Multi-mission cross-calibration: a prerequisite for climate studies based on satellite altimetry

Denise Dettmering and Christian Schwatke

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

IAG Workshop: Satellite Geodesy for Climate Studies
Bonn, Germany, 19.-21.09.2017
Motivation

• Sea level is one of the essential climate variables (ECV) as defined by GCOS and ESA

• Satellite altimetry is able to provide sea surface heights, which are
  ✓ long-term,
  ✓ highly accurate,
  ✓ uniformly sampled (spatially as well as temporally)
  ✓ with (almost) global coverage,
  ✓ with respect to an absolute reference
  … and therefore, satellite altimetry is very valuable for climate studies

• Since 1991, more than ten different altimetry missions have been active (most of them with changing orbit parameters)

• For exploiting the full potential of satellite altimetry, the combination of different missions is mandatory
Satellite altimetry missions since 1991
Missions used in these investigations

1992-2016 (25 years)

<table>
<thead>
<tr>
<th>Mission</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jason-1</td>
<td>01/2002-06/2013</td>
</tr>
<tr>
<td>Jason-2</td>
<td>06/2008 (ongoing)</td>
</tr>
<tr>
<td>Jason-3</td>
<td>01/2016 (ongoing)</td>
</tr>
<tr>
<td>ERS-1</td>
<td>07/1991-03/1996</td>
</tr>
<tr>
<td>ERS-2</td>
<td>04/1995-09/2011</td>
</tr>
<tr>
<td>Envisat</td>
<td>03/2002-04/2012</td>
</tr>
<tr>
<td>Saral</td>
<td>02/2013 (ongoing)</td>
</tr>
<tr>
<td>GFO</td>
<td>02/1998-11/2008</td>
</tr>
<tr>
<td>Cryosat-2</td>
<td>04/2010 (ongoing)</td>
</tr>
</tbody>
</table>
Global sea level change as seen by each mission

Monthly means of global gridded sea level anomalies with respect to mean sea surface MSS CLS11 (1993-2009) based on harmonized corrections (e.g., same correction models whenever possible)

- Continuous increase of GMSL
- Clear annual signal
- Significant offsets between the different missions
NASA missions

offset: -2.22 ± 0.22 cm

- 2.53 ± 0.24 cm

3.00 ± 0.11 cm
NASA missions (shifted)

⇒ Significant discrepancies remain after removing a constant offset
ESA missions: how to define a reference?

Trend ESA missions:

- shifted to each other: \(2.38\) mm / year
- Shifted with respect to NASA missions: \(2.82\) mm / year
Trends per mission

Trends:
Jason-1: 2.84 mm/year
Envisat: 2.62 mm/year

---

<table>
<thead>
<tr>
<th>Mission</th>
<th>Trend Without Calibration</th>
<th>Number of Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOPEX</td>
<td>3.03 +/- 3.92</td>
<td>153</td>
</tr>
<tr>
<td>Jason-1</td>
<td>2.84 +/- 4.71</td>
<td>137</td>
</tr>
<tr>
<td>Jason-2</td>
<td>4.16 +/- 5.02</td>
<td>100</td>
</tr>
<tr>
<td>Jason-3</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>ERS-1</td>
<td>4.33 +/- 6.48</td>
<td>46</td>
</tr>
<tr>
<td>ERS-2</td>
<td>2.56 +/- 7.51</td>
<td>98</td>
</tr>
<tr>
<td>Envisat</td>
<td>2.62 +/- 5.88</td>
<td>118</td>
</tr>
<tr>
<td>SARAL</td>
<td>6.24 +/- 3.94</td>
<td>41</td>
</tr>
<tr>
<td>GFO</td>
<td>2.76 +/- 7.33</td>
<td>101</td>
</tr>
</tbody>
</table>
Regional sea level (Sea level anomalies: June 2014)

⇒ A location-dependent cross-calibration between all missions is necessary in order to ensure consistent long-term products
Approach: Multi-mission crossover analysis

- using all missions since 1992
- building single- and dual satellite crossover differences in all combinations ($\Delta t < 2$ days)
- minimizing crossover differences and along-track consecutive differences in a least squares adjustment
- automated mission weighting by variance component estimation
- TOPEX (later Jason-1, Jason-2, Jason-3) taken as reference mission

Main output:
- time series of radial errors
  - applied as correction to each measurement
  - one consistent set of observations with increased temporal and spatial resolution

Additional outputs (derived from radial errors):
- relative range biases (global mean and per cycle)
- relative instrument drifts
- geographically correlated SSH errors
Global range biases per mission (w.r.t. TOPEX)

Inter-mission offsets yield from a few mm up to more than 60 cm
Example: Jason-1 range bias

Range bias differences (per 10 days) between Jason-1 and Jason-2 (from MMXO)

$\Delta r_{J1} - \Delta r_{J2}$ [m]

formation flight  Interleaved orbit  J1 EOL phase: geodetic orbit

$\Rightarrow$ drift in radial errors (Jason-1 EOL)

$\Rightarrow$ cannot be corrected by applying constant offsets per mission!
Example: Envisat range bias

Range bias differences (per 10 days) between Envisat and Jason-1 (from MMXO)

=> drift in Envisat range bias in the first period
=> cannot be corrected by applying constant offsets per mission!
Geographically correlated errors

large-scale patterns with maximum values around 1 cm

=> will influence regional sea level estimates
Global sea level change (MMXO applied)

⇒ improved inter-mission consistency
⇒ annual signal becomes clearer
Global sea level change (without MMXO)
Global sea level change

Trends (original):
Jason-1: 2.84 mm/year
Envisat: 2.62 mm/year

Trends (with MMXO):
Jason-1: 2.759 mm/year
Envisat: 2.761 mm/year
Regional sea level change (1992-2016)
Conclusion

- Multi-mission altimetry provides the basis for a long-term monitoring of global and regional sea level behavior.
- A careful calibration of the different missions is necessary in order to account for instrumental offsets and drifts, as well as for geographically correlated errors (e.g. due to orbit or model errors).
- The presented multi-mission crossover analysis is a perfect tool to establish a harmonized data base and to provide a reliable time series of global mean sea level usable for climate change studies.