Refining satellite era estimates of global mean sea level rise

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Image by Luis Roca

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CSIRO

IMOS Integrated Marine Observing System

Australian Government Australian Research Council

IGS INTERNATIONAL GNSS SERVICE

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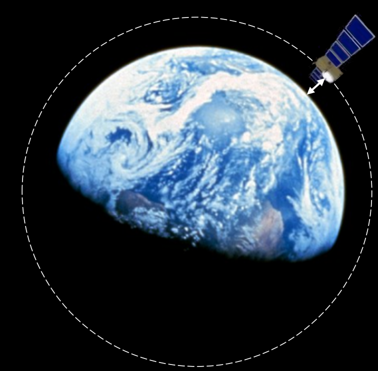
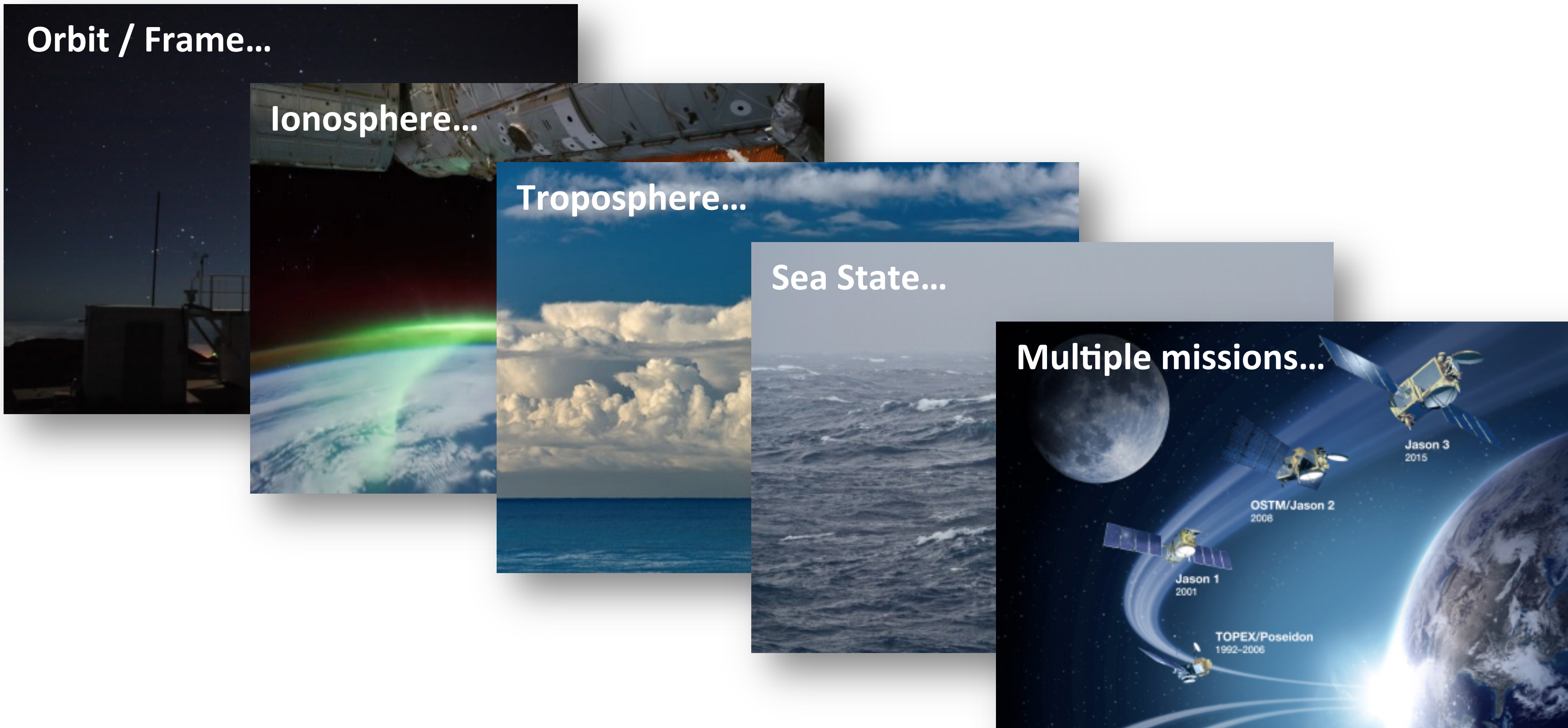


- ~71% of the Earth's surface is covered by ocean
- ~10% of the Earth's surface is covered by water in the form of ice
- ~93% of the excess heat stored on Earth over the last 40 years is stored in the ocean
- Consensus estimate for the rate of global mean sea level change using Jason-series altimetry over 1993-2012 is +3.2 ± 0.4 mm/yr (IPCC AR5, 2013)

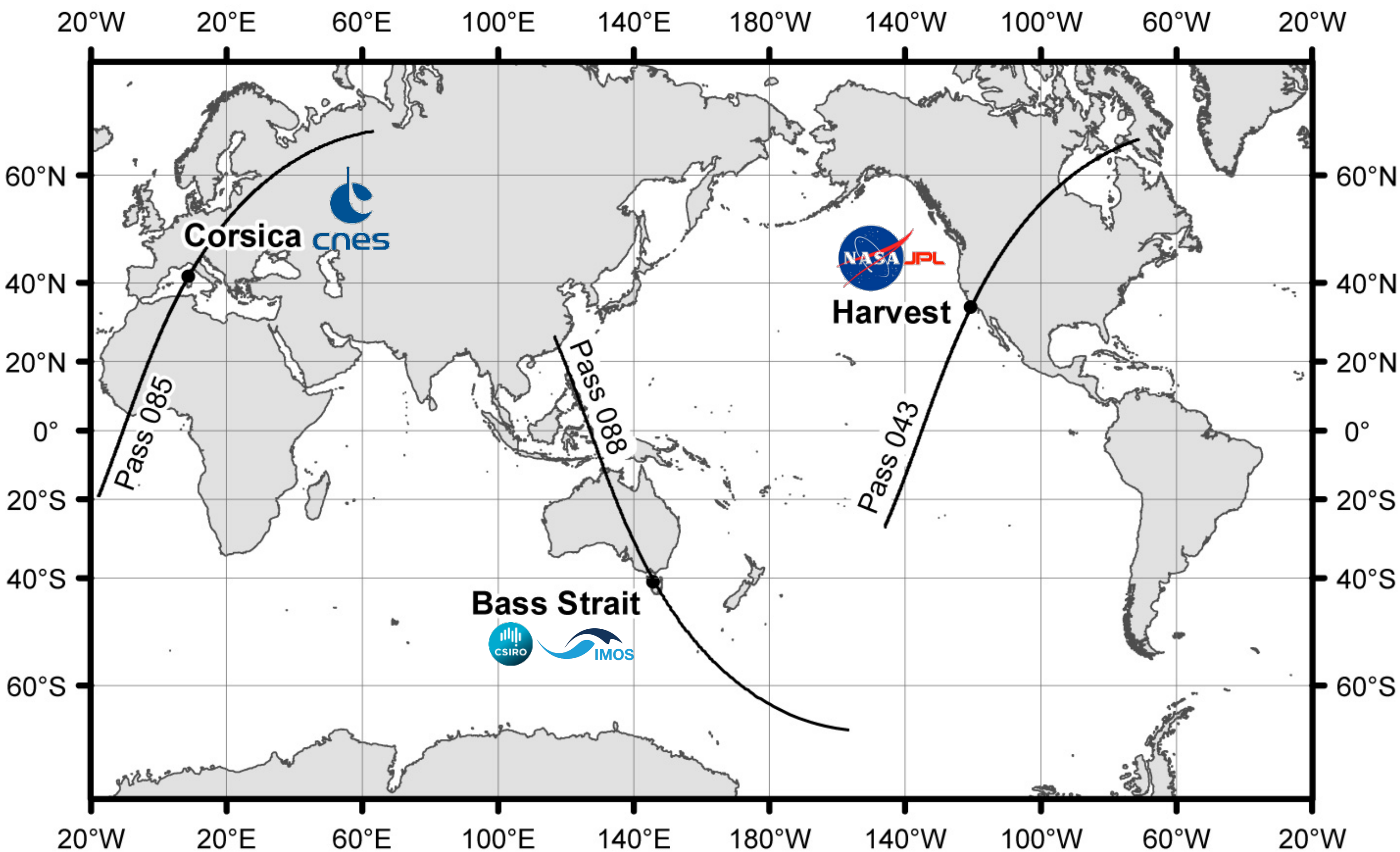
Altimeter GMSL – Why is this difficult?



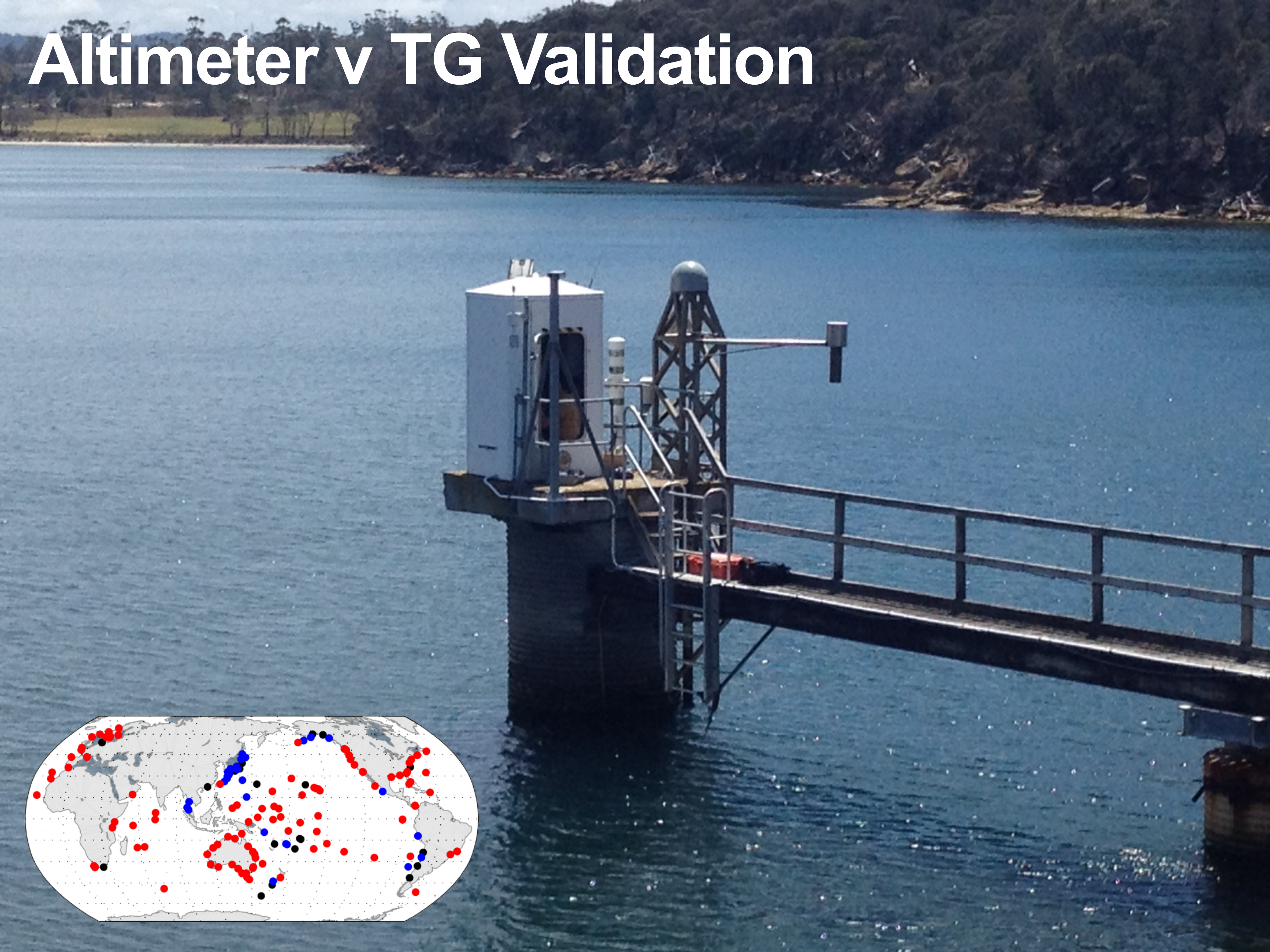
Q1: At what level could the altimeter record be systematically biased?

Q2: At what level can we reconcile different measurements of sea (and land) level change?

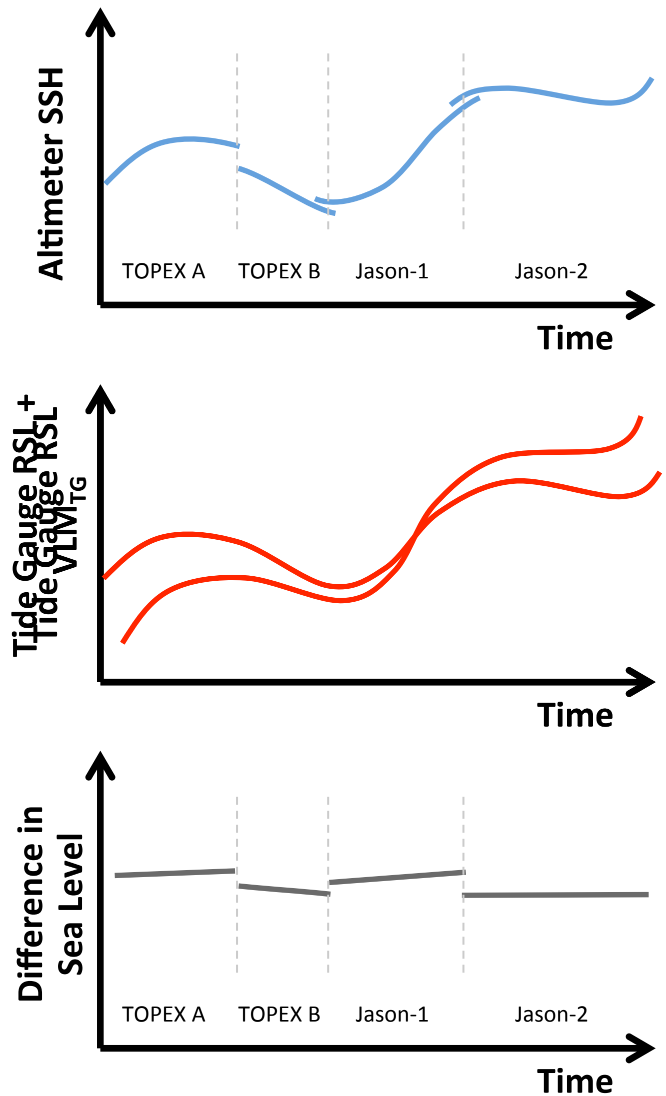
"Absolute" Altimeter Validation



Altimeter v TG Validation



Methods Review: Altimeter - TG



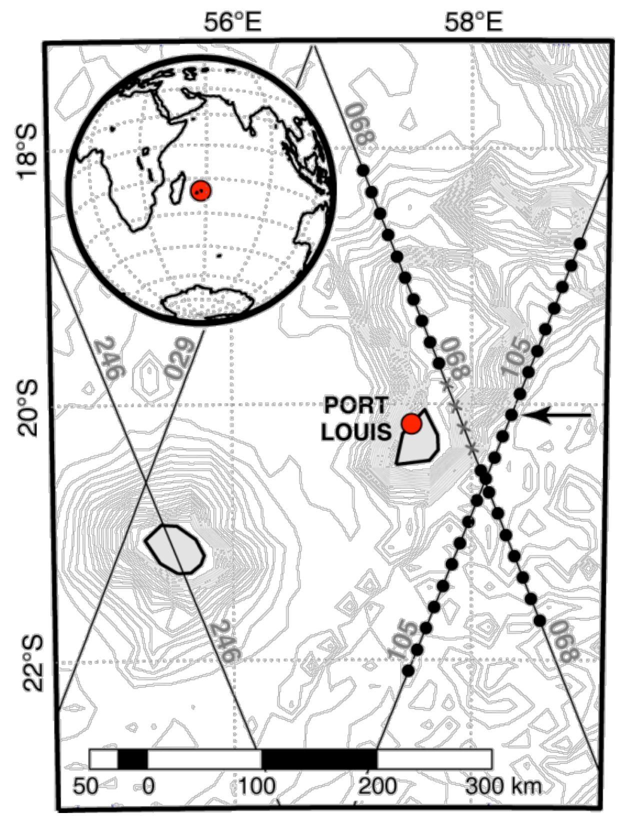
For any given comparison point, we form the difference in sea level (corrected for vertical land motion, VLM, using one of a few different strategies) and then parameterise:

- **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

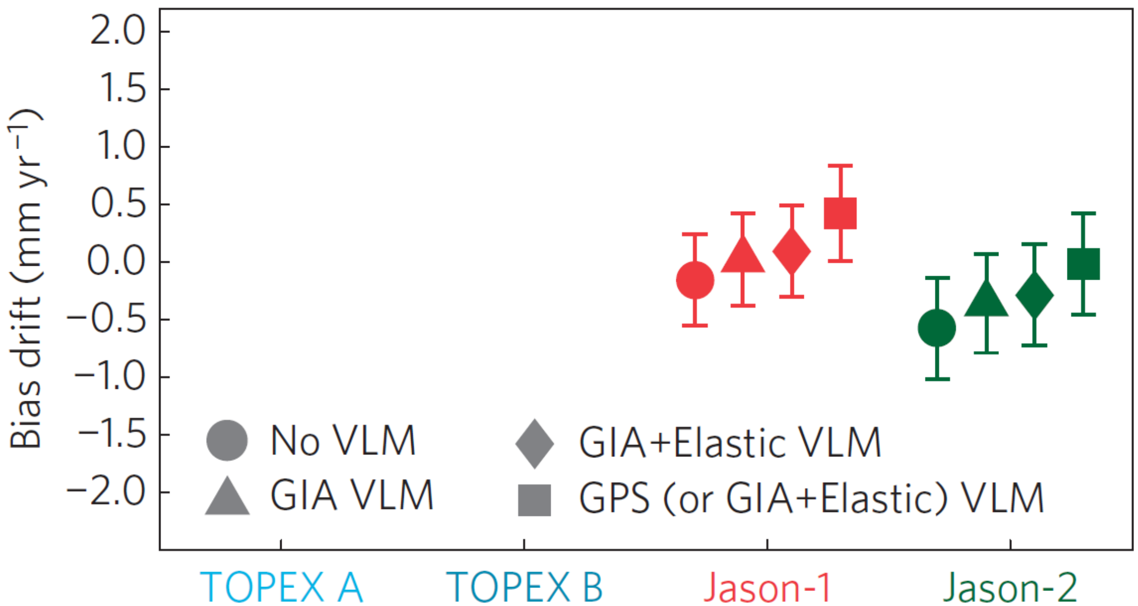
- **Bias drift is estimated for each comparison point, for each mission.**
  - **Comparison point bias drift estimates are stacked to generate mission wise estimates.**
  - **Weights are based on variability about the trend: data driven approach.**

- **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: Altimeter "bias drift"

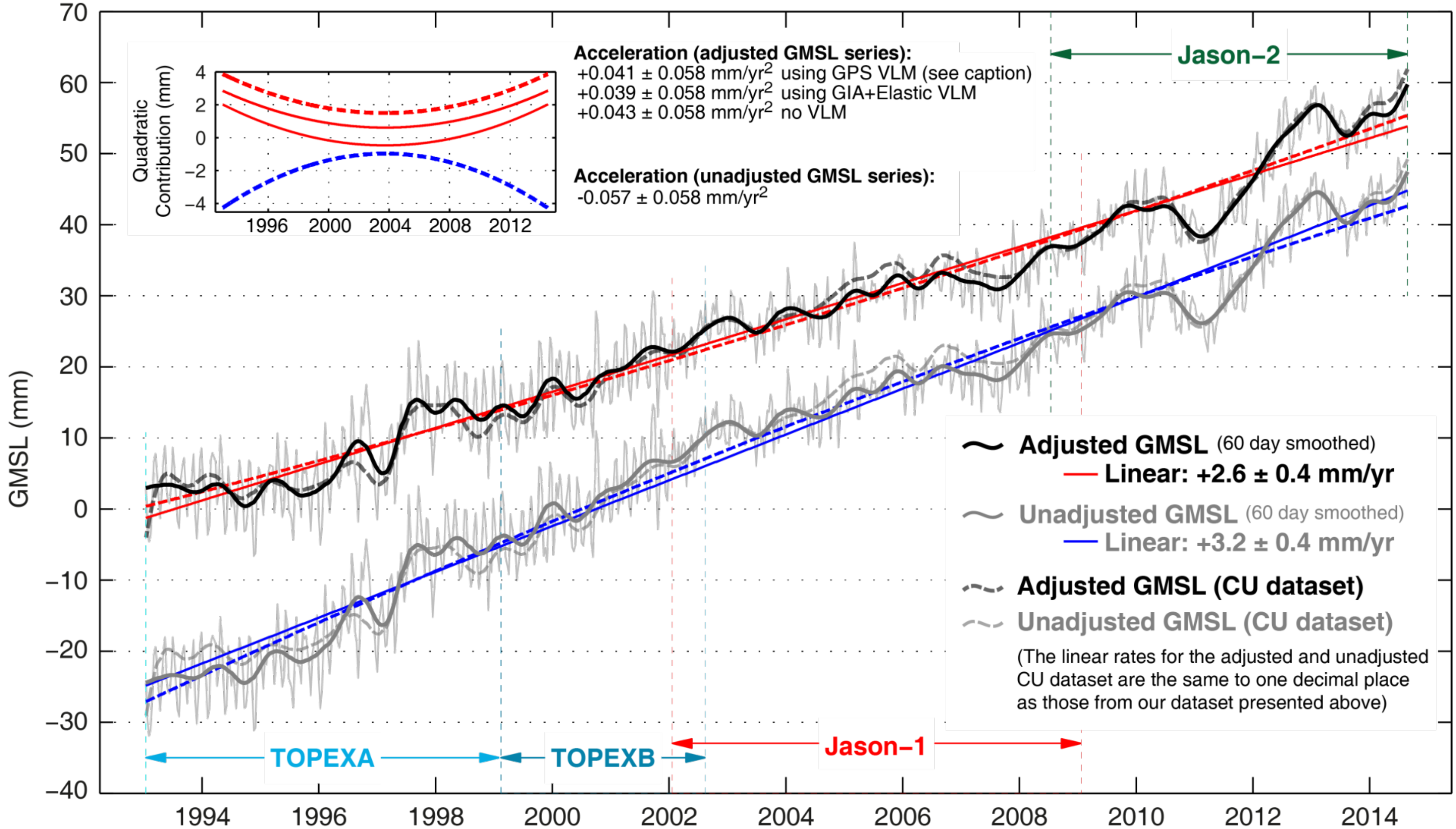
- **Our altimeter bias drift results vary as a function of the VLM applied at the TG.**
- **A positive bias drift implies the altimeter data overestimates the trend in GMSL.**



Watson et al. *Nature Climate Change* 2015

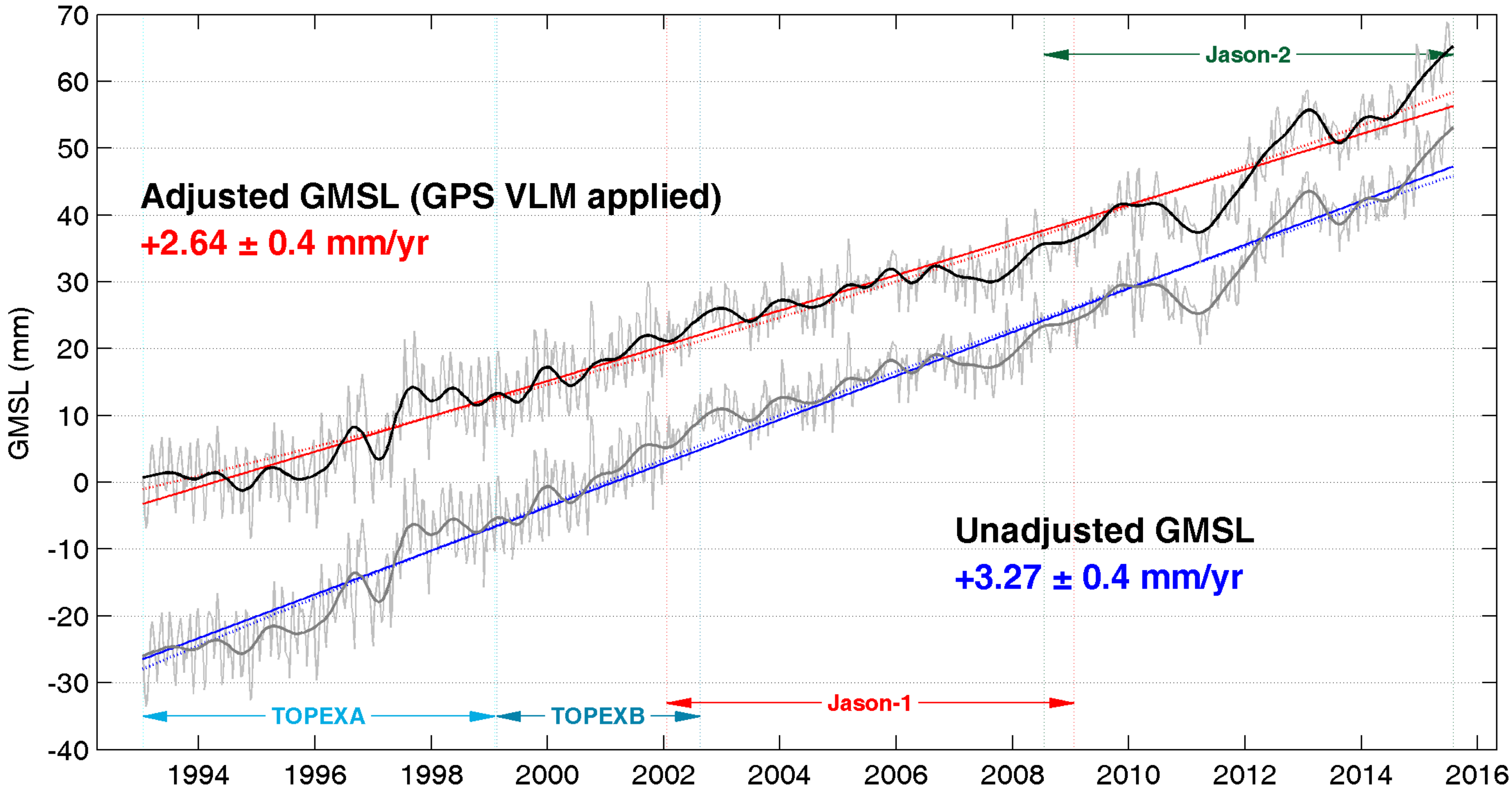
- **Should the best-estimates of systematic bias drift be used to adjust or calibrate GMSL?**

Altimeter GMSL

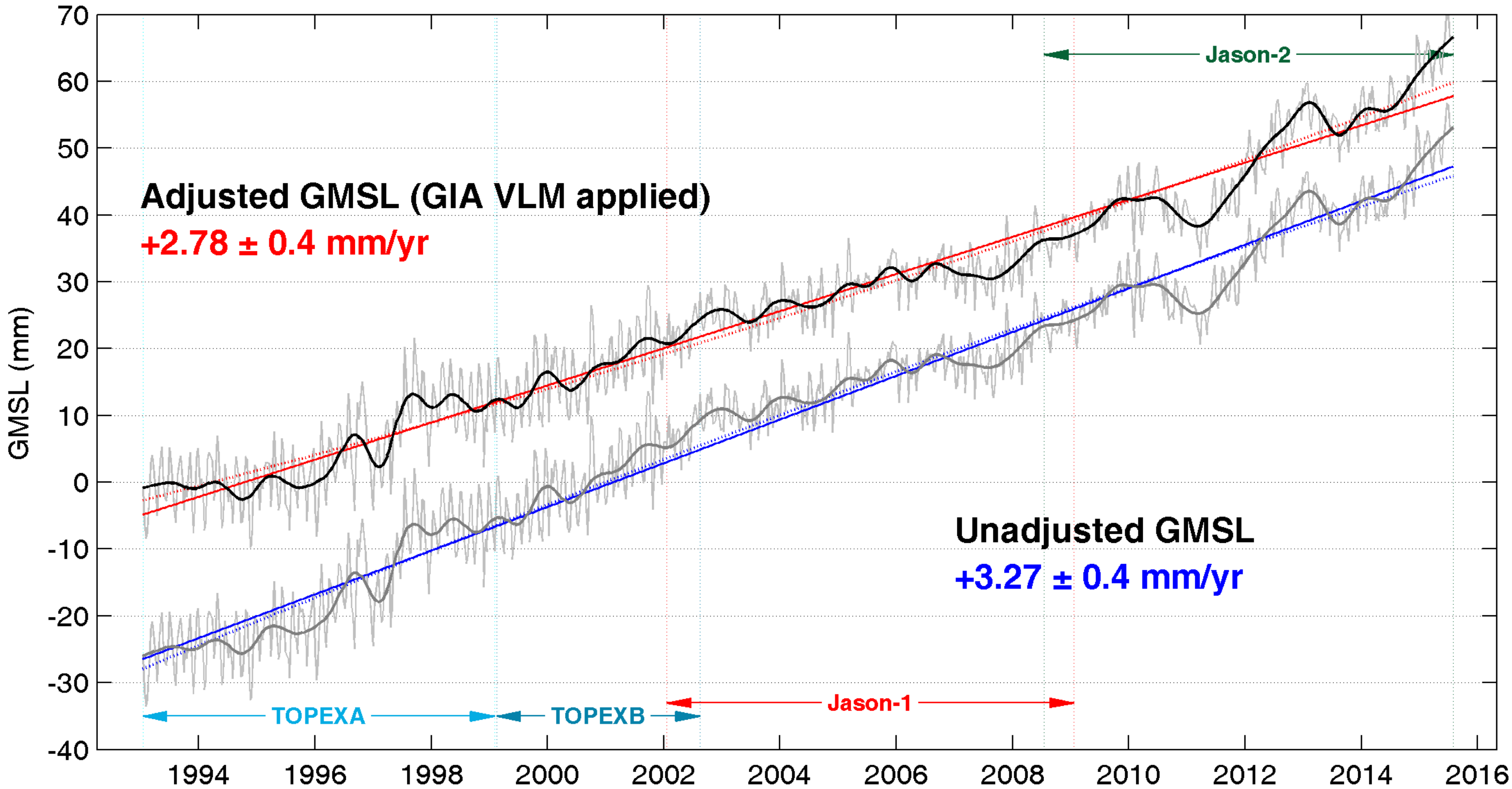


Watson et al. 2015

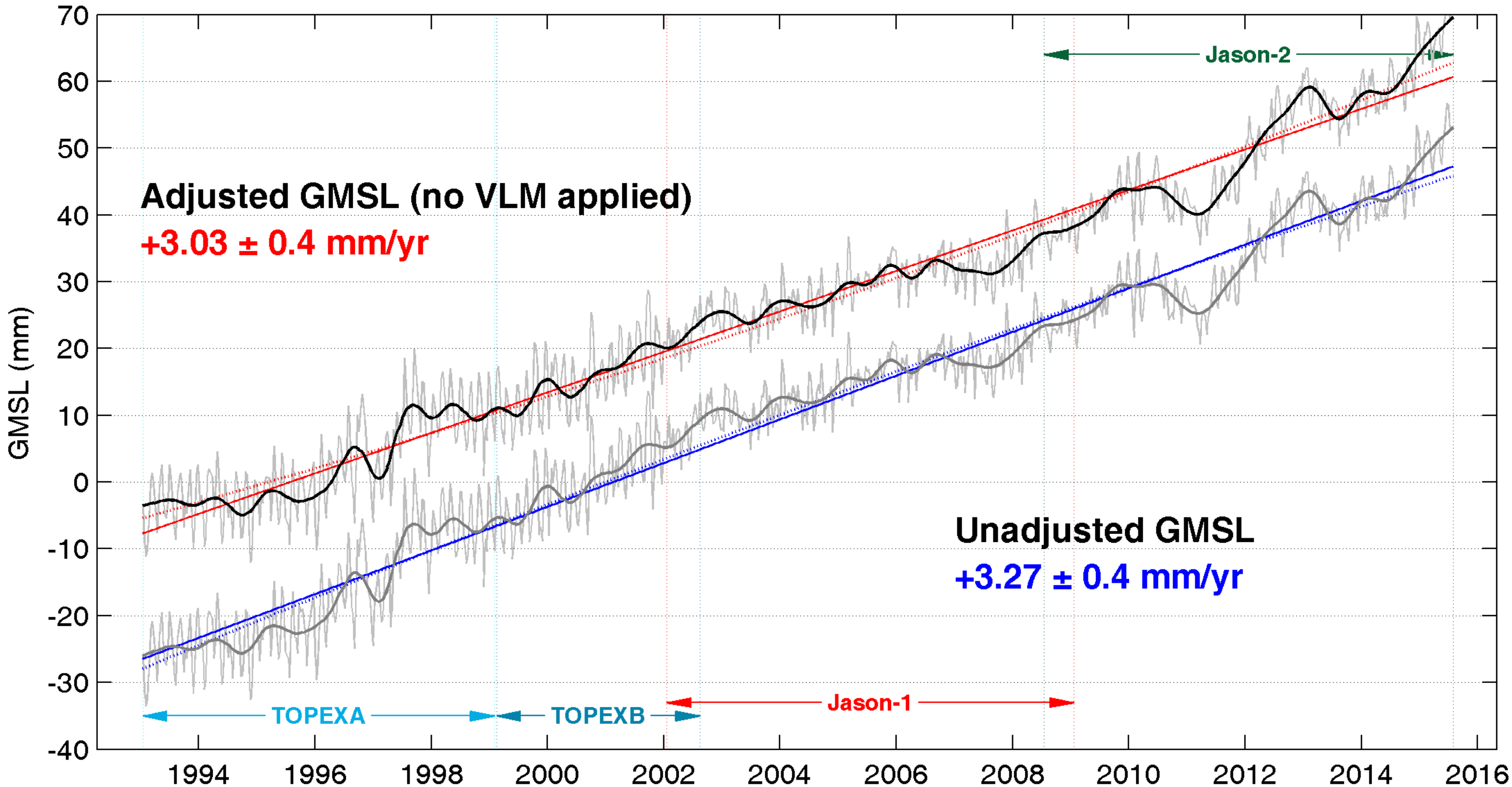
Altimeter GMSL - Updated



Altimeter GMSL - Updated



Altimeter GMSL - Updated



Limitations: Vertical Land Motion

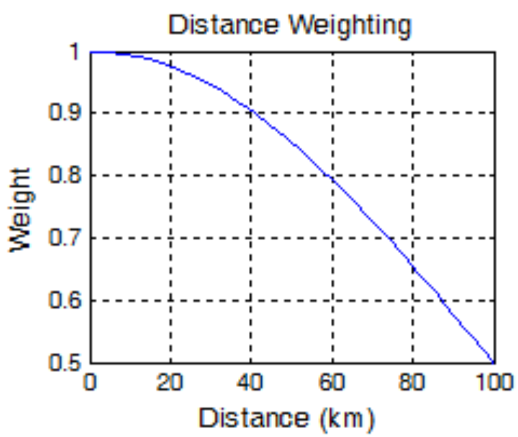
- **Many phenomena influence VLM @ TGs, but limited options for correction:**
- **GIA models:**
  - **Global domain**
  - **Addresses just one component of VLM**
  - **TGs located in continental flexure zones**
  - **Models not perfect and unknown uncertainty.**
- **GNSS:**
  - **Is VLM at the geodetic site representative of VLM at the tide gauge?**
  - **What is the rate and uncertainty at the TG if multiple GPS exist within a certain distance?**
  - **How representative is a linear rate back in time? (TGs with non linear VLM removed apriori).**

Spring Bay tide gauge, Tasmania, Australia

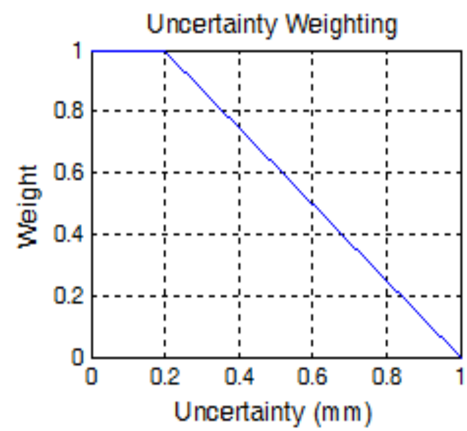
VLM Issues: Multiple GPS / σGPS / σGIA

- **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" ($W=W_1W_2$)**



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



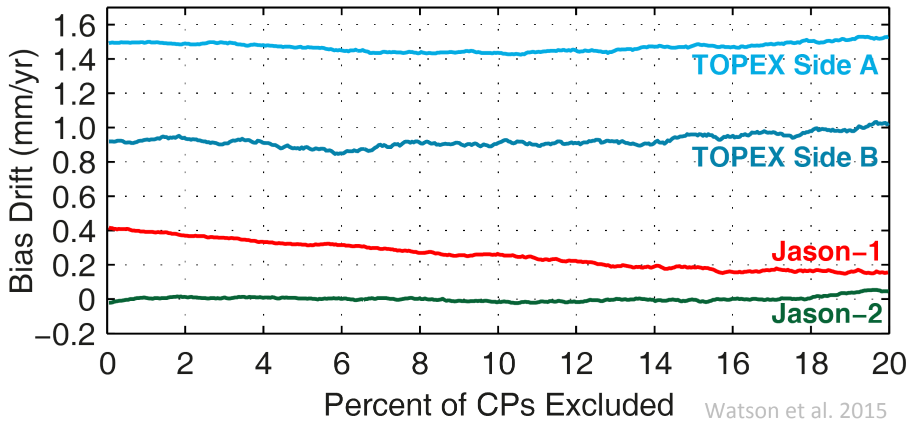
$$W_2 = \begin{cases} 1 \\ -1.25\sigma + 1.25 \\ 0 \end{cases} \quad \text{if } \sigma \leq 0.2$$

- **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

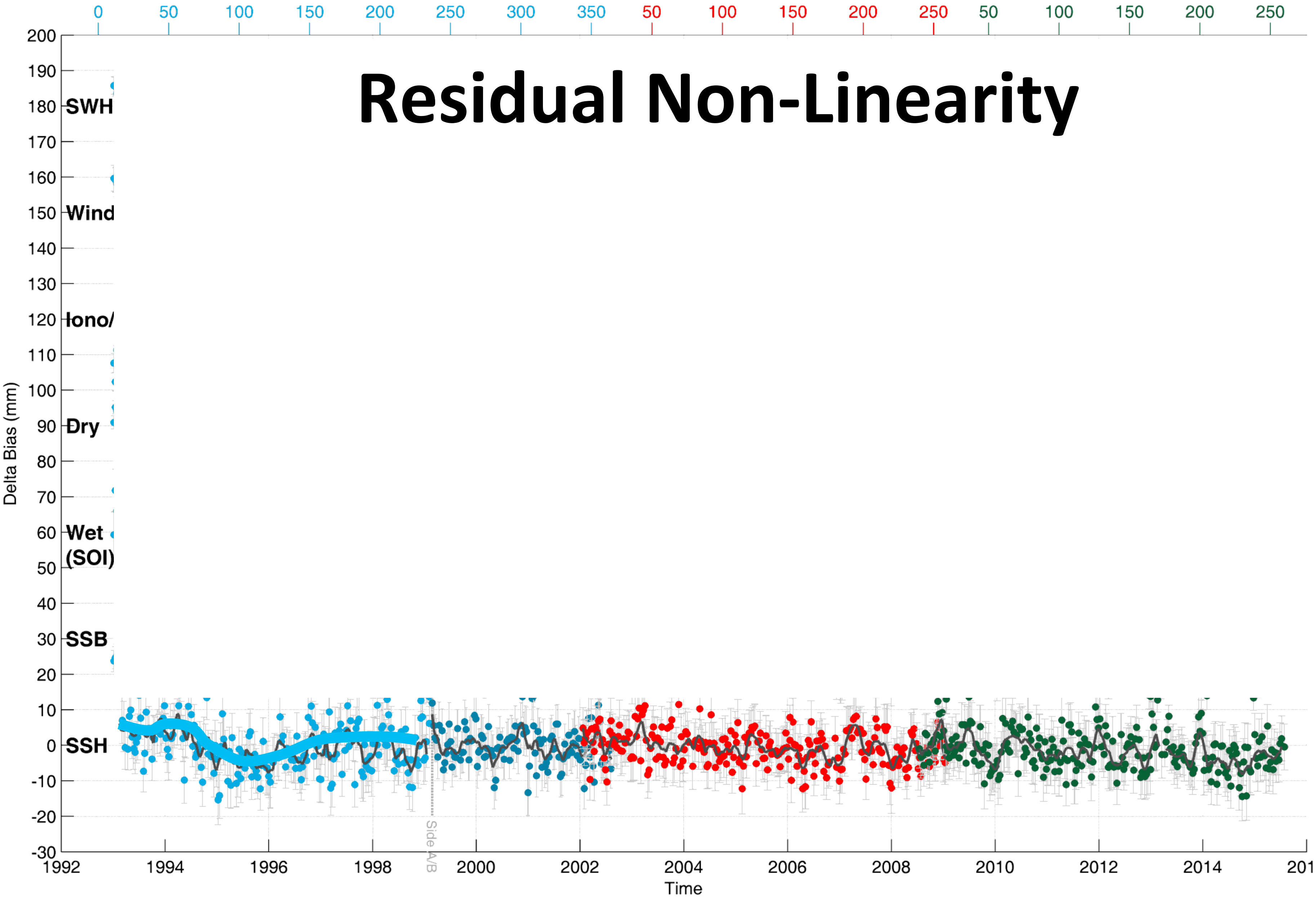
OSTM/Jason-2 – Jason-1

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 of 2)

1. **Tide gauges and associated geodetic infrastructure remain vitally important for satellite altimetry**
   - **Our work suggests TOPEX is yet to be fully understood and is presently slightly overestimating the trend in GMSL.**
   - **Our revised record seems more consistent with the sum of the observed contributions to GMSL. While not yet statistically significant, we see the emergence of an acceleration.**
   - **Further reprocessing of TOPEX is currently underway by mission agencies, first results seem commensurate with our findings, but this remains in progress.**
   - **Ongoing community effort to refine understanding in the different altimeter – TG techniques to validate the record.**

Conclusions (2 of 2)

2. **Vertical land motion along the coast (and at tide gauges) is an ongoing problem that requires further progress.**

   - **Recall that it is r*elative* sea level change that affects the coastal population and environments. VLM fields and altimetry are critical.**
   - **There is an increasing demand for GNSS vertical velocities @ TGs.**
   - **Local relative deformation critical – levelling, InSAR important.**
   - **We encourage efforts within the IGS to further the goals of TIGA.**

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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