# *VIIRS geospatial calibration for SNPP, J1 and beyond*


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# Acknowledgements


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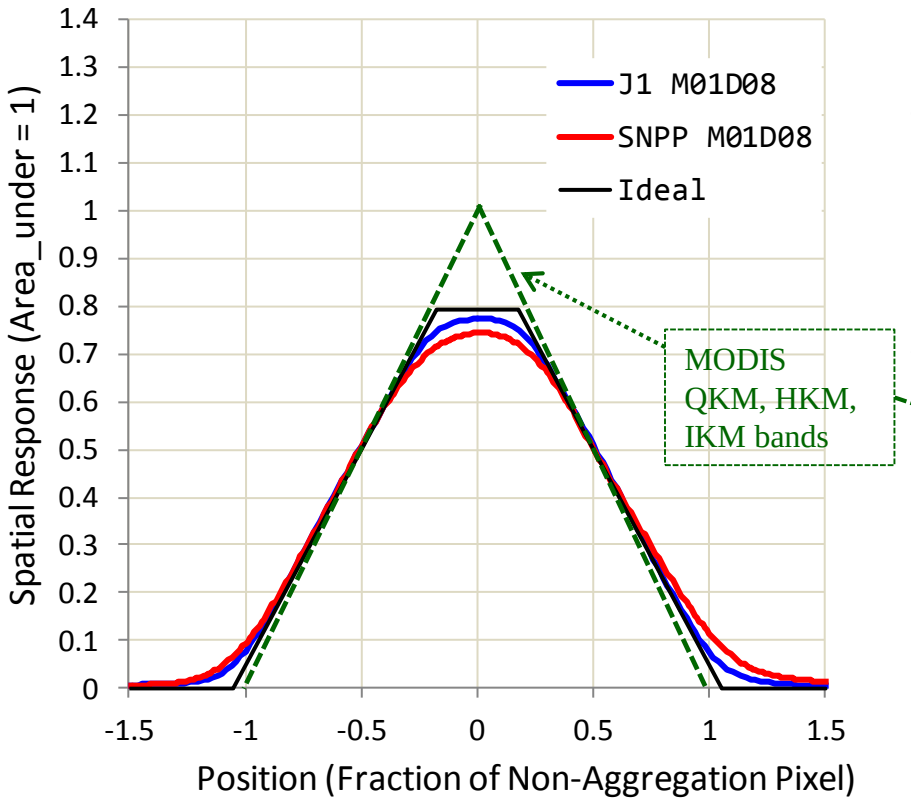
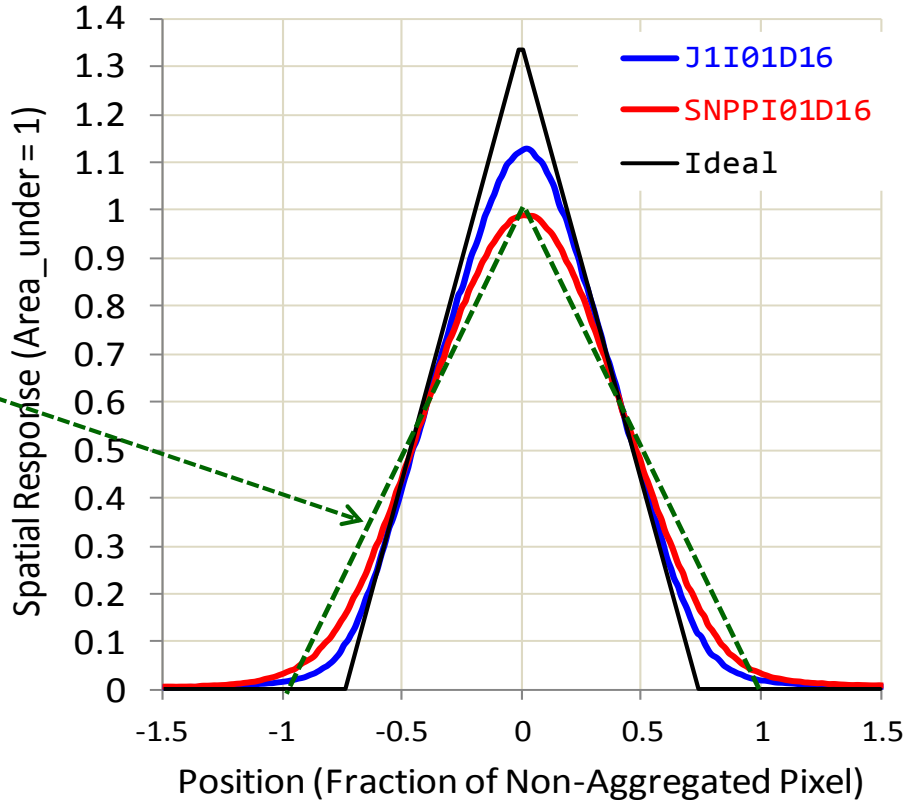
- Thanks the NOAA STAR team, NASA JPSS Project Science Office, NASA VCST Radiometric Calibration Team, UW spectral calibration team, Aerospace team, instrument on-site team & SC I&T on-site team for cooperation and assistance.
- Thanks NASA VIIRS Land SIPS Team for processing control point residuals from both IDPS and LSIPS forward-&re-processed VIIRS geolocation products, and testing Geo LUTs updates.
- Thanks past and current Geo JAMs – Alice Isaacman, Robert Williamson and Rosalie Marley (Rad+Geo now ) -- for helping us resolving DRs in the DPE/DPA/AMP at the GRAVITE
- Thanks NOAA JPSS MOT, NASA FDF, BATC for assistance in understanding the SNPP altitude, ground speed and attitude issues.

# Outline

- Optical calibration -- LSF, DFOV, MTF
- BBR calibration
- Geolocation calibration
- Challenges, concerns, Issues
  - Improvements are in the making
- Concluding Remarks

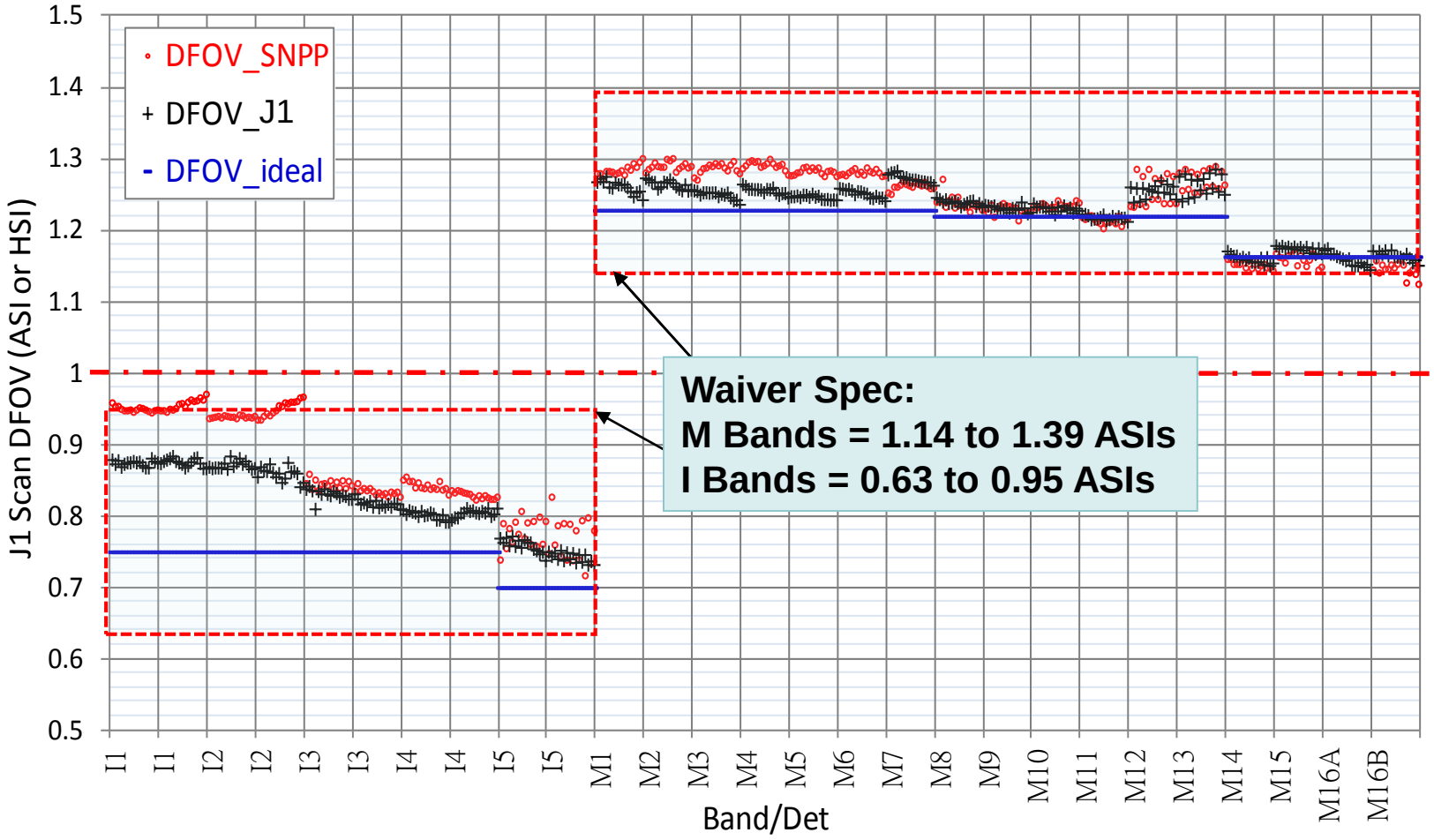
# Optical calibration



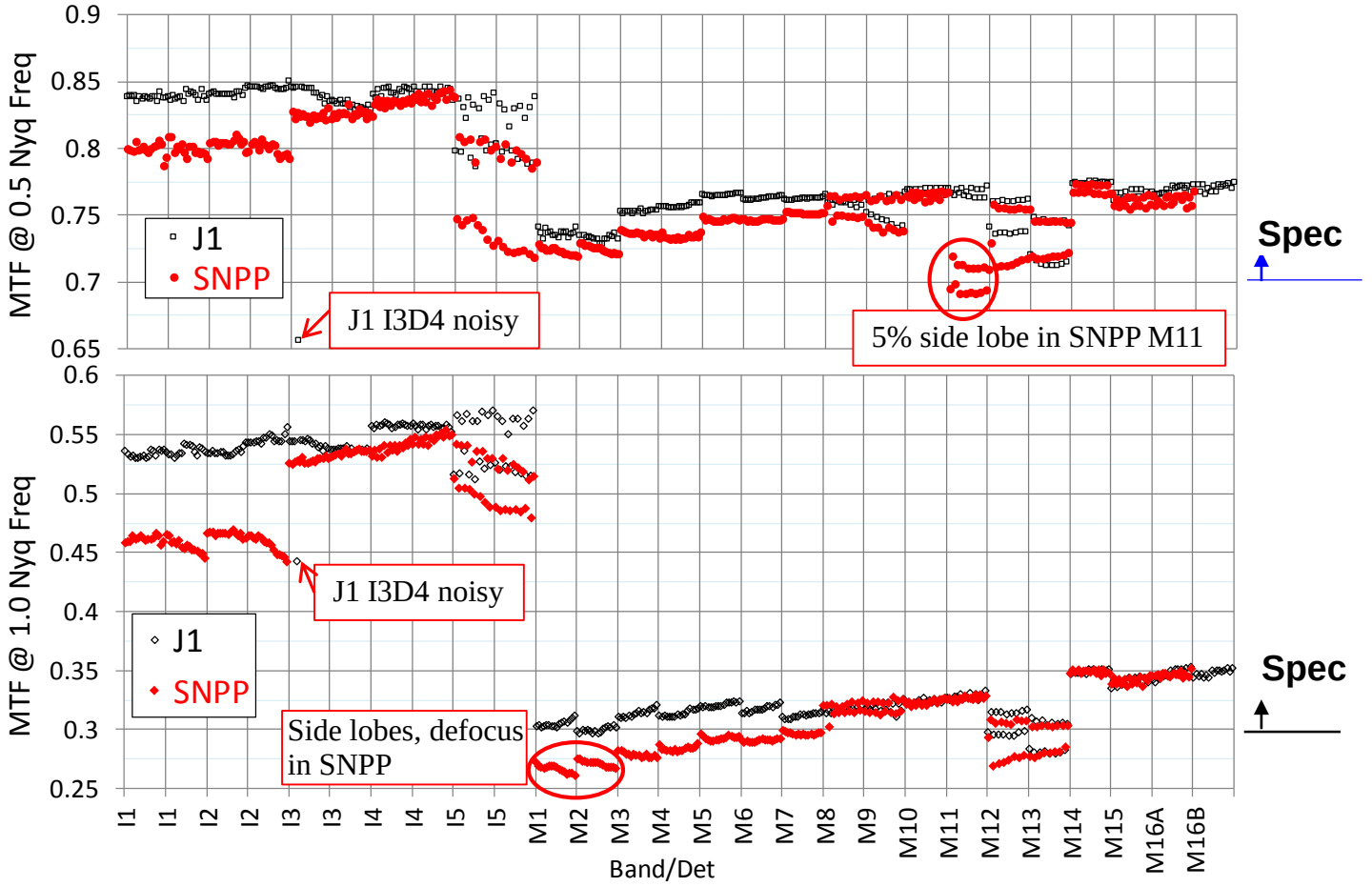

- J1 VIIRS has improved optical system over SNPP
- J2 ~= J1

# Scan LSF → DFOV




- SNPP VIIRS has de-focus in VisNIR bands
- J1 VIIRS has the right focus
- I-bands under-sample the earth at TOA in un-agg zones

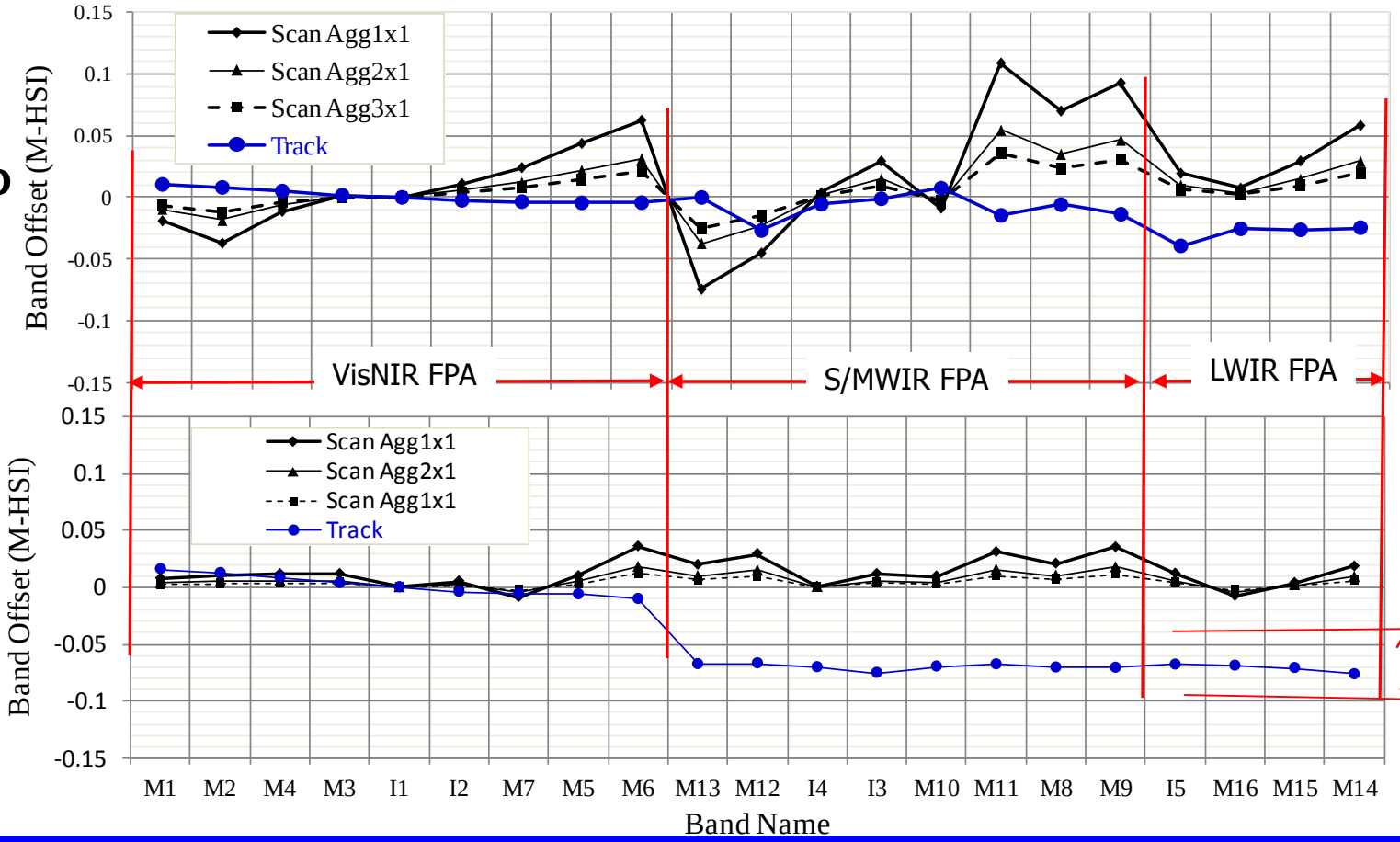
# Scan LSF → MTF




- J1 MTF performs better than SNPP
- I-bands images are sharp, at least at TOA (J1 I3D4 under-performs)
- Track direction LSFs are nearly square, MTF ~= 0.63 at 1.00NF (Nyquist Frequency)

# BBR: M/I band offsets wrt I1

SNPP




J1




- J1 and SNPP are similar in the overall BBR band pair performances
- J1 BBR performs better than SNPP in the scan direction
- In the track direction, J1 Bands on cold FPAs shifted ~ 50 m from bands on VisNIR FPA

# SNPP on-orbit geolocation calibration

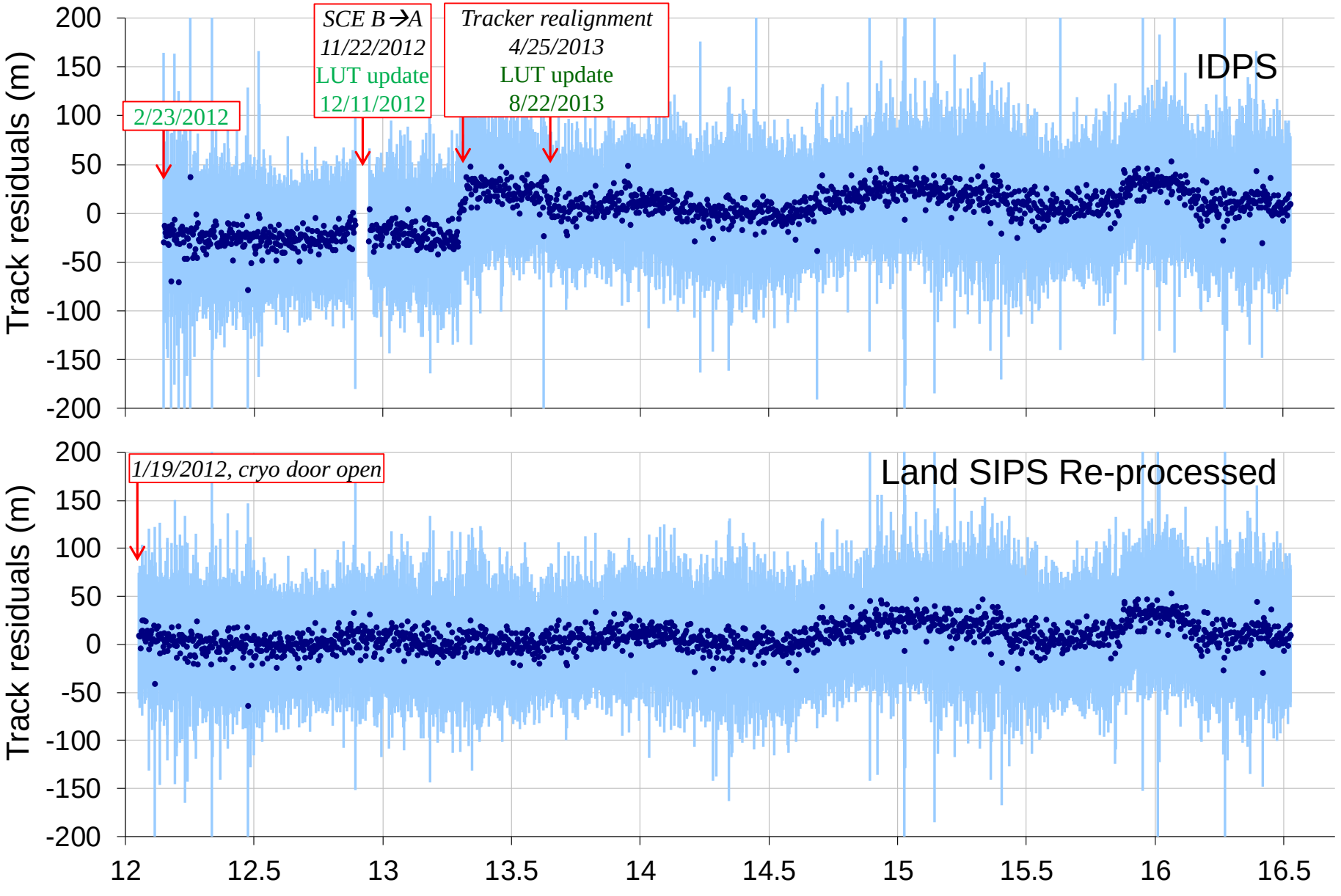
## w/ LUTs Updates

| Update | Date | Description | Comments |
|---|---|---|---|
| a | *1/19/2012* | *Cryo-radiator door open* | *All VIIRS band available, LPEATE re-process start date* |
| 1 | 2/23/2012 | Initial mounting coef. update | Removed bias ~ 1.3 km |
| 2 | 3/30/2012 | Initial DNB FPA center update | Removed bias ~ 1 km |
| b | *11/22/2012* | *Scan control electronics (SCE) was switched from B-side to A-Side* | *Caused bias ~ 300 m for 19 days* |
| 3 | 12/11/2012 | Correction after SCE was switched from B-Side to A-side | Removed bias ~ 300 m |
| 4 | 2/15/2013 | Second, fine DNB FPA center update | Removed DNB bias ~ 300 m |
| 5 | 4/18/2013 | Second, scan angle dependent, fine Geo LUT update | Fine tuned and removed scan dependent biases |
| c | *4/25/2013* | *Star tracker maintenance/re-alignment* | *Caused bias ~ 25 m* |
| 6 | 8/22/2013 | Correction to the star tracker re-alignment | Removed bias ~ 25 m |

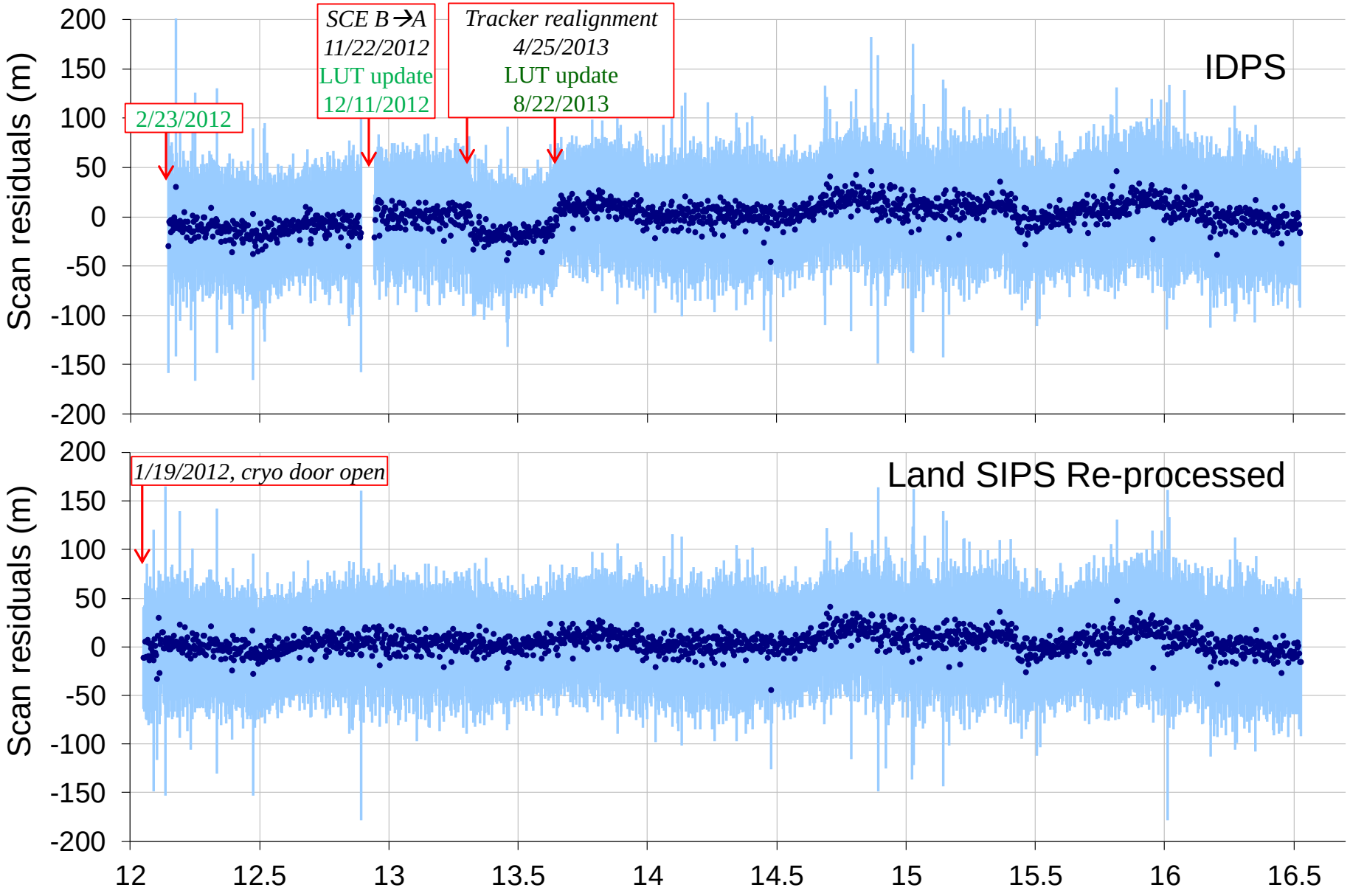
Key: All bands impacted DNB only *External event*

➢ SNPP VIIRS on-orbit geolocation calibration went well

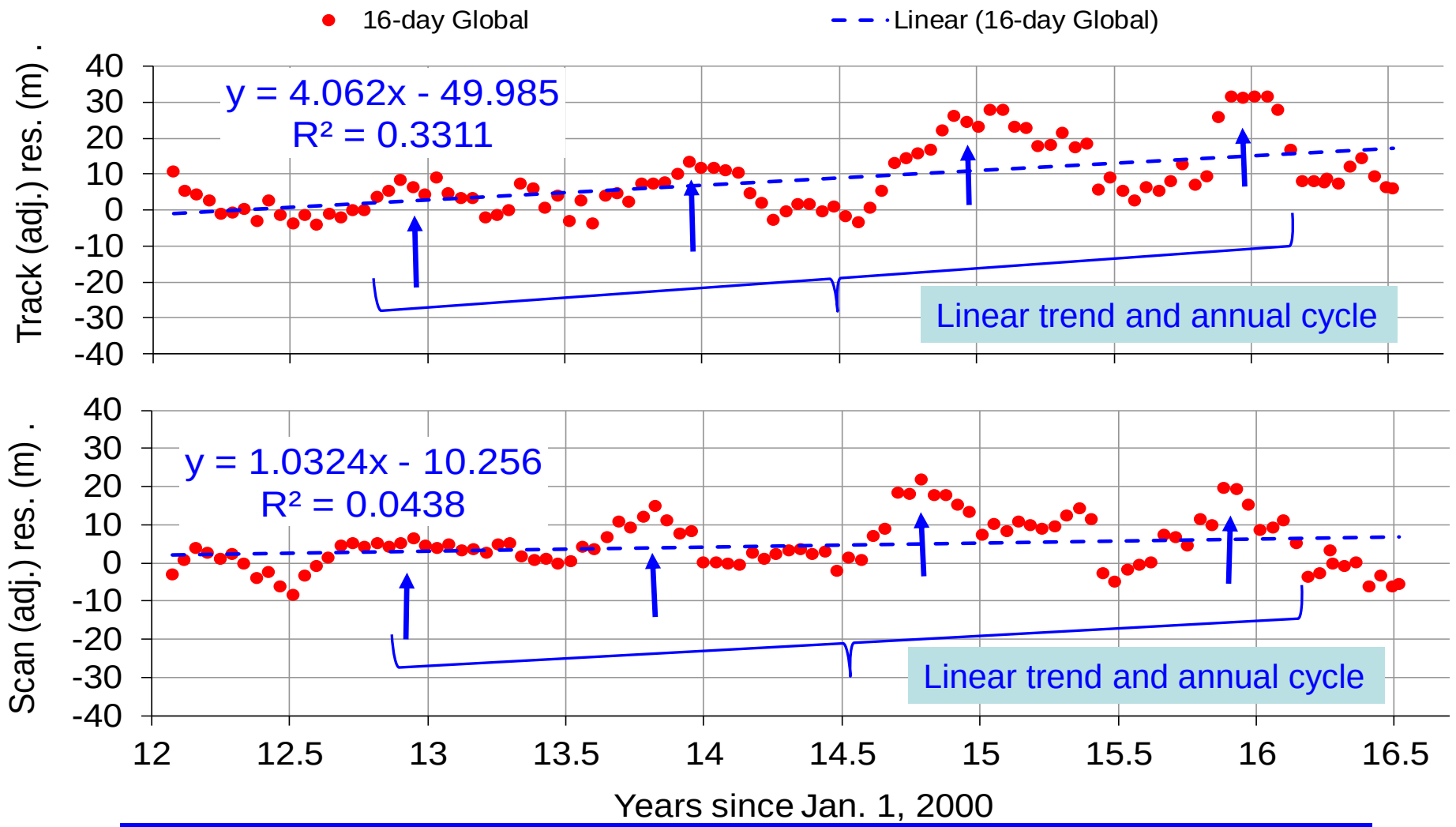
# SNPP VIIRS track residual trends



# SNPP VIIRS scan residual trends



# SNPP geo long-term trending



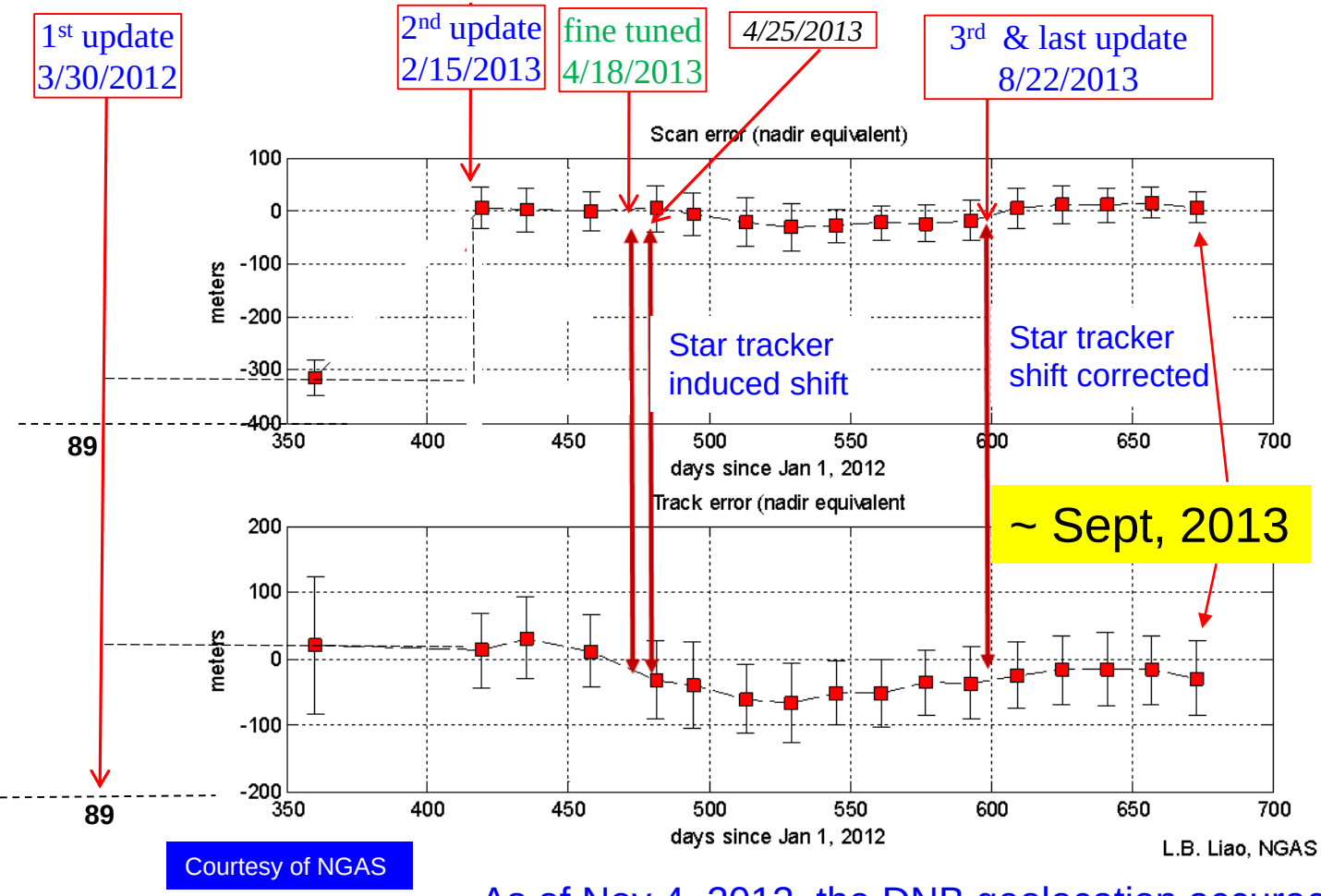

- Small trends and seasonal variations in VIIRS geolocation are correctible

Land SIPS Re-processed, can be corrected

Lin et al., 9 August 2016

# SNPP DNB geolocation error trending

## based on coastal area GCP matching




Courtesy of NGAS

- DNB TC geolocation (appending fields (lat, lon, height, QF)_TC to the ellipsoid DNB geolocation product) was TTOed on **5/22/2014**, 14:30 GMT (data observation time) in IDPS.
- DNB errors track with I1 band errors

As of Nov 4, 2013, the DNB geolocation accuracy is
Scan: 8 ± 33 μrad  Track: -35 ± 68 μrad
**Scan: 7 ± 28 m  Track: -29 ± 57 m over coastal areas**
(nadir equivalent with mean altitude of 838.8 km)

# Overall SNPP geolocation performance

| Residuals | IDPS VIIRS | Land SIPS VIIRS | Aqua MODIS C6 | Terra MODIS C6 |
|---|---|---|---|---|
| Track mean | **4 m** | **8 m** | 2 m | 2 m |
| Scan mean | **1 m** | **4 m** | 0 m | -1 m |
| Track RMSE | **77 m** | **72 m** | 46 m | 43 m |
| Scan RMSE | **62 m** | **61 m** | 53 m | 44 m |
| Data-days | **1580 (4.3 yrs)** | **1635 (4.5 yrs)** | 5040 (13.8 yrs) | 5849 (16.0 yrs) |
| Missing days | **21** | **1** | 10 | 62 |
| Daily matched GCPs w/ I1/B1 | **131** | **131** | 189 | 218 |

- **Nadir equivalent** accuracy (RMSE – Root Mean Square Error) . (MODIS for reference)
  - Meet Spec: 133 m (1σ); **within 20% I1 HSI (375 m) = 75 m @ nadir for VIIRS**
  - Band-to-band mis-registration adds bias to RMSE to other bands: $RMSE = \sqrt{\sigma^2 + \mu^2}$
  - Periods: IDPS 2/23/2012 - - 7/11/2016 except 11/22/2012 – 12/11/2012;
    LandSIPS 1/19/2012 – 7/11/2016
- MODIS – VIIRS differences

➢SNPP VIIRS geolocation uncertainty ~ 70 m (1σ)

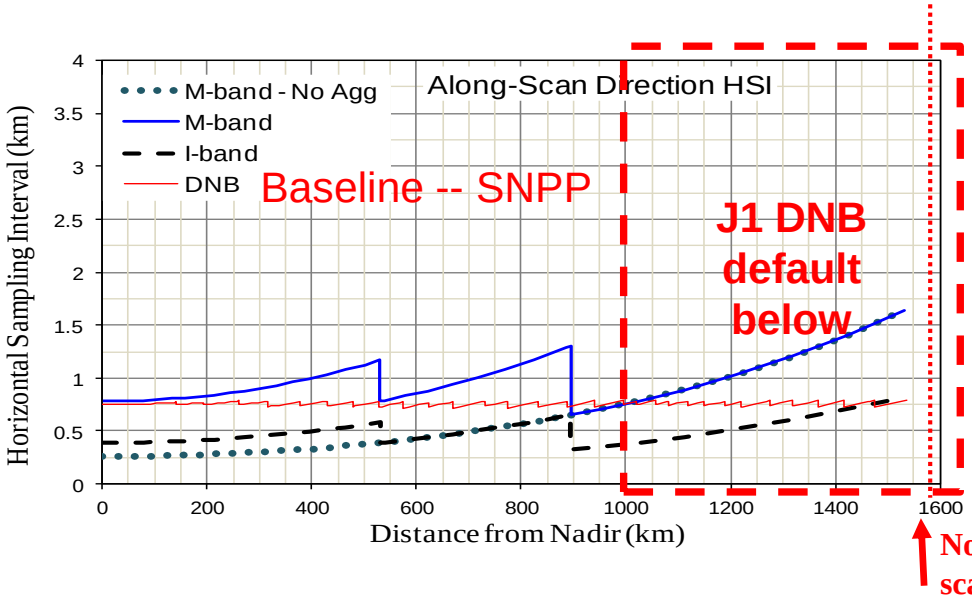
Aqua use definitive ephemeris data → 27 hour latency

SNPP attitude data is not as good, see Slides18 & 28

DEM resolutions: older 1 km for VIIRS vs newer 0.5 km for MODIS C6

Lin et al., 9 August 2016

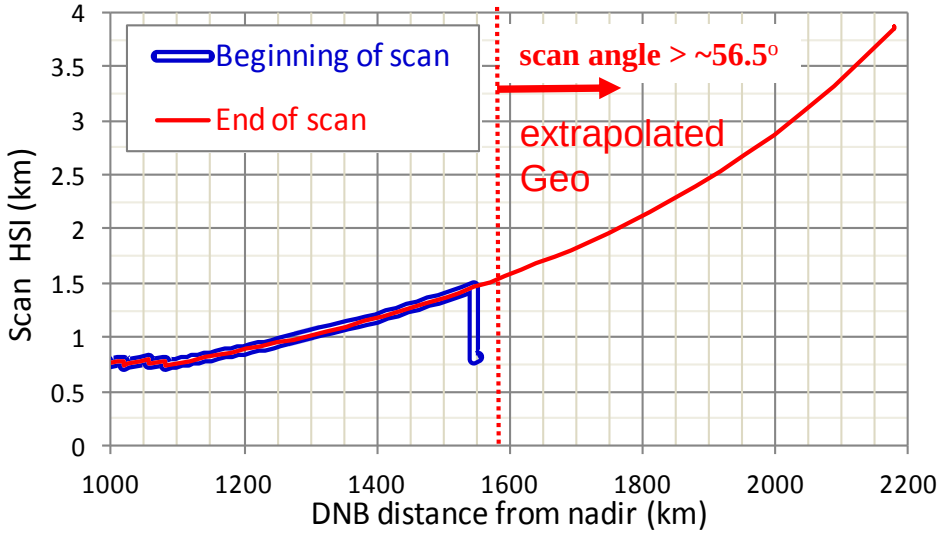
# SNPP & J1 DNB cell sizes in scan direction



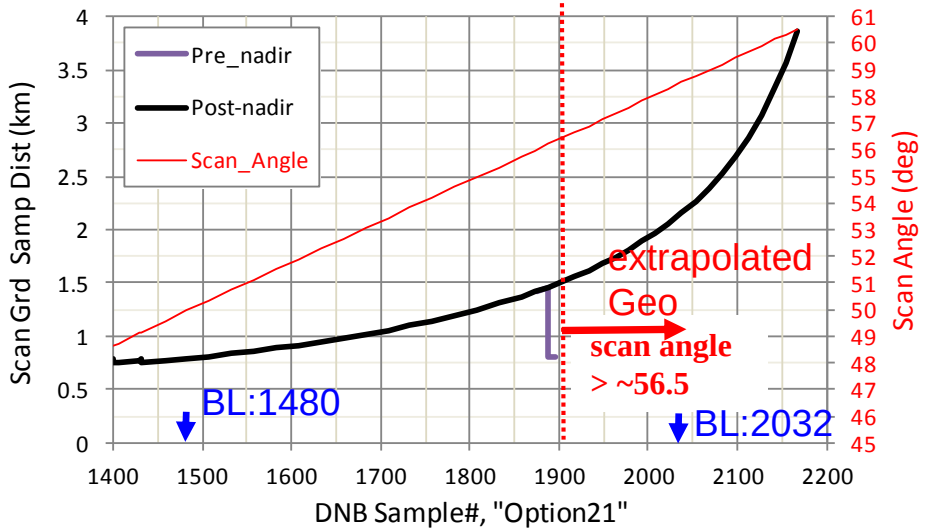

Nominal maximum scan angle (~56.5°)

- DNB LSFs are mostly square
- Baselined pixel size is ~ 750 m
- "Option21" has pixel size up to 1.6 km within 56.5°
- Geolocation is extrapolated post-nadir for scan angle > ~56.5° (pixel size up to 3.9 km @60.5°)

➢J1 DNB cell sizes are not constant as SNPP VIIRS are




"Option21" – default, in km

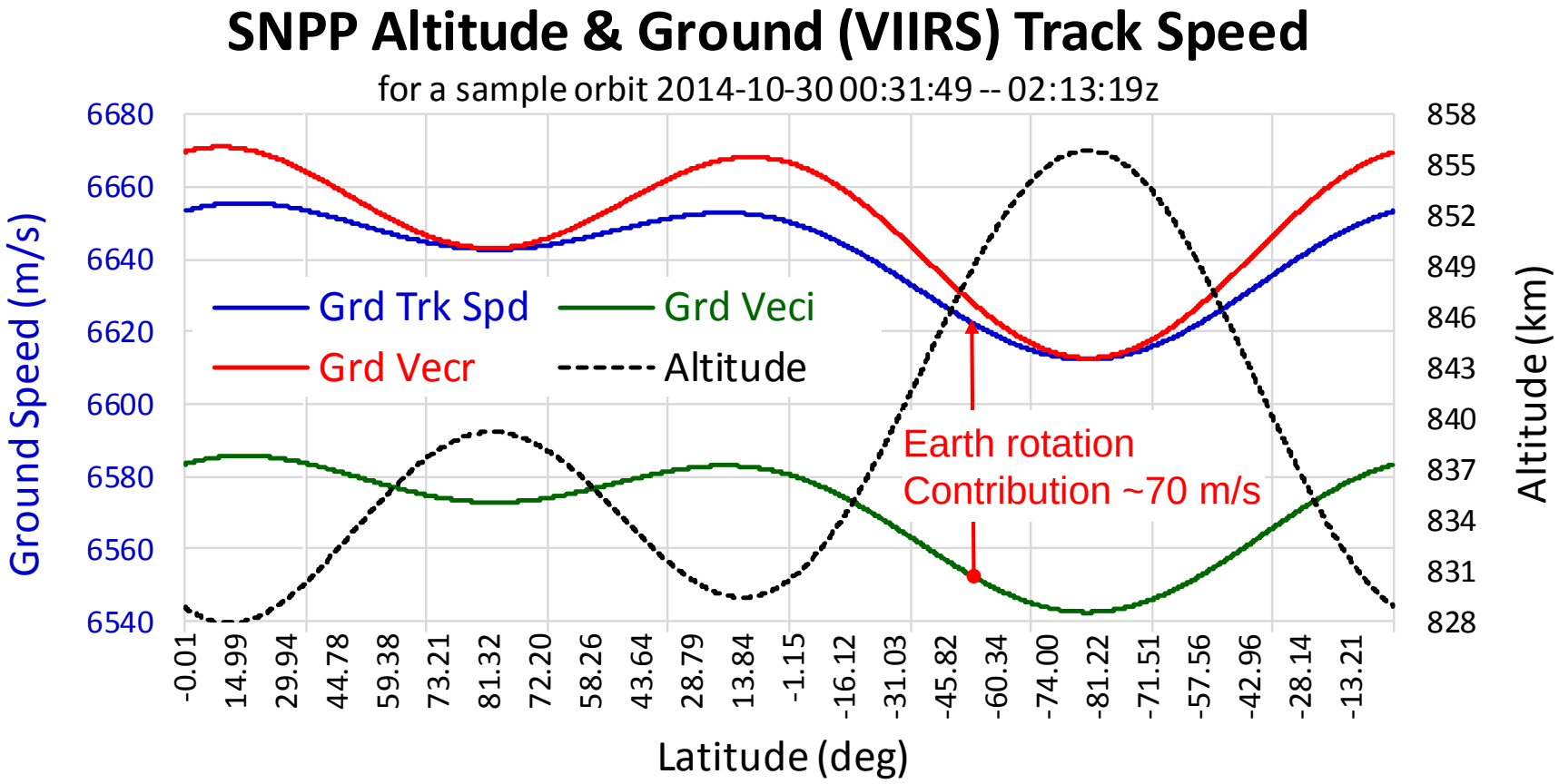



"Option21" – default, in Samp#

# Issues, concerns, challenges

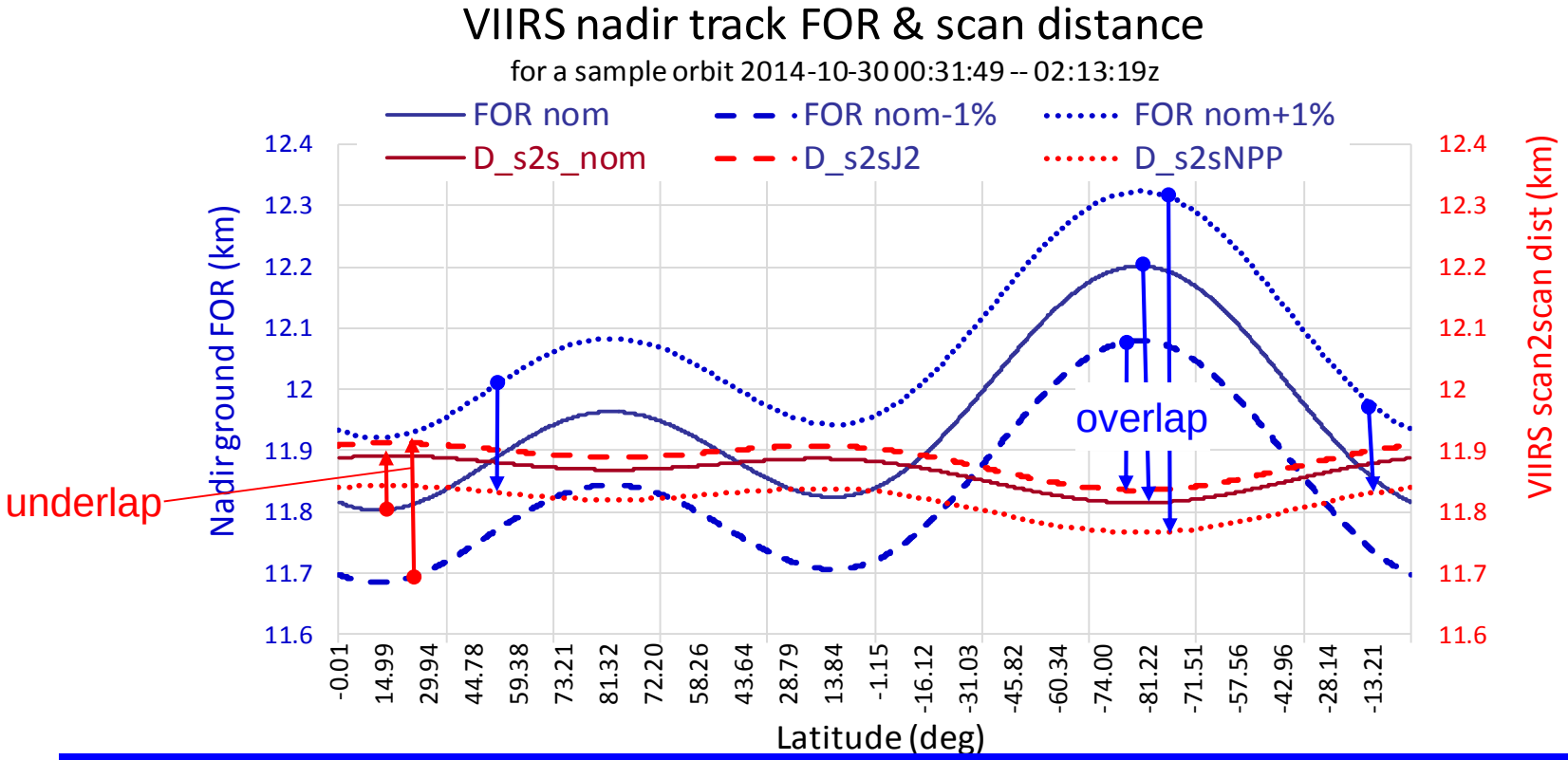
- J1, J2 scan-to-scan underlap

# VIIRS ground track speed carried by SNPP




- Earth rotation contributes to speed in VIIRS track direction due to SNPP inclination angle
- Speed at sub-satellite point (SSP = Vg_ECR) should be a better parameter for future design of VIIRS FPA dimension in the track direction
- Variations in altitude (3.4%) and speed (0.6%) matter - - a 1% change induces ~1/3 I-pixel more/less overlap in the track Field of Regard (FOR) formed by 32 I-detectors

# VIIRS nadir overlap/underlap



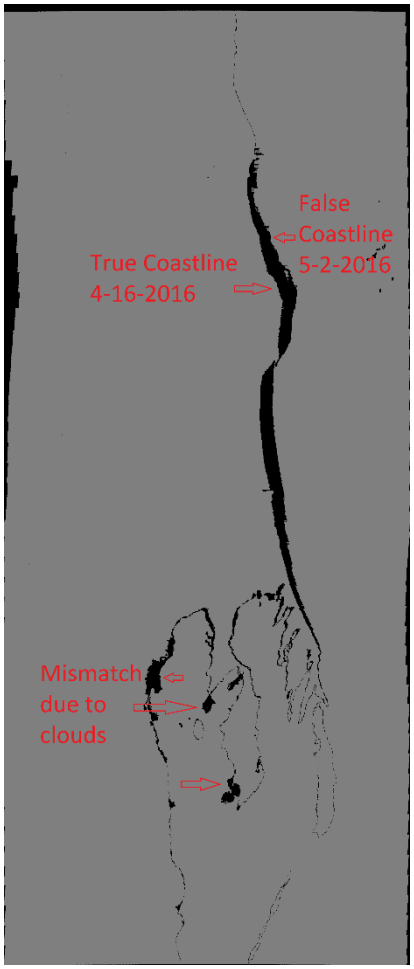

- Scan2scan distances are calculated using scan rate of 3.53107 rad/s for SNPP, nominal 3.51657 for J1, and proposed 3.5104 for J2.
- J1 & J2 VIIRS are expected to have underlap over the equator region
- J3+ should have fixed the problem probably by using SNPP shorter focal length and faster scan rate
- Contribution of earth rotation to the ground speed in the track direction might have been forgotten in the original “system” design

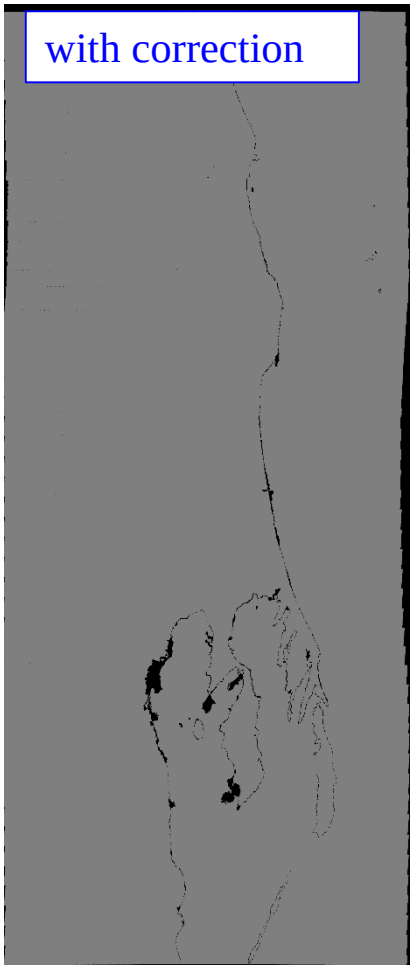
# Issues, concerns, challenges

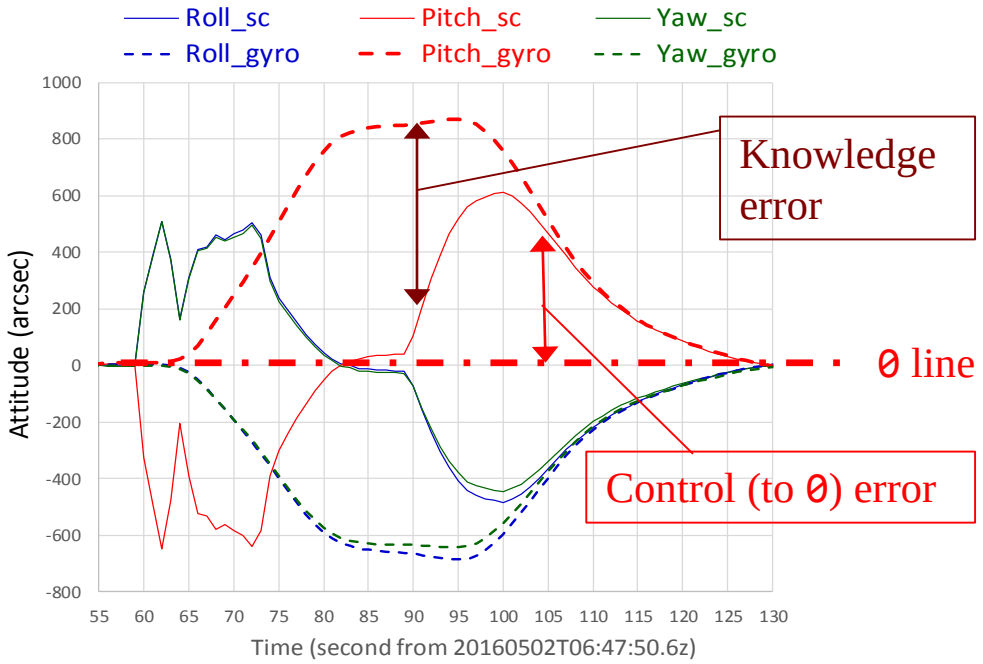
- SNPP attitude system degradation, that affects VIIRS geolocation accuracy

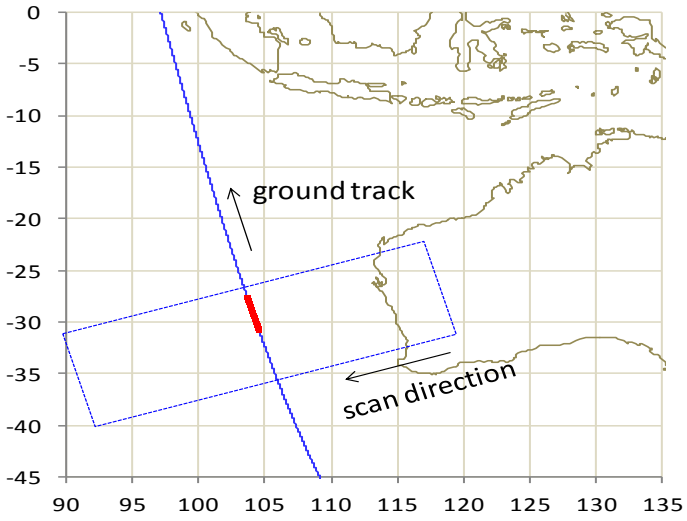
# Attitude control & knowledge errors

2016-05-02 06:48:50 – 06:50:40z




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

# Requirements (NGIID, RevD, 2008-01-07)

**Knowledge error: from truth orientation**

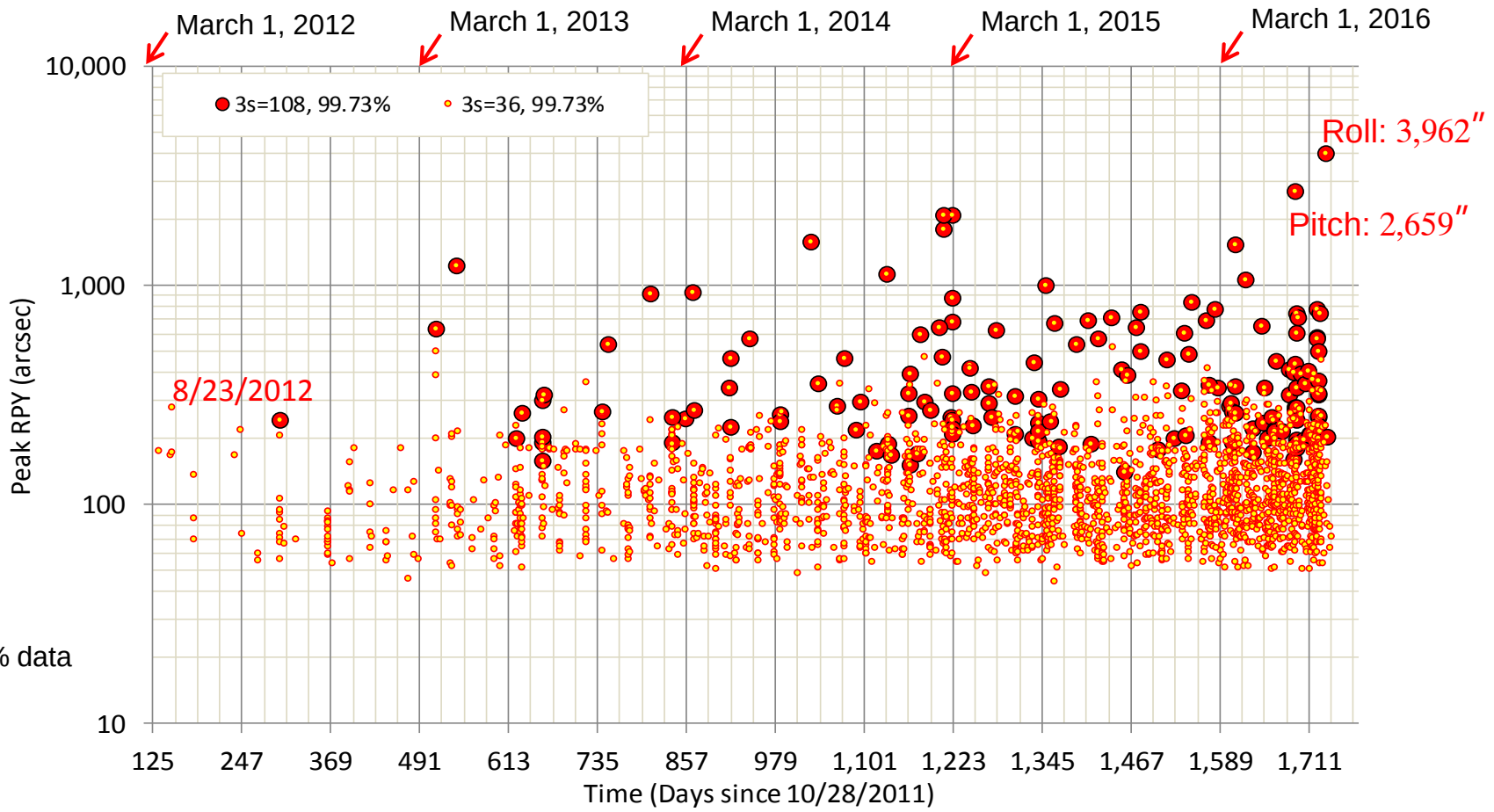
*IF230780 The spacecraft-supplied estimate of the inertial attitude of the Spacecraft Attitude Determination Frame shall be in the J2000.0 frame, be time-tagged and have an error during **any orbit** of less than **30 arcsec** (3 sigma) per axis.*

**Control error: from desired (0) orientation**

*IF230796 For NPP, the Spacecraft Attitude Control Error during **any orbit**, excluding the effects due to jitter, shall be less than **108 arcsec** (3 sigma) per axis during all mission data collection periods.*

The "3 sigma" is interpreted as 99.73% confidence level, i.e., <= 16 second-points out of 6090 second-points per orbit when the error is outside the spec'd value.

# Spec outage and trend

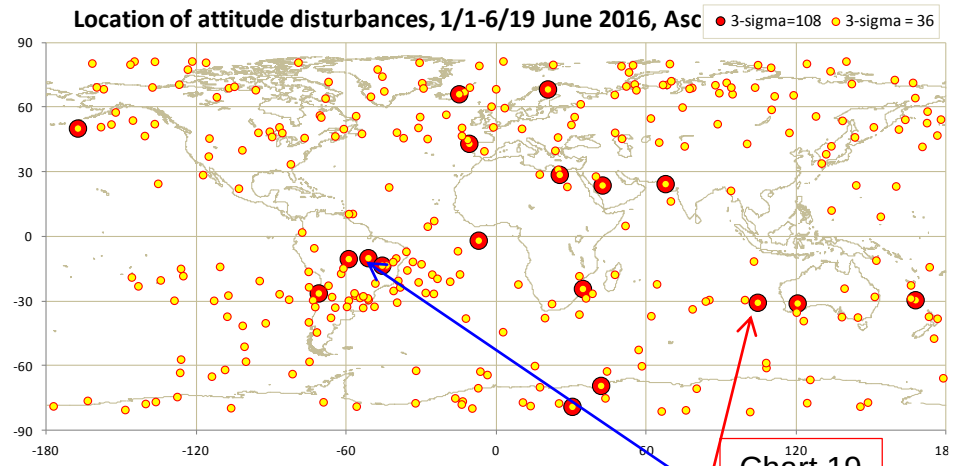


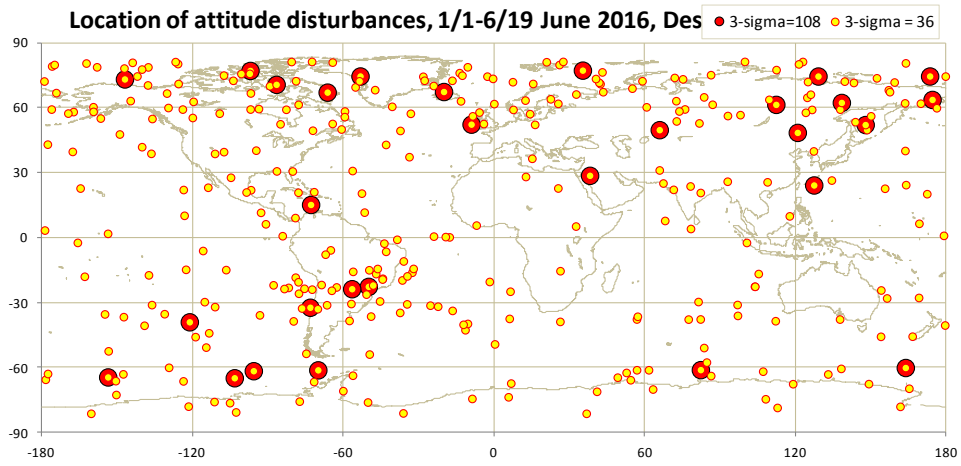

using ~90% data

- Large circles for control spec outage
- Small dots hint knowledge spec outage

# Global distribution

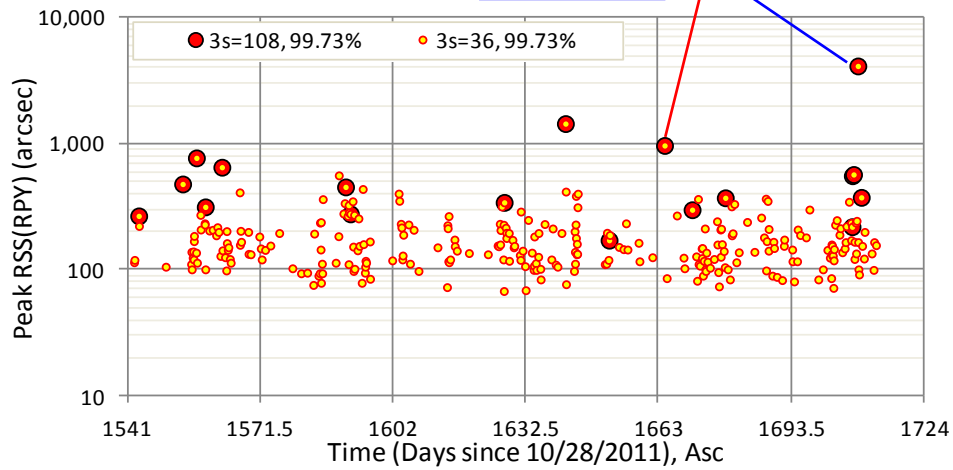
1/1/2016 – 6/19/2016

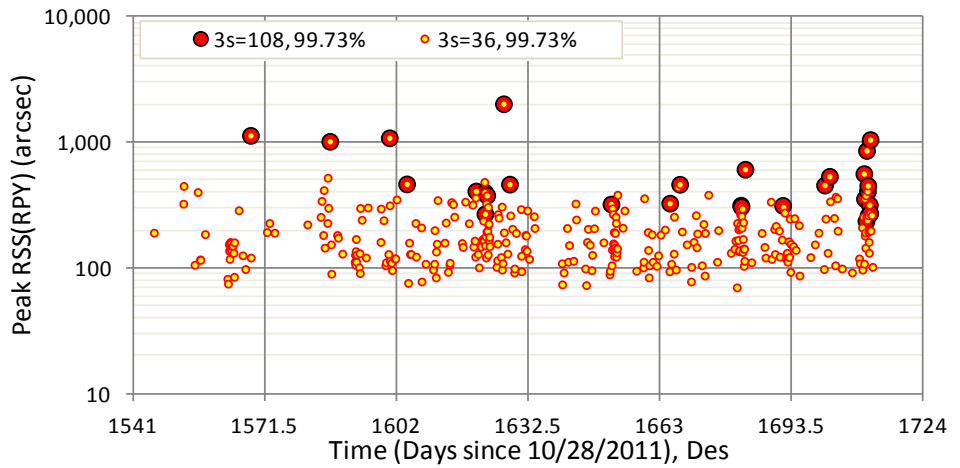



Next chart

Chart 19



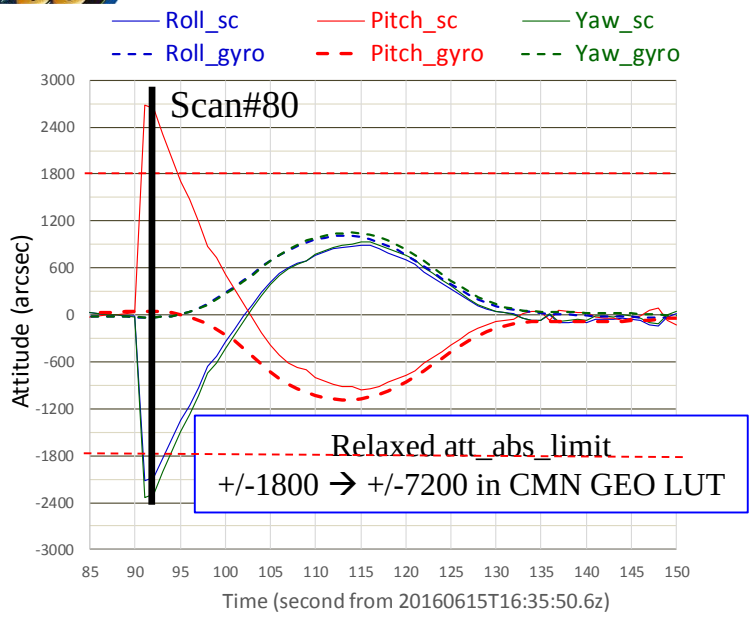



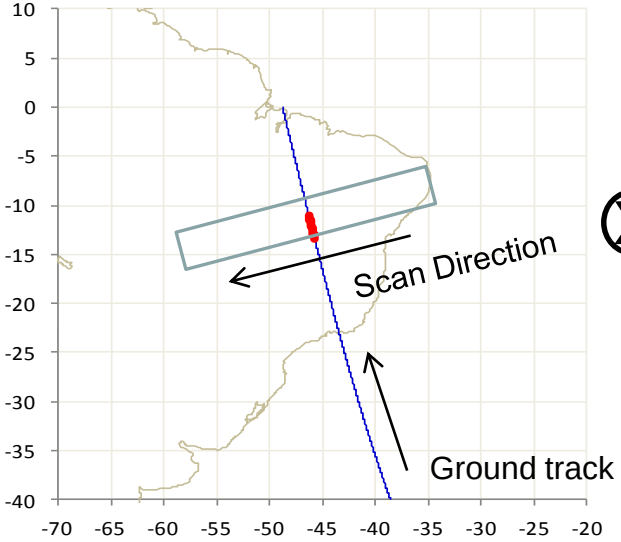

Ascending orbits

Descending orbits

- All over the places, day and night

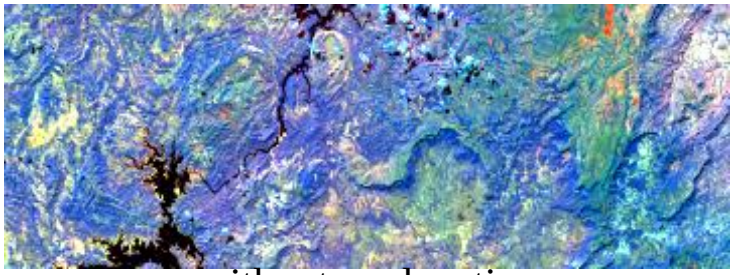
# Attitude errors over 0.7 deg!



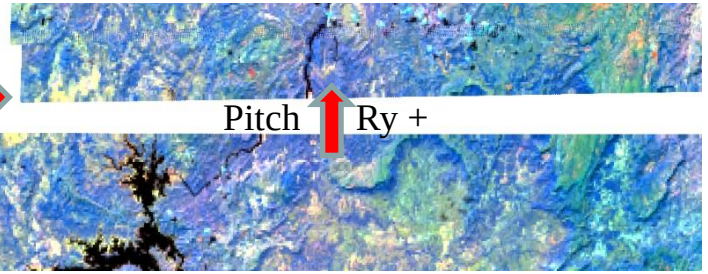


sample 3981 RGB = (I4, I3, I2) sample 3621



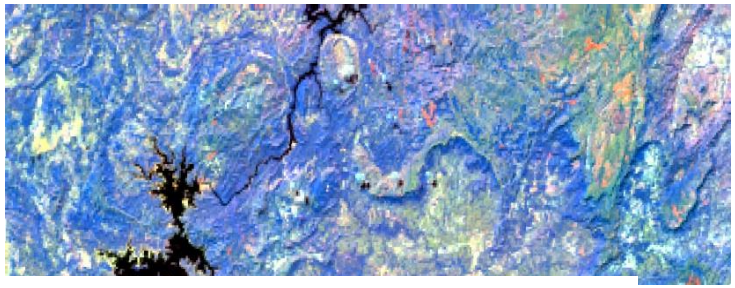

without geolocation

Roll
Rx -




with geolocation

- 5 min granule from 16:35z

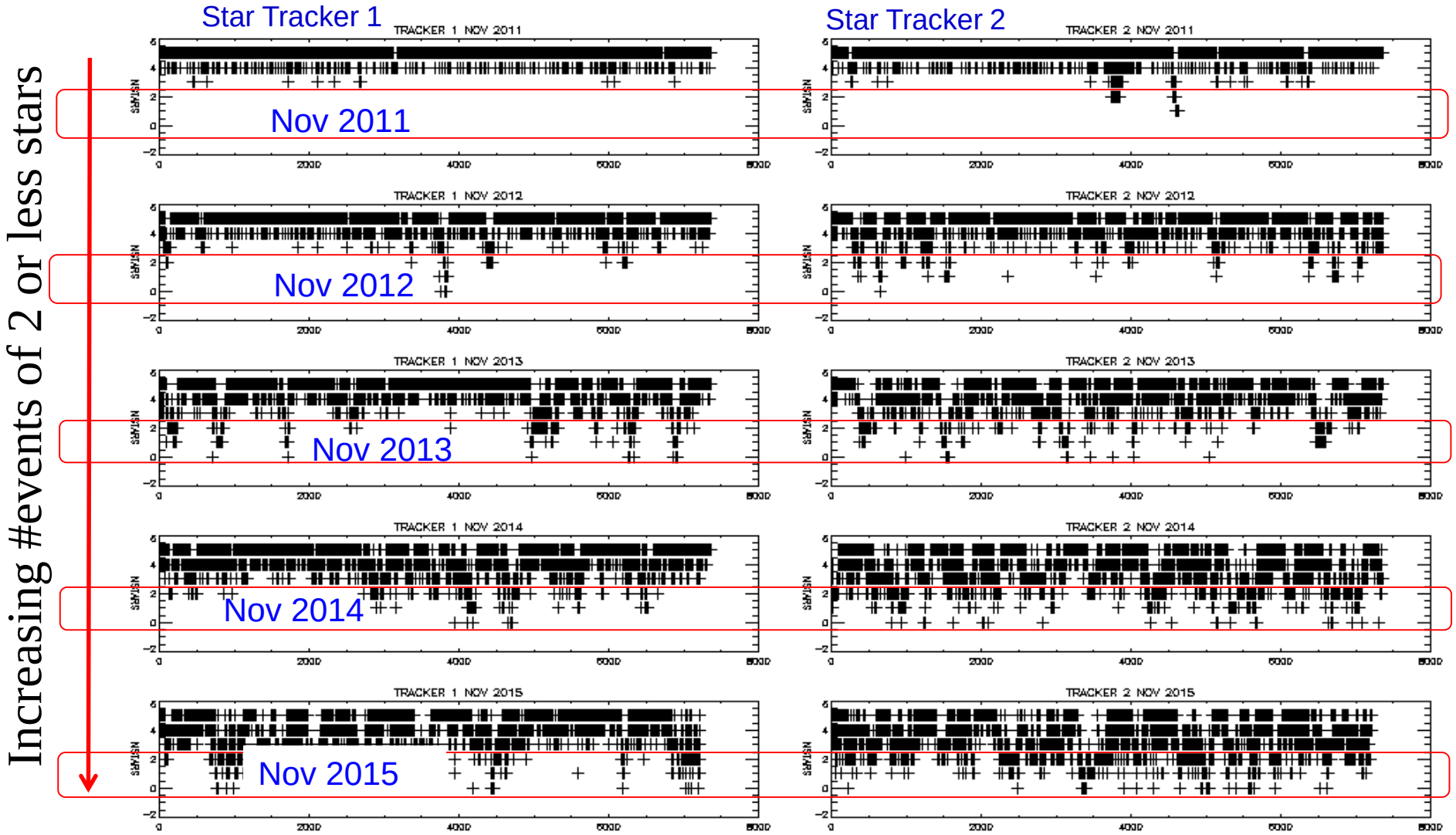


with geolocation, 16 days earlier

➢ VIIRS images "see" the attitude errors

# Fewer and fewer stars are being tracked

Star counts in 2-hour windows

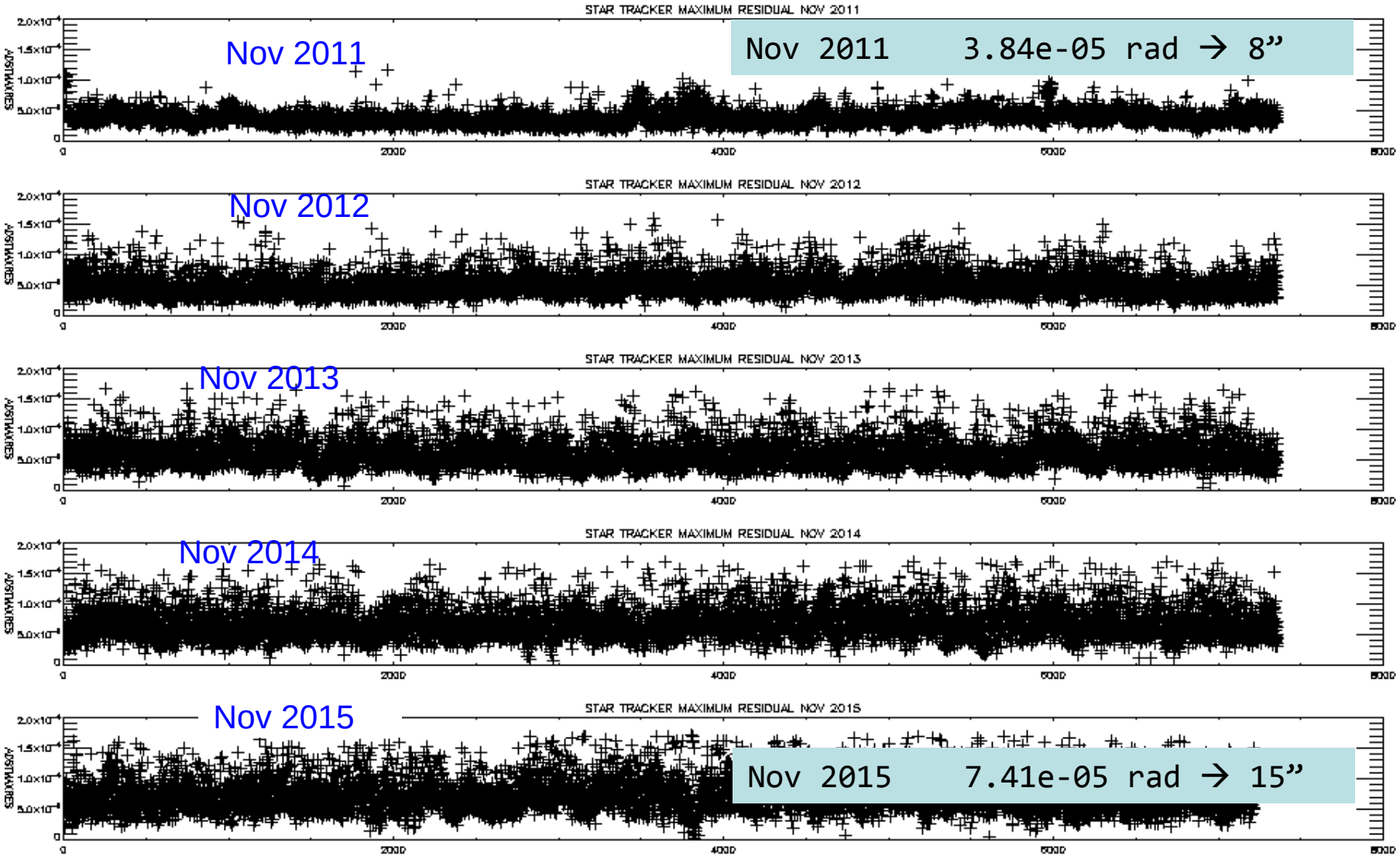



a minimum of 2 stars in both trackers are combined to do attitude determination

➢ The attitude solution relies on one tracker more often

# Star trackers are getting noisier

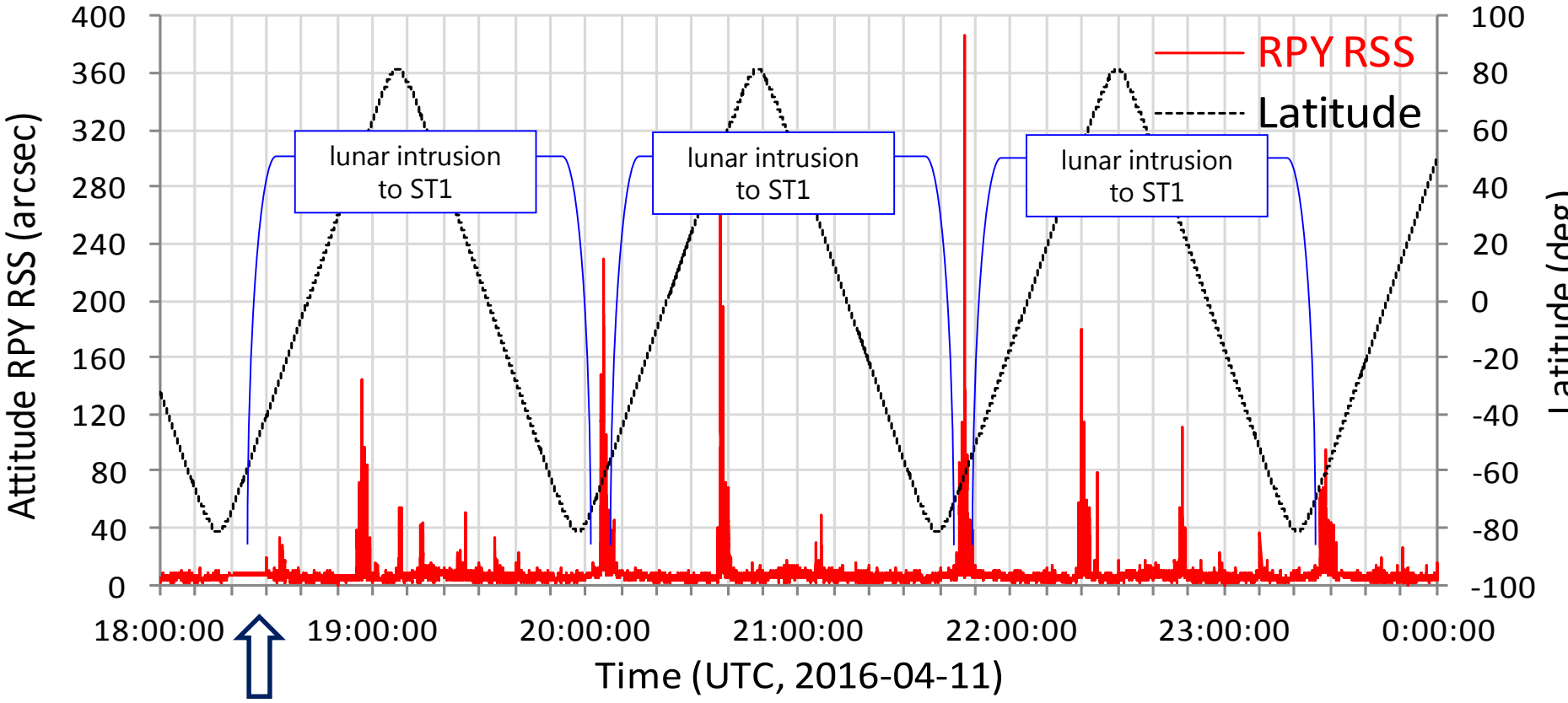
## max residuals in 2-hour windows




- The noise level ~ doubled over the 4+ year life

Lin et. al., 1 Dec 2015

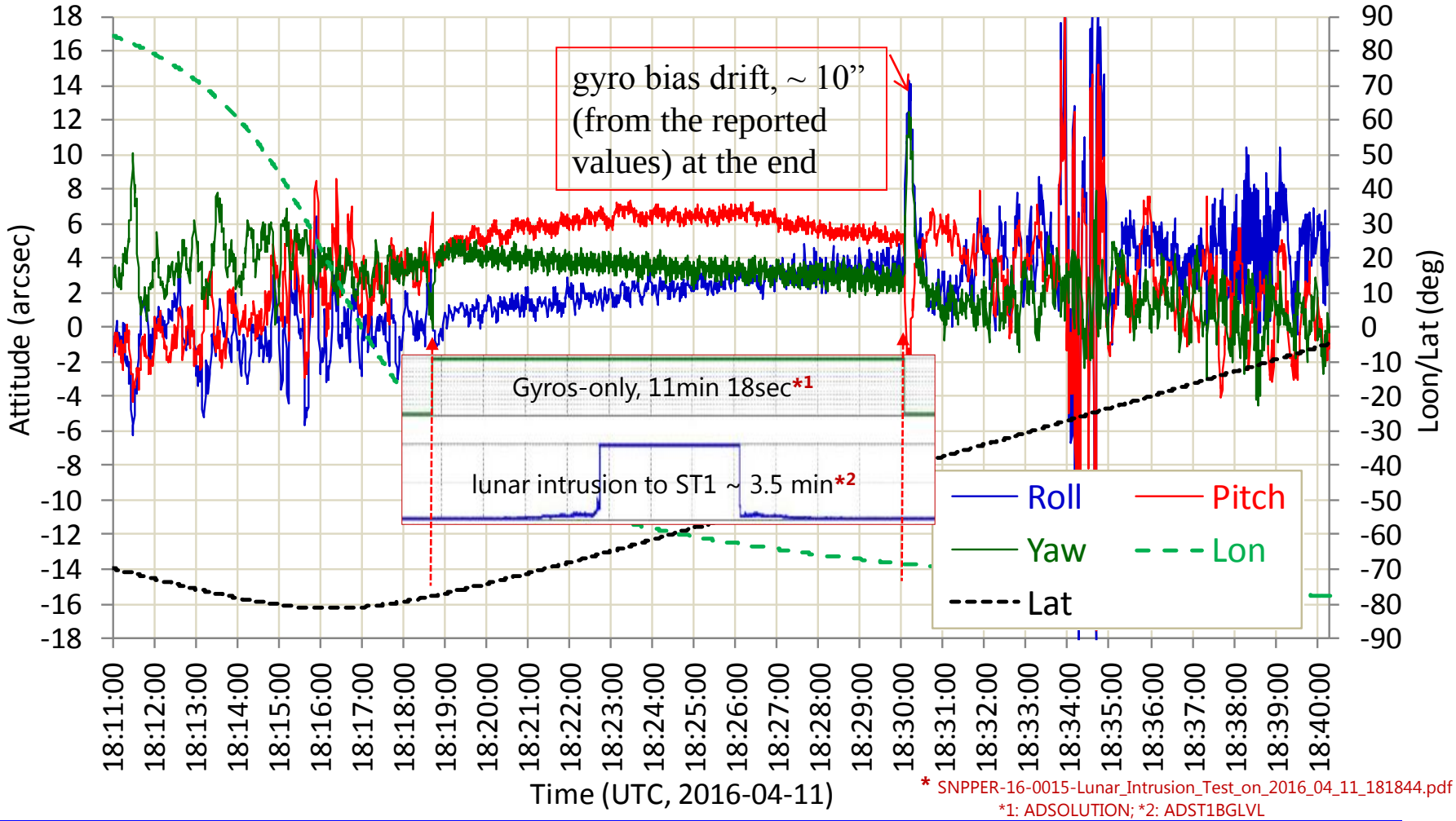
# Gyros-only Test (1/2)




- A test of gyros only masked out attitude excursion induced by lunar intrusion

# Gyros-only Test (2/2)

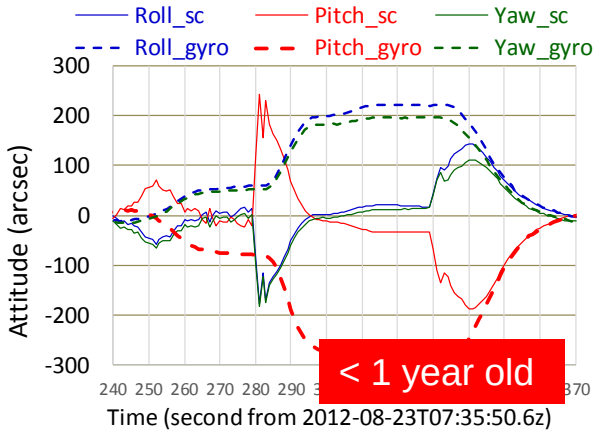
## Results of Gyro-only Test 2016-04-11, 18:18:44 to 18:30:02z

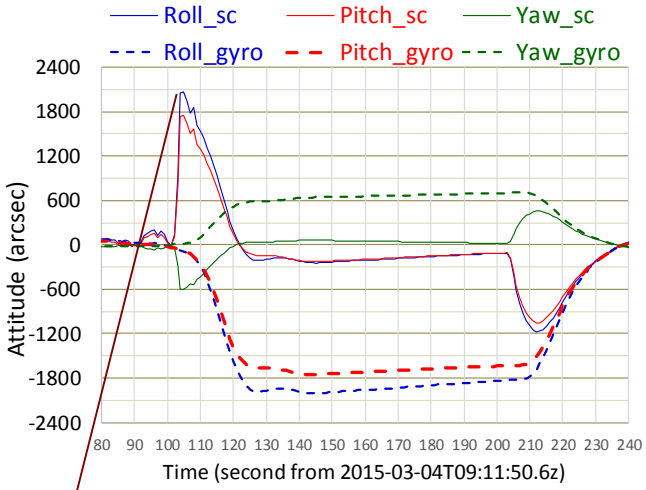


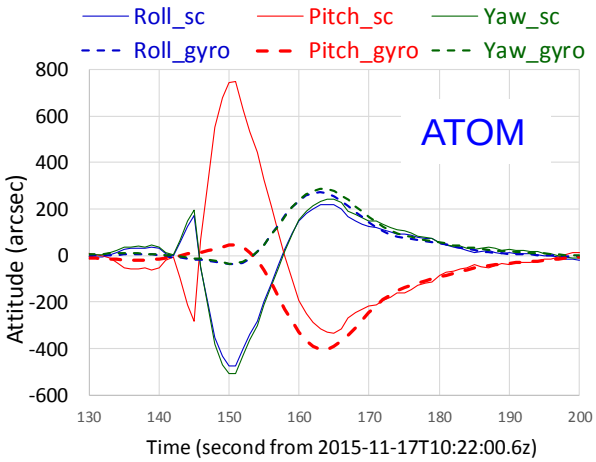

* SNPPER-16-0015-Lunar_Intrusion_Test_on_2016_04_11_181844.pdf
*1: ADSOLUTION; *2: ADST1BGLVL

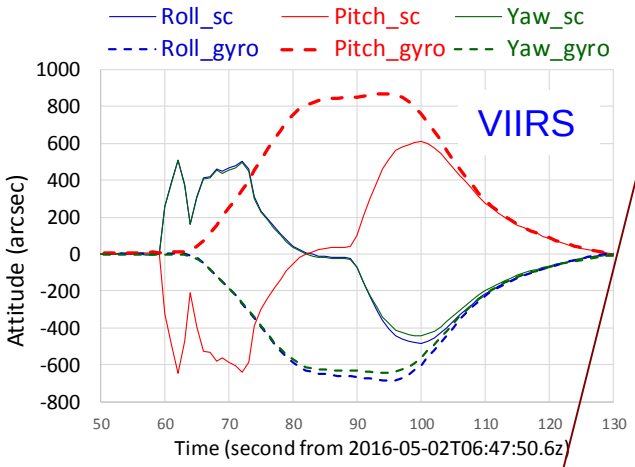
- Gyros-only performed well, drifting ~ 10 arcsec @ end of 11 min 18 sec

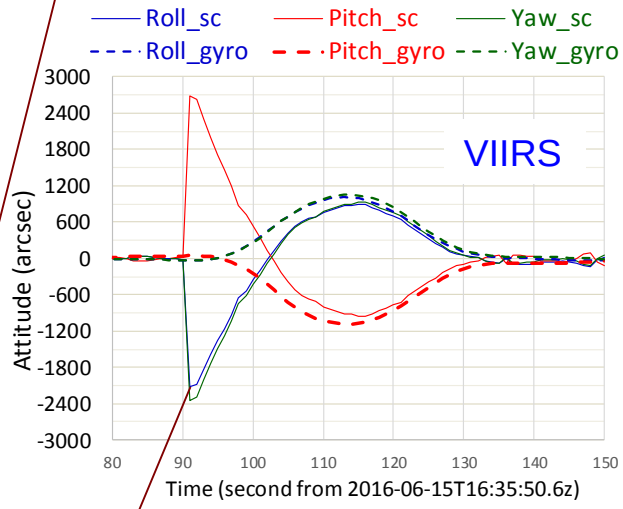
# Attitude re-generated using gyros data in TLM



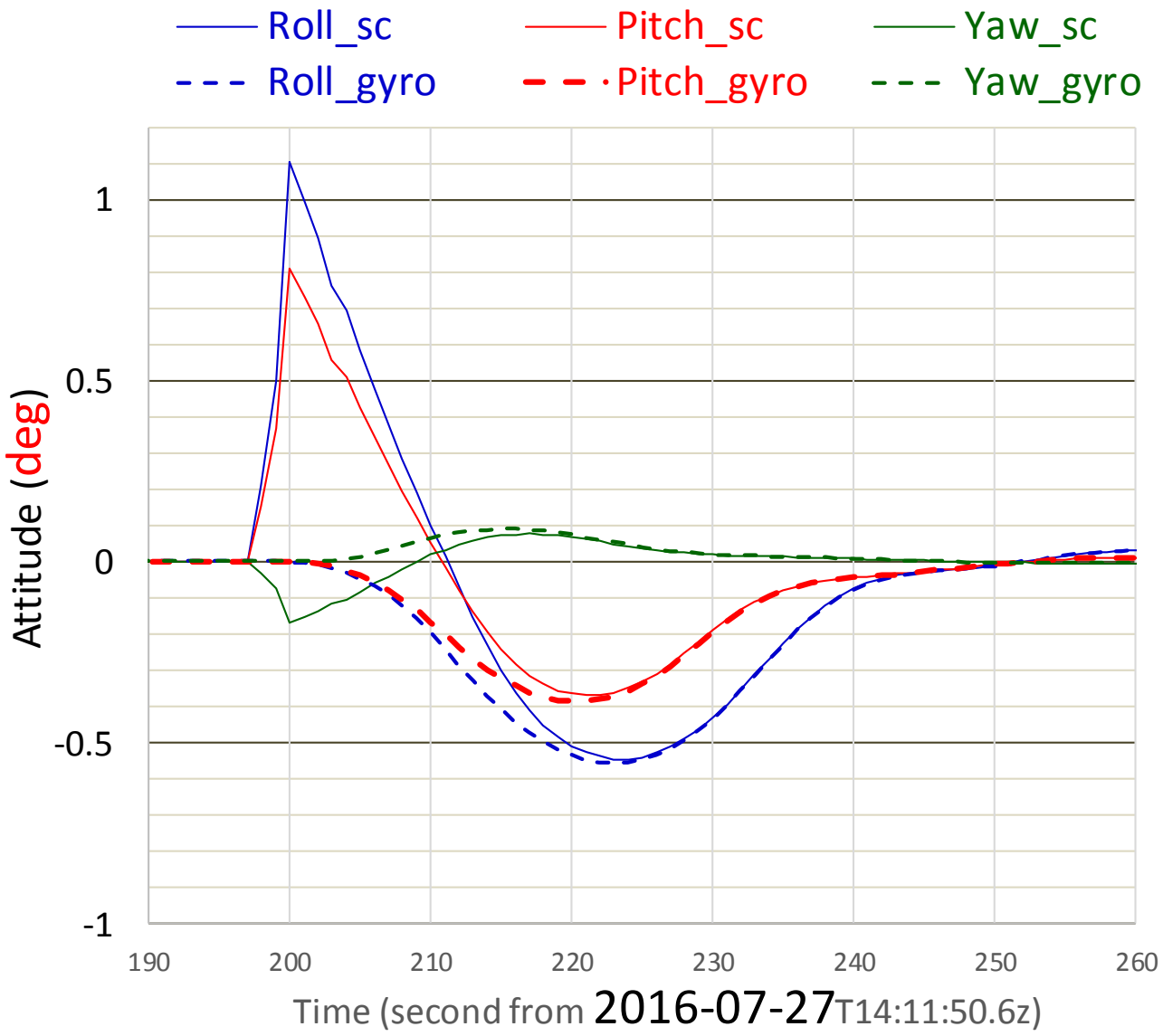




- Prototyping with gyros data looks good up to ~ 30 min, proven by test, VIIRS and ATOM data
- Geolocation errors > 7 km occasionally
- On-orbit system needs fixes to bring attitude to within spec

Un-physical. Indicator of deficiencies in HW/SW

# The latest -- attitude Error > 1°



# Potential paths forward

to correct the behaviors of the SNPP attitude system

1) Extend the time-out for gyros-only from 5-min to 15 min – test done, mostly useful to star catalog uploads
2) Adjust background noise thresholds to enable better star identification -- test done, might have helped reducing magnitude of attitude disturbances, but not enough
3) Lower the temperatures in the trackers – FSW patching under consideration, **scheduled at the end of September, 2016**
4) Adjust coefficients in the ADCS "mixing algorithm" to reduce the sensitivity to the star trackers data and thus reduce attitude errors
5) Map out and mask out malfunctioned CCD cells in the trackers CCD arrays for the attitude solution
6) others (implement Kalman Filter? urgent for J1, be a requirement for J2+)

- Some symptoms diagnosed and "medicines" prescribed
- The "medicines" need to be administered

# Concluding remarks

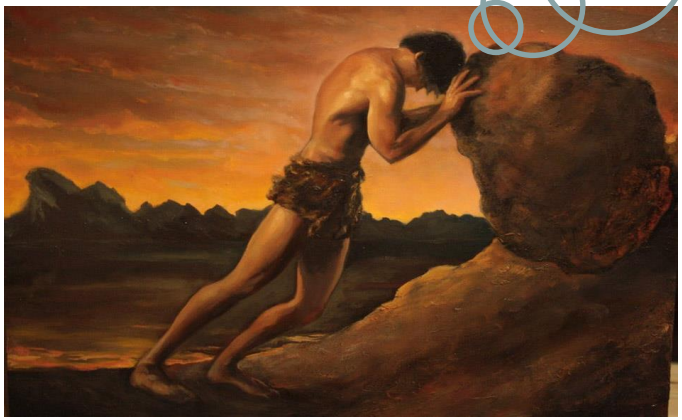
- SNPP VIIRS Geolocation mean errors for I- & M-bands are near 0 and uncertainties are ~ 70 m at nadir, statistically
- J1 geolocation expectations
  - Geolocation will be calibrated on-orbit by control points through LUTs
  - Bands on VisNIR FPA should be good; Bands on cold FPAs will be off ~ 50 m in the track direction
  - DNB geolocation pixels will be larger beyond Sample#1500, 1100 km off nadir
- Challenges, concerns, and issues
  - Challenges: Scan-to-scan underlap, the expectations
    - SNPP VIIRS has no underlap owing to shorter focal length and faster scan rate
    - J1 has underlap of ~1/4 I-pixel near nadir over the equator region
    - J2 has larger underlap over a larger extent of the earth than J1
  - Concern: J1 attitude performance
  - Issue: The SNPP attitude system anomaly, error > 1 deg → geolocation error > 10 km occurred lately. The attitude system (HW & SW) needs maintenance.

# Thank you !

Questions?

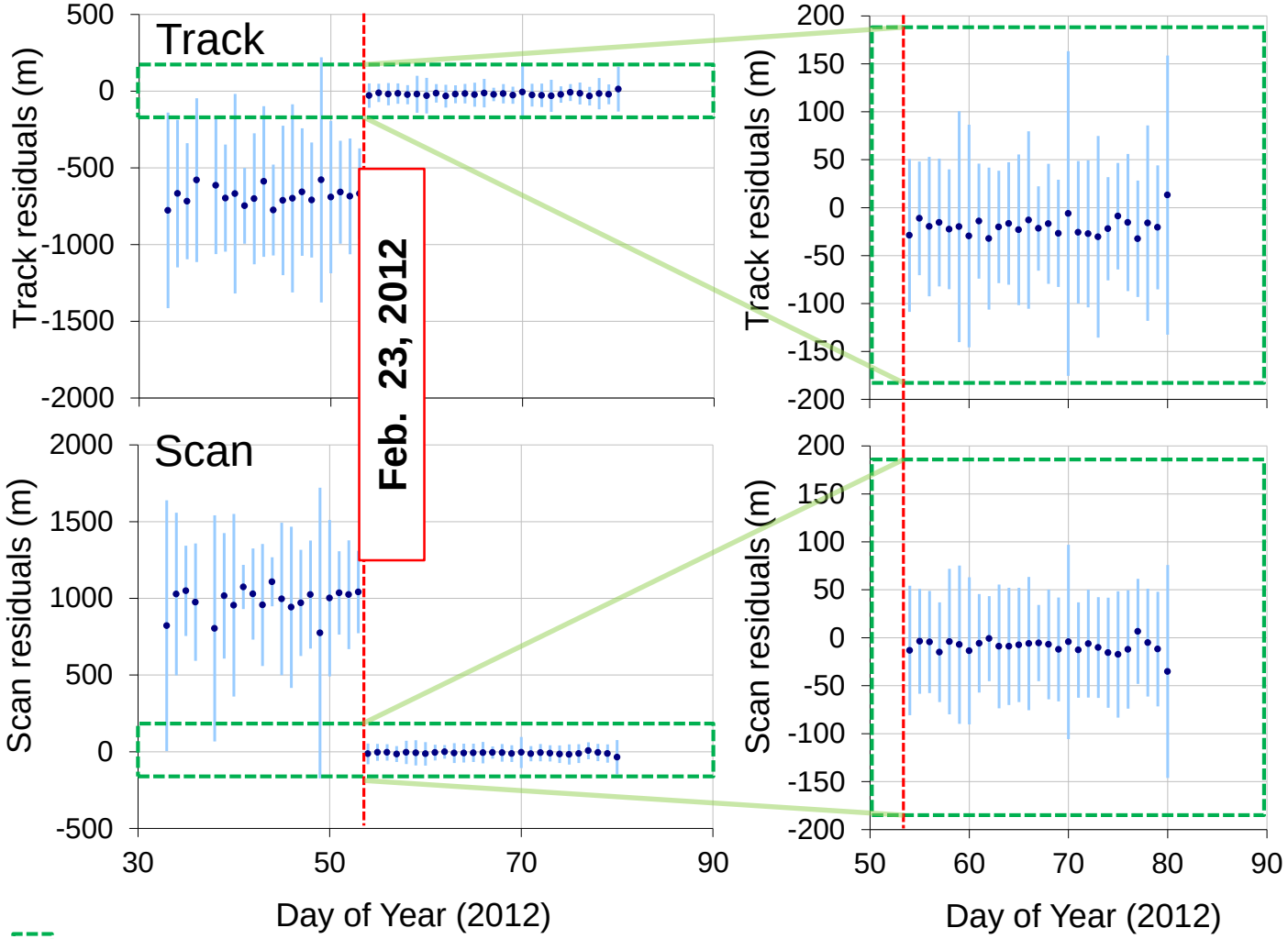
Be aware of assumptions in probability theory.

Be cautious in using statistical methods.



# Backup Slides

# Initial on-orbit geolocation LUTs Update




Error after LUT update (2/23/2012, doy 54)

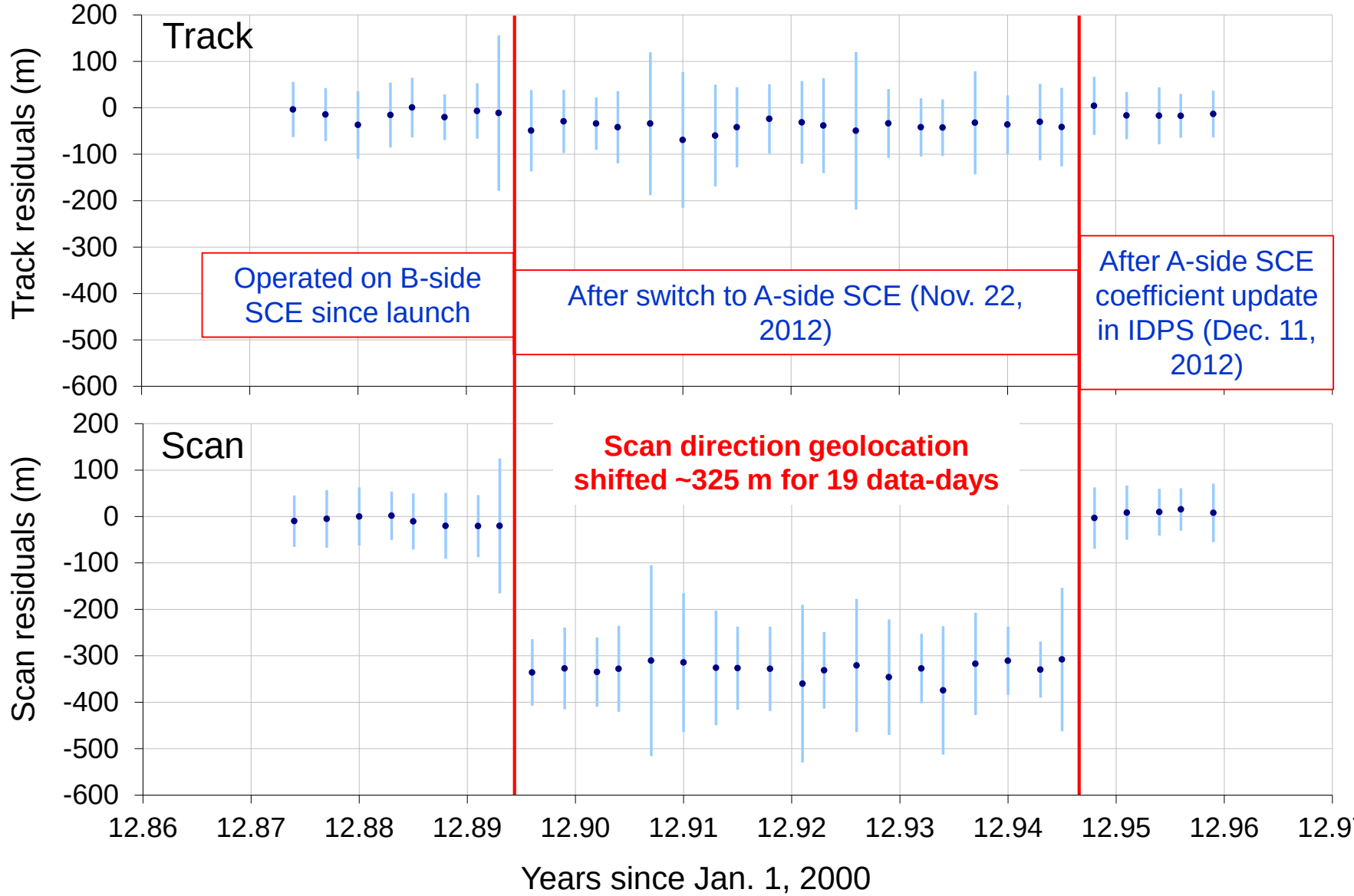
| | Bias (m) | RMSE (m) |
|---|---|---|
| Track | -21 | 80 |
| Scan | -8 | 64 |

27 days with average of 142 matchups/day (minus 12 outliers/day)

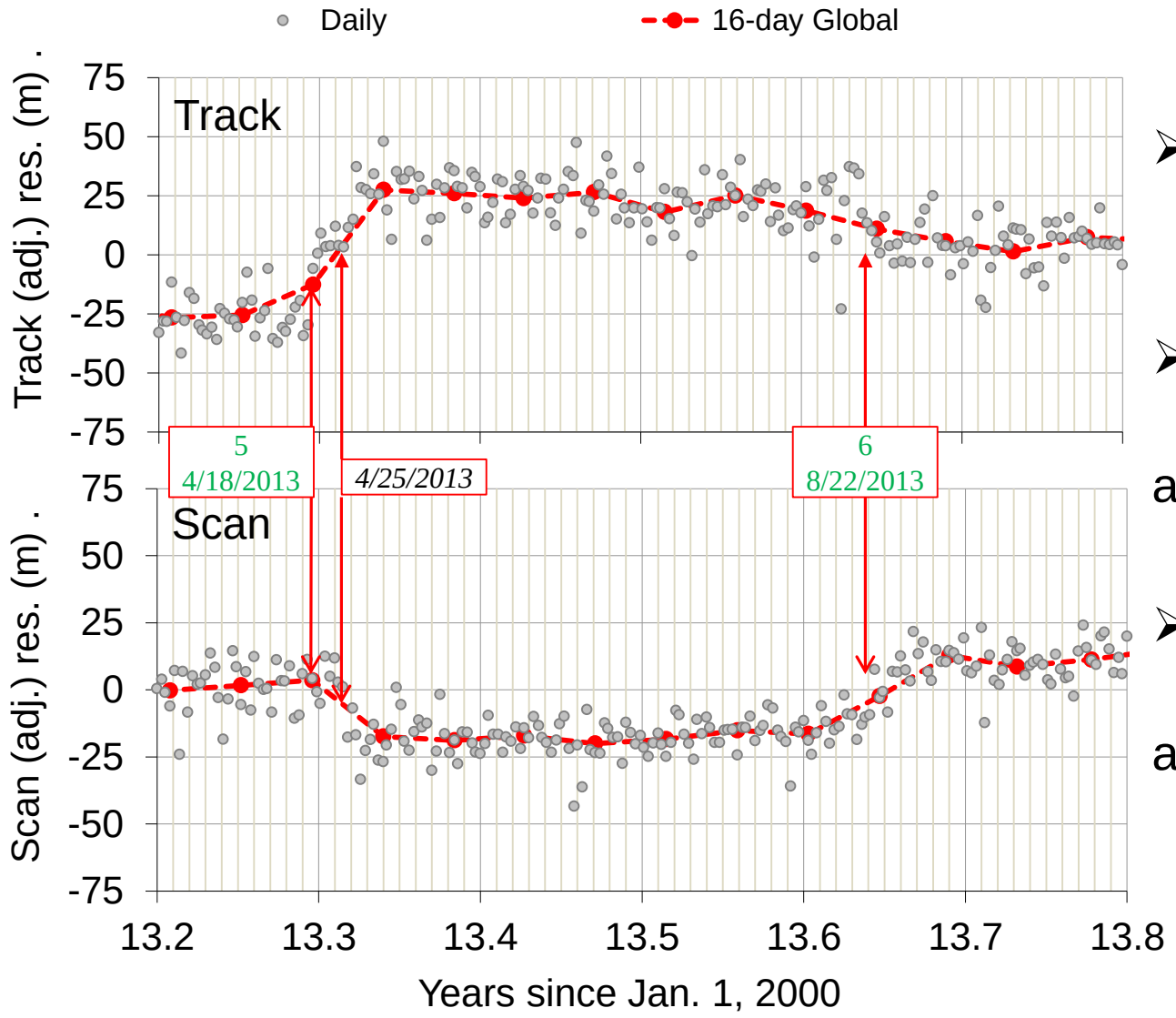
Nadir equivalent units;

**Biases removed: Track -755 m, Scan 1118 m**

# Scan Control Electronics (SCE) Side Switch, Geolocation Error and Correction



# Star Tracker Re-alignment and Correction




- 4/18/2013:
  Geo LUTs fine tuned
- 4/25/2013:
  Star tracker re-alignment
- 8/22/2013
  Error ~ 25 m found and corrected