Error Estimation of the global and regional mean sea level trends from Jason-1&2 and T/P data

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Overview

• Purpose: estimation of the different errors which can impact the global and regional MSL trends

• This presentation is divided into 3 parts:
  - 1) MSL description derived from Jason-1&2 and T/P altimeter missions
  - 2) MSL trend uncertainties for each correction and for orbit calculation
  - 3) Estimation of total error budget
1.1 – MSL description : definition and standards

• Reference Global MSL is calculated from Jason-1, Jason-2 and T/P data :
  – T/P : M-GDR products have been updated with GSFC0809 orbit (ITRF2005, GRACE), non parametric sea state bias (Labroue), and same standards as Jason-1 for other geophysical corrections
  – Jason-1 : Both GDR-B / GDR-C releases are used, a SSH map bias is applied to link each MSL time data series together
  – Jason-2 : GDRs data are used

• Each MSL data series are linked together accurately thanks to the T/P&Jason-1 and Jason-1/Jason-2 formation flying phases :
  – T/P/Jason-1 : global bias (7.55 cm); Jason-1 cycle 11, May 2002
  – Jason-1/Jason-2 : global bias (6.51 cm); Jason-2 cycle 11, October 2008

• Wet troposphere correction, inverse barometer correction, GIA (-0.3 mm/yr) are applied to calculate the MSL

⇒ For more details, see MSL Aviso Website: http://www.aviso.oceanobs.com/msl
1.2 – MSL description: global and regional MSL trend

- After removing annual, semi-annual signals, the GMSL trend is 3.33 mm/yr (with GIA) from January 1993 to May 2009.

- Regional MSL trends are estimated from multi-mission grids (DUACS products).

- Inhomogeneous repartition of the ocean elevation is highlighted: +/- 10 mm/yr.
2.1 – MSL trend uncertainties: Wet troposphere correction

- Radiometer Wet troposphere corrections (Jason-1, T/P, and Envisat) can be impacted by long term instrumental drifts (component ageing, thermal effects, yaw maneuvers, instrument turned off, …)

- Natural targets are used for calibration but this assumes they are independent of any long-term evolution

- Comparisons with meteorological model fields or radiometer correction together is a way to estimate the drift uncertainty

- The daily average indicates trend differences between -0.3 and +0.5 mm/yr

- Regional MSL slope differences (Radiometer/Model) can reach 4 mm/yr in wet areas

⇒ The wet troposphere correction appears to be a main source of error for the MSL calculation: $0.2 \text{ mm/yr} \leq \text{global trend error} \leq 0.3 \text{ mm/yr}$
2.2 – MSL trend uncertainties: orbit calculation

• The impact of orbit solutions on the MSL trends is linked to the reference frames and gravity models applied, especially between hemispheres

• For Jason-1, hemispheric differences using GDR-C orbits instead of GDR-B orbits are also observed close to +/- 1 mm/yr
  ⇒ due to the change from ITRF2000 to ITRF2005 reference frame

• Using GDR-C release, the hemispheric MSL trends are in better agreement

• A similar behavior have been observed for T/P using last GSFC orbit solution with ITRF2005

\[
\begin{align*}
\text{North MSL} & : \text{Slope} = 1.327 \text{ mm/yr} \\
\text{South MSL} & : \text{Slope} = 3.217 \text{ mm/yr}
\end{align*}
\]

\[
\begin{align*}
\text{North MSL} & : \text{Slope} = 1.796 \text{ mm/yr} \\
\text{South MSL} & : \text{Slope} = 2.548 \text{ mm/yr}
\end{align*}
\]
2.2 – MSL trend uncertainties: orbit calculation

• Last orbit solutions modify the hemispheric MSL trends significantly, but the difference is questionable:
  ⇒ Do hemispheric MSL trend differences can be explained by physical processes
  ⇒ It’s not easy to assess them with external sources:
    ⇒ tide gauges: they are few TG in high latitudes (studies on going …)
    ⇒ Argo profiles + GRACE data could also be used
  ⇒ Finally, we can consider at the moment these hemispheric differences as an uncertainty although ITRF2005 improves the orbit calculation

• In addition, the gravity fields have an impact: for instance the omission of long term variations leads to 1.5 mm/yr differences on basin scales.

⇒ As a result of the unequal ocean basins, the error budget due to the orbit calculation is:

  \[ 0.1 \text{ mm/yr} \leq \text{global trend error} \leq 0.15 \text{ mm/yr} \]
2.3 – MSL trend uncertainties: pressure fields

• Operational ECMWF pressures fields could impact the long-term sea level estimate through the inverse barometer and the dry troposphere corrections.

• Differences between NCEP (reanalysis) and ECMWF models highlight a relative weak long term trend difference:
  ⇒ about ~1 Pa/yr ⇔ impact on the global MSL trend is ≤ 0.05 mm/yr

• Inconsistencies between pressure and mean pressure fields (ECMWF) have been also detected in Jason-1 GDR products:
  ⇒ both jumps (+20Pa in 2004 and -20Pa 2006 ⇔ 2.5 mm on the SSH) impact the global MSL trend by 0.2 mm/yr over the Jason-1 period
  ⇒ Other similar errors could be present on T/P time data series

⇒ The error budget due to pressure fields on the global MSL trend is:
  0.05 mm/yr ≤ global trend error ≤ 0.1 mm/yr
2.4 – MSL trend uncertainties: bias error between each data series

- MSL reference derived is split into 4 altimeter series: Topex A, Topex B, Jason-1, Jason-2
  ⇒ In order to connect them correctly, SSH biases have to be applied

- SSH bias uncertainties are estimated:
  ⇒ 1.0 mm ≤ TP A / TP B ≤ 2.0 mm
  ⇒ 0.5 mm ≤ TP / J1 ≤ 1.0 mm
  ⇒ 0.25 mm ≤ J1 / J2 ≤ 0.5 mm

- These uncertainties impact directly the global MSL trend between ±0.10 and ±0.25 mm/yr considering minimal or maximal errors.

⇒ The error budget due to SSH bias uncertainties on the GMSL trend is:
  0.10 mm/yr ≤ global trend error ≤ 0.25 mm/yr
2.5 – MSL trend uncertainties: altimetric parameters

- Altimeter parameters are precisely monitored over all the mission life-time to detect instrumental anomalies (due to ageing for instance)

- However, a potential drift has been detected in the altimeter wind speed (computed from SWH and SIGMA0)

- An uncertainty varying between 2 and 4 cm.s⁻¹/yr can then be considered comparing models (ECMWF, NCEP) and Jason-1 and Envisat

⇒ The error budget due to the sigma0 (through the SSB) on the GMSL trend is: $0.05 \text{ mm/yr} \leq \text{global trend error} \leq 0.1 \text{ mm/yr}$
### 3.1 – Total error budget: summary

<table>
<thead>
<tr>
<th>Source of error for the MSL calculation</th>
<th>MSL trend uncertainties from 1993 to 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minima</td>
</tr>
<tr>
<td>Orbit: Cnes POE (GDR B) for Jason-1 and GSFC (ITRF2000) for T/P.</td>
<td>0.10 mm/yr</td>
</tr>
<tr>
<td>Radiometer Wet troposphere correction: JMR (GDR B) &amp; TMR (with drift correction).</td>
<td>0.20 mm/yr</td>
</tr>
<tr>
<td>Dynamical atmospheric and dry troposphere corrections using ECMWF pressure fields.</td>
<td>0.05 mm/yr</td>
</tr>
<tr>
<td>Sigma0 drift impacting altimeter wind speed and sea state bias correction</td>
<td>0.05 mm/yr</td>
</tr>
<tr>
<td>Bias uncertainty to link TP A / TP B, TOPEX and Jason-1, Jason-1 and Jason-2</td>
<td>0.10 mm/yr</td>
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</tbody>
</table>

**Upper Bound of GMSL Trend Error < 0.9 mm/yr**
3.2 – Total error budget : global MSL trend error

- A 0.9 mm/yr total error budget is a pessimistic point of view : we assume errors are additional (not negatively correlated)
- The quadratic sum leads to value close to 0.45 mm/yr
  ⇒ This method do not take into account the true correlation of error together
- Finally, we used an inverse method to estimate a more realistic error :

\[ x_{est} = R_{xx} H^T (H R_{xx} H^T + R_{yy})^{-1} z \]

- Thanks to this formalism, the covariance of observations can be described in Rvv matrix:
  ⇒ According to the time period (T/P, Jason-1, …)
  ⇒ According to their nature (jump, drift, …)

- The error can be directly deduced in a confidence interval from the formal error multiplied by the adapted student coefficient

⇒ Finally the total error budget of GMSL is :

\[ 0.6 \text{ mm/yr in a confidence interval of 90\%} \]
Conclusion

• This study allows us to describe the global MSL error budget:
  ⇒ GMSL trend = 3.32 mm/yr ± 0.6 mm/yr in a confidence interval of 90%

• Global MSL trend error is in agreement with tide gauge studies (In-Situ Calval session):
  ⇒ T/P+Jason-1 / Tide gauge drift = ± 0.7 mm/yr

• But this MSL error description has to be refined:
  ⇒ Thanks to new altimeter standards: MSL trend error should be reduced
  ⇒ Thanks to supplementary studies in order to estimate altimeter uncertainties better

• For instance, we do not consider any drift on altimeter range in this study:
  ⇒ It might be more realistic considering a drift on TOPEX-A period as highlighted with tide gauge in-situ comparison and in relationship with TOPEX retracked data (see Labroué’s poster).