(Terra, Aqua)

MODIS Geometric Calibration Status

NASA MODIS Characterization Support Team (MCST)
Geometric Calibration Group

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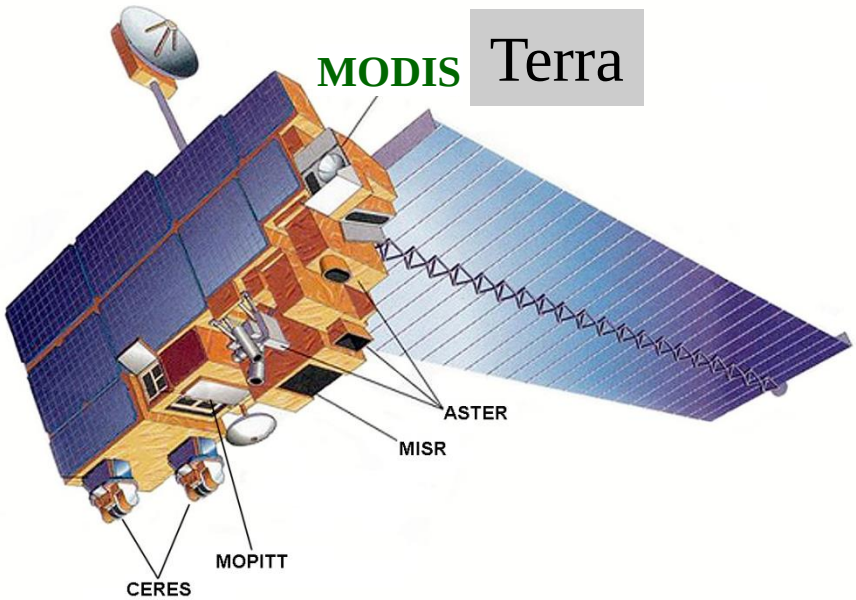
NASA MODIS-VIIRS Calibration Workshop
Virtual
2/25/2021

Outline

- Geolocation performance for MODIS on Terra and Aqua
  - Overall performance
  - Trends & details
- C7 preparation, with improvements
  - Ground control points (GCPs) refresh
  - Offsets for 250 m resolution geolocation
- Conclusions

MODIS Collections timeline



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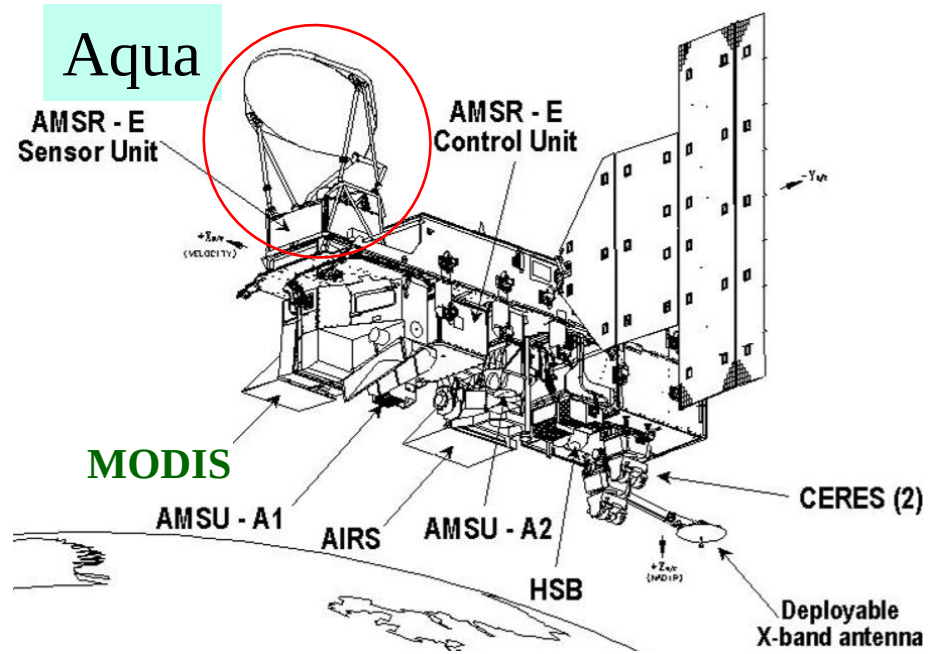

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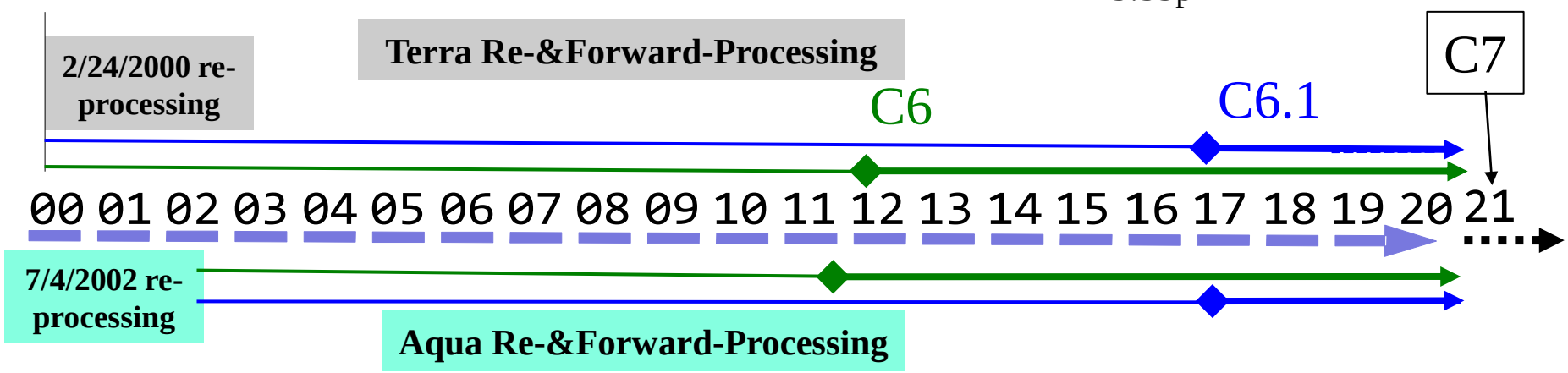


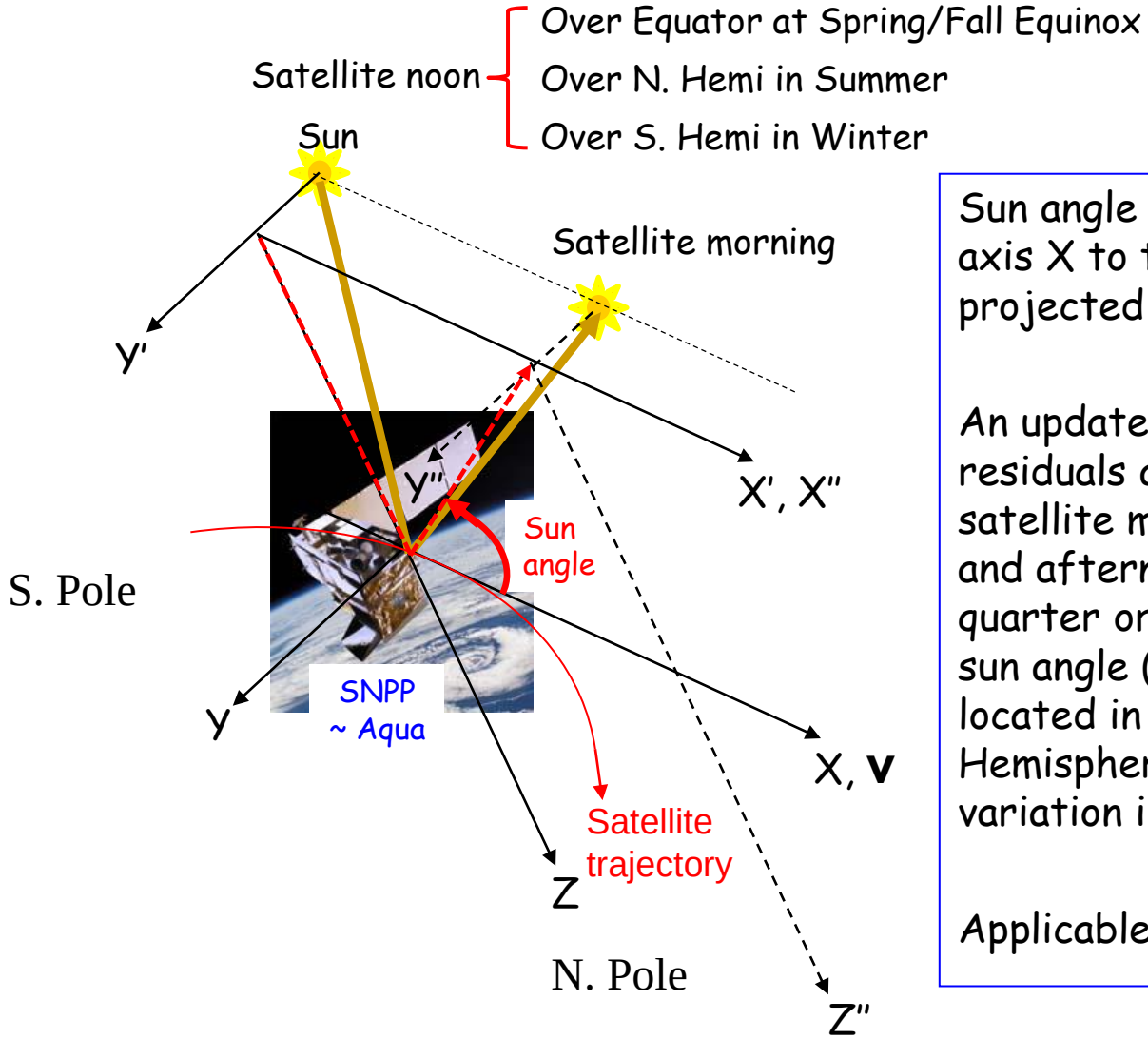
Overall Geolocation performance

Residuals	Terra C6	Aqua C6	Terra C6.1	Aqua C6.1	SNPP VIIRS C2
Track mean	**1m**	**3 m**	**-1 m**	**1 m**	1 m
Scan mean	**0 m**	**2 m**	**0 m**	**1 m**	7 m
Track RMSE	**43 m**	**46 m**	**43 m**	**46 m**	58 m
Scan RMSE	**45 m**	**54 m**	**45 m**	**54 m**	48 m
Data-days	**7584 (20.8 yrs)**	**6771 (18.5 yrs)**	**7588 (20.8 yrs)**	**6771 (18.5 yrs)**	1247 (3.4 yrs)
Missing days	**61**	**14**	**59**	**13**	1
Daily matched GCPs w/ B1/I1	**256**	**220**	**256**	**221**	838

New Chip Library

- **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 → new trend in annual cycle

Orientation of sun angle in the spacecraft coordinate system



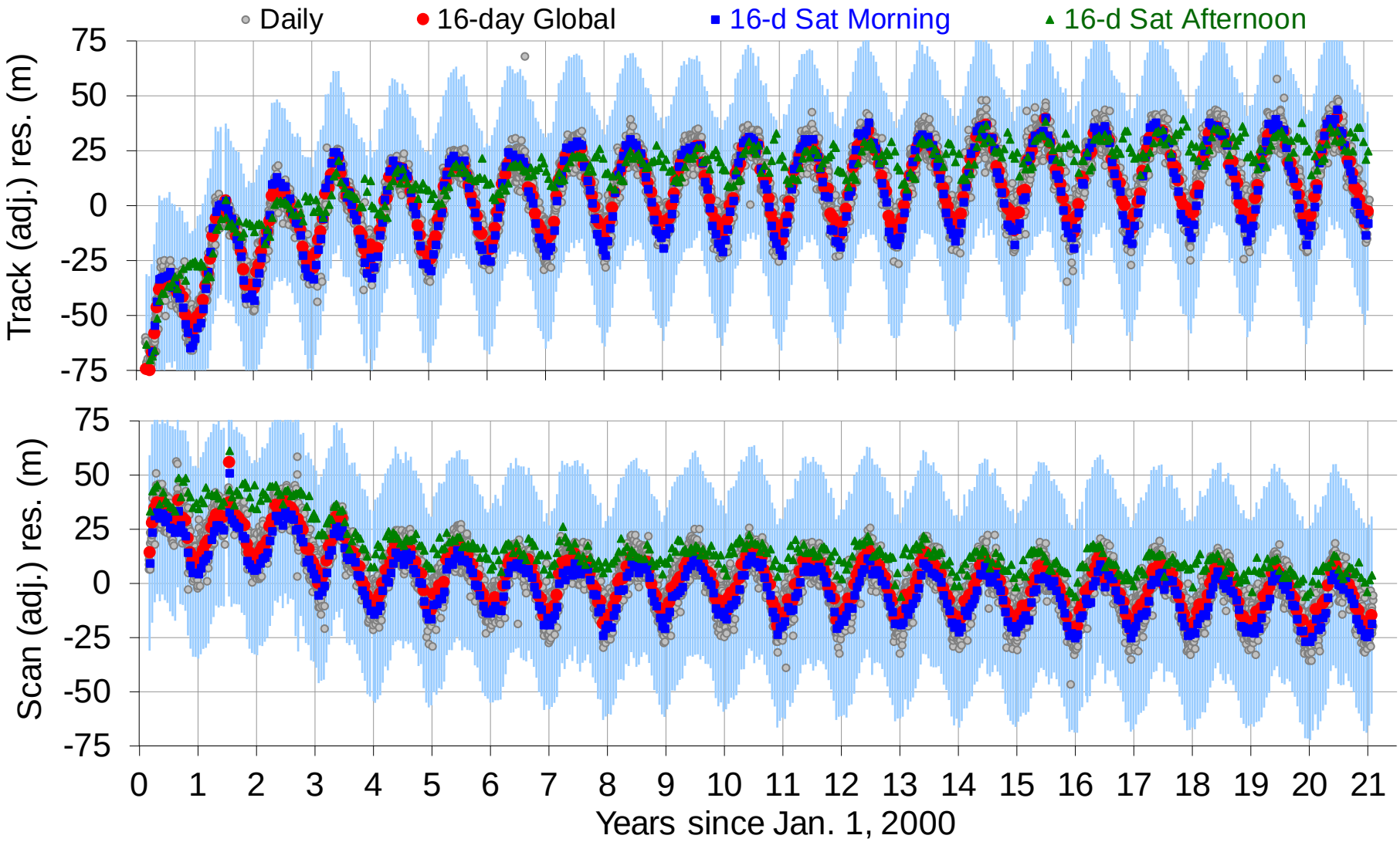
Sun angle = the satellite motion axis X to the sun vector projected on the X-Z orbit plane.

An update: 16-day control point residuals are stratified in the satellite morning (sunrise – noon) and afternoon (noon – sunset) quarter orbits according to the sun angle (from control point located in the S./N. Hemispheres) to reflected the variation in thermal conditions.

Applicable to VIIRS as well.

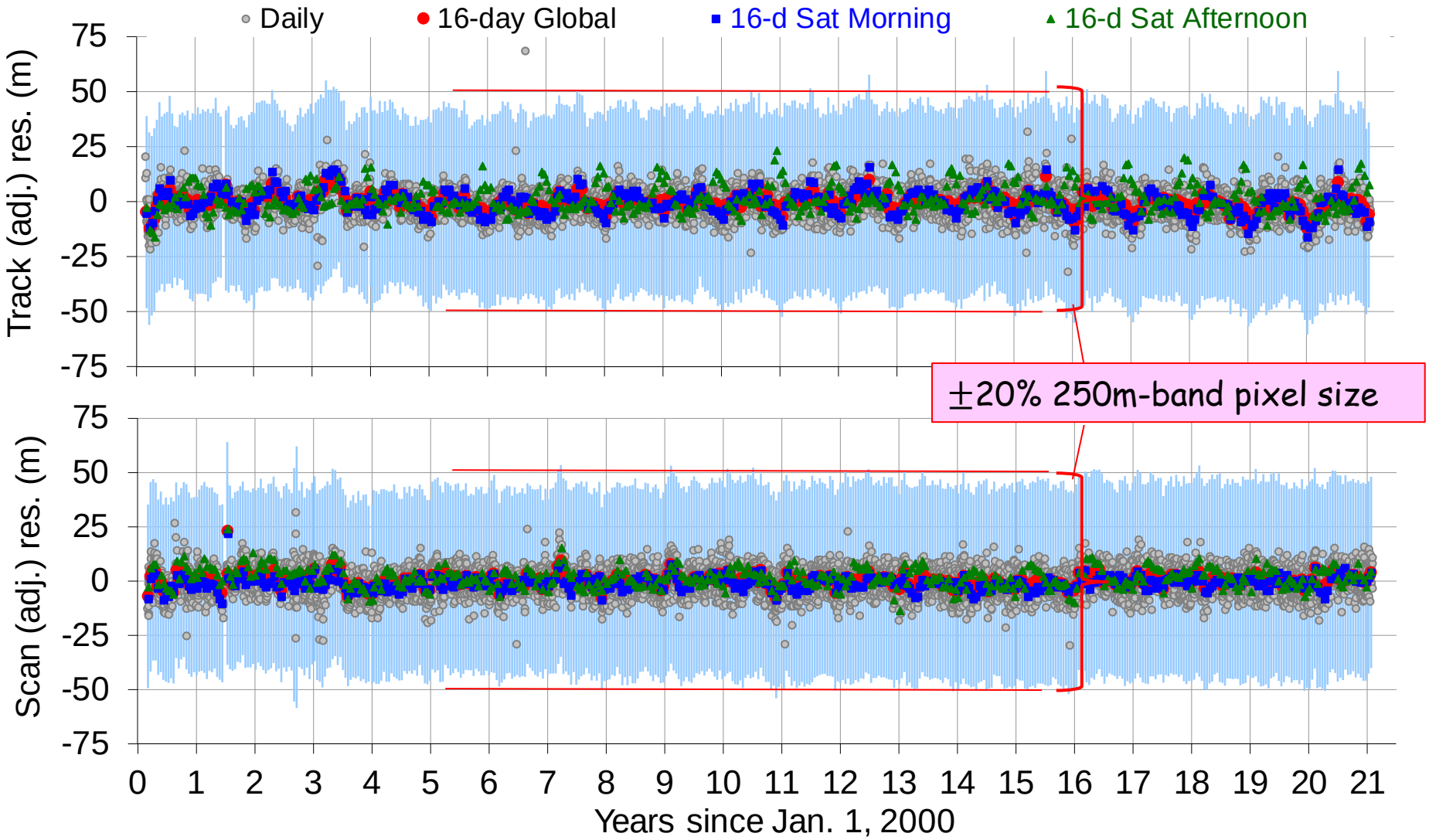
Terra trend and update details

Terra C6.1 long-term trend (uncorrected)



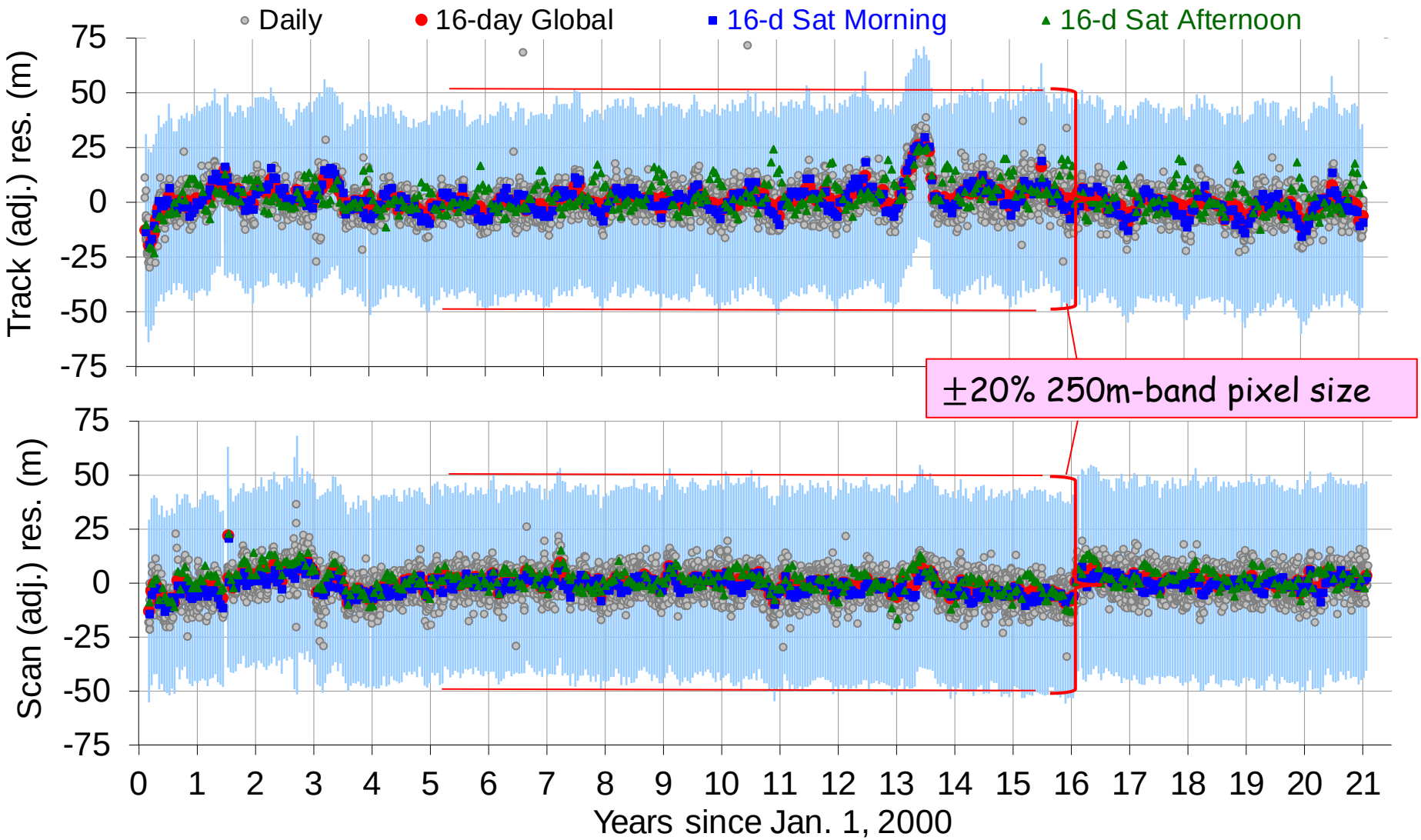
RMSE with no correction: Track: 49 m (+6 m vs C6.1) Scan: 48 m (+3 m vs C6.1)

Actual Terra C6.1 residuals



C6.1 RMSE Track: 43 m Scan: 45 m, nadir equivalent

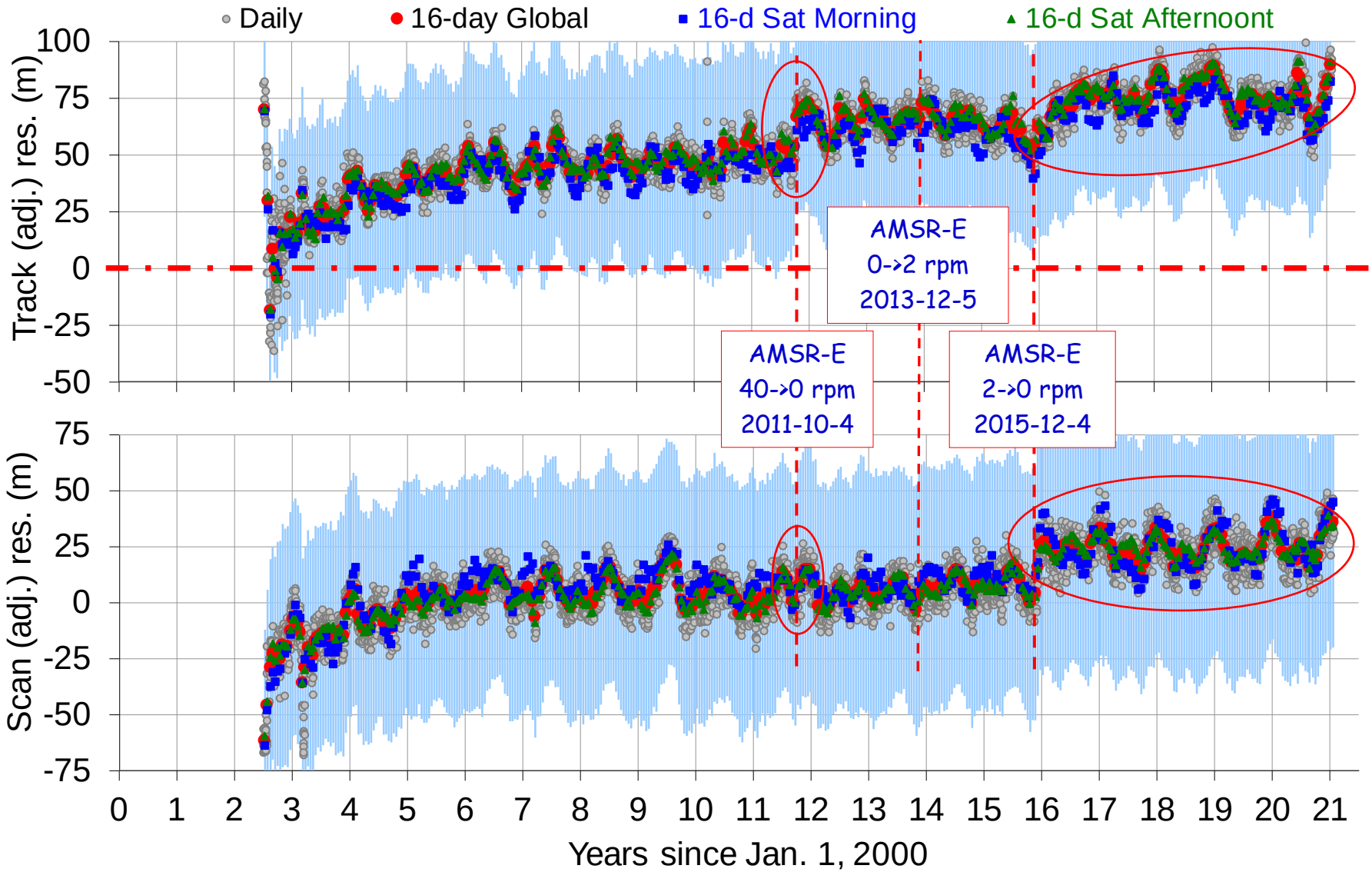
Actual Terra C6 residuals



C6 RMSE Track: 43 m Scan: 45 m, nadir equivalent

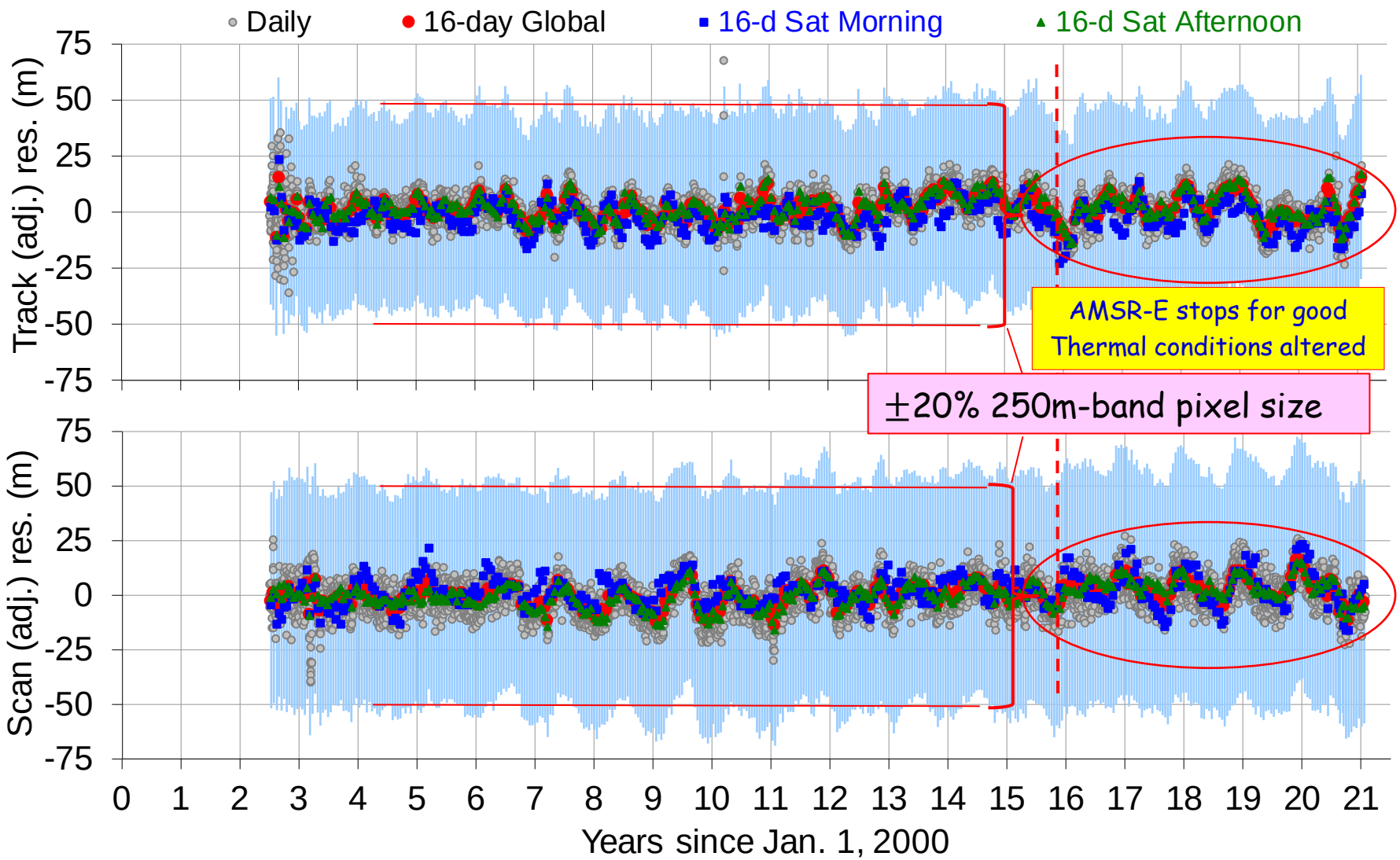
Aqua trend and update details

Aqua C6.1 Long-term Trend (uncorrected)



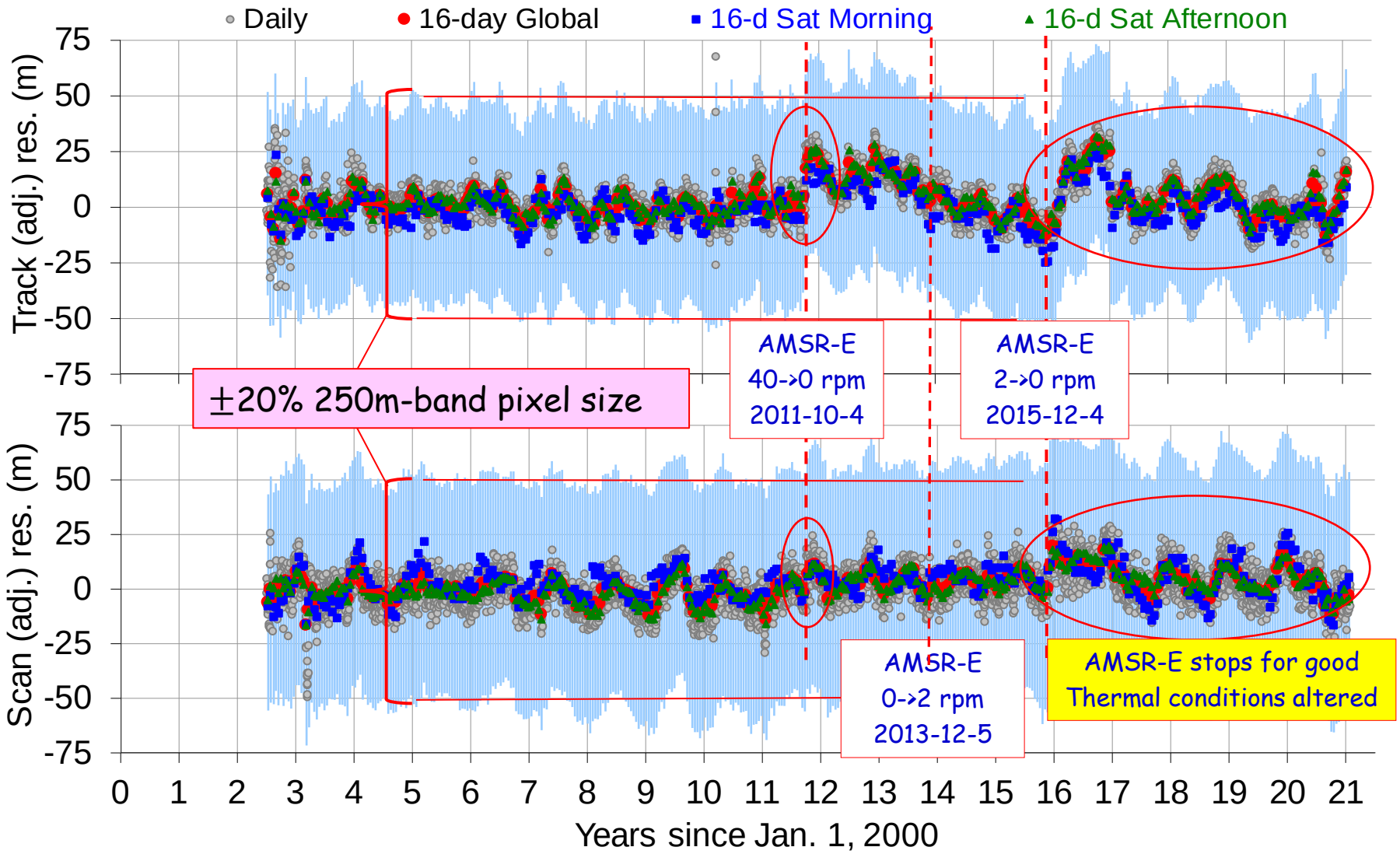
RMSE with no correction: Track: 74 m (+28 m vs C6.1) Scan: 56 m (+2 m vs C6.1)

Actual Aqua C6.1 residuals



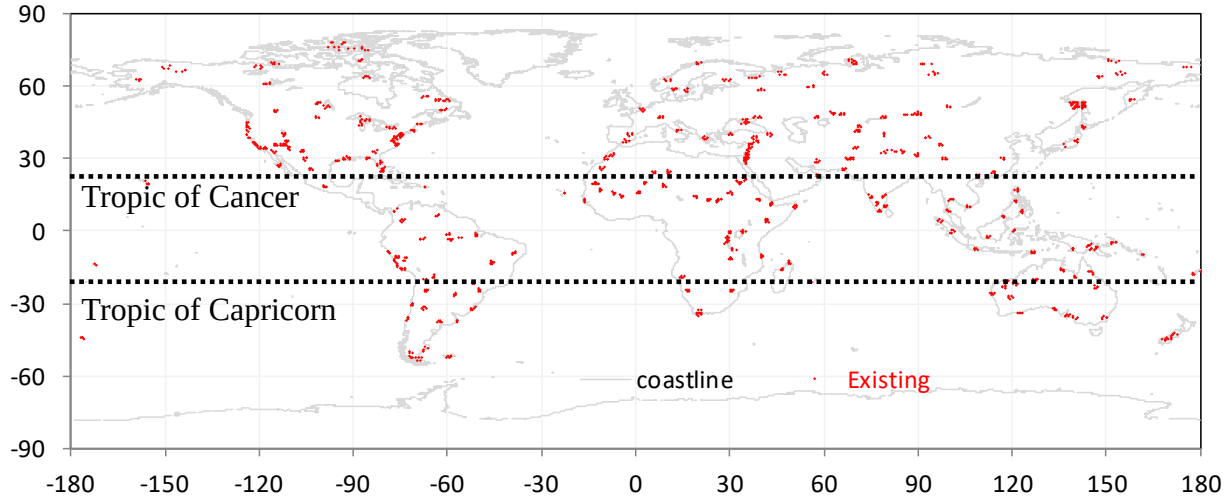
C6.1 RMSE Track: 46 m, Scan: 54 m, nadir equivalent

Actual Aqua C6 residuals



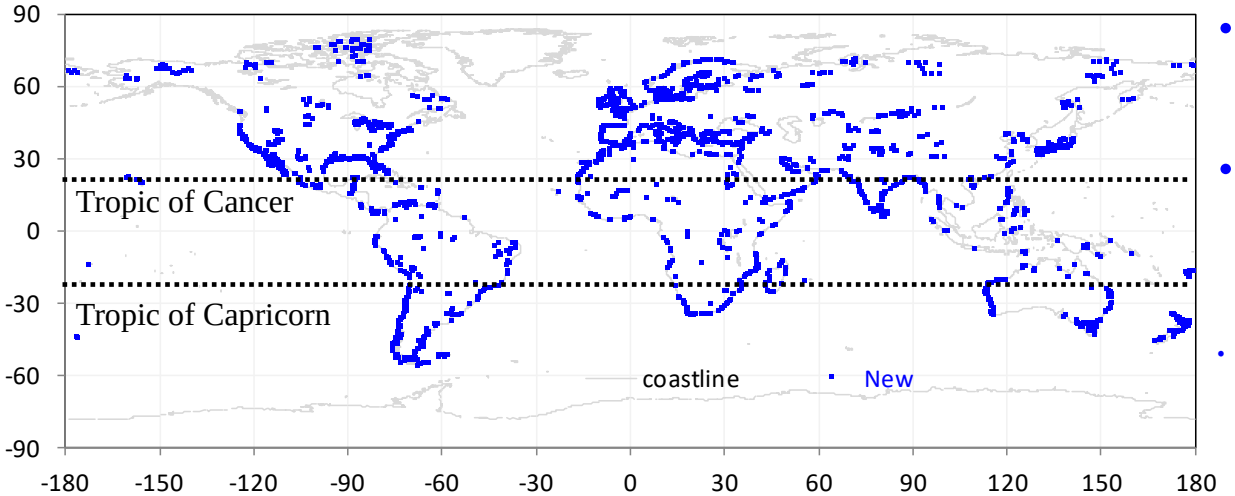
C6 RMSE Track: 46 m, Scan: 54 m, nadir equivalent

GCP refresh & match improvements



- 1214 existing chips mostly from Landsat-7
- 239 daily matches in a 2-year test
- minCCV=0.60, scan angle +/- 45 deg, error range +/- 0.8 pixel

New ground control points (GCPs) will be used in C7 (already used in SNPP C2 and J1/N20 C2.1).



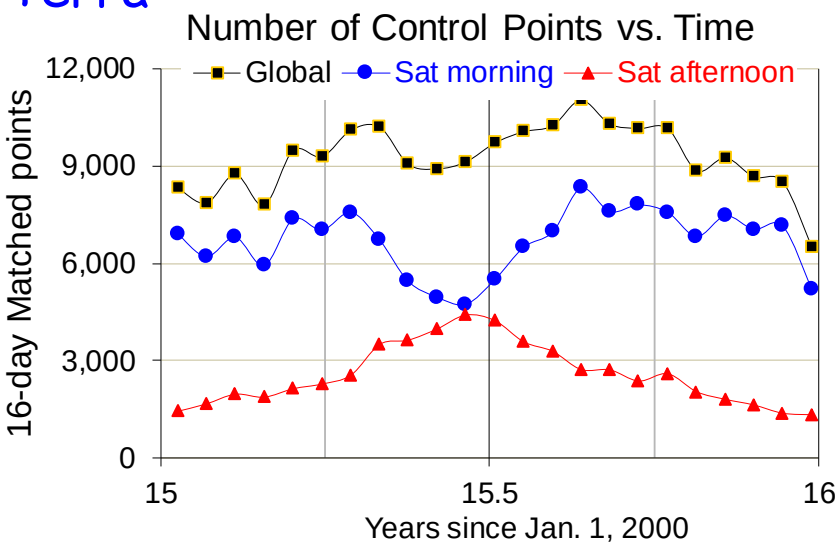
- 2514 (2.1X) new chips from Landsat-8
- 561 (2.3X) daily matches in the same 2-year test
- minCCV=0.85, scan angle +/- 55 deg, error range +/- 2.5 pixel

Lin et al., 25 Feb 2021

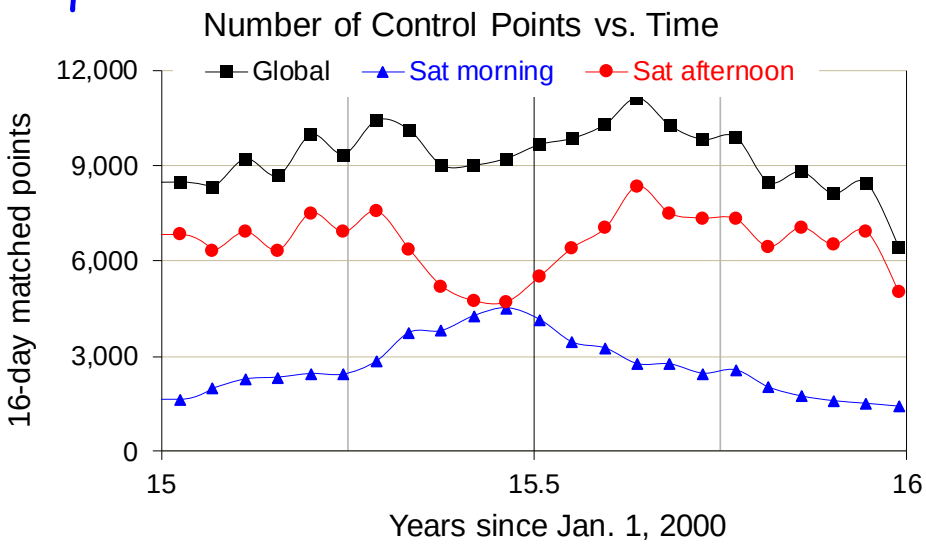
GCPs within tropics seasonally switch side in the satellite mornings/afternoons

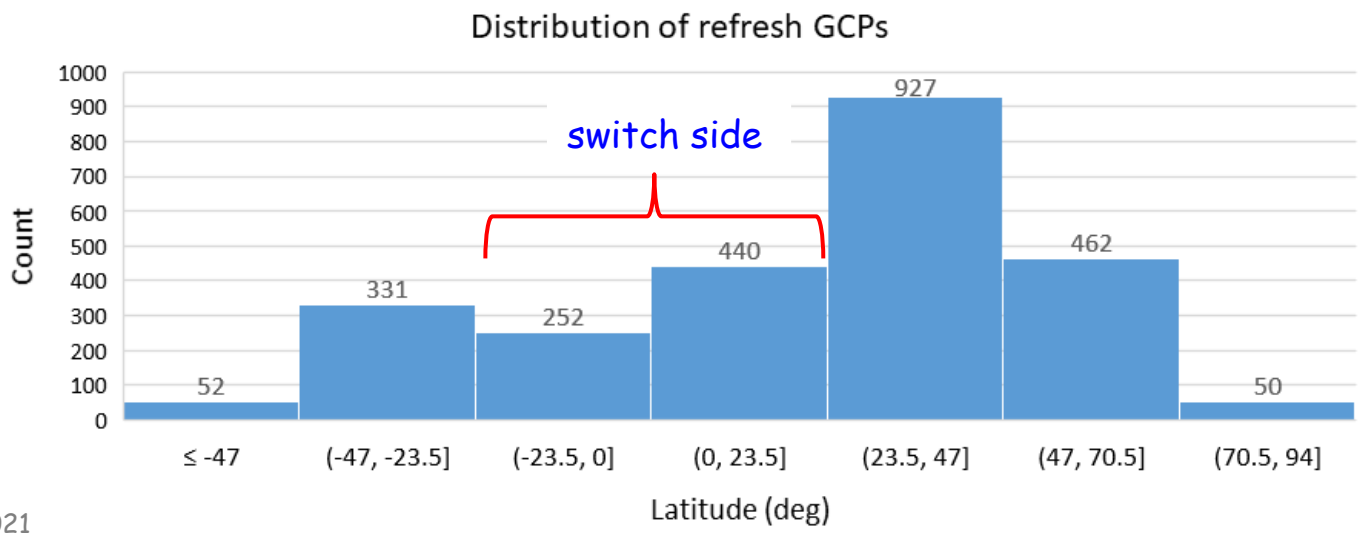
GCP matches in Satellite mornings and afternoons

Terra



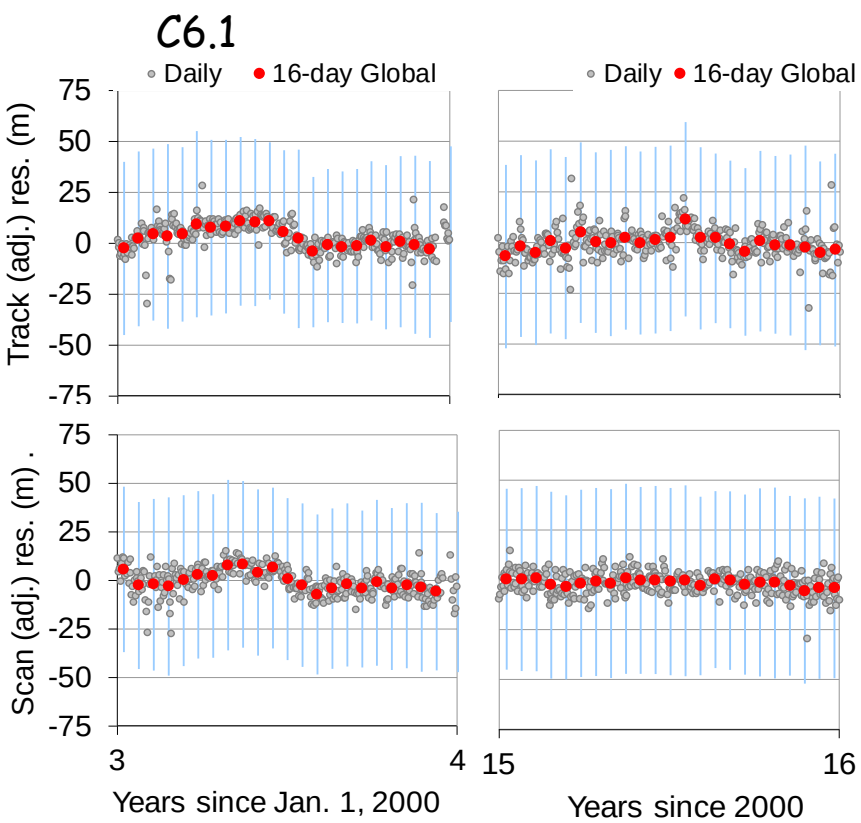
Aqua

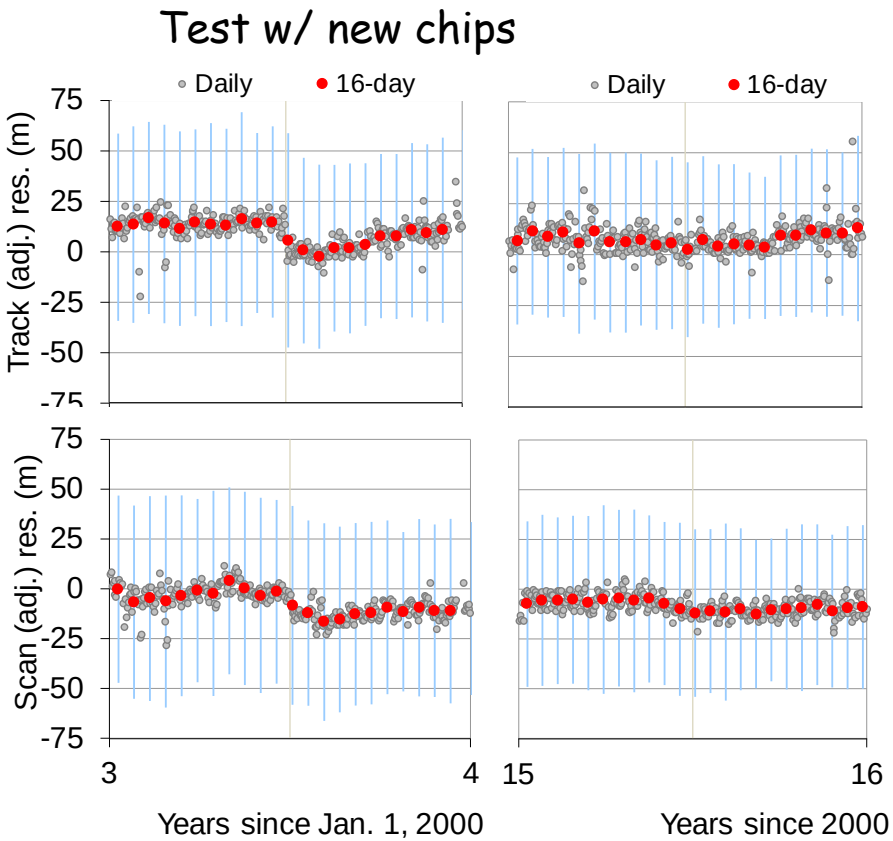


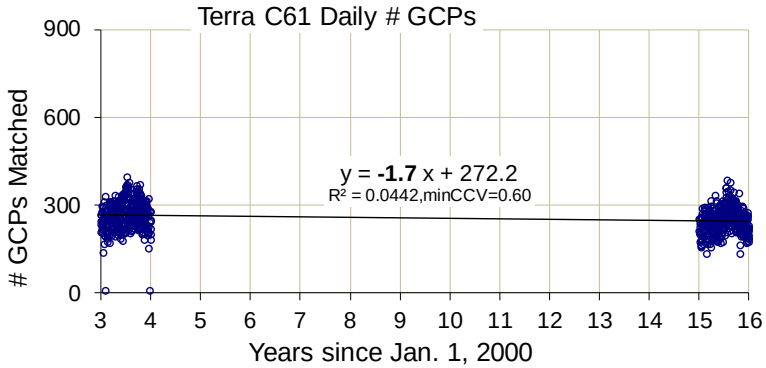


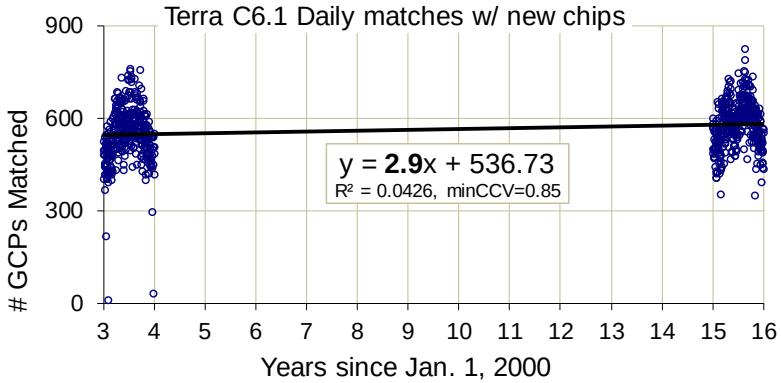
Lin et al., 25 Feb 2021

New chip test results, Terra



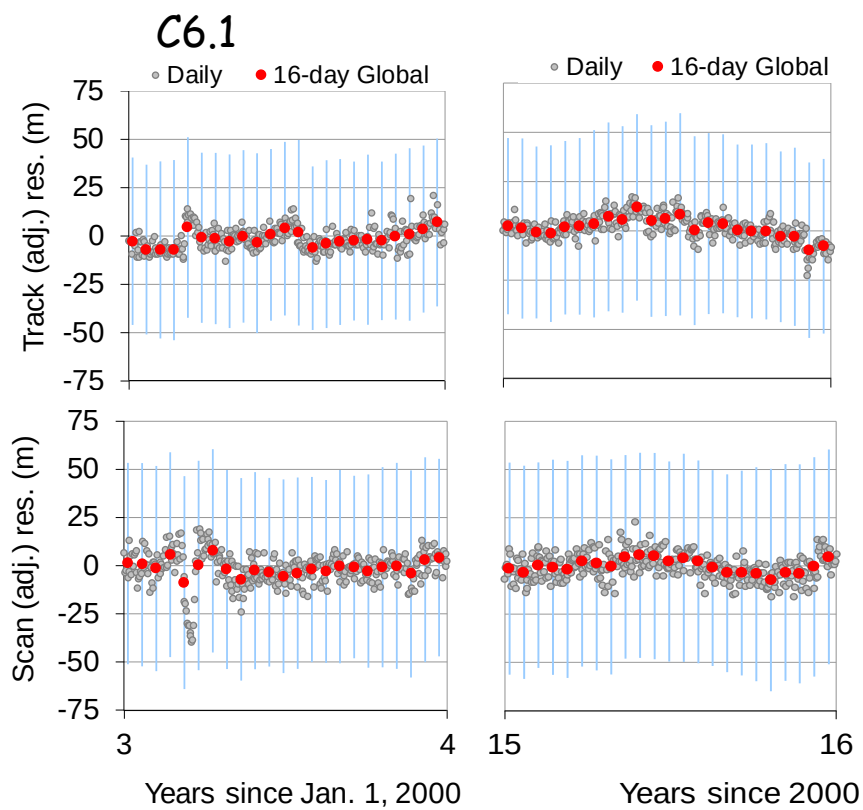


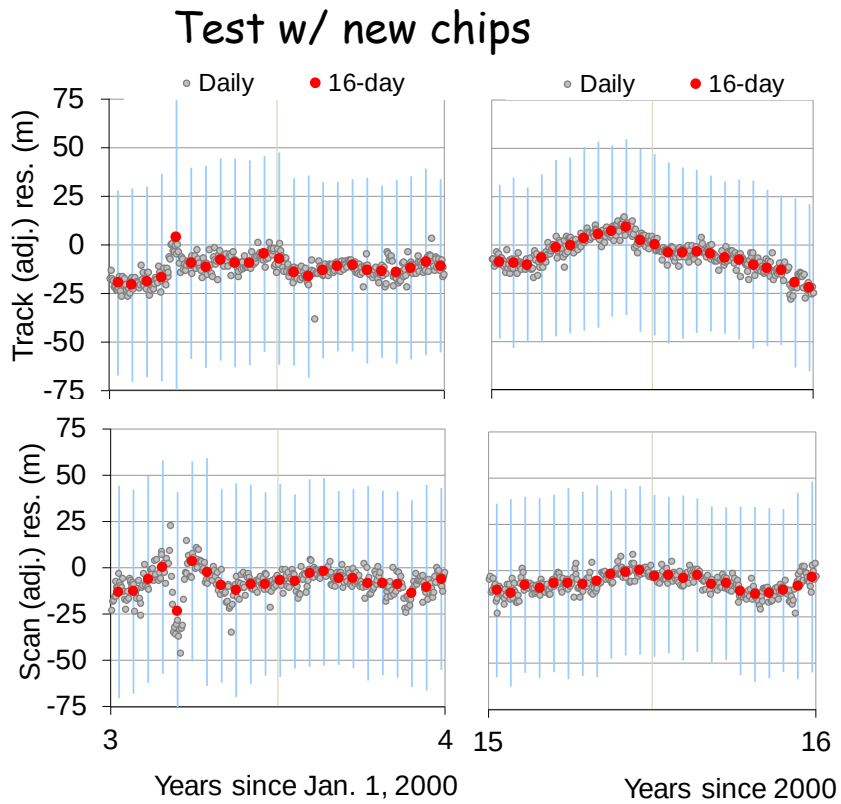


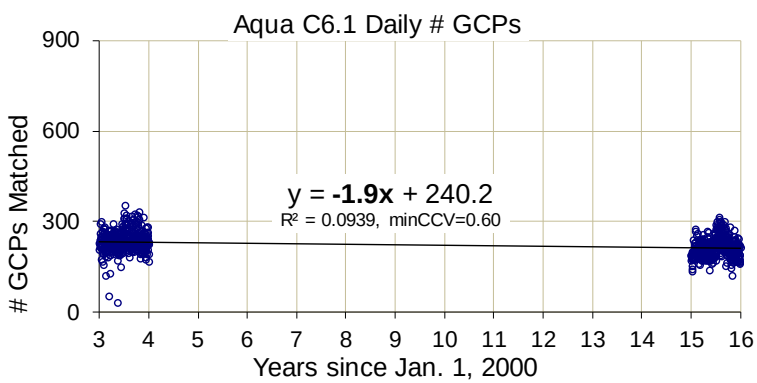


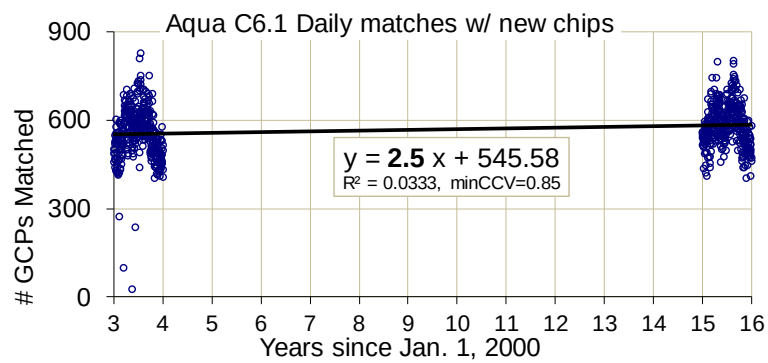
Lin et al.,

New chip test results, Aqua

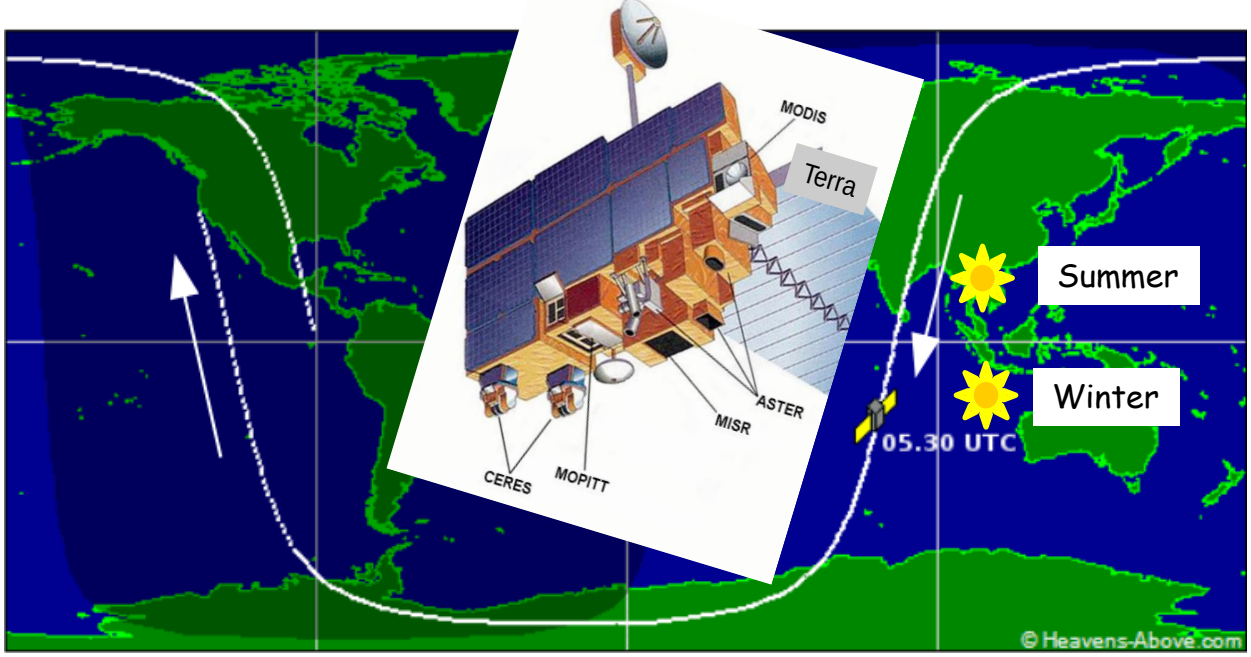


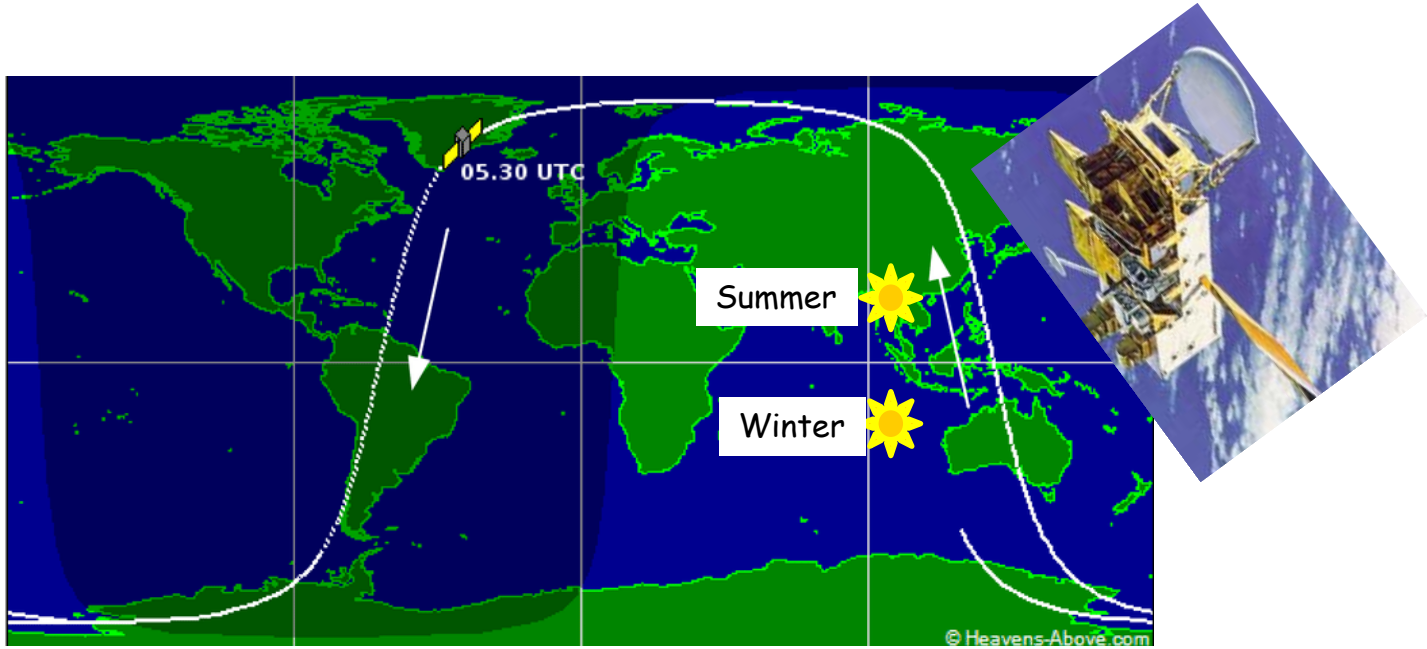




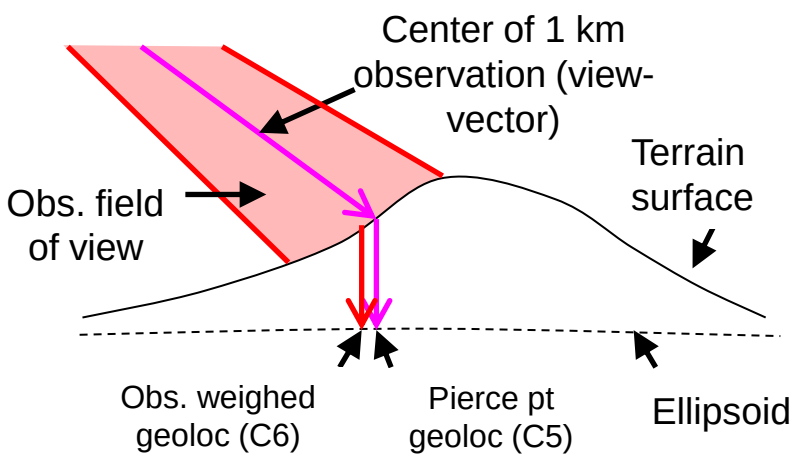


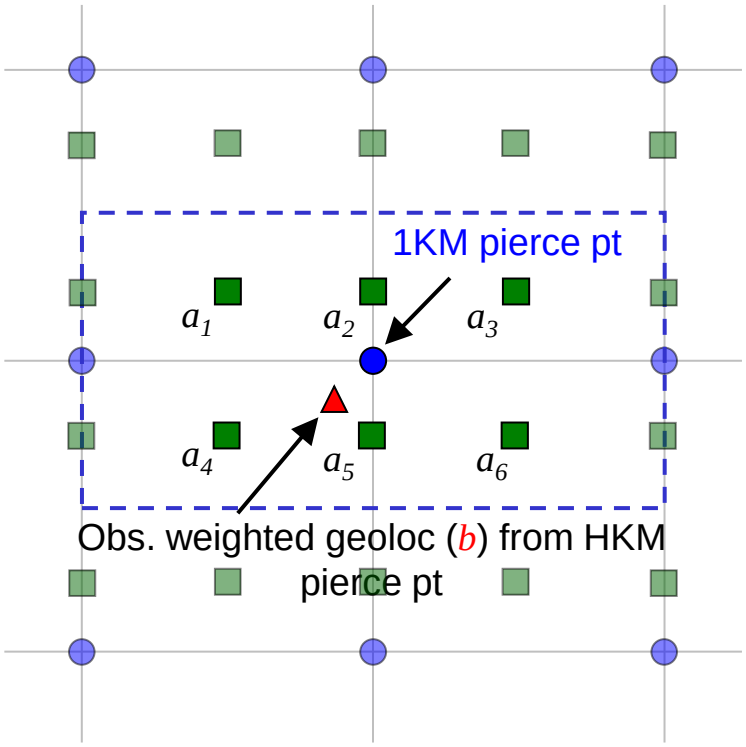
Terra & Aqua MODIS sensors operate in opposite directions, enabling us to detect chips suspected of biased geolocation, 22 out of 2500 chips, at a rate of ~ 1%.





Offsets for HKM and QKM resolutions





- Currently, 1KM output b is weight averaged from HKM geolocation a's
- The 1KM file provides offsets for HKM scan/track/height data fields.
- We are adding fields for QKM offsets similar to HKM offsets

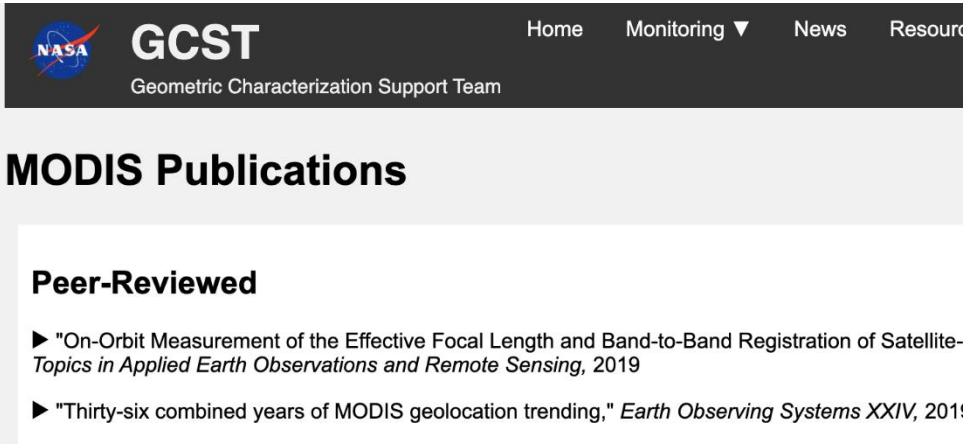
The 500 m offsets fields were added in C6+ in ~2012, see backup slides for details

Future work (C7 is on the way!)

1) Routine monitor and LUTs update as needed
2) Add solar eclipse data field
3) Add 250m offsets, similar to 500m offsets to 1KM resolution. A user's guide is being written to assist their usage.
4) Refresh ground control point chip library
   1) Chips are extended from 24x24 to 42x42 km
   2) Error measurements are extended from ± 45° to ± 55°)
   3) Search area is extended from ± 0.8 to ± 2.5 pixels
5) Create GCST (Geometric Characterization Support Team) website
6) Update LWM (year by year)
7) Update DEM
8) Automate GEO LUT updates

Anything Else?

Any change in priority order?



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 for artifacts in C6 caused by LUT updates
  - AMSR_E stop-go-stop activities on Aqua induced MODIS geolocation errors, which were corrected for in C6.1. C7 will correct for more.
- GCP refresh
  - Denser global distribution helps monitoring geolocation accuracy
- Analysis of orbit lowering – near future
  - No impact on geolocation accuracy is expected
  - Swath width will be slightly narrower
  - Scan-to-scan gaps will be slightly wider

Backup slides:

C6 changes from C5,

sun angle dependent residuals &

scan-to-scan underlaps

HKM offsets in 1KM product

- Currently, we have one 1KM geolocation file per granule
- HKM geolocation can be obtained from offsets within the product

Scan/Track/Height offsets 500m offsets, scan direction int8
(nscans*20:MODIS_Swath_Type_GEO,
mframes*2:MODIS_Swath_Type_GEO)
SDS Attributes:

Attribute Name	Format	Example
units	String	"km IFOV"
scale_factor	float64	0.006
valid_range	int8(2)	-127, 127
_FillValue	int8	-128

- Add fields of QKM offsets from HKM within 1KM product

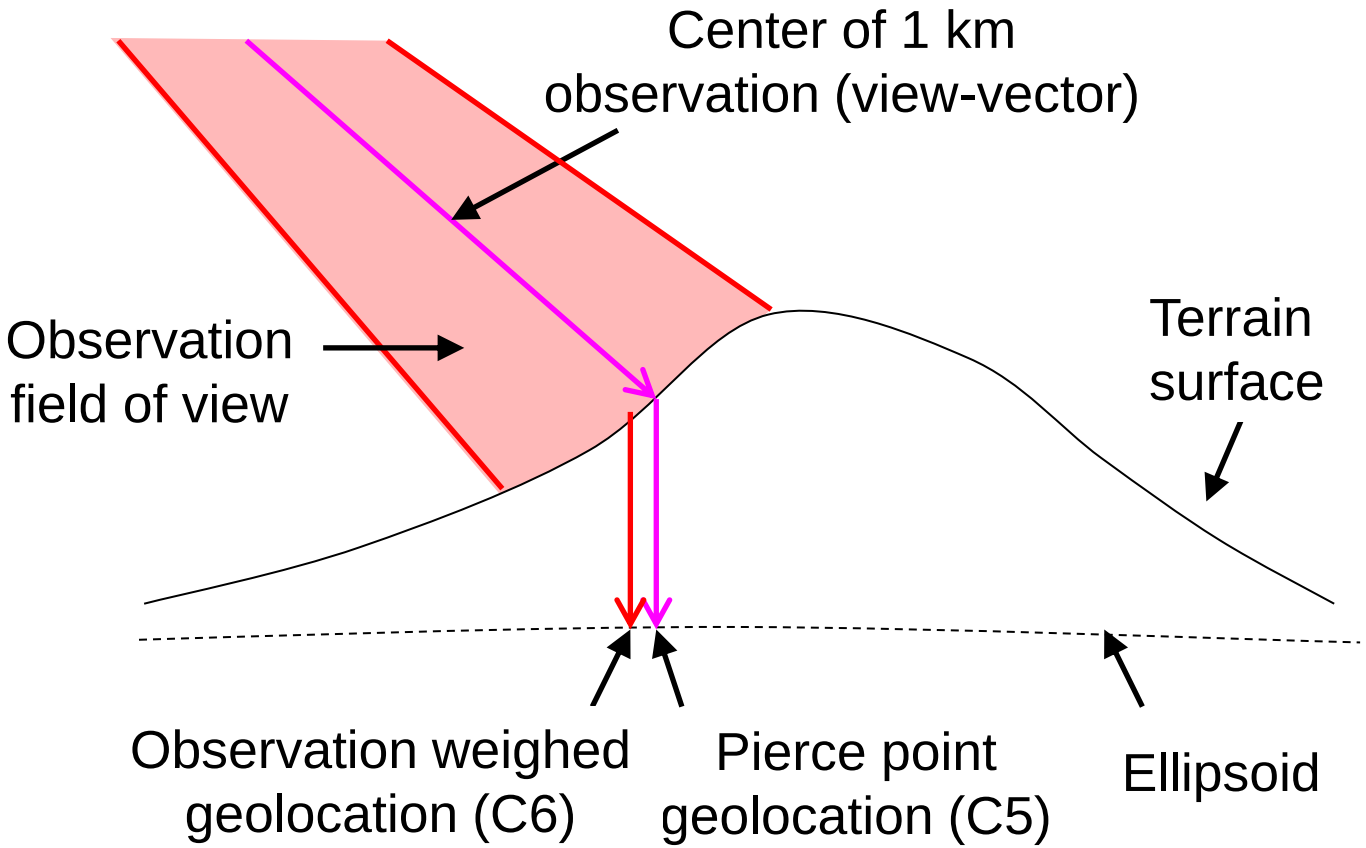
qScan/qTrack/qHeight offsets 250m offsets, scan direction int8
(nscans*40:MODIS_Swath_Type_GEO,
mframes*4:MODIS_Swath_Type_GEO)
SDS Attributes:

Attribute Name	Format	Example
units	String	"hkm IFOV"
scale_factor	float64	0.006
valid_range	int8(2)	-127, 127
_FillValue	int8	-128

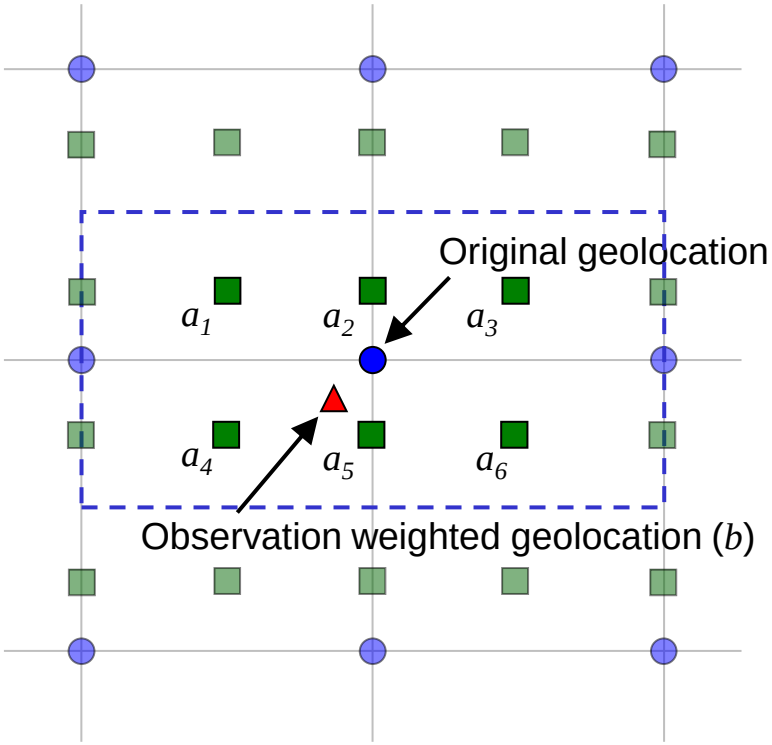
The 500 m offsets fields were added in C6+ in ~2011

C6 Changes from C5 By Robert Wolfe & Team back in ~ 2011

C6 observation weighted terrain correction



Observation weighted terrain correction



– Original 1km geolocation

– 500m geolocation

– Observation weighted geolocation

a_1 to a_6 and b are geocentric cartesian coordinates (x, y, z)

Scan direction

Track direction

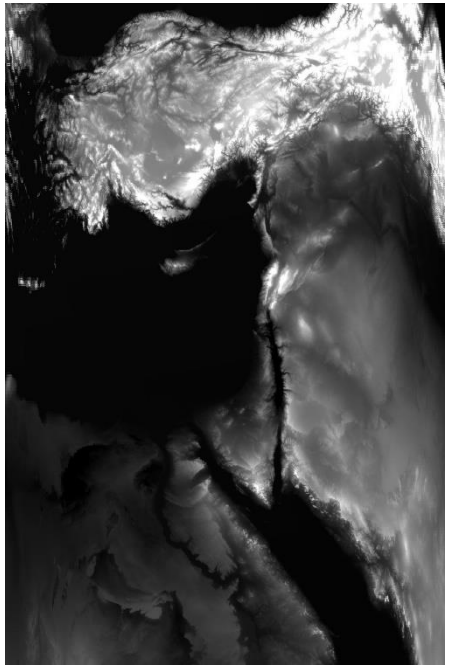
The first order approximation of the observation weighted point is:

$$b = \frac{(a_1 + a_3 + a_4 + a_6)\, w_1 + (a_2 + a_5)\, w_2}{4\, w_1 + 2\, w_2}$$

where $w_1 = 1$ and $w_2 = 2$. These weights approximate the triangular time-integrated weighting function in the scan direction and the rectangular weighting function in the track direction.

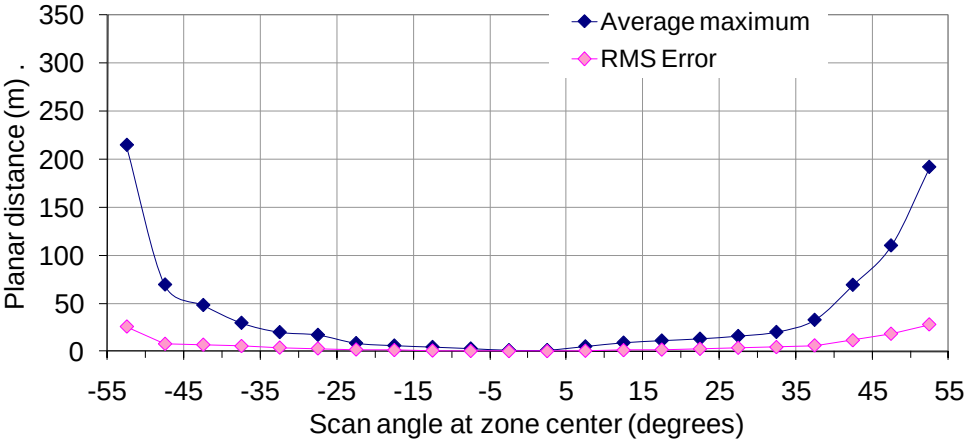
Example: Terra – Middle east

2001/199.0840



Geolocation Elevation
(black: -27m, white: 2069m)

Geolocation difference
current minus obs. weighted
(black: 0m, white: 52m)



New for C6: 500m geolocation (pierce point) is also available, stored as offsets from 1km geolocation (observation weighed)

C6 Changes – Algorithm (Science)

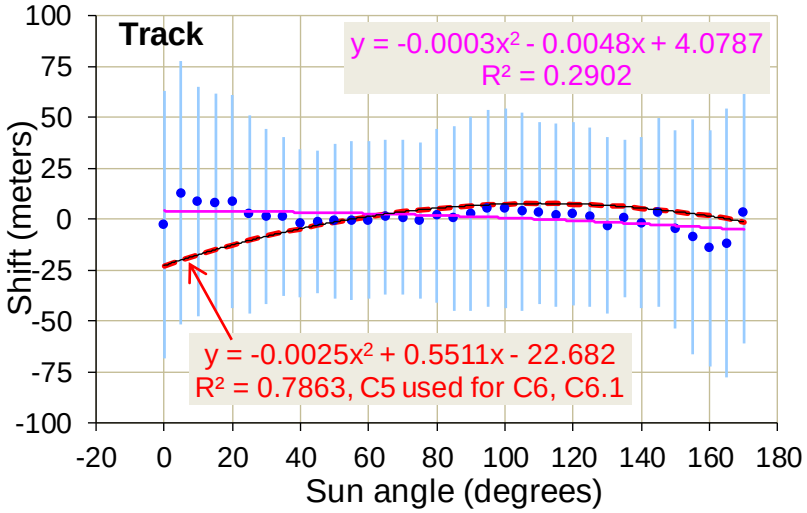
1. Update error analysis: use C5 residuals to update long-term trend, sun-angle corrections and geometric parameter biases
2. Incorporate new ancillary data
   a. Improved 500m Shuttle Radar Terrain Mission (SRTM) Digital Elevation Model data
   b. Improved Land/water mask (500m) developed by UMD
3. Compute 500m geolocation and provide in the form of 8-bit offsets from a bilinear-interpolation of the 1 km data
4. Enhanced 1 km terrain correction (area based)
   - synergistic with 500m geolocation, since weighted average of 500m pixel centers is used to approximate 1km time-integrated weighting function
5. Updated ground control points based on improved GeoCover Landsat 7 products (in conjunction with VIIRS Geolocation activity)

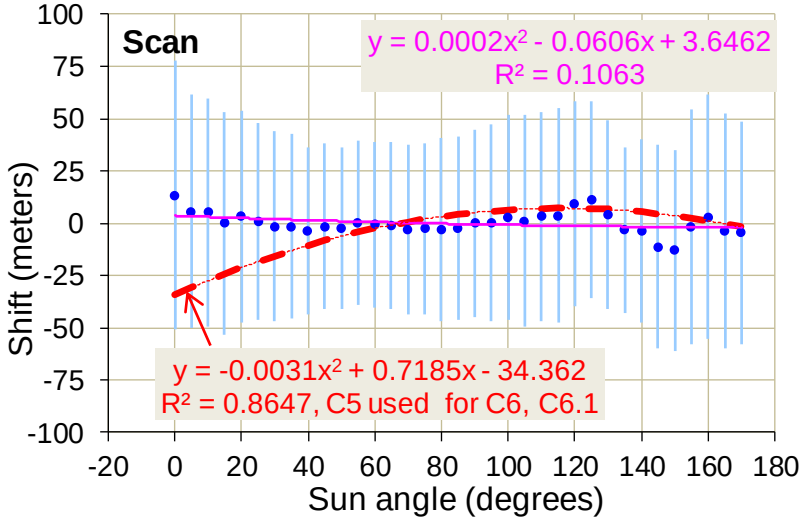
C6 Changes – Other Changes

6. Solar elevation correction (roll, pitch and yaw) written to geolocation product – for transfer to the Control Point Residual files
7. Added scan metadata reporting the quality and type of the ephemeris/attitude data used in the calculations
8. For some users (DB and Oceans): Added file level metadata indicating whether or not terrain correction was performed. *(Terrain correction is always used in MODAPS.)*
9. For DB users: Correct the setting of *attitQuat* when ephemeris source is "MODIS Packet“. When that source is used, the *attitQuat* is currently set to a constant value indicating nominal orientation (roll, pitch, and yaw are all zero). *attitQuat* is used only in the calculation of the solar "elevation" angle correction.

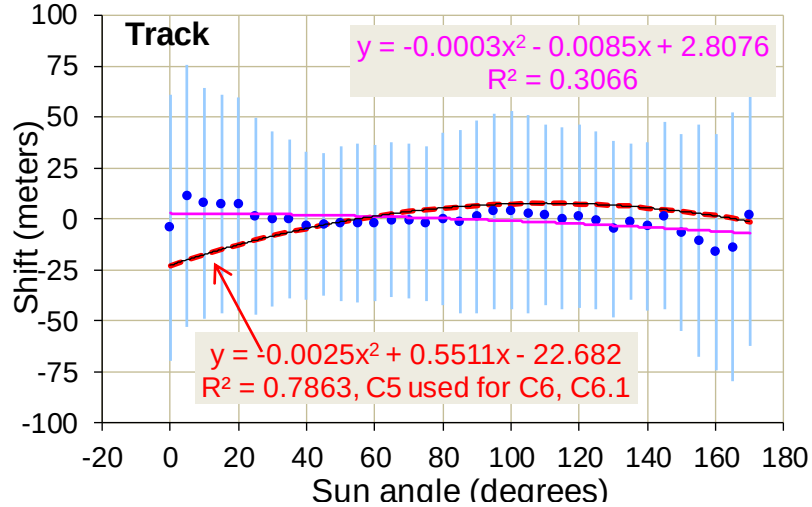
Terra Sun angle Correction

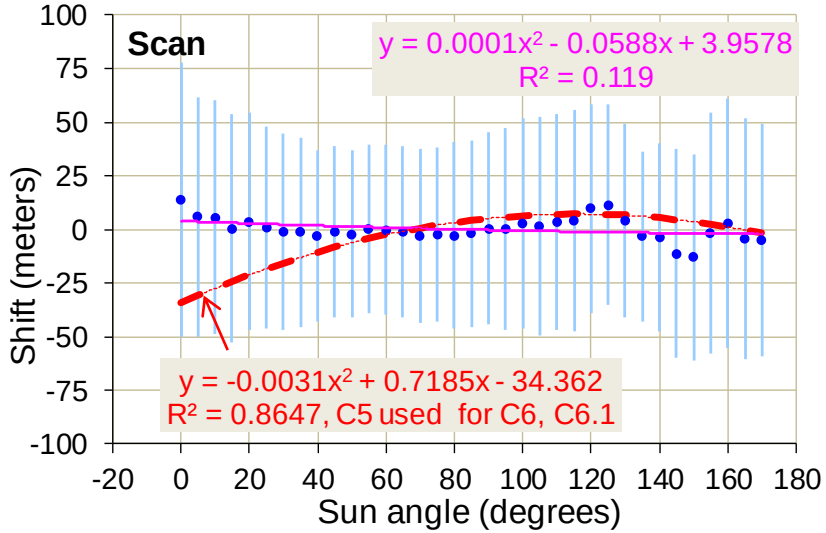
C6 results





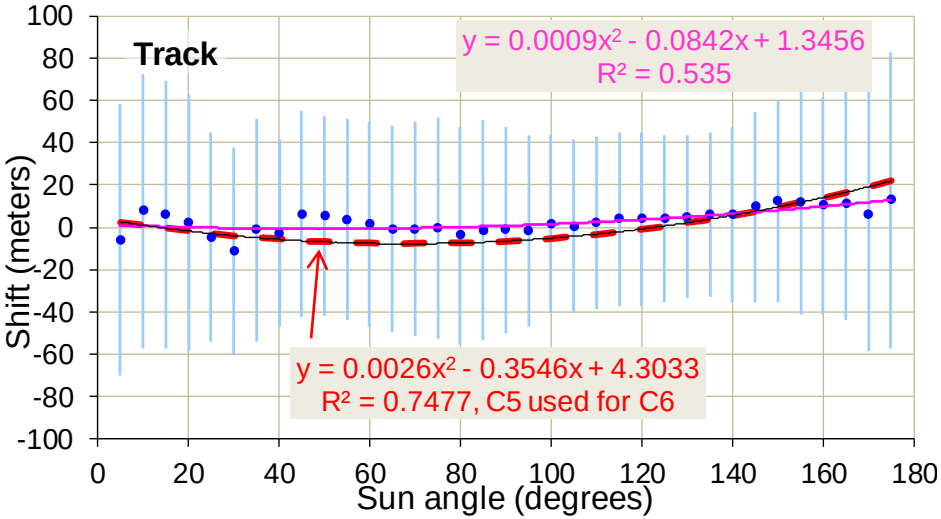
C6.1 results

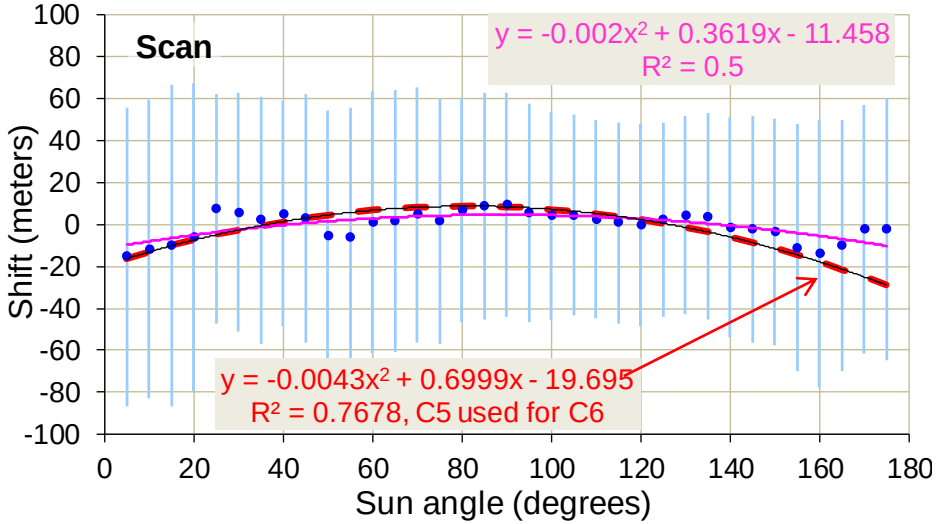




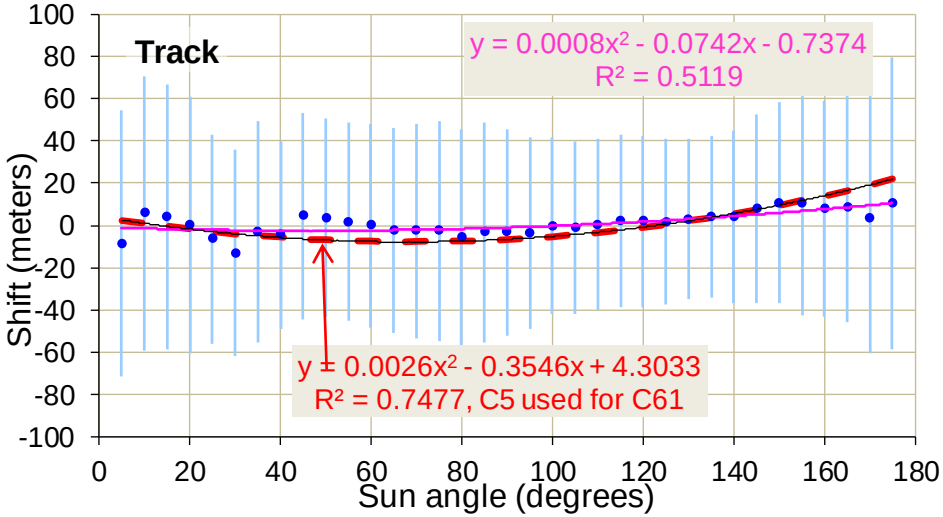
Aqua Sun angle Correction

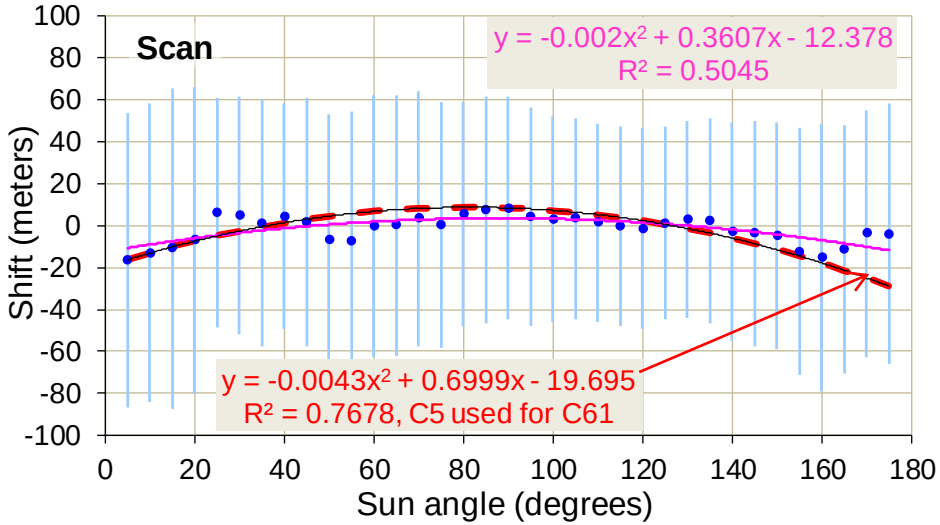
C6 results





C6.1 results

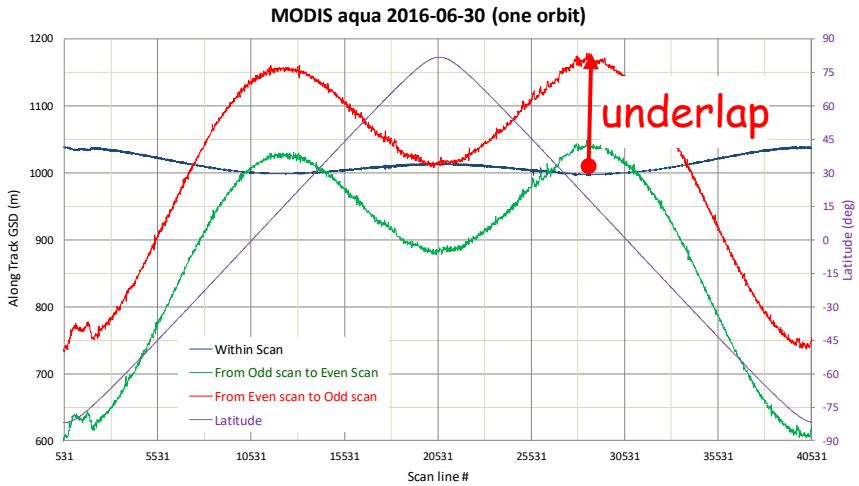


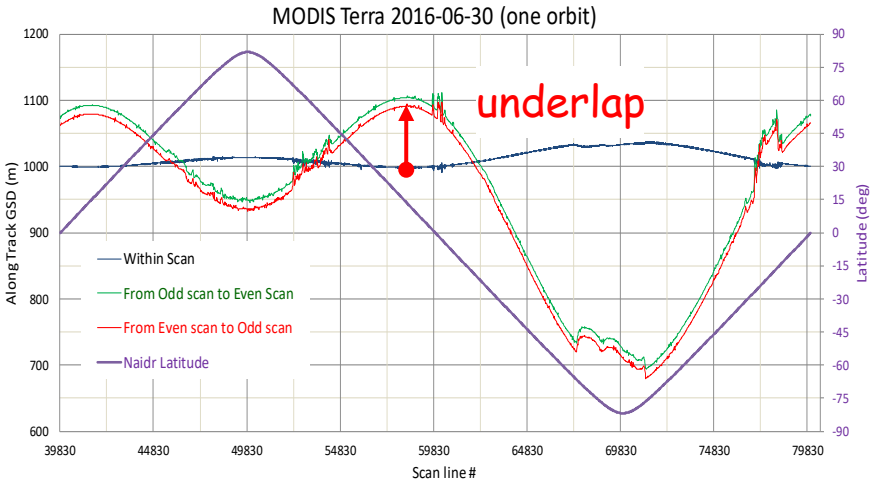


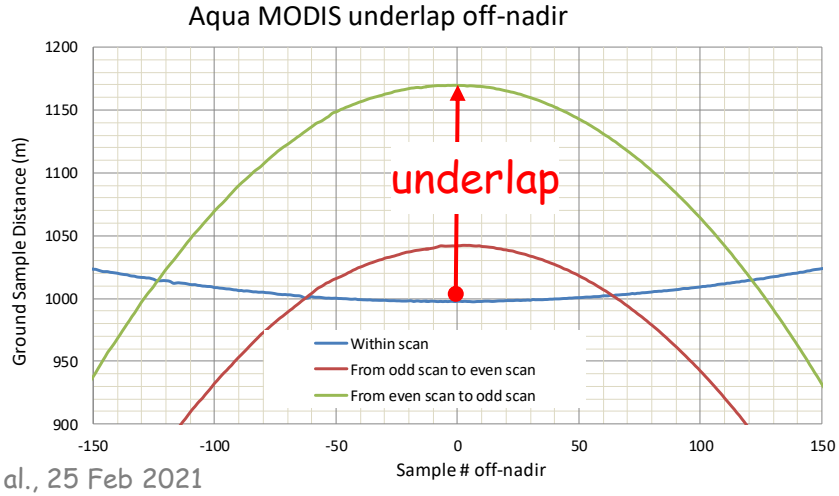
Scan-to-scan underlap w/ nominal EFL

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

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 for J1, V_{ECI} = spacecraft ground speed in the inertial frame, Vearth0 = speed of earth rotation at equator, Overlap < 0 indicates underlap.







- MODIS has underlaps around 15°N at nadir with limited off-scan angles
- After A-train exit ~2022 with a few km lowering, underlaps will be wider