Multi-mission altimetry: joint estimation of relative range biases and radial errors for contemporary missions

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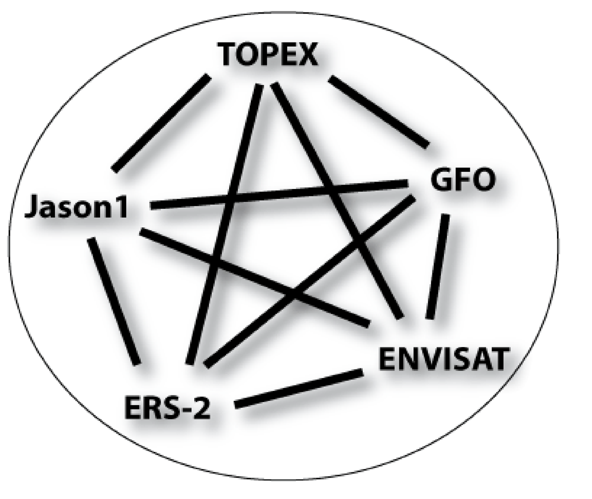
Objectives

A discrete crossover analysis (DCA) is used for the common estimation of radial errors of contemporary altimeter systems. Numerous nearly simultaneous single- and dual-satellite crossovers allow a reliable estimate and dense sampling of the radial errors of all satellites involved. The procedure enables to assess the spectral properties of the radial error components, captures relative range biases and indicates systematic variations due to centre-of-origin shifts. Most challenging is the capability to estimate the geographically correlated mean error. The approach is applied to data of ERS-1, ERS-2, TOPEX, Poseidon, GFO, Jason1, and ENVISAT, with data widely upgraded by retracking efforts and/or improved by new GRACE based orbits.

Table 1. Altimeter mission data used for the present analysis

Mission (Phase)	Cycles	Period	Source	Replacements
TOPEX/Poseidon	001-481	1992/09/23-2005/10/08	MGDR-C AVISO	Chambers SSB correction, FES2004, MWR
Jason1	001-021 119-135	2002/01/15-2005/09/14	GDR-B PODACC	FES2004
	022-118		GDR-A PODACC	FES2004, SSB +2cm
ERS-1 (D, E, F)	102-143	1993/12/20-1995/03/24	OPR-V5 CERSAT	DESO orbits, FES2004, pole tide, MWR
ERS-1 (C & G)	083-101 144-155	1992/04/14-1993/12/20 1995/03/24-1996/04/28	OPR-V6 CERSAT	DEOS orbits, FES2004, pole tide
ERS-2	000-087	1995/04/29-2003/09/15	OPR-V6 CERSAT	DEOS orbits, FES2004, pole tide
ENVISAT	010-040	2002/09/30-2005/09/19	GDR ESA/CNES	FES2004
GFO	100-122	2003/01/01-2003/12/31	GDR NOAA	FES2004



Discrete Crossover Analysis (DCA)

Crossover differences $d' = [\cdots, \Delta x_{ij}, \cdots]$ are modelled

$$\min_{k'x=0} \left\| \begin{bmatrix} D \\ A \end{bmatrix} x = \begin{bmatrix} 0 \\ d \end{bmatrix} \right\|_P^2$$

by the radial errors x_i and x_j of the two passes intersecting at a crossover location. To avoid uncontrolled jumps of the errors, consecutive differences are considered in addition and - together with the crossover differences - minimized by the weighted least squares approach: The combined system has a rank defect of 1 which is solved by a single constraint $k'x = 0$ applied to all errors x_i or any subset of these errors. Here, the sum of all TOPEX errors was forced to be zero.
With growing time difference Δt, both „observation", Δx and $x_i - x_{i+1}$ are down weighted with different half-weight-width. Additional weights are derived from the crossover standard deviation and by cosφ compensating the increasing number of crossovers at high latitude.

Radial error components

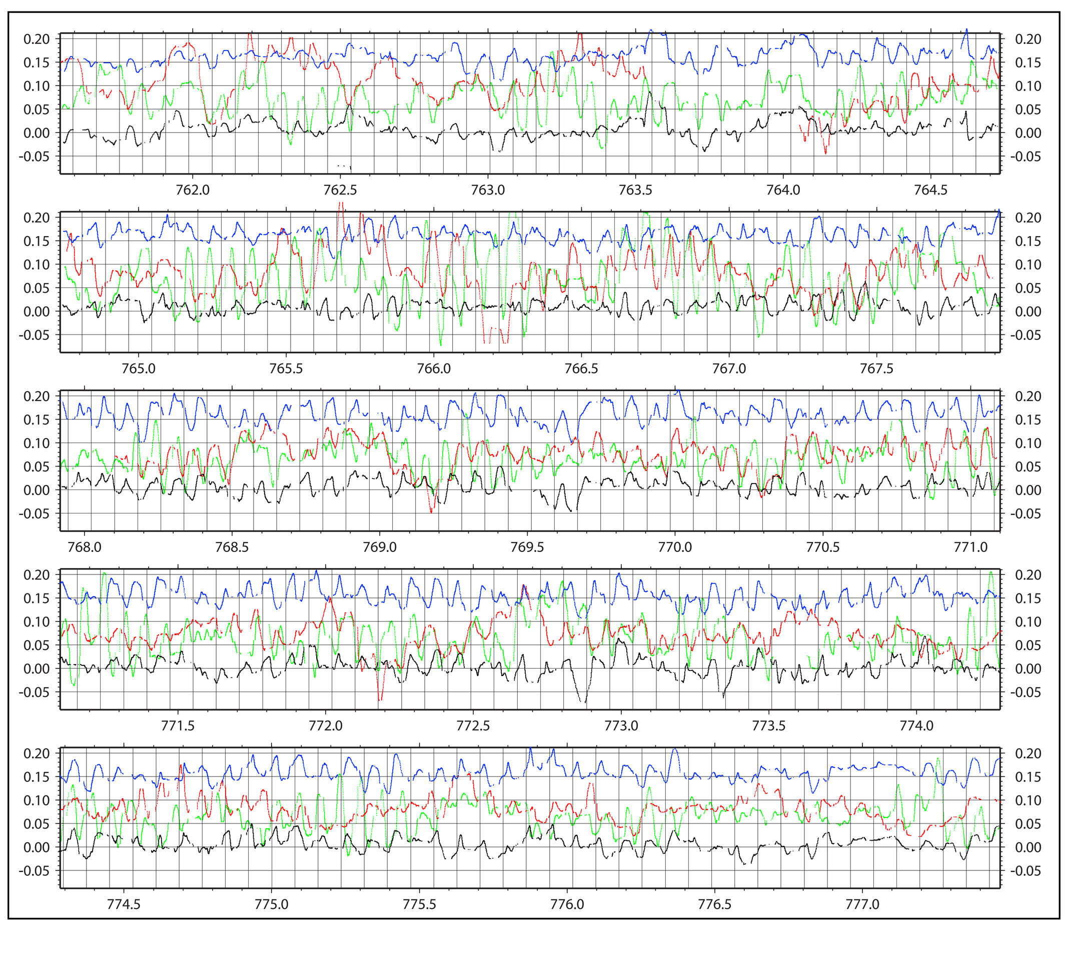


Fig. 2: *Subset of analysis period with the radial error estimates of TOPEX (black), ERS-2 (red), GFO (green) and Jason1 (blue).*

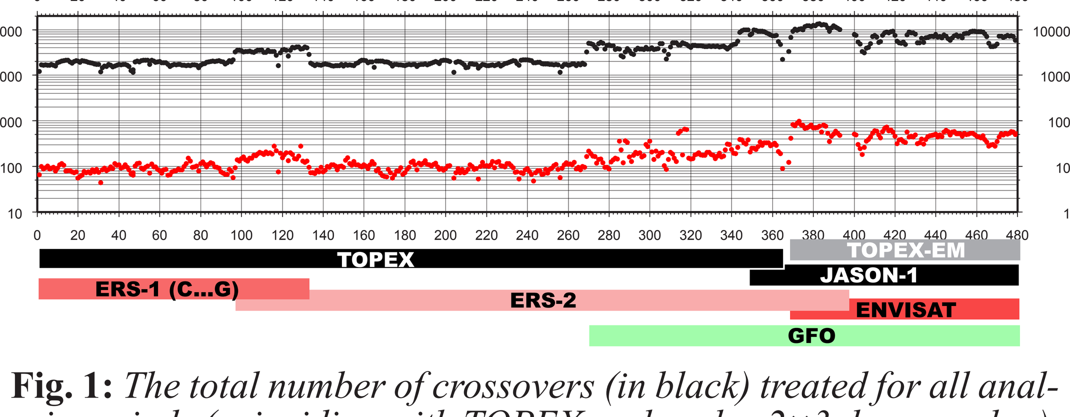


Fig. 1: *The total number of crossovers (in black) treated for all analysis periods (coinciding with TOPEX cycles plus 2×3 days overlap). The crossover adjustment was iterated once skipping crossovers whose residuals exceed a 3σ-criteria (less than 1%, shown in red).*

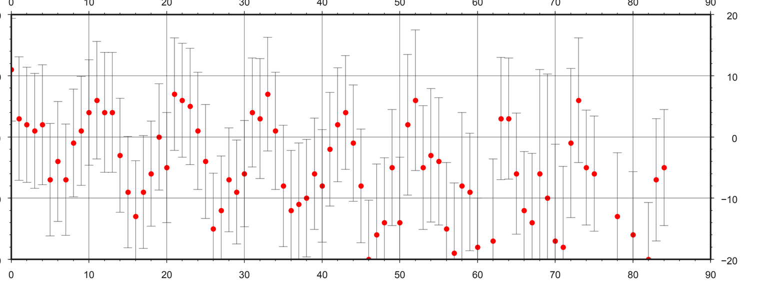


Fig. 5: *The mean values of ERS2 crossover differences exhibit a pronounced annual variation. The non-zero means of crossover differences indicate time bias errors (already identified by the DEOS group). and could explain the reversed centre-of-origin shifts (most definite for dx) between ERS2 and TOPEX shown in figure 4.*

Relative range biases

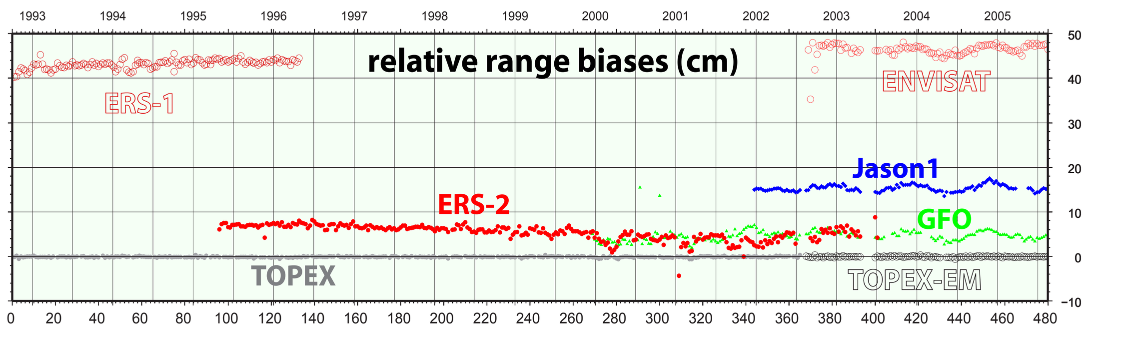


Fig. 3: *Relative range biases (cm) for all missions and 10-day periods analysed. The range biases are relative to TOPEX (later T/P-EM) because the sum of TOPEX (T/P-EM) errors was forced to zero. Note, all biases show weak annual oscillations with similar phasing and amplitude for ENVISAT, Jason1, and GFO since late 2002 – an indication for systematic variations in the TOPEX (T/P-EM) orbits.*

Centre-of-origin shifts

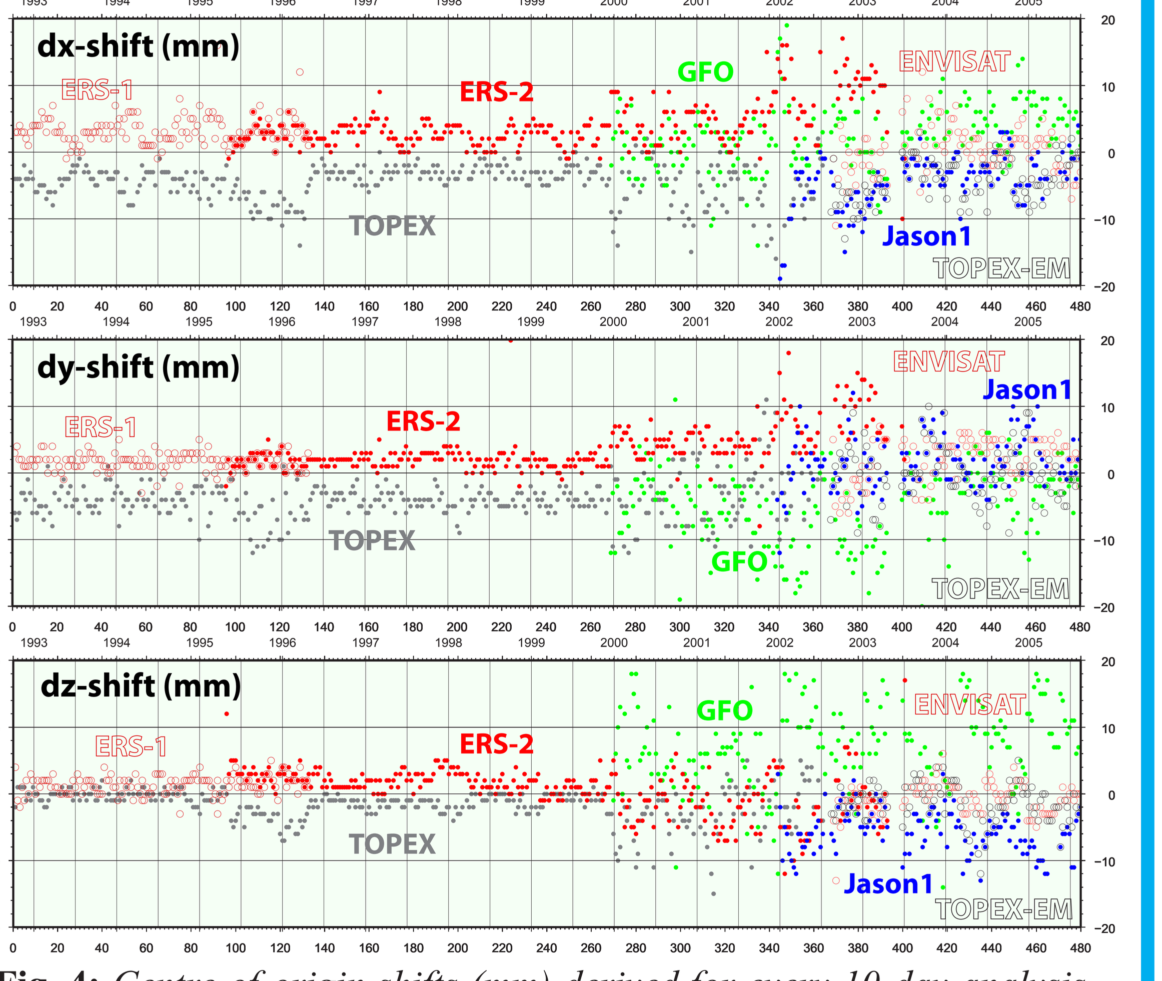
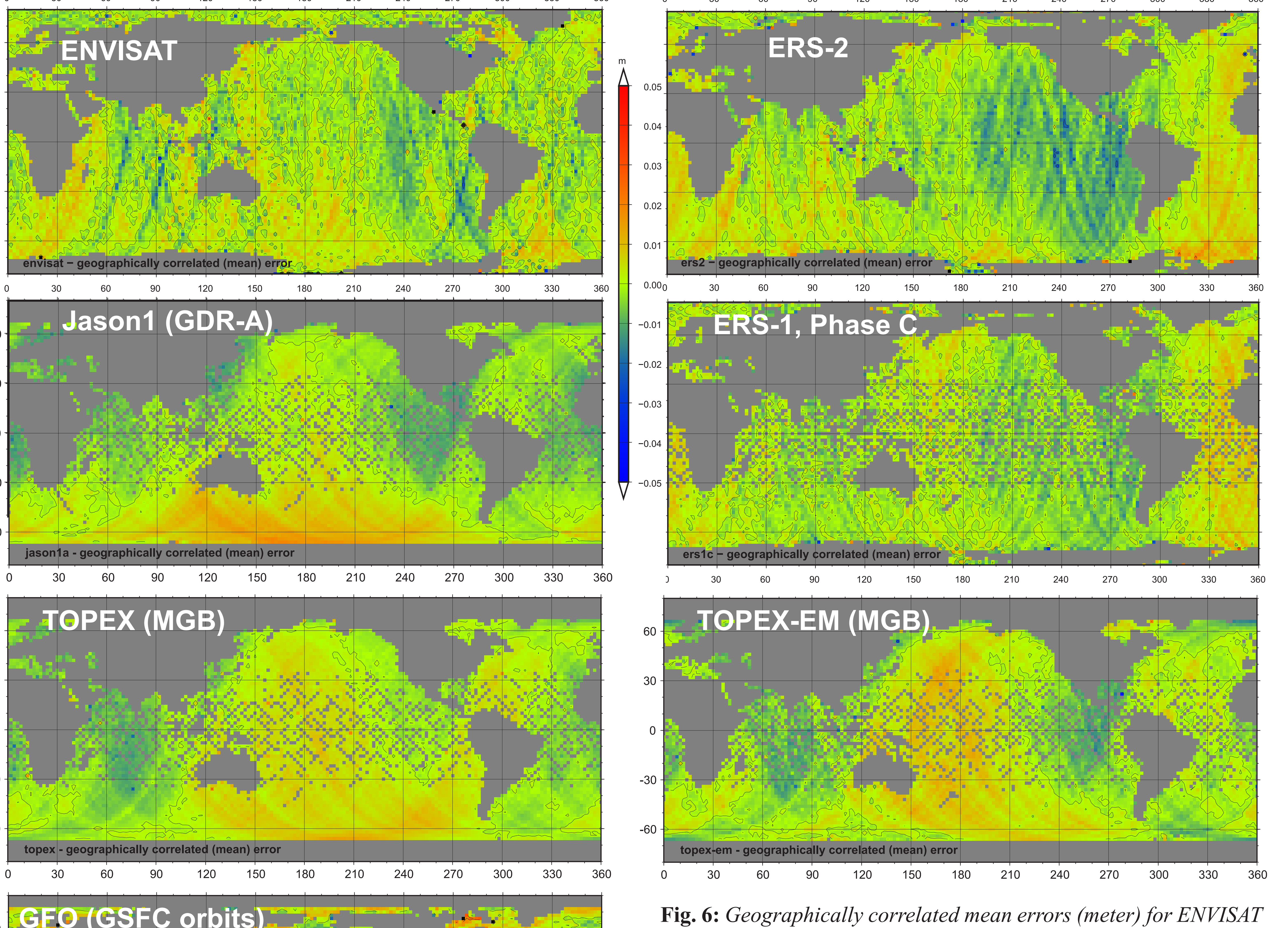


Fig. 4: *Centre-of-origin shifts (mm) derived for every 10-day analysis period from the radial error estimates of each mission. Notable the reversed shifts of ERS-2 and TOPEX. The scatter of the shifts increases significantly from 2000 on. Striking the large z-shifts for GFO - possibly caused by sea state bias errors in the southern ocean.*

Geographically correlated (mean) errors of all altimeter missions



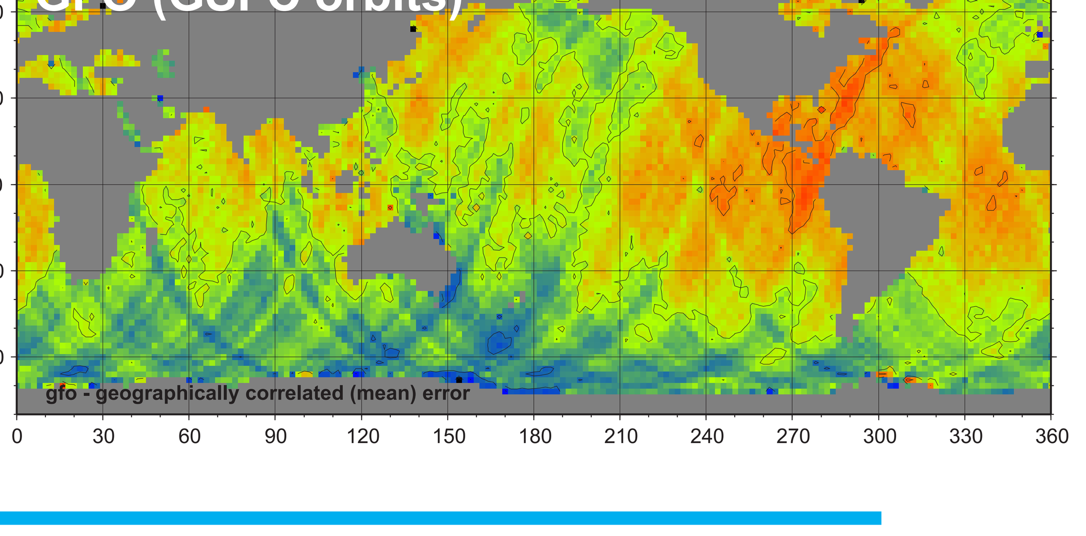


Fig. 6: *Geographically correlated mean errors (meter) for ENVISAT and ERS-2 (top row from left to right), Jason1 and ERS-1, phase C (phase G is similar and not shown), TOPEX and TOPEX-EM, (third row from left to right), and for GFO (left). The mean error pattern for TOPEX and TOPEX-EM are – as expected – very similar. However the mean error of Jason1 differs significantly from TOPEX although Jason1 orbits are also based on JGM3. This is an indication that not only gravity field errors but also other errors (e.g. for sea state bias) map into the mean error. GFO exhibits the most outstanding mean error pattern with up to 4-5 cm around central America and negative values (between -2 and -4 cm) at all southern oceans.*

Conclusions

Global multi-mission crossover analysis was performed for up to five contemporary altimeter satellites. The total set of single- and dual-satellite crossovers creates a strong network with high redundancy and enables a reliable and dense sampling of the radial errors of all satellites.
The error time series allows to assess the spectral properties of the radial component, captures relative range biases and indicates systematic variations of the centre-of-origin realisations. Most challenging is the capability to estimate for all altimeter systems the geographically correlated mean error.

References

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