Suomi NPP VIIRS On-Orbit Geometric Performance Validation

NASA VIIRS Calibration Support Team (VCST)
Geometric Calibration Group

Robert E. Wolfe, NASA/GSFC Code 619
Mash Nishihama, Sigma Space/GSFC
Guoqing (Gary) Lin, Innovim/GSFC
Krishna P. Tewari, Innovim/GSFC
James C. Tilton, NASA/GSFC Code 606

and

Northrop Grumman Aerospace Systems (NGAS)
Lushalan Liao, Stephanie Weiss

Suomi NPP VIIRS SDR Product Review (Validated Maturity)
19 December 2013

Outline

- Major accomplishments since Provisional
- Geolocation Validation for I-/M-Bands and DNB
- Band-to-band co-registration
- Spatial responses
- Discrepancy Reports (DRs), quality flags, challenges and potential improvements
- Conclusions
- Backup
  - DR list, Trending of orbit parameters, RTA/HAM encoder performance, Land PEATE reprocessing, DNB geospatial performance (by NGAS)

Major Accomplishments since Provisional

- Fine tuned I-/M-bands SDR/GEO LUTs and DNB geo LUT (by NG)
- Updated LUTs in responses to
  - Scan control electronics (SCE) side A (switched from side B in November 2012)
  - Star tracker re-alignment in April 2013
- Worked DNB TC geolocation to be implemented in IDPS expected March 2014 (already in NASA Land PEATE since May 2013)
- Reduced geolocation bias from (up to) 20 km to (up to) 1.5 km when SC diaries were delayed to and TLE used in IDPS
- Added quality flags for sync loss and sector rotation
- Verified (further) on-orbit BBR and LSF
- Trended (2 years) SC ephemeris (mean altitude 838.8 ±0.2 km)
- Published papers and made conference presentations
  - 2 peer reviewed papers (TGRS + JGR)
  - 1 SPIE talk/paper and 1 AGU presentation

Geolocation Requirements

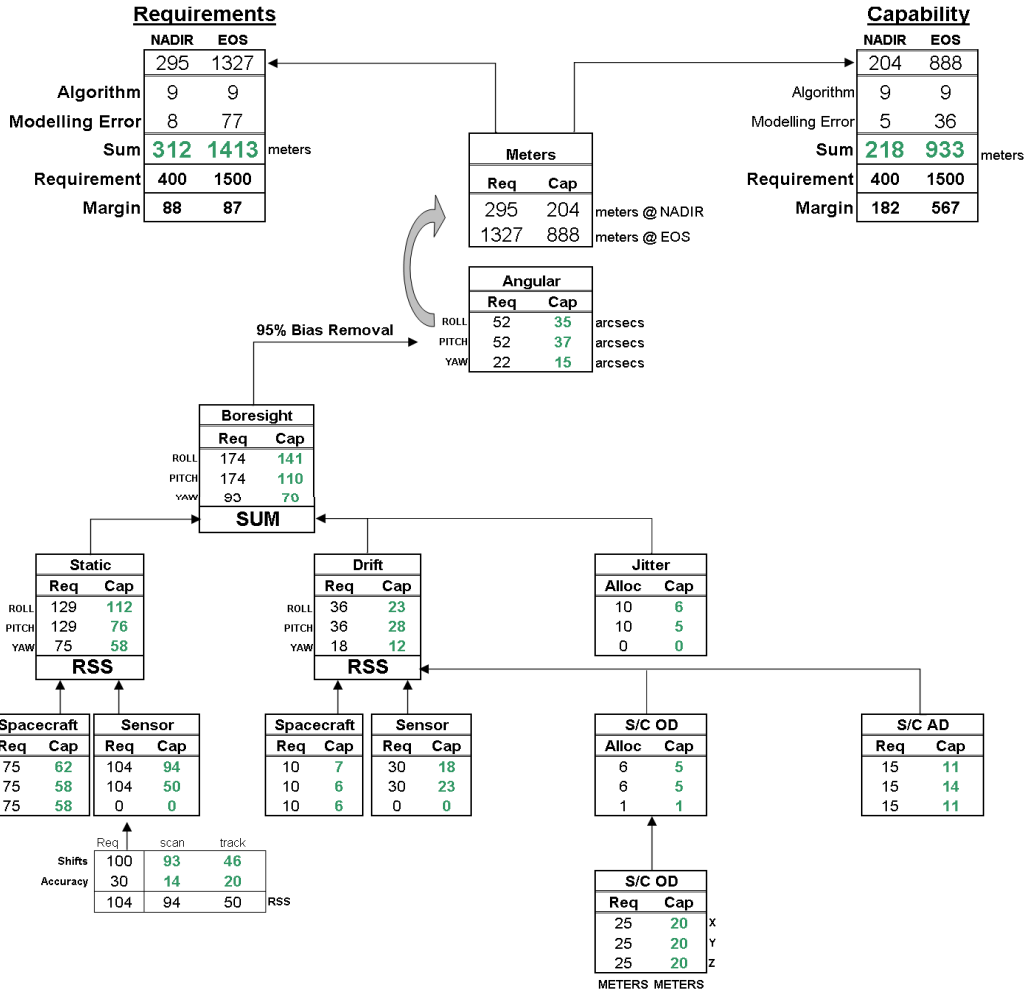
D45143 **NPOESS System Pointing Error Budgets** (Document Date: 04/13/2009)

3.1 VIIRS POINTING KNOWLEDGE UNCERTAINTY

The geolocation mapping uncertainty for VIIRS EDRs is specified as 400 meters (3 sigma) at the satellite Nadir and 1500 meters (3 sigma) at the VIIRS Edge-of-Scan (EOS) which is 56.0 degrees from Nadir.

Figure 3.1 shows the VIIRS pointing knowledge budget which rolls up requirements and capabilities for the NPOESS 1330 spacecraft and the VIIRS sensor..

Figure 3.1 VIIRS Pointing Knowledge Budget for NPOESS 1330 Satellite



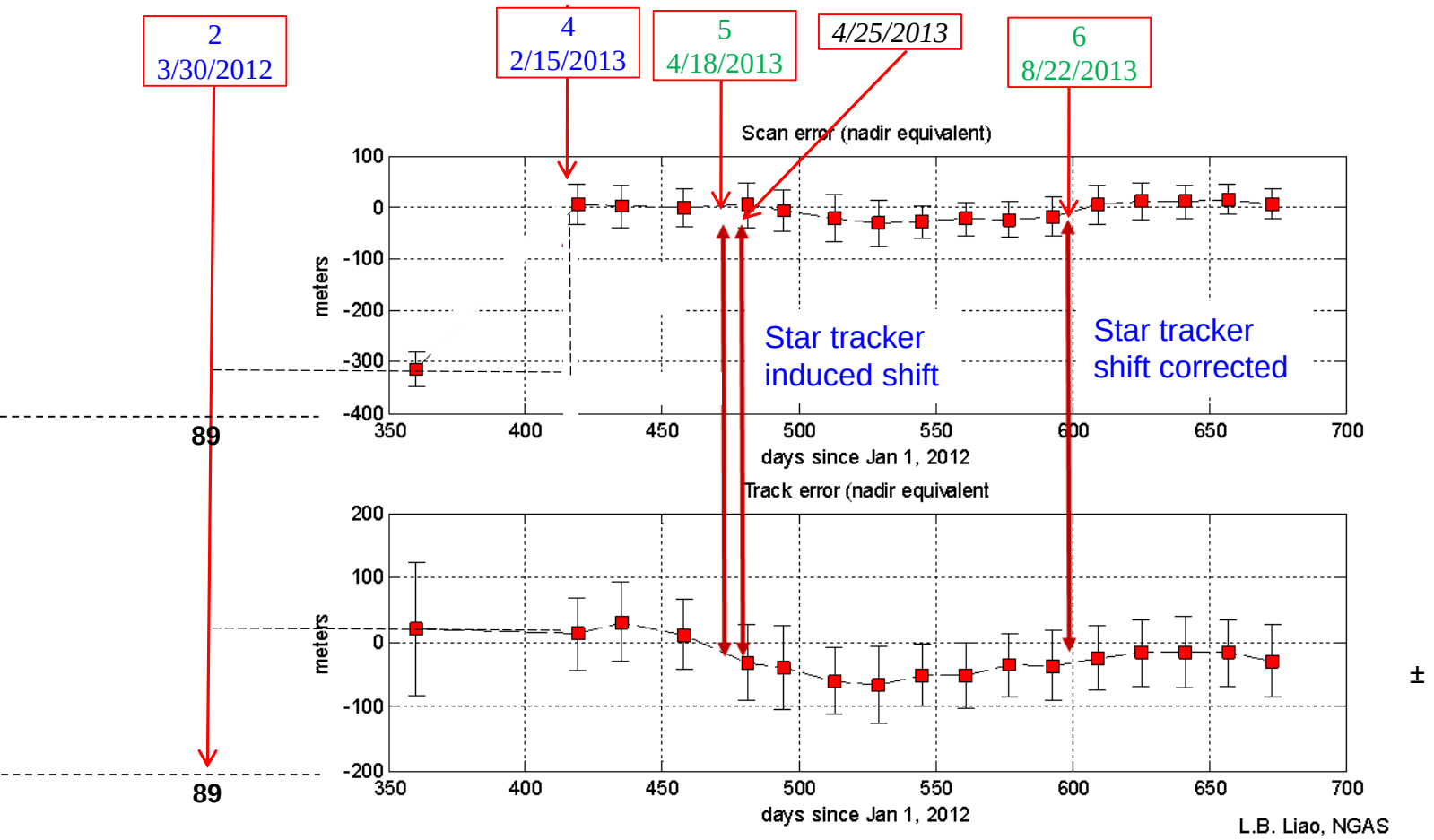
On-orbit Geolocation LUT Updates

Update	Date	Description	Comments
	1/19/2011	*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
	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
	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*

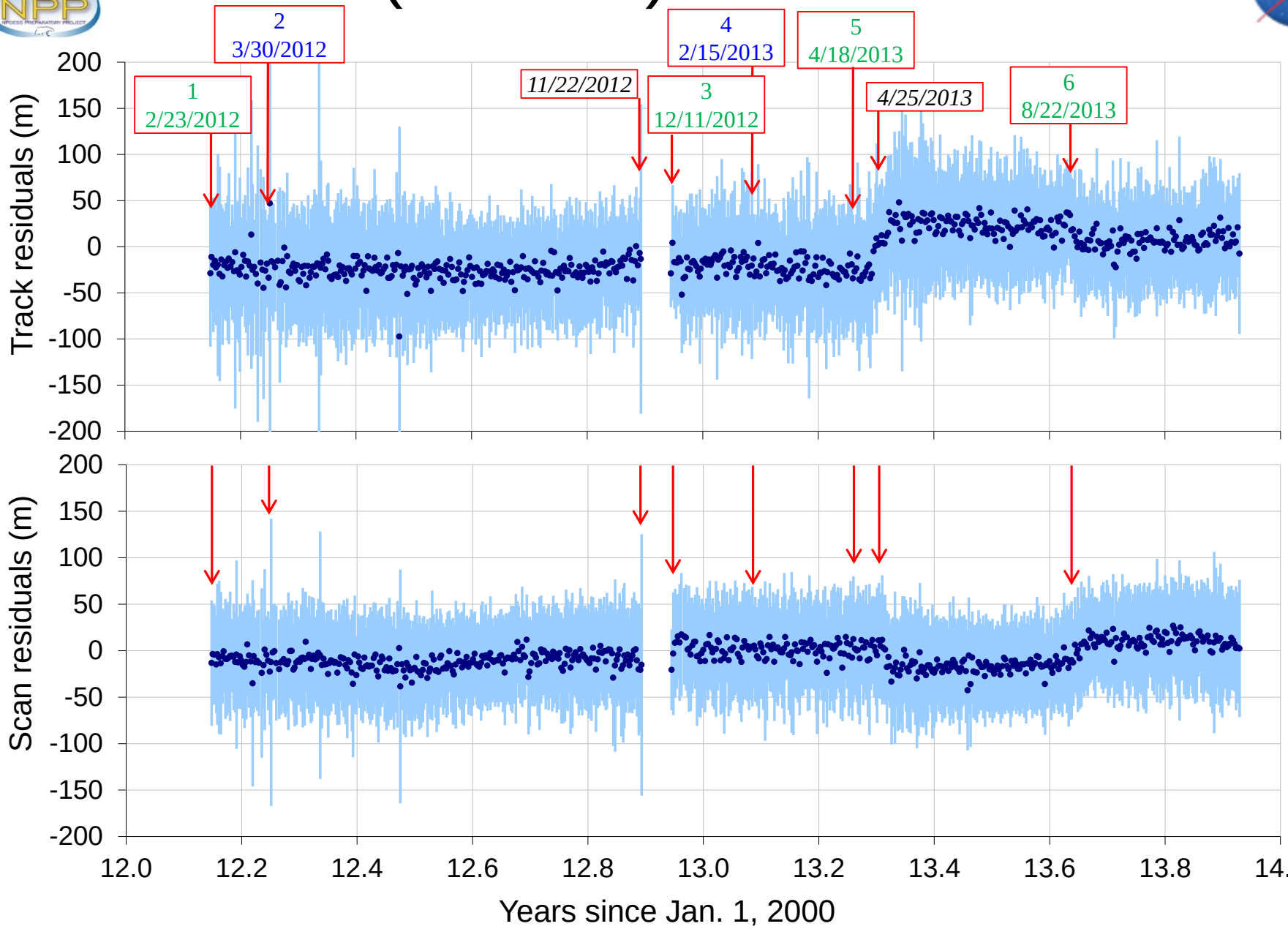
DNB Geolocation

by NGAS

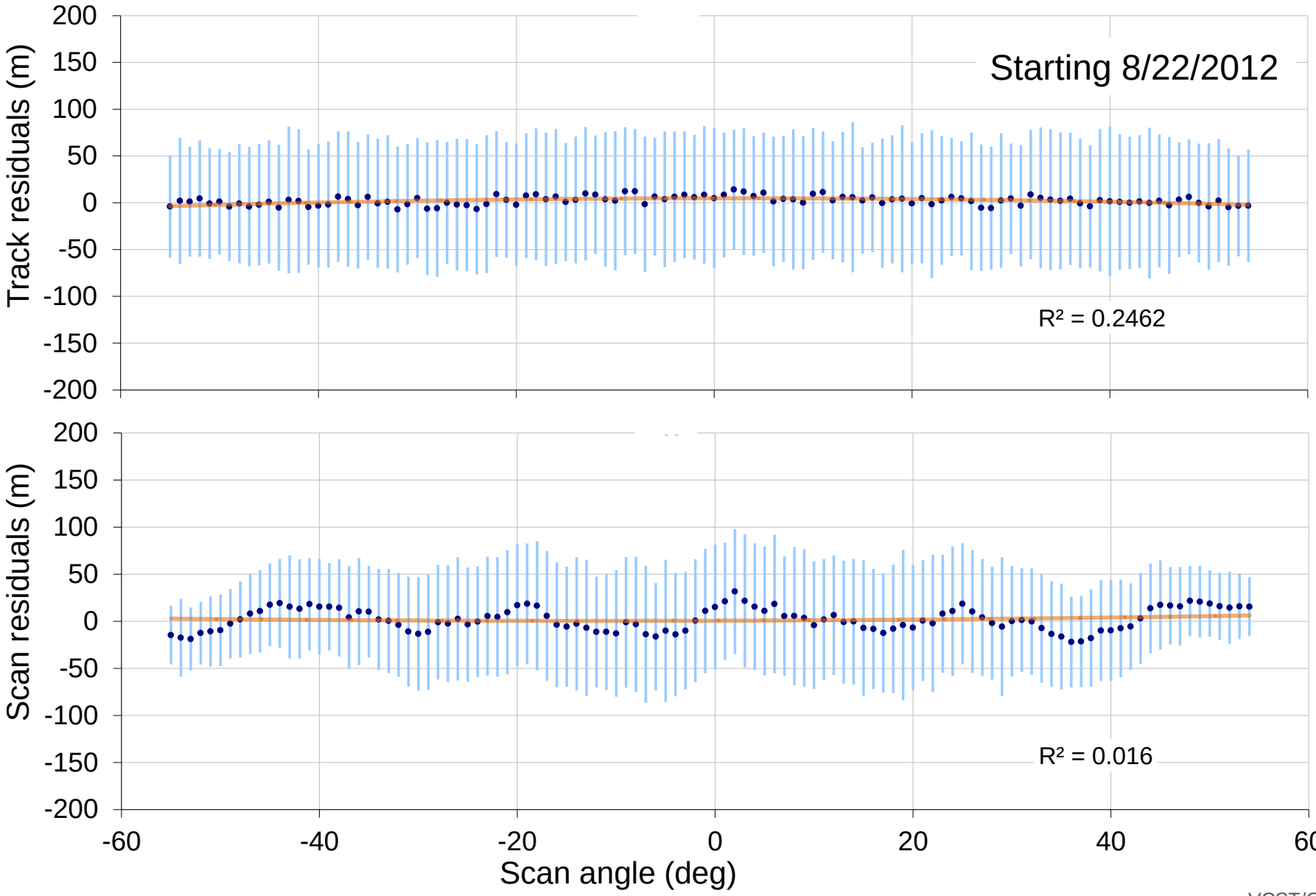


As of Nov 4, 2013, the DNB geolocation accuracy is
Scan: 8 ± 33 μrad Track: -35 ± 68 μrad
Scan: 7 ± 28 m Track: -29 ± 57 m
(nadir equivalent with mean altitude of 838.8 km)

VIIRS (I1 Band) Residual Trend



VIIRS (I1 Band) Scan Angle Residuals



Overall Uncertainty

Residuals	Error (Nadir)	Spec (Nadir)	Error (EOS)	Spec (EOS)
Track mean	-9 m		-20 m	
Scan mean	-7 m		-46 m	
Track RMSE	73 m	133 m	161 m	500 m
Scan RMSE	61 m	133 m	398 m	500 m

- RMSE: Root Mean Square Error (equivalent to unbiased 1 σ)
- Data-days: 632, excluding 18 days right after A/B side switch
- Mean errors are small
- Nadir uncertainties of ~70 m (1 σ) meet spec of 133 m (1 σ) [400 m (3 σ)]
- Edge-of-scan (EOS) uncertainties of ~ 400m (1 σ) meet spec of 500 m (1 σ) [1500 m (3 σ)]

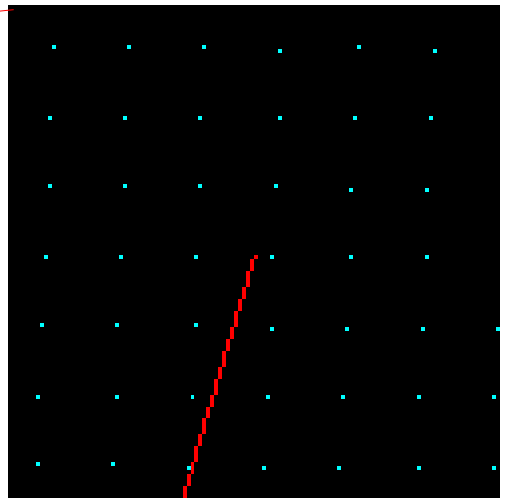
On-Orbit LSF – Bridge

Bands (3,2,1) = (R,G,B)
21 November 2012

Stripes are due to Landat 7 scan line corrector failure. But the center portion is fine.

I-Bands (3,2,1) = (R,G,B)
18 November 2012

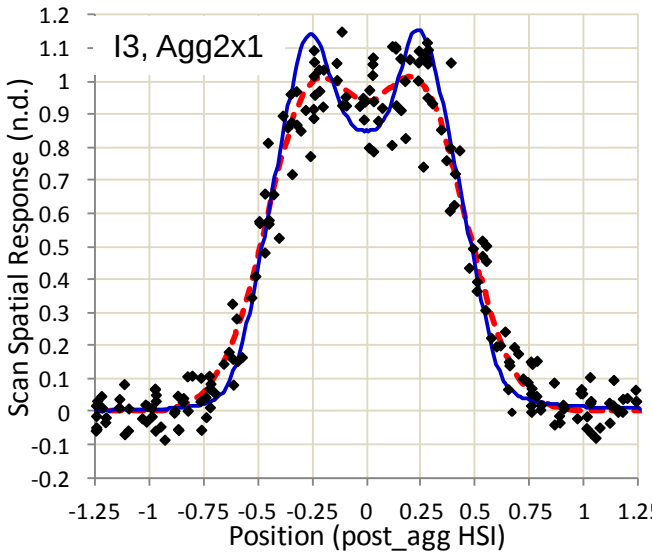
Images are co-geolocated & histogram equalized

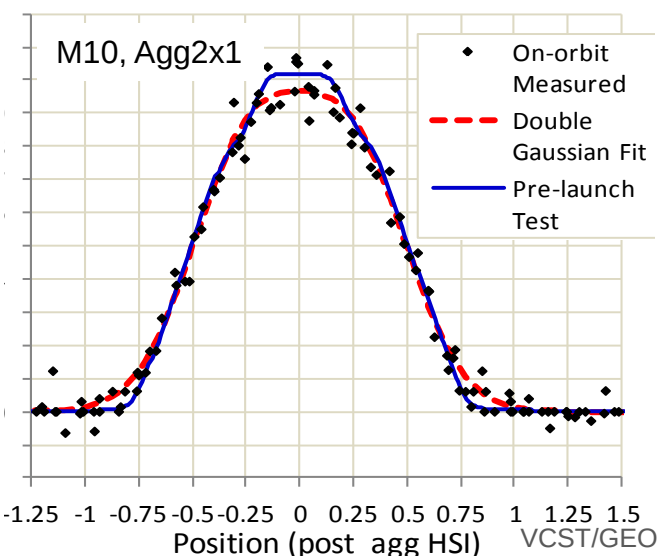


VIIRS pixels (cyan) around the Landsat bridge (red - linear fit)

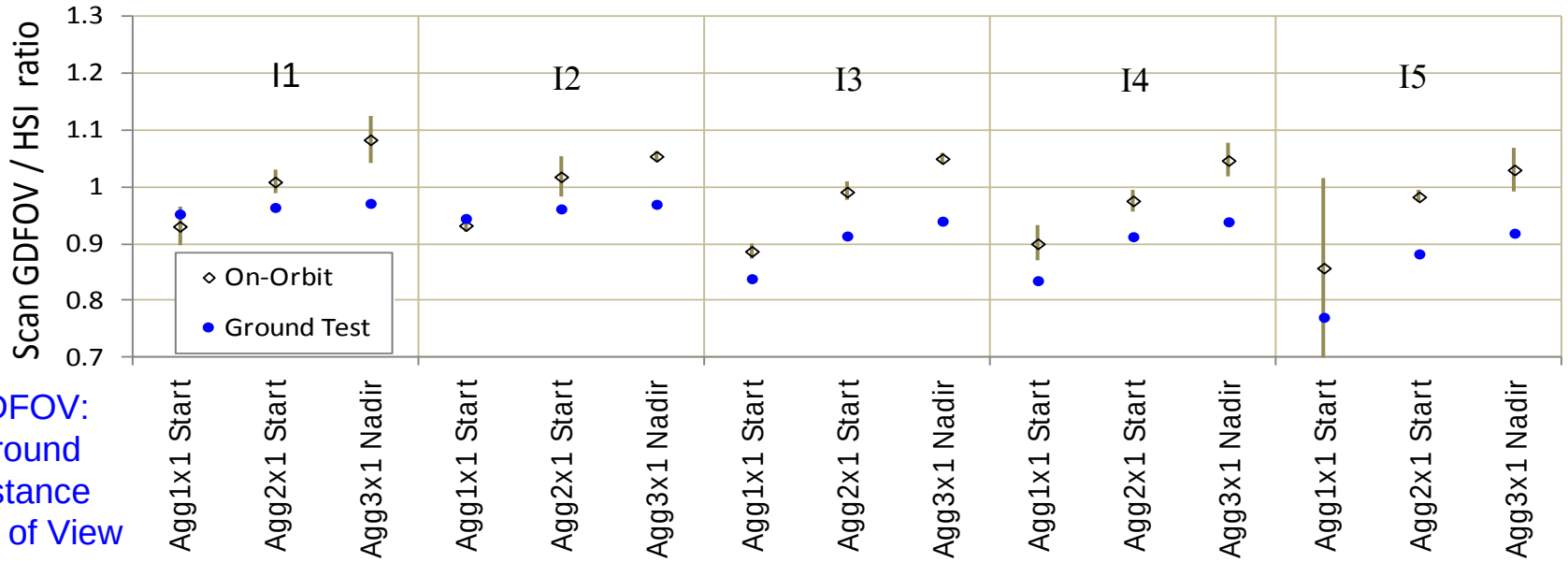
Gaussian functions are used to model pre-aggregated scan LSFs (Line Spread Functions)

Up to 14 scenes for each band each aggregation zone having robust statistics

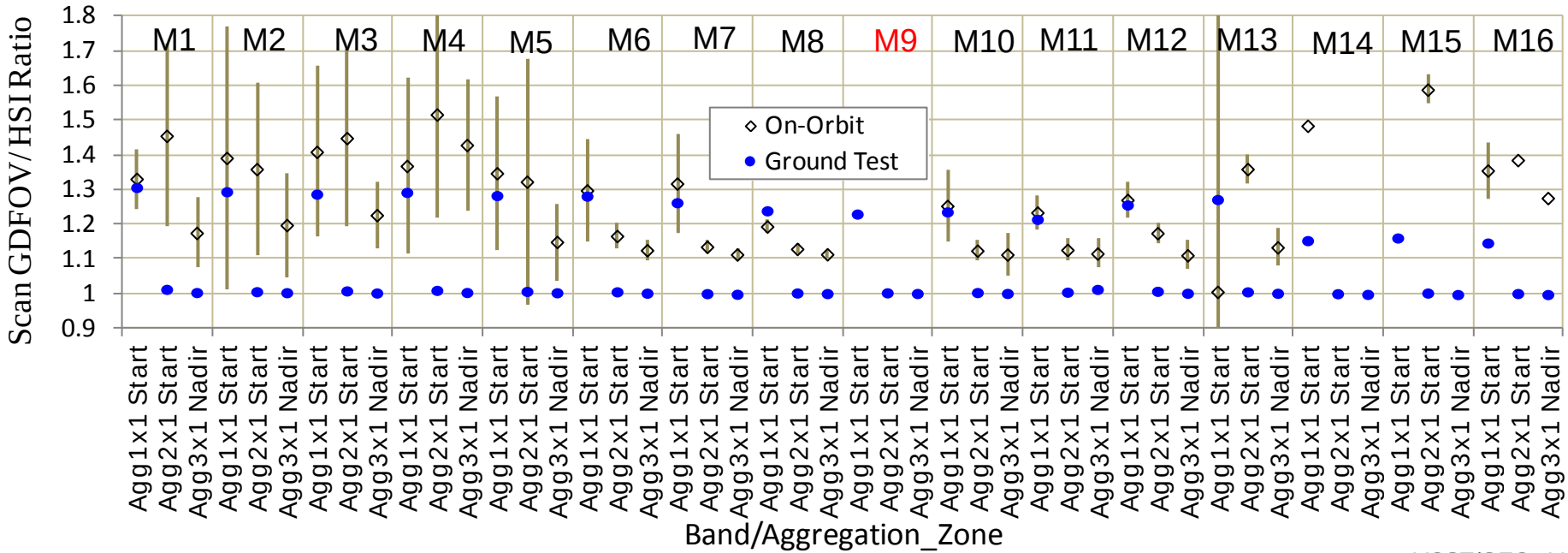




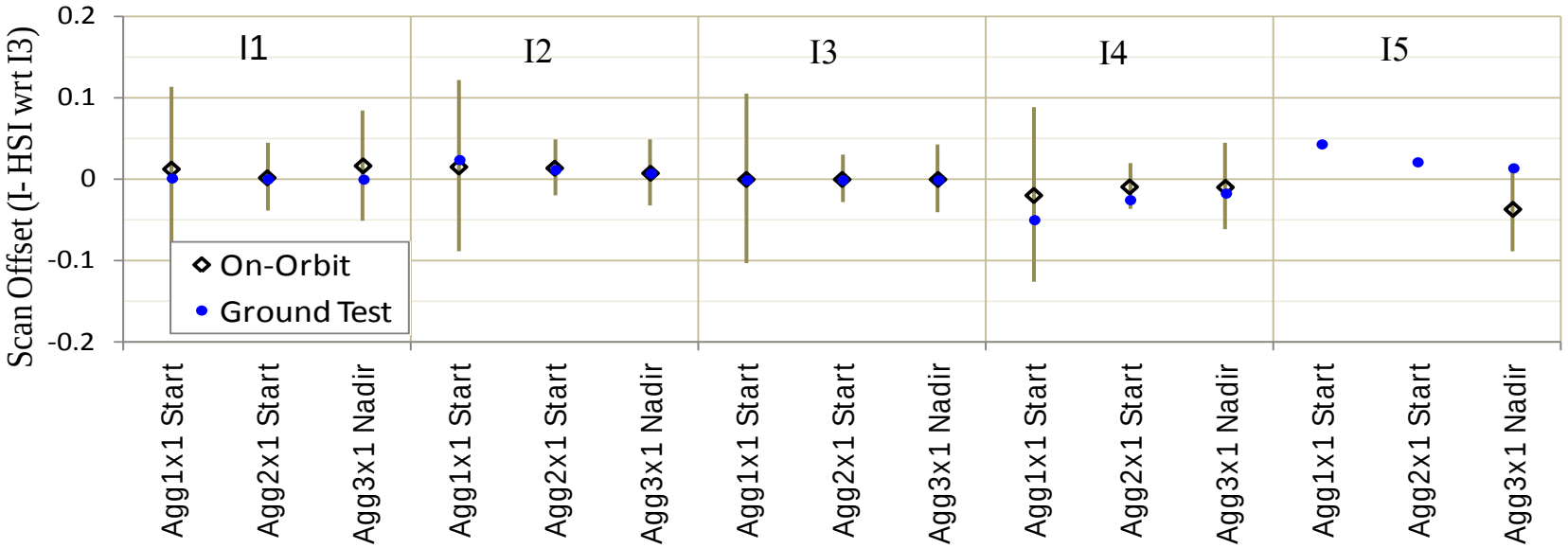
On-orbit scan GDFOV (with robust statistics)

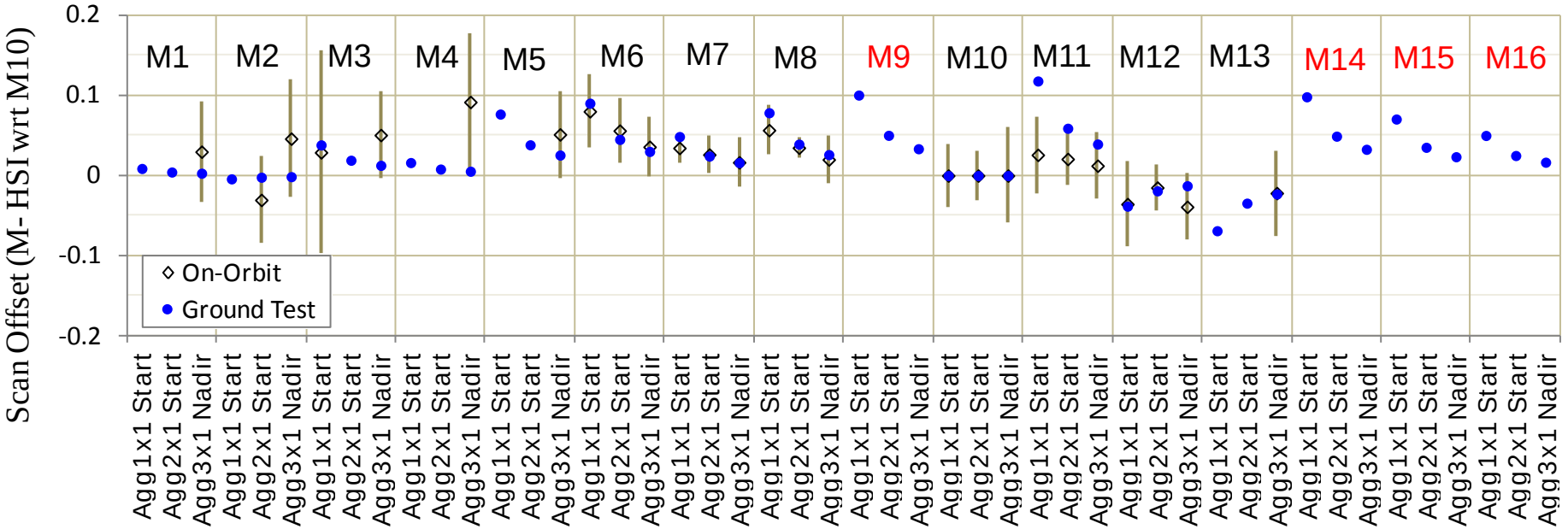


GDFOV: Ground Distance Field of View



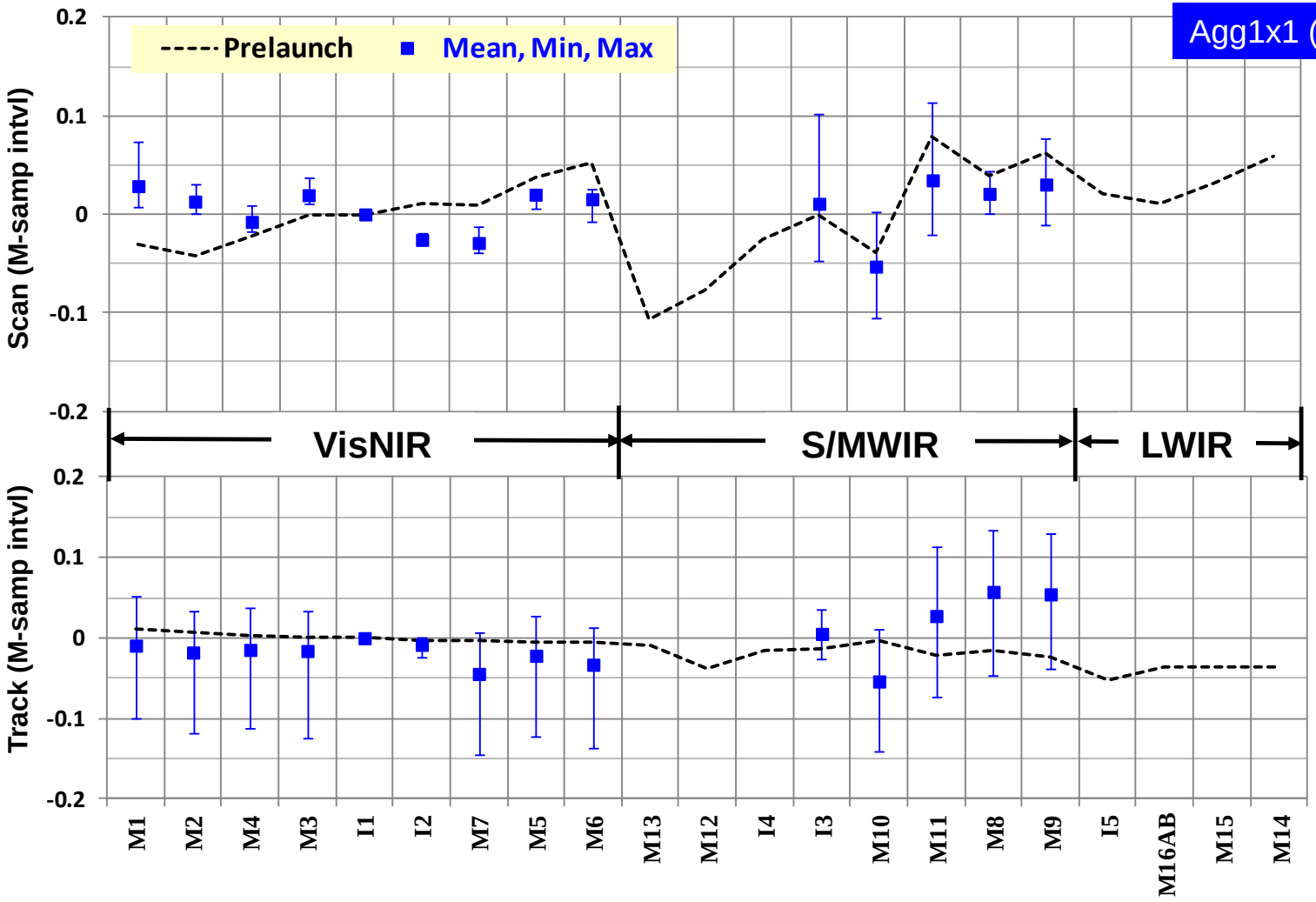
Scan Band Offsets from LSF Retrievals

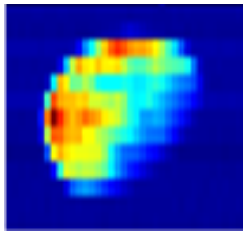




VIIRS Band to Band Registration (BBR)

Agg1x1 (non-aggregated)





M1

Band average BBR (wrt. Band I1) compares well to prelaunch performance

(Some M/LWIR bands are saturated by moon)

DRs and Quality Flags

- DR 4924 adds DNB Terrain Corrected (TC) Geolocation is being worked: CCR-13-1362 discussed at AERB and planned for Mx8.3 (March 2014)
- DR 4767 added flags and fills in both SDR and GEO when RTA/HAM synchronization loss occurs (35 events so far, 100 seconds or less each). New situation was found and DR 7484 will flag additional scans.
- DR 7023 reduced geolocation bias from (up to) 20 km to (up to) 1.5 km when S/C diary from Svalbard does not arrive at IDPS in time and the backup two line elements (TLE) is used. Scan quality flag was checked and found ~0.2% of products used TLE data. DRs 7145, 7146 and 7147 were filed for changes in IDPS production rules or Svalbard SC diary data delivery rules.

Challenges and Potential Improvements

- Challenging to accurately measure on-orbit BBR for all band pairs, especially for those LWIR bands saturated by the moon
- Challenging to accurately measure spatial response characterization for all bands, especially LWIR bands – expect no significant change from pre-launch and no significant impacts on EDRs
- Within orbit thermal correction is likely to be needed – code updated needed
- Long-term monitoring is needed for accurate geolocation and for responses to possible on-orbit events – we are trending and fine tuning as needed
- Digital Elevation Model (DEM) and Land/Water (L/W) mask should be updated (such as those in MODIS Collection 6)
- Geolocation accuracy issues during and right after spacecraft maneuvers needs to be better understood and clearly identified

Conclusions

- VIIRS geometric performance is as expected
- Geolocation mean errors for I-/M-bands are near 0 and uncertainties are ~ 70 m at nadir, meeting specifications at nadir and edge-of-scan
  - Caveat: DNB terrain corrected geolocation product is expected in Mx8.3 in March 2014
- Encoder and scan time/period are nominal
- Orbit and attitude are nominal
- Quality flags are well-understood
- Limited verification of on-orbit spatial responses and BBR agrees with prelaunch measurements
- VIIRS **SDR/Geometric** performance maturity should be rated as **Validated** (except for DNB TC geolocation)

Publications

1. Wolfe, R. E., G. Lin,M. Nishihama, K. P. Tewari, J. C. Tilton, and A. R. Isaacman (2013), **Suomi NPP VIIRS prelaunch and on-orbit geometric calibration and characterization**, J. Geophys. Res. Atmos., 118, 11508–11521, doi:10.1002/jgrd.50873.
2. Cao, C., F.DeLuccia, X. Xiong, R.Wolfe, and F.Weng (2013), **Early on-orbit performance of the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (S-NPP) satellite**, IEEE Trans. Geosci. Remote Sens., doi:10.1109/TGRS.2013.2247768.
3. Guoqing Lin, James C. Tilton, Robert E. Wolfe, Krishna P. Tewari, Masahiro Nishihama (2013), **SNPP VIIRS spectral bands co-registration and spatial response characterization,** Earth Observing Systems XVIII, edited by James J. Butler, Xiaoxiong Xiong, Xingfa Gu, Proc. of SPIE Vol. 8866, 88661G,· doi: 10.1117/12.2023367.
4. Wolfe, R.E., G. Lin, M.Nishihama, K.P. Tewari, E. Montano (2012), "**NPP VIIRS Early On-Orbit Geometric Performance**", Earth Observing Systems XVII, edited by J. J. Butler, X. Xiong, X. Gu, Proc. of SPIE Vol. 8510, 851013, doi: 10.1117/12.929925.
5. Wolfe, R. E., M. Nishihama, G. Lin, K. P. Tewari, and E. Montano (2012), **MODIS and VIIRS geometric performance comparison**, IEEE International Geosci. and Remote Sens. Symposium, Munich, Germany, July, 2012. doi:10.1109/IGARSS.2012.6352484.
6. Lin, G., R. E. Wolfe, M. Nishihama (2011), "**NPP VIIRS Geometric Performance Status**," Earth Observing Systems XVI, edited by James J. Butler, Xiaoxiong Xiong, Xingfa Gu, *Proc. of SPIE, Vol. 8153, pp. 81531V*-81531V-14, doi:10.1117/12.894652.

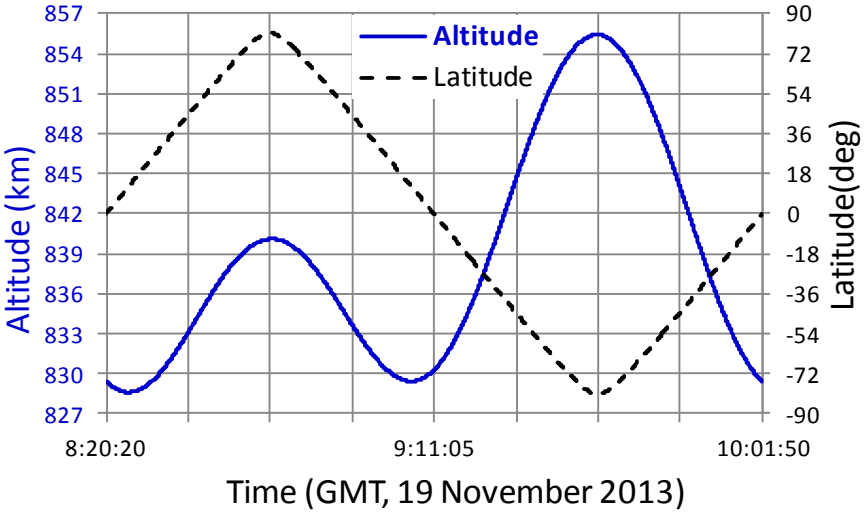
Backup Slides

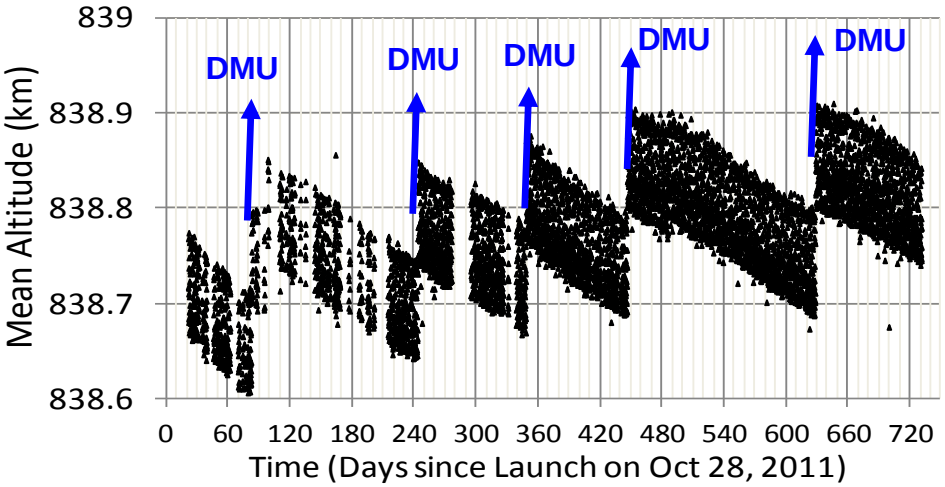
- DR list
- Trending of orbit parameters
- RTA/HAM encoder performance
- Land PEATE reprocessing
- DNB geospatial performance (by NGAS)

Major Geometric related DRs & Status

DR #	Status	Description
4423	Fixed	RTA/HAM timestamps reversal
4428	Resolved	Rotation Matrix in LUT Used by SDSM Code
4629	Completed	Initial on-orbit update of the VIIRS DNB GEO LUT
4703	Completed (Mx6.2)	Add mirror side to VIIRS geolocation products
4737	LUTs ready for SCE switch	Scan Encoder Electronics (SCE) A-side missing in geolocation parameter LUTs
4759	Being verified (Mx6.3/4)	Determine Scan Encoder Electronics Side in Geolocation products
4767	Completed (Mx7.0)	SDR/GEO should be fill and flagged when HAM/RTA sync is lost
4776	Completed (Mx7.0)	Sector Rotation caused erroneous geo results
4795	Completed (Mx7.0)	VIIRS SDR Cal: Add major HAM/RTA sync loss flag to VIIRS SDR Cal
4894	In-Progess (for Mx7.1) confirmation needed	Unexpected high values of Satellite zenith angles
4917	IDPS alerted (June 2013) – closed	IDPS Incorrect Handling of Leap Seconds
4924	In-Progess (for Mx8.3)	VIIRS DNB Geolocation Terrain Correction is needed
7145	In-Progess	VIIRS SDR Controller should wait for the Spacecraft Diary
7146	In-Progess	Replacement VIIRS SDR Granules should be manufactured if the Spacecraft Diary become available post-production
7147	In-Progess	Maintain an IDPS Production History
7203	Completed (Mx7.0)	Degraded VIIRS (and possibly other instruments) geolocation from backup TLE
7443	In-Progess	VIIRS GEO FILL diferences noted in Maneuver granules
7484	In-Progess	Observed toggling in the VIIRS engineering packet sync loss indicator as the instrument is recovering from sync loss

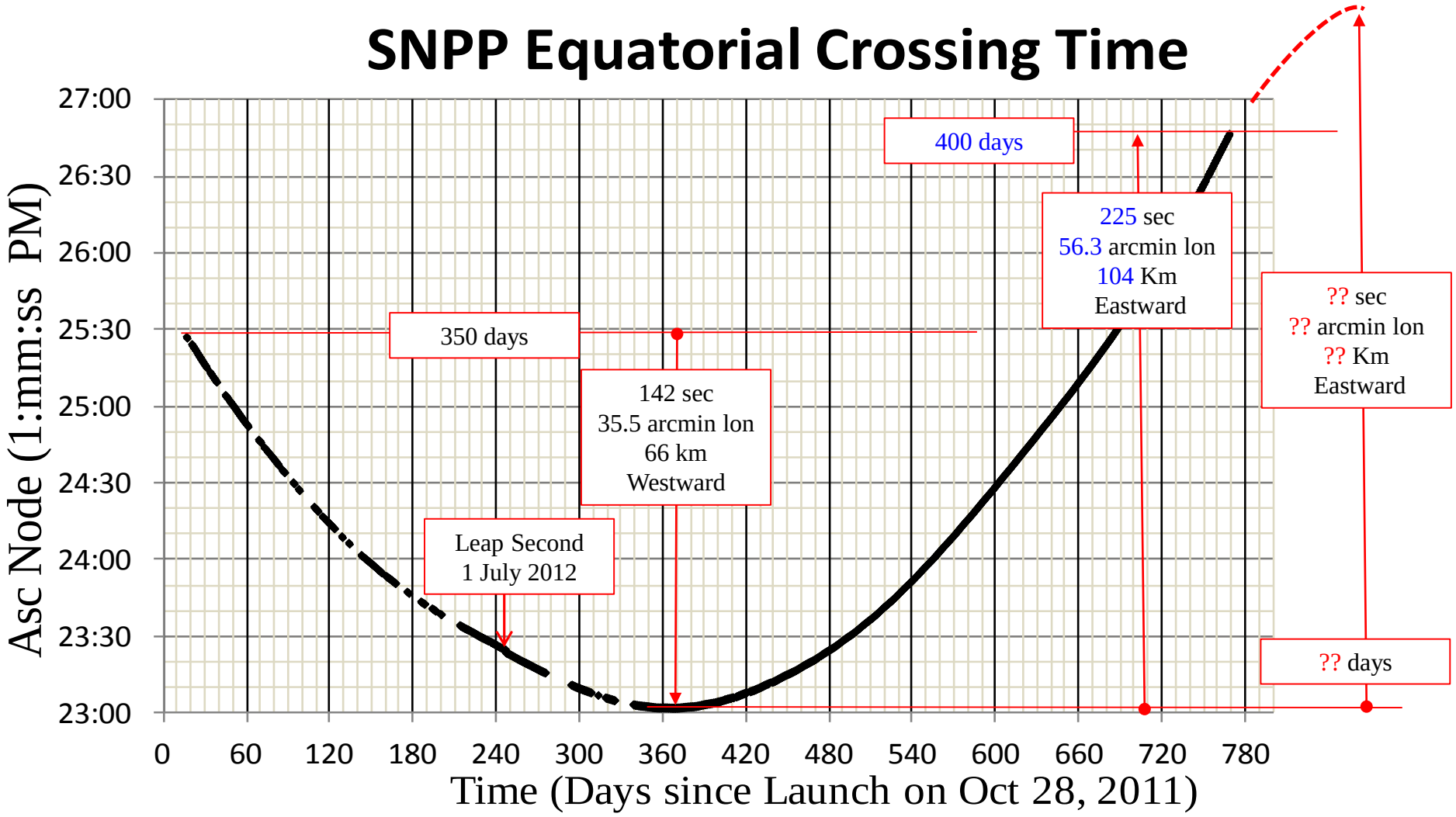
Trends of Orbit Parameters





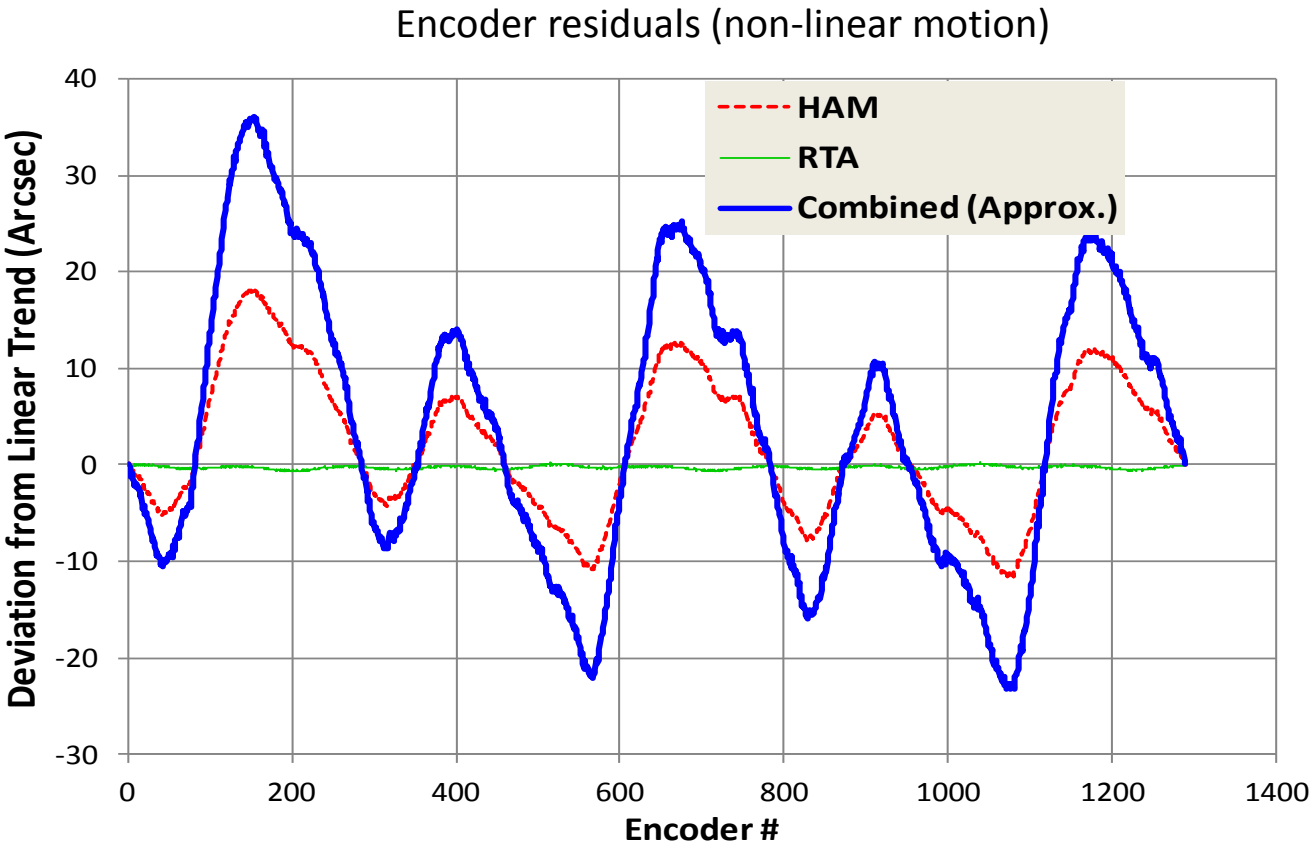
- Altitude (km)
  - Mean: 838.8 ±0.2 Peak-to-Valley
  - Min: 828.5 ±0.6 P-V; Max: 856 ±0.6 P-V; Equator: 829.8 ±1.0 P-V
- Drag make-up (DMU) maneuvers keeps altitude from falling and 16-day ground track repeatable (±20 km P-V)
- Local time of ascending node (LTAN) drifts from 13:25:24 in Nov 2011 westward 66 km to 3:23:02 in Nov 2012 then back eastward 104 km to 13:26:46 in 4 Dec 2013, continues eastward
- Orbital period: 101.5 min ±0.3 sec P-V
- Inclination angle drifts 98.65 → 98.72 deg (0.07 degrees away from the poles) in 2 years, and continues to move away from the poles

Equator-crossing local time



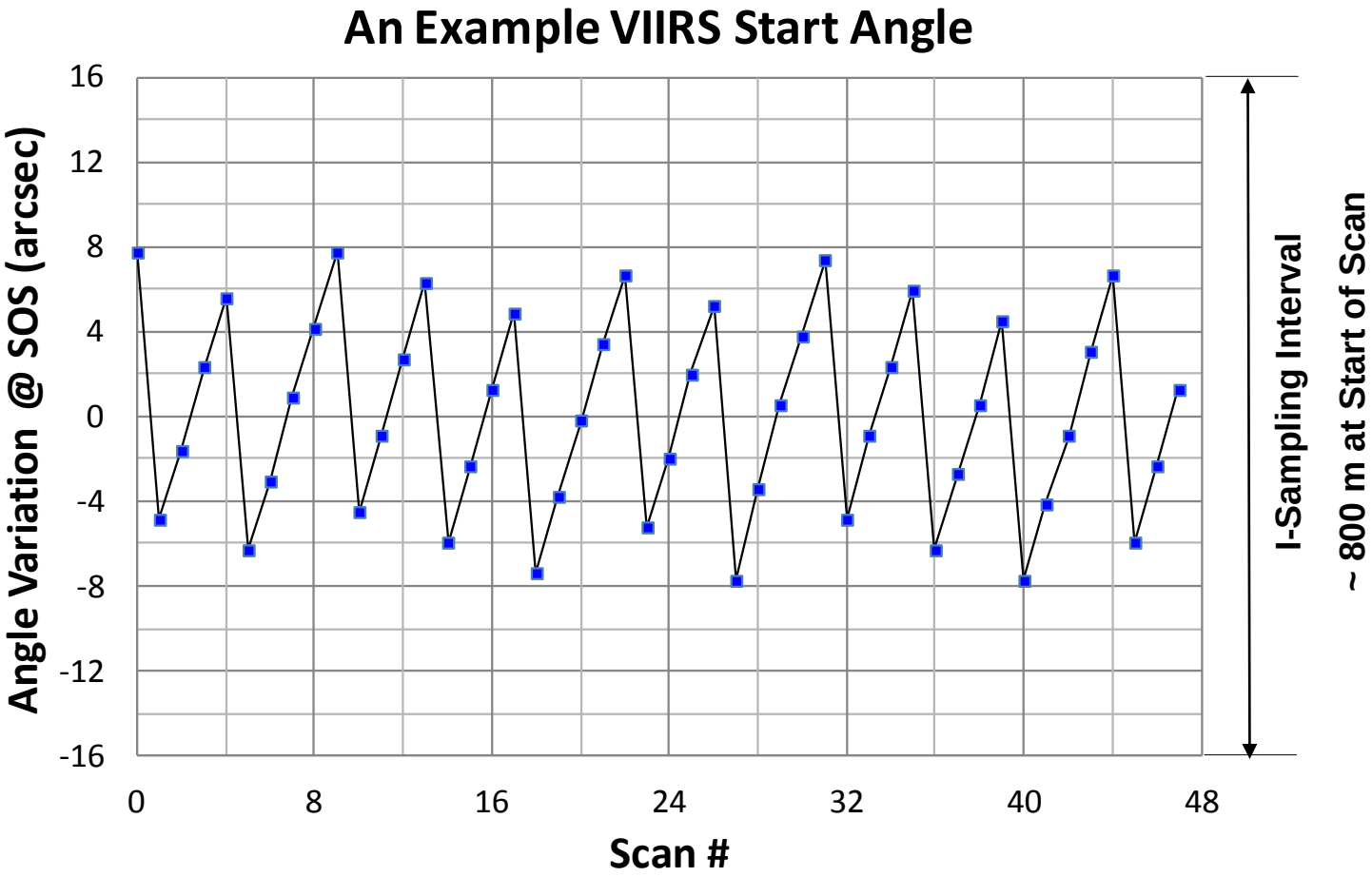
- SNPP Orbit ground track at equator drifted ~66 km westward in 350 days
- It then moves back eastward ~104 km as of 4 Dec 2013 (~ 40 km from launch date)
- SNPP continues moving eastward (sun zenith angle up). It will peak @ ?(future data)

Encoder characterization



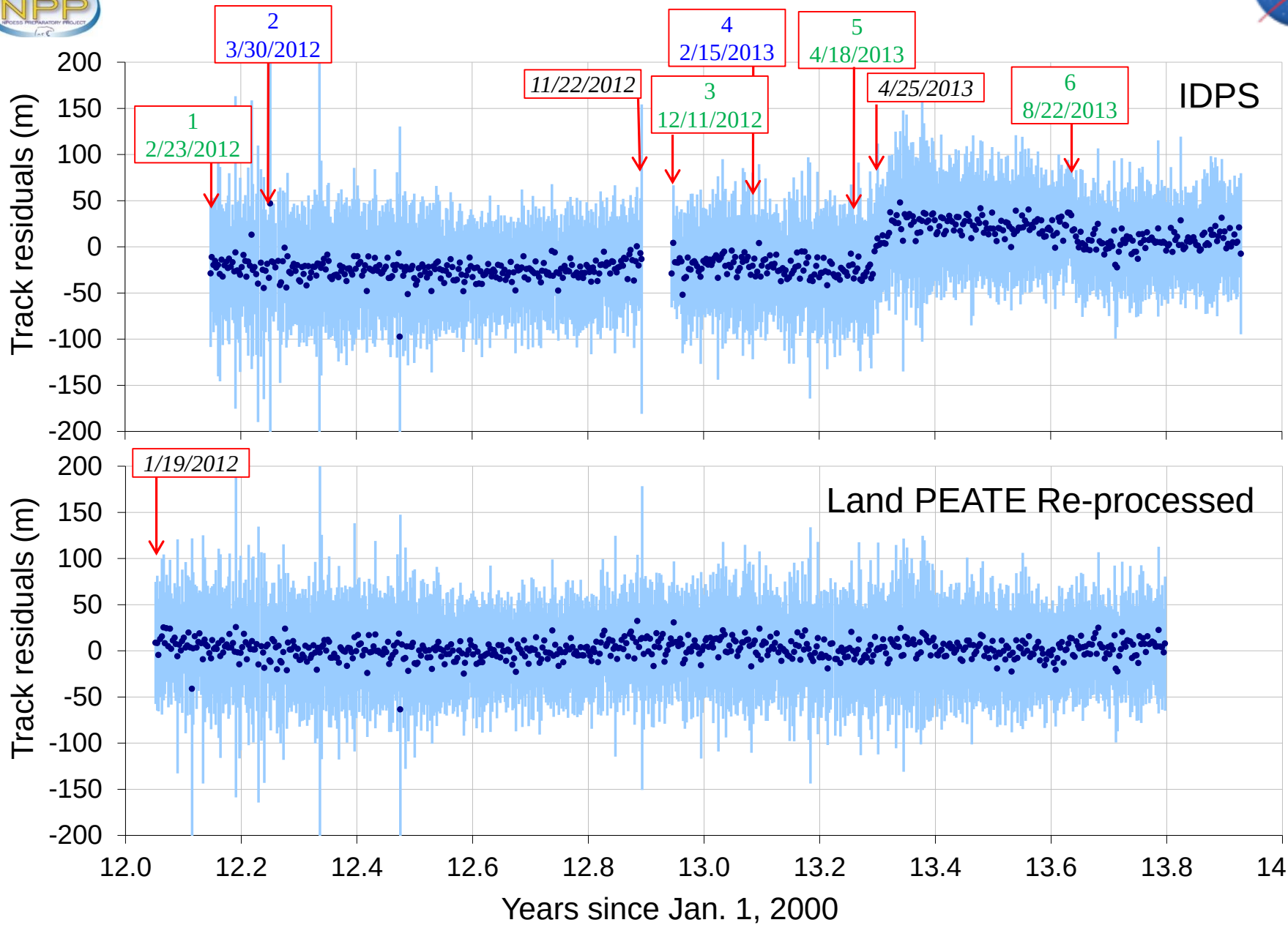
- The linear scan rate of telescope was 3.531 rad/sec on Nov 9, 2011.
- The offset variation is consistent with pre-launch tests (more in NG slides)
- Rotating Telescope Assembly (RTA) and Half Angle Mirror (HAM) encoder datasets had been erroneously swapped in the at-launch IDPS code. The error was corrected, as plotted here, and implemented in IDPS drop Mx5.1 on Dec 19, 2011.

Scan to scan start angle

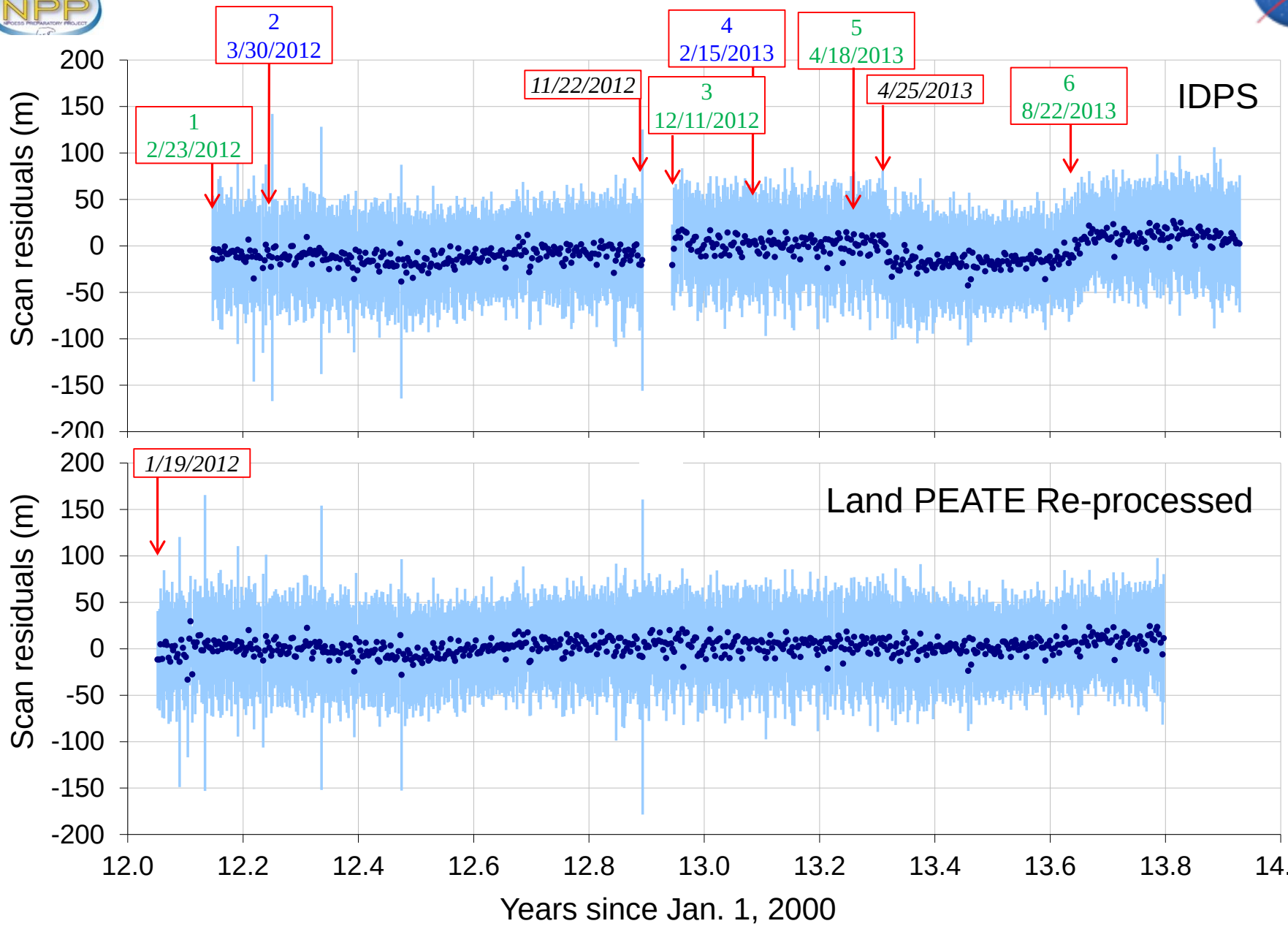


- Variations around -56.34º (used in the geolocation algorithm)
- Magnitude ~ 16 arcsec, half of an I-band scan sampling interval
- Data from one 48-scan (85-sec.) granule on data-day June 27, 2012

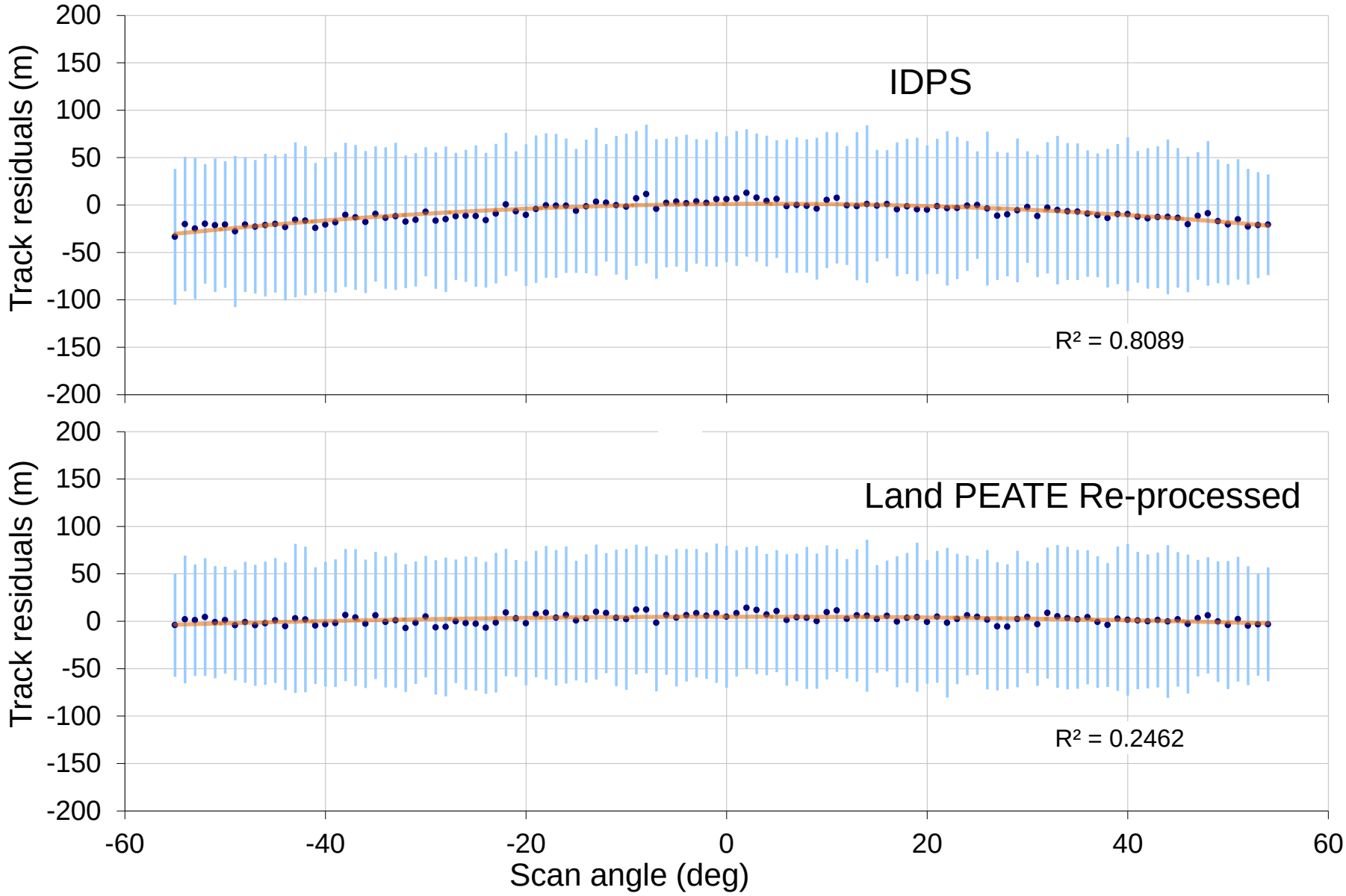
VIIRS Residual Trend



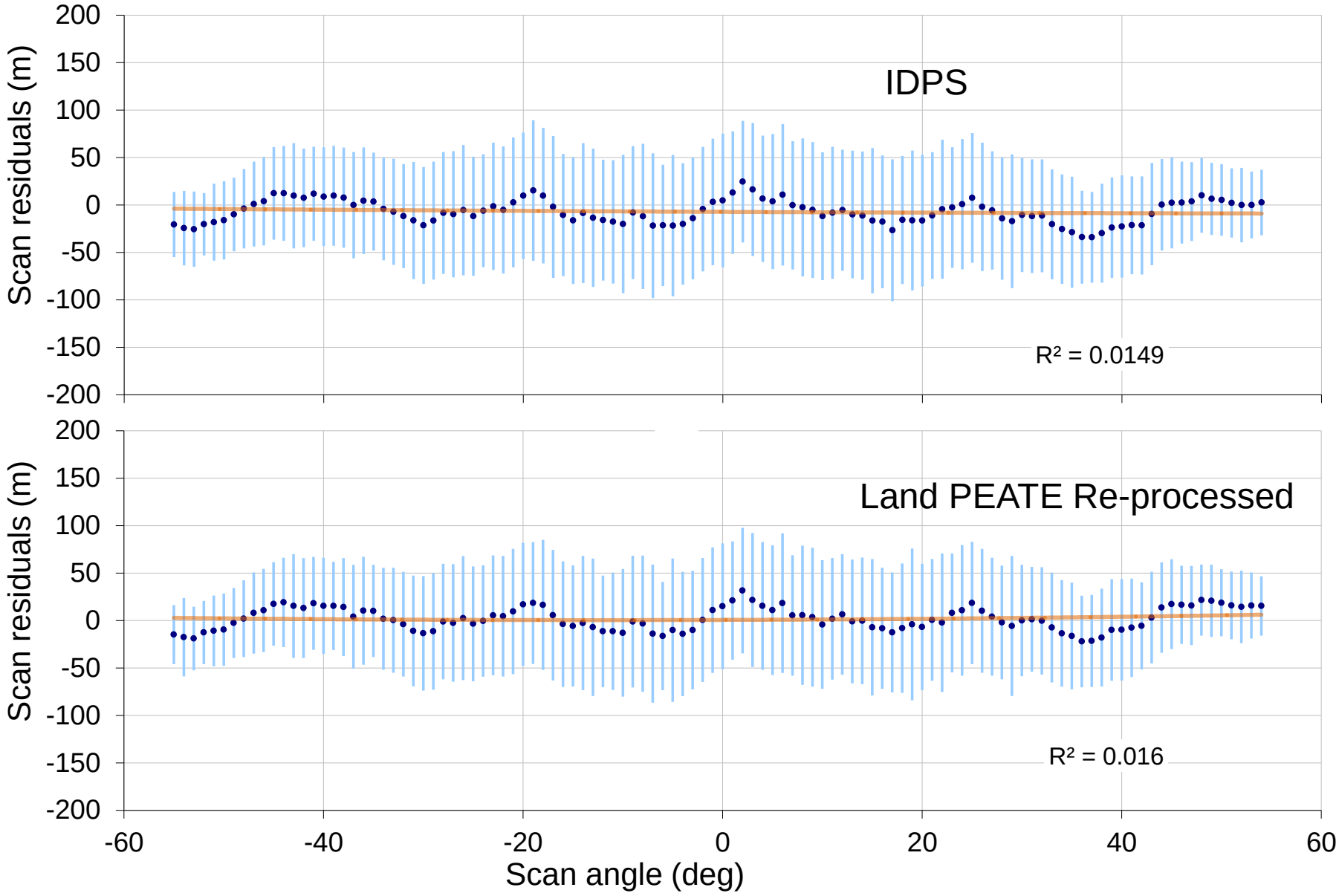
VIIRS Residual Trend



VIIRS Scan Angle Residuals



VIIRS Scan Angle Residuals



Overall Error

Residuals	Error IDPS	Error Land PEATE Re-processed
Track mean	-9 m	2 m
Scan mean	-7 m	2 m
Track RMSE	73 m	69 m
Scan RMSE	61 m	58 m

- Nadir equivalent accuracy (RMSE – Root Mean Square Error)
- Data-days

  IDPS: 632 Land PEATE: 637
- Average CP residuals per day (after filtering)

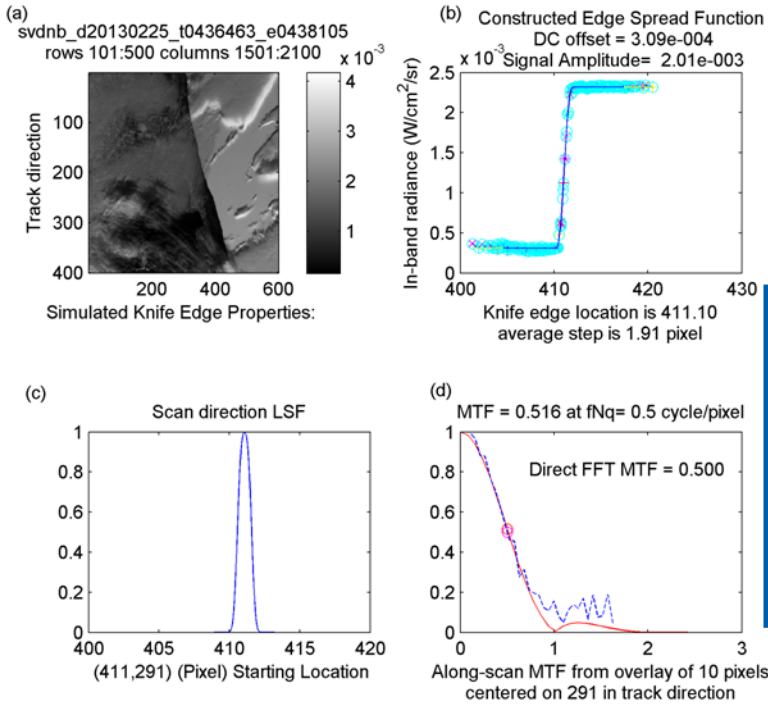
  IDPS: 135 Land PEATE: 138
- Time period:

  IDPS: Feb. 23, 2012 (VIIRS I/M-band LUT update) to Dec. 5, 2013; excluding 18 days right after A/B side switch

  Land PEATE: Jan. 19, 2012 to Oct. 18, 2013

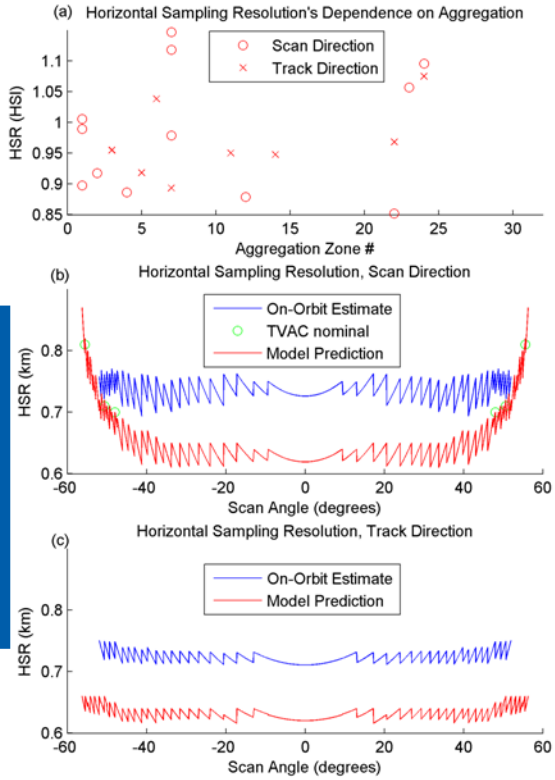
DNB spatial characteristics

by NGAS



Model based line spread function (LSF) construction using ice edge scenes was utilized to retrieve horizontal sampling resolution (HSR). Correction for edge slant was performed in Fourier space.

L.B. Liao, NGAS



DNB HSR is approximately a constant multiple of the horizontal sampling interval (HSI) for aggregation zones 1-24. This results in approximately constant HSR in units of ground distance, with saw tooth pattern that is inherent in the ground HSI. HSR meets the requirement of 800 meters upto scan angle of 52 degrees.