Determining errors in the climate data record

Eric Leuliette[1], Remko Scharroo[1,2], Gary Mitchum[3], and Laury Miller[1]

[1]NOAA/NESDIS/Laboratory for Satellite Altimetry

[2]Altimetrics LLC

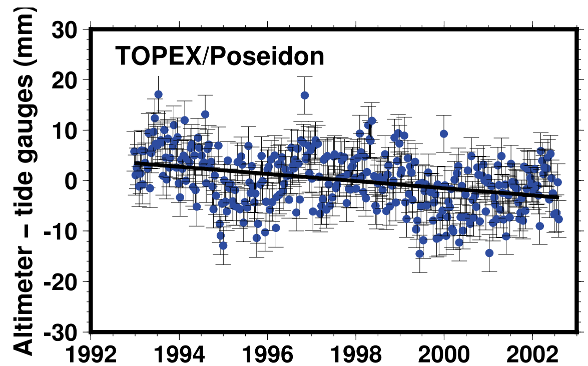
[3]University of South Florida

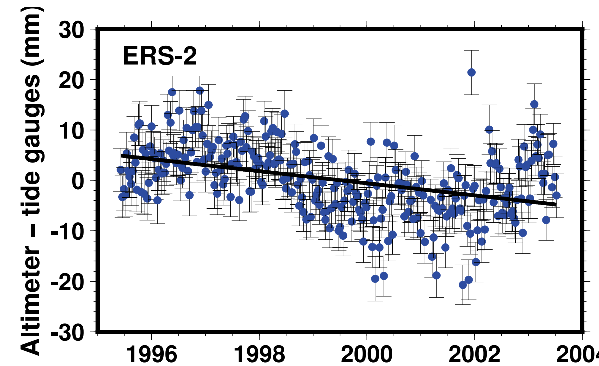
Part 1

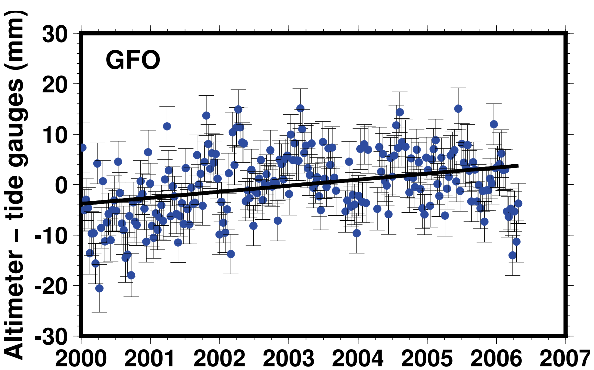
Global and regional error estimates

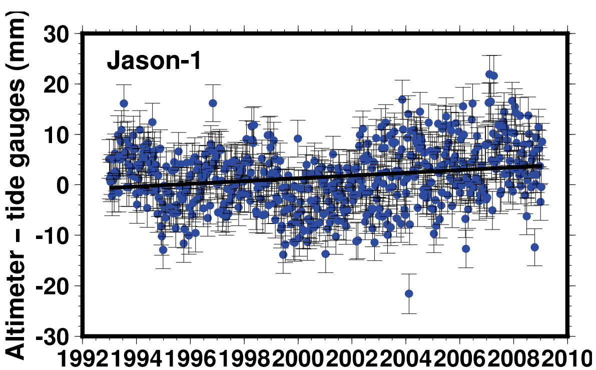
Tide gauge monitoring of all exact repeat missions

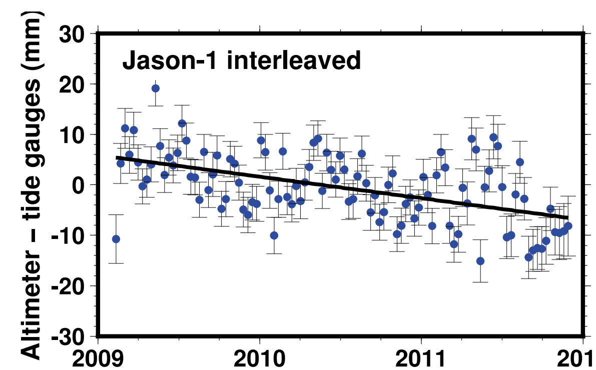
Eight missions/phases are evaluated when fields are updated/added to RADS.

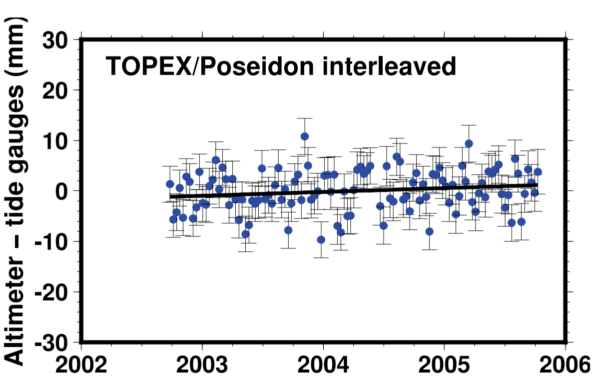


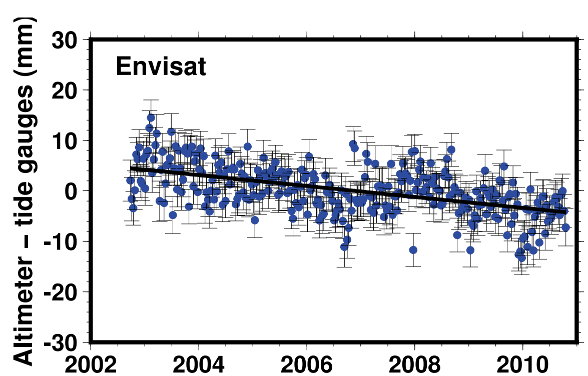


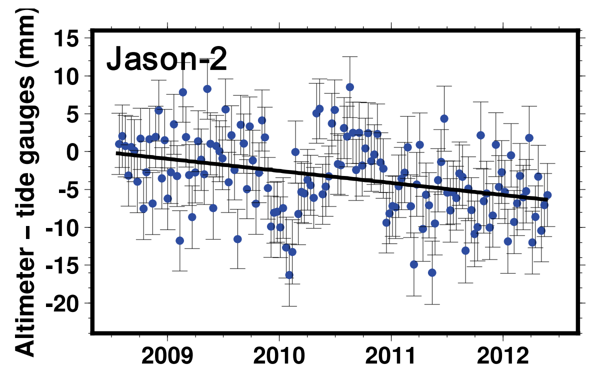












Global statistics: tide gauge and crossovers

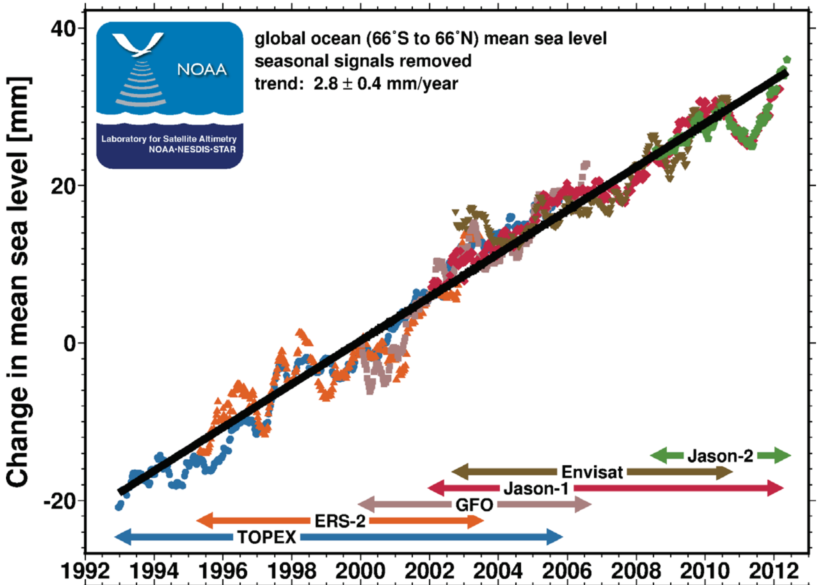
Mission (phase)	Data coverage years	RMS crossover differences (mm)	Drift from tide gauge calibration (mm/year)
Geosat (ERM)	1986–1988	81.5	
ERS-1 (C & G)	1992–1996	73.8	
T/P (reference Side-A)	1993–1999	51.3	–0.7 ± 0.4
T/P (reference Side-B)	1999–2002	46.3	
T/P (interleaved Side-B)	2002–2005	46.9	0.8 ± 0.6
ERS-2	1995–2002	77.9	–1.5 ± 0.4
GFO	2000–2006	65.4	1.2 ± 0.5
Jason-1 (reference)	2001–2008	49.2	0.3 ± 0.5
Jason-1 (interleaved)	2008–2011	50.0	–3.3 ± 0.8
Envisat	2002–2009	52.9	–1.0 ± 0.4
Envisat (extended)	2009–2012	54.7	
Jason-2 (reference)	2008–	50.5	–1.5 ± 0.5
T/P, Jason-1, Jason-2 (ref)	1993–		–0.2 ± 0.4

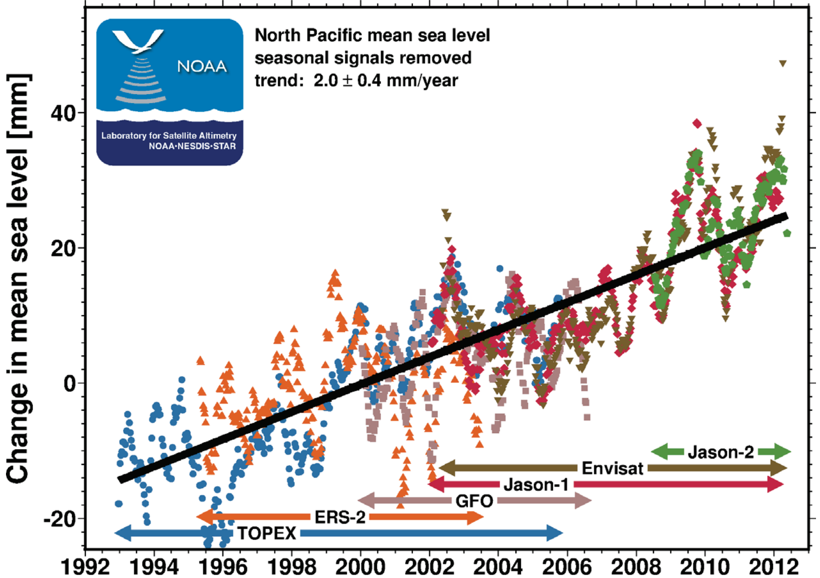
Differences in global and regional sea level

Intermission differences are relatively small in global mean sea level.

<u>Regional</u> variability and intermission differences are larger.

Can we use intermission differences to estimate uncertainties in regional mean sea level?

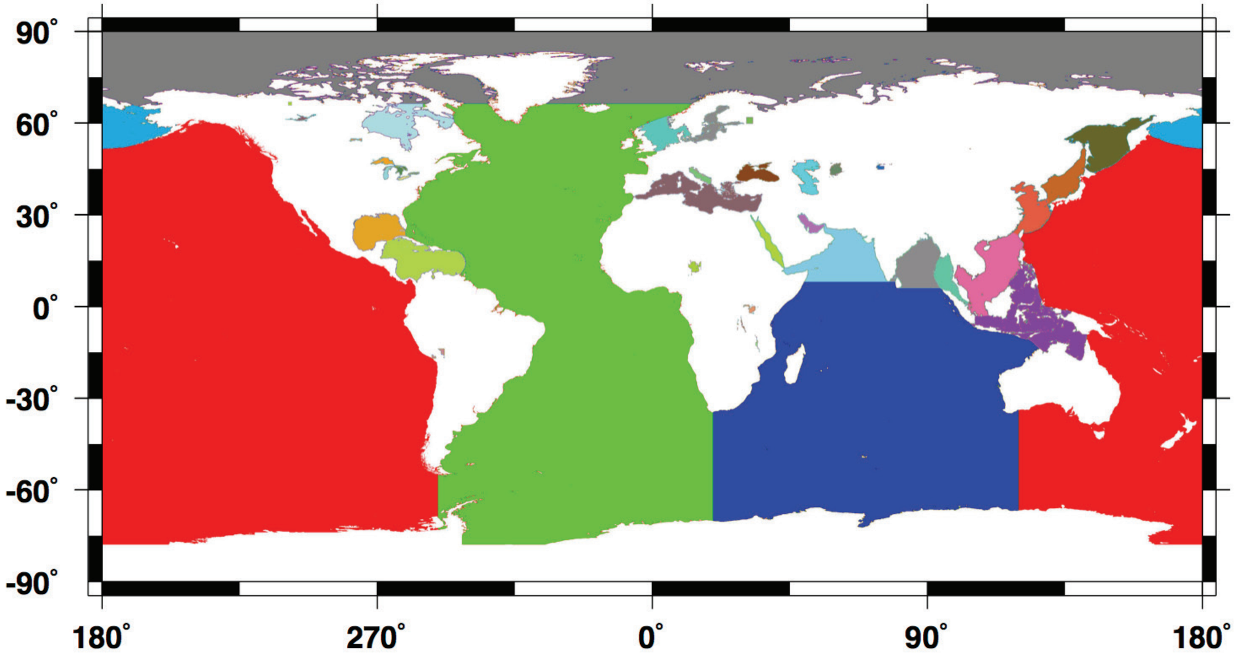




Regional sea level monthly uncertainties

Estimate regional errors by using simple monthly averages:

- Constructed monthly grids (3° x 1°) for each altimeter
- Constructed a mean month from all altimeters
- Estimated sampling uncertainties and instrument errors by using the mean differences among multiple altimeters



Uncertainties in monthly means for major basins

Region	Area (1000 km^2)	St dev (mm)	Scatter about mean (mm) 6 altimeters	Scatter about mean (mm) reference missions
Global		16.5	2.5	1.1
Pacific Ocean	171895	15.9	5.1	1.3
Pacific Tropics	98839	15.4	4.7	1.3
Atlantic Ocean	84228	19.0	4.0	1.7
Indian Ocean	60556	23.8	5.8	2.3

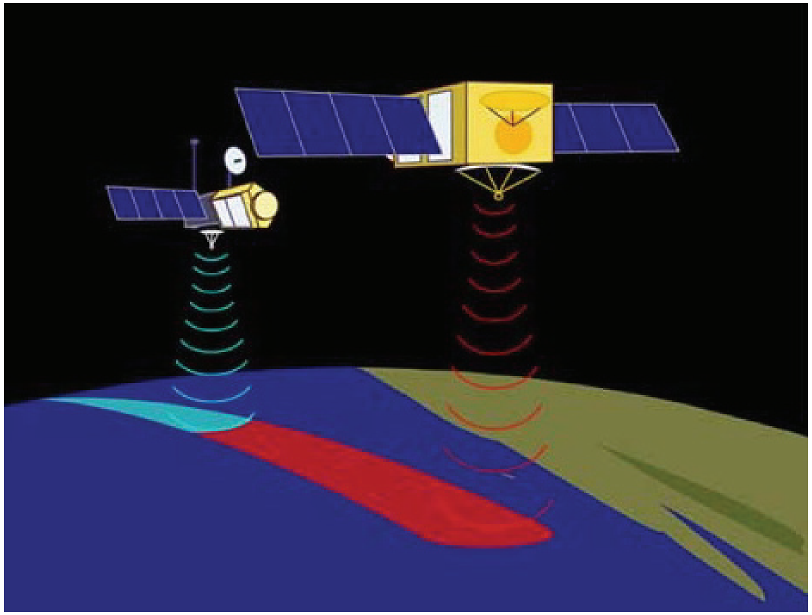
Uncertainties in major marginal seas

Region	Area (1000 km²)	St dev (mm)	Scatter about mean (mm) 6 altimeters	Scatter about mean (mm) reference
Nino3.4	6230	32.3	7.9	2.6
Indonesian Throughflow	4644	81.1	11	3.8
Arabian Sea	4089	48.4	11.8	3.1
South China Sea	3611	46.2	10.7	4.3
Caribbean Sea	2695	29.3	9.5	4.9
Mediterranean Sea	2396	62.5	10.3	4.4
Bering Sea	2289	35.4	7.3	2.8
Bay of Bengal	2185	37.7	14.9	4.2
Gulf of Mexico	1585	53.1	10.5	9.8
Sea of Okhotsk	1575	24.5	8.3	4.1

Uncertainties in marginal and enclosed seas

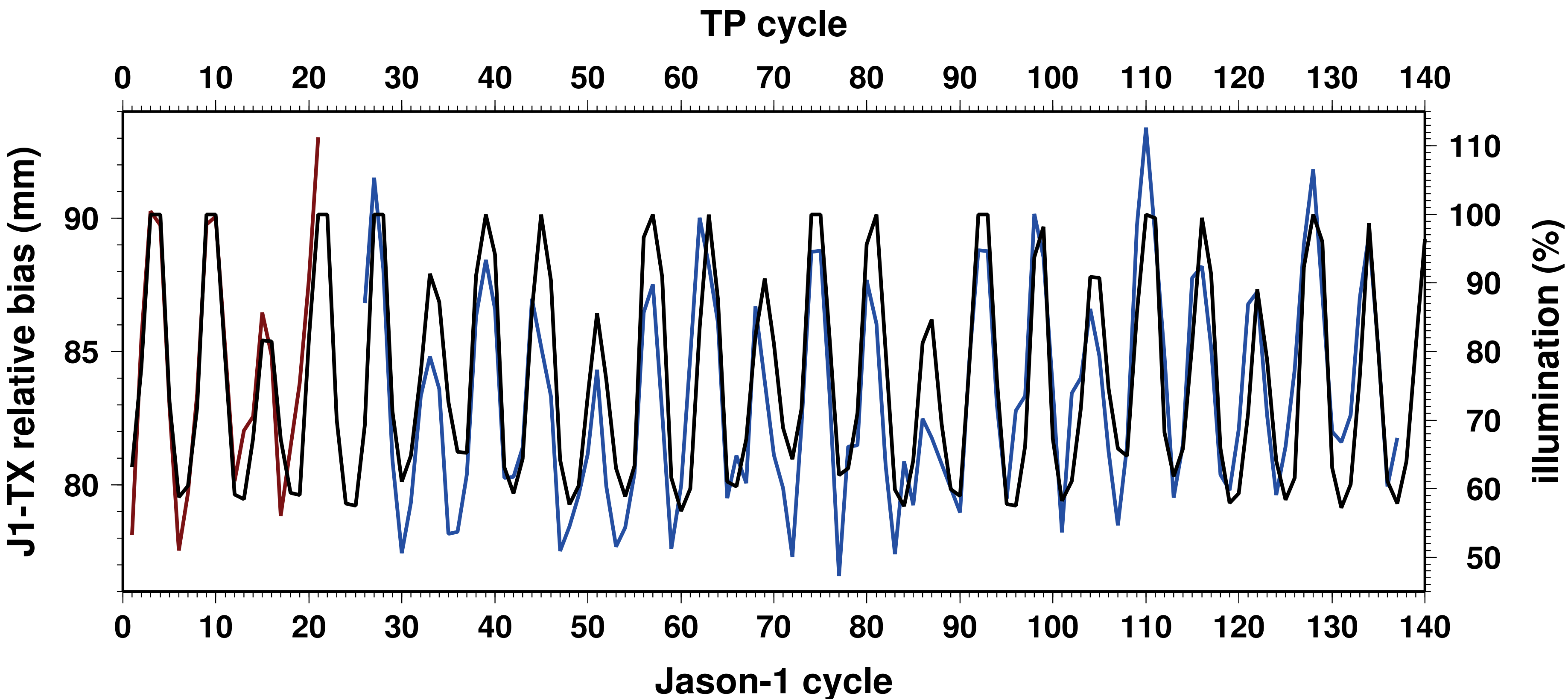
Region	Area (1000 km^2)	St dev (mm)	Scatter about mean (mm) 6 altimeters	Scatter about mean (mm) reference
Yellow Sea	1303	75.8	12.4	6.8
Sea of Japan/East Sea	981	67.8	8.2	5.3
Andaman Sea	815	80.6	14	6.5
North Sea	613	73.9	13.4	9.1
Black Sea	462	81.3	10.5	5.5
Baltic Sea	397	139.7	30.5	16.4
Persian Gulf	238	54.7	23.8	13.9

Part 2: What can we learn about the intermission bias from the differences between TOPEX and Jason-1 during the calibration phase?



J1-TX Bias depends on solar illumination

For per-cycle global means, the J1-TX bias is highly correlated with the amount of time TX and J1 spent in the Sun.



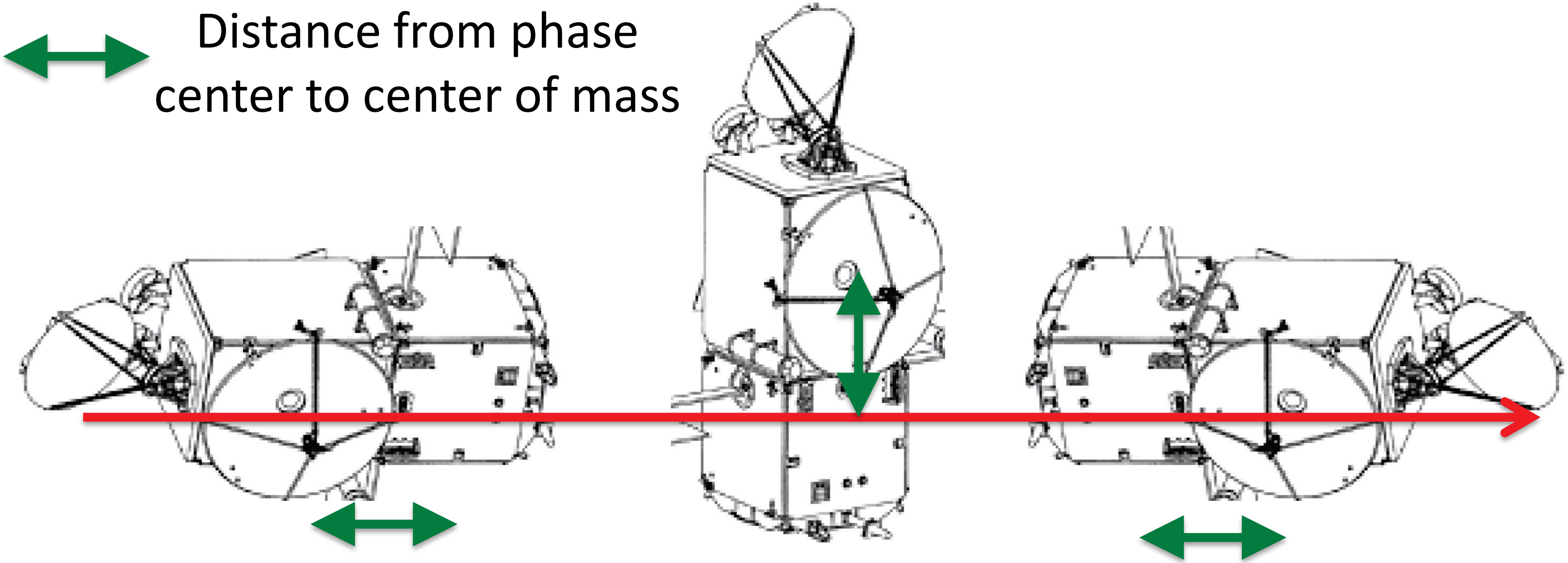
Jason-1/TOPEX calibration phase

Jason-1/TOPEX interleaved phase

Is there a yaw state timing bias?

Depending on yaw position of the spacecraft, the antenna phase center can lead or lag the center of mass.

Exploiting Cryosat's range precision, Smith and Scharroo identified a yaw timing bias between range measurements and altitude interpolation.



Yaw-state bias: a small uncorrected error?

The timing bias would lead to a small range bias:

yaw range bias = cos(yaw) * altimeter phase center–CoM * orbital altitude rate / orbital velocity

orbital_altitude_rate = -15 to 15 m/s

orbital_velocity = 7200 m/s

AltPhaseCenter–CoM = Jason-1 and Jason-2 = 0.674 m; TOPEX = 1.079 m

The yaw timing bias would be 94 µs for Jason and 150 µs for TOPEX.

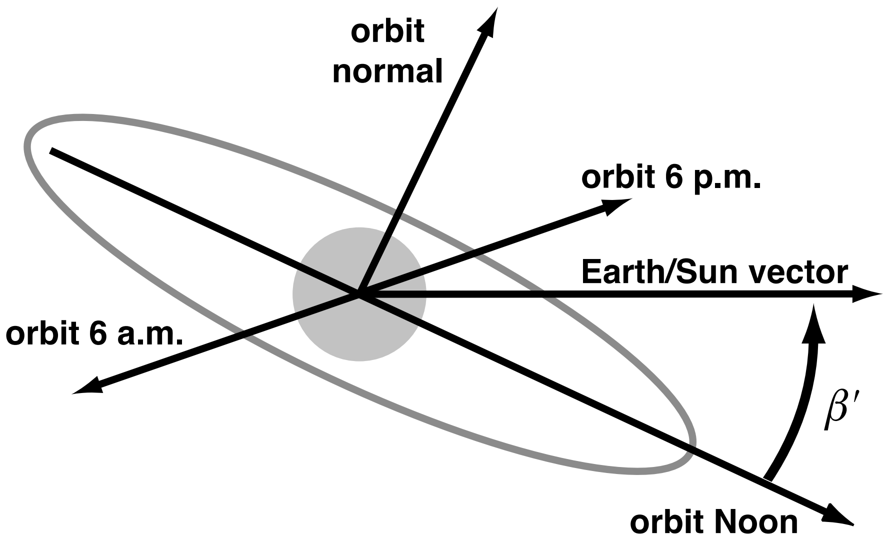
Yaw-state orbit altitude biases would range along-track from ±1.4 mm for Jason and ±2.2 mm for TOPEX.

Can this bias be identified in Jason-TOPEX differences?

Solar angles

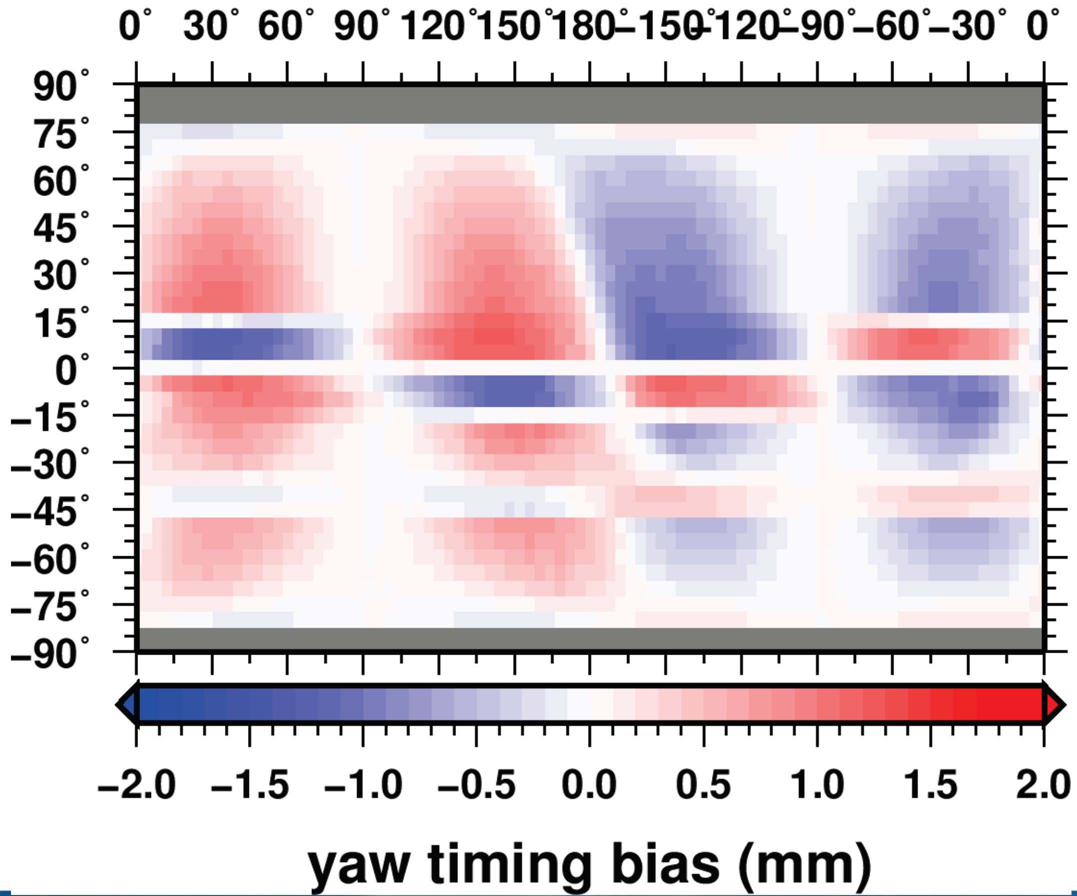
Yaw state depends on solar angles

- α', orbit angle, i.e. the angular separation of the spacecraft from the orbital 6 a.m. position.
- β', solar aspect angle, i.e. the angle between the Earth/Sun position vector and the orbital plane.



Yaw state timing bias

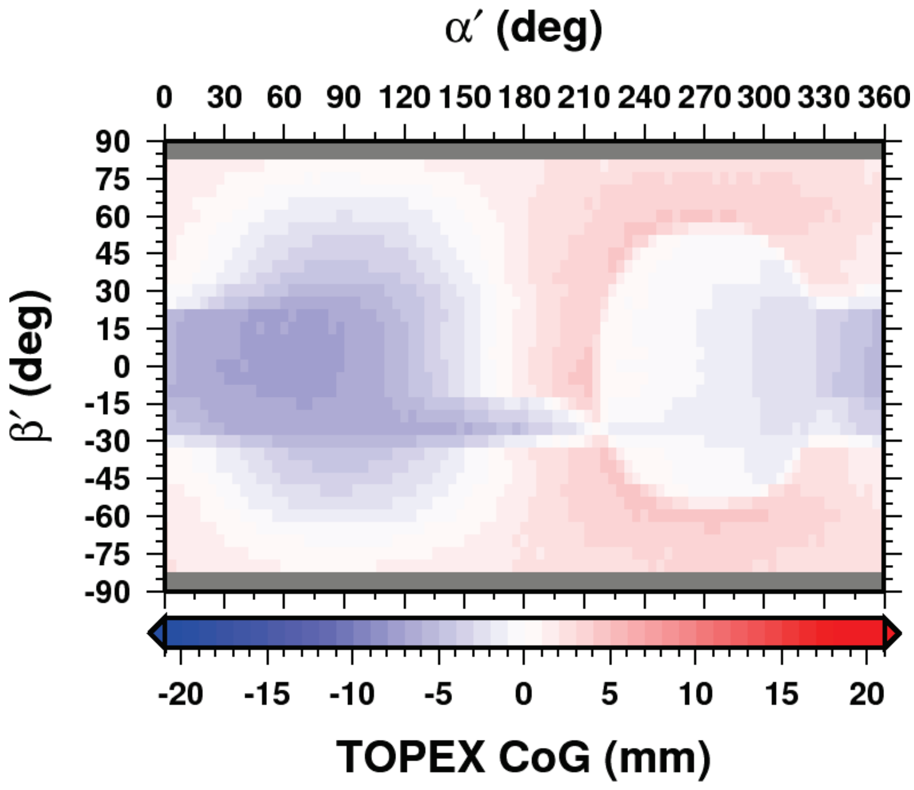
During the calibration phase, the range bias from the yaw state timing bias in terms of solar angles:

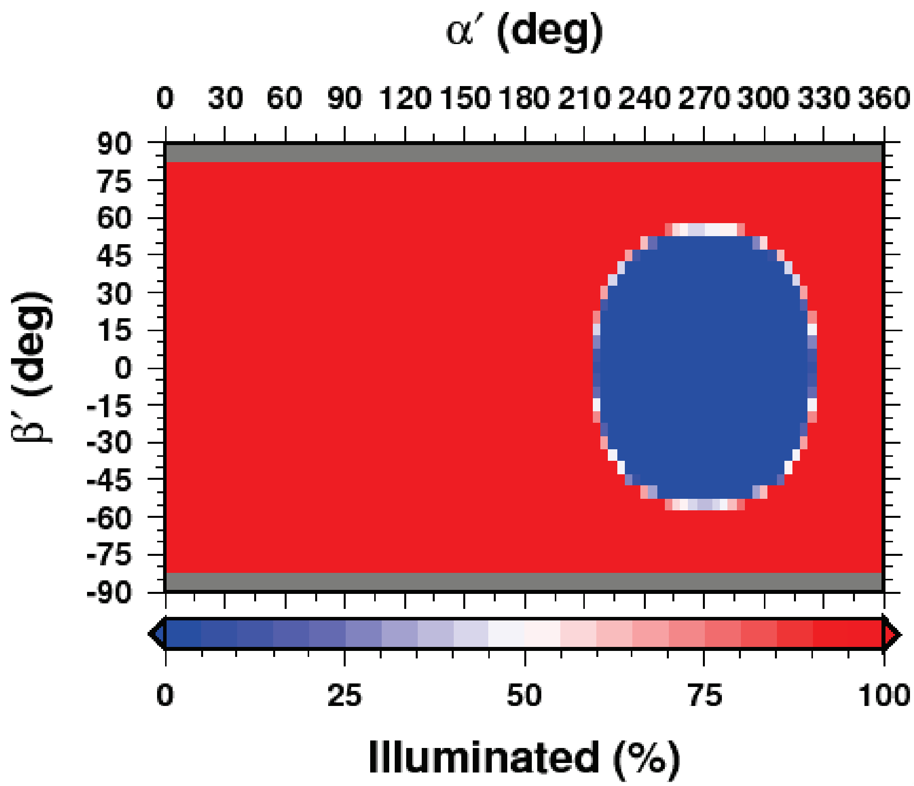


TOPEX center of mass correction

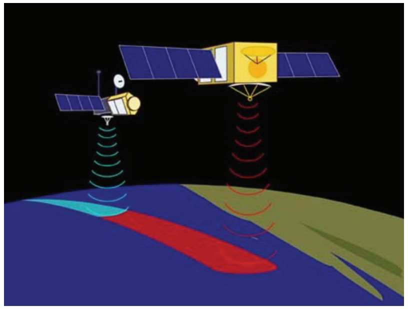
The TOPEX GDRs include a theoretical center of mass correction to account for solar array deformation and position and fuel depletion.

Mean TOPEX CoG correction during the calibration phase





Jason-1 and TOPEX calibration phase differences

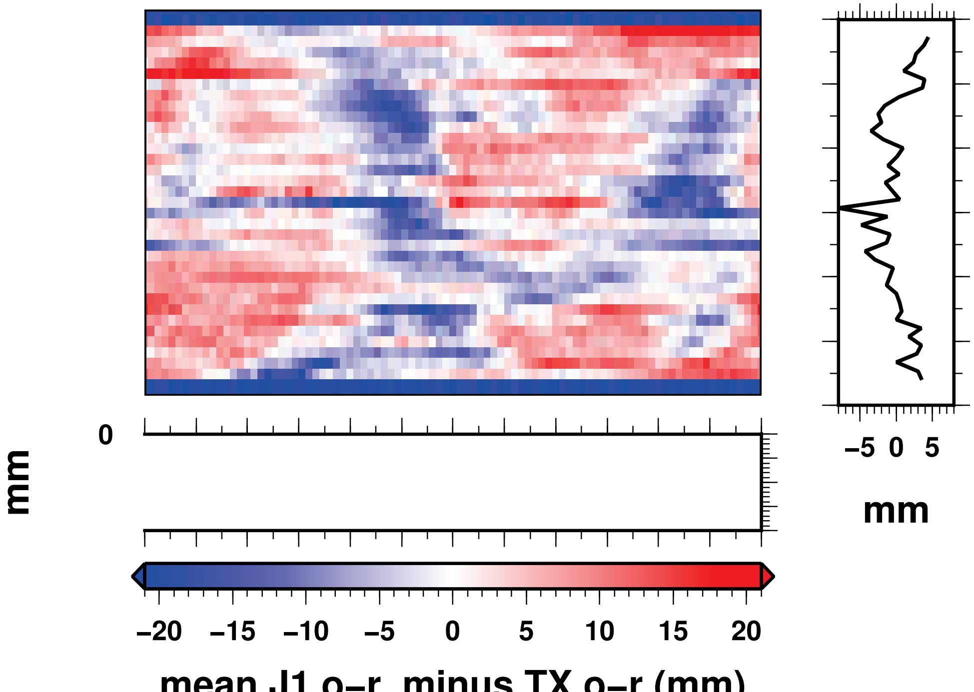


8727638 1-Hz calibration phase differences binned by orbit angle, α', and solar aspect angle, β'

Differences in orbit – range; all other corrections (tides, SSB, ionosphere cancel)

The binned differences range over several cm (st. dev. 8.6 mm).

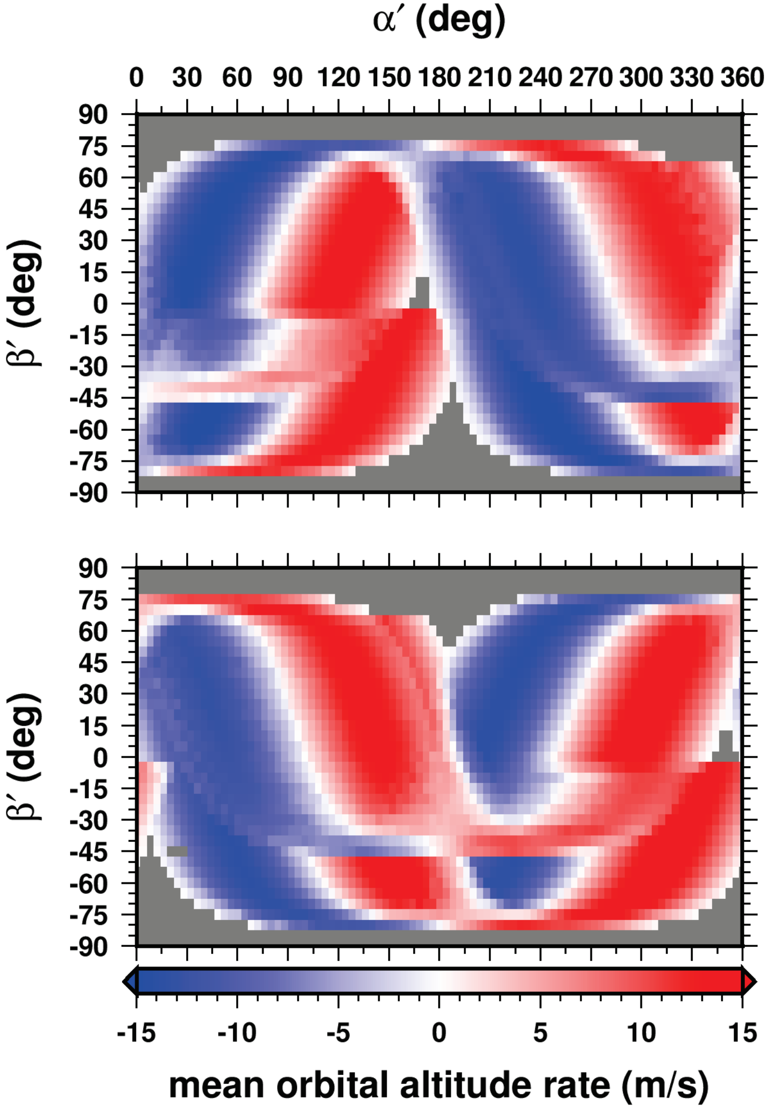
When averaged over solar angle or solar aspect angle, the J1-TX biases are



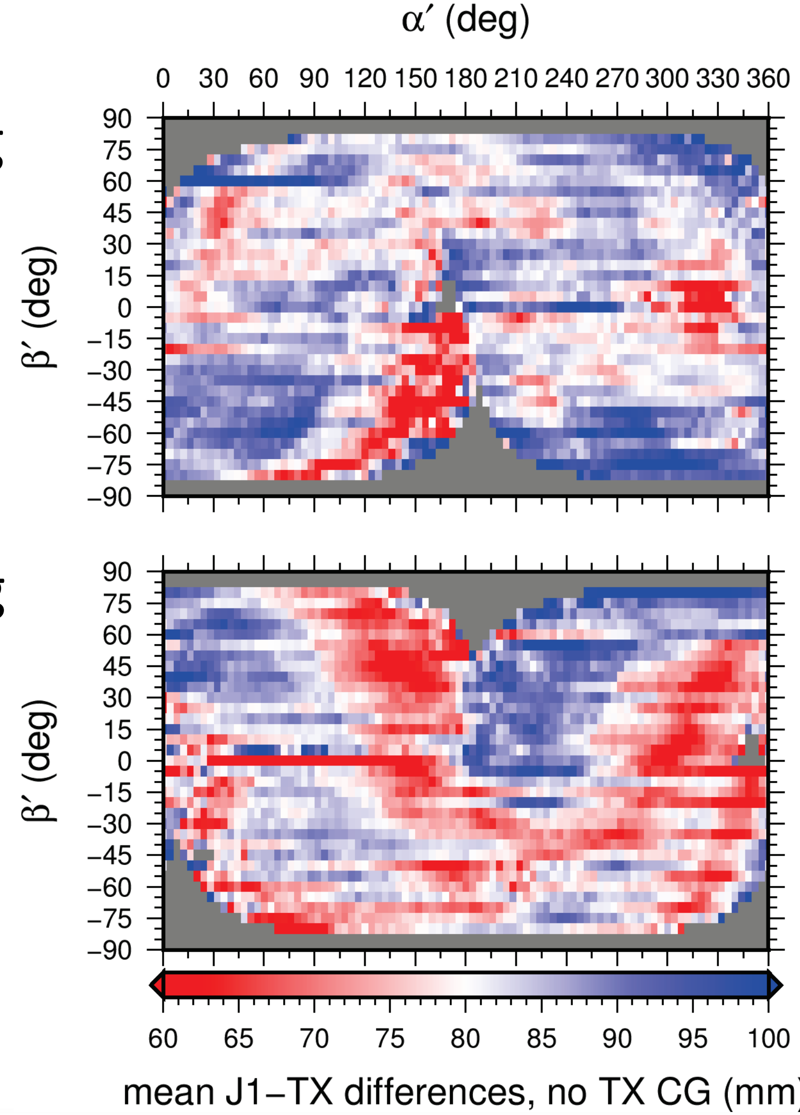
No TX center of mass correction applied

time tag bias: correlated with altitude rate

J1 orbital altitude rate



J1-TX bias



Ascending passes

Descending passes

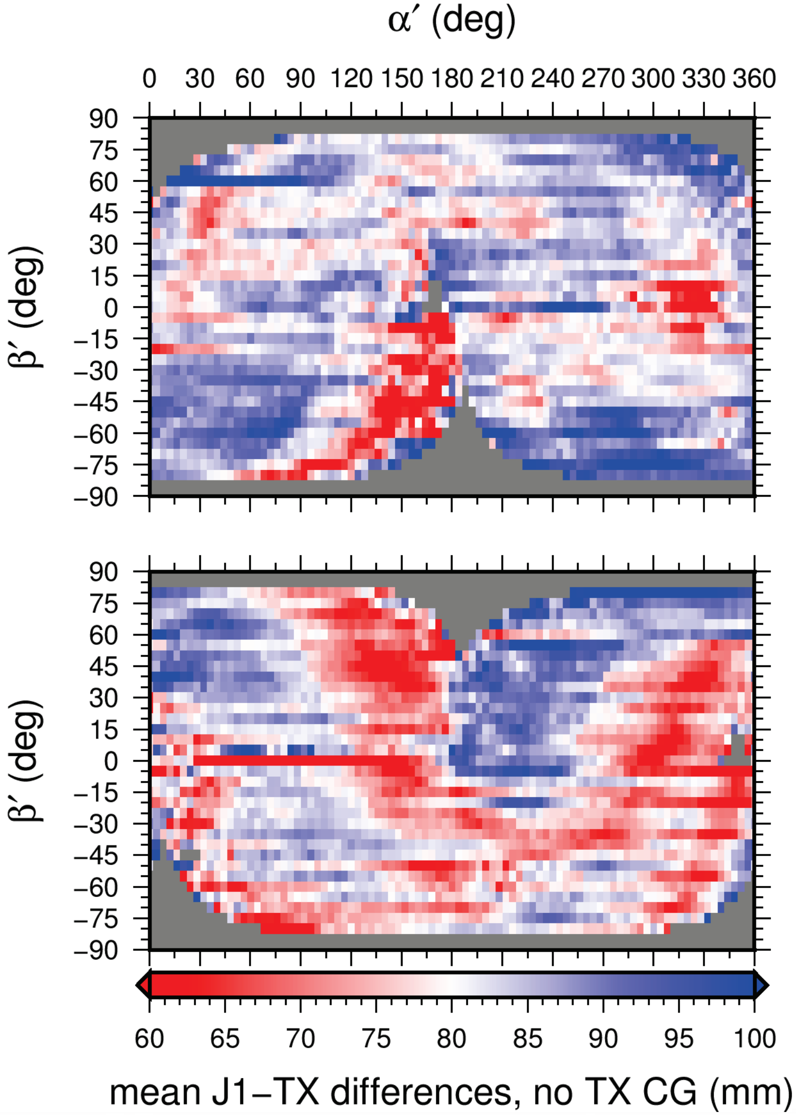
Pseudo time tag bias?

- For the all descending passes and ascending passes when B' –90° to –60° the 1-Hz Jason-1/TOPEX bias has a correlation of –0.162 with orbital altitude rate.
- From a regression:

  J1–TX bias (mm) = –655 μs * orbital altitude rate (m/s)
- Jason-1 GDR-C includes an empirical time tag bias of 280 μs from crossovers "to be added to the altimeter range".
- Sign error in the GDR value or the GDR manual instructions?

Applying the time tag bias correction

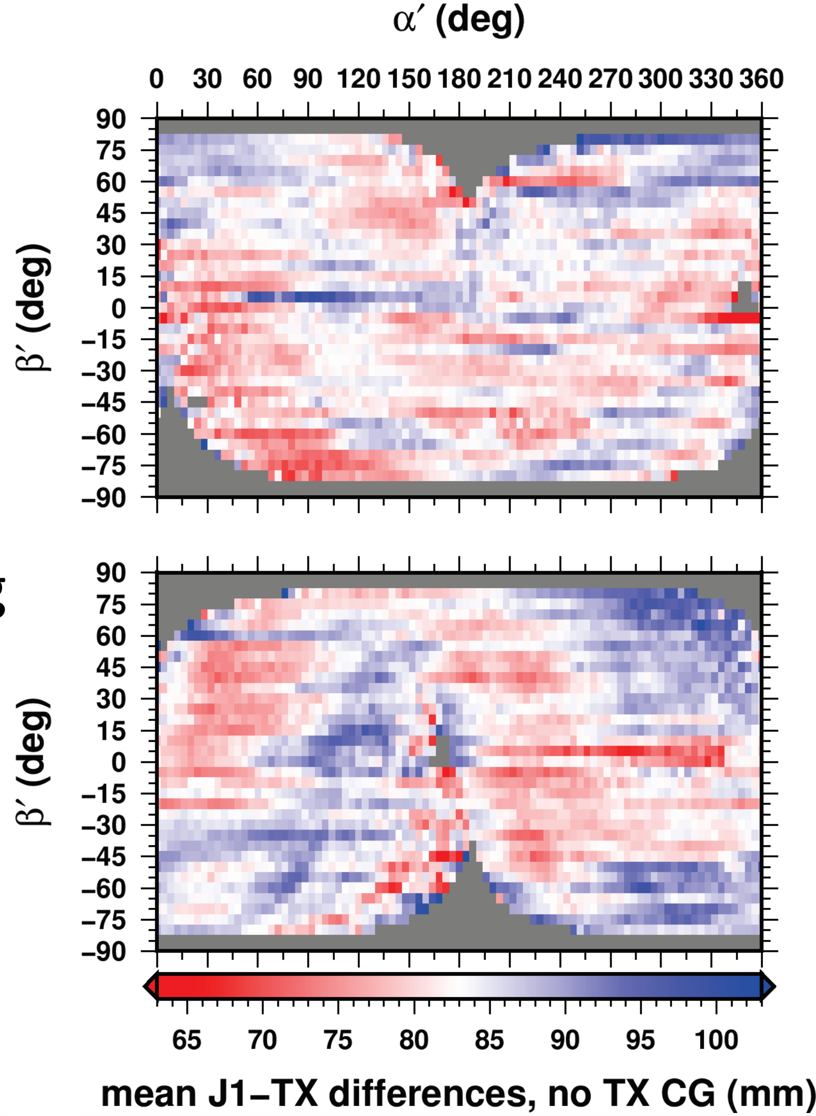
J1-TX bias



Ascending passes

Descending passes

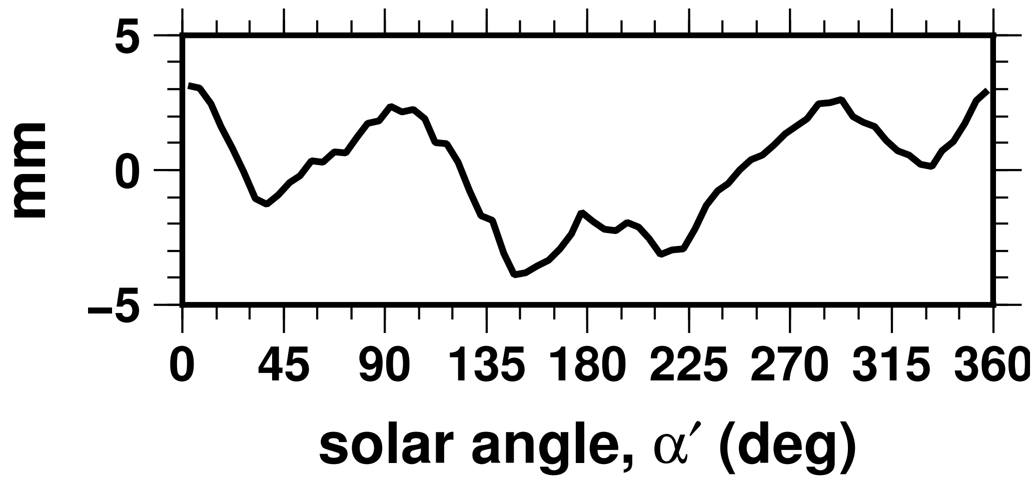
J1-TX bias with correction

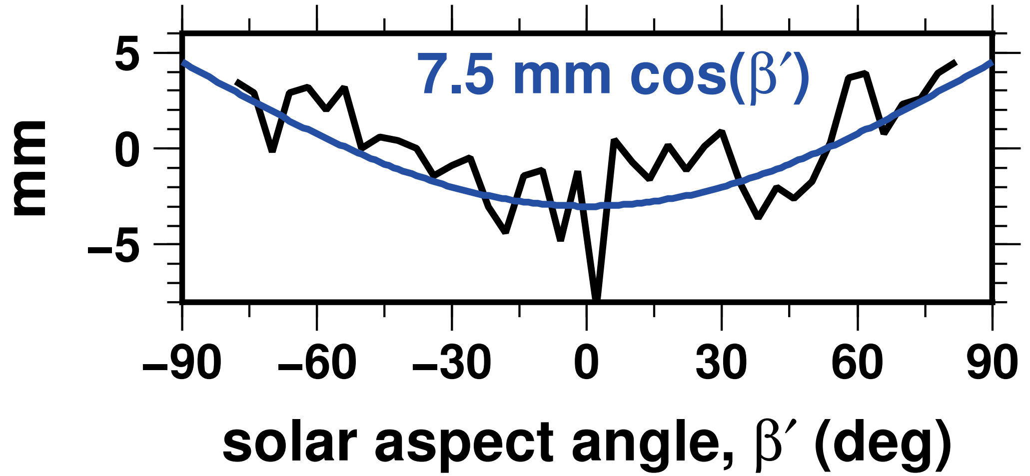


Remaining J1-TX differences

After correcting for the Jason-1 time tag bias, the dependence of the J1-TX bias on solar angle is symmetric about 180° .

The dependence on solar aspect angle β' is 7.5 mm cos(β').





Conclusions and discussion

- Approximate regional sea level uncertainties can be estimated from intermission differences.
  - Should the reference missions have some metric for regional sea level accuracy or stability?
- Differences during the J1–TX calibration phase remain:
  - Is there a sign error in Jason-1 GDR time tag bias?
  - What is the source of the β'/59-day bias?
  - Should the TOPEX center of mass correction be applied?
  - Should we remove a TOPEX time tag bias?
  - Should we be pursuing ~1 mm level errors?