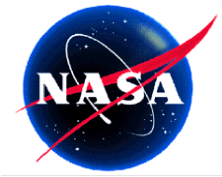

Evaluation of the Use of High Rate Tracking Data for Jason-3 GPS-Based Precise Orbit Determination

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Introduction

- Jason-3 GPS receiver provides tracking data every 10 seconds.
- Heritage JPL GPS POD approach:
  - 5-minute sampled LC and carrier-smoothed PC data.
  - Assumed superior accuracy of JPL's 5-minute clock bias estimates for GPS constellation.
  - Somewhat also related to computational efficiency.
- Evaluate use of higher rate data:
  - 30-second sampled LC and carrier-smoothed PC data.
  - Use JPL's 30-second clock bias estimates for GPS constellation.
  - Consider elevation-dependent data weights.
- Consider internal and external metrics:
  - Orbit differences
  - Post-fit residuals
  - Orbit precision as measured by day-to-day orbit overlaps.
  - Withheld SLR tracking data residuals

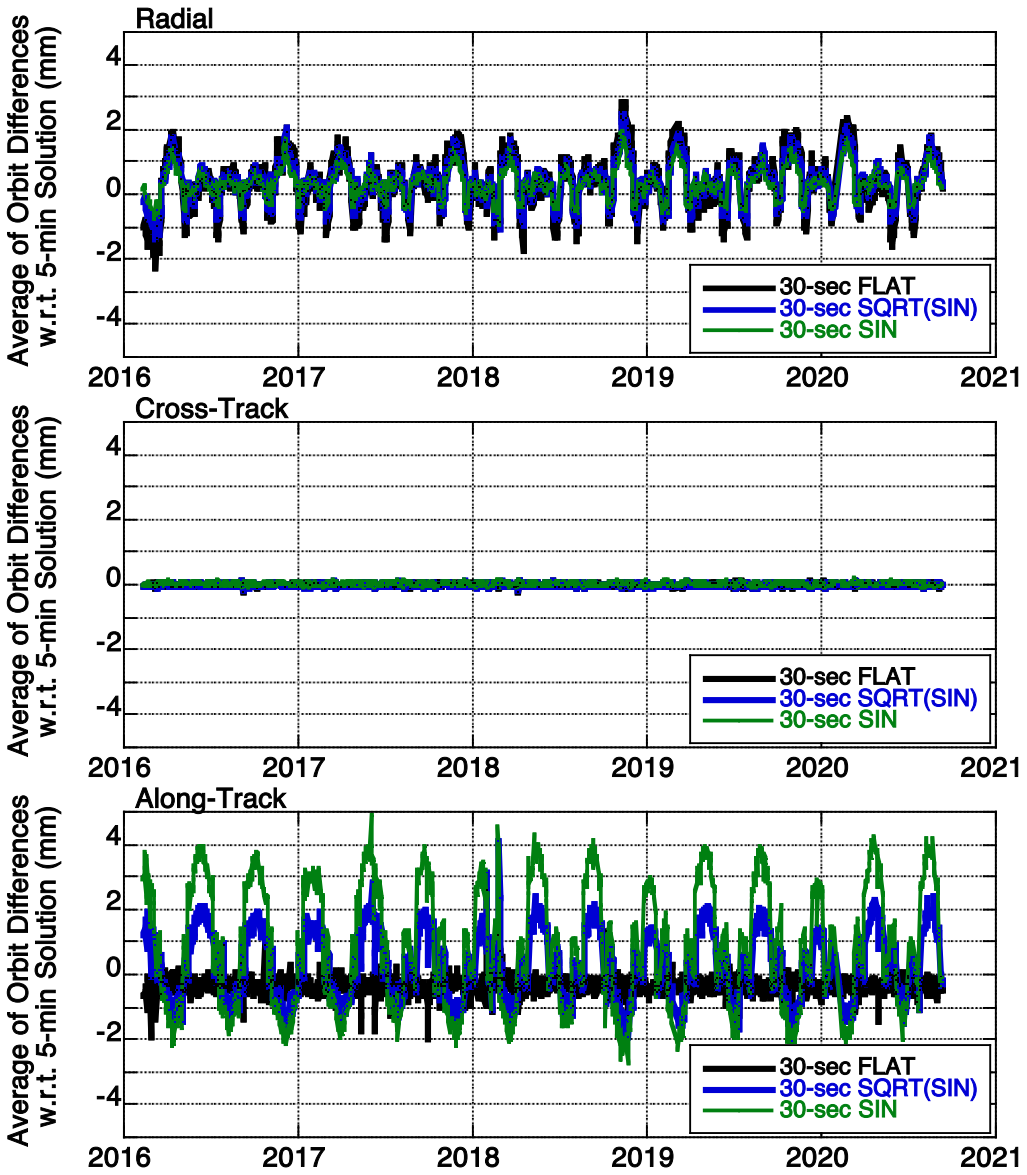
POD Strategy

- Reference solution (**5-min**):
  - 5-minute LC and PC data.
  - 5-minute JPL IGS14 fiducial-fixed GPS orbit/clock products.
- High-rate solutions:
  - 30-second LC and PC data.
  - 30-second JPL IGS14 fiducial-fixed GPS orbit/clock products.
  - Consider solutions with 3 data weights:
    - **30-sec FLAT**: Equal
    - **30-sec SQRT(SIN):** 1/sqrt(sin(elevation))
    - **30-sec SIN**: 1/sin(elevation)
- Intentionally maintain identical relative LC/PC data weights of 1/100 cm as compromise approach given observed post-fit residuals.
  - Future work to investigate alternative relative weights.
- Apply self-consistent antenna calibrations.
  - Generated using same data rate, GPS orbits/clocks, and data weights as used in final POD solutions.

JPL Release 2020a

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** **(2016-02-13 to 2020-09-12)**

Average of Daily Orbit Differences

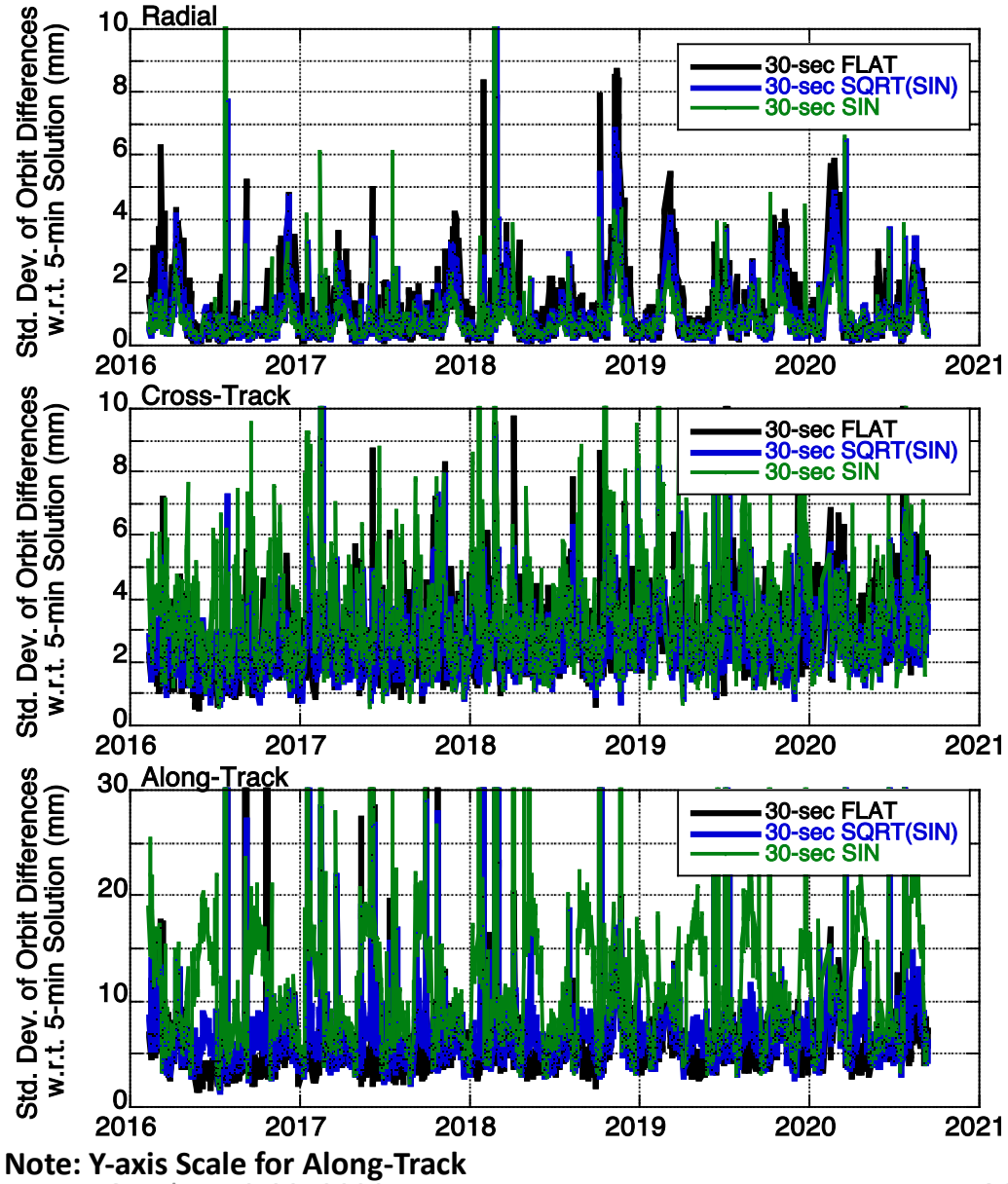


Average from 2016-2020

	FLAT	SQRT(SIN)	SIN
H (mm)	0.4	0.4	0.3
C (mm)	0.0	0.0	0.0
L (mm)	-0.3	0.3	0.8

- 3 mm peak-to-peak 60-day signal in radial orbit differences of 30-sec vs. 5-min solutions.
- Up to 6 mm peak-to-peak orbit differences in along track component arise from elevation-dependent weights.
  - Elevation dependent weighting introduces < 1 mm bias.

Standard Deviation of Daily Orbit Differences



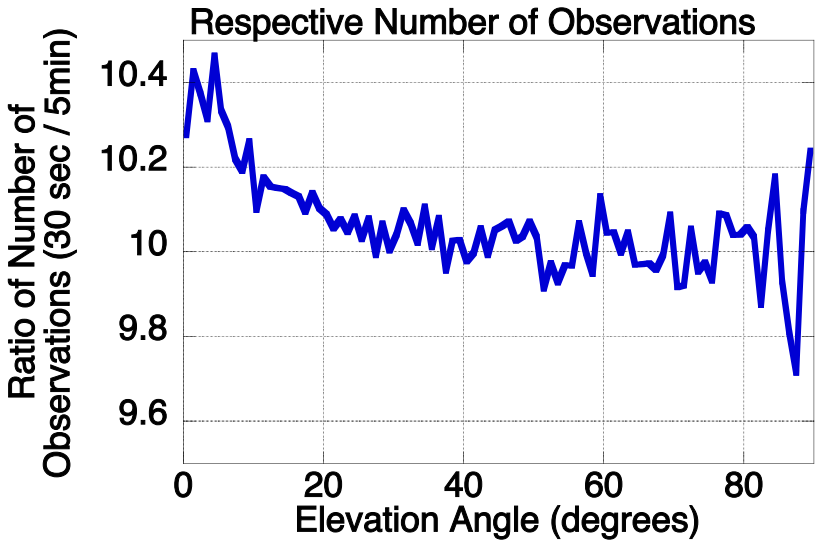
Note: Y-axis Scale for Along-Track

Median from 2016-2020

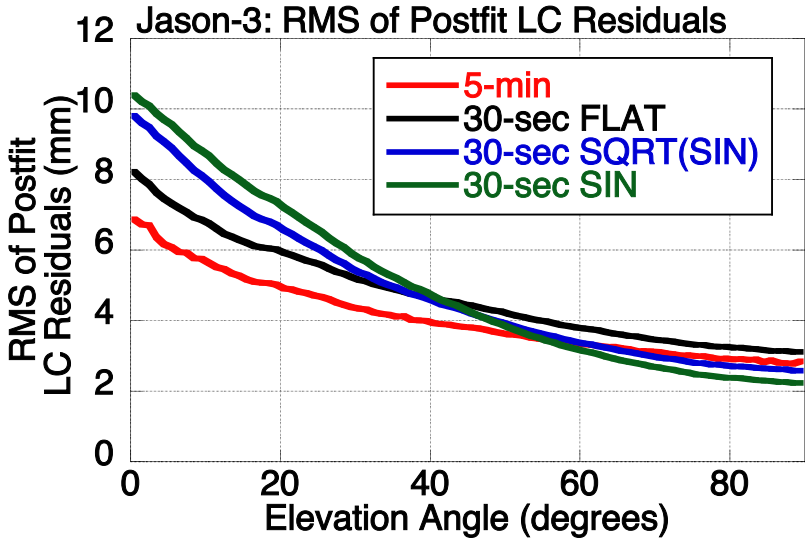
	FLAT	SQRT(SIN)	SIN
H (mm)	0.8	0.7	0.6
C (mm)	2.6	2.4	3.0
L (mm)	1.3	2.4	4.6

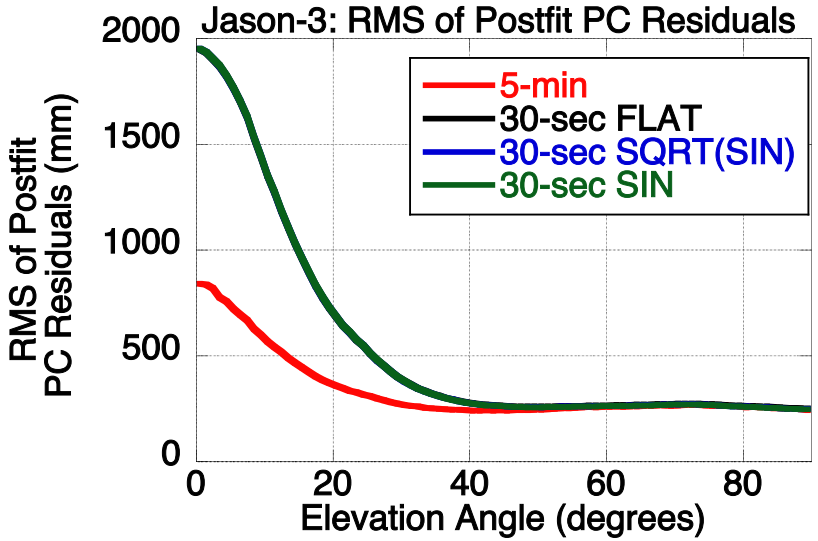
- Radial orbit differences typically < 5 mm (1-sigma).
- Along-track differences amplified when using elevation-dependent weighting.

Post-fit Residuals By Elevation Angle

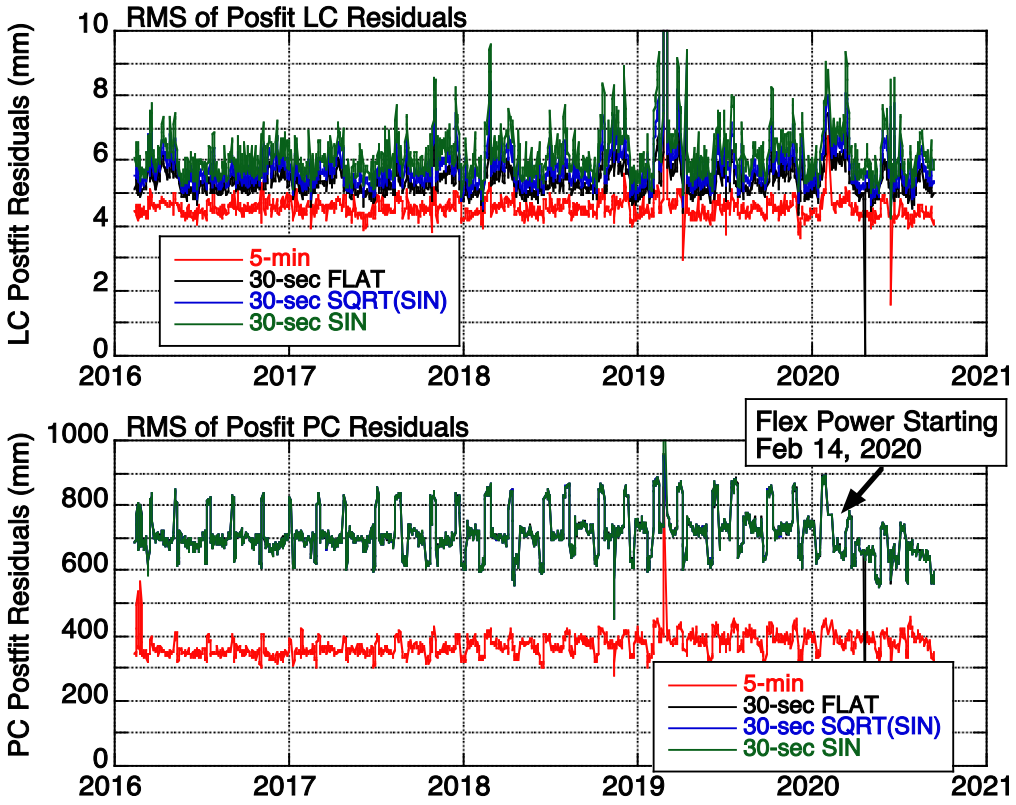


- Expected factor of 10 increase in number of observations from 5-min to 30-sec data.
  - Slightly larger than 10x below 25 degrees likely due 30-sec data effectively enabling lengthening of effective track.
- Expected higher data noise at lower elevations supports elevation-dependent data weighting.
  - Expected increase in elevation dependence when applying elevation dependent data weights.
- Shorter duration carrier-aided smoothing appears to only impact PC data < 40 degrees.
- Higher LC residuals for 30-sec FLAT vs. 5-min suggests slight degradation of 30-sec GPS clock bias estimates.





Temporal Variation of Postfit Residuals

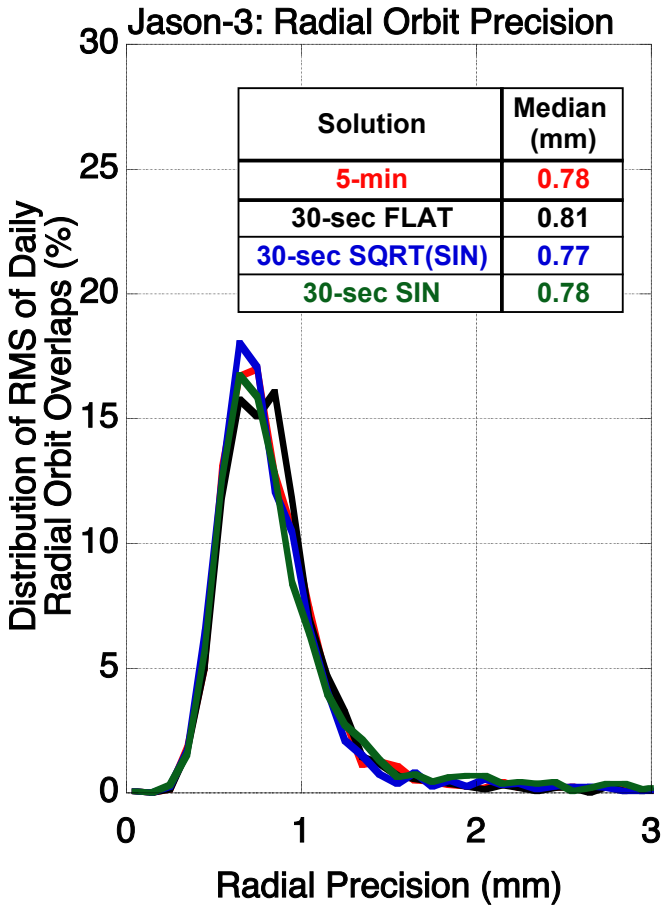


Median from 2016-2020

	LC (mm)	PC (mm)
5-min	4.5	366
30-sec FLAT	5.4	704
30-sec SQRT(SIN)	5.6	703
30-sec SIN	6.0	703

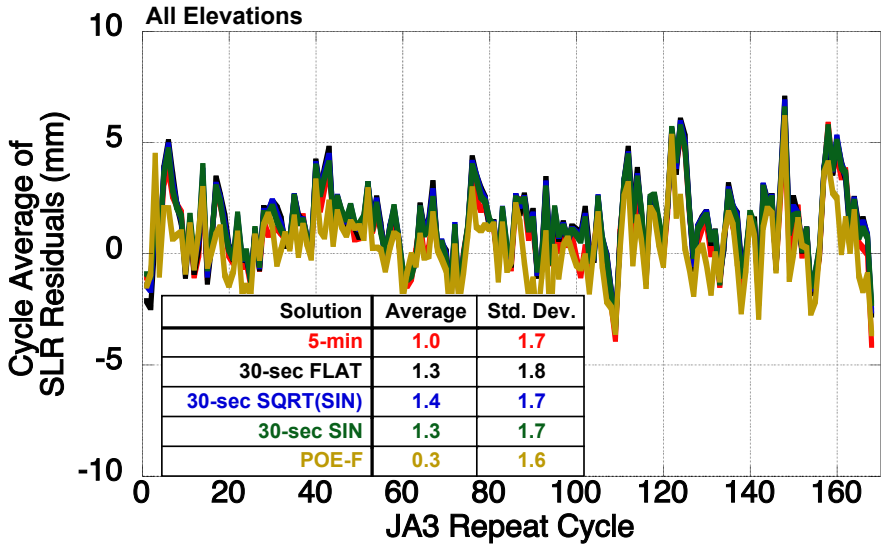
- ~25% increase in phase (LC) residuals when using 30-sec data.
  - Evidence of degradation from 30-sec GPS clock bias estimates vs. 300 sec.
- Factor of 2 increase in range (PC) residuals when using 30-sec data.
- Impact of elevation-dependent weighting distinct in LC but not PC residuals.
- 30-second PC residuals reveal:
  - Amplified yaw state dependence.
    - Yaw state effects in 5-min and 30-sec solutions not related to sampling.
      - Persist when enforcing 15 degree elevation cutoff.
    - Possible thermal effects?
  - Lower residuals after start of Flex Power GPS transmissions starting Feb 14, 2020.

Orbit Precision
(as measured by orbit overlaps)

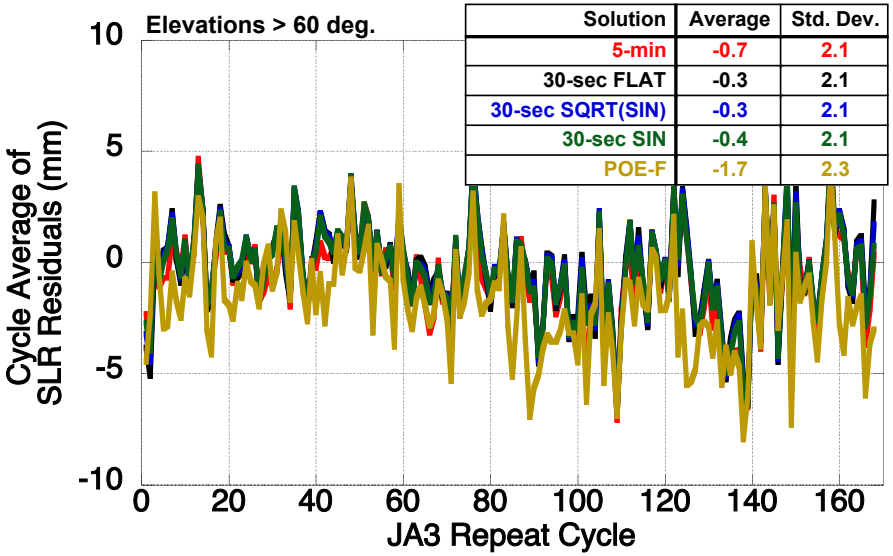


- Orbit precision computed using RMS of differences during middle 5 hours of 6-hour overlap of daily 30-hour solutions.
- High rate data has negligible impact on orbit precision.
  - Likely due to POD approach having only mild stochastic parametrization.
  - Very slight benefit from 30-second data with SQRT(SIN) weighting.

Cycle Averages of SLR Residuals



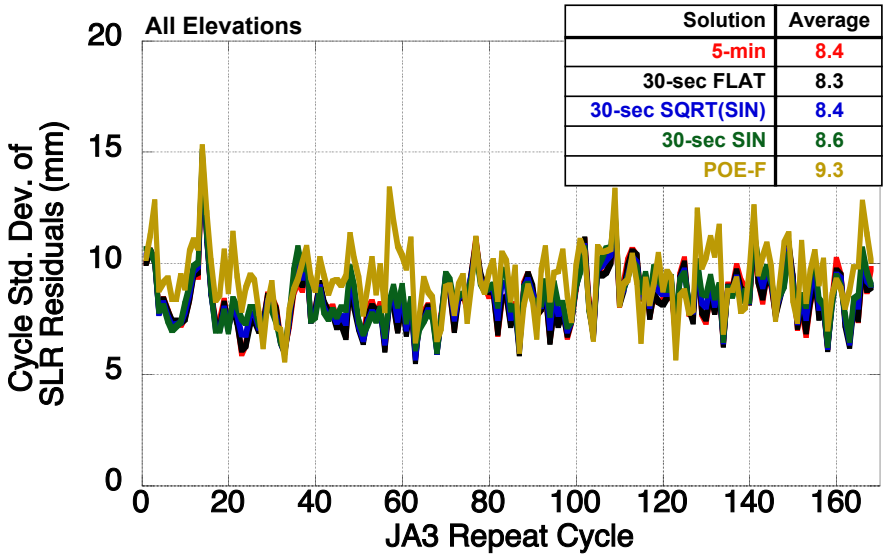
Solution	Average	Std. Dev.
5-min	1.0	1.7
30-sec FLAT	1.3	1.8
30-sec SQRT(SIN)	1.4	1.7
30-sec SIN	1.3	1.7
POE-F	0.3	1.6

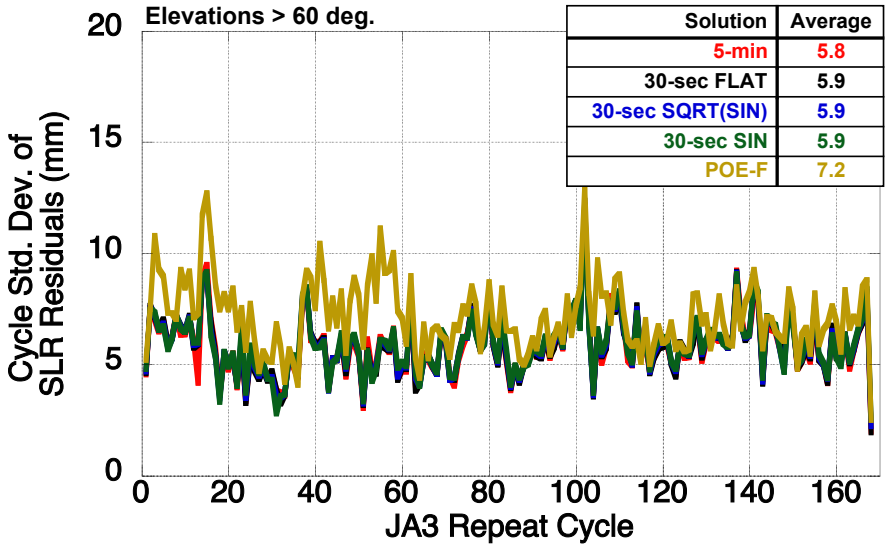


Solution	Average	Std. Dev.
5-min	-0.7	2.1
30-sec FLAT	-0.3	2.1
30-sec SQRT(SIN)	-0.3	2.1
30-sec SIN	-0.4	2.1
POE-F	-1.7	2.3

- Similar results from all GPS-only solutions.
- POE-F closer to zero-average when using all elevations, but further from zero when using high-elevation data.
- SLR stations used in this presentation limited to 6 best performing stations.
  - See backup slides.

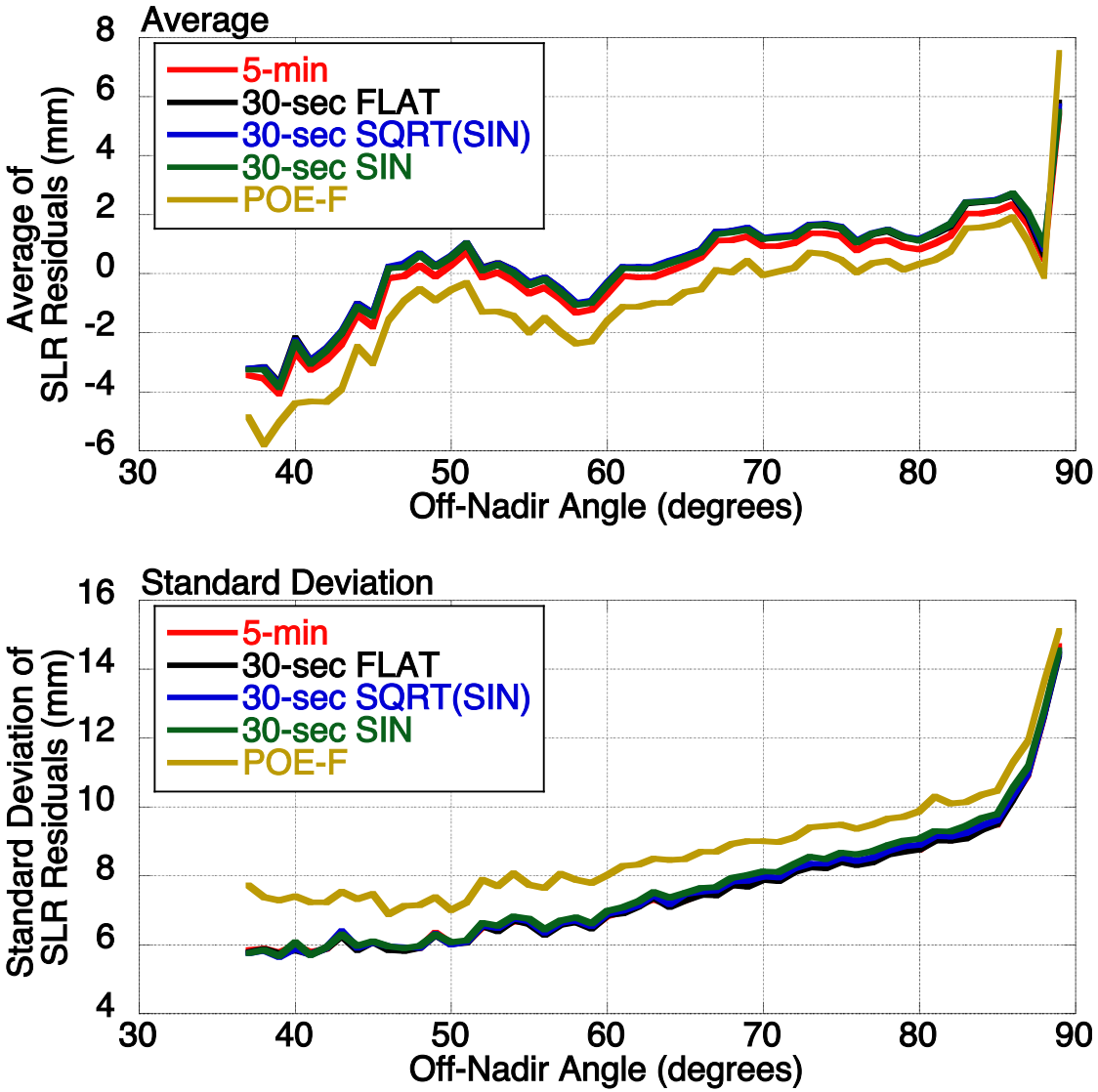
Cycle Standard Deviation of SLR Residuals





- Similar performance of all solutions GPS-only solutions.
- GPS-only solutions have SLR residuals < 6 mm at high elevations.
  - Strong indicator of upper limit in radial orbit accuracy.
- POE-F has higher SLR residuals when using all elevations and limiting to high elevations.

Elevation Dependence of SLR Residuals



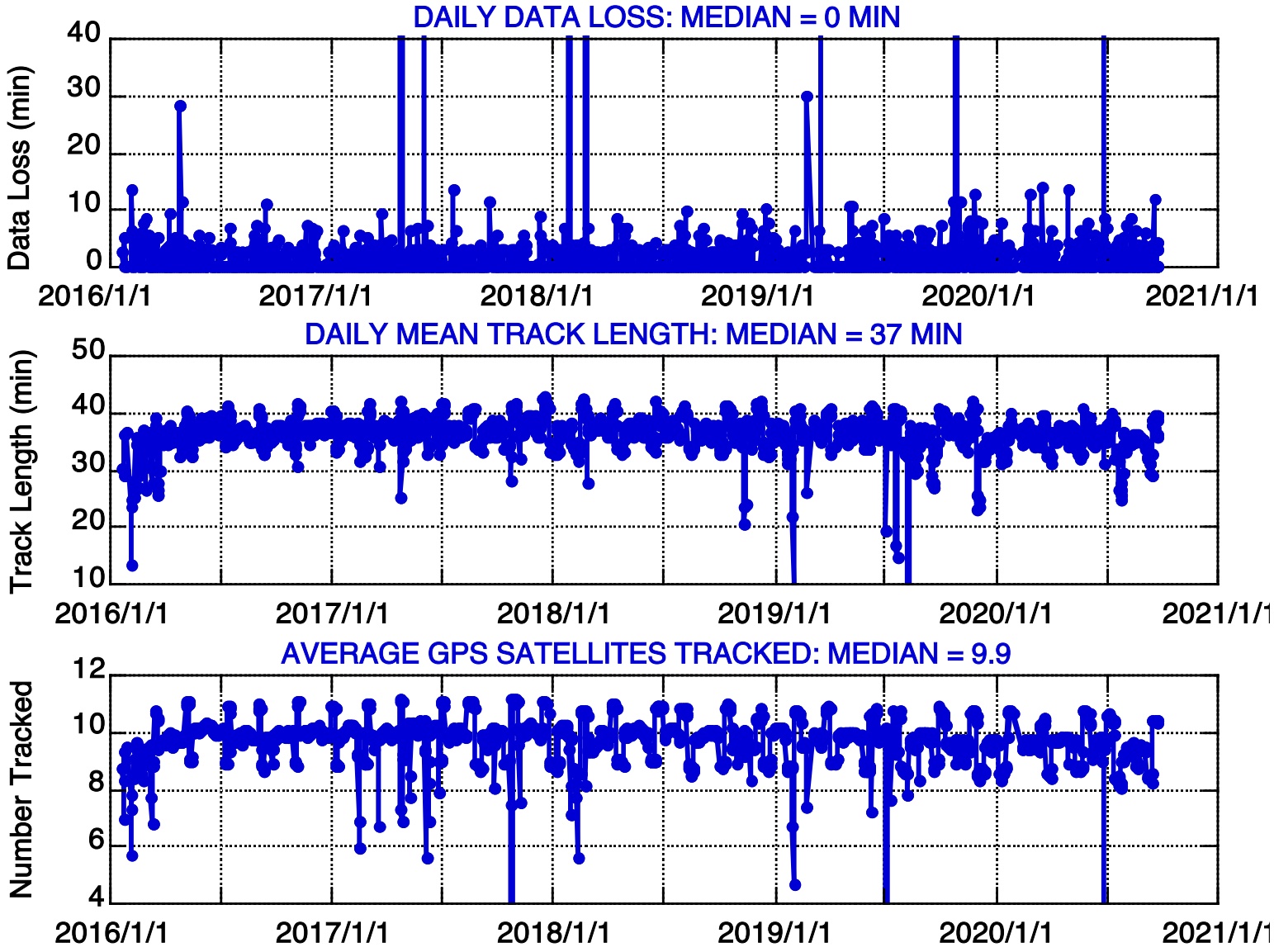
- Similar performance of all GPS-only solutions.
  - 30-sec solutions biased higher than 5-min solutions by ~0.3 mm.
    - Consistent with orbit differences.
- GPS-only solutions biased higher than POE-F by 0.9 mm.
- GPS-only solutions have lower standard deviation than POE-F at all elevations.

Conclusions

- **30-second versus 5-min GPS tracking data does not provide noticeable benefits to Jason-3 GPS-based POD.**
  - As indicated by orbit precision (overlaps) and withheld SLR tracking data.
    - 30-second data with 1/sqrt(sin(elevation)) data weight shows very small improvement in radial orbit precision.
  - Future work to consider down-weighting PC data by factor of 2 to account for higher data noise with 30-second data.
  - Future work to evaluate crossover variance as additional independent metric.
  - 3 mm peak-to-peak 60-day signal in radial orbit differences from 30-second versus 5-minute data.
- 30-second data amplifies 60-day dependence of PC postfit residuals.
  - Might these be associated with thermal effects?
- Up to 6 mm peak-to-peak 60-day signal in along-track component introduced when applying elevation-dependent weighting.
- Withheld SLR residuals suggest GPS-only solutions have radial orbit accuracy of < 6 mm.

Backup

Tracking Metrics for Jason-3 GPS Receiver



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.