(Terra, Aqua) MODIS Geolocation Status

NASA MODIS Characterization Support Team (MCST)
Geometric Calibration Group

Guoqing (Gary) Lin, SSAI/GSFC Code 619
Robert E. Wolfe, NASA/GSFC Code 619
James C. Tilton, NASA/GSFC Code 606
Ping Zhang, Bin Tan, SSAI/GSFC Code 619
John Dellomo, GST/GSFC Code 619

NASA MODIS-VIIRS Science Team Meeting
Calibration Workshop
Silver Spring, MD
10/18/2018

Outline

- Geolocation performance for MODIS on Terra and Aqua
  - Overall performance
  - Trends & details
- Added Info -- scan-to-scan underlaps & on-orbit focal length
- Future work
- Conclusions

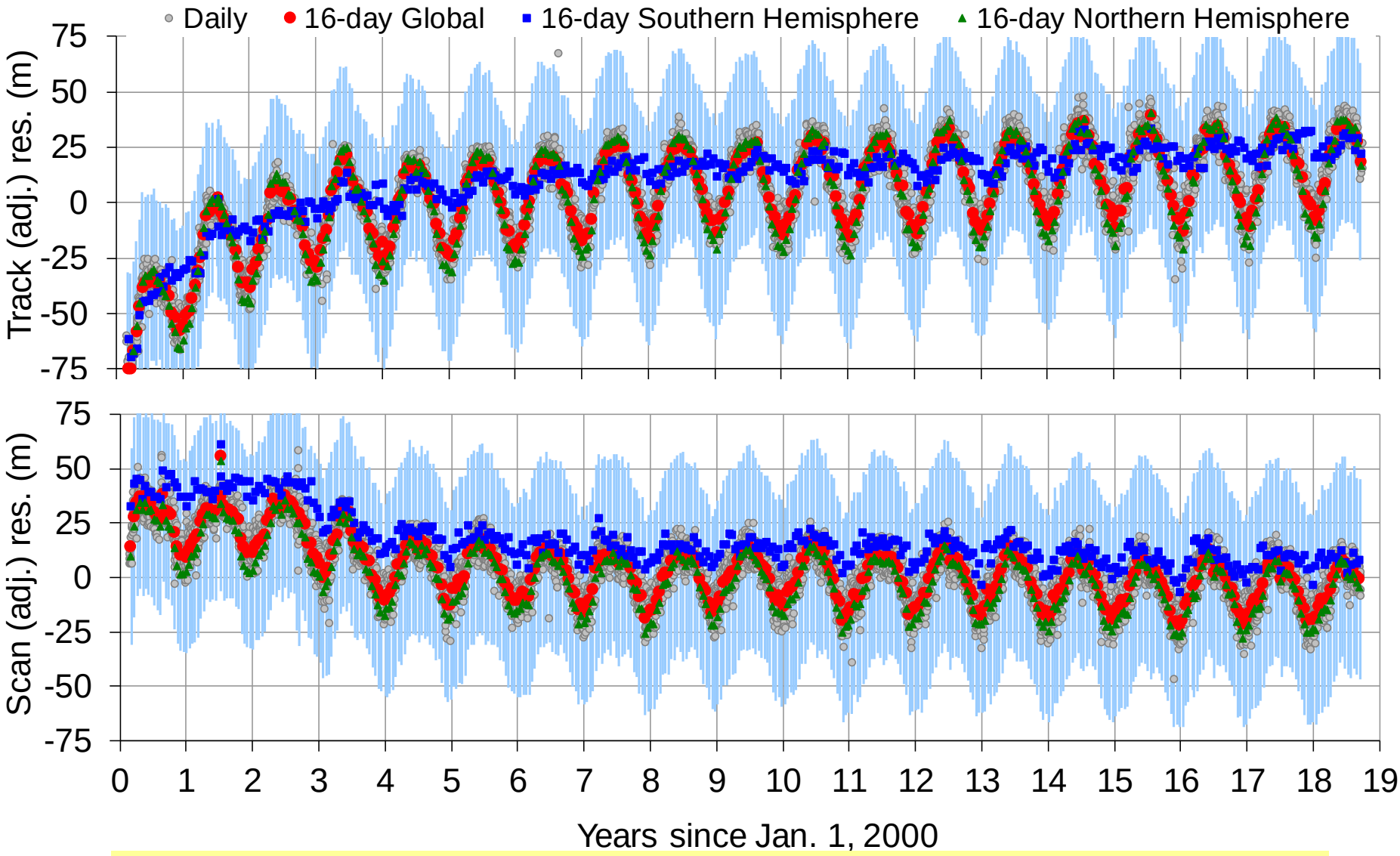
Overall Geolocation performance

Residuals	Terra C6	Aqua C6	Terra C6.1	Aqua C6.1	NPP VIIRS C1
Track mean	**1m**	**3 m**	**0 m**	**1 m**	12 m
Scan mean	**0 m**	**1 m**	**0 m**	**0 m**	4 m
Track RMSE	**43 m**	**47 m**	**43 m**	**46 m**	58 m
Scan RMSE	**44 m**	**54 m**	**44 m**	**53 m**	52 m
Data-days	**6739 (18.4 yrs)**	**5917 (16.2 yrs)**	**6725 (18.4 yrs)**	**5910 (16.2 yrs)**	2447 (6.7 yrs)
Missing days	**61**	**10**	**59**	**10**	1
Daily matched GCPs w/ B1/I1	**258**	**190**	**258**	**223**	204

- **Nadir equivalent** accuracy (RMSE = Root Mean Square Error)
  - Mostly within 20% band B1 HSI (250 m) = 50 m @ nadir (75 m for VIIRS I1);
  - Within 10 % for HKM bands and 5% for KM bands
    - Band-to-band mis-registration to other bands adds bias to RMSE : $RMSE = \sqrt{\sigma^2 + \mu^2}$
- Other features for MODIS geolocation
  - Aqua uses definitive ephemeris data → 27 hour latency (Terra uses TDRSS-based on-board ephemeris)
  - Aqua C6.1 corrected pointing variations (most of them) caused by AMSR_E stop - go slow – full stop activities

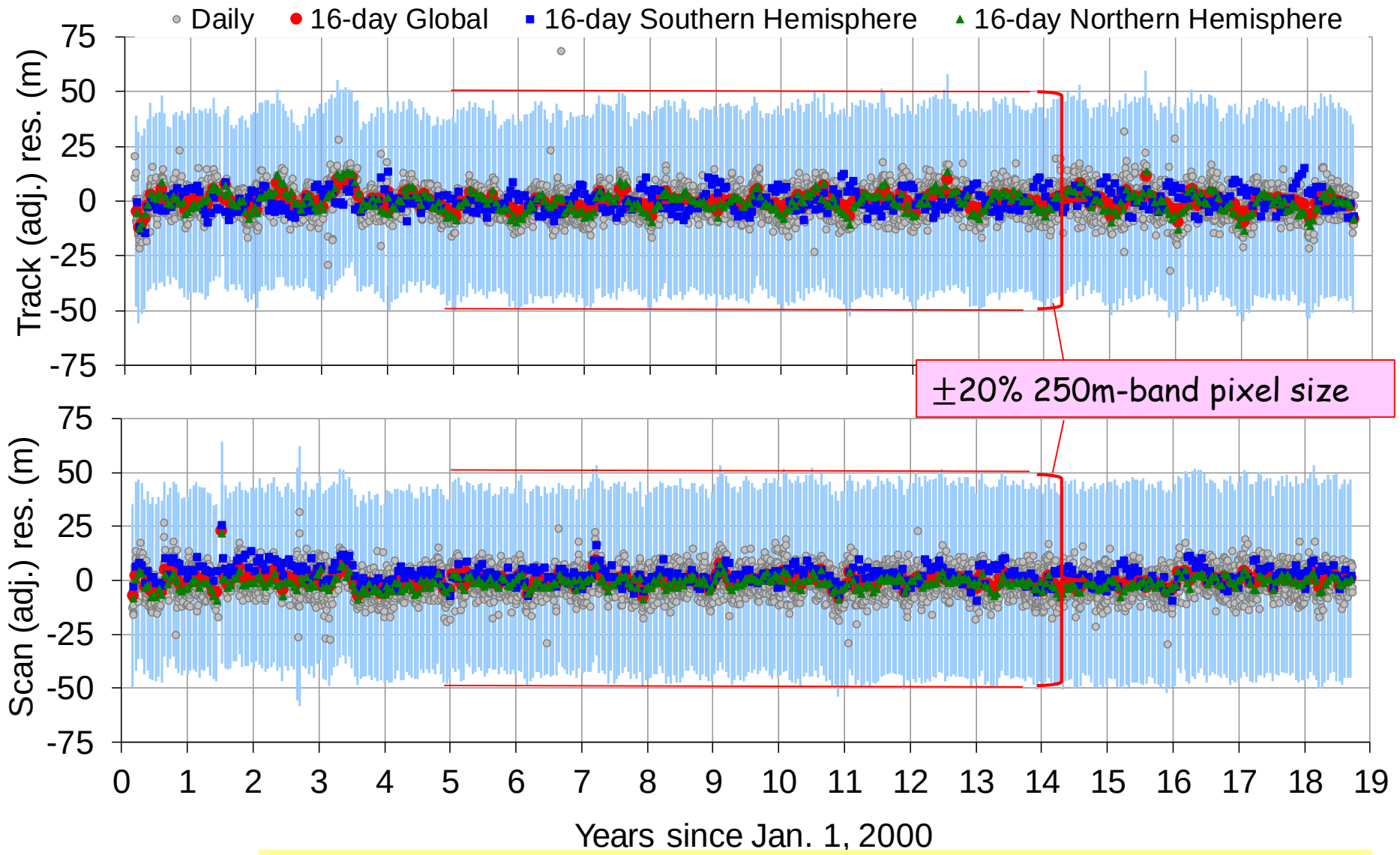
Terra trend and update details

Terra C6.1 long-term trend (uncorrected)



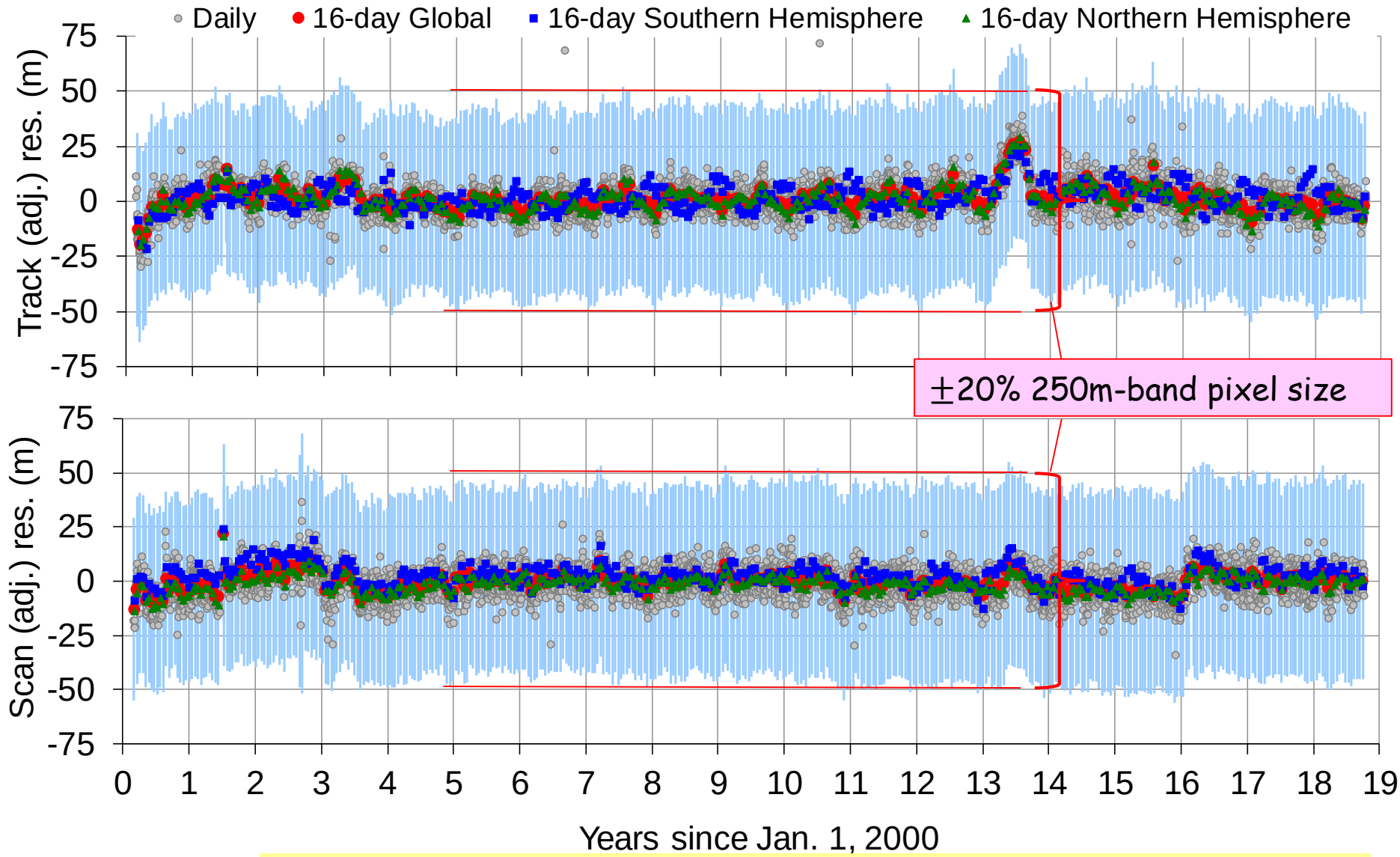
RMSE with no correction: Track: 49 m (+6 m vs C6) Scan: 48 m (+4 m vs C6)

Actual Terra C6.1 residuals



C6.1 RMSE Track: 43 m Scan: 44 m, nadir equivalent

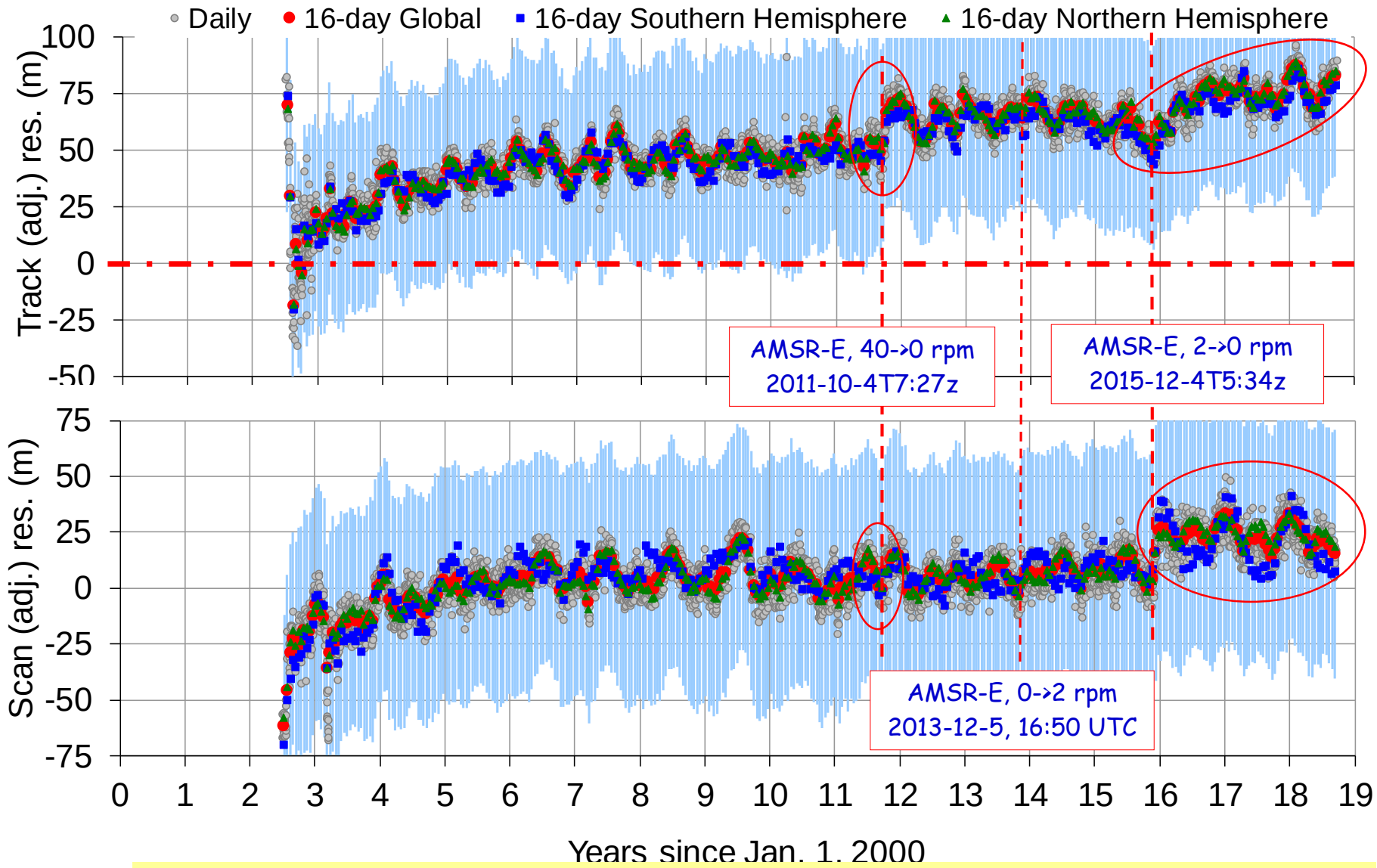
Actual Terra C6 residuals



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

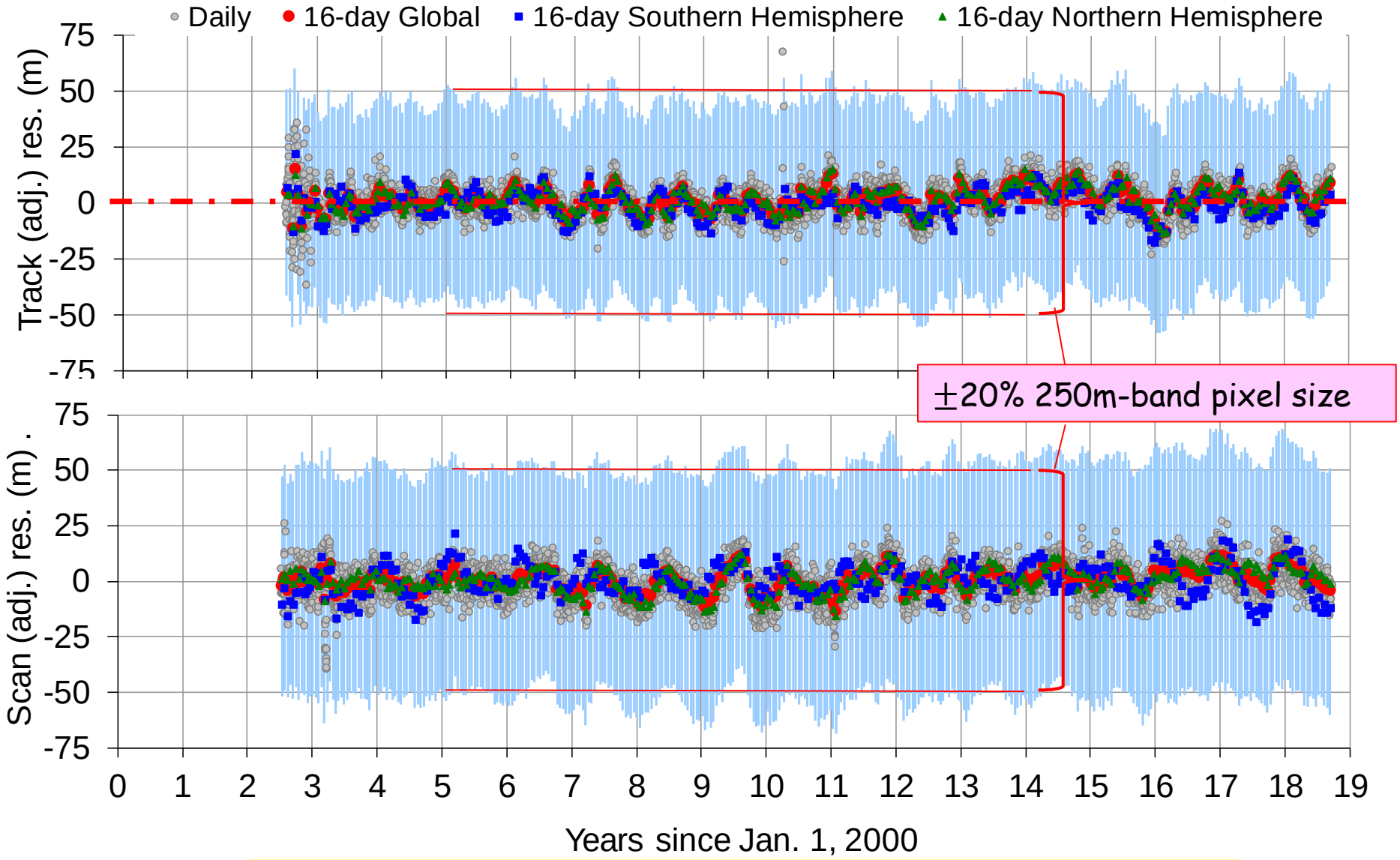
Aqua trend and update details

Aqua C6.1 Long-term Trend (unorrected)



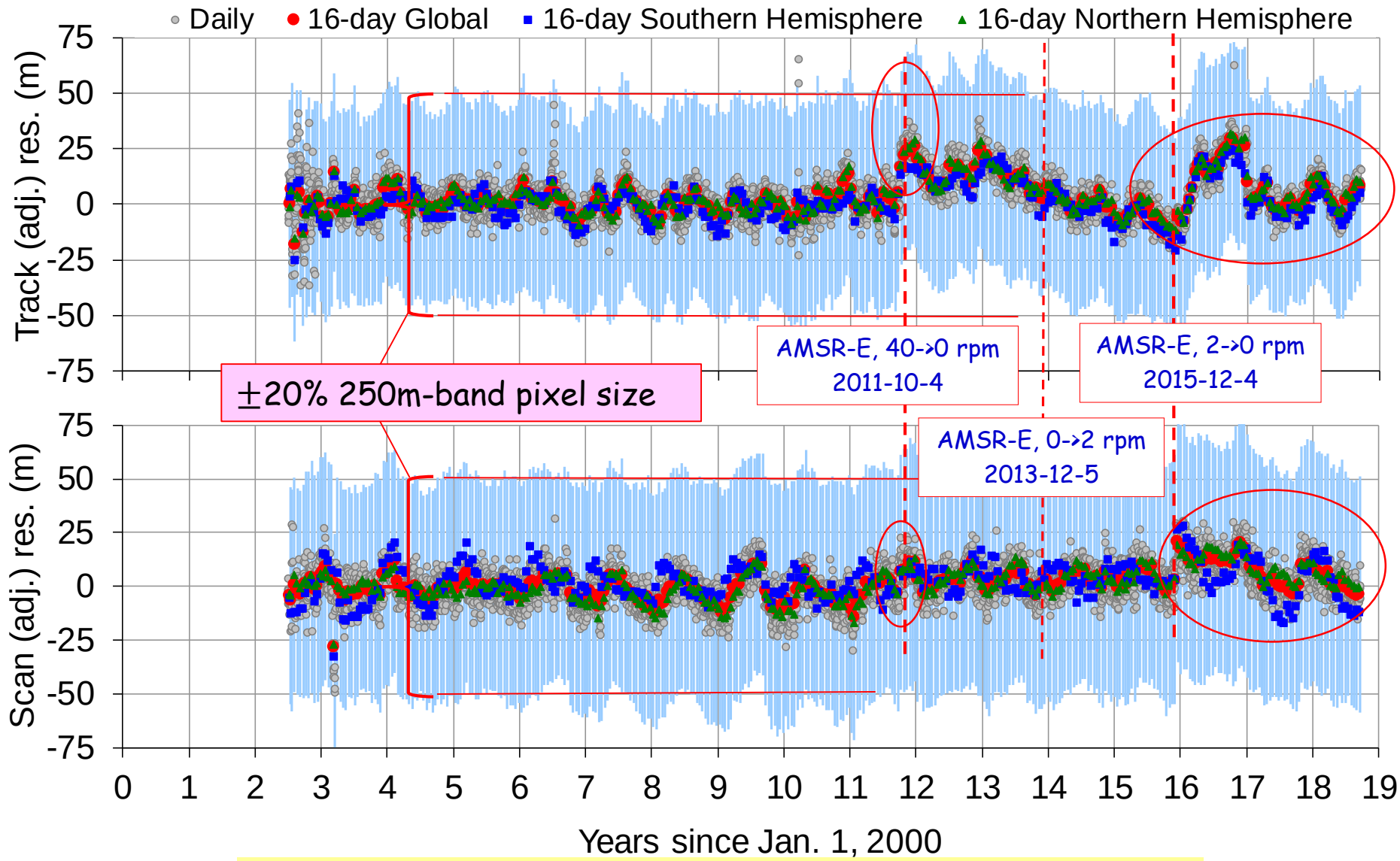
RMSE with no correction: Track: 71 m (+25 m vs C6.1) Scan: 55 m (+2 m vs C6.1)

Actual Aqua C6.1 residuals



C6.1 RMSE Track: 46 m, Scan: 53 m, nadir equivalent

Actual Aqua C6 residuals



C6 RMSE Track: 46 m, Scan: 54 m, nadir equivalent

Leap-second handling

year	June 30	Dec 31	Terra C6	Terra C6.1	Aqua C6	Aqua C6.1
2005		+1	good	good	good	good
2008		+1	good	good	good	good
2012	+1		good	good	Note 1	Note 2
2015	+1		good	good	good	good
2016		+1	good	good	good	good

Notes 1 & 2:

A error was recently found and corrected in the Aqua spacecraft ephemeris and attitude dataset for the first 12 hours from 00z to 12 z on 7/1/2012 after leap-second insertion at the start of the day (2012-06-30T23:59:60z). Data products have been replaced in **Sept. 2018**

Caution: geolocation errors may still be large after leap-second in the first 5-min granule:

2006-01-01T00:00-00:05
2009-01-01T00:00-00:05
2012-07-01T00:00-00:05
2015-07-01T00:00-00:05
2017-01-01T00:00-00:05

We may "hide" the granules upon further examination

https://en.wikipedia.org/wiki/Leap_second

Scan-to-scan underlap

This term is added for JPSS-3&4 VIIRS

$$Overlap = n\frac{p}{F}\boldsymbol{h} - [\boldsymbol{V_{ECI}} - V_{earth0}\,\boldsymbol{\cos i}]T$$

where

n = # detectors,
p = detector "pitch" interval in the track direction,
F = effective focal length (EFL),
T = scan period, tied to F by BBR requirements,

Instrument properties

i = inclination angle, > 90° for MODIS and VIIRS,
V_{ECI} = spacecraft ground speed in the inertial frame,
h = range from instrument to earth terrain surface

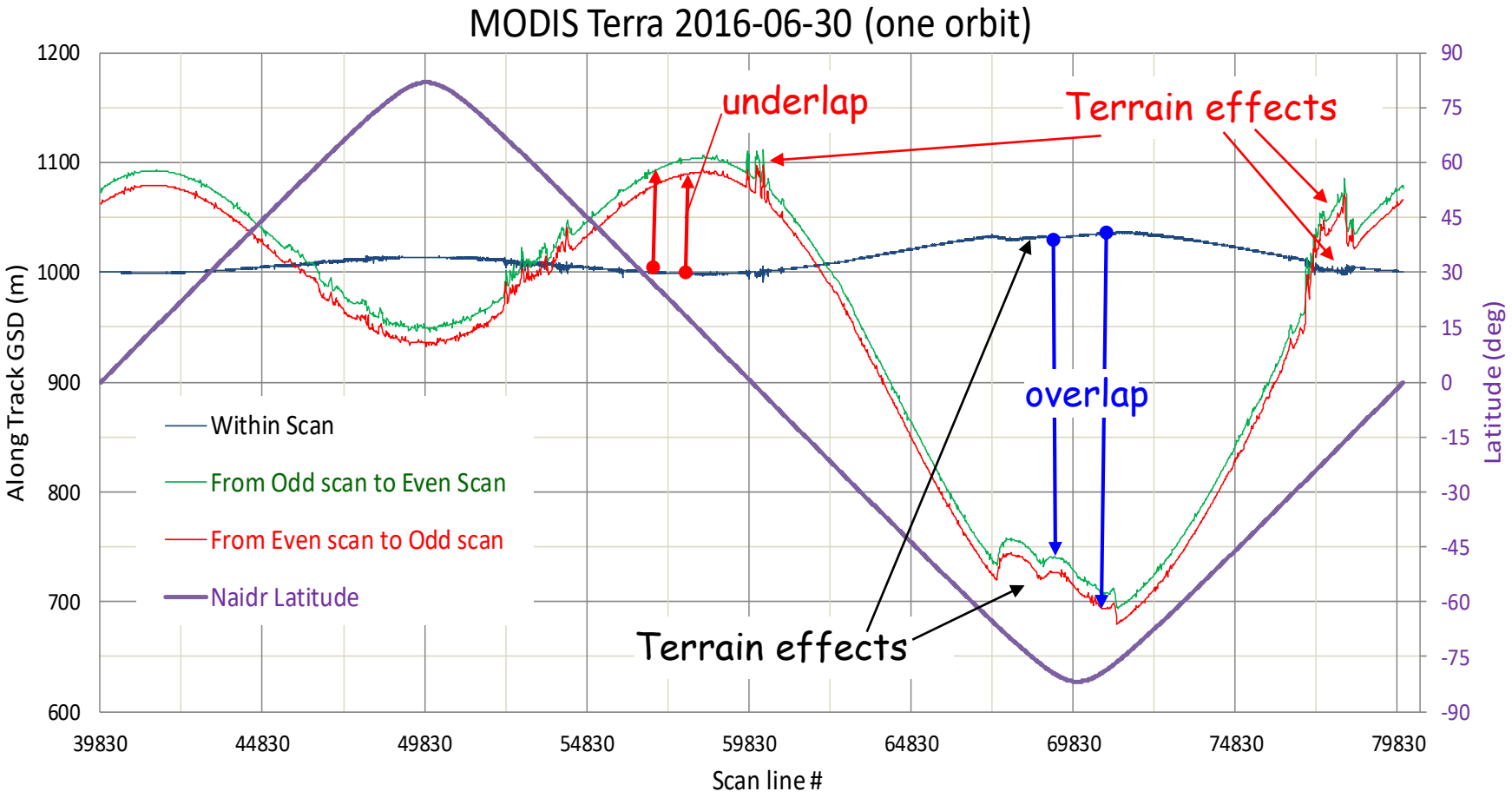
Satellite properties

V_{earth0} = surface speed of earth rotation at equator,

Earth property

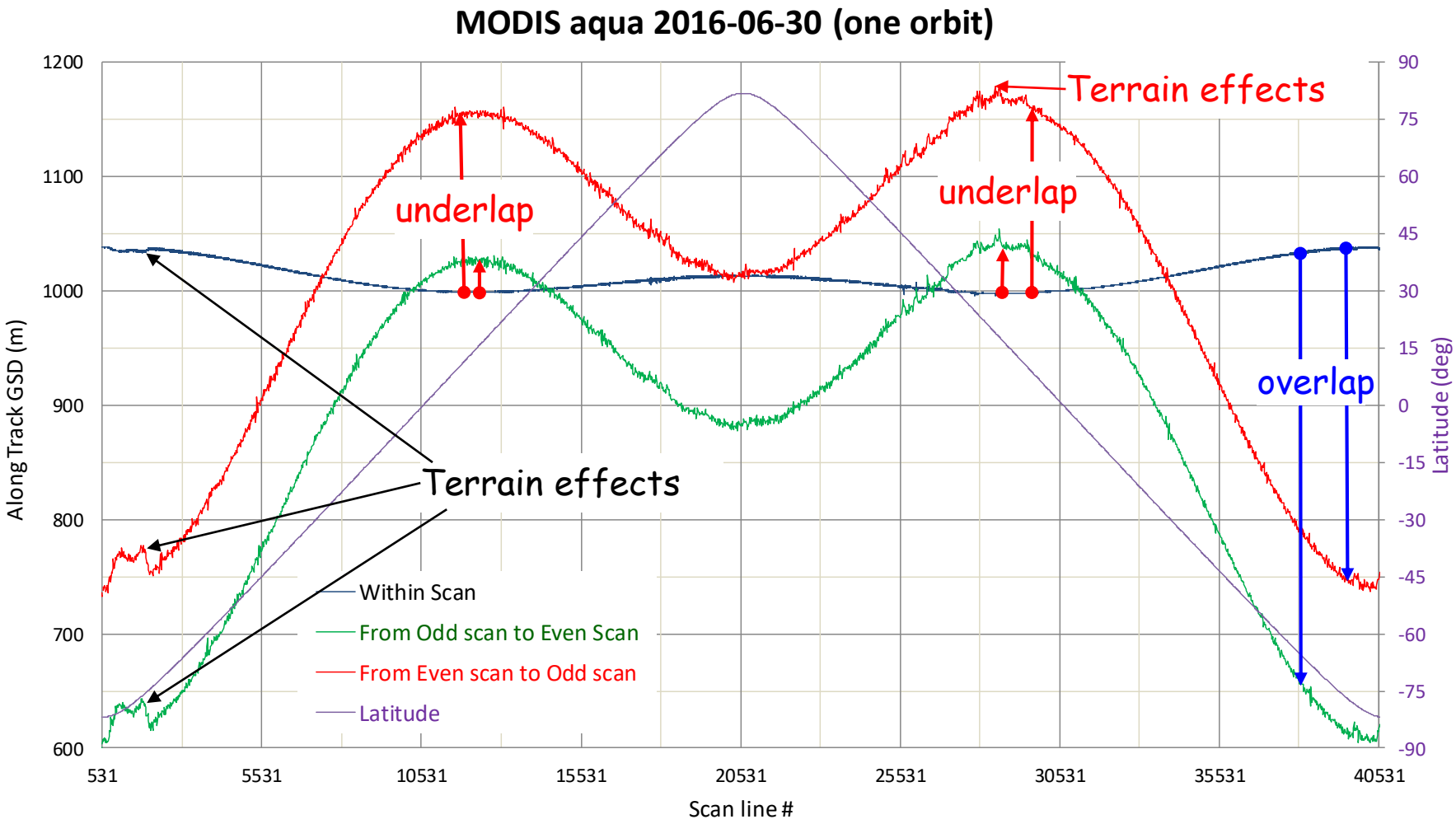
Overlap < 0 ➔ underlap.

Scan-to-scan underlap for Terra MODIS



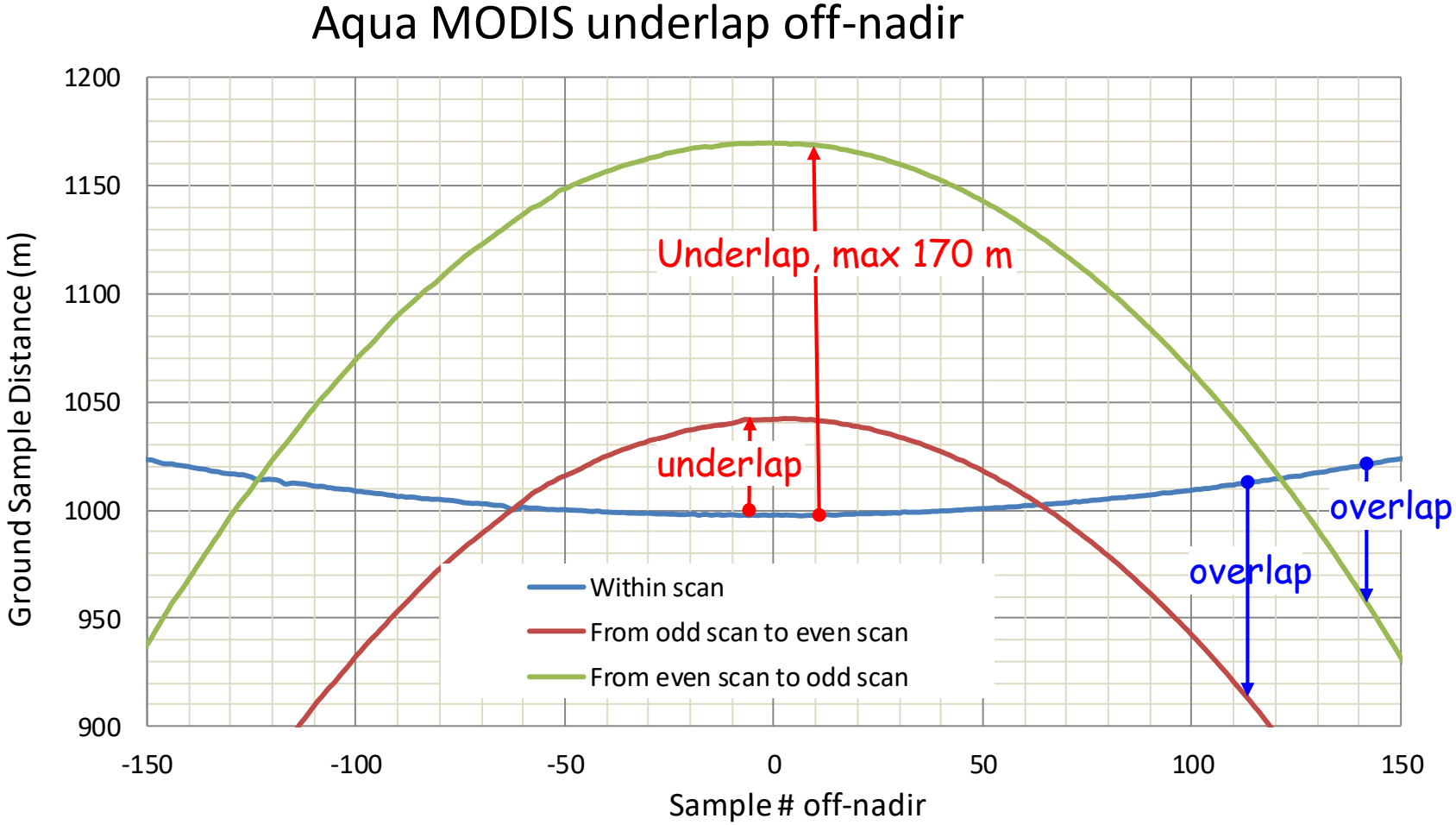
- Terra MODIS has underlap of ~ 90 m around 15°N in all neighboring scans
- High terrain worsens the underlap where it occurs
- The altitude variations, minimal near equator and higher near poles, can be seen from the variations of within scan ground sampling distance (GSD)

Scan-to-scan underlap for Aqua MODIS



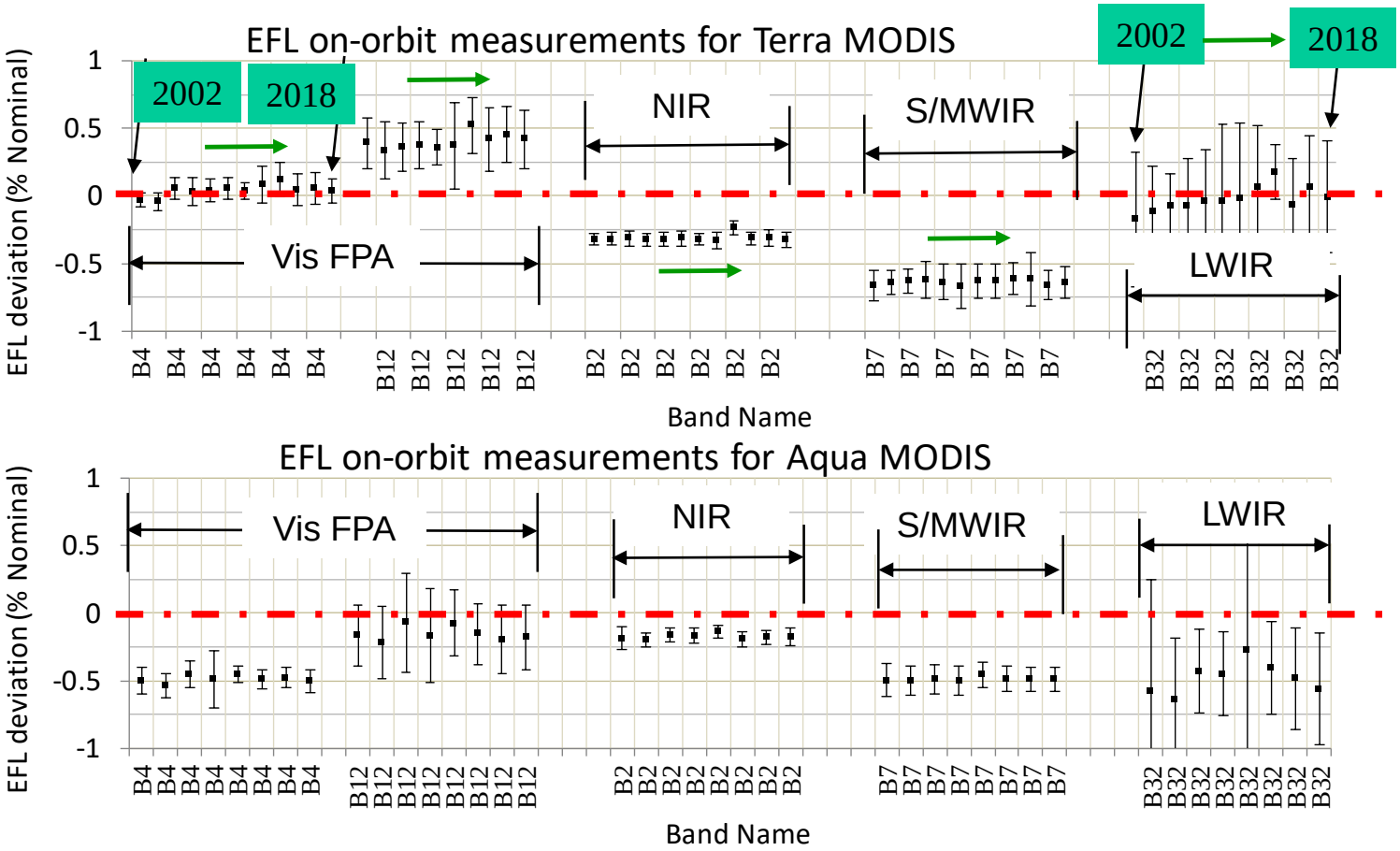
- Aqua MODIS has more serious underlap in alternating scans around 15°N
- Orbit asymmetry due to drifts makes underlap more over descending side (~ 170m) than the ascending side (~ 150 m) in this case, may reverse in another case

Aqua MODIS underlap vs scan sample



- Maximum underlap, if exists, exists at nadir and **around 15°N**
- Due to off-nadir bow-tie effects, scan-to-scan underlap closes off-nadir ~ 122 km for the large one and ~ 60 km for the smaller one in this case.

On-orbit focal length measurements



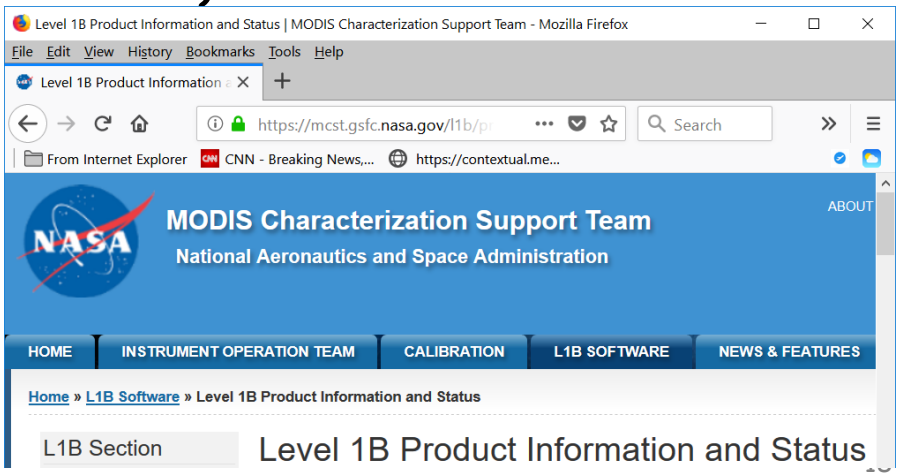
- On-orbit measured effective focal length (EFL) varies among builds and bands.
- A +0.1% EFL change means +10 m change in scan-to-scan underlap where it exits.
  - Band B7 has less underlaps for both Aqua and Terra MODIS
  - Band B12 has more underlaps for Terra MODIS

Future work (C7.0 soon?)

1) Routine monitor and LUTs update as needed
2) Refresh ground control point chip library
    1) Chips are extended from 24x24 to 36x36 km
    2) Error measurements are extended from ± 45° to ± 55°)
3) Automate GEO LUT updates
4) Update DEM, LWM (year by year?)
5) Add 250m offsets(?) to geolocation files (currently 1000m with 500m offsets)
6) Create Level-1 geolocation web (needed?)
    1) similar to L1B

Anything Else?

Any change in priority order above



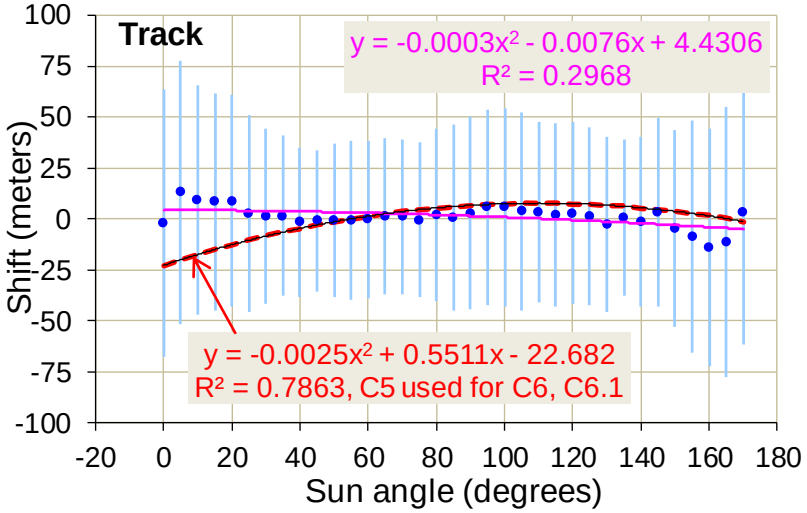
Concluding Remarks

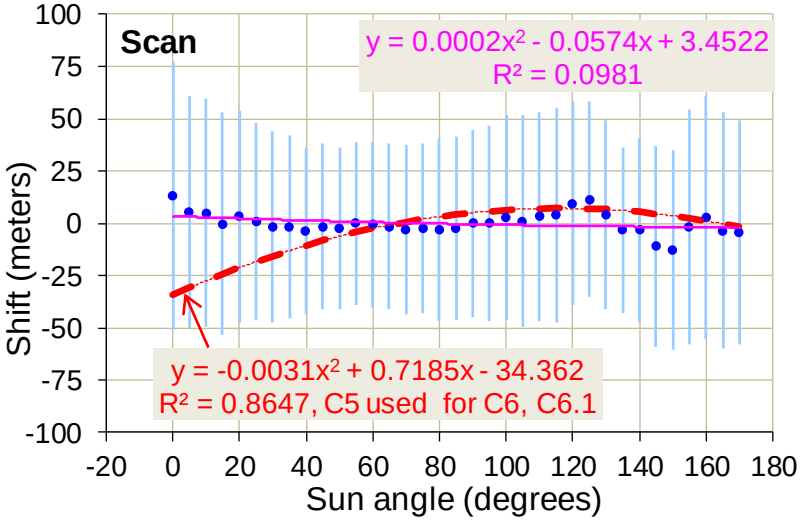
- Geolocation performance for MODIS on Terra and Aqua is good
  - mean errors for band B1 near 0 and uncertainties are ~ 50 m at nadir for the missions, statistically
  - C6.1 corrected artifacts in C6 caused by LUT updates
  - AMSR_E stop-go-stop activities on Aqua induced MODIS geolocation errors, which were corrected in C6.1
  - Scan-to-scan underlaps exist around nadir in the equator regions
    - Maximal underlaps are at nadir near 15^{o}N, at ~ 150 m for Aqua MODIS B2

Backup slides:
sun angle dependent Residuals

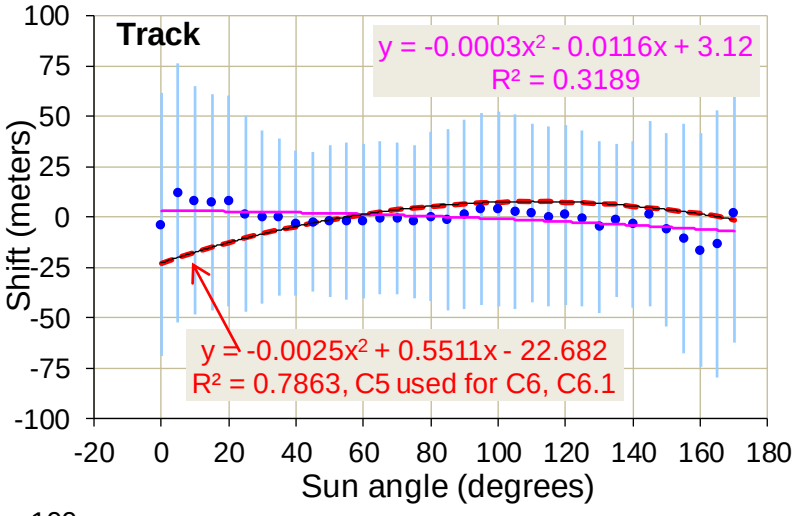
Terra Sun angle Correction

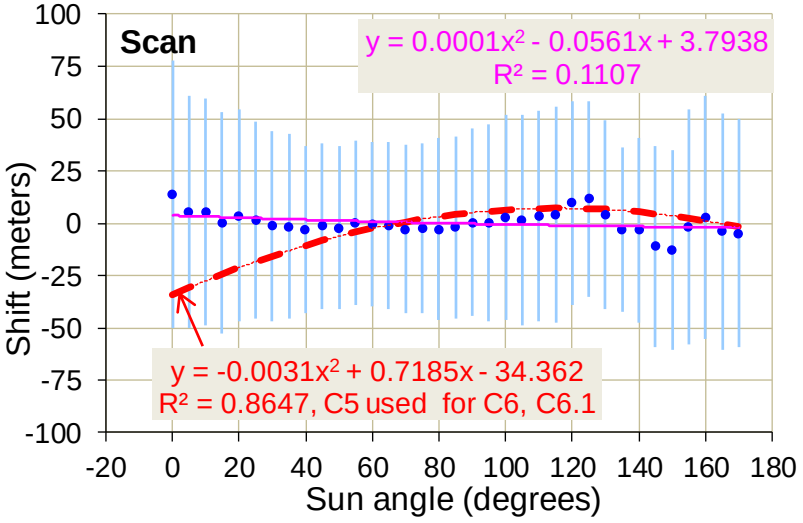
C6 results





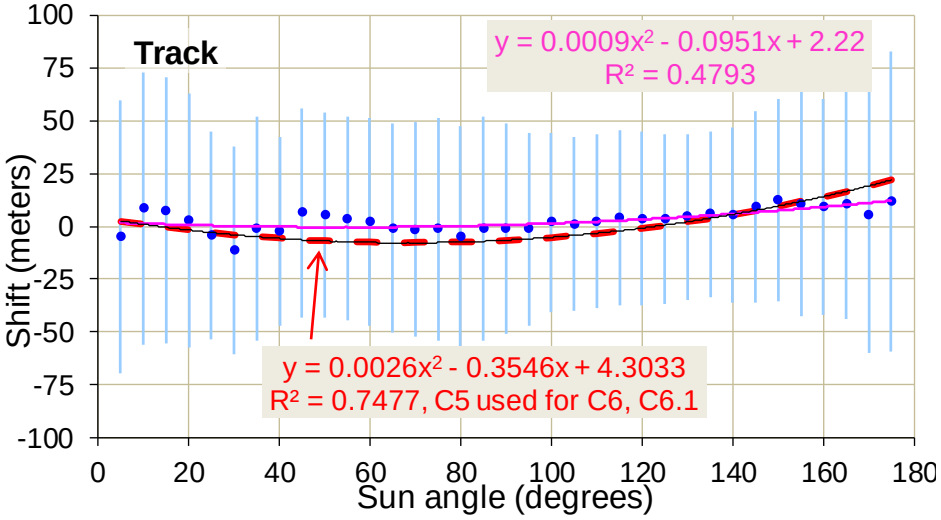
C6.1 results

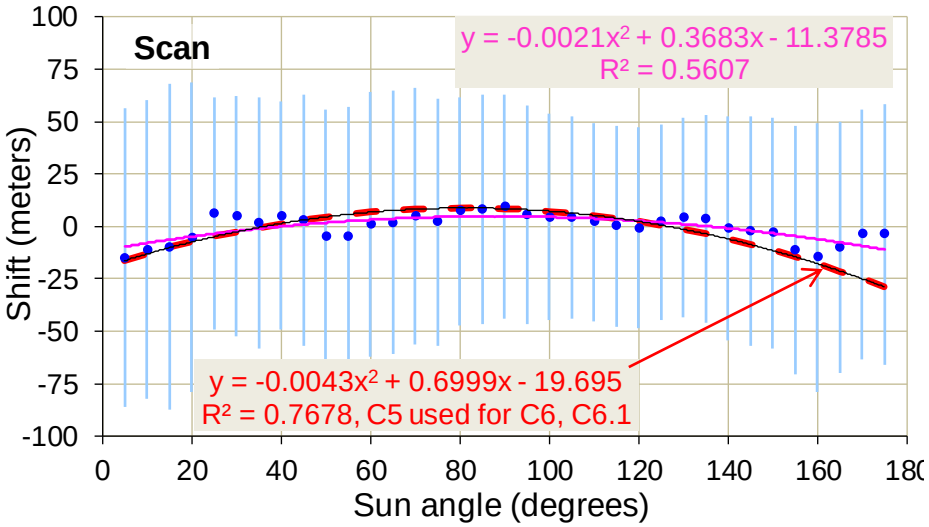




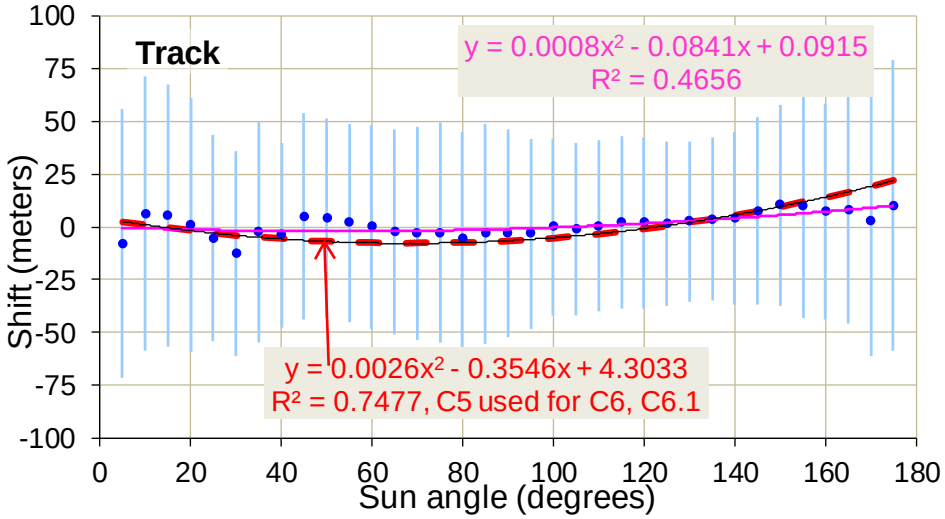
Aqua Sun angle Correction

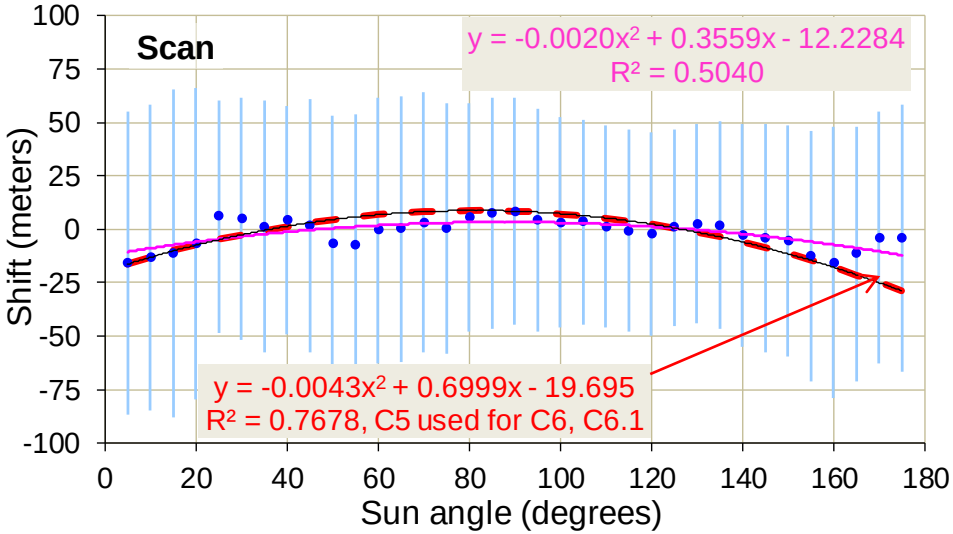
C6 results



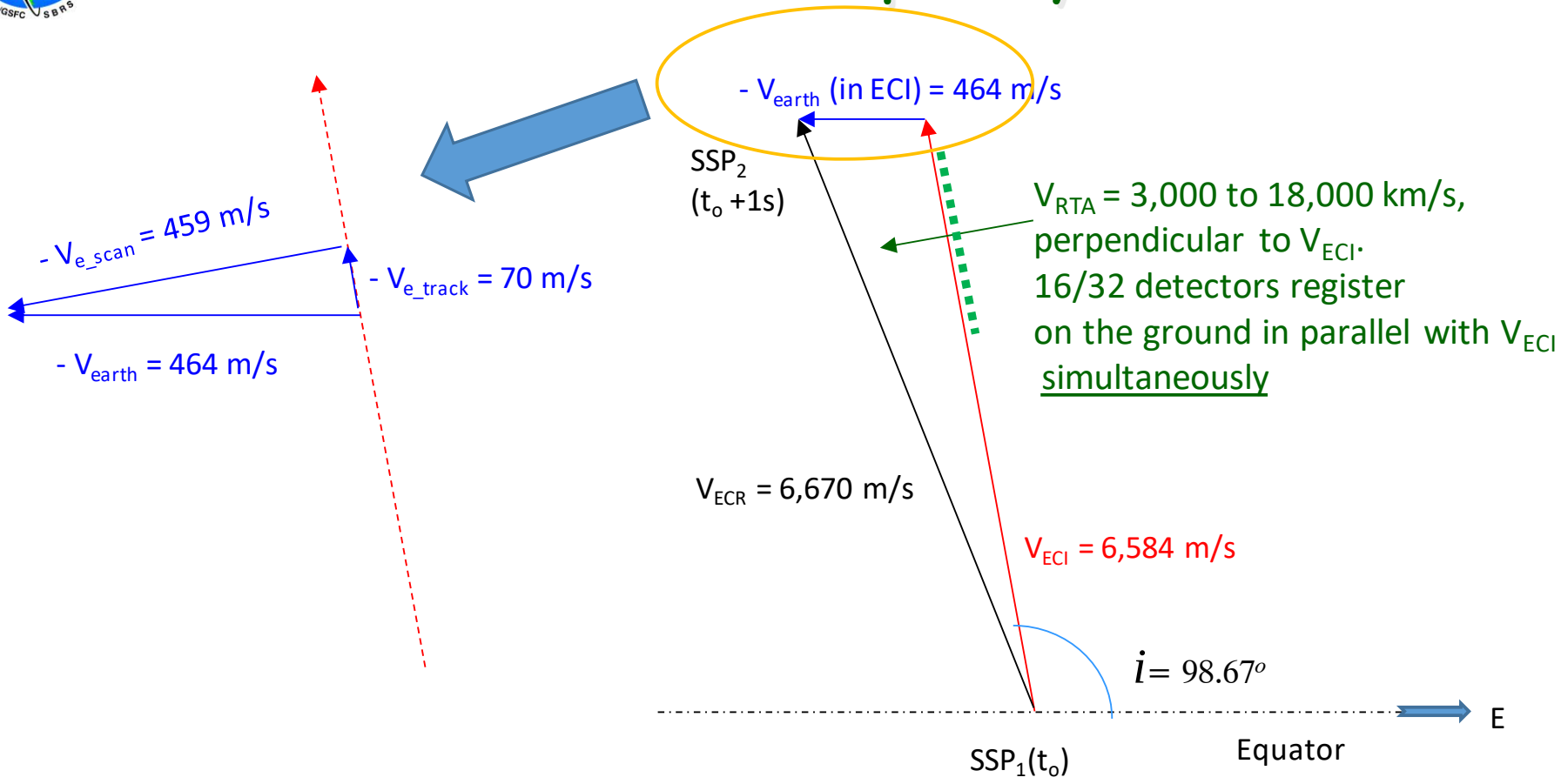


C6.1 results





Root cause – example by VIIRS



- Earth rotation casts a component of speed in the VIIRS track & satellite inclination direction
- A sensor Field of regard (FOR) in the track direction ***FOR = n ASI h*** needs to cover all the time everywhere the scan-to-scan travel distance, i.e. ***FOR*** >= $D_{s2s}=T[V_{ECI} - V_{earth0}\cos(i)]$. Otherwise, scan-to-scan underlap occurs
- For details, see Lin et al (2016),"*Trending of SNPP ephemeris and its implications on VIIRS geometric performance*", Proc. of SPIE, Vol. 9972, 99721K, doi: 10.1117/12.2239043.