VIIRS F1 Pre-Launch Calibration and Characterization: Emissive Band Radiometry

NPP Instrument Calibration Support Team (NICST)
Presented by
Jeff McIntire

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Emissive Band Radiometry: Objectives

- Objectives:
  - Characterize VIIRS sensor in terms of a series of performance metrics
    - dynamic range, NEdT, nonlinearity, ARD, uniformity, characterization uncertainty, stability, gain transition, OBC operability, and detector operability
  - Determine parameters for use in on-orbit (or transition to on-orbit) calibration
    - a0, a1, a2, dn_{SAT}, T_{SAT}, NEdT at T_{TYP}, etc.
  - Investigate anomalies
    - D1 vignetting at low instrument temperatures (below normal operating range)

Emissive Band Radiometry: Tests

- Thermal Vacuum testing:
  - RC-05
    - Calibrate VIIRS emissive bands using external sources (BCS and TMC)
    - Calibrate VIIRS emissive bands using an internal source (OBC)
  - RC-03 (and FOP)
    - Investigate stability of emissive bands
  - RC-01
    - Confirm gain transition of M13
  - ETP-640
    - Check for any unknown sources inside the cavity

Dynamic Range: Definition and Specification

Dynamic Range – extent of the measurement range over which the radiometric model is valid. Metrics are the lower and upper limits of this range (T_{MIN} and T_{MAX}).

Assessment – determine if the emissive bands pre-saturate; compare T_{MAX} to T_{SAT}.

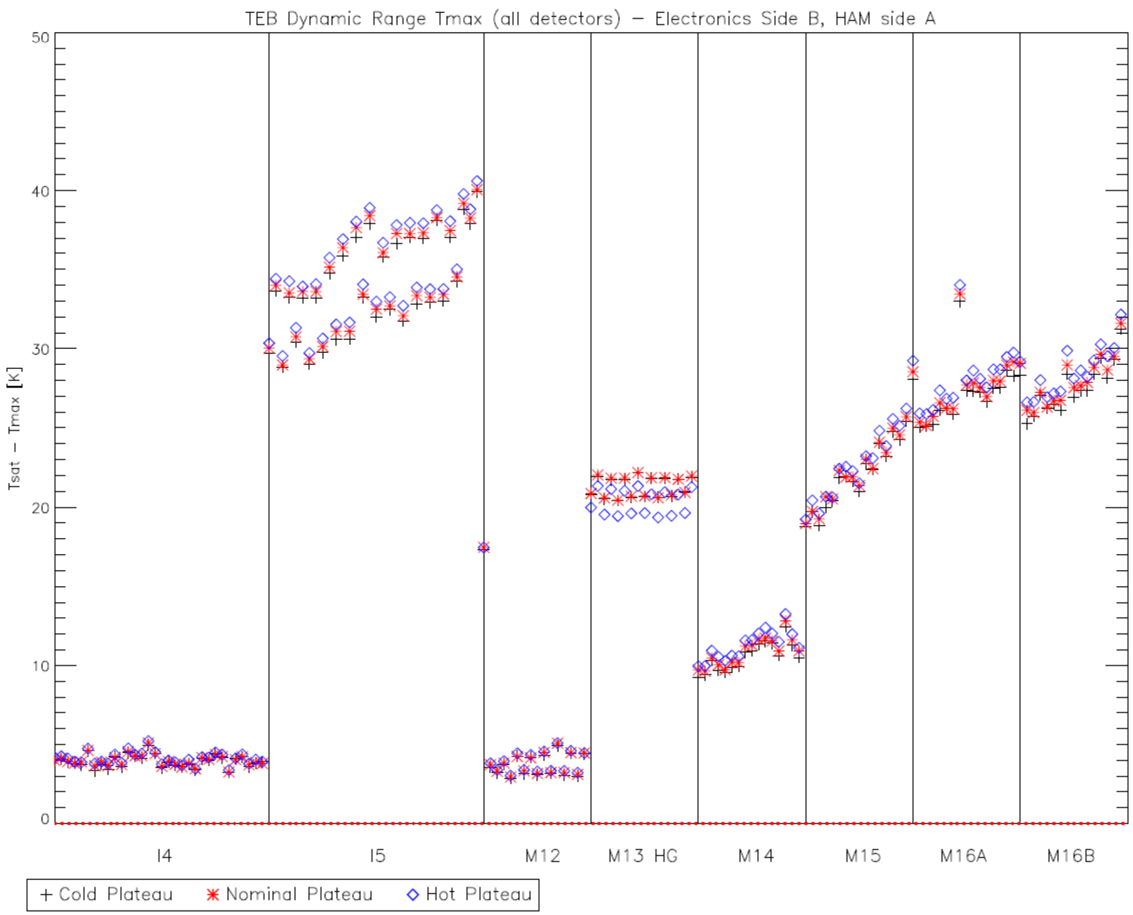
3.1.5.5.2 Emissive bands

SRV0466 The VIIRS Sensor shall be able to measure scene temperatures for the single gain emissive bands between the minimum temperature (T_{MIN}) and the maximum temperature (T_{MAX}) and for the dual gain emissive bands between the High Gain T_{MIN} and the Low Gain T_{MAX} temperatures shown in TABLE 13. [AT]

			Single Gain		Dual Gain			
					High Gain		Low Gain	
Band	**Center Wavelength (nm)**	**Gain Type**	T_{MIN}	T_{MAX}	T_{MIN}	T_{MAX}	T_{MIN}	T_{MAX}
M12	3700	Single	230	353	-	-	-	-
M13	4050	Dual	-	-	230	343	343	634
M14	8550	Single	190	336	-	-	-	-
M15	10763	Single	190	343	-	-	-	-
M16	12013	Single	190	340	-	-	-	-
I4	3740	Single	210	353	-	-	-	-
I5	12350	Single	190	340	-	-	-	-

TABLE 13. Dynamic range requirements for VIIRS Sensor emissive bands

VIIRS Dynamic Range (T_{SAT} - T_{MAX})



Dynamic Range – upper bound

- **All bands saturate above specified T_{MAX}**
- **Bands I4 and M12 saturate 3 – 5 K above T_{MAX}; all other bands have larger margins**
- **M13 low gain (not shown) did not saturate during testing; however highest measured value is above M13 low gain T_{MAX}**
- **Calculated saturation temperatures consistent over full range of instrument conditions**
- **M12-D1 and M16-D8 OOF**

NEdT: Definition and Specification

NEdT (Noise Equivalent delta Temperature) – the variation in the scene temperature that is equivalent to the system noise (i.e. SNR = 1). A measure of resolution for thermal emissive signals which is dependent on the scene which is being observed.

Assessment – the NEdT is computed at a typical scene temperature (T_{TYP}).

Notes:

• The NEdT column corresponds to the minimum required (worst-case) SNR that applies at the end-of-scan. Elsewhere in the scan, aggregation will yield a larger SNR (and consequently a lower NEdT).

• Within the same gain setting, at scene temperatures larger than T_{TYP}, the SNR will be larger than at T_{TYP}.

• For reference, the NEdT values in Table 15 are related to the noise equivalent spectral radiance (NEdL) by the following formula:

$$NEdT = \frac{NEdL}{\left.\frac{\partial L_{BB}}{\partial T}\right]_{T_{TYP}}}$$

where the denominator is the temperature derivative of the Planck spectral radiance function evaluated at the specified T_{TYP} for a given band. For the emissive bands, we define the radiance L_{TYP} as the radiance of a blackbody at the specified T_{TYP}.

			Single Gain		Dual Gain			
					High Gain		Low Gain	
Band	**Center Wavelength (nm)**	**Gain Type**	**T_{TYP}**	**NEdT**	**T_{TYP}**	**NEdT**	**T_{TYP}**	**NEdT**
M12	3700	Single	270	0.396	-	-	-	-
M13	4050	Dual	-	-	300	0.107	380	0.423
M14	8550	Single	270	0.1021	-	-	-	-
M15	10763	Single	300	0.070	-	-	-	-
M16	12013	Single	300	0.072	-	-	-	-
I4	3740	Single	270	2.500	-	-	-	-
I5	12350	Single	210	1.500	-	-	-	-

TABLE 15. Sensitivity requirements for VIIRS Sensor emissive bands

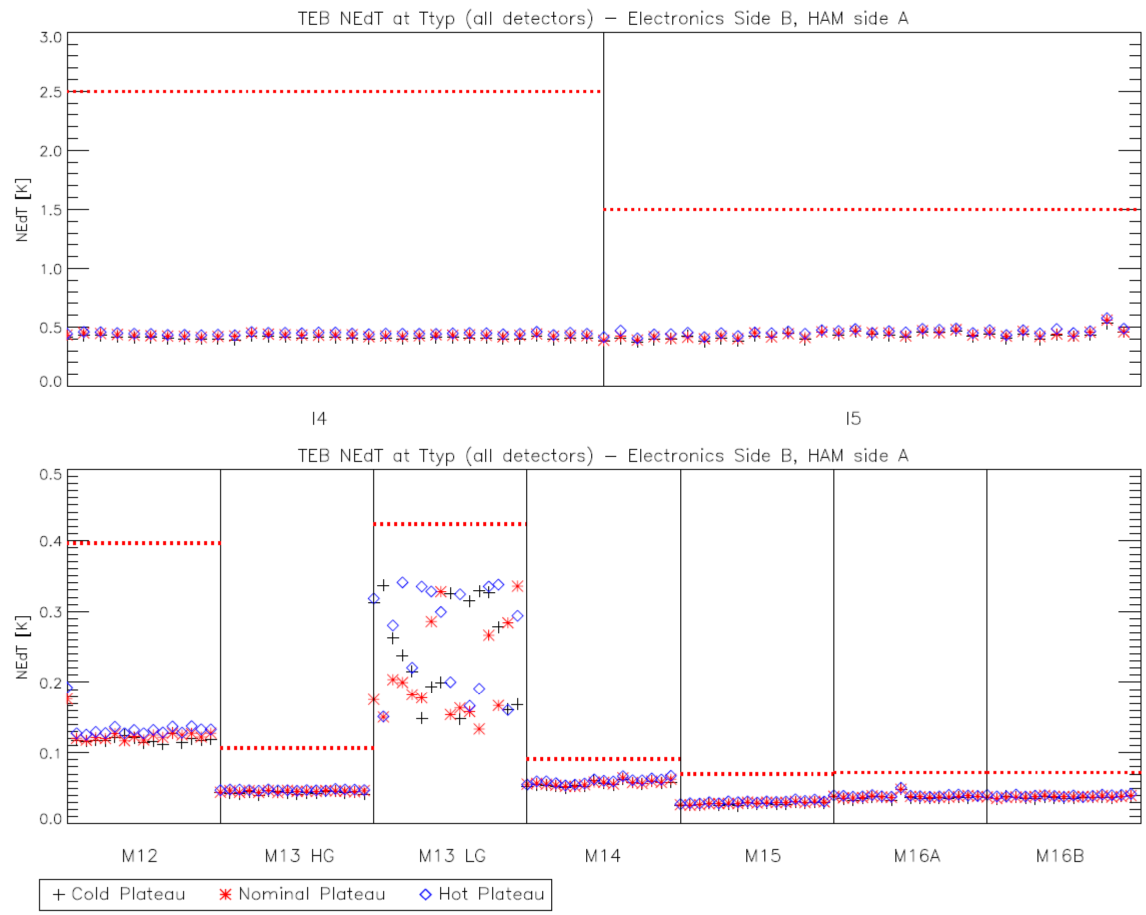
3.1.5.6.2 Emissive bands

SRV0053 The VIIRS sensor emissive bands shall meet the sensitivity requirements of TABLE 15. [T] For each gain state, TABLE 15 lists a required scene temperature, T_{TYP}, at which the specified NEdT applies.

VIIRS NEdT at T_{TYP}

NEdT at T_{TYP}

- **All bands have better than specified resolution**
- **NEdT increases slightly with instrument temperature (increasing dark noise in thermal bands)**
- **M14 is closest in % to the specified limit. This band is known to have higher noise**
- **M12-D1, M16-D8, and I5-D31 OOF**



Nonlinearity: Definition and Specification

Nonlinearity – deviation of measured data from a linear fit of the response versus the background subtracted radiance over the full dynamic range.

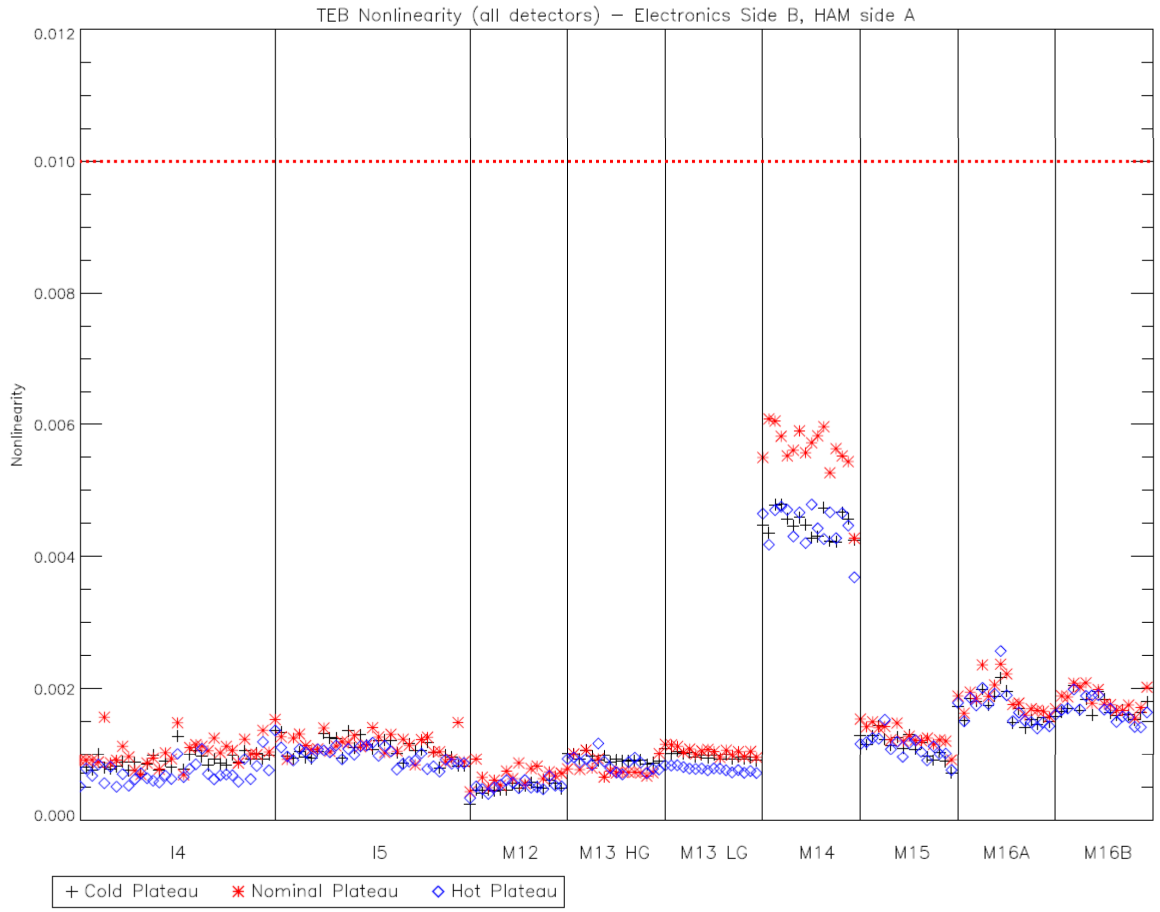
Assessment – the ratio of the maximum residual from a first-order polynomial fit to the response at L_{MAX}; this value is compared to 0.01.

3.1.5.10.4.2 Response linearity

Nonlinearity is defined as the maximum deviation in end-to-end detector channel response (dn) from a best-fit straight line of a plot of response vs at-aperture radiance (L) over the range of L_{MIN} to L_{MAX} given in Table 14 for the reflective bands and over the range of T_{MIN} to T_{MAX} given in Table 15 for the thermal emissive bands.

SRV0595 The nonlinearity (NL) of all spectral bands within a given gain state shall be less than 0.01 of the response at L_{MAX}/T_{MAX}.[AT]

Nonlinearity



Nonlinearity

• All bands exhibit less than the specified deviation from linearity [about 0.2% or less of the response at T_{MAX} for all bands, except M14 (0.6%)]

ARD: Definition and Specification

ARD (Absolute Radiometric Difference) – a determination of the accuracy of the SDR science algorithm by comparison of the retrieved radiance to the true scene radiance.

Assessment – the ARD is defined as the percent difference between the retrieved radiance using the SDR science algorithm and the true radiance of the blackbody source. ARD values plotted at 3 distinct temperatures – 190K/230K (min), 270K (typical), 340K (max).

3.1.5.10.1 Absolute radiometric calibration uncertainty

There are numerous error sources that can contribute to radiometric calibration uncertainty of the VIIRS. All possible error sources identified will be quantified with sufficient accuracy through measurement and/or analysis to verify compliance with the absolute radiometric calibration requirements for uniform scenes (3.1.5.10.2) and for structured scenes (3.1.5.10.3). Initial budgets for the following error sources are listed in Section 7.4: differential out-of-band response, ghosting, wavelength and bandwidth stability, response versus scan angle, and emission versus scan angle.

3.1.5.10.2.3 Moderate resolution emissive bands

For the bands specified as moderate resolution and emissive (TABLE 1), TABLE 17 shows the absolute radiometric calibration uncertainty of spectral radiance for uniform scenes at five scene temperatures. The calibration uncertainties are given as a percentage of the radiance at the different temperatures.

Band	λ_c (µm)	Scene Temperature				
		190K	230K	270K	310K	340K
M12	3.7	NA	7.0%	0.7%	0.7%	0.7%
M13	4.05	NA	5.7%	0.7%	0.7%	0.7%
M14	8.55	12.3%	2.4%	0.6%	0.4%	0.5%
M15	10.763	2.1%	0.6%	0.4%	0.4%	0.4%
M16	12.013	1.6%	0.6%	0.4%	0.4%	0.4%

TABLE 17. Absolute radiometric calibration uncertainty of spectral radiance for moderate resolute emissive bands

Band	Center Wavelength (µm)	Calibration Uncertainty
I4	3.740	5.0%
I5	11.450	2.5%

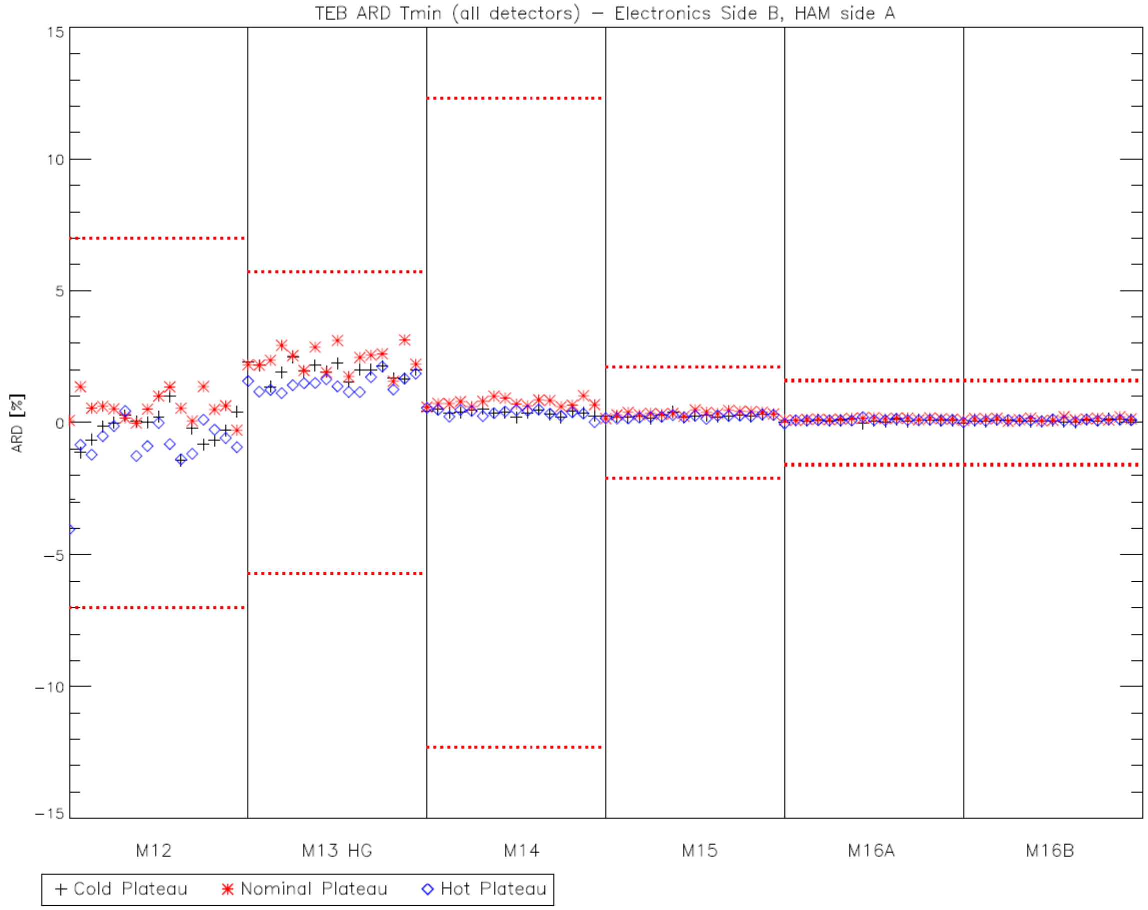
TABLE 18. Radiometric calibration uncertainty for imaging emissive bands

SRV0545 For the bands specified as moderate resolution and emissive, the absolute radiometric calibration uncertainty of spectral radiance shall be equal to or less than the percentages specified in TABLE 17. [A]

3.1.5.10.2.4 Imaging emissive bands

SRV0546 For the bands specified as imaging and emissive (TABLE 1), given a uniform scene of brightness temperature of 267K, the calibration uncertainty of spectral radiance shall be as specified in TABLE 18. [A]

ARD: T_{MIN}



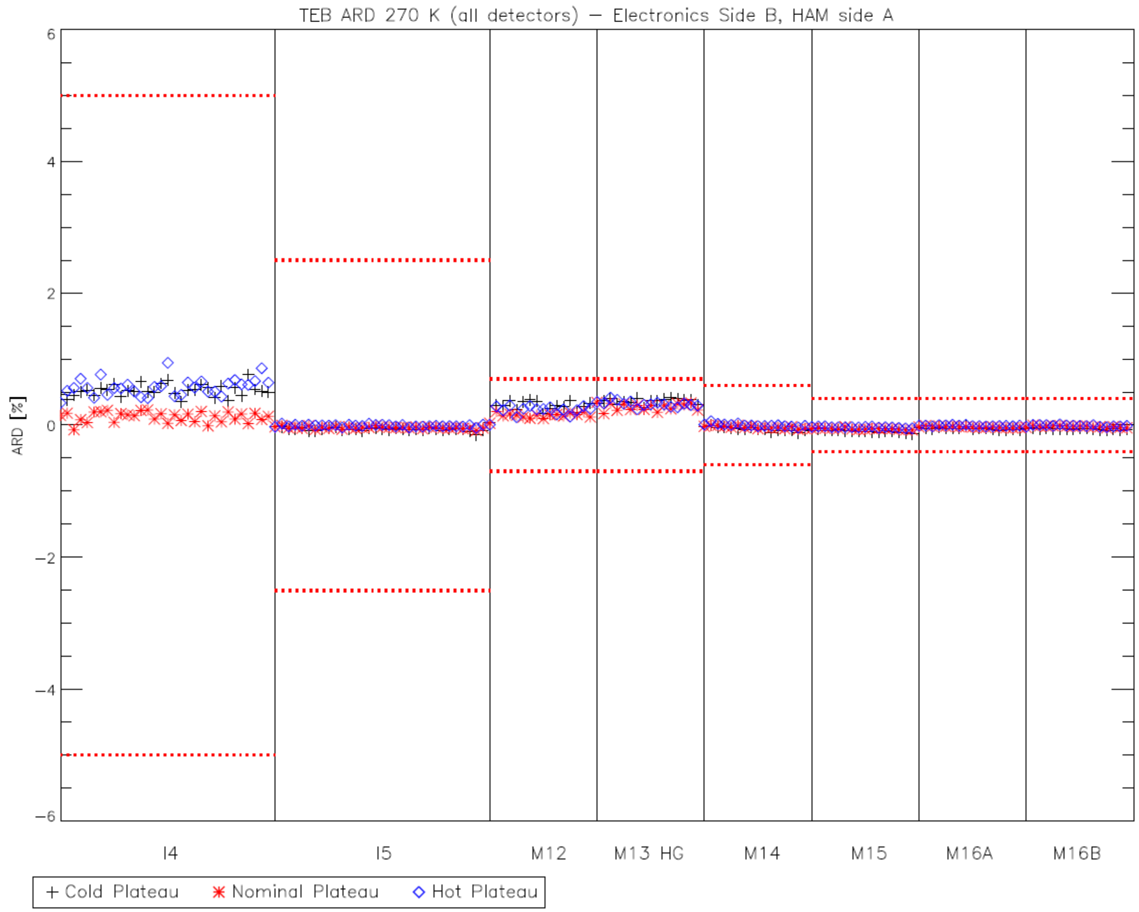
ARD – T_{MIN}

- **All moderate emissive bands are within the specified tolerance on the accuracy of the SDR science algorithm at T_{MIN}**
- **Imaging bands not shown here (ARD only applies to imaging bands at a scene temperature of 267 K)**
- **This specification does not apply to M13 low gain**

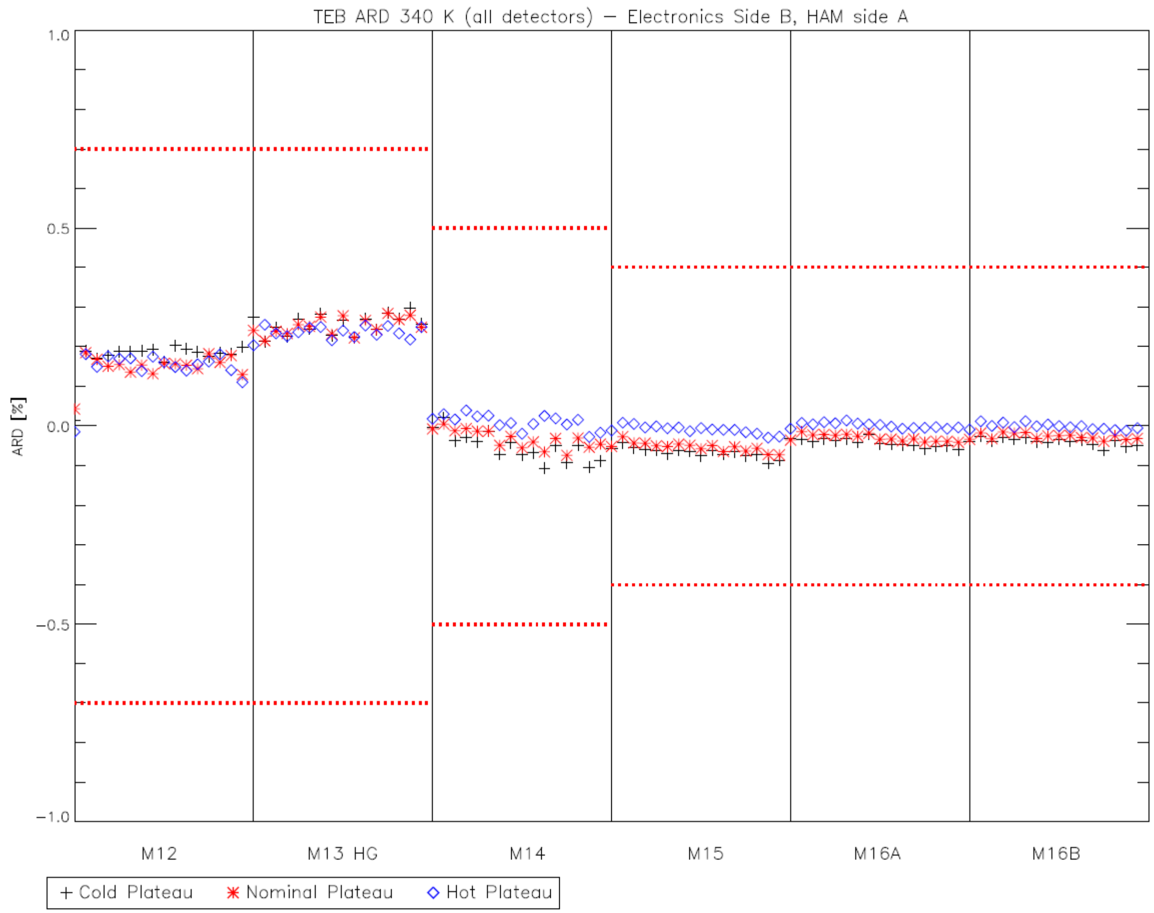
ARD: 270 K

ARD – 270 K

- **All emissive bands are within the specified tolerance on the accuracy of the SDR science algorithm at 270 K**
- **This specification does not apply to M13 low gain**



ARD: 340 K



ARD – 340 K

- **All moderate emissive bands are within the specified tolerance on the accuracy of the SDR science algorithm at 340 K**
- **Imaging bands not shown here (ARD only applies to imaging bands only at a scene temperature of 267 K)**
- **This specification does not apply to M13 low gain**

Detector Uniformity: Definition and Specification

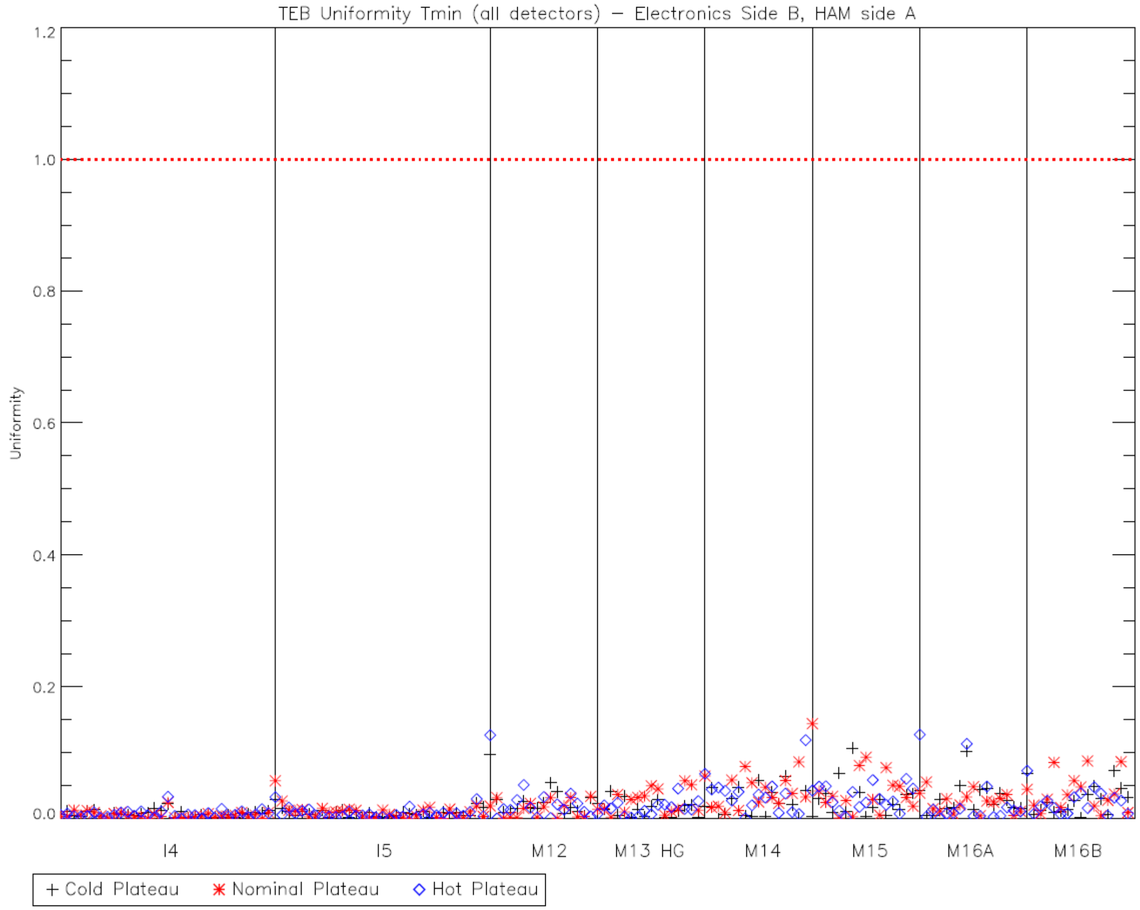
Uniformity – a measure of detector-to-detector striping, by comparing the radiance difference between detectors with the noise.

Assessment – defined as the ratio of the difference between retrieved radiance and band-average retrieved radiance to the NEdL. Uniformity values are plotted at 3 temperatures spanning the required range: T_{MIN} (min), 270K (typical), and 0.9*T_{MAX} (max).

3.1.5.10.2.5 Relative Radiometric Response

SRV0613 The calibrated output of all channels within a band shall be matched to the band mean output within the NEdL / NEdT (1 sigma) when viewing a uniform scene. The matching condition shall be met between radiance levels from L_{MIN} to 0.9 L_{MAX}. [AT]

Uniformity: T_{MIN}



Detector Uniformity – T_{MIN}

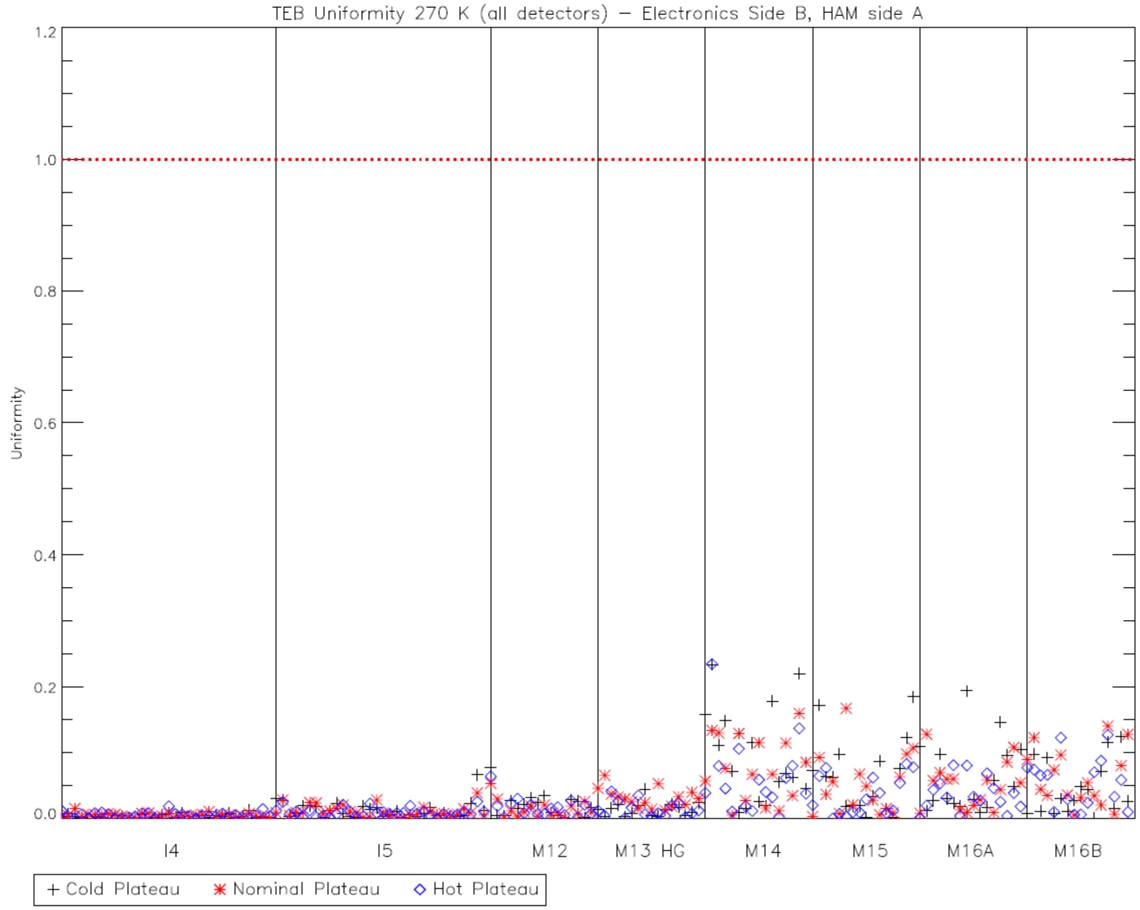
- **Striping is within the noise for all emissive bands at T_{MIN}**
- **M13 low gain (not shown) compliant for all detectors**

Uniformity: 270 K

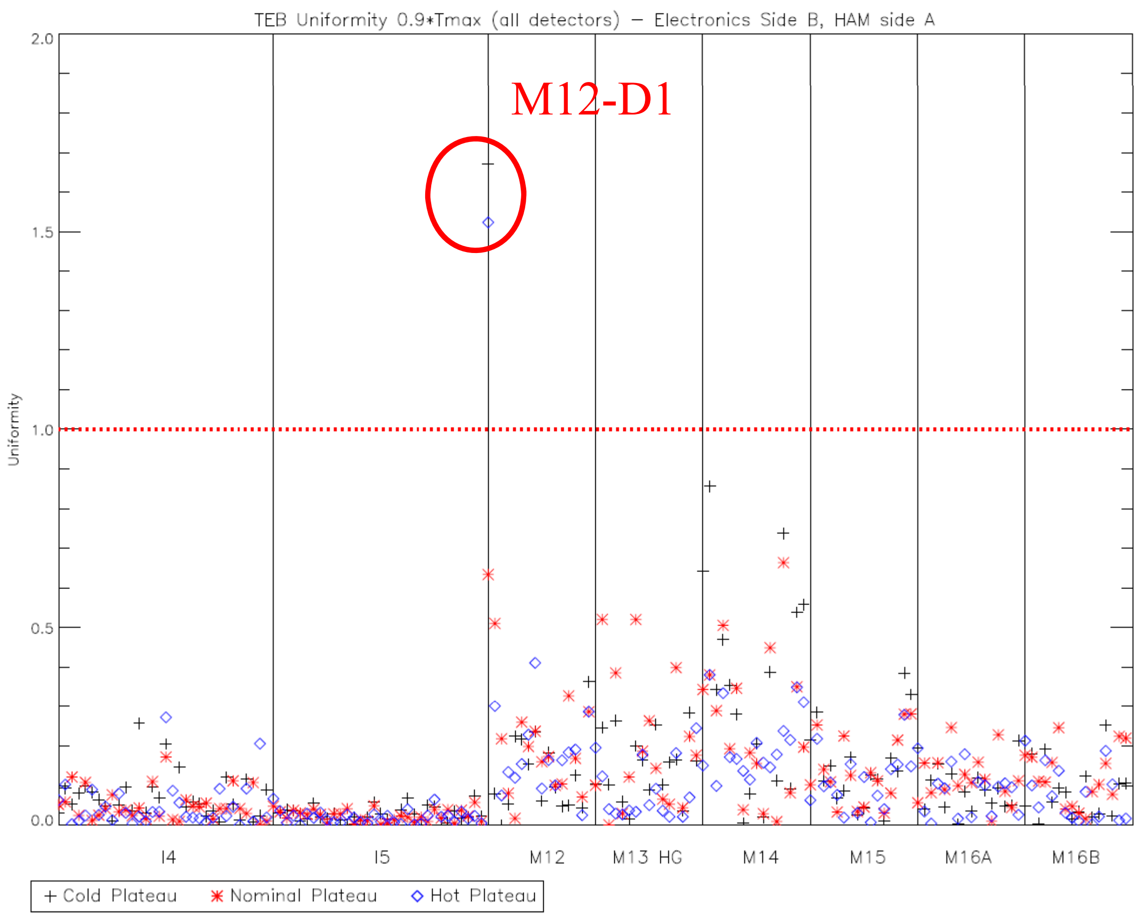
Detector Uniformity – 270 K

• Striping is within the noise for all emissive bands at 270 K

• M13 low gain (not shown) compliant for all detectors



Uniformity: $0.9*T_{MAX}$



Detector Uniformity – $0.9*T_{MAX}$

- **M12-D1 exhibits striping that exceeds the noise (this detector has been declared inoperable by the vendor)**
- **Striping is within the noise for all other emissive bands and detectors at $0.9*T_{MAX}$**
- **M13 low gain (not shown) compliant for all detectors**

Stability: Definition and Specification

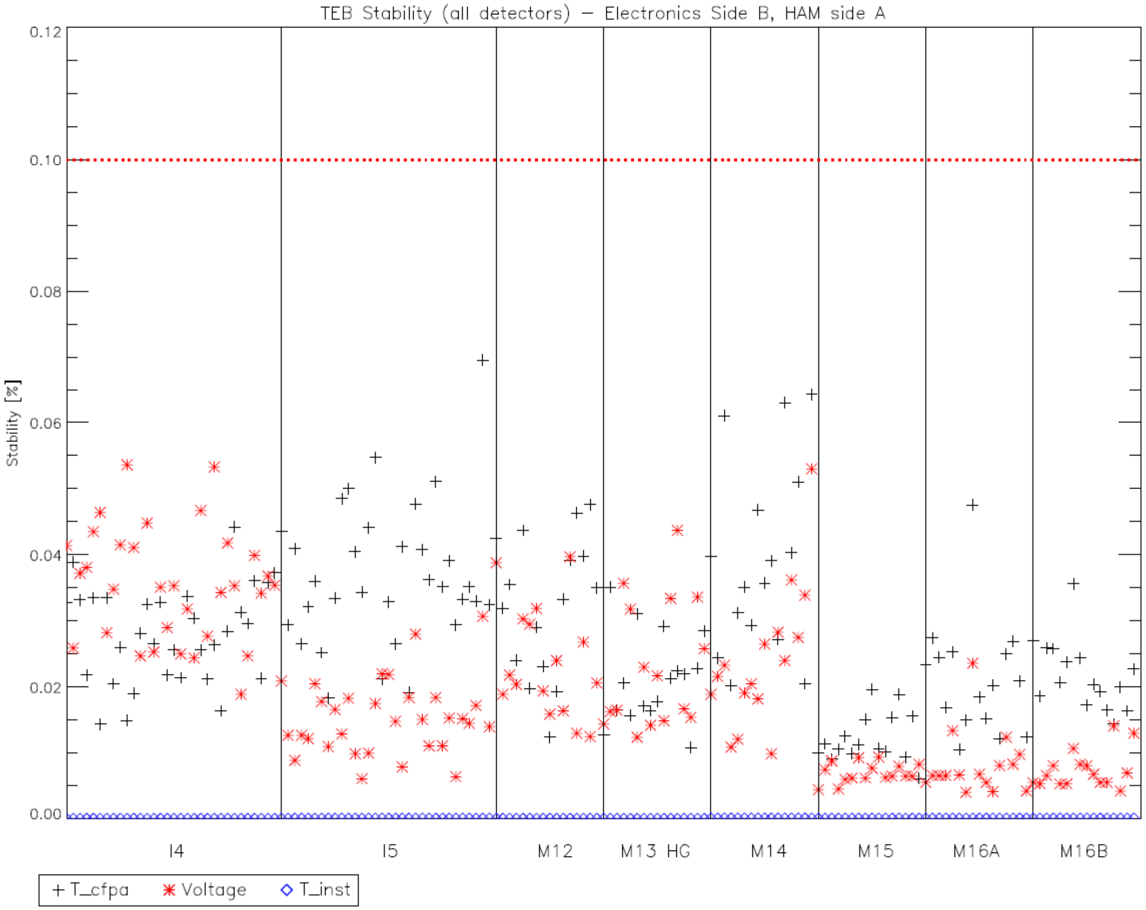
Stability – a measure of radiometric response invariability as the instrument thermal and/or electronic state varies with changing environmental conditions between calibrations (1-scan for TEB).

Assessment – the focus will be on stability with respect to three different variables: instrument temperature, focal plane temperature, and bus voltage. M13 low gain was not measured (expected to behave similarly to M13 high gain).

3.1.5.11 VIIRS sensor stability

SRV0552 The VIIRS sensor response to input radiance shall not change by more than 0.1% for the emissive bands and 0.3% for the reflective bands during the time between successive acquisitions of on-orbit calibration data. [A]

Stability



Stability: Voltage

- **All bands exhibit greater than the specified stability per scan**
- **Note: the Bus Voltage was intentionally transitioned from 32 V to 27 V over a timescale of 138 min**

Stability: Instrument Temperature (Cold – Nominal Transition)

- **All bands exhibit greater than the specified stability per scan (other transitions show comparable results)**
- **Note: the instrument temperature was intentionally transitioned from 267 K to 277 K over a timescale of 580 min**

Stability: FPA

- **All bands exhibit greater than the specified stability per scan**
- **Note: the FPA temperature was intentionally transitioned from 82 K to 78 K over a timescale of 236 min**

Gain Transition: Definition and Specification

Gain transition – a measure of the scene temperature at which the dual gain bands switch from high gain to low gain mode.

Assessment – determine the gain transition scene temperatures over the full range of instrument operating conditions. M13 is the only TEB dual gain band. Note: the parameter that controls the DN at transition is V_ref_gain.

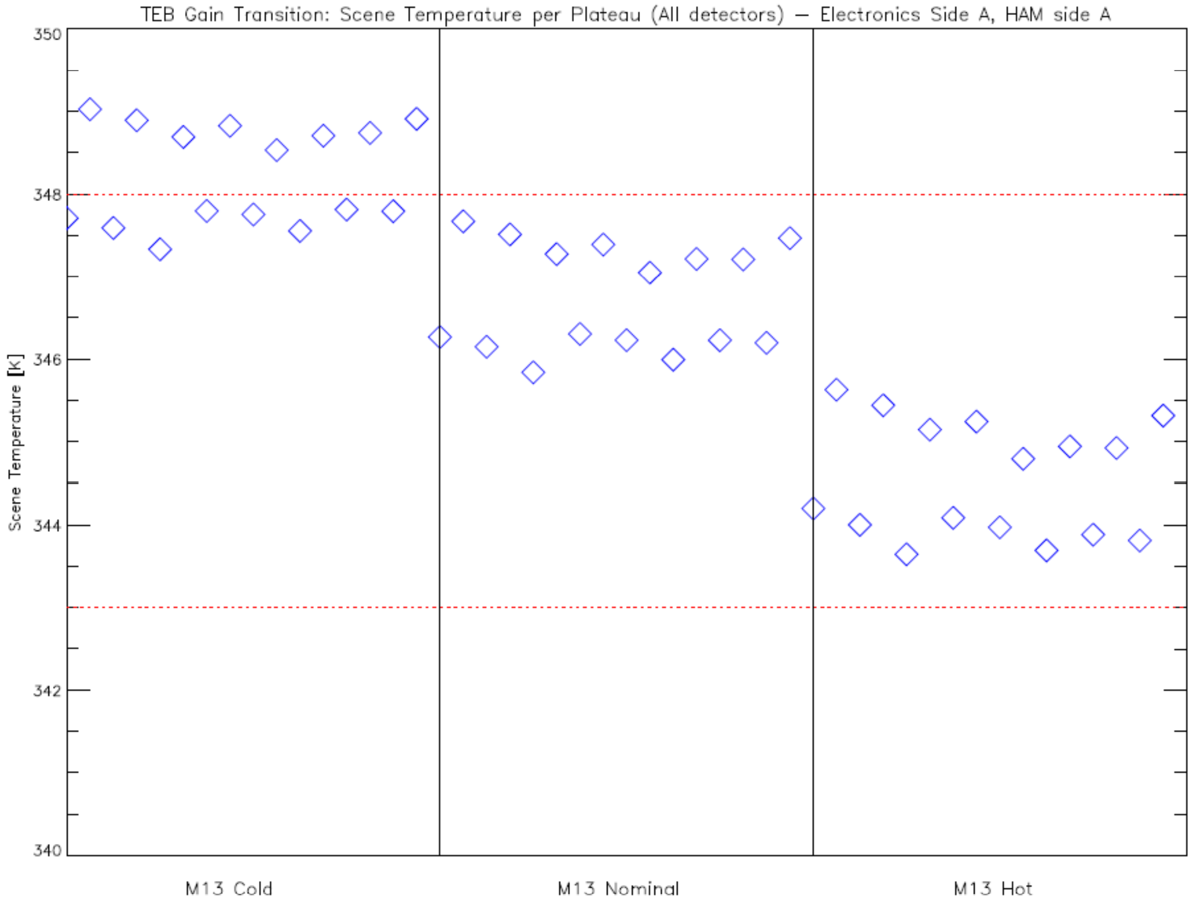
3.1.5.5.2 Emissive bands

SRV0468 For VIIRS Sensor emissive bands that use multiple gain states, the gain switching shall occur at the scene temperatures specified in TABLE 13 with a tolerance of +5.0K and -0.0K. [T]

			Single Gain		Dual Gain			
					High Gain		Low Gain	
Band	**Center Wavelength (nm)**	**Gain Type**	T_{MIN}	T_{MAX}	T_{MIN}	T_{MAX}	T_{MIN}	T_{MAX}
M12	3700	Single	230	353	-	-	-	-
M13	4050	Dual	-	-	230	343	343	634
M14	8550	Single	190	336	-	-	-	-
M15	10763	Single	190	343	-	-	-	-
M16	12013	Single	190	340	-	-	-	-
I4	3740	Single	210	353	-	-	-	-
I5	12350	Single	190	340	-	-	-	-

TABLE 13. Dynamic range requirements for VIIRS Sensor emissive bands

Gain Transition: M13



M13 Gain Transition

- **Using a single value of V_ref_gain, M13 gain transition is not within the specified tolerance for all instrument conditions**
- **Allowed tolerance +5 K; detector spread ~2 K and ~4 K variation over plateau**
- **Possible workaround: using two values of V_ref_gain, M13 gain transition is within the specified tolerance for all instrument conditions (change V_ref_gain at Nominal plateau-like conditions)**

OBC Operability: Definition and Specification

OBC Operability – a series of requirements designed to ensure that the OBC is a well calibrated source capable of maintaining the emissive band calibration on-orbit.

Assessment – the OBC operability is investigated in terms of temperature range and uniformity.

3.1.6.10.5.1 In-flight radiometric calibration for the emissive bands

SRV0091 The VIIRS Sensor shall have an on-board blackbody source for radiometric calibration of the emissive bands.

SRV0092 Calibration data for the VIIRS Sensor on-board blackbody source shall be taken each scan.

SRV0093 VIIRS Sensor on-board blackbody source shall have an emittance greater than 0.996 as viewed by VIIRS.

SRV0094 The emittance of the VIIRS Sensor on-board blackbody source shall be measured to +/- 0.002.

SRV0095 The emitting surface of the VIIRS Sensor on-board blackbody source shall have a temperature uniformity of 0.03 K when operated under temperature controlled or unpowered conditions. Temperature uniformity is defined as the standard deviation of the temperatures measured by the sensors embedded in the OBC BB. {NOTE: OBC is an abbreviation for On-Board Calibrator.}

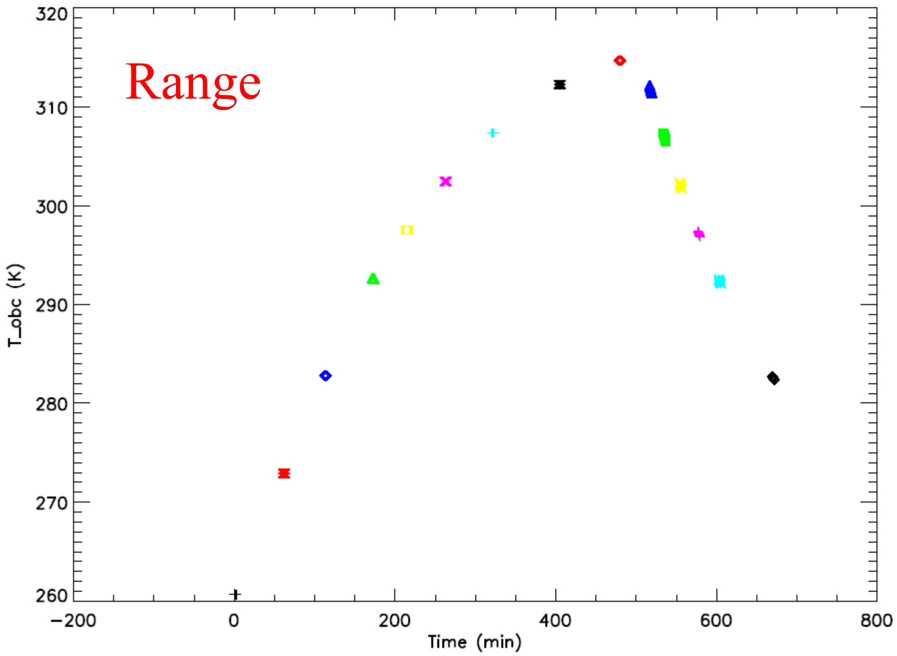
SRV0096 The effective temperature of the on-board blackbody shall be determined within a calibration uncertainty of 0.05 K over a temperature range of sensor ambient temperature to 315 K.

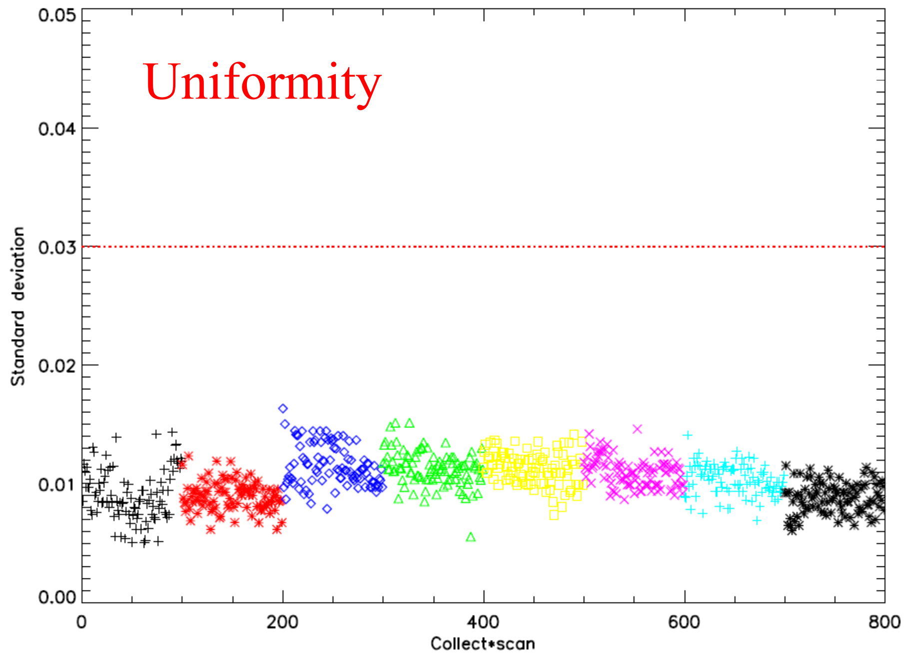
SRV0597 The on-board blackbody shall be a v-groove plate.

SRV0598 The sensor shall be capable of controlling the temperature of the on-board blackbody to a commandable setpoint between approximately ambient and 315 K.

SRV0654 The sensor shall be capable of maintaining the temperature of the on-board blackbody to within +/- 0.2 K of the programmed setpoint temperature.

OBC Operability





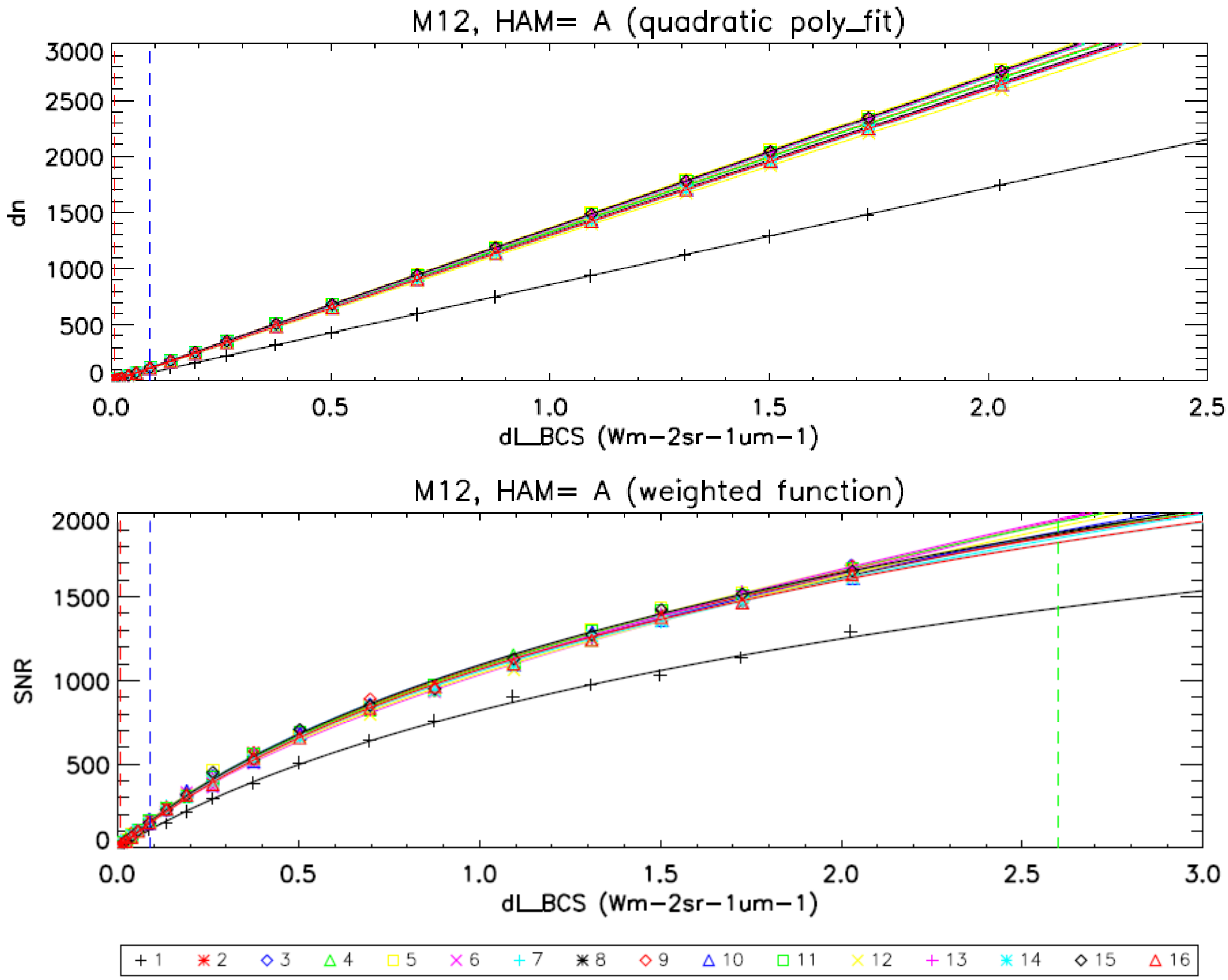
OBC Operability

- **OBC temperature range from ambient to 315 K**
- **OBC thermistor uniformity below 0.03 K**
- **Results shown are from Cold plateau (other plateaus are consistent)**

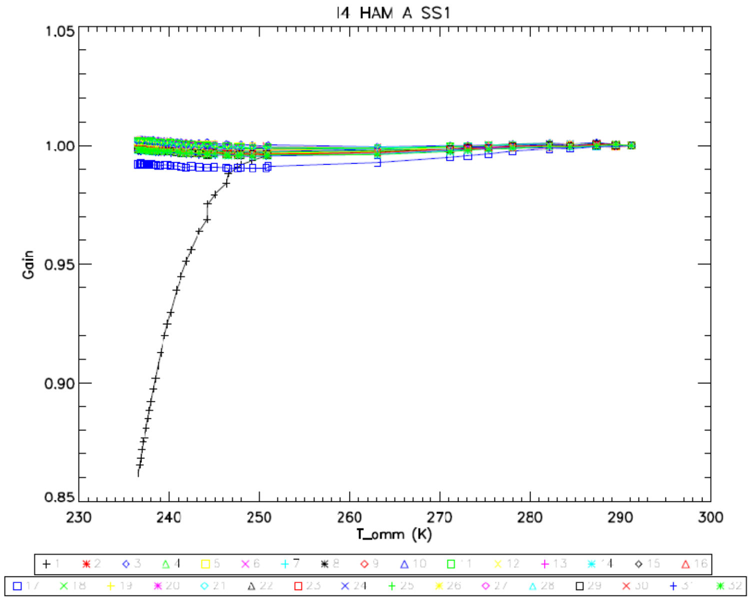
Detector Operability

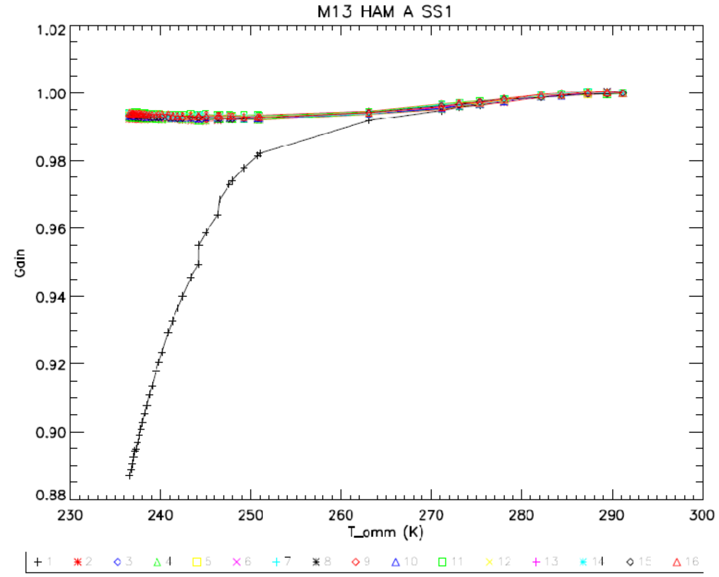
Detector Operability

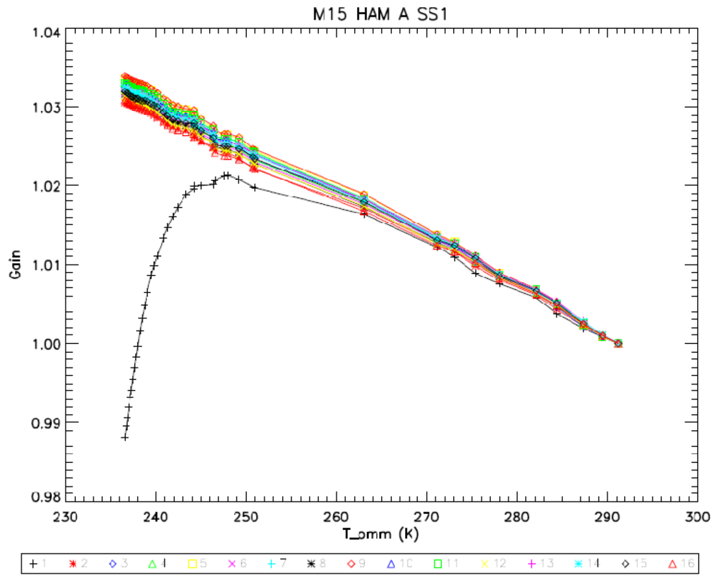
- **Restrictions on the number of inoperable detectors in a given band and focal plane. Community consensus on operability of detectors based on sensitivity and/or radiometric performance.**
- **M12-D1 has been declared inoperable by the vendor**
- **Exhibits consistently OOF behavior in most performance metrics**
- **However, it is still possible to extract valid science data for M12-D1**



Vignetting



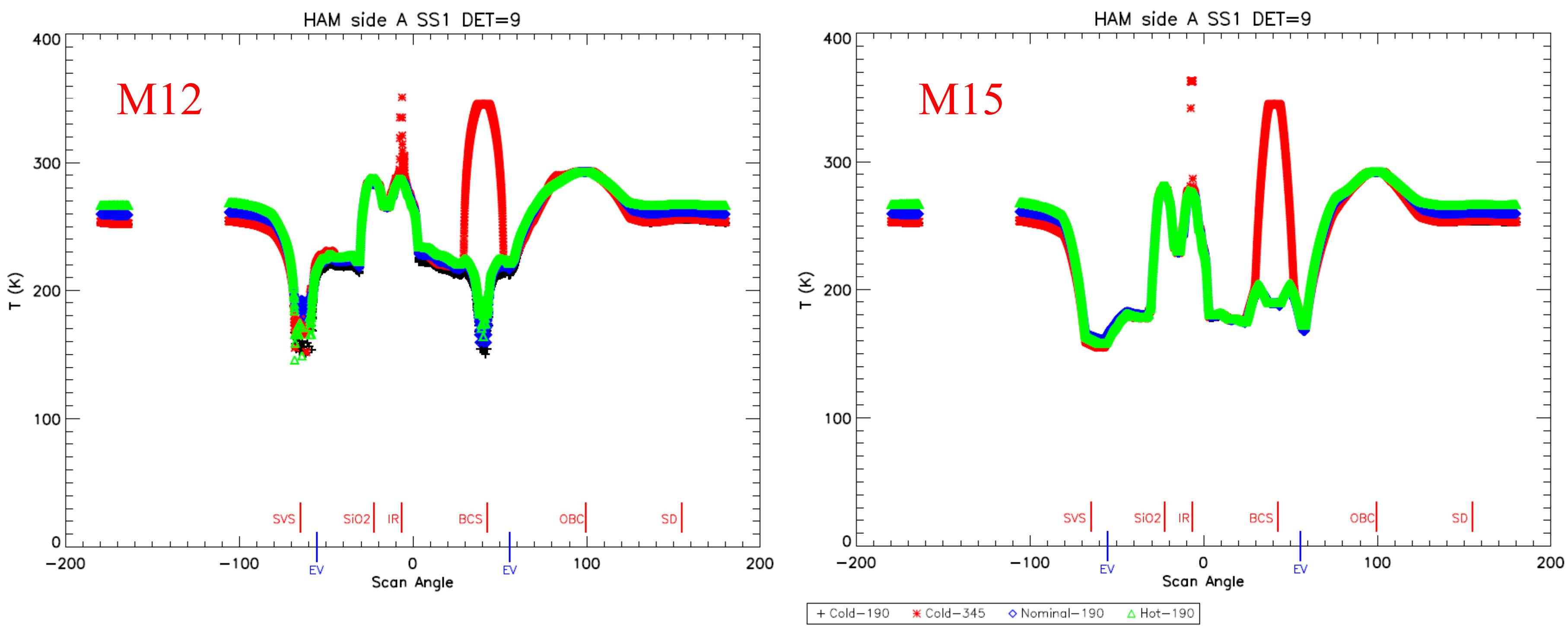




D1 Vignetting

- **Observed in D1 for all bands when the OMM temperature is below ~250 – 255 K**
- **Traced to intermediate field baffle inside the RTA**
- **Occurs below normal operating instrument temperatures**
- **Data shown is from FOP testing**

360 Degree Scan Survey



360 Degree Scan Survey

- **No significant unknown sources detected**
- **Data collected at all instrument conditions (Cold, Nominal, and Hot plateaus)**
- **VIIRS cavity temperature increases about 10 K from plateau to plateau**
- **Major features: SiO2 and IR chamber windows as well as BCS and OBC blackbody sources**

Emissive Band Radiometry Summary

- Dynamic range – No pre-saturation
- NEdT within specified resolution
- Nonlinearity within 1% of the response at T_{MAX}
- No striping is evident (except M12-D1 at high scene temperatures)
- ARD within the specified accuracy
- Stability is within specified limits per scan
- M13 gain transition not operating within the specified tolerance for all instrument conditions
- OBC operating normally
- D1 vignetting (all bands) occurs below 250 – 255 K OMM temperature, which is outside normal operating conditions
- M12-D1 was declared inoperable by vendor; valid science data should still be available

Backup Slides

VIIRS T_{MIN} vs T(SNR=3)

Dynamic Range – lower bound

- **Bands I4 and M14 are possibly contaminated by noise at low scene temperatures within the dynamic range**
- **T(SNR=3) generally increases with instrument temperature**
- **Note – T(SNR=3) difficult to constrain for M15 and M16; however, measurements at T_{MIN} (190 K) indicate that these bands have an SNR well over 100.**
- **Results shown are worst case detector.**
- **Preliminary results - further analysis is in progress.**

Band	T_{MIN} (K)	T(SNR=3) (K)		
		Cold	Nominal	Hot
I4	210	226.3	227.0	227.3
I5	190	168.3	169.5	172.5
M12	230	214.8	215.4	216.7
M13 HG	230	207.1	206.3	206.6
M14	190	199.5	200.3	203.6
M15	190	184.2	186.3	185.8
M16A	190	180.7	175.8	176.9
M16B	190	165.7	170.2	171.5

Characterization Uncertainty: Definition and Specification

Characterization Uncertainty – a measure of the goodness of fit for a second-order polynomial in terms of the fractional radiance residual.

Assessment – defined as the RSS of the average fractional radiance residual and 1 sigma of the fractional radiance residual.

3.1.5.10.4.3 Response Characterization

Within a given state, the VIIRS sensor response at multiple input radiance levels across the specified dynamic range (Lmin to Lmax, Tmin to Tmax) will be best-fit to a second-order polynomial to closely approximate the estimated input radiance (L') using the measured sensor output level (dn) as follows,

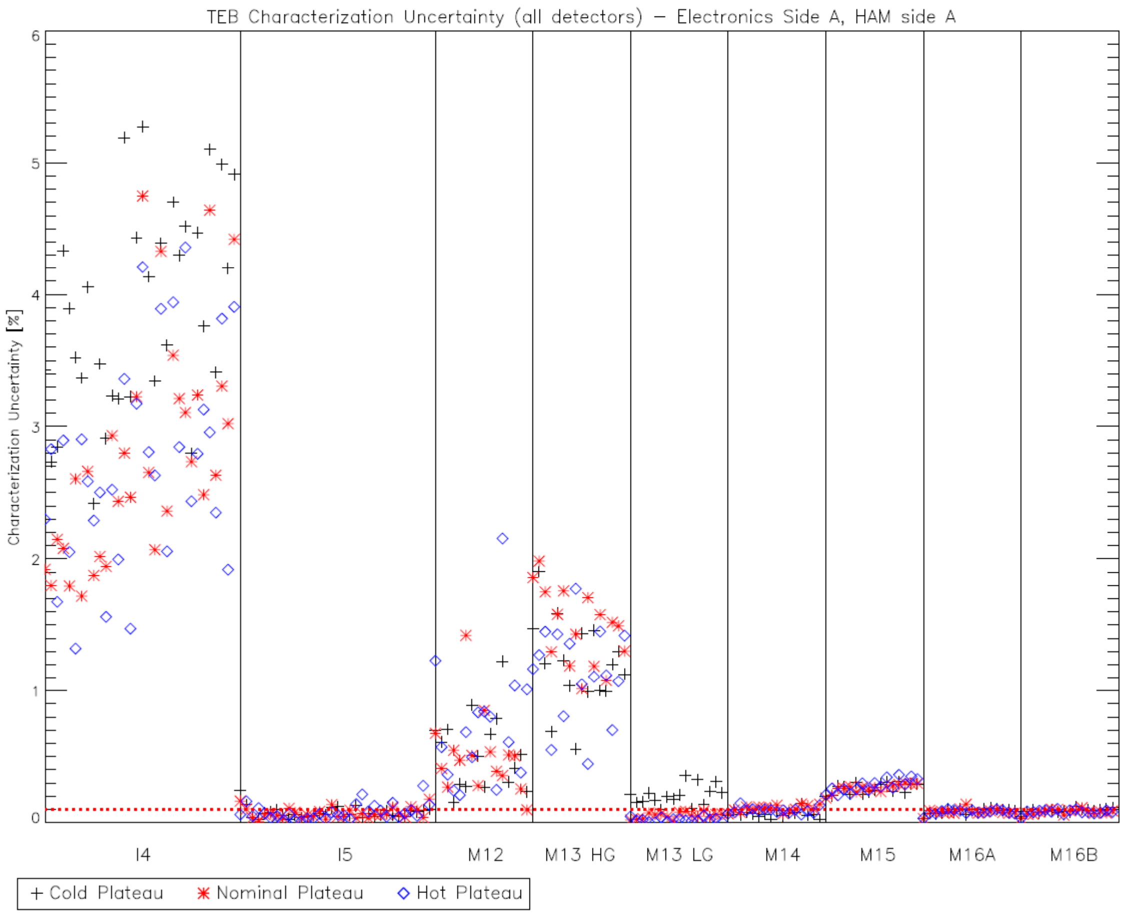
$$L' \approx L'approx = a_0 + a_1 \cdot dn + a_2 \cdot dn^2$$

The sensor response characterization uncertainty at each output level (dn) is defined as

$$\Delta L' = \frac{|L' - L'approx|}{L'}$$

SRV0595 The VIIRS sensor response shall be characterized with an uncertainty better than 0.1% (mean of the ΔL' values plus 1 sigma of the ΔL' values) for the MWIR and LWIR bands. [A]

Characterization Uncertainty



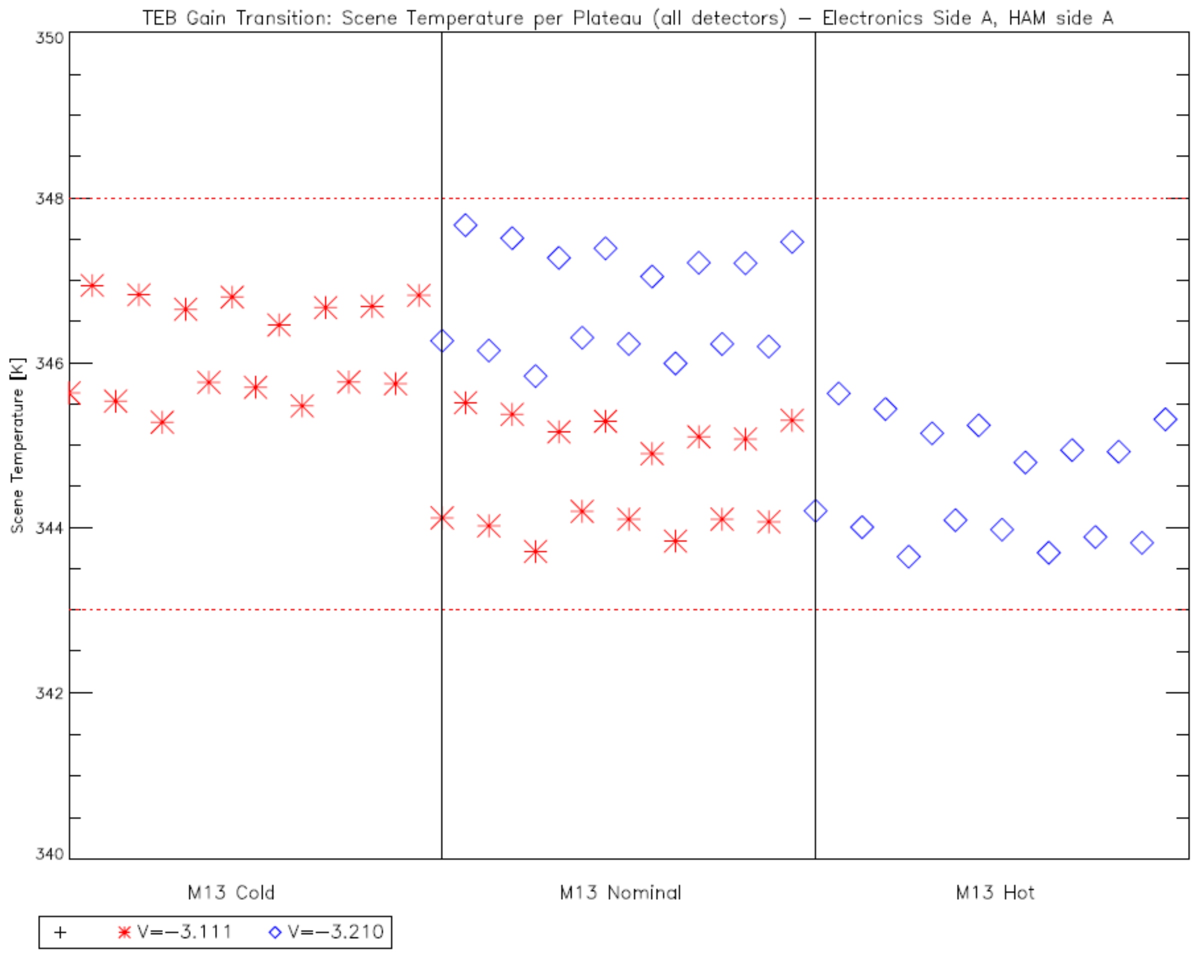
Characterization Uncertainty

- **MWIR exceed the specified limit by large margins; M14 and M15 exceed the specification by a small margin**
- **I5 and M16 close to or below specified limit**
- **The Characterization Uncertainty depends upon the fractional radiance residual, which is large at low radiances**
- **Higher level performance metrics (ARD and Uniformity) also depend heavily on the quality of the fitting and behave within expected limits**

Gain Transition: M13

M13 Gain Transition

- Using two values of V_ref_gain, M13 gain transition is within the specified tolerance for all instrument conditions
- Change V_ref_gain at Nominal plateau-like conditions (T_{OMM} ~ 263 K)



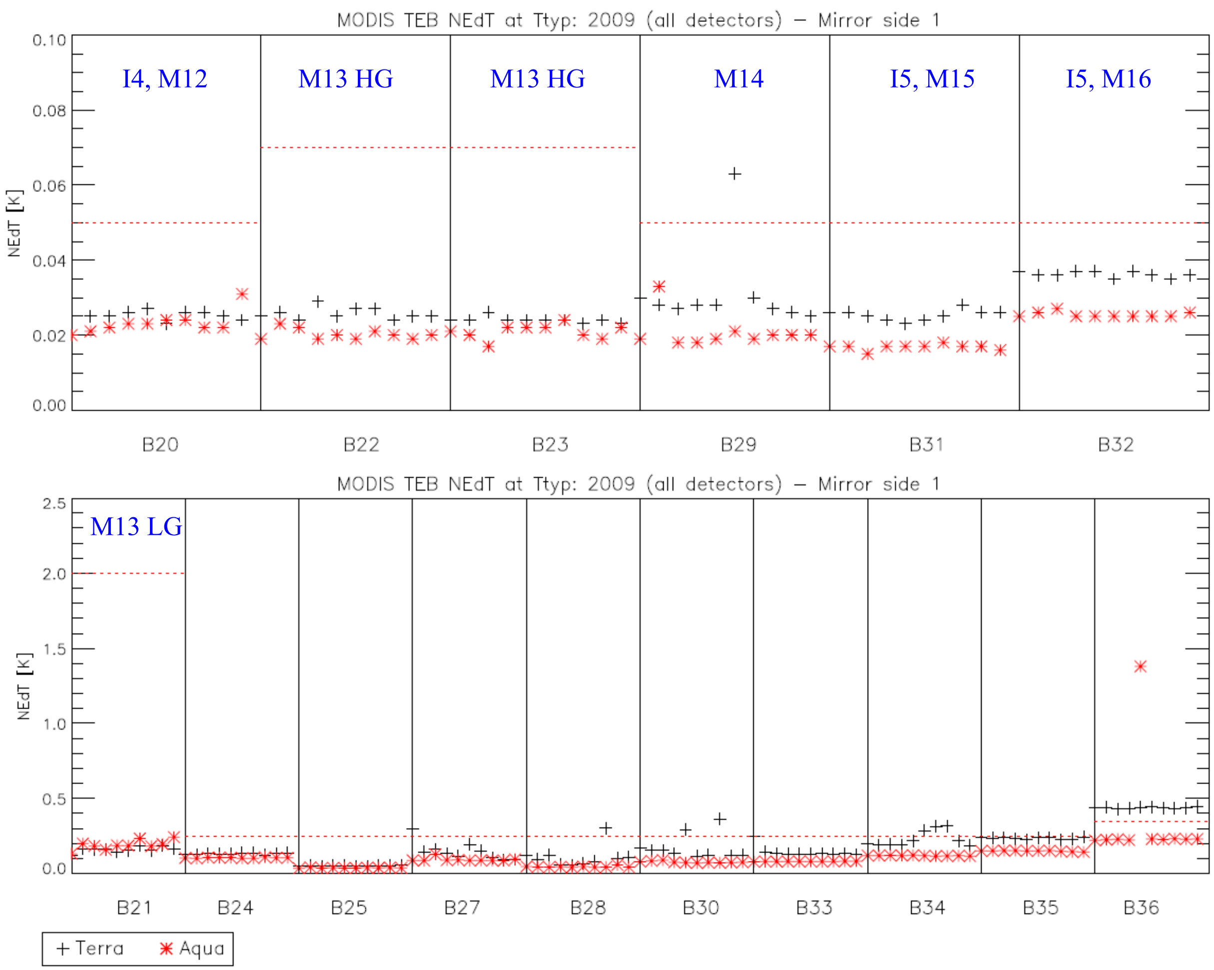
MODIS T_{SAT}

MODIS Band	Band Center (nm)	Bandwidth (nm)	T_{MAX} (K)	Terra T_{SAT} (K)		Aqua T_{SAT} (K)		Comparable VIIRS Band(s)
				Pre Launch	May-07	Pre Launch	May-07	
20	3750	180	335	334.9	336.4	337	337.7	I4, M12
21	3959	59.4	500	477.7	479.0	506	508.2	M13 LG
22	3959	59.4	328	329.4	330.1	331	331.9	M13 HG
23	4050	60.8	328	329.7	330.4	332	332.6	M13 HG
24	4465	65	264	317.0	317.6	318	319.8	
25	4515	67	285	316.2	316.4	318	319.5	
27	6715	360	271	322.7	321.1	317	316.1	
28	7325	300	275	319.4	321.6	319	321.1	
29	8550	300	324	329.5	332.2	329	332.0	M14
30	9730	300	275	357.6	361.4	321	318.6	
31	11030	500	400	391.9	398.9	403	339.5	I5, M15
32	12020	500	400	386.9	396.5	411	341.3	I5, M16
33	13335	300	285	333.7	333.8	298	298.5	
34	13635	300	268	340.9	344.7	324	324.6	
35	13935	300	261	341.5	347.8	301	301.9	
36	14235	300	238	374.5	379.7	309	308.8	

MODIS Dynamic Range – upper bound

- **Pre-saturation occurs for bands 20, 21, 31, and 32 on Terra. No bands pre-saturate for Aqua**
- **Note that this not a direct comparison between VIIRS and MODIS, but a comparison of each with its specification**
- **Saturation temperature tends to increase over life**
- **Results courtesy of MCST**

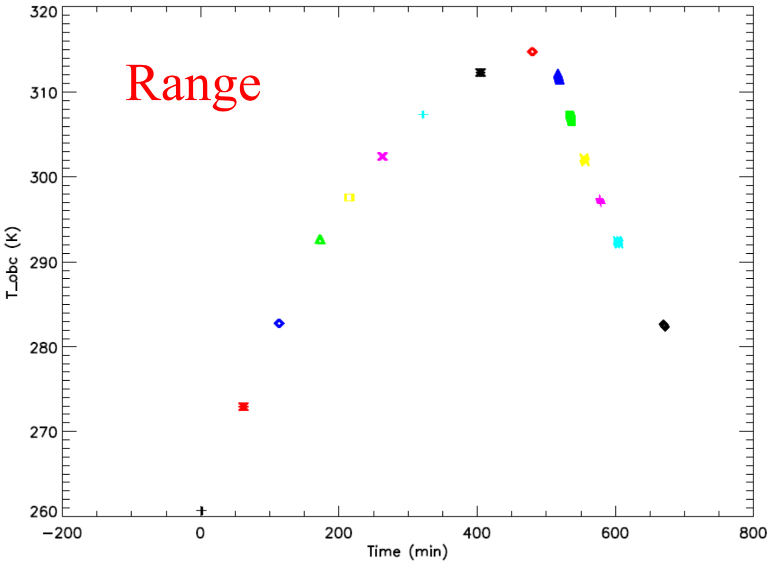
MODIS NEdT at T_{TYP}



NEdT at T_{TYP}

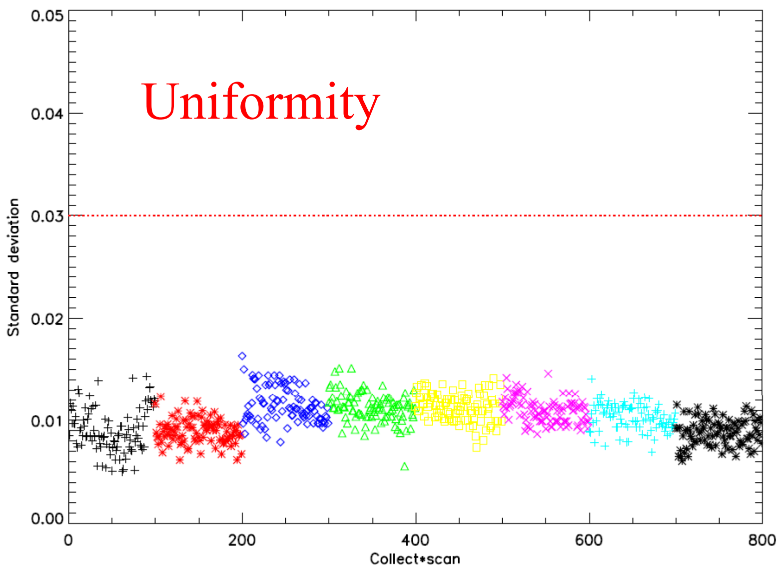
- **Some detectors in B27, B28, B29, B30, B34, and B36 exceed the specified resolution (mostly on Terra)**
- **Comparable VIIRS bands are marked**
- **Note that this not a direct comparison between VIIRS and MODIS, but a comparison of each with its specification**
- **Data from 2009 on-orbit**
- **Results courtesy of MCST**

OBC Operability



Commandable Setpoint

Setpoint (K)	Temperature (K)
260.0	260.8
272.5	273.0
282.5	282.9
292.5	292.7
297.5	297.6
302.5	302.5
307.5	307.5
312.5	312.4
315.0	314.8



OBC Operability

- **OBC temperature range from ambient to 315 K**
- **OBC thermistor uniformity below 0.03 K**
- **OBC temperature not within +/-0.2 K of setpoints at lower scene temperatures**
- **Results shown are from Cold plateau (other plateaus are consistent)**

Detector Operability: Definition and Specification

Detector Operability – restrictions on the number of inoperable detectors in a given band and focal plane.

Assessment – community consensus on operability of detectors based on sensitivity and/or radiometric performance.

3.1.6.12 Detector Operability

SRV0102 No more than one detector element in a given spectral band shall fail to meet the specified sensitivity or radiometric calibration requirements.
SRV0473: Among the set of all detectors in the SWIR and MWIR bands, no more than two detector elements shall fail to meet the specified sensitivity or radiometric calibration requirements.
SRV0625: Non-operable detectors, if any, that are located on any single FPA, other than the DNB shall not be located in the same rows, and preferably not in adjacent rows.

List of Thermal Vacuum Tests

Test ID	Test Use
RC-01	Gain Transistion
RC-02	Radiometric Calibration (RSB)
RC-03	Radiometric Stability (RSB + TEB)
RC-05	Radiometric Calibration (TEB)
FP-4	BBR
FP-6	LSF / MTF
FP-15	IB RSR / crosstalk
FP-16	OOB RSR/ optical and electrical crosstalk
FP-18	DITL
Si-4	Ecal / cross-strapping
SI-6	Noise
ETP-622	LWIR Offsets
ETP-635	Attenuator Approach Verification
ETP-640	360 Degree Scan Survey
ETP-655/663	Polarized Crosstalk / Filter Spread Function
FOP	Radiometric Stability