Multi-Mission Crossover Analysis:

Merging 20 years of altimeter data into one consistent long-term data record

Denise Dettmering and Wolfgang Bosch
Deutsches Geodätisches Forschungsinstitut (DGFI), München
dettmering@dgfi.badw.de

Centre of Geodetic Earth System Research

Motivation

The satellite altimeter scenario of the past two decades provides continuous and precise monitoring of the ocean surface with a beneficial spatio-temporal sampling. Since 1992 two or more contemporaneous missions are continuously available (see Fig. 2). For climate studies a consistent long-term data record is a fundamental requirement. However, combining missions with different sampling capabilities requires a careful preprocessing and calibration of all altimeter systems. A global multi-mission crossover analysis is able to connect the measurement from individual missions and merge them to one consistent long-term data record even if some of the missions are not operating on a repeat ground track.

Method: Multi-Mission Crossover Analysis (MMXO)

The Multi-Mission Crossover analysis (MMXO) takes advantage of the high redundancy provided by a multiple surveying of the sea surface through contemporaneous altimeter missions. The redundancy is expressed by short-term single- and dual-satellite crossover differences Δx_{ij} in all combinations. Together with consecutive radial errors δx_i they are minimized by a least squares adjustment, which includes a variance component estimate to achieve an objective relative weighting between different missions.

Main steps:

1) Computation of single and dual-satellite crossover differences Δx_{jk} in all combinations
2) Minimizing both $\Delta x_{jk} = x_j - x_k$ and $\delta x_i = x_{i+1} - x_i$ and estimation of radial errors x_i at all crossover points
3) Derivation of relative range biases, center-of-origin shifts as well as common error components of ascending and descending passes

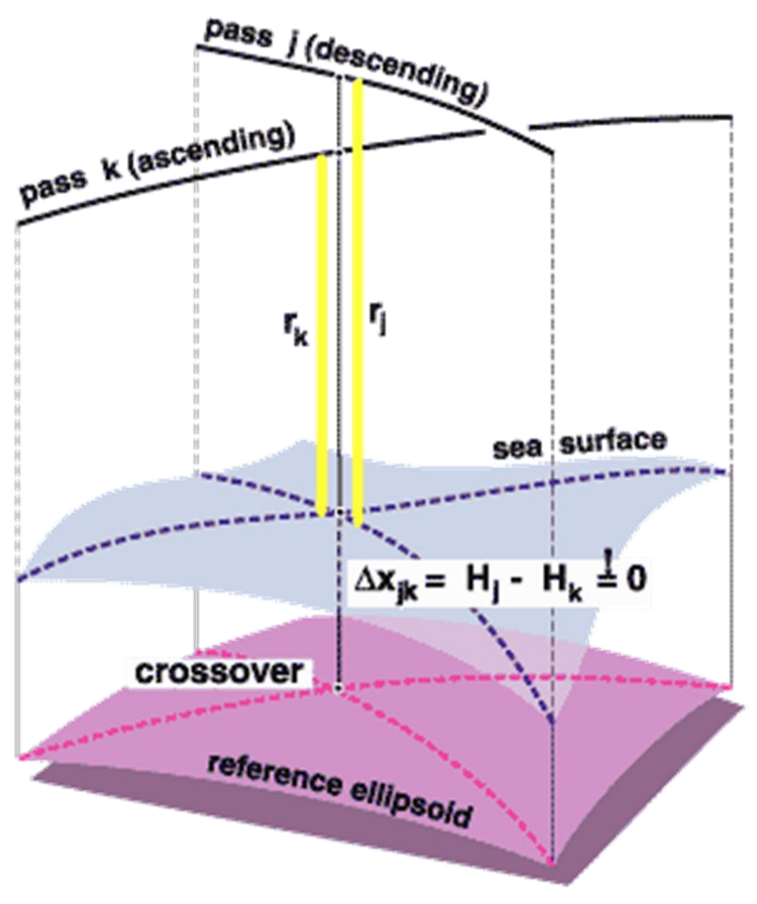

Fig. 1: Crossover differences

Output:

Time series of radial errors for each mission, which is used to derive

- Empirical auto-covariance functions of the radial errors
- Geographically correlated errors (GCE)
- Mean range bias Δr (per 10 day cycles)
- Mean differences in the center-of-origin realization $\Delta x, \Delta y, \Delta z$ (10 day cycles)
- Global mean range bias for each mission (w.r.t. reference mission, TOPEX)

Radial Errors

MMXO results in a time series of radial errors for every mission.
For Jason-1 it consists of more than 4.3 million error estimates with an average sampling distance of about 15 seconds (over ocean area only).

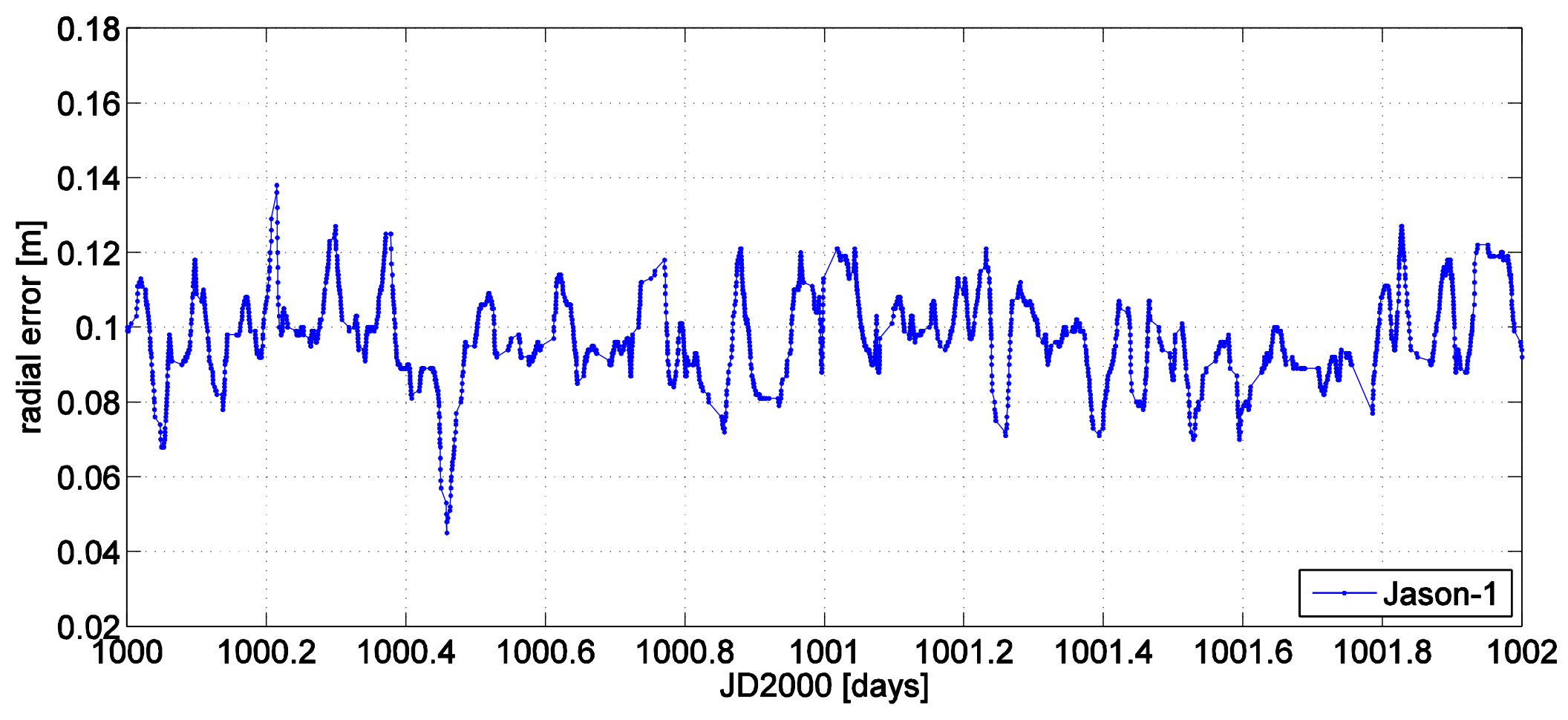

Fig. 3: Radial errors for Jason-1 for a subset of 2 days in September 2002

Time Series of Range Biases

For each 10-day cycle one range bias is computed. These time series can indicate possible instrument drifts (e.g. Envisat first mission phase) or outliers (e.g. Envisat in 2006, offset between side A and side B of ~1.7cm).

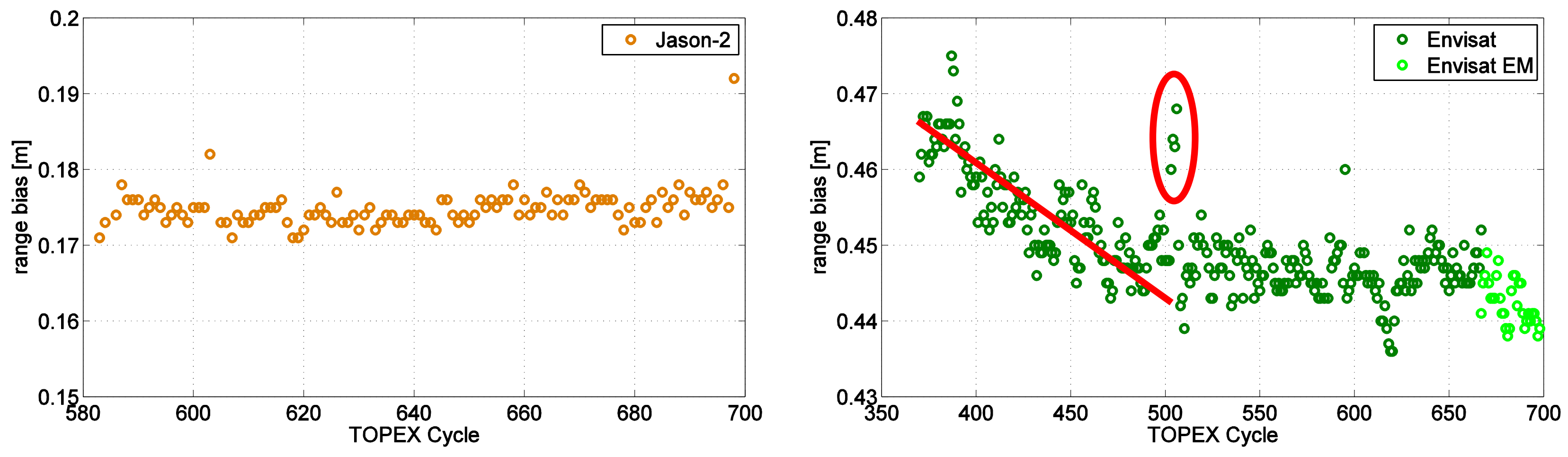

Fig. 4: Range bias of Jason-2 (left) and Envisat (right) w.r.t. TOPEX

Range Biases

For each mission included in the MMXO one global mean range bias has been computed. As these values can reach up to half a meter, it is important to take them into account when combining different altimeter missions.

	Range Bias [cm] <Mission> - TOPEX
Jason-1	9.9 ± 0.1 cm
Jason-2	17.4 ± 0.2 cm
ERS-1	44.1 ± 0.8 cm
ERS-2	6.9 ± 0.7 cm
Envisat (repro)	45.0 ± 0.6 cm
GFO	2.1 ± 0.4 cm
ICESat*	-3.9 ± 2.3 cm
Cryosat^{+}	-58.6 ± 0.4 cm

Tab. 1: Global mean range bias (<mission> - TOPEX [cm])

**ICESat range bias differs for each laser period.*
$^{+}$Cryosat result is based on baseline A data.

Input Data

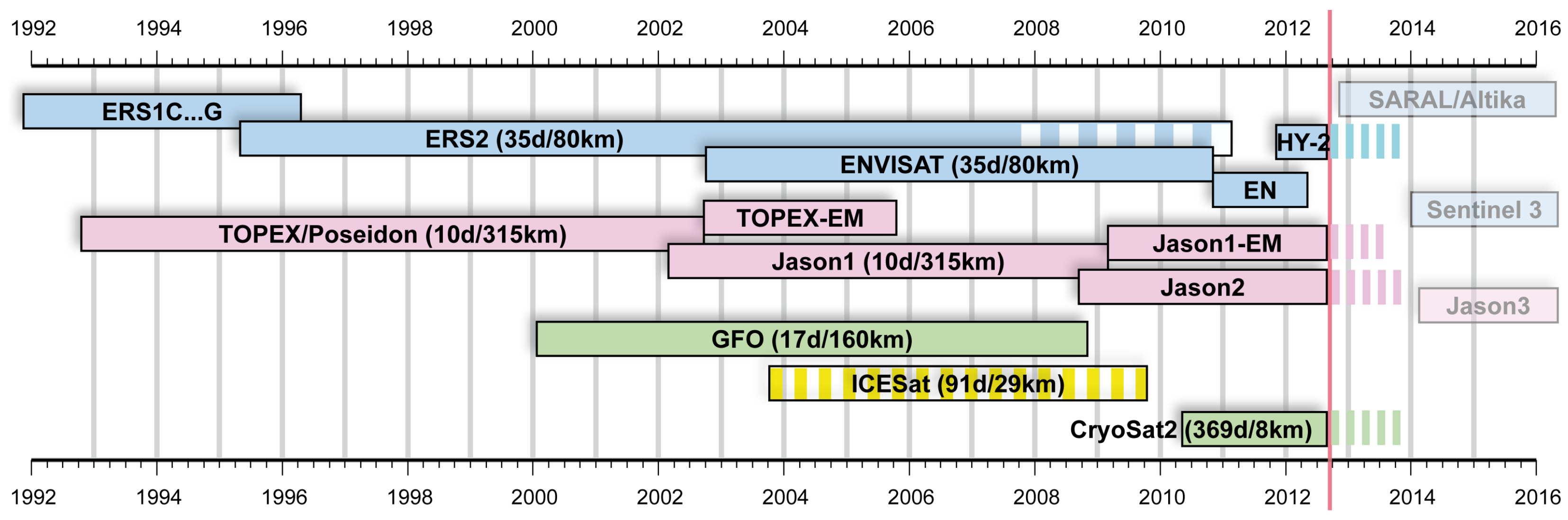

Fig. 2: Overview on Altimeter systems providing measurements in the last 20 years

Data from all missions since 1992 are used for the MMXO. In order to get consistent calibration results, it is necessary to harmonize these data sets as far as possible. To achieve this, identical reference ellipsoids (TOPEX) are used as well as same geophysical corrections whenever possible (EOT11a, DAC). Moreover, actual orbits for each mission are used.

Empirical Auto-Covariance Functions (EACF)

The stochastic properties of radial errors can be characterized by EACFs (see Fig. 5 for three of the involved missions).

The radial errors have variances between approximately 180 and 400 mm² (1.3 … 2.0 cm standard deviation). All EACFs show relative maxima after the first and second orbital revolution implying increasing correlations between measurements on neighboring ground tracks – an early indication of geographically correlated error patterns.

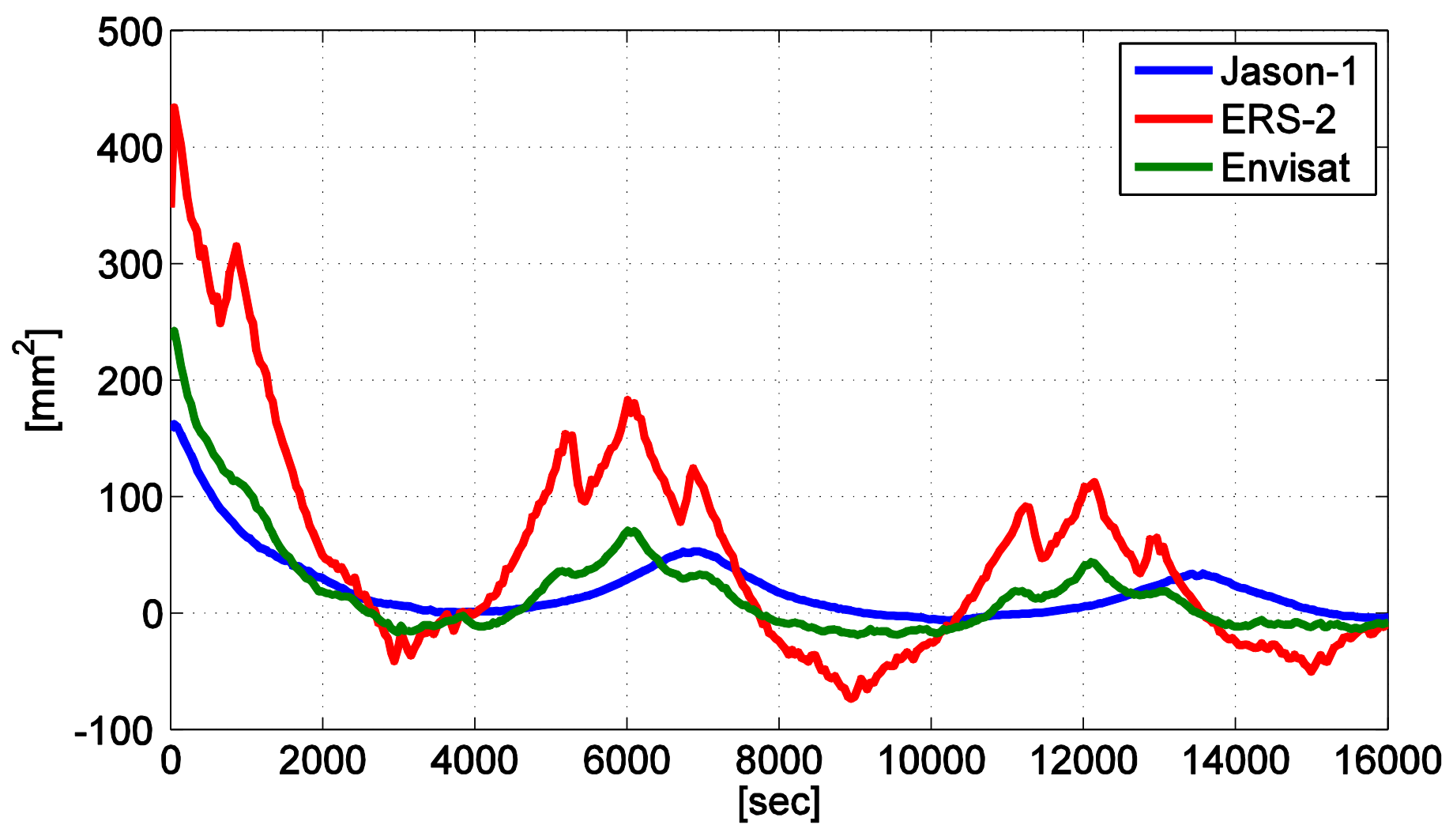

Fig. 5: EACFs for Jason-1, Envisat, and ERS-2

Geographically Correlated Errors (GCE)

Error components having the same sign for ascending and descending passes are called geographically correlated errors (GCE). The MMXO is able to reveal GCE from the estimated radial errors for each of the involved missions. GCE mainly represent problems in precise orbit determination (POD) but also include other geographically correlated effects. Reprocessed orbits can significantly reduce the GCE, e.g. for ERS-1 and ERS-2 (see Fig. 6).

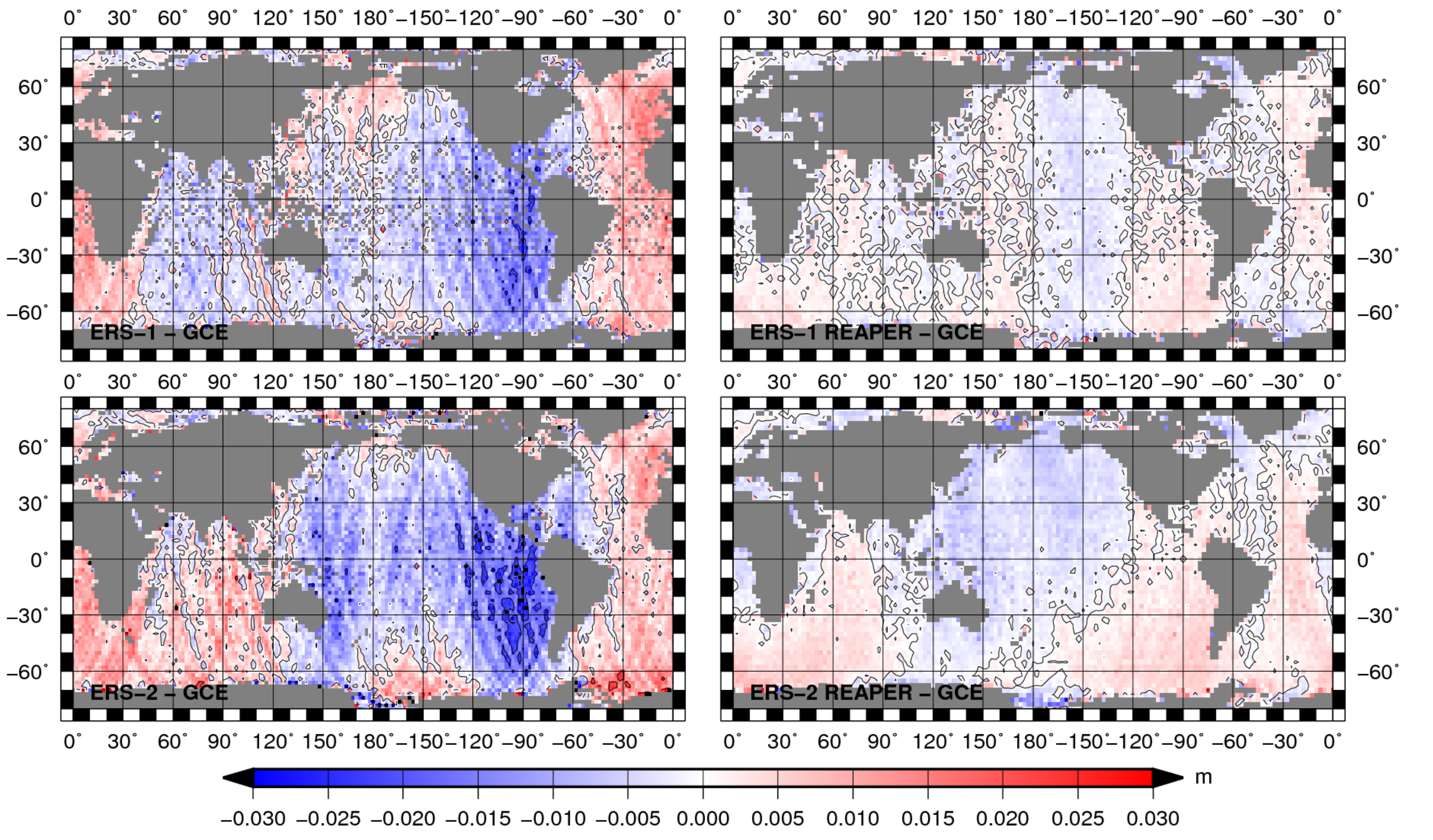

Fig. 6: Geographically correlated error for ERS. The left hand side is computed with early DEOS orbits and the right hand side with the new REAPER orbits. The RMS is improved from 7.7 mm to 2.8 mm for ERS-1 (top) and from 9.5 mm to 3.7 mm for ERS-2 (bottom).

References:

Bosch W.: Discrete Crossover Analysis. IAG Symposium, Vol. 130, 131-136, Springer, 2007
Bosch W., Savcenko R.: Satellite Altimetry - Multi-Mission Cross Calibration. IAG Symposium, Vol. 130, 51-56, Springer, 2007
Dettmering D., Bosch W.: Global Calibration of Jason-2 by Multi-Mission Crossover Analysis. Marine Geodesy, 33:S1, 150-161, 2010
Dettmering D., Bosch W.: Envisat radar altimeter calibration by multi-mission crossover analysis. ESA Publication SP-686, 2010

Symposium “20 Years of progress in radar altimetry” & OSTST, 24-29 September 2012, Venice, Italy