Validating the altimeter sea level record using tide gauges and estimates of land motion

Christopher Watson[1,2], Benoit Legresy[3,2], John Church[4], Matt King[1], Alvaro Santamaría-Gómez[5]

1. Discipline of Geography and Spatial Sciences, University of Tasmania, Hobart, Australia.
2. Integrated Marine Observing Sytem, Hobart, Australia
3. CSIRO Oceans and Atmosphere. Hobart, Australia.
4. 53 Salamanca Square, Battery Point, Australia.
5. Université de La Rochelle / CNRS, La Rochelle, France.

❶ Review

- Watson et al. (2015) used the tide gauge network combined with estimates of vertical land motion (VLM) to investigate systematic error within the altimeter sea-level record.
- Significant error or 'bias drift' was reported, affecting the early part of the record (TOPEX-A) in particular.
- Estimates of bias drift (Fig 1) varied with different treatments of VLM applied at the tide gauge.
- The bias drift estimated for TOPEX-A suggests that this part of the altimeter record overestimates the trend in global mean sea level (GMSL).
- Application of the estimated bias drifts to the sea level record (Fig 2) suggested a reduction in the rate of rise in GMSL from +3.2 mm/yr to +2.6-2.9±0.4 mm/yr, depending on the VLM adopted.
- Watson et al. (2015) was unable to definitively attribute the cause of the estimated bias drift, but pointed towards various issues associated with the reprocessing required for TOPEX.
- Reprocessed TOPEX data is yet to be made available. How will the GMSL from this record compare with that from Watson et al. (2015)?

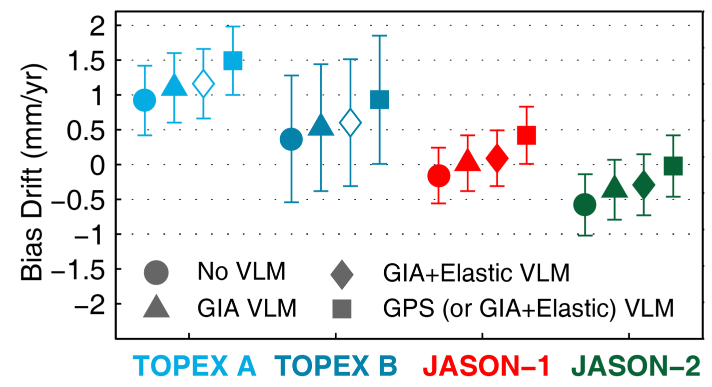

Fig 1: Estimates of bias drift for each altimeter mission as a function of vertical land motion applied at the tide gauge. Figure reproduced from Watson et al. (2015).

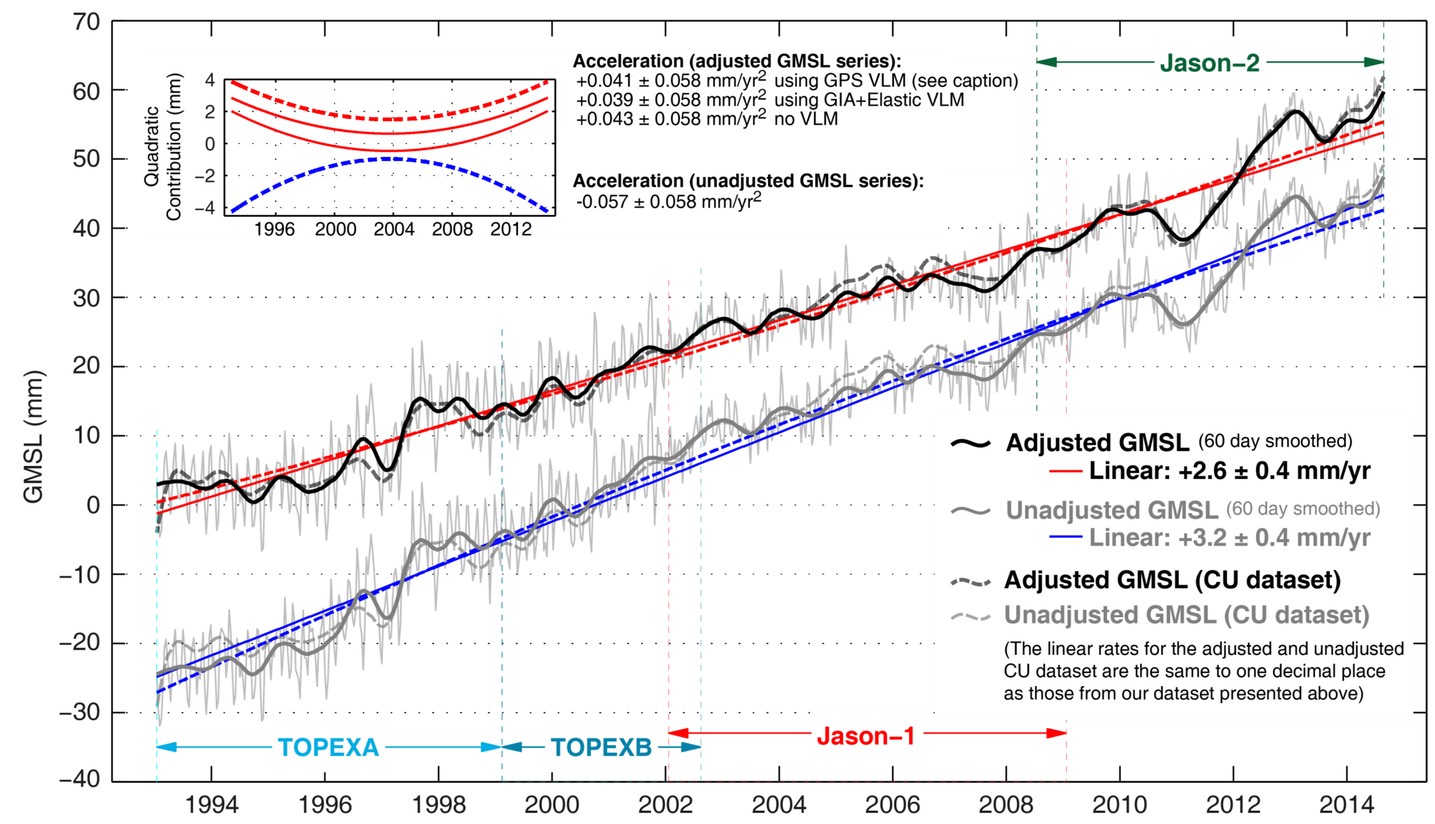

Fig 2: Adjusted (upper) and unadjusted (lower) satellite altimeter GMSL time series, arbitrarily offset. Adjusted series uses GPS-based VLM estimates (where unavailable for a specific TG, otherwise GIA+Elastic VLM is substituted). Annual and semi-annual periodic terms removed, (thin grey line is unfiltered, thick line is 60-day low-pass filtered). Linear and linear-plus-quadratic fits are shown as continuous and dashed lines, respectively. The inset shows quadratic components highlighting that the adjusted acceleration (insignificant) is invariant to VLM treatment. Figure reproduced from Watson et al. (2015).

❷ What can tide gauges tell us about TOPEX-A?

- Altimeter – TG residuals for the TOPEX-A mission (assuming a linear model for bias drift) are clearly non linear (Fig 3).
- A piece-wise linear model (3 equal segments) for TOPEX-A bias drift linearises the residuals, yet yields comparable (slightly lower, but with higher uncertainty) adjusted GMSL compared with the standard linear model.
- Not applying the so-called cal-1 mode correction for TOPEX partially linearises the residuals (Fig 4) and reduces the previous bias drift by ~50%, accounting for a large component of the variation in the GMSL rate observed by Watson et al. (2015).
- As expected, this is not the full story. Stacked environmental corrections (Fig 4), using the same weighting strategy as used to derive SSH bias drift, are illuminating in terms of highlighting additional issues with TOPEX-A:
  - The last ~50 cycles of TOPEX-A reveal interrelated anomalies in SSH, significant wave height, wind speed and sea state bias, relative to the remainder of the record (see circled, Fig 4).
  - Each of these issues point toward known issues associated with waveform reprocessing. They also point toward the need for consistency between SSB models and reprocessed data.
  - The intra-mission (TOPEX A to B) bias remains important for GMSL (note 1 mm at the A/B boundary is ~0.06 mm/yr in GMSL over the full record).
- This work highlights the importance of "altimeter – TG" comparisons using diverse algorithms and approaches in order to comprehensively validate the GMSL climate record.

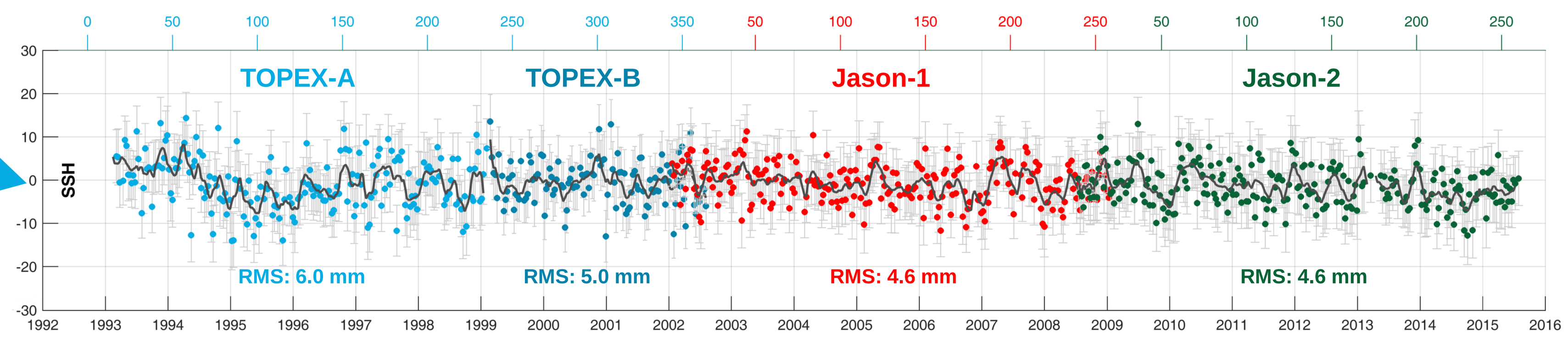

Fig 3: Altimeter – TG residuals from Watson et al (updated). Note the non-linearity of the residuals for the TOPEX-A period (the cal-1 mode correction has been applied to TOPEX).

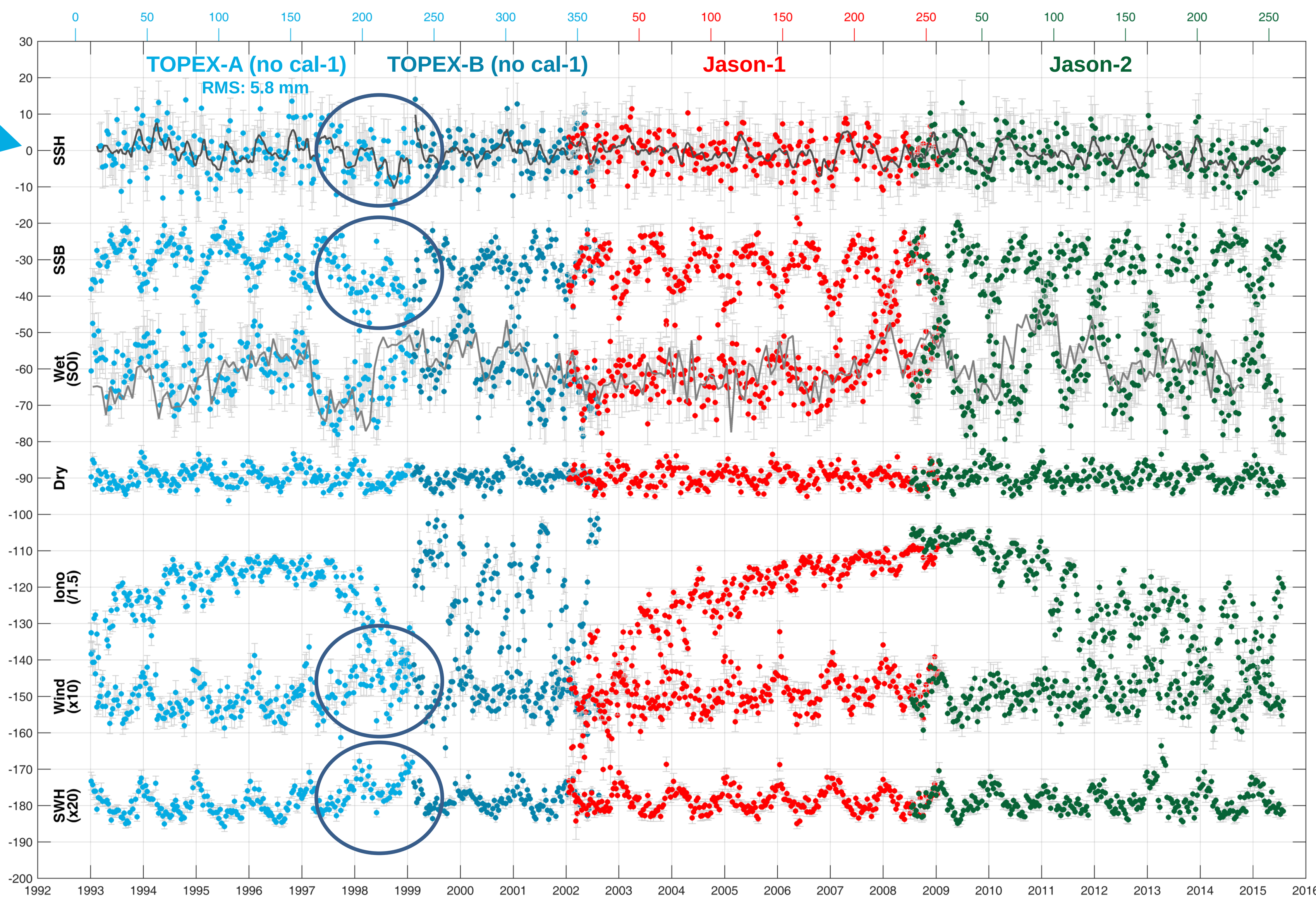

Fig 4: Altimeter – TG residuals (top) without the cal-1 mode correction applied for TOPEX. The lower series reflect cycle-by-cycle stacked environmental corrections using the same weighting strategy as used for SSH bias drift (mission wise offsets removed, Southern Oscillation Index (SOI) shown over wet delay). These stacked series are useful as a qualitative indicator of changed instrument behaviour throughout the record. Circled data of interest for TOPEX-A.

❸ What happens until TOPEX is re-released?

- Completion of the TOPEX reprocessing, with resolution of the cal-1 mode correction and inclusion of a consistent SSB across side-A and side-B is required to resolve present uncertainty in GMSL during the TOPEX period.
- Updated data for OSTM/Jason-2 appears nominal with bias drift insignificantly different from zero (-0.15 ± 0.36 mm/yr, RLR6 GPS VLM).
- Experiments using the OFAM-JRA55 GCM model used in the Australian Community Climate and Earth-System Simulator (1/10 degree, daily, JRA55 atmospheric, Zhang et al., 2016) show potential for reducing variability in the altimeter-TG residual:
  - Application of the model difference (CP_{ALT} – TG) results in a 4-16% reduction in variance of bias drift estimates.

❹ Conclusions

- Altimeter – TG comparisons remain vital to the validation of GMSL.
- Issues identified by Watson et al. (2015) with TOPEX appear at least partially related to the cal-1 mode correction – this is clearly not the full story given other range related effects.
- Further improvements to the technique are likely. Unassimilated high resolution GCM data (differenced between offshore and the TG) are promising. Evolving GPS VLM requires further investigation.
- We look forward to the release of the TOPEX reanalysis for community wide analysis.

References

Watson, C.S., N.J. White, J.A. Church, M.A. King, R.J. Burgette and B. Legresy. (2015). Unabated global mean sea-level rise over the satellite altimeter era. *Nature Climate Change*. Doi:10.1038/nclimate2635.

Zhang, X., P. Oke, M. Feng, M. Chamberlain, J. Church, D. Monselesan, C. Sun, R. Matear, A. Schiller, and R. Fiedler (2016), A near-global eddy-resolving OGCM for climate studies., Geoscientific Model Development Discussions, doi:10.5194/gmd-2016-17

UNIVERSITY of TASMANIA AUSTRALIA

CSIRO

IMOS Integrated Marine Observing System

IMOS is supported by the Australian Government through the National Collaborative Research Infrastructure Strategy and the Super Science Initiative.

As part of its commitment to ocean remote sensing infrastructure, IMOS supports an Australian contribution to the calibration and validation of satellite altimetry. For further information, visit: www.imos.org.au