



# Pre-Launch Radiometric Calibration of the S-NPP and JPSS-1 VIIRS Day/Night Bands

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# VIIRS Day-Night Band Characteristics



## Four different CCDs covering 3 gain stages

- LGS, MGS, HGA, HGB
- Identical CCDs/material; sub-pixel aggregation, time-delay integration, and an ND filter on the LGS yield different gains



## 32 different aggregation modes across scan

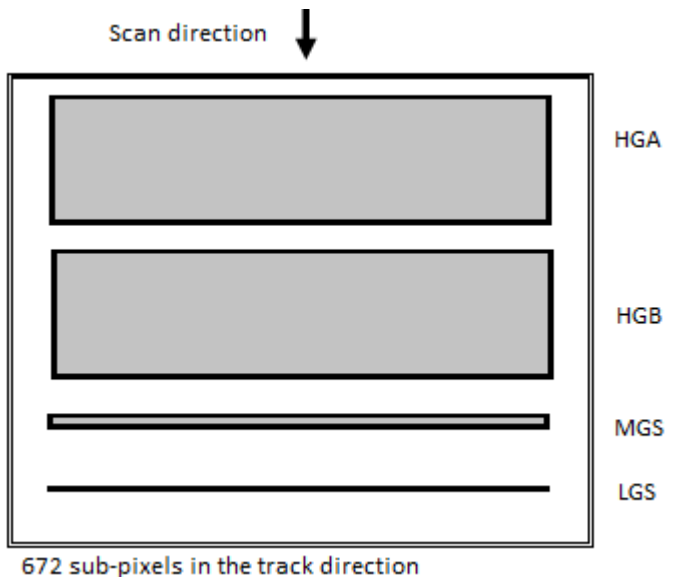
- Maintains HSI near constant 750m across all scan angles

## Dynamic Range spans 7 orders of magnitude

- $L_{min} = 3.0 \times 10^{-5} \text{ Wm}^{-2}\text{sr}^{-1}$
- $L_{max} = 200 \text{ Wm}^{-2}\text{sr}^{-1}$

## Wide bandpass allows the DNB to collect more light

- Bandpass = 500-900nm





# Pre-Launch Radiometric Testing Goals

## Assess compliance with the sensor specification:

- Dynamic range
- Sensitivity
- Uniformity
- Radiometric Uncertainty
  - Non-Linearity (S-NPP VIIRS only)

Gain State	Calibration Uncertainty	Radiance level at which calibration uncertainty is to be evaluated
Low	5% 10%	One-half of maximum radiance for low gain state Minimum radiance for low gain state
Medium	10% 30%	Maximum radiance for medium gain state Minimum radiance for medium gain state
High	30% 100%	Maximum radiance for high gain state Minimum radiance for High gain state

## Determine Coefficients for use in initial on-orbit LUTS:

- Offset tables
- Calibration coefficients



# DNB Calibration Equation



$$L_{EV}(G, D, H, S) = a_0(G, D, H, A) + a_1(G, D, H, A) * [DN_{EV}(G, D, H, S) - DN_0(G, D, H, S)]$$

## **DN<sub>0</sub>**

- Determined prelaunch for each gain state, G; detector, D; HAM side, H; and sample, S.
- On-orbit these are determined from dark data; new moon, pitch maneuver, or cal sector trending

## **a<sub>0</sub>**

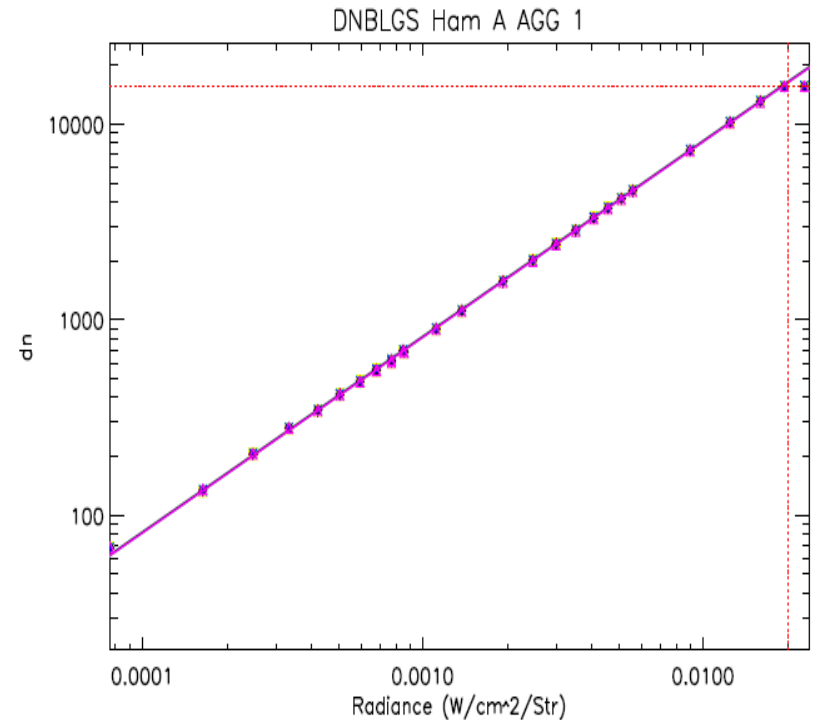
- Set to zero

## **a<sub>1</sub>**

- Determined through the prelaunch test Radiometric Characterization test 2 (RC-2) for each gain state, G; detector, D; HAM side, H; and aggregation mode, A by a linear fit of dn vs radiance.
- On orbit this is determined via the SD calibration for the LGS and transferred to the other gain stages using the ratio of signal in co-registered pixels in the overlapping region of the dynamic range.

## RC-2 Part 1

- VIIRS rotates viewing an integrating sphere illuminated by a combination of up to 18-200W, 9-45W, and 10-10.4W lamps
- The lamps are combined to form up to 39 different radiance levels
- These radiance levels are characterized before testing by the vendor (Raytheon) using their radiometric transfer assembly at the center wavelength of each band.
- During testing the sphere is monitored by a silicon photodiode with a filter wheel covering wavelengths from 400nm to 900nm.
- Radiance levels fall within the dynamic range of the LGS and some MGS aggregation modes though only modes 1, 15, and 32 are tested
- Performed on both primary and redundant electronics at all performance plateaus

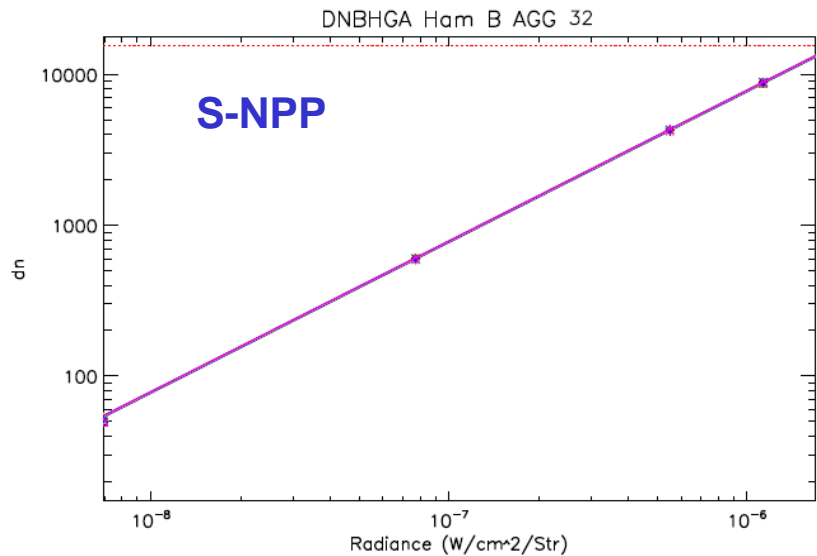


S-NPP DNB LGS Aggregation mode 1

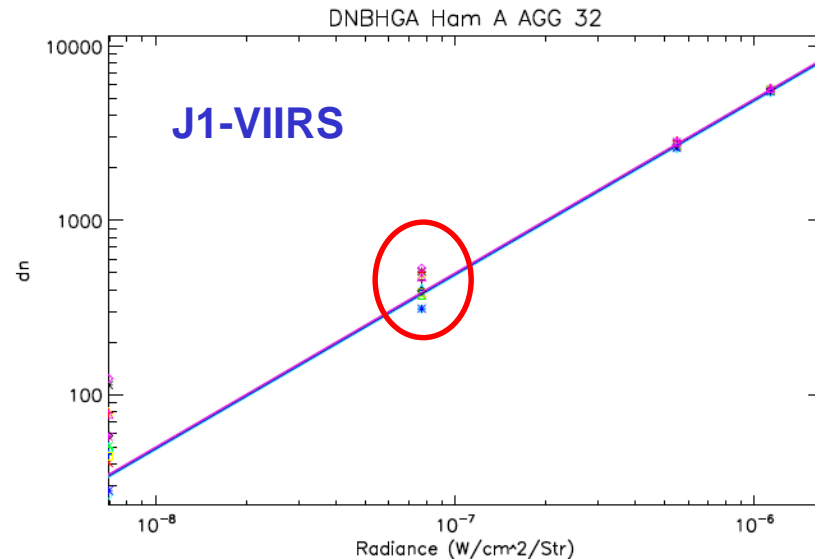


## RC-2 Part 2

- VIIRS rotates viewing an integrating sphere illuminated in 19 different radiance levels
- The brightest level used is the lowest level from part 1. All subsequent levels are formed by either a single 8w or 0.5w lamp operated with a derated current.
- Radiance levels are characterized in the same way as part 1, however the silicon photodiode is not sensitive enough to measured the lowest 0.5w levels
- Radiance levels are with the dynamic range of the MGS and HGS aggregation with modes 1, 7, 11, 15, 26, and 32 are tested
- This test was performed on both primary and redundant electronics and at all three temperature plateaus used in performance testing for S-NPP VIIRS
- During J1 testing this test was only performed once early in the TVAC test program because an issue was found in low radiance in aggregation mode 32.

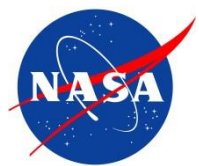


+1 ✖ 2 ◊ 3 △ 4 □ 5 × 6 + 7 ✖ 8 ◊ 9 △ 10 □ 11 × 12 + 13 ✖ 14 ◊ 15 △ 16



+1 ✖ 2 ◊ 3 △ 4 □ 5 × 6 + 7 ✖ 8 ◊ 9 △ 10 □ 11 × 12 + 13 ✖ 14 ◊ 15 △ 16

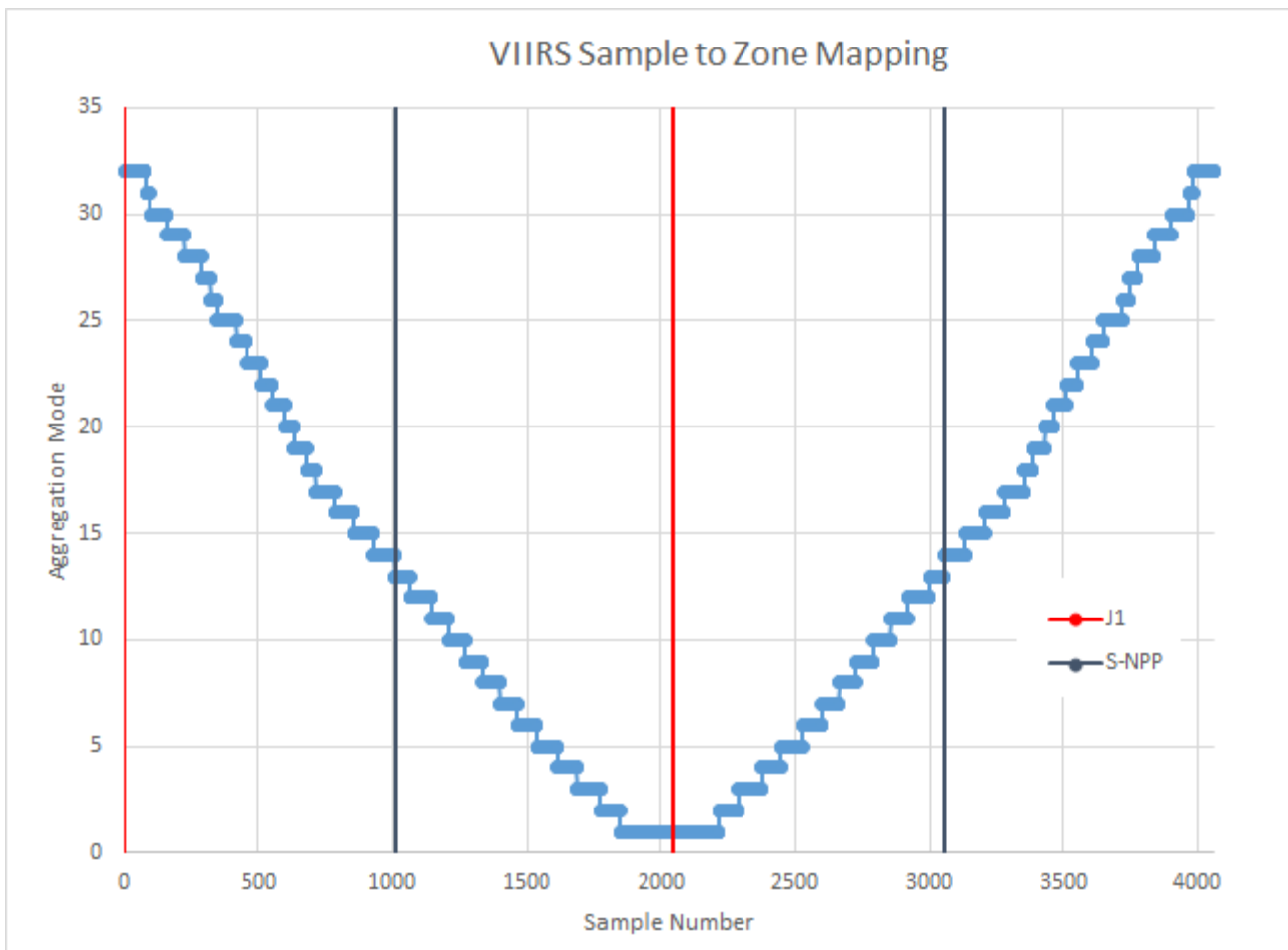
- Nonlinear behavior that was not observed in S-NPP VIIRS testing was found in aggregation mode 32
- In response to this Raytheon changed the test plan removing part 2 from J1 VIIRS testing and expanding part 4



## RC-2 Part 4

- Part 4 was added as a special test during S-NPP testing to assess the inter-aggregation zone uniformity requirement, which limits the difference in retrieved radiance in adjacent aggregation modes viewing a uniform scene.
- **SNPP configuration**
  - Scanning collects in fixed aggregation modes 8,9,10 and 28,29,30,31 were performed as well as staring tests with auto aggregation.
  - A limited number of light levels were used (9) covering the dynamic range of the LGS, MGS and HGS.
  - Scanning collects were performed in the same manner as parts 1 and 2
  - Staring collects recorded data staring at the SIS as then staring at dark blackbody for the background
  - Diagnostic collect window was placed at the center of the EV
- **J1 Configuration**
  - Part 2 of the test was eliminated and the scanning collects of part 4.
  - Additional light levels were added making a total of 27 levels spread over the dynamic range and a collect at each light level with an attenuator screen was included effectively doubling the available levels.
  - Diagnostic collect window was placed at the start of the EV





- The location of the diagnostic collect window in S-NPP VIIRS testing only recorded data in modes 1-13
- Placing the diagnostic window at the start of scan allowed all modes to be recorded



# Test Overlap Between Instruments

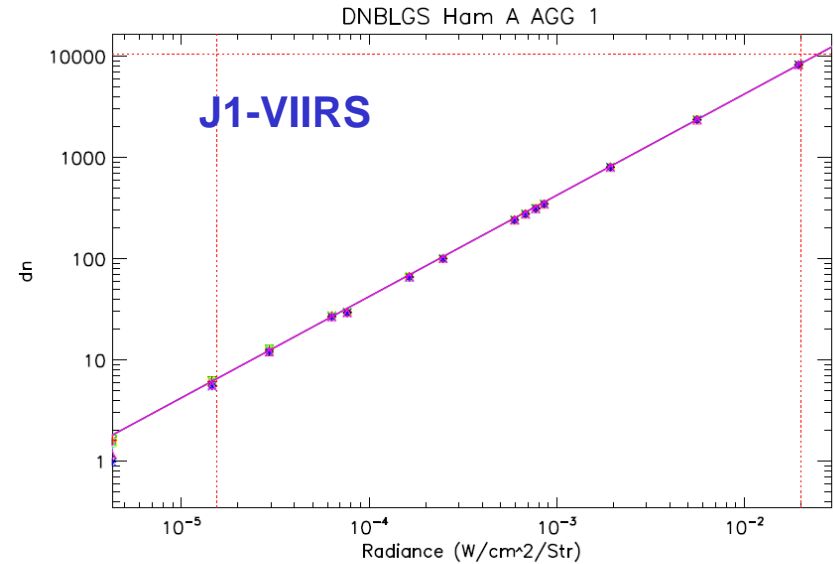
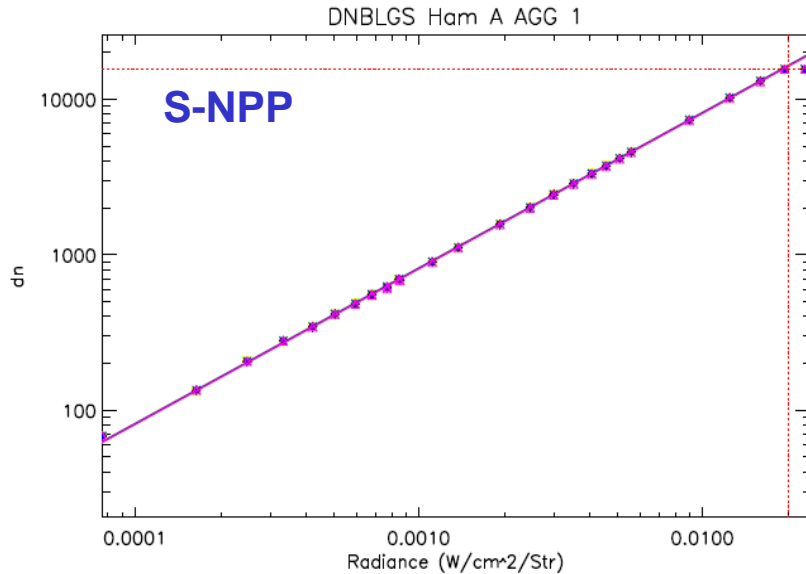


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Gain stages tested
S-NPP Part 1	39														39																	39	LGS, MGS
J1 Part 1	39														39																	39	LGS, MGS
S-NPP Part 2	19						19				19				19											19						19	MGS, HGS
J1 Part 2	19						19				19				19											19						19	MGS, HGS
S-NPP Part 4	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9													9	9	9	9	LGS, MGS, HGS	
J1 Part 4	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	LGS, MGS, HGS	

\* Scanning Part 4 Collections not shown

	Tested in Staring mode
	Tested in Scanning mode
	Tested in both Staring and Scanning
	Tested only once
N	Is the number of light levels in the test

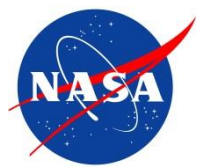
- The J1 VIIRS DNB was tested far more comprehensively than S-NPP VIIRS
- Only 19 of the 32 aggregations modes used in the EV were tested during pre-launch testing of S-NPP VIIRS
- 13 of those 19 were only characterized at a single instrument temperature using 1/3 the light levels used in J1-VIIRS



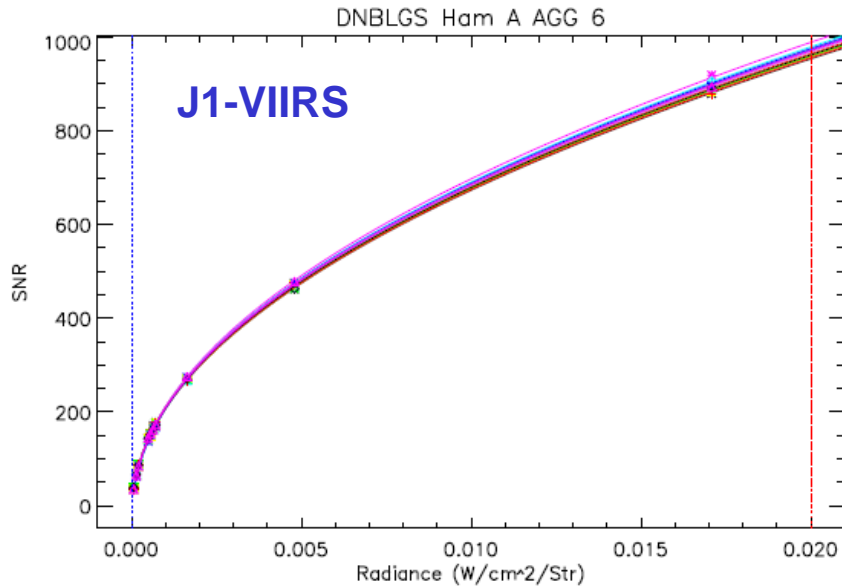
+1 ✖ 2 ◊ 3 △ 4 □ 5 × 6 + 7 ✖ 8 ◊ 9 △ 10 □ 11 × 12 + 13 ✖ 14 ◊ 15 △ 16

+1 ✖ 2 ◊ 3 △ 4 □ 5 × 6 + 7 ✖ 8 ◊ 9 △ 10 □ 11 × 12 + 13 ✖ 14 ◊ 15 △ 16

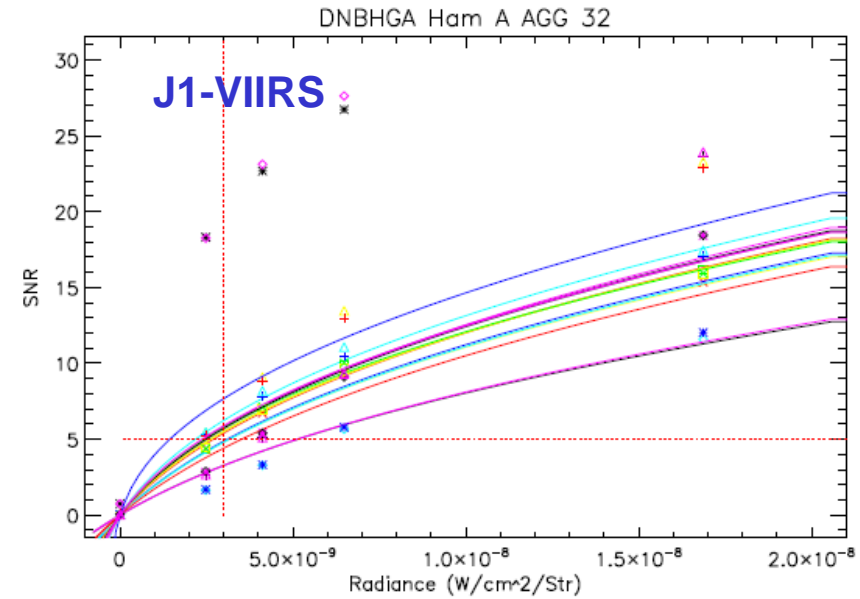
- For both instruments only the aggregation mode 1 (most sensitive) had any issue passing the dynamic range requirement.
- Results shown here for Nominal performance plateau have S-NPP barely compliant and J1-VIIRS barely non-compliant, though this assessment flips at different instrument temperatures.



# Sensitivity Requirement Assessment



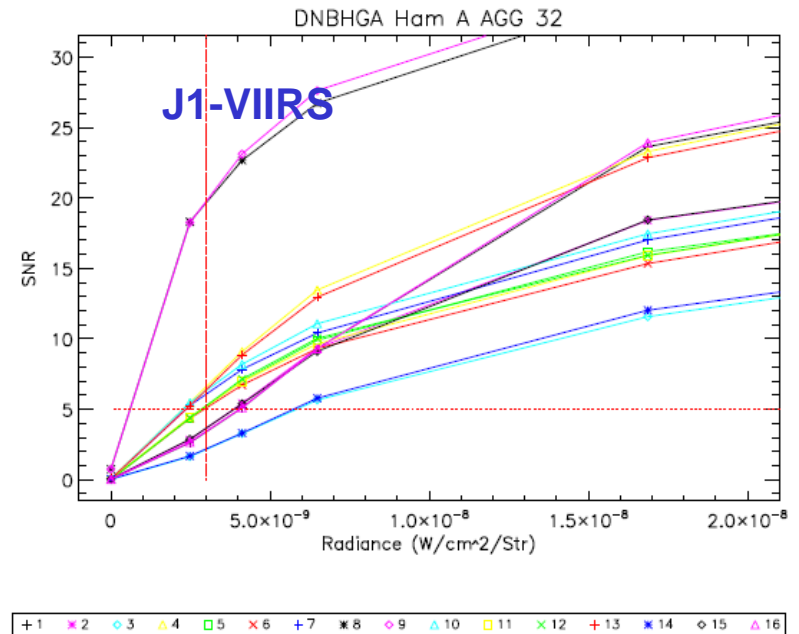
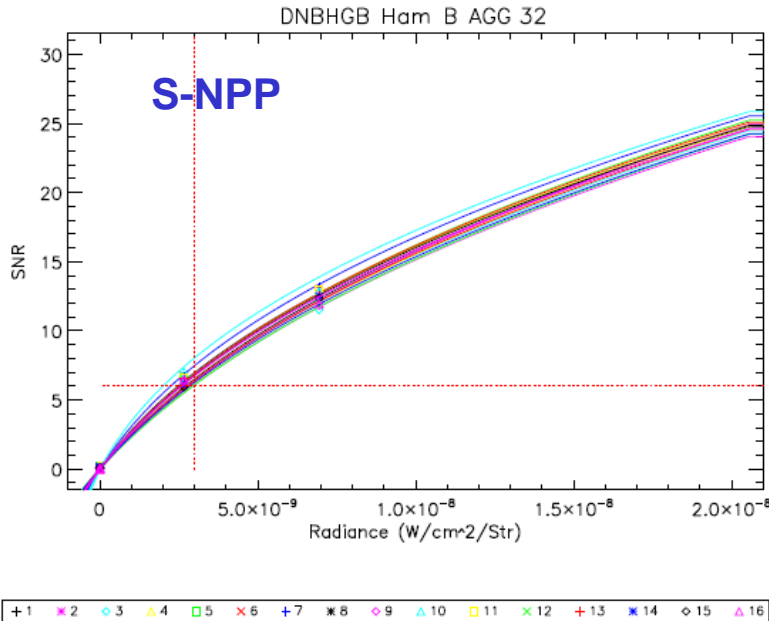
+1 \* 2 ◊ 3 △ 4 □ 5 × 6 + 7 \* 8 ◊ 9 △ 10 □ 11 × 12 + 13 \* 14 ◊ 15 △ 16



+1 \* 2 ◊ 3 △ 4 □ 5 × 6 + 7 \* 8 ◊ 9 △ 10 □ 11 × 12 + 13 \* 14 ◊ 15 △ 16

The SNR for all scan angles less than 53 degrees must be at least 6 and at scan angles greater than 53 greater than 5.

- This requirement is most challenging to meet towards the end of scan
- The non-linearity in J1 VIIRS at the end of scan caused the fits to diverge from the data



In this mode 32 example more detectors from J1 VIIRS fail to meet the requirement than S-NPP.



# Sensitivity Compliance Table



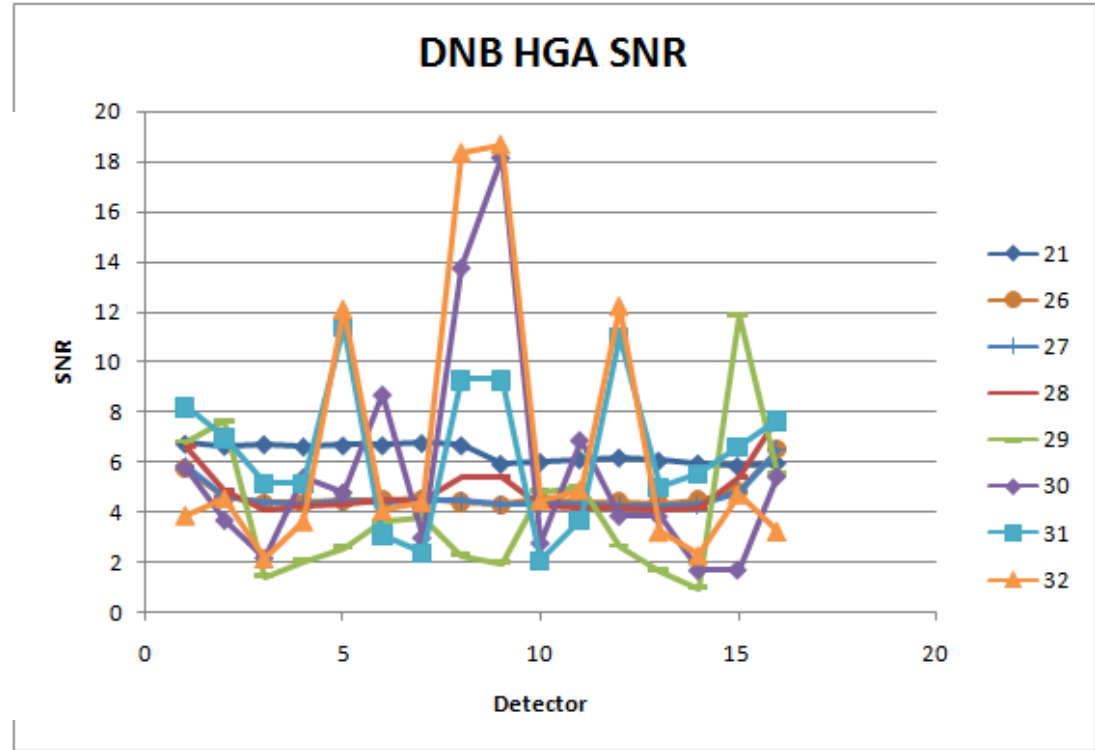
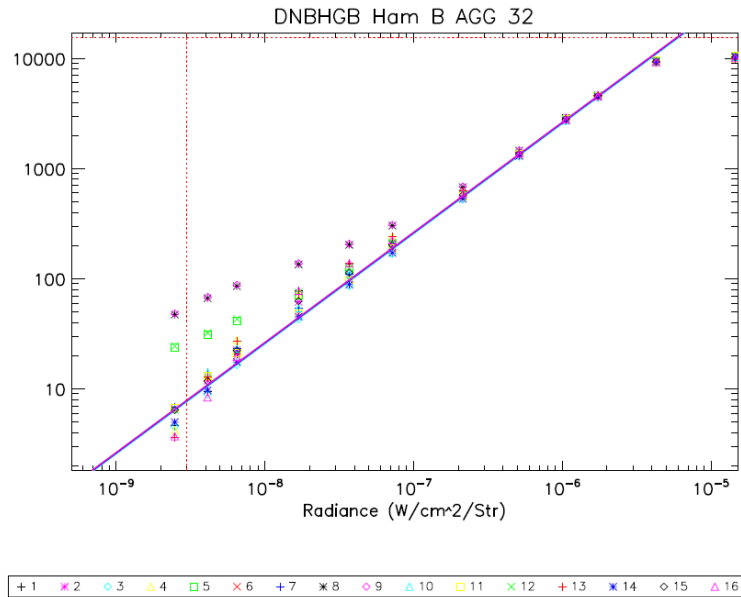
## S-NPP

HGS Band Average SNR at L <sub>min</sub>																																
Agg Mode	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
SNR	27.2	25.8	24	23.6	17.6	16.5	15.5	15.4	13.4	12.6	13.6	13	NA	NA	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.2	NA	6.5	6	5.7	5.8	5.5
Spec	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5	5
Margin	353%	330%	300%	293%	193%	175%	158%	157%	123%	110%	127%	117%	NA	NA	67%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3%	NA	30%	20%	14%	16%	10%

## J1-VIIRS

HGS Band Average SNR at L <sub>min</sub>																																
Agg Mode	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
SNR	25.5	25.0	24.2	23.2	16.9	16.1	15.2	15.6	13.5	12.6	15.5	13.6	10.3	9.4	8.7	7.9	7.5	6.9	6.4	6.1	5.6	5.3	4.8	4.5	5.4	5.3	5.2	5.4	5.7	6.1	6.6	7.4
Spec	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.0	5.0	5.0	5.0	5.0
Margin	326%	317%	304%	287%	181%	168%	153%	161%	124%	110%	159%	127%	71%	56%	44%	32%	24%	14%	7%	2%	-7%	-12%	-20%	-25%	-10%	-11%	-14%	9%	15%	22%	33%	48%

The S-NPP band average SNR meets the requirement with low margin and is slight higher on average.



Though the J1 band average SNR for modes 28-32 is above the requirement this caused driven by the most non-linear detectors. Many detectors will fail to meet the specification.



# J1 VIIRS Use-As-Is Solution



## Option 21

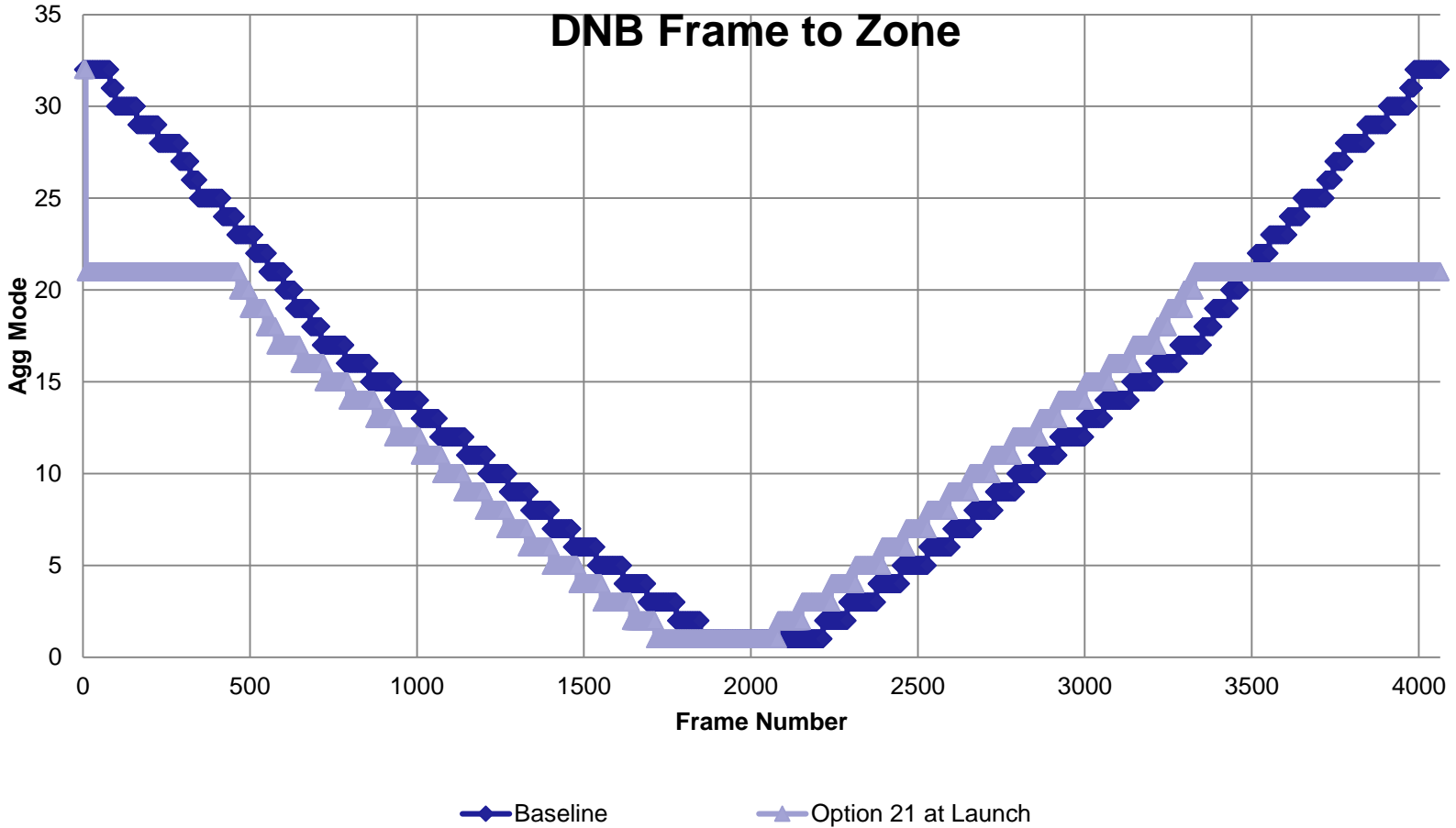
- Only use aggregation modes 1 through 21 (and 32 for 8 samples)
- Improves the calibration accuracy
  - Large deviations from a linear trend will not result in huge errors at low radiance
  - Impact of low radiance non-linearity will not affect the SD transfer to the MGS and LGS which relies on low signal LGS and MGS measurements
- Spatial resolution will decrease
- EV will be asymmetric

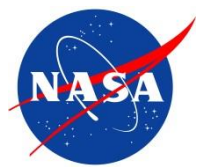
**Option 21 will be used initially at launch.**





# J1 Frame to Zone Mapping Option 21





# Sensitivity Compliance Table – OP21



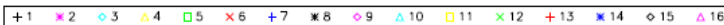
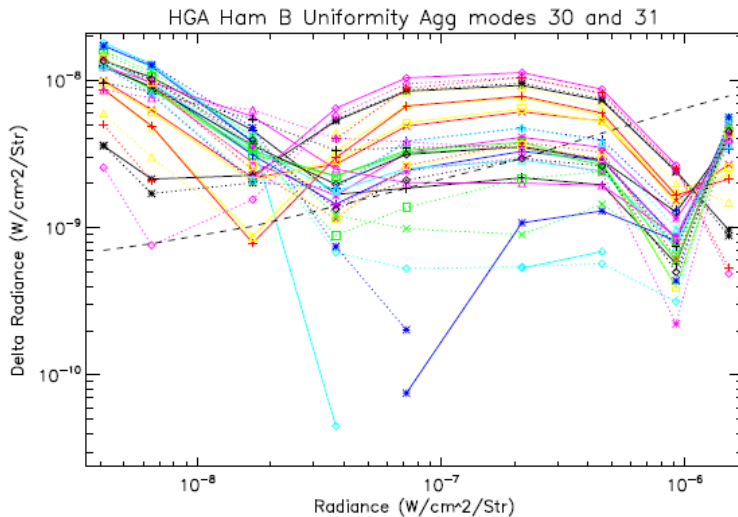
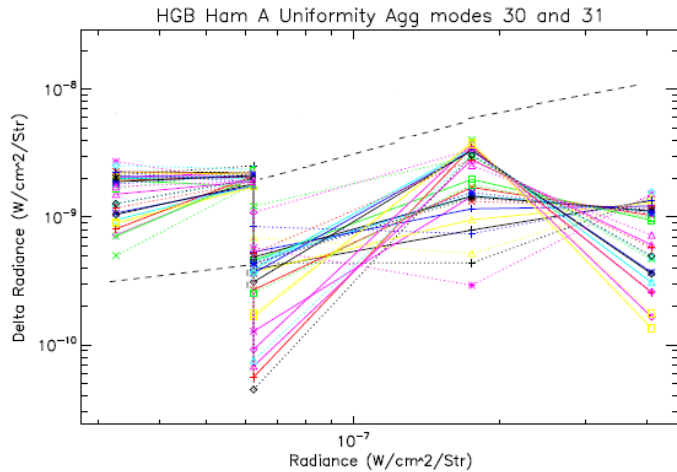
## S-NPP

HGS Band Average SNR at $L_{min}$																																
Agg Mode	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
SNR	27.2	25.8	24	23.6	17.6	16.5	15.5	15.4	13.4	12.6	13.6	13	NA	NA	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.2	NA	6.5	6	5.7	5.8	5.5
Spec	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5	5
Margin	353%	330%	300%	293%	193%	175%	158%	157%	123%	110%	127%	117%	NA	NA	67%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3%	NA	30%	20%	14%	16%	10%

## J1-VIIRS

HGS Band Average SNR at $L_{min}$																															
Agg Mode	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21 < 53 Deg				22 > 53 Deg						
SNR	25.5	25	24.2	23.2	16.9	16.1	15.2	15.6	13.5	12.6	15.5	13.6	10	9.4	8.7	7.9	7.5	6.9	6	6	5.6				5.6						
Spec	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6				5						
Margin	326%	317%	304%	287%	181%	168%	153%	161%	124%	110%	159%	127%	71%	56%	44%	32%	24%	14%	7%	2%	-7%				12%						

Under option 21 there is only a compliance deficiency in mode 21 at scan angles less than 53 degrees



- Inter-aggregation mode

When the DNB views a scene of uniform radiance  $L$  the magnitude of the difference in time-averaged and spatially averaged calibrated pixels shall be less than the greater of

- $0.005xL$
- $1/2 \sigma$

Averaging is performed over no more than 0.5 degrees in scan and the requirement applies from  $L_{min}$  to  $0.9 L_{max}$ .

- Intra-aggregation mode

The standard deviation of the time-averaged and spatially averaged calibrated scene pixels from the 16 detectors within an aggregation mode is limited to the same value as the inter-agg uniformity requirement.

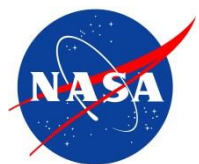


# Uniformity Performance Matrix



		Aggregation Mode																																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32				
S-NPP VIIRS	LGS																																				
	MGS																																				
	HGA																																				
	HGB																																				
S-NPP VIIRS	LGS																																				
	MGS																																				
	HGA																																				
	HGB																																				

- Red = the aggregation mode fails either the inter-agg uniformity with an adjacent mode or the intra-agg uniformity spec is failed within that mode for at least 1 light level.
- Black = uniformity test not collected for S-NPP VIIRS
- Option 21 will improve performance here because zones at the end of scan fail at far more levels and in more detectors than 21.



# Summary



- The J1 DNB was more thoroughly characterized through additions to the test program because of the discovery of non-linear behavior at the end of scan.
- J1 DNB performance significantly worse than S-NPP in the end of scan aggregation modes (above 26) in the baseline configuration, but to non-linear behavior at low radiance.
- Option 21, the at-launch use-as-is fix for J1-VIIRS, removes the final 11 end-of-scan aggregation modes where non-linear behavior is present which also removes most instances of non-compliance in the J1 sensitivity and uniformity requirements.
- The use of option 21 on orbit alleviates concerns with the impact of low radiance non-linearity to the transfer of the SD calibration to the MGS and HGS.
- Both S-NPP and J1-VIIRS saturate slightly below the specification in the most sensitive aggregation mode of the LGS.
- SNR performance is similar in J1 and NPP VIIRS.



# Acknowledgements



Raytheon test team

Government Data Analysis Working Group (Jim McCarthy)

Shihyan Lee