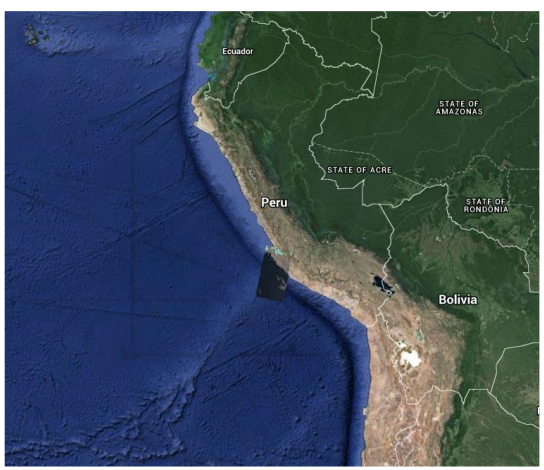

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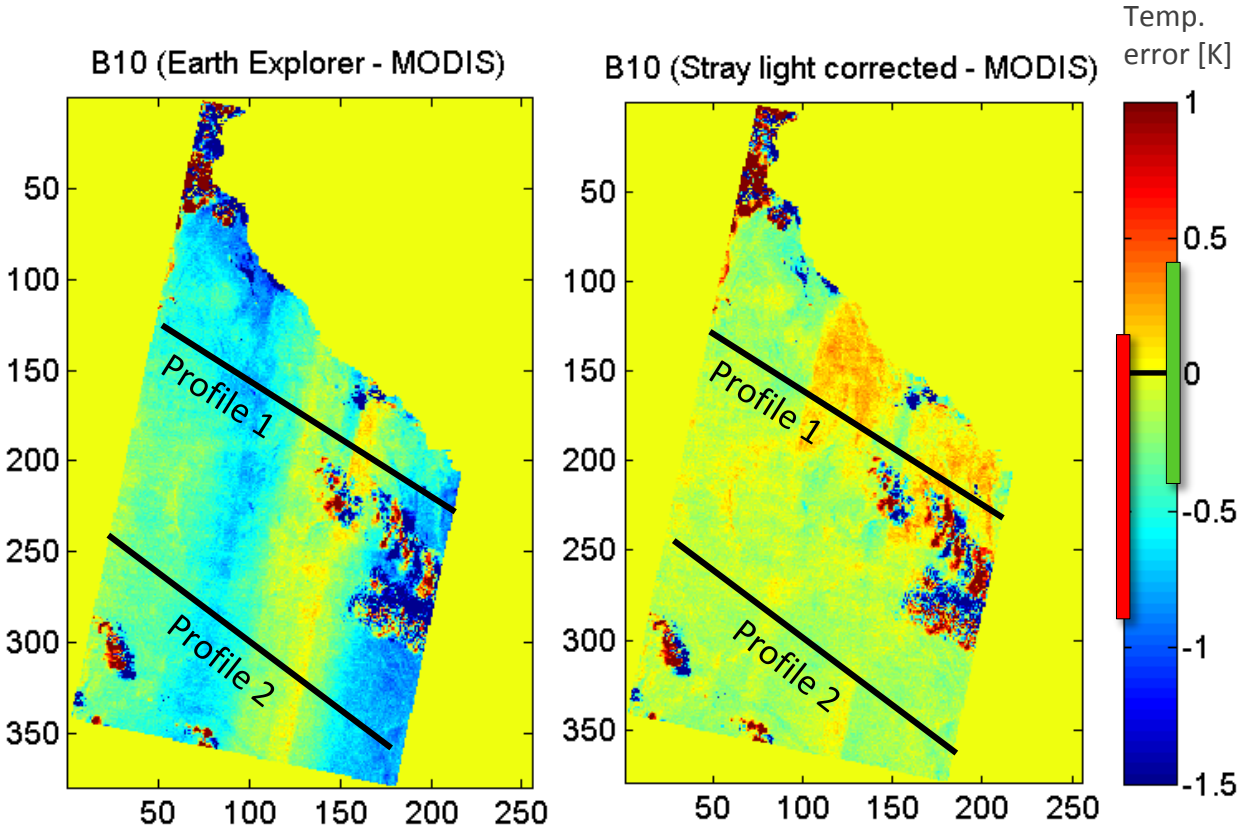

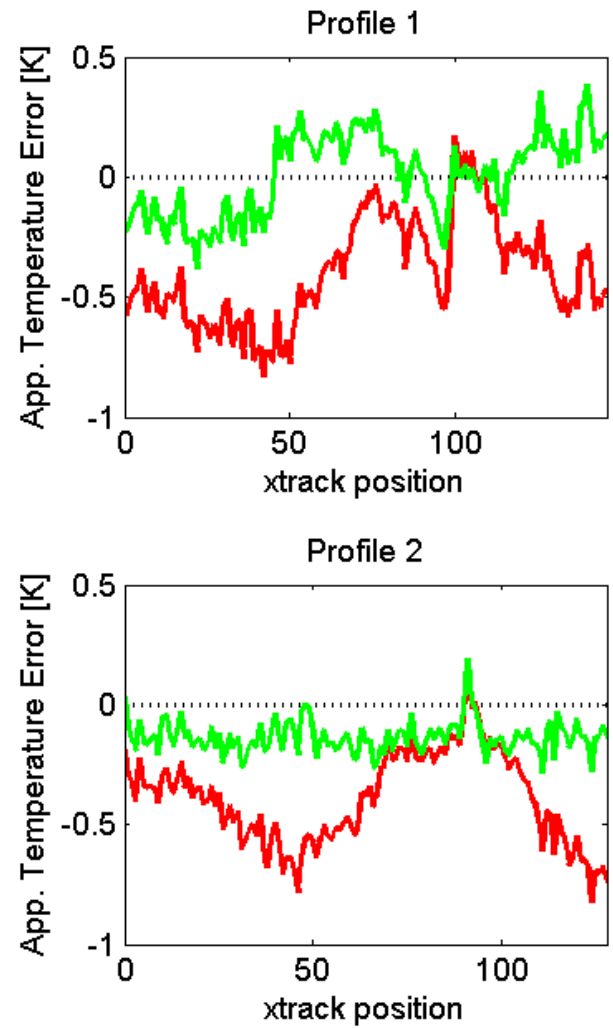

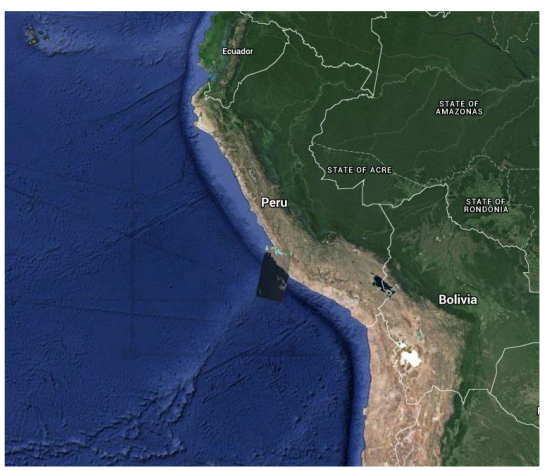

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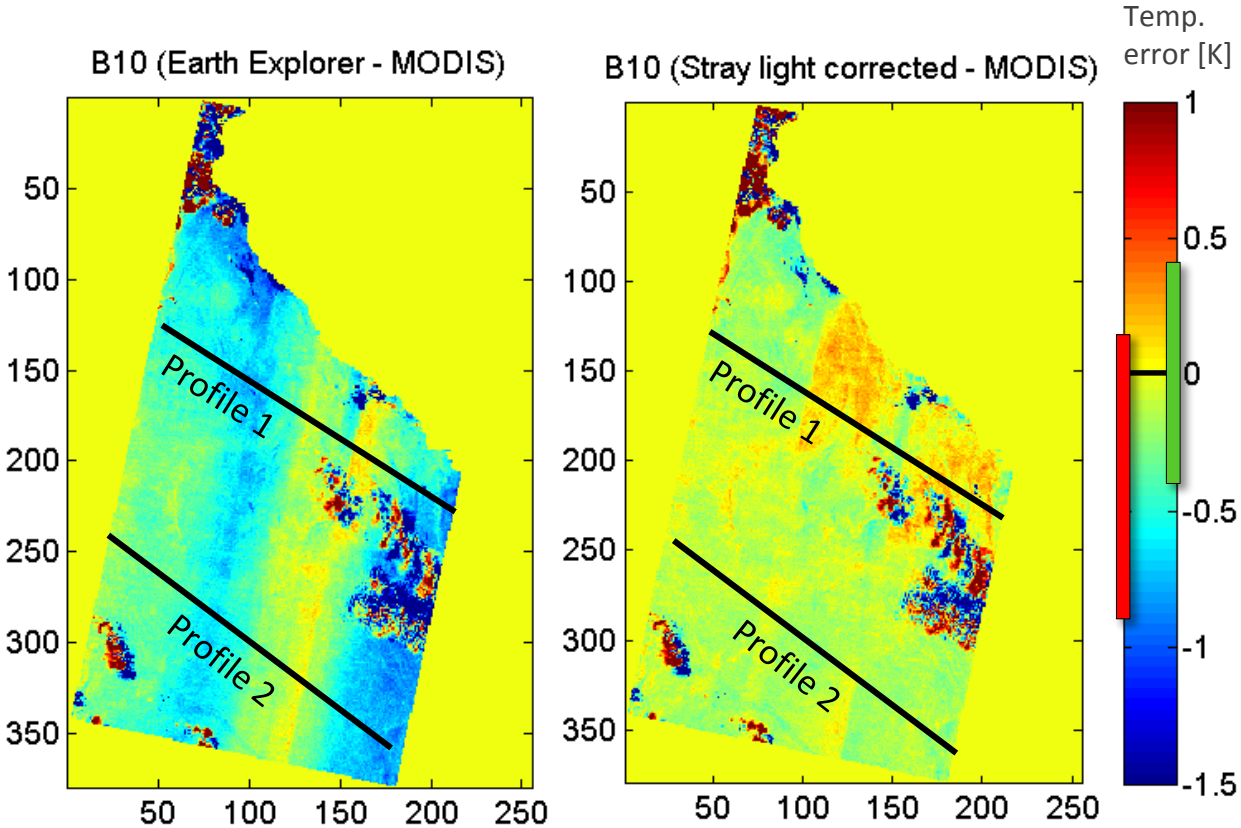

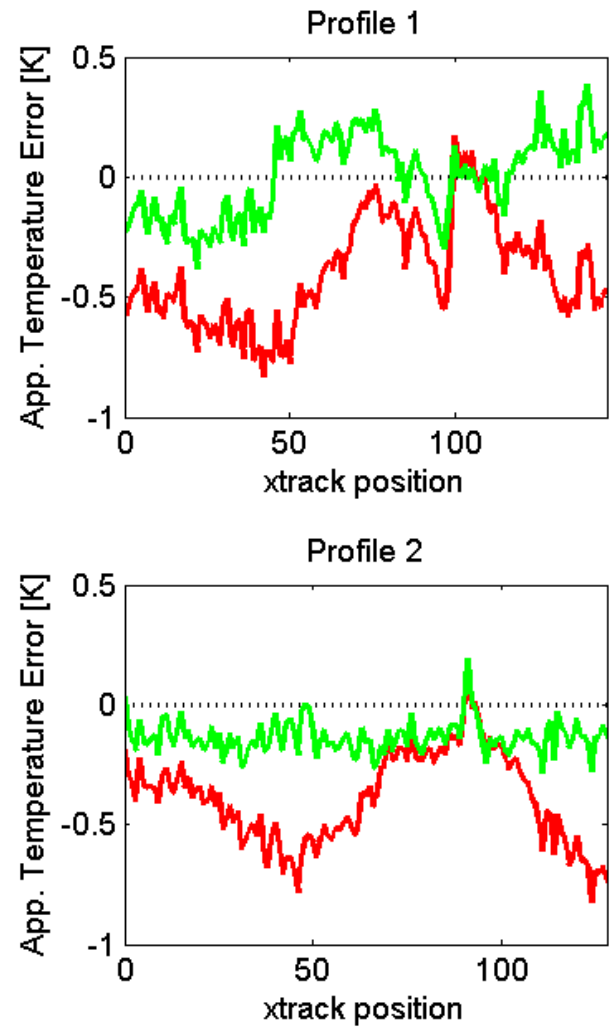

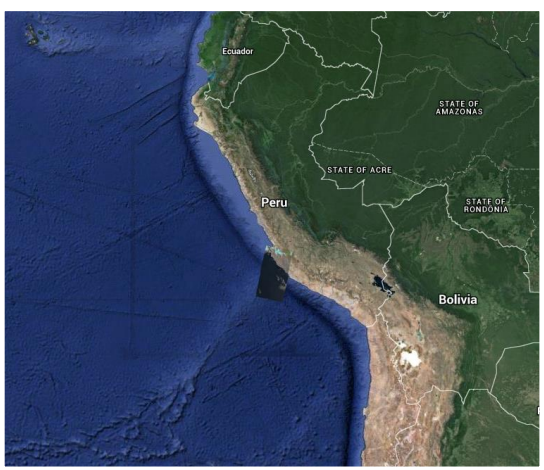

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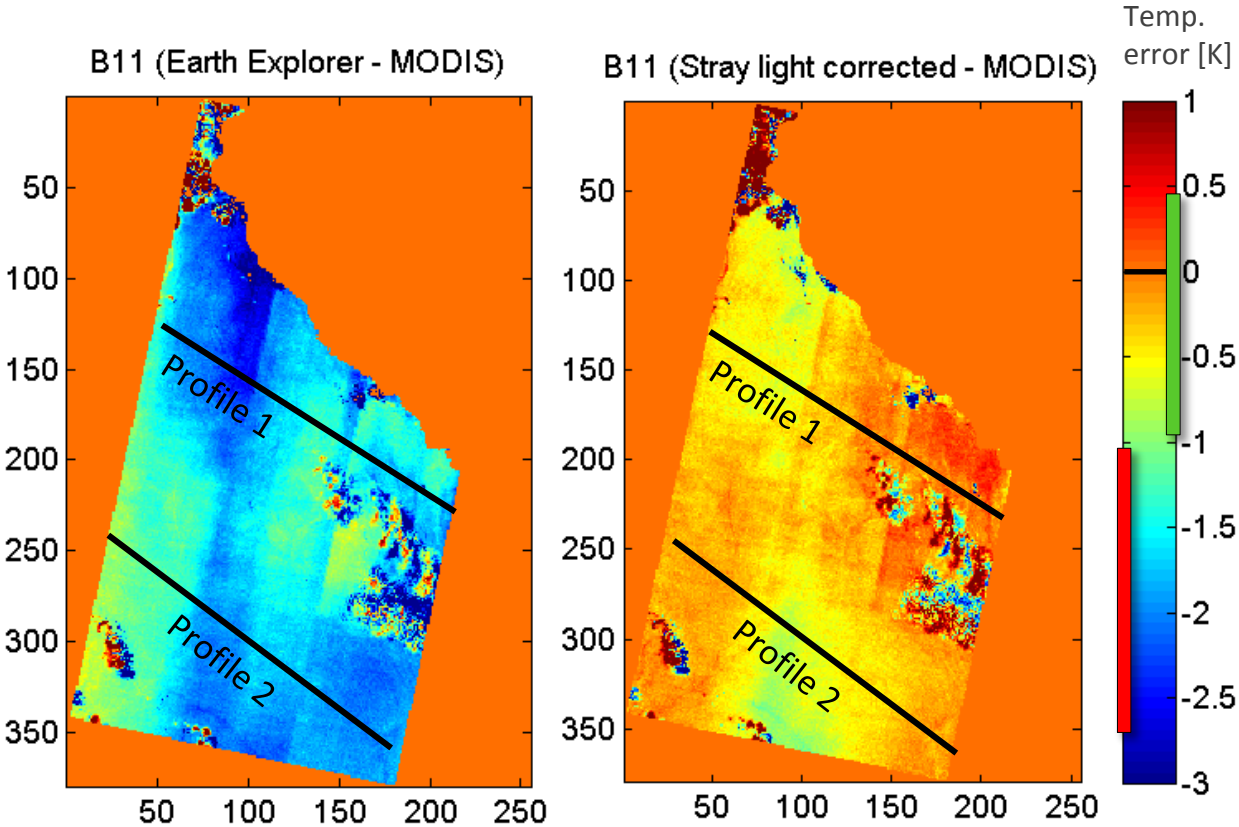
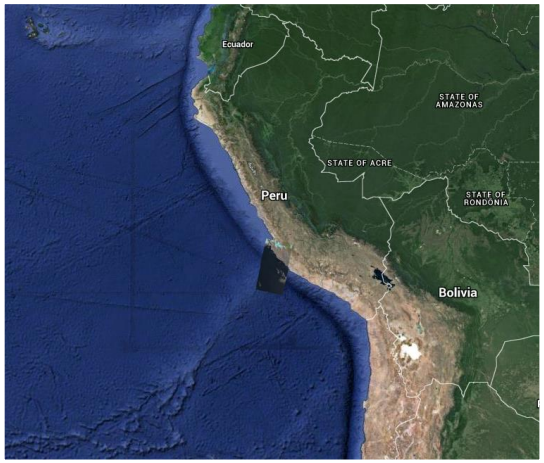
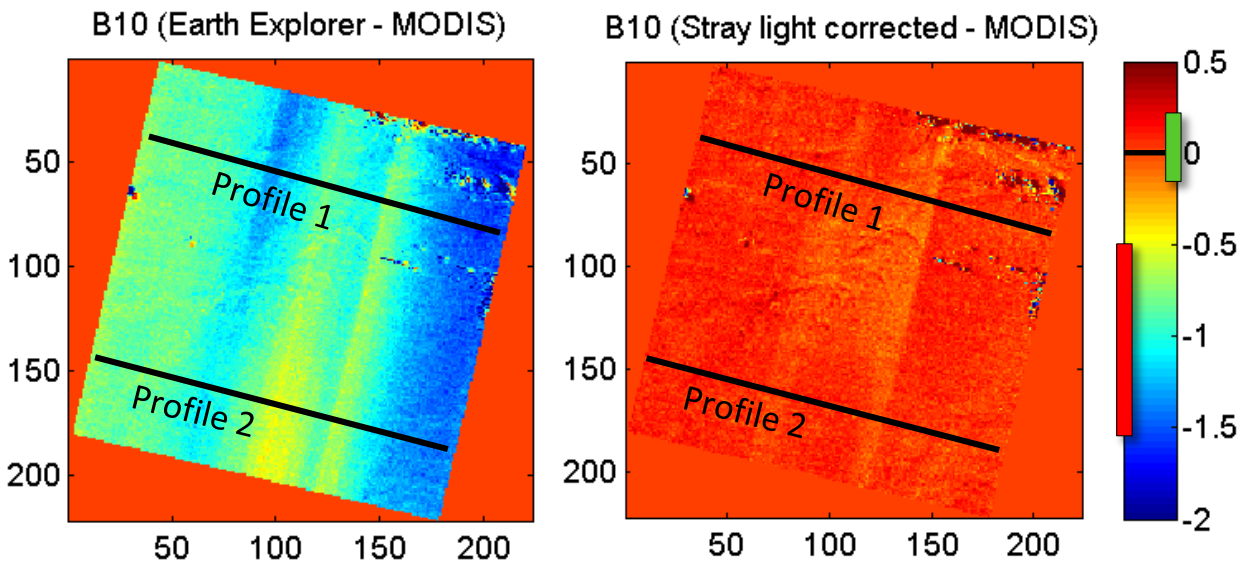
Path 006, Row 070: Band 11

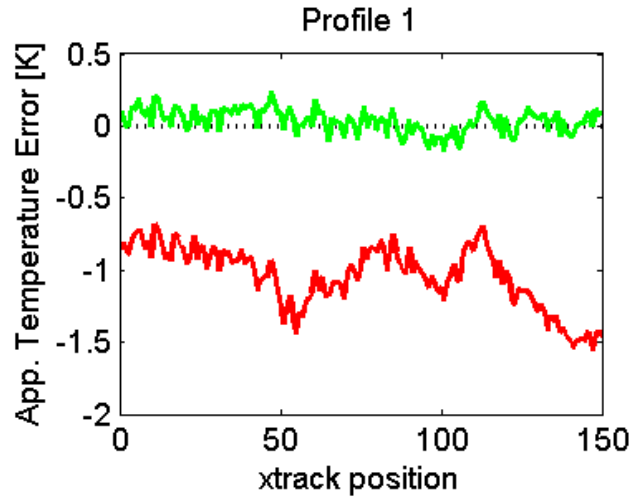


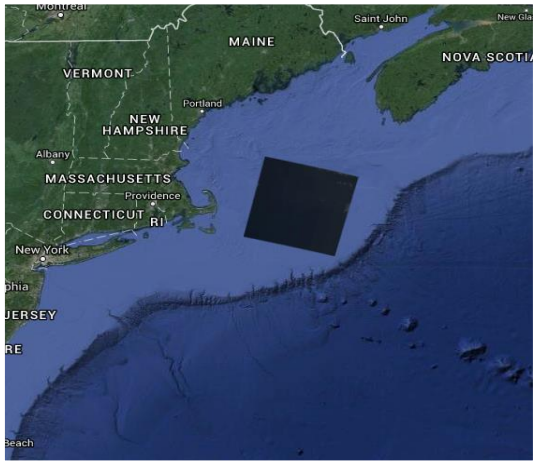


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.380	0.315	1.782	0.353	-1.742	-0.162
Profile 2	0.300	0.206	1.754	0.500	-1.728	-0.456

Path 010, Row 030: Band 10

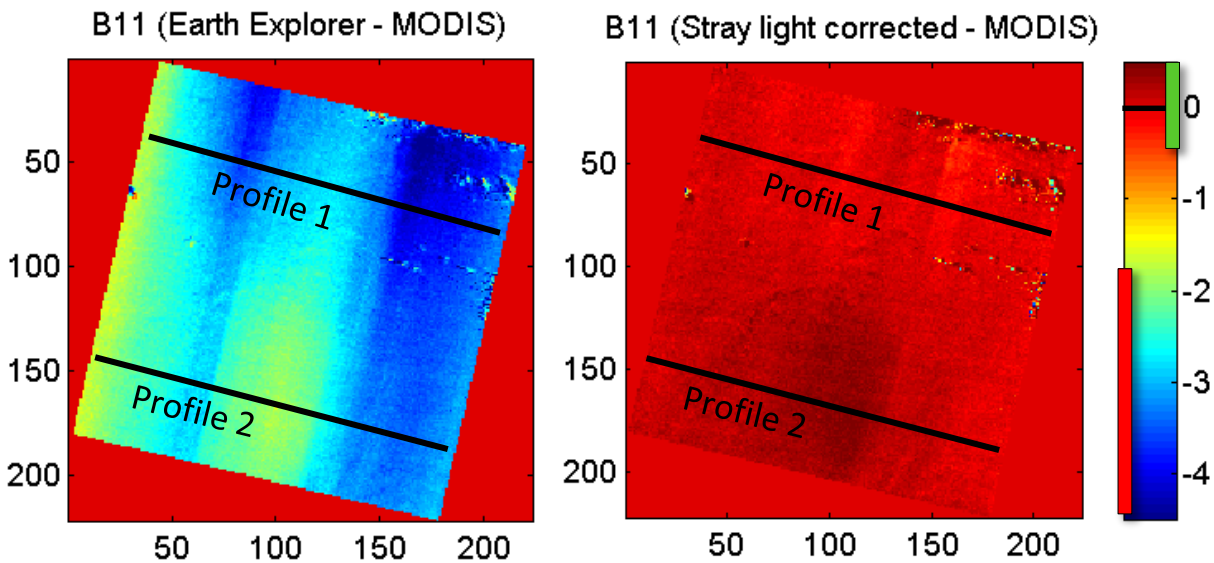


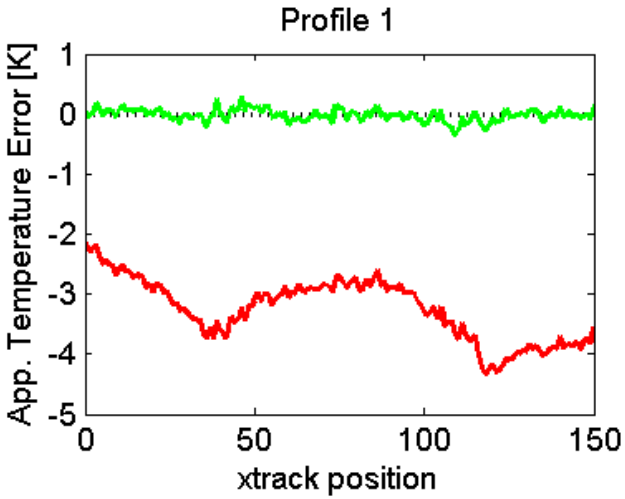


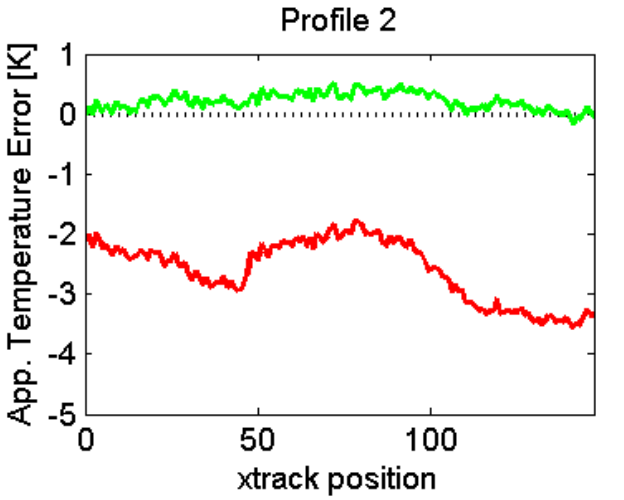


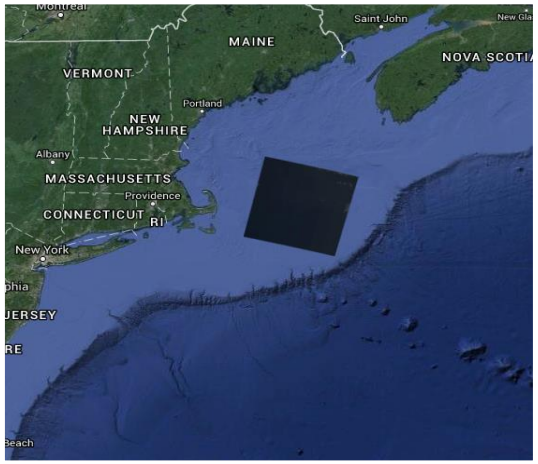
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.213	0.081	1.066	0.088	-1.045	0.034
Profile 2	0.221	0.070	0.924	0.094	-0.897	0.063

Path 010, Row 030: Band 11



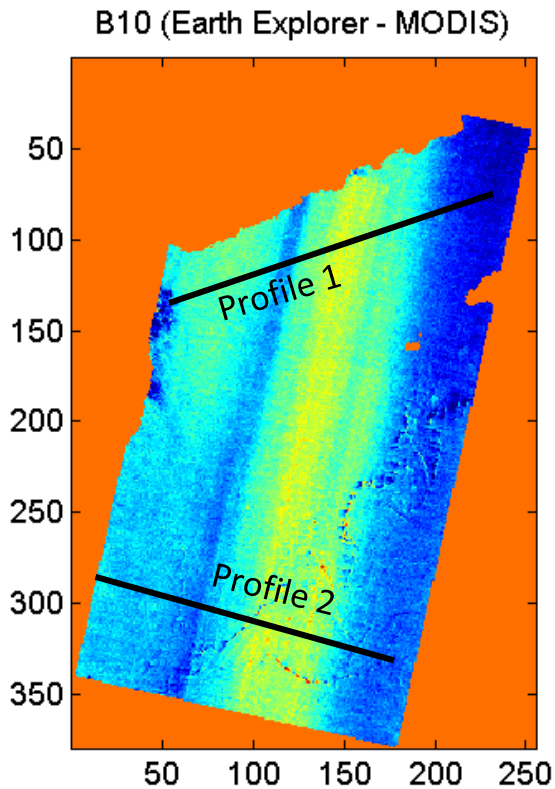


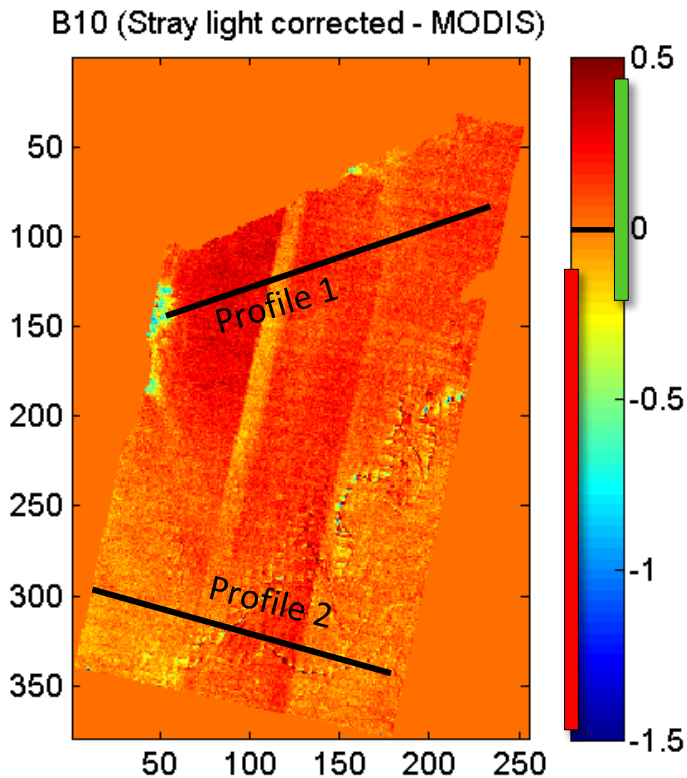


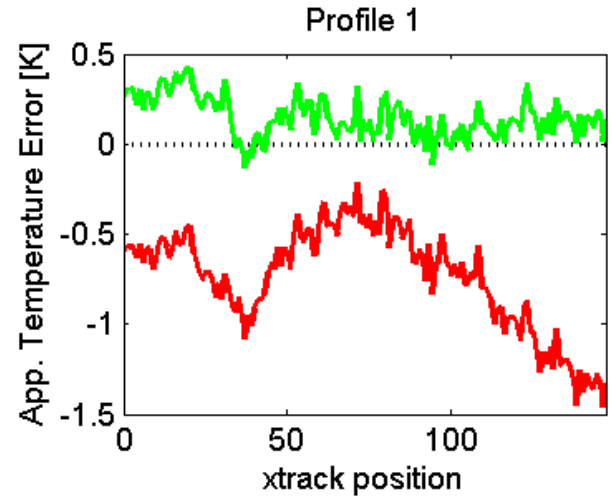


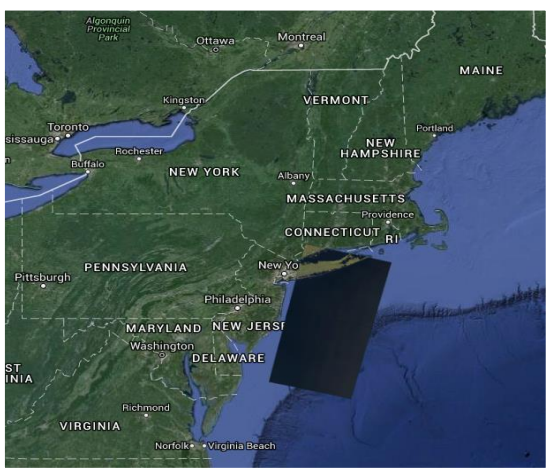
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.518	0.101	3.300	0.103	-3.259	-0.024
Profile 2	0.515	0.141	2.650	0.253	-2.600	0.210

Path 013, Row 032: Band 10



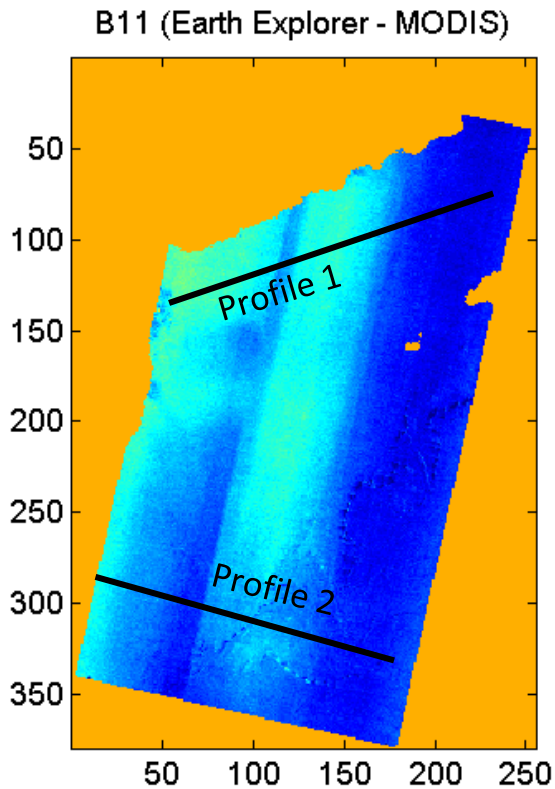


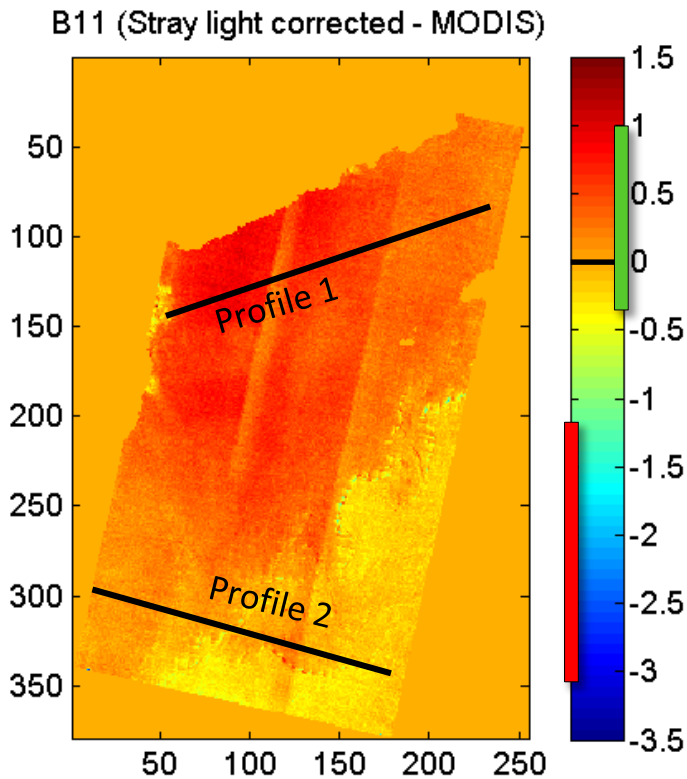


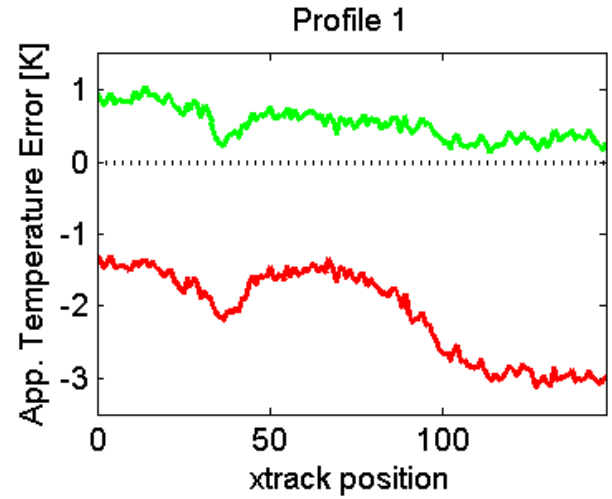


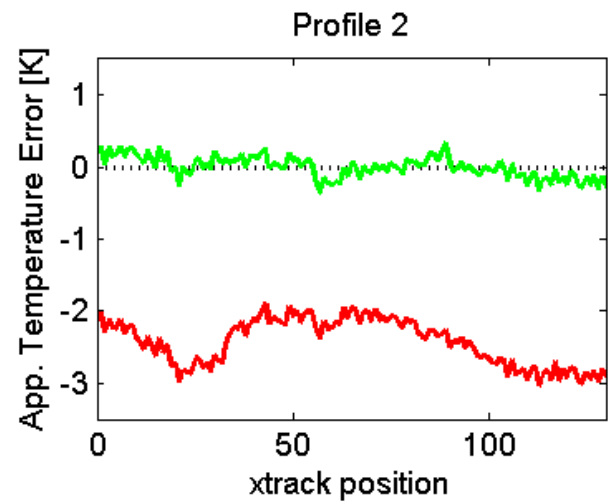
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.288	0.116	0.797	0.185	-0.744	0.144
Profile 2	0.245	0.095	0.795	0.099	-0.756	0.030

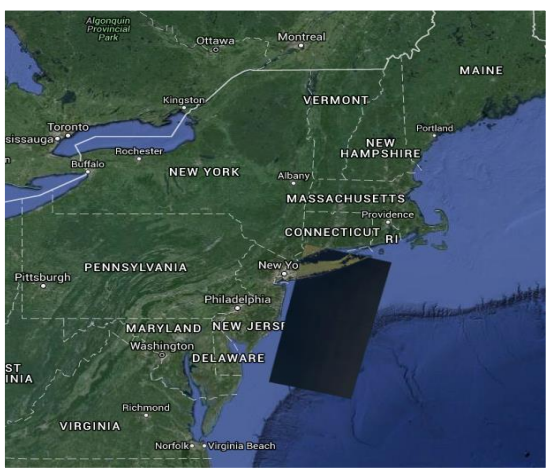
Path 013, Row 032: Band 11





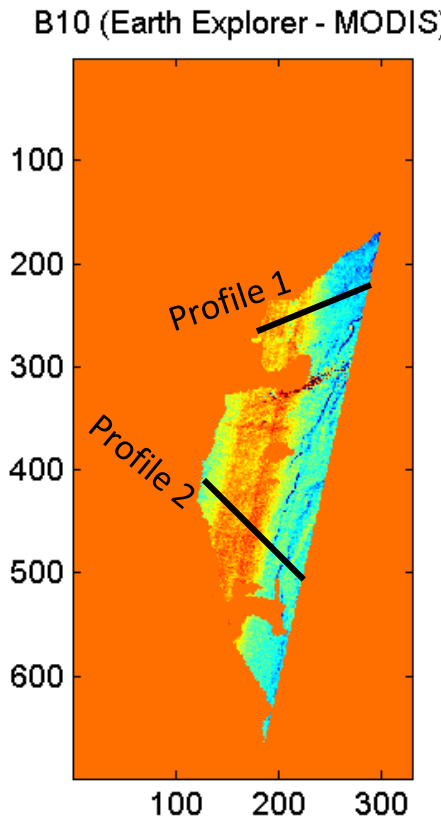


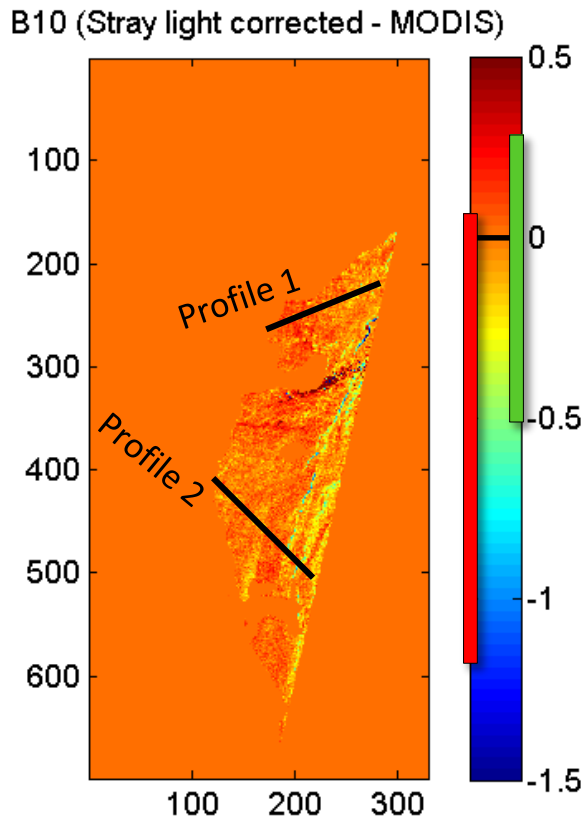


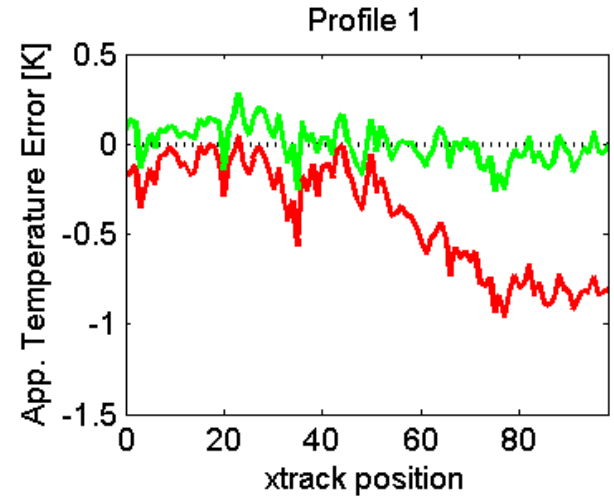


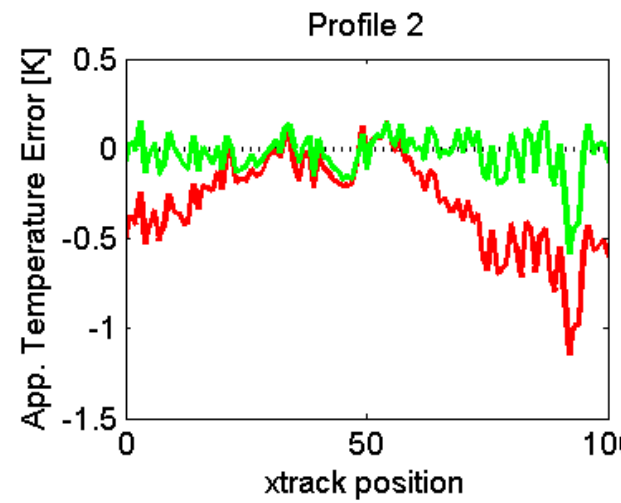
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.621	0.224	2.188	0.569	-2.098	0.524
Profile 2	0.322	0.151	2.455	0.151	-2.434	-0.002

Path 016, Row 039: Band 10



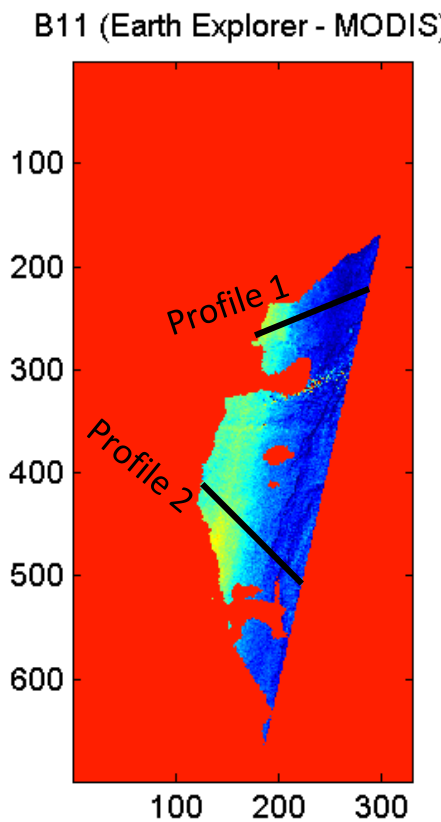


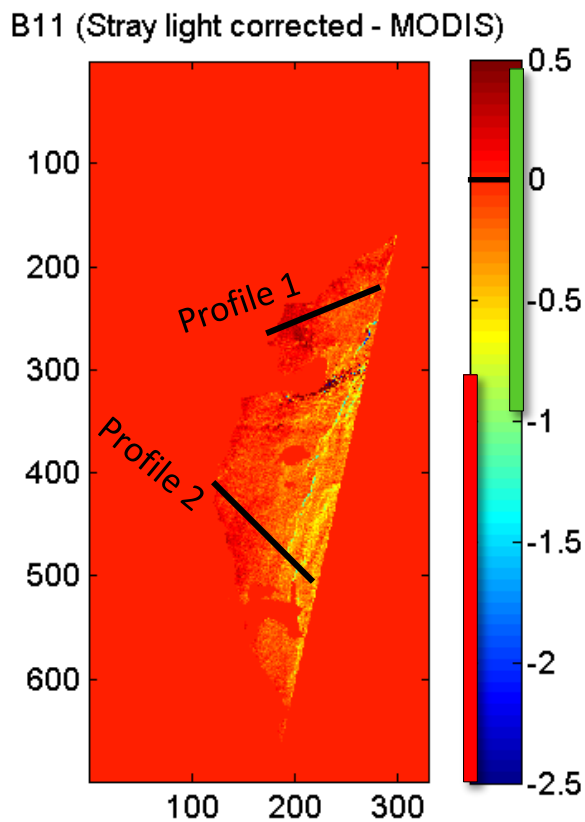


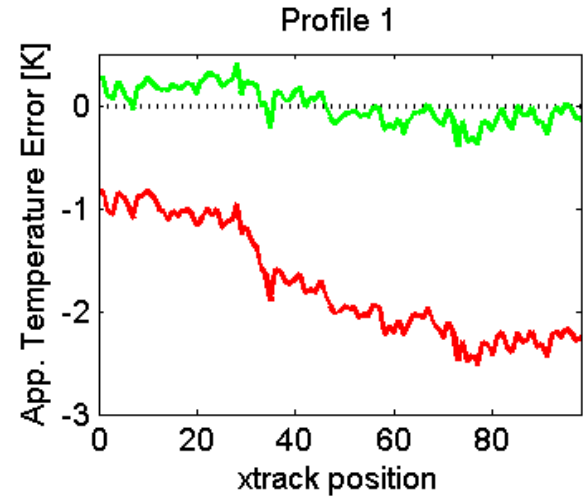


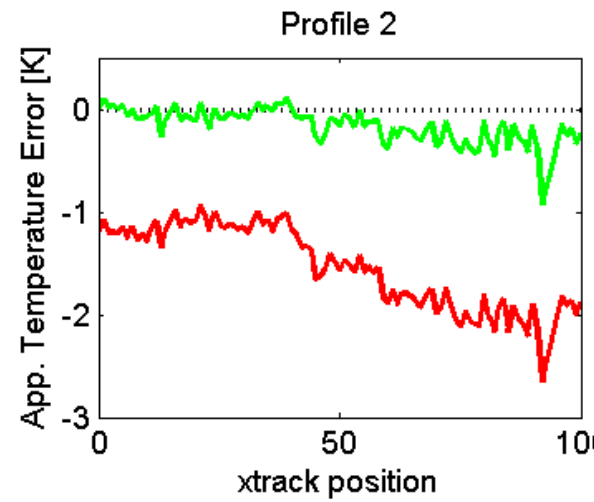
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.305	0.105	0.505	0.104	-0.404	0.001
Profile 2	0.263	0.123	0.400	0.128	-0.303	-0.036

Path 016, Row 039: Band 11



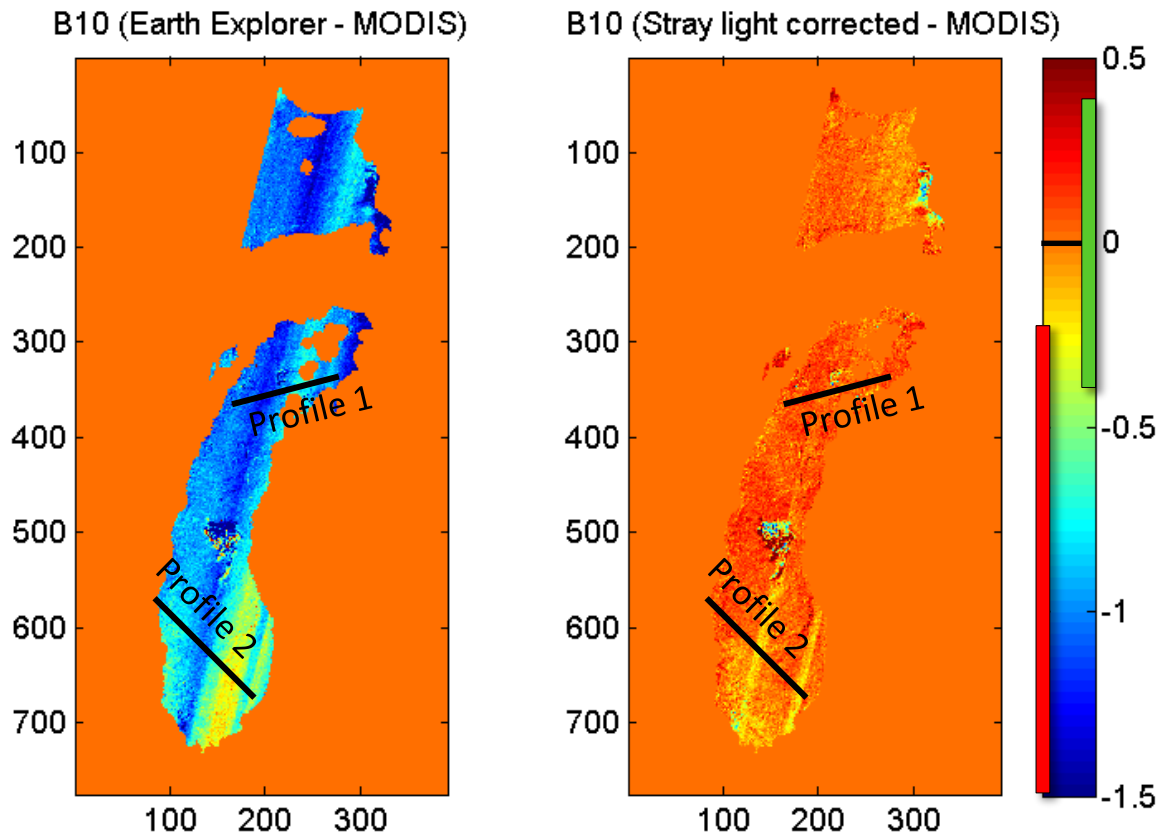


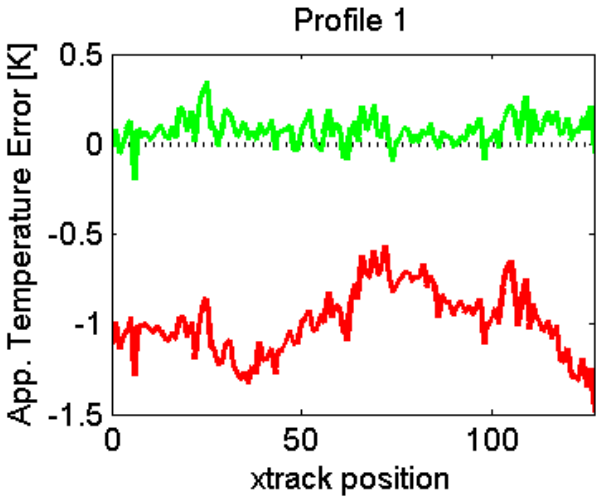


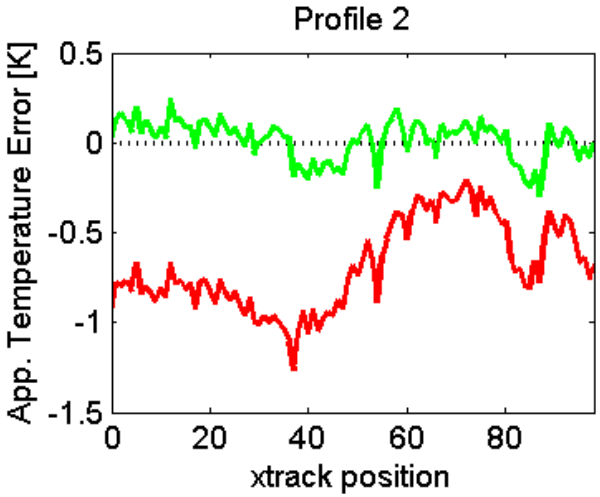


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.543	0.176	1.825	0.175	-1.743	0.001
Profile 2	0.411	0.175	1.603	0.241	-1.550	-0.166

Path 022, Row 030: Band 10

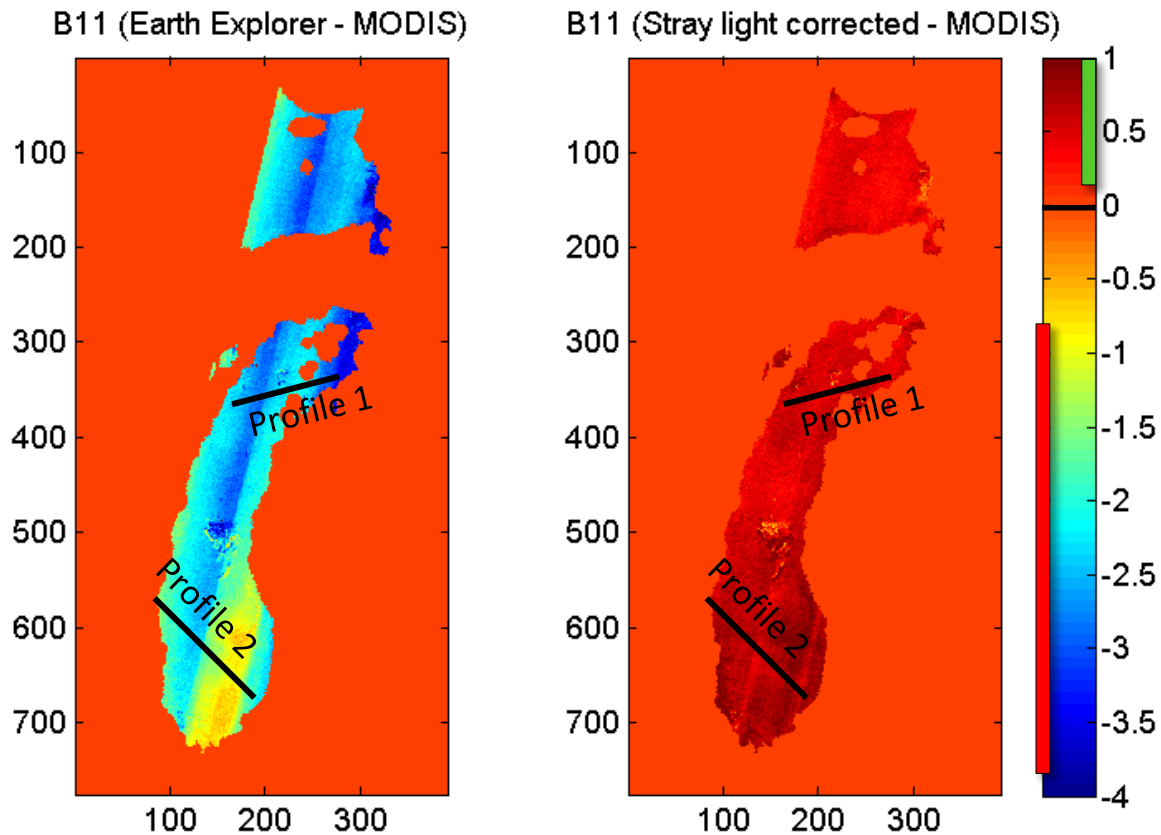


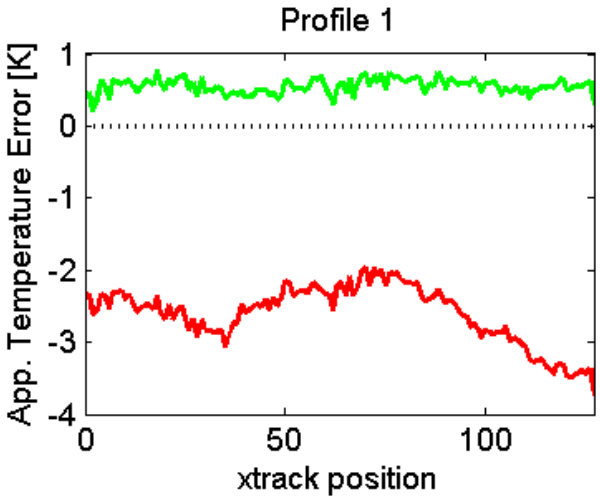


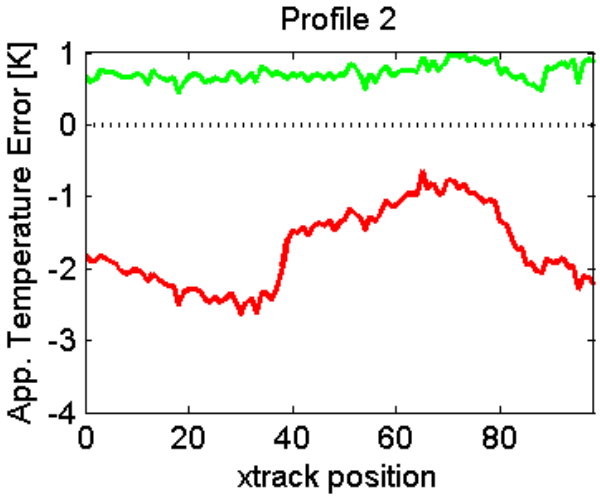


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.185	0.081	1.010	0.109	-0.993	0.073
Profile 2	0.247	0.110	0.735	0.110	-0.693	0.013

Path 022, Row 030: Band 11

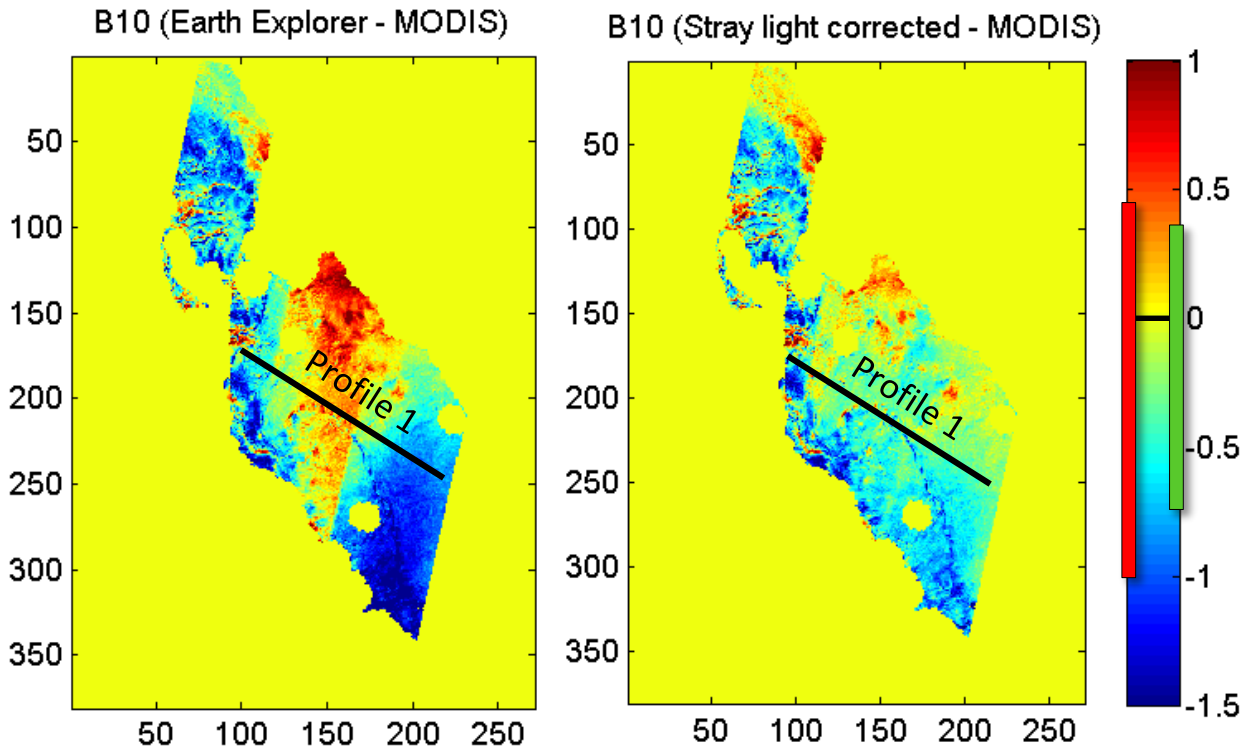


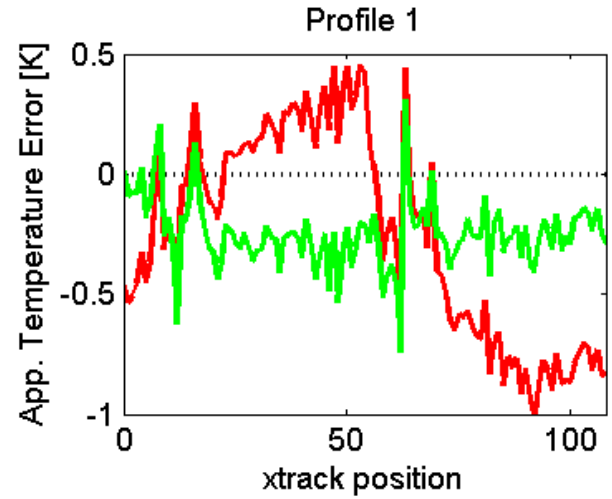


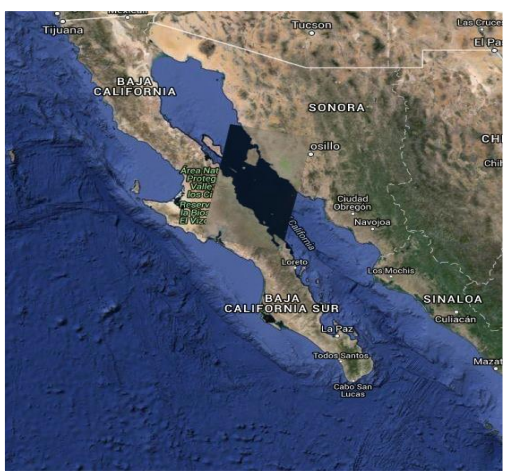


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.401	0.103	2.638	0.556	-2.608	0.547
Profile 2	0.548	0.116	1.801	0.728	-1.716	0.718

Path 035, Row 040: Band 10

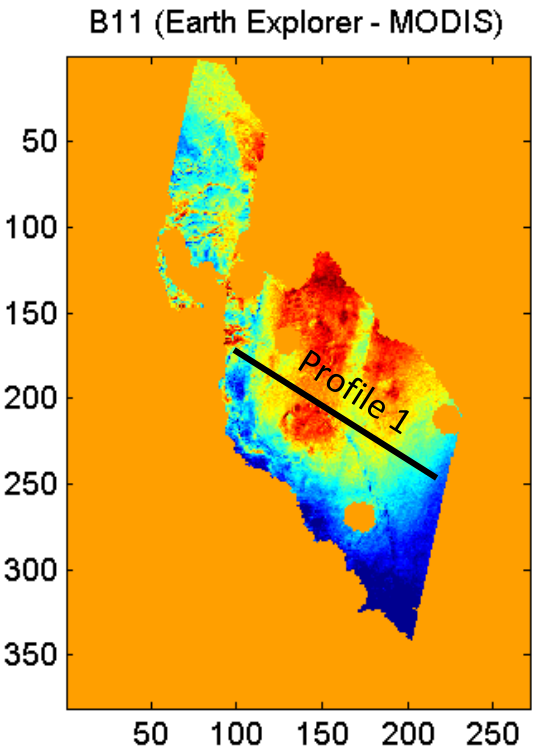


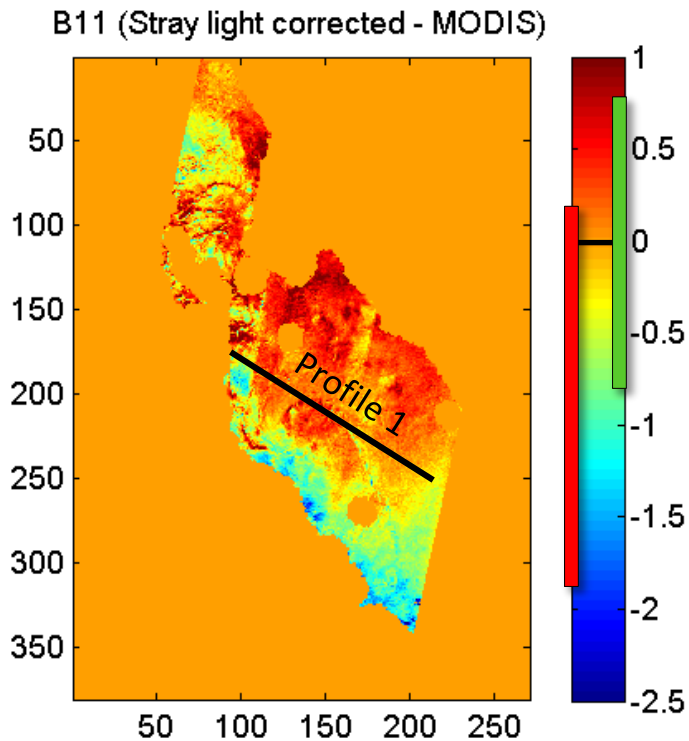


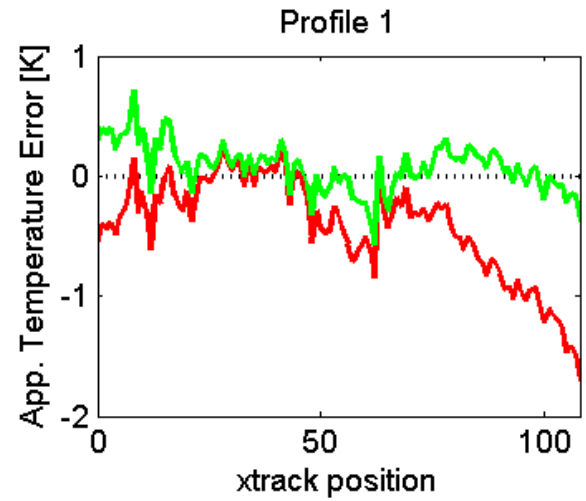


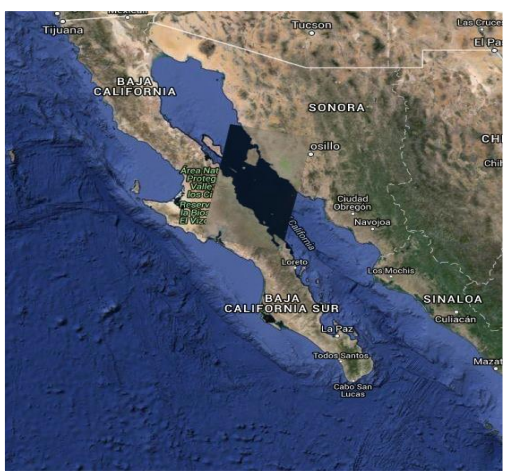
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.431	0.146	0.501	0.288	-0.259	-0.249

Path 035, Row 040: Band 11



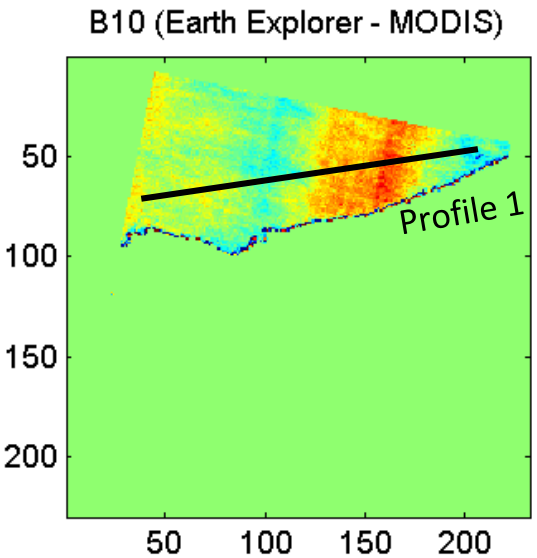


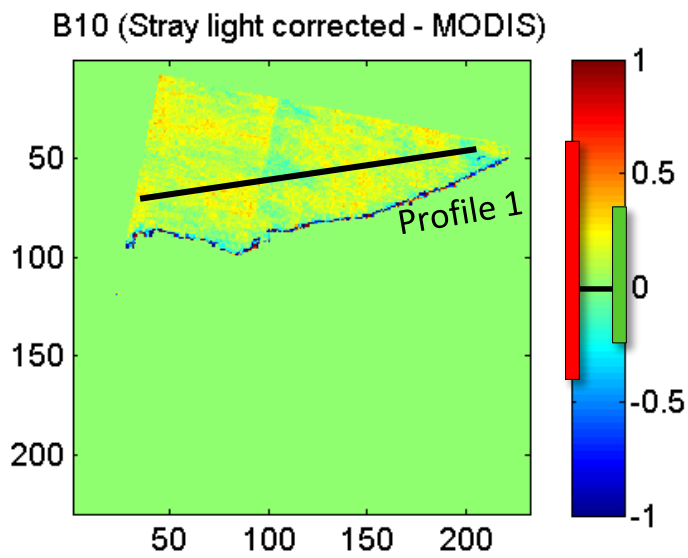


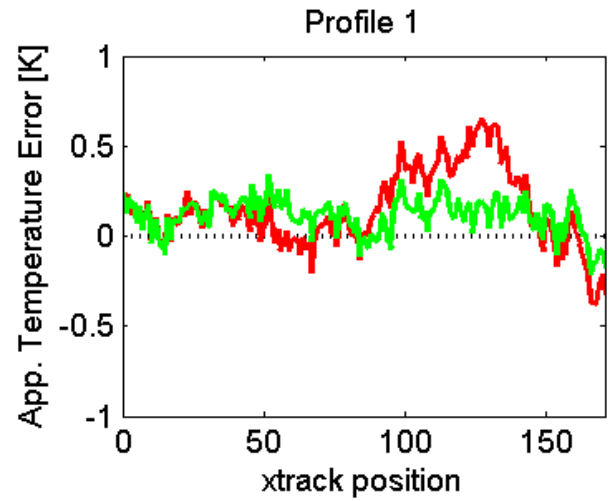


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.421	0.200	0.591	0.212	-0.417	0.072

Path 112, Row 074: Band 10

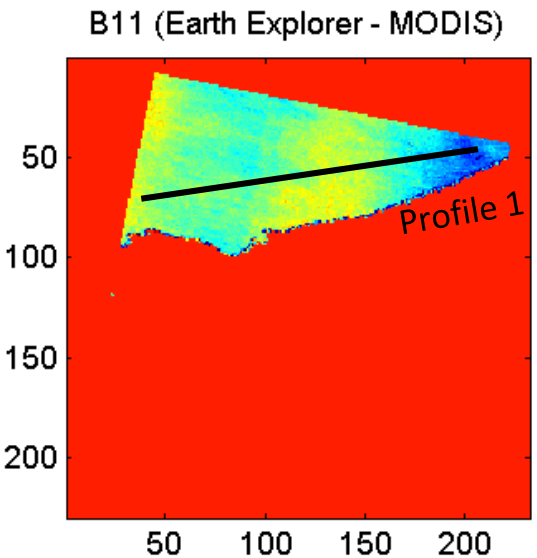


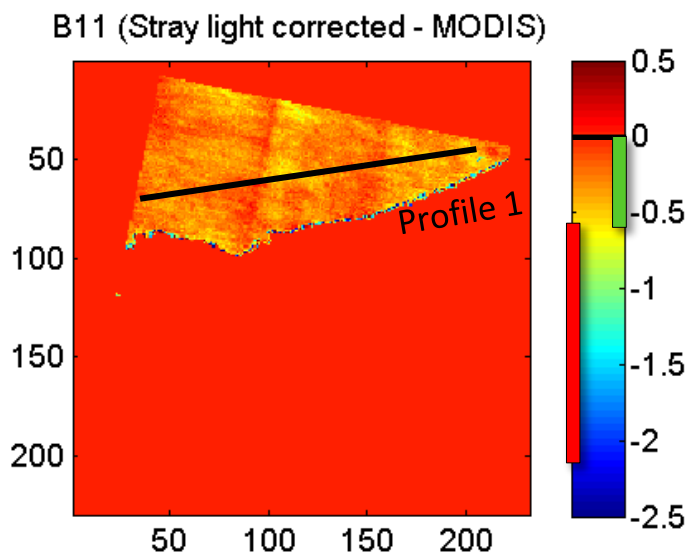


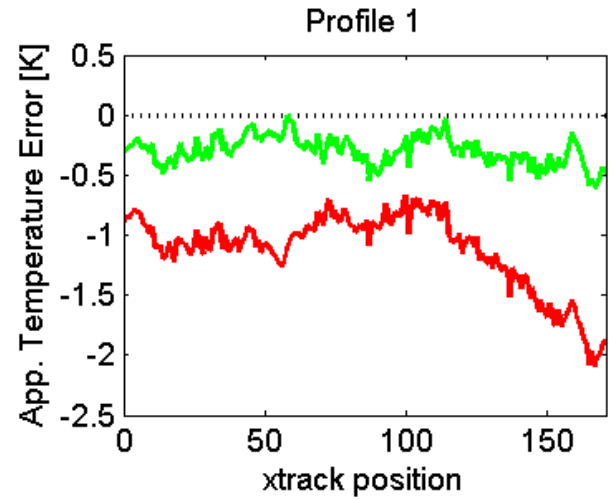


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.214	0.101	0.261	0.149	0.150	0.111

Path 112, Row 074: Band 11

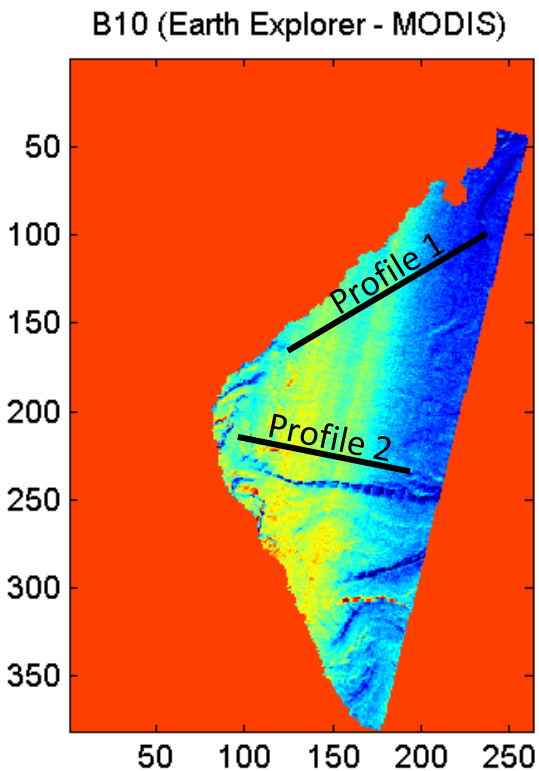


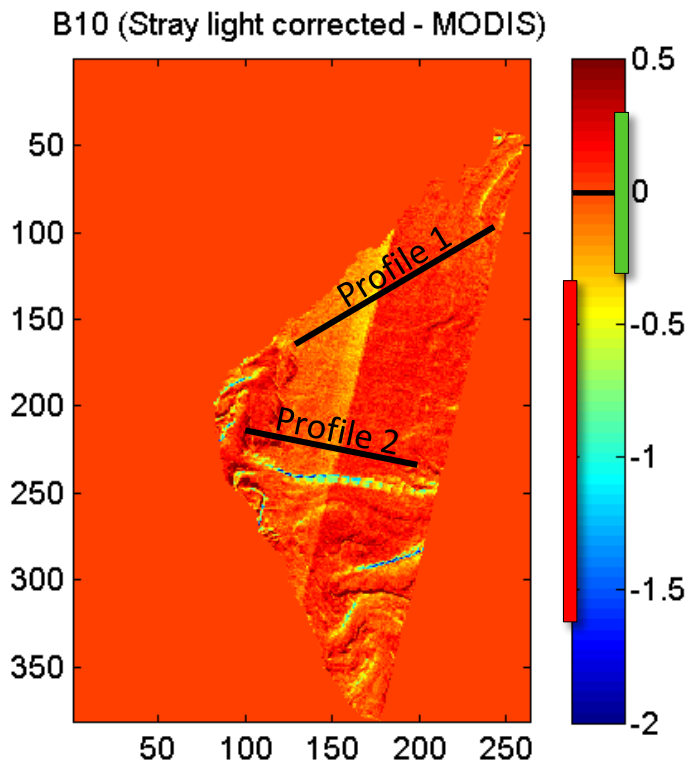


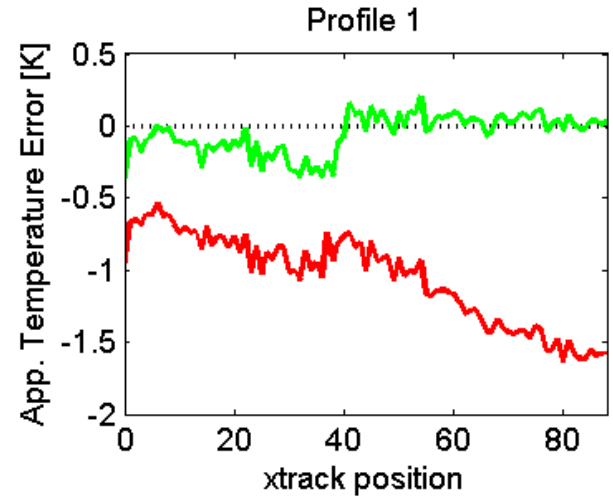


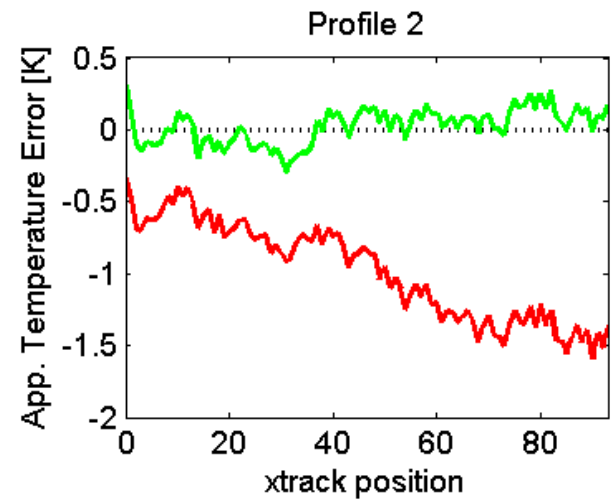
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.321	0.119	1.171	0.323	-1.126	-0.300

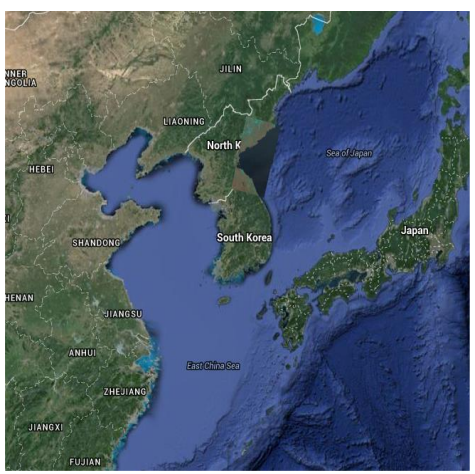
Path 115, Row 032: Band 10





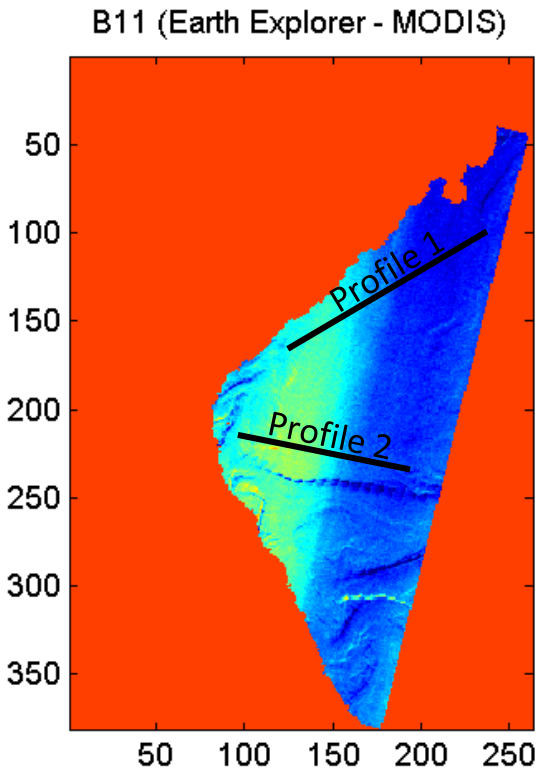


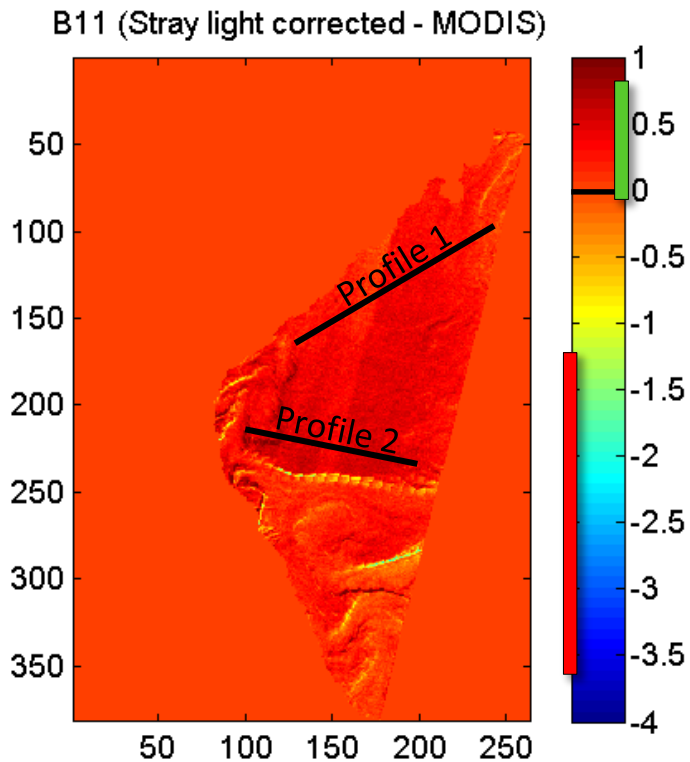


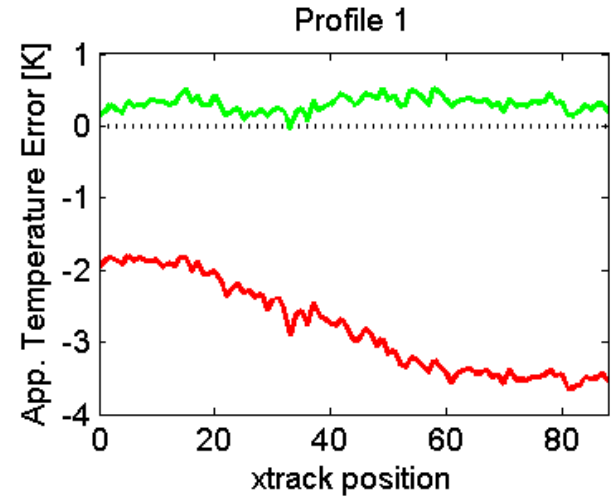


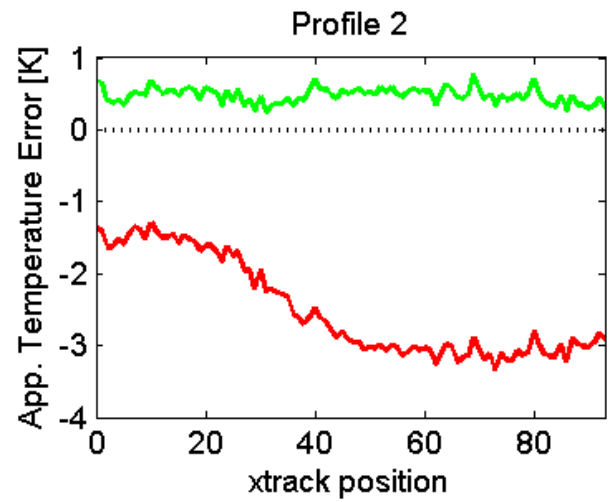
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.312	0.138	1.101	0.149	-1.057	-0.057
Profile 2	0.340	0.124	1.043	0.126	-0.987	0.024

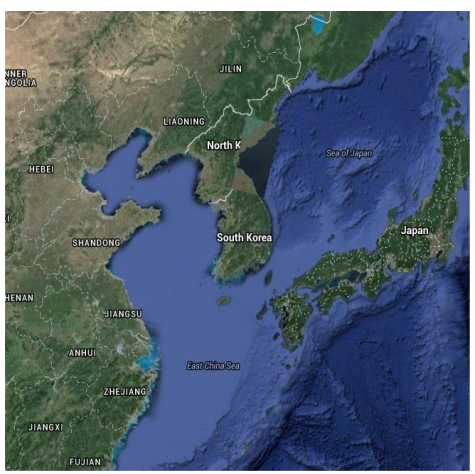
Path 115, Row 032: Band 11





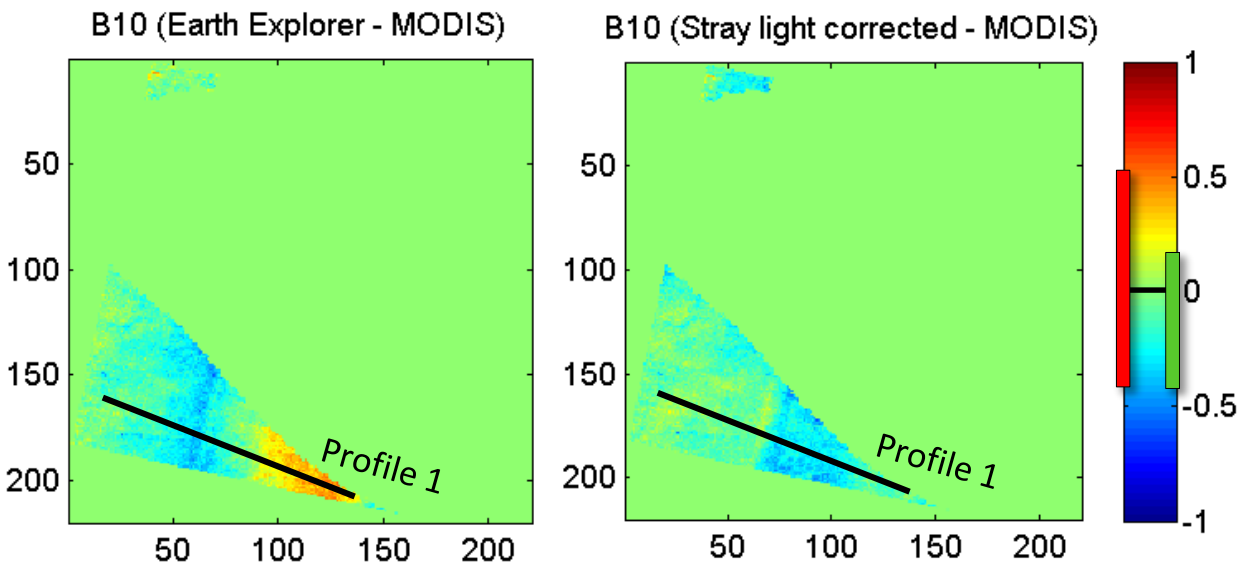


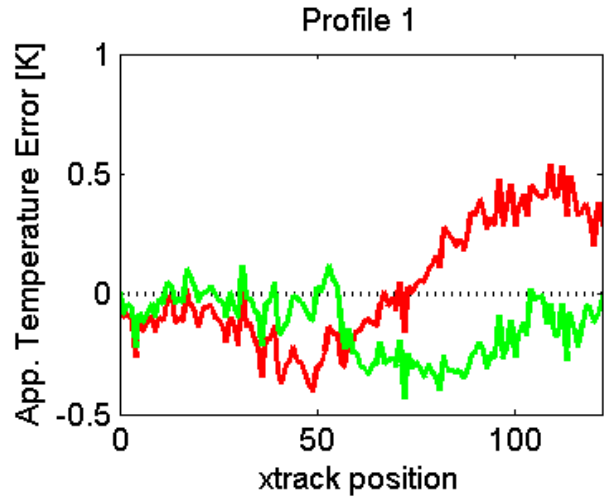


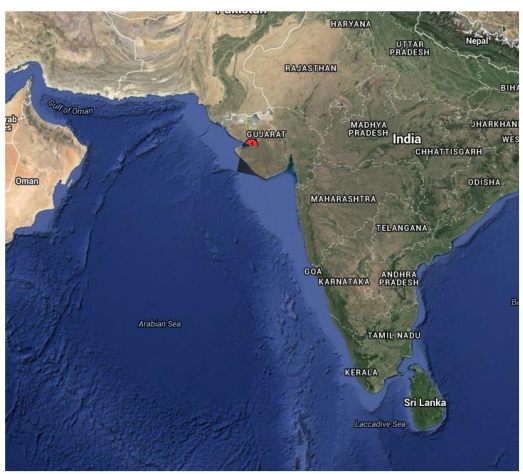


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.639	0.104	2.873	0.316	-2.802	0.298
Profile 2	0.678	0.106	2.587	0.486	-2.498	0.475

Path 150, Row 045: Band 10

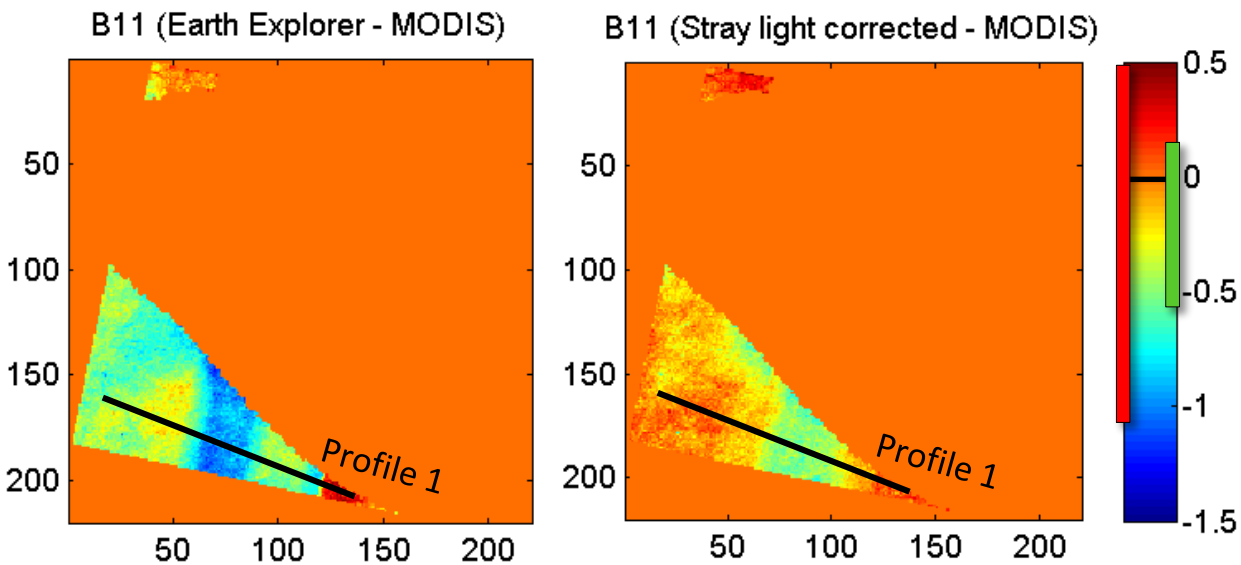


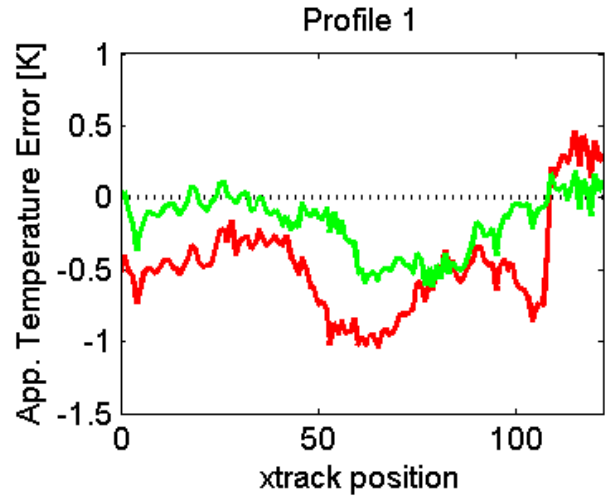


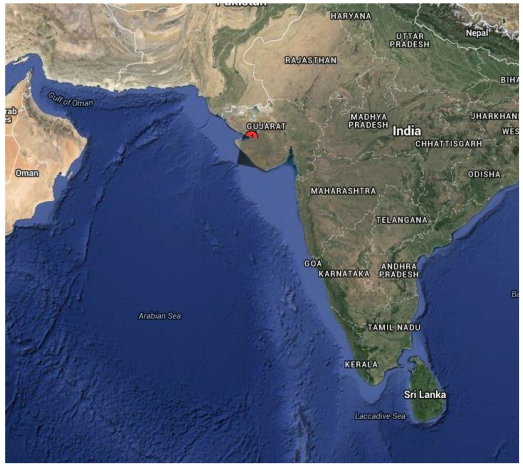


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.252	0.131	0.253	0.186	0.031	-0.132

Path 150, Row 045: Band 11

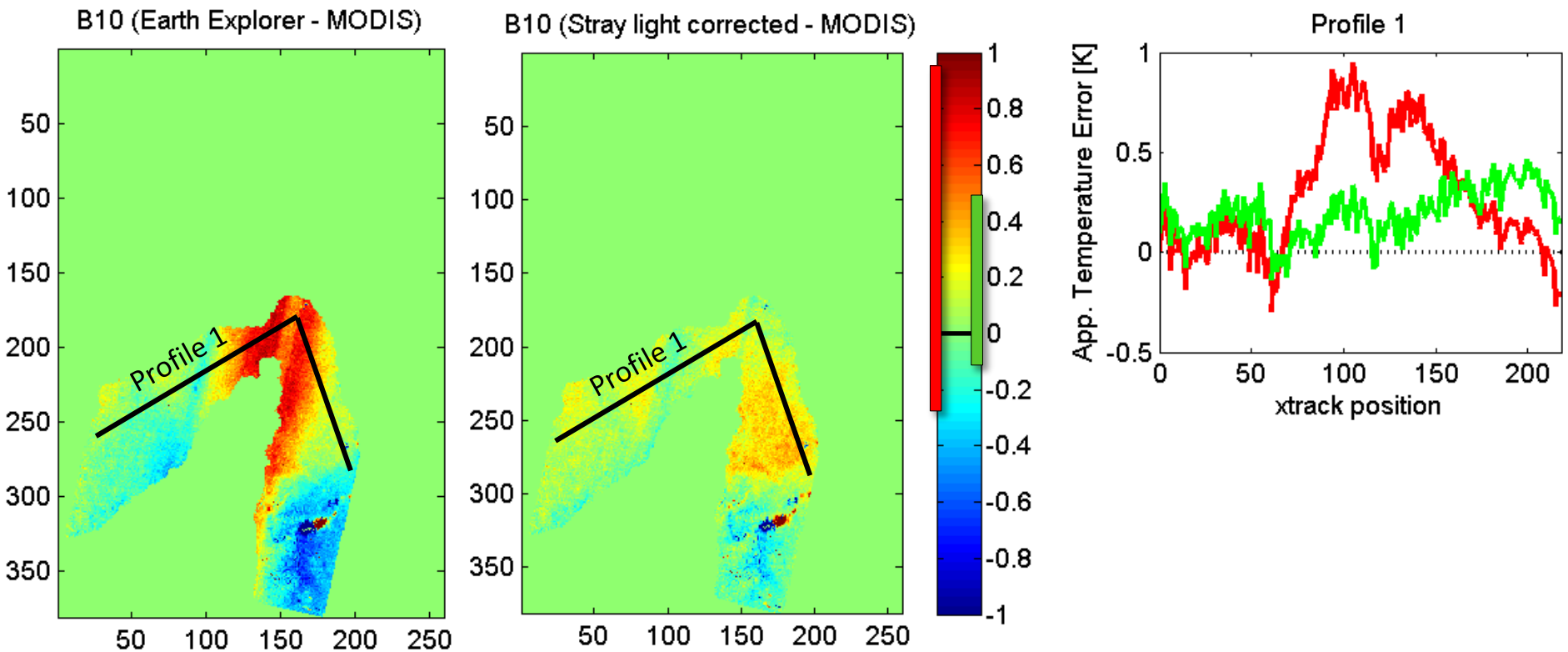






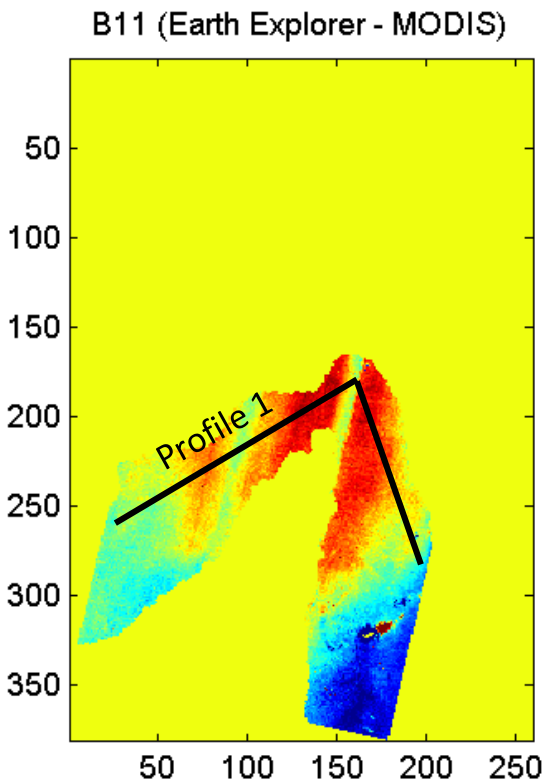
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.345	0.206	0.584	0.274	-0.472	-0.181

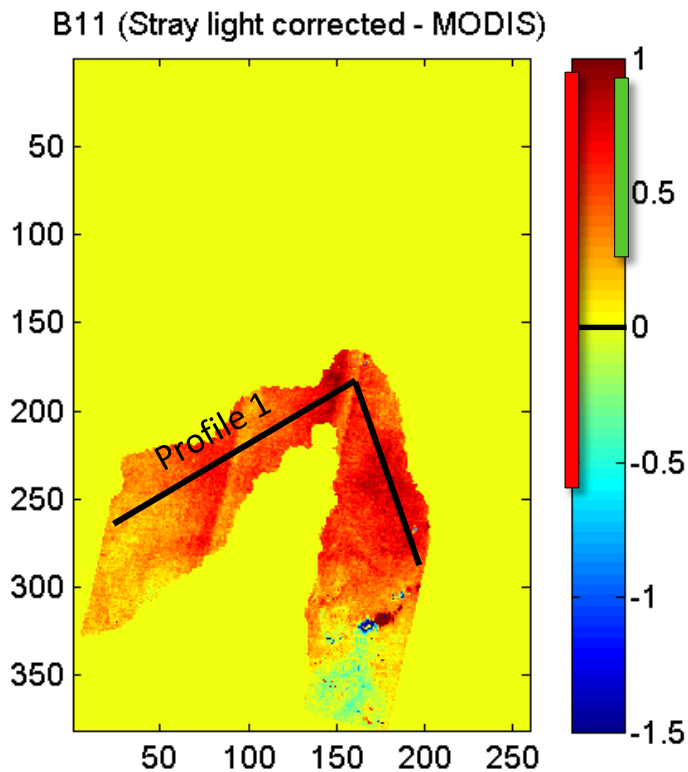
Path 160, Row 042: Band 10

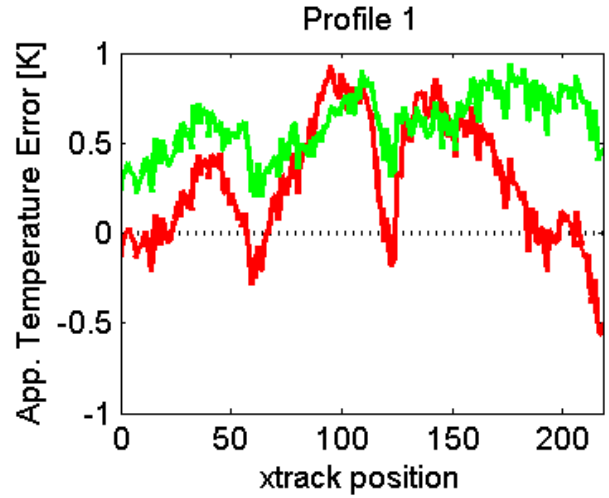


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.299	0.126	0.412	0.229	0.284	0.191

Path 160, Row 042: Band 11

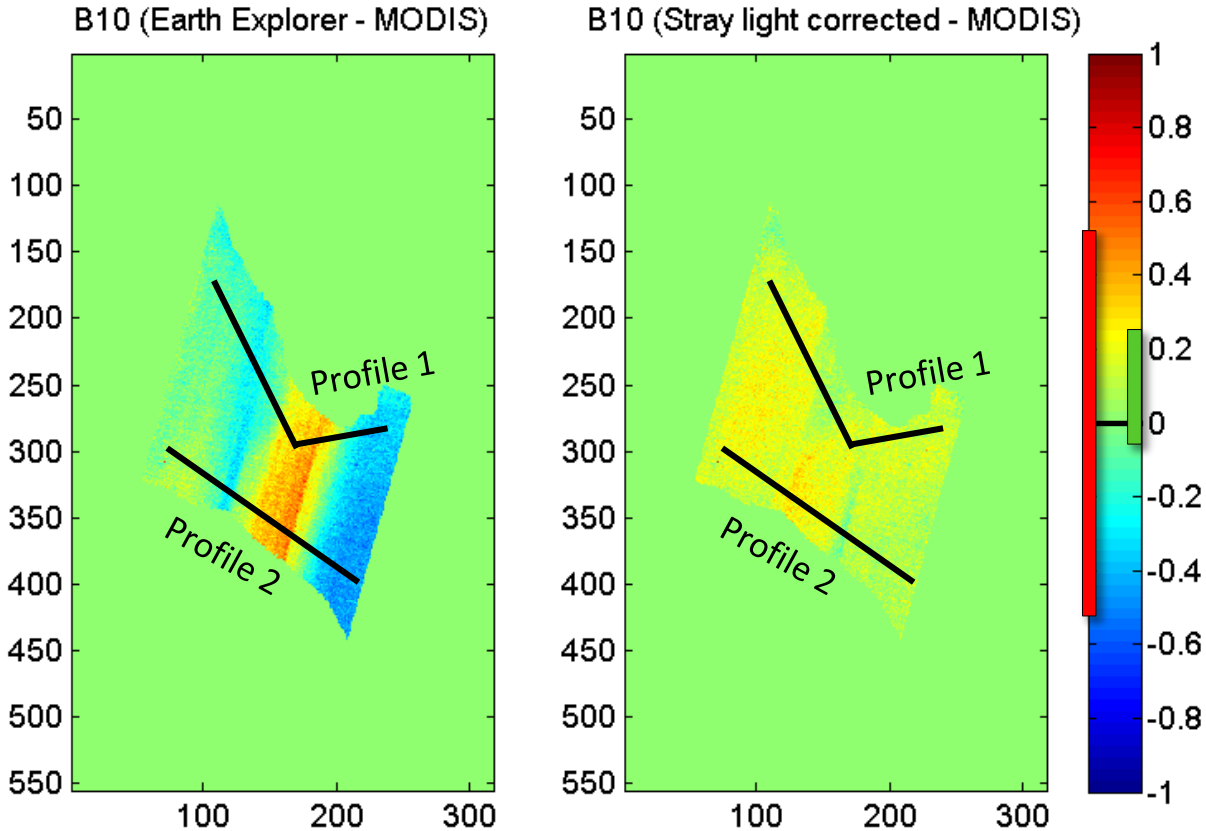


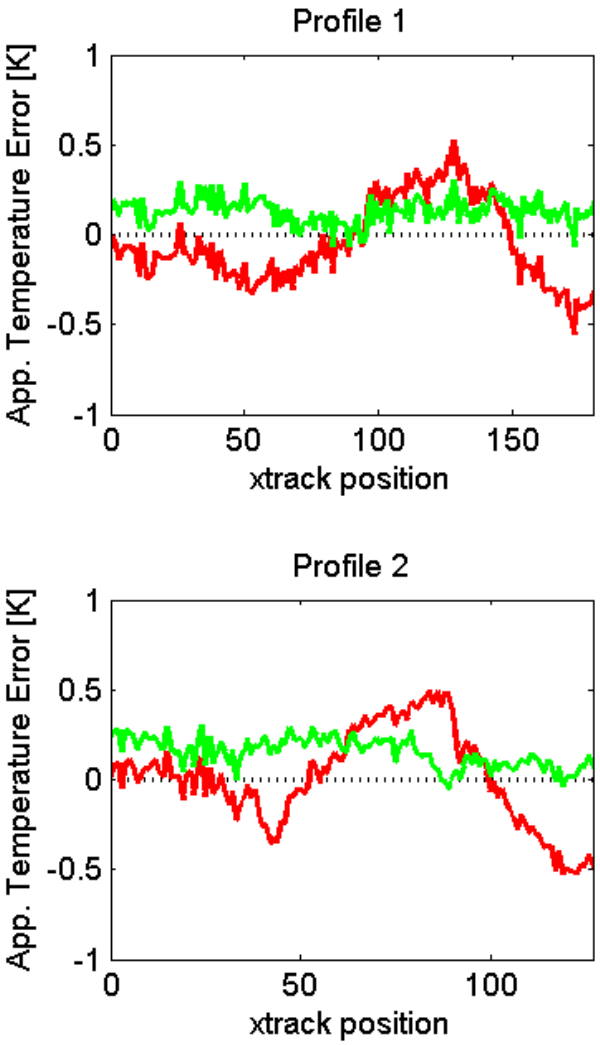




	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.337	0.171	0.435	0.617	0.276	0.593

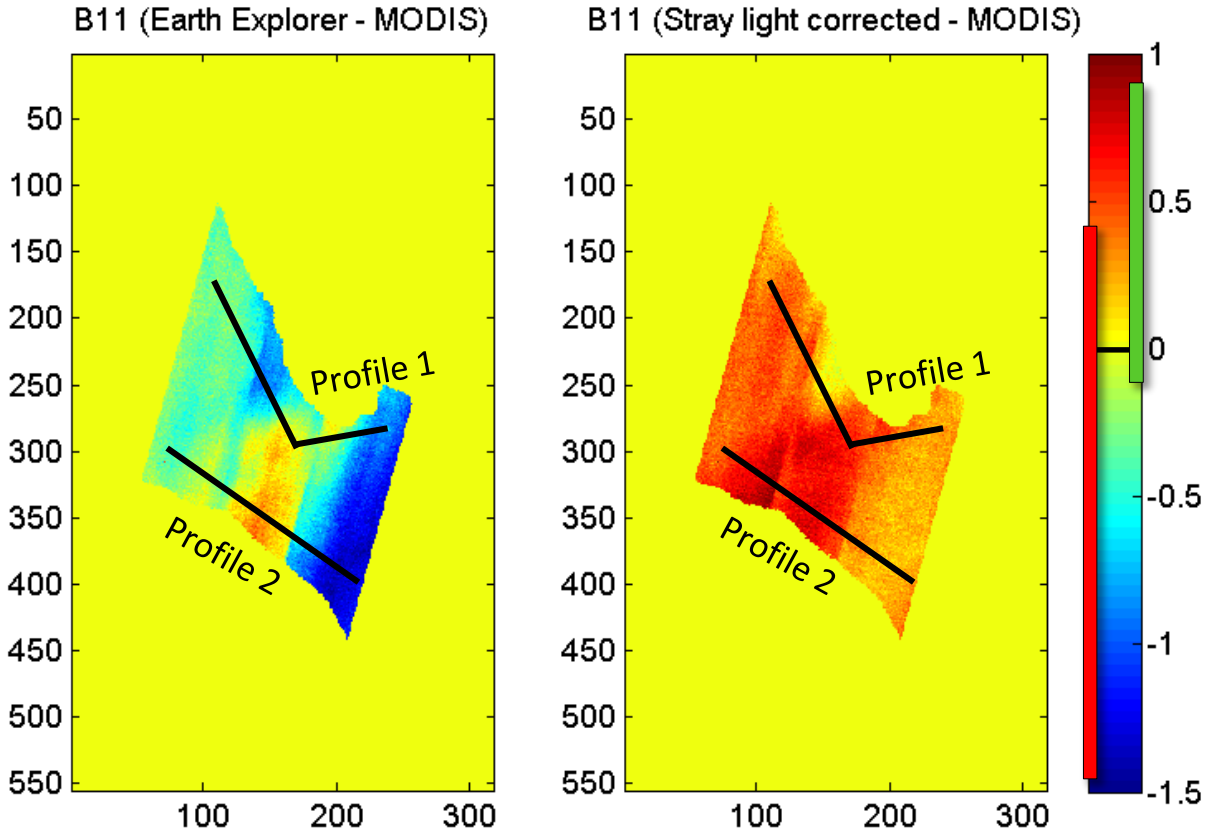
Path 163, Row 041: Band 10

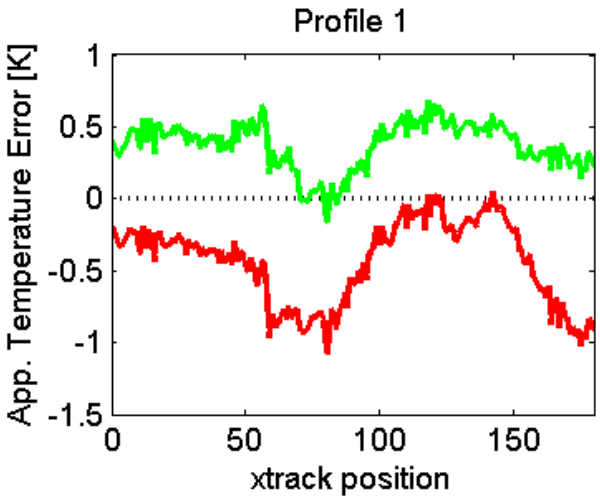




	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.230	0.071	0.235	0.145	-0.051	0.127
Profile 2	0.267	0.083	0.266	0.171	0.008	0.149

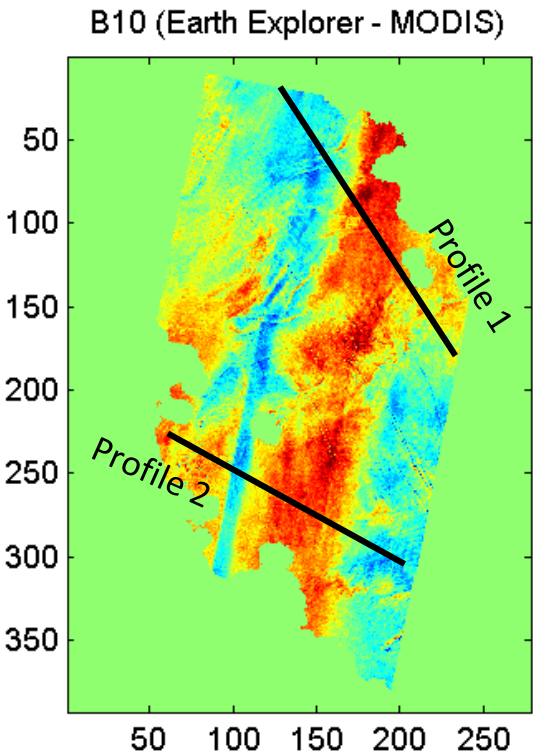
Path 163, Row 041: Band 11

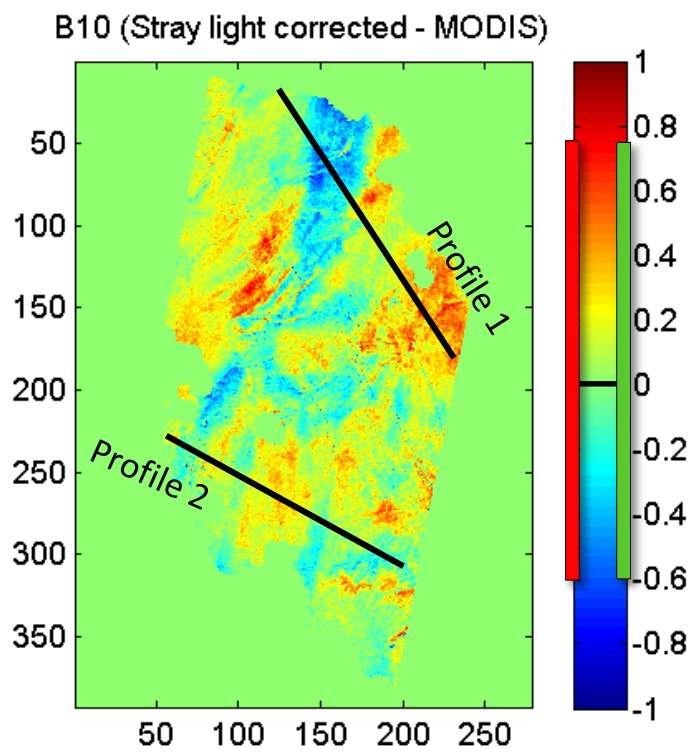


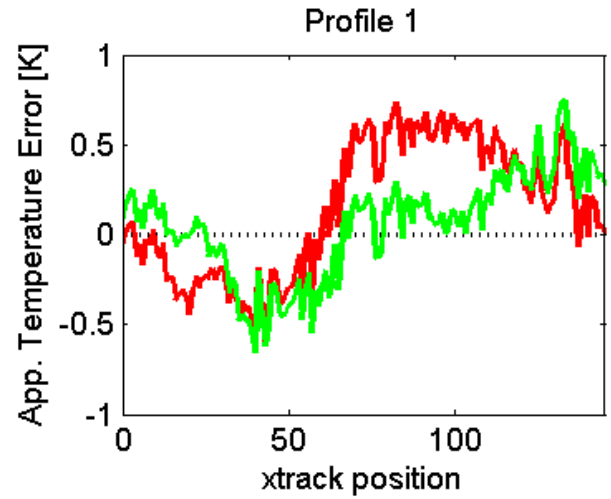


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.287	0.167	0.526	0.403	-0.441	0.367
Profile 2	0.475	0.200	0.585	0.562	-0.343	0.525

Path 172, Row 043: Band 10

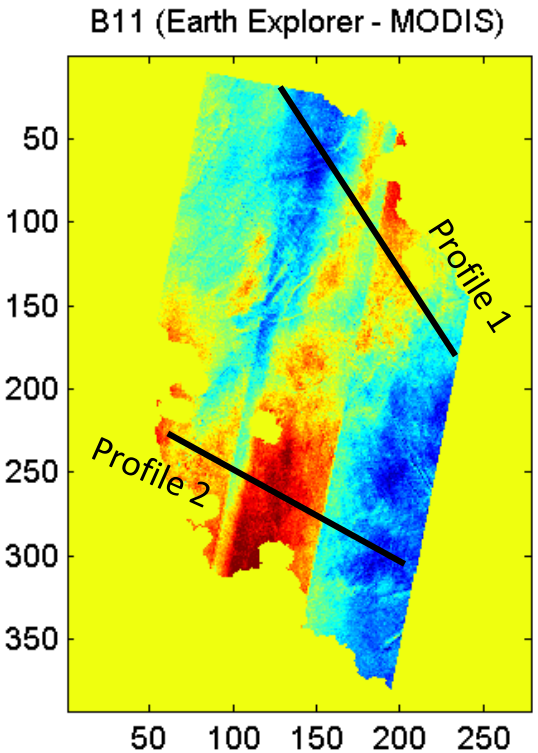


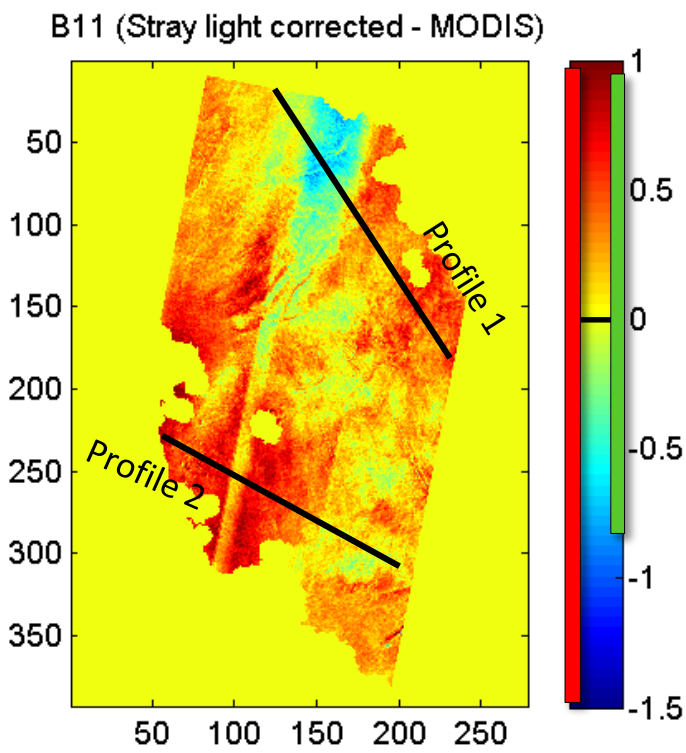




	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.374	0.291	0.398	0.294	0.142	0.048
Profile 2	0.319	0.183	0.419	0.192	0.274	0.061

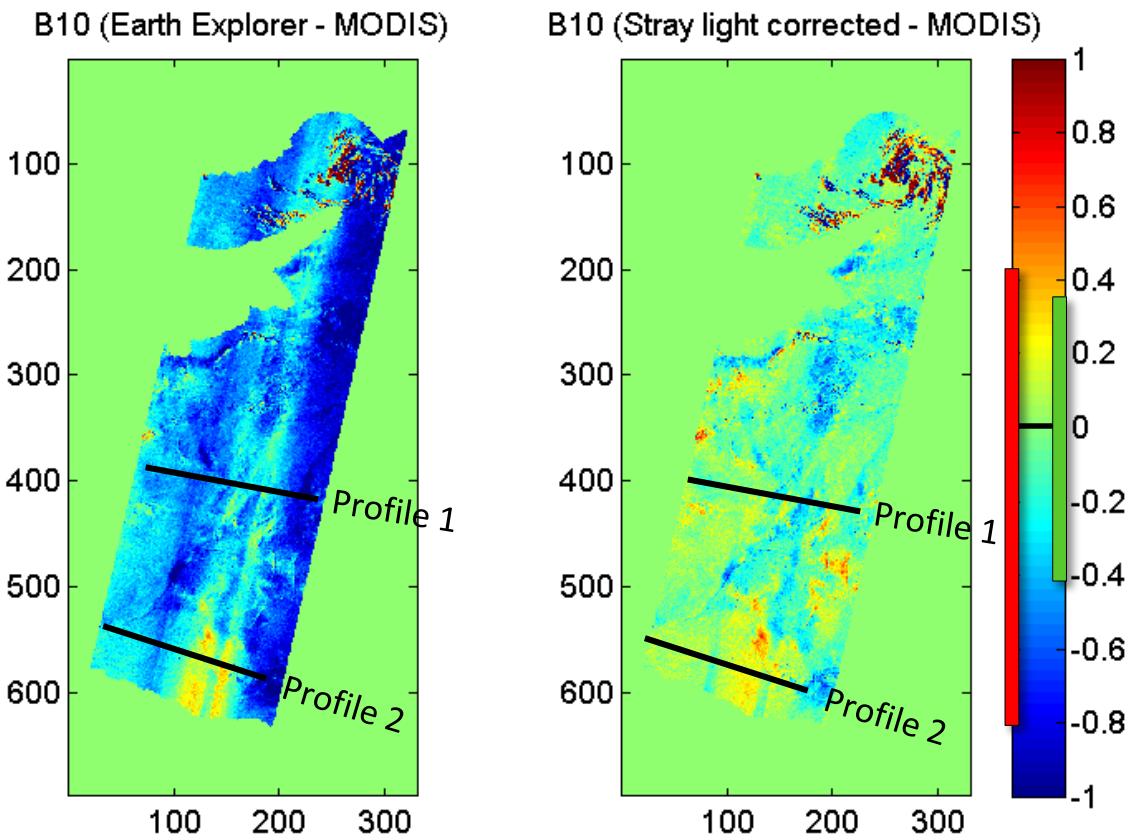
Path 172, Row 043: Band 11

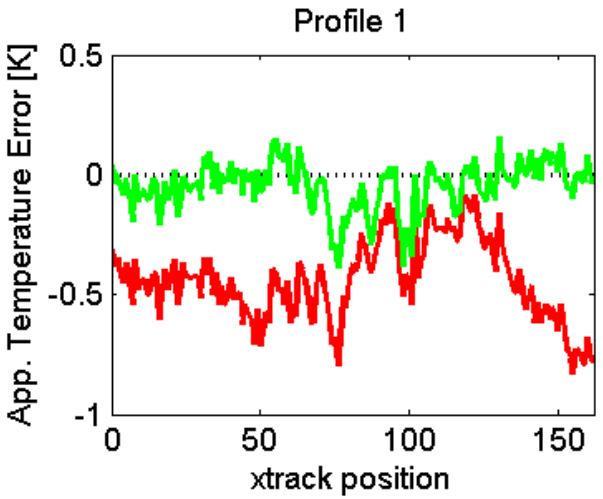


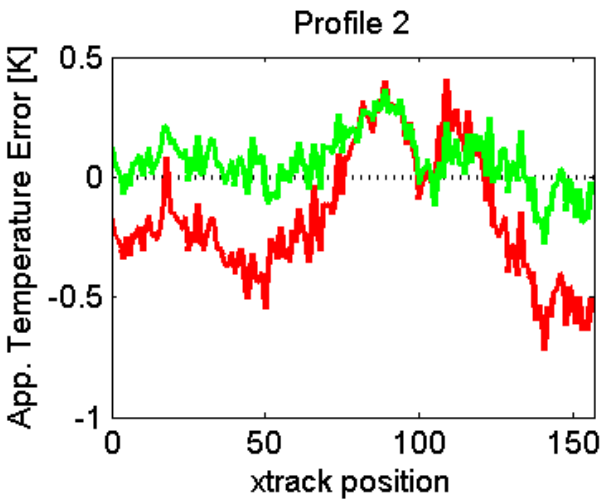


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.435	0.364	0.557	0.371	-0.350	0.078
Profile 2	0.589	0.283	0.592	0.456	0.074	0.358

Path 176, Row 037: Band 10

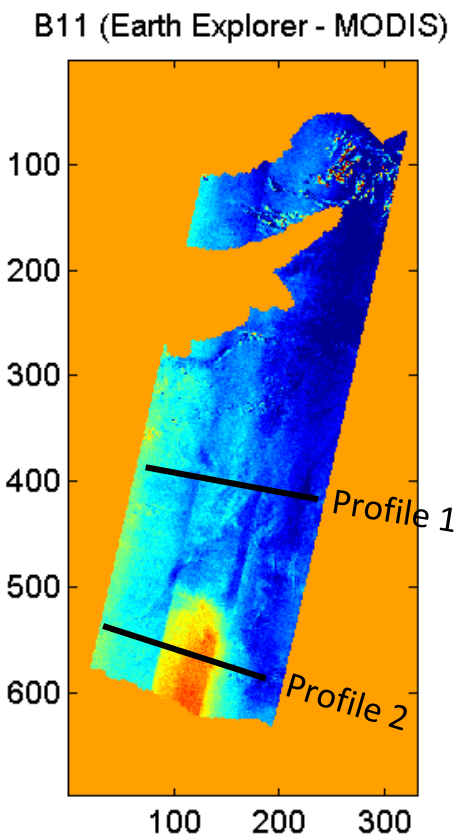


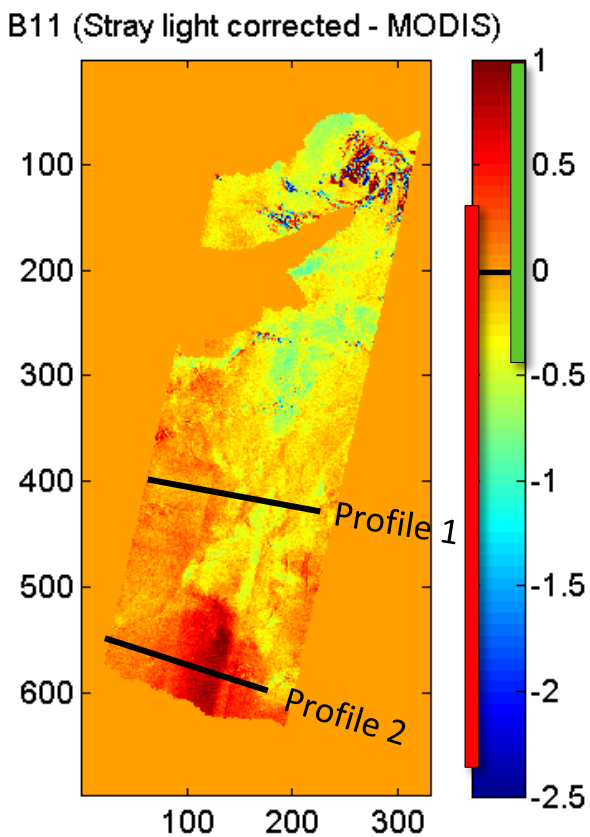


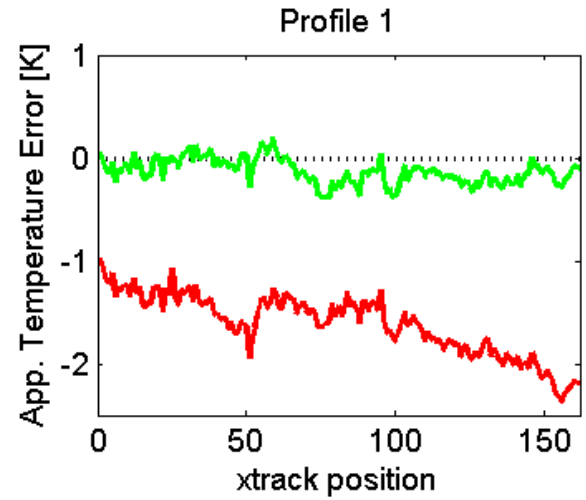


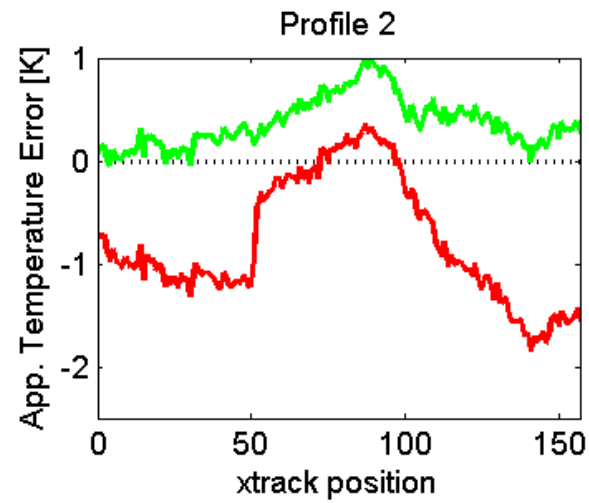
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.166	0.105	0.475	0.116	-0.445	-0.052
Profile 2	0.264	0.121	0.312	0.135	-0.168	0.062

Path 176, Row 037: Band 11



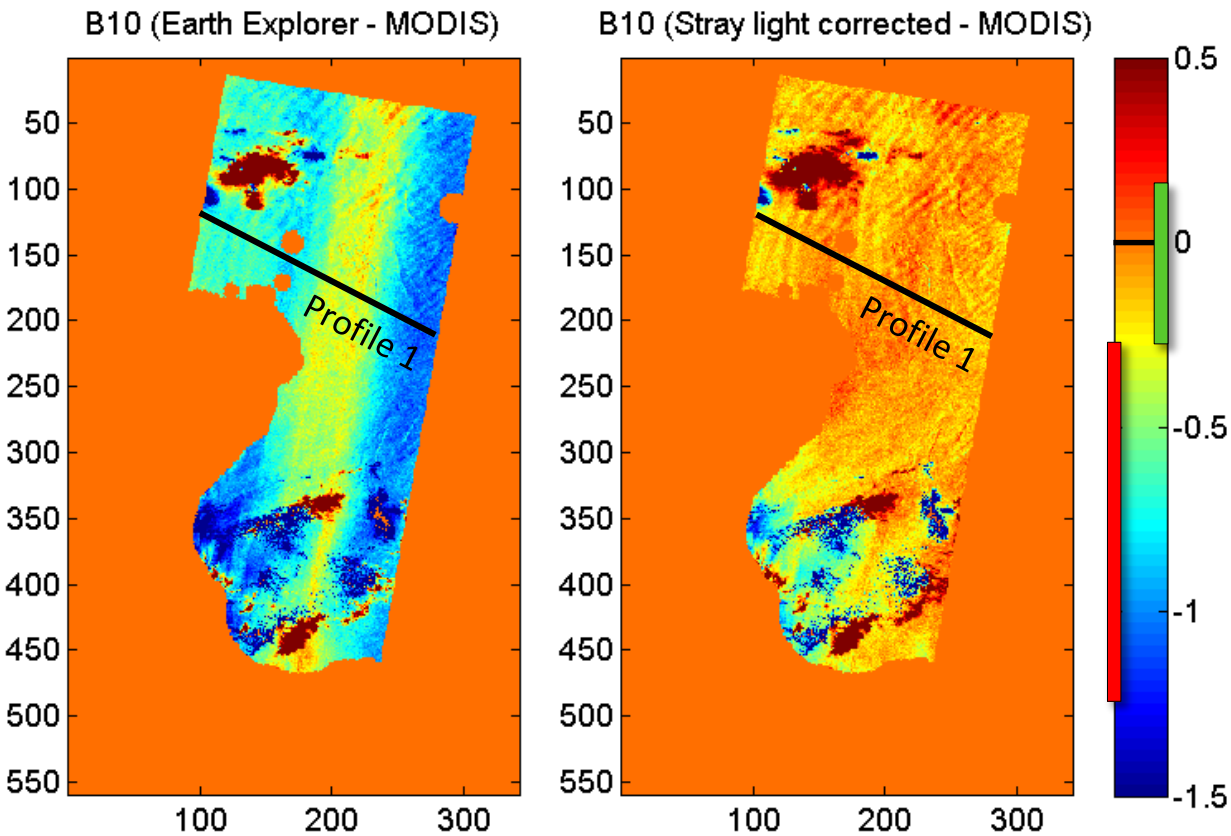


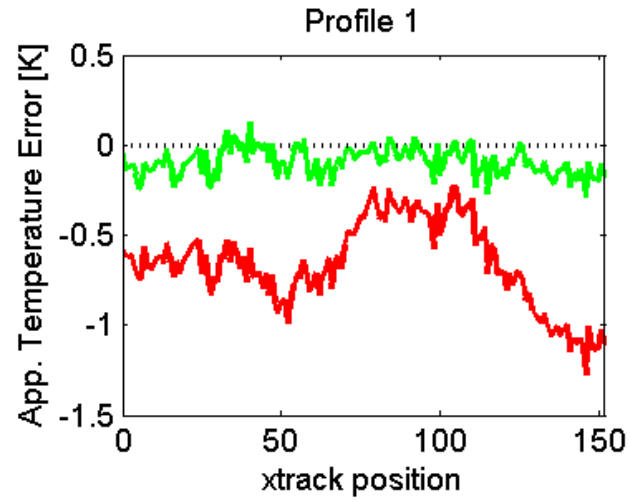




	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.301	0.123	1.642	0.182	-1.615	-0.134
Profile 2	0.603	0.242	0.991	0.442	-0.788	0.371

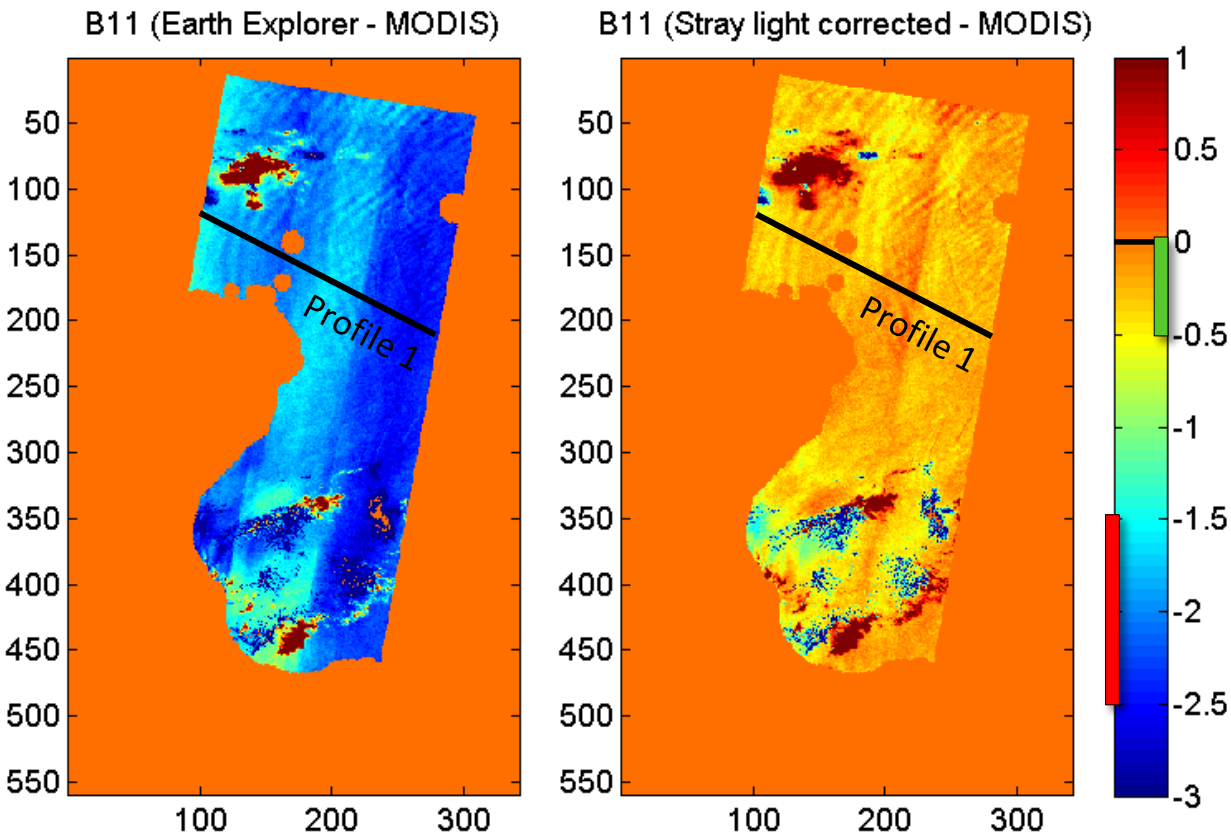
Path 188, Row 035: Band 10

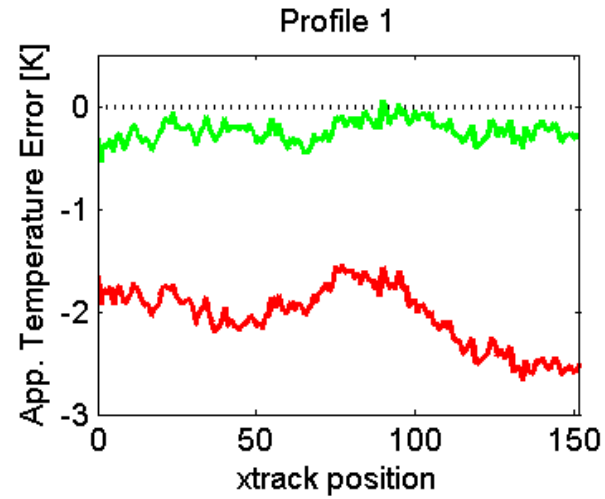




	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.236	0.077	0.703	0.123	-0.662	-0.095

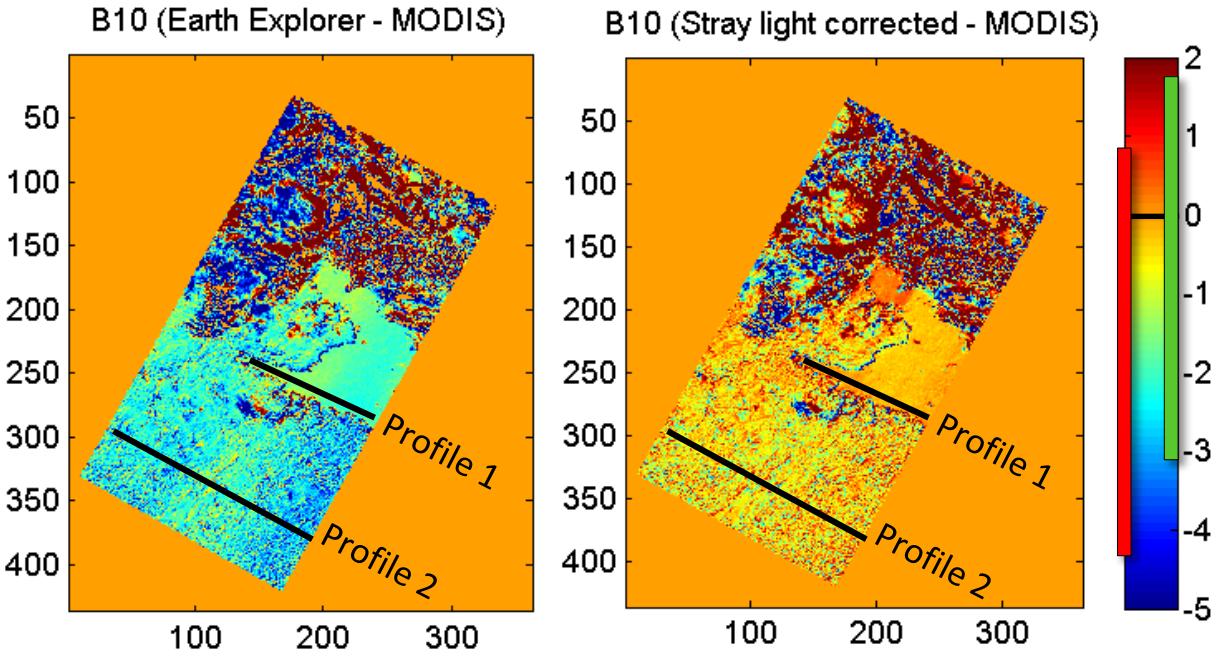
Path 188, Row 035: Band 11

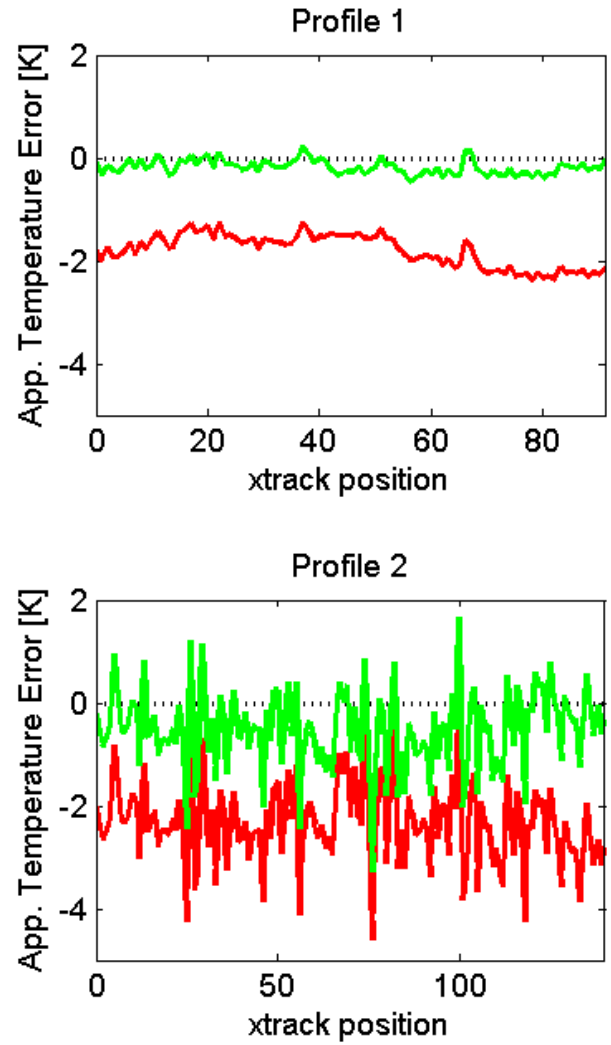




	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.296	0.105	2.072	0.265	-2.051	-0.243

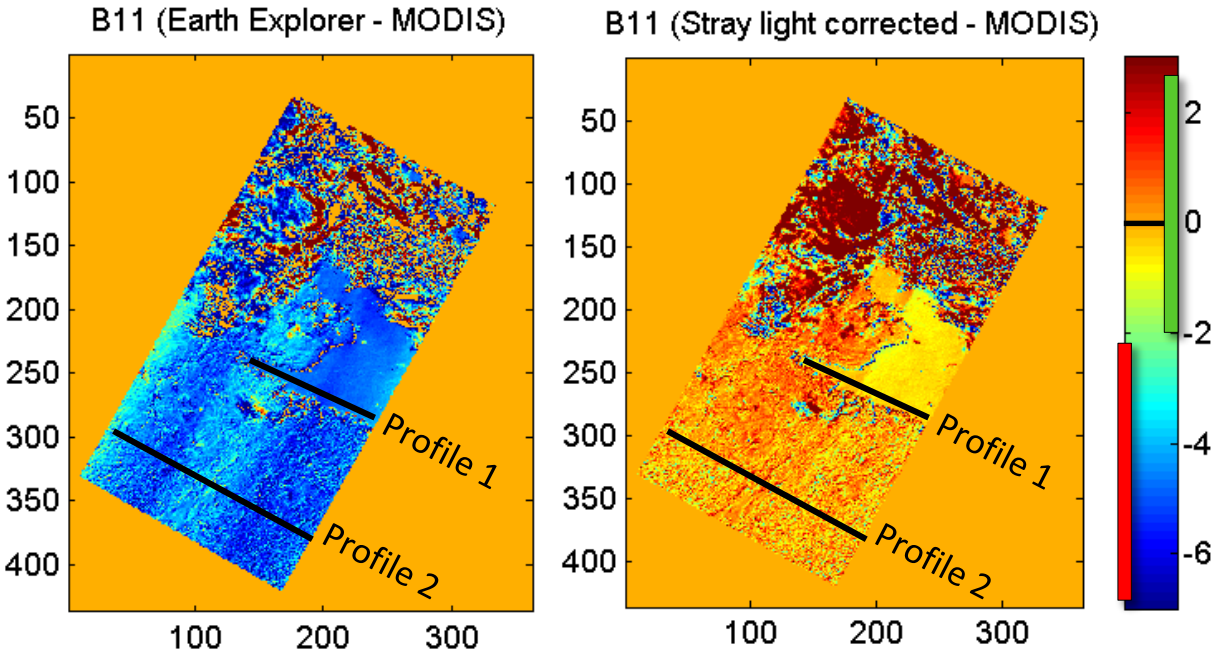
Path 191, Row 010: Band 10

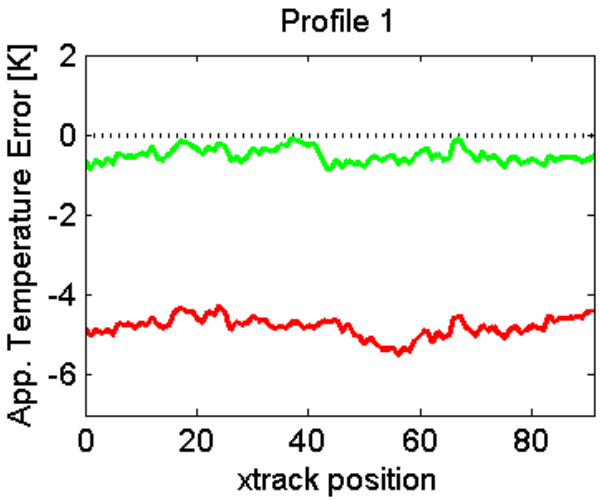


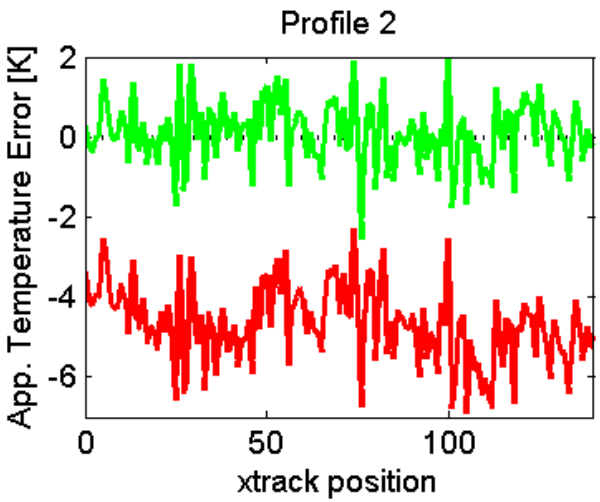


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.317	0.138	1.832	0.231	-1.805	-0.186
Profile 2	0.797	0.773	2.497	0.944	-2.368	-0.546

Path 191, Row 010: Band 11

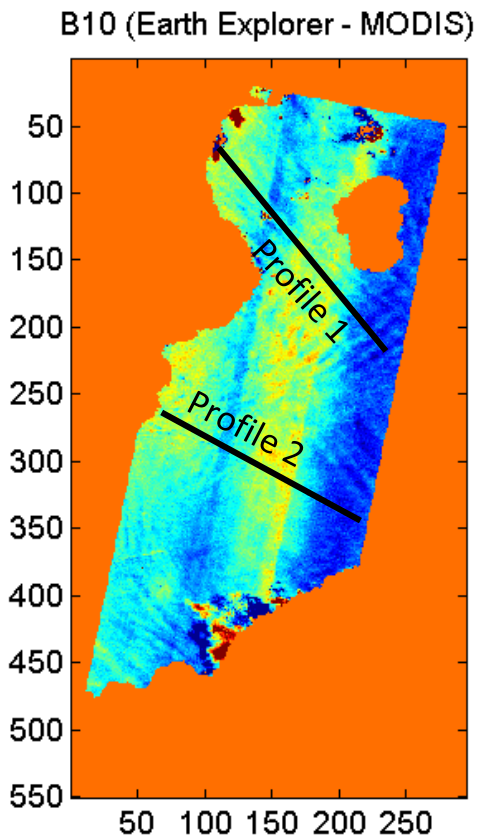


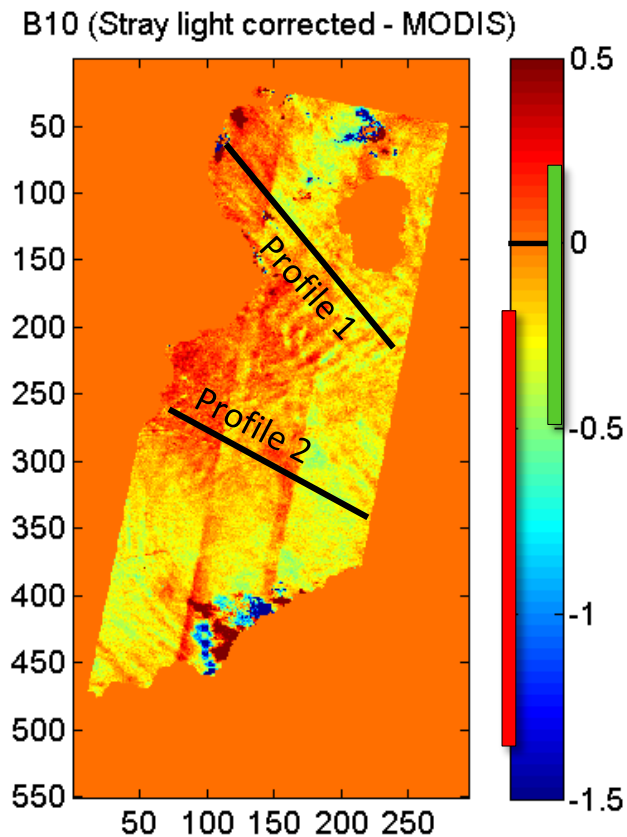


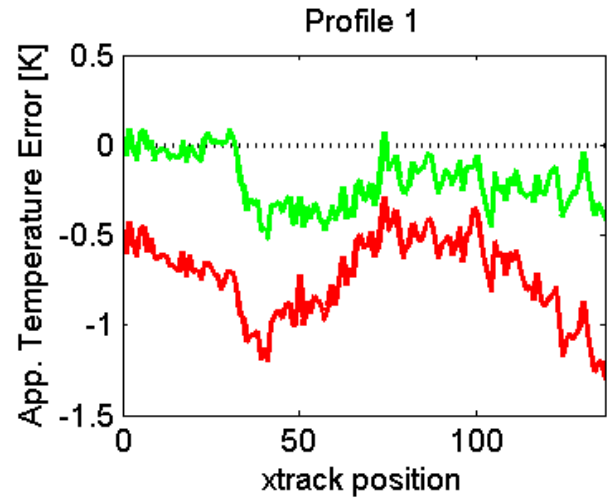


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.254	0.186	4.807	0.553	-4.800	-0.521
Profile 2	0.975	0.814	4.803	0.814	-4.703	0.064

Path 198, Row 033: Band 10

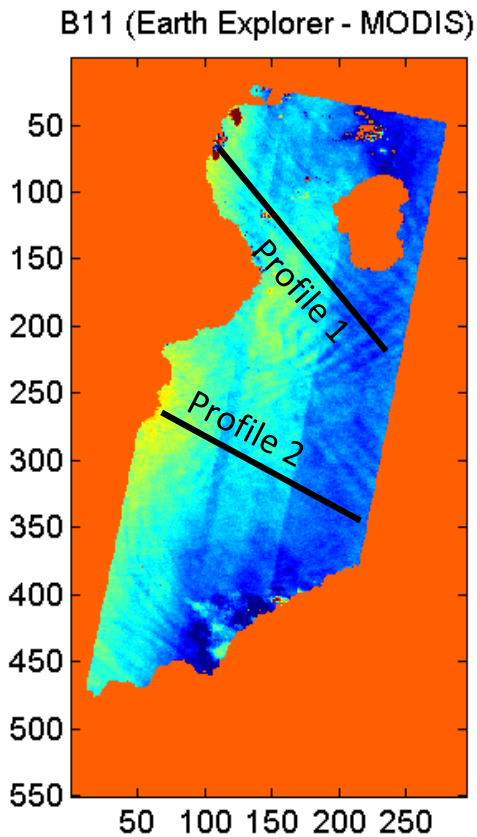


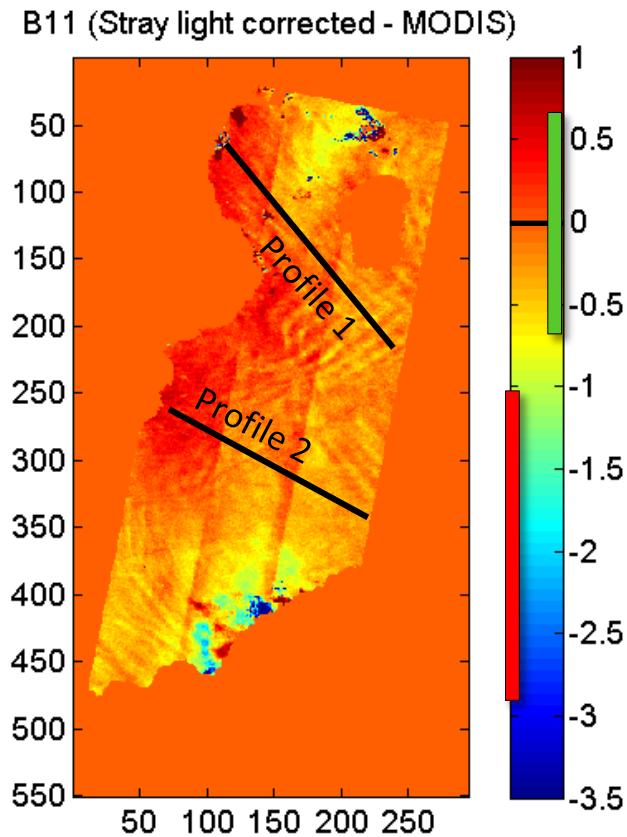


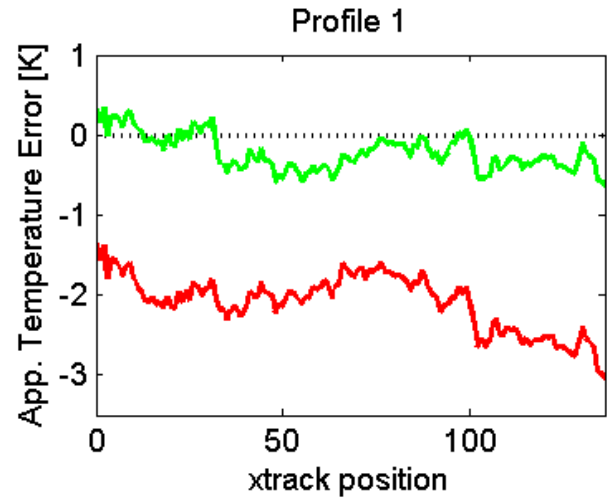


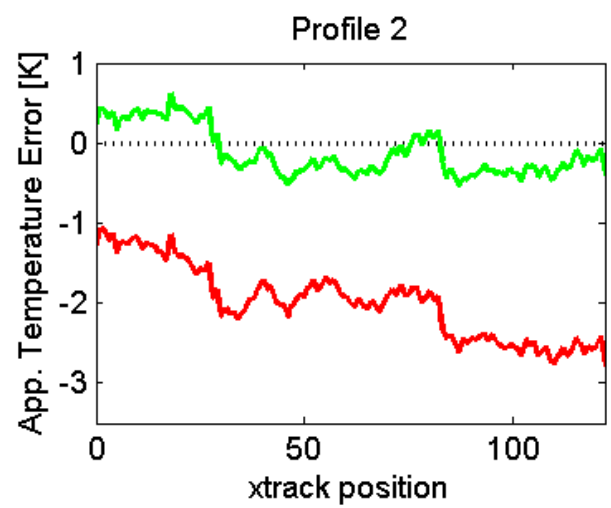
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.224	0.150	0.767	0.251	-0.734	-0.202
Profile 2	0.288	0.174	0.731	0.213	-0.672	-0.124

Path 198, Row 033: Band 11



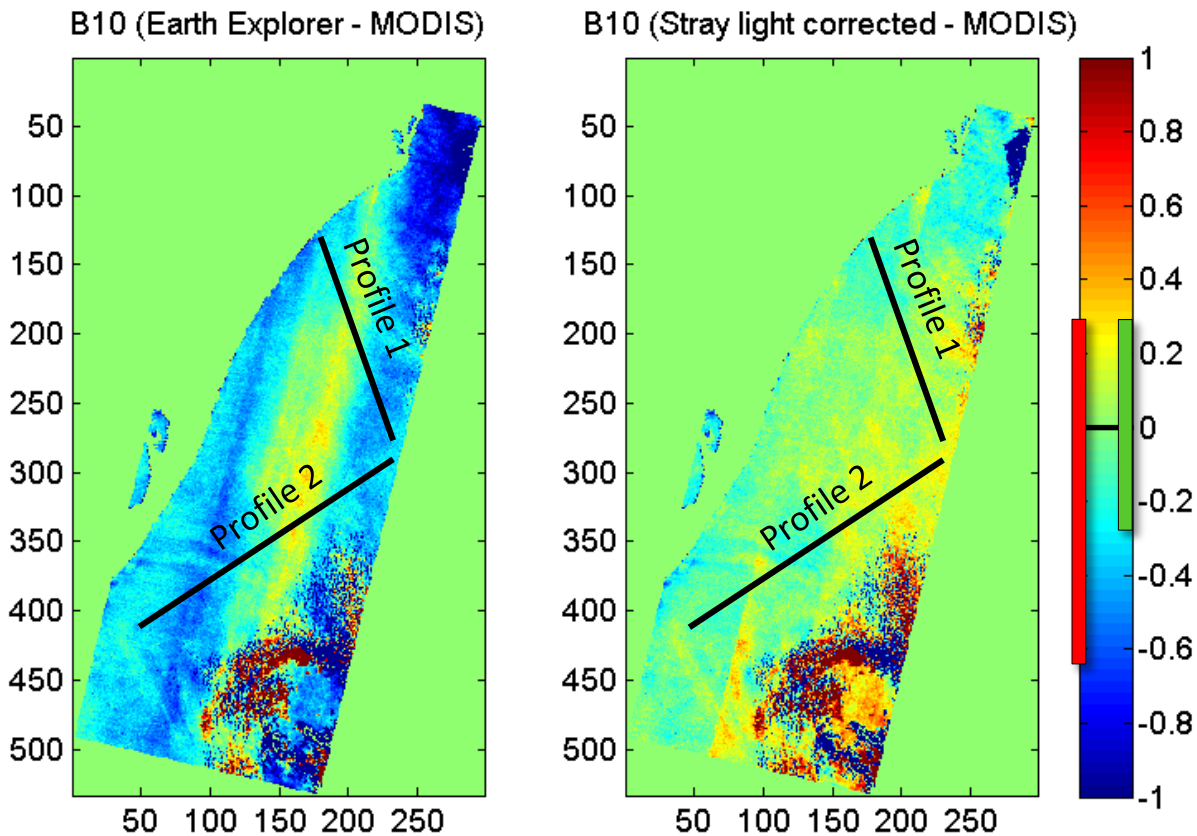


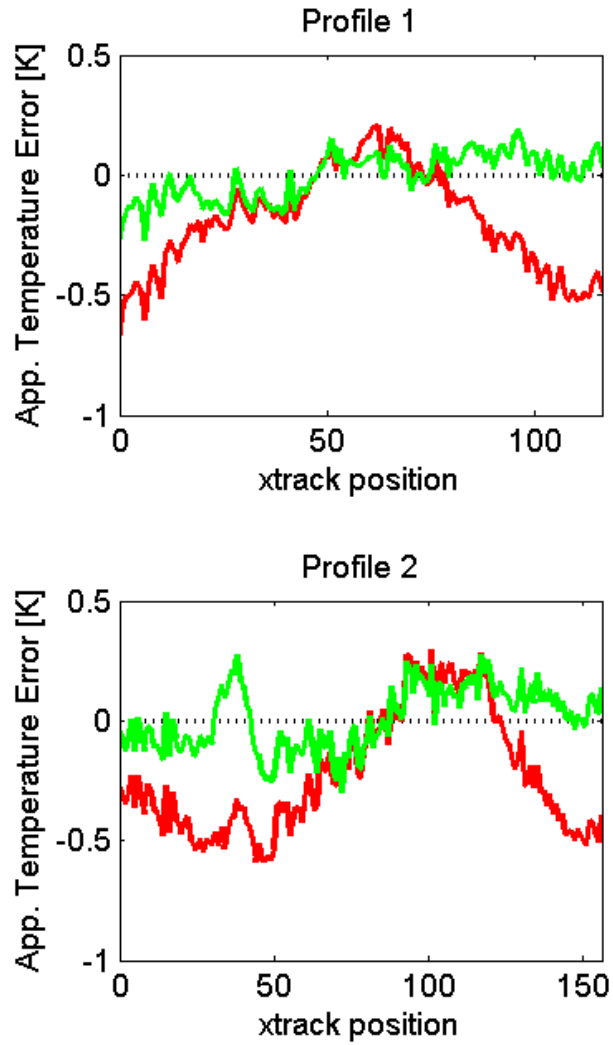


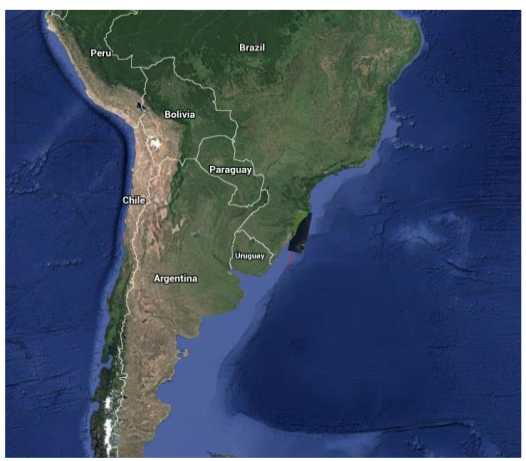


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.352	0.223	2.121	0.314	-2.092	-0.221
Profile 2	0.462	0.299	2.045	0.322	-1.992	-0.122

Path 220, Row 080: Band 10

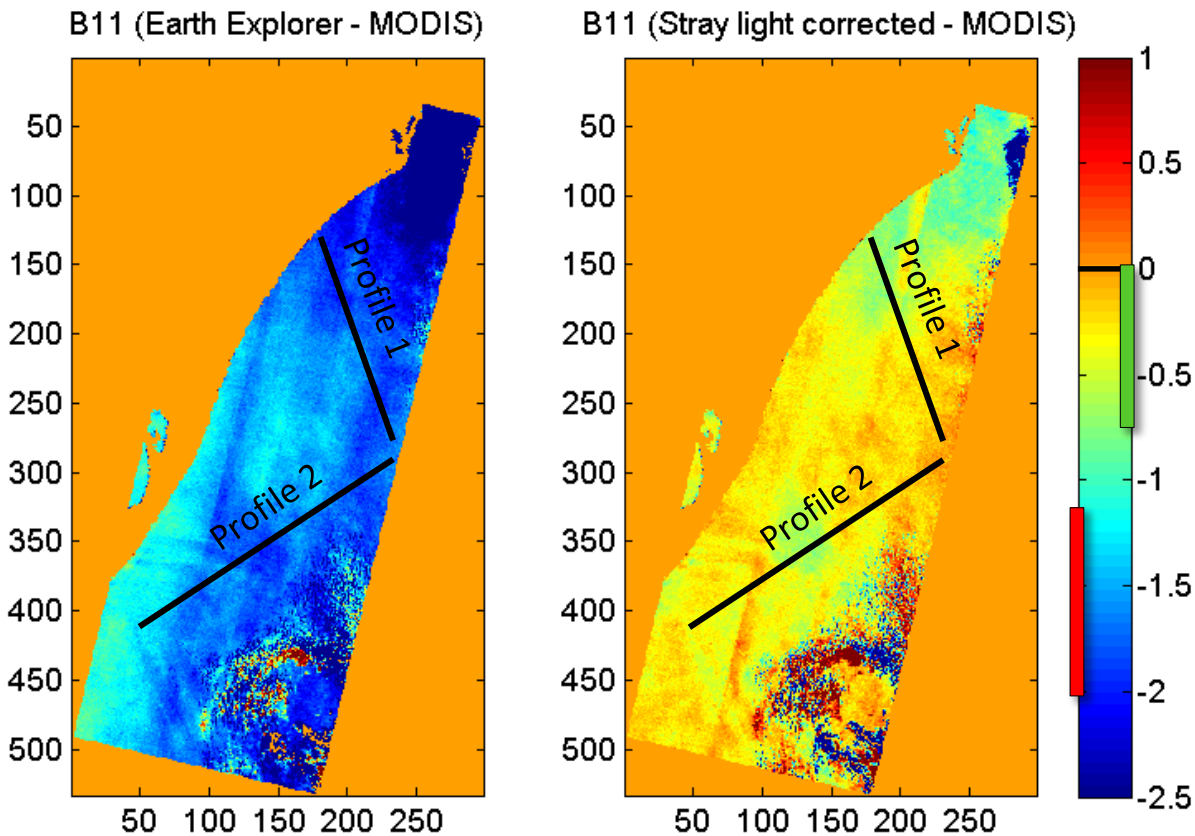


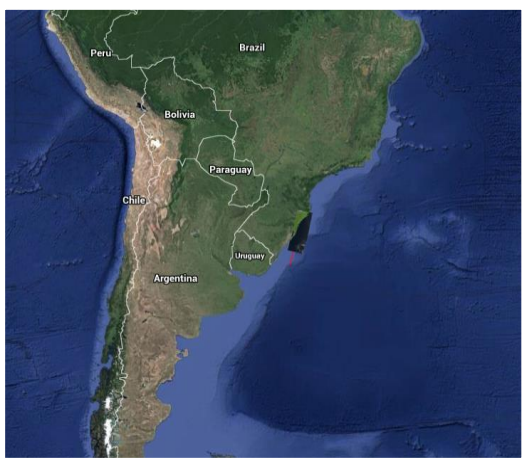


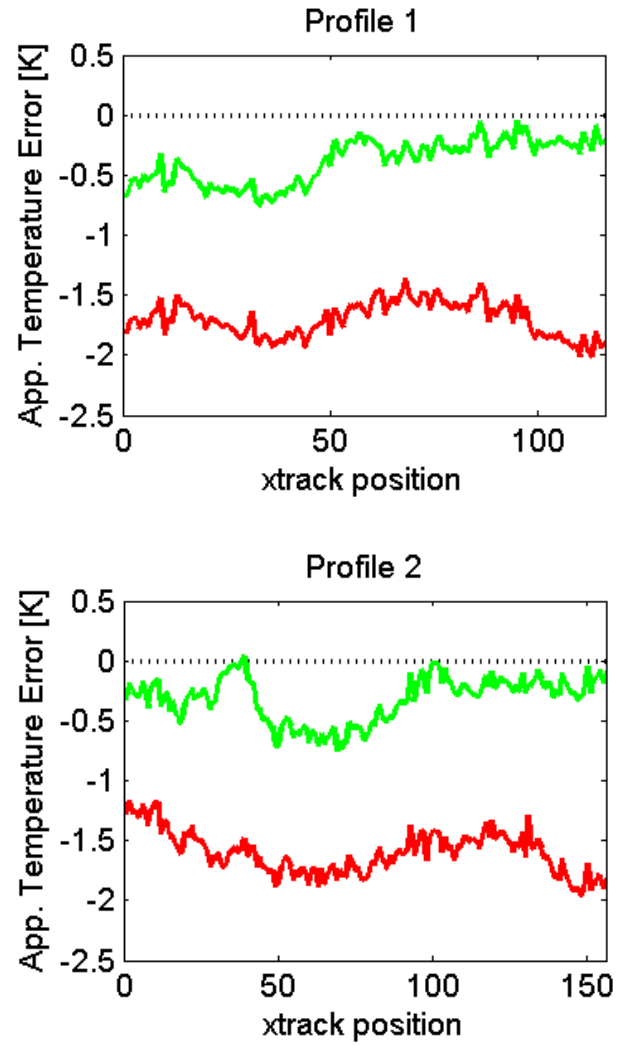


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.213	0.099	0.284	0.099	-0.189	-0.008
Profile 2	0.251	0.132	0.336	0.132	-0.225	0.005

Path 220, Row 080: Band 11

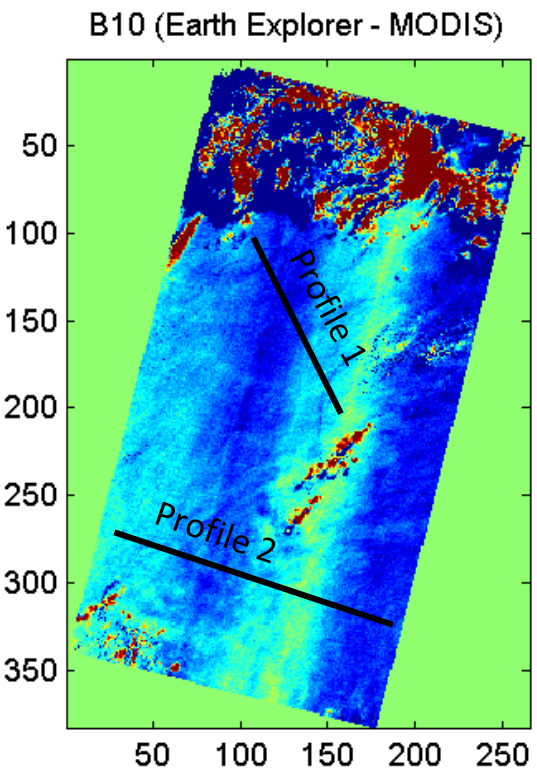


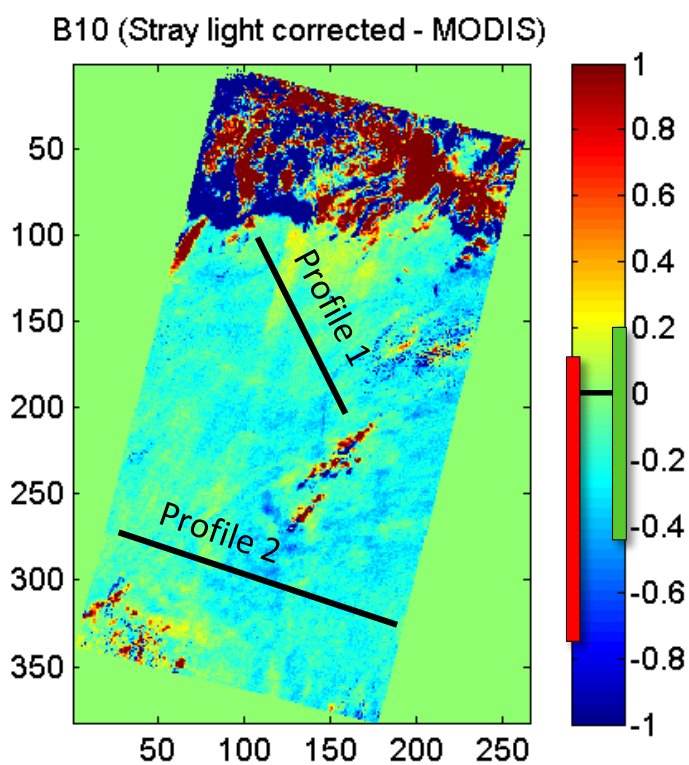


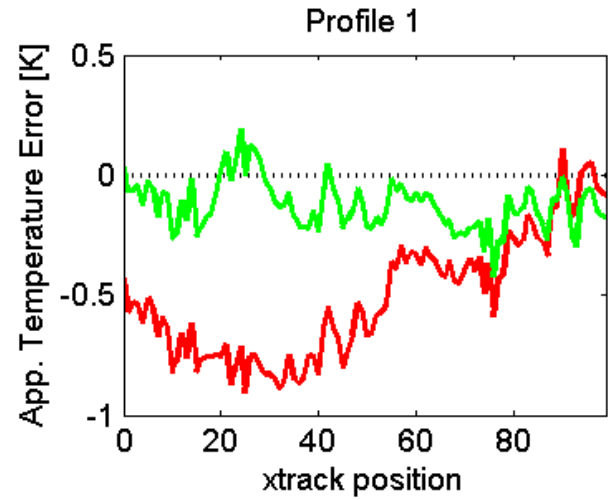


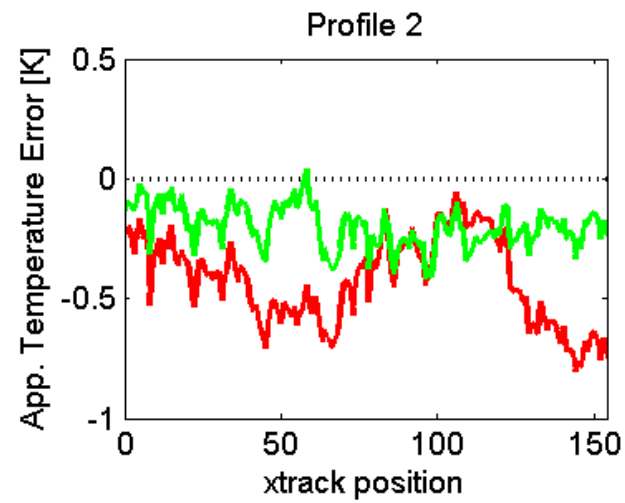
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.146	0.186	1.710	0.431	-1.704	-0.390
Profile 2	0.179	0.190	1.613	0.373	-1.603	-0.321

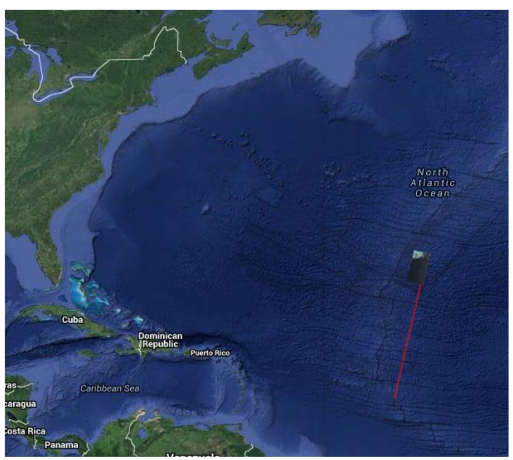
Path 223, Row 041: Band 10





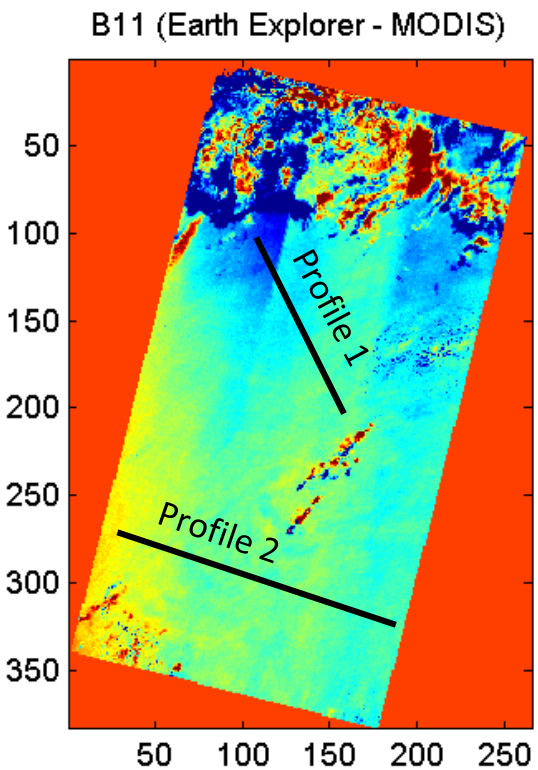


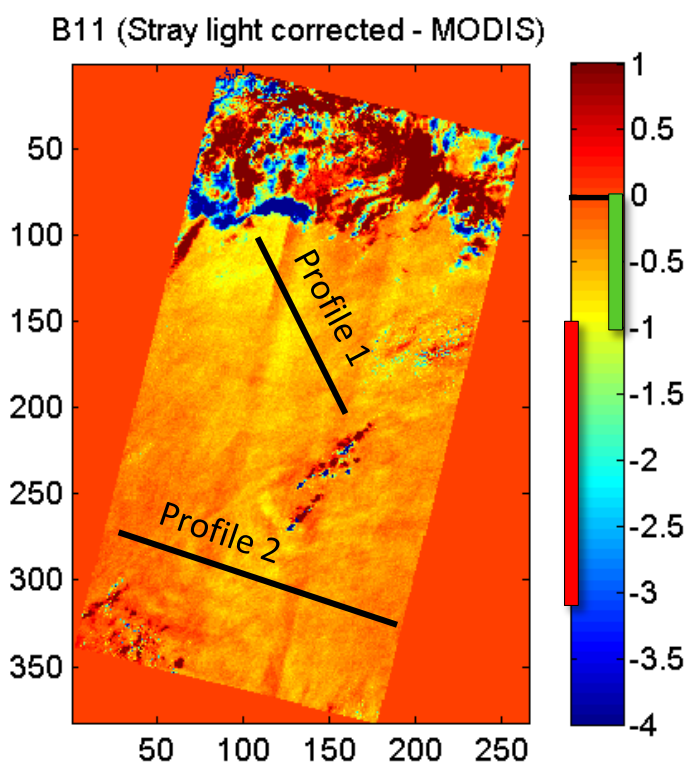


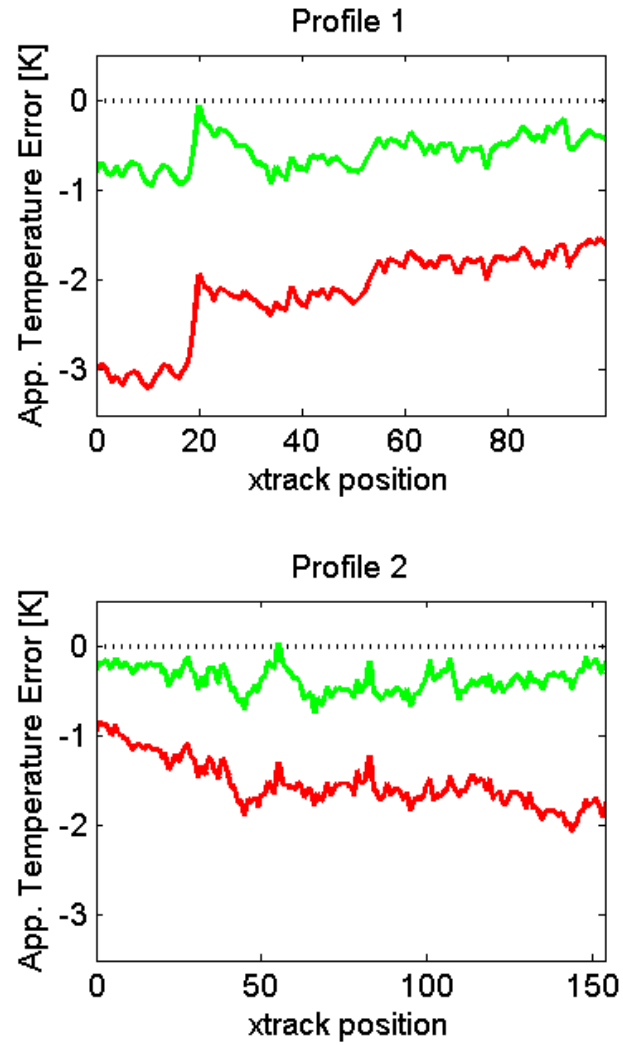


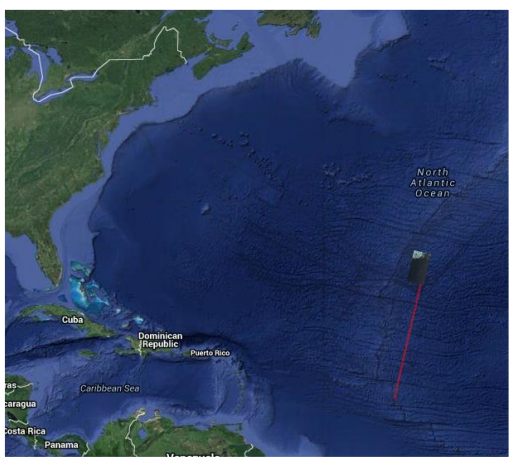
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.257	0.104	0.573	0.162	-0.512	-0.125
Profile 2	0.181	0.089	0.462	0.220	-0.425	-0.201

Path 223, Row 041: Band 11



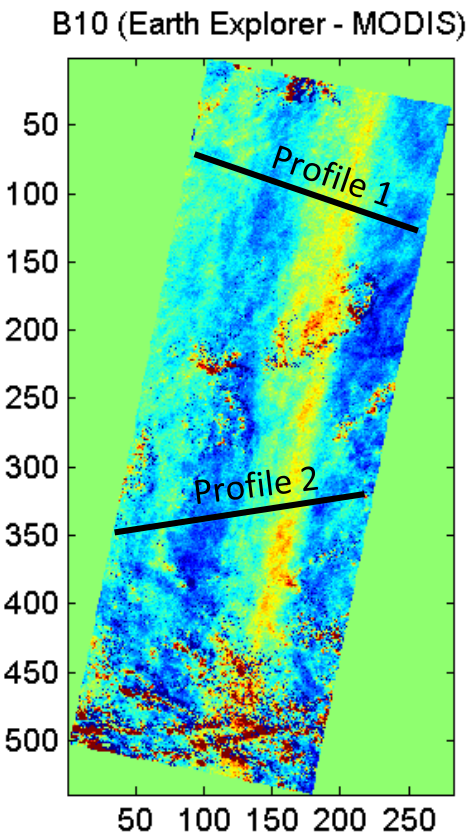


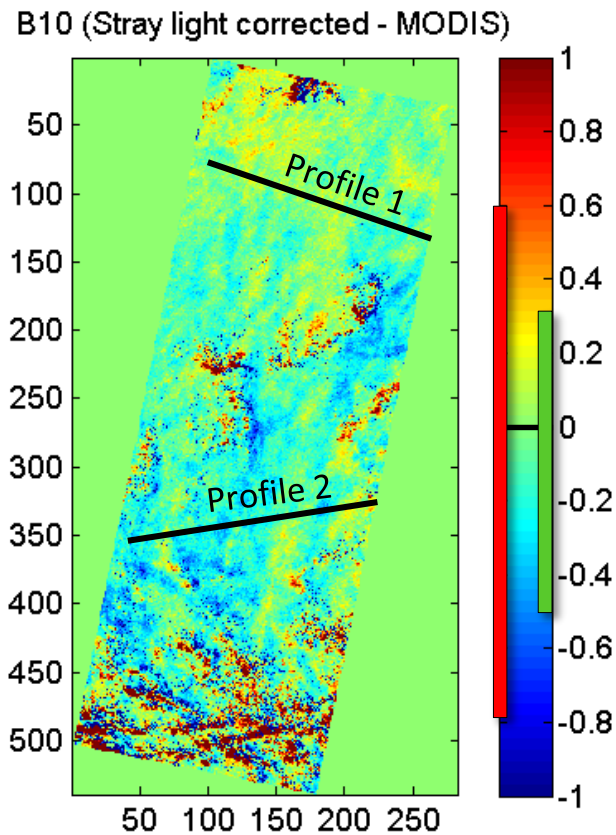


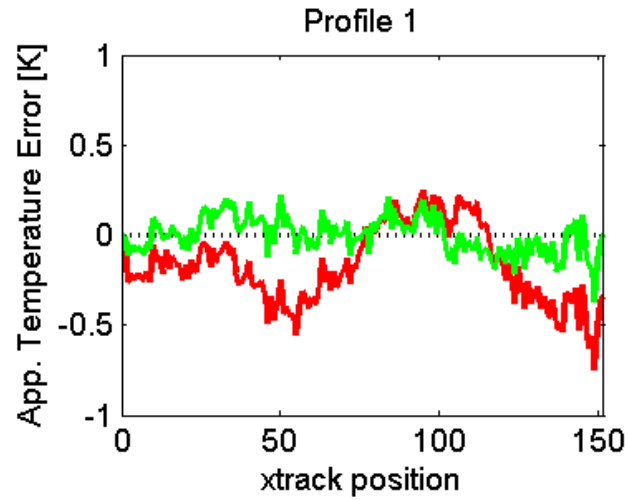


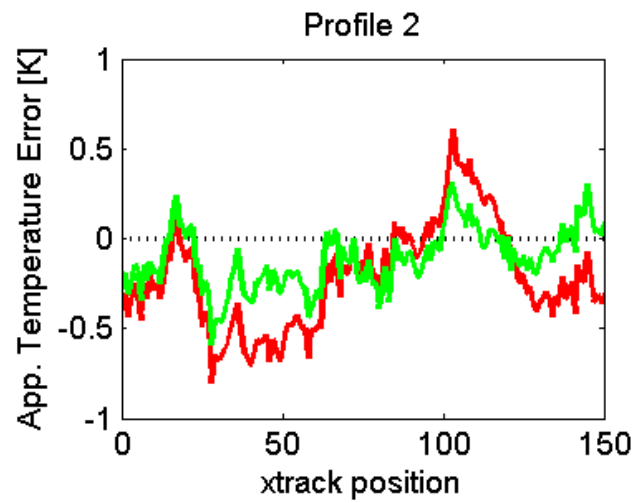
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.487	0.190	2.211	0.617	-2.158	-0.587
Profile 2	0.263	0.142	1.556	0.404	-1.534	-0.378

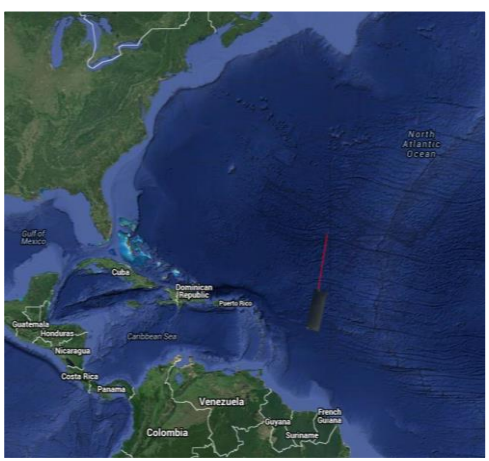
Path 230, Row 045: Band 10





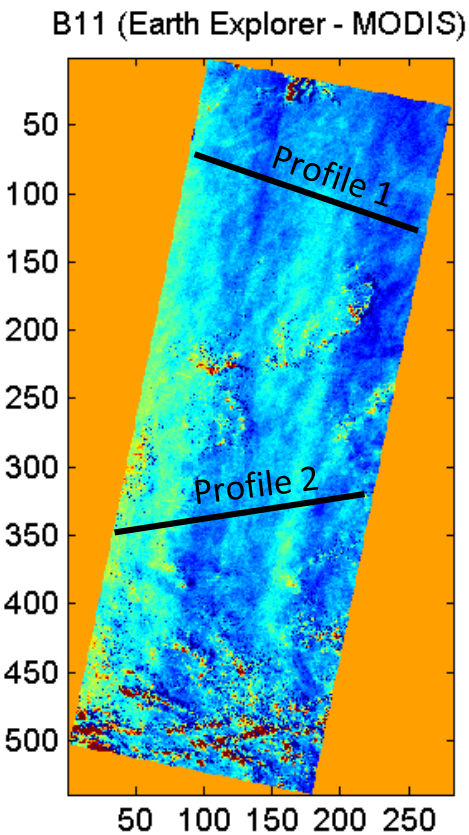


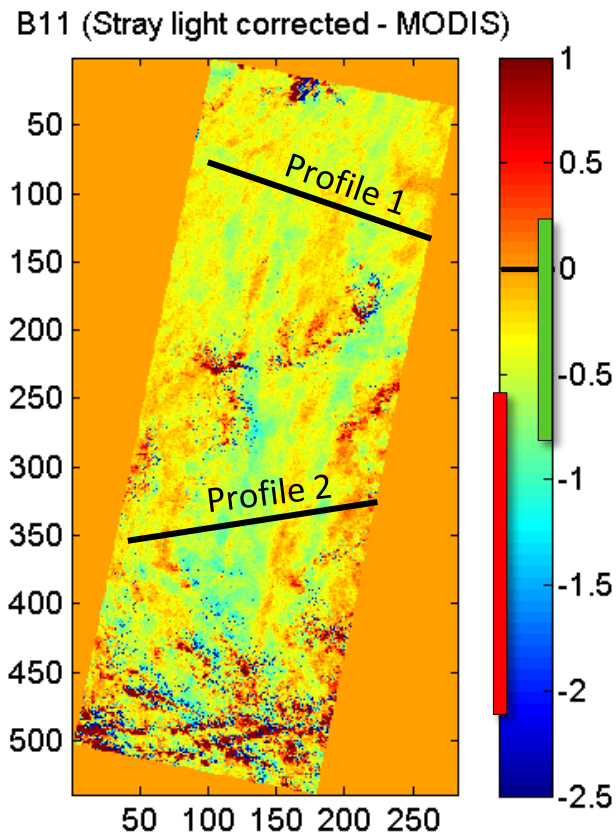


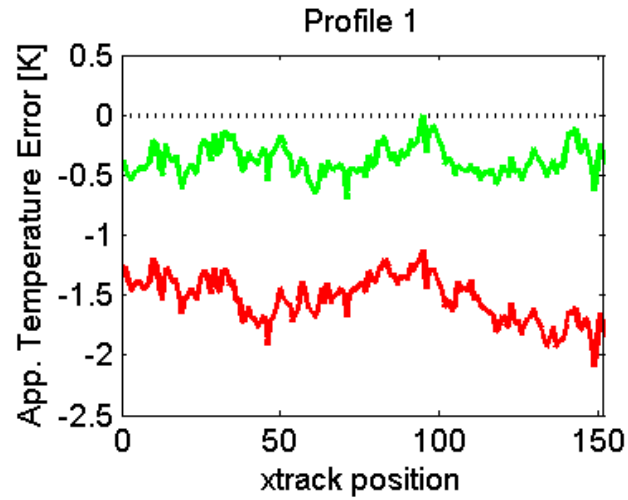


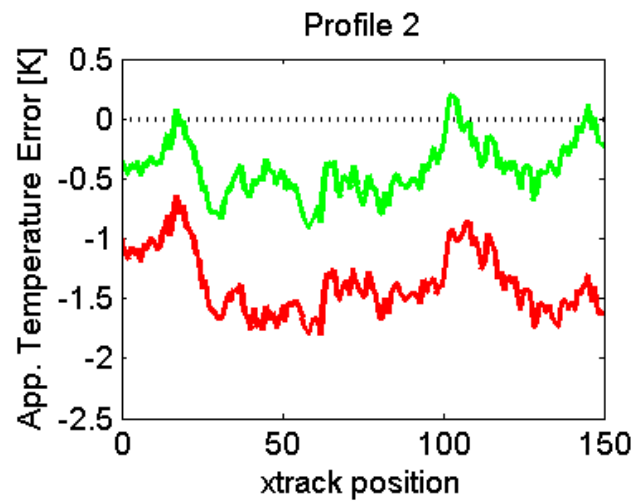
	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.209	0.102	0.271	0.102	-0.173	-0.006
Profile 2	0.287	0.168	0.360	0.204	-0.219	-0.116

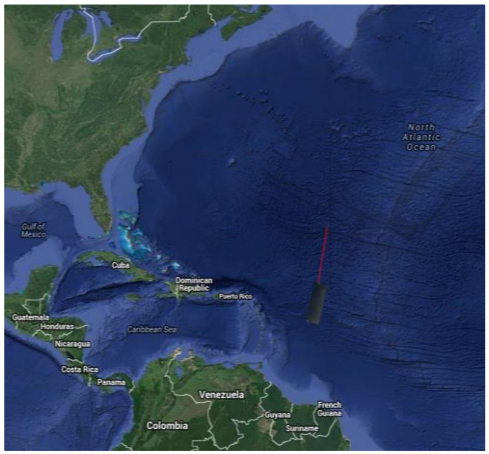
Path 230, Row 045: Band 11





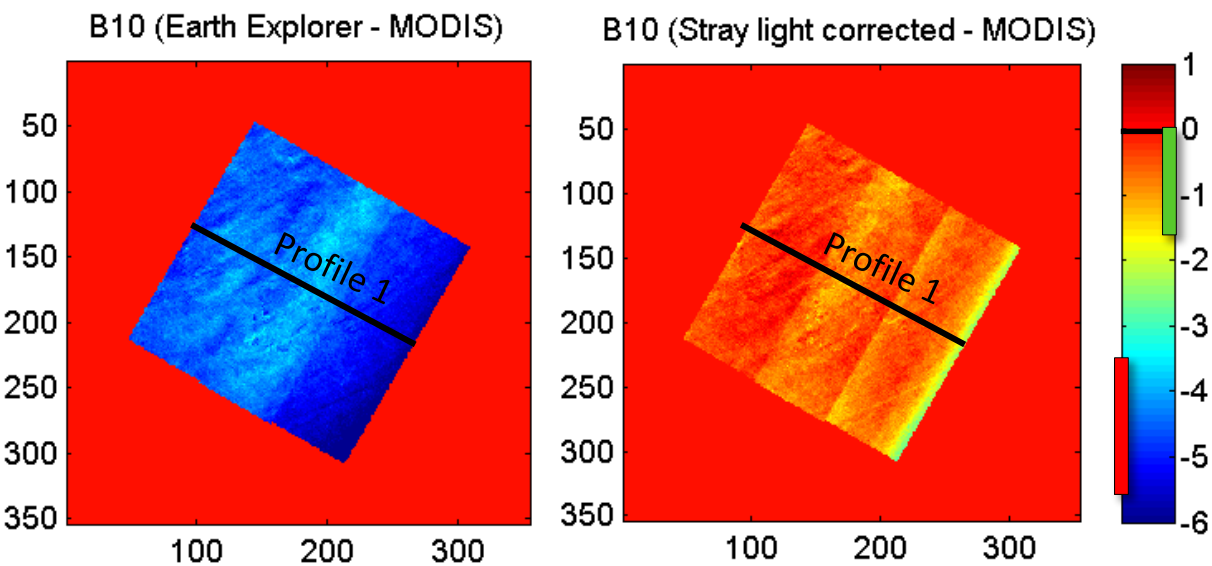


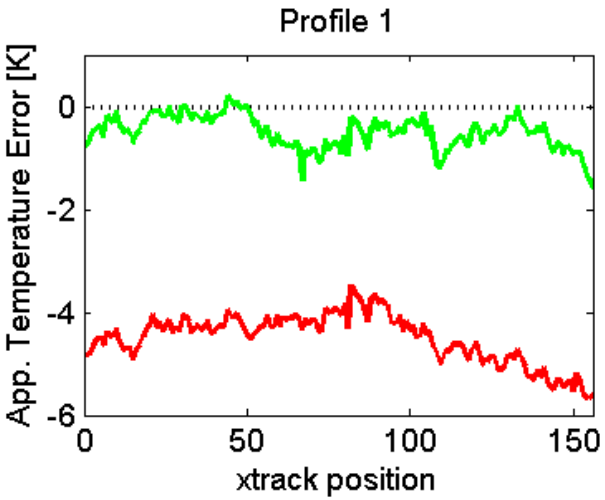


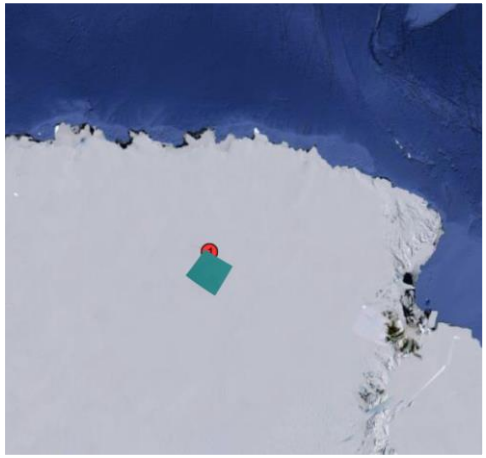


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.188	0.126	1.547	0.400	-1.535	-0.380
Profile 2	0.265	0.229	1.406	0.475	-1.381	-0.417

Path 087, Row 113: Band 10

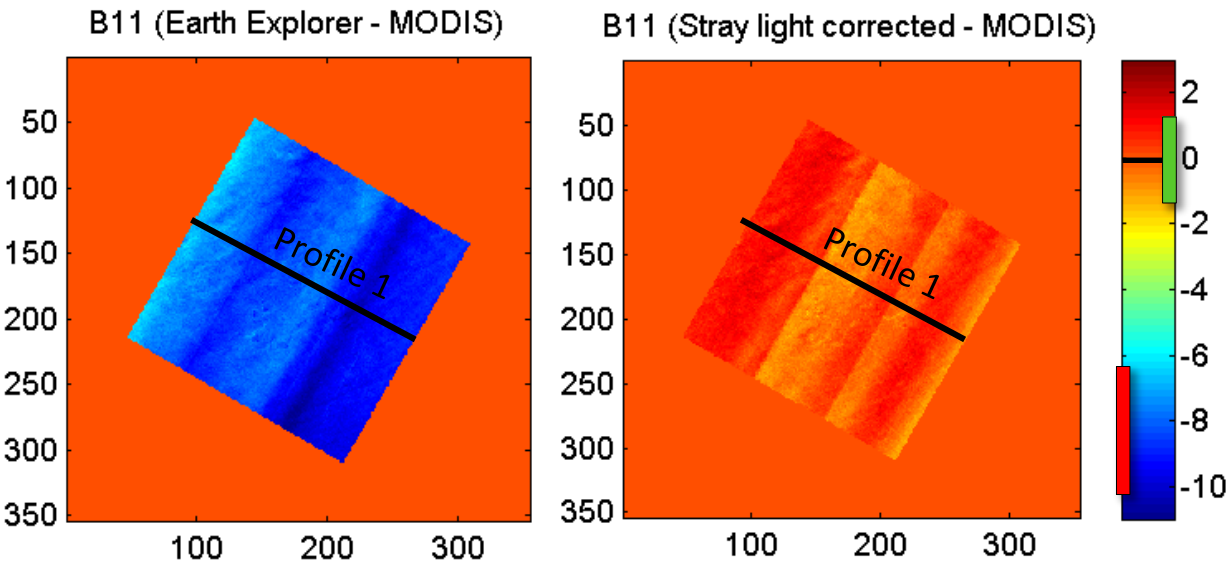


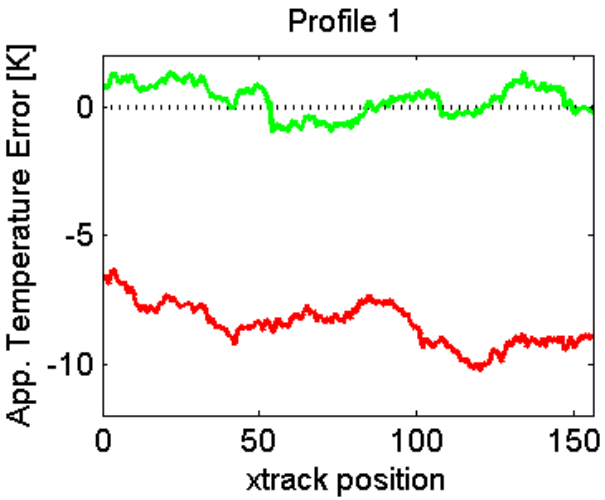


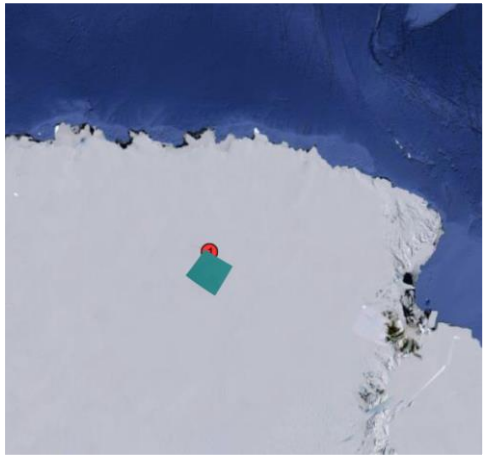


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.480	0.332	4.531	0.603	-4.506	-0.504

Path 087, Row 113: Band 11

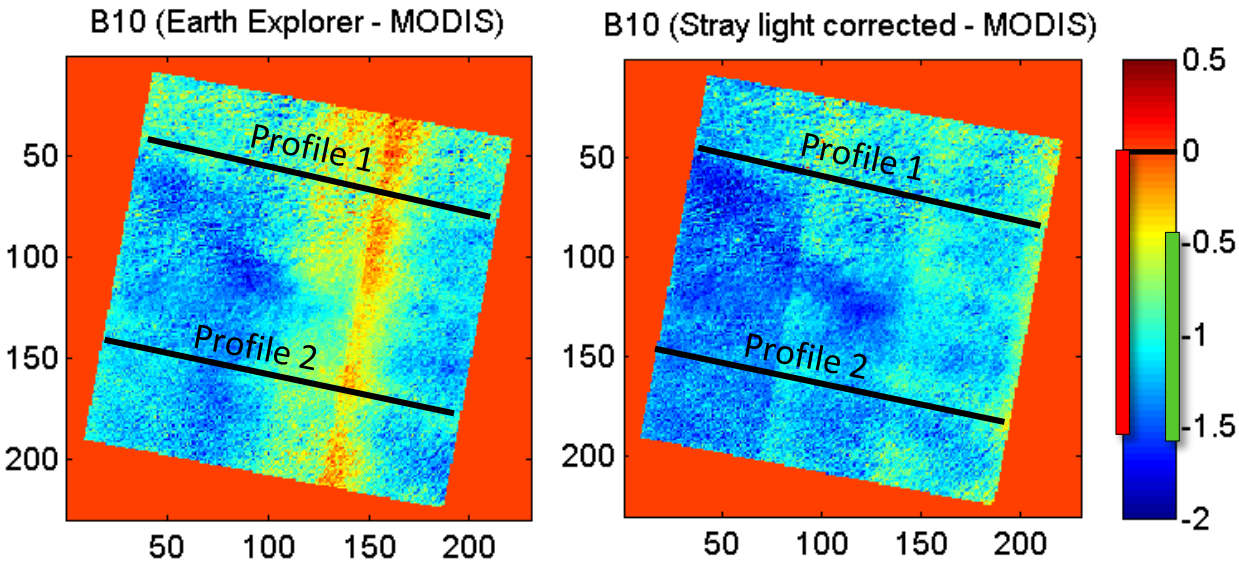


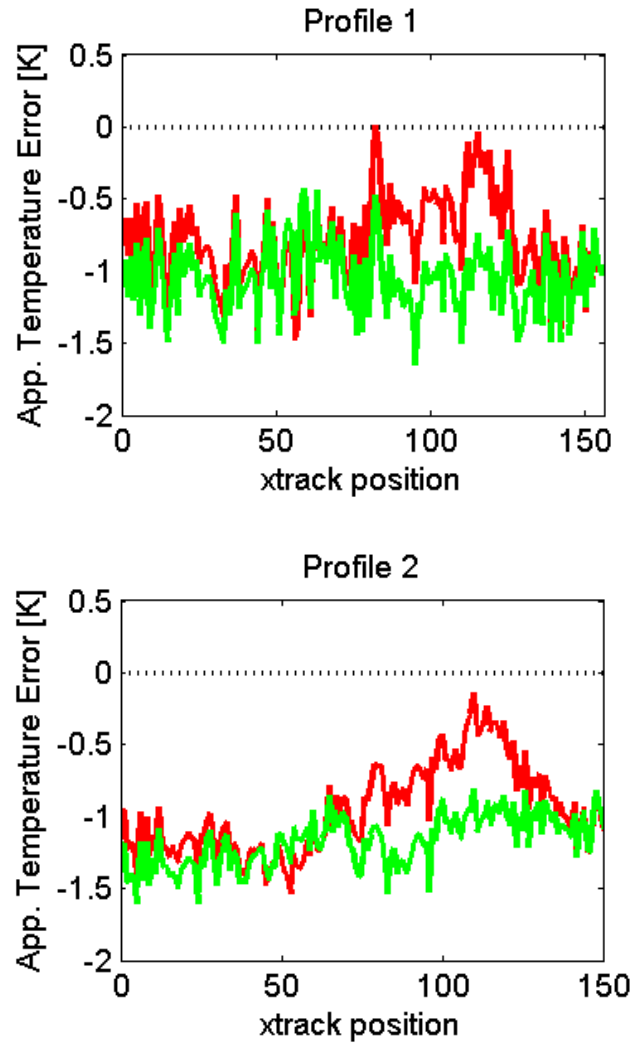




	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.836	0.625	8.505	0.667	-8.464	0.237

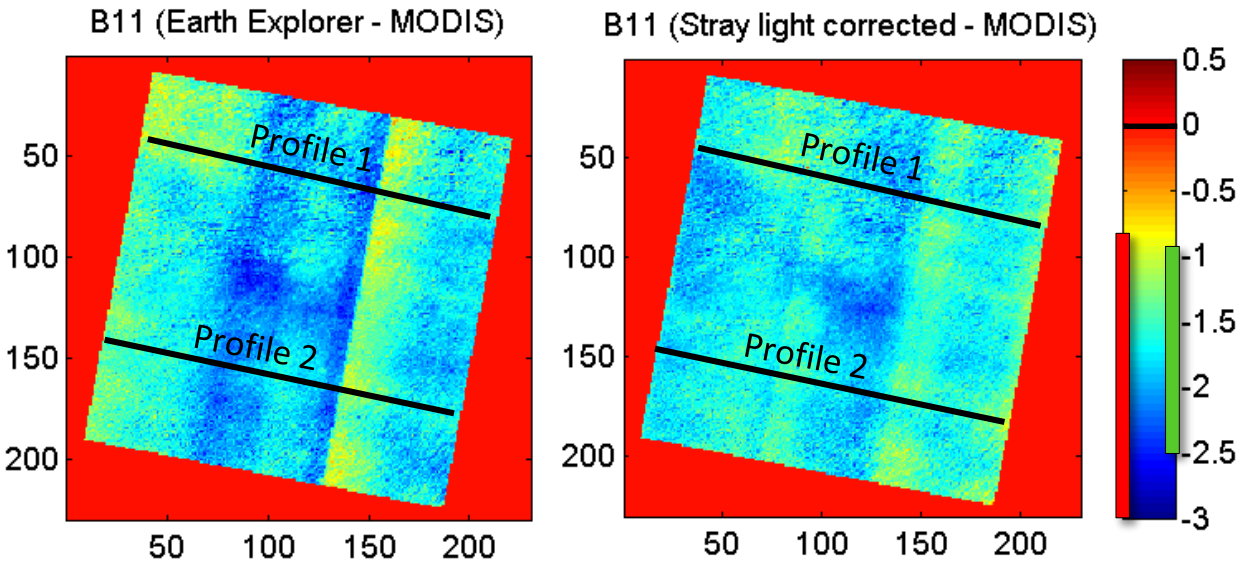
Path 198, Row 046: Band 10

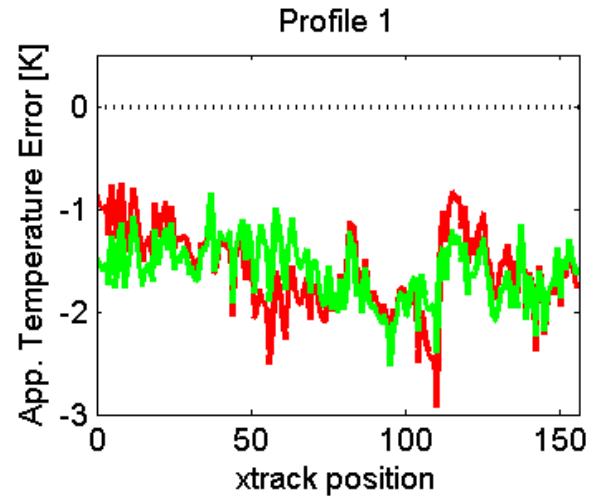


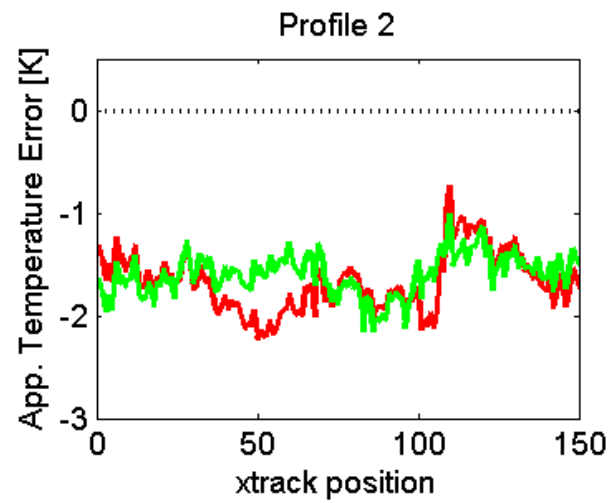


	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.304	0.242	0.853	1.089	-0.797	-1.062
Profile 2	0.311	0.179	1.008	1.193	-0.959	-1.179

Path 198, Row 046: Band 11

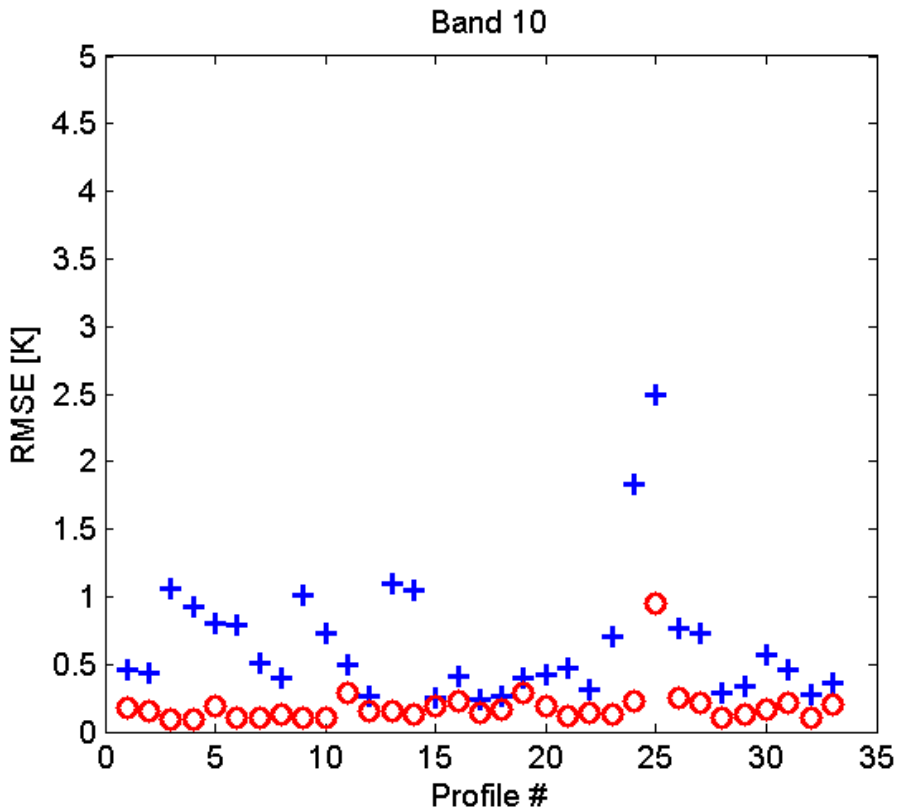


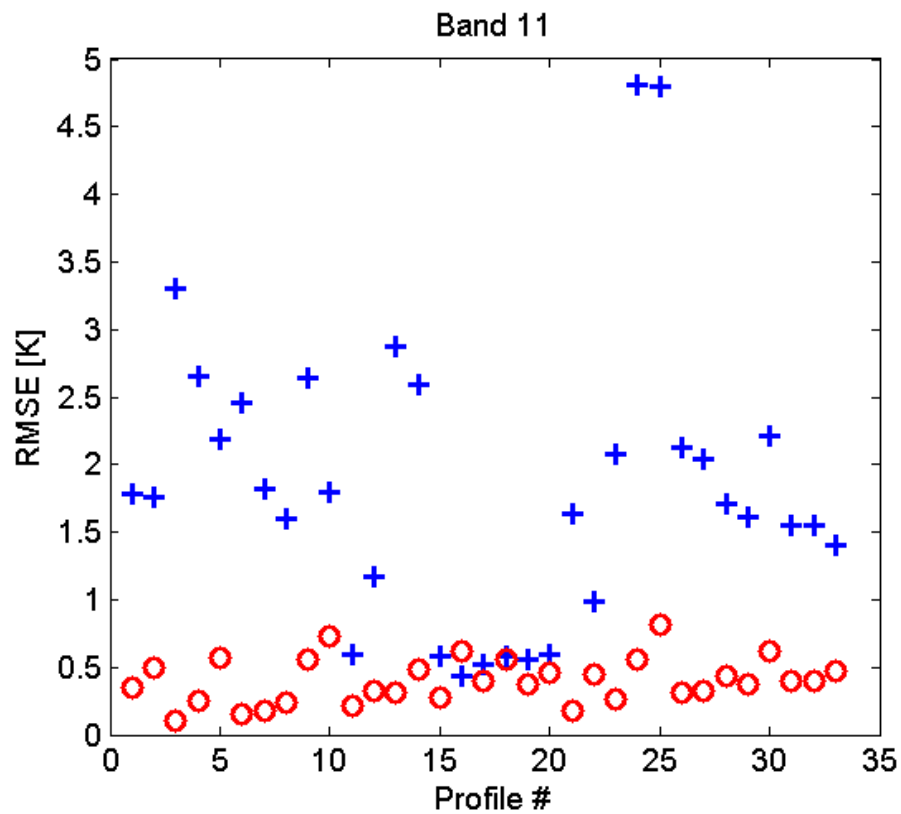




	Std. Deviation [K]		RMS error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.417	0.302	1.651	1.646	-1.597	-1.618
Profile 2	0.288	0.202	1.704	1.620	-1.680	-1.608

RMSE summary ("absolute calibration"):

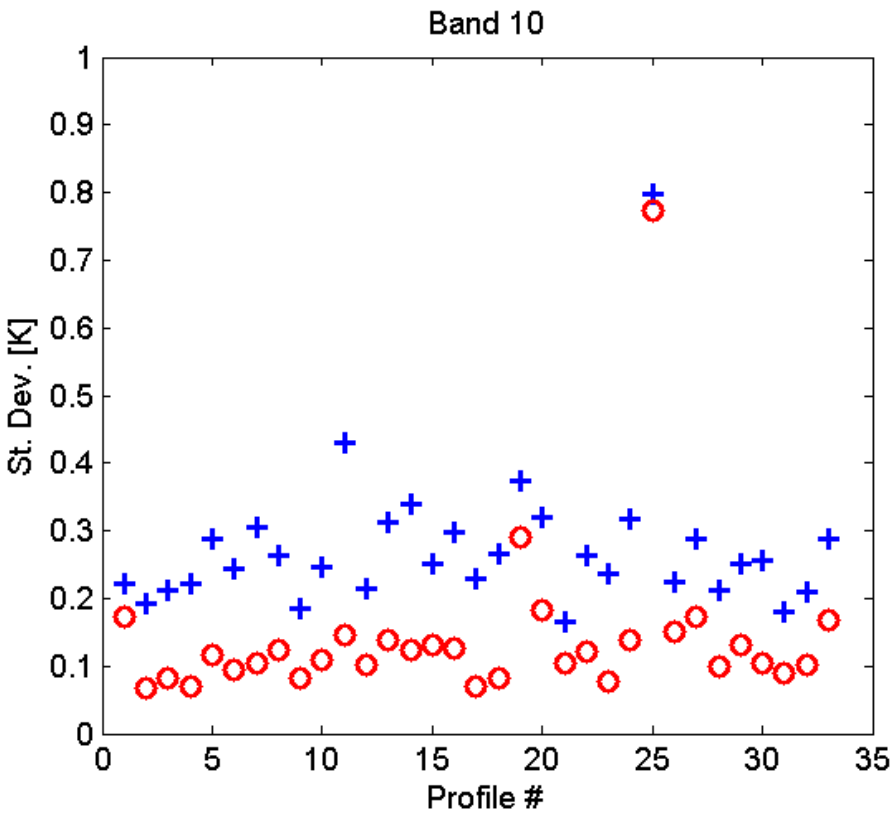


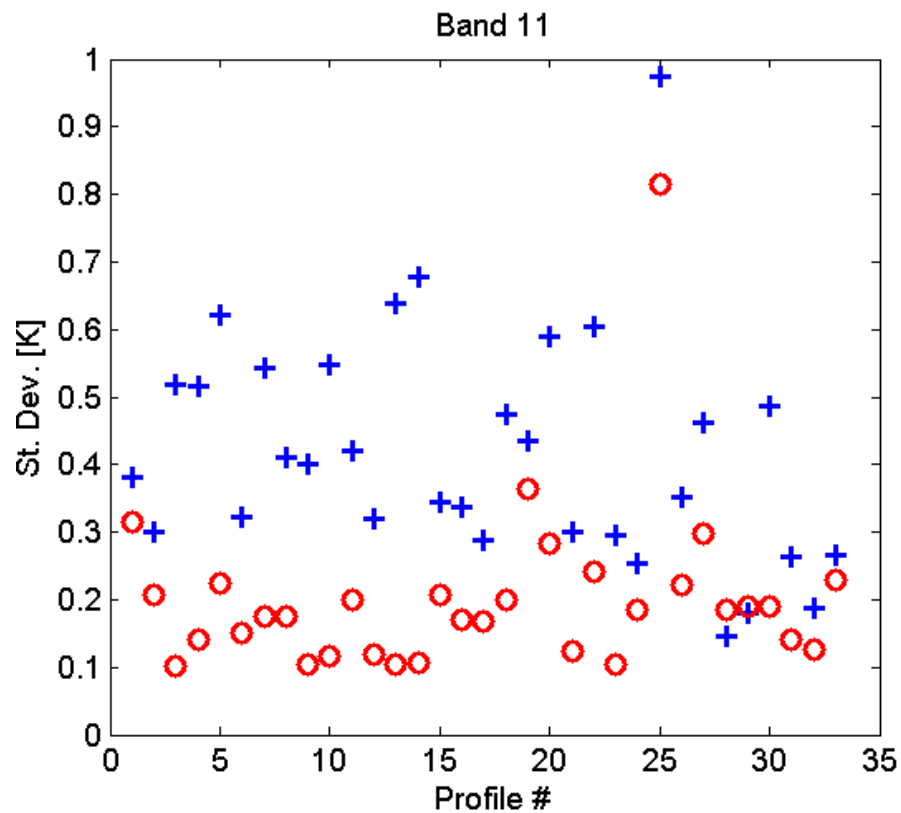


+ Current Product

o Stray Light Corrected

St Dev. Summary ("relative calibration"):





+ Current Product

o Stray Light Corrected

Additional Absolute Cal Analysis for Cold Scenes

Brian Wenny (NASA Goddard) compared Terra/MODIS with TIRS over Antarctica.

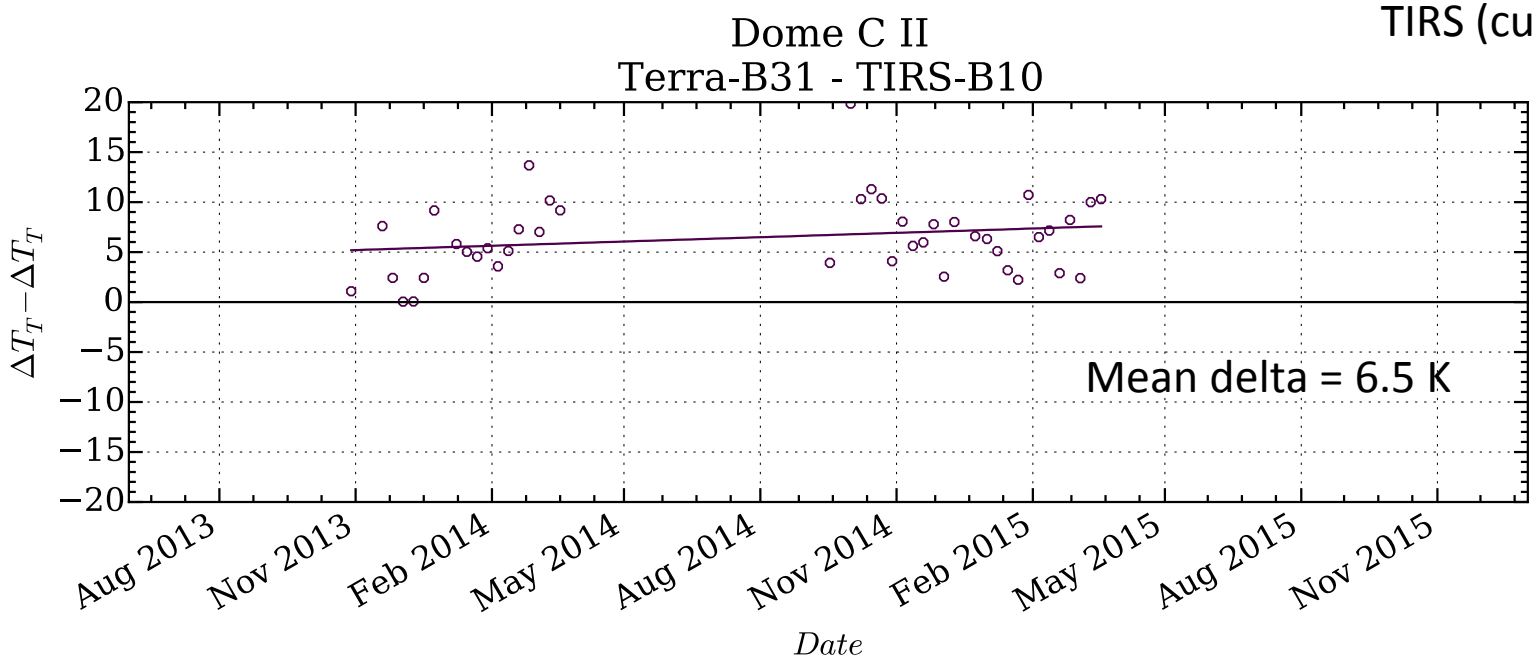
- Compared TIRS current product (from Earth Explorer) to MODIS
- Compared TIRS stray light corrected product to MODIS

AGU Poster:

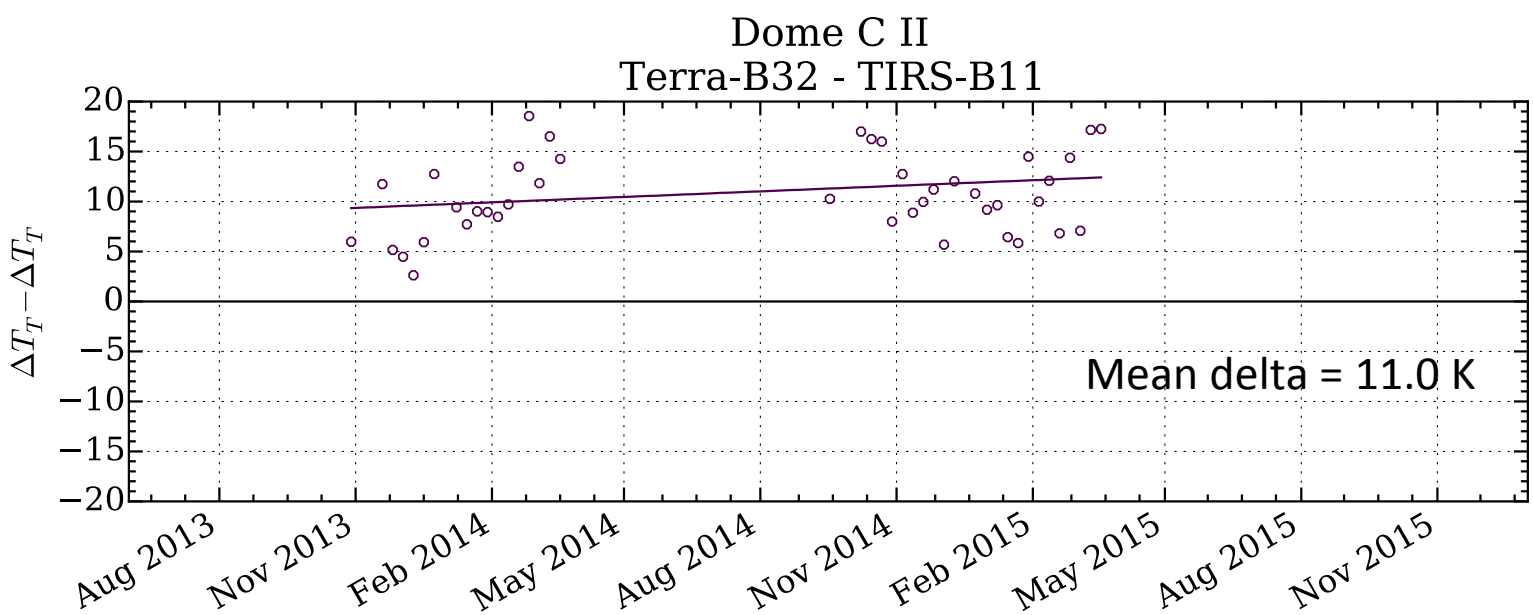
- Wenny, Angal, Brinkmann, Montanaro, Thome, and Xiong. "Assessing Landsat 8 TIRS calibration stability using MODIS." *Calibration and Validation of Satellite Microwave, Infrared, and Solar Reflective Observations III*. American Geophysical Union (AGU) Fall Meeting, 2015.

MODIS vs TIRS difference for Dome-C, Antarctica

TIRS (current product)



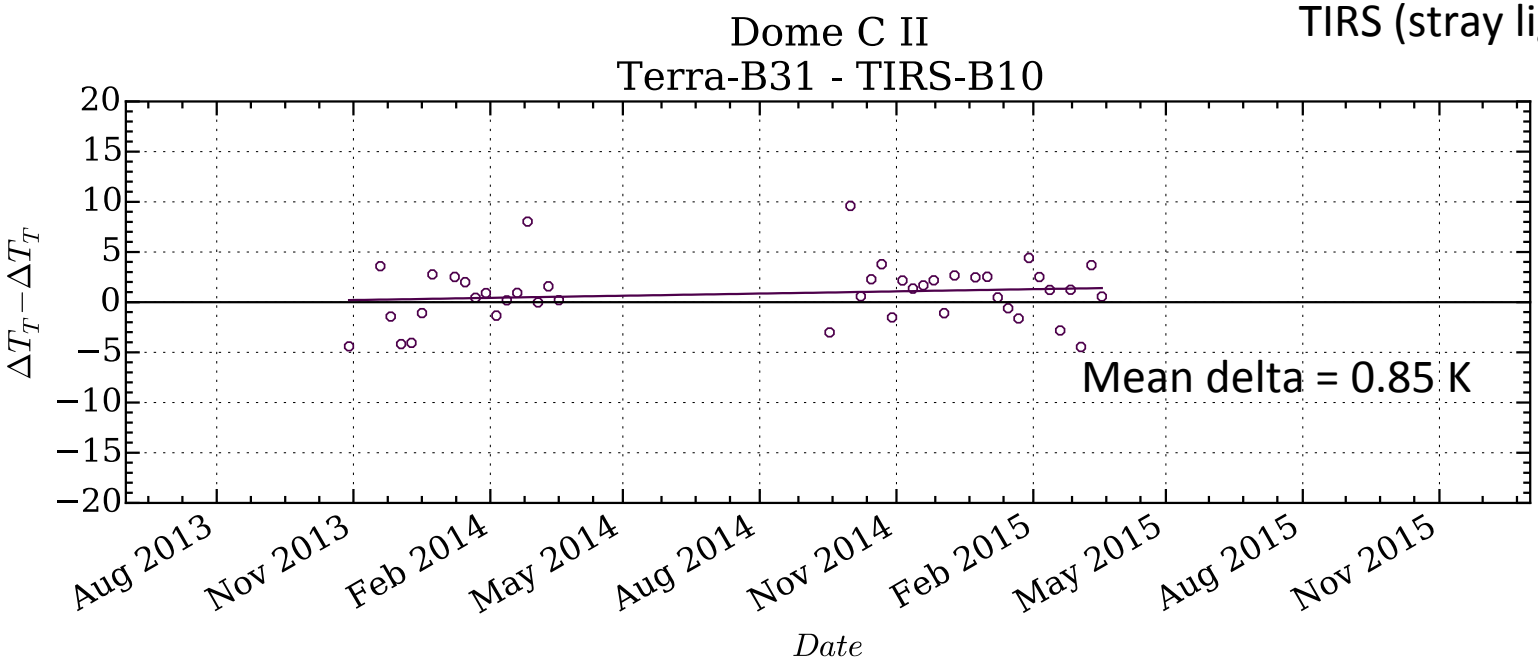
$\mu = 6.480$
$\sigma = 3.844$
$\beta_0 = 3.754$
$\beta_1 = 4.72e{-}03$
$R^2 = 0.047$
t−val = 1.426
p−val = 0.161



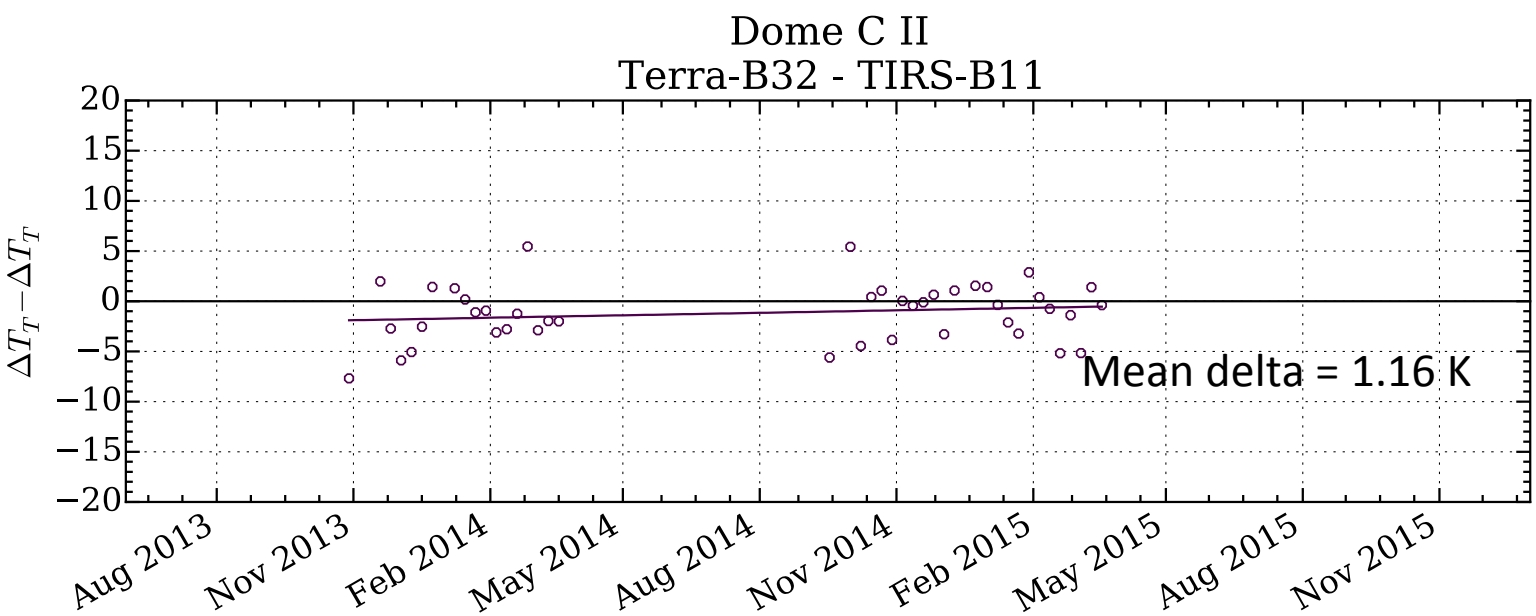
$\mu = 11.002$
$\sigma = 4.742$
$\beta_0 = 7.502$
$\beta_1 = 6.06e{-}03$
$R^2 = 0.051$
t−val = 1.487
p−val = 0.145

MODIS vs TIRS difference for Dome-C, Antarctica

TIRS (stray light corrected)



$\mu = 0.850$
$\sigma = 2.922$
$\beta_0 = -0.516$
$\beta_1 = 2.37e-03$
$R^2 = 0.021$
t−val = 0.927
p−val = 0.359



$\mu = -1.163$
$\sigma = 2.871$
$\beta_0 = -2.721$
$\beta_1 = 2.70e-03$
$R^2 = 0.028$
t−val = 1.080
p−val = 0.286

Next Step

Path Forward:

- Finalizing TIRS-on-TIRS method for implementation into LPGS
  - tweak algorithm for hot and cold scenes

Pepsi Challenge to the Science Team:

- Do you have a favorite scene you want corrected?

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Aaron Gerace (gerace@cis.rit.edu)