S-NPP VIIRS Thermal Emissive Bands Performance and Calibration Improvements

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VCST, NASA/GSFC

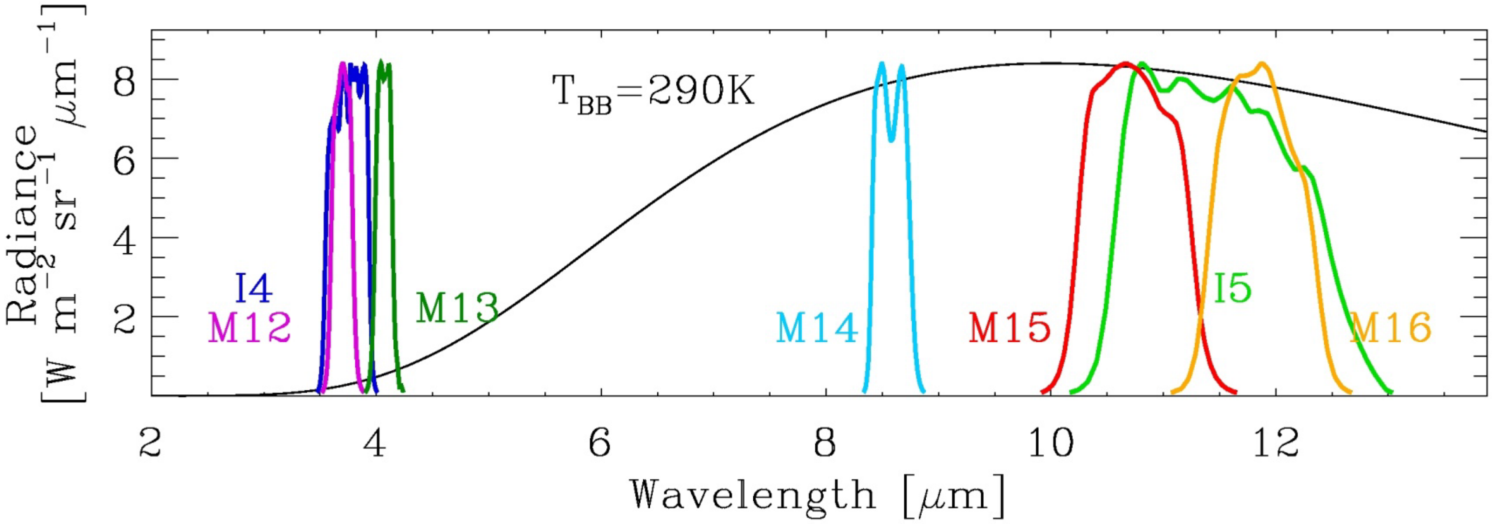
Acknowledgements: VIIRS SDR Team Members
VCST Members

Outline

- **TEB Calibration**
- **On-orbit Performance**
  - ✓ BB performance
  - ✓ Detector short-term stability and long-term response (F-factors)
  - ✓ Detector noise characterization (NEdT)
  - ✓ Trending during WUCD
- **Potential Improvements and Uncertainty Estimates**
  - ✓ Uncertainty assessment
  - ✓ Improving M13LG calibration
  - ✓ Average vs per-scan F-factor
  - ✓ Moon in SV processing
- **Conclusions**

Thermal Emissive Bands (TEB)

5 M-bands and 2 I-bands, covering wavelengths from 3.7 to 12μm



Band	**I4**	**I5**	**M12**	**M13**	**M14**	**M15**	**M16**
Wavelength [μm]	3.74	11.45	3.70	4.05	8.55	10.76	12.01

Calibrated using an on-board blackbody (BB):

- ✓ Scaling factor "F-factor" is derived and applied each scan.
- ✓ Warm-up and cool-down (WUCD) cycles are performed quarterly to fully characterize TEB detector response, including offset and nonlinear terms.

TEB Calibration Methodology

VIIRS Earth View radiance is retrieved following ATBD Eq.(116)

$$L_{EV}(B,\theta) = \frac{F(B)\sum_{i=0}^{2} c_i(B)dn^i(B) - \Delta L_{bg}(B,\theta)}{RVS(B,\theta)},$$

dn: detector response
c_i: calibration coefficients
RVS: response versus scan-angle

where the $\Delta L_{bg}(B,\theta)$ is the background difference between the EV and SV path:

$$\Delta L_{bg}(B,\theta) = (RVS(B,\theta) - RVS_{SV}(B))\left[\frac{(1-\rho_{RTA}(B))}{\rho_{RTA}(B)} L_{RTA} - \frac{1.}{\rho_{RTA}(B)} L_{HAM}\right],$$

the F-factor is derived each scan for each band, detector, and HAM-side:

$$F(B) = \frac{RVS_{BB}(B)L_{ap}(B) + \Delta L_{bg}(B,\theta_{BB})}{\sum_{i=0}^{2} c_i dn_{BB}{}^i},$$

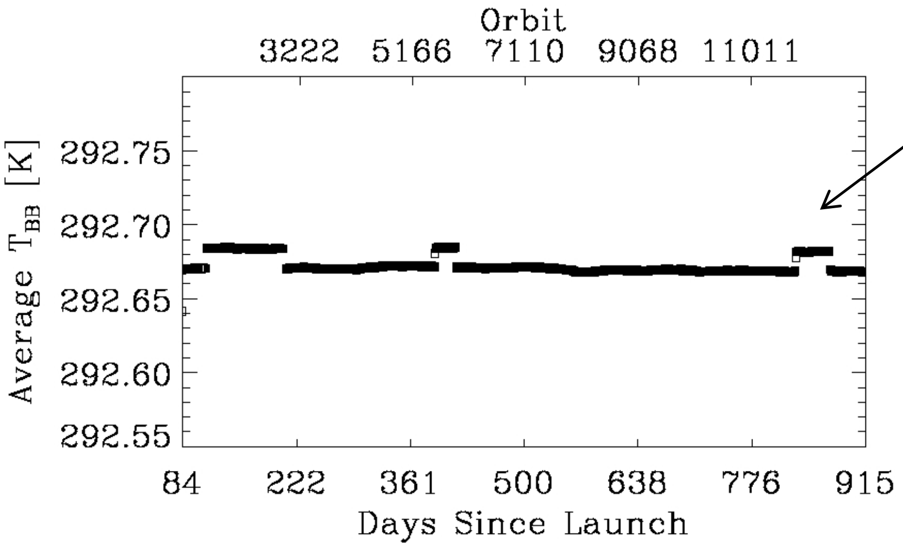
Estimated BB radiance

Retrieved BB radiance

and the aperture radiance from the BB is:

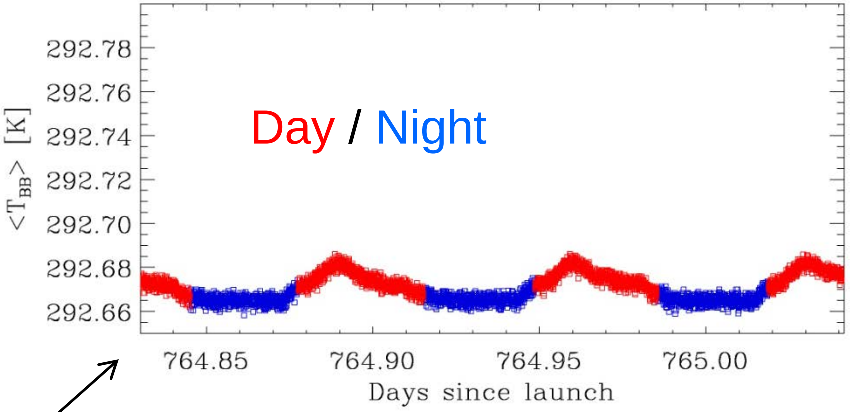
$$L_{ap}(B) = \varepsilon L_{BB} + (1-\varepsilon)(F_{RTA}L_{RTA} + F_{SH}L_{SH} + F_{CAV}L_{CAV})$$

BB Performance



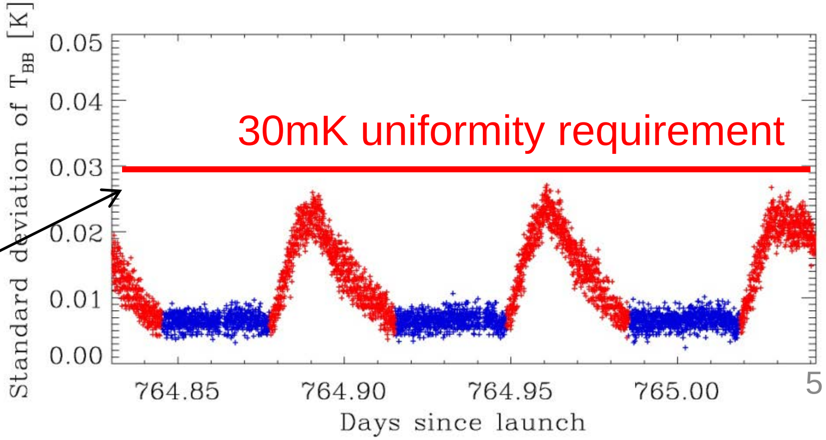
Long-term trend of daily-averaged T_{BB}

- Stable to within a few mK.
- ~15mK offsets were due to the use of two different T_{BB} settings.



Short-term stability (scan-by-scan T_{BB}):

- Orbital variations of individual thermistors up to 40mK
- Variations in average temperature ~ 20mK
- Temperature difference between individual thermistors up to 60mK
- **BB uniformity meets the requirement with standard deviation less than 30mK**



Detector Short-term Stability

Detector responses (F-factors) show small orbital variations:

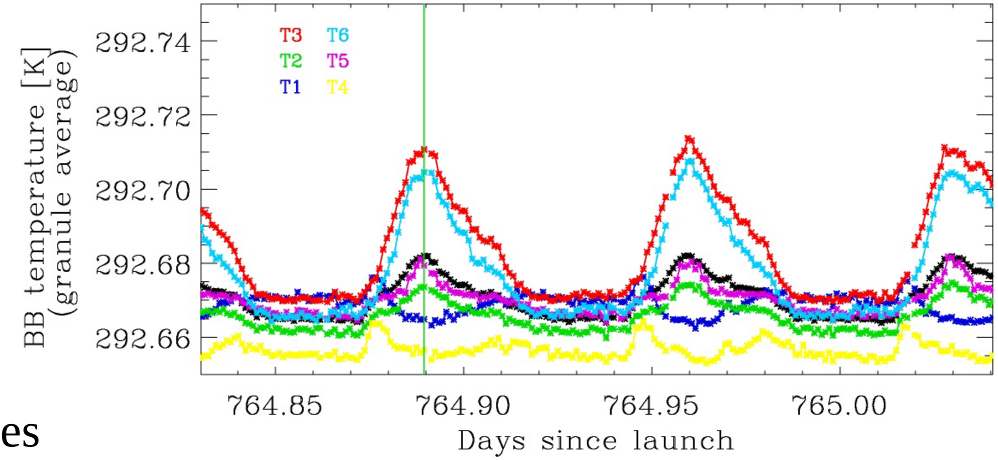
±0.2% or less for scan-by-scan

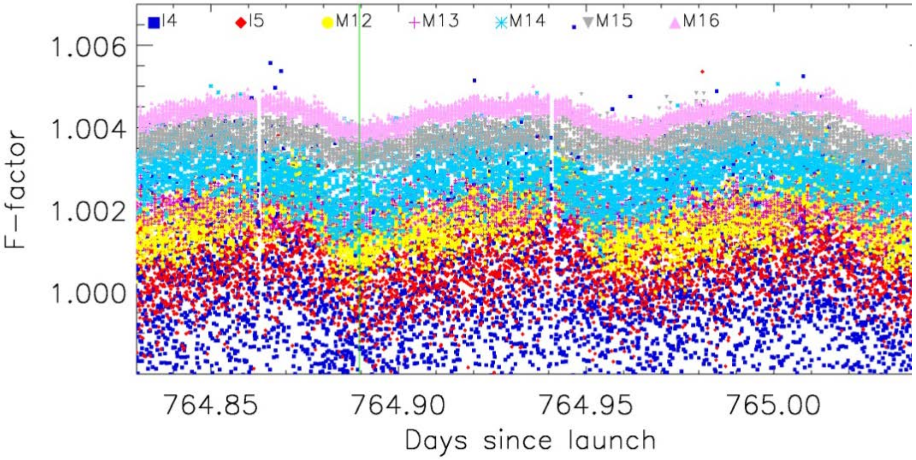
±0.1% or less for granule average

Would using averaged F-factors improve SDR product?

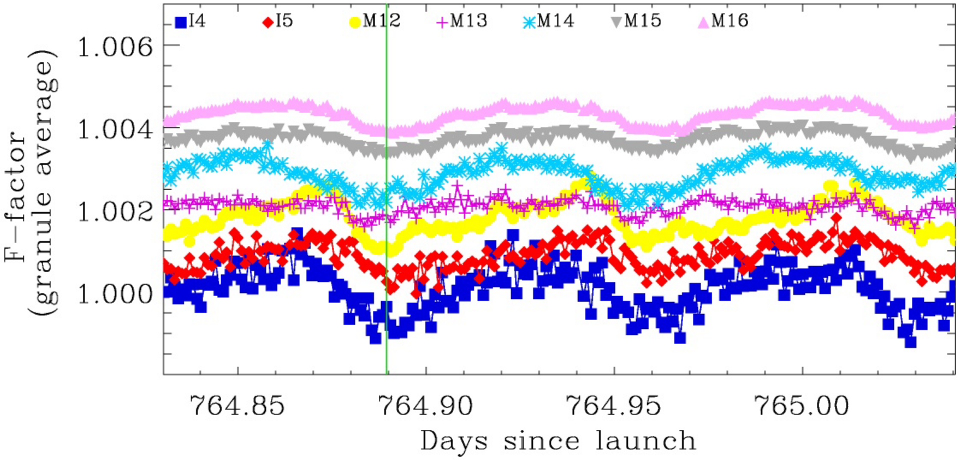
F-factor orbital variations correlate with T_{BB} variations and instrument temperatures variations.

Orbits: 10853, 10854, 10855





Scan-by-scan (HAM-A)

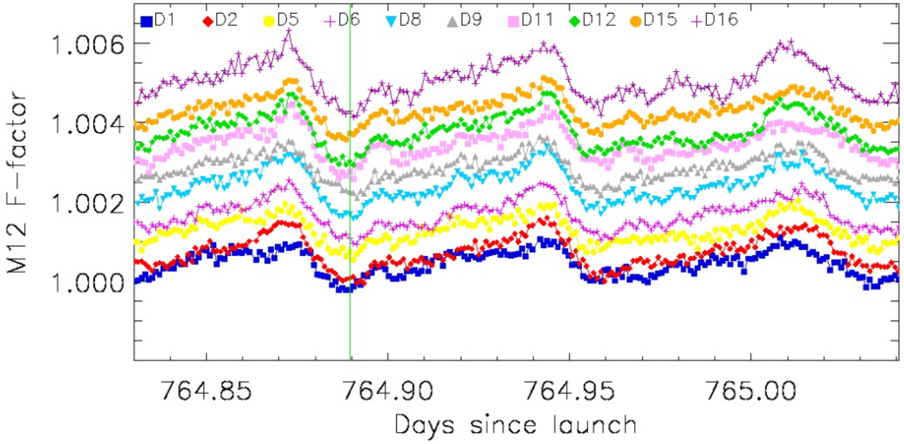


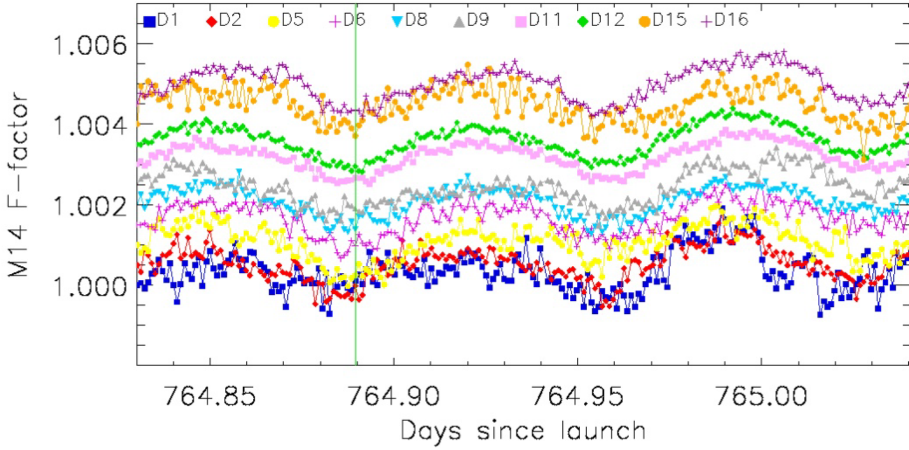
Granule average (HAM-A)

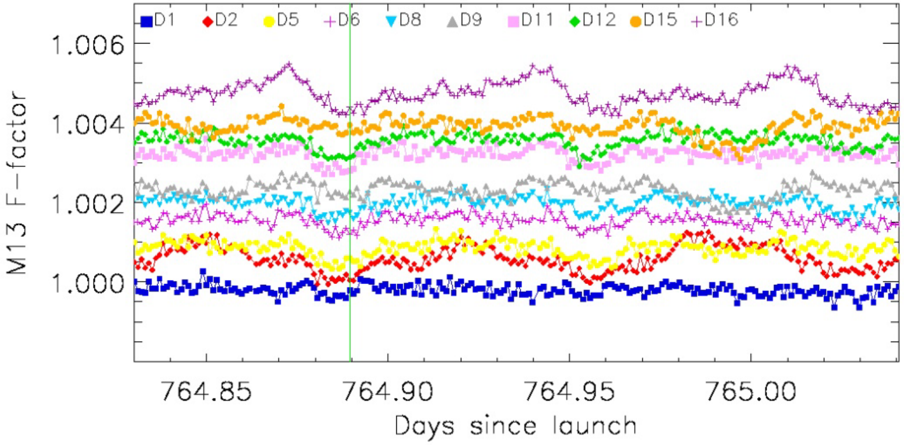
* For clarity the F-factors are shifted.

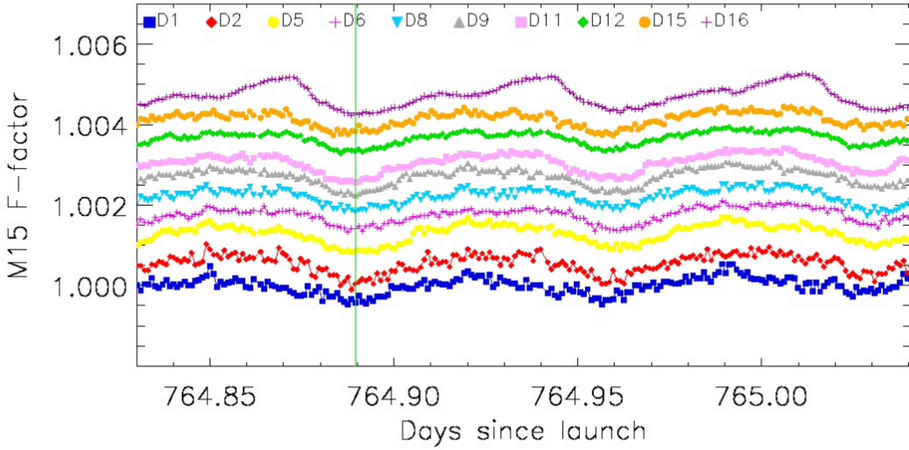
Short-term Stability- Individual Detectors

Orbits: 10853, 10854, 10855









Granule average (HAM-A)

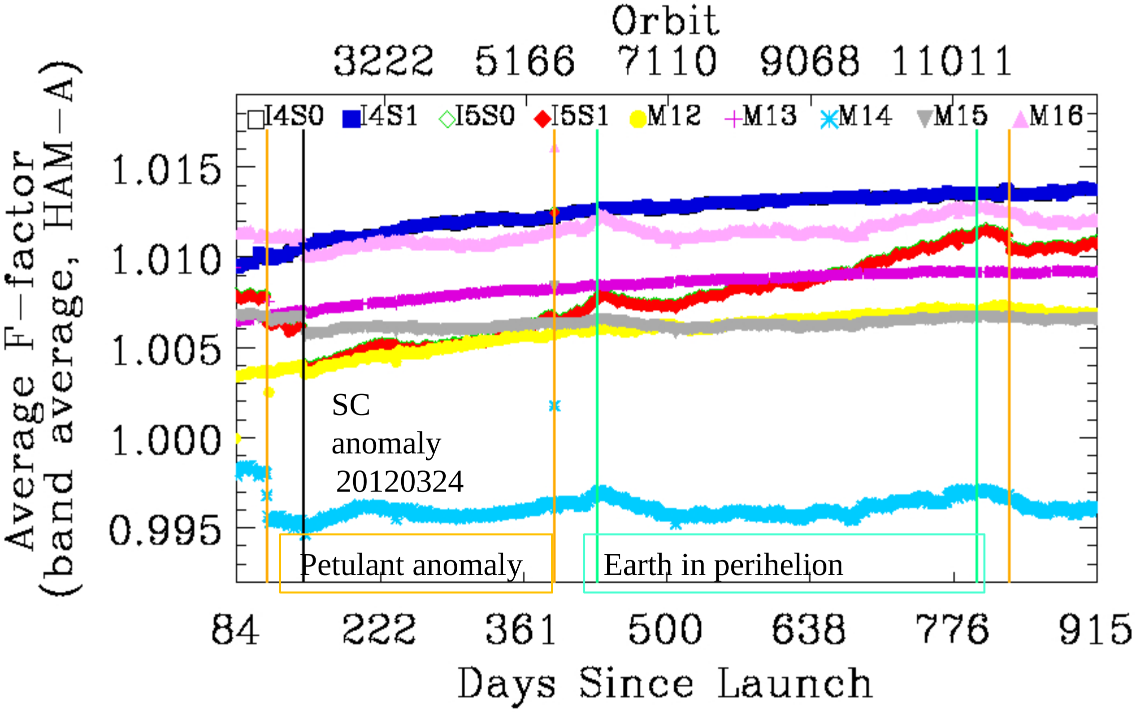
M16 (not shown) similar to M15; same D16 our of family behavior

* For clarity the F-factors are shifted.

Detector Long-term Response

Daily average F-factor trend:

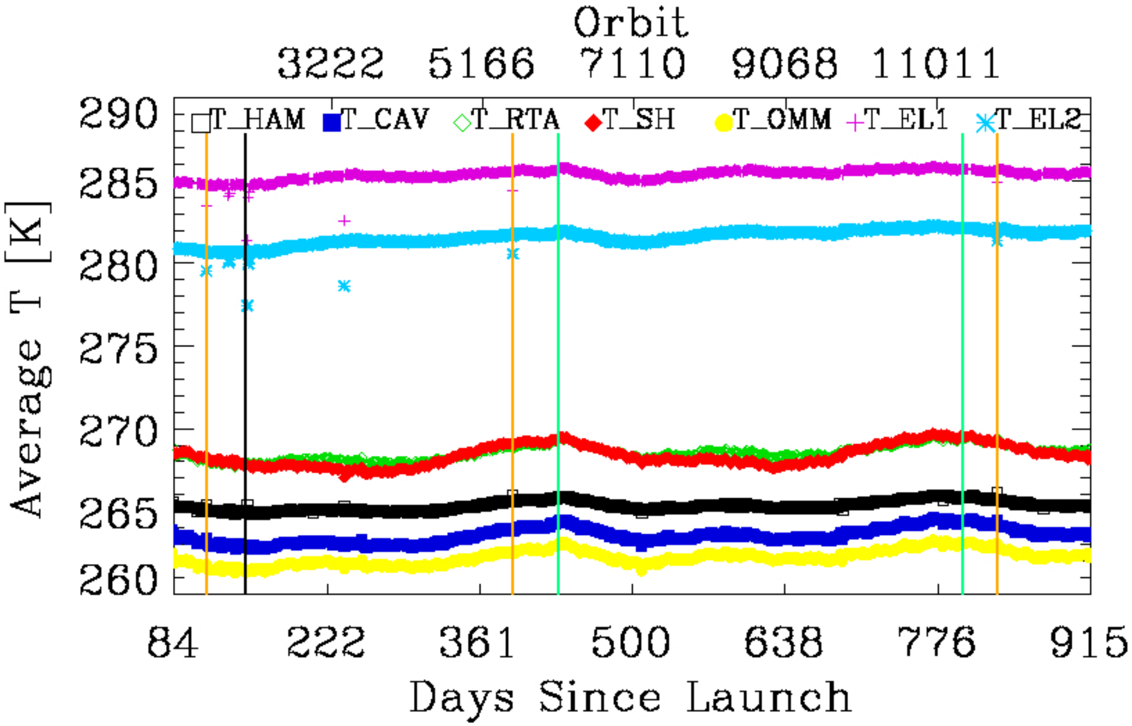
- From 1/20/2012 (orbit 1200) to 4/30/2014 (orbit 12983)
- I5 shows the most noticeable trend of 0.68%, followed by M12 and I4 of 0.33% and 0.32%, respectively
- Discontinuities in the trend are coincident with S/C anomalies during which the CFPA and/or instrument temperatures changed.
- Features in LWIR bands F-trend appear to coincide with the passage of the Earth through perihelion.



Band	**I4**	**I5**	**M12**	**M13**	**M14**	**M15**	**M16**
Average F-factor: 03 26 2012	1.0105	1.0040	1.0035	1.0070	0.9946	1.0056	1.0101
Average F-factor: 04 30 2014	1.0137	1.0109	1.0068	1.0092	0.9961	1.0066	1.0121
Trend [%]	0.32	0.68	0.33	0.22	0.15	0.09	0.19

Instrument Temperatures Trend

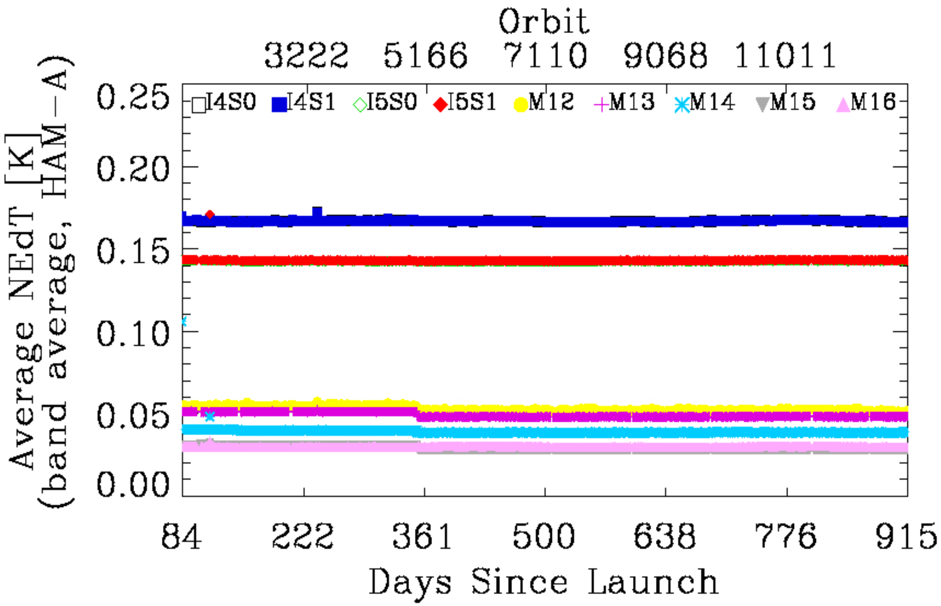
- Discontinuities in the instrument temperatures trends coincident with discontinuities in the F-factor trends shown on previous slide.
- Features in instrument temperature trends appears to coincide with the passage of the Earth through perihelion. The F-factor for LWIR bands shows features at the same time.



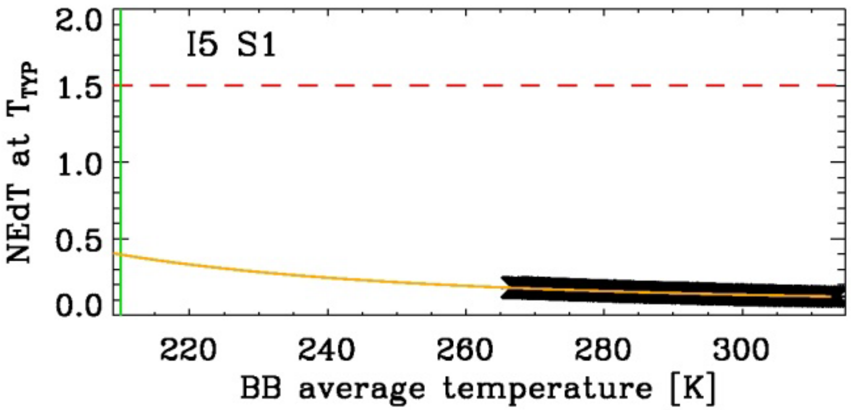
Detector Noise Characterization (NEdT)

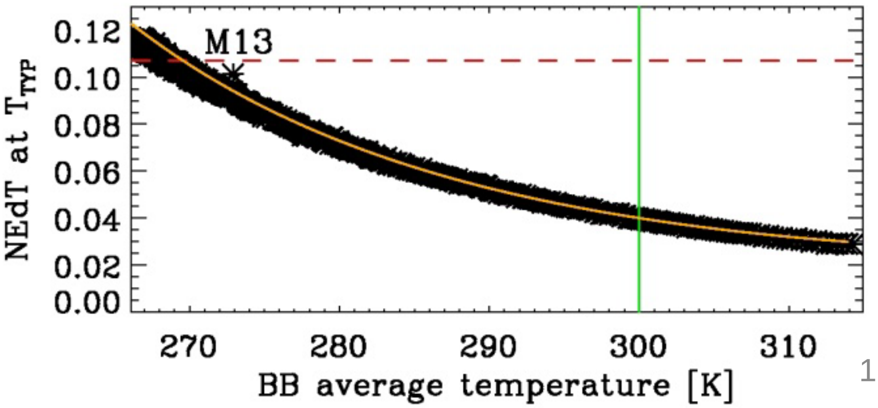
$$NEdT = \frac{NEdL}{\partial L / \partial T} = \frac{L}{SNR\, \partial L / \partial T}$$

- NEdT routinely trended at 292.5K: stable since the CFPA temperatures reached ~80K (orbit 1200). Band averaged values are within 0.2 K for I bands and 0.07 K for M bands



- NEdT at T_{TYP} derived periodically from BB WUCD data: stable and meeting the sensor design requirements by a wide margin:





Detector Noise Characterization (NEdT)

NEdT at T_{TYP} (derived from BB cool-down data)

Band	T_{TYP} [K]	NEdT at Ttyp [K]									
		Requirement	02/12	05/12	09/12	12/12	03/13	06/13	09/13	12/13	03/14
I4	270	2.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
I5	210	1.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
M12	270	0.396	0.13	0.13	0.13	0.11	0.12	0.12	0.12	0.12	0.12
M13	300	0.107	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
M14	270	0.091	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
M15	300	0.070	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
M16	300	0.072	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

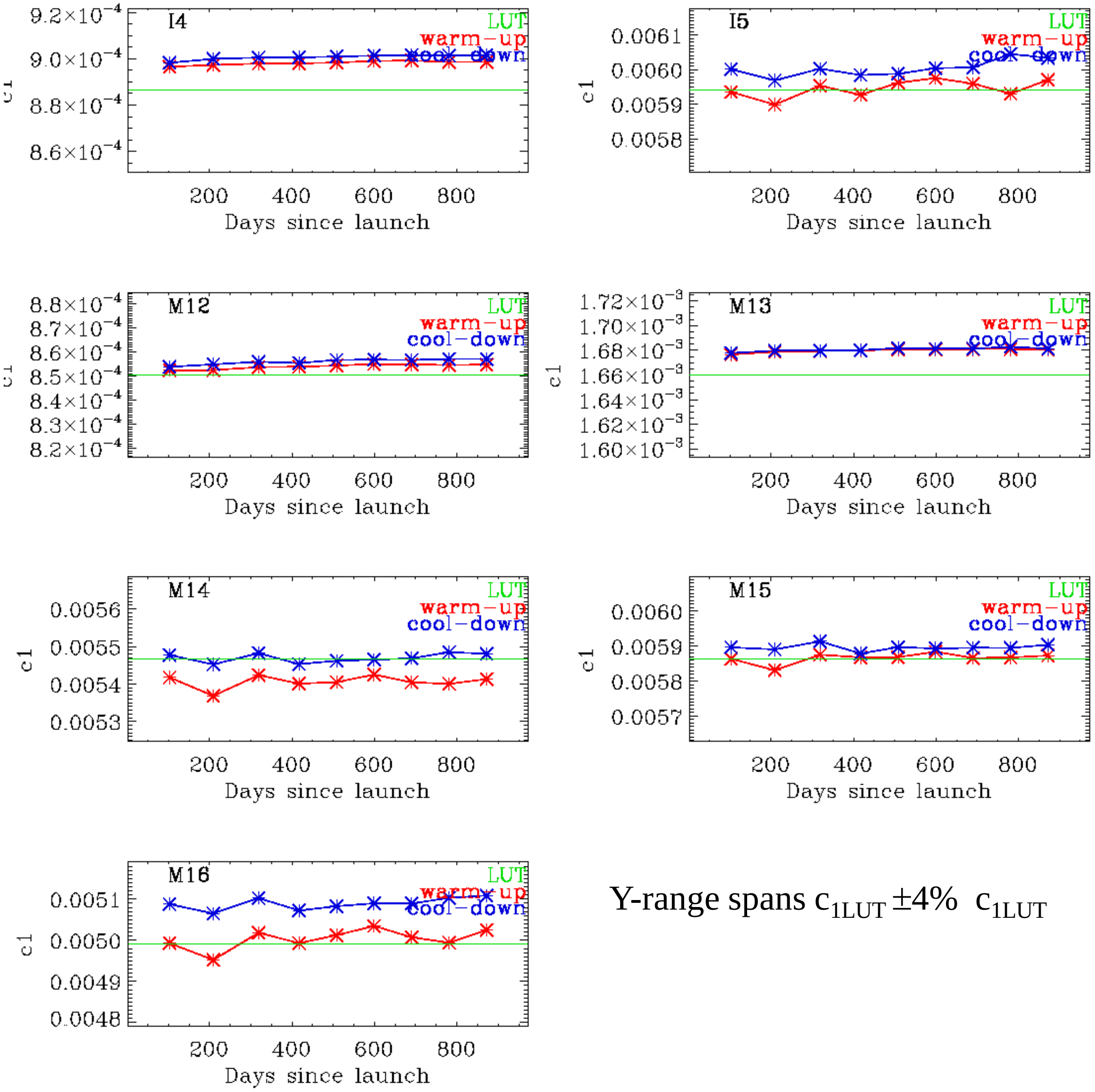
Continue to meet the sensor design requirements

Calibration Coefficients – Band-average c1

- Band-average c1 coefficients, as derived from the nine WUCD cycles performed till Mar 2014, are shown in red (WU data), and blue (CD data) in comparison with pre-launch (green) values.

- Band-average c1 coefficients derived during WUCD cycles are within 1.9% on average (at M16 CD) from pre-launch values.

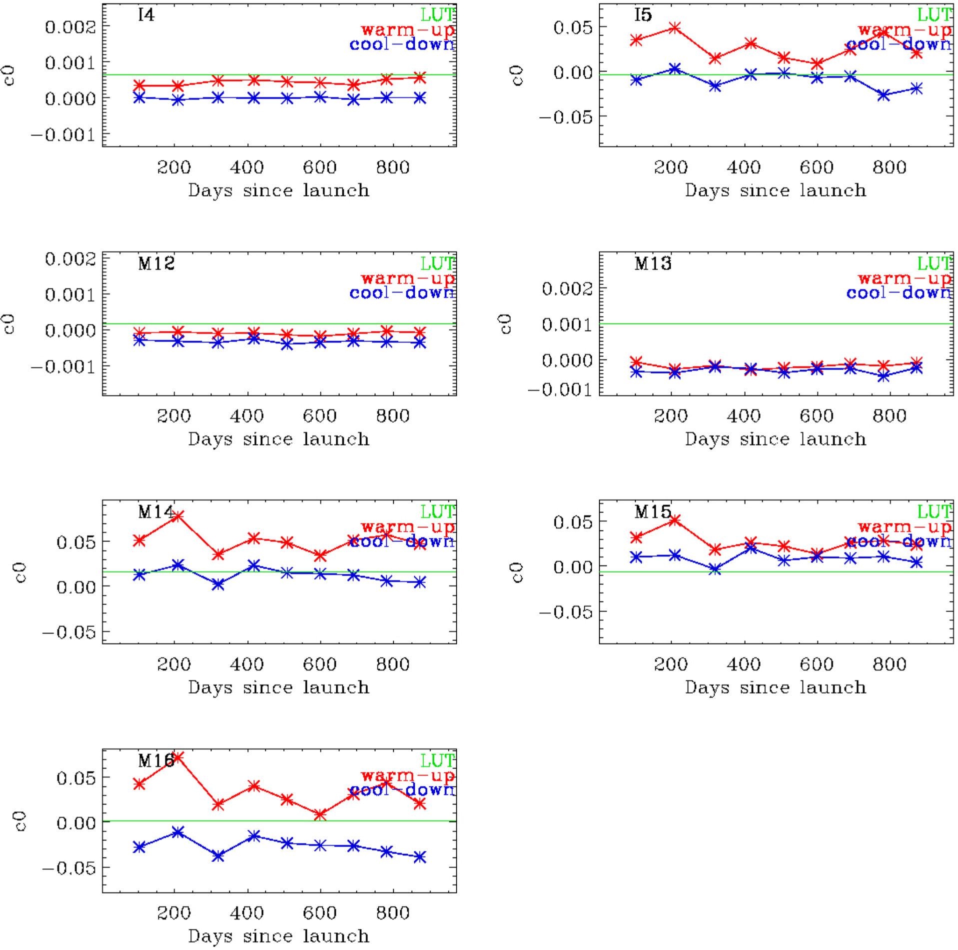
- An offset between WU and CD results is present through the nine WUCDs, especially for LWIR bands.



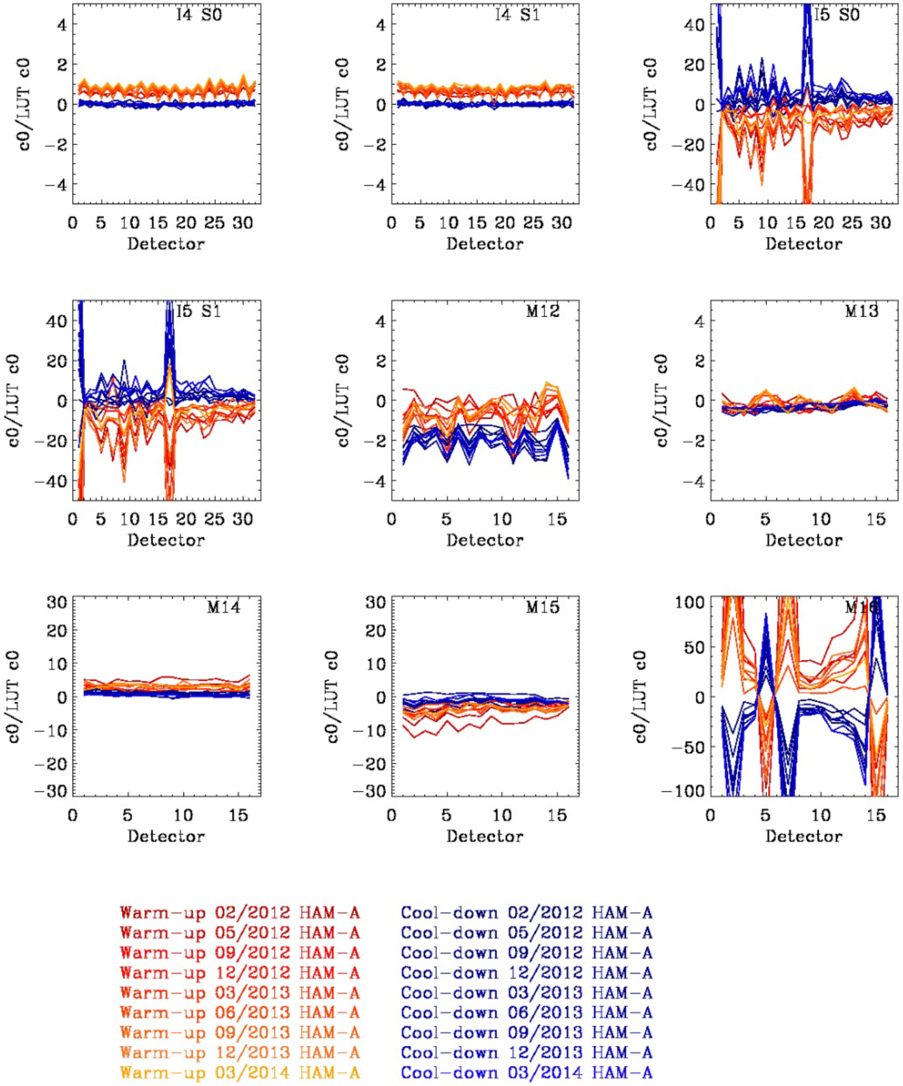
Y-range spans c_{1LUT} ±4% c_{1LUT}

C_0 Coefficients

Band average c_0



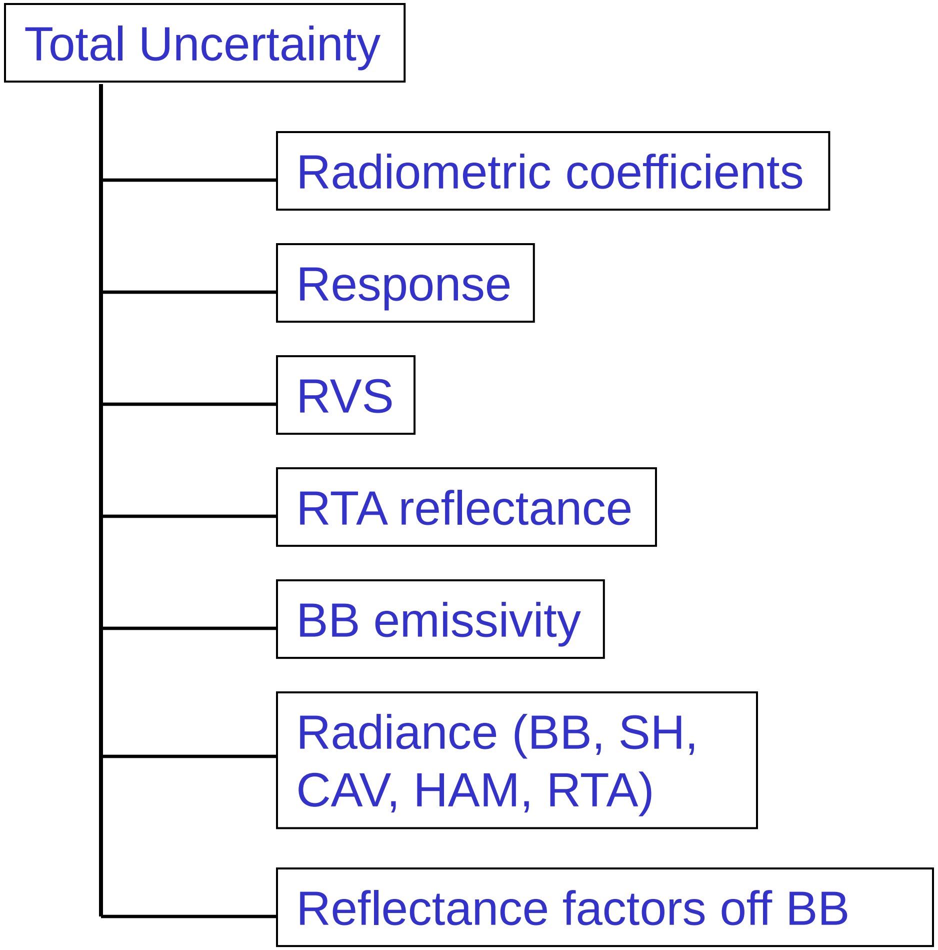
Detector specific c_0/c_{0LUT}



Y-range spans: c_{0LUT} ±0.002 (MWIR),
c_{0LUT} ±0.1 (LWIR)

Uncertainty Estimates

- EV retrieved radiance uncertainty propagated using standard NIST formulation (k=1)
- Some uncertainty contributors determined pre-launch by the instrument vendor: RTA reflectance BB emissivity
- Radiometric coefficient and RVS uncertainties determined from NASA pre-launch analysis
- Uncertainties investigated for a range of input signal levels and scan angles



Total Uncertainty

- Radiometric coefficients
- Response
- RVS
- RTA reflectance
- BB emissivity
- Radiance (BB, SH, CAV, HAM, RTA)
- Reflectance factors off BB

Comparison to Requirement [K]

Uncertainty specifications

Defined in terms of %, at particular uniform scene temperatures, converted to K

Estimates exceed the specification at lower scene temperatures for bands M12 and M13

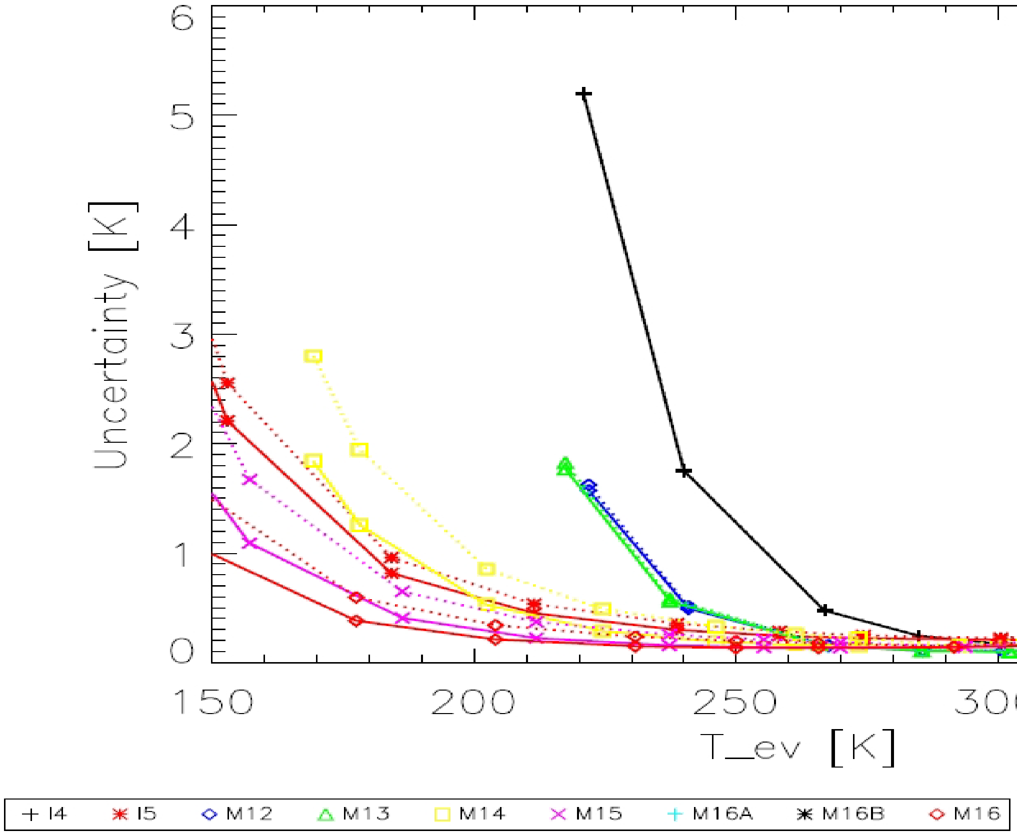
Band	267 K
I4 spec	0.91
I4 estimate	0.468
I5 spec	1.4
I5 estimate	0.226

Band	190 K	230 K	270 K	310 K	340 K
M12 spec	---	0.92	0.13	0.17	0.21
M12 estimate	---	1.11	0.13	0.07	0.09
M13 spec	---	0.85	0.14	0.19	0.23
M13 estimate	---	1.01	0.14	0.07	0.10
M14 spec	2.60	0.75	0.26	0.23	0.34
M14 estimate	0.95	0.26	0.12	0.12	0.20
M15 spec	0.56	0.24	0.22	0.28	0.34
M15 estimate	0.42	0.18	0.12	0.13	0.19
M16 spec	0.48	0.26	0.24	0.31	0.37
M16 estimate	0.35	0.16	0.12	0.14	0.19

Uncertainty [K]

Uncertainty contributors:

- **Dominant for MWIR bands are the relative BB radiance uncertainty and the relative EV *dn* uncertainty (increasing rapidly with decreasing scene temperature).**
- **The LWIR bands uncertainties are dominated by the c_0, RVS, and EV *dn* relative uncertainties, which increase with decreasing scene temperatures.**



M13 LG Calibration

M13 low gain: No scan by scan F factor correction

Prelaunch analysis differs between Government team (Aerospace and VCST) and sensor subcontractor – current LUT. Government team results are:

- ✓ **c_1 = 0.142** - 7% higher than LUT value **c_{1LUT} = 0.132**;
- ✓ **c_0 = 0** - inconsistent with **c_{0LUT} = 1.15**

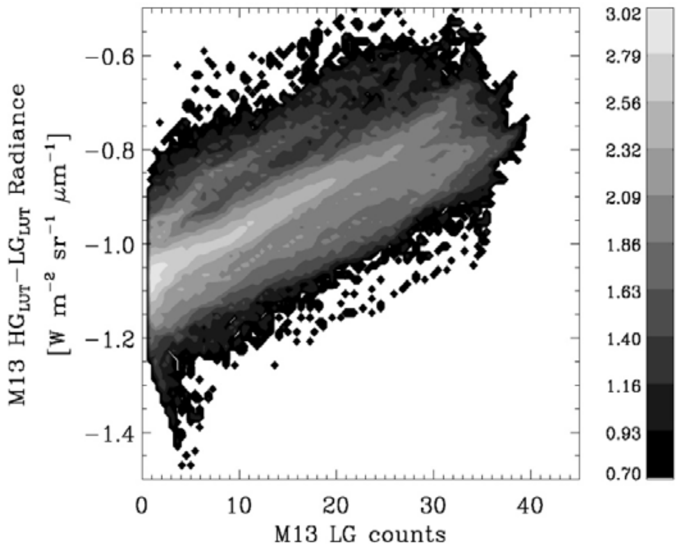
Proposal:

Update M13 low gain coefficients based on Government team pre-launch analysis, which is consistent with results from on-orbit calibration

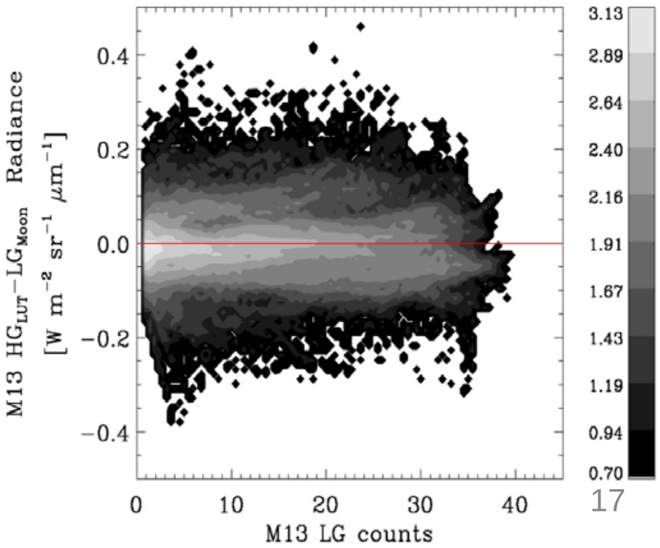
On-orbit comparison of lunar images in M13 LG and M13 HG - supports Government team pre-launch results:

- ✓ **c_1 = 0.142**; 7% higher than c_{1LUT} -consistent with Gov. team pre-launch
- ✓ **c_0 = 0** consistent with Gov. team pre-launch

M13 LG c_{1LUT}, c_{0LUT}



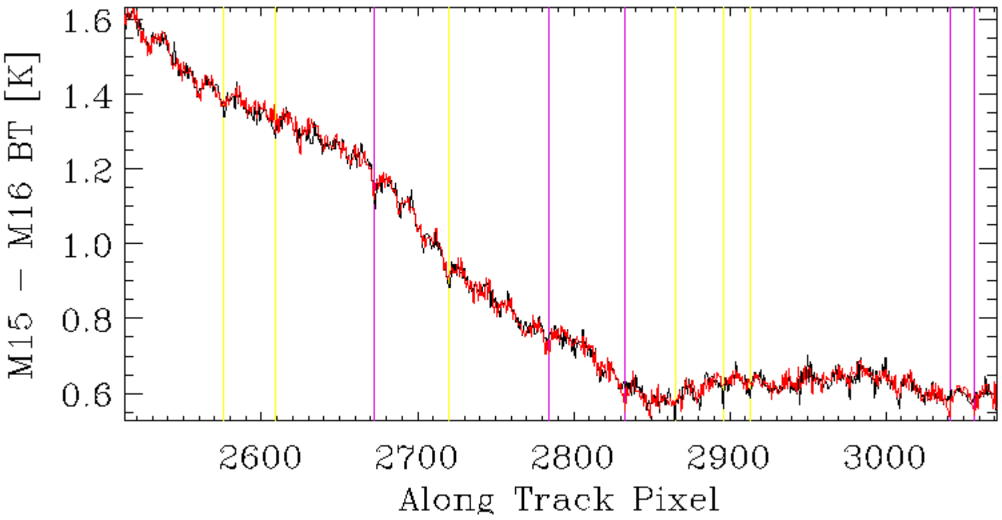
M13 LG c_1=0.142, c_0=0

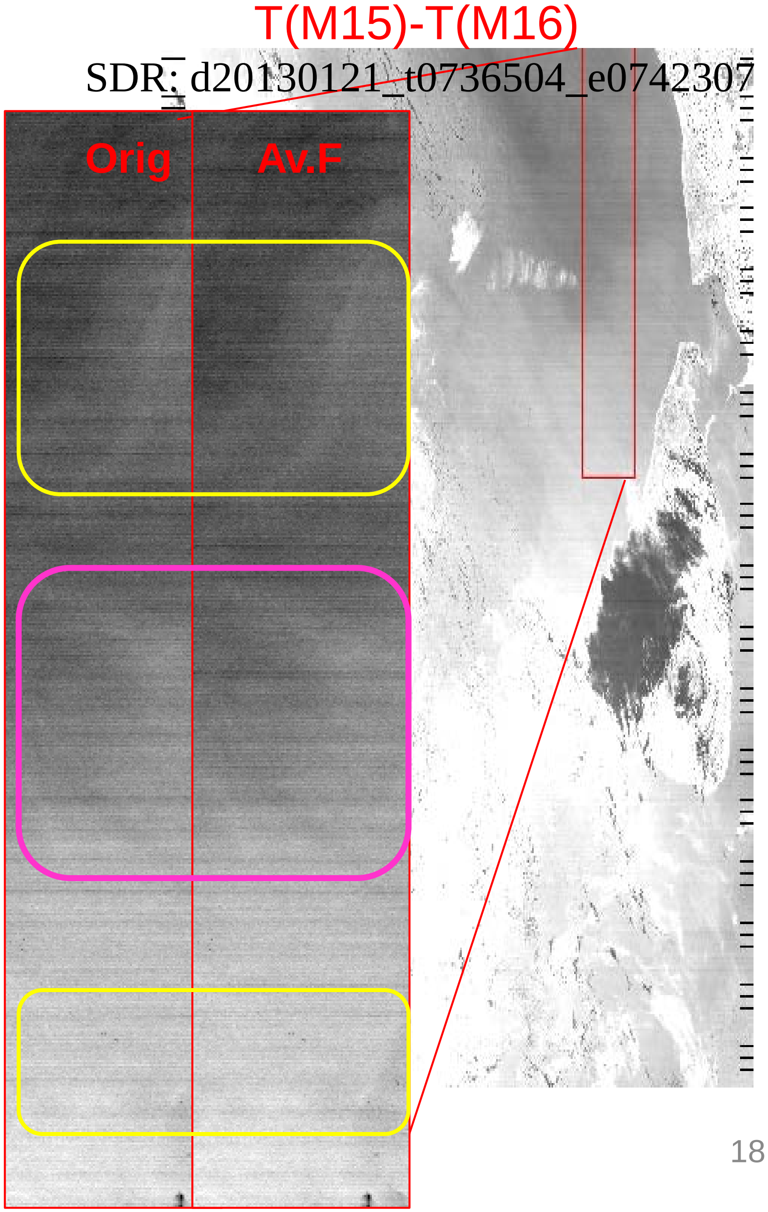


Effect of F-factor Noise

Evaluating the effect of using average F-factors

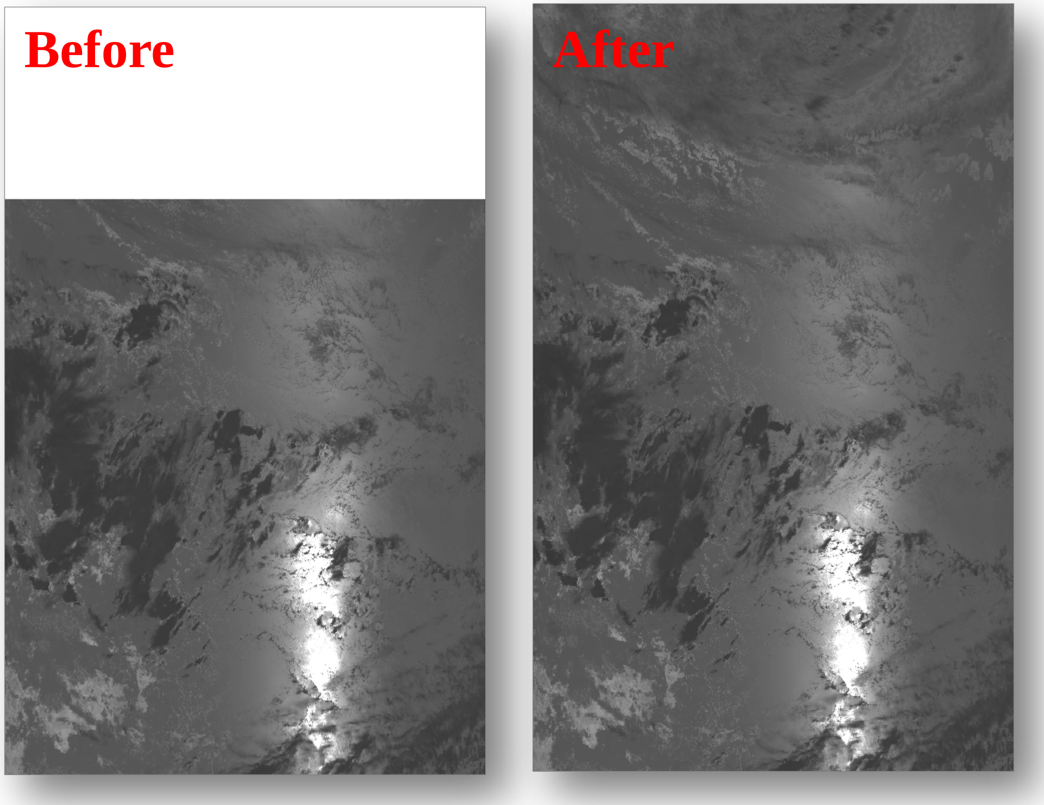
- The VCST VIIRS SDR code was modified to apply average F-factors instead of per-scan F-factors for TEB calibration.
- The F-factors for each band, detector, HAM are averaged over 24 scans.
- Using average F-factors does not significantly impact the SDR product.
- Striping on the noise level affects SST products based on M15 and M16 brightness temperatures.





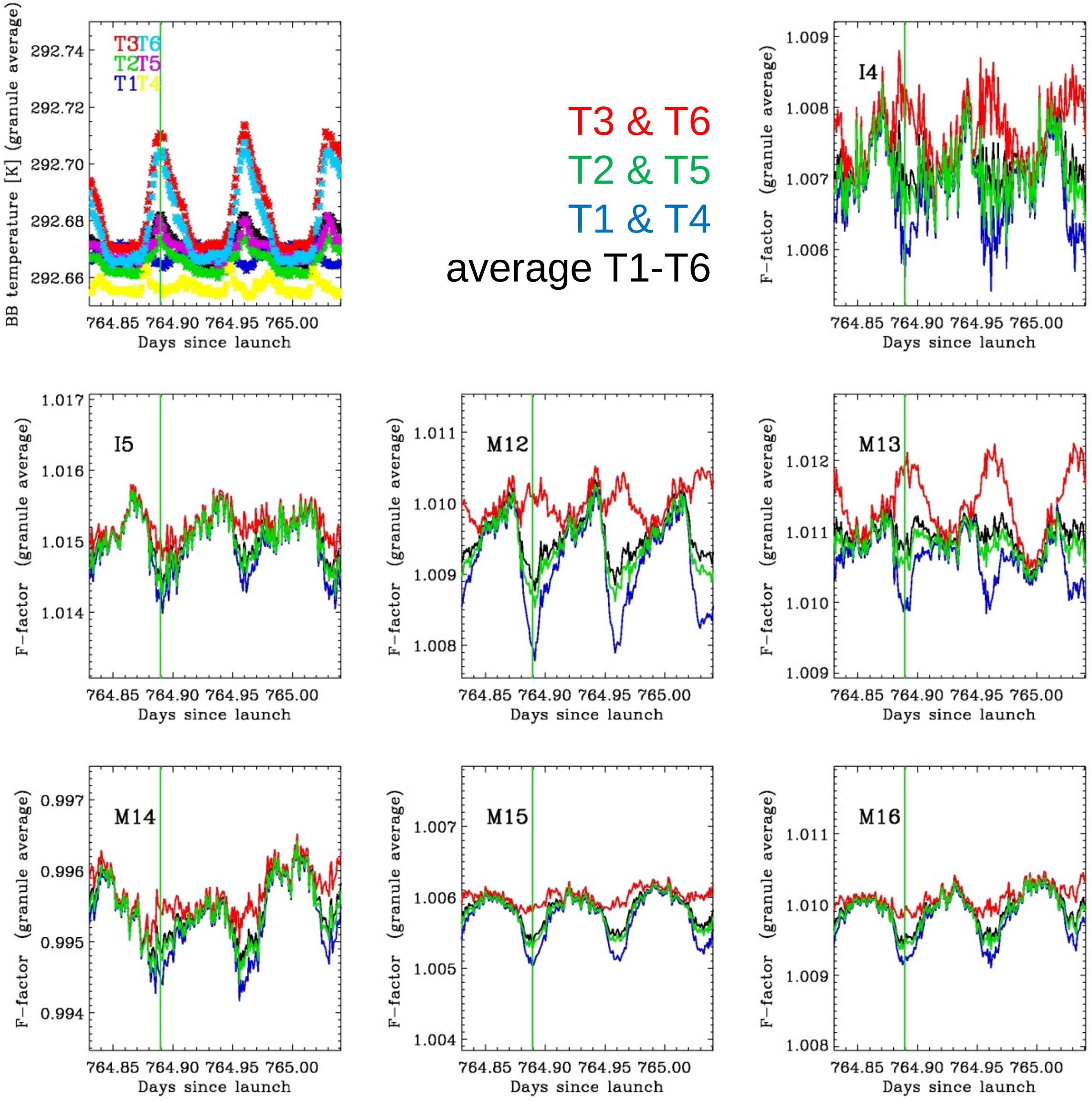
TEB Calibration when Moon in SV

- Currently for TEB, Fill values are assigned in EV SDR when the Moon is in the SV.
- Improved algorithm computes the mean and standard deviation of a 48-frame sample each scan. Then the outlier samples (Moon intrusion) with selected rejection scheme are identified and excluded from the SV average for background subtraction.



Images of calibrated radiance from 4 consecutive Band **M12** SDRs, generated with current SDR code (left) and modified (right) calibration algorithms (Data: Jan 22, 2013; Time 22:24:02). [Reference SPIE 2013, 8866-72]

F-factors Orbital Variation Reduction



- F-factor orbital variations are present, on the order of 0.05-0.1 %.

- Changing the BB thermistor weighting can reduce the F-factor orbital variations. Using T3 and T6 yield less variation for most bands (except M13).

- Improving the background model which would also reduce the F-factor orbital variations.

Conclusions

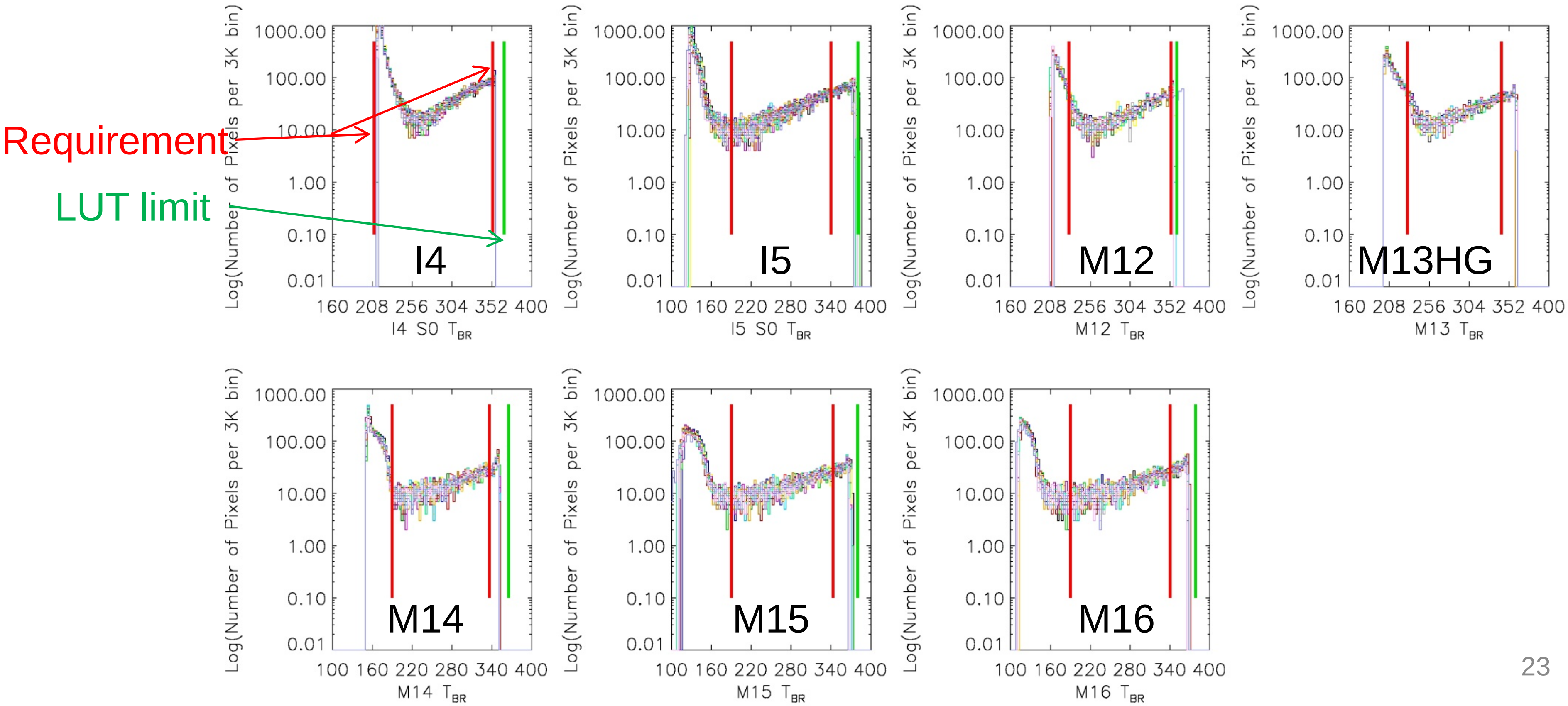
- S-NPP VIIRS on-orbit BB long-term (2+ yr) performance is very stable. Short-term (orbital) temperature variations are present but within the uniformity requirement of 30mK
- Detector response (F-factor) trending is stable, with I5 showing maximum band-average trend of 0.68% followed by M12 and I4. Small orbital variations are present (0.05-0.1%)
- No change is observed for TEB detector noise characteristics. NEdT at Ttyp is in compliance with the requirements
- Uncertainty estimates: TEB meet calibration requirements for most scene temperatures; M12 and M13 have slightly larger than specified UC at low scene temperatures; Larger uncertainties in M13 low gain (above 350 K)
- Improvements: Updates to M13 LG offset and linear coefficients to improve calibration; Modifications to the SDR code/algorithm to allow TEB calibration to be performed when the Moon is in SV; Modifications to SDR code to apply average F-factor do not have significant impact.

Back Up

Dynamic Range Verification

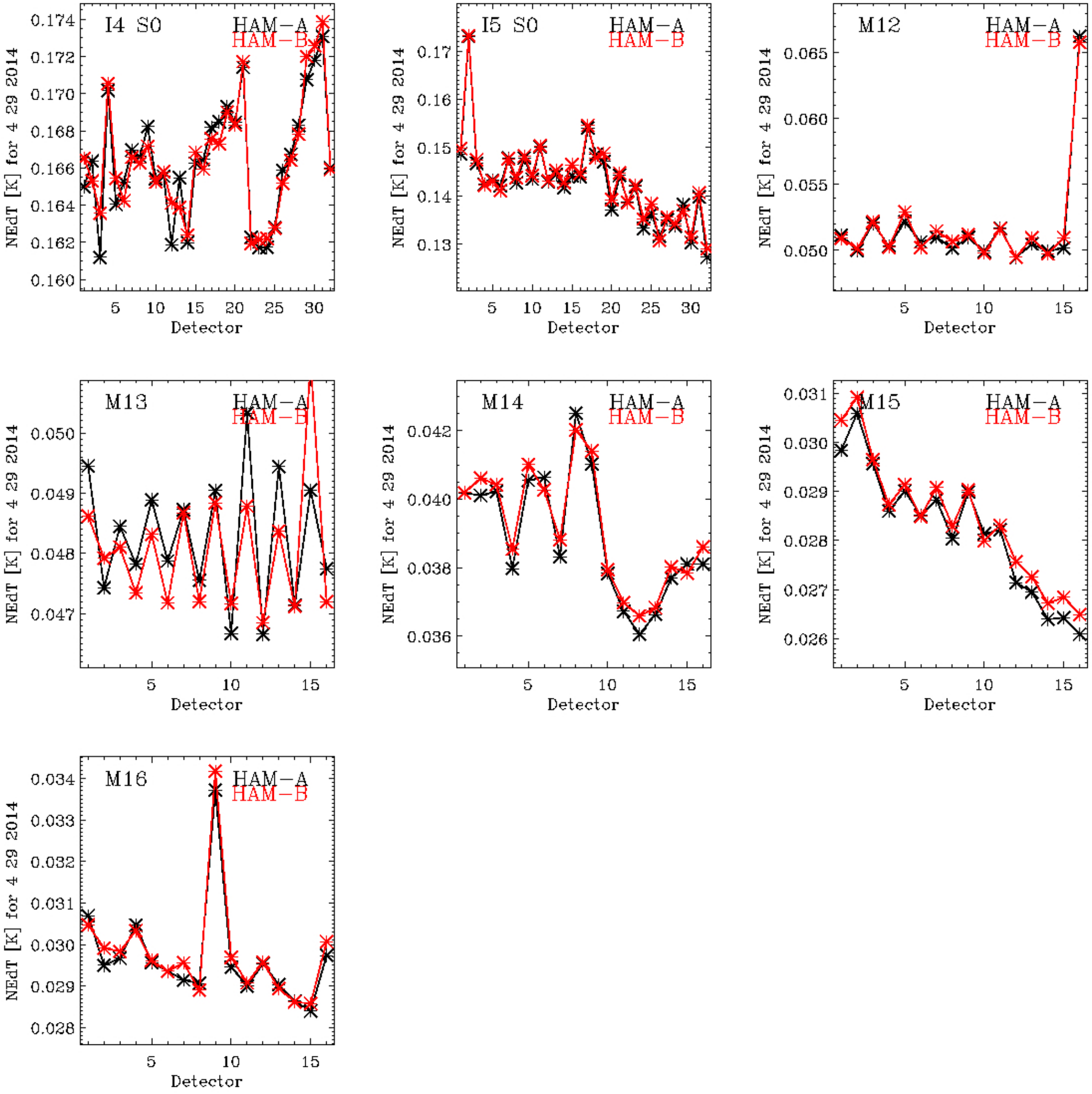
Dynamic range verified using scheduled Lunar observations

- All detectors of all TEB bands meet the Tmin (marginal non-compliance at I4) and Tmax requirements
- For some detectors of some bands the radiance limits in the Radiance-to-Temperature LUT do not extend to the largest possible unsaturated radiance



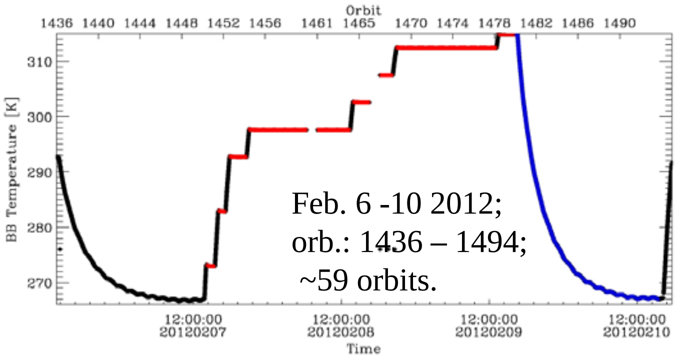
Detector Specific NEdT

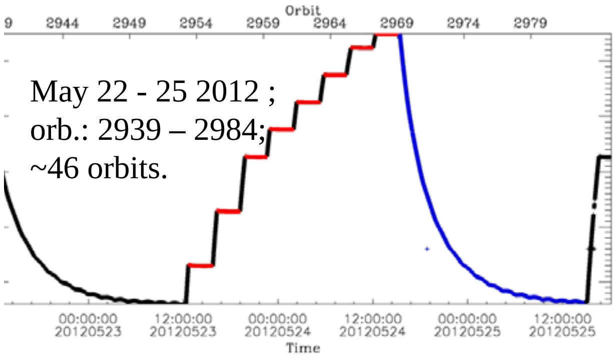
- Detector specific NEdT is stable through the mission.

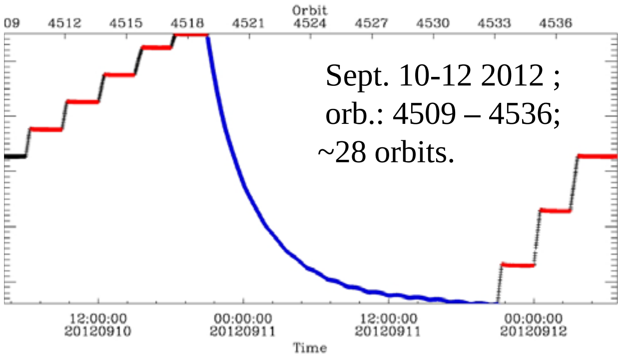


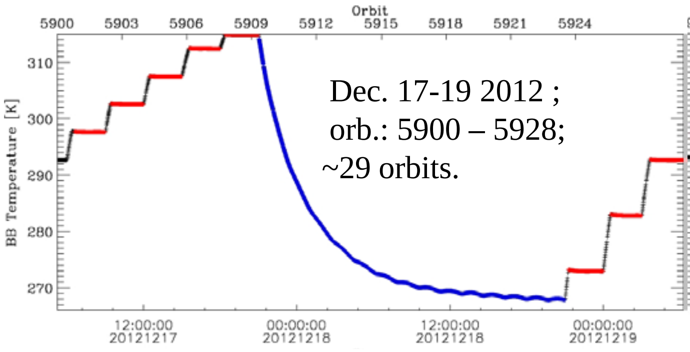
Warm-up Cool-down (WUCD) Cycles

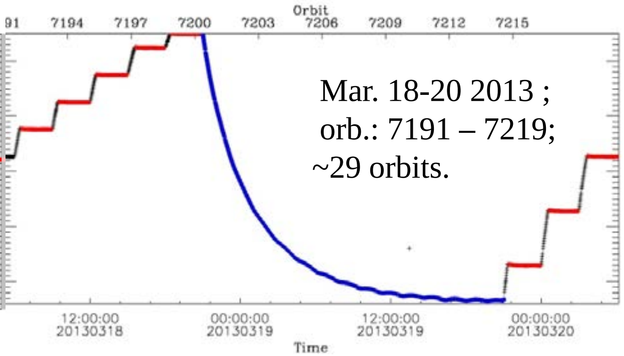
WUCD cycles performed: Feb, May, Sep, Dec 2012; Mar, Jun, Sep, Dec 2013, Mar 2014

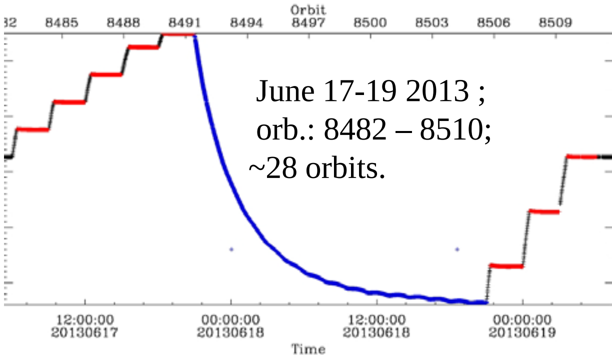

Feb. 6 -10 2012;
orb.: 1436 – 1494;
~59 orbits.

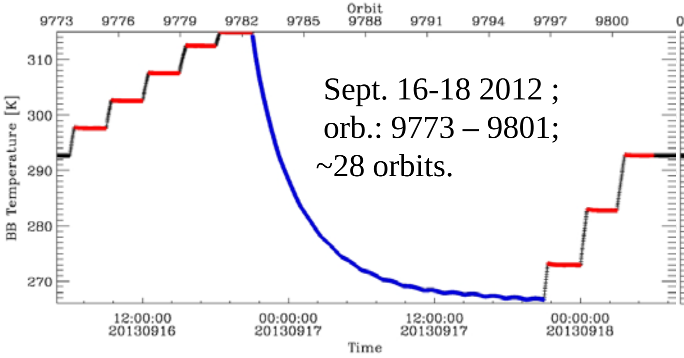

May 22 - 25 2012 ;
orb.: 2939 – 2984;
~46 orbits.

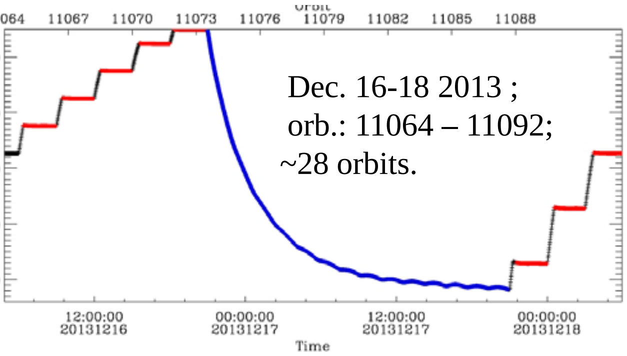

Sept. 10-12 2012 ;
orb.: 4509 – 4536;
~28 orbits.

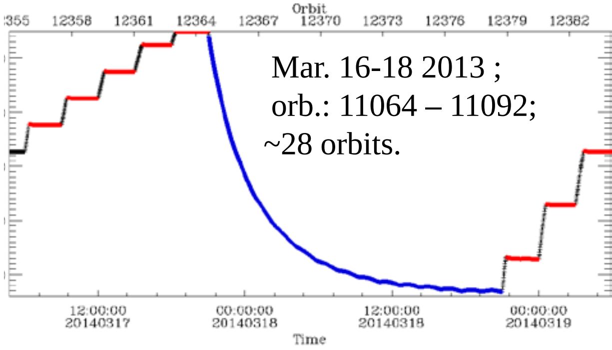

Dec. 17-19 2012 ;
orb.: 5900 – 5928;
~29 orbits.


Mar. 18-20 2013 ;
orb.: 7191 – 7219;
~29 orbits.


June 17-19 2013 ;
orb.: 8482 – 8510;
~28 orbits.


Sept. 16-18 2012 ;
orb.: 9773 – 9801;
~28 orbits.

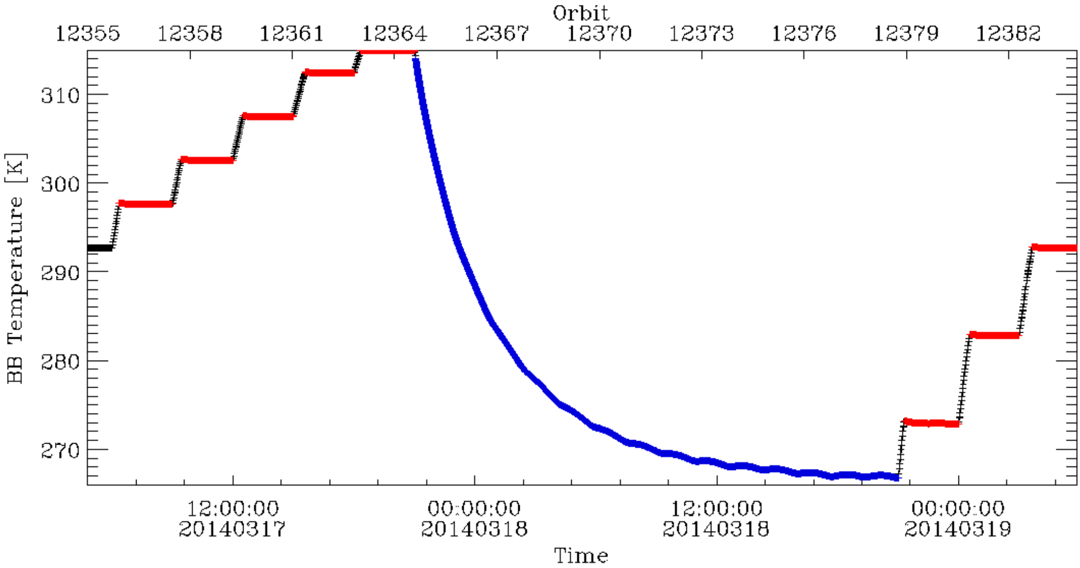

Dec. 16-18 2013 ;
orb.: 11064 – 11092;
~28 orbits.


Mar. 16-18 2013 ;
orb.: 11064 – 11092;
~28 orbits.

WUCD 17-19 Mar 2014 Data Selection

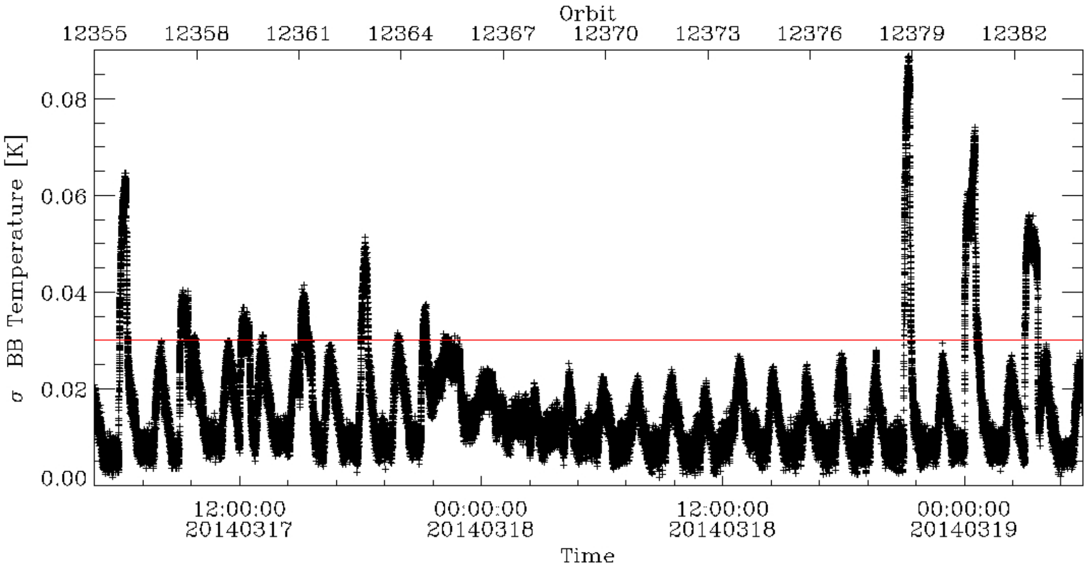
Warm-up:

- Orbits: 12355 – 12364; 12378 – 12383
- T_{BB} set to: 297.5K, 302.5K, 307.5K, 312.5K, 315.0K and 272.5K, 282.5K, 292.5K,
- The scans used (~40700) are highlighted in red.



Cool-down:

- Orbits: 12364 – 12378.
- T_{BB} range: 266.8K to 315K;
- The scans used (~47700) are shown in blue.

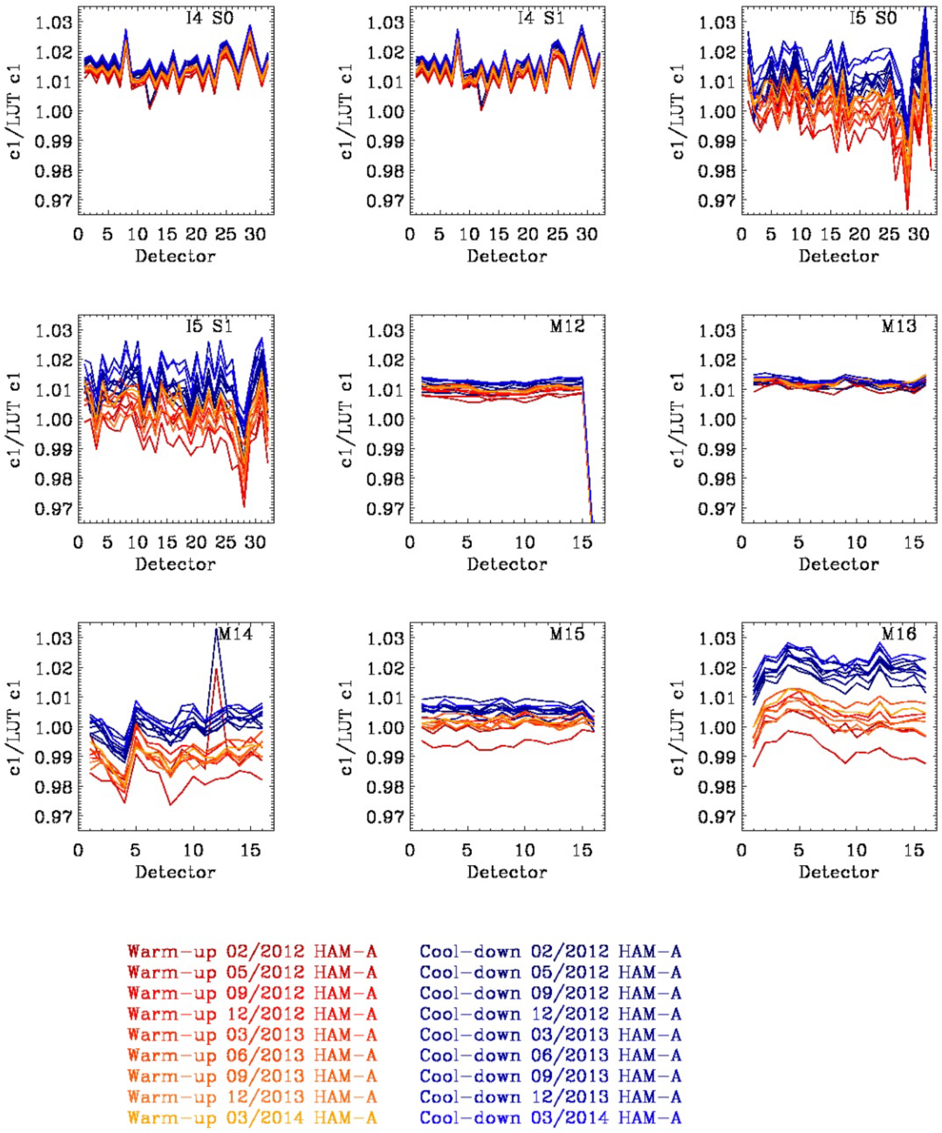


Calibration Coefficients – c1/LUT

Band average c1 difference

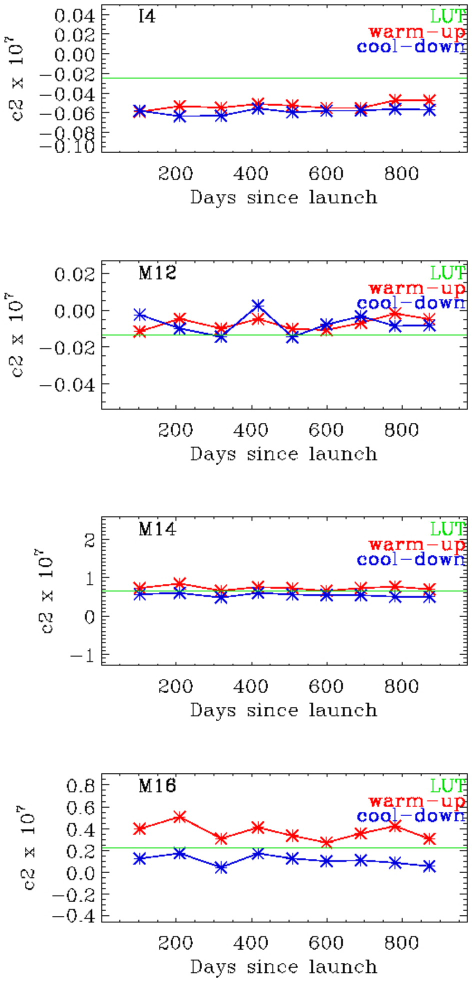
$100* (c1_{on\text{-}orbit} - c1_{LUT})/c1_{LUT}$:

	I4	I5	M12	M13	M14	M15	M16
WU 02/12 [%]	1.2	-0.8	0.4	1	-1.1	-0.2	-0.3
CD 02/12 [%]	1.5	0.6	0.6	1.2	0.2	0.4	1.6
WU 05/12 [%]	1.2	-0.6	0.4	0.9	-1.7	-0.6	-0.8
CD 05/12 [%]	1.6	0.5	0.7	1.3	-0.6	0.3	1.1
WU 09/12 [%]	1.3	0.2	0.6	1.2	-0.8	0.2	0.5
CD 09/12 [%]	1.6	1	0.8	1.7	0.3	0.9	2.2
WU 12/12 [%]	1.3	-0.2	0.6	1.2	-1.2	0.1	0.03
CD 12/12 [%]	1.6	0.7	0.8	1.2	-0.2	0.3	1.6
WU 03/13 [%]	1.4	0.4	0.6	1.2	-1.1	0.1	0.4
CD 03/13 [%]	1.7	0.8	0.9	1.3	-0.1	0.6	1.8
WU 06/13 [%]	1.4	0.6	0.7	1.2	-0.7	0.4	0.9
CD 06/13 [%]	1.7	1.1	0.9	1.3	-0.01	0.5	2
WU 09/13 [%]	1.5	0.3	0.7	1.2	-1.1	0.1	0.3
CD 09/13 [%]	1.7	1.1	0.9	1.3	0.05	0.6	2
WU 12/13 [%]	1.4	-0.18	0.7	1.2	-1.2	0.1	0.05
CD 12/13 [%]	1.7	1.7	0.9	1.4	0.4	0.6	2.2
WU 03/14 [%]	1.4	0.5	0.7	1.2	-1.0	0.2	0.7
CD 03/14 [%]	1.7	1.6	0.9	1.3	0.3	0.7	2.4



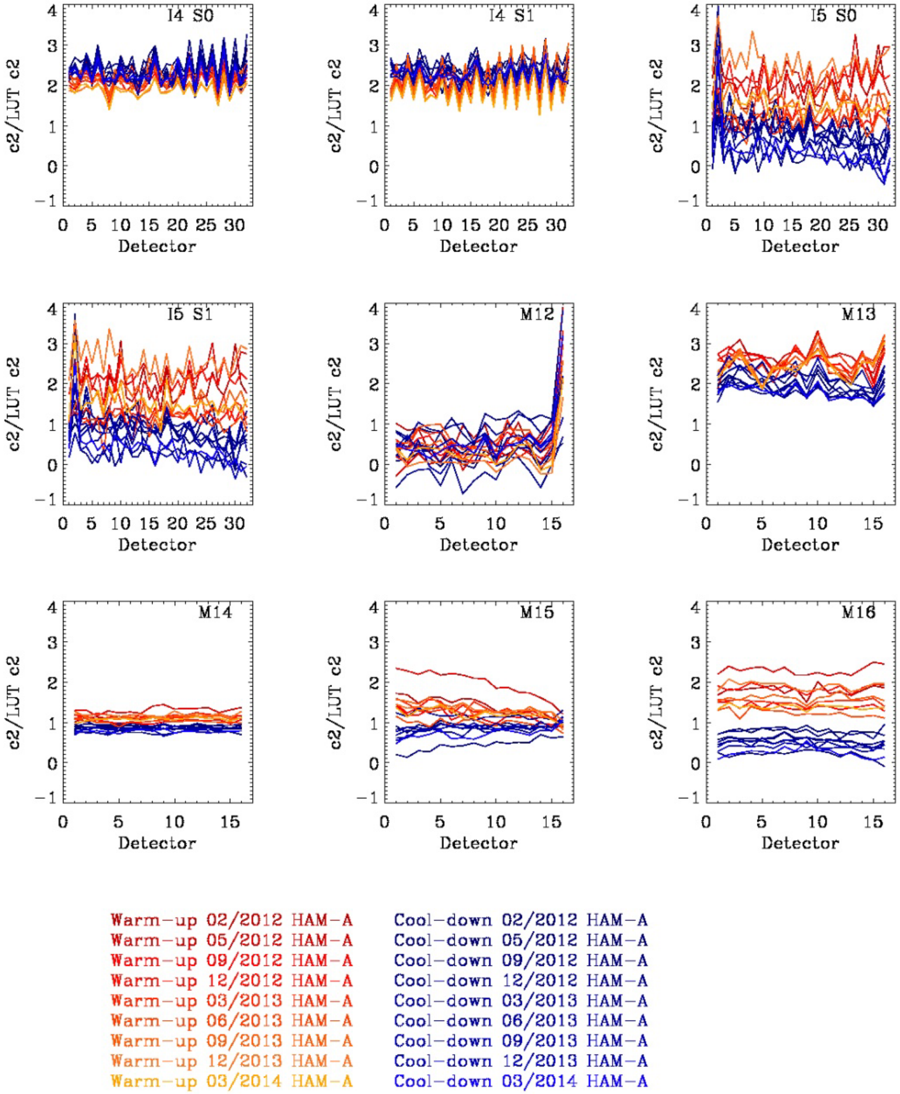
C2 Coefficients

Band average c_2



Y-range spans $c_{2LUT} \pm 3 \times c_{2LUT}$

Detector specific c_2/c_{2LUT}



Comparison to Requirement [%]

Uncertainty specifications

Defined in terms of %, at particular uniform scene temperatures

Estimates exceed the specification at lower scene temperatures for bands M12 and M13

Band	267 K
I4 spec	5.00
I4 estimate	2.55
I5 spec	2.50
I5 estimate	0.41

Band	190 K	230 K	270 K	310 K	340 K
M12 spec	---	7.00	0.70	0.70	0.70
M12 estimate	---	8.98	0.71	0.27	0.32
M13 spec	---	5.70	0.70	0.70	0.70
M13 estimate	---	7.50	0.69	0.26	0.31
M14 spec	12.30	2.40	0.60	0.40	0.50
M14 estimate	4.82	0.84	0.28	0.21	0.29
M15 spec	2.10	0.60	0.40	0.40	0.40
M15 estimate	1.59	0.47	0.22	0.19	0.22
M16 spec	1.60	0.60	0.40	0.40	0.40
M16 estimate	1.24	0.37	0.21	0.18	0.20

Uncertainty [K]

Uncertainty contributors:

- **Dominant for MWIR bands are the relative BB radiance uncertainty and the relative EV *dn* uncertainty (increasing rapidly with decreasing scene temperature).**
- **The LWIR bands uncertainties are dominated by the c_0, RVS, and EV *dn* relative uncertainties, which increase with decreasing scene temperature.**