Assessing Altimeter Bias Drift
Using Tide Gauges and Estimates of Vertical Land Motion

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❶ Aims and Motivation

We seek to further understand the error characteristics in the evolving 20+ year altimeter climate record through analysis of altimeter – tide gauge (TG) differences. We test sensitivity to a range of different Vertical Land Motion (VLM) data as well as altimeter data treatments, varying orbit and environmental corrections commonly used in the literature for global and regional sea level studies.

❷ Data

- Altimeters*:* We analyse different treatments of data from the TOPEX, Jason-1 and OSTM/Jason-2 missions.

Version	TOPEX	Jason-1	OSTM/Jason-2
v1	As per GDR-B	As per GDR-C	As per GDR-T
v2	v1 with TMR and yaw state corrections	v1 with JMR UPD and EXP corrections	v1 with AMR update
v3	v2 with Chambers et al (2003) SSB.	-	-
v4	v3 with GSFC std0905 orbits.	v2 with GSFC std0905 orbits.	v2 with GSFC std0905 orbits.
v6	-	-	v2 with GSFC std1201 orbits

- Tide Gauges*:* 157 tide gauges, hourly data from the NTC and UHSLC archives.
- GPS VLM*:* GPS rates from King et al (2012).
- GIA VLM*:* GIA estimates of VLM using the ICE5G VM2 model from Tamisiea (2011).

❸ Approach

- Includes multiple altimeter passes per TG and multiple Comparison Points (CPs) per pass.
- Allows for a 'self selection' process to down weight outliers (e.g. following an earthquake or from an unresolved tide gauge datum issue).
- Integrates GPS and GIA estimates of VLM.
- Permits flexible editing based on a range of quality metrics at the CP, pass, TG, inter/intra-mission level.

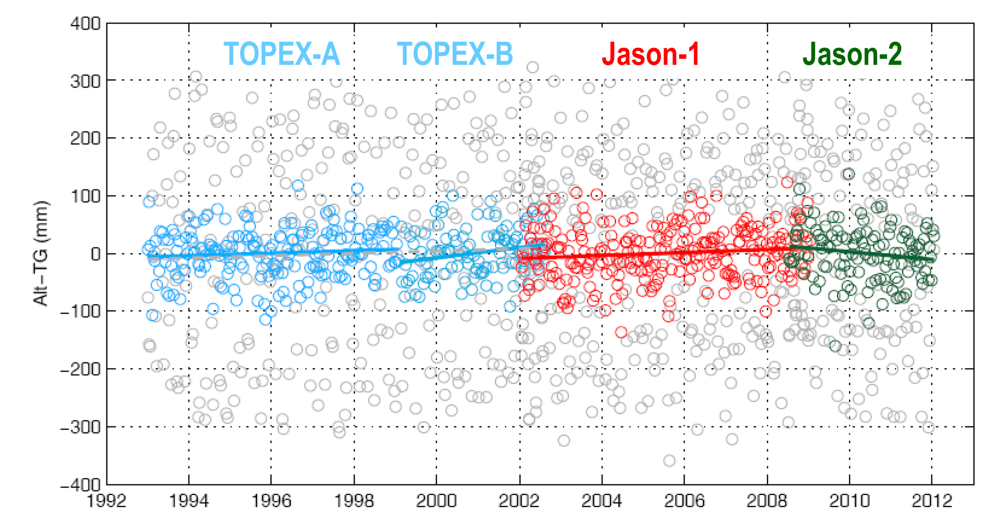

Figure 1: Example analysis at an individual comparison point. Grey circles show ALT – TG series prior to tidal and across track gradient correction (coloured circles are post-correction). Coloured lines are linear bias-rates (fit to coloured circles, offset removed, corrected for VLM) and are specific to this comparison point and the various altimeter missions.

❹ Methods Overview

For each tide gauge we extract GPS (<100km) and GIA estimates of VLM, remove obvious outliers and flag proximity to significant thrust earthquakes.

We then calculate ALT - TG time series at every comparison point (CP) with sufficient useful data, and solve for the tidal component using the multi-mission time series (Figure 1).

For each mission and at each CP, a bias-drift rate is calculated, and quality statistics saved. These rates are then combined to produce bias-drift rates and error estimates for each mission.

❺ Sample Bias Rates:
TGs: Brest and Betio

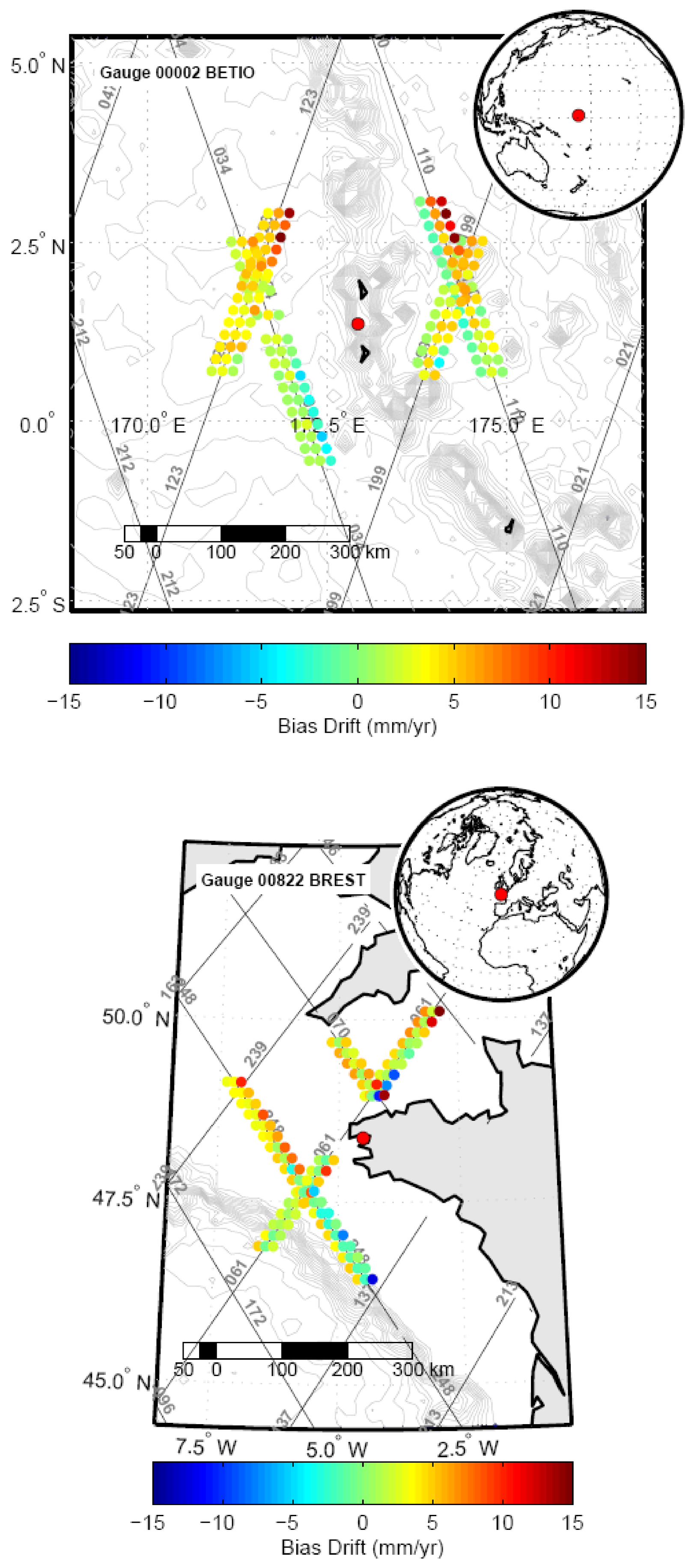

Figure 2: Each pass shows bias drift estimates at each CP from TOPEX A&B (dots west of ground track), Jason-1 (dots on ground track) and OSTM/Jason-2 (dots east of ground track).

The differences highlight the need to further understand possible low frequency contributions to the ALT – TG time series (oceanographic and meteorological effects). Non-linear VLM must also be considered at many sites.

❻ Results

- Small but systematic differences are observed between bias-drift estimates using different altimeter treatments (Table 1).
- Uncertainty in bias drift estimates approaches ±0.5 mm/yr (1-sigma) over 7 years (e.g. Jason-1).
- Application of GIA VLM, or where available, GPS VLM brings Jason-1 and OSTM/Jason-2 rates closer to zero, but the opposite for TOPEX A&B (Table 2). GPS VLM has larger influence than GIA VLM.

ALT Version			TOPEX Side A&B		TOPEX Side A		< REL BIAS >	TOPEX Side B		< REL BIAS >	Jason-1		< REL BIAS >	OSTM/Jason-2	
TOPEX	Jason-1	Jason-2	Rate (mm/yr)	RMS (mm)	Rate (mm/yr)	RMS (mm)		Rate (mm/yr)	RMS (mm)		Rate (mm/yr)	RMS (mm)		Rate (mm/yr)	RMS (mm)
1	1	1	-1.00 ± 0.37	6.53	-0.43 ± 0.58	6.93	< -7.0 ± 2.9 >	0.52 ± 0.98	5.58	< 100.2 ± 2.6 >	0.05 ± 0.54	5.21	< 73.7 ± 2.2 >	-0.44 ± 0.94	5.87
2	2	2	-0.29 ± 0.37	6.81	0.75 ± 0.58	6.95	< -7.7 ± 2.9 >	0.54 ± 0.97	6.03	< 96.8 ± 2.6 >	0.06 ± 0.54	5.34	< 72.7 ± 2.1 >	-0.48 ± 0.92	5.87
3			0.50 ± 0.37	6.58	0.79 ± 0.58	7.00	< -2.4 ± 2.9 >	0.53 ± 0.97	6.06	< 91.0 ± 2.6 >					
4	**4**	**4**	**0.52 ± 0.37**	**6.32**	**0.92 ± 0.57**	**6.81**	**< -2.7 ± 2.8 >**	**0.56 ± 0.99**	**5.65**	**< 91.9 ± 2.5 >**	**0.11 ± 0.54**	**5.26**	**< 72.7 ± 2.1 >**	**-0.43 ± 0.97**	**6.02**
		6											< 73.5 ± 2.1 >	-0.56 ± 0.89	6.16
# of TGs | Passes | CPs:			(85 | 180 | 2110)		(86 | 183 | 2128)			(80 | 167 | 1657)			(96 | 197 | 2191)			(82 | 176 | 1834)	

Table 1: Bias drift rates as a function of altimeter treatment. GPS/GIA VLM, and earthquake editing applied. Grey shading highlights our preferred solution given consistent orbits. (+)ve bias rate = altimeter over estimating in situ trend.

Same Solution

VLM			TOPEX Side A&B		TOPEX Side A		< REL BIAS >	TOPEX Side B		< REL BIAS >	Jason-1		< REL BIAS >	OSTM/Jason-2	
GPS	GIA	Eq Edits	Rate (mm/yr)	RMS (mm)	Rate (mm/yr)	RMS (mm)		Rate (mm/yr)	RMS (mm)		Rate (mm/yr)	RMS (mm)		Rate (mm/yr)	RMS (mm)
Yes	Yes	Yes	**0.52 ± 0.37**	**6.32**	**0.92 ± 0.57**	**6.81**	**< -2.7 ± 2.8 >**	**0.56 ± 0.99**	**5.65**	**< 91.9 ± 2.5 >**	**0.11 ± 0.54**	**5.26**	**< 72.7 ± 2.1 >**	**-0.43 ± 0.97**	**6.02**
NO	NO	Yes	-0.09 ± 0.37	6.10	0.34 ± 0.58	6.73	< -2.7 ± 2.8 >	-0.01 ± 0.99	5.59	< 91.9 ± 2.5 >	-0.44 ± 0.54	5.16	< 72.7 ± 2.1 >	-0.92 ± 0.97	5.99
NO	Yes	Yes	0.00 ± 0.37	6.10	0.43 ± 0.58	6.73	< -2.7 ± 2.8 >	0.10 ± 0.99	5.59	< 91.9 ± 2.5 >	-0.33 ± 0.53	5.17	< 72.7 ± 2.1 >	-0.81 ± 0.97	6.00
Yes	NO	Yes	0.54 ± 0.38	6.34	0.95 ± 0.58	6.82	< -2.7 ± 2.8 >	0.58 ± 0.99	5.65	< 91.9 ± 2.5 >	0.13 ± 0.54	5.27	< 72.7 ± 2.1 >	-0.43 ± 0.98	6.02

Table 2: Bias drift rates from preferred altimeter treatment (Table 1) as a function of different applications of VLM.

- Our standard solution conservatively removes all TGs within 400 km of any thrust earthquakes (plunge > 45, M_w > 6.0). Removing this criteria and editing based only on minimum threshold of number of data points shows our technique is not overly sensitive to earthquakes or datum errors (Table 3). This increases number of gauges by up to ~50%

VLM			TOPEX Side A&B		TOPEX Side A		< REL BIAS >	TOPEX Side B		< REL BIAS >	Jason-1		< REL BIAS >	OSTM/Jason-2	
GPS	GIA	Eq Edits	Rate (mm/yr)	RMS (mm)	Rate (mm/yr)	RMS (mm)		Rate (mm/yr)	RMS (mm)		Rate (mm/yr)	RMS (mm)		Rate (mm/yr)	RMS (mm)
Yes	Yes	Yes	**0.52 ± 0.37**	**6.32**	**0.92 ± 0.57**	**6.81**	**< -2.7 ± 2.8 >**	**0.56 ± 0.99**	**5.65**	**< 91.9 ± 2.5 >**	**0.11 ± 0.54**	**5.26**	**< 72.7 ± 2.1 >**	**-0.43 ± 0.97**	**6.02**
Yes	Yes	NO	0.66 ± 0.34	5.59	1.26 ± 0.51	5.63	< -2.7 ± 2.5 >	0.38 ± 0.81	5.30	< 90.9 ± 2.0 >	0.38 ± 0.43	4.54	< 72.4 ± 1.8 >	-0.56 ± 0.88	5.09

Table 3: Bias drift rates from preferred altimeter treatment (Tables 1&2) as a function of earthquake editing. Highlights benefits of automated weighting scheme based on bias drift uncertainty at each CP.

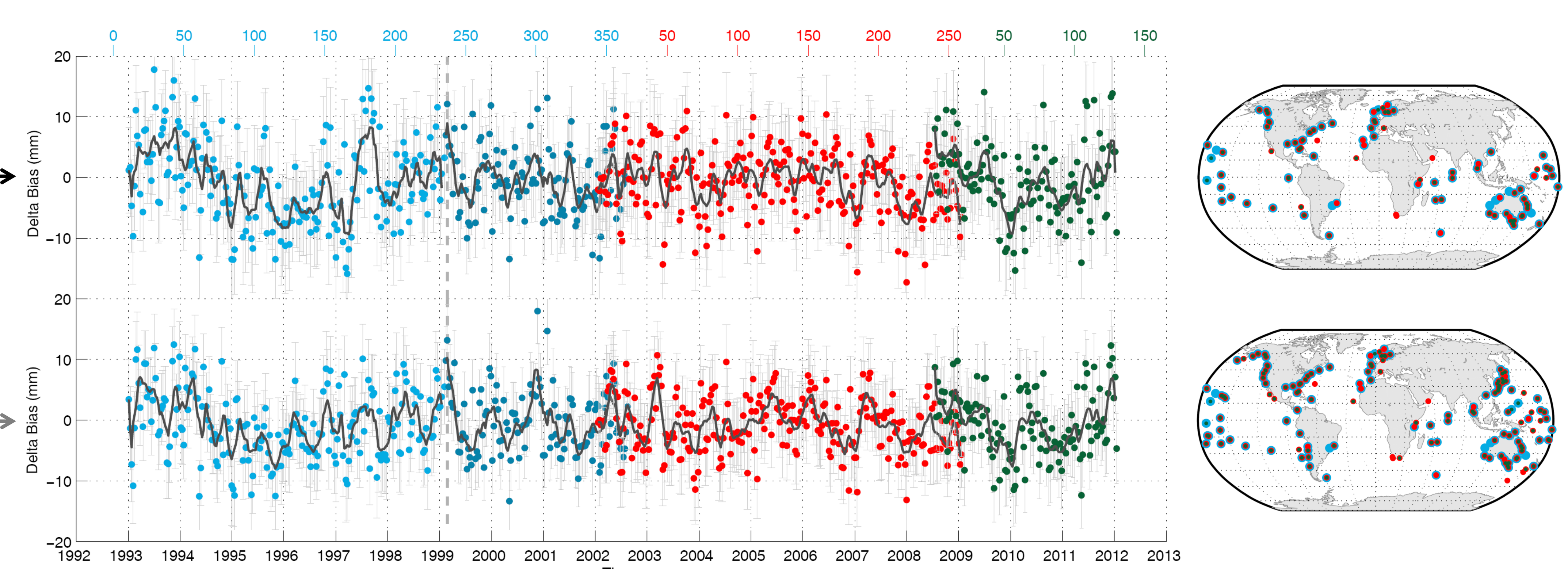

Figure 3: Delta-bias time series, i.e. weighted average of cycle-by-cycle residuals (DRIFT REMOVED), weighted using uncertainties of CP bias drift rates. Top panel removes CPs below the threshold distance to earthquakes. Bottom panel does not (as per Table 3). Solid line is a 60-day moving average. Maps show gauges included in solutions. Dominant periodic energy in delta-bias time series is centred at ~58.5 days (TOPEX), ~58.5, 87.3 & 365 days (Jason-1) and ~58.5 & 365 days (OSTM/Jason-2).

❼ Conclusions and Future Directions

- Bias drift results for TOPEX-B, Jason-1 and OSTM/Jason-2 are not statistically different from zero.
- TOPEX-A and A&B show (+)ve bias significant at 1-sigma (depending on VLM). TOPEX-A shows non-linear bias residuals (Figure 3). The systematic signal remaining in the residuals across all missions requires further investigation.
- This technique shows reduced sensitivity to earthquakes and datum offsets given the automated weighting strategy.
- Analysis at the TG level shows increased understanding of error structure in ALT – TG is required, and highlights the difficulty of using ALT – TG to infer VLM.
- We seek to further test sensitivity to editing criteria and better understand regional filtering options for GPS estimates of VLM.

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References

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