25 YEARS OF PROGRESS IN RADAR ALTIMETRY SYMPOSIUM

IDS WORKSHOP

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Ponta Delgada, São Miguel Island
Azores Archipelago, Portugal

Copernicus POD Service – Sentinel-3 orbit determination based on DORIS observations

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Overview of Copernicus POD Service

- **Payload Data Ground Segment (PDGS):**
  - Processing the scientific data
  - Provider of GPS and attitude data to the CPOD Service
  - User of the orbits and platform files from the CPOD Service

- **Sentinels Flight Operations Segment (FOS):**
  - Orbits, manoeuvre and satellite mass evolution
  - ESOC for S1 and S2; EUMETSAT for S3

- **Centre National d'Études Spatiales (CNES):**
  - S-3 orbital and attitude products, DORIS data

- **ILRS - SLR data provider:**
  - International Laser Ranging Service –ILRS- centres

- **External Validation:**
  - AIUB, CNES, DLR, ESOC, TU Delft, TUM, EUM, CLS, (JPL)
  - Provision of independent orbital products

- **External GNSS data Provider (EGP):**
  - VERIPOS; provider of high accurate GPS orbits and clocks products
  - **magicGNSS:** in-house back-up GPS provider

- **External Auxiliary providers:**
  - Atmospheric gravity models, EOPS and leap seconds, etc.

- **CPOD Quality Working Group (CPOD QWG):**
  - Monitoring the quality of CPOD products
  - Definition of enhancements (algorithms, standards, etc.)
Sentinel-3 orbit determination

### Requirements of POD Products

<table>
<thead>
<tr>
<th>Category</th>
<th>Latency</th>
<th>Orbit Accuracy</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>RT</td>
<td>N/A</td>
<td>DORIS on-board Navigation solution</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GPS on-board Navigation solution</td>
</tr>
<tr>
<td>NRT</td>
<td>30 min</td>
<td>10 cm radial RMS 1-sigma (target of 8 cm)</td>
<td>CPOD (@ Marine and Land PDGS)</td>
</tr>
<tr>
<td>STC</td>
<td>1.5 days</td>
<td>4 cm radial RMS 1-sigma (target of 3 cm)</td>
<td>CPOD (@ GMV) CNES</td>
</tr>
<tr>
<td>NTC</td>
<td>25 days</td>
<td>3 cm radial RMS 1-sigma (target of 2 cm)</td>
<td>CPOD (@ GMV) CNES</td>
</tr>
</tbody>
</table>

- The official Sentinel-3 orbit products from the CPOD Service are all based on GPS observations only, SLR measurements are used for validation (NTC), no DORIS observations are used until now.

- Regular Service Reviews are done to compare the NTC orbit solutions against solutions from the POD QWG (AIUB, CNES, CLS/GRGS, DLR, ESOC, EUMETSAT, TUD, TUM).

- Except the solution from CLS/GRGS (DORIS-only) and CNES (GPS+DORIS combined) all other orbit solutions are GPS-only.
Sentinel-3A orbit determination

Comparison results from the last RSR#11 (Feb – May 2018)

<table>
<thead>
<tr>
<th></th>
<th>Radial</th>
<th>Along-track</th>
<th>Cross-track</th>
<th>3D</th>
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</thead>
<tbody>
<tr>
<td>AIUB</td>
<td>0.85</td>
<td>0.77</td>
<td>0.57</td>
<td>1.29</td>
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<tr>
<td>AING</td>
<td>0.43</td>
<td>0.78</td>
<td>0.65</td>
<td>1.10</td>
</tr>
<tr>
<td>CNES</td>
<td>0.59</td>
<td>1.26</td>
<td>0.67</td>
<td>1.56</td>
</tr>
<tr>
<td>CPOD</td>
<td>0.60</td>
<td>1.14</td>
<td>0.81</td>
<td>1.53</td>
</tr>
<tr>
<td>DLR</td>
<td>0.51</td>
<td>0.74</td>
<td>0.72</td>
<td>1.16</td>
</tr>
<tr>
<td>ESOC</td>
<td>0.44</td>
<td>0.64</td>
<td>0.47</td>
<td>0.91</td>
</tr>
<tr>
<td>EUM</td>
<td>0.72</td>
<td>1.80</td>
<td>1.52</td>
<td>2.48</td>
</tr>
<tr>
<td>TUDG</td>
<td>0.70</td>
<td>0.61</td>
<td>0.64</td>
<td>1.14</td>
</tr>
<tr>
<td>TUM</td>
<td>0.50</td>
<td>0.82</td>
<td>0.71</td>
<td>1.20</td>
</tr>
<tr>
<td>GRG</td>
<td>0.72</td>
<td>2.00</td>
<td>1.75</td>
<td>2.79</td>
</tr>
</tbody>
</table>

SLR validation from the last RSR#11 (Feb – May 2018)

<table>
<thead>
<tr>
<th></th>
<th>AING</th>
<th>AIUB</th>
<th>CNES</th>
<th>DLR</th>
<th>ESOC</th>
<th>EUM</th>
<th>GRG</th>
<th>TUDG</th>
<th>TUM</th>
<th>CPOD</th>
<th>COMB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (cm)</td>
<td>0.43</td>
<td>-0.16</td>
<td>0.48</td>
<td>0.52</td>
<td>0.50</td>
<td>0.18</td>
<td>0.43</td>
<td>0.38</td>
<td>0.50</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Std Dev (cm)</td>
<td>1.04</td>
<td>1.13</td>
<td>1.32</td>
<td>0.82</td>
<td>0.97</td>
<td>1.79</td>
<td>1.62</td>
<td>0.94</td>
<td>1.34</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>RMS (cm)</td>
<td>1.13</td>
<td>1.14</td>
<td>1.40</td>
<td>0.97</td>
<td>1.09</td>
<td>1.80</td>
<td>1.68</td>
<td>1.01</td>
<td>1.43</td>
<td>0.96</td>
<td></td>
</tr>
</tbody>
</table>
DORIS processing @ CPOD Service

- A processing scheme for DORIS-based orbit determination is set up in parallel to the operational GPS-only S-3A/B orbit determination process.
- Until now, no regular/automatic quality control is set up.

- 10 sec DORIS phase observables are converted to range-rate observations, GPS-derived orbit is used as a-priori information.

The key data of the DORIS processing are:

- Three-day arc length (72 hours)
- Estimation of
  - 1 radiation pressure coefficient
  - 10/24h atmospheric drag scale factors
  - 2/24h sets of CPR along-track and cross-track sine+cosine parameters
- Elevation cut-off angle of 10° for DORIS observations, no elevation-dependent weighting
- Tropospheric zenith delays per station pass
- Range-rate bias per station pass
Orbit solutions based on DORIS

- **DORIS-only** solution, SLR is used for validation

- **GPS (30 sec)+DORIS combined** solution, SLR is used for validation

- **Sentinel-3A:**
  - 1 June 2017 – 31 May 2018 (RSR#09 - #11)
  - Comparison to CLS/GRGS, CNES and combined (from QWG) orbits
  - SLR validation

- **Sentinel-3B:**
  - 1 May – 31 July 2018
  - Comparison to CPOD NTC GPS-only solution
  - Comparison to combined (from QWG) orbit, 8 -14 June 2018
  - SLR validation
DORIS processing: number of observations

- Number of totally available and used DORIS observations for both orbit processing schemes for Sentinel-3A and -3B.
- Number of observations is (not surprisingly) correlated to number of tracking stations.
DORIS processing: Range-rate RMS

- Range-rate RMS (mm/s) for Sentinel-3A and -3B shows similar performance.
- The values for S-3B are a bit larger than the values for S-3A.
S-3A DORIS orbits: Comparisons

Daily mean offsets (m) between S-3A DORIS orbits and CLS/GRGS orbits (left) and QWG combined orbits (right)

- Small radial offset between CLS/GRGS and CPOD DORIS orbits, variable along-track offsets, significant cross-track offsets
Daily radial and 3D RMS (cm) of S-3A DORIS orbits w.r.t different orbit solutions

- All comparisons are similar
S-3A DORIS+GPS orbits: Comparisons

Daily mean offsets (m) between S-3A DORIS+GPS orbits and CLS/GRGS orbits (left) and QWG combined orbits (right)

- Small offsets in all directions
- Radial and cross-track offsets constant over time, along-track offsets variable
S-3A GPS+DORIS orbits: Comparisons

Daily radial and 3D RMS (cm) of S-3A GPS+DORIS orbits w.r.t different orbit solutions

- RMS values much smaller than for CPOD DORIS orbits
- Comparison to DORIS-only orbits (CLS/GRGS) is worst
- Comparison to CPOD GPS-only orbits is best (not surprising)
S-3B DORIS and GPS+DORIS orbits: Comparisons

Daily RMS values (cm) of S-3B DORIS (left) and S-3B GPS+DORIS (right) orbits w.r.t CPOD GPS orbits, one week of QWG combined orbits are available as well

- Larger differences in May due to many manoeuvres
- Differences are stable since tandem phase has been reached (6 June)
Daily mean offsets (cm) and RMS (cm) of SLR validation

- Nine SLR stations used, station elevation cut-off angle at 10°
- Sentinel-3A and -3B orbits show similar performance.
- Mean offsets of DORIS-only orbits are smaller but with larger noise.
- RMS values of DORIS-only orbits are significantly larger than for the combined GPS+DORIS orbits
SLR residuals for 15 May 2018

- Differences between SLR residuals of DORIS orbits (purple) and of GPS+DORIS orbits (green) can clearly be seen.
SLR residuals for 15 May 2018

S-3A

S-3B

• Differences between SLR residuals of DORIS orbits (purple) and of GPS+DORIS orbits (green) can clearly be seen.
SLR residuals for 15 May 2018 – GPS+DORIS orbits

- Different colors for different SLR stations
- Different markers for the two satellites
  - S3A: square
  - S3B: X
- Several stations track both satellites during the same passes (satellites were not yet in final tandem phase)
Improvements for S-3A - antenna offset calibration

- Independent investigations of different groups (DLR, CNES) revealed a
  - **+1 cm shift in y-direction** („cross-track“) of all antenna positions (GPS, DORIS, SLR)
    => CNES GDR-F for Sentinel-3 satellites
  or
  - **-1 cm shift in y-direction** of the CoG coordinates

=> Investigation of these new setups by doing a reprocessing of the DORIS and GPS+DORIS solutions based on this new configuration
Daily mean offsets (cm) and RMS (cm) of SLR validation

- Nine SLR stations used, station elevation cut-off angle at 10°
- Mean offsets are equivalent (within sub-mm)
- RMS values decrease by 0.9 mm for both orbit solutions
Summary and future plans

- Quality and performance assessment for S-3A & S-3B DORIS orbits from the CPOD Service are shown.
- The performance of the S-3A & S-3B CPOD DORIS orbits is good and promising.
- The DORIS orbits are, however, not yet on the same level as other DORIS or GPS(+DORIS) orbits. In particular the SLR validation reveals larger (~doubled) RMS values than for other S-3A/S-3B orbit products.
- The combined DORIS+GPS orbits show a very good performance, probably mainly due to the strength of the GPS observations.
- Proposed new antenna offsets/CoG coordinates give slightly better results

⇒ Further investigations to improve the DORIS orbits are still needed
  - find the best elevation cut-off angle and the best elevation-dependent weighting scheme
  - check again the conversion of the DORIS phase observables to range-rate
  - find the optimal a priori sigma for the DORIS observations
  - find the optimal relative weighting scheme between the different observation techniques for a combined orbit solution
Thank you for your attention!

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