GPS-Based Jason-2 and Jason-3 Precision Orbit Determination Solutions in the IGS14 Reference Frame

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September 27, 2018

Introduction

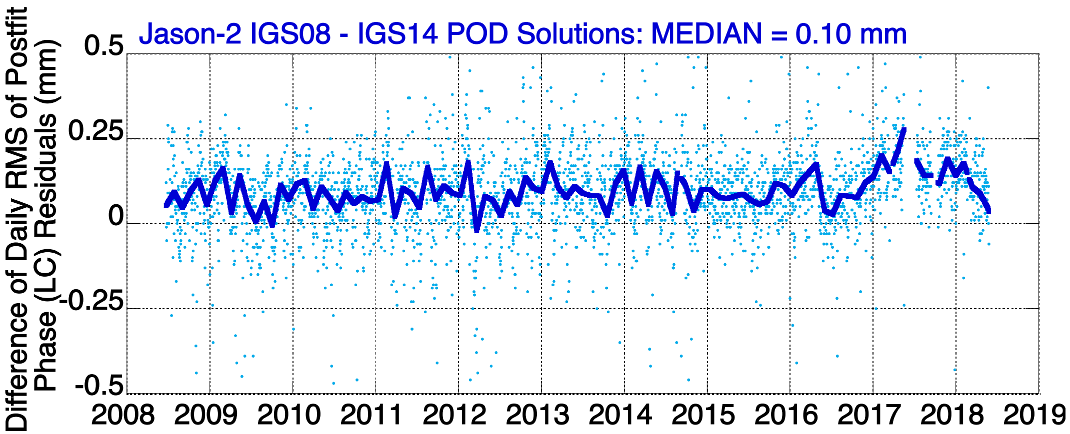
- Evaluate impact of new reference frame on Jason-2/3 GPS-based POD solutions.
  - From IGS08 to IGS14
  - Updated in-flight antenna calibration.
- Compare to CNES GDR-E and GDR-F, GSFC solutions.
  - SLR residuals.
  - Independent SSH crossover variance metrics.

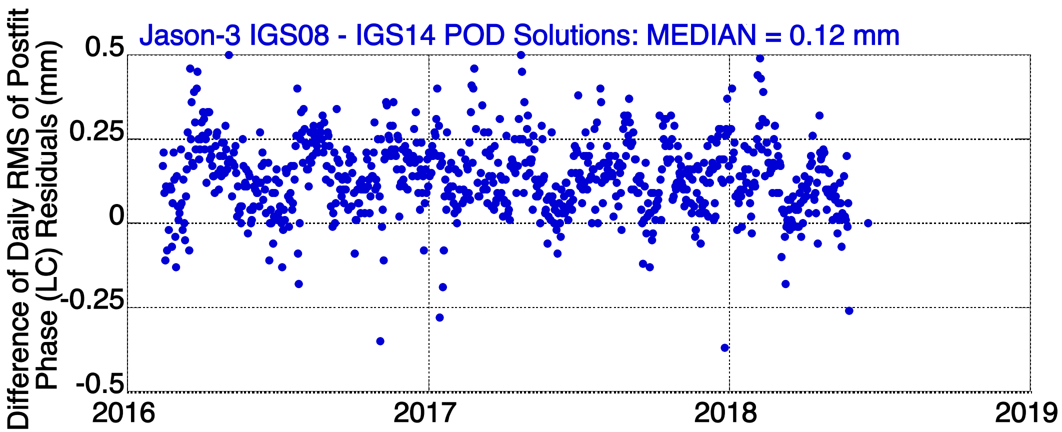
Parameter	Value
Orbit Arc	30-hours (daily)
Gravity Field	EIGEN-6S4.v2
AOD	Release 6
Tide Model	GOT4.8ac
Pole Tide Model	IERS 2010
Attitude	Quaternions
Solar Panel Orientation	Reported Values
GPS Orbits/Clocks	**JPL Finals IGS14**
Data Weights	1 cm LC, 100 cm PC
Elevation Angle Cutoff	0 degrees
Minimum Track Length	10 minutes
Antenna Calibration	Chamber (pre-launch) and **Updated In-Flight**

Realization of Frame in JPL's GPS-based POD of Jason-2/3

- JPL's Jason GPS-based POD solutions realize reference frame from orbit and clock solutions for GPS constellation.
  - Ground stations NOT used directly in POD.
  - Tie to frame strengthened through ambiguity resolution using wide-lane and phase biases relative to ground network adopted when generating constellation orbit/clock solutions.
  - JPL IGS Analysis Center generated reprocessed orbit and clock solutions for the GPS constellation (2002-present) using the IGS14 reference frame.
    - Released on June 5, 2018.
    - Previous standard was IGS08 reference frame.
  - JPL's Release 2018a GPS-based Jason-2/3 POD solutions use these recent IGS14-based GPS orbit and clock solutions with self-consistent antenna calibration.
    - Jason-2: Cycles 1-602.
    - Jason-3: Cycles 1-92

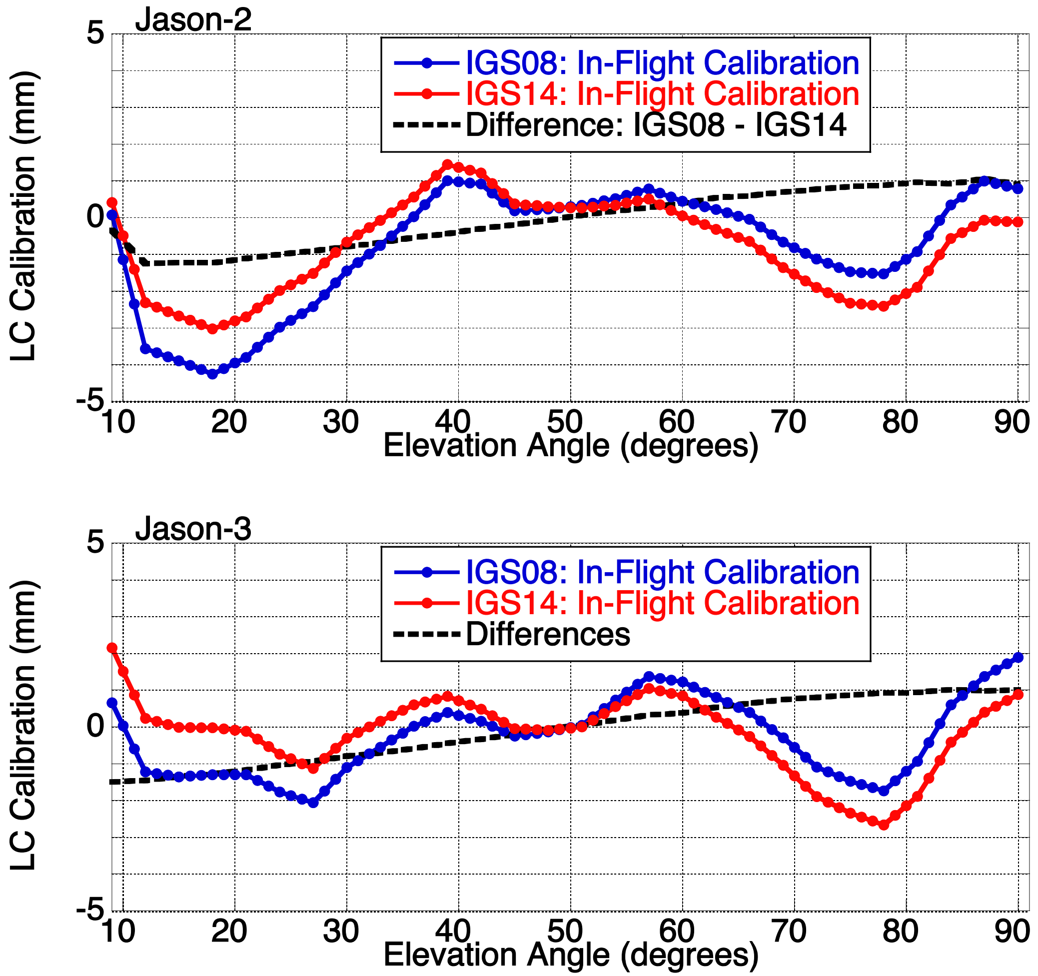
Lower RMS of Post-fit Residuals: IGS08 to IGS14





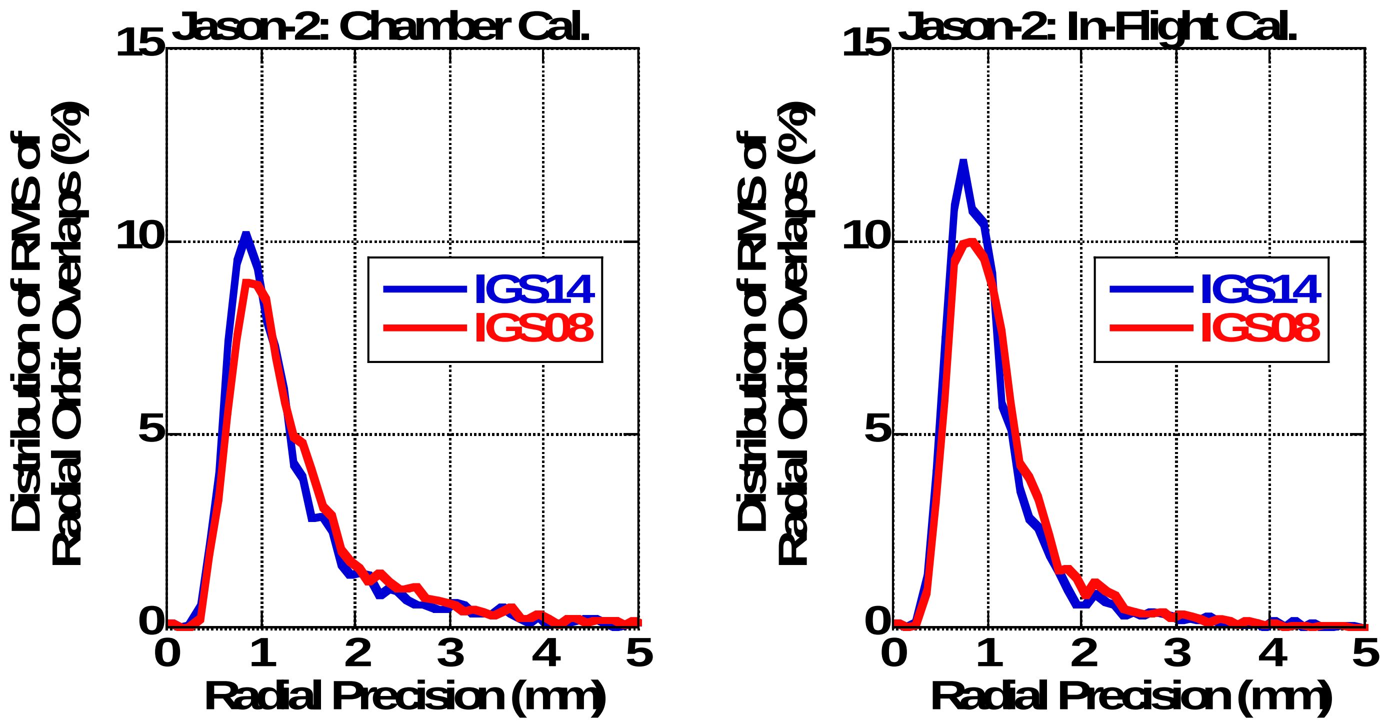
- Controlled test:
  - Only Difference: Input orbit and clock solutions for GPS constellation: IGS08 vs. IGS14.
  - Identical pre-launch chamber antenna calibration.
    - i.e., **independent of frame.**
  - Identical POD strategy.
  - Identical input tracking data.
- Lower post-fit RMS of phase (LC) residuals with IGS14-based GPS constellation orbit and clock solutions.
- Note: Typical post-fit LC RMS ~ 4 mm.
  - 0.1 - 0.25 mm is 2 - 6%.

Consistent Impact on In-Flight Antenna Calibration on Jason-2 and Jason-3



- In-flight calibration determined as an adjustment ("correction") to chamber calibration.
  - **"Correction" shown in figures.**
- Frame-specific calibration for each antenna generated using in-flight data.
- Consistent impact of frame on in-flight calibration.
  - Elevation-dependent slope with 2 mm peak-to-peak from 10-90 degrees.

Improvement of Jason-2 Radial Orbit Precision: IGS08 to IGS14

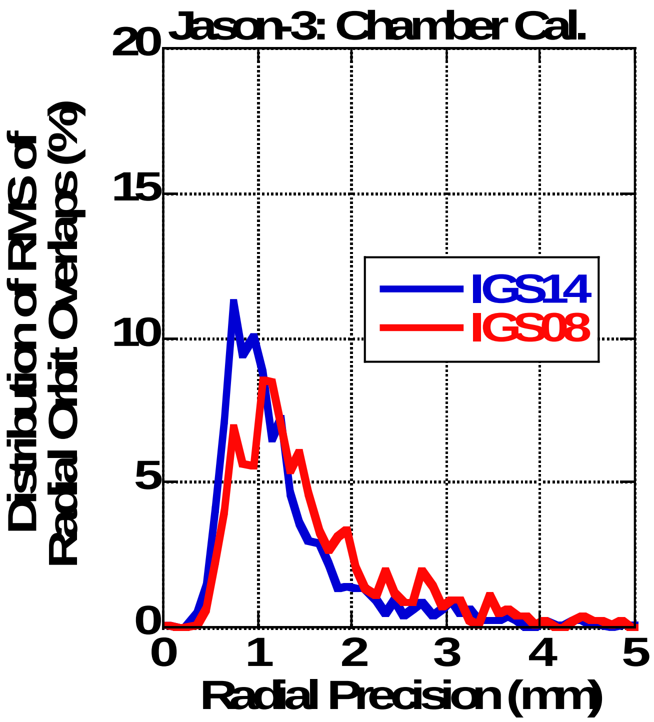


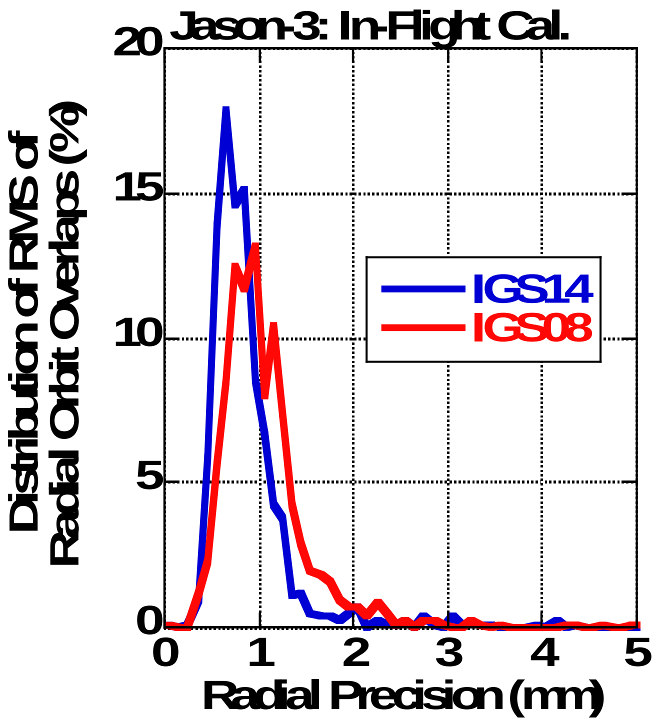
- Precision improvements from:
  – IGS14-based GPS orbit/clock products.
  – In-Flight Calibration

Median of Radial Precision (mm)

	IGS08	IGS14
Chamber Cal.	1.2	1.1
In-Flight Cal.	1.0	0.9

Improvement of Jason-3 Radial Orbit Precision: IGS08 vs. IGS14



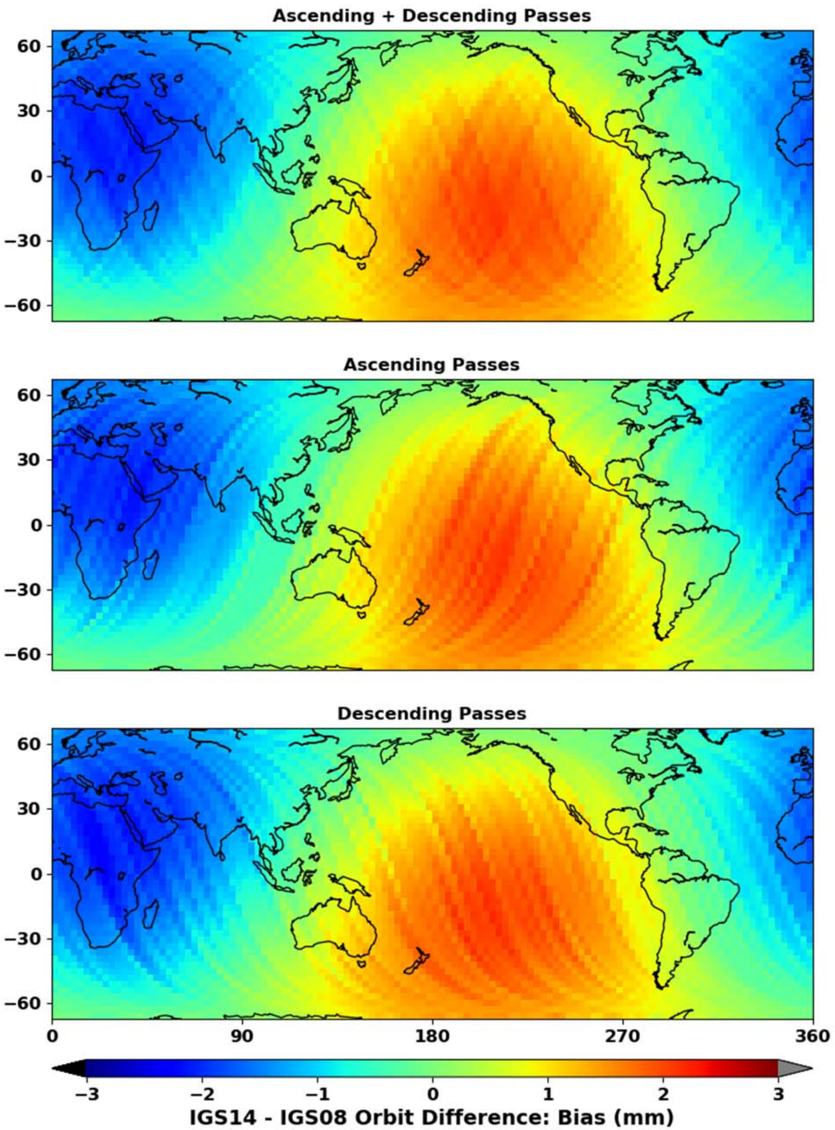


- Precision improvements from:
  - IGS14-based GPS orbit/clock products.
  - In-Flight Antenna Calibration

Median of Radial Precision (mm)

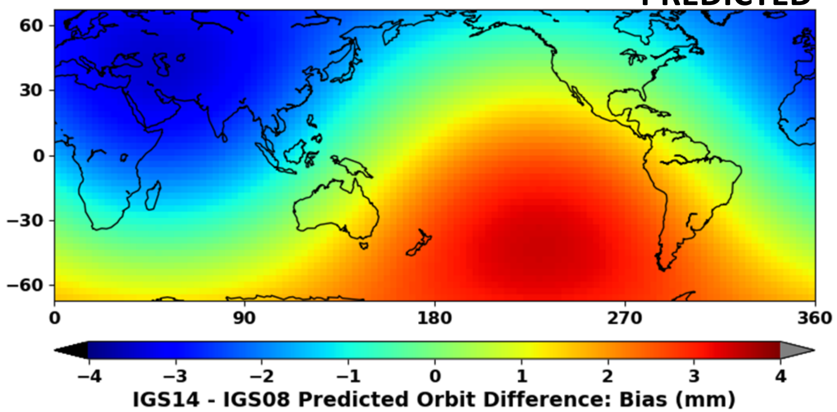
	IGS08	IGS14
Chamber Cal.	1.3	1.1
In-Flight Cal.	1.0	0.8

Impact on Orbit Centering: IGS08 vs. IGS14

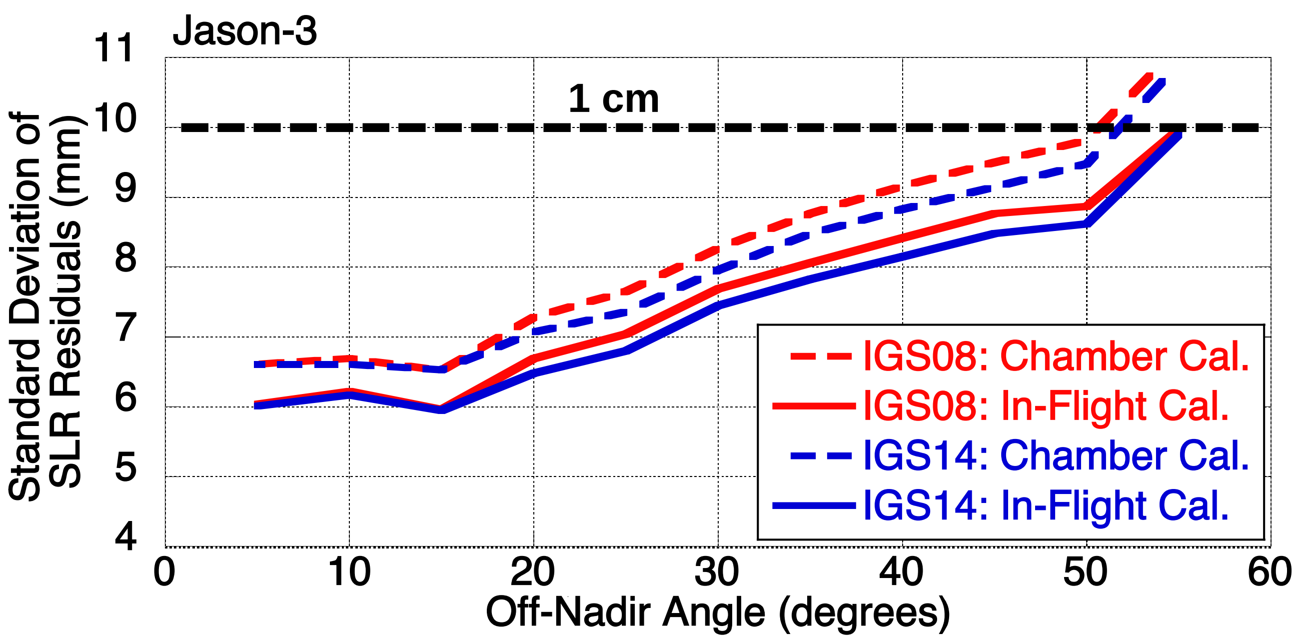


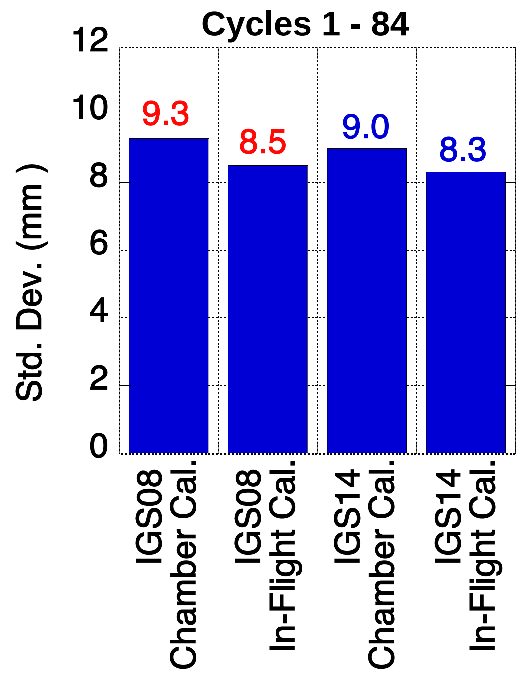
- Map radial orbit differences from Jason-3 cycles 1-84.
  - Simultaneously fit bias, drift, beta prime (118 days) period, annual period.
  - Epoch for bias is cycle 1.
- Primary impact is on orbit centering.
  - Smaller than predicted by ITRF14/ITRF08 translation and slightly shifted north/west:
    - (X, Y, Z)=(1.6, 1.9, 2.4) mm
- Also considered:
  - Drift: < 0.5 mm/yr
  - Beta-prime period: < 0.5 mm
  - Annual period: < 0.5 mm.

PREDICTED



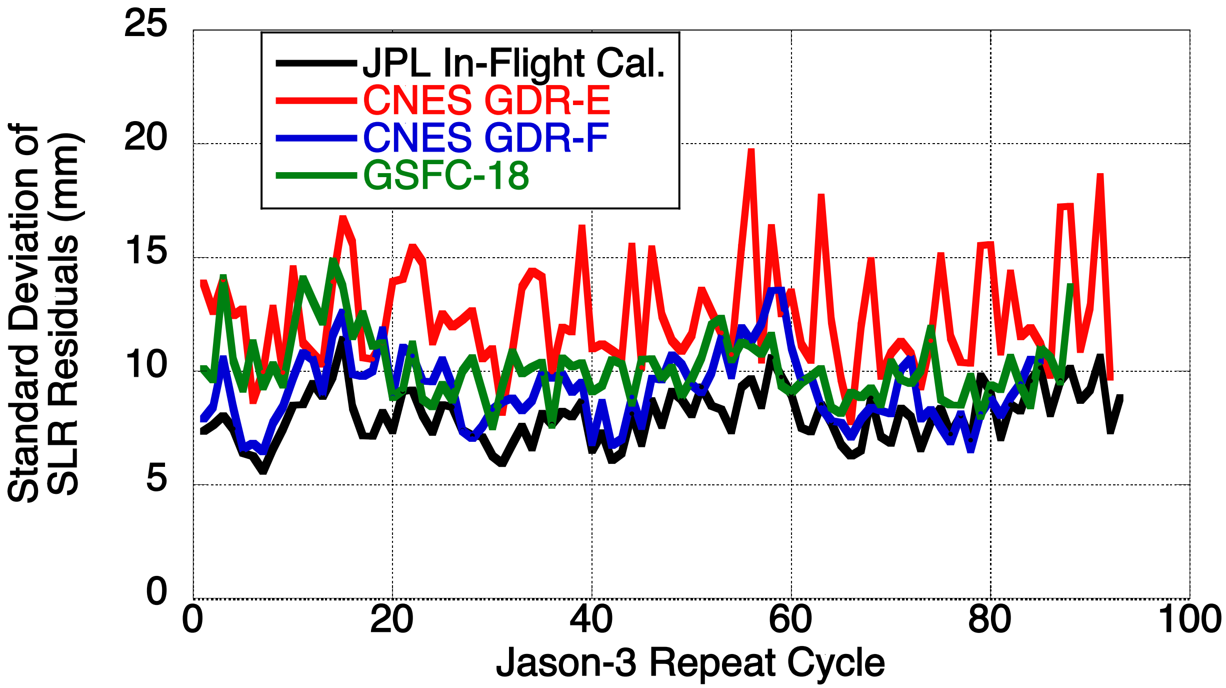
Independent Validation Using SLR Residuals: Jason-3 IGS08 vs. IGS14

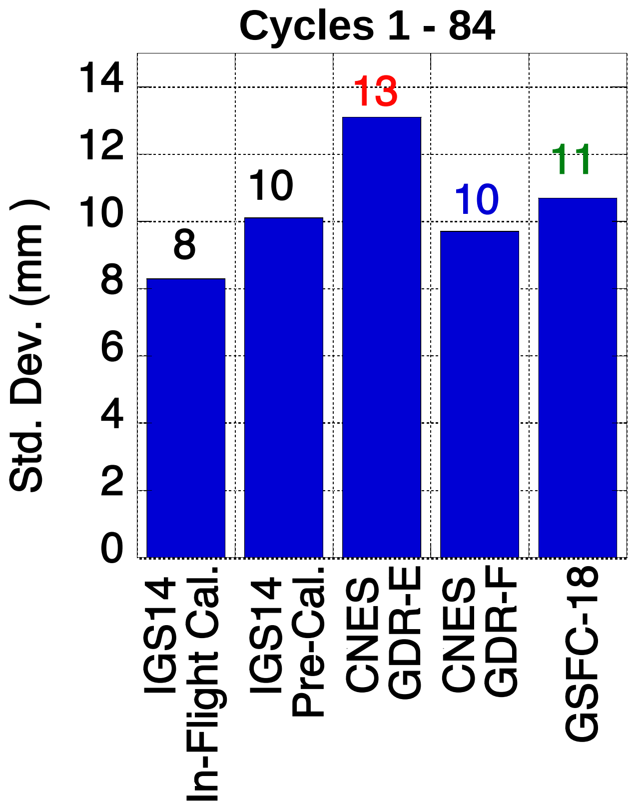




- Primary improvements:
  - > 20 degree off-nadir angles from transition to IGS14 GPS orbit/clock products.
  - All elevations from in-flight antenna calibration.
  - Not a completely fair comparison: Using ITRF14 SLR station positions

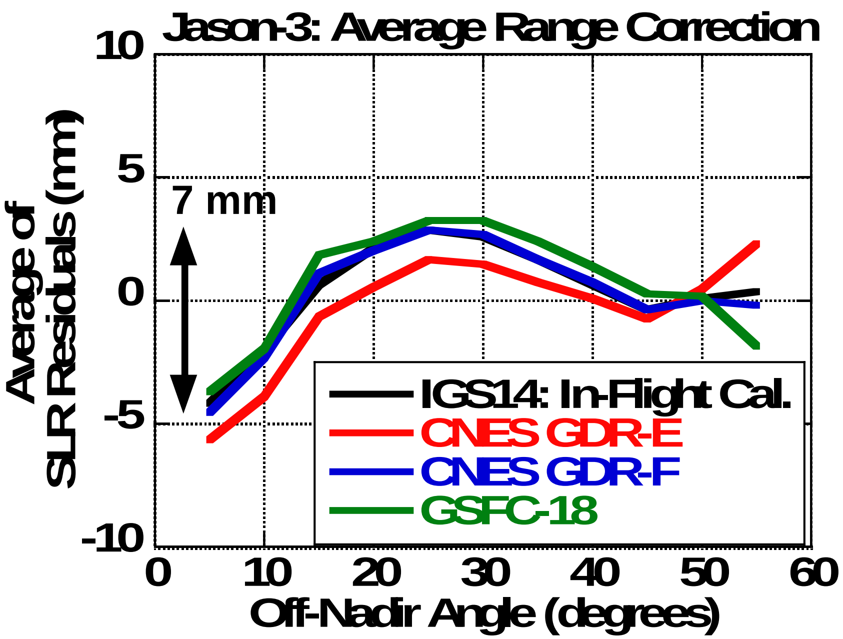
Time Series of Jason-3 SLR Residuals (All Elevations)

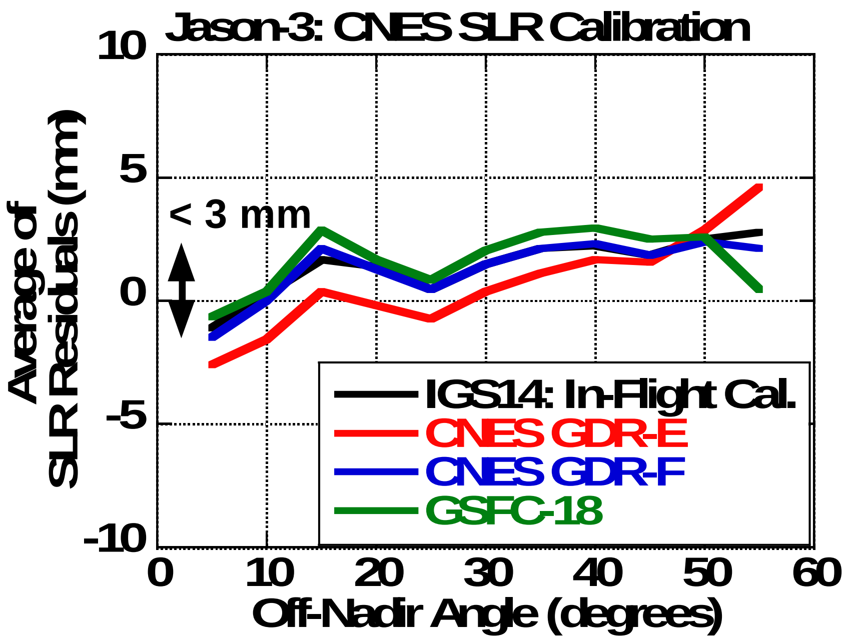




- ~1 cm or better for JPL's IGS14, CNES GDR-F, and GSFC-18 solutions.
  - GDR-F is significant improvement over GDR-E.

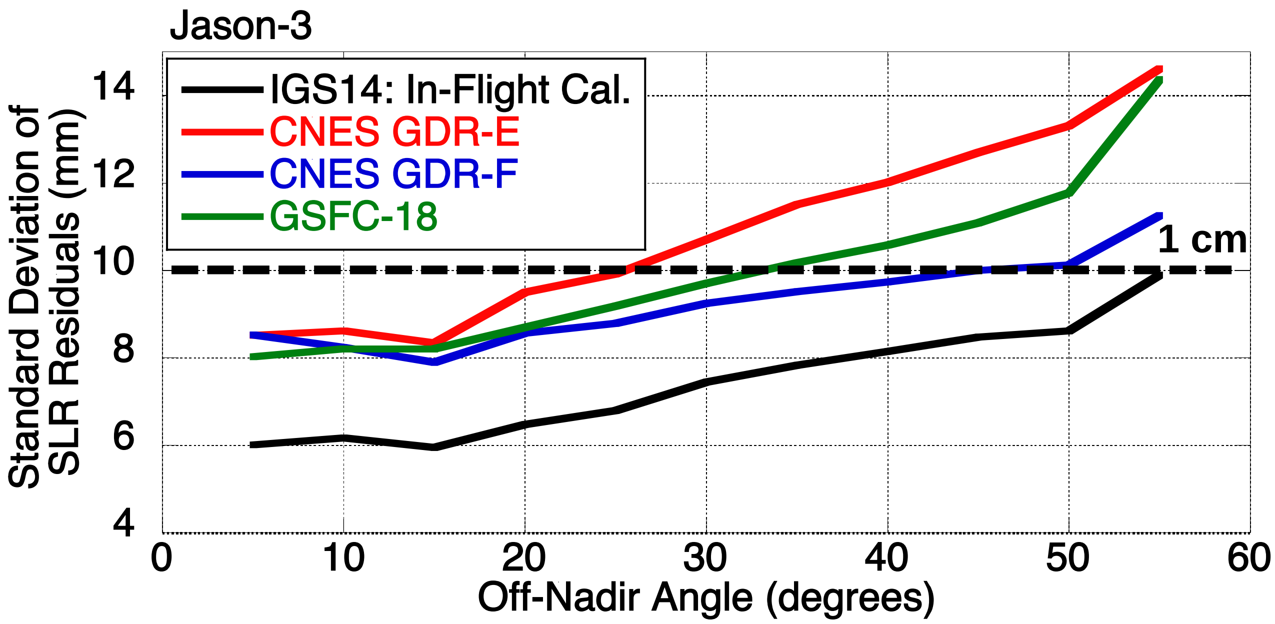
Impact of Jason-3 LRA Calibration on Off-Nadir Angle Dependencies

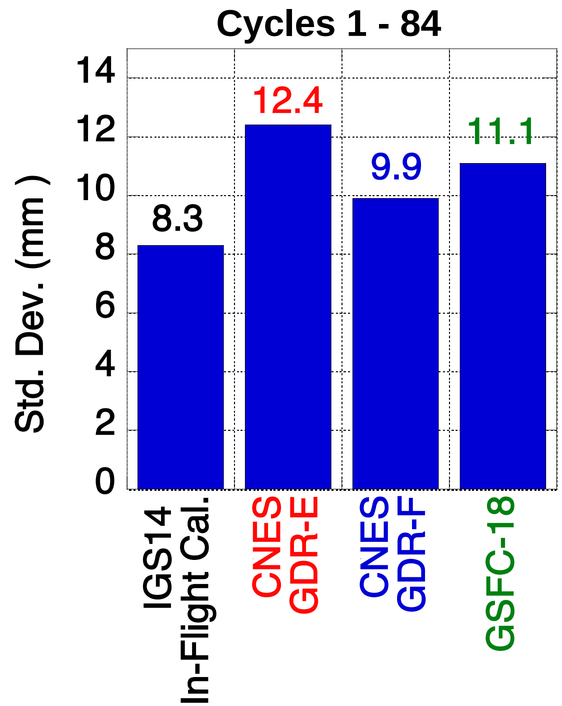




- Compare two LRA calibrations:
  - Manufacturer-recommended “average range correction” of -46 mm.
  - Theoretical calibration from Mercier and Couhert, August 2, 2017.
- Theoretical calibration “flattens” average of SLR residuals.
  - Remainder is approximately 2 mm bias > 15 degrees.

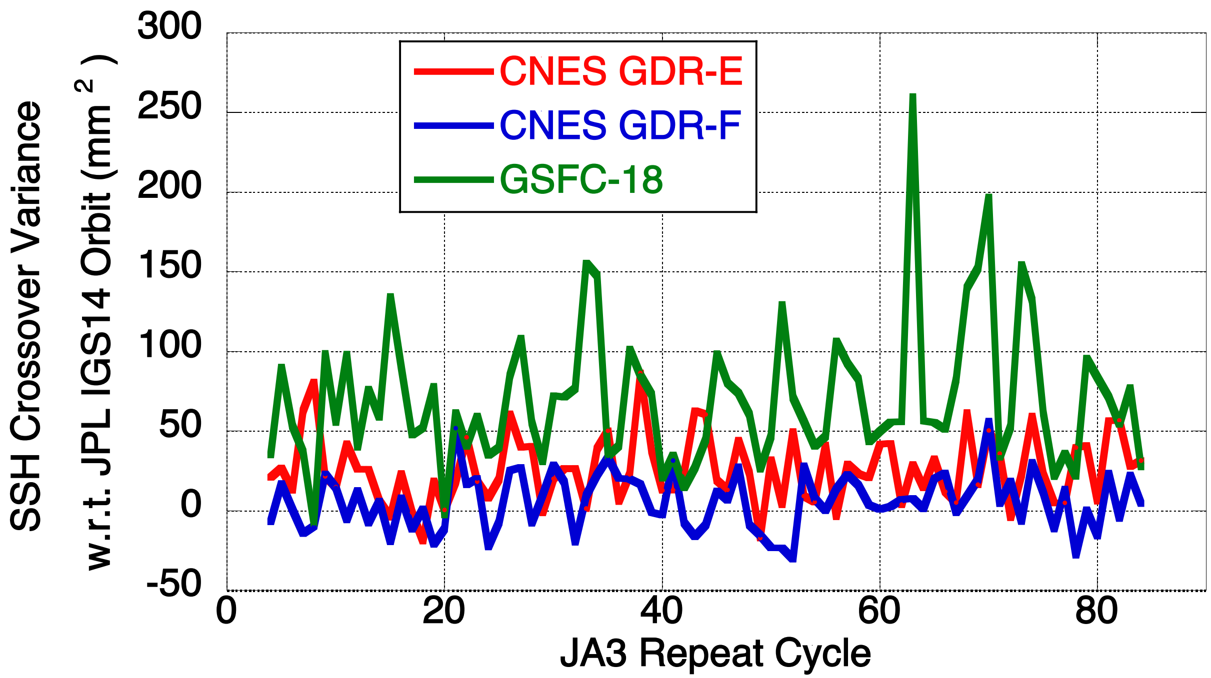
SLR Residual Variance as Function of Off-Nadir Angle

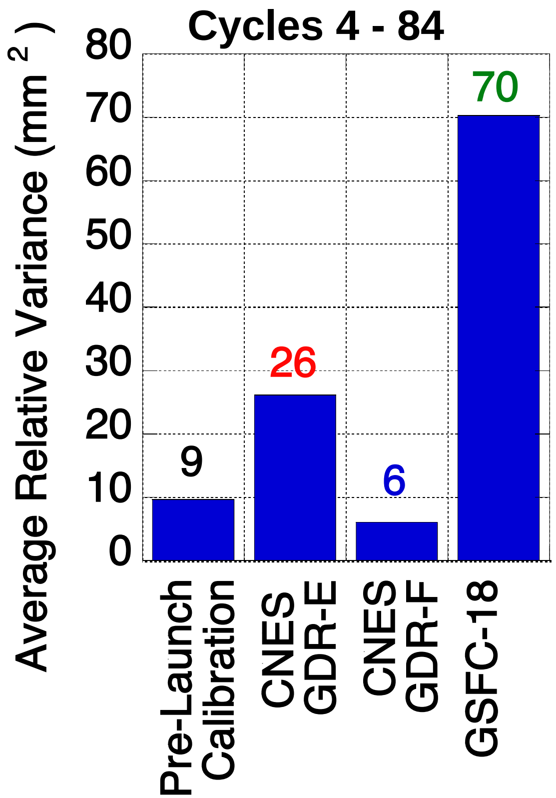




- All solutions have SLR residual standard deviation < 1 cm at close to nadir.
  - Most representative of radial orbit accuracy.
- JPL solution 1-2 mm lower than other solutions.
  - 6 mm close to nadir.

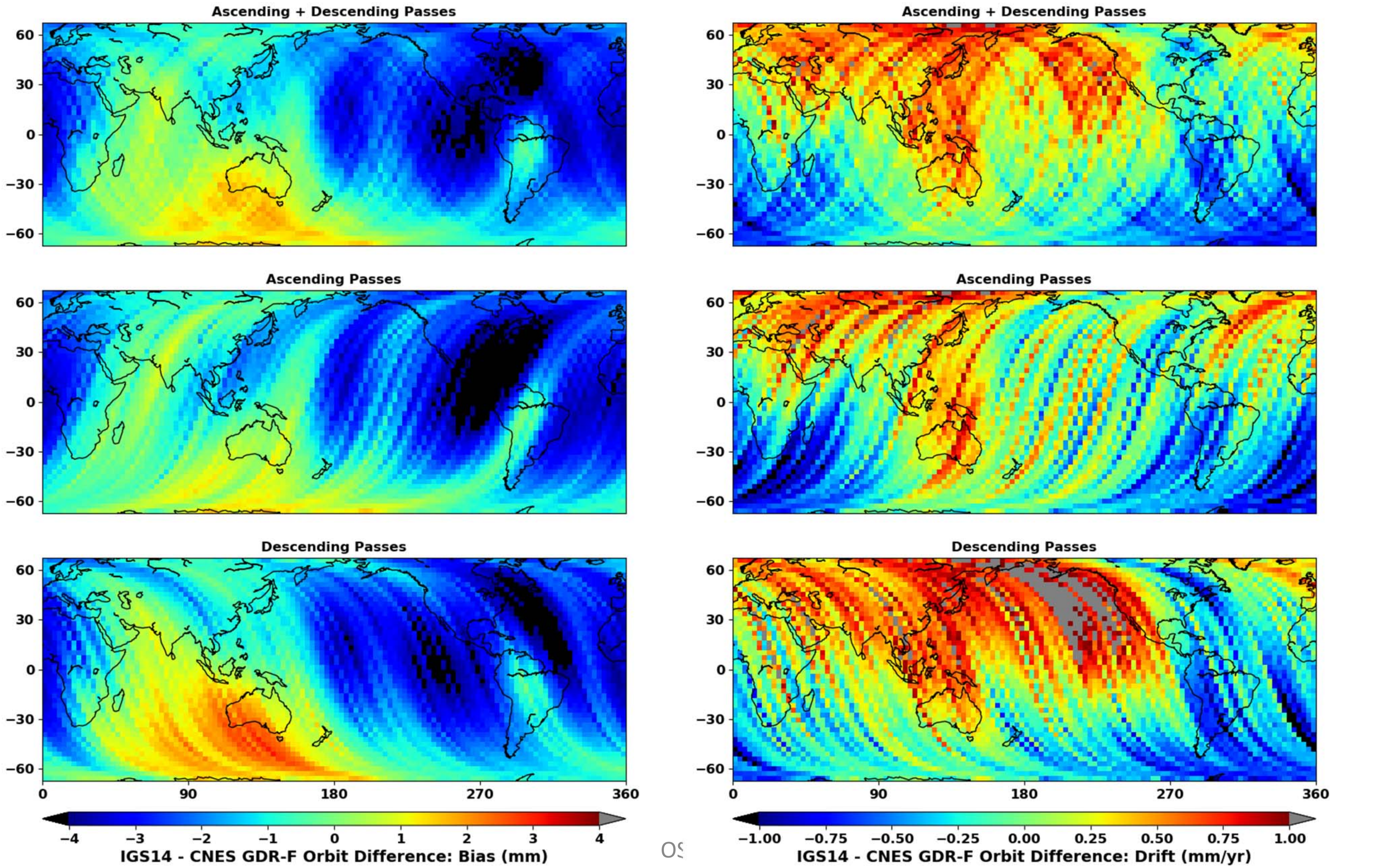
JA3 SSH Crossover Variance Tests (Relative to JPL IGS14 with In-Flight Antenna Calibration)



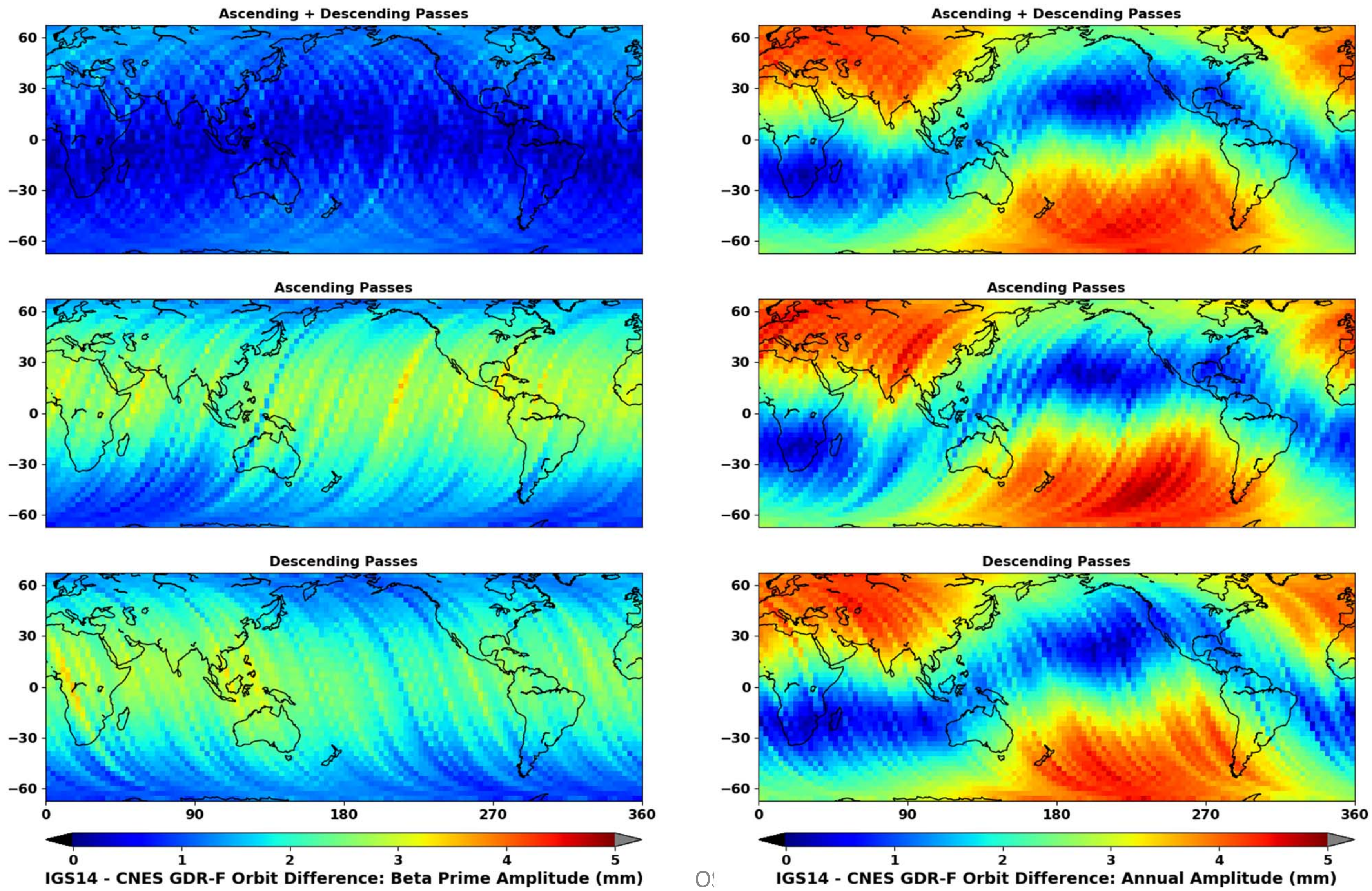


- In-flight antenna calibration reduces variance by ~10 mm^2.
- CNES GDR-F is significant improvement over GDR-E (20 mm^2).
- GDR-F and JPL IGS14 are comparable (within 10 mm^2).

JPL RLS18a vs. CNES GDR-F
Mapping Orbit Differences: Bias and Drift



JPL RLS18a vs. CNES GDR-F
Mapping Orbit Differences: Beta Prime and Annual



Summary

- New IGS14-based orbit and clocks solutions for GPS constellation enable small improvements to Jason-2 and Jason-3 POD.
  - Smaller postfit residuals, < 1 mm radial precision, < 1 cm SLR residual standard deviation across all elevations.
- LRA theoretical calibration (Mercier and Couhert) ”flattens” elevation-angle dependencies.
  - Apparent 2 mm bias remains at off-nadir angles > 15 degrees.
  - Could potentially map into overall 2 mm network range bias.
- Jason-3 CNES GDR-F and JPL’s Release 18a solutions have very similar performance.
  - SSH crossover variance within 10 mm^2.
  - East/West shift in centering, and annual differences < 5 mm.
- Independent SLR data suggest radial orbit accuracies of 8 mm or better for most orbit solutions.

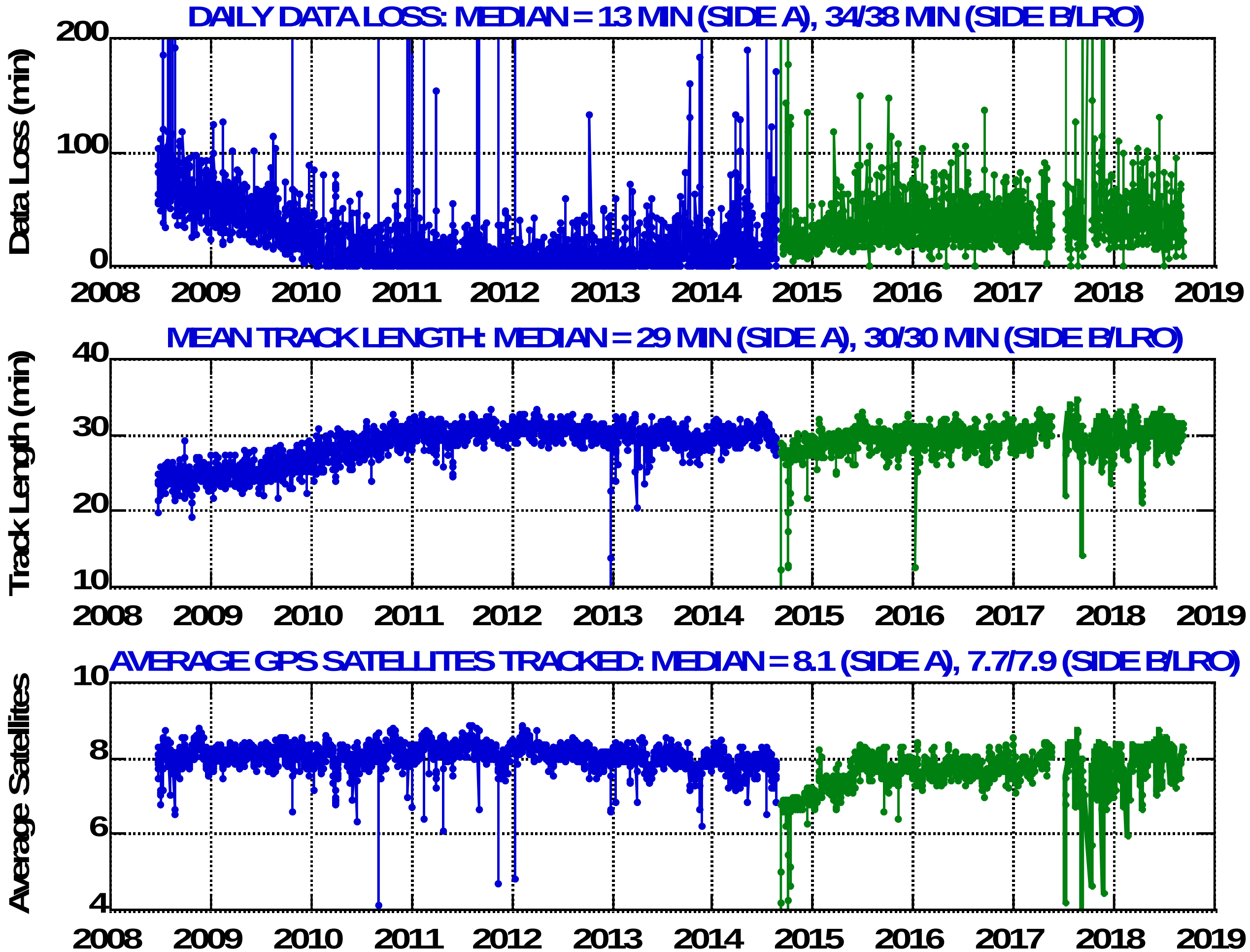
Backup

List of SLR Stations Used in This Study

Station ID	Station Name
7090	Yarragadee, Australia
7501	Hartebeesthoek, South Africa
7810	Zimmerwald, Switzerland
7825	Mt Stromlo, Australia
7839	Graz, Austria
7840	Herstmonceux, United Kingdom

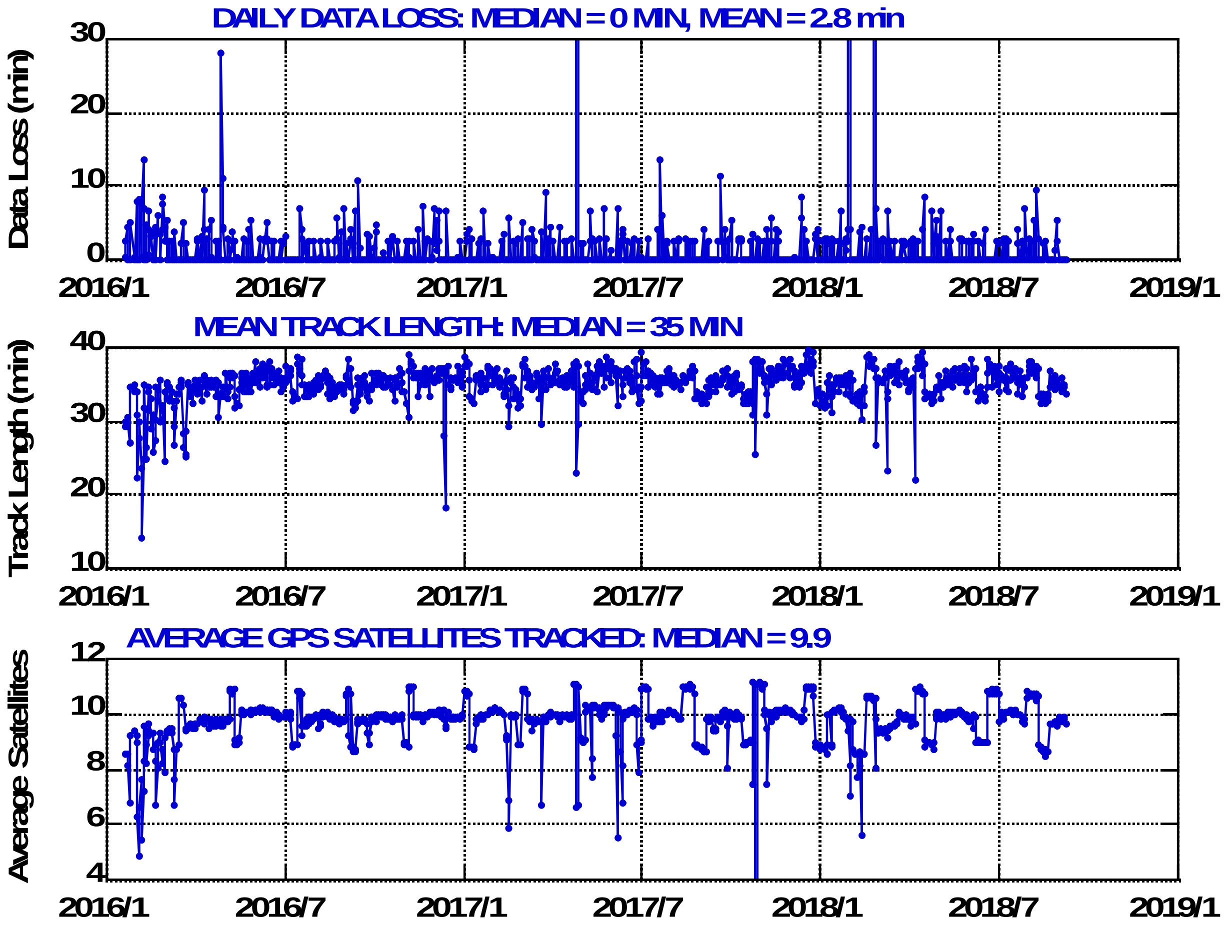
- SLR residuals indicated station biases < 3 mm, low standard deviation of residuals, and large number of observations.
- Also considered the following stations, but excluded due to > 3mm station biases or low number of samples.
- 7105, 7119, 7841, and 7124
- (Greenbelt, Haleakala, Potsdam, and Tahiti)

Jason-2 GPS Receiver Performance



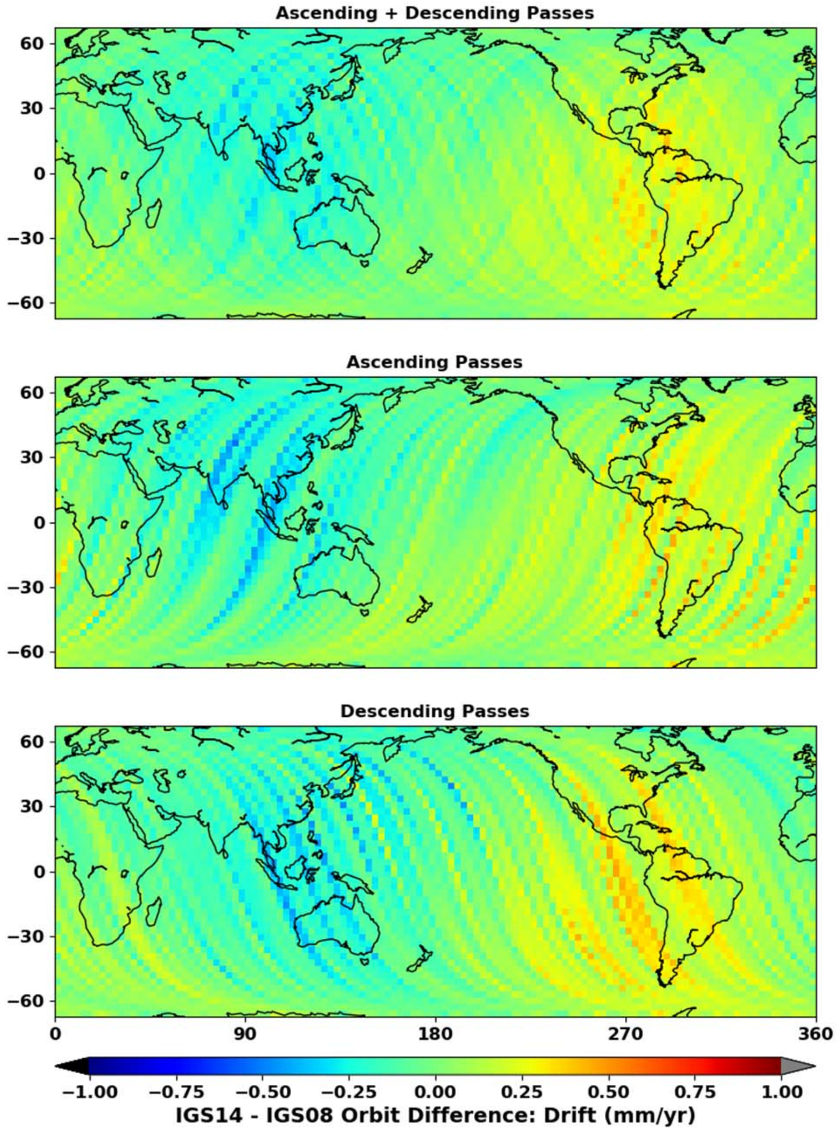
- Side-B turned on 2014-09-08.
  - Max Sats = 8.
- Max Sats modified:
  - 10: 2015-01-20
  - 12: 2015-03-04
- Jason-2 Safehold:
  - 2017-05-17 to 2017-07-02.

Jason-3 GPS Performance



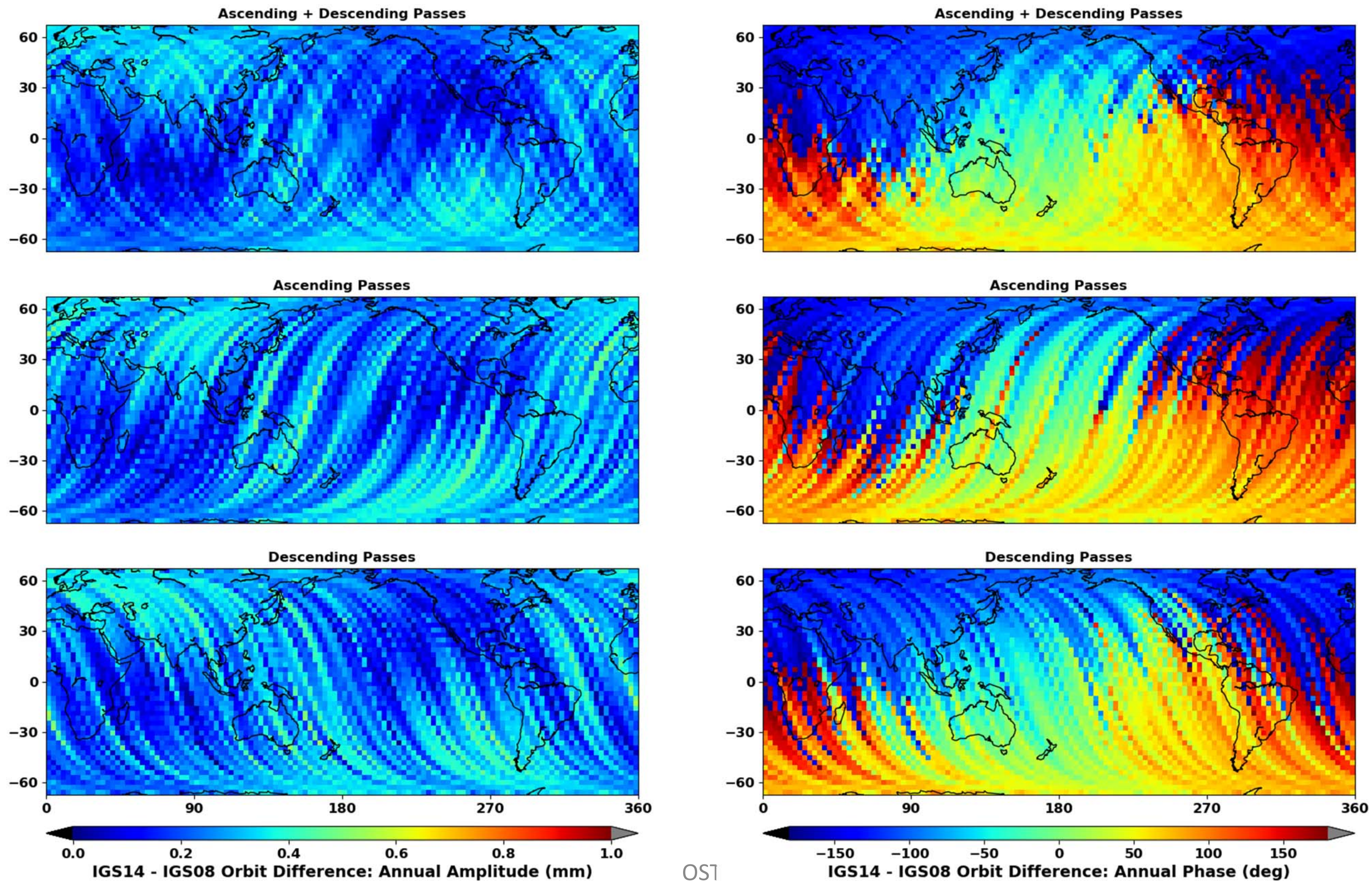
- Scrubbing enabled: 2016-02-29
- Higher data return than Jason-2.
  - More satellites.
  - Fewer data gaps.
- Fixed yaw periods evident in tracking coverage.
  - Reduced tracking when flying "forward" (heading of 0 degrees).

IGS14 vs. IGS08: Drift

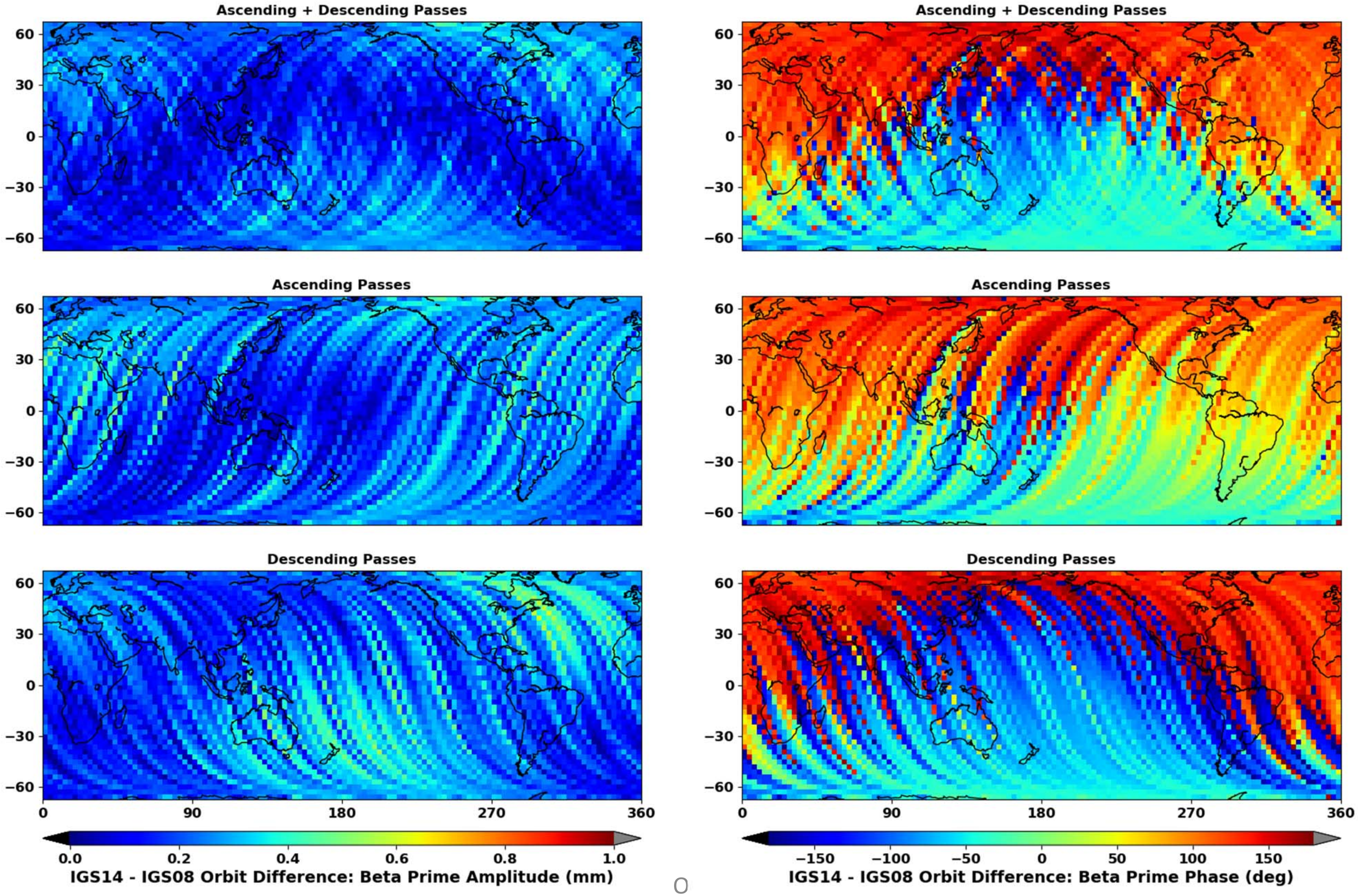


- < 0.5 mm/yr

IGS14 vs. IGS08: Annual Amplitude and Phase



IGS14 vs. IGS08: Beta Prime Amplitude and Phase



JPL IGS14 vs. CNES GDR-F Beta Prime and Annual Phase