Improved orbit time series for the TOPEX & Jason missions from 1992-2020

F.G. Lemoine¹, N.P. Zelensky², B.D. Beckley³, D.S. Chinn³, A. Belli⁴, D.E. Pavlis²

(1) NASA GSFC, Greenbelt, Maryland, USA
(2) ESSIC, University of Maryland, College Park, Maryland, U.S.A.
(3) KBR Inc., Greenbelt, Maryland, USA
(4) NPP/USRA @ NASA GSFC, Greenbelt, Maryland, USA
New TOPEX & Jason 1-3 Orbits

Summary:

Orbits based on updated standards and a complete reprocessing were delivered to the NASA MeaSUREs (Integrated Multi-Mission Ocean Altimeter Data for Climate Research (MEaSUREs-SSH, https://podaac.jpl.nasa.gov/MEaSUREs-SSH). These orbits (std2006) are available for other users of the OSTST and will be distributed through the NASA GSFC NCCS dataportal. The standards used (based on ITRF2014 and implementing other improvements) represent refinements of the preliminary orbits we delivered in 2019 (std1808a) and tvg0012. This delivery to MEaSUREs updates the previous delivery (std1504_dpod2014, Beckley et al. (2017).

Comparisons to independent orbits (CNES/POEF, JPL/Reduced-dynamic orbits) for Jason-3) show RMS radial orbit agreement of 5-7 mm for Jason-3 for these new orbits (std2006), compared to 7-9 mm radial RMS agreement for the std1504_dpod2014 set of orbits.
### GSFC POD Strategy for new orbits

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GEODYN</td>
<td>1612</td>
<td>2002</td>
</tr>
<tr>
<td>gravity</td>
<td>GSFC5x5 model + GOCO02s</td>
<td>new GSFC 5x5 model (tvg0075) + GOCO05s</td>
</tr>
<tr>
<td>atmosphere gravity</td>
<td>ECMWF 50x50, 6-hour</td>
<td>GFZ 90X90 3-hr from ECMWF (cf. GRACE FO, RL06)</td>
</tr>
<tr>
<td>mean pole</td>
<td>IERS2010</td>
<td>IERS2014 (linear)</td>
</tr>
<tr>
<td>integration step size</td>
<td>30 seconds</td>
<td>15 seconds</td>
</tr>
<tr>
<td>Solar Rad. Pressure</td>
<td>old TSI, Cr=0.945</td>
<td>new TSI, tuned SA+, X-, tuned Cr/arc</td>
</tr>
<tr>
<td>DORIS/DPOD2014</td>
<td>Version 0.4, w. updates</td>
<td>Version 4.0</td>
</tr>
<tr>
<td>elev. cutoff (DORIS)</td>
<td>10 deg.</td>
<td>7 deg.</td>
</tr>
<tr>
<td>DORIS data weighting</td>
<td>constant w. elevation</td>
<td>elevation-dependent (J2 &amp; J3)</td>
</tr>
<tr>
<td>SLR/SLRF2014</td>
<td>SLRF2014 w. updates</td>
<td>SLRF2014 (v200428).</td>
</tr>
<tr>
<td>LRA phase center</td>
<td>constant correction</td>
<td>constant + elevation correction.</td>
</tr>
<tr>
<td>SLR Data Handling</td>
<td>gsfc2014(ILRS 2010)</td>
<td>gsfc2020 (from ILRS, 06-16-2020)</td>
</tr>
<tr>
<td>est. C31/S31 per arc</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>OPR parameters</td>
<td>12-hr</td>
<td>24-hr</td>
</tr>
</tbody>
</table>
Why is modelling TVG before 2003 necessary?

Compare Altimeter Crossover variance differences for GOCO5s & a prior model (GOCO2S+old-GSFC5X5) with TVG modelling. Negative differences => improvement for GOCO05s.

Need a separate solution because the GRACE-era rates from 2003-2014, should not be projected backward in time.

Update the previous series (1992-2014, extended) developed as part of ITRF2014 as part of the GSFC IDS/DORIS contribution for ITRF2020.

Use New standards as a priori

• GOCC05s (from GRACE & GOCE) is the general background model. We ignore the GRACE-derived linear rates prior to 2003.

• GFZ-provided AOD (RL06) to 90x90 & associated air tides.

• IERS2014 linear mean pole.

• VMF1 for DORIS Troposphere correction.

• New ILRS-supplied SLR/CoM corrections (Rodriguez et al., 2019, J Geodesy).

• Bi-weekly instead of weekly solutions.

New TVG solution: tvg0075

The idea is to provide a consistent background geophysical model from 1992 to 2020.
New bi-weekly SLR+DORIS 17-satellite Gravity solutions (2)

New bi-weekly SLR+DORIS 17-satellite Gravity solutions (2)

New bi-weekly SLR+DORIS 17-satellite Gravity solutions (3)

TOPEX/Poseidon (TP) test summary
1992-11-01 to 2004-10-02 (cycles 5-446)

### Residuals computed with External Ephemeris (cycles 5-446)

<table>
<thead>
<tr>
<th>SLR+DORIS Orbits</th>
<th>DORIS (mm/s)</th>
<th>SLR (cm)</th>
<th>Xover (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>std1504_dpod2014</td>
<td>0.5078</td>
<td>1.659</td>
<td>5.609</td>
</tr>
<tr>
<td>std2006</td>
<td>0.5070</td>
<td>1.769</td>
<td>5.610</td>
</tr>
</tbody>
</table>

### RMS orbit differences (std2006-Test) (cycles 5-446)

<table>
<thead>
<tr>
<th>Test Orbits</th>
<th>Radial (mm)</th>
<th>Cross-trk (mm)</th>
<th>Along-trk (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>std1504_dpod2014</td>
<td>4.8</td>
<td>26.4</td>
<td>26.0</td>
</tr>
</tbody>
</table>
### Jason-1 (J1) Residual summary
**2002-01-15 to 2009-01-26 (cycles 1-259)**

<table>
<thead>
<tr>
<th>Residuals computed with External Ephemeris</th>
<th>DORIS (mm/s)</th>
<th>SLR (cm)</th>
<th>Xover (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLR+DORIS Orbits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>std1504_dpod2014</td>
<td>0.3826</td>
<td>0.933</td>
<td>5.507</td>
</tr>
<tr>
<td>std1808a (GOCO05s)</td>
<td>0.3825</td>
<td>1.046</td>
<td>5.482</td>
</tr>
<tr>
<td>std2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPR 12hr</td>
<td>0.3825</td>
<td>1.148</td>
<td>5.480</td>
</tr>
<tr>
<td>OPR 24hr</td>
<td>0.3822</td>
<td>1.204</td>
<td>5.482</td>
</tr>
</tbody>
</table>
# Jason-1 (J1) Orbit Difference summary
2002-01-15 to 2009-01-26 (cycles 1-259)

## RMS orbit differences (jpl11a-Test) cycles 9-162

<table>
<thead>
<tr>
<th>Test Orbit</th>
<th>Radial (mm)</th>
<th>Cross-trk (mm)</th>
<th>Along-trk (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>std1504_dpod2014</td>
<td>8.4</td>
<td>26.5</td>
<td>30.5</td>
</tr>
<tr>
<td>std1808a (GOCO05s)</td>
<td>7.9</td>
<td>26.4</td>
<td>27.0</td>
</tr>
<tr>
<td>std2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12hr OPR</td>
<td>7.8</td>
<td>26.0</td>
<td>26.0</td>
</tr>
<tr>
<td>24hr OPR</td>
<td>8.2</td>
<td>22.6</td>
<td>26.8</td>
</tr>
</tbody>
</table>

## RMS orbit differences (std2006(24hr OPR)-Test) cycles 1-259

<table>
<thead>
<tr>
<th>Test Orbit</th>
<th>Radial (mm)</th>
<th>Cross-trk (mm)</th>
<th>Along-trk (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>std1504_dpod2014</td>
<td>7.3</td>
<td>21.5</td>
<td>24.8</td>
</tr>
<tr>
<td>std1808a (GOCO05s)</td>
<td>6.3</td>
<td>20.2</td>
<td>18.9</td>
</tr>
<tr>
<td>std2006 (12-hr OPR)</td>
<td>5.0</td>
<td>15.3</td>
<td>12.9</td>
</tr>
<tr>
<td>GDRE (CNES)</td>
<td>8.0</td>
<td>25.0</td>
<td>31.4</td>
</tr>
</tbody>
</table>
## Jason-2 (J2) Residual summary

**2008-01-15 to 2016-10-02 (cycles 1-303)**

<table>
<thead>
<tr>
<th>SLR+DORIS Orbits</th>
<th>DORIS (mm/s)</th>
<th>SLR (cm)</th>
<th>Xover (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>std1504_dpod2014</strong></td>
<td>0.3829</td>
<td>1.021</td>
<td>5.312</td>
</tr>
<tr>
<td>std1808a (GOCO05s)</td>
<td>0.3895</td>
<td>1.150</td>
<td>5.285</td>
</tr>
<tr>
<td><strong>std2006</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12hr OPR</td>
<td>0.3894</td>
<td>1.164</td>
<td>5.280</td>
</tr>
<tr>
<td>24hr OPR</td>
<td>0.3896</td>
<td>1.205</td>
<td>5.285</td>
</tr>
<tr>
<td>GDRE</td>
<td>0.3826</td>
<td>1.202</td>
<td>5.237</td>
</tr>
<tr>
<td>jpl18a</td>
<td>0.3907</td>
<td>1.220</td>
<td>5.236</td>
</tr>
</tbody>
</table>

Residuals computed with External Ephemeris

### Jason-2 (J2) Orbit Difference summary
2008-01-15 to 2016-10-02 (cycles 1-303)

<table>
<thead>
<tr>
<th>Test Orbit</th>
<th>Radial (mm)</th>
<th>Cross-trk (mm)</th>
<th>Along-trk (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS orbit differences (jpl18a-Test) cycles 1-303</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>std1504_dpod2014</td>
<td>7.1</td>
<td>24.3</td>
<td>29.3</td>
</tr>
<tr>
<td>std1808a (GOCO05s)</td>
<td>5.9</td>
<td>21.7</td>
<td>24.1</td>
</tr>
<tr>
<td>std2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12hr OPR</td>
<td>5.4</td>
<td>22.7</td>
<td>23.0</td>
</tr>
<tr>
<td>24hr OPR</td>
<td>6.0</td>
<td>21.5</td>
<td>24.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Orbit</th>
<th>Radial (mm)</th>
<th>Cross-trk (mm)</th>
<th>Along-trk (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS orbit differences (std2006(24hr OPR)-Test) cycles 1-303</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>std1504_dpod2014</td>
<td>6.2</td>
<td>18.8</td>
<td>22.0</td>
</tr>
<tr>
<td>std1808a (GOCO05s)</td>
<td>5.0</td>
<td>15.2</td>
<td>14.8</td>
</tr>
<tr>
<td>std2006 (12hr OPR)</td>
<td>3.8</td>
<td>11.8</td>
<td>9.6</td>
</tr>
<tr>
<td>gdre (CNES)</td>
<td>6.2</td>
<td>17.6</td>
<td>23.2</td>
</tr>
</tbody>
</table>
# Jason-3 (J3) Residual summary
2016-02-17 to 2019-08-09 (cycles 1-128)

<table>
<thead>
<tr>
<th>Residuals computed with External Ephemeris</th>
<th>DORIS (mm/s)</th>
<th>SLR (cm)</th>
<th>Xover (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLR+DORIS Orbits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><code>std1504_dpod2014</code></td>
<td>0.4197</td>
<td>1.144</td>
<td>5.357</td>
</tr>
<tr>
<td><code>std1808a (GOCO05s)</code></td>
<td>0.4195</td>
<td>1.196</td>
<td>5.302</td>
</tr>
<tr>
<td><code>std2006</code></td>
<td><strong>0.4192</strong></td>
<td><strong>1.092</strong></td>
<td><strong>5.280</strong></td>
</tr>
<tr>
<td><code>jpl19a</code></td>
<td>0.4197</td>
<td>1.181</td>
<td>5.261</td>
</tr>
</tbody>
</table>

### Jason-3 (J3) Orbit Difference summary
**2016-02-17 to 2020-04-23 (cycles 1-154)**

#### RMS orbit differences (jpl19a-Test) cycles 1-154

<table>
<thead>
<tr>
<th>Test Orbit</th>
<th>Radial (mm)</th>
<th>Cross-trk (mm)</th>
<th>Along-trk (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>std1504_dpod2014</td>
<td>7.9</td>
<td>29.8</td>
<td>31.8</td>
</tr>
<tr>
<td>std1808a (GOCO05s)</td>
<td>6.2</td>
<td>21.4</td>
<td>24.8</td>
</tr>
<tr>
<td>std2006</td>
<td>5.6</td>
<td>19.5</td>
<td>22.6</td>
</tr>
<tr>
<td>POEF (CNES)</td>
<td>3.8</td>
<td>6.3</td>
<td>8.7</td>
</tr>
</tbody>
</table>

#### RMS orbit differences (std2006-Test) cycles 1-154

<table>
<thead>
<tr>
<th>Test Orbit</th>
<th>Radial (mm)</th>
<th>Cross-trk (mm)</th>
<th>Along-trk (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>std1504_dpod2014</td>
<td>7.7</td>
<td>33.0</td>
<td>26.7</td>
</tr>
<tr>
<td>std1808a (GOCO05s)</td>
<td>4.3</td>
<td>18.6</td>
<td>15.7</td>
</tr>
<tr>
<td>POEF (CNES)</td>
<td>6.3</td>
<td>25.4</td>
<td>26.9</td>
</tr>
<tr>
<td>std2006 (DORIS equal wt)</td>
<td>1.3</td>
<td>4.9</td>
<td>4.8</td>
</tr>
</tbody>
</table>
The previous (std1504_dpod2014) orbits showed an RMS radial agreement with the CNES/POEF of 7-9 mm, whereas the new orbits (std2006) show agreement at 5-7 mm radial RMS.
SSH differences for MEAsURES altimetry using the std2006 orbits over the tandem orbit periods: (TOPEX/Jason1 & Jason1/Jason2)

SSH differences for MEAsURES altimetry using the std2006 orbits over the tandem orbit periods: (Jason2/Jason3)

std1504_dpod2014 (previous)
std2006 (new)

Mean = -29.3 mm
Sdev = 1.1 mm

Mean = -29.0 mm
Sdev = 1.0 mm
Tide gauge comparison with MEaSUREs altimetry using the new std2006 orbits: Tide gauge distribution

Tide gauge comparisons by Gary Mitchum, Univ. S. Florida.
Tide gauge comparison with MEaSUREs altimetry using the new std2006 orbits (TOPEX & Jasons 1-3):
Altimeter – Tide Gauge residuals

Altimetry - Tide Gauge rate = -0.03 +/- 0.4 mm/y
Standard deviation = 4.2 mm

Tide gauge comparisons by Gary Mitchum, Univ. S. Florida.

Summary

(1) We have produced a new series of SLR+DORIS "dynamic" orbits (std2006) based on a newer GRACE+GOCE-based gravity model, more detailed modelling of Time-variable gravity (biweekly 5x5), application of the IERS2014 linear mean pole, improved SRP modeling and other change.

(2) The new orbit series (std2006) is improvement over the previous series (std1504_dpod2014). The ensemble of orbit tests and comparisons (GSFC, JPL, CNES) allow us to assert that the radial orbit error on Jason-2, Jason-3 are now at the level of 6-7 mm radial RMS.

Future work:
(1) The std2006 orbits will be made available through the NASA GSFC NCCS dataportal, and possible other sources (such as the data centers of the International DORIS Service).
(2) A manuscript is in preparation to summarize the work that has been accomplished.