(SNPP + J1/N20 + J2/N21 + J3 + J4)

# VIIRS Geometric Calibration Status

NASA VIIRS Characterization Support Team (VCST)
Geometric Calibration Group

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NASA MODIS/VIIRS Calibration Workshop

1 May 2023, In-person

(last in-person Nov 2019; last one on 25 Feb 2021, virtual)

# Outline

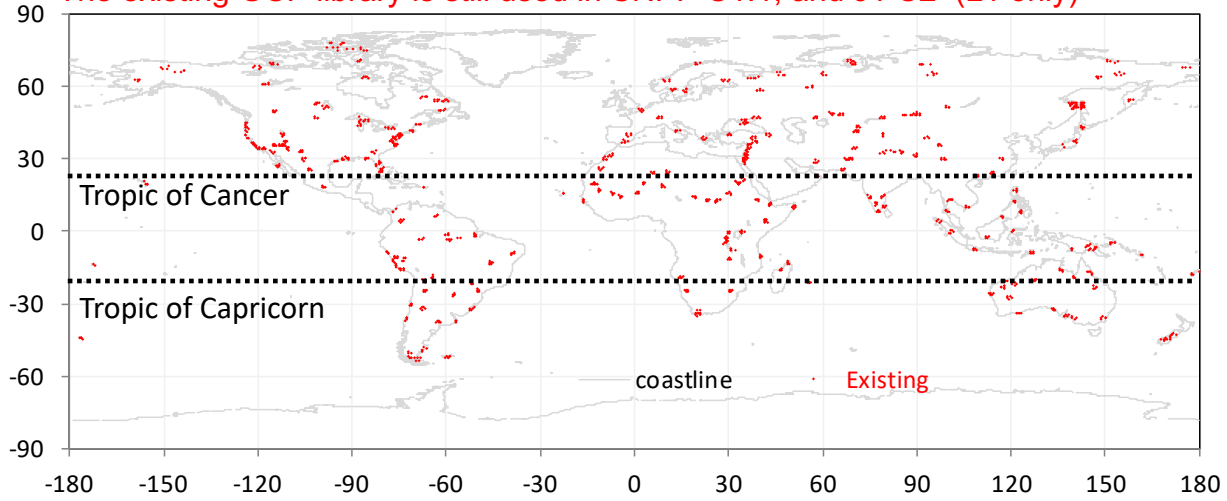
- Changes since STM in Feb 2021
- SNPP VIIRS Geolocation in C1.1, C2
- J1/N20 VIIRS Geolocation in C2, C2.1
- J2/N21 VIIRS initial Geolocation in “C2”
- Expectations for J3, J4 VIIRS
- Plan in future work
- Conclusions

# Changes since last STM

1) Refreshed ground control point (GCP) chip library from Landsat-8 images, generating ~ 4X as many daily matches as in the existing GCP library
    1) fully utilized in SNPP C2
    2) J1/N20 C2.1 (in L1, but used to generate C2 in L2+ products)
    3) J2/N21 “C2”, test archive
2. SNPP C2 also implemented
    1) Kalman Filter for attitude improvement
    2) VIGMU (VIIRS instrument geometric model update)
    3) Temporal pointing correction
3. J2 launched on 11/10/2022, became NOAA-21
4. J3 VIIRS is in I&T with spacecraft
5. J4 VIIRS completed ambient tests

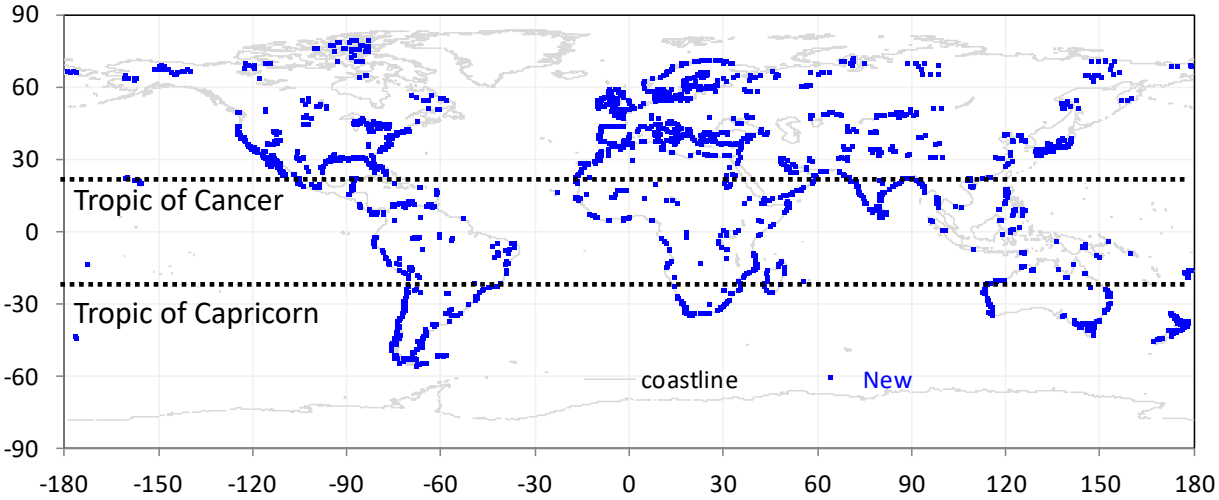
# GCP refresh & match improvements

The existing GCP library is still used in SNPP C1.1, and J1 C2 (L1 only)




- 1214 existing chips mostly from Landsat-7
- 24 x 24 km$^2$ chip size
- 196 daily matches
- Error search
  - ± 56 deg scan angle
  - ± 2.5 pixels
  - 0.85 minCCV

New ground control points (GCPs) are used in SNPP C2, J1 C2.1, and J2 "C2".




- 2514 (2.1X) new chips from Landsat-8
- 42 x 42 km$^2$ chip size
- 841 (4.3X) daily matches
- Error search
  - ± 56 deg scan angle
  - ± 2.5 pixels
  - 0.85 minCCV

GCPs within tropics seasonally switch side in the satellite mornings/afternoons

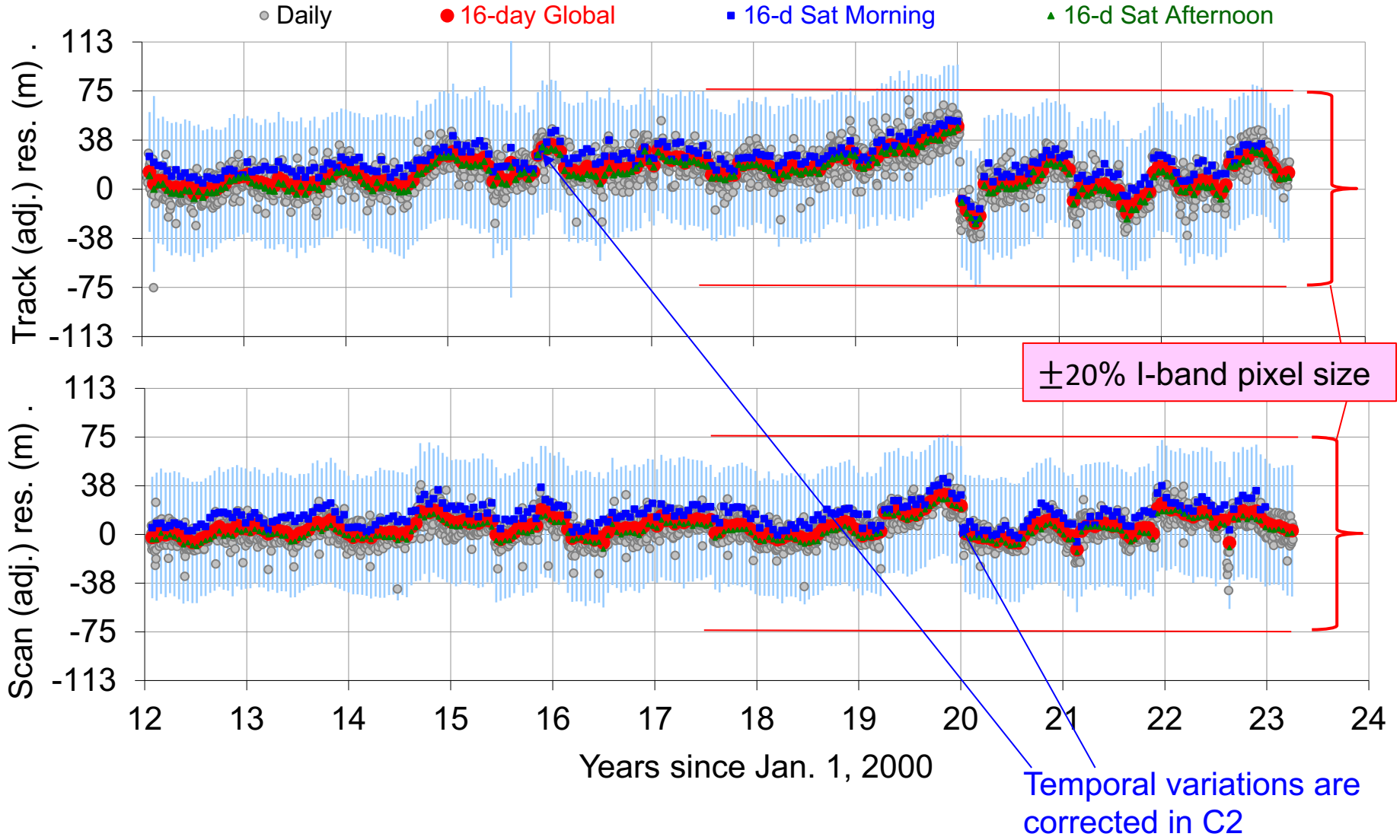
# VIIRS Geolocation Performance

| Residuals | SNPP C1.1 | SNPP C2 | J1/N20 C2 | J1/N20 C2.1 | J2/N21 "C2" |
|---|---|---|---|---|---|
| Track mean | **14 m** | **2m** | **2m** | **-4 m** | **-8 m** |
| Scan mean | **5 m** | **5 m** | **-2 m** | **5 m** | **2 m** |
| Track RMSE | **59 m** | **59 m** | **55 m** | **57 m** | **60 m** |
| Scan RMSE | **53 m** | **48 m** | **50 m** | **47 m** | **48 m** |
| Data-days | **4081 (11.2 yrs)** | **4081 (11.2 yrs)** | **1917 (5.2 yrs)** | **1917 (5.2 yrs)** | **73 (0.2 yrs)** |
| Missing days | **16** | **16** | **3** | **3** | **1** |
| Daily matched GCPs w/ I1 | **199** | **845** | **194** | **838** | **846** |

New Chip Library

- **Nadir equivalent** accuracy (RMSE – Root Mean Square Error)
  - Meet Spec: 125 m (1σ); **within 20% I1 HSI (375 m) = 75 m @ nadir**
  - Band-to-band mis-registration to other bands adds bias to RMSE to : $RMSE = \sqrt{\sigma^2 + \mu^2}$
- SNPP C2 uses Kalman filter for attitude improvement, VIGMU to remove oscillations in scan direction, and time-dependent instrument-to-spacecraft interface angles to remove temporal pointing variations
- New chip library is used in SNPP C2 and J1/N20 C2.1 re-processing
- J2/N21 data archive is currently in test archive, "C2", and using the new chip library

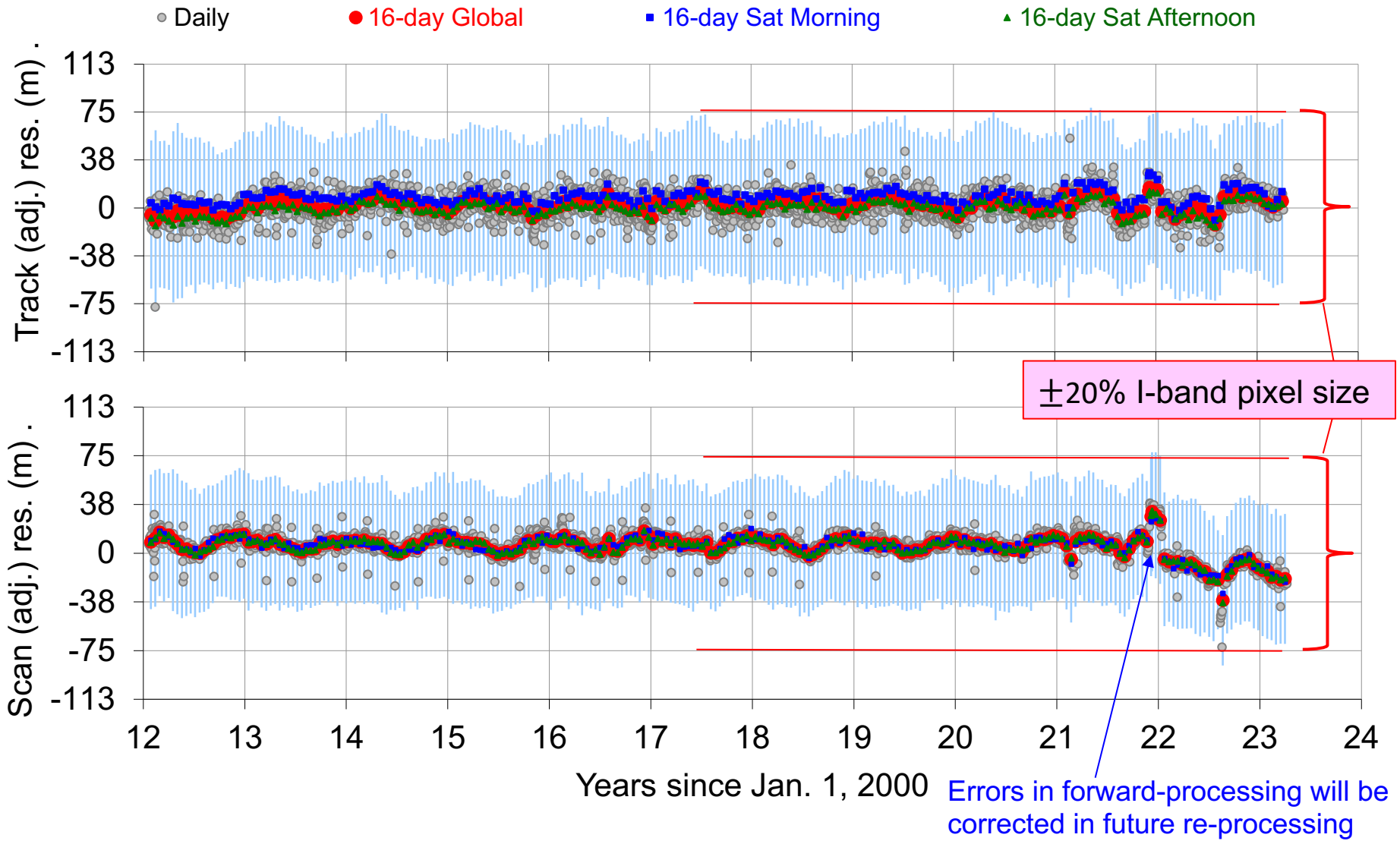
# SNPP C1.1 geolocation errors




C1.1 RMSE Track: 53 m Scan: 48 m, nadir equivalent

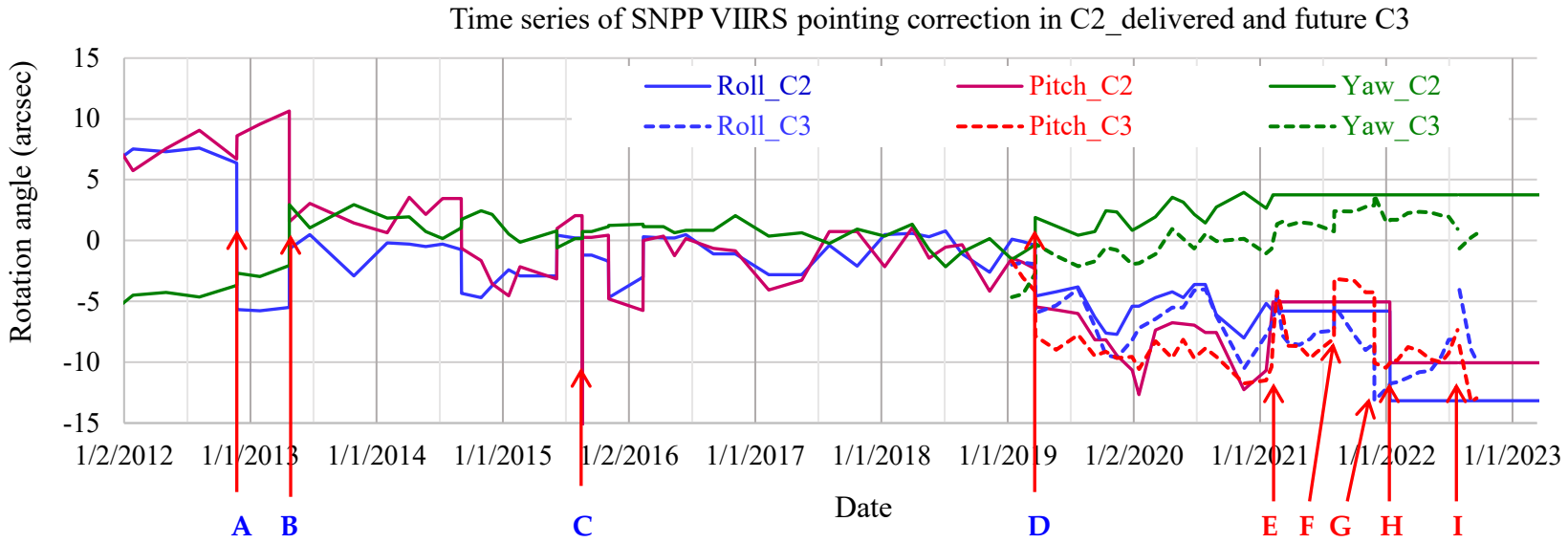
# SNPP C2 geolocation errors

New Chip Library




C2 RMSE Track: 59 m Scan: 48 m, nadir equivalent

# Time series for SNPP VIIRS pointing correction



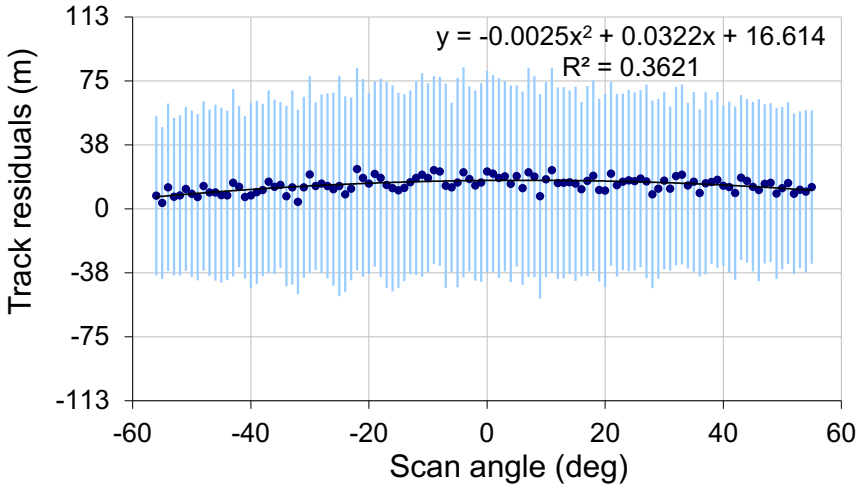

Events:

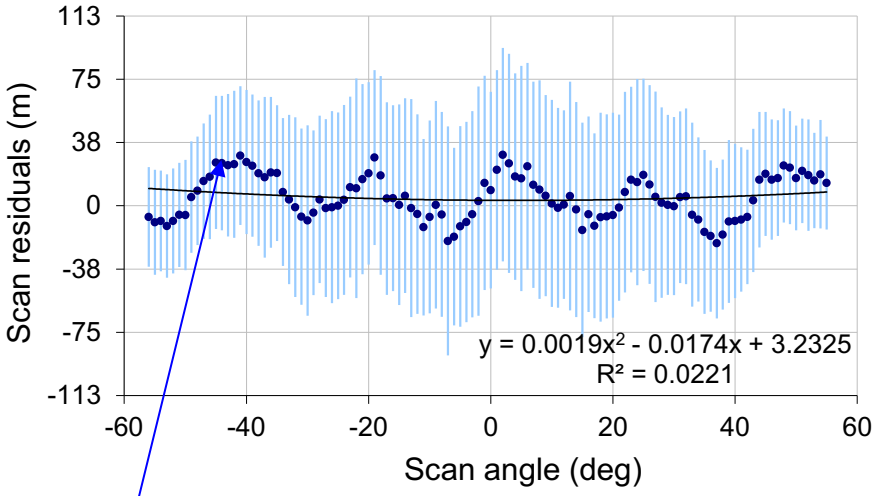
A. 2012-11-22, side switch of VIIRS scan control electronics
B. 2013-4-25, erroneous star trackers realignment
C. 2015-8-19, 1-second time error onboard of SNPP (213 arcsec pitch error) for 7 hours
D. 2019-3-22, Star Tracker-2 reset
E. 2021-2-8, LUTs updates for forward processing in constant values
F. 2021-8-3, safe hold and sun pointing
G. 2021-11-27, Global Positioning System (GPS) had issued a "0" leap second
H. 2022-1-13, LUTs updates for forward processing in constant values
I. 2022-7-26, safe hold and sun pointing

These are corrected for in C2.

# SNPP scan profiles

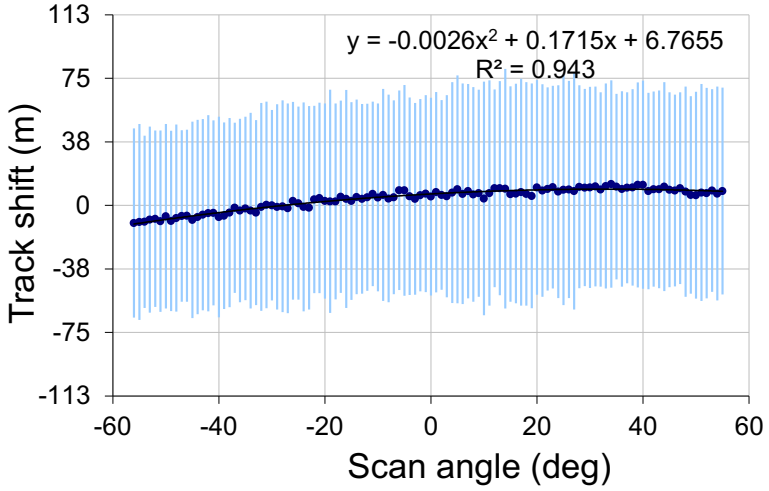
## C1.1 results (old chip lib)

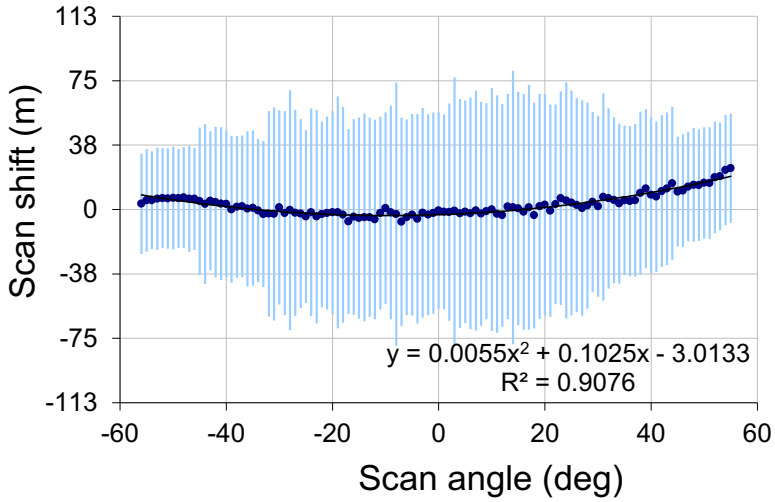



Strange pattern is corrected in C2

## C2 results (new chip lib)

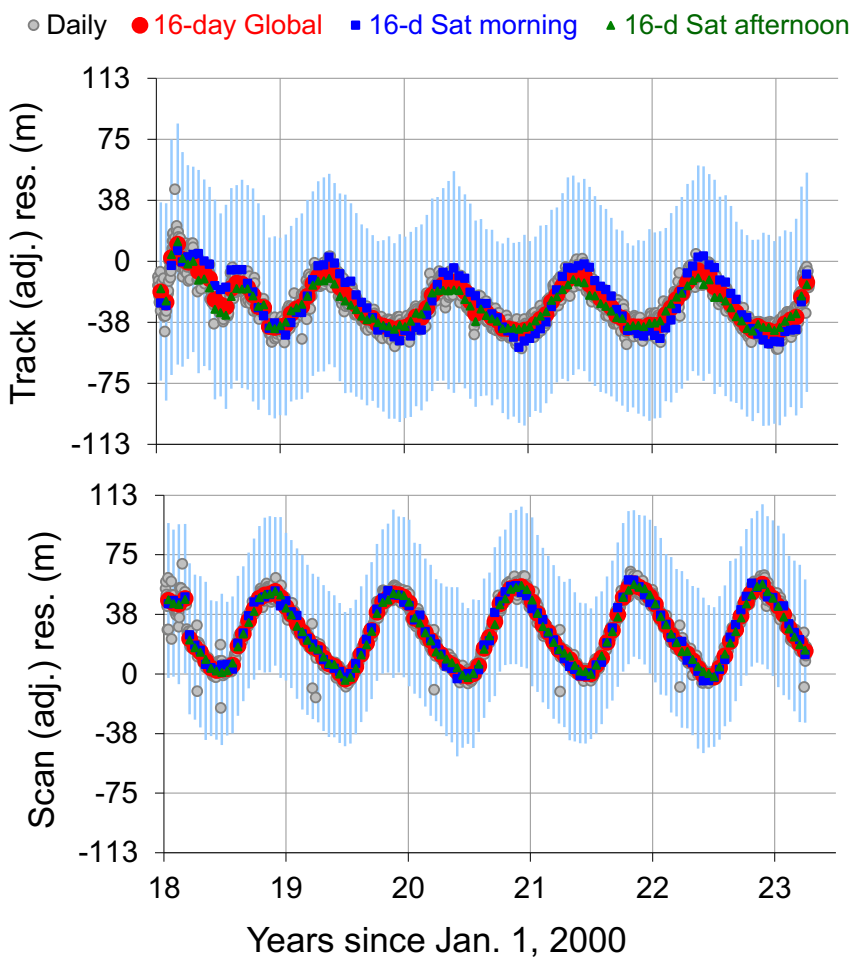


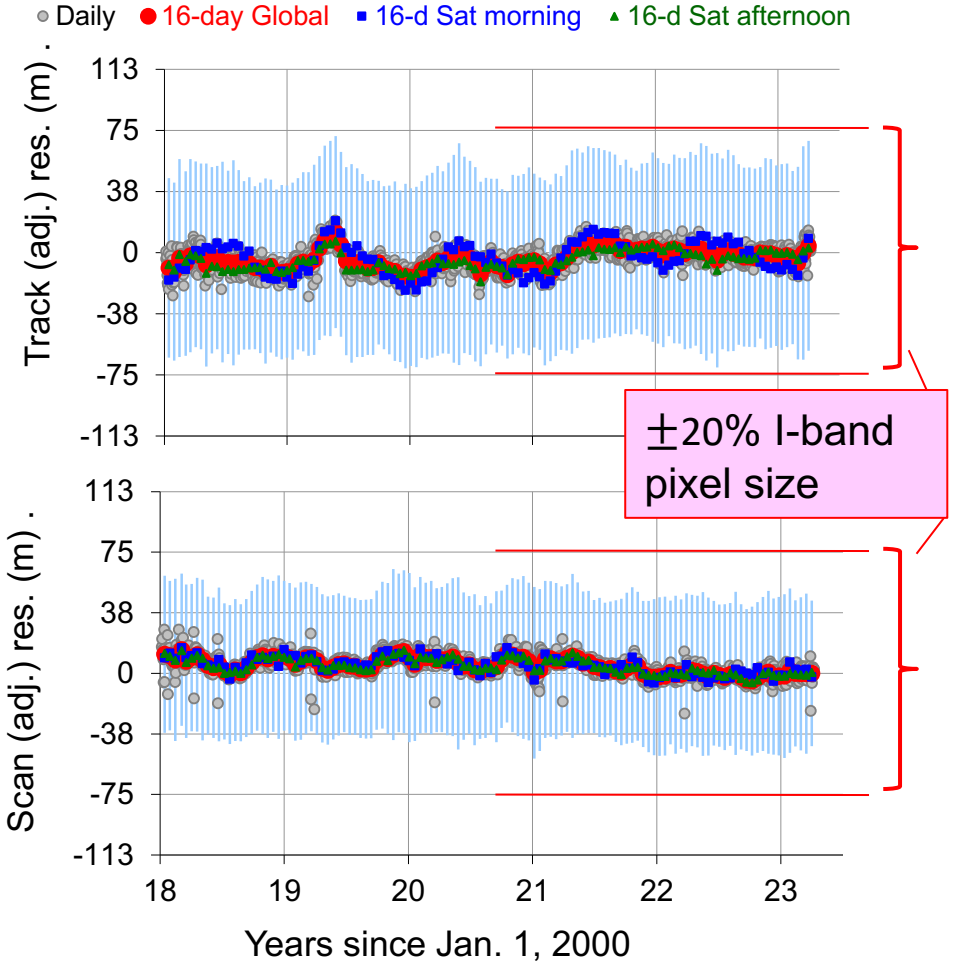

- VIGMU (VIIRS instrument geometric model update) is implemented in C2
- Tilt and curvature will be corrected in the future

# J1/N20 C2.1 geolocation errors

## Uncorrected



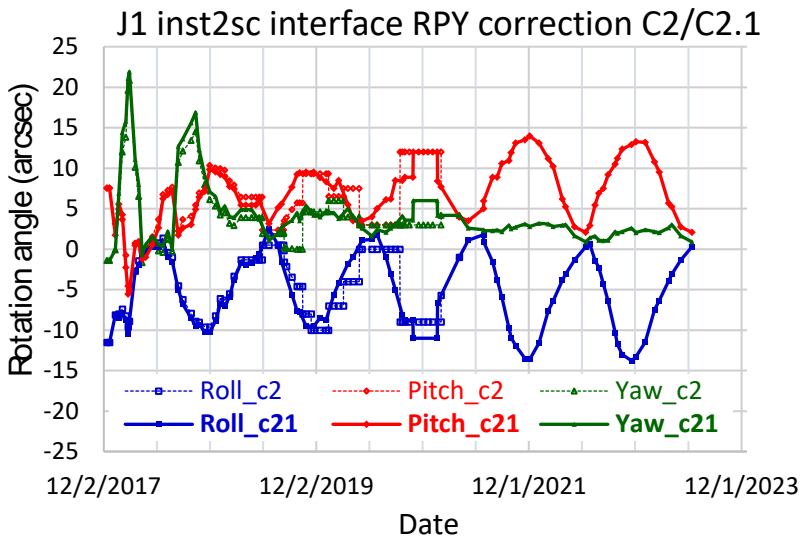

## Corrected for temporal variation



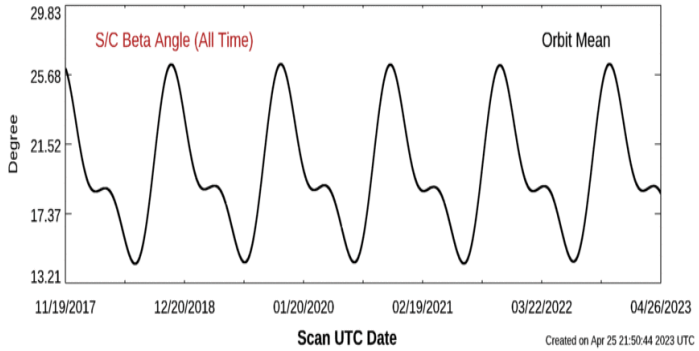

C2.1 RMSE Track: 57 m Scan: 47 m, nadir equivalent

# J1/N20 C2 geolocation errors

## Pointing correction

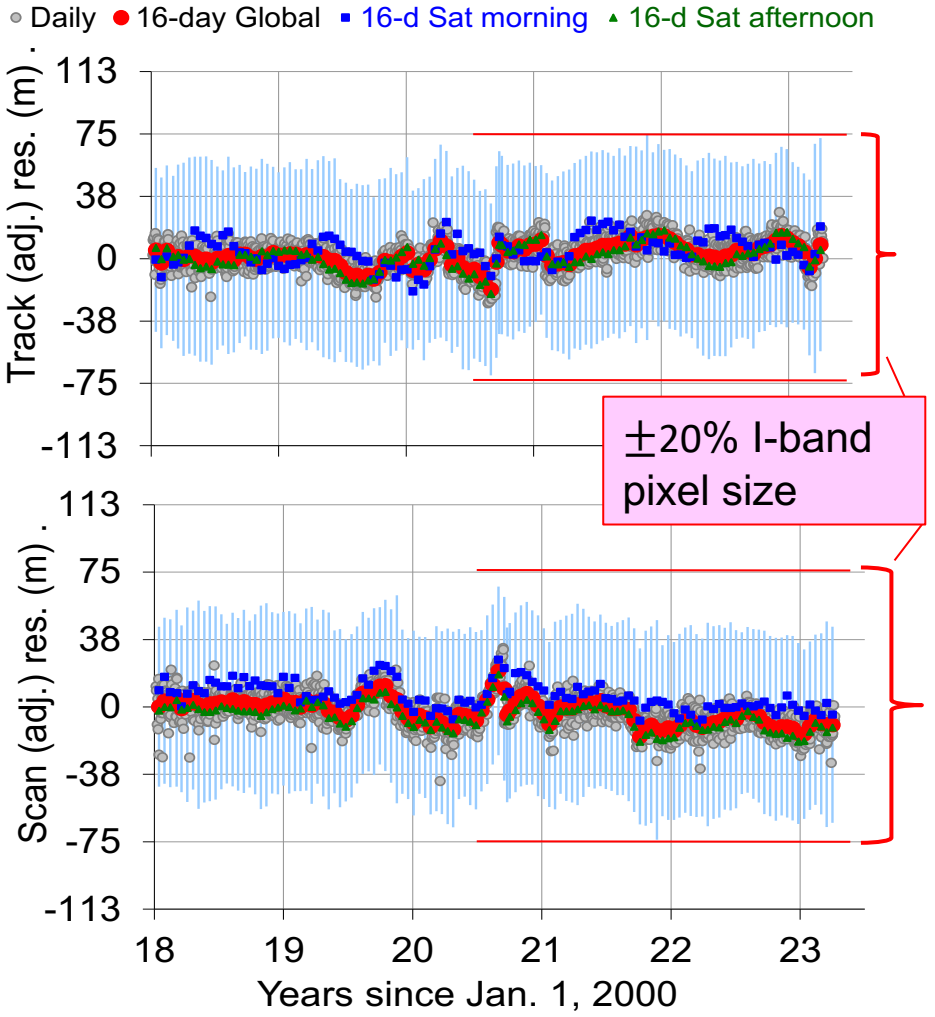



Pointing variation is likely related to beta angle




Courtesy: https://www.star.nesdis.noaa.gov/icvs/status_N20_sc.php

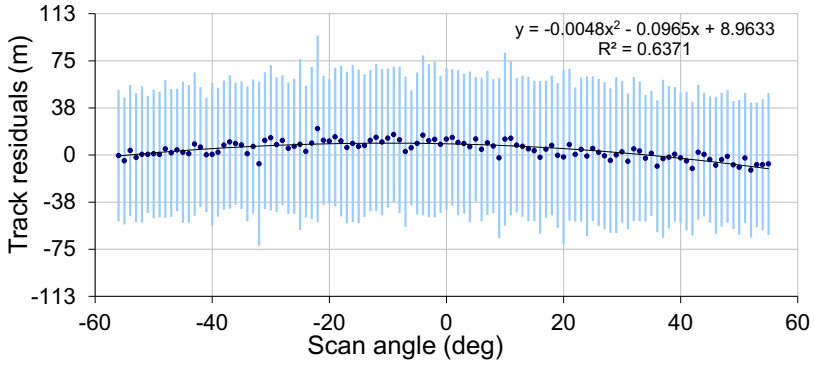
Old Chip Library

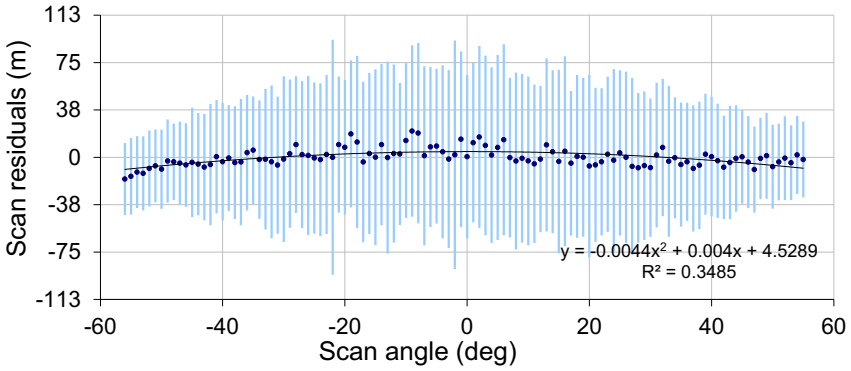



C2 RMSE Track: 55 m Scan: 50 m, nadir equivalent

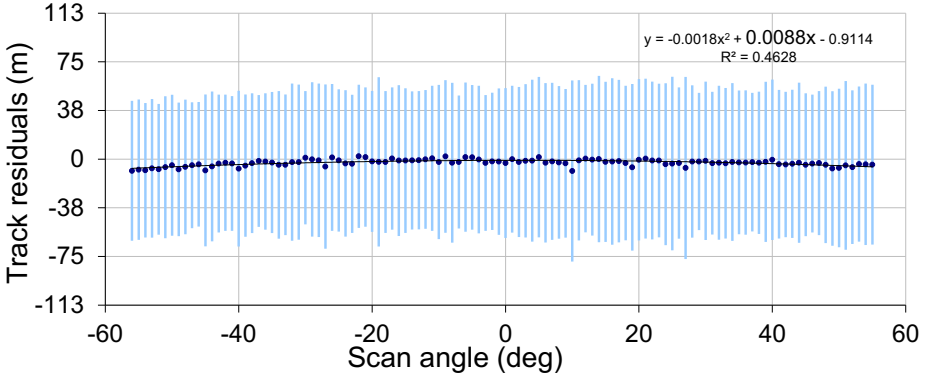
# J1/N20 scan profiles

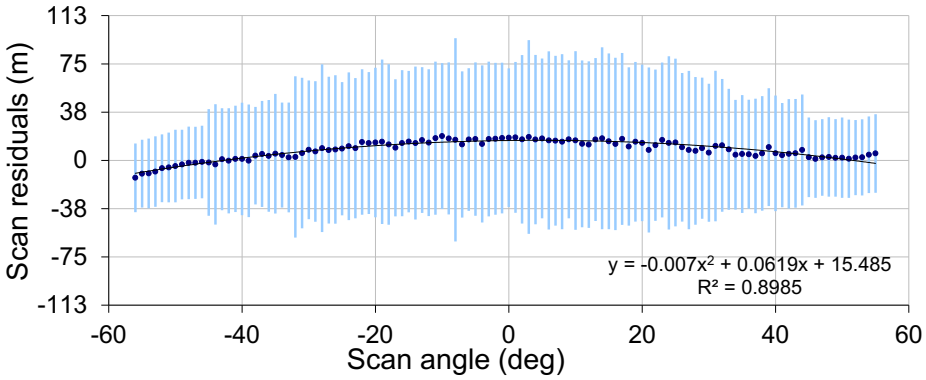
## C2 results (old chip lib)




## C2.1 results (new chip lib)

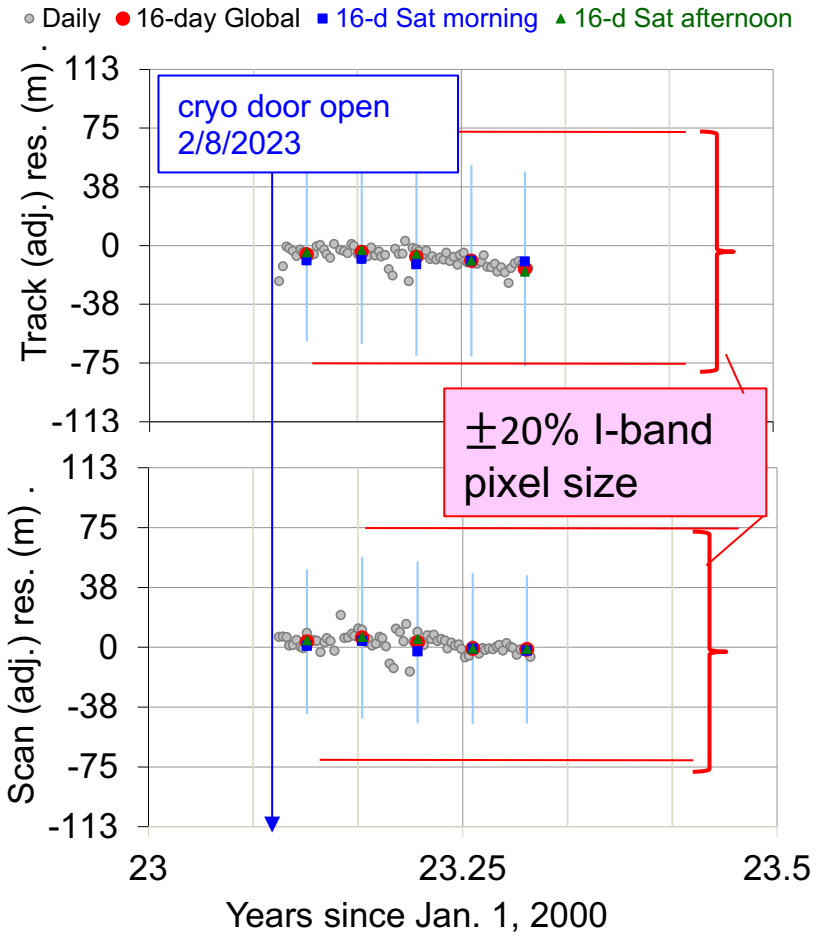


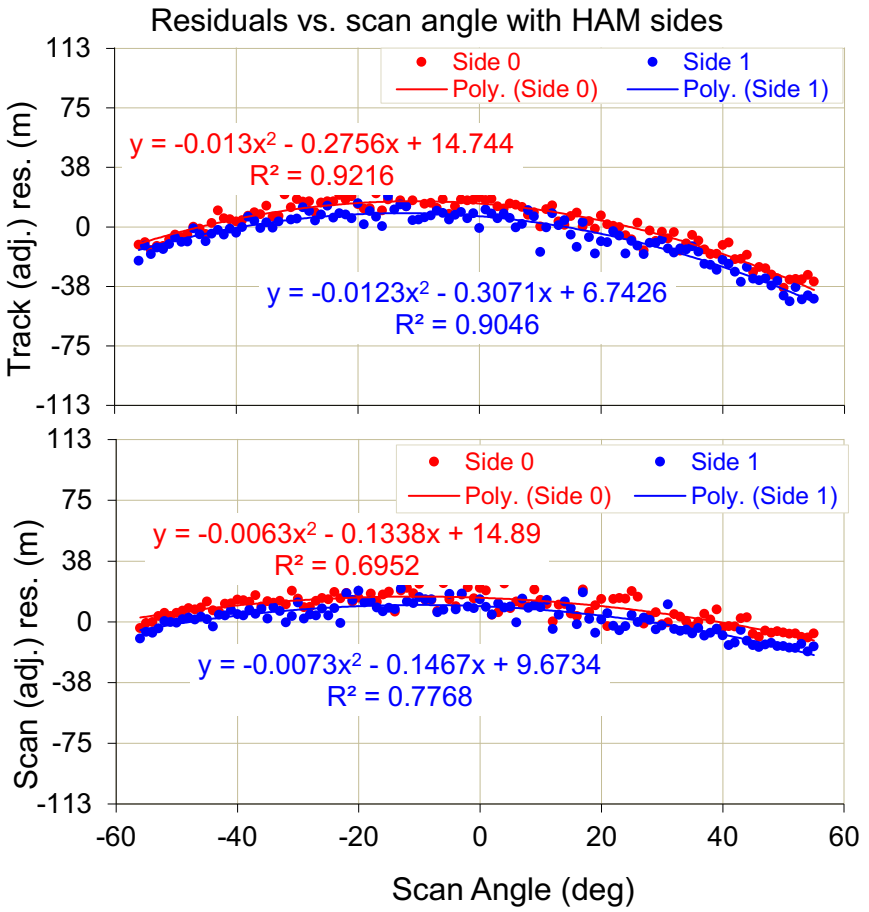

VIGMU (VIIRS instrument geometric model update) implemented in J1 C2+

# J2/N21* “C2” geolocation errors

## After first on-orbit correction




## Scan angle profiles




* J2 launched: 11/10/2022; Nadir door opened 12/5/2022; Geolocation LUTs updated 12/22/2022.
* Ka antenna transmitter failed 12/16/2022; Redundant Ka antenna activated 2/2/2023.
* J2 “C2” is currently in a test archive.

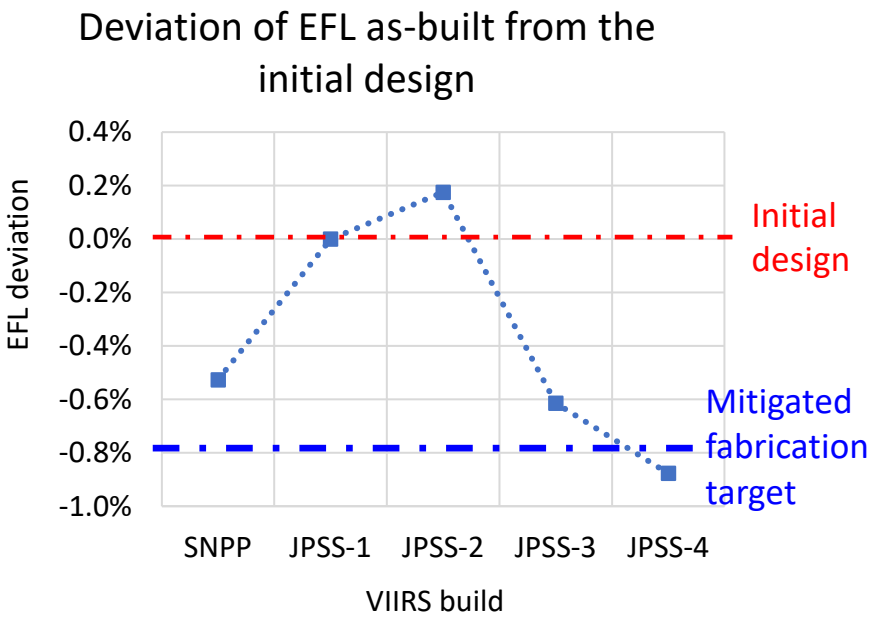
“C2” RMSE Track: 61 m Scan: 48 m, nadir equivalent

# Expectations for J3, J4 VIIRS

- J3 is in I&T with SC while J4 completed ambient tests
- J3, J4 Geolocation – should be good with on-orbit calibration
- J3, J4 Effective Focal Length (EFL) & scan period are shortened to mitigate scan-to-scan underlaps →Swath width increases

**As-built VIIRS EFLs and scan rates and EV coverages**

| | EFL (mm) | Scan rate (rad/s) | Scan period T (s) | EV scan angle (deg) | EV ground distance (km) |
|---|---|---|---|---|---|
| SNPP | 1135 | 3.531 | 1.7793 | ± 56.28 | ± 1530 |
| JPSS-1 | 1141 | 3.517 | 1.7867 | ± 56.04 | ± 1510 |
| JPSS-2 | 1143 | 3.510 | 1.7899 | ± 55.94 | ± 1500 |
| JPSS-3 | 1134 | 3.535 | 1.777 | ± 56.34 | ± 1535 |
| JPSS-4 | 1131 | 3.546 | 1.772 | ± 56.5 | ± 1550 |



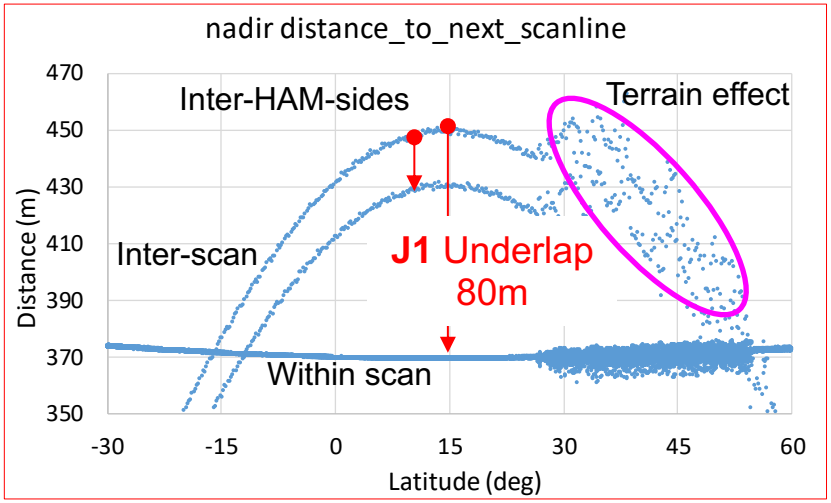

$$Overlap = n\frac{p}{F}h - [V_{ECI} - V_{earth0}\cos i]T, \quad \text{if} < 0 \rightarrow \text{underlap}$$

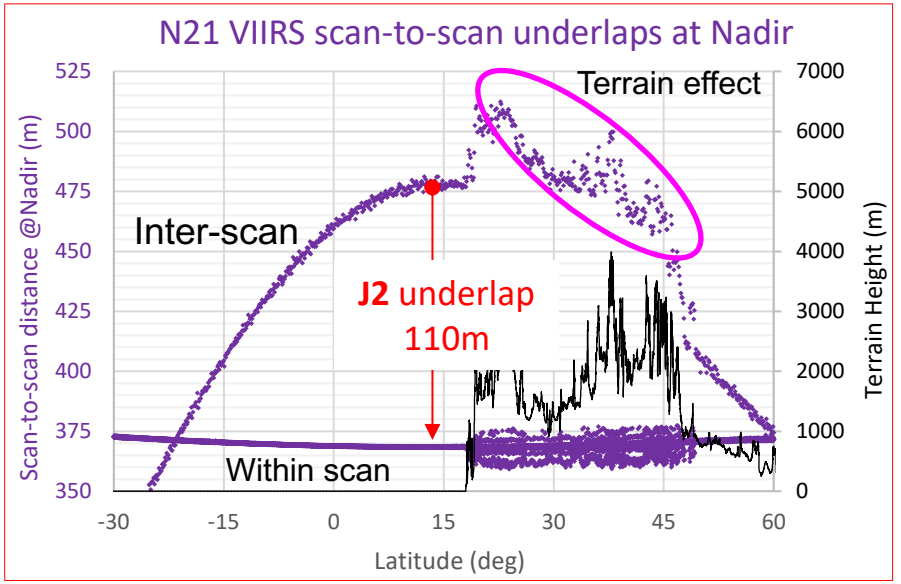
where **F = effective focal length**, p = detector "pitch" interval in the track direction, n = # detectors, h = range from satellite to earth terrain surface altitude, **T = scan period**, *i*=inclination angle (in ECI) > 90 deg, $V_{ECI}$ = spacecraft ground speed in the inertial frame, Vearth0 = speed of earth rotation at equator, Overlap < 0 indicates underlap.

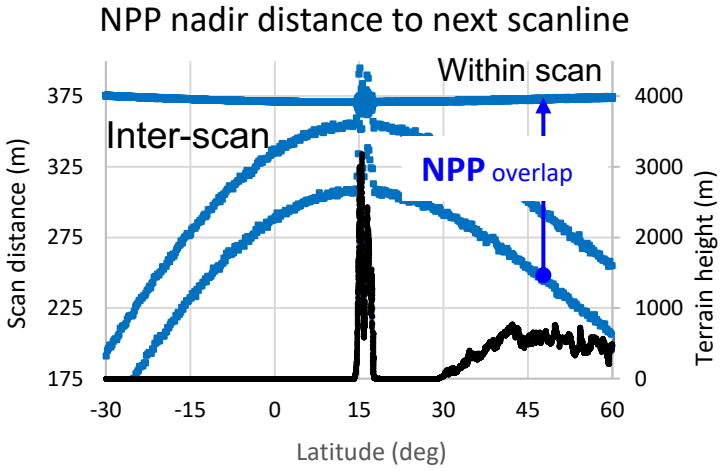
# Scan-to-scan underlaps

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

where **F = effective focal length** = Mag x aft optic focal length, p = detector "pitch" interval in the track direction, n = # detectors, h = range from satellite to earth terrain surface altitude, **T = scan period**, *i*=inclination angle (in ECI) > 90 deg, $V_{ECI}$ = spacecraft ground speed in the inertial frame, Vearth0 = speed of earth rotation at equator, Overlap < 0 indicates underlap.



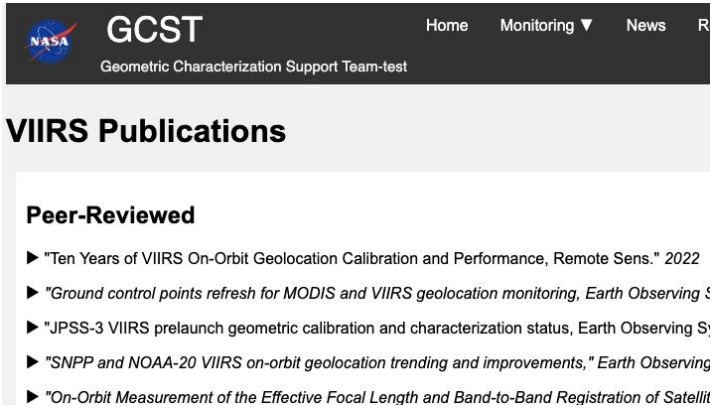

- Underlaps occur near 15ºN, close off going north and south and off-nadir scan angles.
- High terrain widens/creates the underlaps.
- J2 has most of this issue
- SNPP has almost none of the issue because of its shorter focal length (~0.5%).
- J3, J4 mitigate the issue by shortening EFL & scan period

# Future work

1) Routine monitor and LUTs update as needed
2) Update LWM (year by year)
3) Create GCST (Geometric Characterization Support Team) website
4) Create ground control point chip library in multi-spectral bands and implement in geolocation monitoring system (Landsat-8 band B6 chips available now for VIIRS band I3 geolocation error detection)
5) Update DEM from 1 km to 500m or finer resolution
6) Refine LUTs to correct for scan angle dependent biases
7) Replace SNPP and J1 ephemeris in SC diary with GPS data
8) Automate GEO LUT updates

Anything else?

Any change in priority order?



# Conclusions

- SNPP VIIRS geolocation performance is good
  - Mean errors for I- & M-bands are ~ 10 m and uncertainties @1-$\sigma$ are ~ 60 m at nadir, statistically.
  - C2 perform better after implementing: 1) Kalman Filter for attitude; 2) VIGMU (VIIRS instrument geometric model update); 3) temporal pointing correction; 4) new GCP library.
- J1/N20 VIIRS geolocation performance is good
- J2/N21 VIIRS initial on-orbit geolocation is good
- J3 VIIRS is being integrated with SC and J4 VIIRS completed ambient tests
  - Shorter EFL and scan period mitigate scan-to-scan underlaps

# Questions?

Local arithmetic mean $A_k = \frac{1}{N_k}\sum_{i=1}^{N_k} x_{ki}$ Local Stdev $S_k = \sqrt{\frac{1}{N_k - 1}\sum_{i=1}^{N_k}(x_{ki} - A_k)^2}$

Global arithmetic mean $\boldsymbol{A = \frac{1}{N}\sum_{k=1}^{M}(N_k A_k)}$ , $N = \sum_{k=1}^{M} N_k$

Global Stdev $\boldsymbol{S = \sqrt{\frac{1}{N-1}\sum_{k=1}^{M}[N_k(A - A_k)^2 + (N_k - 1)S_k{}^2]}}$

Root-mean-square-error (1-σ) $RMSE = \sqrt{\frac{N-1}{N}S^2 + A^2}$

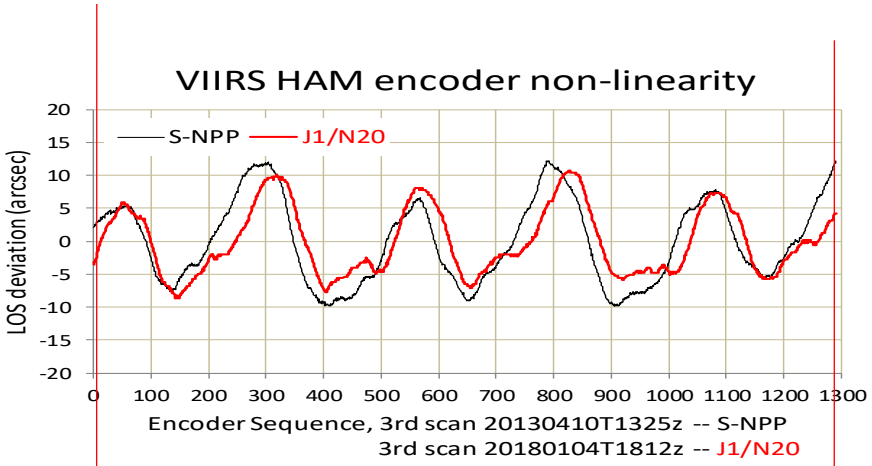
3-σ error bound $E = |A| + 3S$

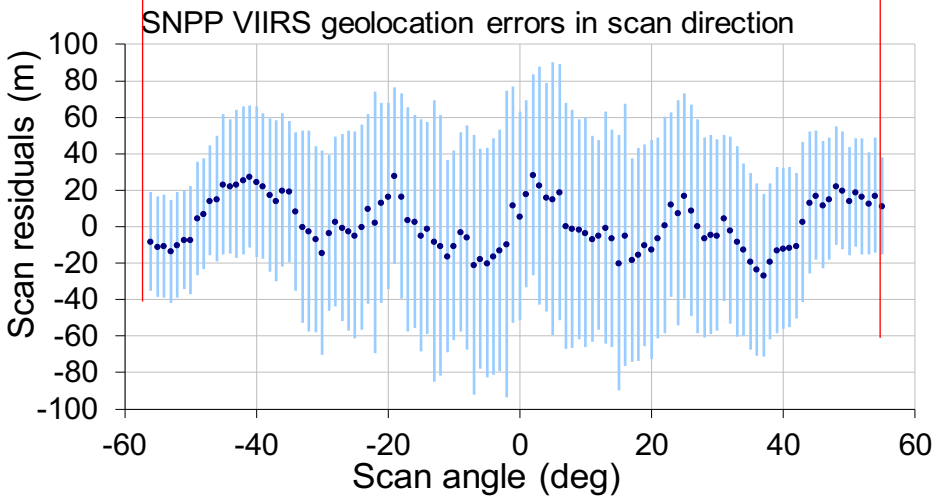
Some short-term anomalous $\boldsymbol{A_k}$ , $\boldsymbol{S_k}$ may be buried in long-term A, S.

Thank you !

# Backup Slides

# VIGMU:
## VIIRS instrument geometric model update




- Puzzle: ground geolocation SW is supposed to correct RTA/HAM motion non-linearity
- Long term trend from SNPP VIIRS still shows the pattern, but in the opposite direction

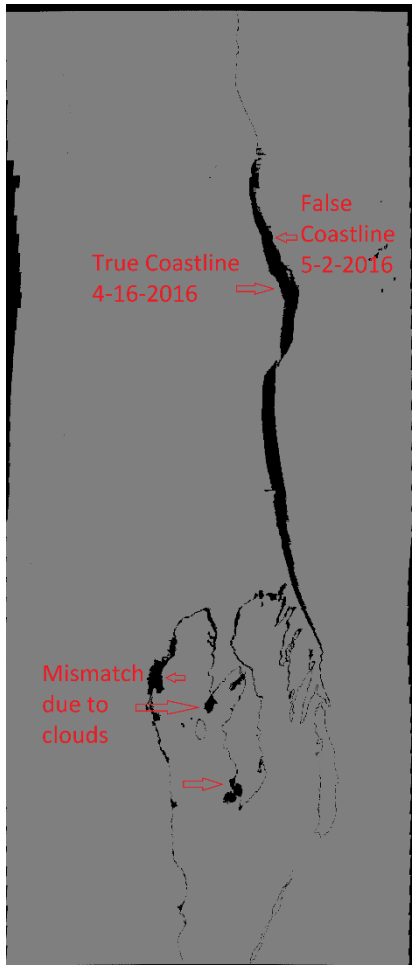
## Answer:

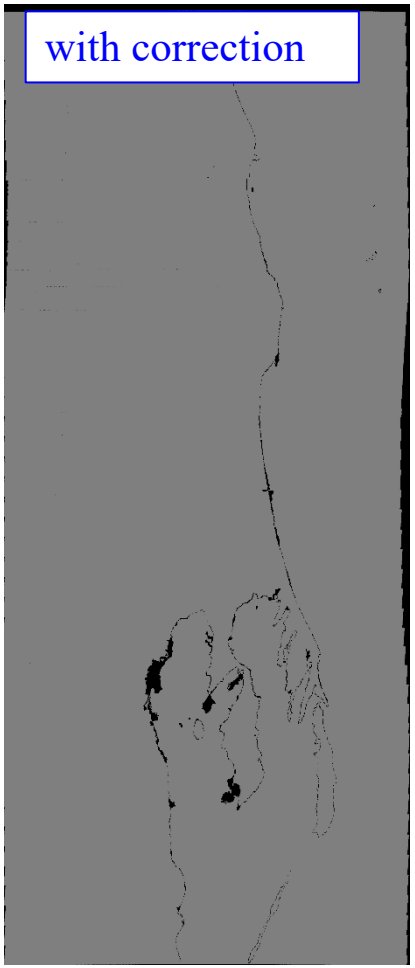
Lsight = Ltel - 1/M ( Ltel – Lhamvector)

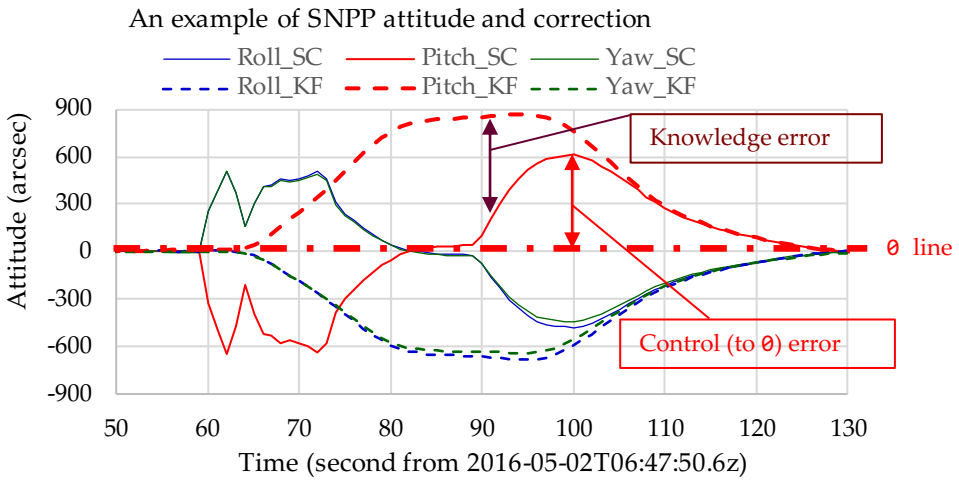
where M = -4 (not +4 as we are currently using), which affects line of sight due to the parts of RTA/HAM motion non-linearity (non-synchronization), which are relatively small

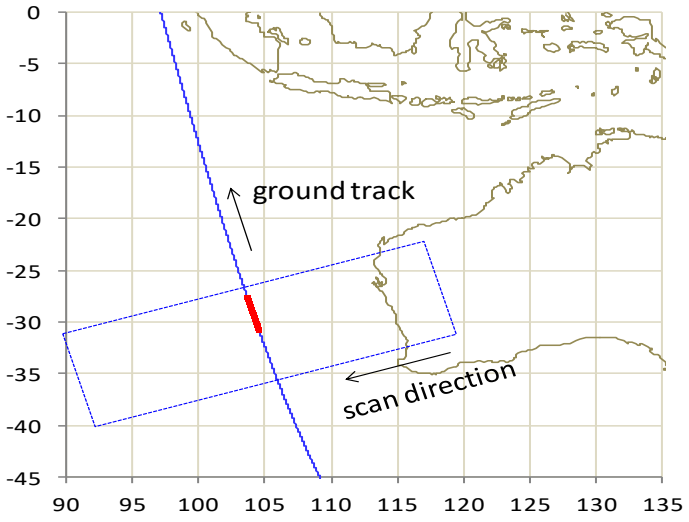
# SNPP Attitude control & knowledge errors

2016-05-02 06:48:50 – 06:50:40z



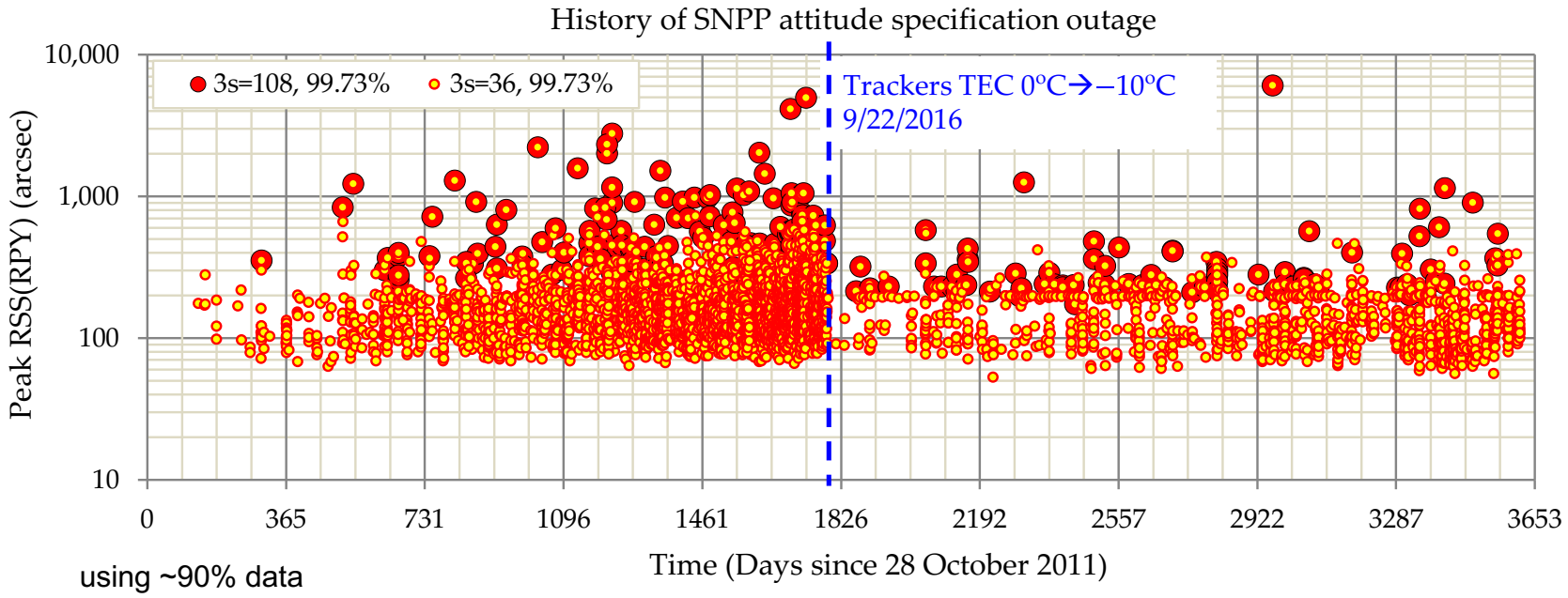




- Western Australian coast (south up)
- Difference in “land”/”Water” masks from data 16 days earlier

Lin et al., 1 May 2023

# SNPP SC attitude performance

## - - Spec outage and trend

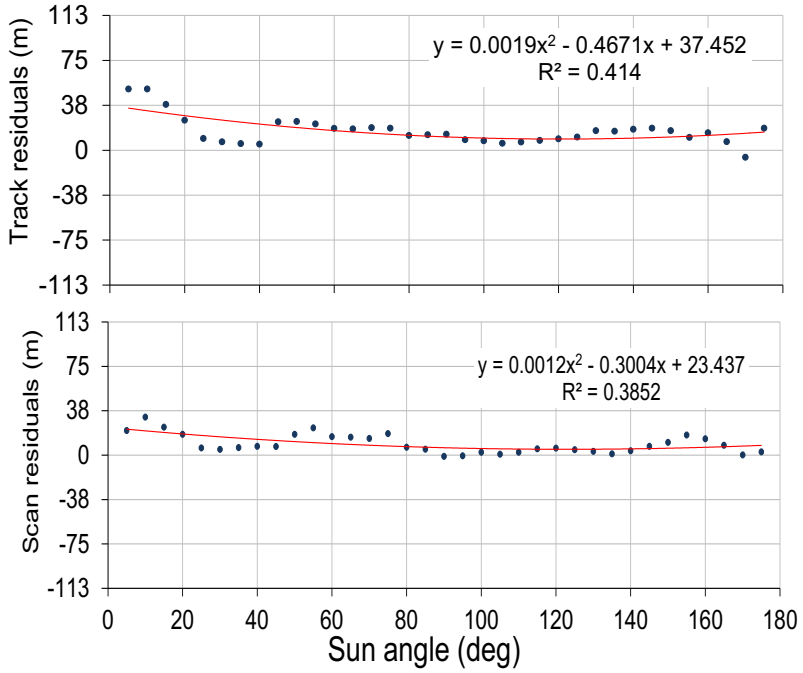



- Large circles for control spec outage; Small dots hint knowledge spec outage
- Star tracker cooling improved SNPP attitude performance
- We are seeking for further improvements[1]
- SW with Kalman filter to refine the attitude for NASA SIPSs is implemented in C2
- J1 is performing better

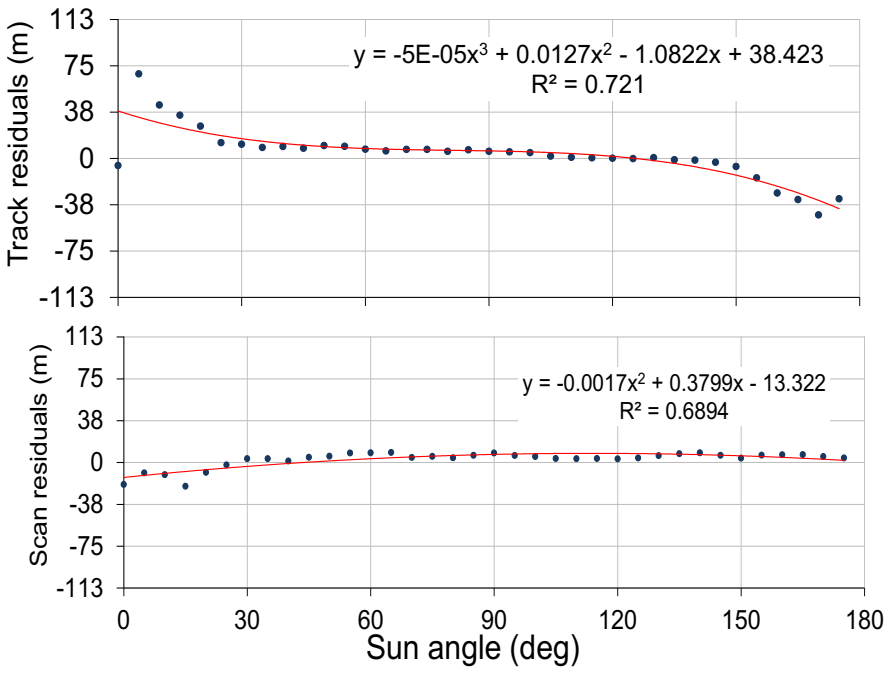
1. My eRooms > S-NPP Flight Operations and Support > FARB > All Discussion Topics--Artifacts and Minutes > DR 6348--SNPP STAR TRACKER DEGRADATIONS OVER MISSION LIFE: ATTITUDE EXCURSIONS AND LUNAR INTRUSIONS > SNPP ADCS and Geolocation Report

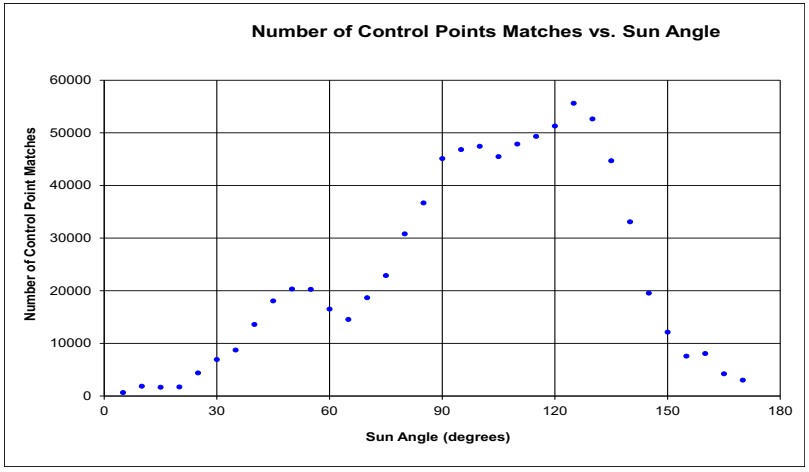
# Sun angle dependence

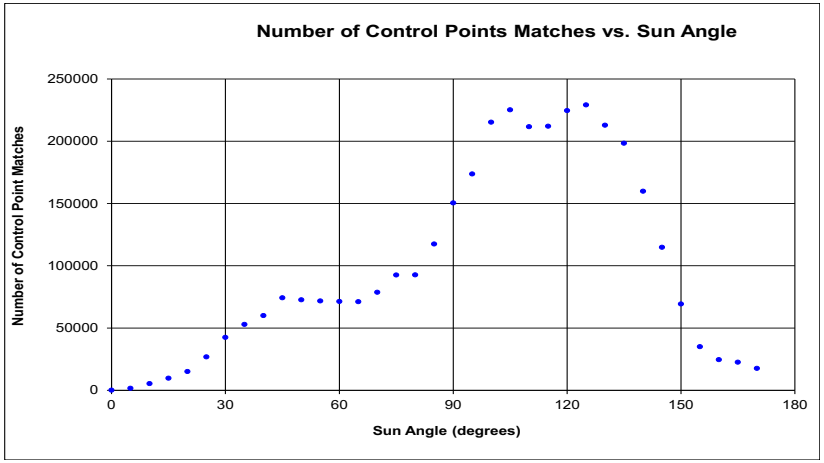
## SNPP C1.1 (old chip lib)




## SNPP C2 (new chip lib)

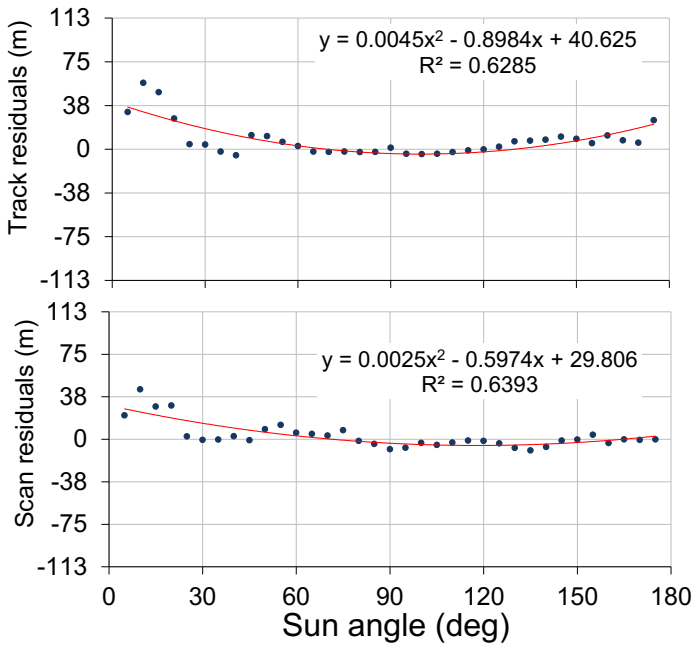


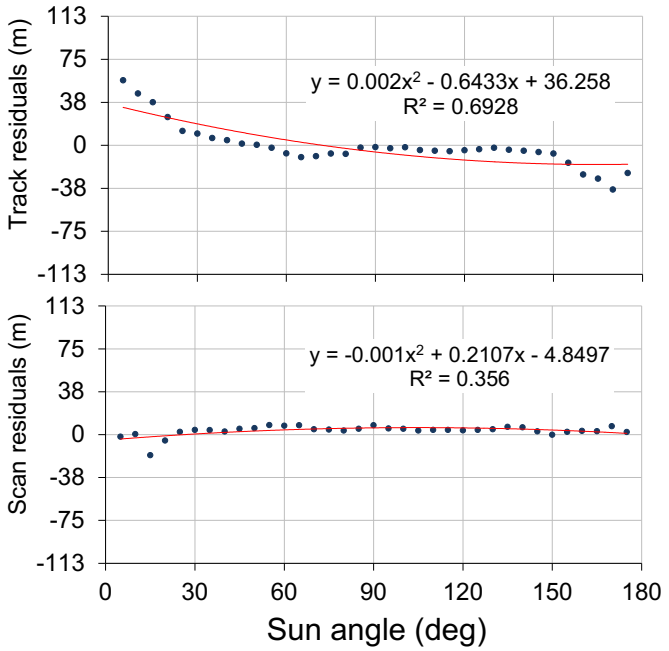



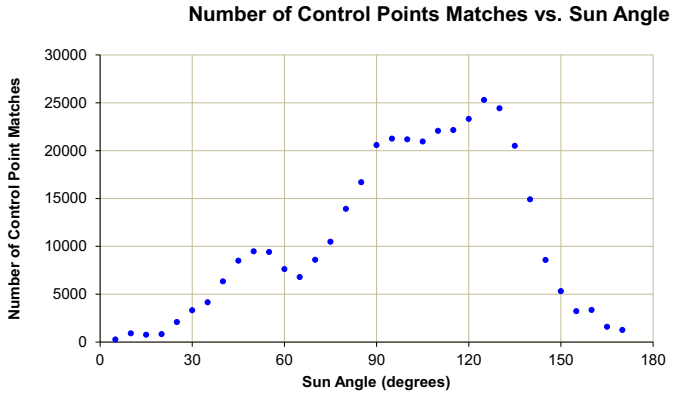
# Sun angle dependence

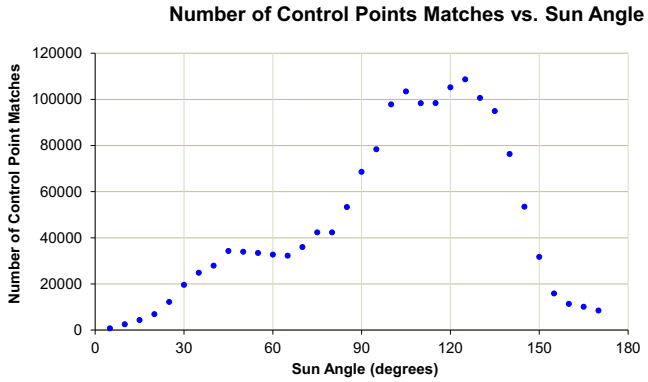
J1/N20 C2 (old chip lib)



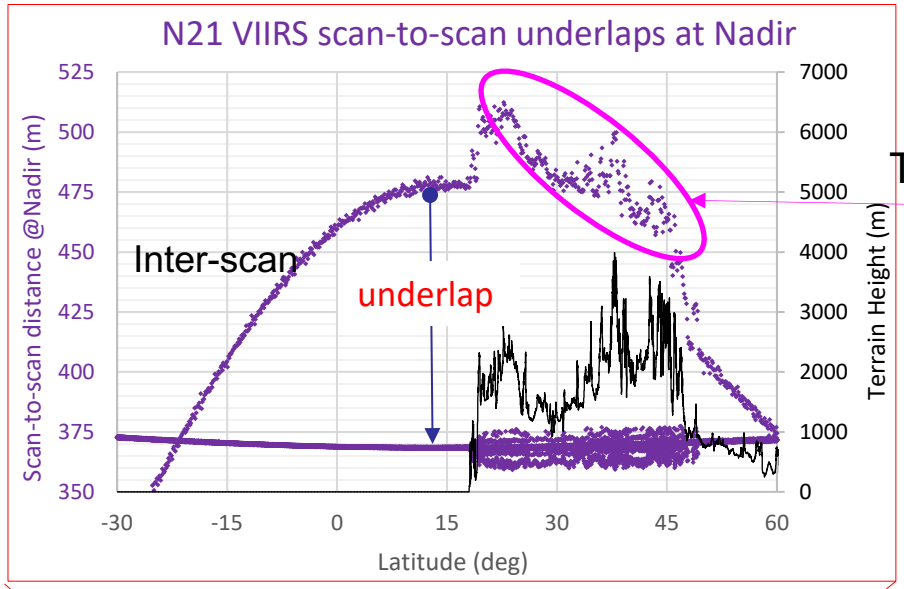

J1/N20 C2.1 (new chip lib)

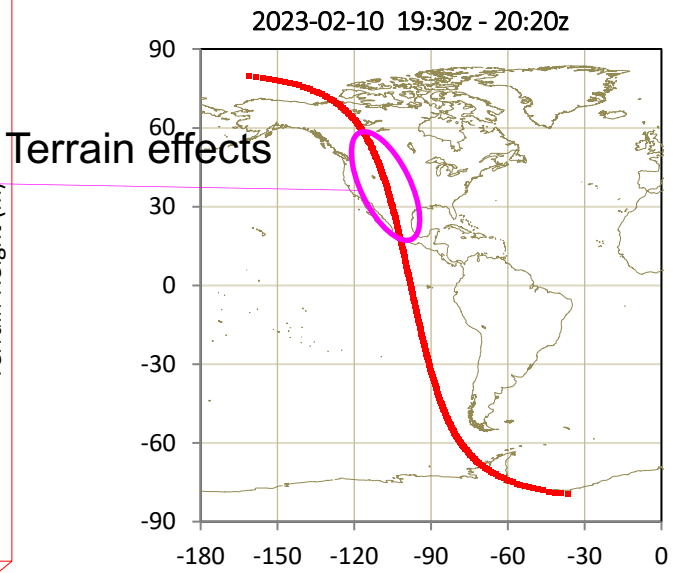


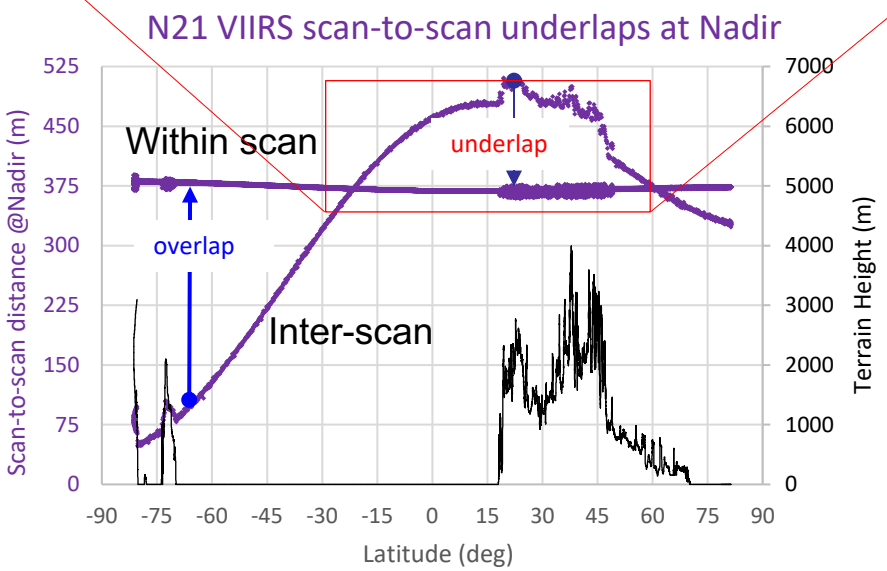



# J2 VIIRS Scan-to-scan underlaps



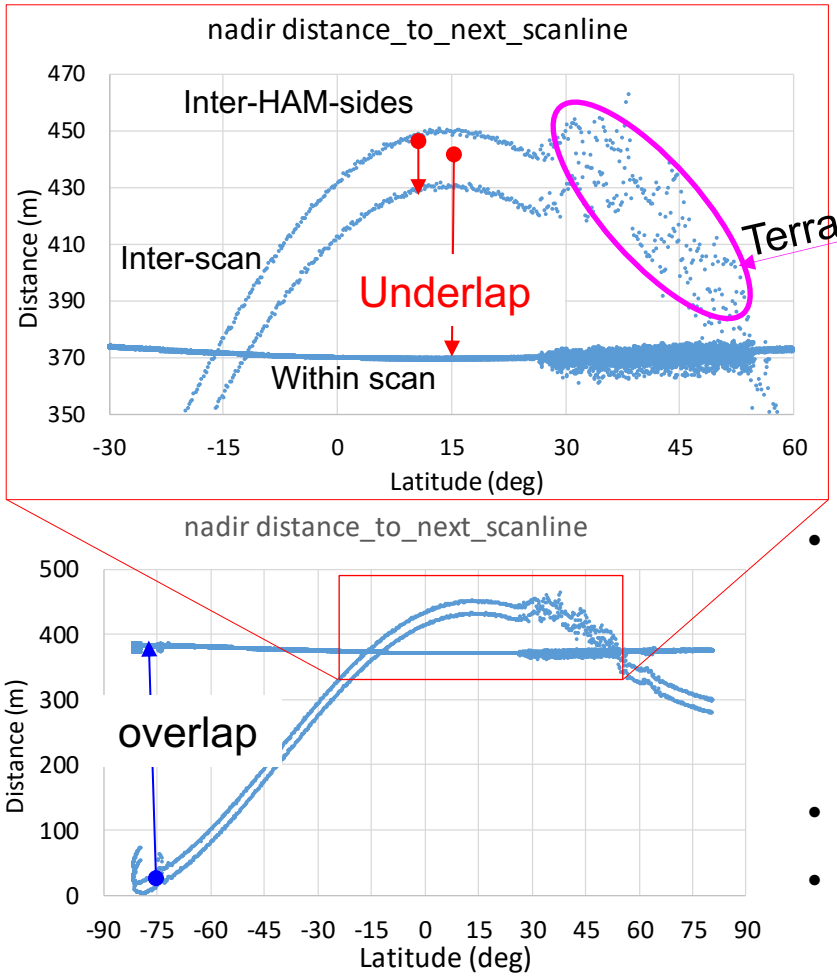

- Widest underlaps occur at nadir near 15°N at ~100 m in this case. They narrow down as N21 goes north or south due to increasing altitude.
- High terrain widens the underlaps.
- N20 VIIRS has smaller underlap (next chart)
- SNPP VIIRS has less of this issue because of its shorter focal length and faster scan speed (~0.5%) than N20 VIIRS

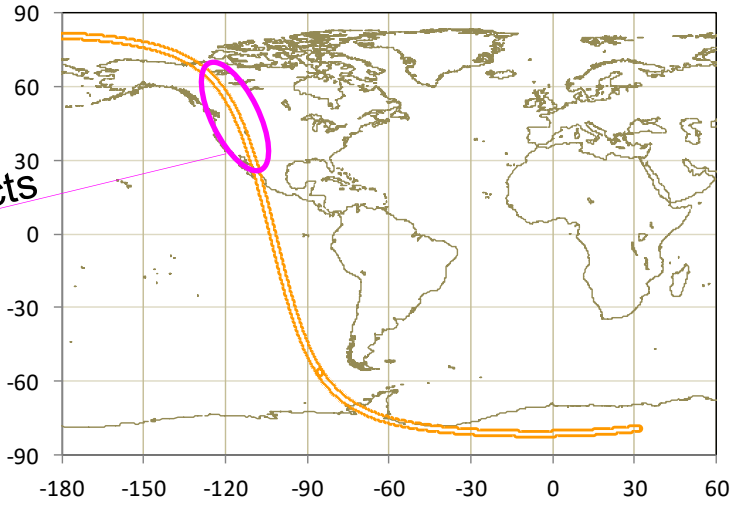
Lin et al., 1 May

# J1 VIIRS 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 = Mag x aft optic focal length, p = detector "pitch" interval in the track direction, n = # detectors, h = altitude, T = scan period, *i*=inclination angle (in ECI) < 90 deg for J1, $V_{ECI}$ = 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 faster scan speed (~0.5%)

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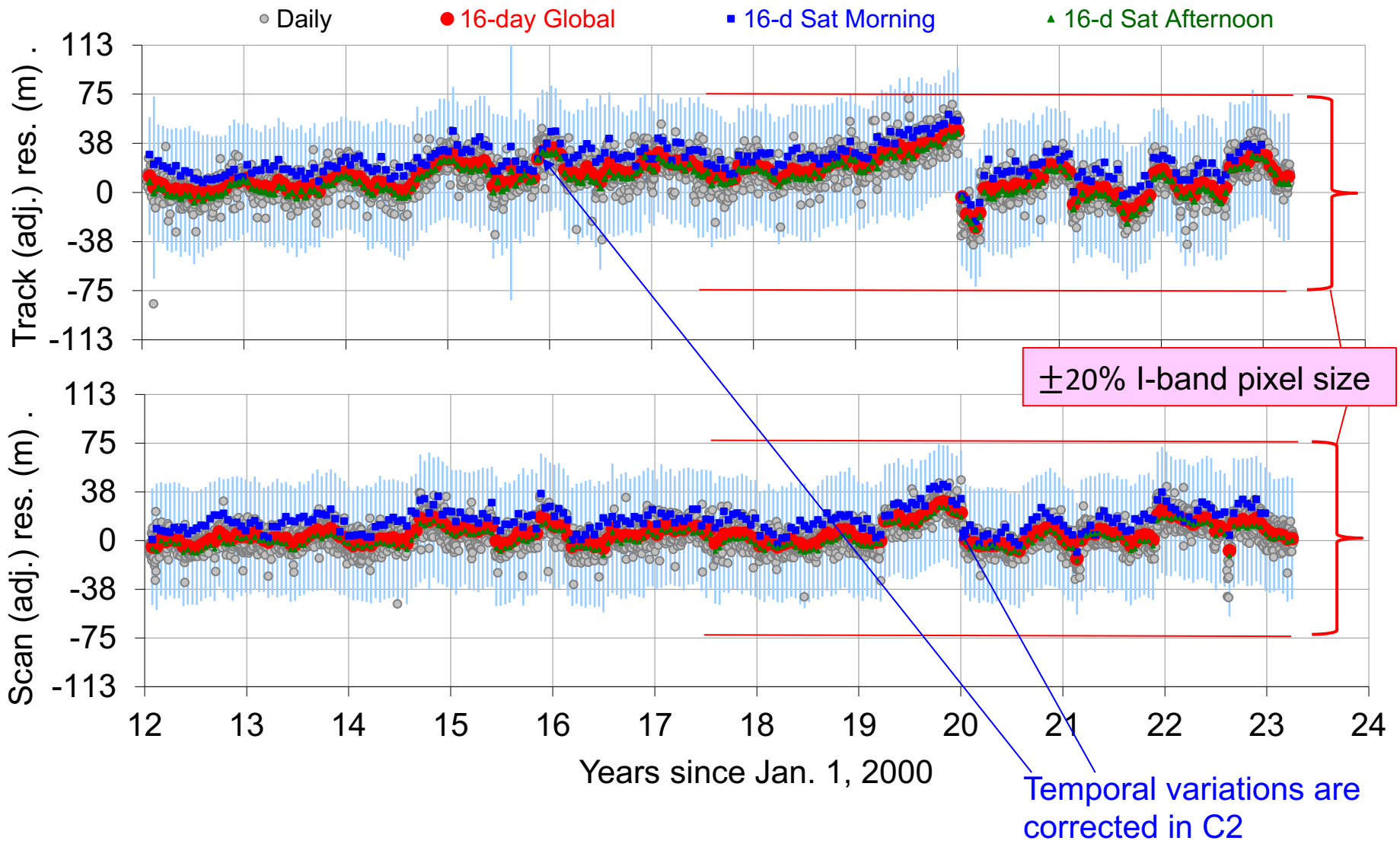
# SNPP C1 NRT as5000 geolocation errors




C1 RMSE Track: 51 m Scan: 46 m, nadir equivalent minCCV=0.90

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