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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit Arc</td>
<td>30-hours (daily)</td>
</tr>
<tr>
<td>Gravity Field</td>
<td>EIGEN-GRGS.RL04 (linear mean pole, degree 1 = 0)</td>
</tr>
<tr>
<td>AOD</td>
<td>Release 6</td>
</tr>
<tr>
<td>Ocean Tide Model</td>
<td>GOT4.8ac</td>
</tr>
<tr>
<td>Pole Tide Model</td>
<td>IERS 2010 (linear mean pole)</td>
</tr>
<tr>
<td>Attitude</td>
<td>Quaternions</td>
</tr>
<tr>
<td>Solar Panel Orientation</td>
<td>Reported Values</td>
</tr>
<tr>
<td>GPS Orbits/Clocks</td>
<td>JPL Finals IGS14 (Fiducial Fixed)</td>
</tr>
<tr>
<td>Data Weights</td>
<td>1 cm LC, 100 cm PC</td>
</tr>
<tr>
<td>Elevation Angle Cutoff</td>
<td>0 degrees</td>
</tr>
<tr>
<td>Minimum Track Length</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Antenna Calibration</td>
<td>Updated In-Flight Calibration (2016-02-13 to 2020-09-12)</td>
</tr>
</tbody>
</table>
### Average of Daily Orbit Differences

- **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.

### Average from 2016-2020

<table>
<thead>
<tr>
<th></th>
<th>FLAT</th>
<th>SQRT(SIN)</th>
<th>SIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>H (mm)</td>
<td>0.4</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>C (mm)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>L (mm)</td>
<td>-0.3</td>
<td>0.3</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Standard Deviation of Daily Orbit Differences

Note: Y-axis Scale for Along-Track

October 19-23, 2020

Median from 2016-2020

<table>
<thead>
<tr>
<th></th>
<th>FLAT</th>
<th>SQRT(SIN)</th>
<th>SIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>H (mm)</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>C (mm)</td>
<td>2.6</td>
<td>2.4</td>
<td>3.0</td>
</tr>
<tr>
<td>L (mm)</td>
<td>1.3</td>
<td>2.4</td>
<td>4.6</td>
</tr>
</tbody>
</table>

• 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 to 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

- ~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?

### Median from 2016-2020

<table>
<thead>
<tr>
<th></th>
<th>LC (mm)</th>
<th>PC (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-min</td>
<td>4.5</td>
<td>366</td>
</tr>
<tr>
<td>30-sec FLAT</td>
<td>5.4</td>
<td>704</td>
</tr>
<tr>
<td>30-sec SQRT(SIN)</td>
<td>5.6</td>
<td>703</td>
</tr>
<tr>
<td>30-sec SIN</td>
<td>6.0</td>
<td>703</td>
</tr>
</tbody>
</table>
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

- 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.
• 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.
Tracking Metrics for Jason-3 GPS Receiver

- **DAILY DATA LOSS:** Median = 0 min
- **DAILY MEAN TRACK LENGTH:** Median = 37 min
- **AVERAGE GPS SATELLITES TRACKED:** Median = 9.9
List of SLR Stations Used in This Study

<table>
<thead>
<tr>
<th>Station ID</th>
<th>Station Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>7090</td>
<td>Yarragadee, Australia</td>
</tr>
<tr>
<td>7105</td>
<td>Greenbelt</td>
</tr>
<tr>
<td>7810</td>
<td>Zimmerwald, Switzerland</td>
</tr>
<tr>
<td>7825</td>
<td>Mt Stromlo, Australia</td>
</tr>
<tr>
<td>7839</td>
<td>Graz, Austria</td>
</tr>
<tr>
<td>7840</td>
<td>Herstmonceux, United Kingdom</td>
</tr>
</tbody>
</table>

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