Long term absolute calibration from the Harvest, Corsica and Bass Strait sites

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(with acknowledgements to respective in-situ teams)

Please come and see individual group posters! (#28, #34, #41)

NASA JPL Jet Propulsion Laboratory California Institute of Technology UNIVERSITY of TASMANIA IMOS Integrated Marine Observing System OCA AZUR

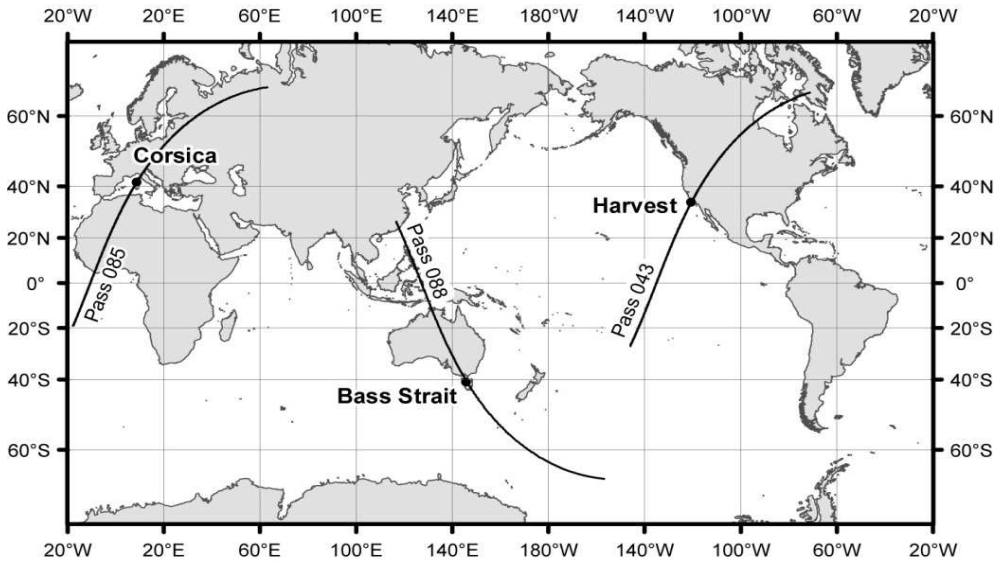
Overview

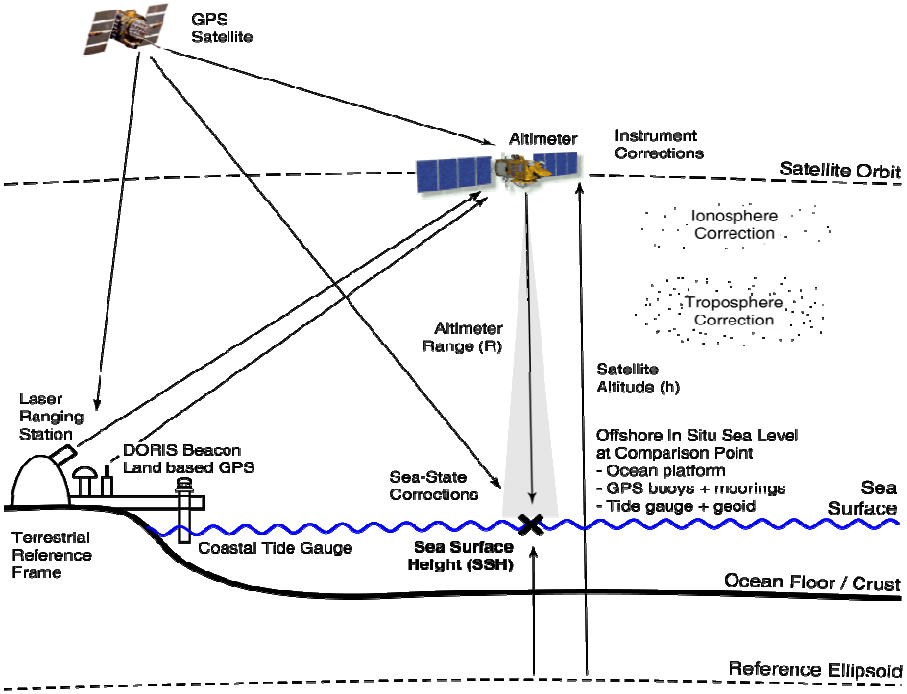
The fundamental goal is shared between the three absolute calibration sites:

- *Determine cycle-by-cycle SSH at a chosen comparison point in an absolute reference frame. Comparison against altimeter SSH yields absolute bias.*
- *Long term continuous monitoring is key.*

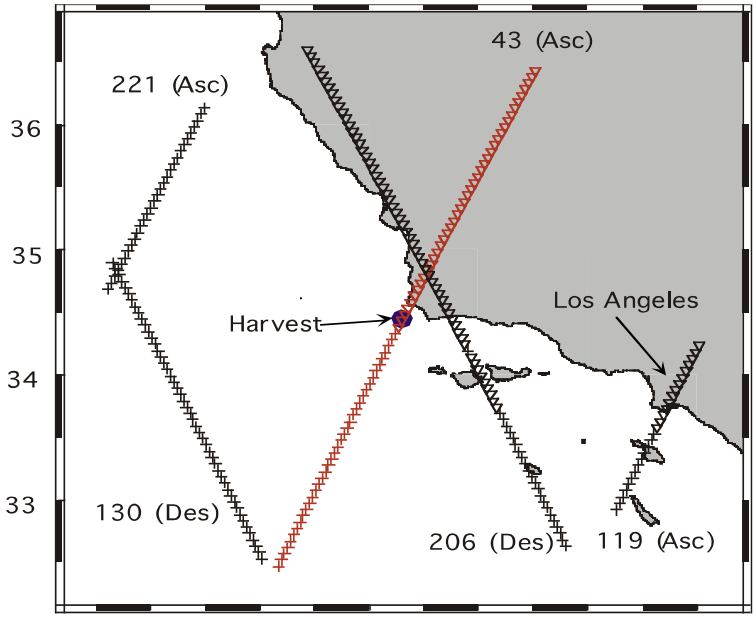
Harvest, Corsica and Bass Strait each tackle the problem slightly differently. Each site provides different characteristics.

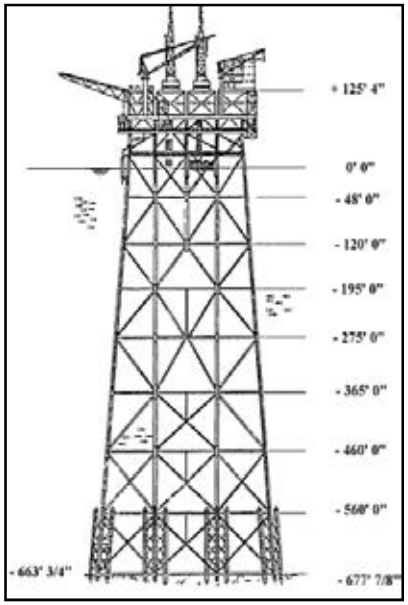
- *Result informs our understanding of the evolving altimeter sea level record.*
- *Similarly, we continue to learn about in situ side of the equation.*

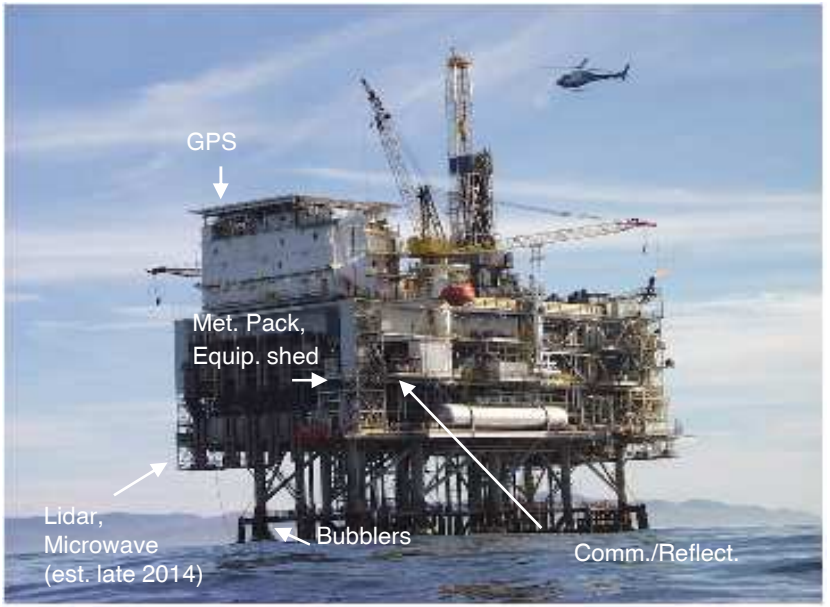




Harvest Experiment

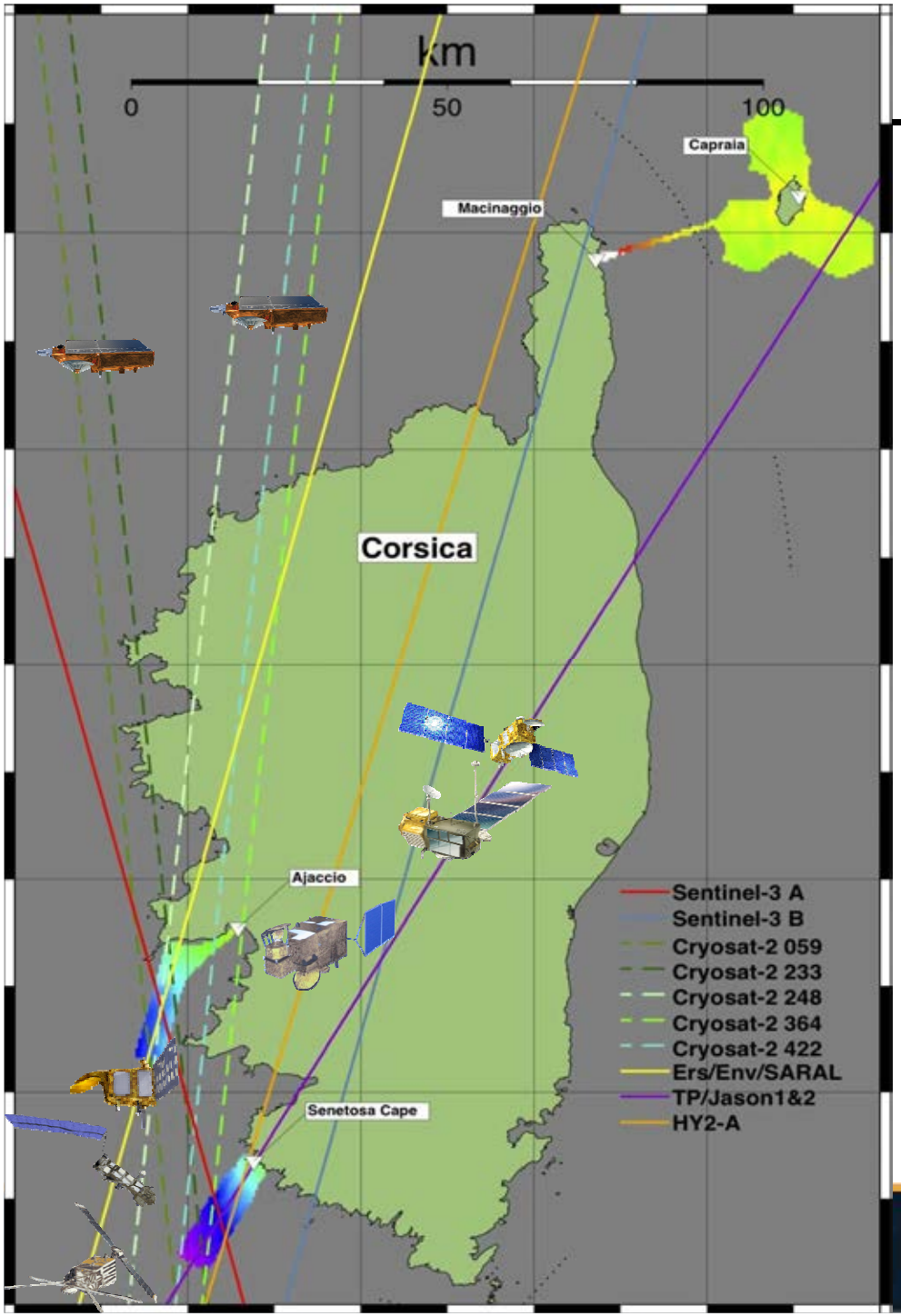






- **NASA Prime Verification Site for High-Accuracy (Jason-class) Altimetry**
  - Open-ocean location along 10-d repeat track (by design)
  - 10-km off coast of central California
  - Continuous monitoring for over two decades (established 1992 prior to TOPEX/Poseidon launch).
- **Recent operational/research highlights**
  - Upgrade of tide gauges in advance of Jason-3 launch, including new microwave sensor (est. 12/14).
  - Atomic (Rb) clock installed (9/14) to support improved GPS-based estimates of platform position.
  - Extension of calibration footprint for SARAL/AltiKa.
  - Successful retrieval of water level from digital communications satellite signals (Shah et al., 2013).

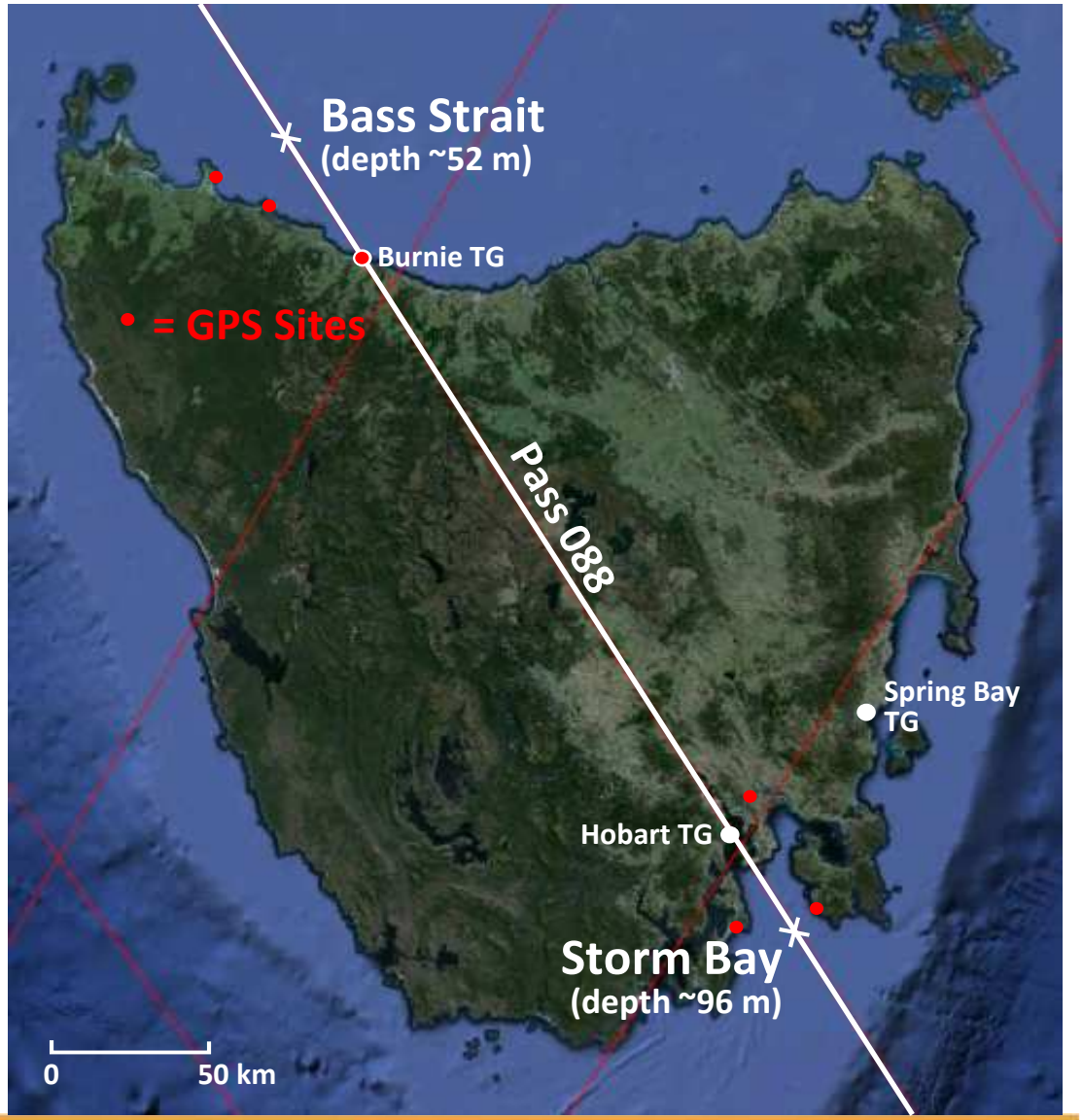
Corsica Experiment



- Senetosa CNES calibration site established in 1998 (equipped with 4 pressure tide gauges)
- Open-ocean altimeter readings connected to tide gauges via detailed local geoid model
  - Derived from intensive GPS buoy and catamaran surveys along ground track. Extension to Ajaccio (2005) and Capraia (2004)
  - Open-ocean verification location for GPS zodiac deployments.
- Ajaccio supports SARAL, ERS-2, EnviSat
  - Fiducial point near Ajaccio equipped with GPS / FTLRS / DORIS.
  - Ajaccio radar tide gauge (SHOM) (*New one since 2009/09/16, moved 2012/04/03)*
- Some CryoSat-2 and HY2-A also cross the region allowing absolute calibration.

Bass Strait Experiment

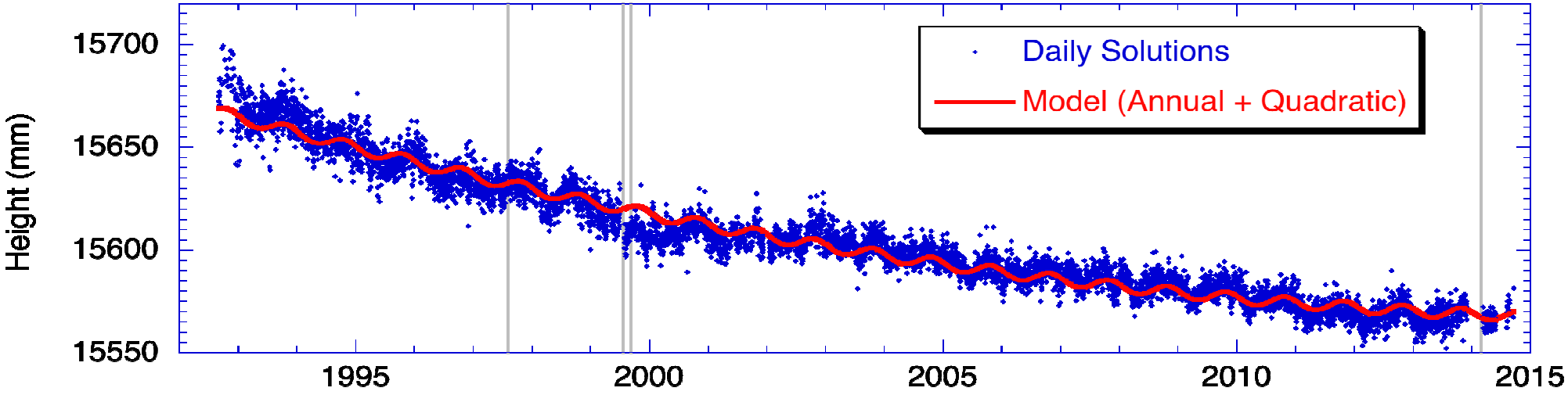
- **Bass Strait site:**
  - Tide gauge, moored ocean sensors, GPS buoys and two cGPS sites.
  - Mix of direct (mooring + datum from GPS) and (in)direct (tide gauge + diff in tides + datum from mooring/GPS).
- **Storm Bay site:**
  - As above but operational since 2009.
  - Useful in aiding explanation of along track differences in absolute bias.



Intermediate Results

Vertical Land Motion

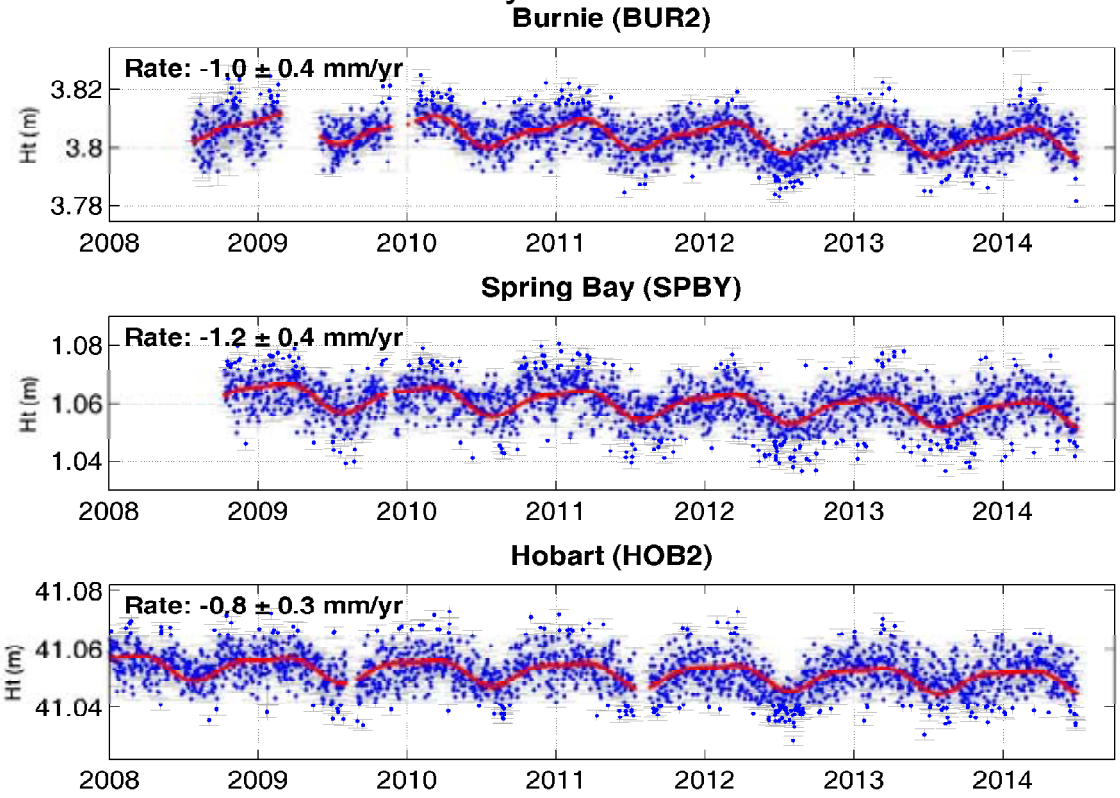
Harvest: Vertical Seafloor Motion



- Active production platform fixed to seafloor in ~200 m of water.
  - Hosts one of the oldest GPS stations in the global network (est. prior to 1992 launch of T/P).
- Time series based on daily precise point positioning in IGb08 realization of ITRF2008.
  - Uses latest (V2.1) JPL re-processed GPS satellite orbit and clock products.
  - Integer phase ambiguities resolved using single-receiver techniques (Bertiger et al., 2010).
- Non-linear subsidence correlated with hydrocarbon production (1994 peak).
  - Annual motions correlated with seasonal contraction and expansion.
- Errors in vertical position/rate estimated from competing solutions (Haines et al., 2013).
  - ~1 cm for absolute geocentric height.
  - Lowest vertical rate error (< 1 mm yr^{-1}) for Jason-1 (interior of the GPS record).

Bass Strait: Vertical Land Motion

- Estimates of VLM at the Bass Strait site in previous studies have been equivocal.
- Coherent subsidence across SE Australia is now emerging (see King et al., GRL, 2012, and White et al., ESR, 2014).
- These VLM estimates, together with more GPS buoy deployments have enabled revision of our datum for Bass Strait and Storm Bay.



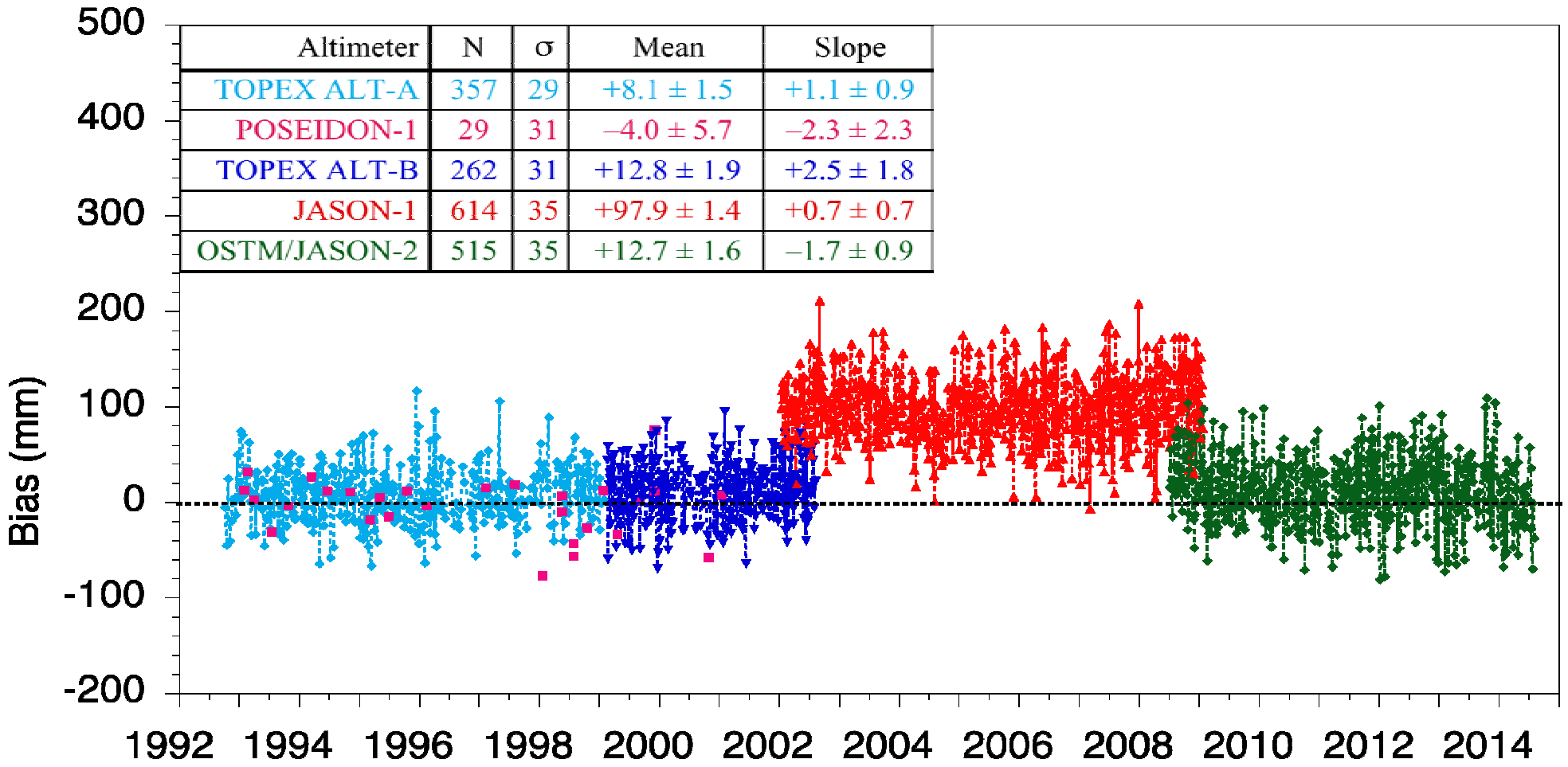
Results

Absolute Bias

Combined Long-Term Calibration Record

Nominal Time Series *(1777 total overflights)*

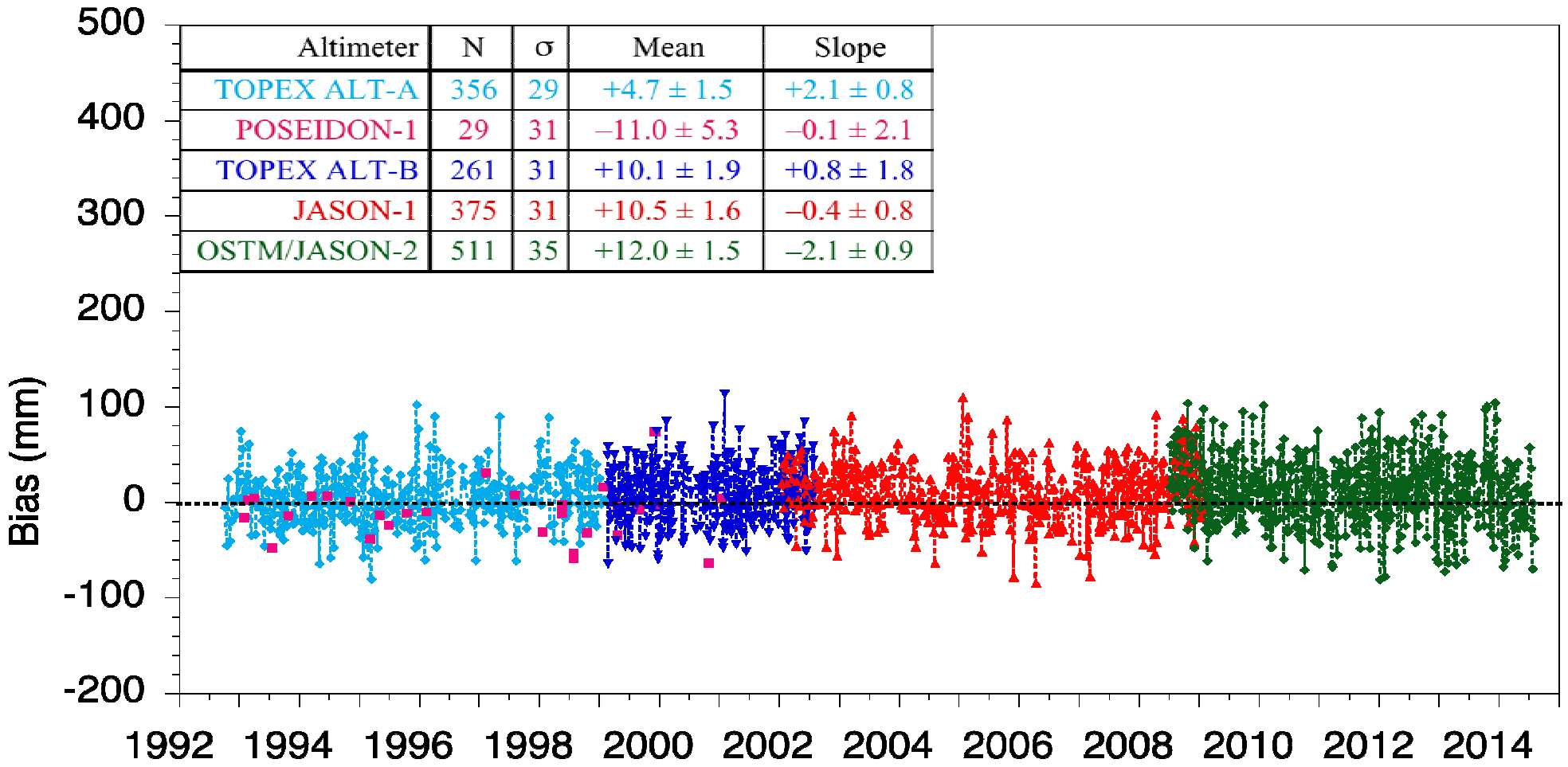
Altimeter	N	σ	Mean	Slope
TOPEX ALT-A	357	29	+8.1 ± 1.5	+1.1 ± 0.9
POSEIDON-1	29	31	–4.0 ± 5.7	–2.3 ± 2.3
TOPEX ALT-B	262	31	+12.8 ± 1.9	+2.5 ± 1.8
JASON-1	614	35	+97.9 ± 1.4	+0.7 ± 0.7
OSTM/JASON-2	515	35	+12.7 ± 1.6	–1.7 ± 0.9



Combined Long-Term Calibration Record

Enhanced Time Series *(1532 overflights; Jason-1 @ Bass Strait pending)*

Altimeter	N	σ	Mean	Slope
TOPEX ALT-A	356	29	+4.7 ± 1.5	+2.1 ± 0.8
POSEIDON-1	29	31	–11.0 ± 5.3	–0.1 ± 2.1
TOPEX ALT-B	261	31	+10.1 ± 1.9	+0.8 ± 1.8
JASON-1	375	31	+10.5 ± 1.6	–0.4 ± 0.8
OSTM/JASON-2	511	35	+12.0 ± 1.5	–2.1 ± 0.9



Results

Radiometer Comparisons

Harvest: Wet Troposphere Delay (GPS vs. Radiometer)

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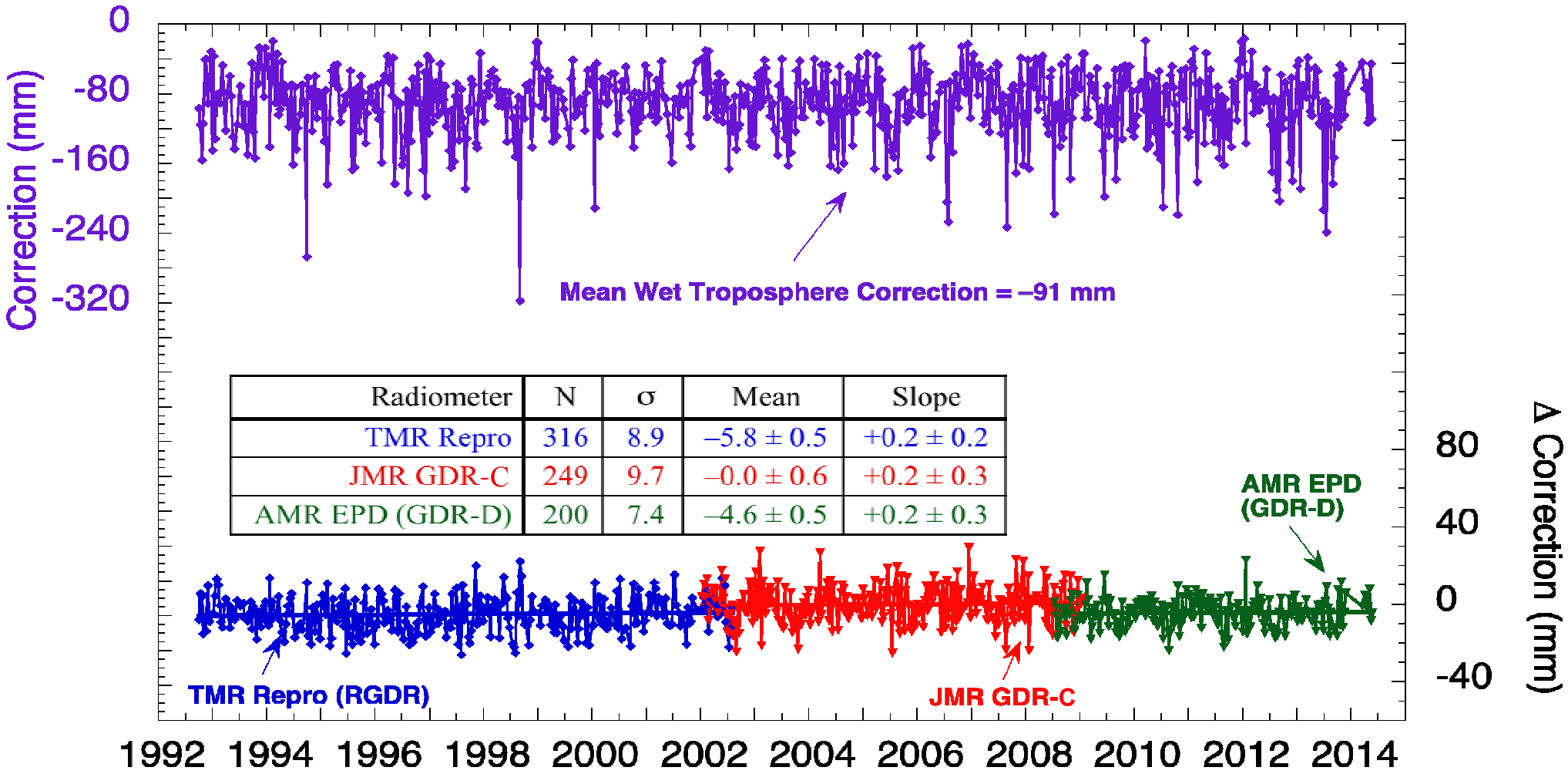
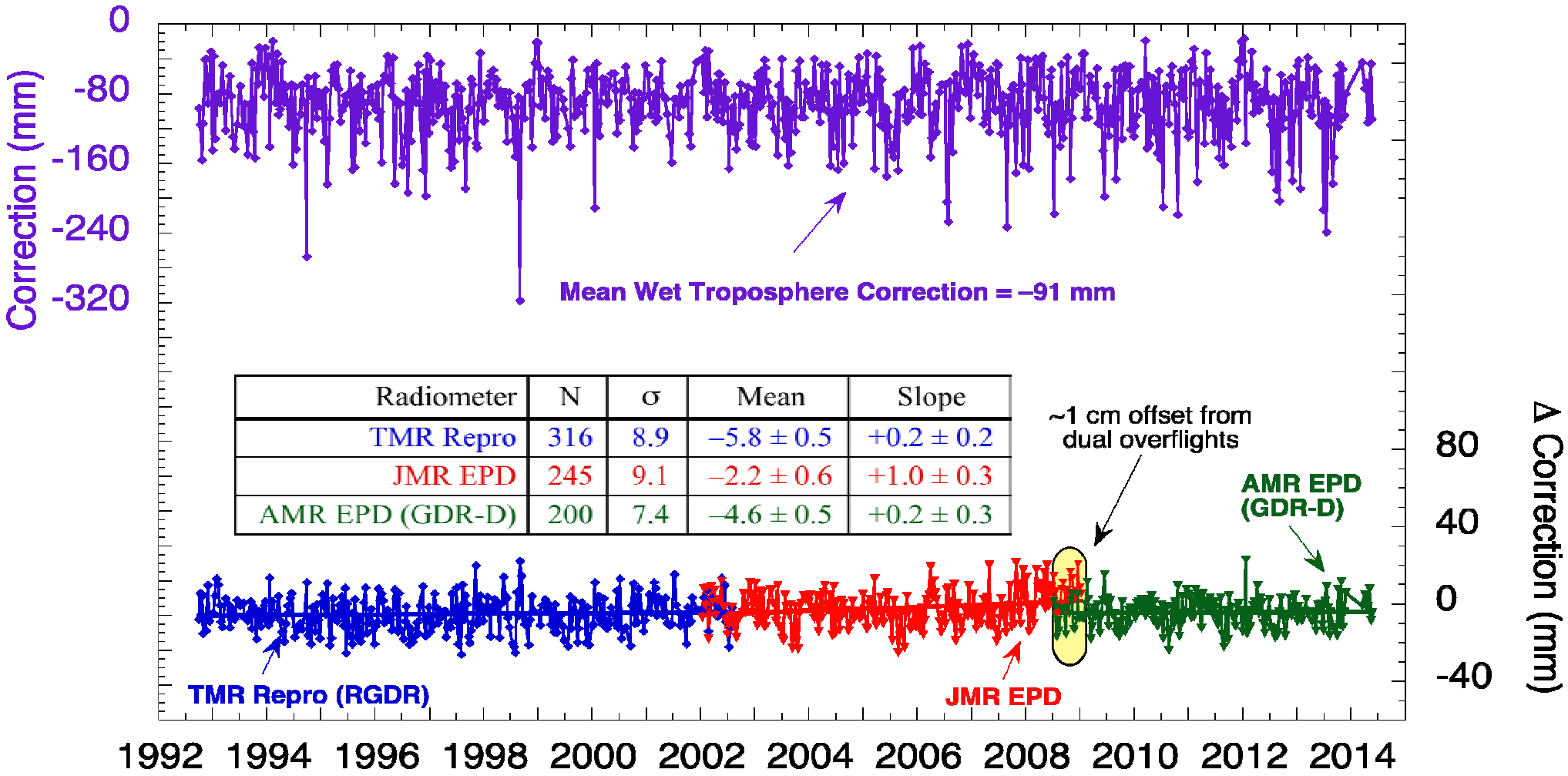


Harvest: Wet Troposphere Delay (GPS vs. Radiometer)

Jet Propulsion Laboratory
California Institute of Technology



Harvest: Wet Troposphere Delay (GPS vs. Radiometer)

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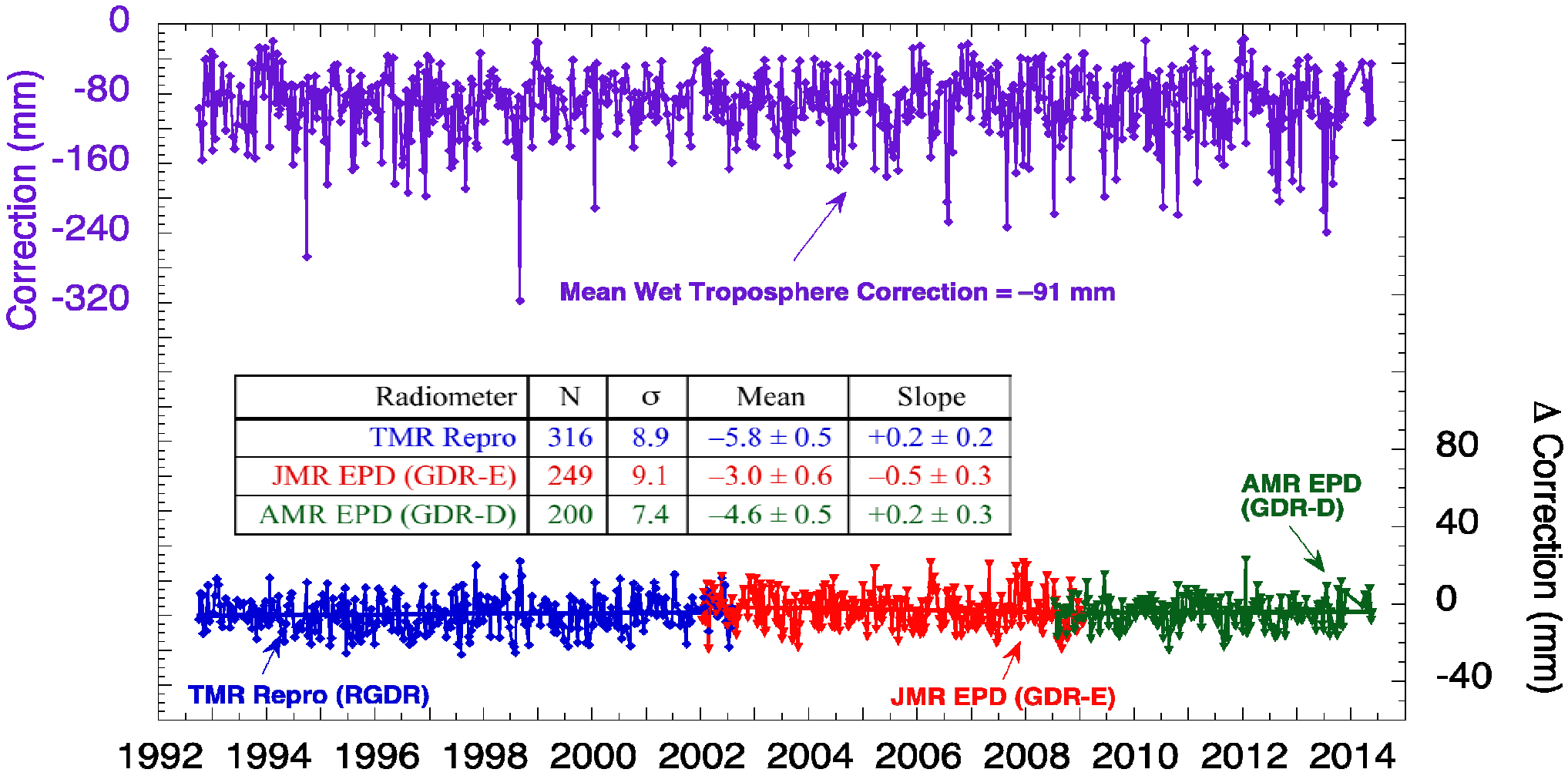
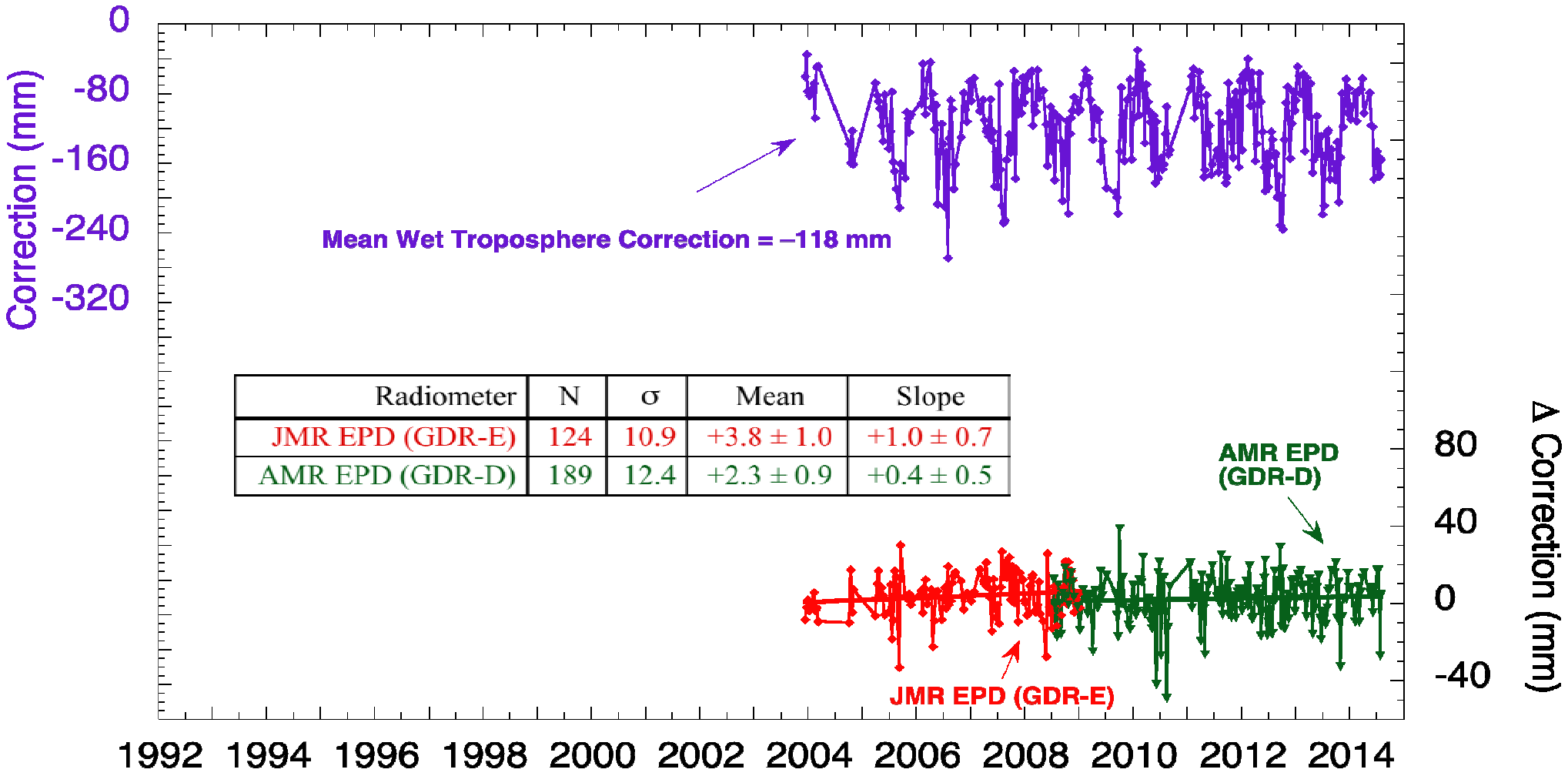


Corsica: Wet Troposphere Delay (GPS vs. Radiometer)



Concluding Remarks (1 of 4)

- **Vertical land motion:**
  - All sites are reliant on GPS estimates for VLM, Corsica is the only site with negligible VLM.
  - Bass Strait is reliant on the assumption of linear VLM back to the TOPEX period given lack of long term GPS c.f. Harvest.

- **Land contamination effects:**
  - Contamination is arguably most problematic at Corsica. Understanding this informs the connection between the coast and open ocean.
  - All sites have faced land contamination in wet delay estimates: the evolution in enhanced radiometer products has addressed this well as evidenced with comparison against GPS.

Concluding Remarks (2 of 4)

- **In situ sea surface height determination:**
  - Subtle differences between in situ technologies contribute to marginally different noise characteristics at each site.
  - Intra site differences are informative:
    - Direct vs indirect SSH at Corsica yields differences at ~1-2 cm level.
    - At Bass Strait, there is negligible absolute difference (by design), but reduction in noise between mooring and tide gauge derived absolute bias for Jason-2 (< = 32mm to < = 23 mm, n = 121).
  - Each site has a different means of realizing an absolute datum
    - Systematic error contribution here likely 10-20 mm.
  - Sites will continue to evolve – e.g. multiple in situ technologies, regional dSSH observations and models in the vicinity of CPs etc.

Concluding Remarks (3 of 4)

- **Absolute bias estimates:**
  - The three sites provide a useful insight into the effect of continuing improvements in processing algorithms / corrections.
  - Combined absolute bias estimates show absolute SSH bias is now largely insignificantly different from zero across TOPEX, Jason-1 and OSTM/Jason-2.
  - Each site is yielding useful calibration results for other missions (e.g. SARAL, Envisat, see posters and other talks).
  - Similarity in absolute bias estimates is striking, despite differences in approaches.

Concluding Remarks (4 of 4)

- **Bias drift estimates:**
  - Our understanding here is improving, but this remains challenging.
  - Direct approach here likely to yield smallest uncertainty given one less contribution to the error budget.
  - Site specific variability as a function of wet delay treatment can be significant (0.5 – 1.5 mm/yr).
  - For Bass Strait, the change in trend b/w Jason-1 and Jason-2 remains puzzling. Anomalous Jason-2 rate also evident in Storm Bay results.
  - Bias drift at a single site pushes all components of the measurement system to the limit: geodetic positioning, water level, altimetry, orbits, troposphere, reference frames etc.

Questions?

Come and see posters #28, #34, #41!

Altimeter	N	σ	Mean	Slope
TOPEX ALT-A	356	29	+4.7 ± 1.5	+2.1 ± 0.8
POSEIDON-1	29	31	–11.0 ± 5.3	–0.1 ± 2.1
TOPEX ALT-B	261	31	+10.1 ± 1.9	+0.8 ± 1.8
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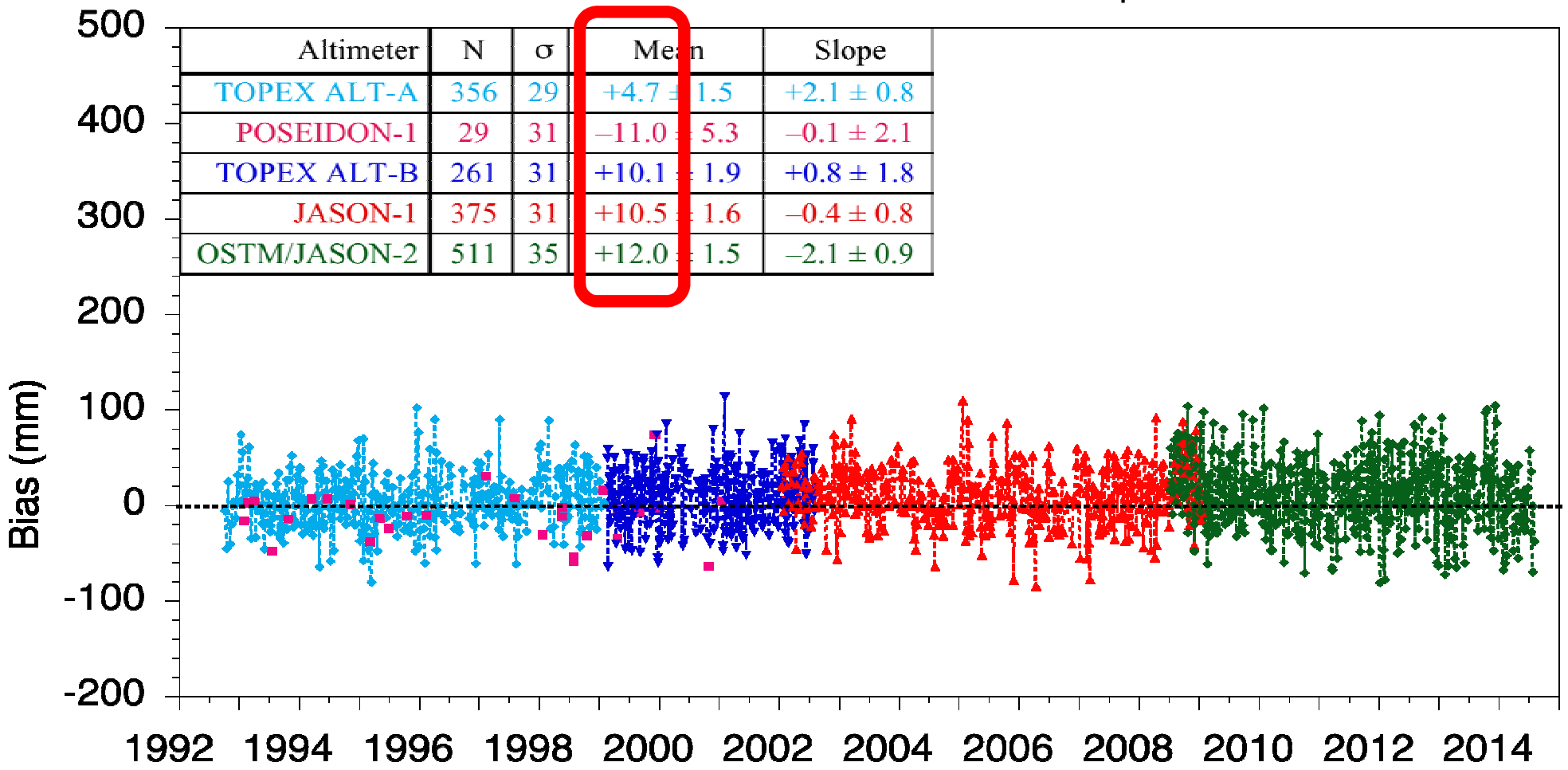
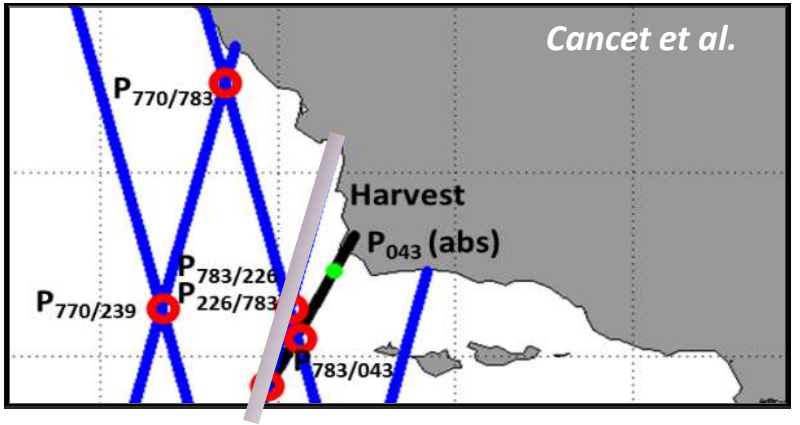



cnes
EUMETSAT
›OSTST meeting
›SARAL/Altika workshop
›IDS workshop
www.ostst-altimetry-2014.com
New frontiers of altimetry
Lake Constance - Germany,
27-31 October 2014

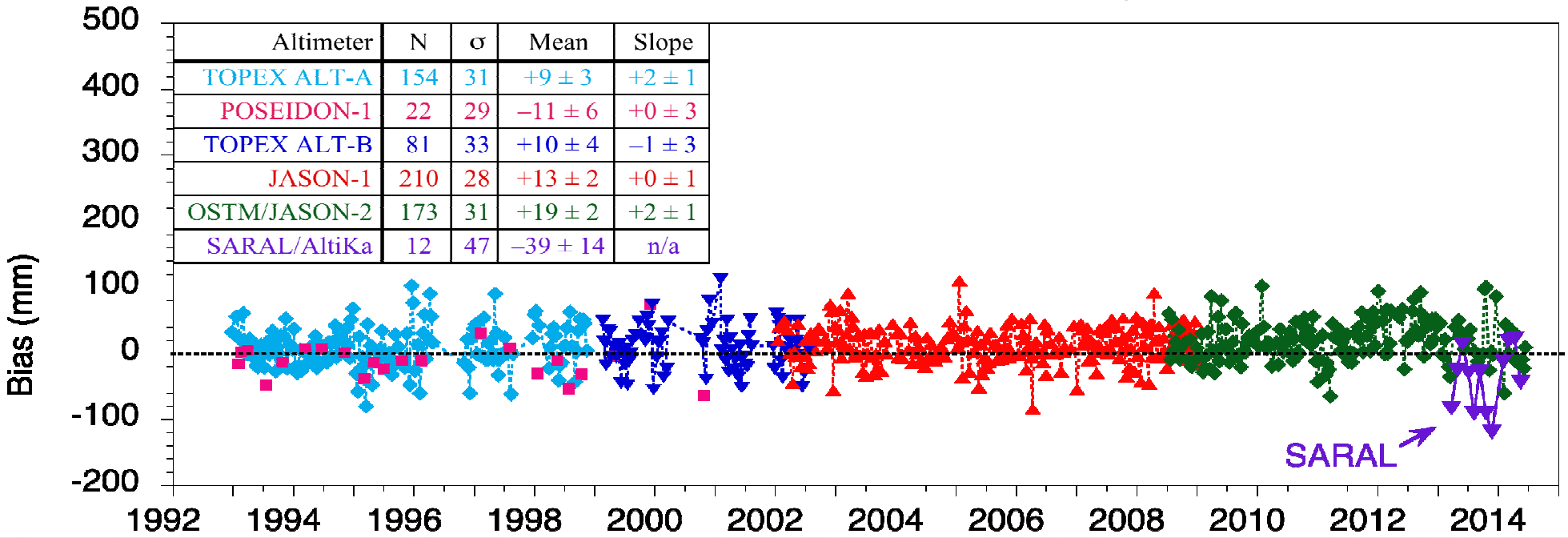
Spares

Regional Calibration: SARAL/AltiKa Results

- Regional calibration approach developed for Harvest by Cancet et al.
  - Use neighboring inter-satellite crossovers.
  - Successfully demonstrated for ENVISAT.
- For SARAL, direct (PCA) approach used.
  - Des. pass 226 only 18 km from platform (open ocean).
  - Gradient from average of CLS2011 and DTU2013



Altimeter	N	σ	Mean	Slope
TOPEX ALT-A	154	31	+9 ± 3	+2 ± 1
POSEIDON-1	22	29	–11 ± 6	+0 ± 3
TOPEX ALT-B	81	33	+10 ± 4	–1 ± 3
JASON-1	210	28	+13 ± 2	+0 ± 1
OSTM/JASON-2	173	31	+19 ± 2	+2 ± 1
SARAL/AltiKa	12	47	–39 ± 14	n/a



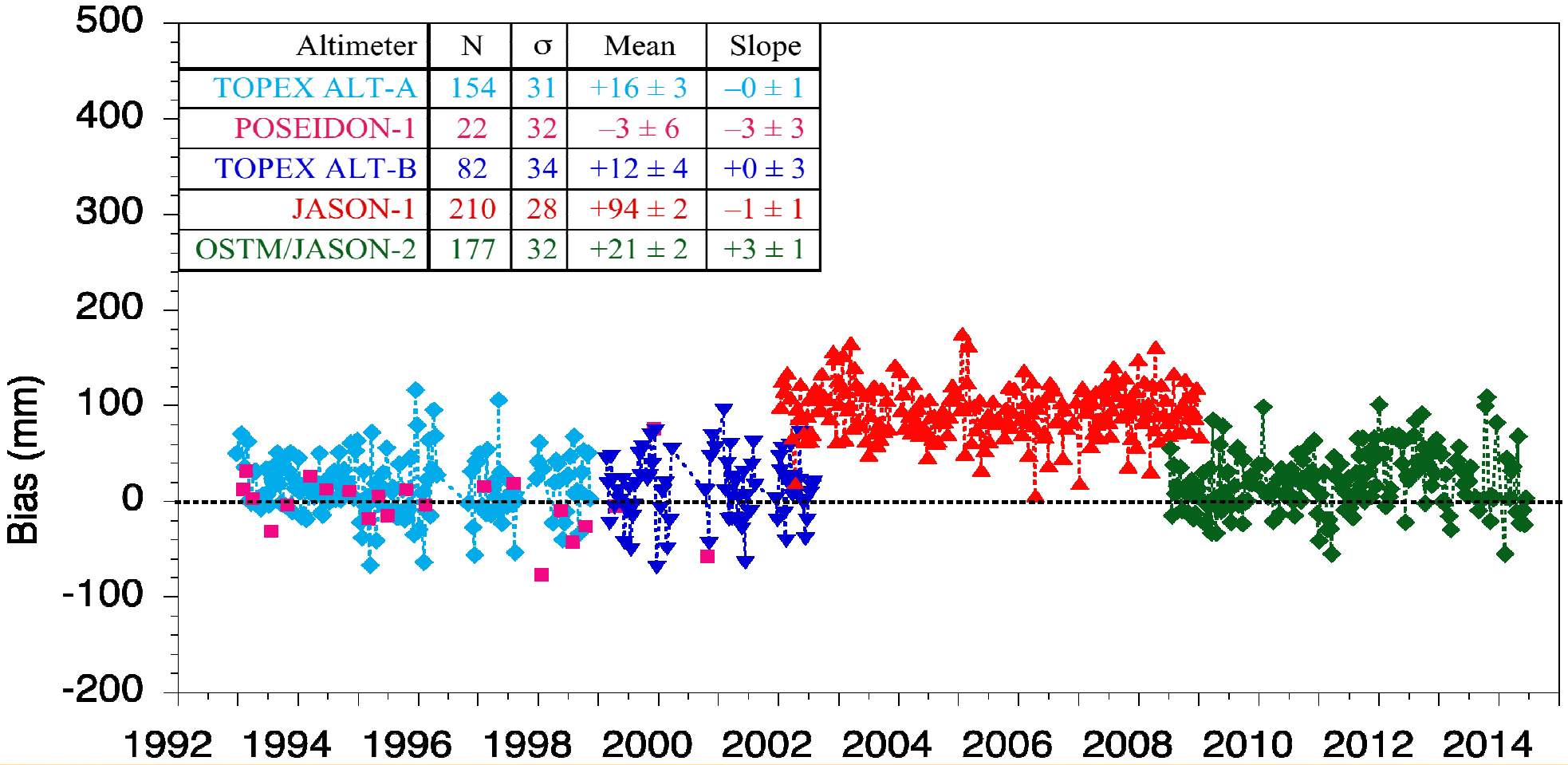
Harvest Long-Term Calibration Record

Jet Propulsion Laboratory
California Institute of Technology

Nominal Time Series *(Using current GDR standards)*

T/P: MGDR; **Jason-1:** GDR-C; **Jason-2**: GDR-D

Altimeter	N	σ	Mean	Slope
TOPEX ALT-A	154	31	+16 ± 3	–0 ± 1
POSEIDON-1	22	32	–3 ± 6	–3 ± 3
TOPEX ALT-B	82	34	+12 ± 4	+0 ± 3
JASON-1	210	28	+94 ± 2	–1 ± 1
OSTM/JASON-2	177	32	+21 ± 2	+3 ± 1



Harvest Long-Term Calibration Record

Enhanced Time Series *(Using preliminary updates to GDR standards)*

T/P: MGDR + repro. orbits (*Lemoine et al.*) and repro. wet trop. (*Brown et al.*); **Jason-1:** GDR-C + MLE4 SSB + CNES repro. orbit + JMR GDR-E (*Brown et al.*) + POS-2 range corrections (*Desjonquères et al.);* **Jason-2**: GDR-D + GPS-based orbit

Altimeter	N	σ	Mean	Slope
TOPEX ALT-A	154	31	+9 ± 3	+2 ± 1
POSEIDON-1	22	29	–11 ± 6	–0 ± 3
TOPEX ALT-B	81	33	+10 ± 4	–1 ± 3
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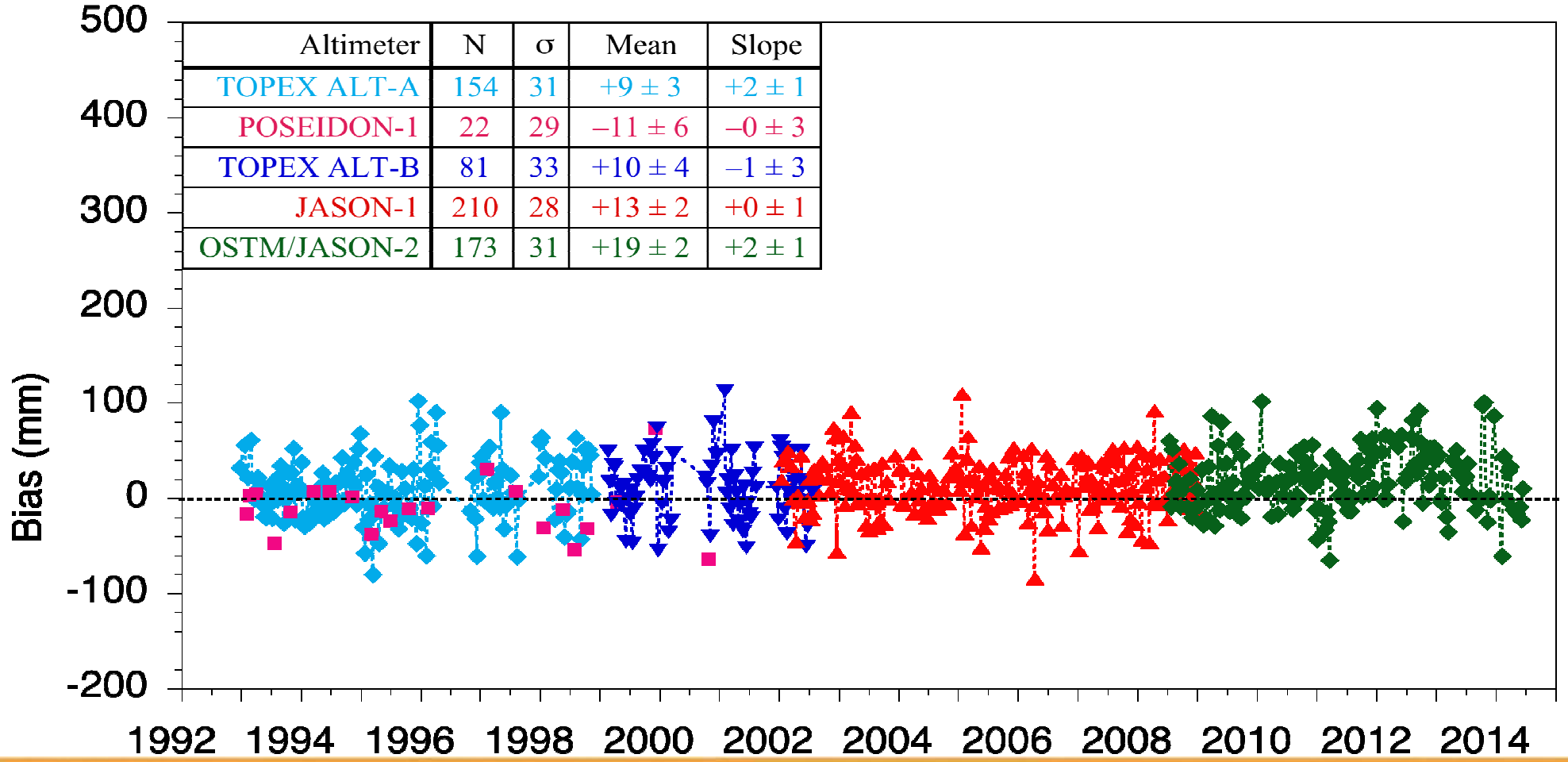
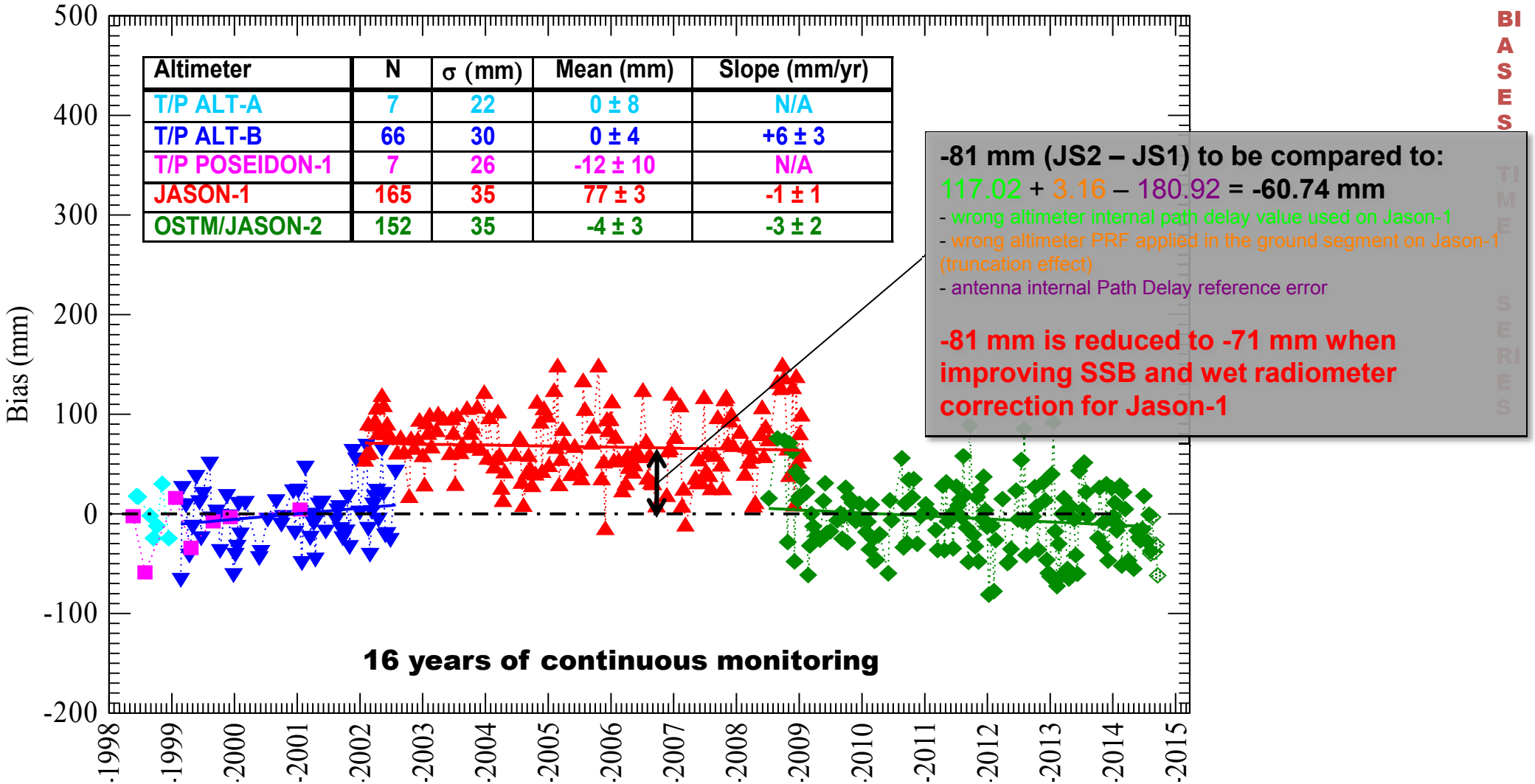




Altimeter	N	σ (mm)	Mean (mm)	Slope (mm/yr)
T/P ALT-A	7	22	0 ± 8	N/A
T/P ALT-B	66	30	0 ± 4	+6 ± 3
T/P POSEIDON-1	7	26	-12 ± 10	N/A
JASON-1	165	35	77 ± 3	-1 ± 1
OSTM/JASON-2	152	35	-4 ± 3	-3 ± 2

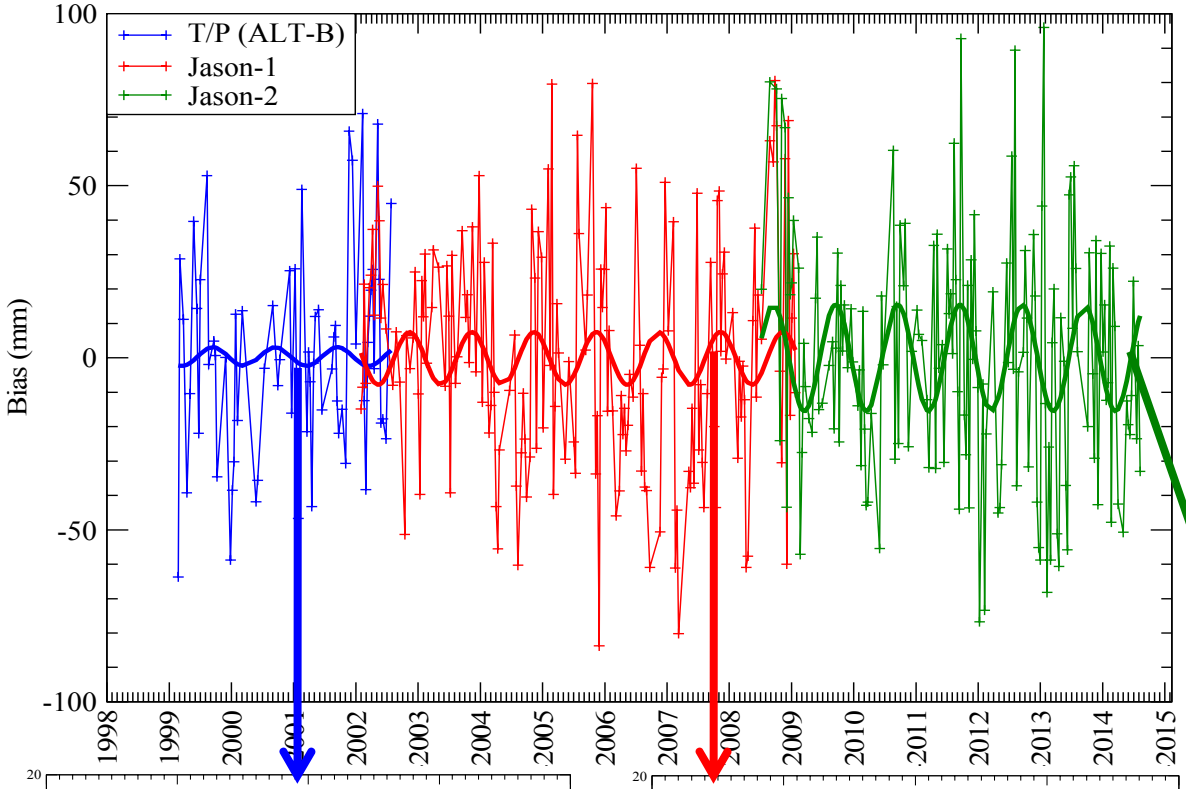
Products used (processed with NO altimeter land contamination effect):

T/P: MGDR + TMR replacement products + std0905 orbits (GSFC)

Jason-1: GDR-C (cycle 1 to 259)

Jason-2: GDR-D (cycle 1-183) MLE4 = -4 ±3 mm

Jason-2: GDR-D (cycle 1-183) MLE3 = +22 ±4 mm => ≠ by 26 mm (mainly SSB)

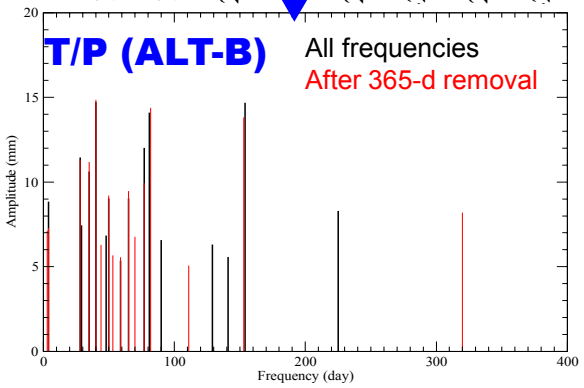


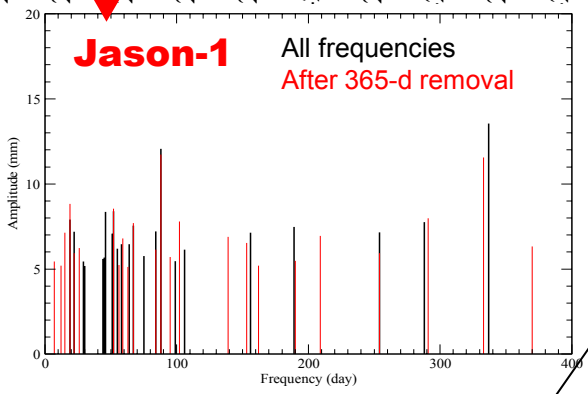
Drift with/without annual cycle removal

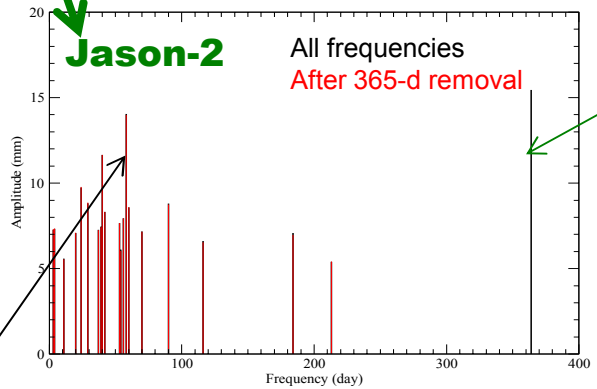
Altimeter	Drift (mm/yr)	Formal error (mm/yr)	Drift (mm/yr)	Formal error (mm/yr)	Annual Amplitude (mm)
	Without annual cycle removal		With annual cycle removal		
T/P - ALT-B	5.6	3.5	5.7	3.5	2.7
Jason-1 - Poseidon-2	-1.0	1.3	-1.3	1.3	7.7
Jason-2 - Poseidon-3	-3.0	1.6	-2.6	1.6	15.4

Removing the annual signals changes the drift by 0.3-0.4mm/yr for Jason-1&2 and leads to less discrepancy between both satellites

The annual signal in Jason-2 bias time series is reduced from 17mm to 15mm since last year analysis but still there. This needs to be further investigated: Corrections?
=> Nothing seen from neither wet or iono corrections (using differences with model)



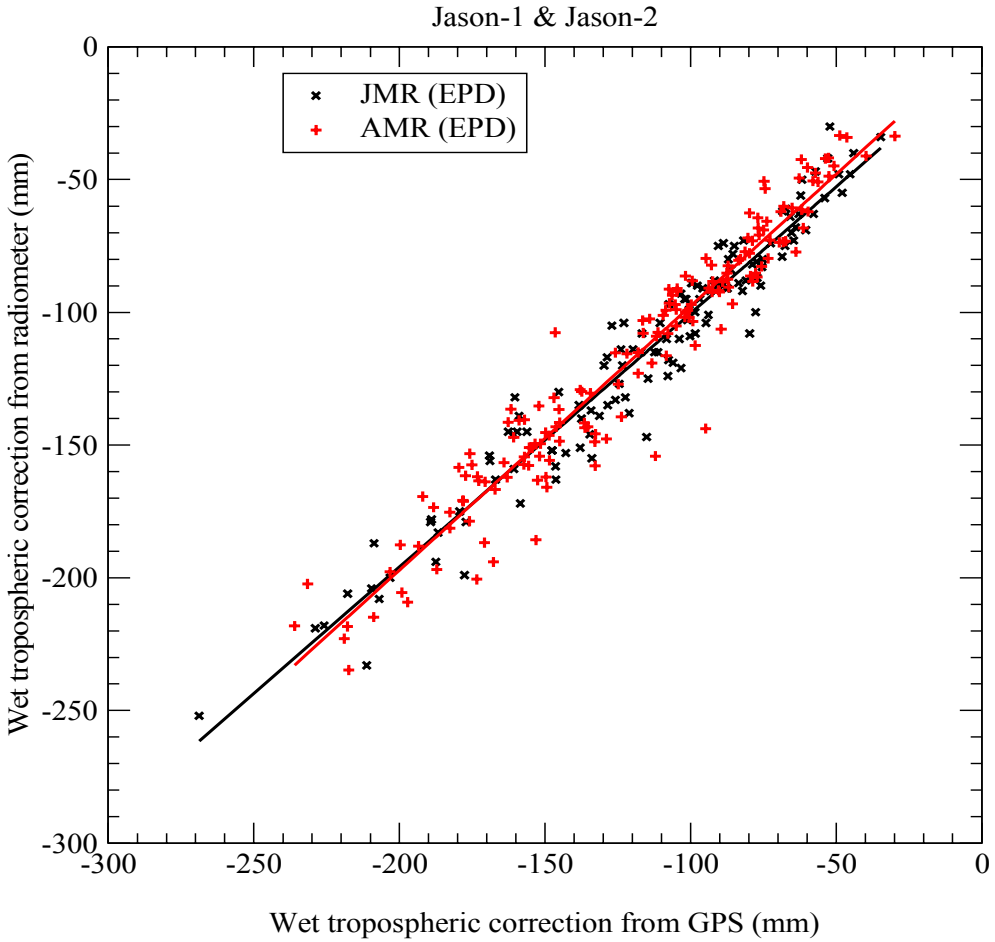




No clear 59-d neither annual signal (365-d) for neither T/P nor Jason-1

The 59-d frequency remains even after removing the annual signal (365-d)

FREQUENCY ANALYSIS



On the whole set of data, JMR and AMR using the Enhanced Path Delay (EPD) product developed by Brown (2010) **agree with GPS at the millimeter level in an averaged sense (0 mm for JMR and +2 mm for AMR) with a standard deviation of 11 mm and 12 mm** respectively.

The long time series of JMR & AM vs. GPS comparisons at the Corsica site also permits monitoring of drifts in the path delay measurements.

The use of the EPD products also shows an improvement in term of stability and the **estimated drift for JMR & AMR is negligible (respectively +0.5 ±0.7 mm/yr and -0.2 ±0.6 mm/yr)**, as the associated standard error is at the same level. For AMR the stability is improved compared to the study performed over the first 114 cycles.

During the FFP for common overflights (12), JMR – AMR are negligible: mean = -3.0 mm / StD = 8.6 mm

Radiometers minus GPS wet troposphere correction

Instrument	Mean (mm)	σ* (mm)	Drift (mm/yr)	Formal error (mm/yr)	Correlation (%)	Slope
JMR/EPD** - GPS	0	11	+0.5	0.7	97.2	0.95
AMR/EPD** - GPS	2	12	-0.2	0.6	96.5	0.99

*σ is the standard deviation.

**Enhanced Path Delay (EPD) for AMR (Advanced Microwave Radiometer) onboard Jason-2 and JMR (Jason-1 Microwave Radiometer) onboard Jason-1.

Bass Strait: Buoy vs Moorings