VIIRS F1 Pre-Launch Calibration and Characterization:

Reflective Solar Band Radiometry

NPP Instrument Calibration and Support Team (NICST)

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Objectives

- Characterize VIIRS sensor using a series of performance metrics
  - Dynamic range, SNR, nonlinearity, uniformity, characterization uncertainty, gain transition
- Determine parameters for use in on-orbit (or transition to on-orbit) calibration
  - Calibration coefficients
- Characterize VIIRS sensor's stability
  - Temporal stability (~100 minutes, one-orbit), variation with FPA and ASP temperature, and change in bus voltage

Tests

- RC1 – At ambient environment and thermal vacuum, preliminary radiometric characterization and gain transition
- RC2 – At thermal vacuum, intensive radiometric characterization
  - Six combinations of three plateaus (cold, nominal, and hot) and two ASPs
  - Two lights sources: SIS100 and TMC (only for bands M1-M3 at low gain)
  - Multiple radiance levels generated with the combinations of three different types of lamps: 200W, 45W, and 8W
  - Relationship between incident radiance and instrument response
- RC3 – At thermal vacuum, short-time stability of the radiometric performance
  - With fixed SIS100 radiance level
  - Temporal variation
  - Both instrument and ASP temperatures varied
  - Variation with bus voltage

Radiance versus Response

Algorithms

Radiance versus Response – a quadratic equation is applied to describe the relationship between radiance and the instrument response

$$L = a_0 + a_1 \cdot dn + a_2 \cdot dn^2$$
$$= a_1 \cdot [a_0 / a_1 + dn + (a_2 / a_1) \cdot dn^2]$$
$$= [c_0 + dn + c_2 \cdot dn^2] / g$$

where $c_0 = a_0/a_1$, $c_2 = a_2/a_1$, and $g = 1/a_1$.

Assessment

- Dynamic range – RC2
- c_0, c_2, and g – RC2
- Nonlinearity – RC2
- SNR – RC2
- Characterization uncertainty – RC2
- Non-uniformity among detectors – RC2
- Gain switch – RC1
- Stability – RC3

Note

- c_0 and c_2 cannot be updated on-orbit
- g will be updated on-orbit with SD calibration

Determination of the calibration coefficients

- **Calibration coefficient ratios**

In RC2 measurements, an attenuator was used to reduce the light intensity of the source. With the same SIS or TMC radiance level

$$\tau = \frac{c_0 + dn_{in} + c_2 \cdot dn_{in}^2}{c_0 + dn_{out} + c_2 \cdot dn_{out}^2}$$

where τ, dn_{in}, and dn_{out} are the transmittance of the attenuator, response of the instrument with attenuator in and that with the attenuator out. Fit the equation to the measured data at different radiance levels with a least-mean-square approach (LMSA).

- **Calibration coefficients**

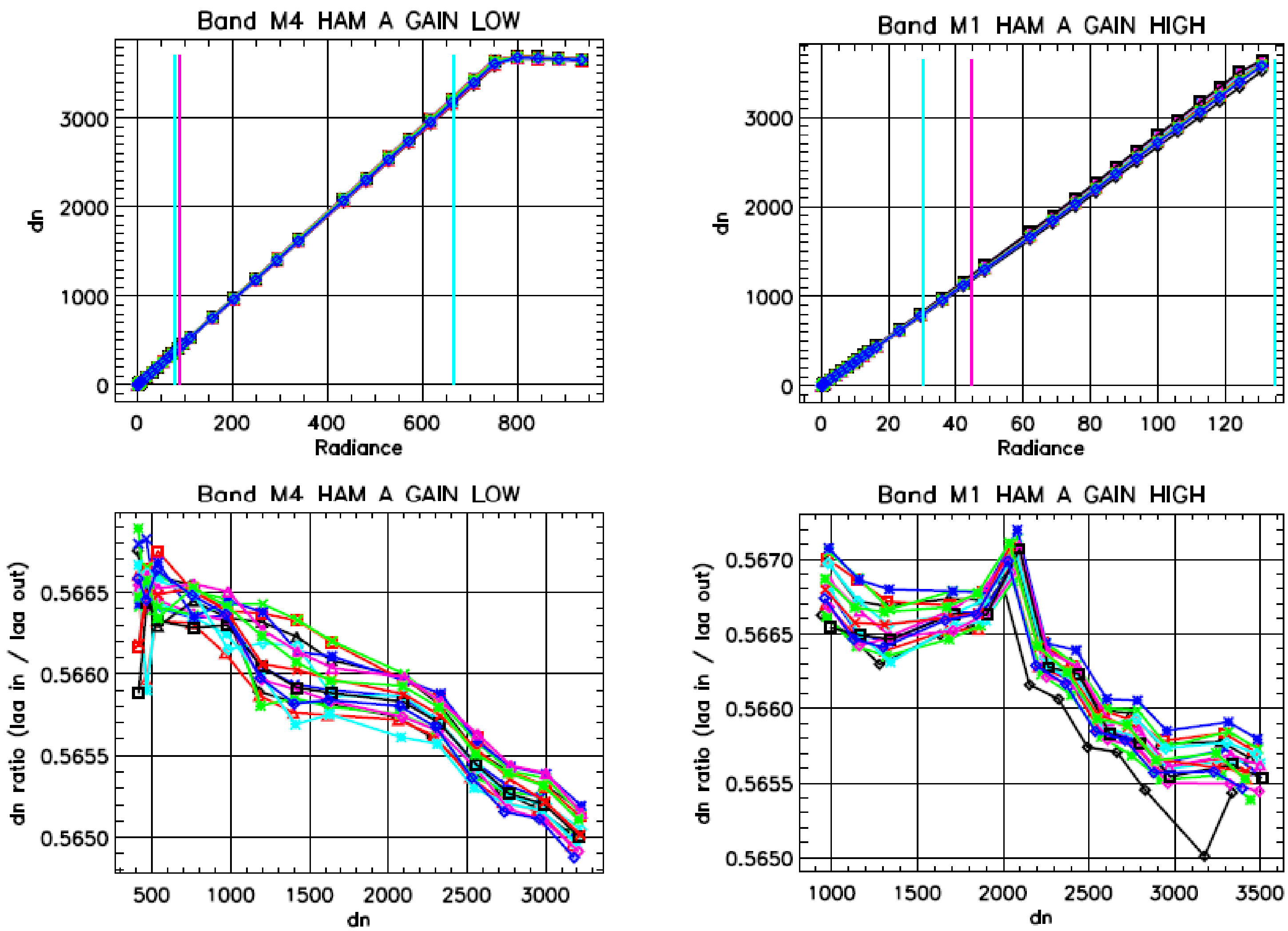
For the linear coefficient

$$a_1 = L / (c_0 + dn_{out} + c_2 \cdot dn_{out}^2)$$

Get a_1 by fitting the equation to the measured data at different radiance levels with a least-mean-square-fit approach.

Response versus Radiance

Data



Dynamic Range

Specification

Dynamic Range – the lower and upper limits, representing the extent of the measured signal (in radiance units)

Assessment – determine if the reflective solar bands pre-saturated; compare L_{MAX} to L_{SAT}.

Specification

SRV0055 The VIIRS Sensor shall be able to measure scene spectral radiance for the single gain reflective bands between the minimum radiance (L_{min}) and the maximum radiance (L_{max}) and for the dual gain reflective bands between the High Gain L_{min} and the Low Gain L_{max} radiances shown in TABLE 1.

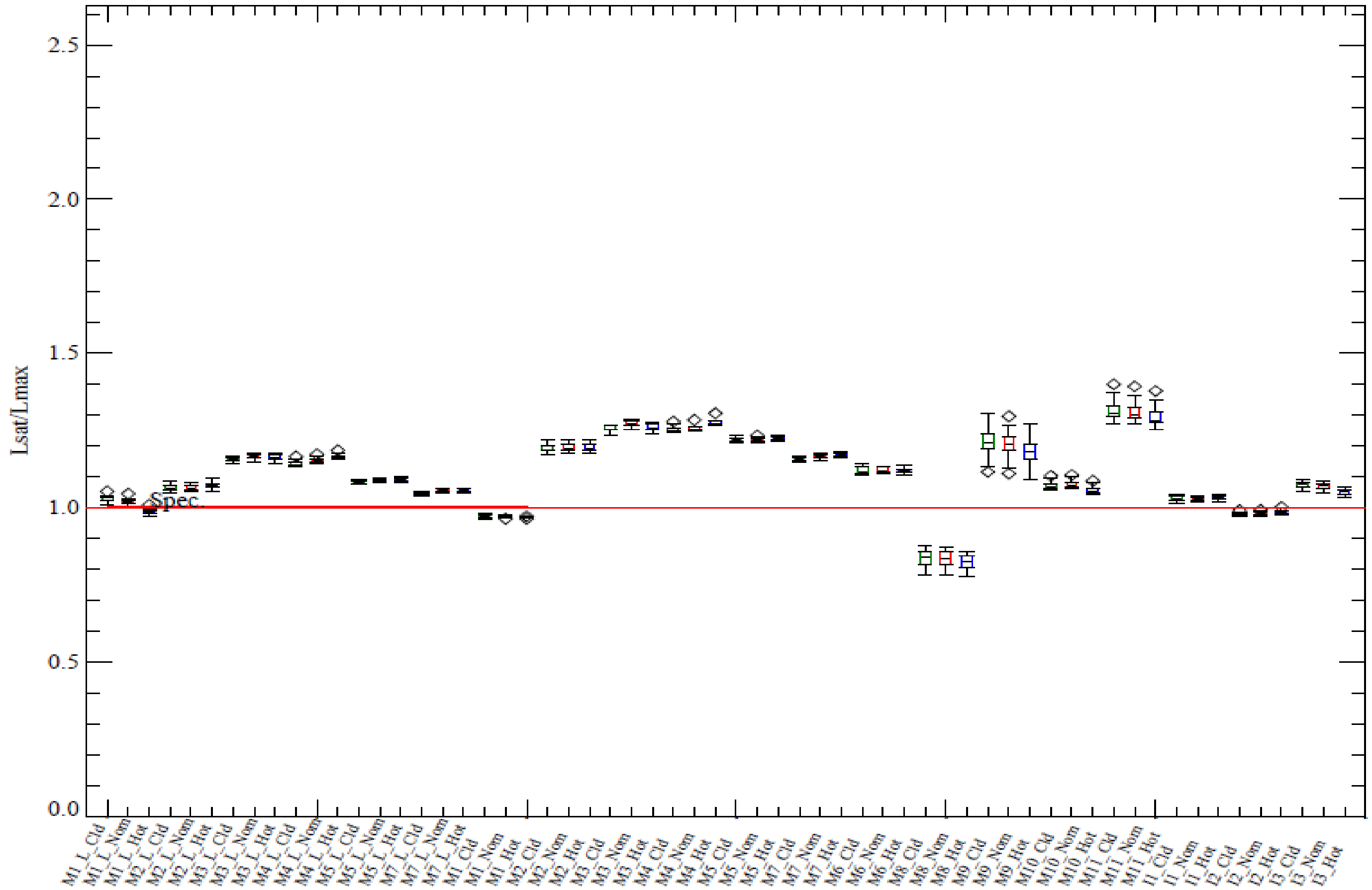
SRV0465 For VIIRS Sensor reflective bands M1 and M2 the gain switching shall occur between +50% and -0% of the spectral radiance levels specified in TABLE 1; for bands M3, M4, M5 and M7 the gain switching shall occur between +20% and -0% of the spectral radiance levels specified in TABLE 1.

TABLE 1. Dynamic range requirements for VIIRS Sensor reflective bands

			Single Gain		Dual Gain			
					High Gain		Low Gain	
Band	Center Wavelength (nm)	Gain Type	L_{min}	L_{max}	L_{min}	L_{max}	L_{min}	L_{max}
M1	412	Dual	-	-	30	135	135	492
M2	445	Dual	-	-	26	127	127	687
M3	488	Dual	-	-	22	107	107	702
M4	555	Dual	-	-	12	78	78	667
M5	672	Dual	-	-	8.6	59	59	651
M6	746	Single	5.3	41	-	-	-	-
M7	865	Dual	-	-	3.4	29	29	349
M8	1240	Single	3.5	123.7	-	-	-	-
M9	1378	Single	0.6	77.1	-	-	-	-
M10	1610	Single	1.2	71.2	-	-	-	-
M11	2250	Single	0.12	31.8	-	-	-	-
I1	640	Single	5	718	-	-	-	-
I2	865	Single	10.3	349	-	-	-	-
I3	1610	Single	1.2	72.5	-	-	-	-

Dynamic Range

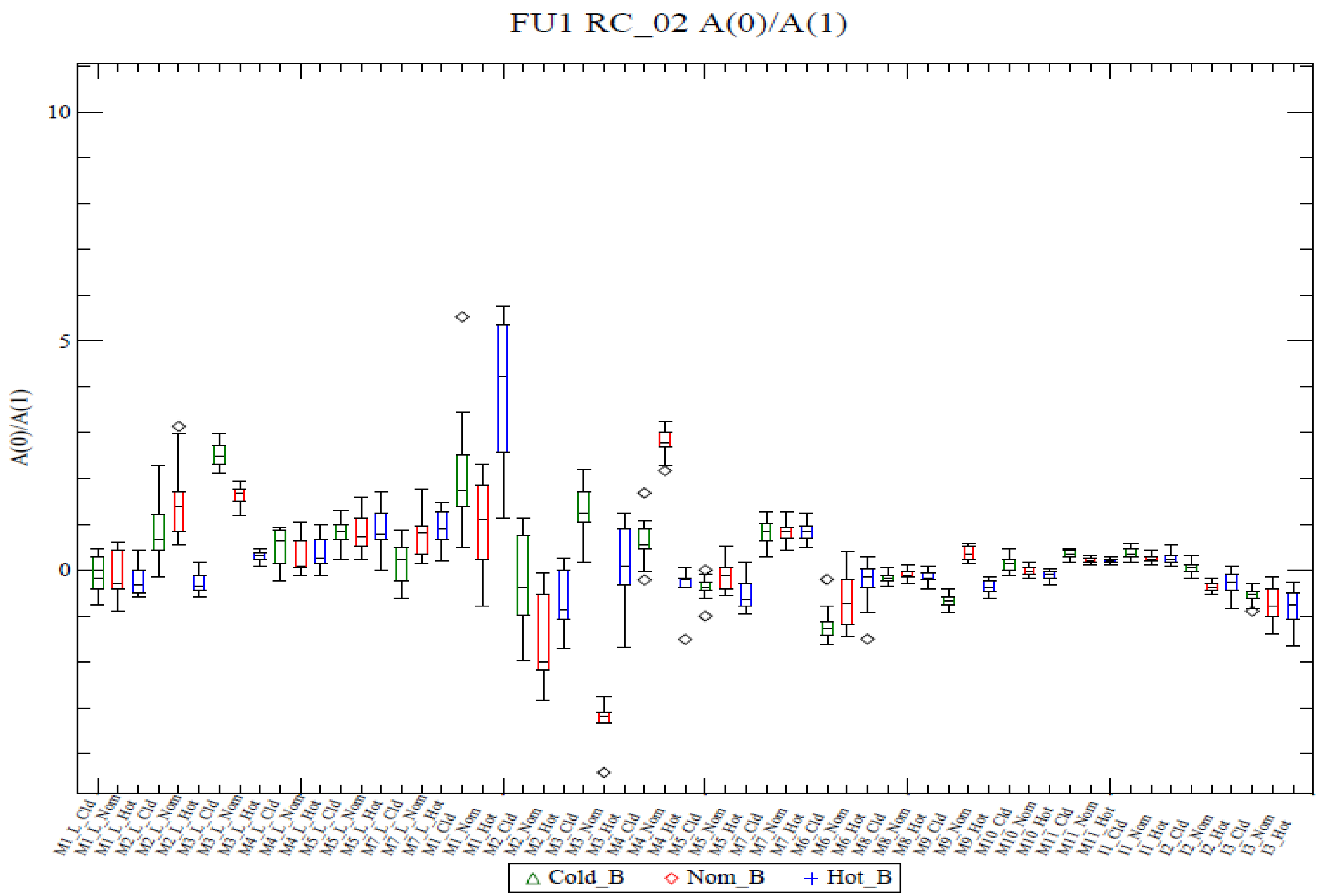
Performance



Bands M1 in high gain, M8, and I2 saturate below the specified L_{max}. Band M1 in low gain saturates below specified L_{max} at hot plateau**.** A waiver has been approved for M8.

Fitted Calibration Coefficients

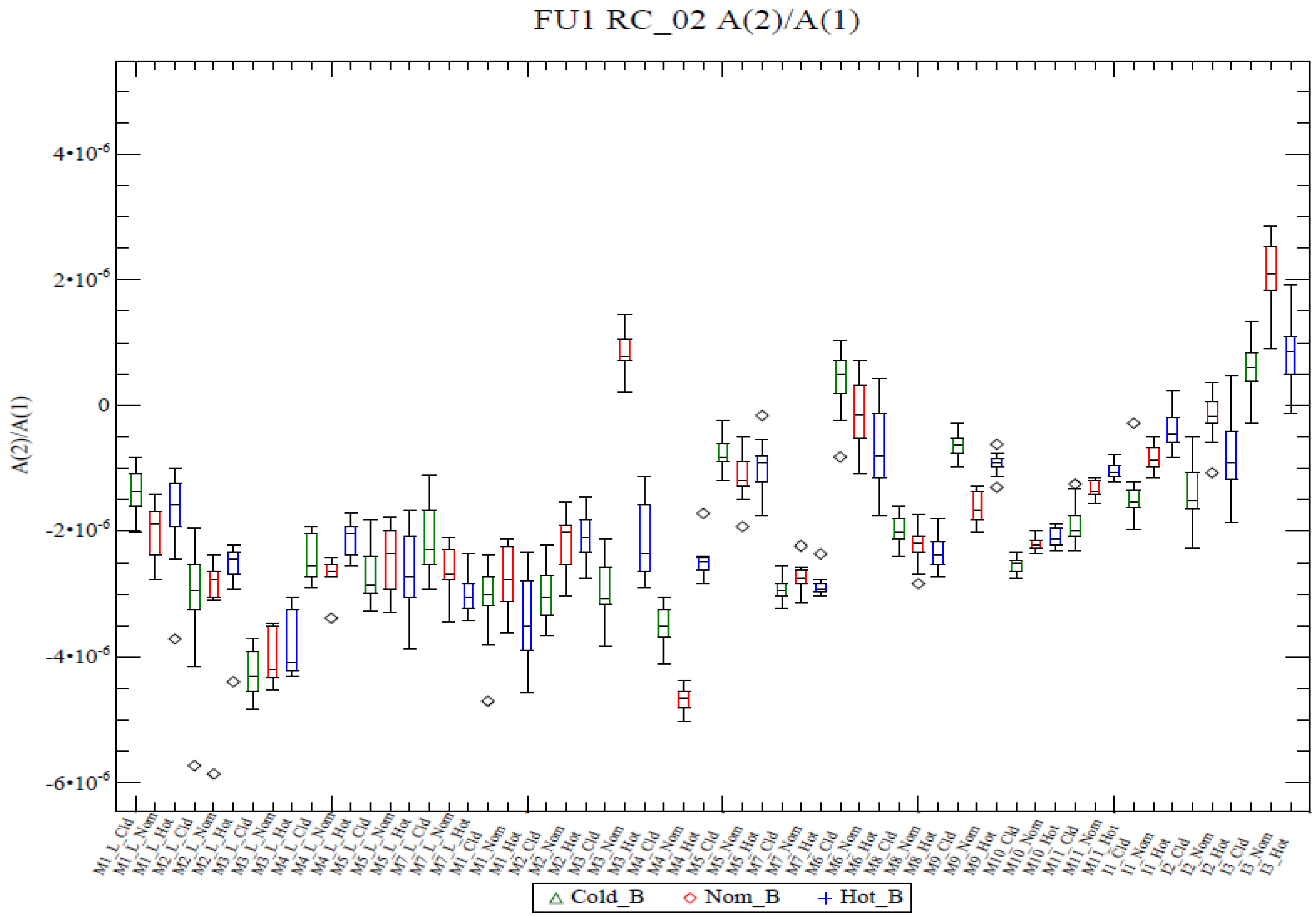
Offset term (c_0)



The offsets are within the range of -6 – 6. Short wavelength bands have larger offsets.

Fitted Calibration Coefficients

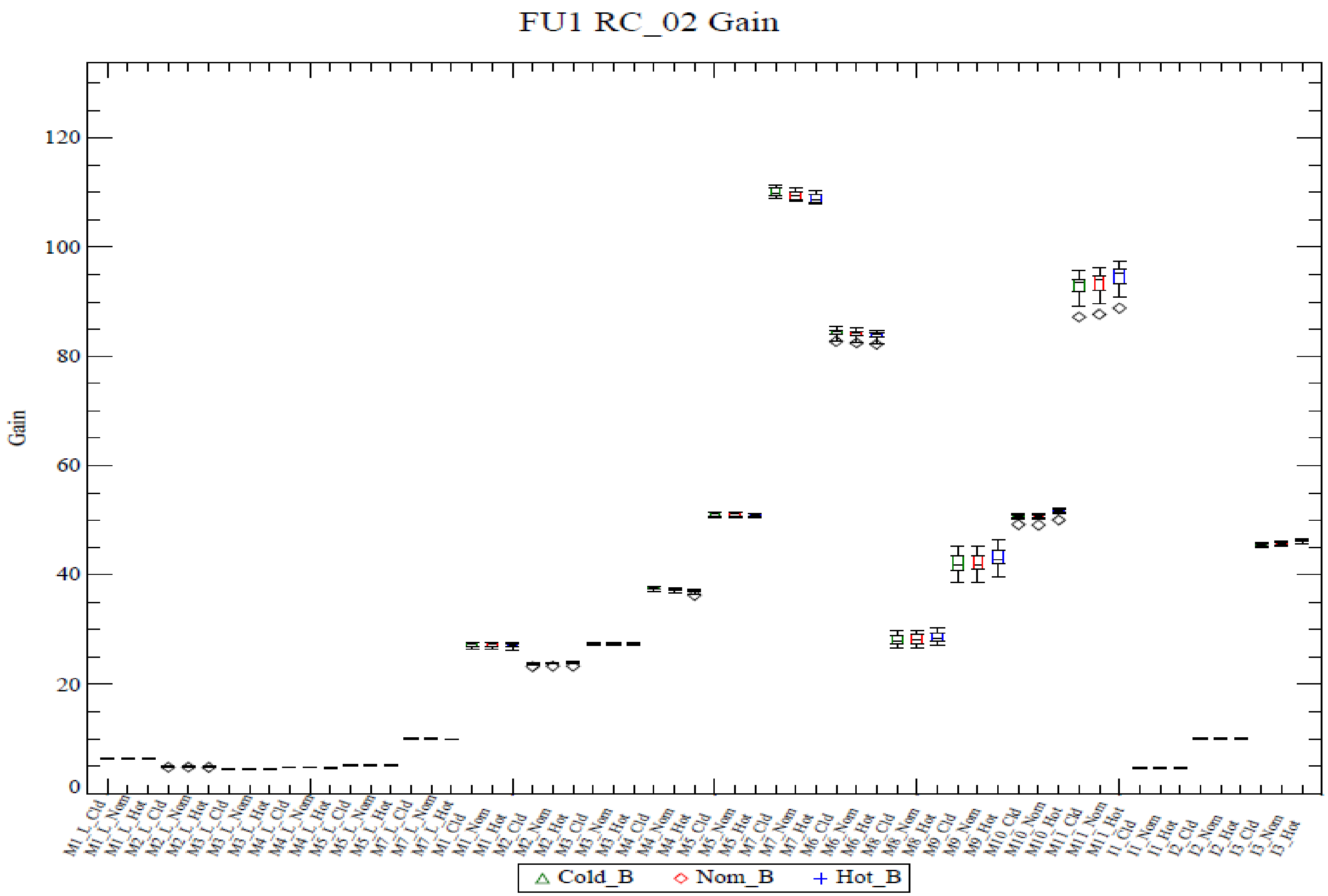
Non-linear term (c_2)



Short wavelength bands have larger non-linear effect.

Fitted Calibration Coefficients

Gain ($1/a_1$)



Nonlinearity

Algorithms 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}.

Specification

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}.

Response Nonlinearity

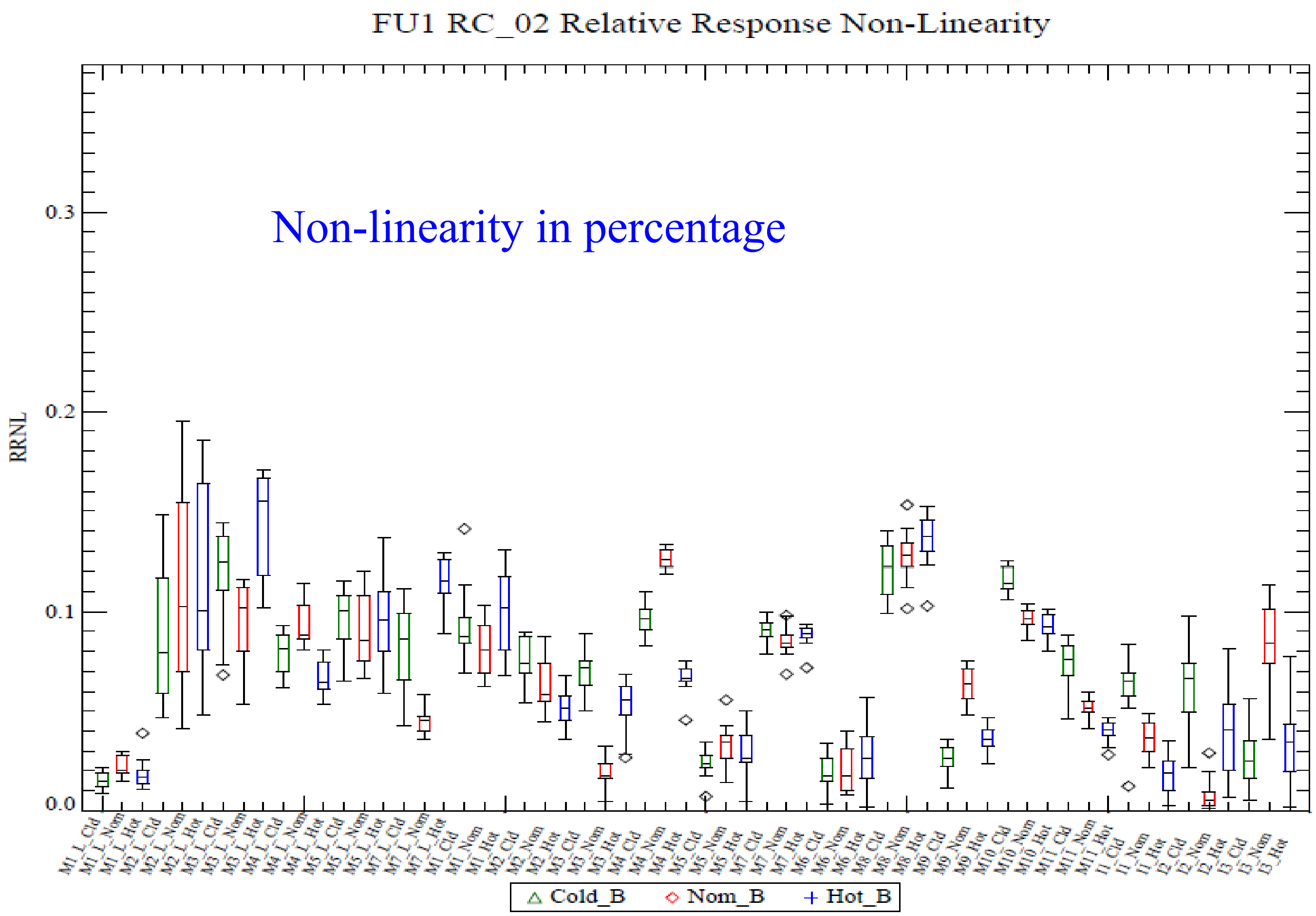
Nonlinearity is defined as the maximum deviation in end-to-end detector channel response (dn) from a best-fit straight line of a plot of response vs at-aperture radiance (L) over the range of L_{MIN} to L_{MAX} given in Table 1 for the reflective bands. The nonliearity in percentage can be expressed as

$$RRNL = \frac{100 \cdot |a_2|}{8 \cdot L_{max}} \cdot (dn_{max} - dn_{min})^2$$

where dn_{max} and dn_{min} are the responses at the L_{max} and L_{min}, respectively

Nonlinearity

Performance



Non-linearity are within specified requirements (spec is 1%) for all reflective solar bands

SNR

Algorithms and Specification

SNR – Signal to noise ratio, scene radiance dependent

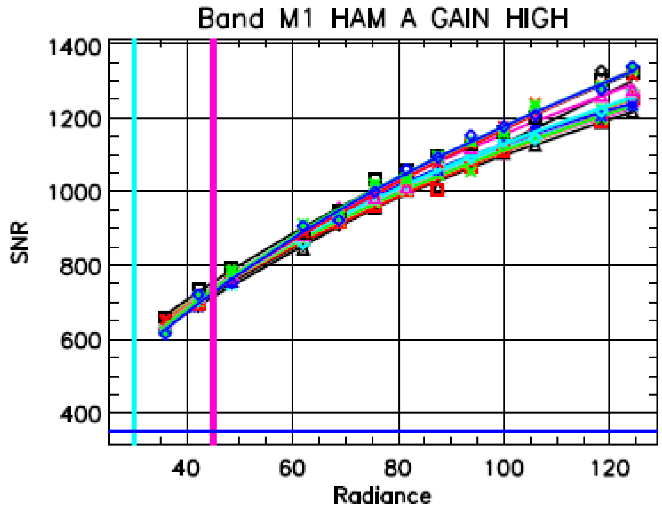
Assessment – the SNR at a typical scene radiance (L_{typ}).

Specification

SRV0051: The VIIRS sensor reflective bands shall meet the sensitivity requirements at Ltyp listed in Table 2

Table 2. Sensitivity requirements for VIIRS Sensor reflectance bands

			Single Gain		Dual Gain			
					High Gain		Low Gain	
Band	Center Wavelength (nm)	Gain Type	L_{typ}	SNR	L_{typ}	SNR	L_{typ}	SNR
M1	412	Dual	-	-	44.9	352	155	316
M2	445	Dual	-	-	40	380	146	409
M3	488	Dual	-	-	32	416	123	414
M4	555	Dual	-	-	21	362	90	315
M5	672	Dual	-	-	10	242	68	360
M6	746	Single	9.6	199	-	-	-	-
M7	865	Dual	-	-	6.4	215	33.4	340
M8	1240	Single	5.4	74	-	-	-	-
M9	1378	Single	6	83	-	-	-	-
M10	1610	Single	7.3	342	-	-	-	-
M11	2250	Single	0.12	10	-	-	-	-
I1	640	Single	22	119	-	-	-	-
I2	865	Single	25	150	-	-	-	-
I3	1610	Single	7.3	6	-	-	-	-



Algorithms

- Noise, σ, is calculated as the standard deviation across scan which is then averaged across sample.
- Noise is fitted to the square root of a quadratic form

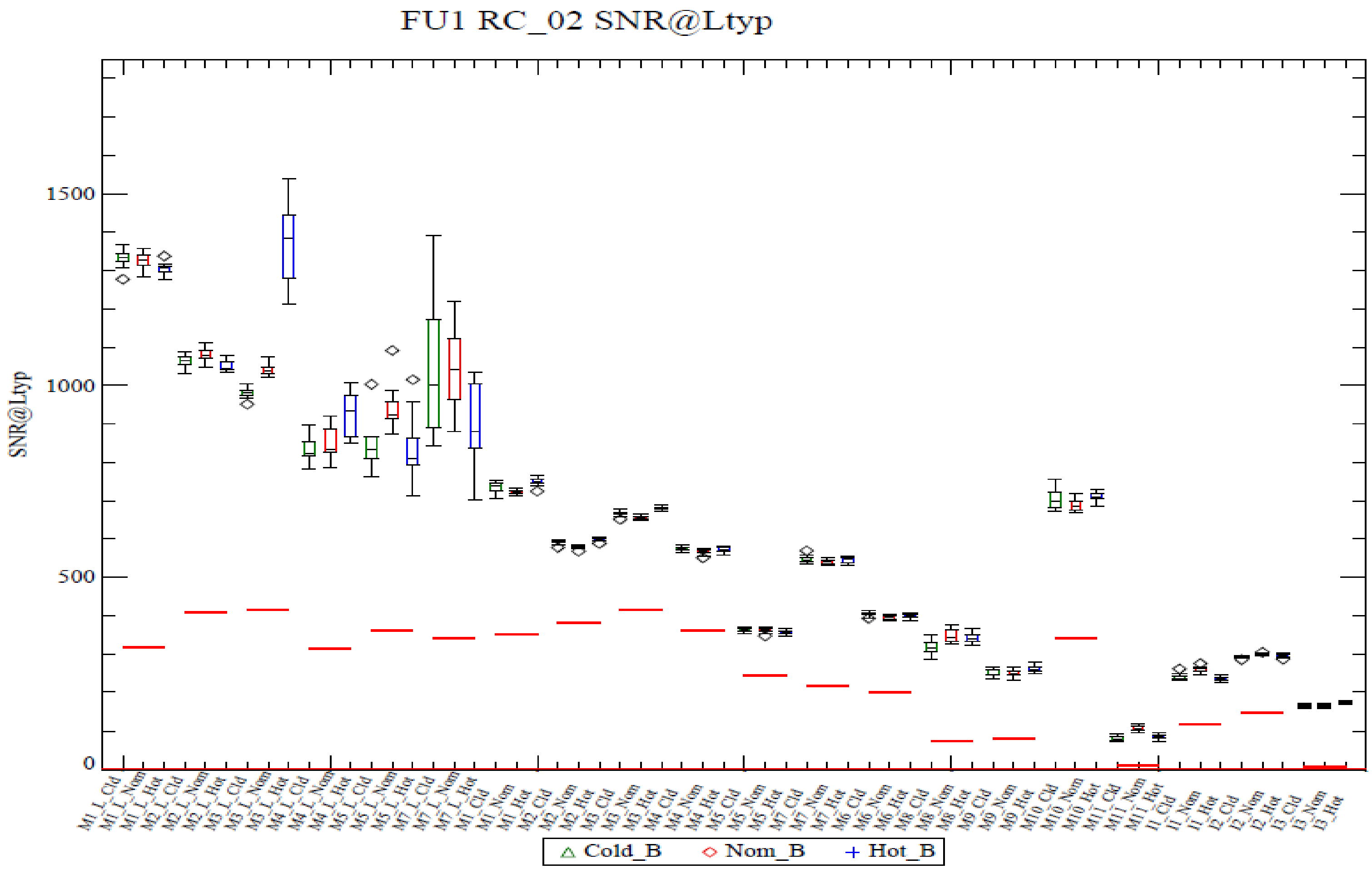
$$\sigma = \sqrt{c_0 + c_1 L + c_2 L^2}$$

- SNR at L_{typ}

$$SNR_{typ} = \frac{L_{typ}}{\sqrt{c_0 + c_1 L_{typ} + c_2 L_{typ}^2}}$$

SNR

Performance



SNR are within specified requirements for all reflective solar bands

Characterization Uncertainty

Algorithms 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 sum of the average fractional radiance residual and 1 sigma of the fractional radiance residual.

Specification

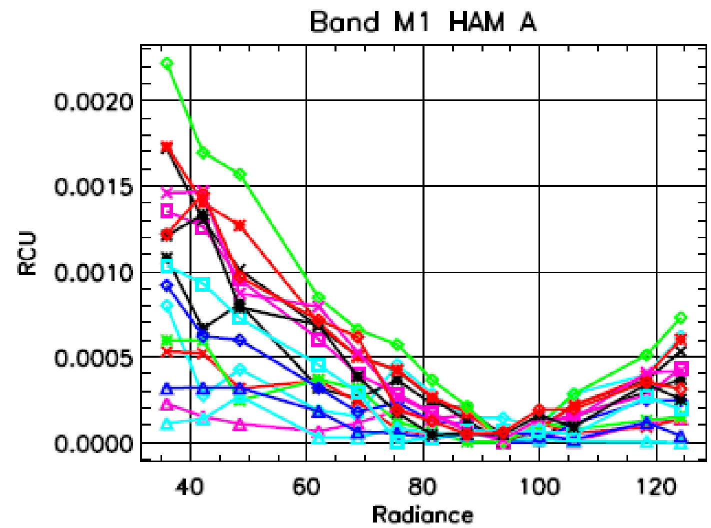
SRV0595 The VIIRS sensor response shall be characterized with an uncertainty better than 0.3% (mean of the ΔL' values plus 1 sigma of the ΔL' values) for the VisNIR and SWIR bands.

Algorithm

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

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

where L is the radiance computed with the fitted quadratic form and L' is the input radiance. Since the reported input radiance has errors comparable to 0.3%, the detector averaged L is used as input radiance L' in the analysis.



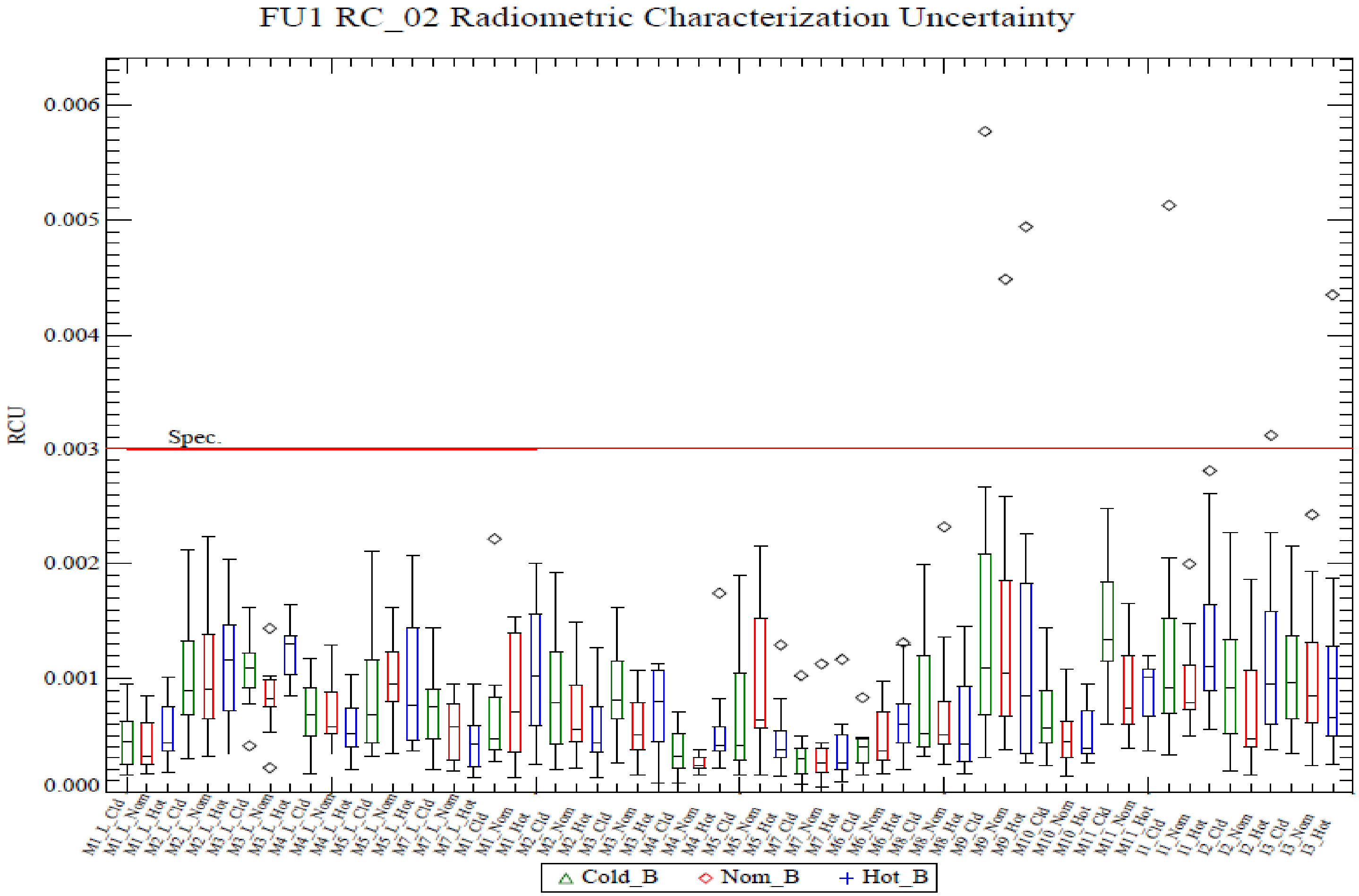
- The characterization uncertainty is calculated by

$$\overline{\Delta L} = \frac{\sum_i \Delta L_i \cdot w_i}{\sum_i w_i}, \quad \sigma^2 = \frac{\sum_i (\overline{\Delta L} - \Delta L_i)^2 \cdot w_i}{\sum_i w_i}, \quad RCU = \overline{\Delta L} + \sigma$$

where w_i is the weight for the ith data point, which is inversely proportional to the density of the data points in the radiance domain and calculated by $|L_{i+1} - L_i|$.

Characterization Uncertainty

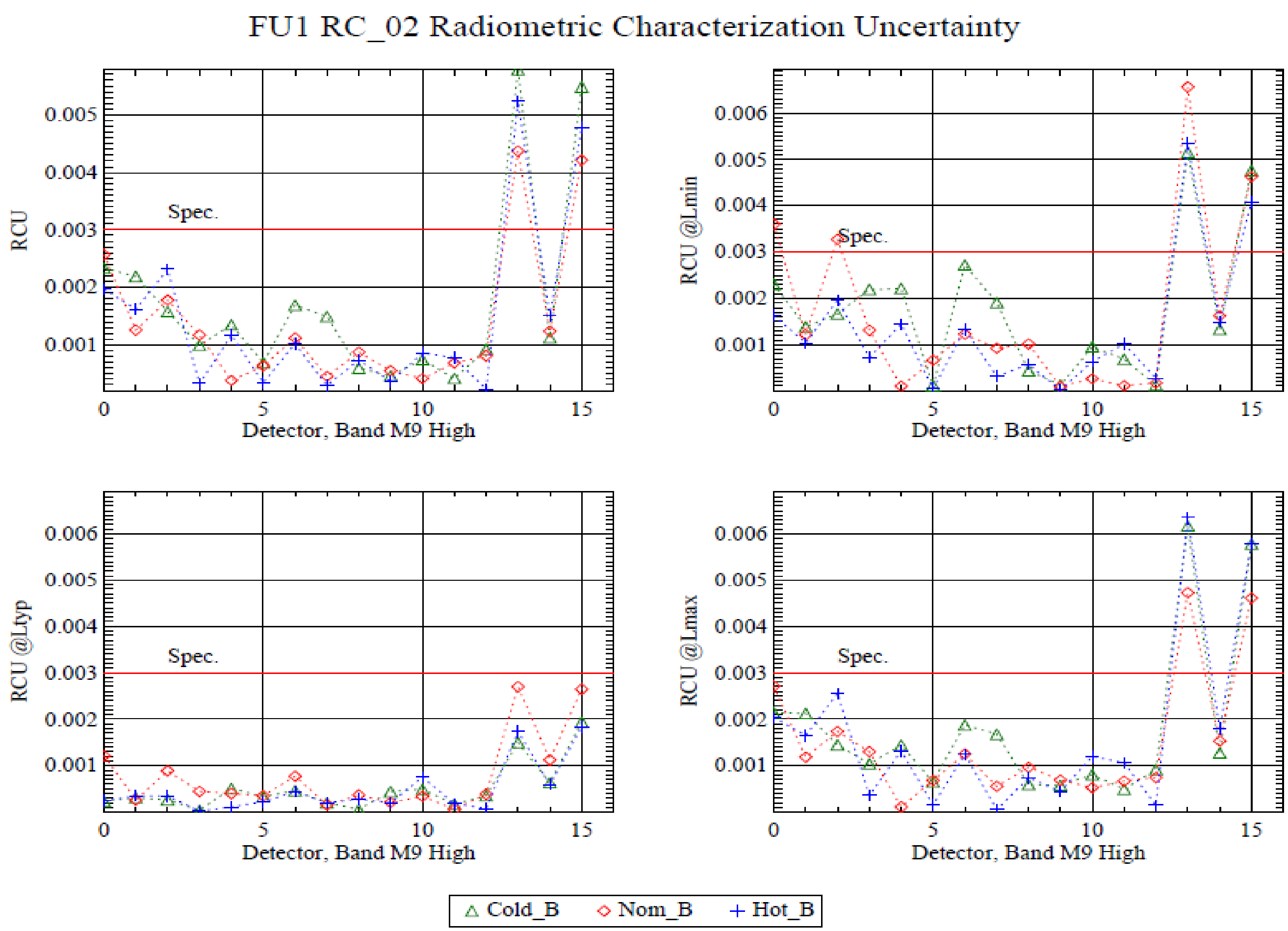
Performance



Only a few detectors in bands M9 and I1-I3 do not satisfy the specification

Characterization Uncertainty

Performance



The characterization uncertainty is larger at the edges of the dynamic range

Uniformity

Algorithms and Specification

Uniformity – the ratio of the difference between retrieved radiance and band-average retrieved radiance to the NEdL.

Assessment – detector-to-detector striping

Specification

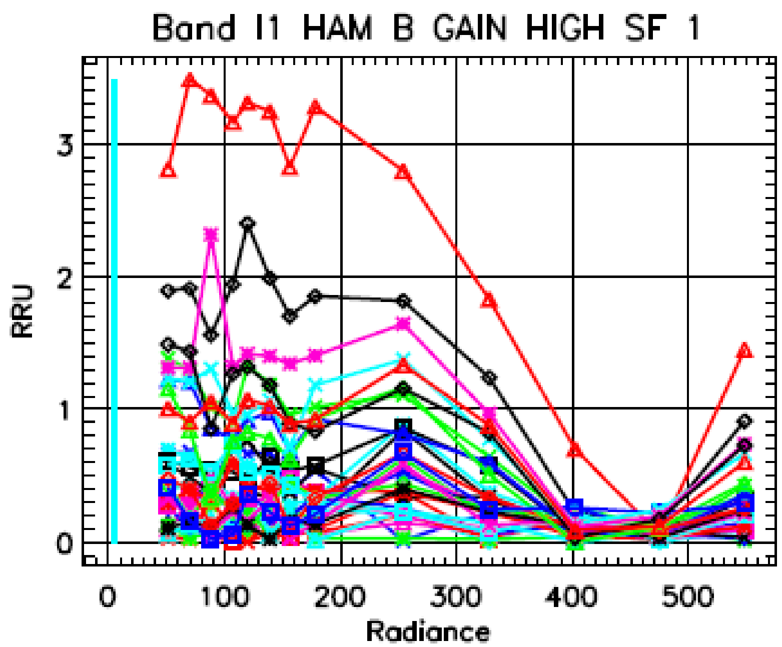
SRV0613 The calibrated output of all channels within a band shall be matched to the band mean output within the NEdL (1 sigma) when viewing a uniform scene. The matching condition shall be met between radiance levels from L_{MIN} to 0.9 L_{MAX}.

Algorithms

- The uniformity at ith output level, $dn_i(d)$, is defined as

$$RRU_i = \frac{\left| L_i(d) - \langle L_i(d) \rangle_d \right|}{\langle NEdL_i(d) \rangle_d}$$

where $L_i(d)$ is the radiance computed with the fitted quadratic form of detector d and $dn_i(d)$.



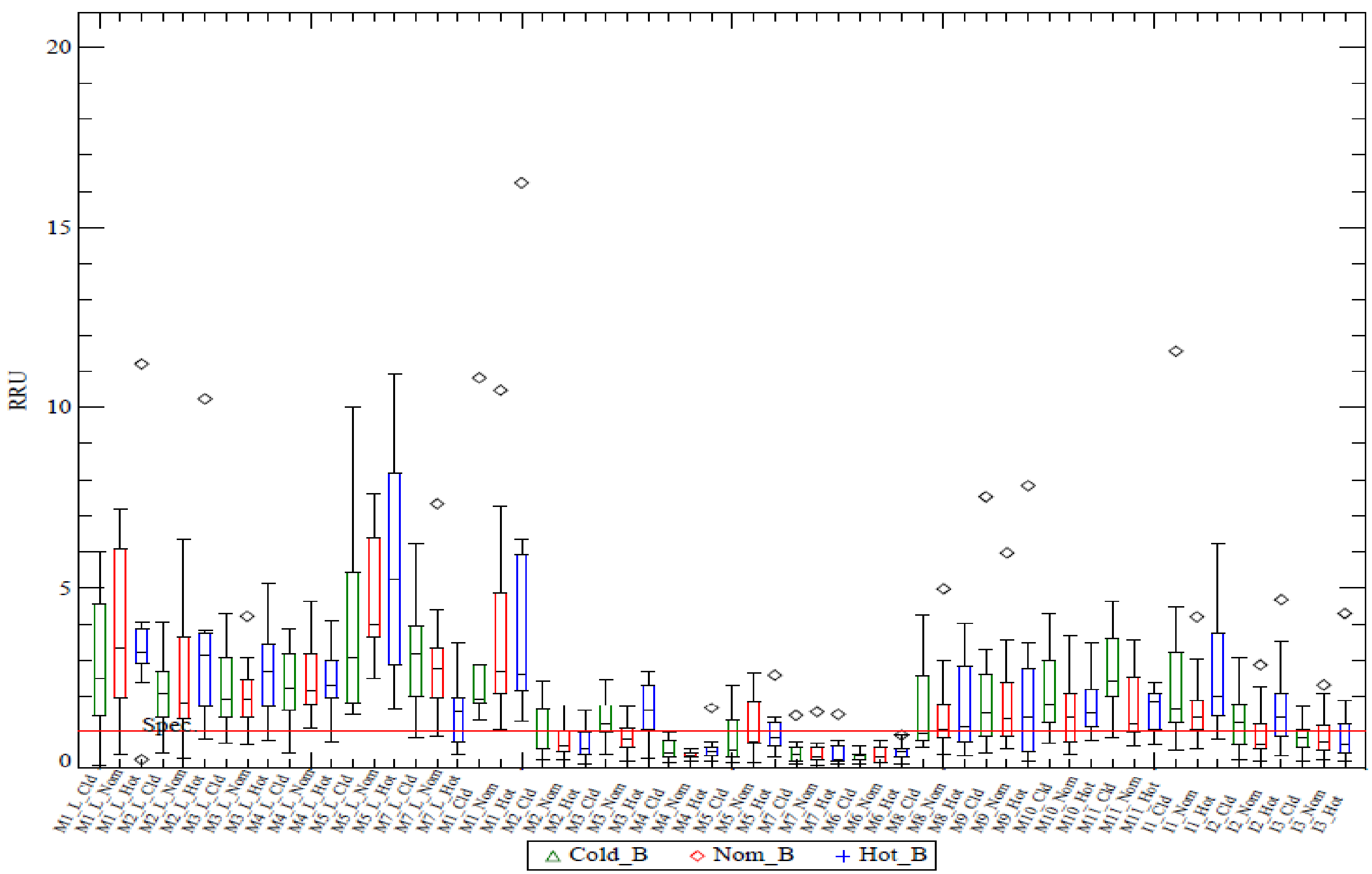
- The characterization uncertainty is calculated by

$$RRU = \max(RRU_i)$$

Uniformity

Performance

FU1 RC_02 Relative Response non-Uniformity



There are detectors in all bands except M6, which do not satisfy the specification

Stability

Specification and Algorithms

Stability – a measure of radiometric response invariability as the instrument thermal and/or electronic state varies with changing environmental conditions between calibrations.

Assessment – stability with respect to four different variables: time (~100 minutes, period of the satellite orbit), FPA temperature, ASP temperature, and bus voltage.

Specification

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

Algorithms

- Temporal variation (RC-03 part 1)

With a linear approximation, gain is given by

$$g = dn / L$$

- Temperature dependence (RC-03 part 2)

With a linear approximation, the dependence of the gain on either the FPA or ASP temperature can be expressed

$$g(t) = g(t_{Nom})[A(0) + A(1) \cdot t]$$

where

$$t_{FPA} = T_{FPA} - T_{Nom\_FPA}$$

$$t_{ASP} = T_{ASP} - T_{Nom\_ASP}$$

The reference temperatures selected are

T_{Nom_FPA} = -13°C and T_{Nom_ASP}=20°C

- Bus voltage dependence (RC-03 part 3)

With a linear approximation, the dependence of the gain on the bus voltage is

$$g(t) = g(v_{Nom})[A(0) + A(1) \cdot (v - v_{Nom})]$$

Stability

Short-term (~100 minutes) stability (%)

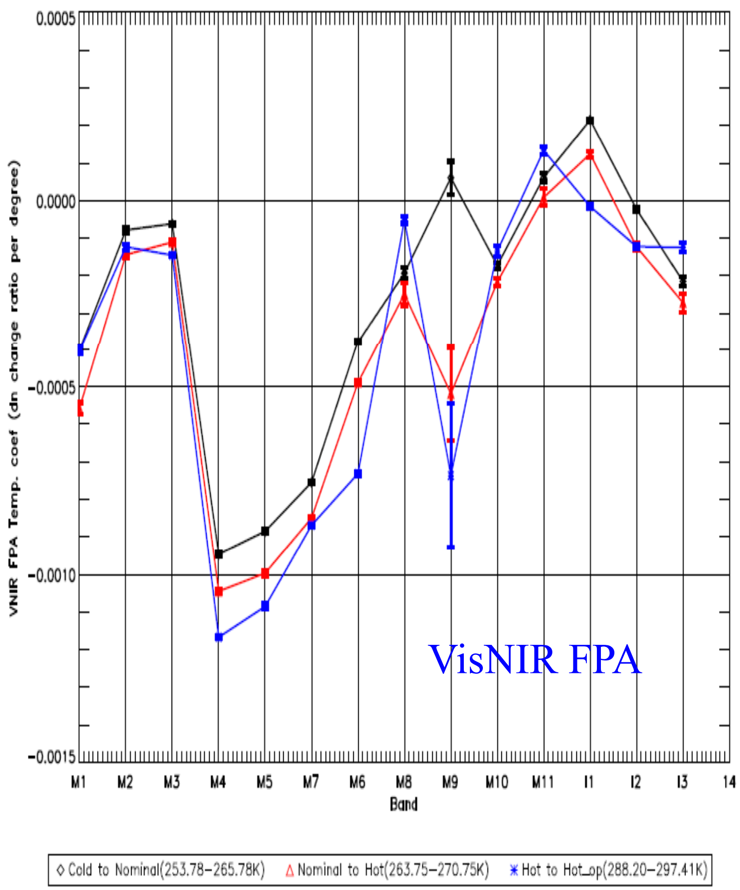
Table 3. band averaged maximum gain variation

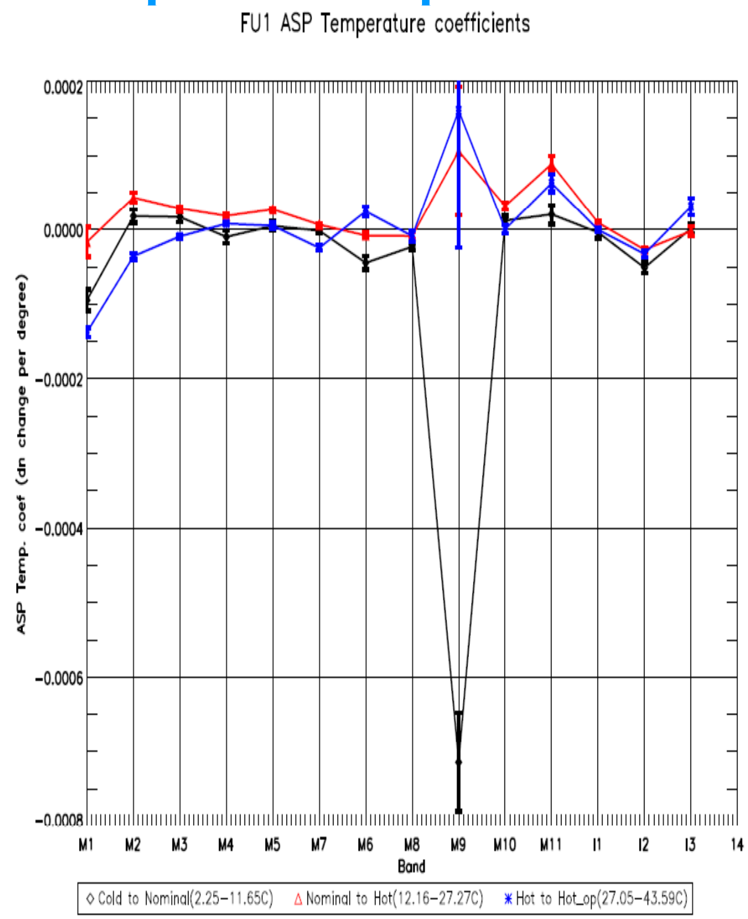
Eside	Intg Time	M1	M2	M3	M4	M5	M7	M6
A	Nominal	0.077	0.035	0.009	N/A	N/A	N/A	0.011
	1	0.083	0.04	0.009	0.02	N/A	N/A	0.018
	2	0.192	0.113	0.048	0.032	0.023	0.042	0.004
B	Nominal	0.046	0.023	0.008	N/A	N/A	N/A	0.028
	1	0.072	0.02	0.011	0.013	N/A	N/A	0.022
	2	N/A	0.162	0.067	0.037	0.033	0.011	0.008
Eside	**Intg Time**	**M8**	**M9**	**M10**	**M11**	**I1**	**I2**	**I3**
A	Nominal	N/A	N/A	N/A	0.107	0.017	0.019	0.005
	1	N/A	0.059	0.074	0.112	0.019	0.02	0.005
	2	0.015	0.031	0.068	0.103	0.02	0.004	0.043
B	Nominal	N/A	N/A	N/A	0.056	0.009	0.022	0.012
	1	N/A	0.063	0.038	0.056	0.011	0.013	0.013
	2	0.009	0.046	0.034	0.045	0.013	0.006	0.028

The short-term stability (about 100 minutes between consecutive tests) is less than 0.3% (spec is 0.3%). It is within 0.1% for the majority of bands.

Stability

VisNIR FPA and ASP Temperature Dependence





VIIRS FU1 reflective solar bands are quite insensitive to variation of the VisNIR FPA and ASP temperatures

Stability

Bus Voltage

Table 4. Radiometric gain change % per bus voltage change (Cold plateau, E-side B)

Det	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	I1	I2	I3
0	0.013	-0.013	-0.006	0.000	-0.003	-0.001	0.006	-0.004	-0.051	-0.021	-0.030	-0.006	0.005	-0.021
1	0.015	-0.014	-0.007	0.000	-0.004	0.000	0.006	-0.005	-0.051	-0.021	-0.036	-0.006	0.005	-0.021
2	0.015	-0.014	-0.007	0.000	-0.003	0.000	0.006	-0.006	-0.050	-0.022	-0.032	-0.006	0.005	-0.023
3	0.014	-0.013	-0.006	0.000	-0.004	-0.001	0.007	-0.005	-0.051	-0.021	-0.033	-0.006	0.005	-0.022
4	0.016	-0.013	-0.007	0.000	-0.004	0.000	0.006	-0.004	-0.051	-0.022	-0.034	-0.006	0.005	-0.022
5	0.016	-0.013	-0.006	0.000	-0.002	0.000	0.006	-0.004	-0.051	-0.020	-0.030	-0.006	0.005	-0.022
6	0.014	-0.013	-0.006	0.000	-0.003	0.000	0.006	-0.005	-0.051	-0.021	-0.032	-0.005	0.005	-0.020
7	0.015	-0.013	-0.006	-0.001	-0.003	0.000	0.006	-0.007	-0.050	-0.023	-0.033	-0.006	0.005	-0.021
8	0.016	-0.012	-0.006	0.000	-0.004	0.000	0.006	-0.006	-0.051	-0.021	-0.032	-0.007	0.005	-0.022
9	0.017	-0.012	-0.006	0.000	-0.004	-0.001	0.006	-0.005	-0.050	-0.022	-0.032	-0.006	0.005	-0.022
10	0.016	-0.013	-0.006	0.000	-0.003	0.000	0.006	-0.005	-0.051	-0.022	-0.033	-0.006	0.005	-0.021
11	0.017	-0.013	-0.006	0.000	-0.004	-0.001	0.006	-0.005	-0.050	-0.023	-0.034	-0.006	0.005	-0.021
12	0.016	-0.014	-0.005	0.000	-0.004	0.000	0.006	-0.006	-0.051	-0.021	-0.032	-0.006	0.005	-0.023
13	0.016	-0.013	-0.006	0.000	-0.004	0.000	0.006	-0.005	-0.050	-0.022	-0.035	-0.006	0.005	-0.022
14	0.017	-0.013	-0.006	-0.001	-0.003	0.000	0.006	-0.006	-0.048	-0.022	-0.032	-0.006	0.005	-0.022
15	0.015	-0.013	-0.006	0.000	-0.004	-0.001	0.006	-0.005	-0.052	-0.022	-0.034	-0.006	0.005	-0.022
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.006	0.005	-0.023

The gain variation is less than 0.26% for all bands (spec is 0.3%) in the voltage range of 27V – 32V.

Dual Gain Band Transition

Specification and measured data

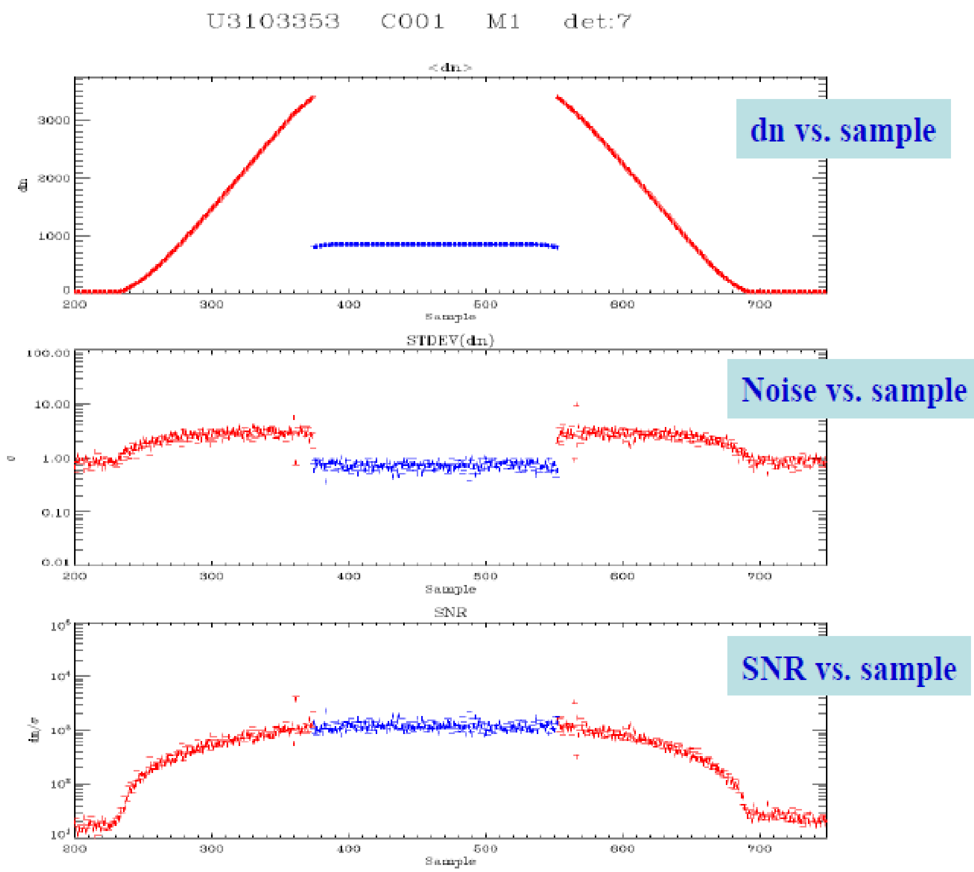
Gain transition – a measure of the scene radiance at which the dual gain bands switch from high gain to low gain mode.

Assessment – gain transition of dual gain bands

Specification

SRV0465 For VIIRS Sensor reflective bands M1 and M2 the gain switching shall occur between +50% and -0% of the spectral radiance levels specified in TABLE 1; for bands M3, M4, M5 and M7 the gain switching shall occur between +20% and -0% of the spectral radiance levels specified in TABLE 1.

RDW043 requests relaxation to +50% for all VIS/NIR dual-gain bands.



Noise responses are observed before H-L and after L-H gain transitions

Dual Gain Band Transition

Performance

Gain transition at cold plateau

Band	HAM	H-L			L-H		
		avg_dn_tran/4095	min_dn_tran/4095	min_dn_tran/dn_max	avg_dn_tran/4095	min_dn_tran/4095	min_dn_tran/dn_max
M1	A	0.83	0.82	0.90	0.83	0.82	0.90
M1	B	0.83	0.82	0.90	0.83	0.82	0.90
M2	A	0.83	0.82	1.10	0.83	0.82	1.10
M2	B	0.83	0.82	1.10	0.82	0.82	1.10
M3	A	0.84	0.83	1.16	0.84	0.83	1.16
M3	B	0.84	0.83	1.15	0.84	0.83	1.15
M4	A	0.83	0.83	1.15	0.83	0.83	1.15
M4	B	0.83	0.83	1.15	0.83	0.83	1.16
M5	A	0.83	0.82	1.12	0.83	0.82	1.12
M5	B	0.83	0.83	1.12	0.83	0.82	1.12
M7	A	0.84	0.83	1.06	0.84	0.83	1.06
M7	B	0.84	0.83	1.06	0.83	0.83	1.06

All reflective dual-gain bands transition above L_{max} except band M1.

Reflective Band Radiometry Summary

- Dynamic range
  - Band M1 saturates below L_{max} at high gain for all plateaus and at low gain for hot plateau
  - Band I2 saturates below L_{max}
  - Band M8 saturates below L_{max} (waiver)
- SNR is within specified requirements
- Nonlinearity is within 1% of the response at L_{max}
- Characterization Uncertainty is with the specified limits for most bands except a few detectors in bands M9 and I1-I3. For these four bands, a few edge detectors do not satisfy the specification
- For uniformity, only band M6 is within the specification; all other bands do not satisfy the specification.
- Stability is within specified limits with the period of one-orbit (~100 minutes) and bus voltage. No anomalous variation with FPA and ASP temperature change was found.
- Gain transition are within the specified tolerance for all dual gain bands except band M1.