Assessing satellite era sea level change using tide gauges and estimates of land motion

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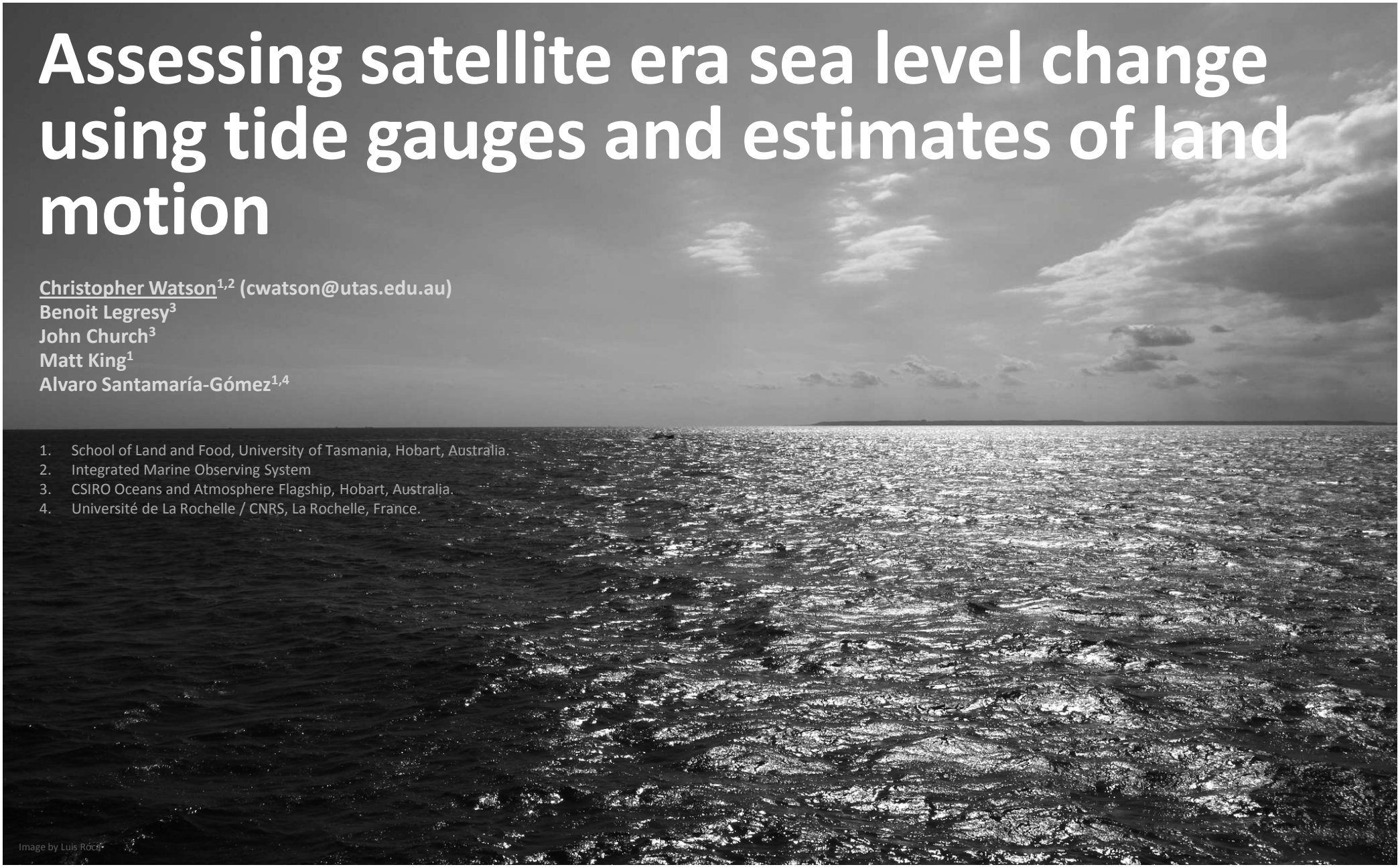

Image by Luis Roca

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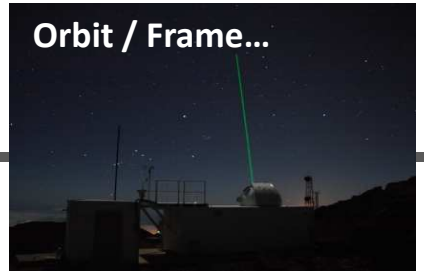
Altimeter era GMSL

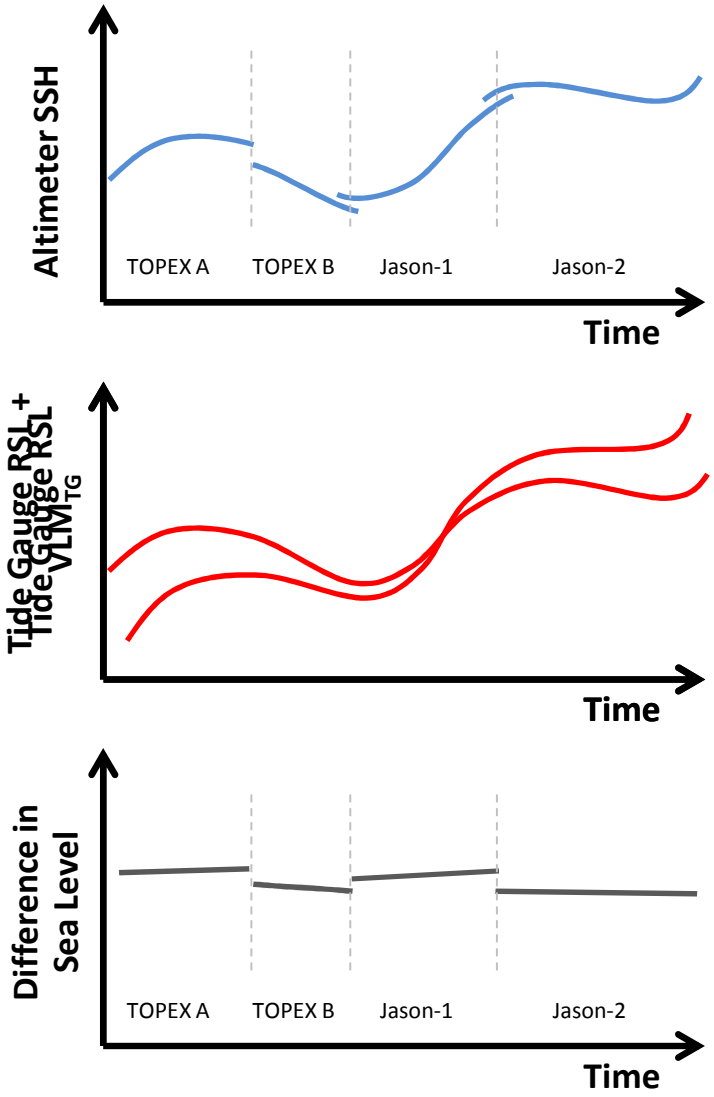
- TOPEX/Jason series sea level time series now approaching 23 years. Rate over 1993-2012 is +3.2 ± 0.4 mm/yr. (IPCC AR5, 2013)
- Our comparison of altimeter data against TGs corrected for land motion suggests that the early part of the altimeter record is not yet fully understood (Watson et al., 2015)

> Q: At what level can we reconcile different measurements of sea (and land) level change?

1. Review our method to highlight some specific details.
2. Recap key results / review some of the underlying assumptions and sensitivity tests undertaken.
3. Conclusions and ongoing work.



Methods Review: Altimeter - TG

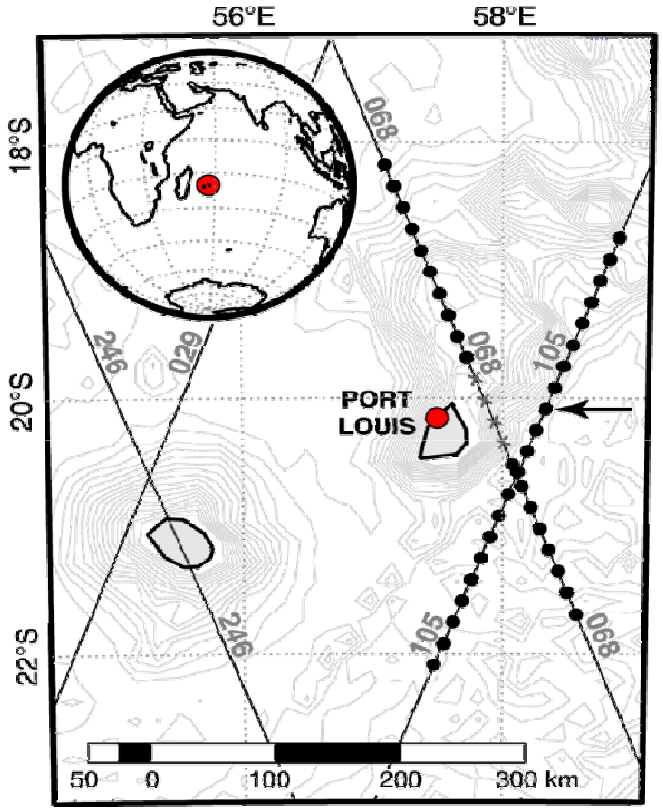


For any given comparison point, we form the difference in sea level (corrected for vertical land motion, VLM, using one of a few different strategies) and then parameterise:

- **Mission specific offsets**
- **Residual tide and across-track SSH slope**
- **Mission specific residual systematic error ("bias drift") modelled as a simple linear term.**

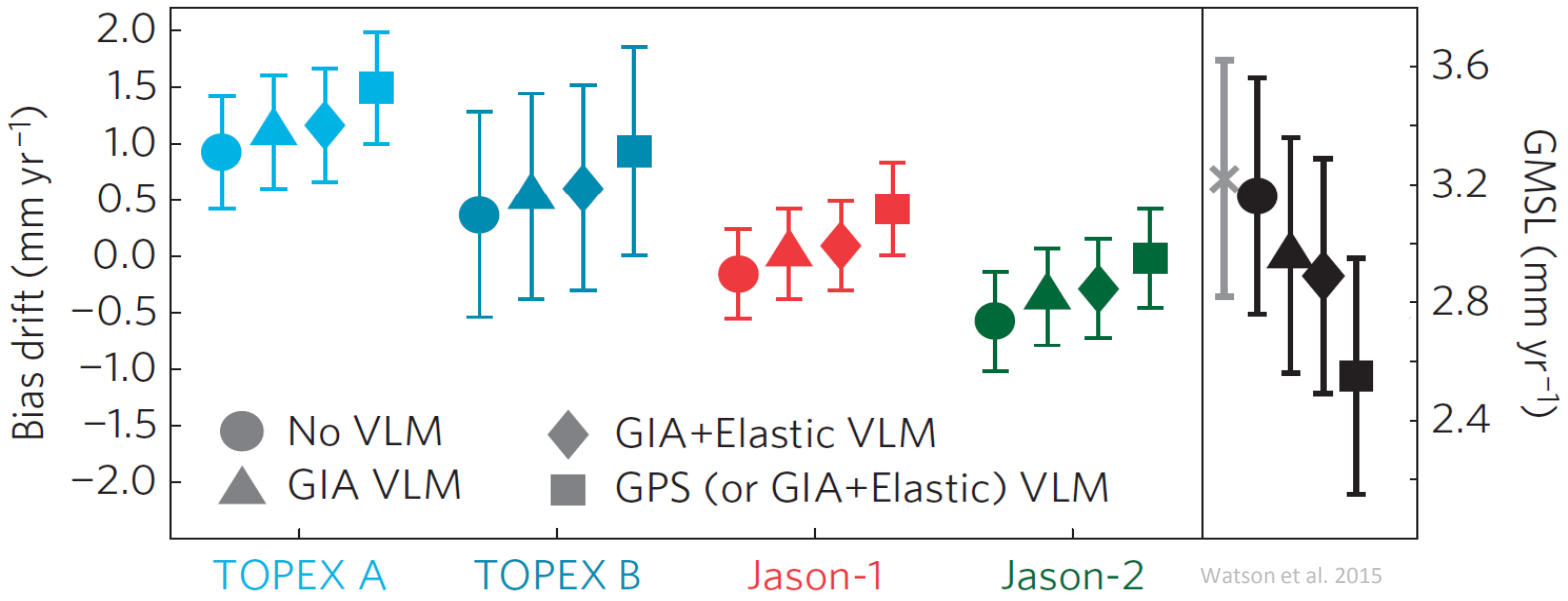
Methods Review: Altimeter - TG

- **Bias drift is estimated for each comparison point, for each mission.**
  - **Comparison point bias drift estimates are stacked to generate mission wise estimates.**
  - **Weights are based on variability about the trend: data driven approach.**
- **Variability about the trend is dominated by residual ocean dynamics given the different spatial sampling (TG vs altimeter).**
- **Uncertainty in land motion at the tide gauge is added prior to estimating the mission wise bias drifts.**
- **Various thresholding is undertaken (e.g. data completeness, gross outliers, earthquakes etc)**

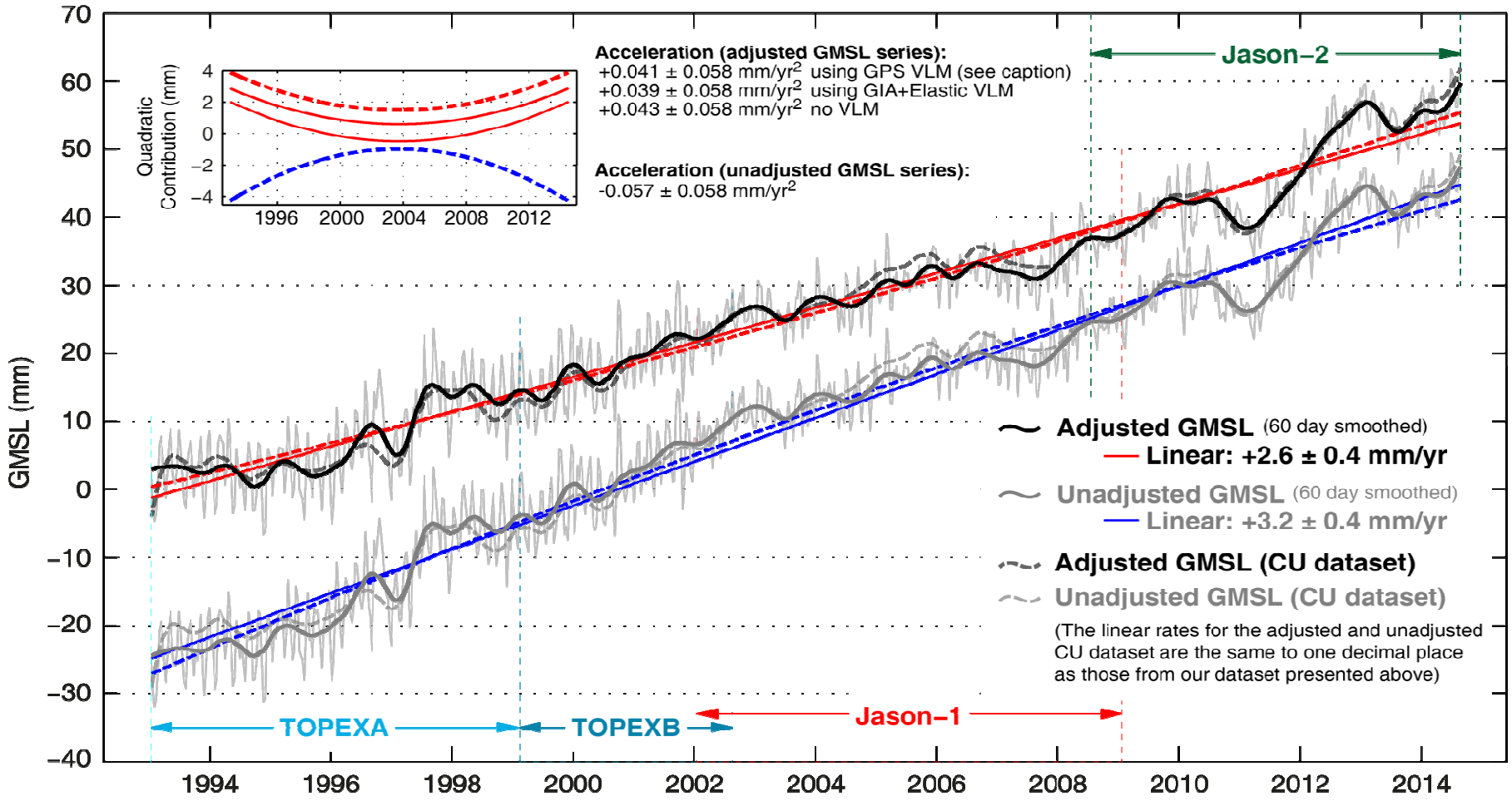


Results Recap: Bias drift

- **Our altimeter bias drift results vary as a function of the TG VLM applied.**
- **A positive bias drift implies the altimeter data overestimates the trend in GMSL.**

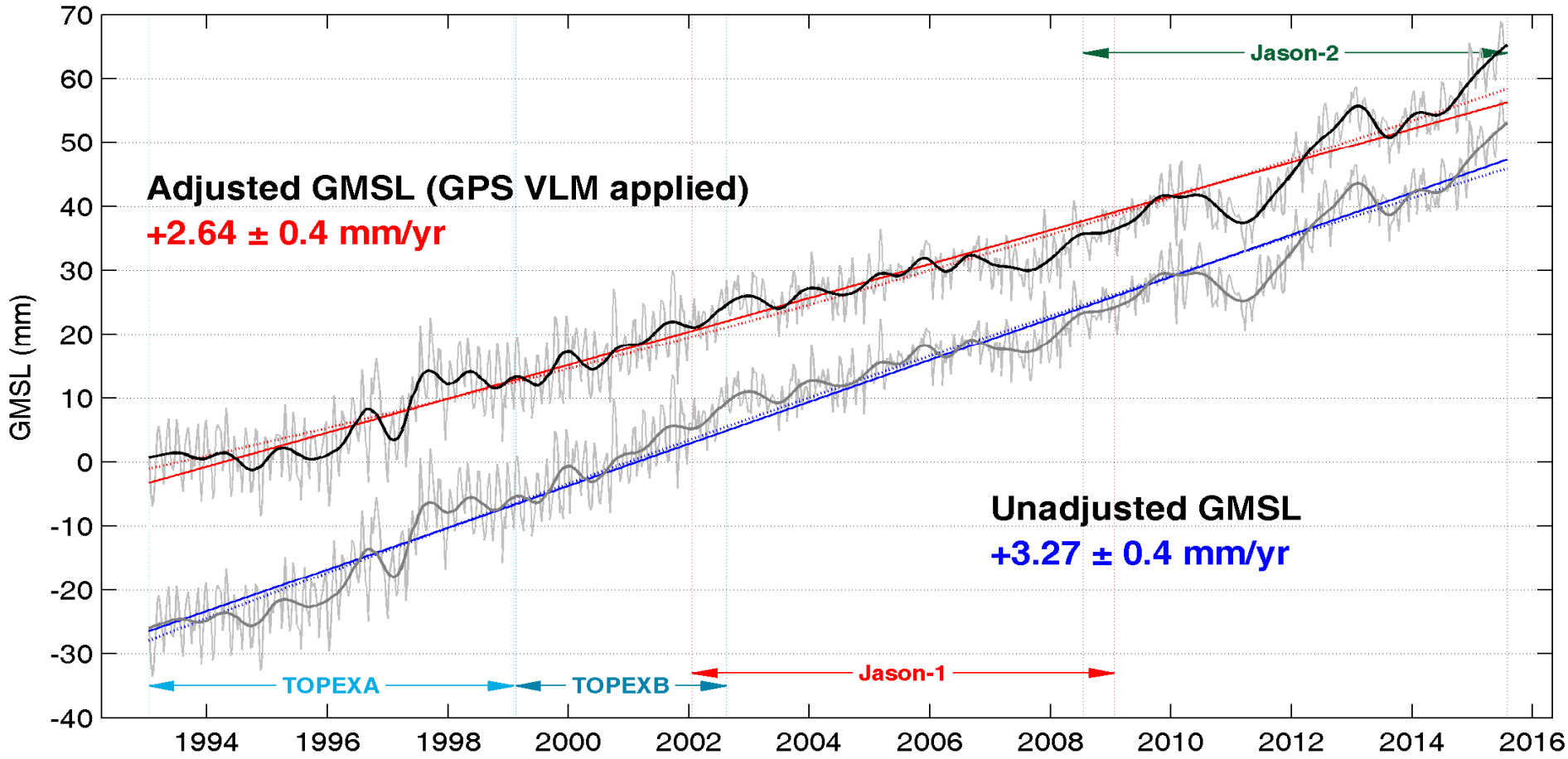


Altimeter GMSL

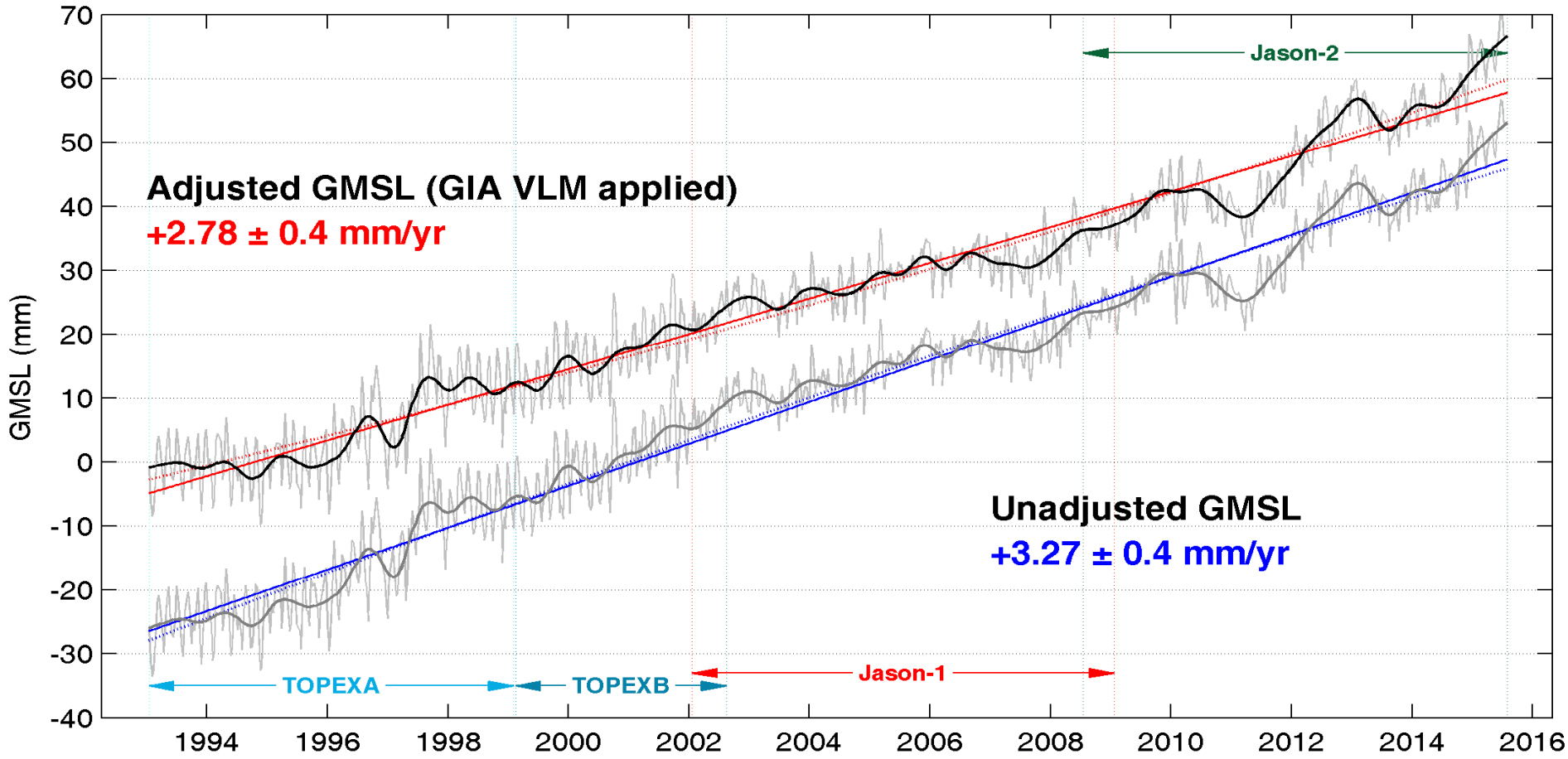


Watson et al. 2015

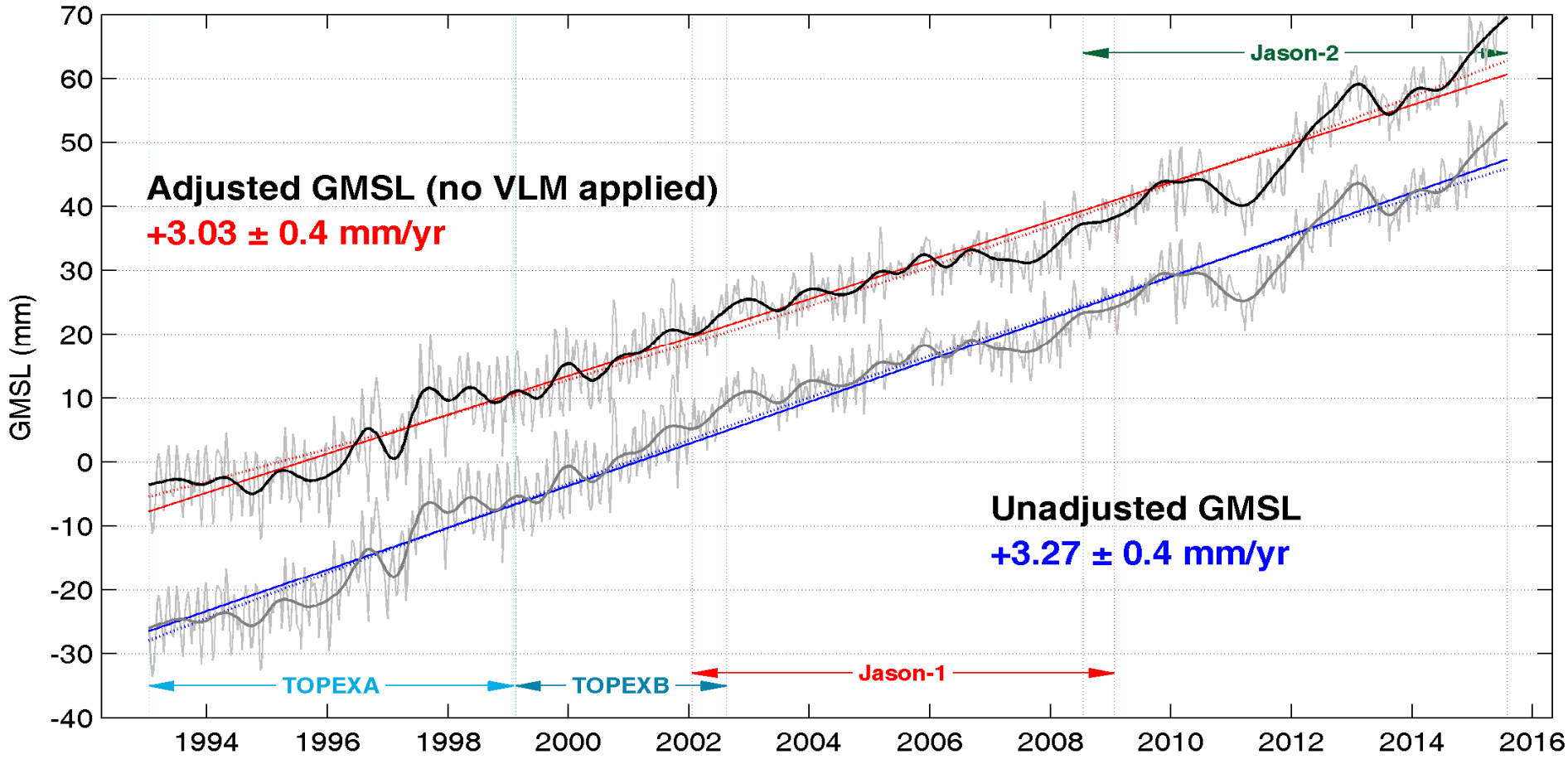
Altimeter GMSL - Updated



Altimeter GMSL - Updated



Altimeter GMSL - Updated



Dealing with Vertical Land Motion

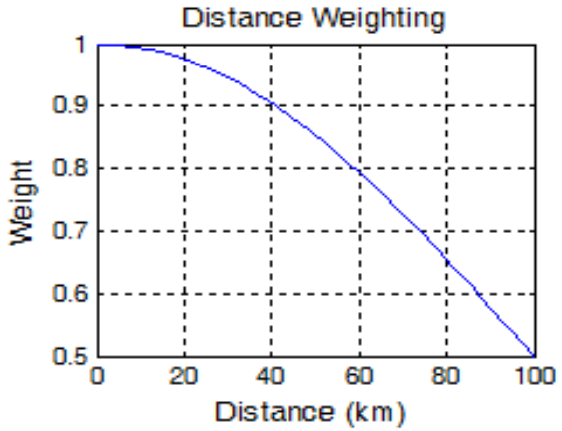
- **Many phenomena influence VLM @ TGs, but limited options for correction:**
- **GIA models:**
  - **Global domain**
  - **Addresses just one component of VLM**
  - **TGs located in continental flexure zones**
  - **Models not perfect and unknown uncertainty.**
- **GNSS (GPS):**
  - **Is VLM @ GPS representative of VLM @ TG?**
  - **What is the rate and uncertainty at the TG if multiple GPS exist within a certain distance?**
  - **GPS has its own challenges (offsets, multipath, antenna PVC, technique specific biases etc) (See later talks, e.g. Santamaría-Gómez, Plagge)**
  - **Linear rates are extrapolated in time (TGs with non linear VLM removed).**

Spring Bay tide gauge, Tasmania, Australia

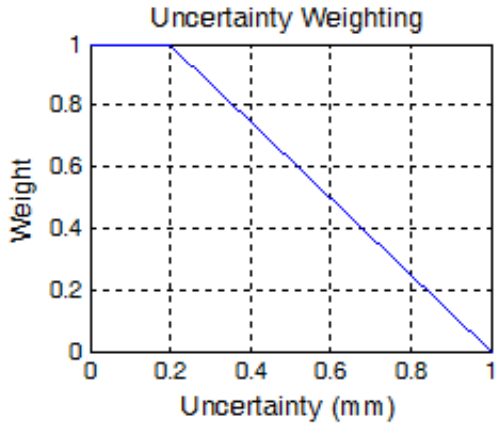
VLM Issues: Multiple GPS / σGPS / σGIA

- 69% of our TGs have one or more GPS sites within 100 km
- 24% of our TGs only have a single GPS within 100 km. Of these:
  - 78% of these are within 10 km
  - 90% within 25 km.

- Where we have multiple GPS, we arbitrarily form the weighted average rate (and uncertainty), where the weight is derived from the product of a "distance weight" and an "uncertainty weight" ($W=W_1W_2$)



$$W_1 = 0.5\cos(2\pi\, d/400) + 0.5$$



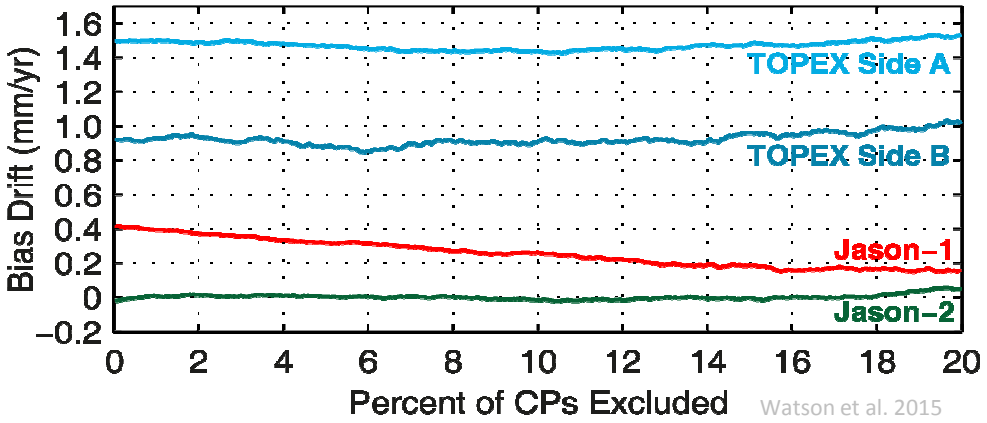
$$W_2 = \begin{cases} 1 & if\ \sigma \le 0.2 \\ -1.25\sigma + 1.25 & if\ 0.2 < \sigma < 1 \\ 0 & if\ \sigma \ge 1 \end{cases}$$

- When reverting to using GIA when GPS is not available, what uncertainty should be used? (we arbitrarily choose ± 1 mm, larger than the mean GPS uncertainty)

Sensitivity Testing

Reporting of sensitivity tests is vital to understanding technique specific differences when comparing altimeter data with tide gauges.

1. **Sensitivity to specific TGs** **-> do a small percentage of TGs have a large influence?**
   -> we sequentially remove the top 20% of highest weighted CPs



Watson et al. 2015

2. **Sensitivity to VLM** **-> what is the influence of VLM vs GIA only vs GPS (reverting to GIA)?**
   -> does the specific GPS solution have an overly large influence?
   -> we reported differences in GPS VLM between King et al and ULR5 (mean -0.13 mm/yr, WRMS of 0.7 mm/yr)
   -> we have since implemented ULR6 which yields bias drift estimates 0.13 to 0.25 mm/yr lower than Watson et al. 2015

Sensitivity Testing

3. **Inter/intra mission relative biases** -> how do these compare with global estimates?
   -> Note: changing the A/B bias by 1 mm changes the GMSL trend by 0.06 mm/yr over the duration of the record

TOPEX A / B Relative Bias:

TOPEX side B – TOPEX side A

Our Approach: **-2.9** ± 2.5 mm

Formation Flight Relative Biases:

Jason-1 – TOPEX side B

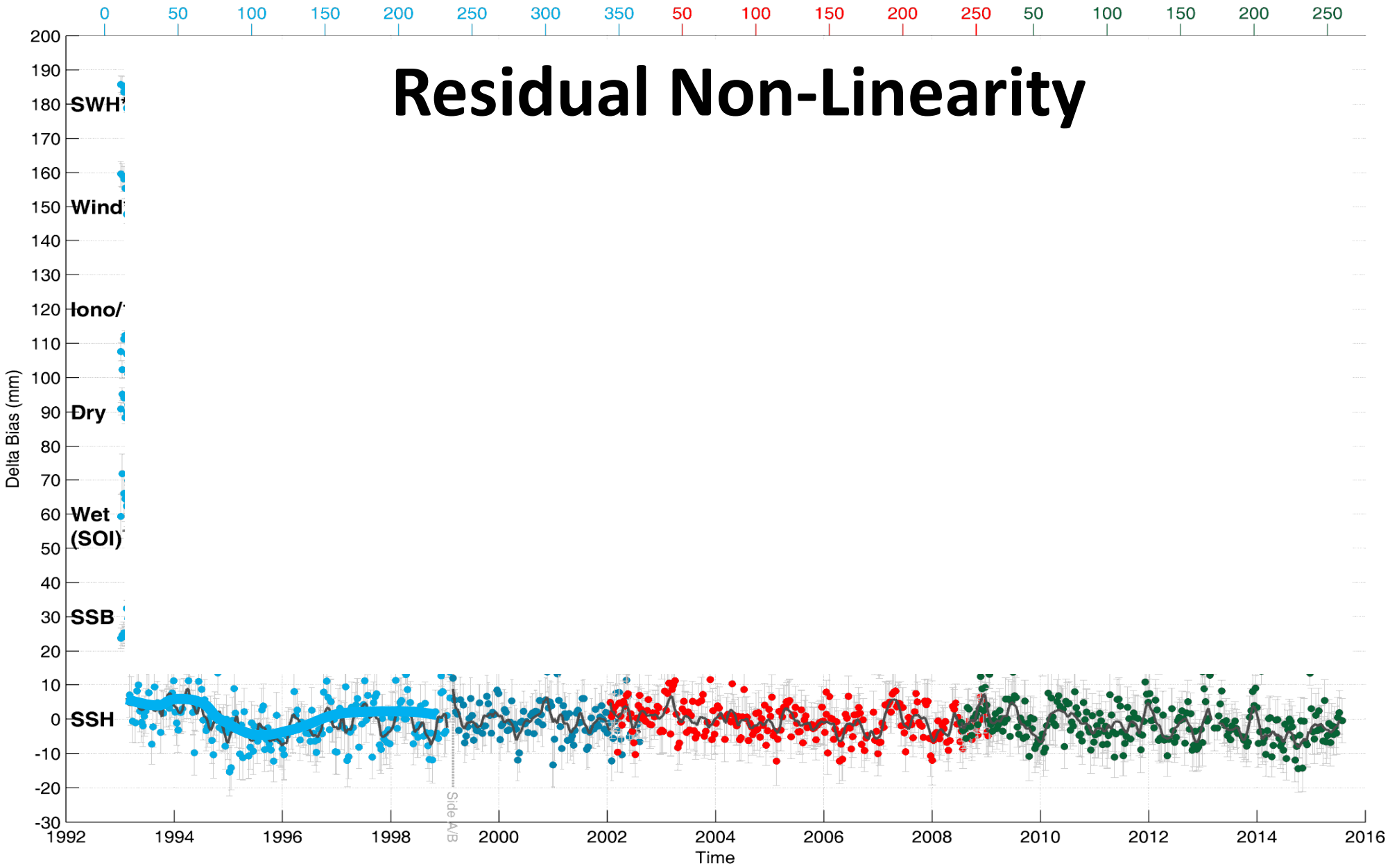
Global Mean: **+85.9** ± 1.2 mm
Our Approach: **+86.1** ± 2.0 mm

OSTM/Jason-2 – Jason-1

Global Mean: **-73.2** ± 0.5 mm
Our Approach: **-73.8** ± 1.5 mm

4. **Sub-setting TOPEX side A** -> Test effect of removing start/finish of TOPEX side A
5. **Altimeter processing comparison** -> CSIRO v CU comparison showed only small differences
6. **Multi-mission bias drift** -> If you concatenate TOPEX A, TOPEX B, Jason-1 and Jason-2 (using appropriate relative biases), is the result in terms of adjusted GMSL consistent with that from applying mission-specific bias drifts?

Residual Non-Linearity



SSH Residual: RMS: 6.2 mm RMS: 5.2 mm RMS: 4.8 mm RMS: 5.0 mm

Conclusions

1. Tide gauges remain an important tool – our work suggests TOPEX is yet to be fully understood and is overestimating the trend in GMSL.
2. Land motion at tide gauges is a complex problem that requires further progress in order to better understand a) altimeter vs in situ data and b) 20th C estimates of GMSL change.
3. We have the following analyses to complete on return from OSTST:
   - TOPEX Climate Data Record (RGDR) (Callahan et al.)
   - Jason-1 GDR-E (CNES/JPL)
4. We're interested in assessing the impact of products such as GPD+ and ALES on our results -> this may be informative.
5. We are in the initial phase of modifying our approach to repeat our analysis using EnviSat and AltiKa data.

Questions?

Reference:
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*, *5*(6), 565-568, doi: 10.1038/nclimate2635.

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Spares

Updated Results