What sea-level drifts can be detected at global and regional scales by comparing recent altimetry missions together: S3A, Jason-3 and Saral-Altika?

OSTST | October 19-23, 2020 | Virtual Meeting

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Objectif of this study is:

- To provide the global and regional MSL drift detection capability comparing recent altimeters missions (S3A, Jason-3 and Saral/Altika) and analysing the sensitivity of the method:
  - A focus on the detection of S3-A global and regional MSL drift using SAR-mode data is provided

GMSL evolution is well monitored with a good description of its error and uncertainties (Ablain et al., 2019)

However the description of potential GMSL drift on recent altimeter missions is quite challenging over short period (3-5 years).
- Method based on (Ablain et al., 2019)
  - The estimator of $\beta$ with the OLS approach is noted $\hat{\beta} \sim (X^t X)^{-1} X^t y$
  - with the following distribution taking into account the error variance-covariance matrix:
    $$\hat{\beta} = N(\beta, (X^t X)^{-1} (X^t \Sigma X) (X^t X)^{-1})$$
- $\Sigma$ derived from the error budget description
- HF and MF error variance are computed directly from the GMSL difference signal:
  - GMSL computed with AVISO method from Marine L2P products
  - Comparison of GMSL time series after interpolation on the same time sample (usually using the Topex-Jason mission cycles as reference periods)
- High frequency errors: altimeter noise, geophysical corrections, orbits ...
  - Correlated errors ($\lambda = 2$ months)
  - $\sigma = 1.2$ mm
- Medium frequency errors: geophysical corrections, orbits ...
  - Correlated errors ($\lambda = 1$ year)
  - $\sigma = 1$ mm
- Low frequency errors: wet tropospheric correction (WTC)
  - Correlated errors ($\lambda = 5$ years)
  - $\sigma = 1.1$ mm (\(\Leftrightarrow\) to 0.2 mm/yr for 5 years)
  - $\sigma = 0$ (model WTC error are cancelled between 2 missions)
- Low frequency errors: orbits (Gravity fields)
  - Correlated errors ($\lambda = 10$ years)
  - $\sigma = 0.5$ mm (\(\Leftrightarrow\) to 0.05 mm/yr for 10 years)
  - $\sigma = 0.5$ mm * sqrt(2)
- Long-term drift errors: orbit (ITRF) and GIA
  - Drift error
  - $\delta = 0.12$ mm/yr
  - $\delta = 0.1$ * sqrt(2)
  - (GIA error is removed between 2 missions)

From Ablain et al. 2019
Drifts and uncertainties on S3A compared to J3 and AL (period 07/2016 to 04/2020):
  ○ No significative J3 vs AL drift makes for a strong basis for comparison with S3A
  ○ S3 vs J3 and AL both find approx 1.3 +/- 0.4 mm/yr drift (68% C.L.)

Data updated from Ablain, OSTST, Chicago, Oct. 2019:
  ○ + 1 year period
  ○ reprocessing with more homogeneous data

The origin of this drift has been explained by altimetry experts (see J.Aublanc, OSTST 2020)
The sensibility of error budget has been studied for high frequency errors.

Uncertainties are computed for different HF and MF cut-off frequencies:
- Low impact from the variation of the MF frequency.
- Variations of the HF period has a high impact on the computed uncertainties for short time periods: up to 25%.
- The currently chosen periods HF = 2 months and MF = 1 year correspond to a minimum in estimated uncertainties.

HF variance is computed as the variance of the residue from a low-pass Lanczos filter at the HF frequency. MF variance is computed as the variance of the difference of the residue from a low-pass Lanczos filter at the MF freq. and the signal filtered at the HF freq.
GMSL drift uncertainty

- Uncertainties evaluated for:
  - current method with frequencies HF=2m and MF=1y
  - all combinations of frequencies HF in [2m, 1y] and MF in [6m, 1y]
- For time periods < 3y:
  - current method (HF=2m, MF=1y) is the least conservative i.e. yields lower uncertainties than other combinations
- At 3y, drift unc. between [0.5, 0.75] mm/yr
- At 5y, drift unc. between [0.25, 0.4] mm/yr
- At 10y, drift unc. < 0.25 mm/yr
- A more robust approach must be devised for short time periods

Min/max of uncertainties computed for all HF variations between 2 months and 1 year and all MF variations between 6 months and 1 year, for different time periods.
● Regional MSL drift and associated uncertainties have been analyzed at regional scales
● From experience, regional drifts in altimetry are very difficult to detect by such a direct approach because of the ocean variability that is not observed in the same way

● Such an approach is especially effective between the tandem phase

● However, our intention is to quantify precisely the level of uncertainty reached as a function of the period duration and also of the size of the regional area analysed by the direct method.

Regional MSL trend differences between S3A and J3: are there significant?
• Same method than the one used at global scale, based on *(Ablain et al., 2019)*
• HF and MF errors computed directly from regional MSL signals
• Low frequency (WTC) and long-term drift errors (orbit, GIA) values taken from *Prandi et al. 2020*

<table>
<thead>
<tr>
<th>Source of errors</th>
<th>Error category</th>
<th>Jason-2/3 GMSL uncertainty level (1σ)</th>
<th>GMSL differences Uncertainty level (at 1σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High frequency errors: altimeter noise, geophysical corrections, orbits ...</td>
<td>Correlated errors (λ = 2 months)</td>
<td>location dependent</td>
<td>location dependent</td>
</tr>
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<td>Medium frequency errors: geophysical corrections, orbits ...</td>
<td>Correlated errors (λ = 1 year)</td>
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<td>Low frequency errors: wet tropospheric correction (WTC)</td>
<td>Correlated errors (λ = 5 years)</td>
<td>location dependent</td>
<td>location dependent</td>
</tr>
<tr>
<td>Long-term drift errors: orbit</td>
<td>Drift error</td>
<td>δ = 0.33 mm/yr</td>
<td>δ = 0.33 * sqrt(2) mm/yr</td>
</tr>
<tr>
<td>GIA</td>
<td>Drift error</td>
<td>location dependent</td>
<td>δ = 0 mm/yr (GIA error is removed between 2 missions)</td>
</tr>
</tbody>
</table>

*From Prandi et al. 2020 (submitted)*
• Uncertainties evaluated for different box sizes and different time periods
• HF and MF variance is computed from S3/J3 but results for other missions are very similar
• Regional drifts under 2 mm/yr can be detected for time periods of over:
  ○ 4.5 years for box sizes $\geq 18^\circ$
  ○ 6 years for box sizes $\geq 12^\circ$
  ○ 8 years for box sizes $\geq 6^\circ$
• Regional drifts under 1 mm/yr can be detected for time periods of over 8 years for box sizes $\geq 18^\circ$
• The C3S requirement of detecting 0.5 mm/yr drifts at regional scale is not achievable using this method over a mission’s life cycle.

*Evolution of uncertainties depending on the mission period for different box sizes (from 3°x3° to 36°x36°).*
Regional MSL drift uncertainty

- Regional MSL drift and uncertainties, and drift probability are evaluated on S3A/J3, for box sizes of 6°, represented as deviation from the mean GMSL S3A/J3 drift.
- Zones with high computed drifts also have high drift uncertainties: simply a reflection of high ocean variability in those zones.
- Method accuracy insufficient to detect regional drifts on S3A/J3.
The GMSL comparison between recent altimeter missions highlights a significant S3A GMSL (based on SAR mode) drift from 07/2016 to 04/2020 compared to SARAL/Altika and Jason-3:
   ◆ +1.3 mm/yr with an uncertainty of 0.4 mm/yr (68% confidence level)
   ◆ no significant drift detected between Jason-3 and SARAL/Altika
   ◆ Cross-comparisons with S3B GMSL have also been performed but results must be consolidated.

Our uncertainty estimation is sensitive to the error budget allocated especially at high frequencies and for short period lower than 3 years:
   ◆ An improved and more robust approach is contemplated in order to better estimate uncertainties over short periods of time and thus help detect drifts quicker.

Regional scales:
   ◆ Regional drifts <= 1 mm/yr can be detected for time periods of over 8 years at 2000 km spatial scale
   ◆ Detection of drift lower than 0.5 mm/yr as expressed by C3S requirements is impossible at regional scale: **new calibration method must be foreseen to be able to verify this level of requirement** (see Ablain presentation, error session or [https://www.essoar.org/doi/10.1002/essoar.10502856.1](https://www.essoar.org/doi/10.1002/essoar.10502856.1))