(Terra, Aqua) MODIS Geolocation Status

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NASA MODIS-VIIRS Science Team Meeting
Calibration Workshop
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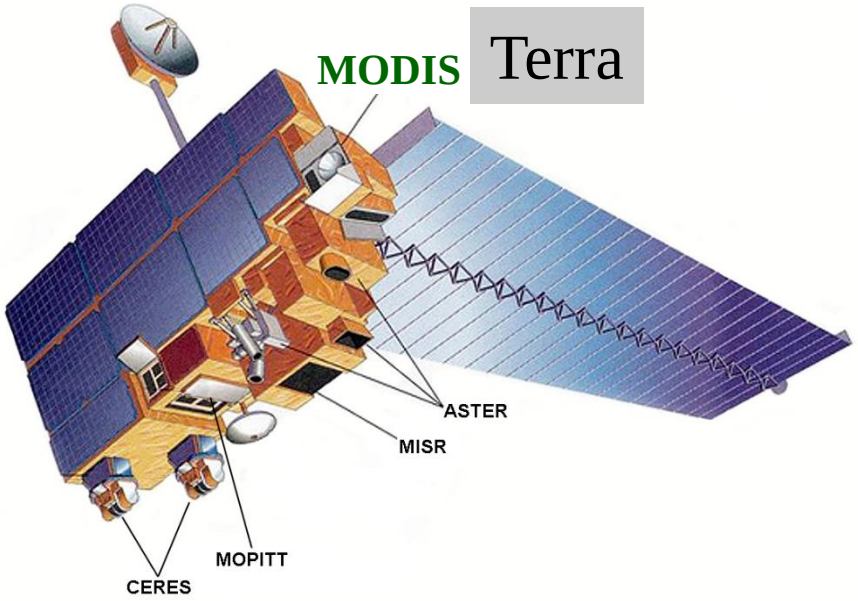
Outline

- Geolocation performance for MODIS on Terra and Aqua
  - Overall performance
  - Trends & details
- Scan-to-scan underlaps & on-orbit focal length
- Future work + a question to the users
- Conclusions

MODIS sensors on Terra & Aqua



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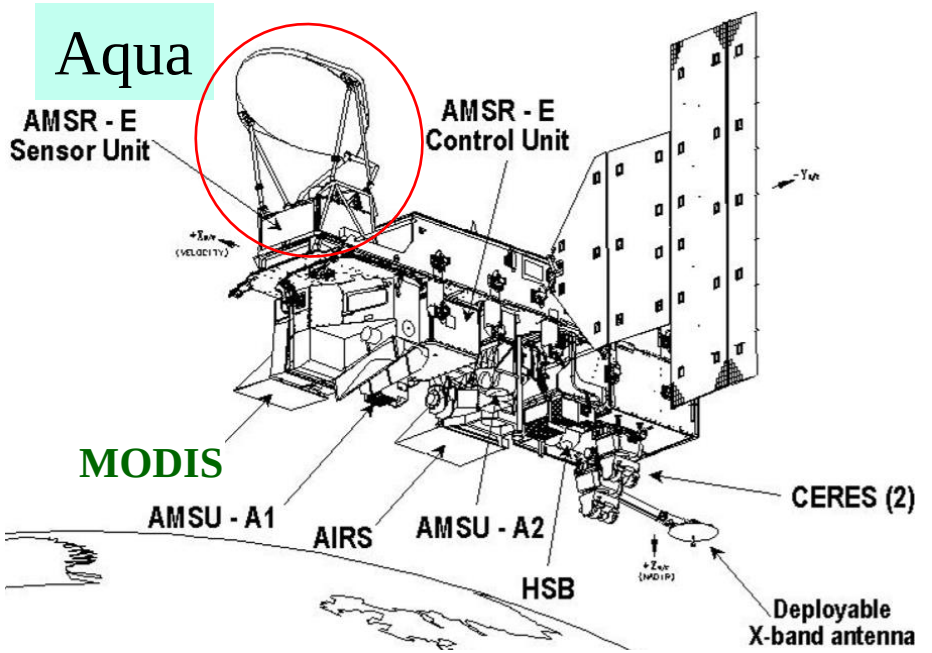

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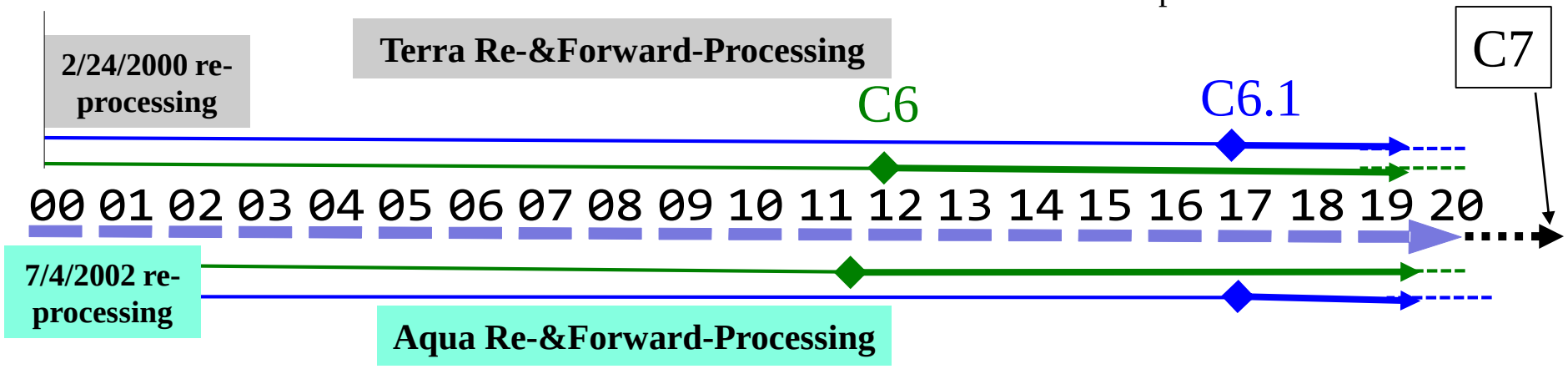


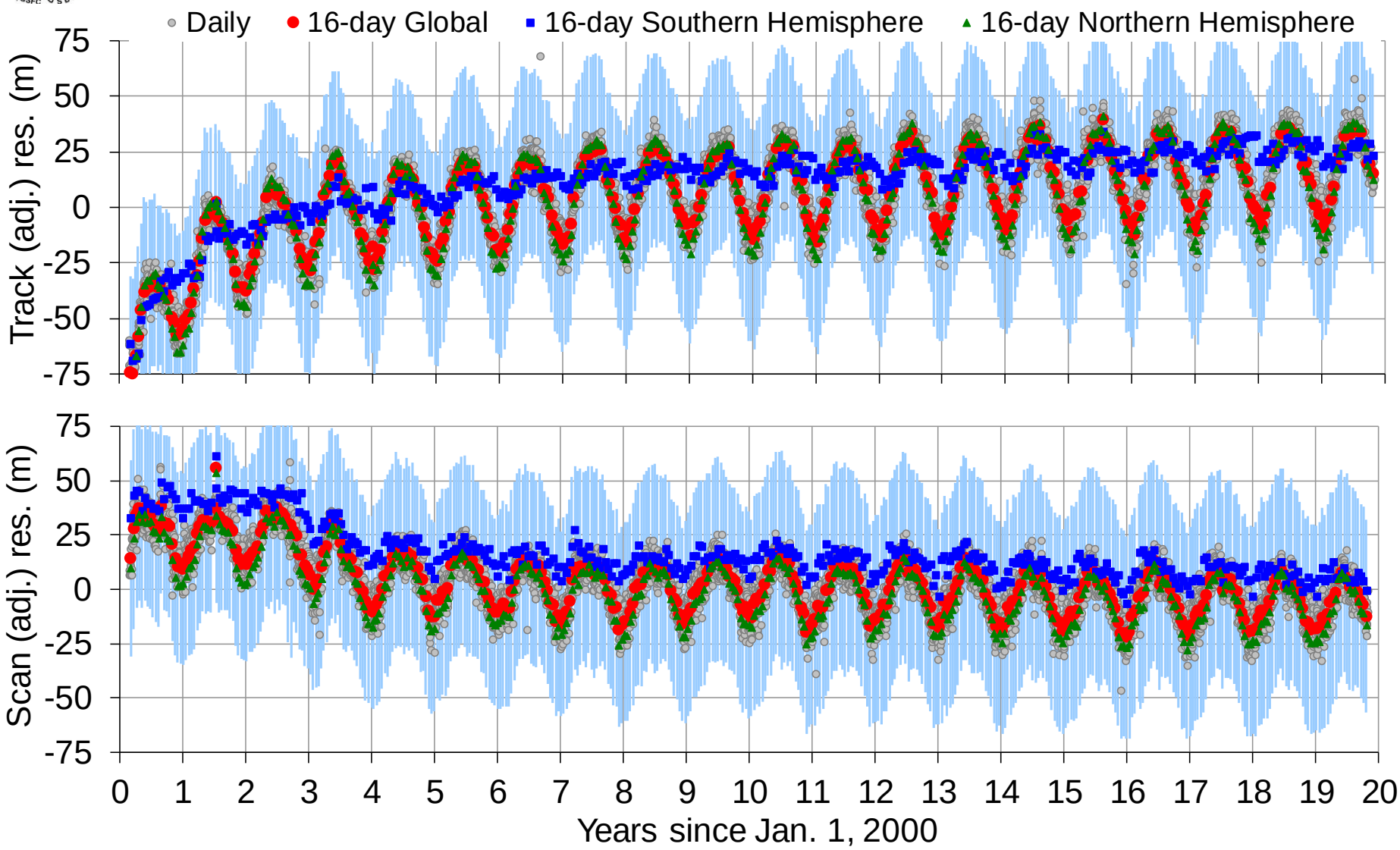
Overall Geolocation performance

Residuals	Terra C6	Aqua C6	Terra C6.1	Aqua C6.1	N20 VIIRS C2
Track mean	**1m**	**3 m**	**0 m**	**1 m**	-1 m
Scan mean	**0 m**	**2 m**	**0 m**	**0 m**	2 m
Track RMSE	**43 m**	**46 m**	**43 m**	**46 m**	55 m
Scan RMSE	**45 m**	**54 m**	**45 m**	**53 m**	49 m
Data-days	**7121 (19.5 yrs)**	**6310 (17.3 yrs)**	**7125 (19.5 yrs)**	**6310 (17.3 yrs)**	669 (1.8 yrs)
Missing days	**61**	**10**	**59**	**10**	3
Daily matched GCPs w/ B1/I1	**258**	**222**	**258**	**222**	193

- **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

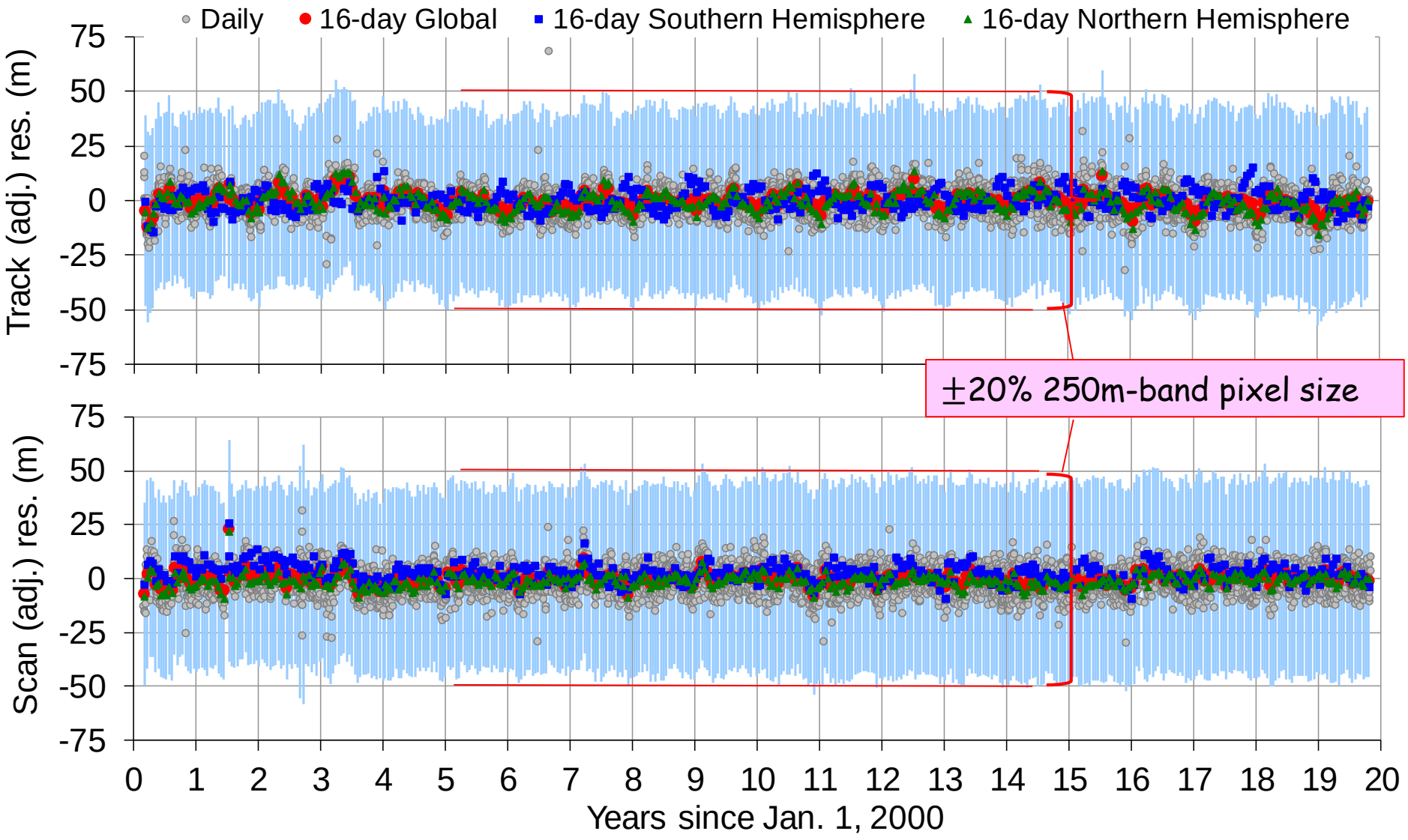
Terra trend and update details

Terra C6.1 long-term trend (uncorrected)



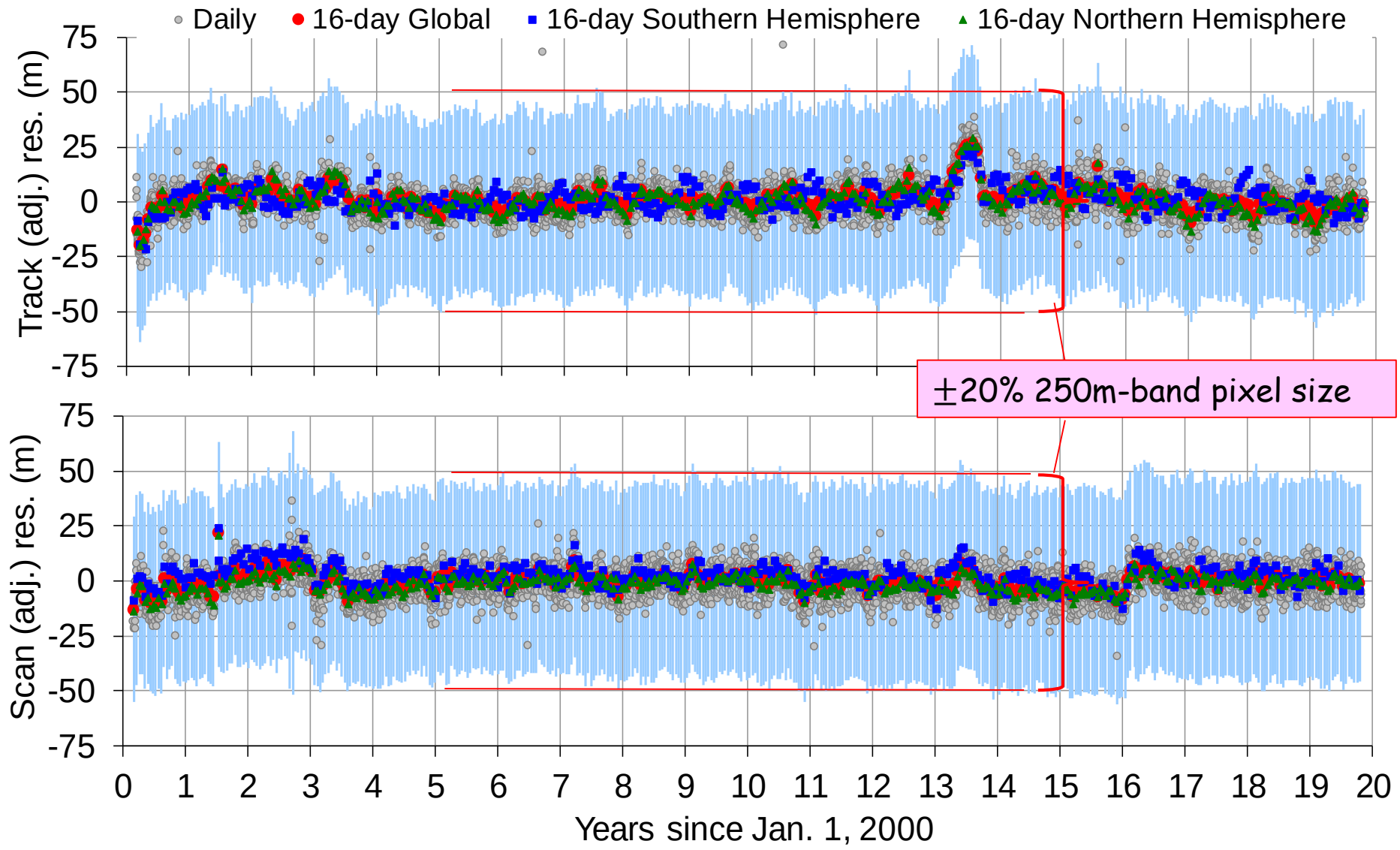
RMSE with no correction: Track: 49 m (+6 m vs C6) Scan: 48 m (+3 m vs C6)

Actual Terra C6.1 residuals



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

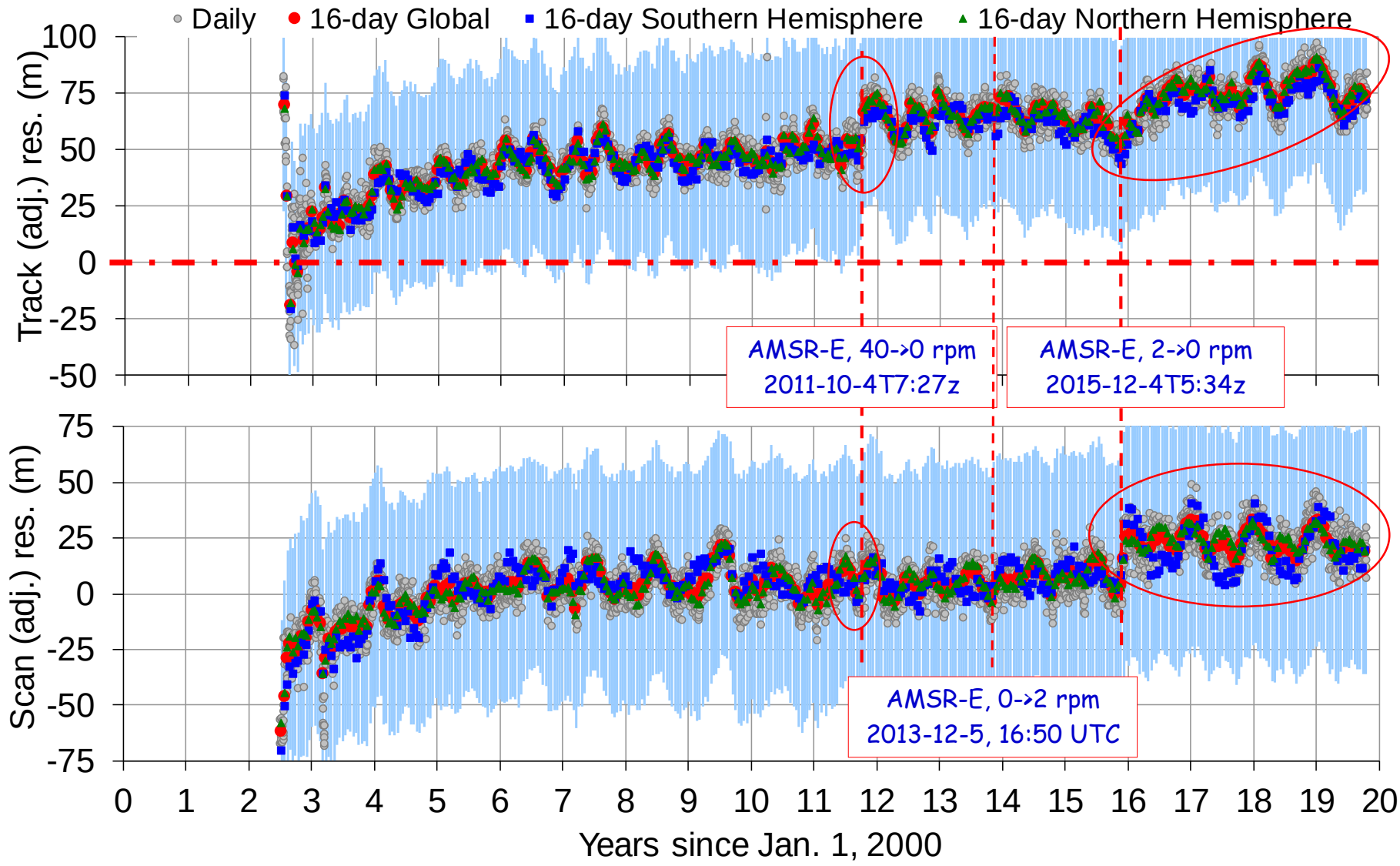
Actual Terra C6 residuals



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

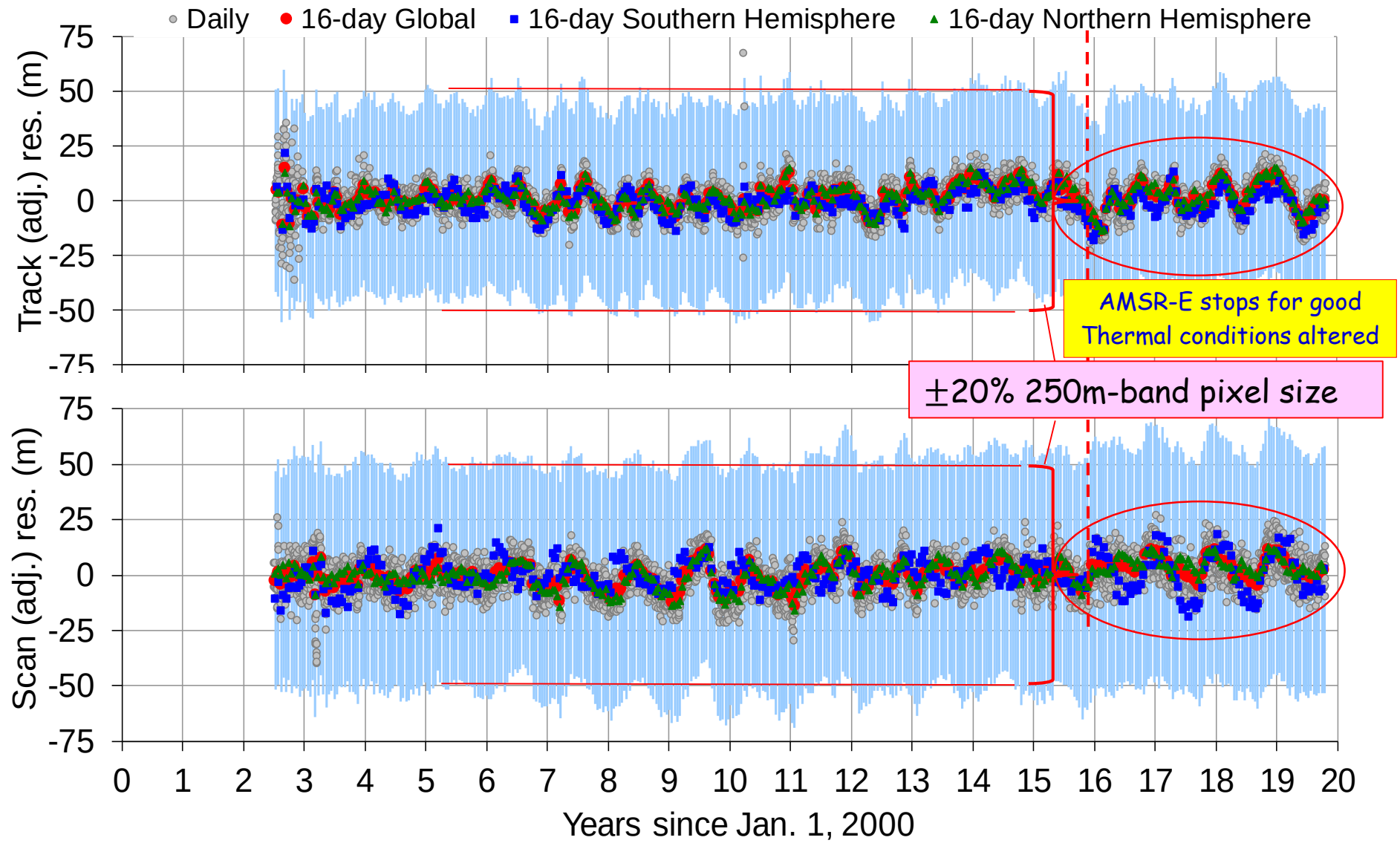
Aqua trend and update details

Aqua C6.1 Long-term Trend (uncorrected)



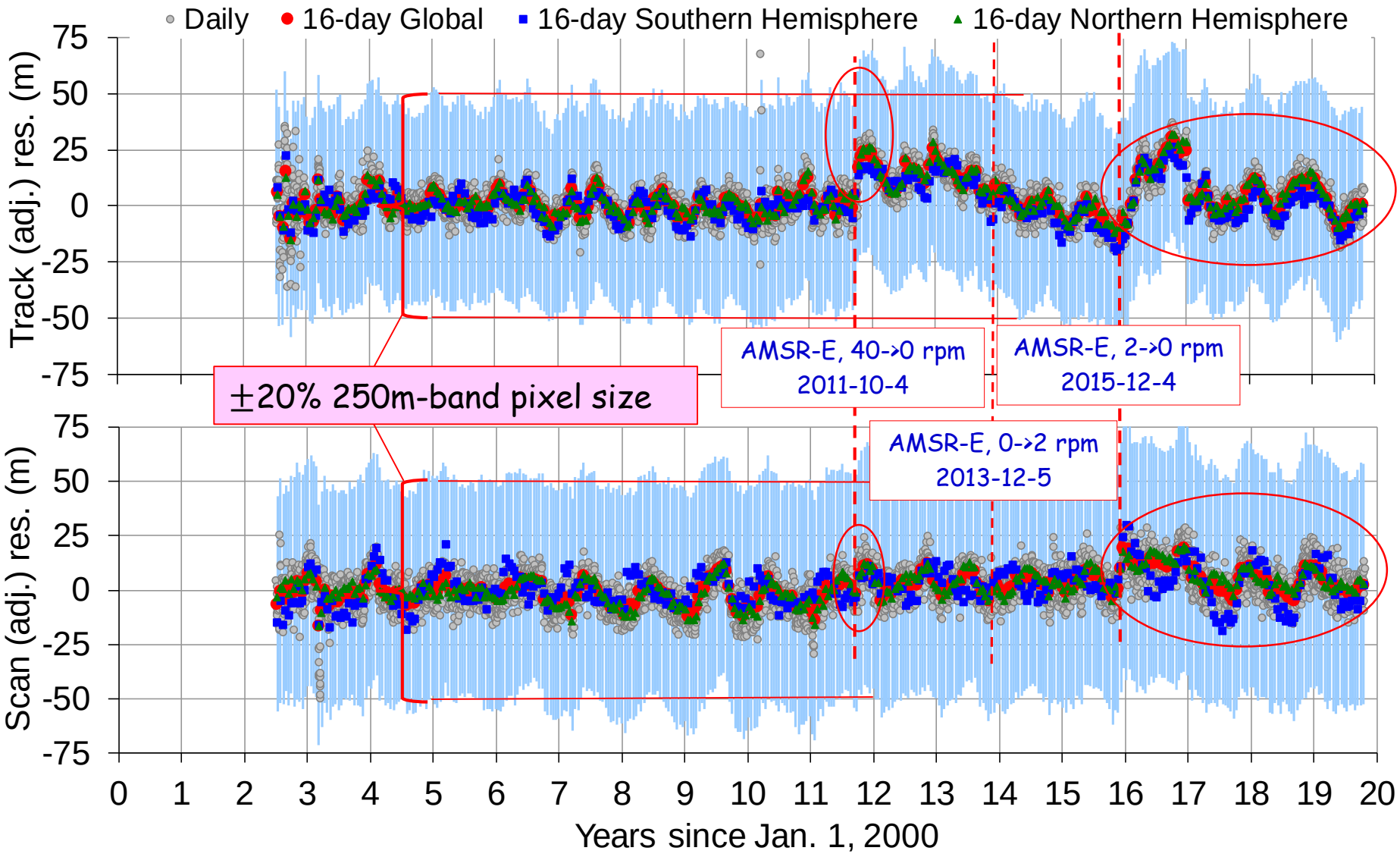
RMSE with no correction: Track: 73 m (+27 m vs C6.1) Scan: 55 m (+2 m vs C6.1)

Actual Aqua C6.1 residuals



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

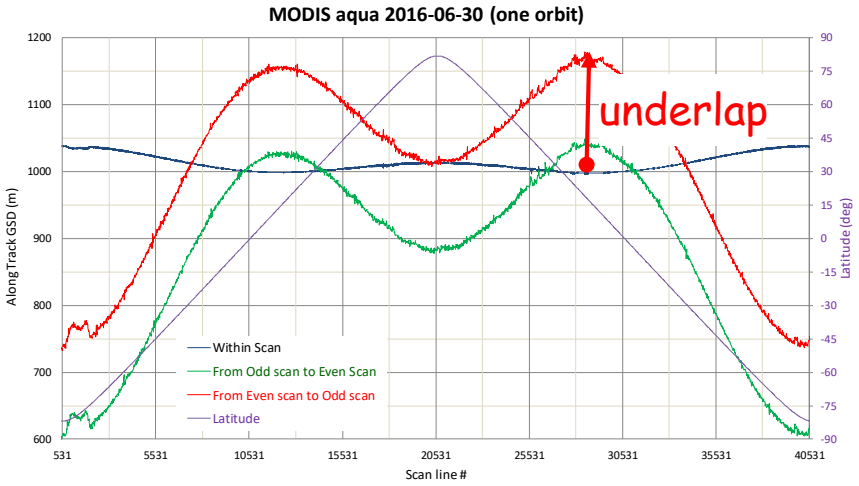
Actual Aqua C6 residuals

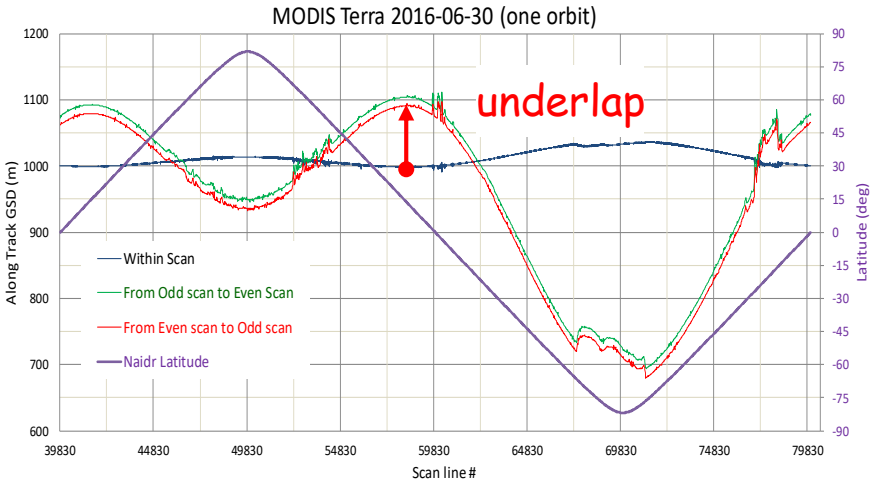


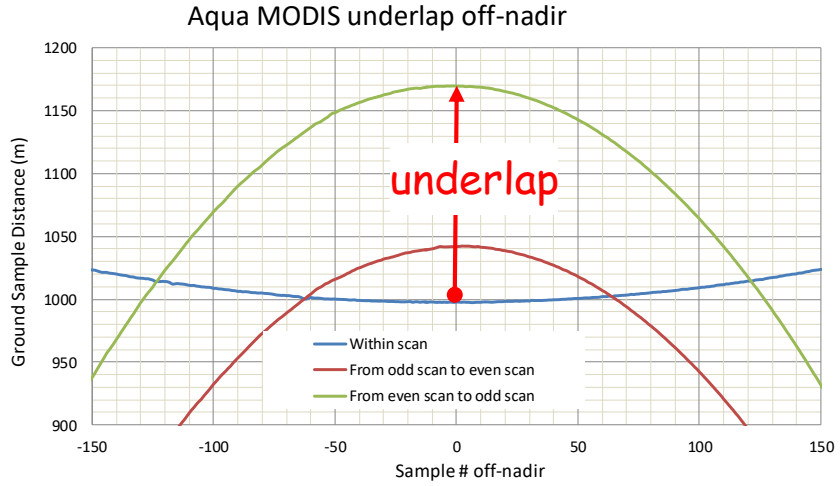
C6 RMSE Track: 46 m, Scan: 54 m, nadir equivalent

Scan-to-scan underlap w/ nominal EFL

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

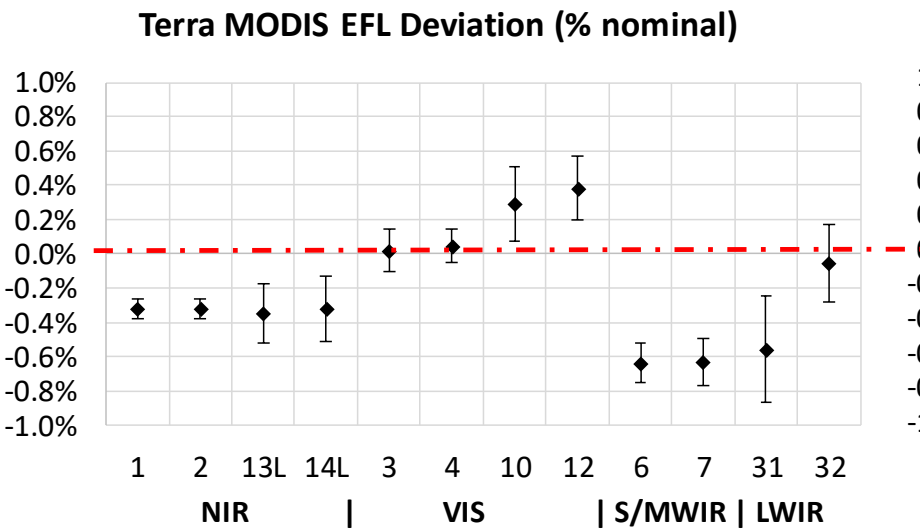


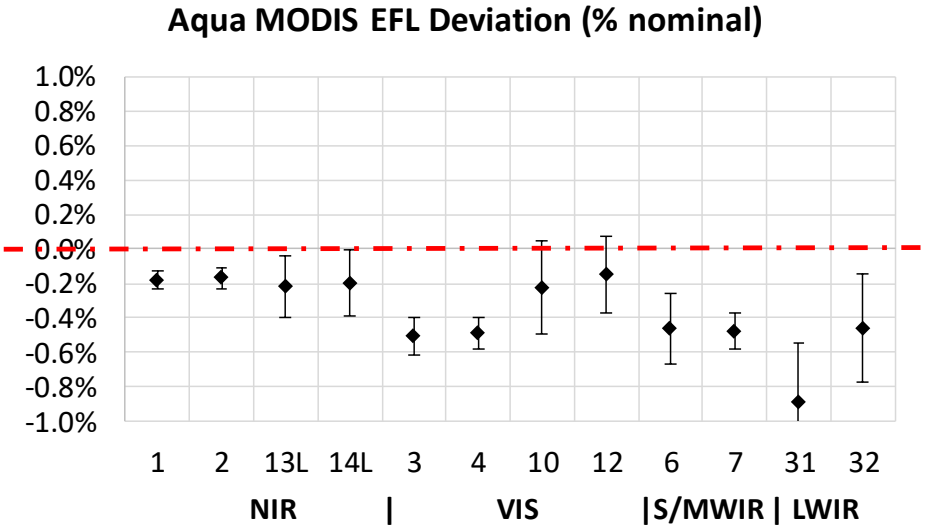




- MODIS has underlaps around 15°N at nadir with limited off-scan angles
- After ~2022 A-train exit a few km, underlaps will be wider

On-orbit focal length measurements





- On-orbit measured effective focal length (EFL) varies among builds and bands.
  - EFL in Terra MODIS has higher disperse among bands than that in Aqua MODIS
- A +0.5% EFL change means +50 m change in scan-to-scan underlap where it exits.
  - Bands 6,7,31 have shorter EFL, thus less underlaps for both Aqua and Terra MODIS
  - Band B12 for Terra MODIS has longer EFL, thus more underlaps
- C7 re-processing will incorporate measured[1] EFL

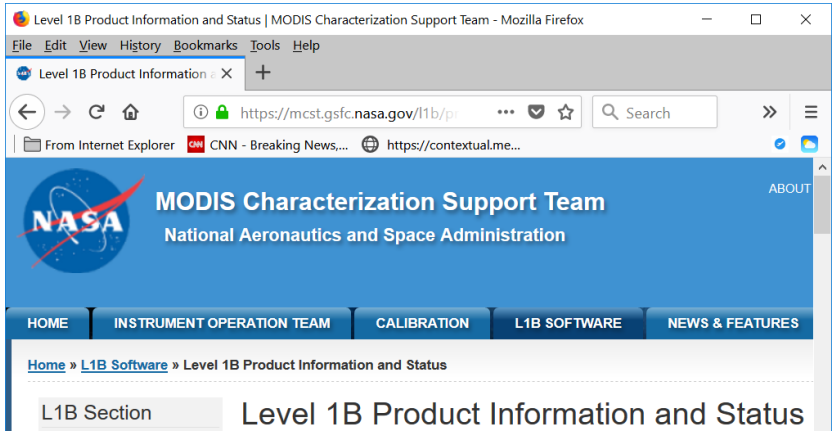
1. J.C. Tilton, R.E. Wolfe, G. Lin, and J.J. Dellomo, "On-Orbit Measurement of the Effective Focal Length and Band-to-Band Registration of Satellite-Borne Whiskbroom Imaging Sensors." *Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, (accepted 10/19/2019), doi:10.1109/JSTARS.2019.2949677.

Future work (C7 is in-work!)

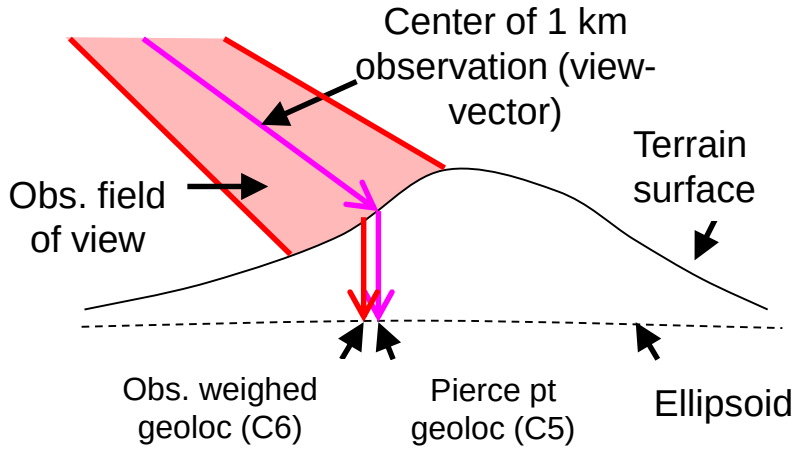
1) Routine monitor and LUTs update as needed
2) Add solar eclipse data field
3) Add 250m offsets? → more next slide
4) Refresh ground control point chip library
    1) Chips are extended from 24x24 to 42x42 km
    2) Error measurements are extended from ± 45° to ± 55°)
5) Automate GEO LUT updates
6) Update DEM
7) Update LWM (year by year?)
8) Create Level-1 geolocation web
    1) similar to L1B

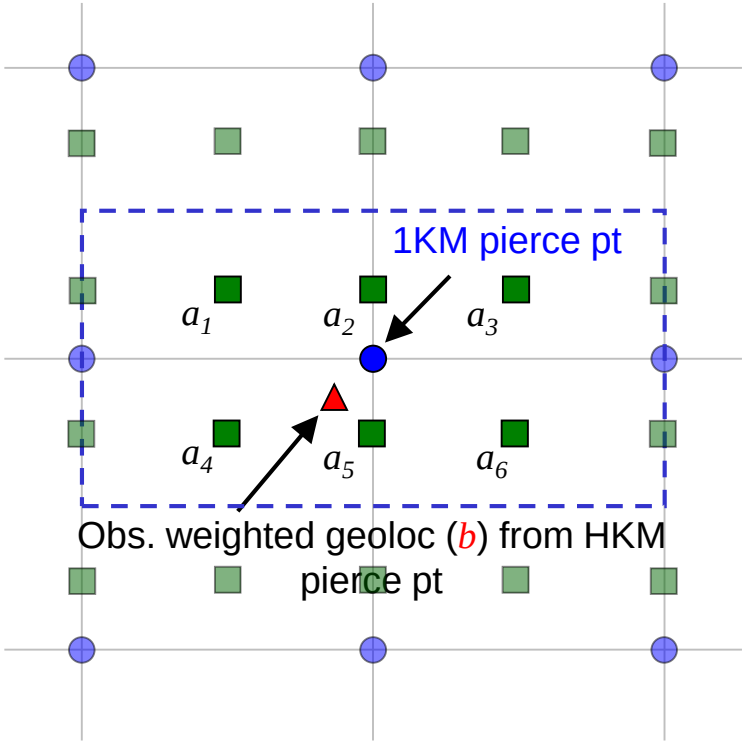
Anything Else?

Any change in priority order above



A Question to users





- Currently, 1KM output b is weight averaged from HKM geolocation a's
- The 1KM file provides offsets for HKM scan/track/height data fields.
- How many of you use the HKM offsets?
- Do you want additional fields for QKM m offsets or an additional HKM geo file?
- The additional field (or file) will provide more accurate geolocation for QKM resolution dataset, especially over the mountainous areas

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

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.
  - 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
    - Measured band-dependent EFL values make underlaps vary among bands
    - C7 will use measured EFL
    - Lowering orbit by 4 km or more will increase underlaps after A-Train exit

Poster: "Joint 3D-Wind Retrievals with Stereoscopic Views from MODIS and GOES" by J.L. Carr, D.L. Wu, R.E. Wolfe, H. Madani, G. Lin, B. Tan. Also paper of the same title in *Remote Sens.* 11, no. 18: 2100; doi:10.3390/rs11182100.

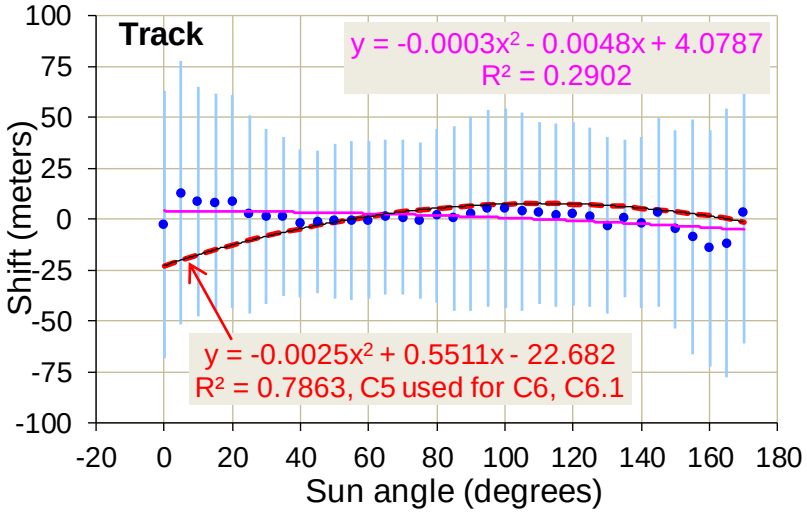
Backup slides:

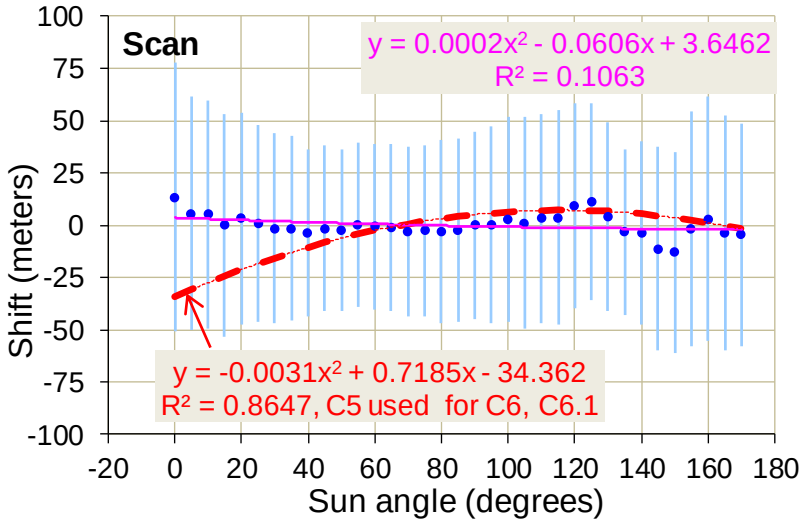
sun angle dependent Residuals

& C6 changes from C5

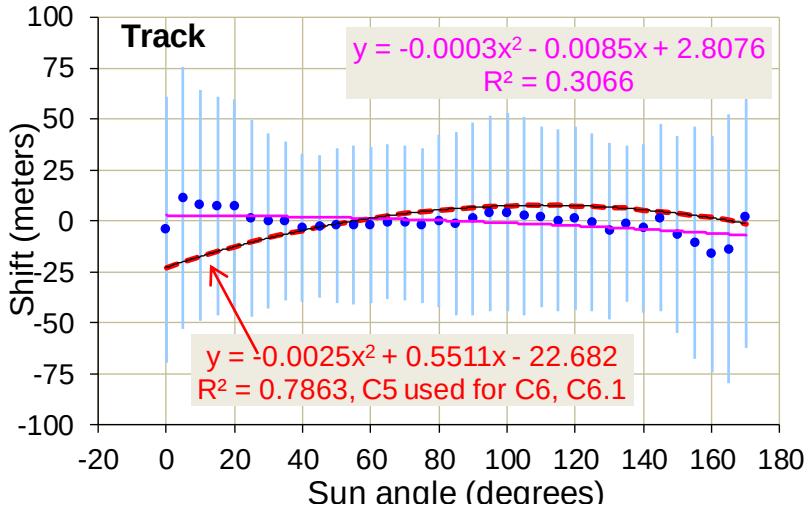
Terra Sun angle Correction

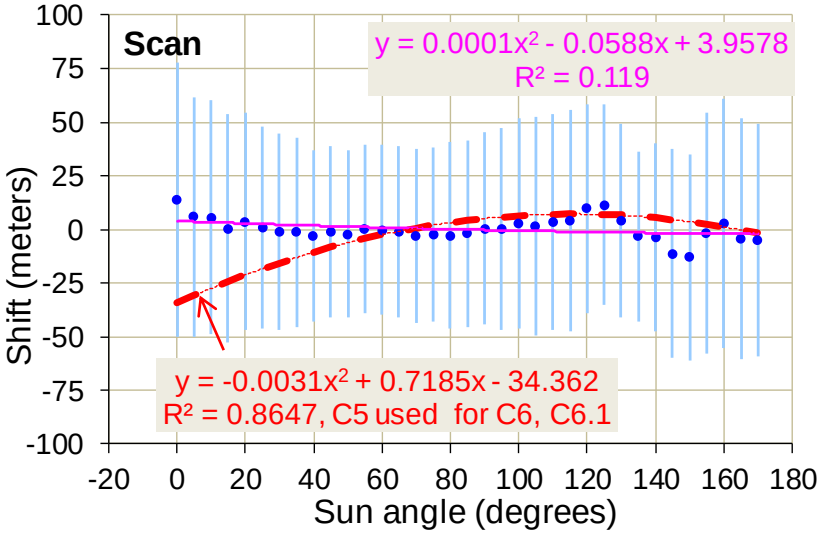
C6 results





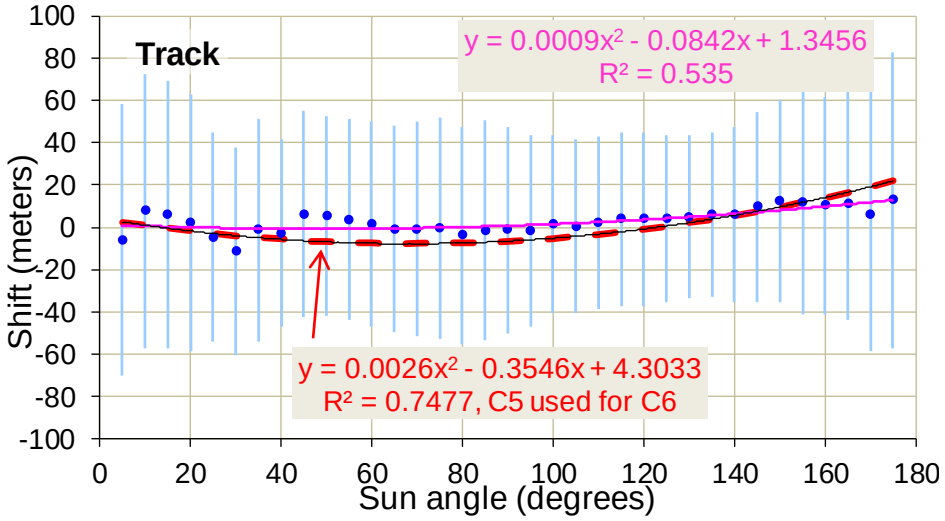
C6.1 results

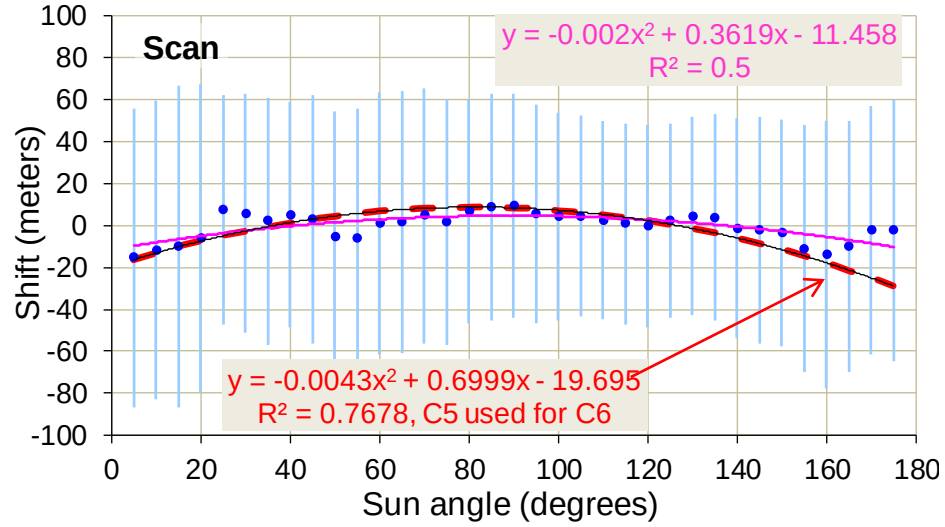




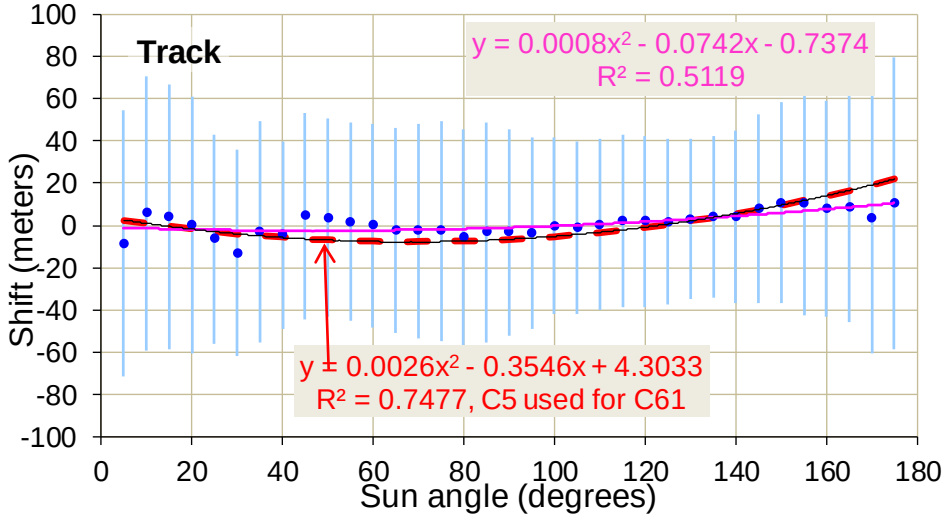
Aqua Sun angle Correction

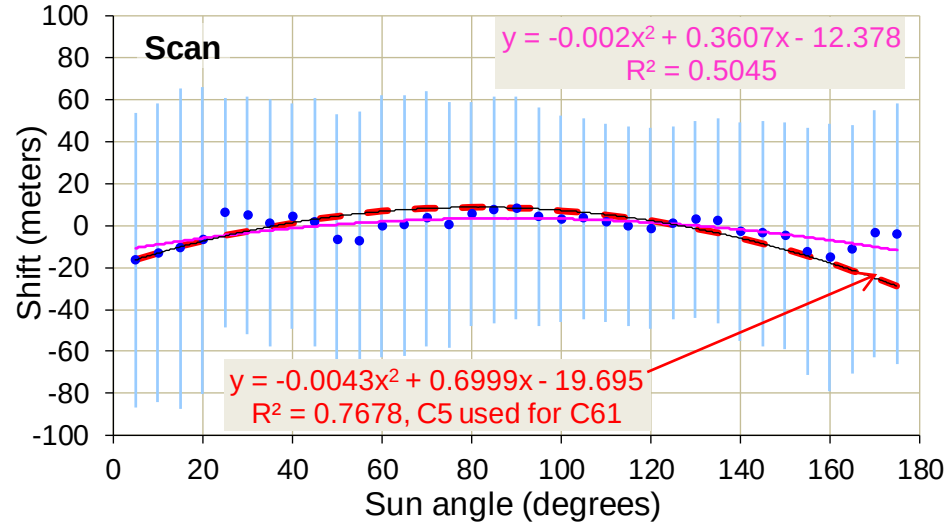
C6 results





C6.1 results





A Question to users

- Currently, we have one 1KM geolocation file per granule
- How many of you use the geolocation fields?

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

- Do you want additional fields or an additional HKM geo file?

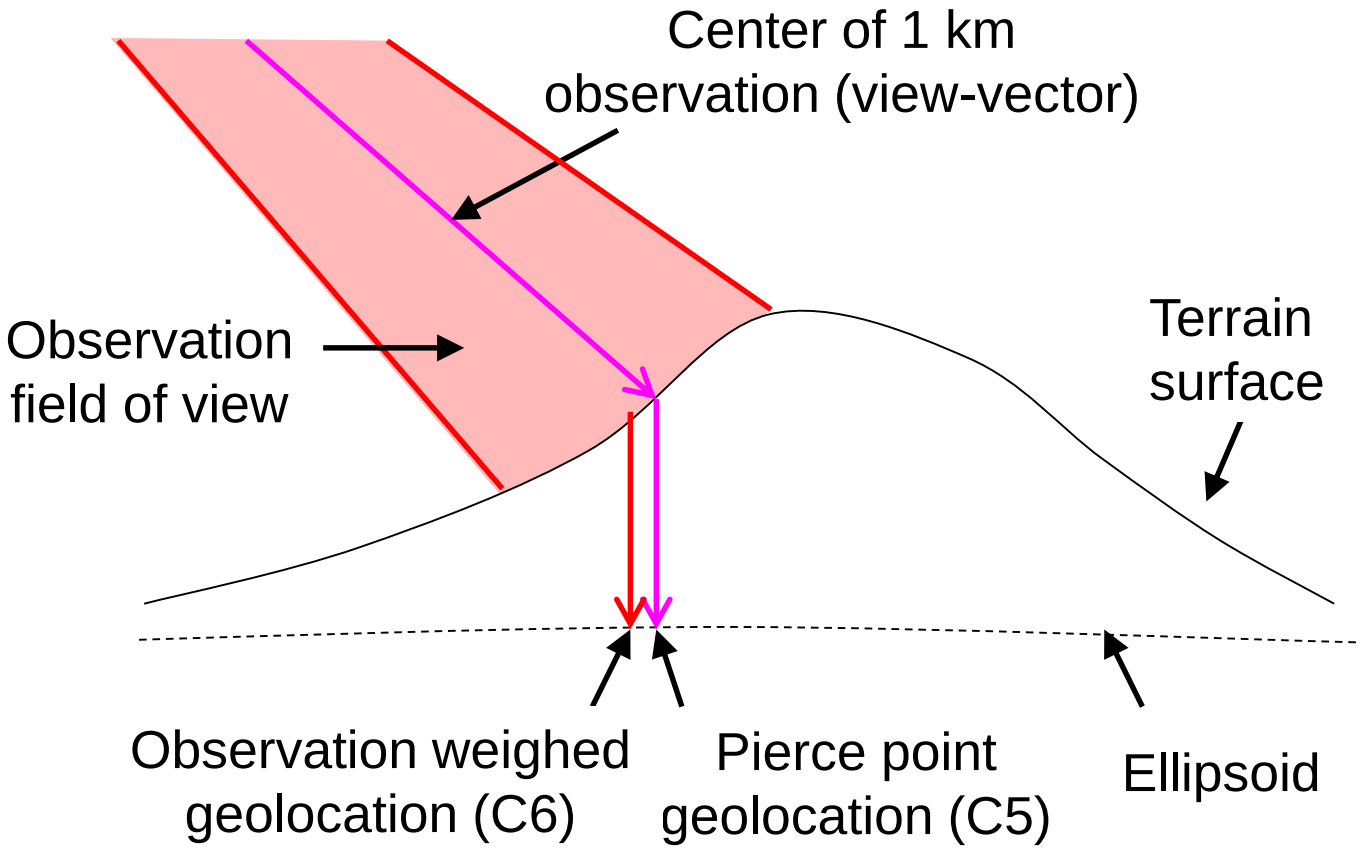
Scan/Track/Height offsets 250m offsets, scan direction int8
(nscans*40:MODIS_Swath_Type_GEO,
mframes*4:MODIS_Swath_Type_GEO)
SDS Attributes:

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

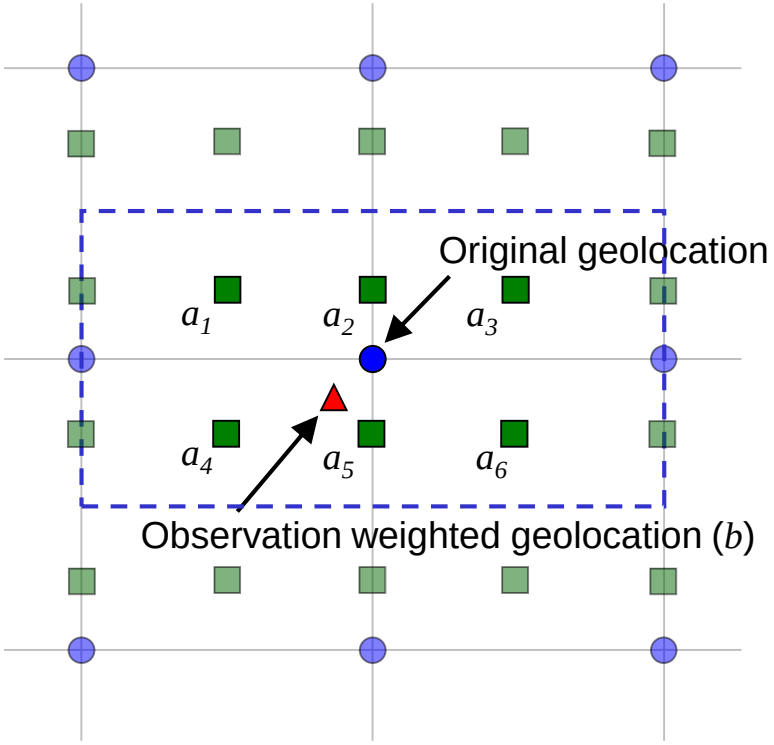
The 500 m offsets fields were added in C6+ in ~2012, see backup slides for details

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

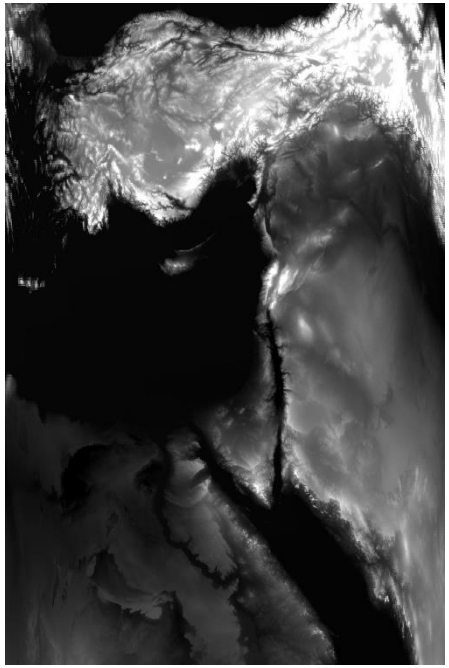
The first order approximation of the observation weighted point is:

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

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.

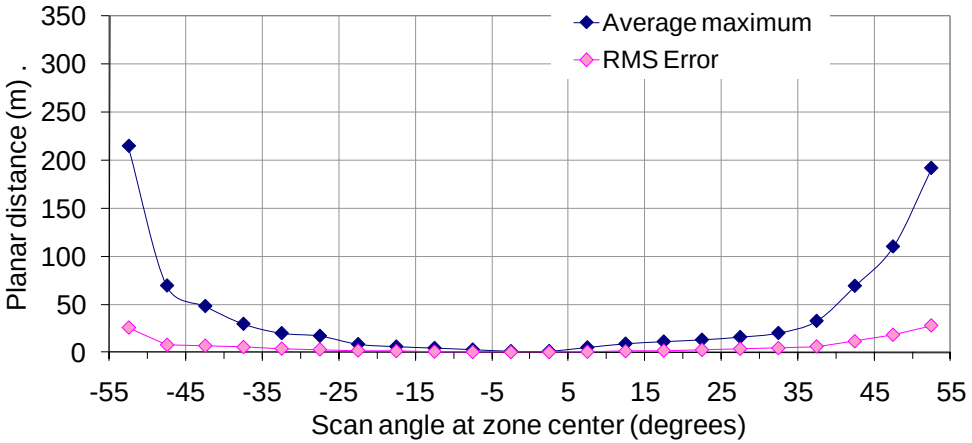
Example: Terra – Middle east

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.