Status DORIS Rinex Processing at GSFC

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Outline

• Status Preliminary DORIS Rinex (Pandor) Processing (CDDIS import)
  • Jason-2 (to Sep 2016)
  • Jason-3 (to Sep 2016, operational)
  • SARAL (to Jan 2016)
  • Cryosat-2 (to Jan 2016)
  • HY2A (to Jan 2016)

• Improvements to DORIS Rinex Processing
  • Jason-2 Belli USO frequency correction tests
  • Relativity (included in operational processing)
Jason-2 DORIS Residuals (mm/s) 080712-160831 (cycles 1-300a)
DORIS residuals binned by elevation angle
(Jason2 - Jason3 Inter-comparison Period)
# Jason-2 GSFC std1504-based orbit performance 080712-160831 (cycles 1-300a)

<table>
<thead>
<tr>
<th>Test SLR+DORIS orbits</th>
<th>DORIS points</th>
<th>SLR points</th>
<th>DORIS RMS (mm/s)</th>
<th>SLR RMS (cm)</th>
<th>Xover RMS (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>std1504</td>
<td>162513</td>
<td>4109</td>
<td>0.3810</td>
<td>0.877</td>
<td>5.325</td>
</tr>
<tr>
<td>std1504_rx (DORIS Rinex)</td>
<td>171739</td>
<td>4210</td>
<td>0.4113</td>
<td>0.901</td>
<td>5.322</td>
</tr>
</tbody>
</table>

* independent altimeter GDR data cycles 1-297

[Graph showing Jason-2 Radial RMS orbit differences (mm) cycles 1-300a]

10/31/16
### SARAL std1504-based orbit performance

<table>
<thead>
<tr>
<th>Test</th>
<th>DORIS Points</th>
<th>SLR Points</th>
<th>DORIS RMS (mm/s)</th>
<th>SLR RMS (cm)</th>
<th>Xover RMS (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLR+DORIS orbits</td>
<td>75120</td>
<td>1063</td>
<td>0.4191</td>
<td>1.517</td>
<td>5.562</td>
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<tr>
<td>std1504</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>std1504_rx (DORIS Rinex)</td>
<td>72086</td>
<td>1063</td>
<td>0.4492</td>
<td>1.571</td>
<td>5.658</td>
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</table>

* independent altimeter GDR data 131117-140809

![SARAL RMS Radial orbit differences (V2-Rinex)](image)
WD25 DORIS-only V2 / Rinex Residuals (mm/s)

Jason-2 DORIS-only Orbit residuals (mm/s)

Cryosat-2 DORIS-only Orbit residuals (mm/s)

SARAL DORIS-only Orbit residuals (mm/s)

HY2A DORIS-only Orbit residuals (mm/s)
WD25 DORIS-only (V2 – Rinex) Radial orbit differences (mm)
# WD25 DORIS-only V2 / Rinex orbit POD Summary

<table>
<thead>
<tr>
<th>Satellite</th>
<th>DORIS data</th>
<th>points</th>
<th>Residual RMS (mm/s)</th>
<th>Radial RMS* difference (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jason-2</td>
<td>V2</td>
<td>113350</td>
<td>0.3736</td>
<td></td>
</tr>
<tr>
<td>080713-160103</td>
<td>Rinex</td>
<td>121945</td>
<td>0.3960</td>
<td>1.8</td>
</tr>
<tr>
<td>SARAL</td>
<td>V2</td>
<td>57246</td>
<td>0.4114</td>
<td>2.0</td>
</tr>
<tr>
<td>130324-160103</td>
<td>Rinex</td>
<td>57141</td>
<td>0.4326</td>
<td></td>
</tr>
<tr>
<td>Cryosat-2</td>
<td>V2</td>
<td>50240</td>
<td>0.4080</td>
<td>3.6</td>
</tr>
<tr>
<td>100606-160103</td>
<td>Rinex</td>
<td>50387</td>
<td>0.4452</td>
<td></td>
</tr>
<tr>
<td>HY2A</td>
<td>V2</td>
<td>66930</td>
<td>0.3986</td>
<td>2.6</td>
</tr>
<tr>
<td>111107-160103</td>
<td>Rinex</td>
<td>68751</td>
<td>0.4271</td>
<td></td>
</tr>
</tbody>
</table>

* orbit difference outliers removed
Improvements to DORIS Rinex Processing
\[ \Delta \text{satellite USO frequency} : 2^{\text{nd}} \text{ order polynomial fit} \]

Rinex frequency offset estimates include satellite clock error and Relativistic bias/drift.
Using T2L2 A. Belli (ASR 2015) has computed USO frequency offset corrections for Jason-2 available on the Internet in hourly and minute series.
External JPL GPS orbit (jpl14a) indicates the Belli minute series offers an improvement over the hourly
POD Test Span: Jan 3 - Mar 23, 2013

Velocity correction = \( \frac{\text{Belli frequency correction}}{F_{2\text{GHz}}} \) * c
POD Performance: Belli -vs- Rinex USO corr. negative residuals => improvement for Belli
POD Degradation over periods with excursions in the Belli corrections: Toulouse residuals by pass

Jason-2 DORIS Rinex (Belli-nominal) residuals difference by pass - TLSB
POD test span: Jan 3 - Mar 23, 2013 (cycles 166-173)

- residual difference Belli_1-hour
- residual difference Belli_1minute
- Belli (hourly) USO offset
For correction to RINEX data:
1) use orbit data to compute $U_r$ and $V_r$ which vary in time.
2) assume a single station position to compute $U_e$ and $V_e$ which do not vary in time.
3) periodic terms obtained upon removing an estimated offset+rate from the total relativity correction.

\[
\Delta V_{REL} = \frac{1}{c} \left[ U_r - U_e + \frac{V_r^2 - V_e^2}{2} \right]
\]

\[
U = \frac{GM}{r} \left( 1 - \left( \frac{a_e}{r} \right)^2 \right) J_2 \frac{3\sin^2(\phi) - 1}{2}
\]

With $J_2 = 1.0826264 \times 10^{-3}$
Relativity periodic terms are due only to the satellite and will be identical for any ground station.

Jason-2 clock DORIS relativistic correction sensitivity to station latitude

- station lat = 00 deg
- station lat = 90 deg
- station lat = 40 deg

mm/s vs minutes past epoch
Jason-3 Rinex DORIS Residuals (mm/s) with / without Periodic Relativistic Corrections
Conclusions


b) Jason-2 SLR+DORIS orbits using either V2 or Rinex are comparable in accuracy; the SARAL Rinex orbits may be slightly less accurate.

c) Rinex POD appears less stable than V2 – data editing? Including SLR improves stability.

d) The Belli Jason-2 USO corrections improve Rinex POD, but correction estimates must be edited.

e) Periodic relativity terms improve Rinex residuals
Range Rate from DORIS Rinex phase and corrections to observed measurement

\[
\text{rrate } (T^c) = \lambda_1 \left( \Phi_1(T_i) - \Phi_1(T_{i-1}) \right) / (T_i - T_{i-1}) \quad (\text{Mercier 2015})
\]

\[
= \left( D(T^c_i) - D(T^c_{i-1}) \right) / \Delta T + c(\Delta t_r - \Delta t_e) / \Delta T
\]

\[
+ \Delta_{\text{satellite USO frequency}} + \Delta_{\text{ionosphere}} + \Delta_{\text{relativity}}
\]

where

\(D(T^c)\): distance between emitter (e) and receiver (r) 2GHz phase centers at coordinate TAI time \((T^c)\), and includes refraction effects.

\((\Delta t_r - \Delta t_e)/\Delta T\): satellite-beacon clock frequency offset difference; \(\Delta t\) clock offset between i and i-1 times; \(\Delta T = 10\) TAI seconds.

and

\(\Delta_{\text{satellite USO frequency}}\): Polynomial fit to offset estimates

\(\Delta_{\text{ionosphere}}\): 1\textsuperscript{st} order correction \((\text{Lemoine 2015})\)

\(\Delta_{\text{relativity}}\): Periodic terms
Rinex range rate GEODYN processing:

\[
\text{range rate} + \text{USO frequency bias (per pass)} + \Delta_{\text{troposphere}} + \Delta_{\text{phase center}}
\]

where

\[\Delta_{\text{troposphere}}: \text{VMF1 (plus bias/pass)}\]
\[\Delta_{\text{phase center}}: \text{update satellite antenna Z offset and Starec station Up eccentricity to ionosphere-free positions}\]
Jason-2 RMS radial orbit differences (mm)
(remove 3 Rinex problem arcs)
Example of Belli hourly and minute series