Overview of JPSS VIIRS geometric **calibration** and **validation**

NASA VIIRS **Characterization** Support Team (VCST)
Geometric Calibration Group
Guoqing (Gary) Lin[1,2], Robert E. Wolfe[2]

1, Science Systems Applications, Inc., Lanham, MD
2, NASA Goddard Space Flight Center, Greenbelt, MD

Contributors:
James C. Tilton[2], Ping Zhang[1,2], John Dellomo[3,2],
Bin Tan[1,2], Carol Davidson & Land SIPS Team[1,2]
3, Global Science & Technology, Inc., Lanham, MD

SBG Workshop, 12 - 14 June, 2019, Washington, DC
CalVal Session: Thursday, 13 June 2019

Outline

- Introduction
  - Motivation, VIIRS whiskbroom scanner
- Focal length
  - Effects on geolocation, BBR & scan-to-scan underlaps
- Spatial response tests
  - MTF, under-/over-sampling, optical/electronics anomalies
- Band-to-band registration (BBR) tests
  - Crucial for Level-2 data retrievals
- Pointing and geolocation
- Long term trending and correction
- Other issues, concerns and challenges
- Concluding Remarks

Artifacts from MODIS are mentioned sometimes

Motivation

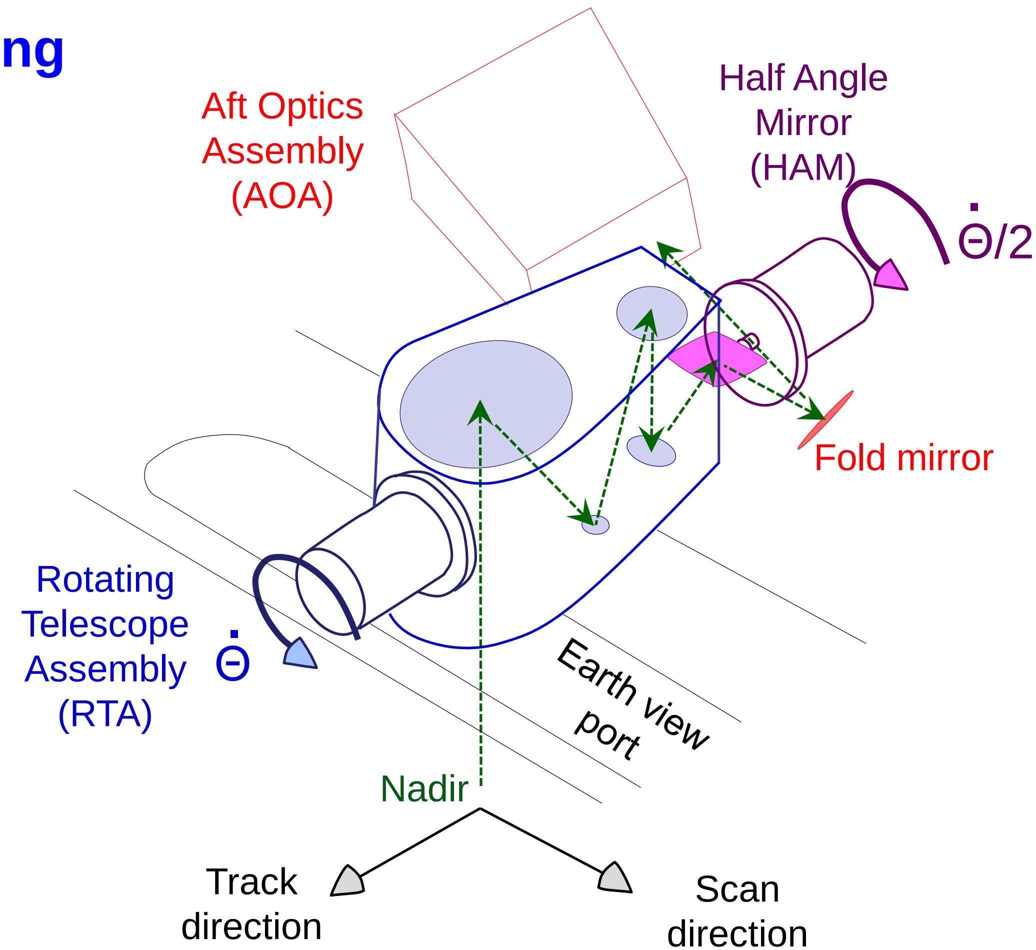
- For accurate Level-2 data retrievals
  - Geolocation accuracy is usually better than ½ pixels (3σ)
  - Band-to-band registration (BBR) is usually > 80% sample overlap (3σ)
- Keys to mission success
  - Well written geometric requirements
  - Good pre-launch test and analysis plan
  - Good post-launch CalVal plan

Whiskbroom VIIRS scanner

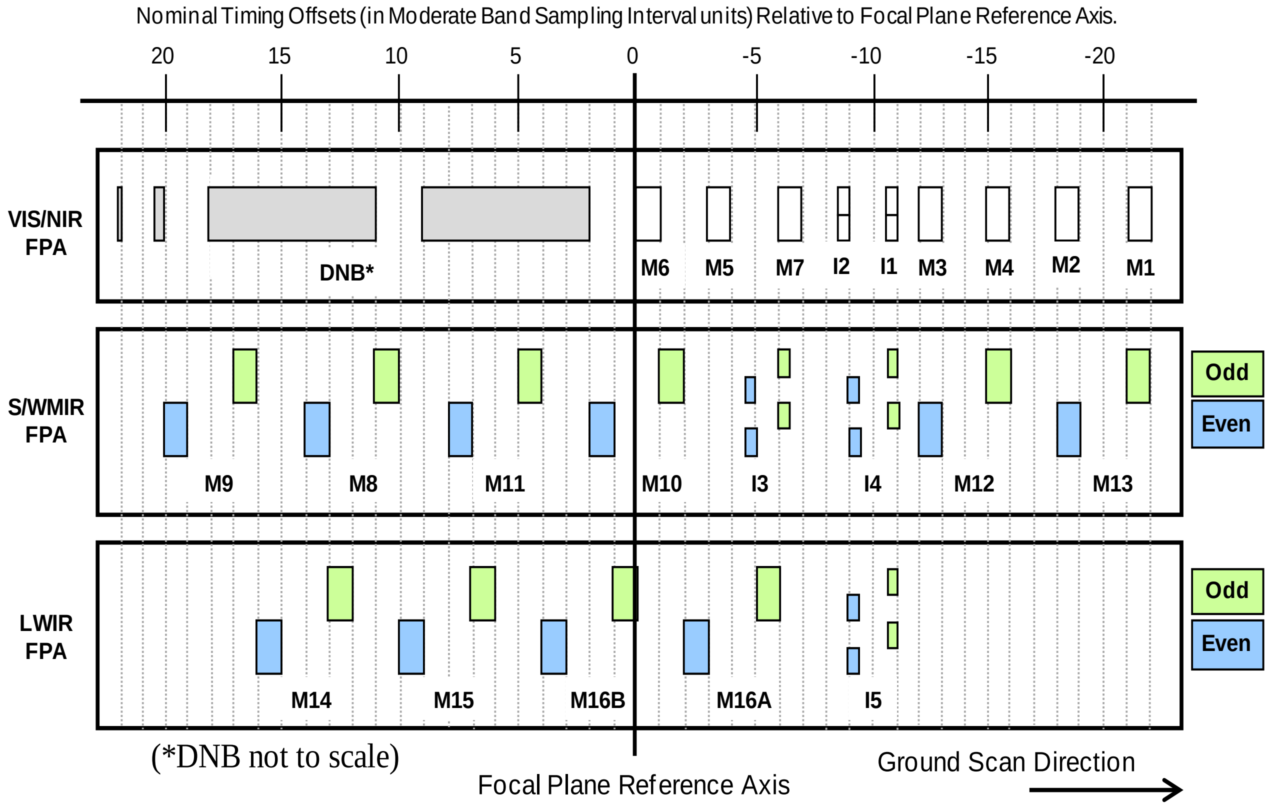
VIIRS (Visible Infrared Imaging Radiometer Suite) scanning geometry

Rotating Telescope Assembly (RTA) captures light from the Earth and other calibration sectors.

Half Angle Mirror (HAM) de-rotates incoming light into the fixed Aft Optics Assembly (AOA) that houses the detectors.



VIIRS Band/Detector Physical Layout



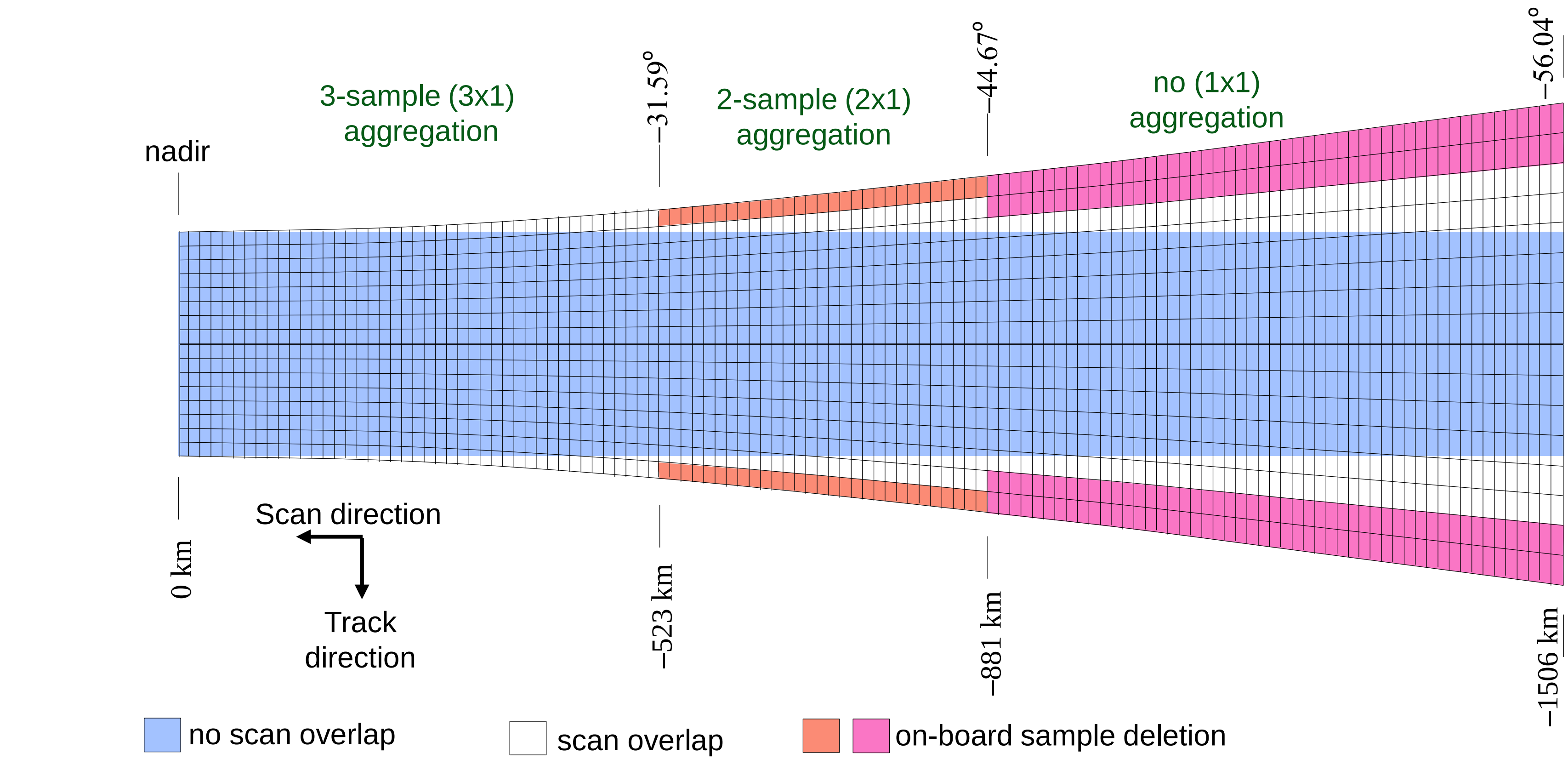
All I-bands across the focal plane assemblies (FPAs) are located close together to mitigate on-orbit jitter impact
Shortwave midwave infrared (S/WMIR) FPA bands spread out the most in scan direction, 38 samples apart from M13 to M9

3 focal planes: VisNIR, SWMIR, LWIR; + 1 Day-Night band (DNB) (no BBR Spec)
21 bands (16 M-bands (M16A, M16B merged in space or just sent down one), 5 I-bands)
16 detectors in each M-band (750x750 m nadir); 32 detectors in each I-band (375x375m)

Ground coverage:
M-band Sample, Aggregation Sample Numbers & Pixel Size

Pixel size = HSI: Horizontal Sampling Interval

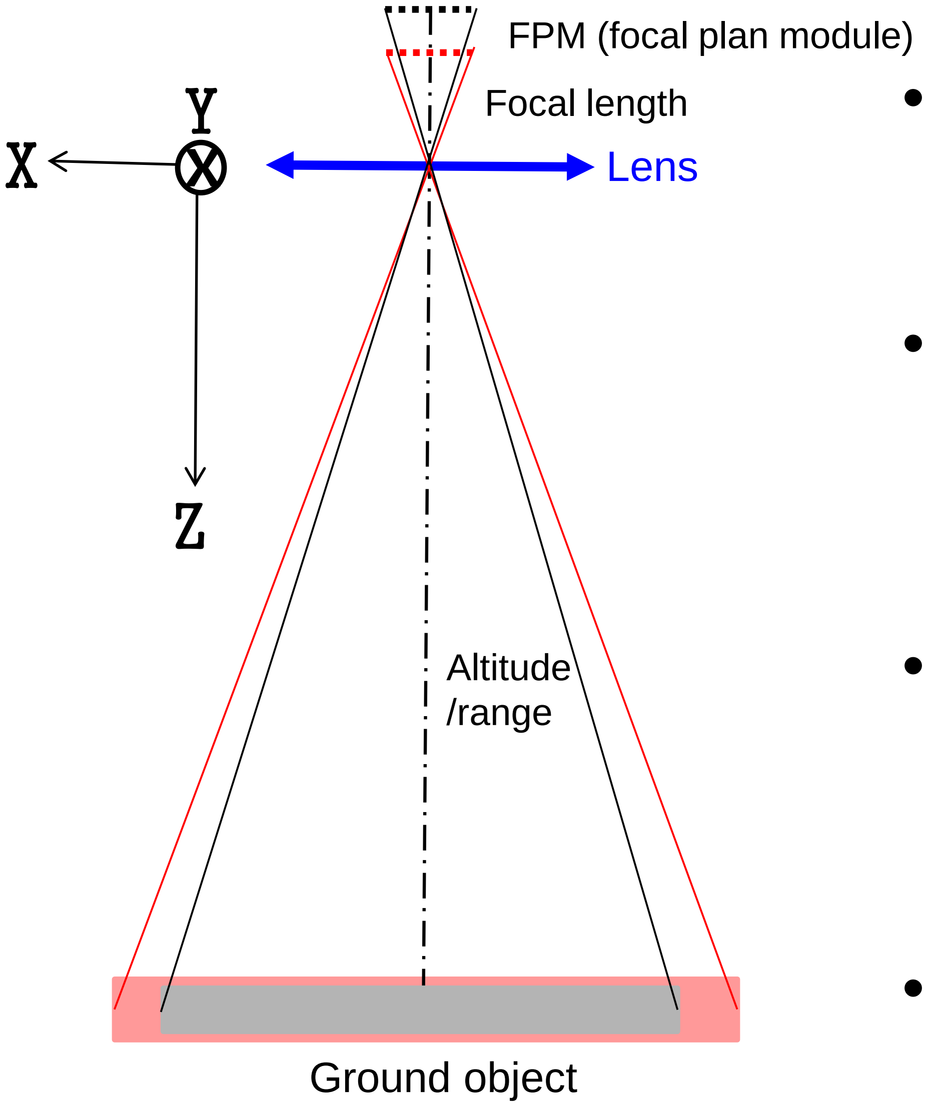
Sample No.	1600(3152)	1009(1377)	1008(1376)	641(641)	640(640)	1(1)
HSI Scan (m)	771(257)	1152(384)	768(384)	1277(638)	638(638)	1600(1600)
HSI Track (m)	738	888		1113		1603



On-board sample deletion deletes 2 M-band (4 I-band) detectors in the 2 sample aggregation zone and 4 M-band (8 I-band) detectors in the no-aggregation zone. The numbers in parentheses for the "Sample no." and "HSI Scan (m)" are for dual-gain M-bands before aggregation, SDR of which are available to the ground as intermediate products.

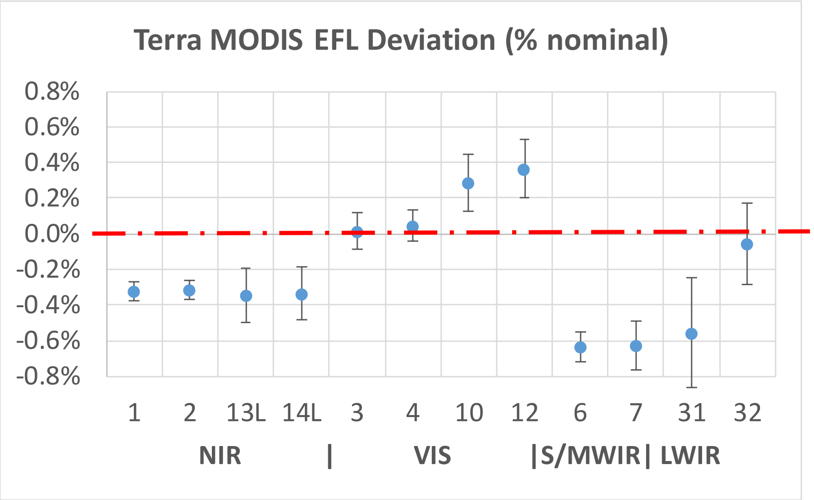
 Using altitude 828 km over the equator. Nominal EFL & scan rate in **J1** (**SNPP 0.4% faster**)

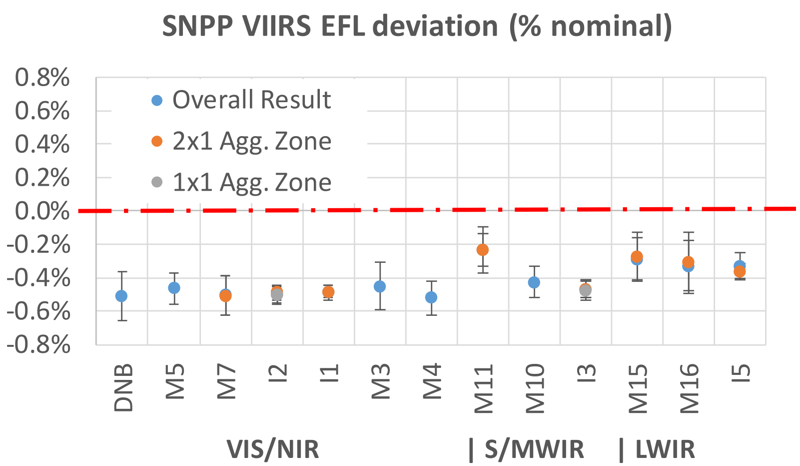
Focal length

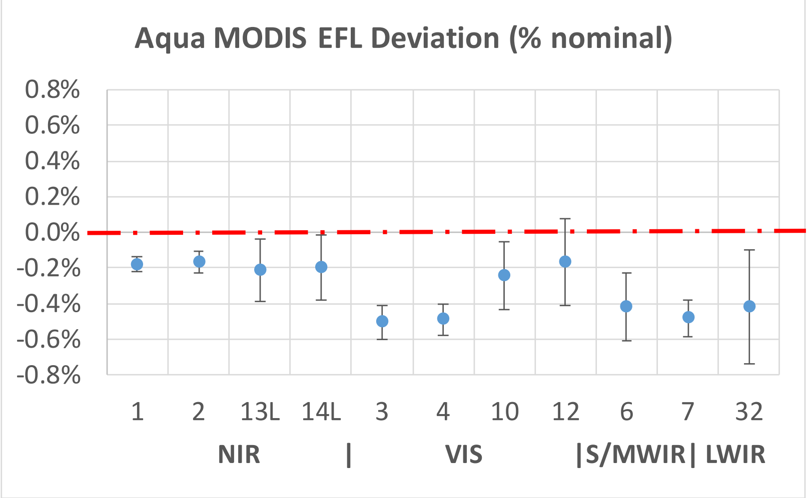


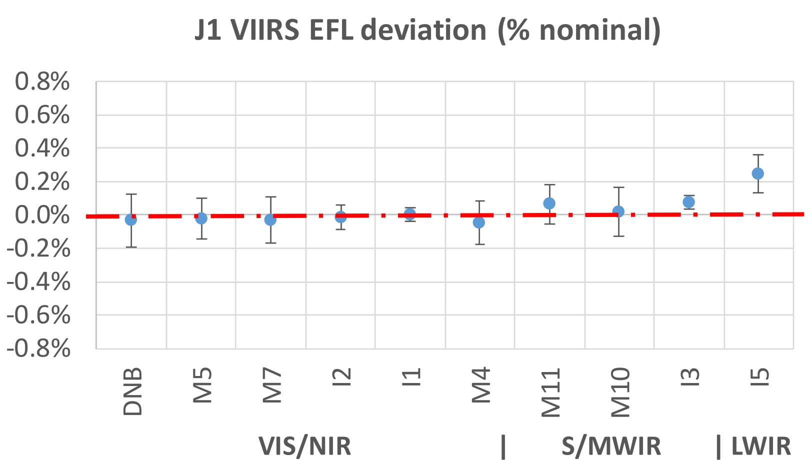
- A small variation of focal length results in appreciable geolocation errors.
- It also results in BBR errors for detectors at the ends of arrays and bands far apart on the focal plane(s)
- It may result in scan-to-scan underlaps in the track direction in cross-track scanner design
- It affects the complexity of instrument optics (& cost)

MODIS & VIIRS focal length variations







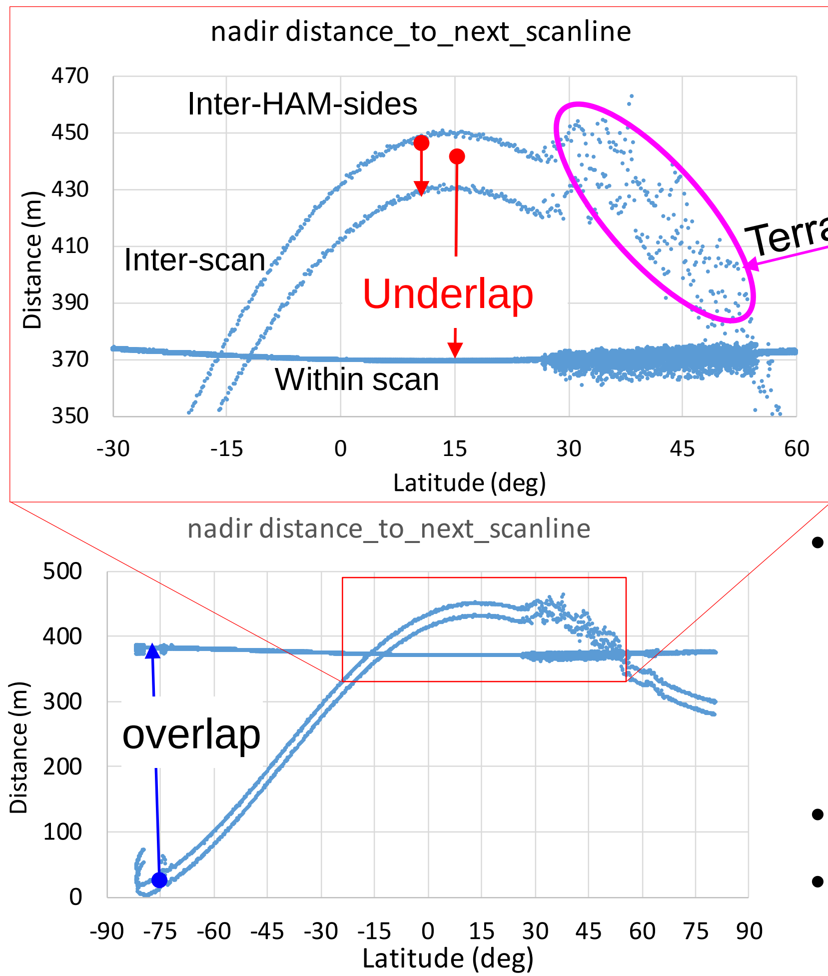


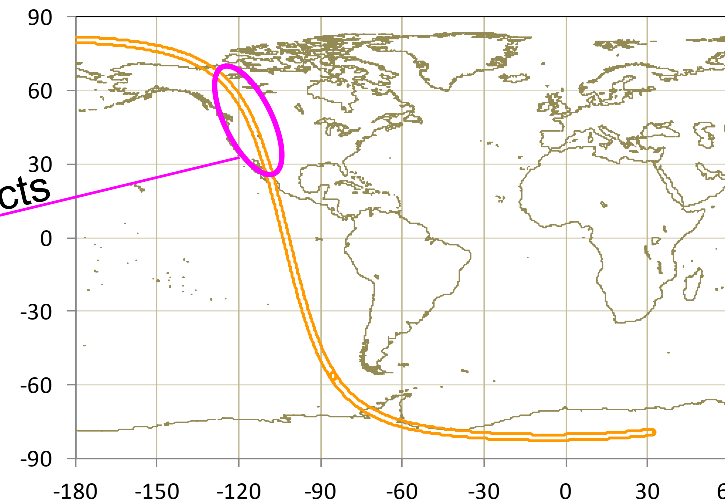
- A 0.5 % difference in EFL (effective focal length) can cause the geolocation of the center of the first or last of the 40 MODIS 250 m detectors to have a systematic error of 24 m at nadir.
- A 0.5 % EFL error without scan rate adjustment results in VIIRS M13-M9 BBR error a 48 m nadir equivalent offset in the scan direction in the non-aggregated zones

Scan-to-scan underlaps

$$Overlap = n\frac{p}{F}h - [V_{ECI} - V_{earth0}\cos i]T, \quad \text{if} < 0 \rightarrow \text{underlap}$$

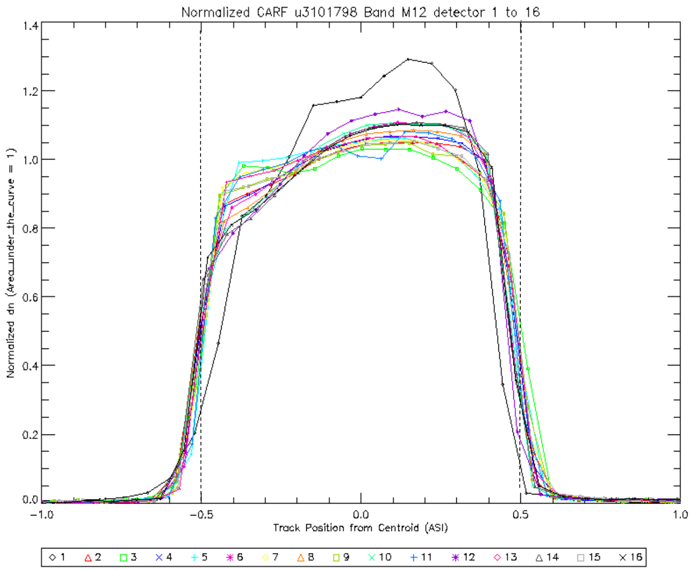
where F = effective focal length, p = detector "pitch" interval in the track direction, n = # detectors, h = range, T = scan period, *i*=inclination angle (in Earth Centered Inertial frame) > 90 deg for VIIRS/MODIS, V_{ECI} = spacecraft ground speed in the inertial frame, Vearth0 = speed of earth rotation at equator, Overlap < 0 indicates underlap.

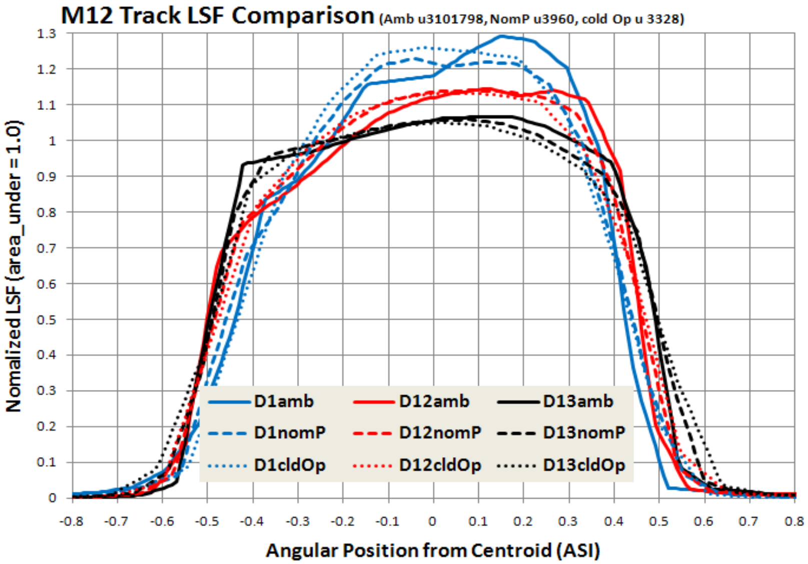




- Widest underlaps occur at nadir near 15N at ~ 70 m in this case. They narrow down as J1 goes north or south due to increasing altitude. They also close in off nadir angles (@ ~10 deg) due to bowtie effects
- High terrain widens the underlaps.
- SNPP VIIRS has less of this issue because of its shorter **focal length** and **scan rate** (~0.4%)

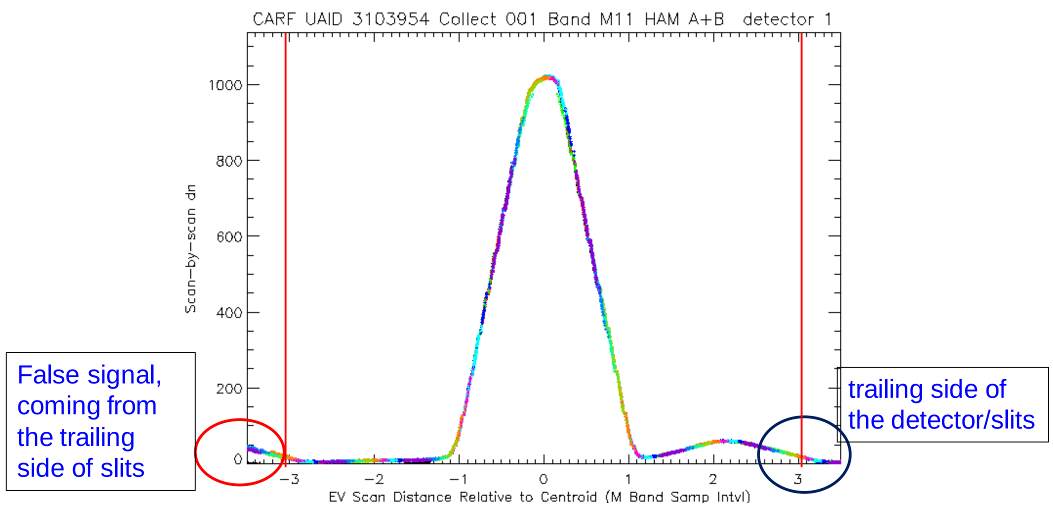
Track LSF anomalies

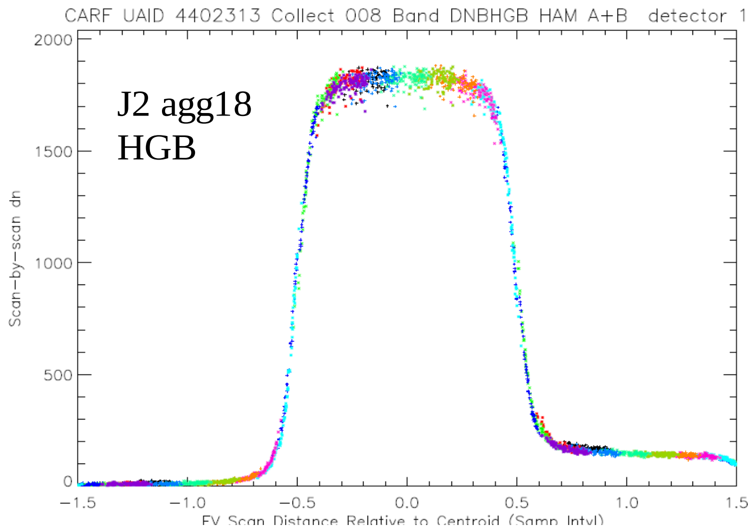




- Track LSFs (line spread functions) are obtained by instrument staring into stepping illuminated reticle slits
- SNPP VIIRS band M12 was found having anomalous LSFs in the track direction due to workmanship
- The detector #1 has the worst performance, which went through **additional** testing under thermal vacuum conditions.

Scan LSF anomalies



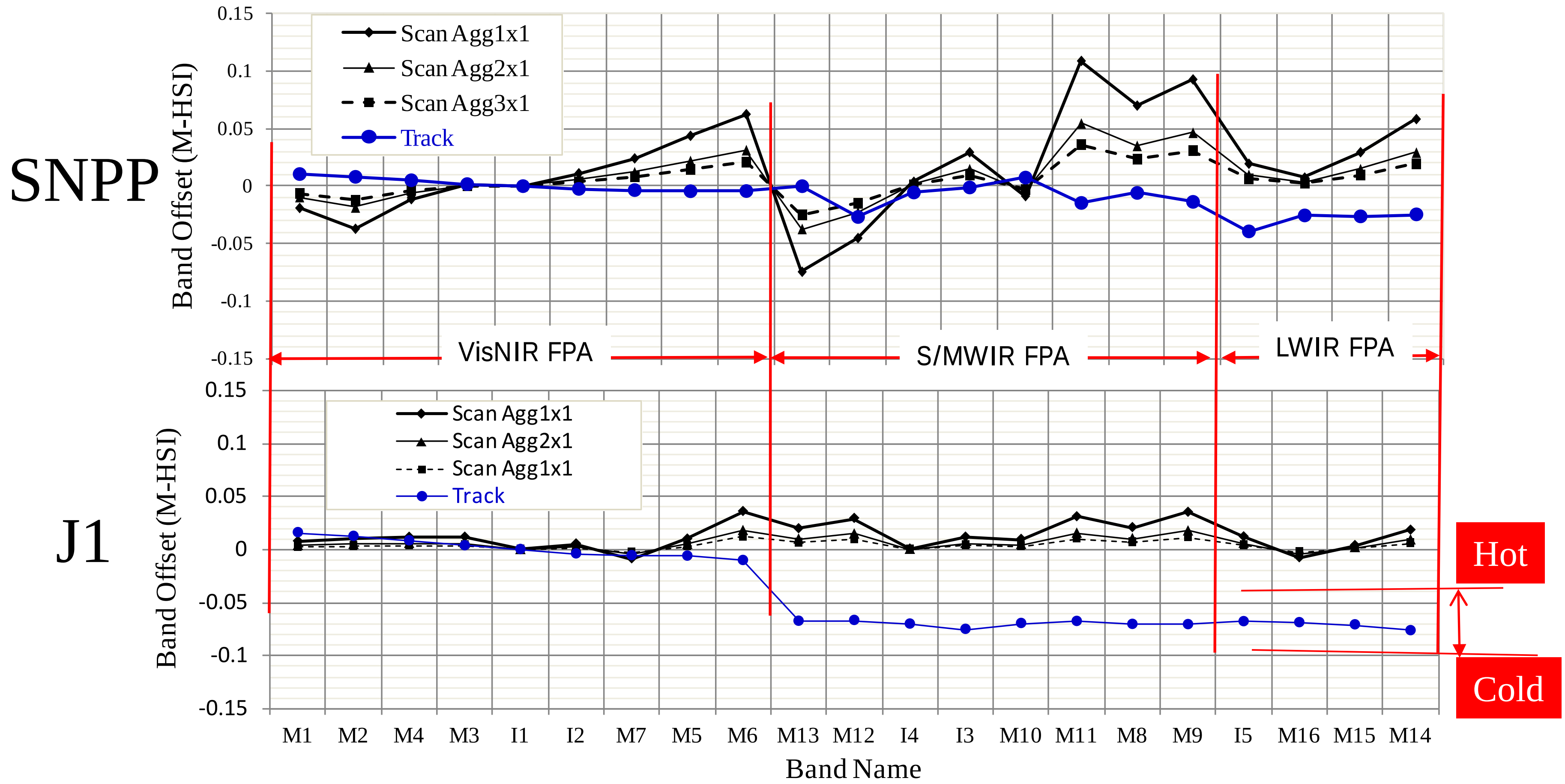


- Scan LSFs are obtained by instrument scanning static and phased illuminated reticle slits
- SNPP VIIRS M11 scan LSFs
- Suspected internal reflection
- The LSFs are parameterized in MTF (modulation transfer function), under-/over-sampling, etc

- J2 Scan LSFs from 2nd (B) high gain detector array (HGB) in DNB
- Electronics anomaly
- Incorrect voltage setting causes the charge in the current sample to remain behind in the transfer gate and be deferred into the next sample in the scan direction

BBR test results

Good BBR is crucial for Level-2 data retrievals

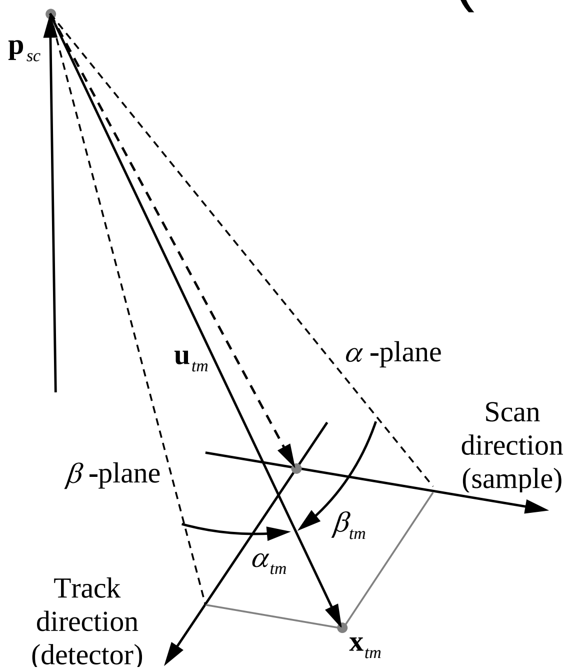


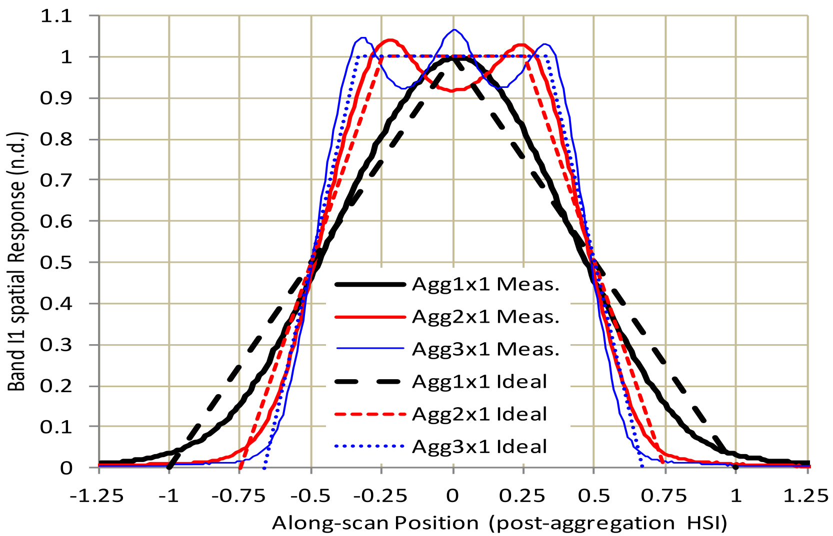
- SNPP VIIRS scan rate is not fast (~0.4%>nominal) enough to match the shortened focal length (~0.5%<nominal) that results in higher BBR errors in the scan direction
- J1 bands on cold FPAs shifted ~ 50 m from bands on VisNIR FPA in the track direction (affects downlink w/ differential encoding→data compression)

Pointing and geolocation

- Pre-launch instrument pointing tests mainly align nadir pointing (encoders) in the earth view (among other alignments in other sectors), which is used in look-point equation for ground geolocation product processing.
- Pre-launch spacecraft tests include instrument-to-spacecraft interface rotation matrix, which is usually corrected for proper geolocation in on-orbit operations.
- On-orbit spacecraft (SC) ephemeris (position & velocity) provides along-track nadir pointing. Attitude provides correction for SC nadir pointing.
- RTA/HAM timestamps provide off-nadir along-scan motion and pointing to the ground.

On-orbit geolocation error detection CPM (control point matching) program

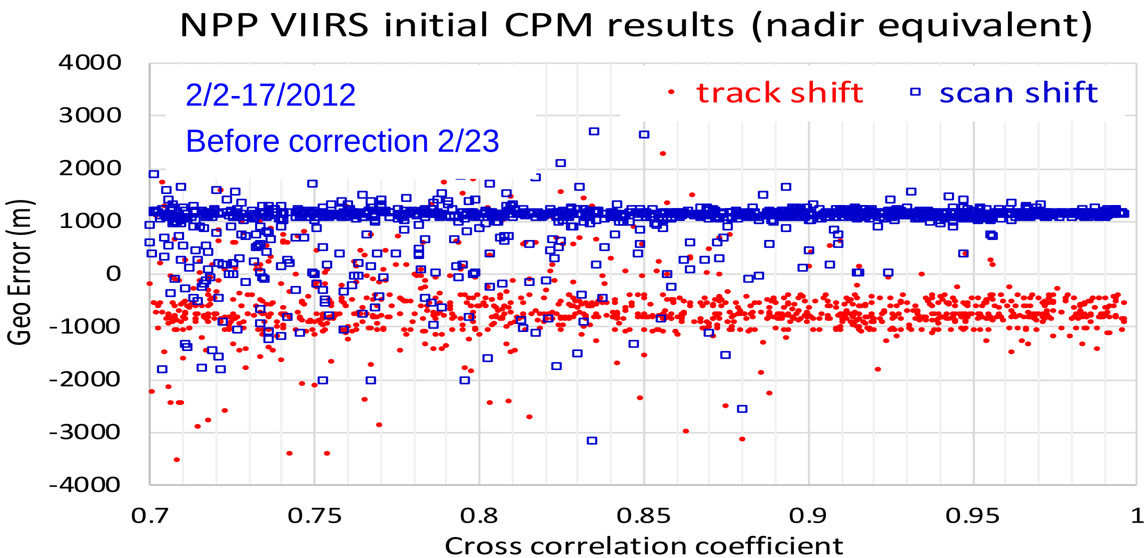




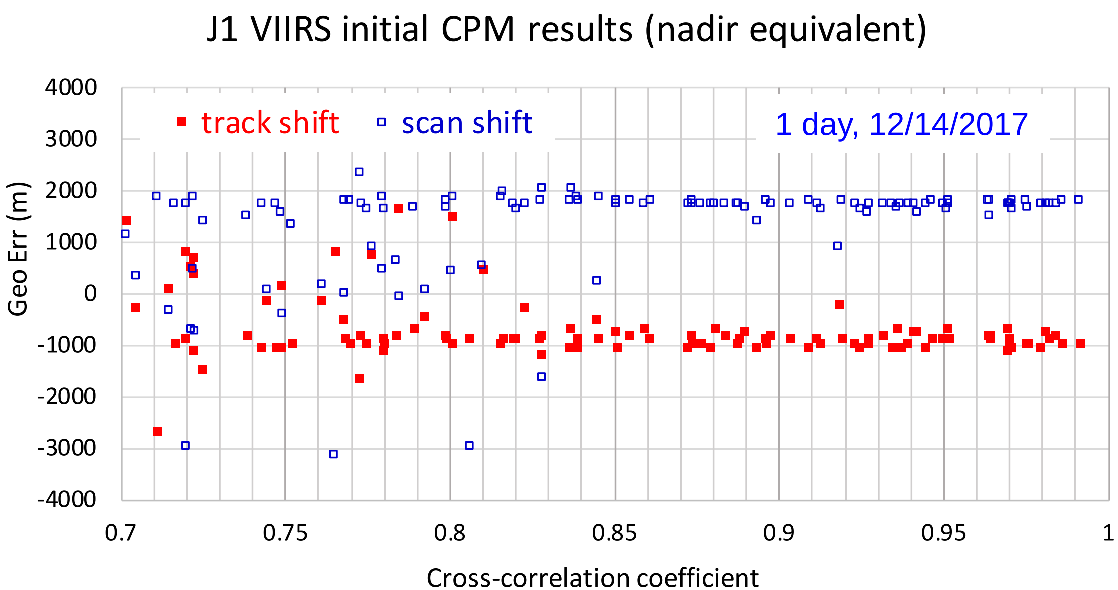
- LSFs are used to simulate VIIRS band I1 (0.62 – 0.68 µm) images
- Square LSF in track direction (& scan direction for DNB)
- Triangular LSF in scan direction for VIIRS, trapezoidal LSFs in Agg2x1 and Agg3x1 zones for VIIRS

- Landsat red band (0.63 – 0.69 µm) 30 m resolution
- Mostly cloud clear sub-scenes 800x800-pixels (24 x 24 km) (to be refreshed to 1400x1400-pixels (42 x 42 km))

Initial SNPP/J1 VIIRS geolocation



- SNPP launched
  - 2011-10-28
- nadir door opened
  - 2017-11-21
- Track offset ~ -1 km
- Scan offset ~ +1 km
- RTA mirror tungsten degradation extended initial CalVal period



- J01 launched
  - 2017-11-18T09:47z
- nadir door opened
  - 2017-12-13T16:45z
- Track offset ~ -1 km
- Scan offset ~ +2 km

Initial on-orbit corrections

SNPP VIIRS geolocation parameter lookup tables (LUTs) updates

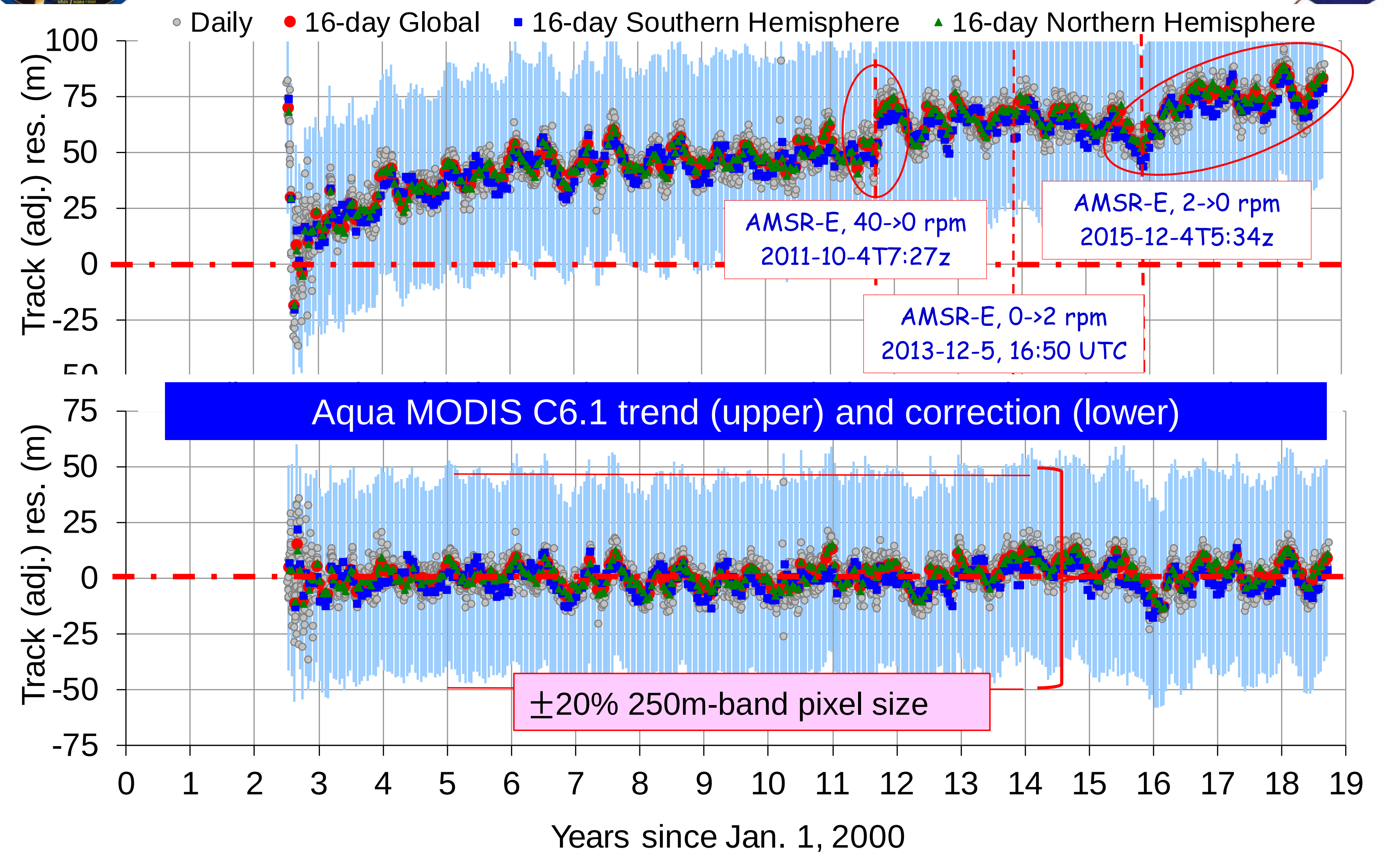
Parameters	At-launch	LPEATE r1 2012-02-23	Deltas "r1" – "At-launch"
Roll (")	33.2	-227.3	-260.5
Pitch (")	41.2	153.2	112.0
Yaw (")	-59.3	95.4	144.7

J1/N20 VIIRS GEO LUTs updates

Parameters	At-launch	LSIPS r1 2018-01-03	Deltas "r1" – "At-launch"
Roll (")	0.9	-423.5	-424.4
Pitch (")	51.1	300.5	249.4
Yaw (")	80.5	99.4	18.9

Here, roll, pitch and yaw are instrument-to-spacecraft mounting angles
NASA LPEATE (Land Product Evaluation and Analysis Tool Element) has evolved to LSIPS (Land Science Investigator-led Processing System)

Long term trending and correction



The stop-go-stop of the AMSR-E (Advanced Microwave Scanning Radiometer - Earth Observing System) antenna dish on the zenith deck affects thermal conditions of MODIS

Other issues, concerns & challenges

- Leap second handling
- Orbit maintenance maneuver handling
- Star catalog upload handling
- Star trackers re-alignment handling
- Star trackers degradation
- Onboard clock drifts
- Downlink bandwidth

Details of these may be discussed at other times.

But,
the spacecraft design needs to take these into consideration.

Concluding Remarks

- Instrument focal length is a defining parameter affecting geolocation, BBR, optics design (& cost)
- Pre-launch testing is important to validate designs
- BBR (> 80% overlap) is crucial for Level-2 data retrieval
- A network of ground control points (chips) is needed to detect and correct geolocation errors
  - Terrain correction (DEM (Digital Elevation Model) w/ compatible resolution) is needed for terrestrial applications
- Long term monitoring is needed to correct possible geolocation drifts to achieved better than ½ pixels (3σ) accuracy
- Orbit operations need to be considered in designs
- Well written requirements, good pre-launch test & post-launch CalVal plans are keys to mission success