Performance of the Jason-3 GPS Receiver and Resulting GPS-based Precise Orbit Determination Solutions

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Introduction

- Evaluate strategies for handling geocenter motion through GPS orbit/clock products.
- Differences with CNES POE-F and GSFC solutions.
  - SLR residuals.
  - Independent SSH crossover variance metrics.
- Evaluate post-fit residuals for useful information.

JPL Release 2019a

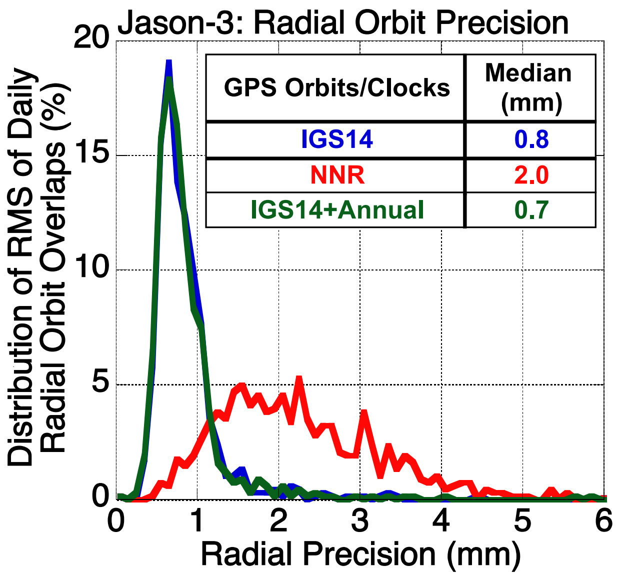
Parameter	Value
Orbit Arc	30-hours (daily)
Gravity Field	**EIGEN-GRGS.RL04** **(linear mean pole, degree 1 = 0)**
AOD	Release 6
Ocean Tide Model	GOT4.8ac
Pole Tide Model	IERS 2010 **(linear mean pole)**
Attitude	Quaternions
Solar Panel Orientation	Reported Values
GPS Orbits/Clocks	JPL Finals IGS14 **(Fiducial Fixed)**
Data Weights	1 cm LC, 100 cm PC
Elevation Angle Cutoff	0 degrees
Minimum Track Length	10 minutes
Antenna Calibration	**Updated In-Flight Calibration** **(2016-02-15 to 2019-09-21)**

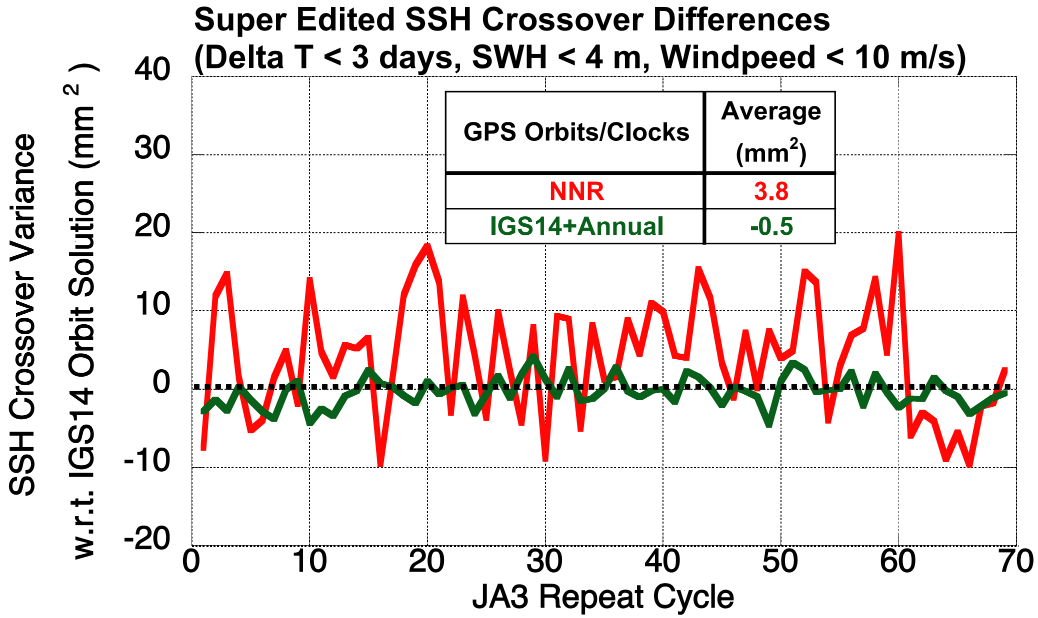
GPS Orbit and Clock Products

- Typical approach for Jason-3 POD:
  - Fix orbit positions and clocks of transmitting GPS satellites to ground network solutions (JPL IGS Analysis Center).
  - Independently solve for Jason-3 orbit positions and receiver clock.
- Consider Jason-3 POD solutions with three different types of network solutions for GPS satellite orbit/clock solutions.

Label	Description
IGS14	GPS orbit/clocks with ground network constrained to have **no net translation, scale, and rotation with respect to IGS2014.** • GPS orbits/clocks should be tied to center of mass at secular time scales.
NNR	GPS orbit/clocks with ground network constrained to have **no net rotation with respect to IGS2014.** • GPS orbits/clocks should be tied to GPS-based daily center of mass. • Subject to daily noise, and GPS inconsistencies w.r.t. SLR/VLBI-based ITRF.
IGS14+Annual	GPS orbit/clocks with ground network constrained to have **no net translation, scale, and rotation with respect to IGS2014 with annual geocenter motion** (from SLR, Altamimi et el., 2016) • GPS orbits/clocks should be tied to center of mass at annual and longer time scales.

Relative Jason-3 POD Performance: Radial Orbit Overlaps and Relative SSH Crossover Variance



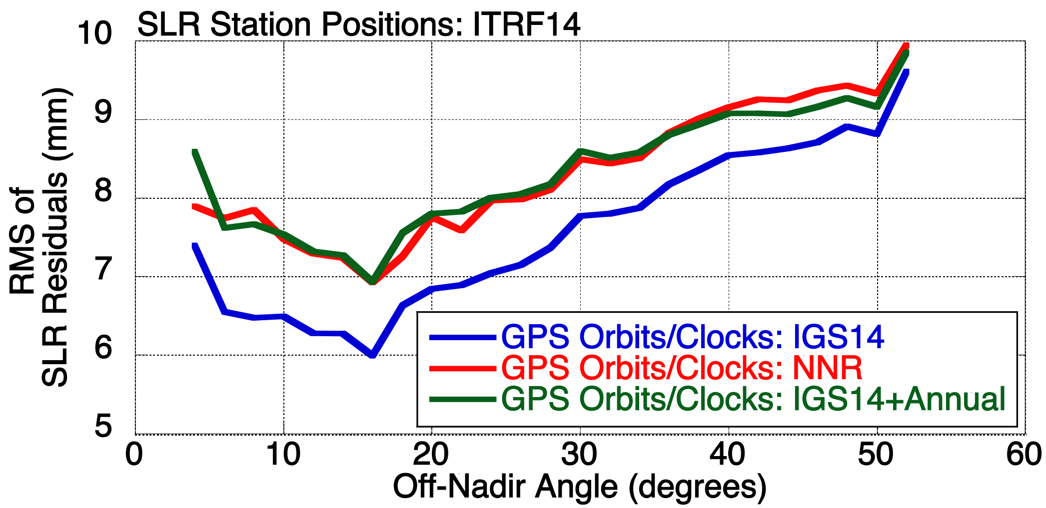


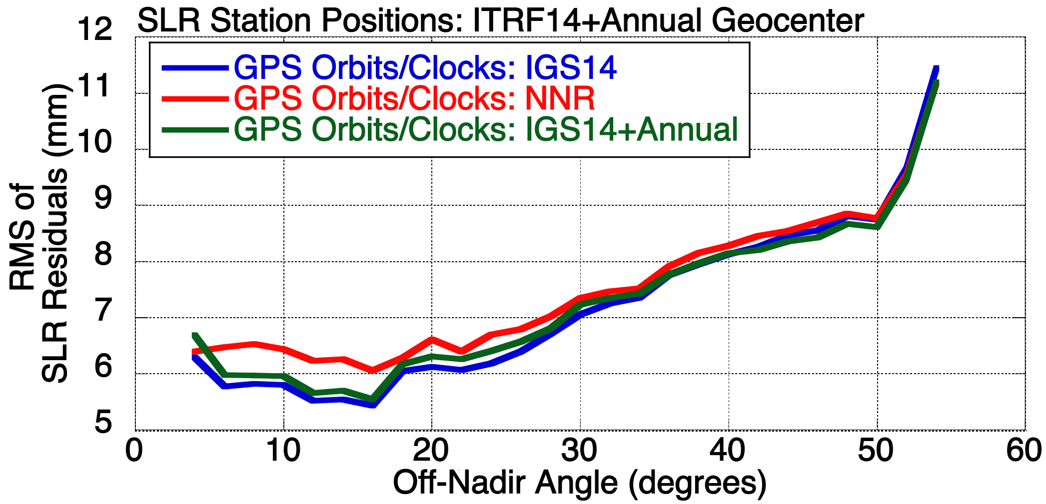
- Two fiducial-fixed GPS satellite orbit/clock products (IGS14 and IGS14+Annual) result with similar Jason-3 POD performance.
- No-net-rotation GPS satellite orbit/clock product results in significantly worse radial orbit precision, and mostly higher SSH crossover variance.
  - Likely source is daily noise in GPS-based realization of CM.

Independent Performance Assessment using SLR

SLR Station Positions: ITRF14 vs. ITRF14+Annual Geocenter

Jason-3 Cycles 1-69

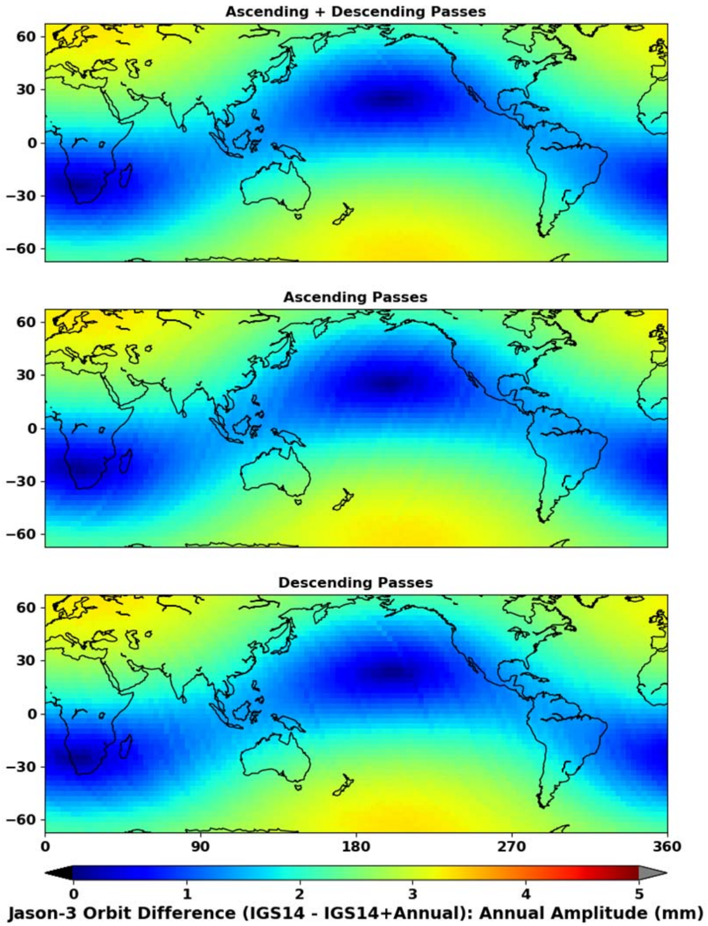




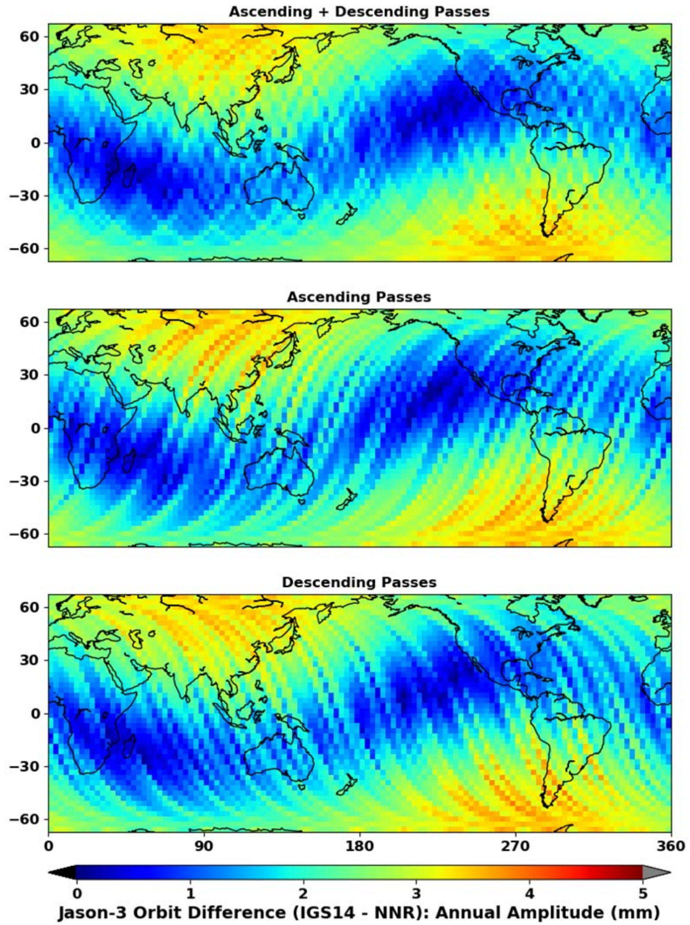
- SLR Stations: ITRF14:
  - Expected lower variance of SLR residuals with IGS14 fiducial-fixed GPS satellite orbits/clocks.
    - Annual geocenter motion not modeled in both the SLR station positions and in GPS network solutions.
- SLR Stations: ITRF+Annual Geocenter motion:
  - Closer performance of all three solutions.
  - All three Jason-3 orbit solutions have lower variance of SLR residuals than when annual geocenter motion not modelled in SLR station positions.
    - Our Jason-3 POD solutions have closer ties to Earth's CM regardless of GPS satellite orbits/clocks.
  - Jason-3 POD solutions using either of the fiducial-fixed GPS orbits/clocks (IGS14 and IGS14+Annual) have similar performance.
  - Best performance with IGS14 fiducial-fixed GPS satellite orbits/clocks.

Geographically Correlated Radial Orbit Differences: Annual Period

IGS14 – IGS14+Annual

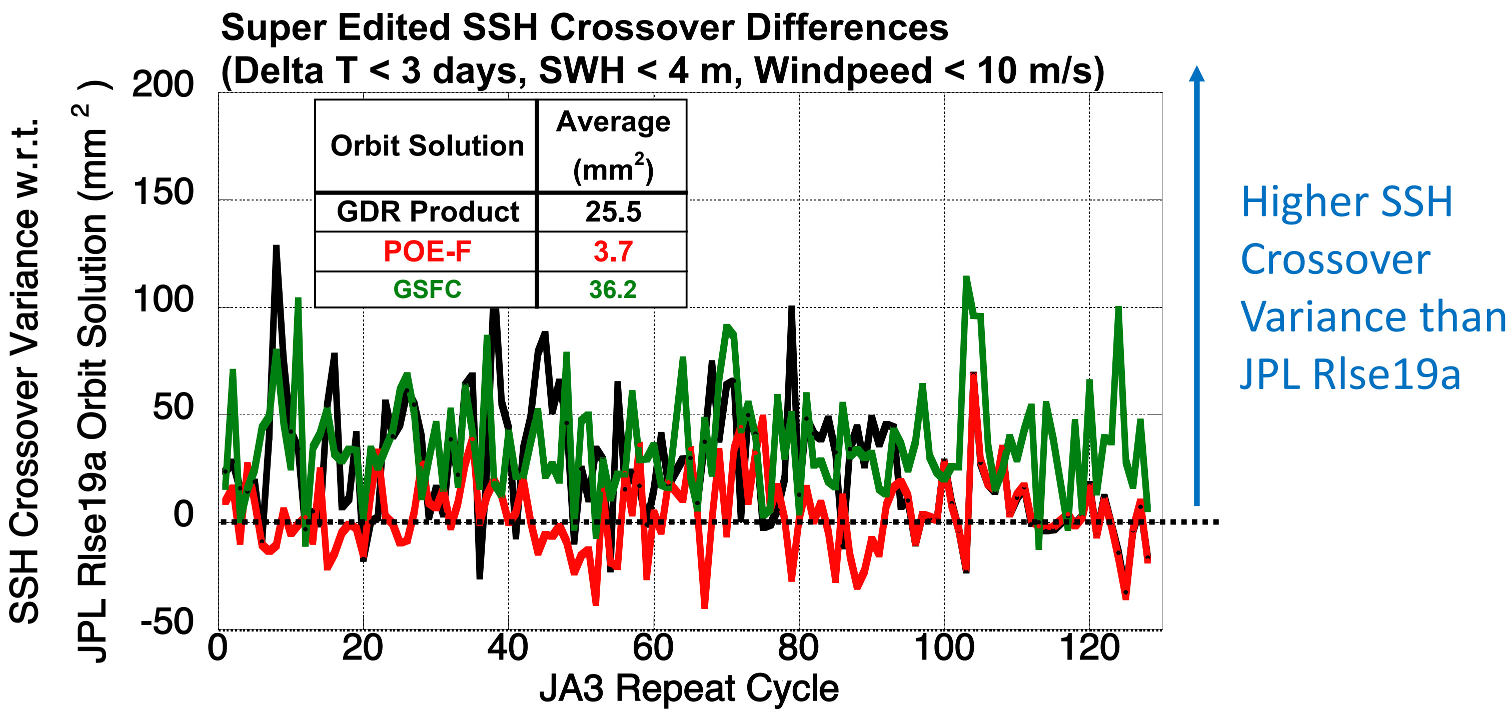


IGS14 – NNR



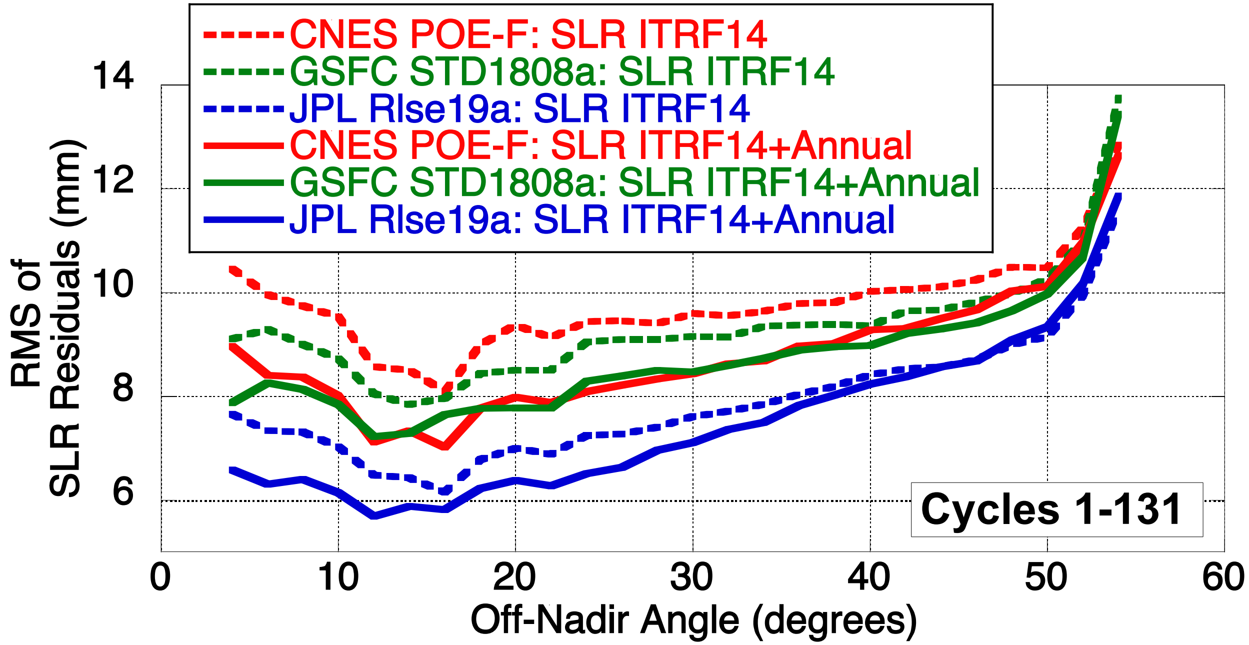
- Millimeter level orbit differences with similar pattern but shifted in longitude.
  - Exposes differences in GPS-based realization of CM compared to ITRF14.

SSH Crossover Variance Relative to JPL Rlse19a



- Jason-3 GDR products transitioned from POE-E to POE-F standards starting with cycle 95.
  - Significant improvement in SSH crossover variance with POE-F.
- JPL's GPS-based Release 2019a and CNES POE-F have similar performance.

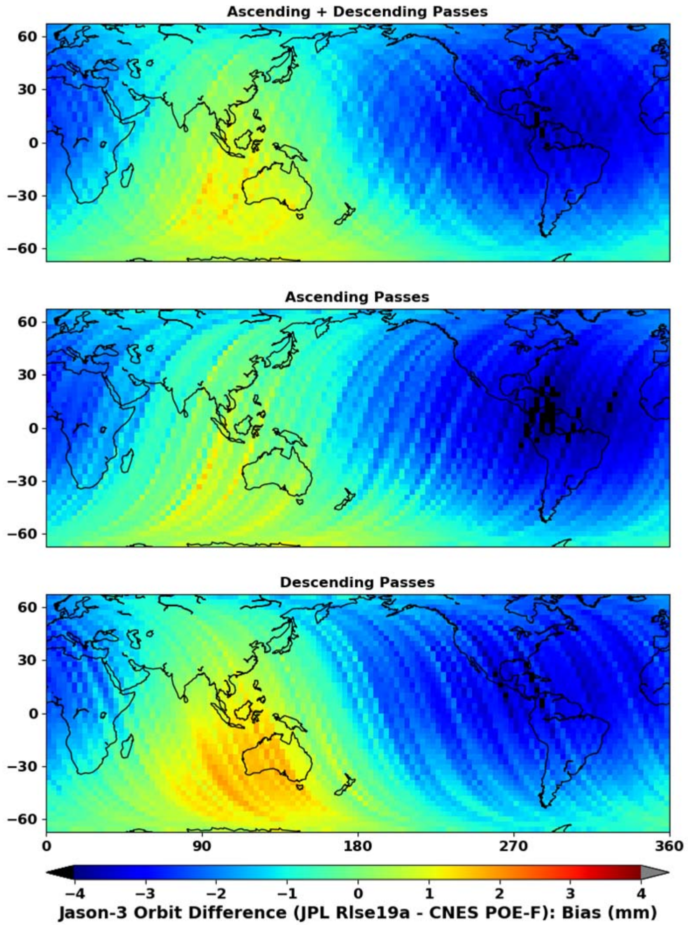
Independent Validation using SLR Observations



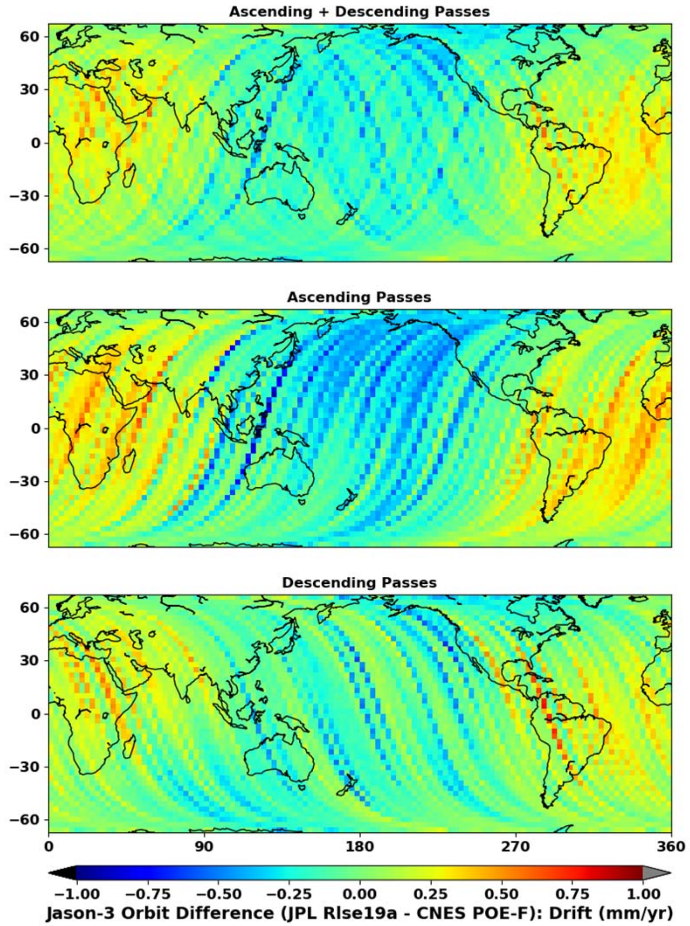
- Applying annual geocenter motion to SLR station positions improves (lowers) variance of SLR residuals for all solutions (JPL RIse19a, CNES POE-F, and GSFC).
  - All orbit solutions have closer ties to Earth's center of mass at annual periods and longer.
- JPL RIse19a has lower standard deviation of SLR residuals at all off-nadir angles by 1-2 mm.
- High elevation residuals (low off-nadir angle) suggest JPL RIse19a has radial orbit accuracy of < 7 mm.

Geographically Correlated Orbit Differences: JPL Release 19a vs. CNES POE-F (Bias and Drift)

Relative Bias



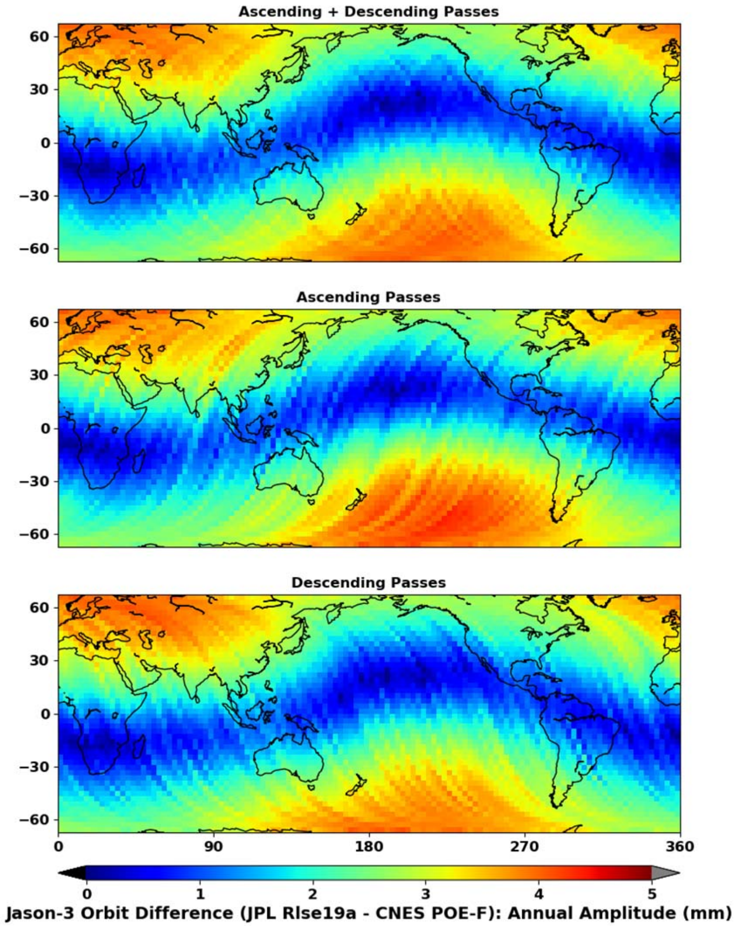
Relative Drift



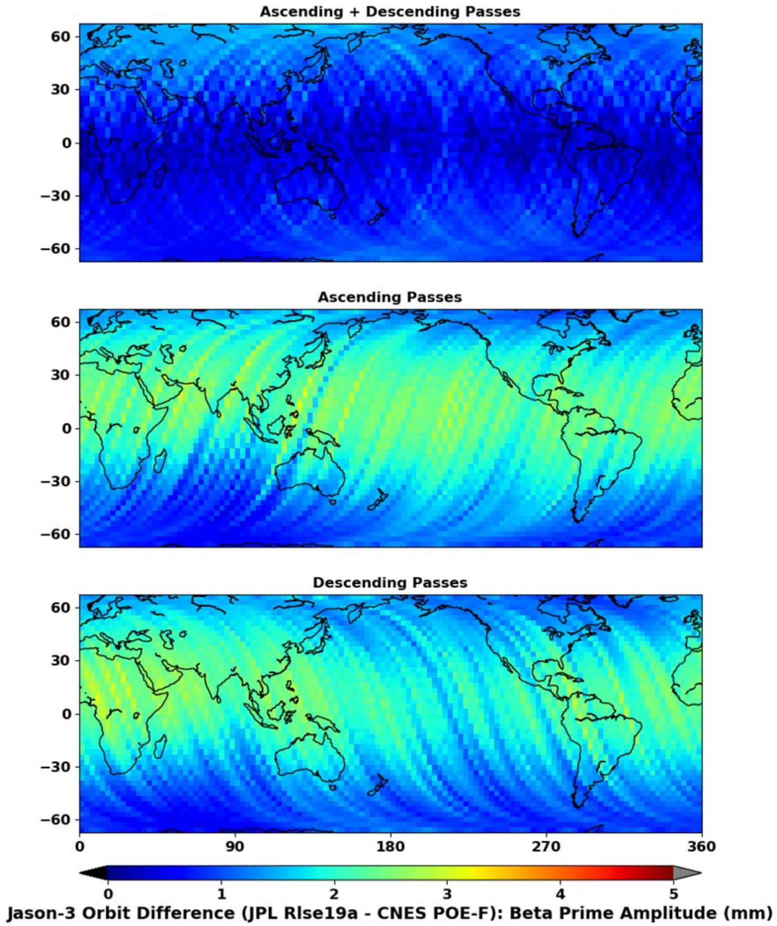
- Additional 1 year of comparisons reveals smaller bias and drift between two orbit solutions.
  - Relative bias of +/- 4 mm, and relative drift of +/- 0.5 mm/year.

Geographically Correlated Orbit Differences: JPL Release 19a vs. CNES POE-F (Annual and BetaPrime)

Annual

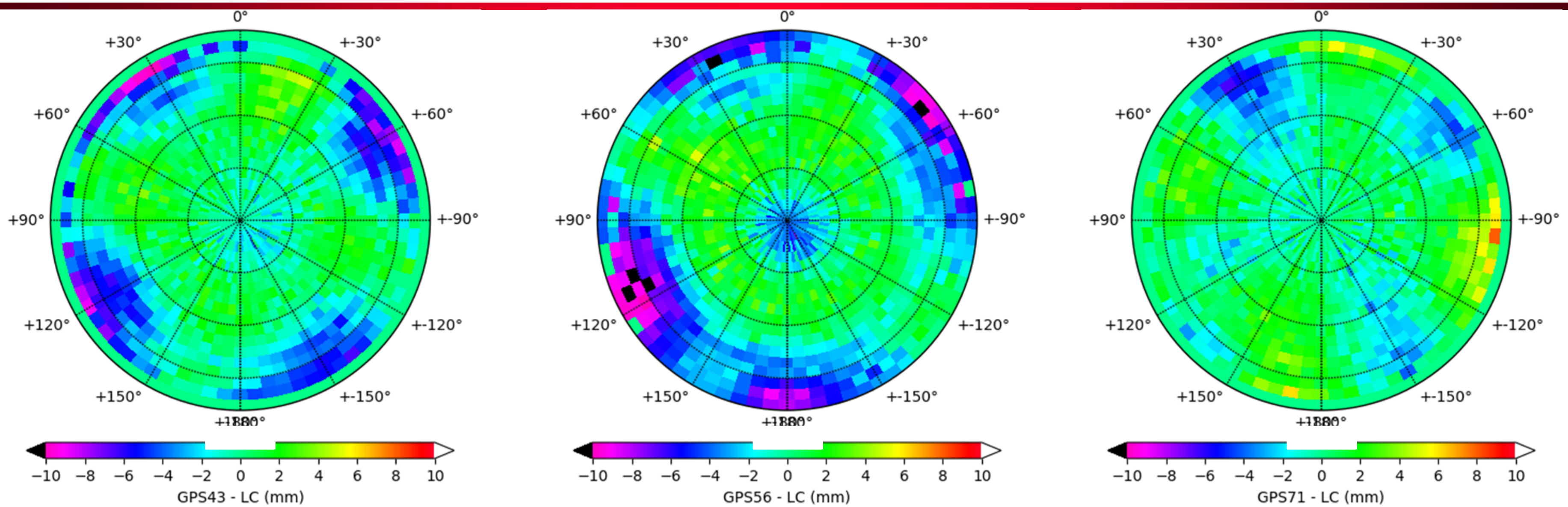


Beta Prime



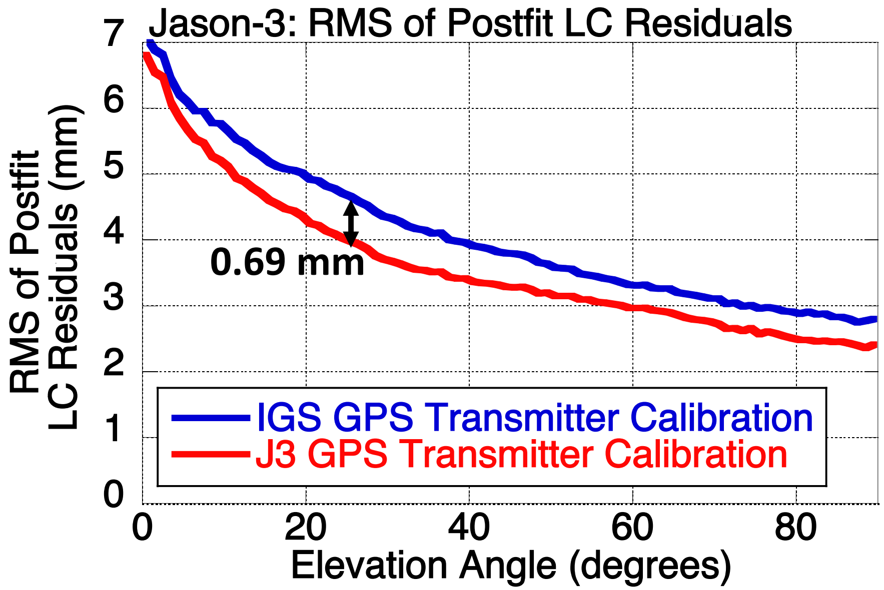
- At annual period, similar patterns as observed between JPL's IGS14 and IGS14+Annual orbit solutions, but with larger amplitude.

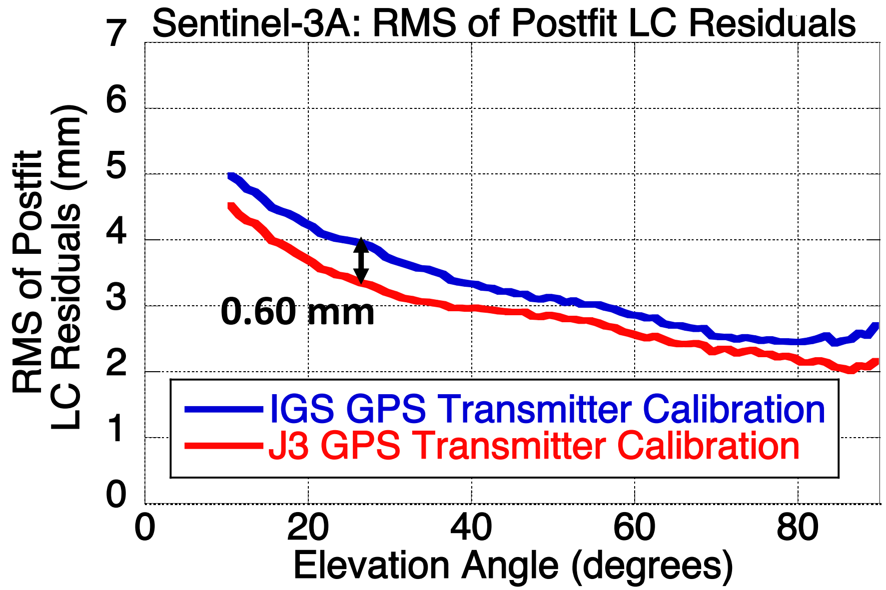
“Signals of Opportunity” in Jason-3 Post-fit Residuals



- IGS transmitter calibrations do not contain any azimuthal variations.
- Average Jason-3 Release19a postfit residuals by GPS satellite.
  - JPL Rlse19a solutions computed using IGS transmitter calibrations and in-flight Jason-3 data.
  - In-flight Jason-3 calibration contains average of any errors in the IGS transmitter calibrations.
- JPL Release 19a residuals reveal strong (up to 10 mm) azimuthal variations for many GPS satellites.
  - Block averaged azimuthal variations reported by Haines et al. (2015) using TOPEX and GRACE data.
  - Corresponds to transmitter antenna elements.

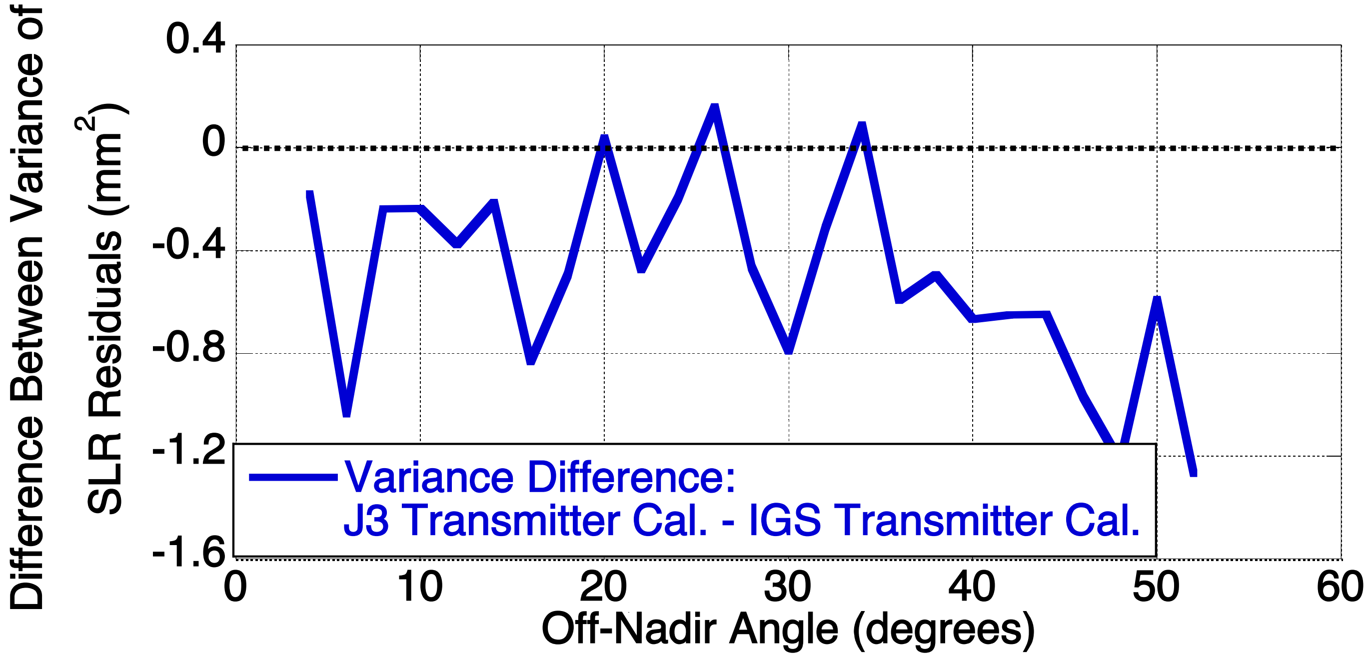
Application of Jason-3 based GPS Transmitter Calibrations to Jason-3 and Sentinel-3A POD





- Apply to precise orbit determination of Jason-3 and Sentinel-3A with same fiducial-fixed GPS orbit/clock products.
  - Construct transmitter calibration as sum total of “background” IGS calibration and ”correction” derived from Jason-3 post-fit residuals.
- Postfit residuals for both J3 and S3A improve (smaller) when using GPS transmitter calibrations derived from Jason-3, instead of IGS calibrations.
  - As much as 20% reduction in variance of phase residuals.
  - Expected for J3 given that calibration is derived from J3 post-fit residuals.
  - **Assessment with independent S3A satellite validates the Jason-3 based transmitter calibration correction.**
- Improvements primarily observed at mid-elevations of 10-40 degrees.
  - Corresponds to elevations where azimuthal variations in transmitter calibrations are largest.

Validating Transmitter Calibrations with SLR Residuals



- Jason-3 POD accuracy improves when using “correction” for GPS transmitter calibration.
  - Variance of independent SLR residuals improves at most elevations.
  - Average variance reduction: 0.5 mm^2

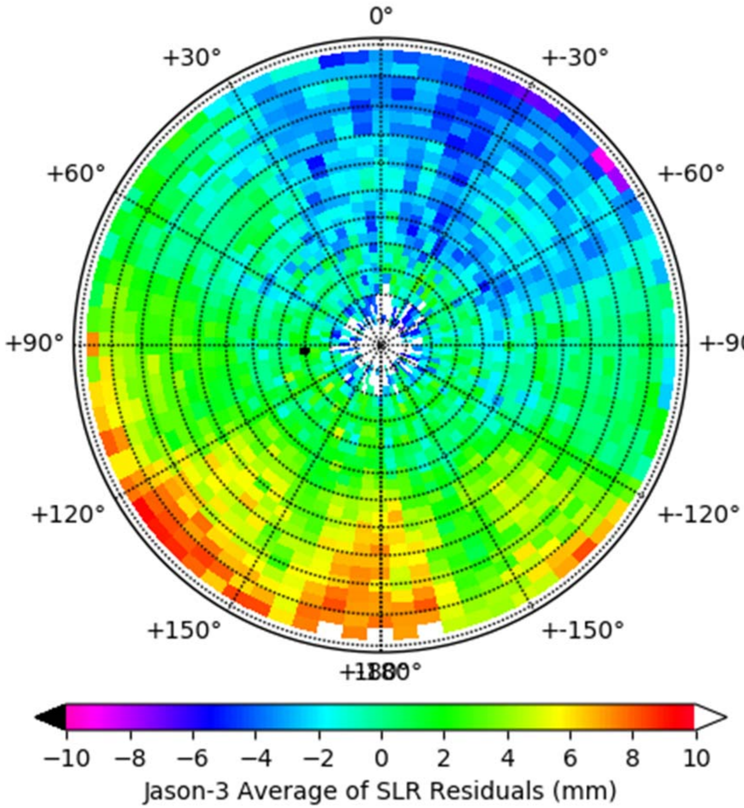
Conclusions

- Fiducial-fixed GPS orbit/clock products provide best Jason-3 POD performance.
  - Verified through radial orbit overlaps, SSH crossover variance, and independent SLR tracking data residuals.
- JPL's Release19a, CNES POE-F, and GSFC are have closer ties to Earth's center of mass at annual periods and longer.
  - Verified through independent SLR observations.
- Similar SSH crossover variance performance from JPL Rlse19a and CNES POE-F.
- Systematic geographically correlated bias (+/- 4 mm) and drift (+/- 0.5 mm) observed in radial orbit differences between JPL's Rlse19a and CNES POE-F orbit solutions.
  - Perhaps explains different performance in SLR residuals.
- JPL Rlse19a radial orbit accuracy < 7 mm.
  - Supported by high elevation SLR residuals.
- Jason-3 GPS residuals offer useful information about azimuthal variations in GPS transmitter calibrations.
  - Provide benefits for Jason-3 and S3A POD.
  - Lower post-fit residuals and lower variance of SLR residuals.

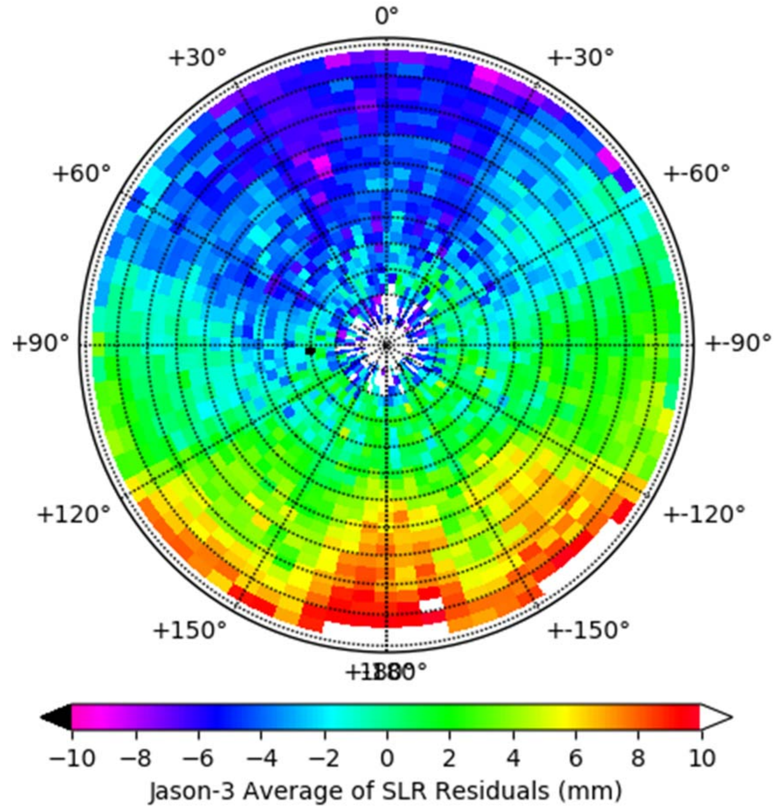
Backup

Average of SLR Residuals

JPL Rlse19a



CNES POE-F



- Systematic along-track errors observed in both JPL Rlse19a and CNES POE-F.
- JPL Rlse19a has lower average of SLR residuals at all elevations.

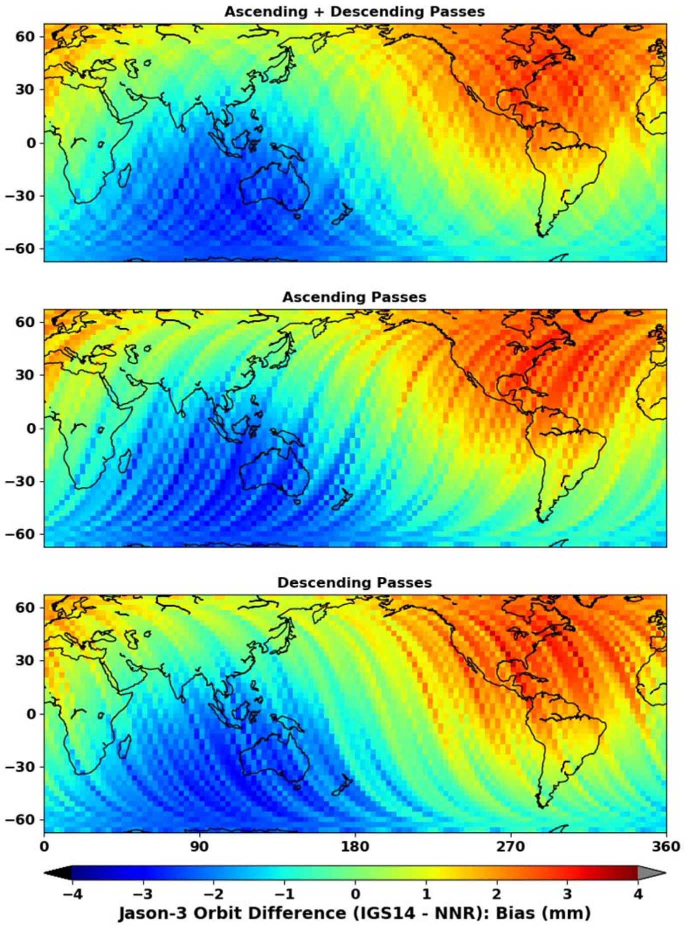
List of SLR Stations Used in This Study

Station ID	Station Name
7090	Yarragadee, Australia
7105	Greenbelt
7810	Zimmerwald, Switzerland
7825	Mt Stromlo, Australia
7839	Graz, Austria
7840	Herstmonceux, United Kingdom

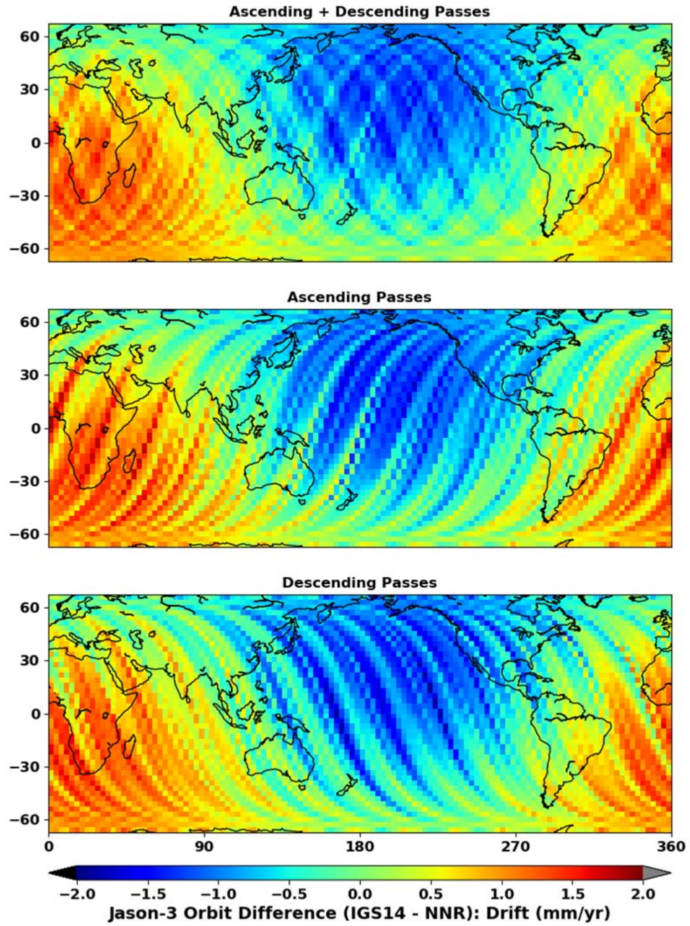
- SLR residuals indicated station biases < 5 mm, low standard deviation of residuals, and large number of observations.

Geographically Correlated Radial Orbit Differences: IGS14-NNR Bias and Drift

IGS14 – NNR: Bias



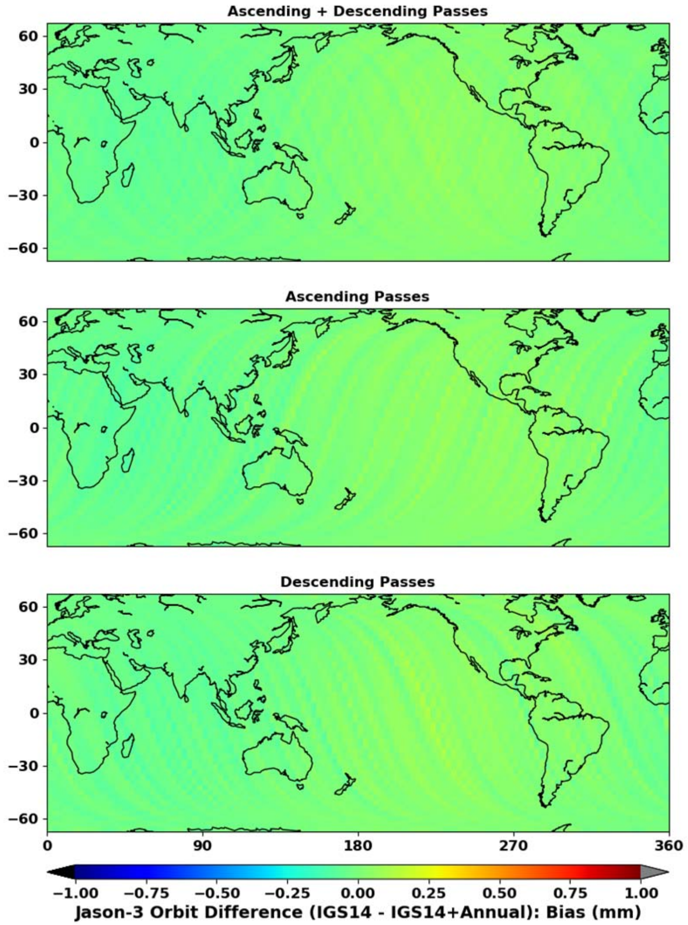
IGS14 – NNR: Drift



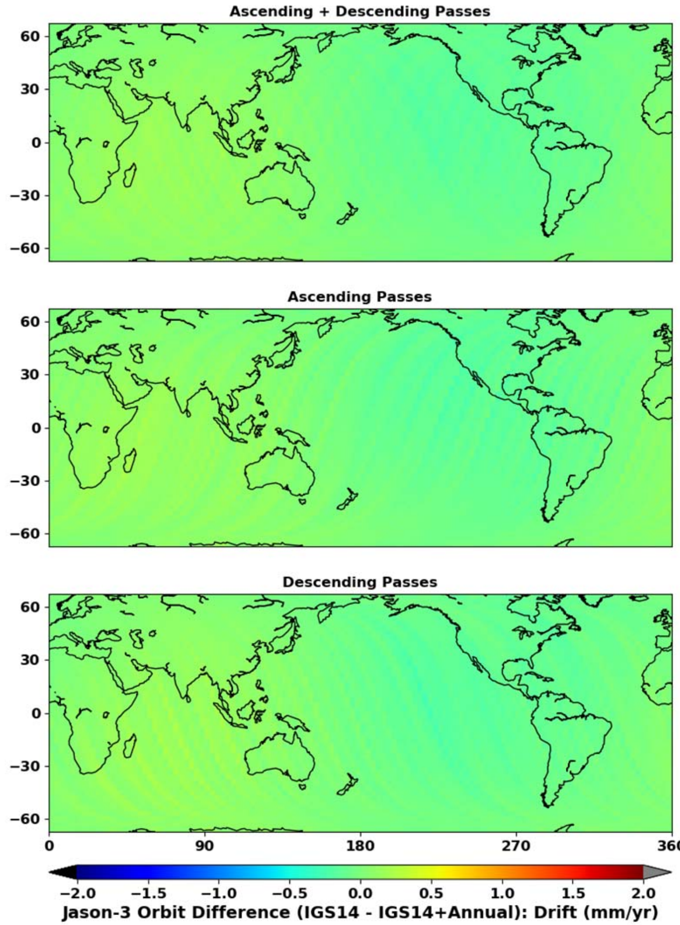
- Large bias and drift in Jason-3 POD solutions using IGS14 and NNR GPS orbits/clocks.
- Negligible bias and drift in differences between Jason-3 orbits solutions using IGS14 and IGS14+Annual GPS orbits/clocks.

Geographically Correlated Radial Orbit Differences: IGS14-IGS14+Annual Bias and Drift

IGS14 – IGS14+Annual: Bias



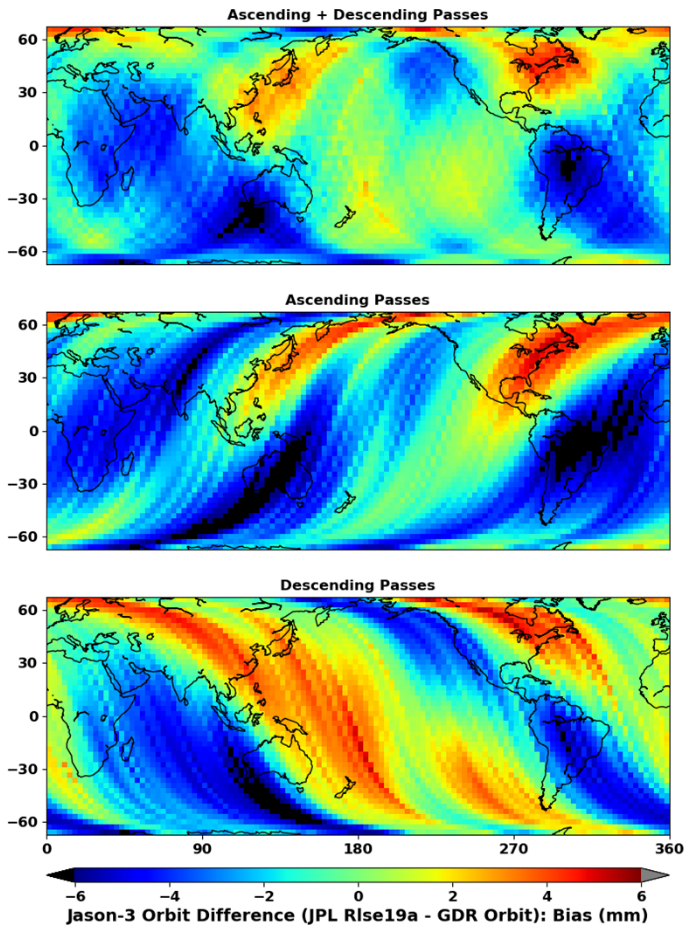
IGS14 – IGS14+Annual: Drift



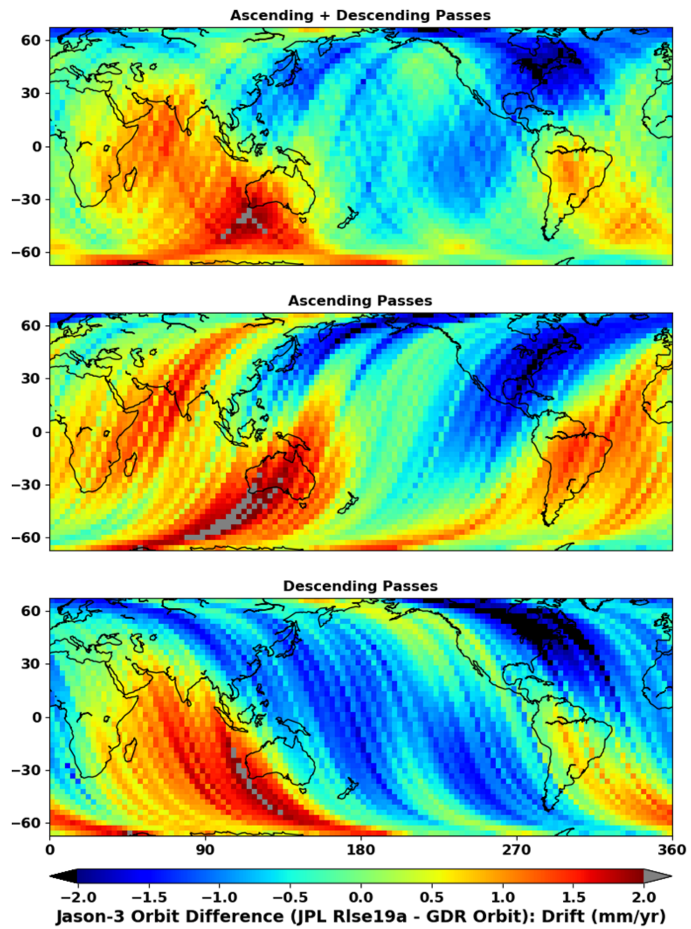
- Negligible bias and drift in differences between Jason-3 orbits solutions using IGS14 and IGS14+Annual GPS orbits/clocks.

Geographically Correlated Radial Orbit Differences: JPL Rlse19a – GDR Orbit: Bias and Drift

Bias

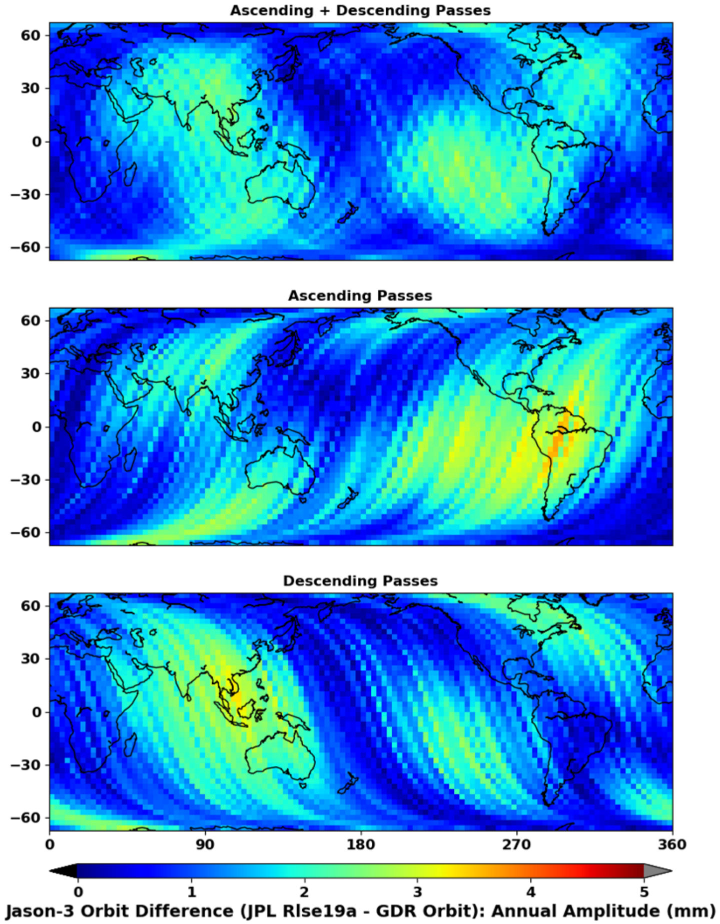


Drift

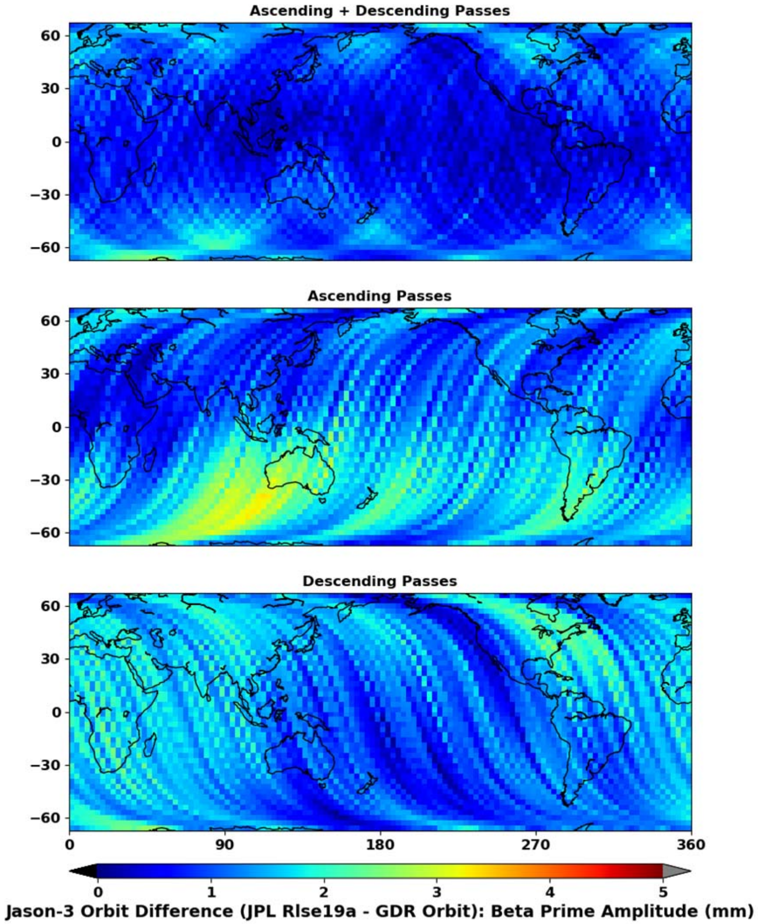


Geographically Correlated Radial Orbit Differences: JPL Rlse19a – GDR Orbit: Annual and Beta Prime

Annual



Beta Prime



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