# (Terra, Aqua) MODIS Geolocation Status

MODIS-VIIRS Science Team Meeting
Calibration Workshop

April 15, 2013 → 5/1/2014 → 5/18/2015→**6/6/2016**

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James Kuyper,
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and Bin Tan

Geometric Calibration Group
NASA GSFC Code 619

# Geolocation C5/C6 results

## Terra

- Excellent results –Root Mean Square Error (RMSE) in nadir equivalent units is better than accuracy goal (50 m)
- Large errors occur ~1.5 hr after maneuvers (about 12 per year)
  - accuracy in following orbit suspect

## Aqua

- Good results – RMSE is better than goal (50 m) in track direction but slightly over goal in scan direction (but much better than specification – 150 m)
- Definitive ephemeris is used for best results – causes up to 27 hr processing delay

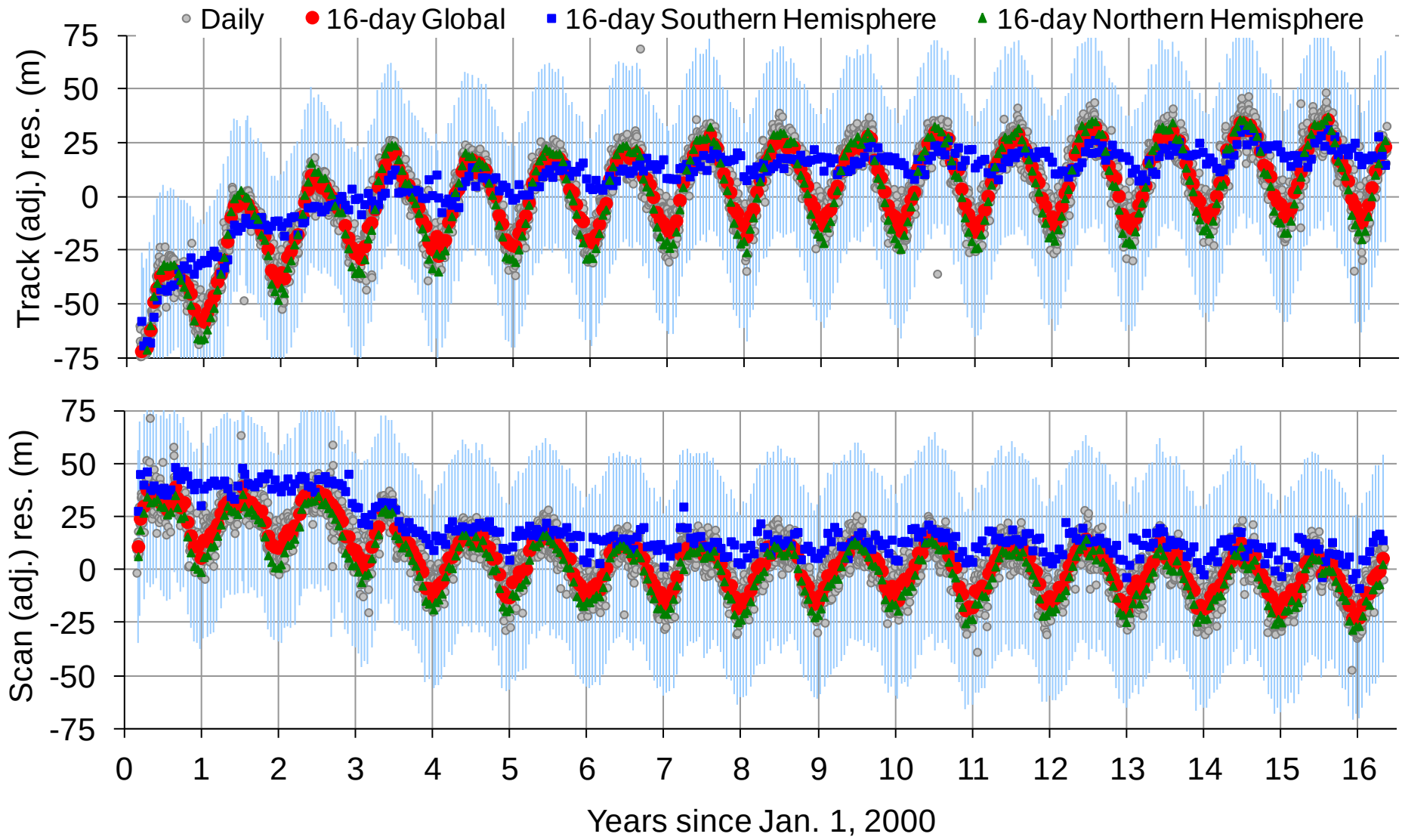
Results up to April 30, 2016

| | Terra | | Aqua | |
|---|---|---|---|---|
| | C5 | C6 | C5 | C6 |
| Along-track RMSE (m) | 44 | 43 | 47 | 46 |
| Along-scan RMSE (m) | 44 | 44 | 53 | 53 |
| Years of Data | 15.8 | 16.0 | 13.6 | 13.8 |
| Ground Control Point Match-ups/day | 260 | 218 | 224 | 189 |
| Days missing (no residuals) | 134 | 62 | 99 | 10 |

Note: These results are for MODIS Band 1, which is used in the control point matchup. Other bands must be offset by the band-offsets published by the MODIS calibration team.

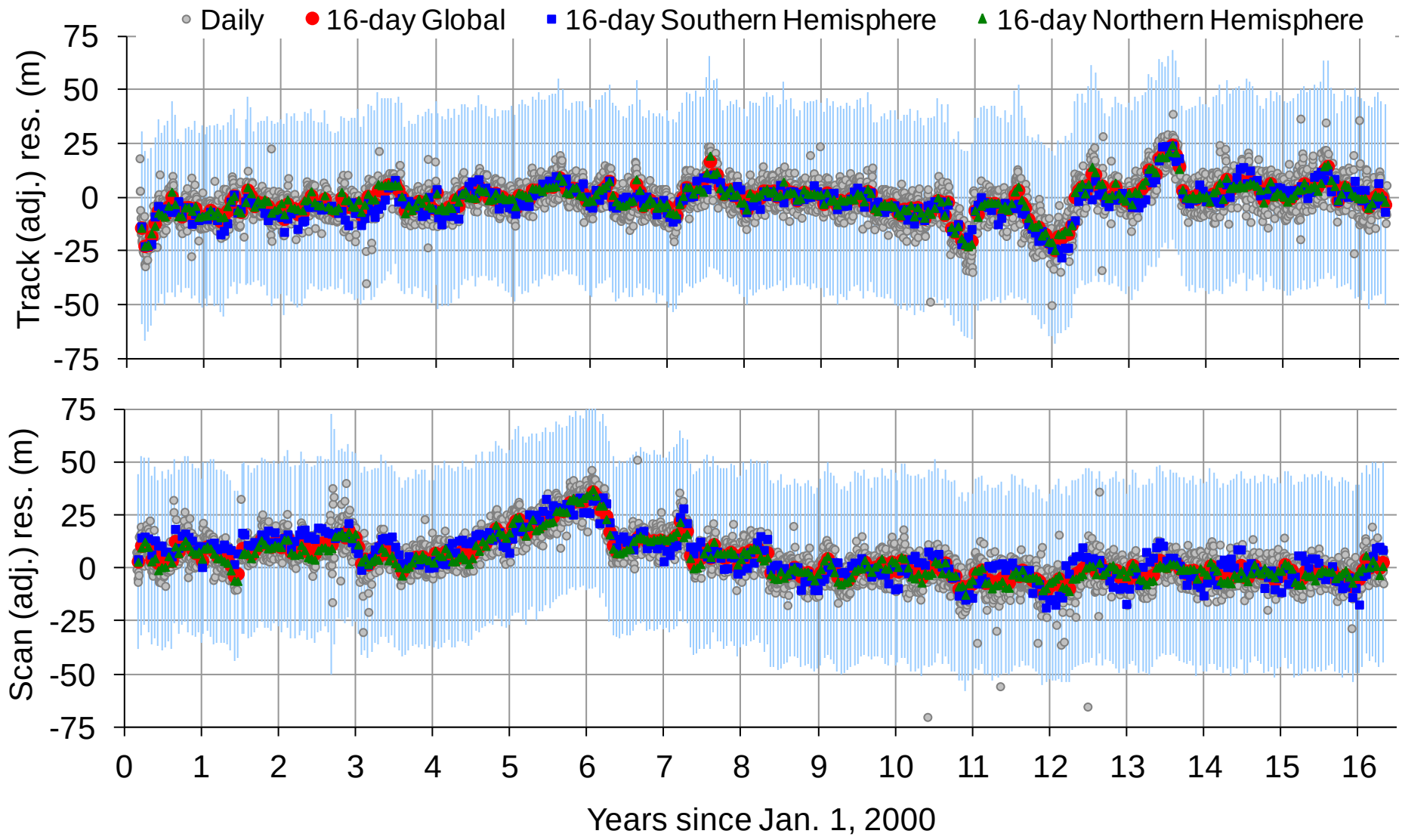
# Terra trend and update details

# Terra C6 long-term trend (uncorrected)



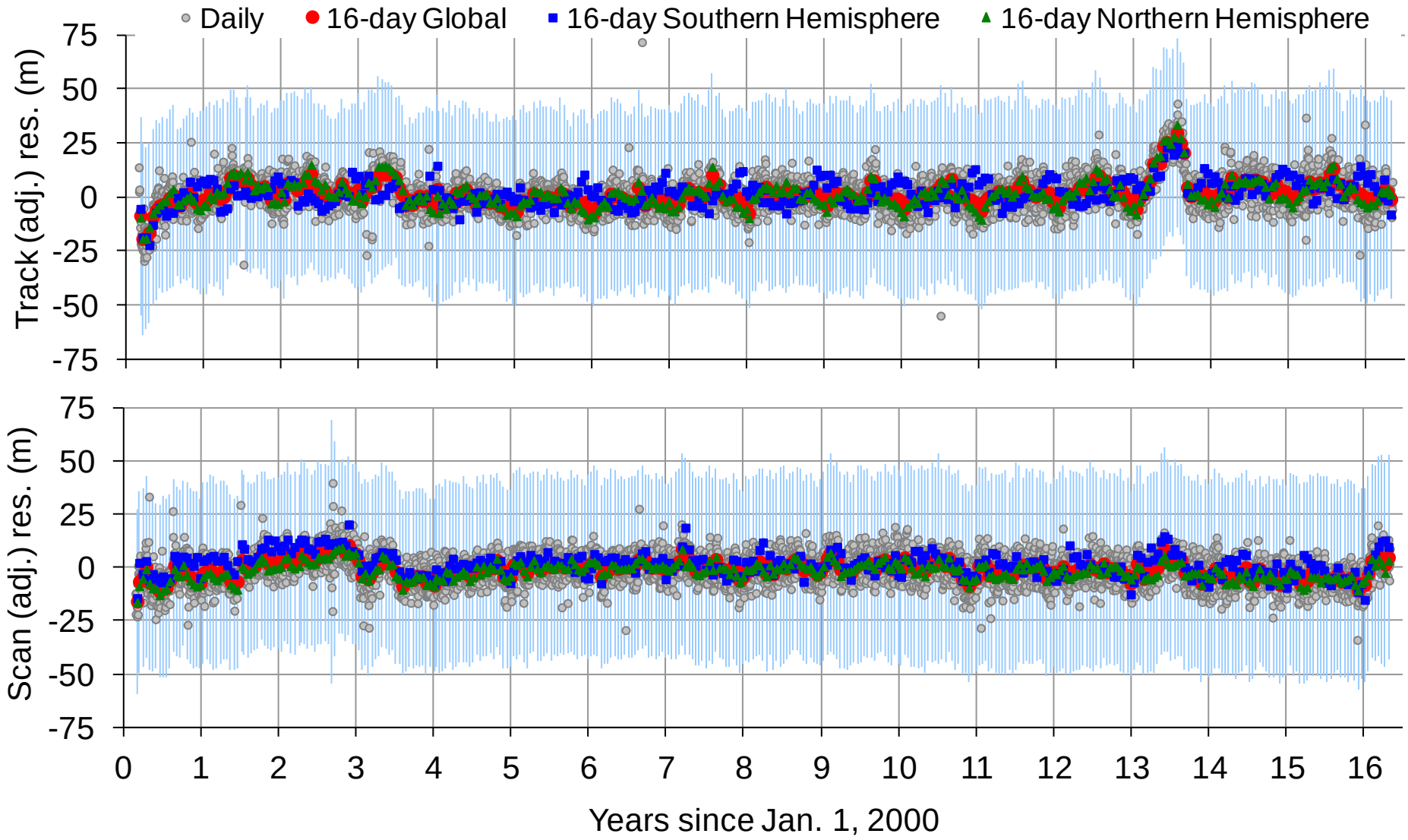

RMSE with no correction: Track: 49 m (+6 m vs C6) Scan: 48 m (+4 m vs C6)

# Actual Terra C5 residuals



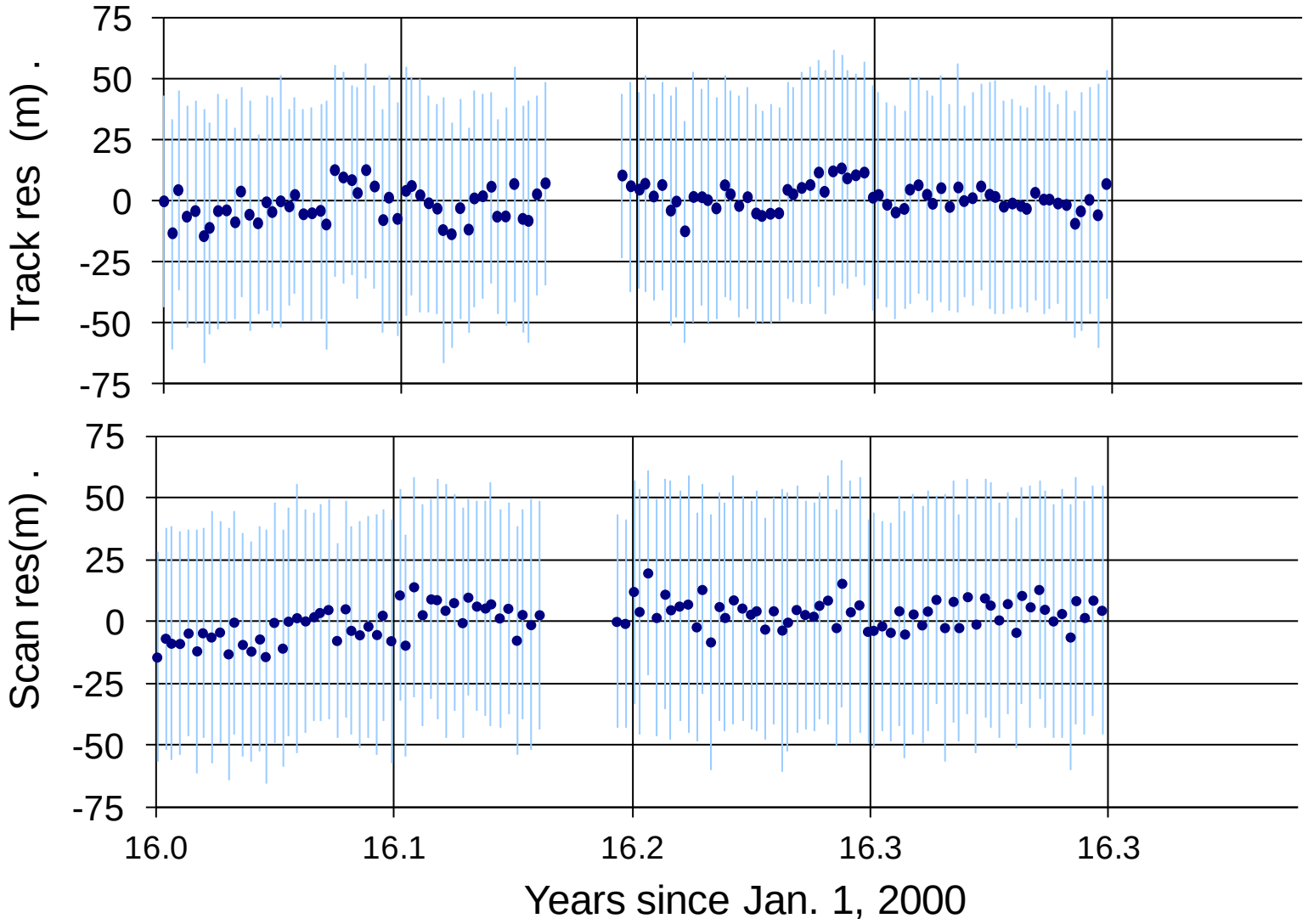

C5 RMSE Track: 44 m Scan: 44 m, nadir equivalent

# Actual Terra C6 residuals




C6 RMSE Track: 43 m Scan: 44 m, nadir equivalent

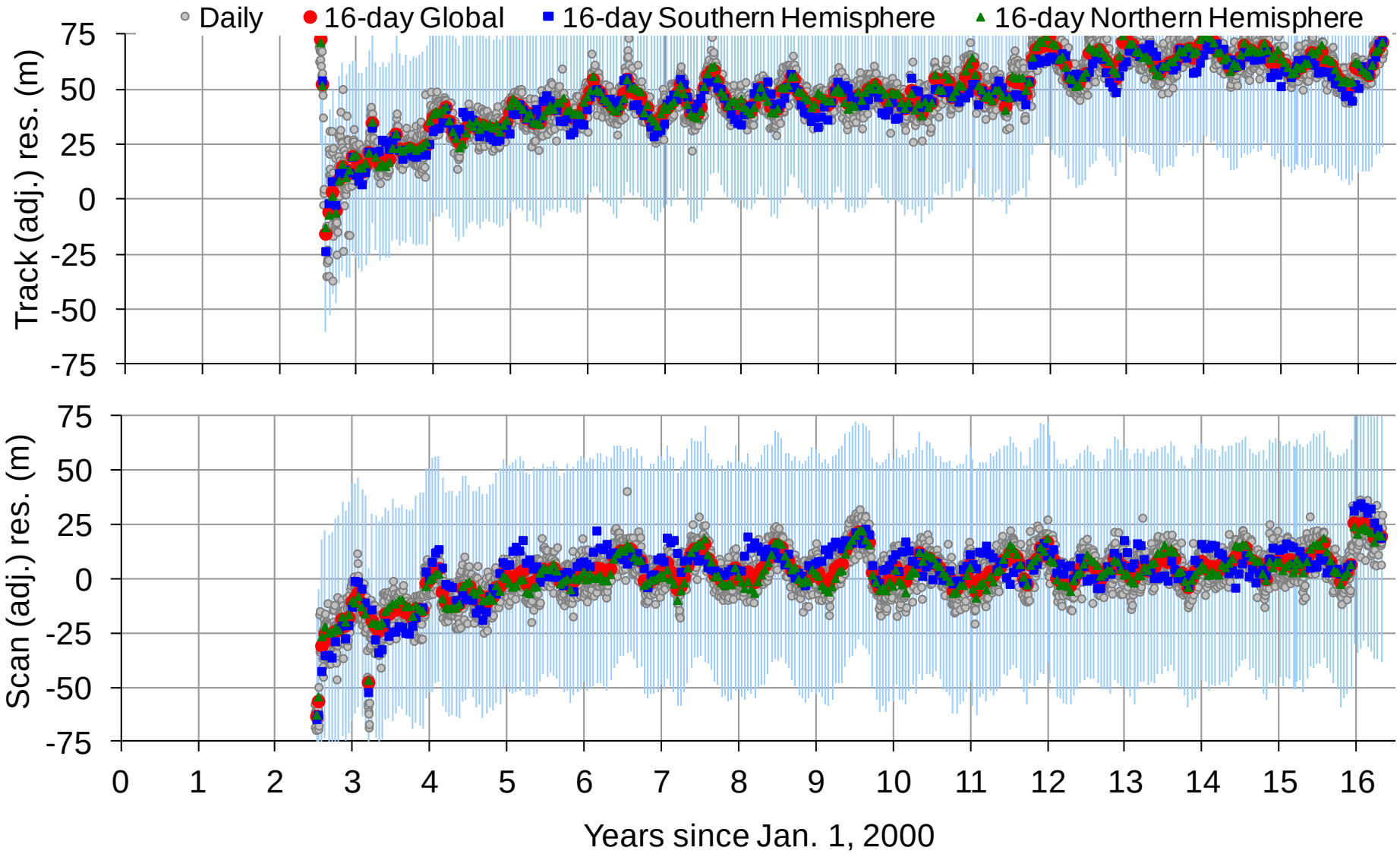
# Terra Safe Hold




- Pointing/geolocation look ok after re-activation

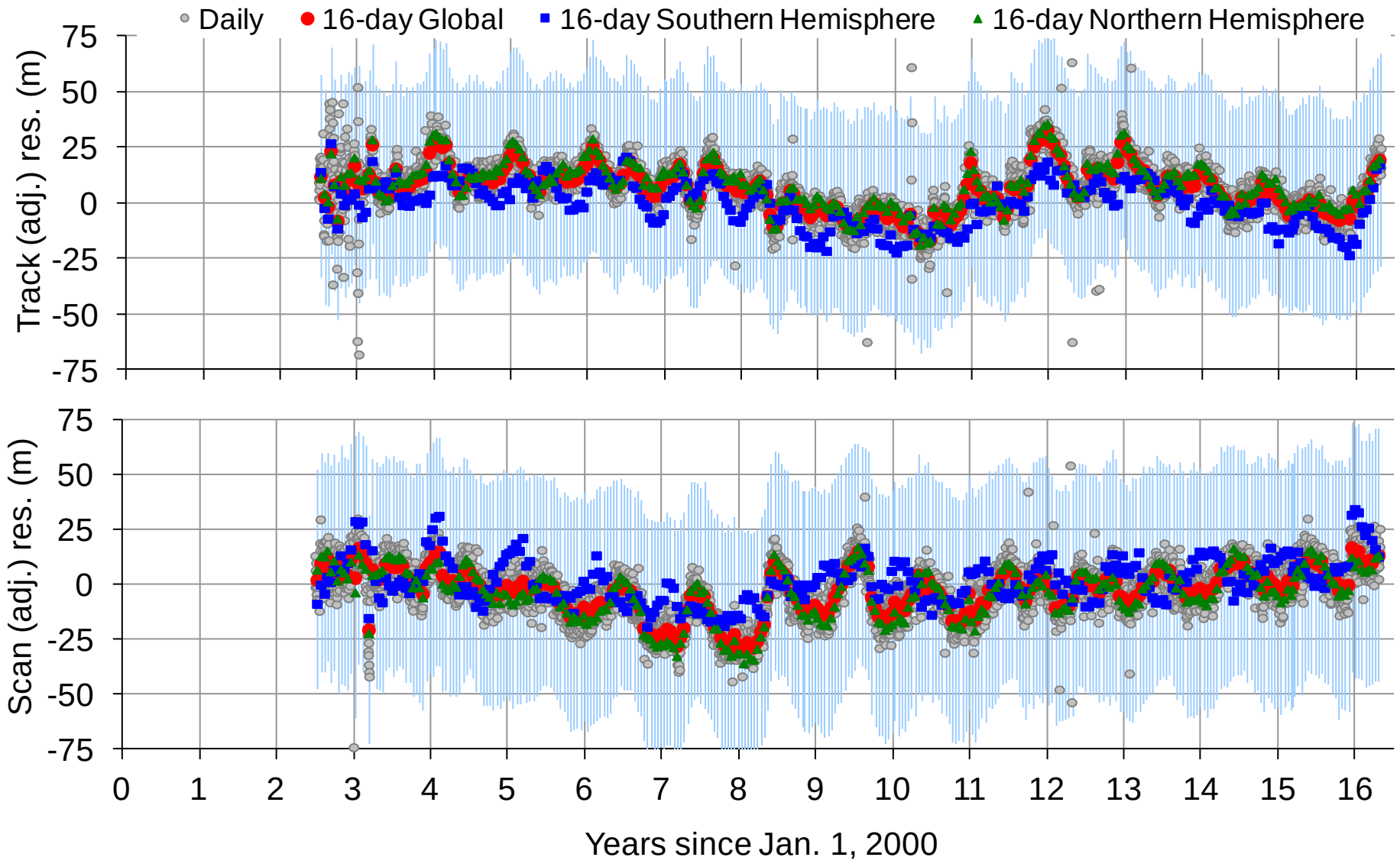
# Aqua trend and update details

# Aqua C6 Long-term Trend (unorrected)



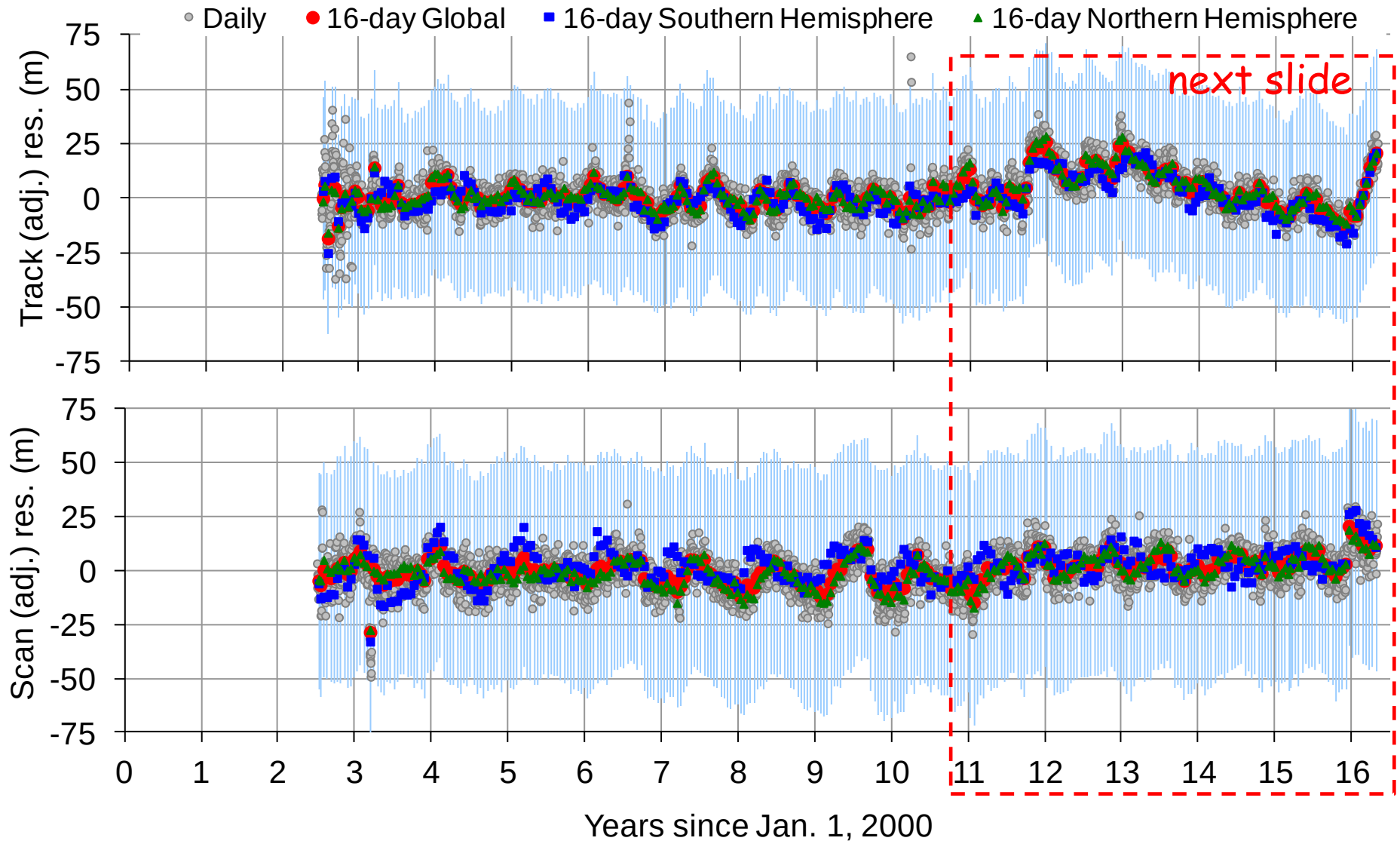

RMSE with no correction: Track: 68 m (+22 m vs C6) Scan: 54 m (+1 m vs C6)

# Actual Aqua C5 residuals



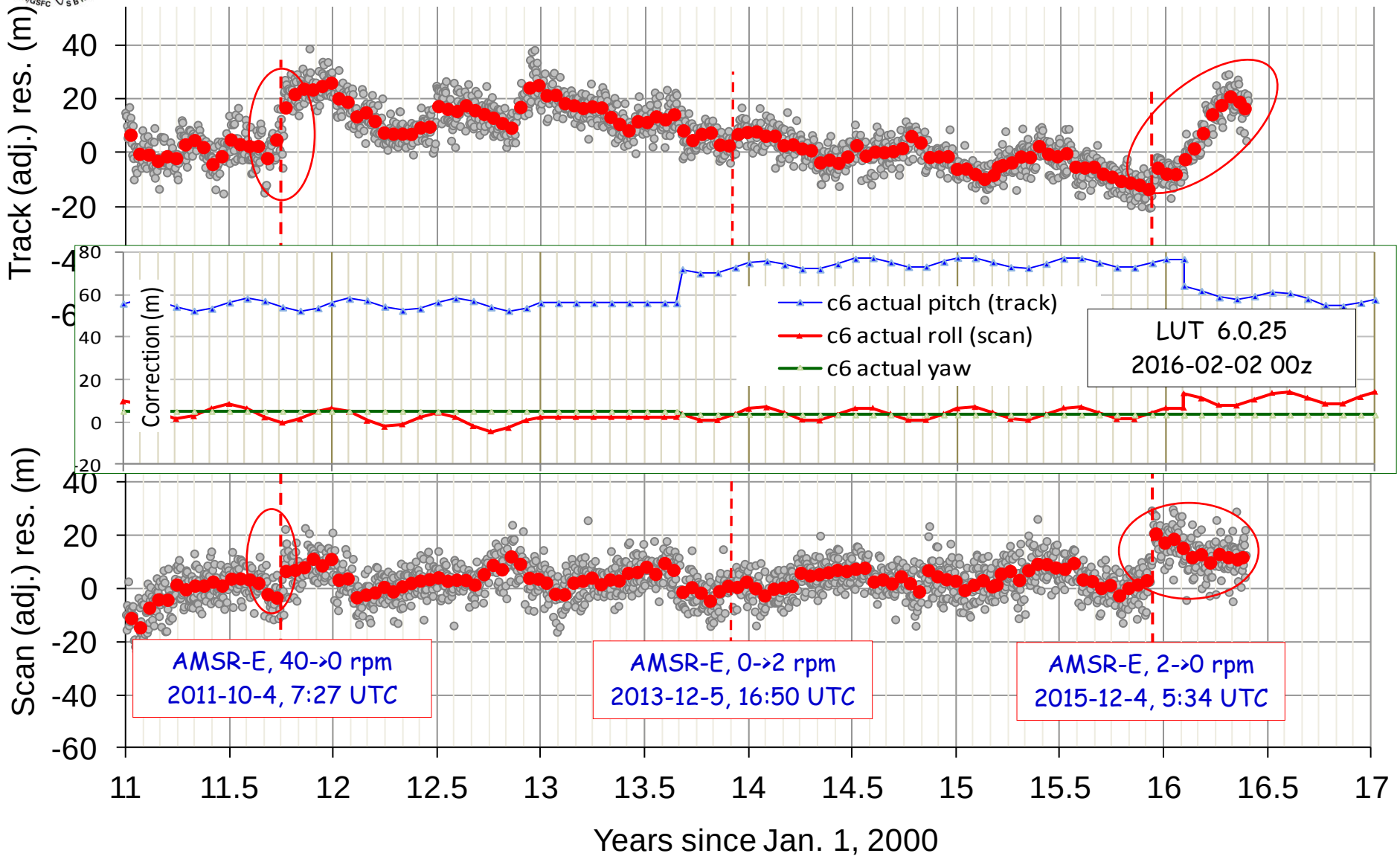

C5 RMSE Track: 47 m, Scan: 53 m, nadir equivalent

# Actual Aqua C6 residuals




C6 RMSE Track: 46 m, Scan: 53 m, nadir equivalent

# Effects of AMSR-E (in)activities




- LUT update soon (shown here are plots from C6)

# Future work

1) Routine monitor and LUTs update as needed
2) Update to correct AMSR-E effects in Aqua geolocation from late 2011
3) C7 update?
4) Update of Landsat ground control point chip library

# Concluding Remarks

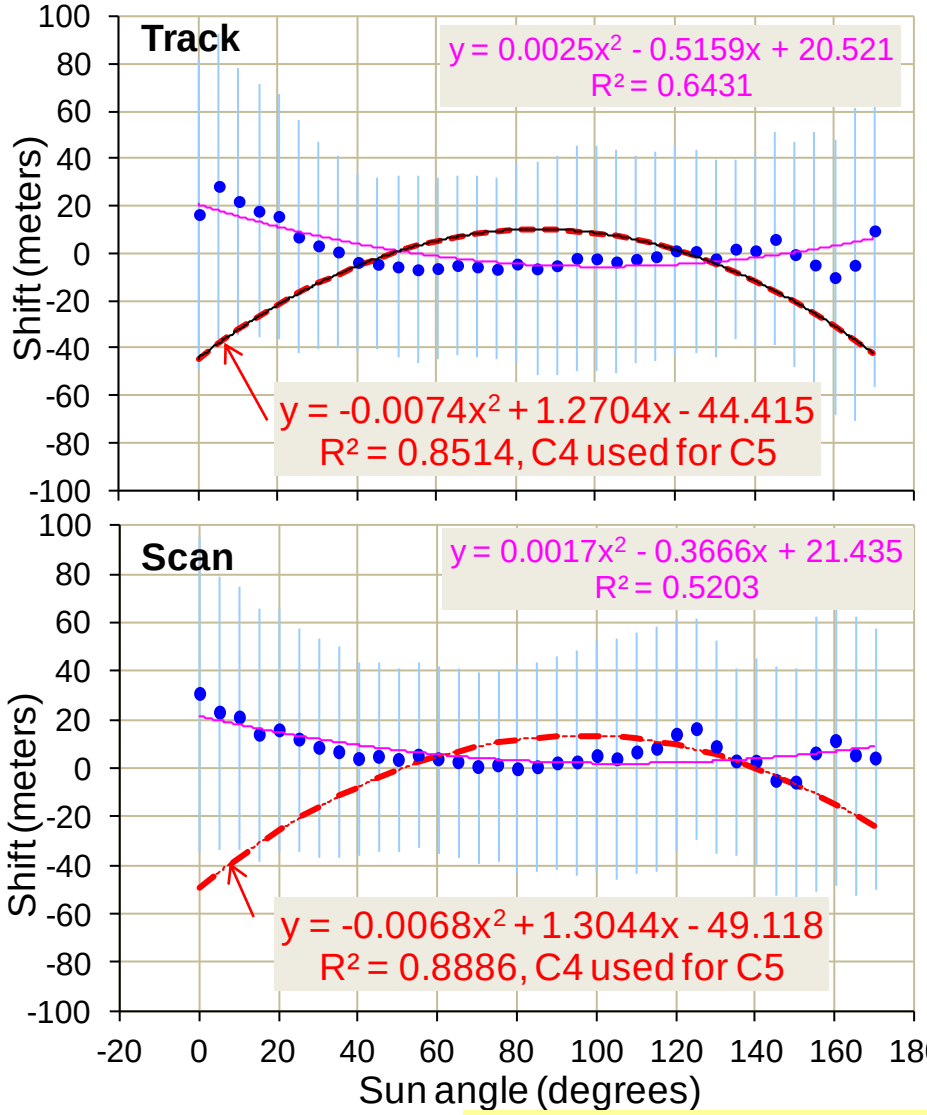
| Residuals | Terra C5 | Aqua C5 | Terra C6 | Aqua C6 | VIIRS C1.1 |
|---|---|---|---|---|---|
| Track mean | **-1 m** | **7 m** | **2 m** | **2 m** | 8 m |
| Scan mean | **5 m** | **-3 m** | **-1 m** | **0 m** | 5 m |
| Track RMSE | **44 m** | **47 m** | **43 m** | **46 m** | 72 m |
| Scan RMSE | **44 m** | **53 m** | **44 m** | **53 m** | 61 m |
| Data-days | **5777 (15.8 yrs)** | **4951 (13.6 yrs)** | **5849 (16.0 yrs)** | **5040 (13.8 yrs)** | 1566 (4.3 yrs) |
| Missing days | **134** | **99** | **62** | **10** | 1 |
| Daily matched GCPs w/ B1/I1 | **260** | **224** | **218** | **189** | 130 |

- **Nadir equivalent** accuracy (RMSE – Root Mean Square Error)
  - Mostly within 20% band B1 HSI (250 m) = 50 m @ nadir ;
  - Within 10 % for HKM bands and 5% for KM bands
    - Band-to-band mis-registration adds bias to RMSE to other bands: $RMSE = \sqrt{\sigma^2 + \mu^2}$
- Other features for MODIS geolocation
  - Aqua uses definitive ephemeris data → 27 hour latency (Terra uses TDRSS-based on-board ephemeris)
  - C6 uses 0.5 km resolution DEM for terrain corrections (C5 uses older 1 km DEM, same as the VIIRS), plus other improvements over C5

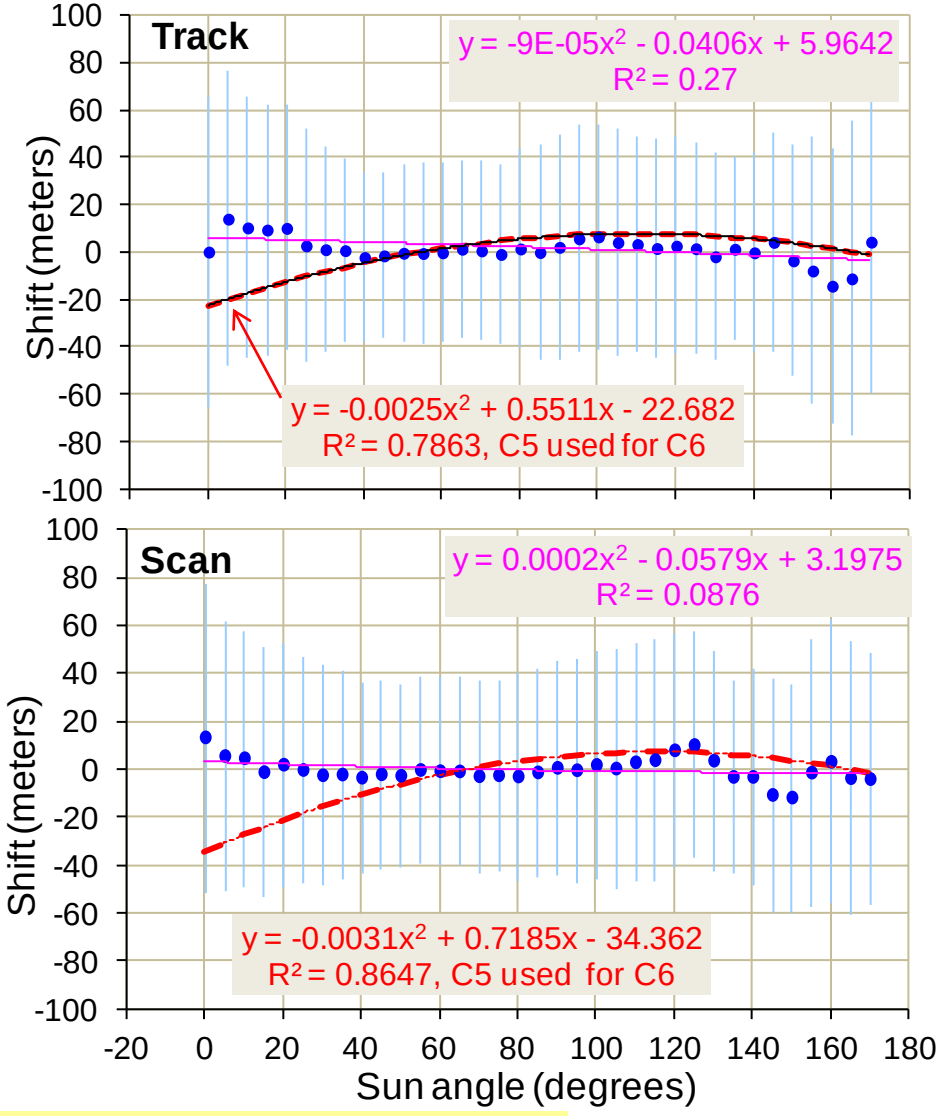
# Backup slides:
# sun angle dependent Residuals

# Terra Sun angle Correction

## C5 results



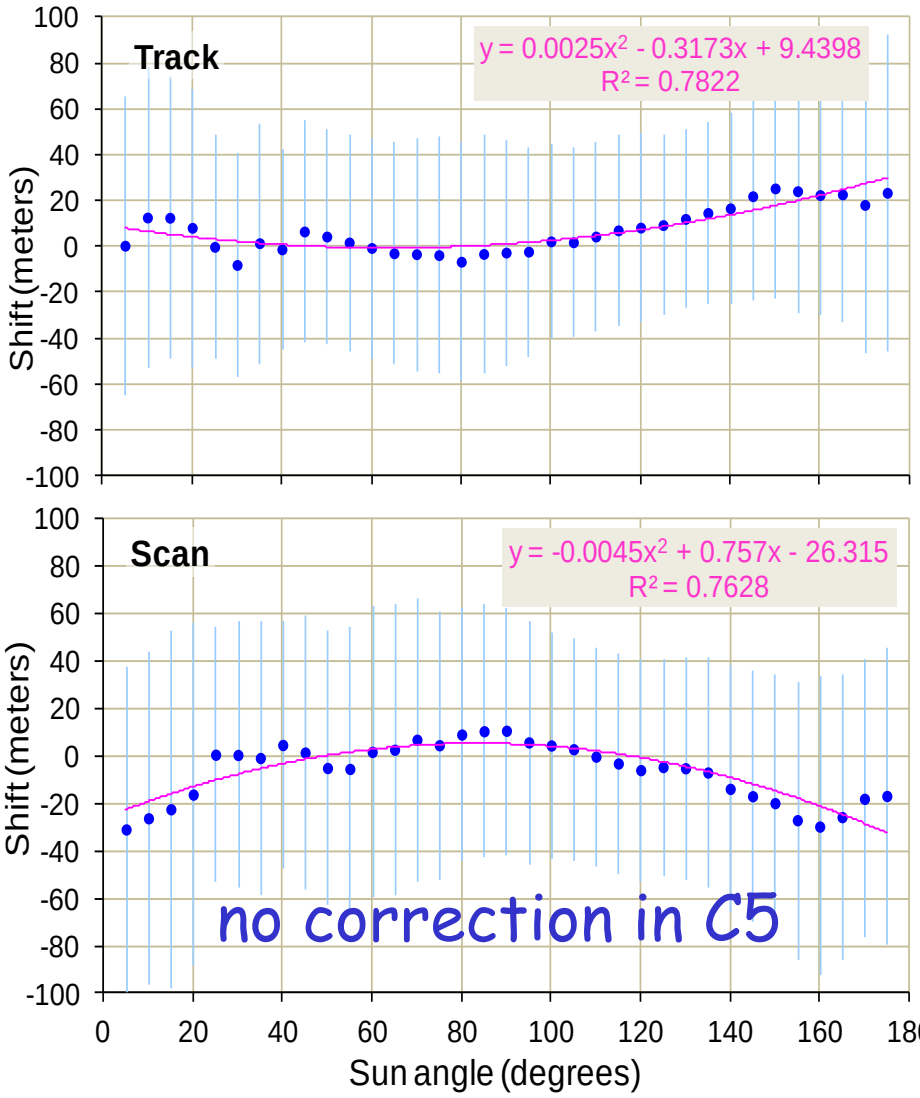

## C6 results



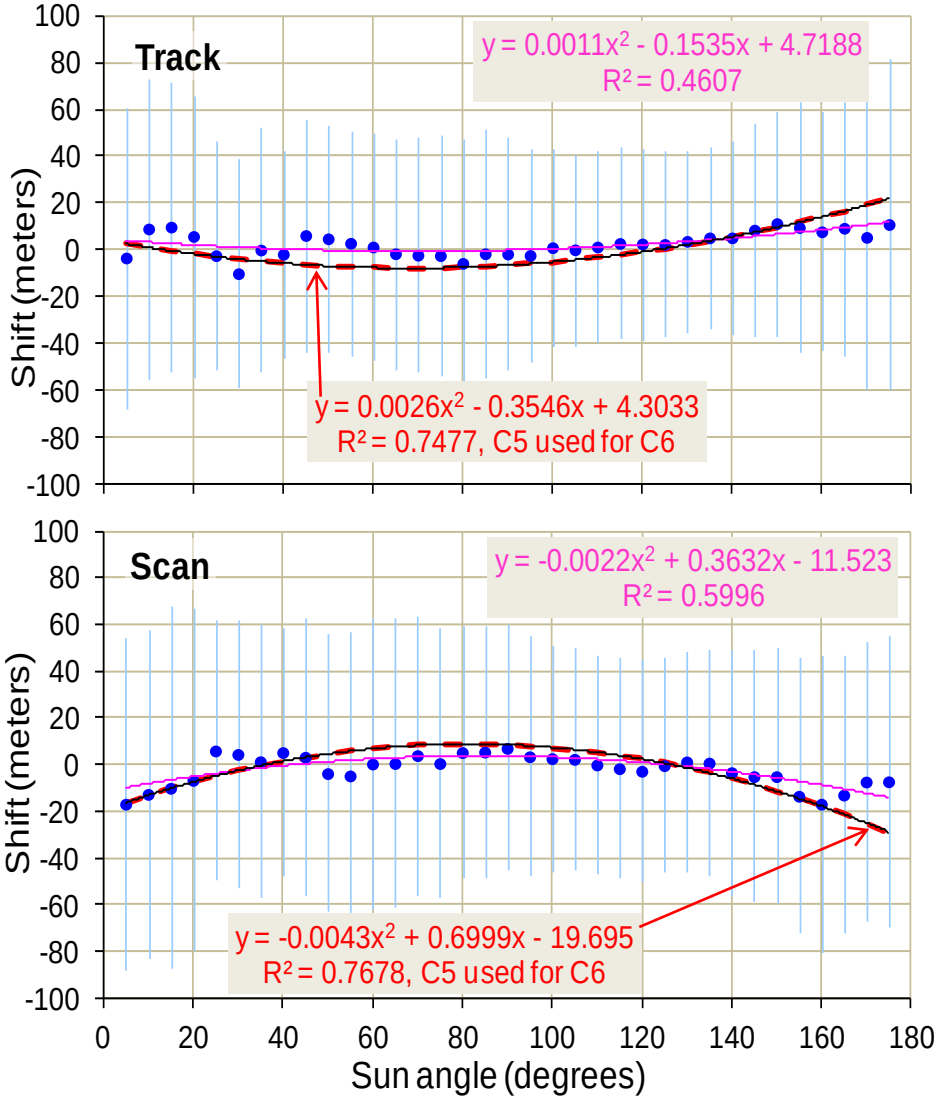

Small overcorrection in C5 – was corrected in C6

# Aqua Sun angle Correction

## C5 results




## C6 results



# (SNPP+J1) VIIRS Geolocation Status

NASA VIIRS Characterization Support Team (VCST)
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NASA MODIS/VIIRS STM Calibration Workshop
Silver Spring, Maryland
18 May 2015 → **6 June 2016**

# Acknowledgements


- Thanks Carol Davidson & her Land SIPS (formerly Land PEATE) Team for processing control point residuals and possible two line element (TLE) use from both IDPS and LSIPS forward-&re-processed VIIRS geolocation products, and testing Geo LUTs updates

- Thanks Geo JAMs -- Robert Williamson (now moved on) & Rosalie Marley -- for helping us resolving DRs in the AMP (formally DPA) at the GRAVITE

- Thanks Fred Patt of NASA Ocean Group for helping us resolving issues related to ephemeris and attitude data

# Outline

- Geolocation Performance and Trends
  - I- & M-bands geolocation
  - DNB geolocation, up to ~ 9/1/2013
- Remaining issues, concerns and challenges
- Some expectations of J1 VIIRS
- Conclusions

# Overall Geolocation Performance

| Residuals | IDPS | Land SIPS C1.1 | Aqua MODIS C6 | Terra MODIS C6 |
|---|---|---|---|---|
| Track mean | -1 m | **8 m** | 2 m | 2 m |
| Scan mean | -1 m | **5 m** | 0 m | -1 m |
| Track RMSE | 75 m | **72 m** | 46 m | 43 m |
| Scan RMSE | 61 m | **61 m** | 53 m | 44 m |
| Data-days | 1127 (3.1 yrs) | **1566 (4.3 yrs)** | 5040 (13.8 yrs) | 5849 (16.0 yrs) |
| Missing days | 21 | **1** | 10 | 62 |
| Daily matched GCPs w/ I1/B1 | 130 | **130** | 189 | 218 |

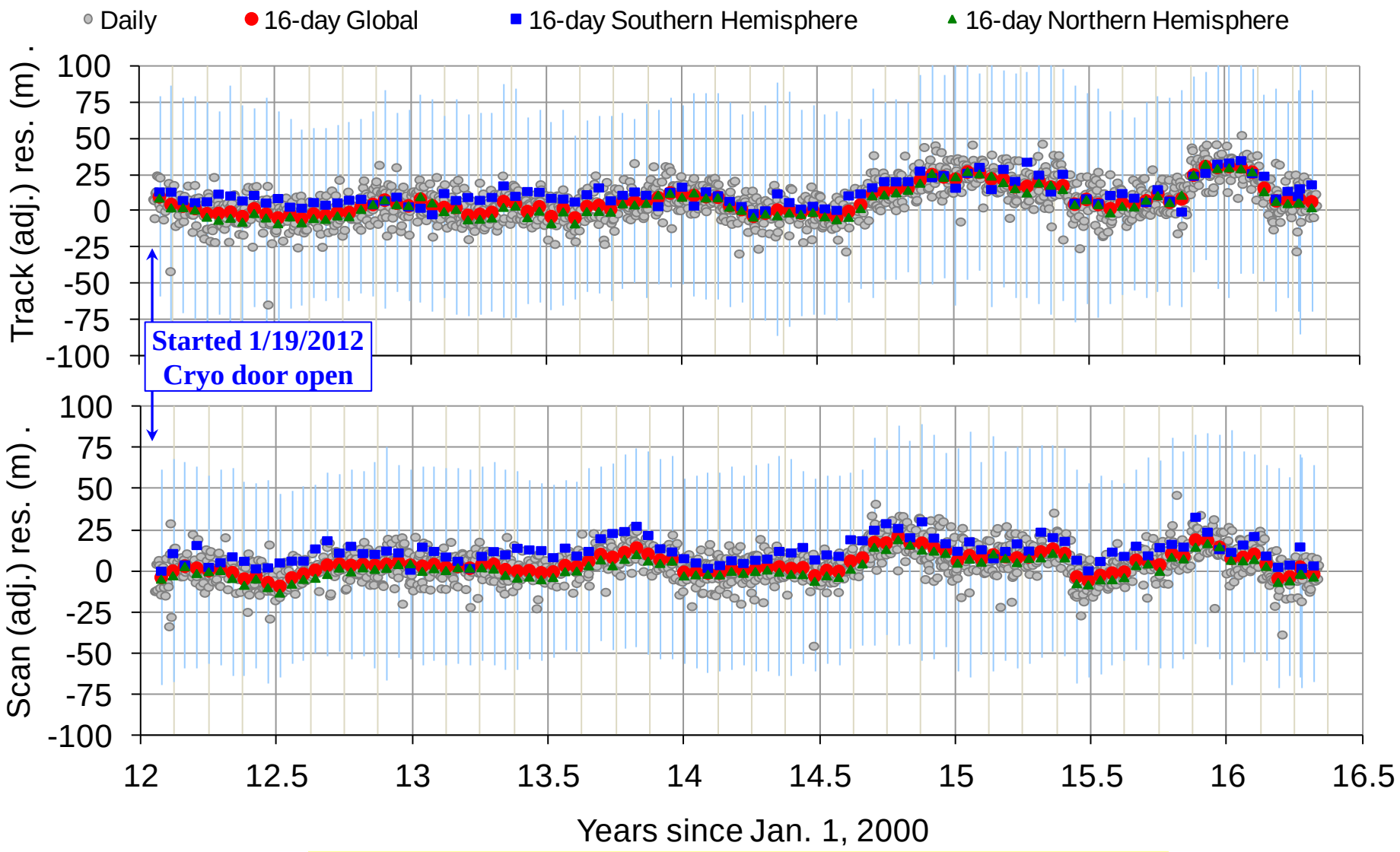
- **Nadir equivalent** accuracy (RMSE – Root Mean Square Error) . (MODIS for reference)
  - Meet Spec: 133 m (1σ); **within 20% I1 HSI (375 m) = 75 m @ nadir for VIIRS**
  - Band-to-band mis-registration adds bias to RMSE to other bands**:** $RMSE = \sqrt{\sigma^2 + \mu^2}$
  - Land PEATE/SIPS time period: 19 Jan 2012 to 3 May 2016
- MODIS – VIIRS differences

  Aqua use definitive ephemeris data → 27 hour latency

  SNPP attitude data is not as good, see Slides10 & 11

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

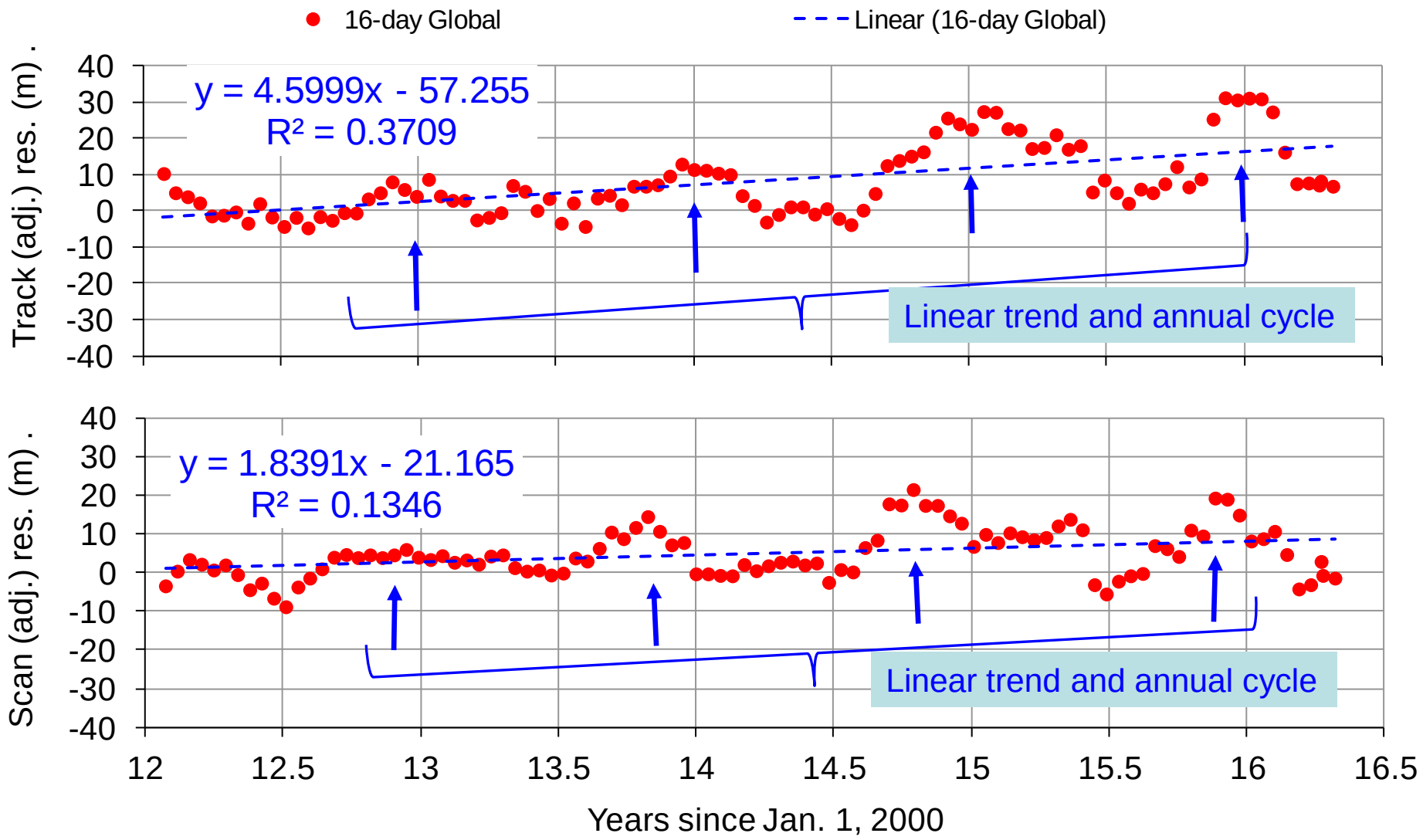
# NASA LSIPS C1.1 geolocation errors




C1.1 RMSE Track: 72 m Scan: 61 m, nadir equivalent

Lin et al., 6 June 2016

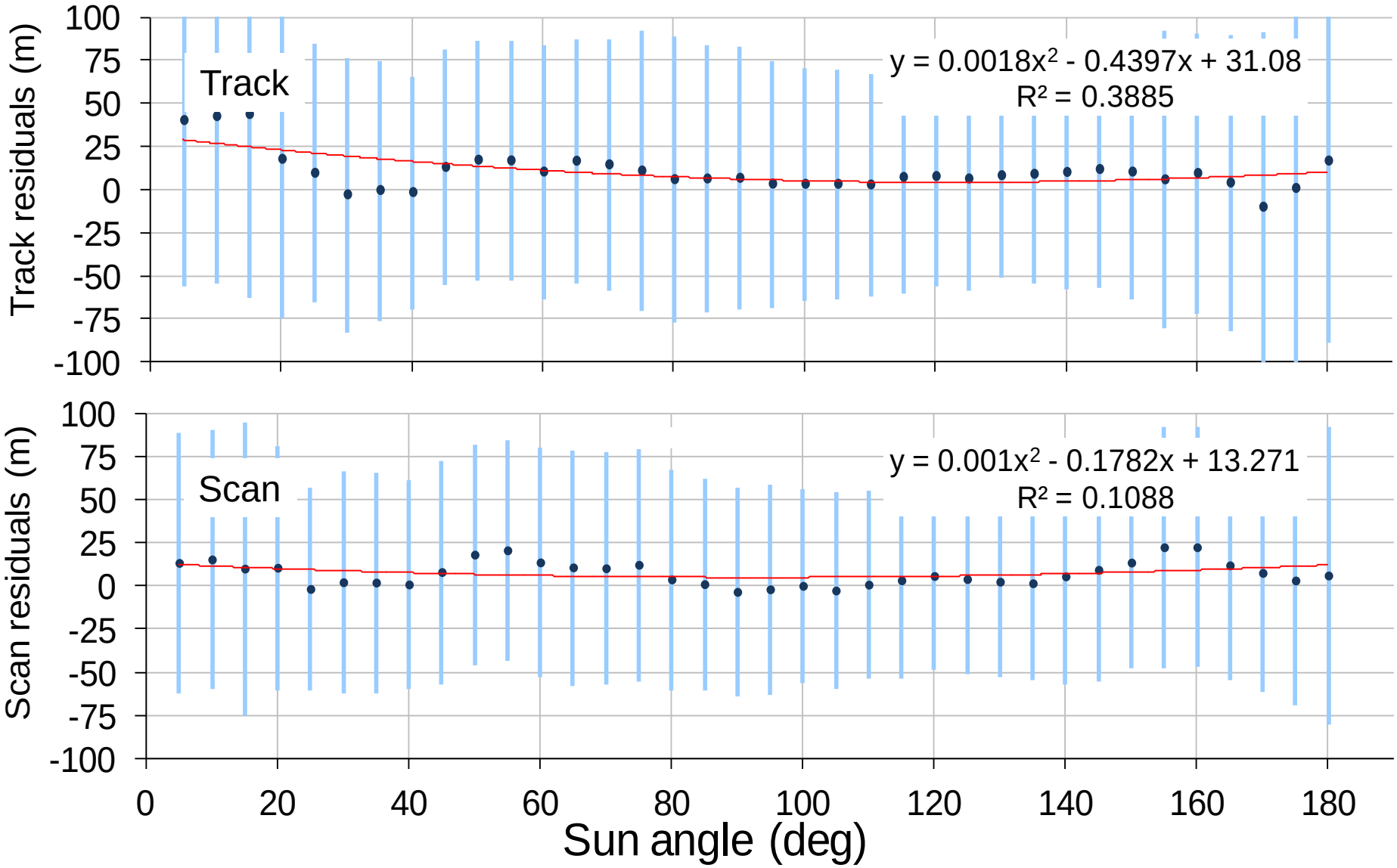
# Possible Long-Term Trending and Correction




Land SIPS Re-processed, will be corrected

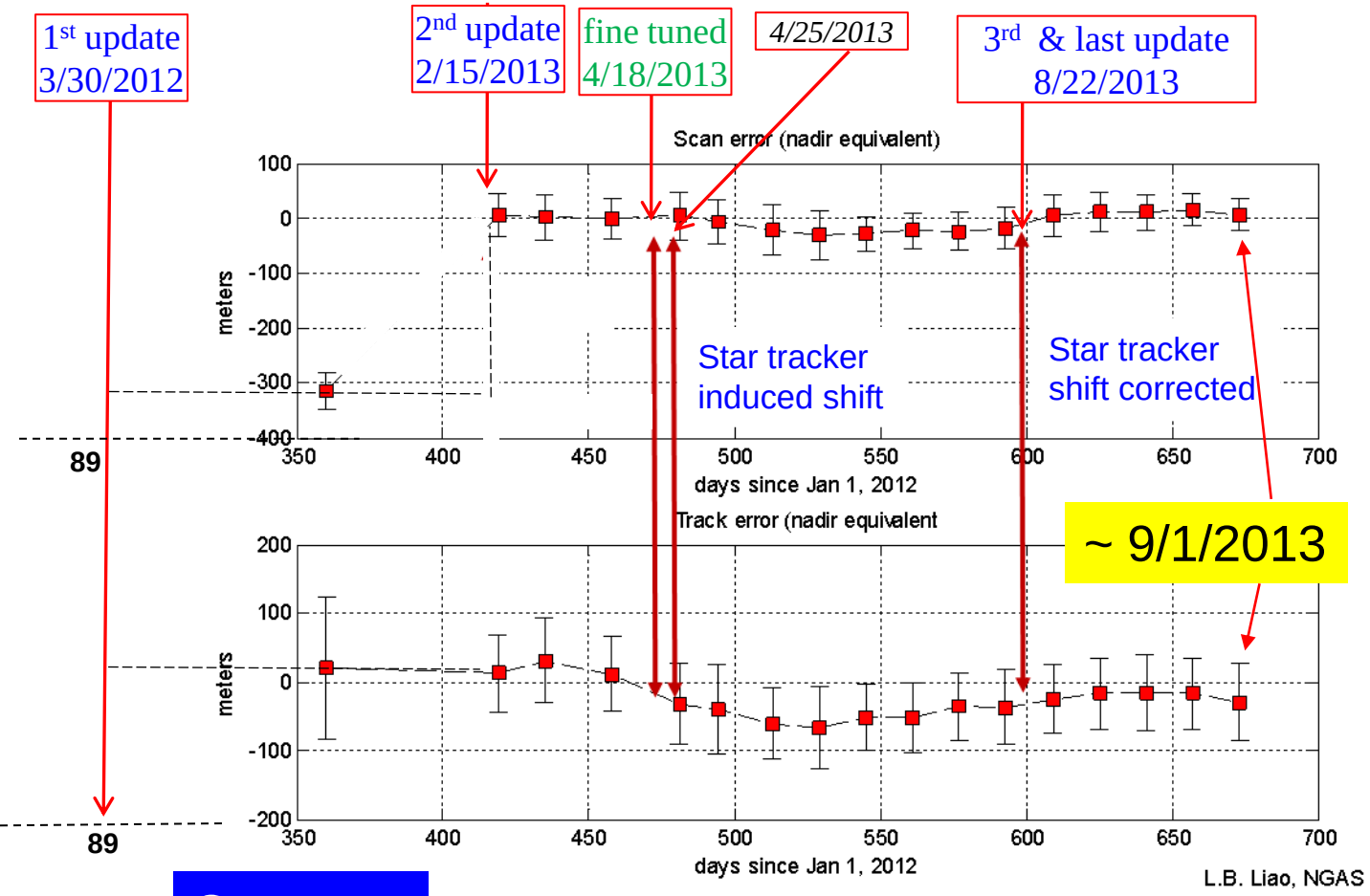
Lin et al., 6 June 2016

# VIIRS Sun Angle Residuals




Land SIPS Re-processed, will be corrected

# DNB geolocation error trending based on coastal area GCP matching




- 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

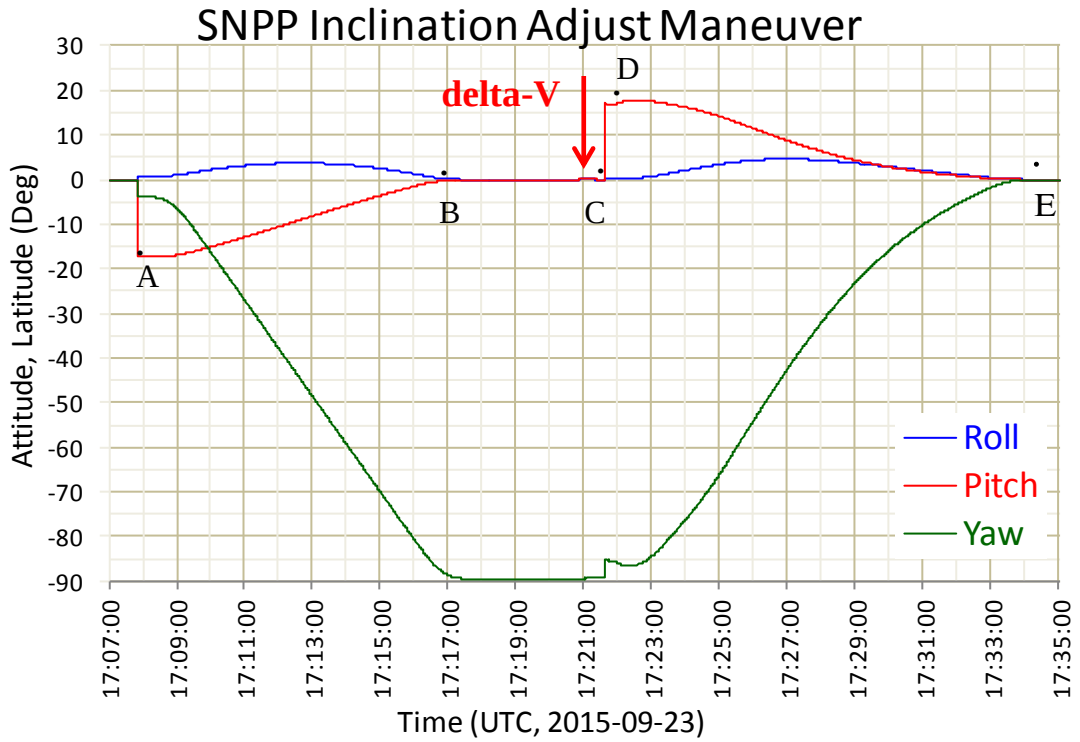
no more monitoring

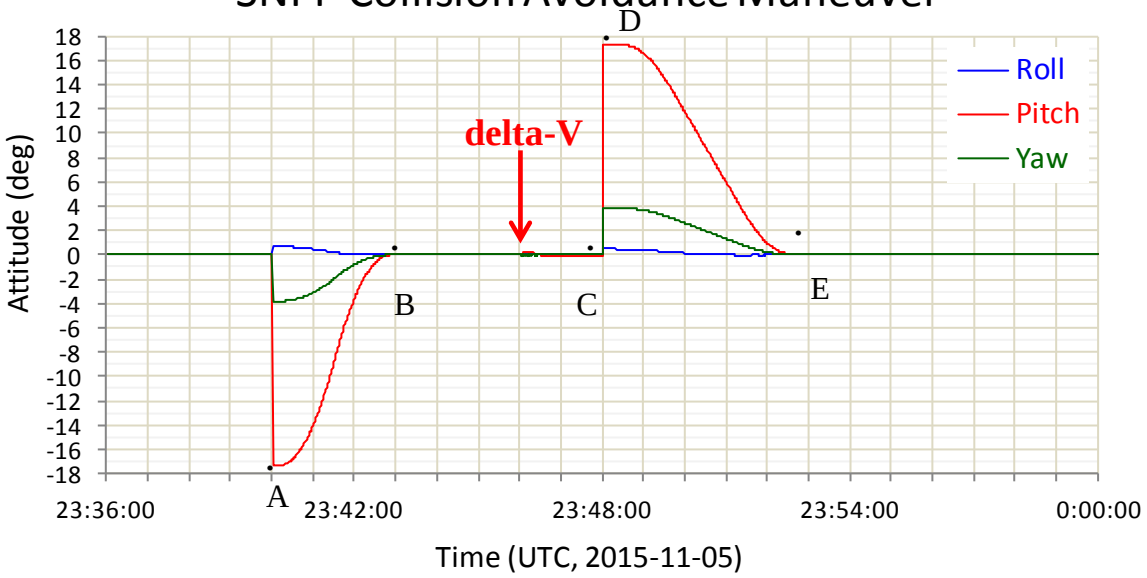
Courtesy of NGAS

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)

Lin et al., 6 June 2016

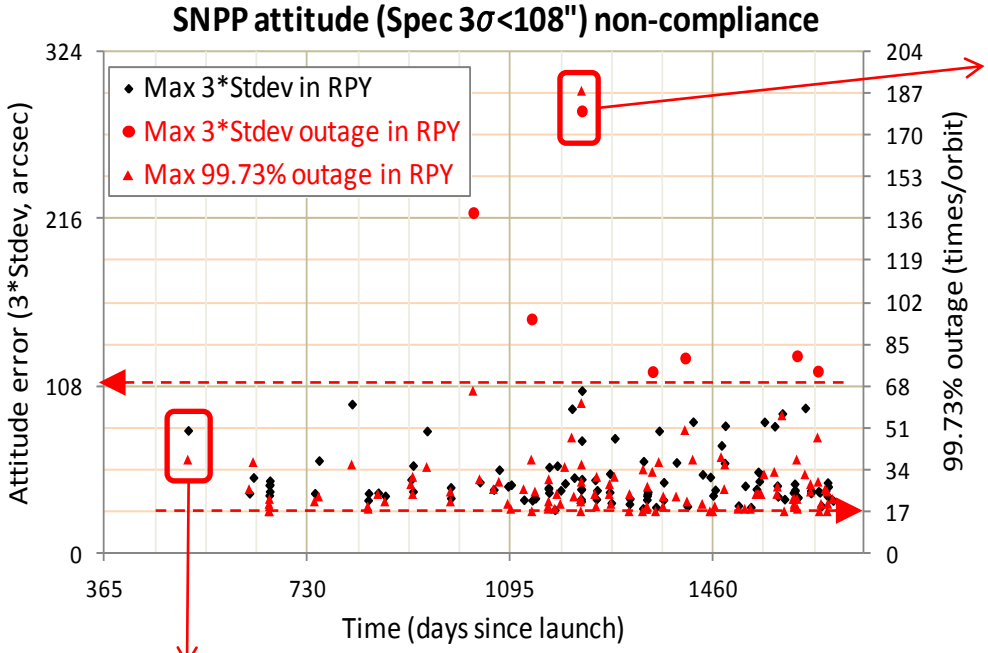
# “False” attitude reported during delta-V maneuvers

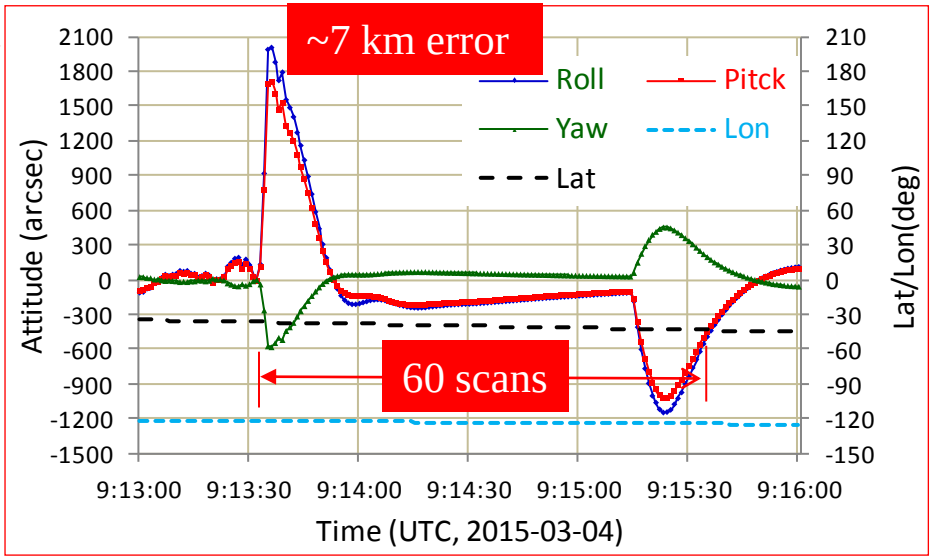


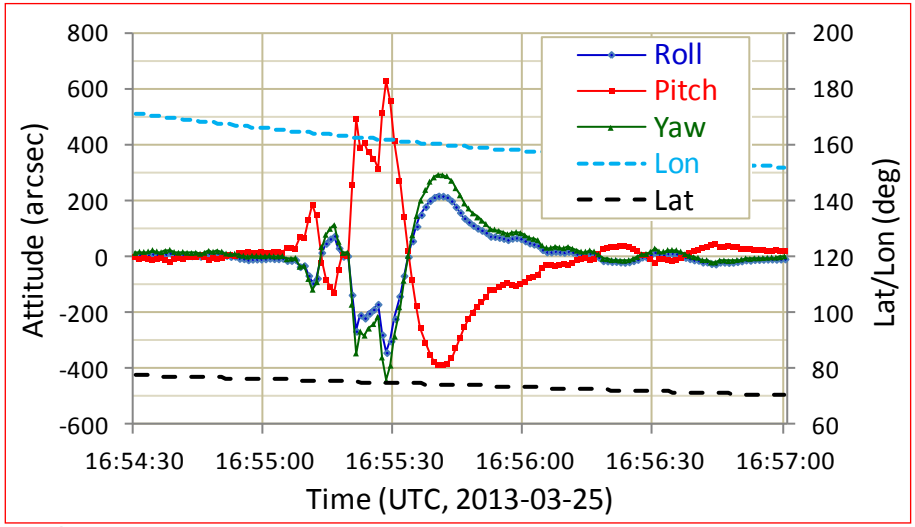




- On-orbit control reference frame is changed ~ 17 deg to orient the SC for thruster burns between points A & C.
- Geolocation error ~ 250 km between A & C
- We plan to mask the VIIRS geolocation with FILLs

# SNPP attitude issues



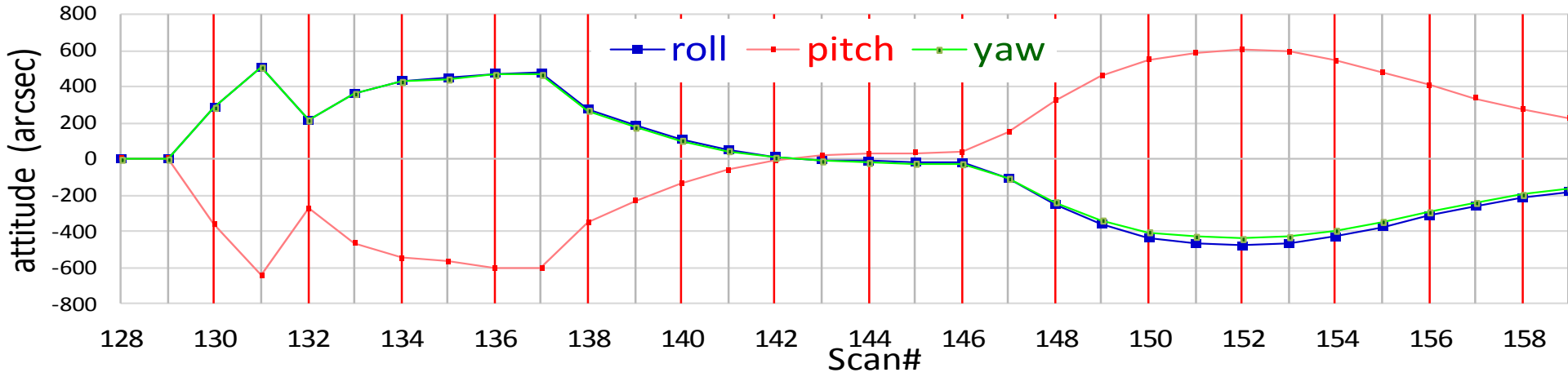




- SNPP attitude under-performed, in 99.73% interpretation of 3σ, as early as 2013-03-25
- The MOT is working with the Flight Project and the SC vendor to tune the star trackers
- We plan to flag/mask geolocation for 100 < |R, P, Y| < 1800 arcsec (> 1800 arcsec already has geolocation masked)

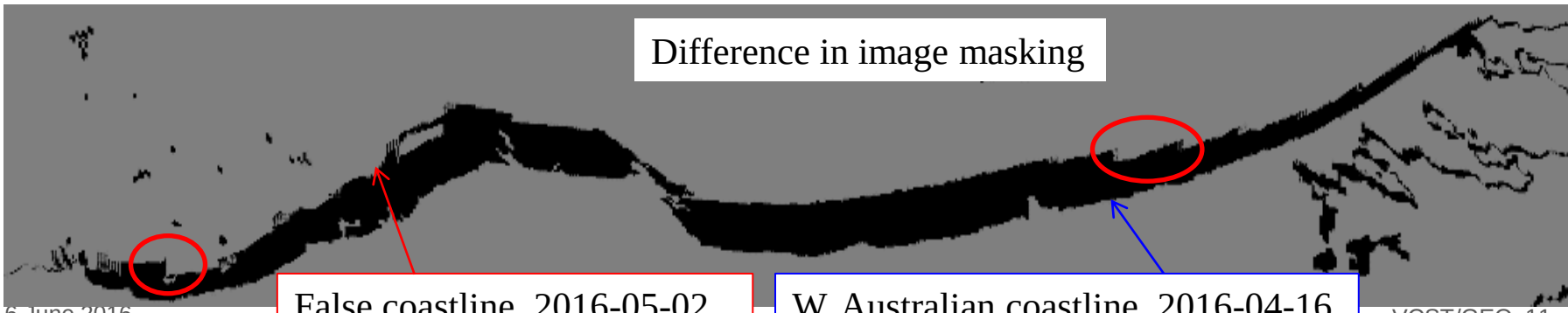
Thanks Fred Patt and NASA FDF for support

# Attitude error

## 2016-05-02 06:48:50 – 06:50:40z

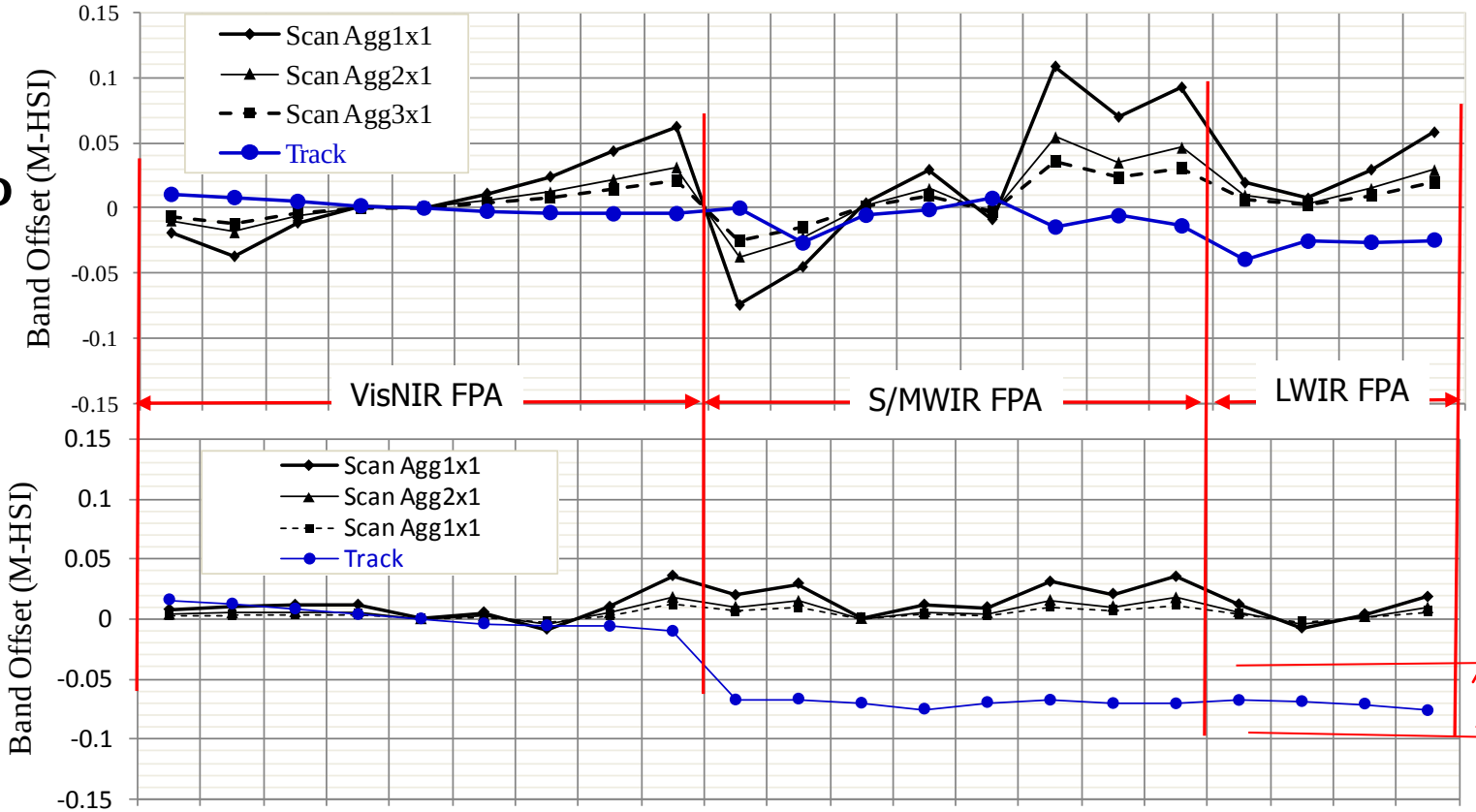






# J1 VIIRS M/I band offsets wrt I1

SNPP

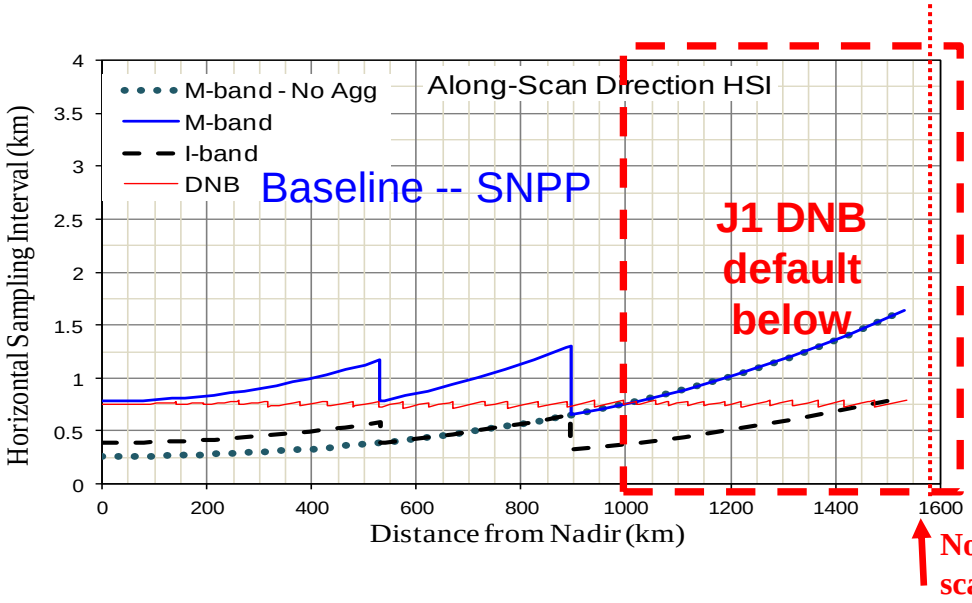



J1

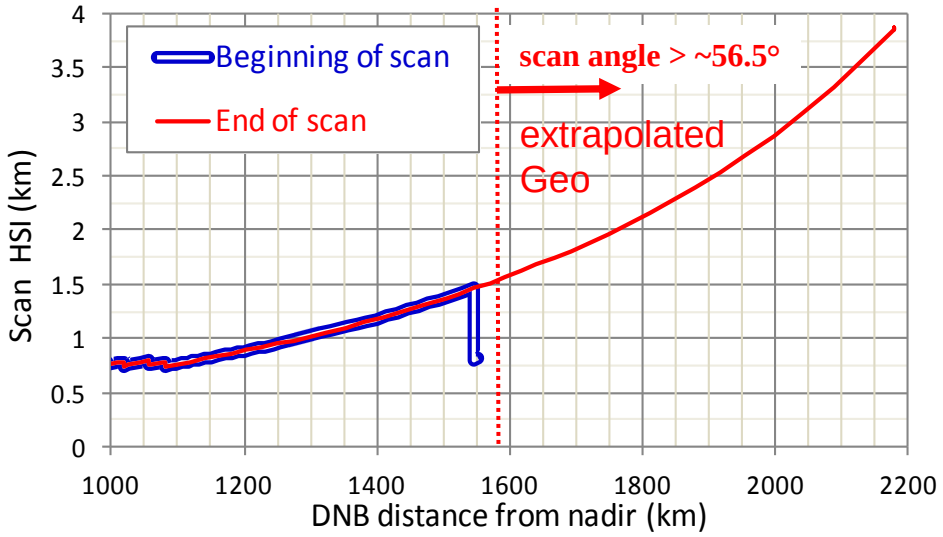



- J1 scan rate is nominal @3.517 rad/sec (SNPP 3.531)
- Overall BBR band pair performances are compatible between J1 and SNPP
- J1 Bands on SWMWIR and LWIR FPAs shifted from bands on VisNIR FPA, ~ 7% for M-bands and ~ 14% for I-bands. Mapping uncertainties are affected $RMSE = \sqrt{\sigma^2 + \mu^2}$

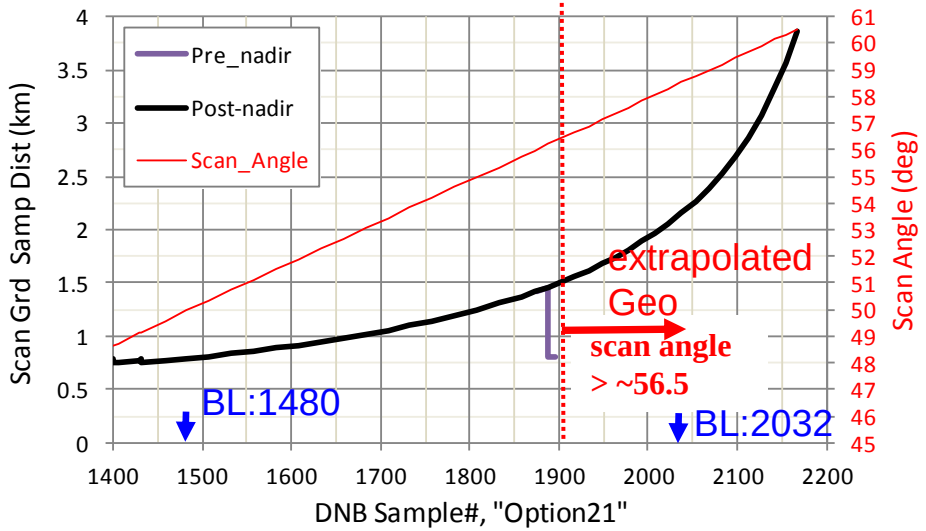
# J1 DNB Geometric Performance




- 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°)




"Option21" – default, in km



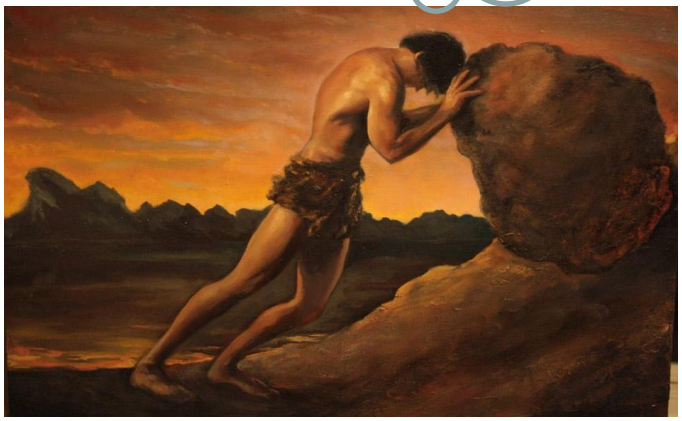

"Option21" – default, in Samp#

# Conclusions

- SNPP VIIRS geolocation performance is good
  - The attitude system underperforms, geolocation error of 7 km occurred occasionally. Attitude/star trackers need maintenance.
- Geolocation mean errors for I- & M-bands are near 0 and uncertainties are ~ 70 m at nadir, statistically
  - Caveat: DNB geolocation errors are not monitored after ~9/1/2013
- J1 geolocation expectations
  - Bands on VisNIR FPA should be good; Bands on cold FPAs will be ~ 50 m off in the track direction
  - DNB geolocation pixels will be larger beyond S#1480, 1100 km off nadir
  - DNB geolocation accuracy will be TBD

# Questions?

- Do random variables exist?
- Where can we find biases & remove them?
- What do we mean by “mean values?”
  - in what time/spatial scales?
  - in any functional forms?
- Is ergodicity a fair assumption?



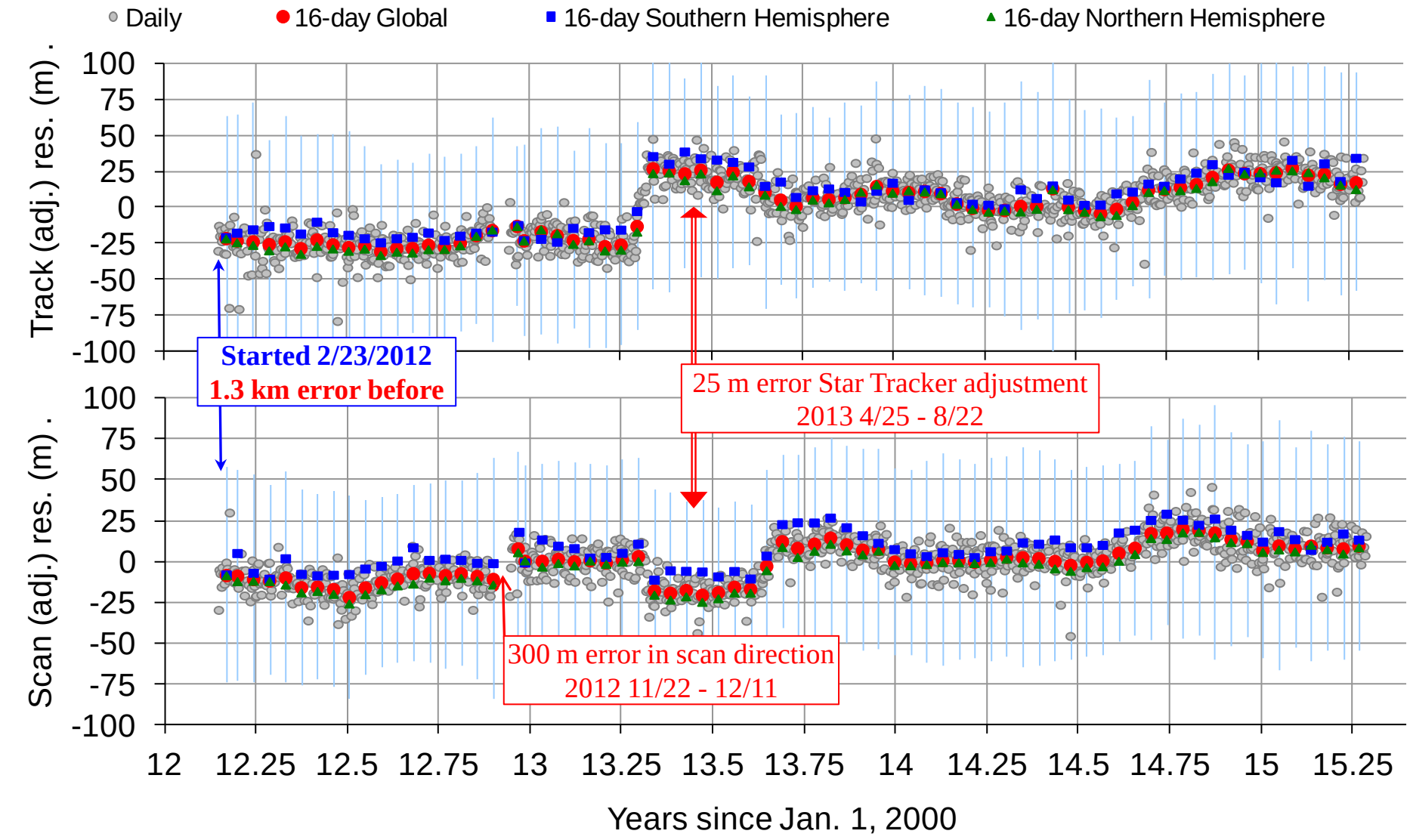
# Backup Slides

# On-orbit Geolocation LUT Updates

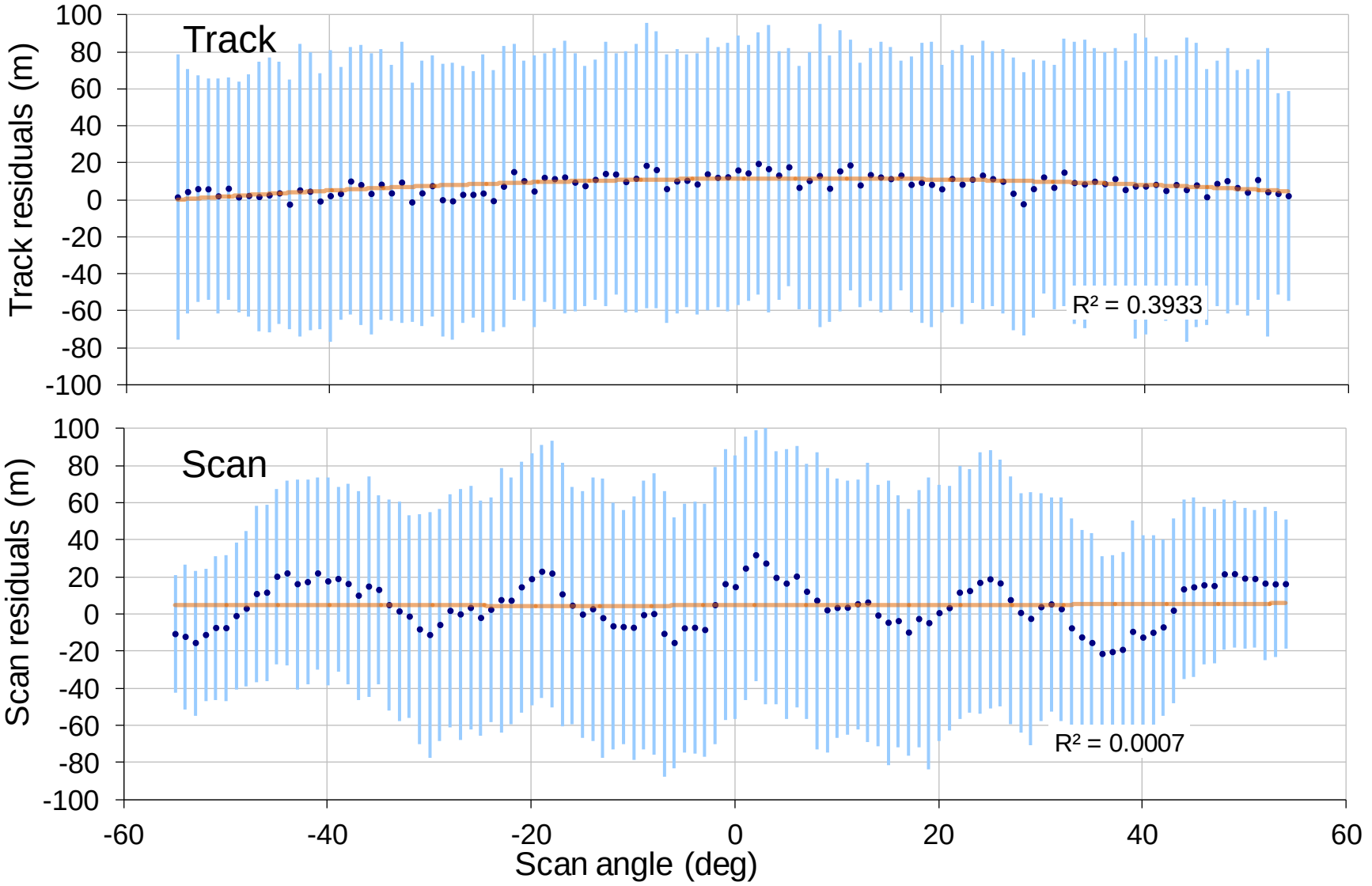
| Update | Date | Description | Comments |
|---|---|---|---|
| a | *1/19/2012* | *Cryo-radiator door open* | *All VIIRS band available, LPEATE re-process start date* |
| 1 | 2/23/2012 | Initial mounting coef. update | Removed bias ~ 1.3 km |
| 2 | 3/30/2012 | Initial DNB FPA center update | Removed bias ~ 1 km |
| b | *11/22/2012* | *Scan control electronics (SCE) was switched from B-side to A-Side* | *Caused bias ~ 300 m* |
| 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*

# IDPS (NRT) geolocation errors



# VIIRS Scan Angle Residuals




Land SIPS Re-processed

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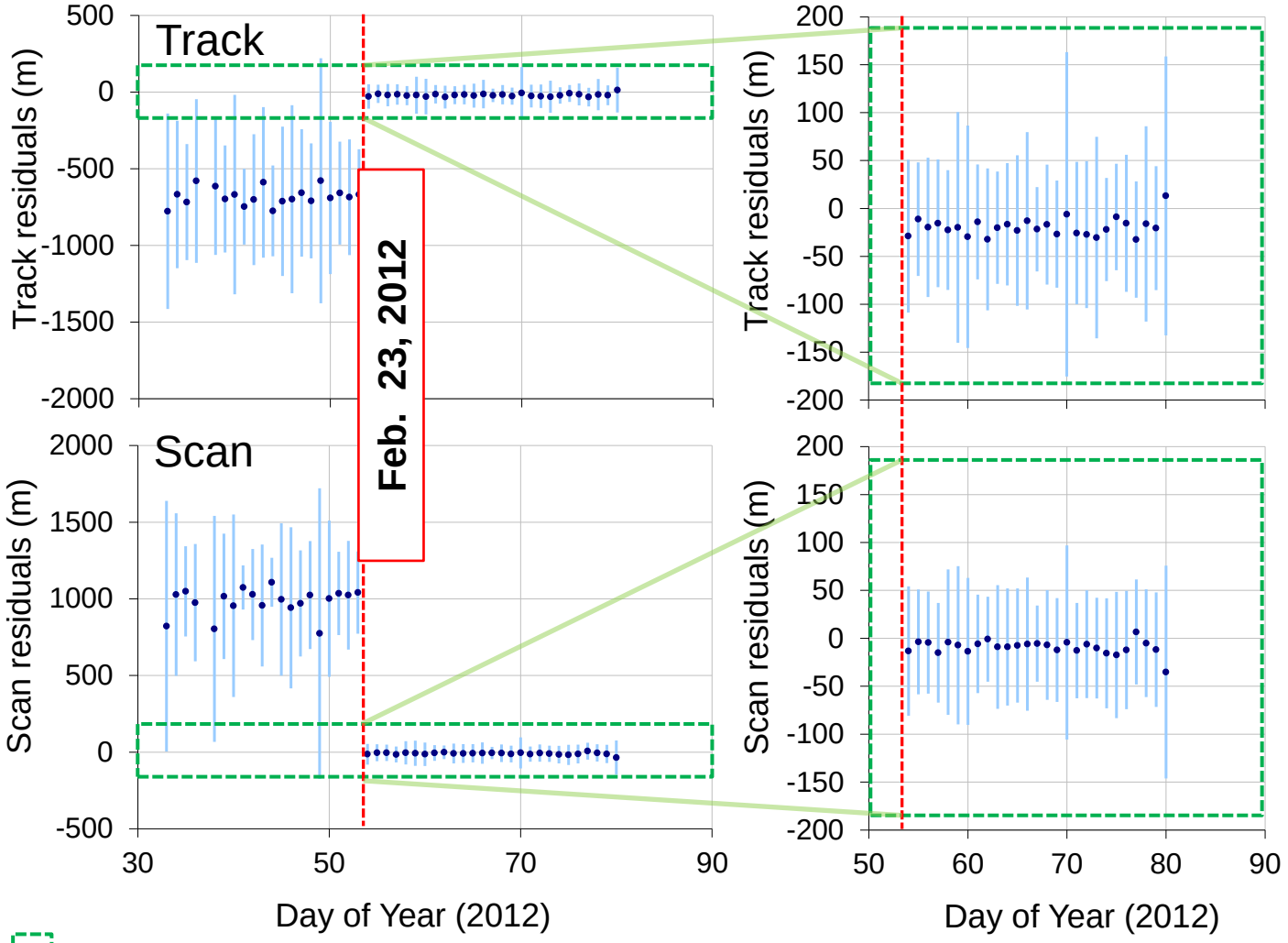
# Initial on-orbit geolocation LUTs Update




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

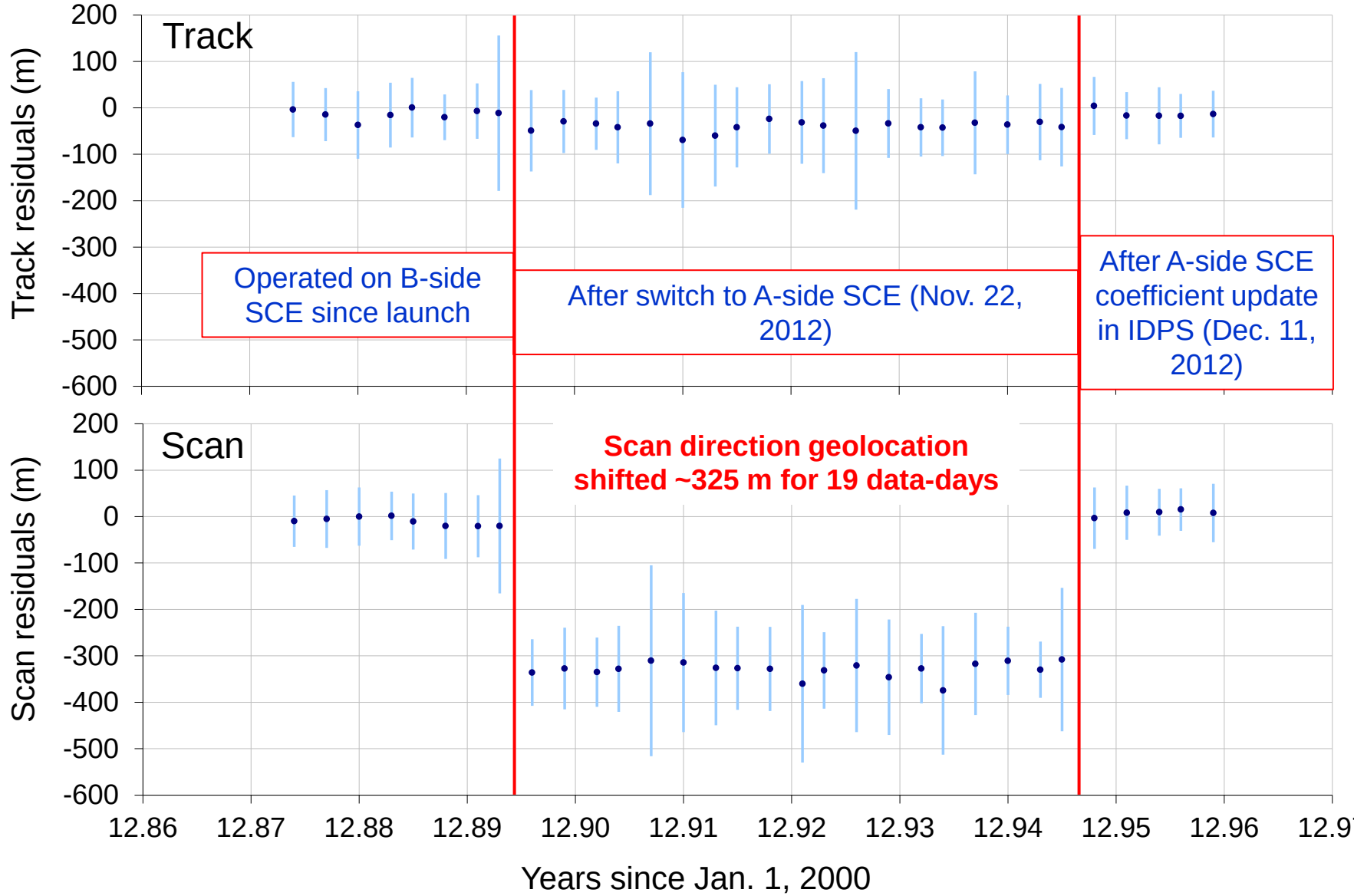
| | Bias (m) | RMSE (m) |
|---|---|---|
| Track | -21 | 80 |
| Scan | -8 | 64 |

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

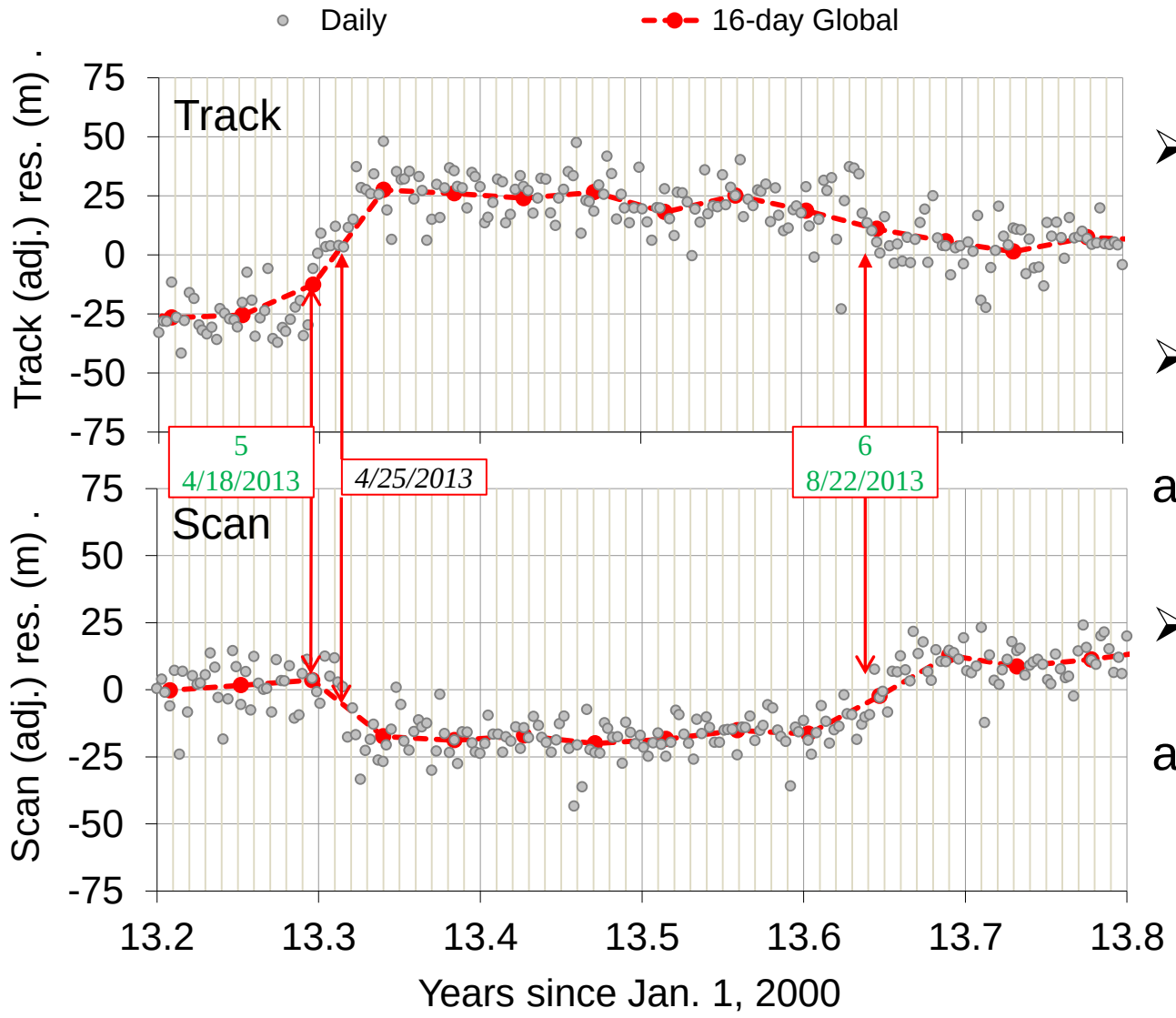
Nadir equivalent units;

**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

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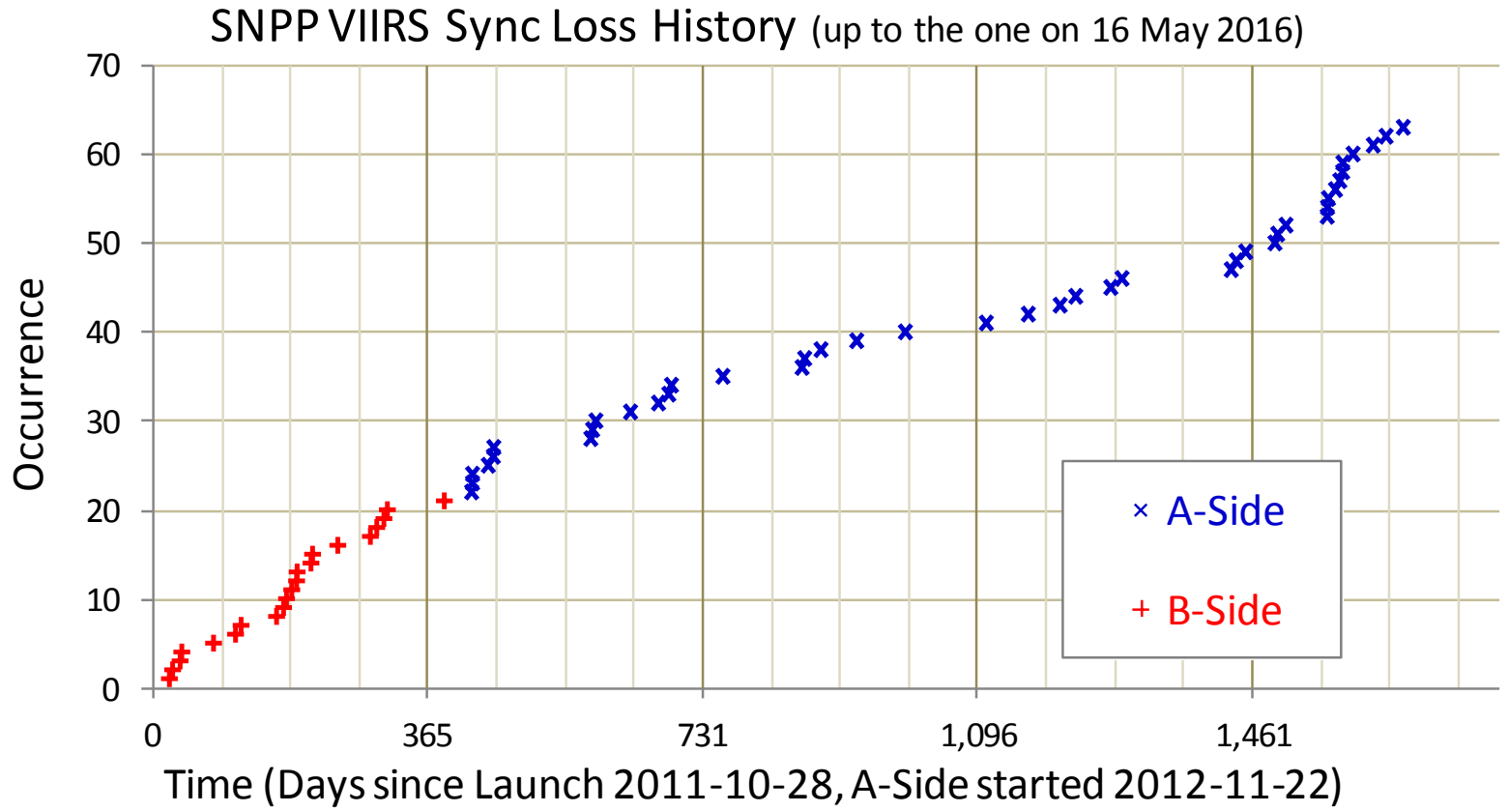
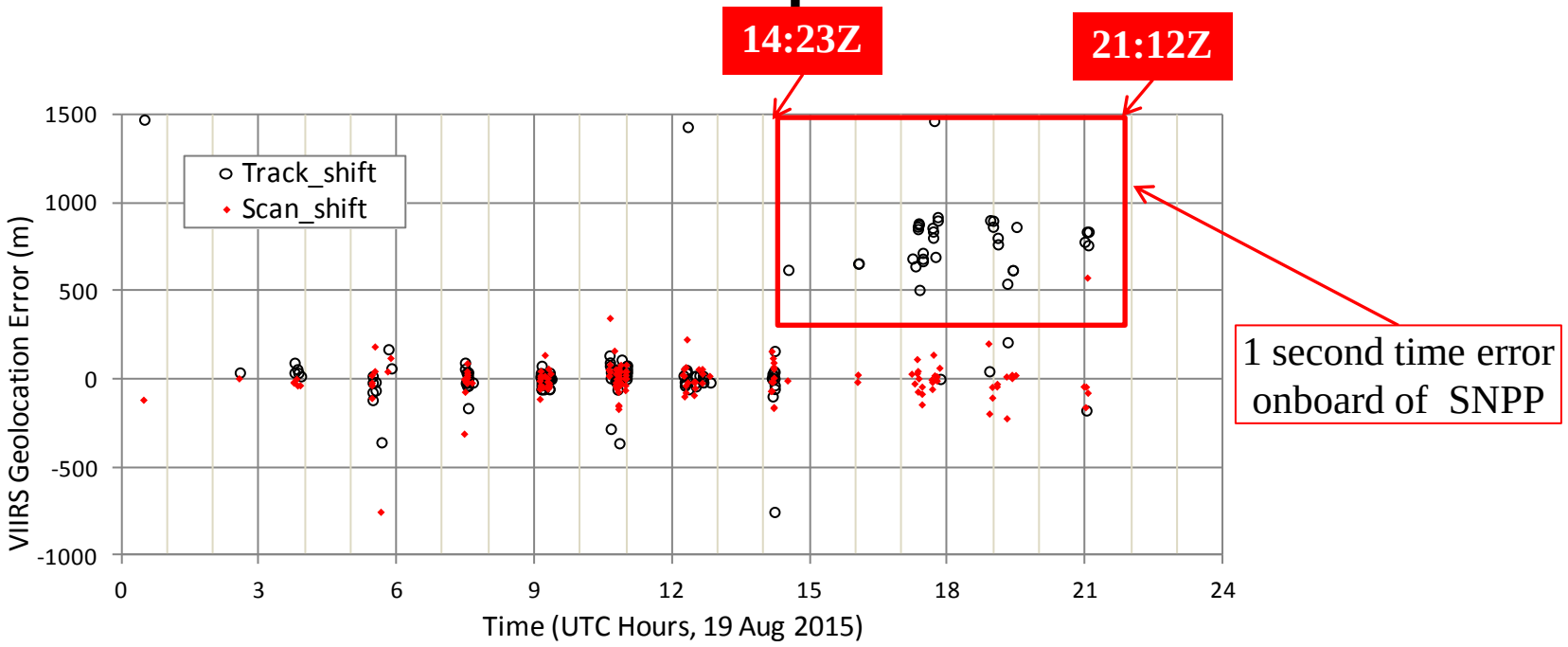
# RTA/HAM sync losses




- Sync losses happen more frequently lately
- Sync losses cause data loss (events detected and flagged in SDR/Geo SW)
- 63 times so far, ~ 100 sec each (60 scans), equivalent to 1.0 orbits total

# An outlier period

Error in time code




- "SCC Clock slope was performed on August 19, 2015 at 14:23Z"
- "SCC Clock was demonstrating a +999.989 ms drift relative to the GPS time, "
- LPEATE/LSIPS archives exclude the datasets now. Could "manually" correct time error later.

# SNPP, & J1+, “824 km orbit”

SNPP Altitude: μ =838.8 km, Max = 856 km, Min = 828 km