Multi-mission cross-calibration: a prerequisite for climate studies based on satellite altimetry

Denise Dettmering and Christian Schwatke

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

IAG Workshop: Satellite Geodesy for Climate Studies
Bonn, Germany, 19.-21.09.2017

Motivation

- Sea level is one of the essential climate variables (ECV) as defined by GCOS and ESA

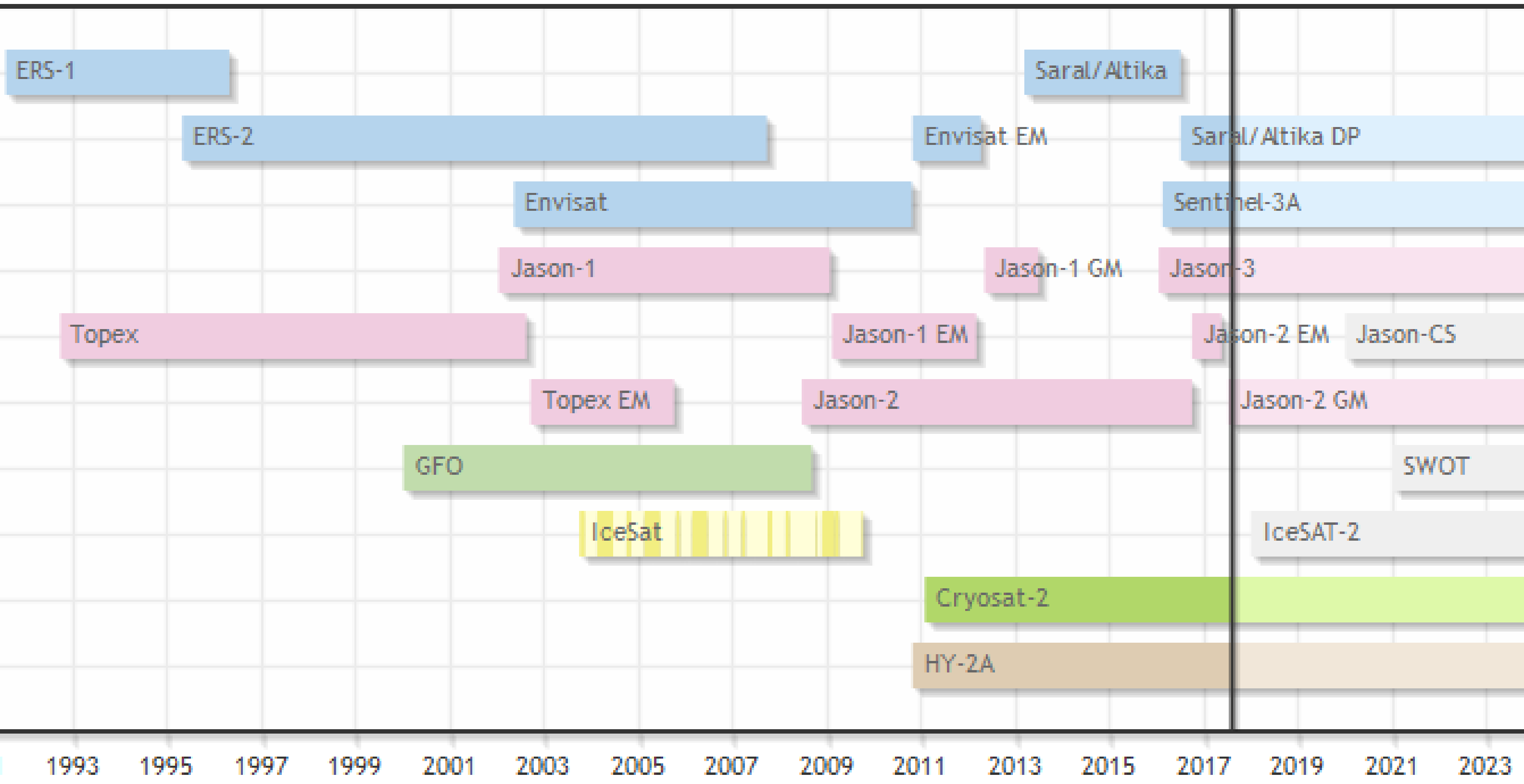
- Satellite altimetry is able to provide sea surface heights, which are
  - ✓ long-term,
  - ✓ highly accurate,
  - ✓ uniformly sampled (spatially as well as temporally)
  - ✓ with (almost) global coverage,
  - ✓ with respect to an absolute reference

  … and therefore, satellite altimetry is very valuable for climate studies

- Since 1991, more than ten different altimetry missions have been active (most of them with changing orbit parameters)

- For exploiting the full potential of satellite altimetry, the combination of different missions is mandatory

Satellite altimetry missions since 1991



Missions used in these investigations

1992-2016 (25 years)

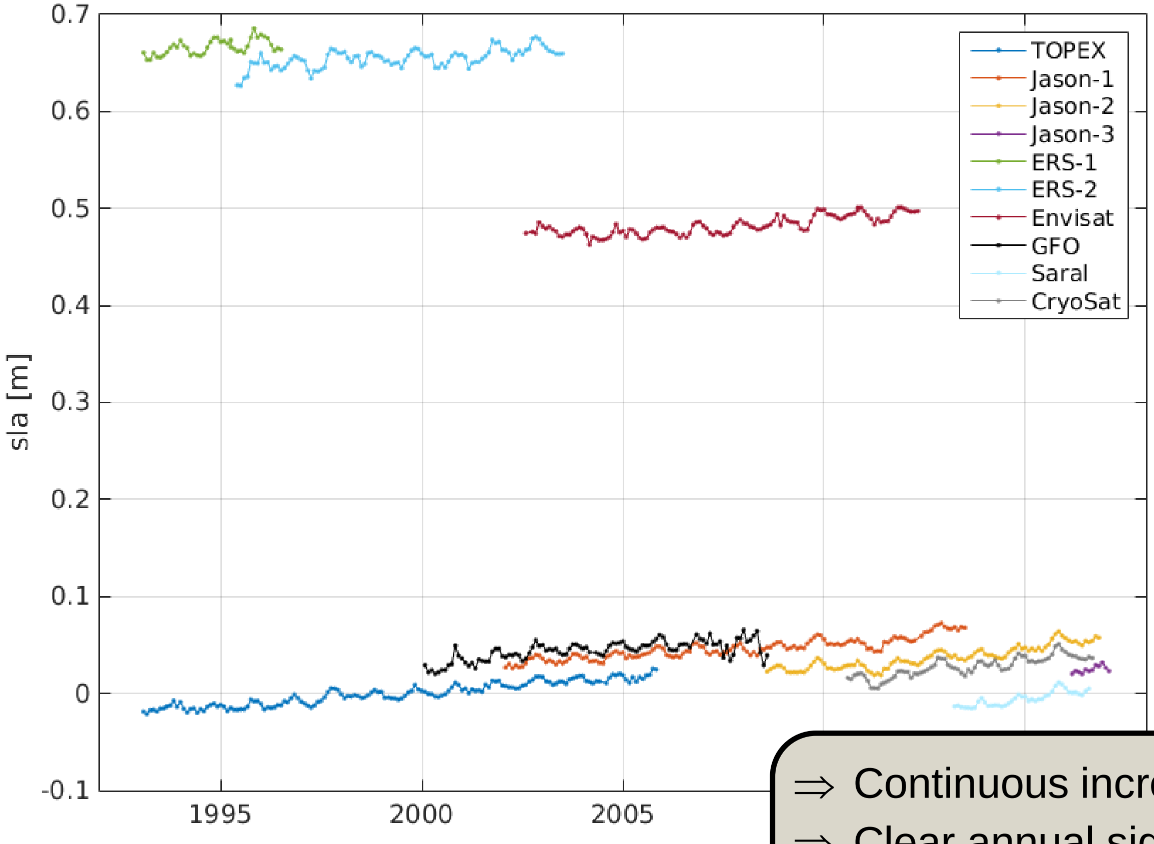
TOPEX	09/1992-01/2006
Jason-1	01/2002-06/2013
Jason-2	06/2008 (ongoing)
Jason-3	01/2016 (ongoing)
ERS-1	07/1991-03/1996
ERS-2	04/1995-09/2011
Envisat	03/2002-04/2012
Saral	02/2013 (ongoing)
GFO	02/1998-11/2008
Cryosat-2	04/2010 (ongoing)

Global sea level change as seen by each mission

Monthly means of global gridded sea level anomalies

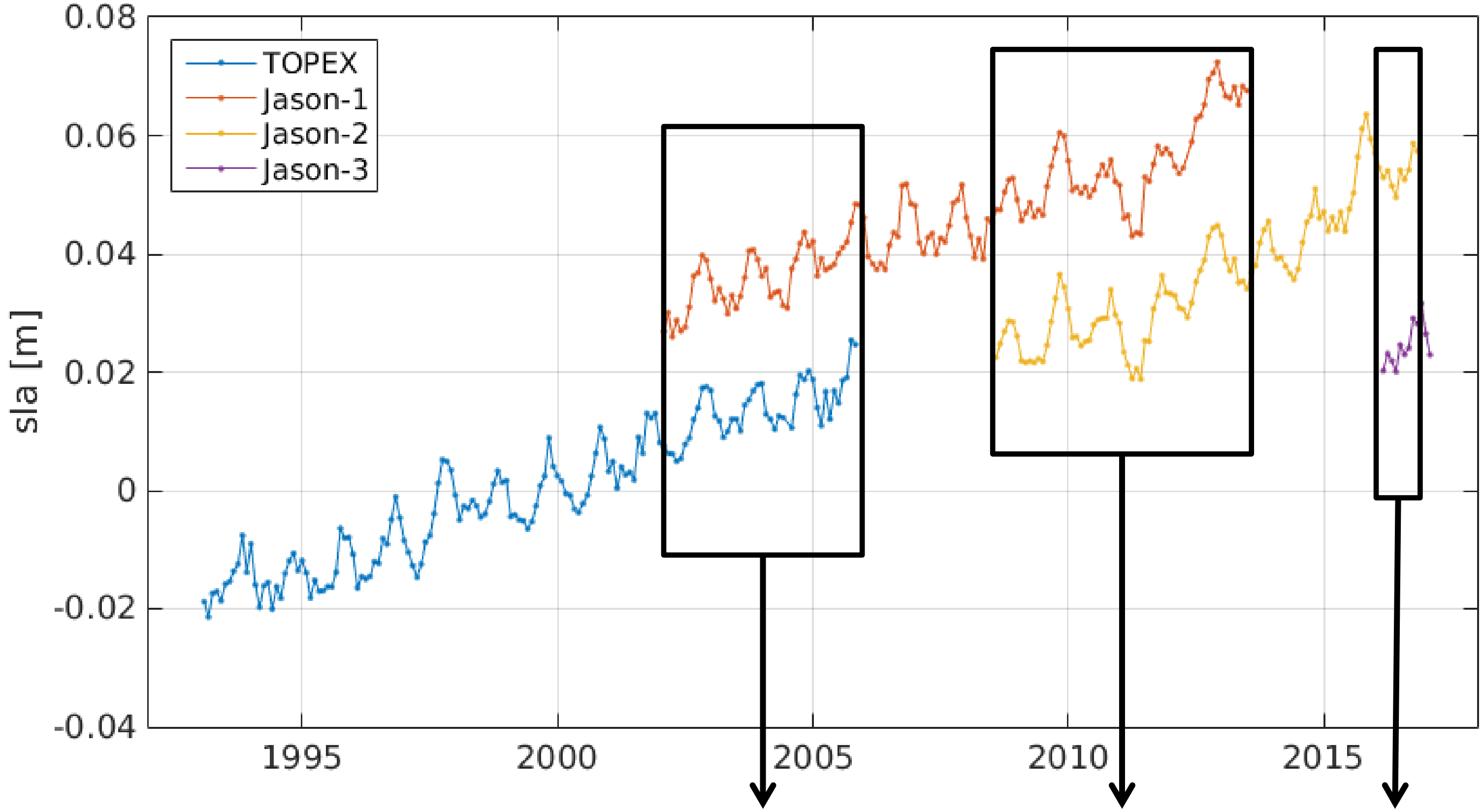
with respect to mean sea surface MSS CLS11 (1993-2009)

based on harmonized corrections (e.g., same correction models whenever possible)



- ⇒ Continuous increase of GMSL
- ⇒ Clear annual signal
- ⇒ Significant offsets between the different missions

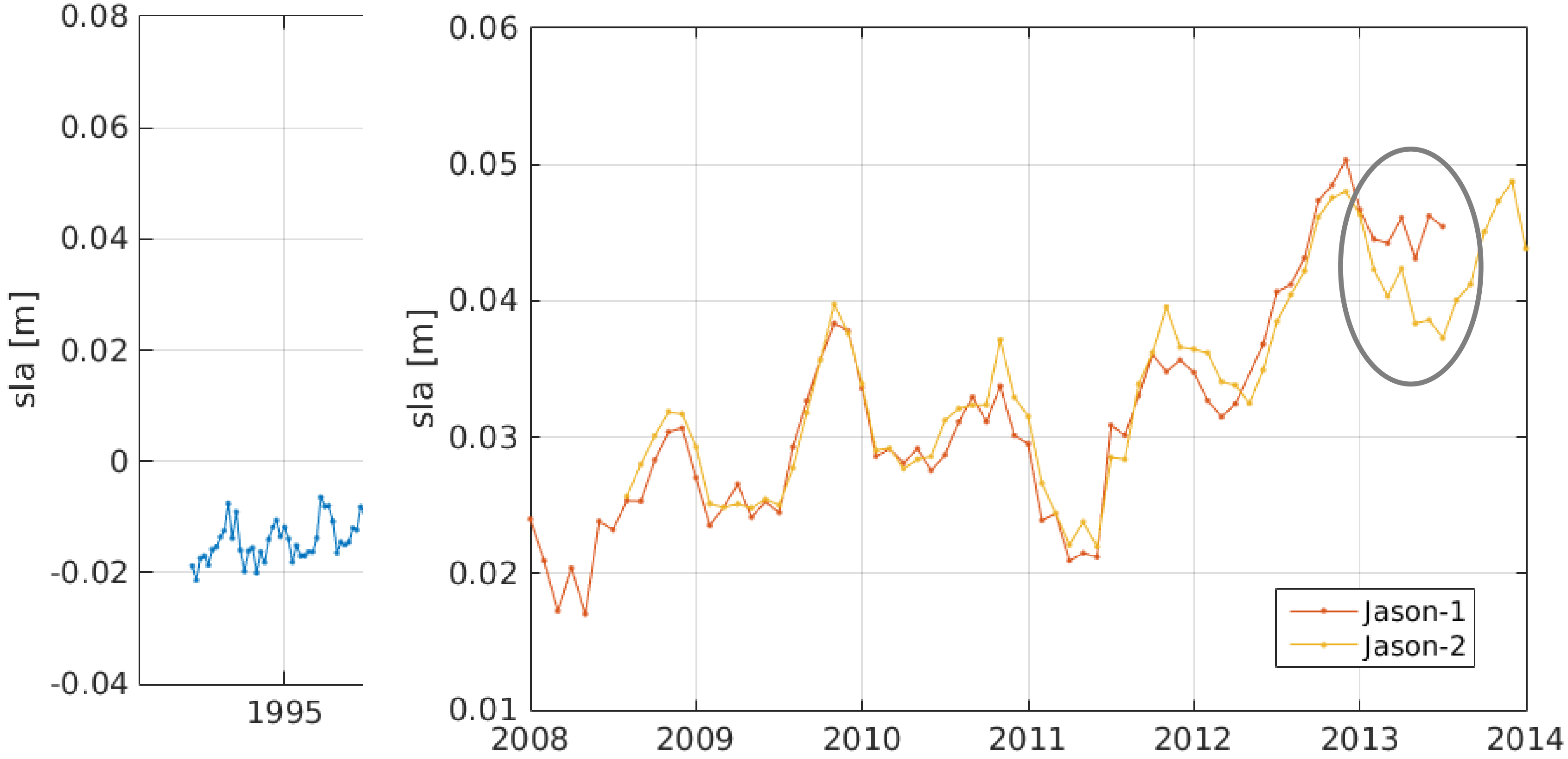
NASA missions



offset: -2.22 ± 0.22 2.53 ± 0.24 3.00 ± 0.11 cm

#45 #59 #9

NASA missions (shifted)

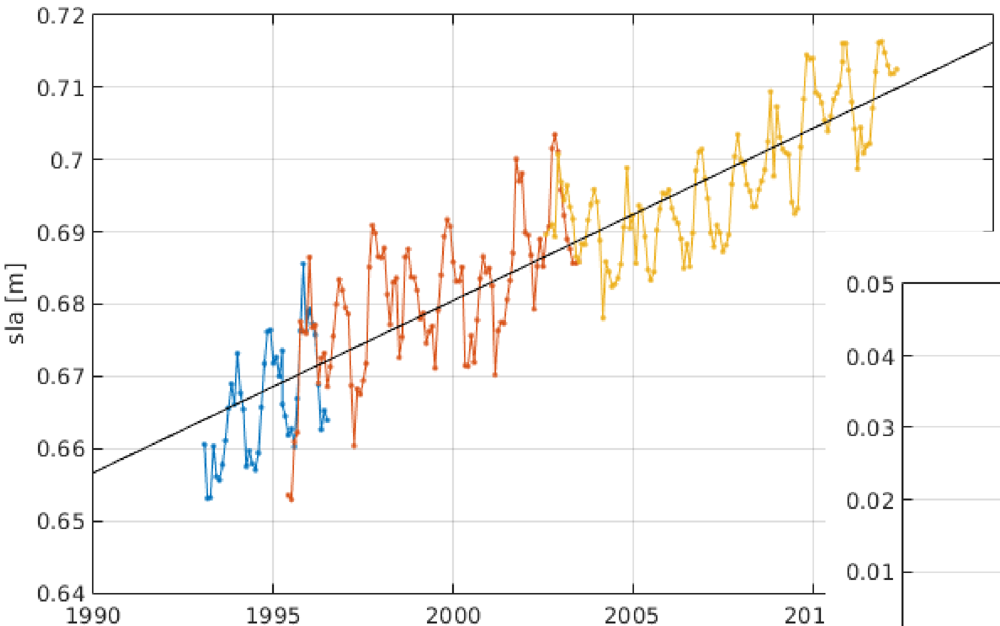


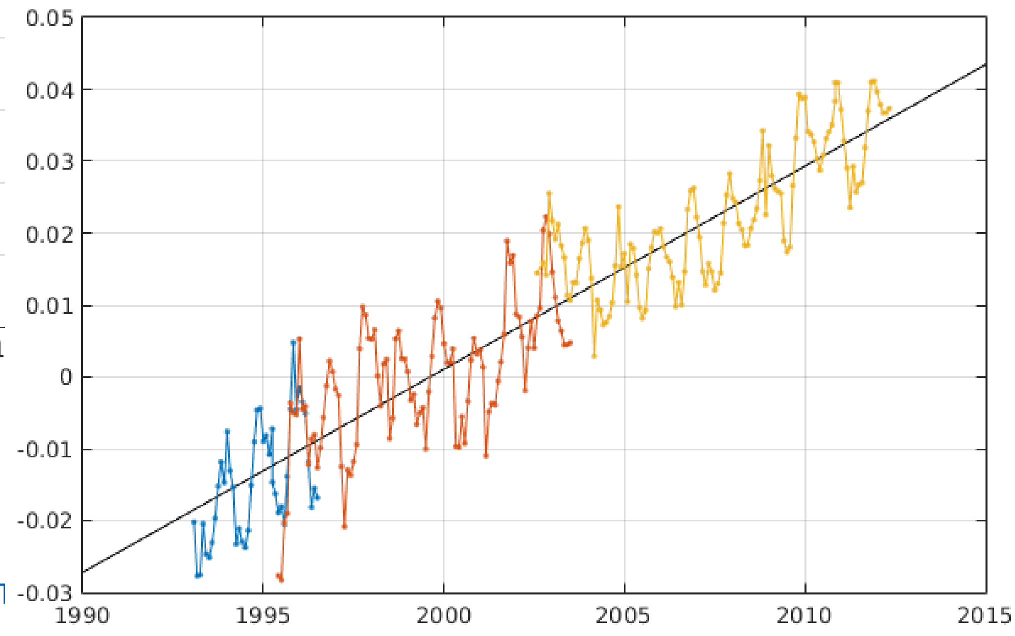
⇒ Significant discrepancies remain after removing a constant offset

ESA missions: how to define a reference?

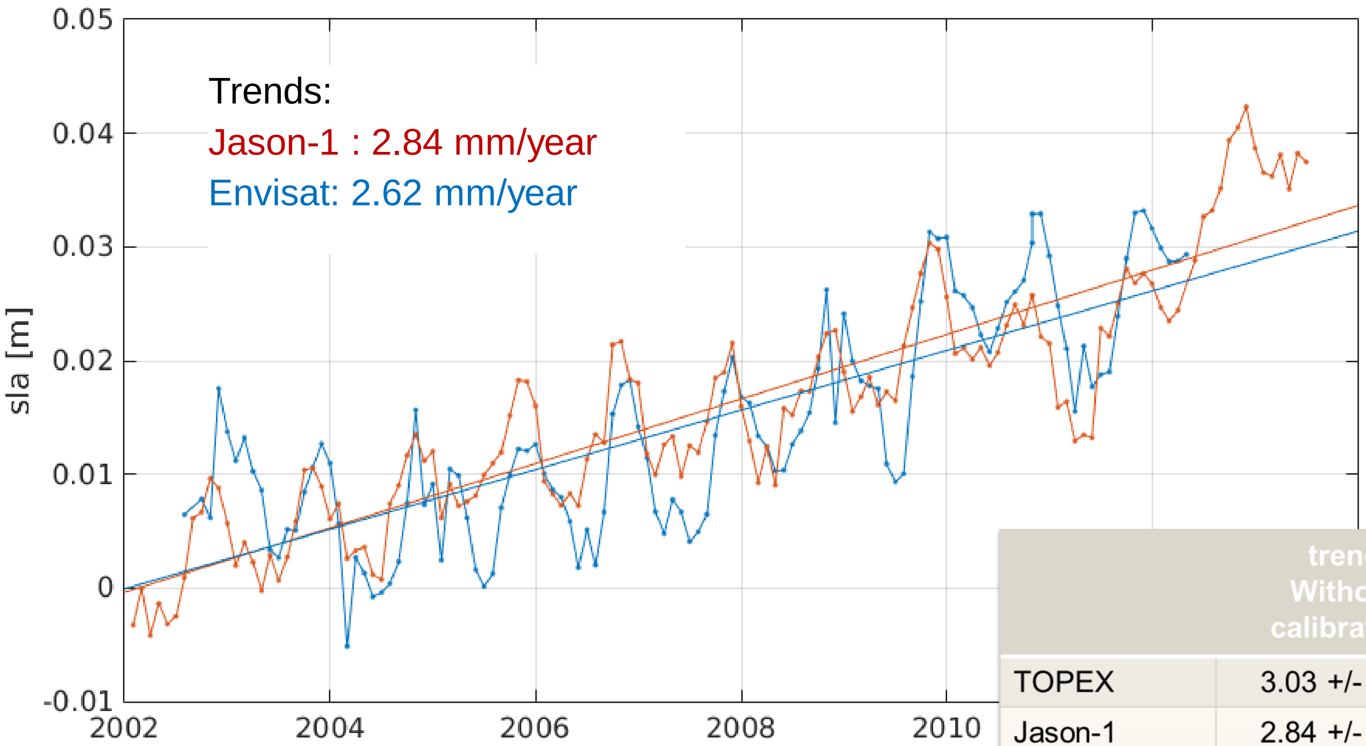
Trend ESA missions:

- shifted to each other: **2.38 mm / year**
- Shifted with respect to NASA missions: **2.82 mm / year**



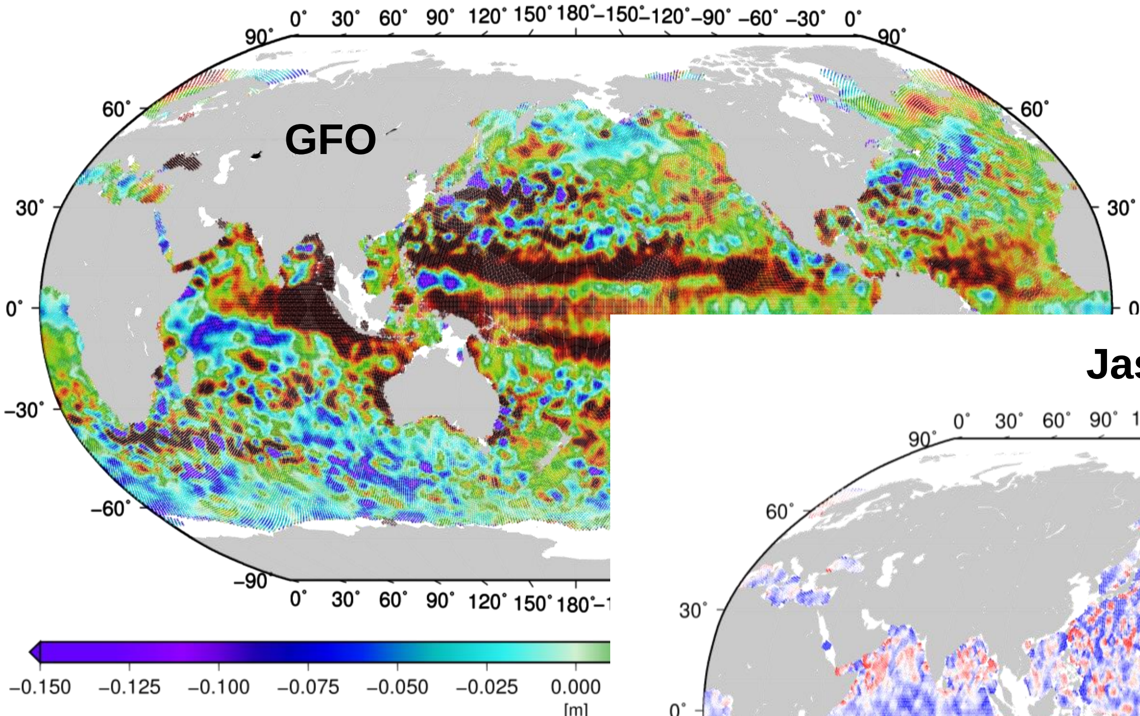


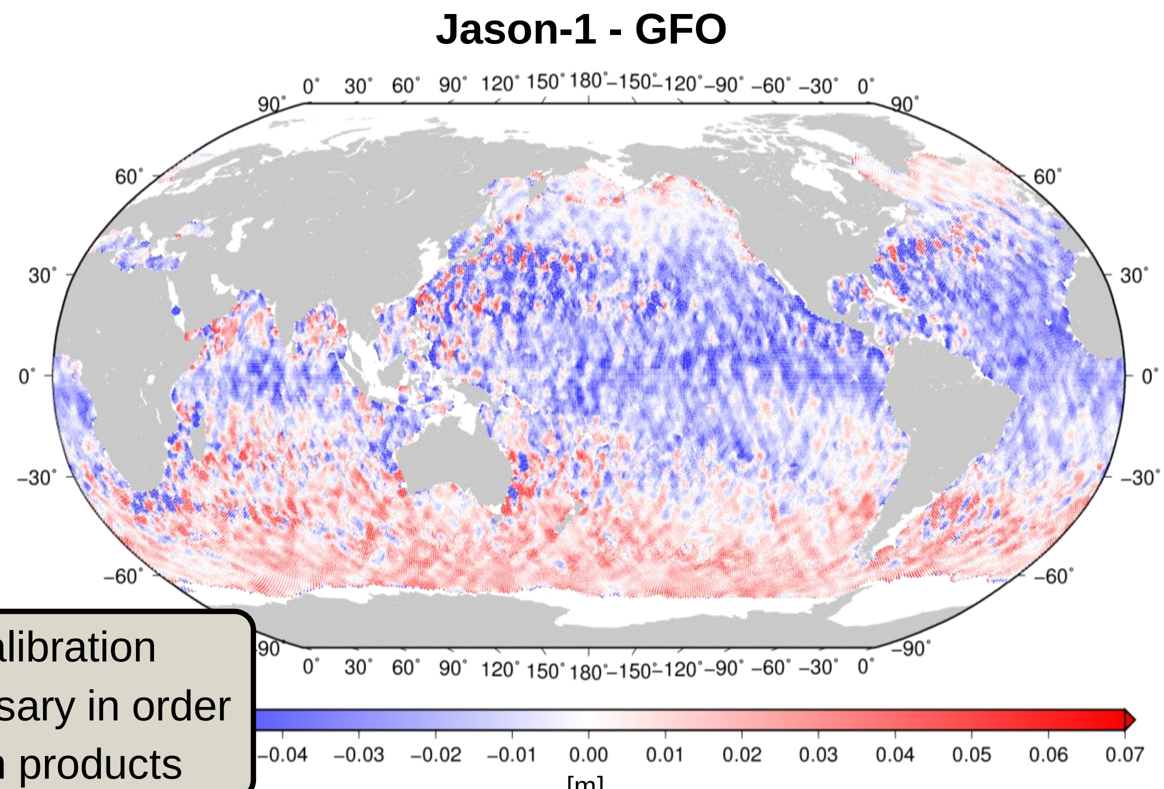
Trends per mission



	trend Without calibration	Number of points
TOPEX	3.03 +/- 3.92	153
Jason-1	2.84 +/- 4.71	137
Jason-2	4.16 +/- 5.02	100
Jason-3	-	12
ERS-1	4.33 +/- 6.48	46
ERS-2	2.56 +/- 7.51	98
Envisat	2.62 +/- 5.88	118
SARAL	6.24 +/- 3.94	41
GFO	2.76 +/- 7.33	101

Regional sea level (Sea level anomalies: June 2014)

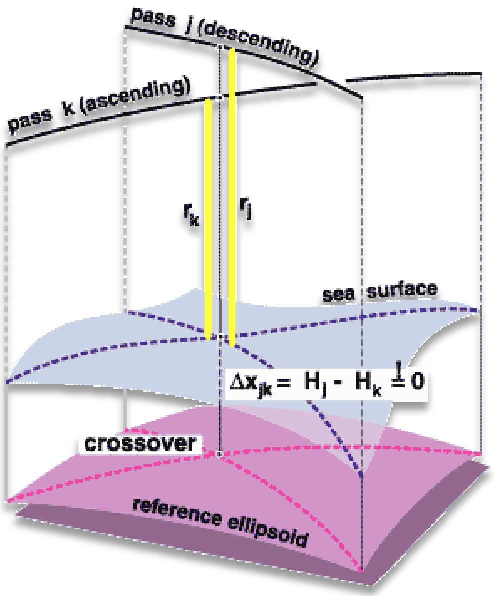




⇒ A location-dependent cross-calibration between all missions is necessary in order to ensure consistent long-term products

Approach: Multi-mission crossover analysis

- ❑ using all missions since 1992
- ❑ building single- and dual satellite crossover differences in all combinations (Δt < 2 days)
- ❑ minimizing crossover differences and along-track consecutive differences in a least squares adjustment
- ❑ automated mission weighting by variance component estimation
- ❑ TOPEX (later Jason-1, Jason-2, Jason-3) taken as reference mission



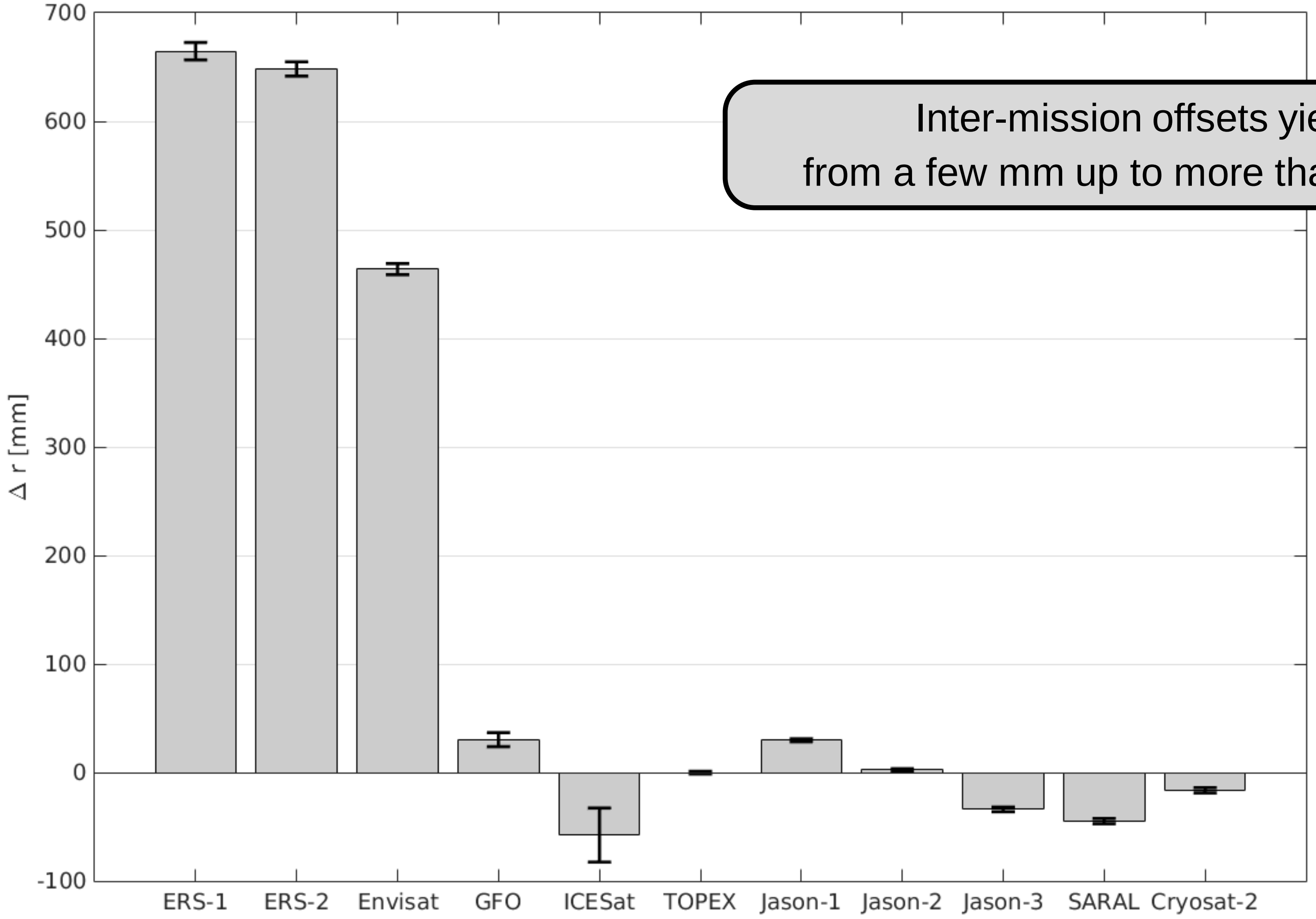
Main output:

- time series of radial errors
  - => applied as correction to each measurement
  - => one consistent set of observations with increased temporal and spatial resolution

Additional outputs (derived from radial errors):

- relative range biases (global mean and per cycle)
- relative instrument drifts
- geographically correlated SSH errors

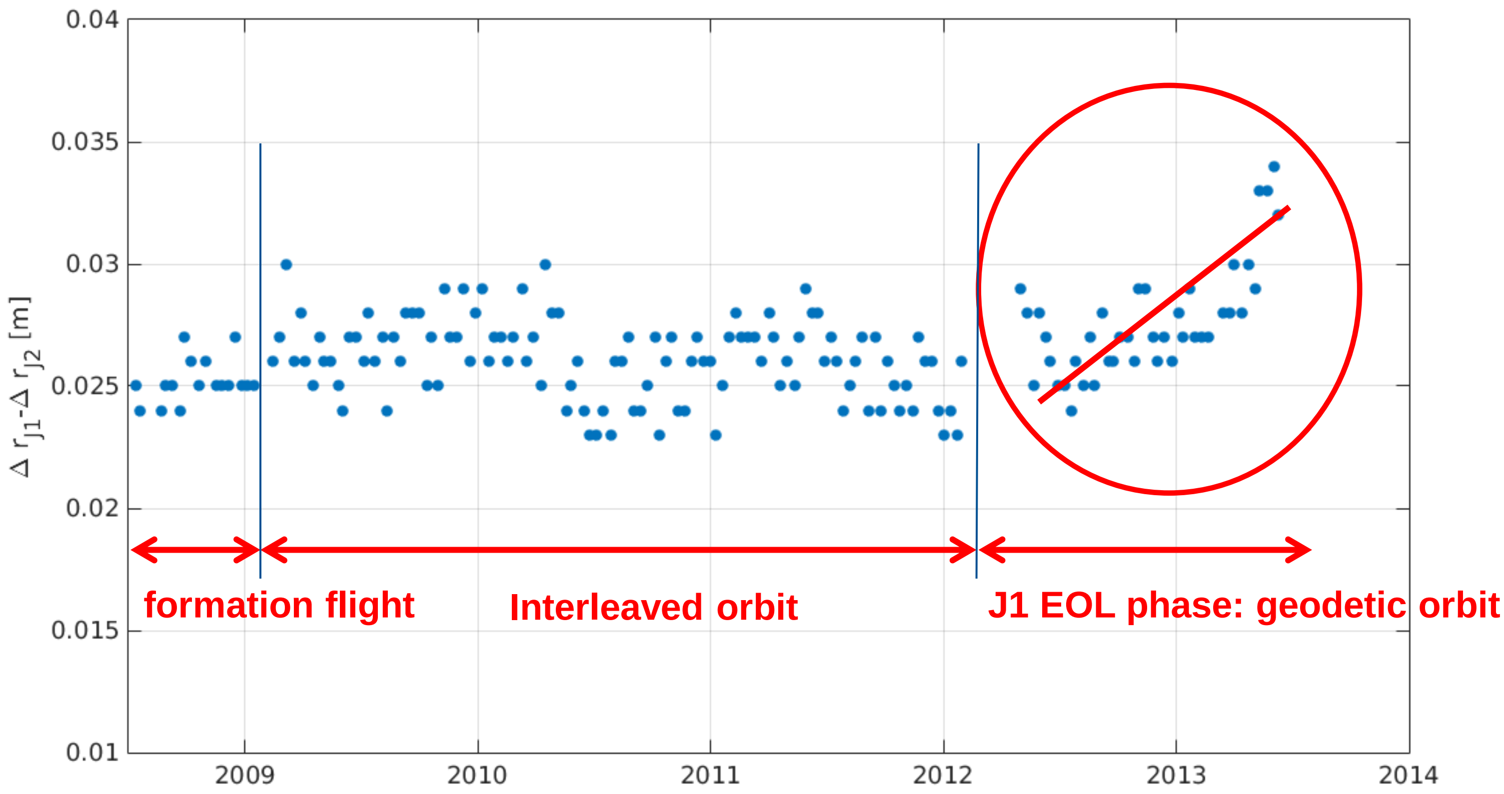
Global range biases per mission (w.r.t. TOPEX)



Inter-mission offsets yield
from a few mm up to more than 60 cm

Example: Jason-1 range bias

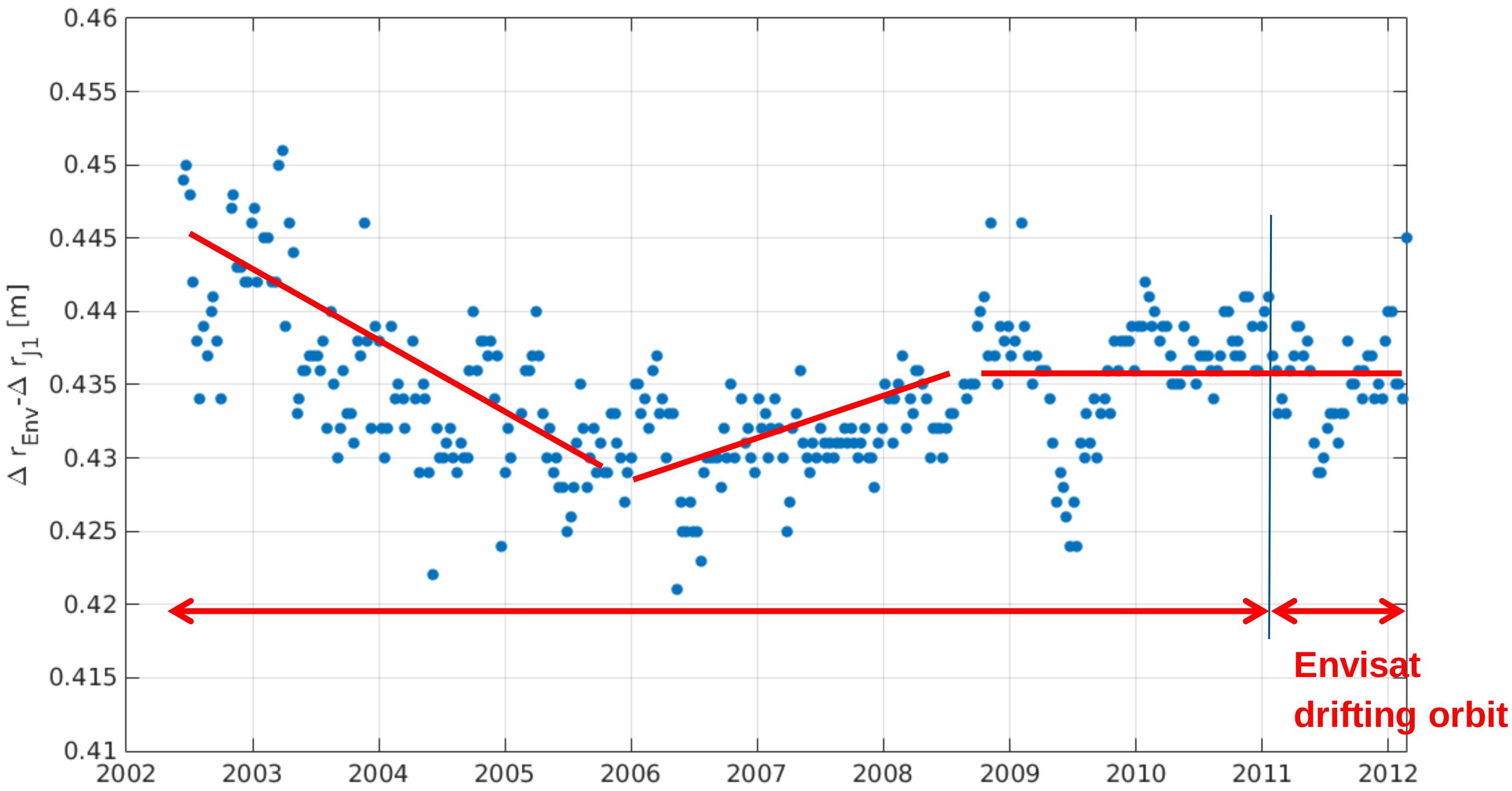
Range bias differences (per 10 days) between Jason-1 and Jason-2 (from MMXO)



=> drift in radial errors (Jason-1 EOL)
=> cannot be corrected by applying constant offsets per mission!

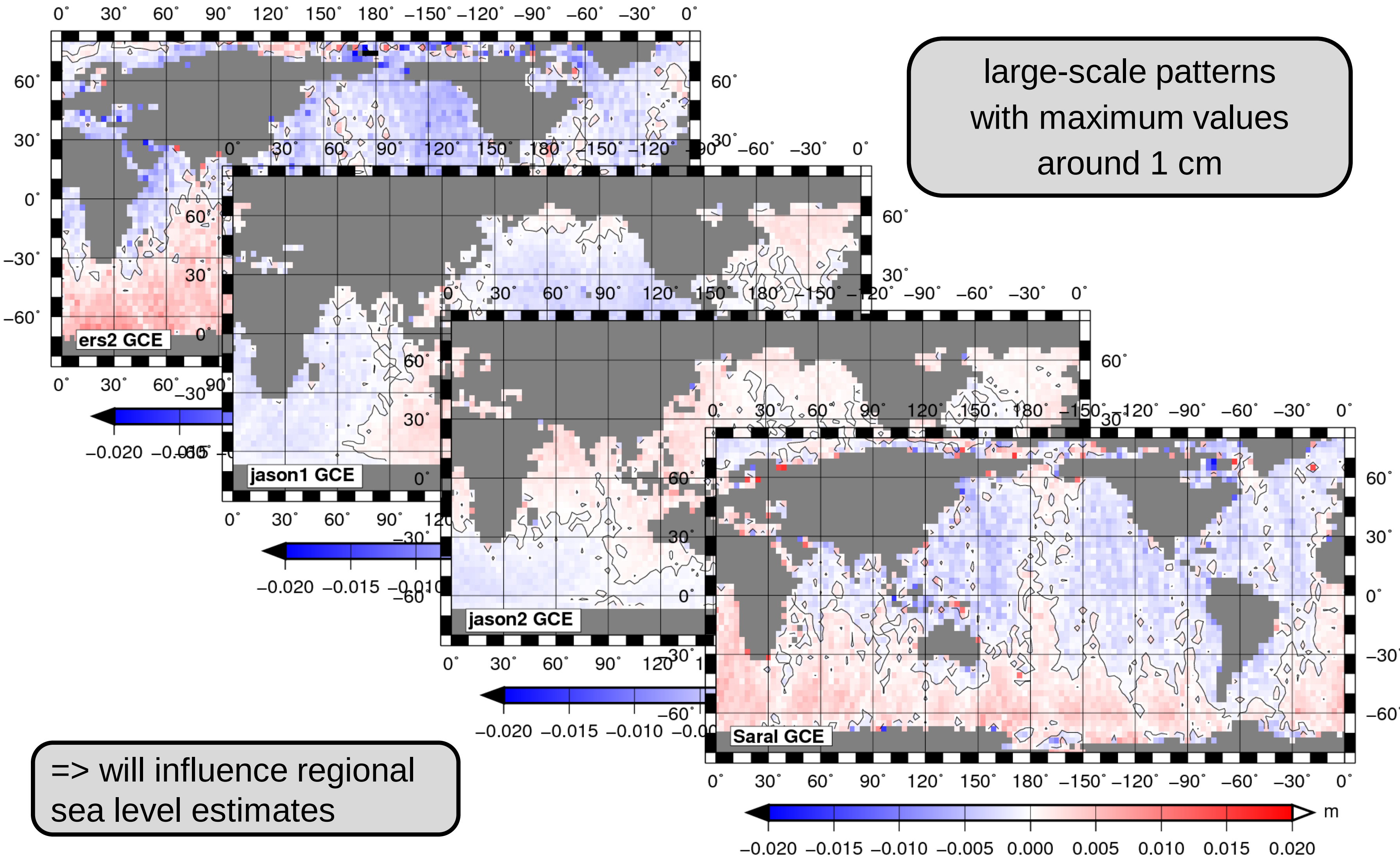
Example: Envisat range bias

Range bias differences (per 10 days) between Envisat and Jason-1 (from MMXO)



=> drift in Envisat range bias in the first period
=> cannot be corrected by applying constant offsets per mission!

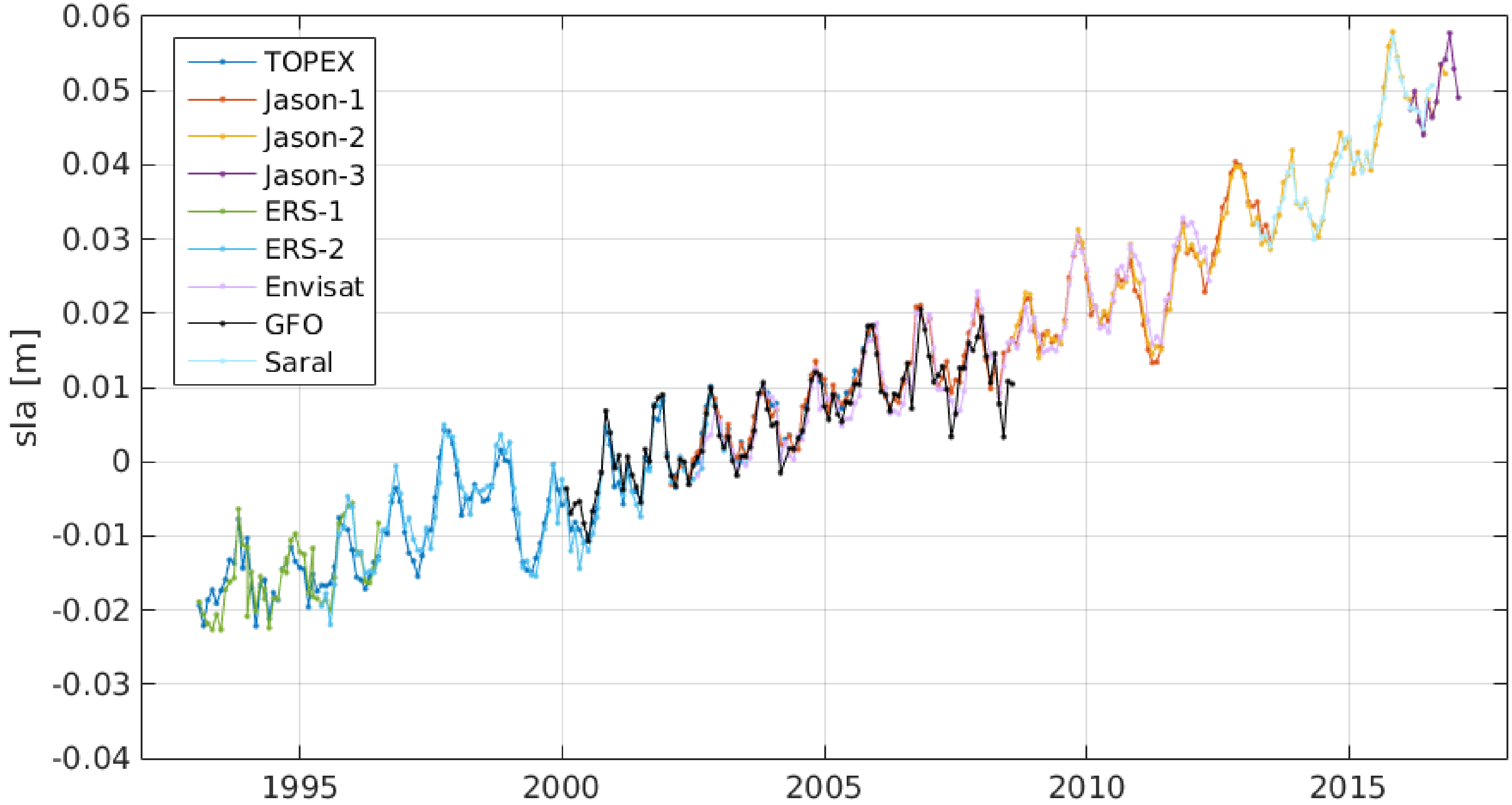
Geographically correlated errors



large-scale patterns
with maximum values
around 1 cm

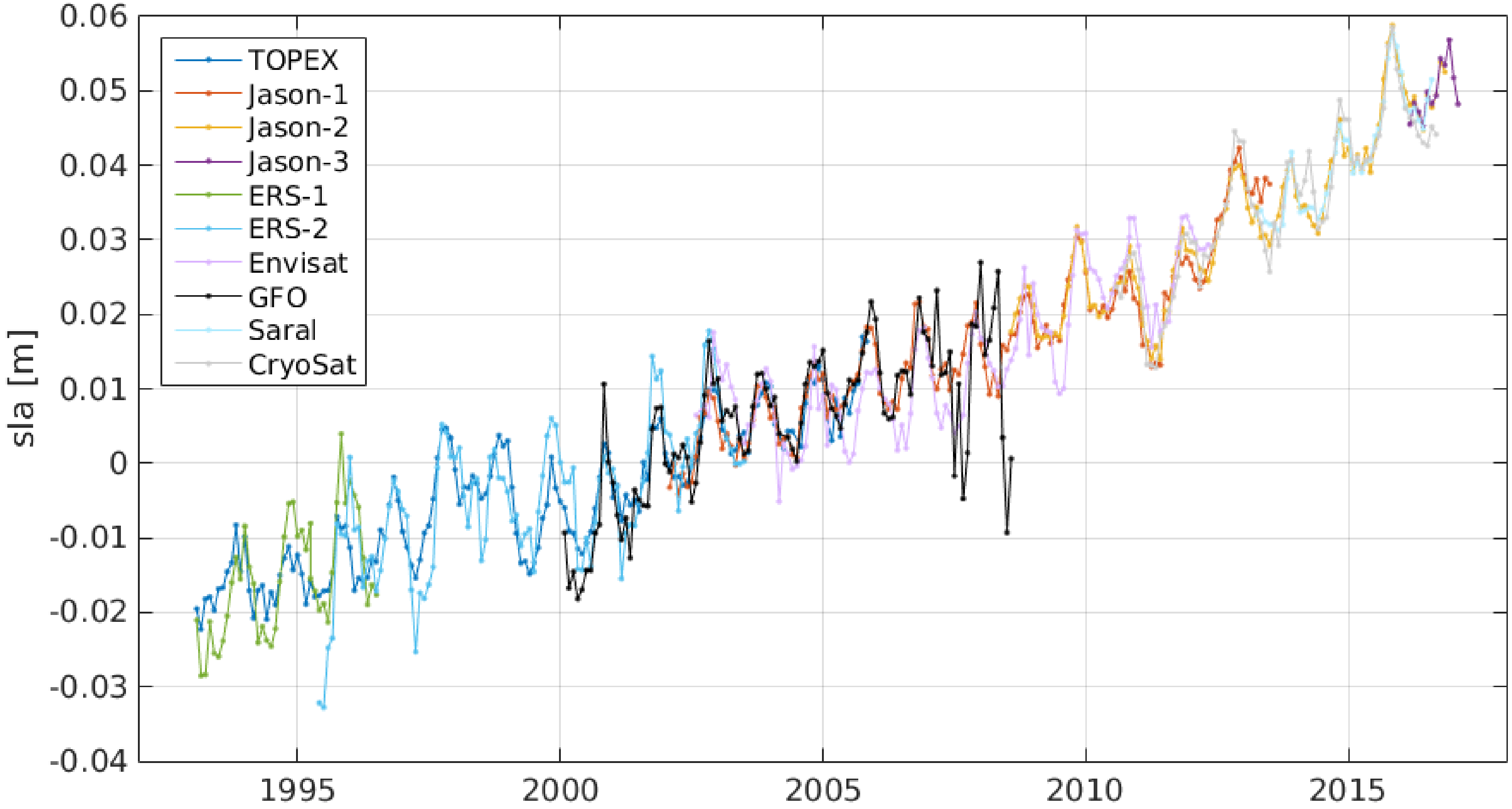
=> will influence regional
sea level estimates

Global sea level change (MMXO applied)

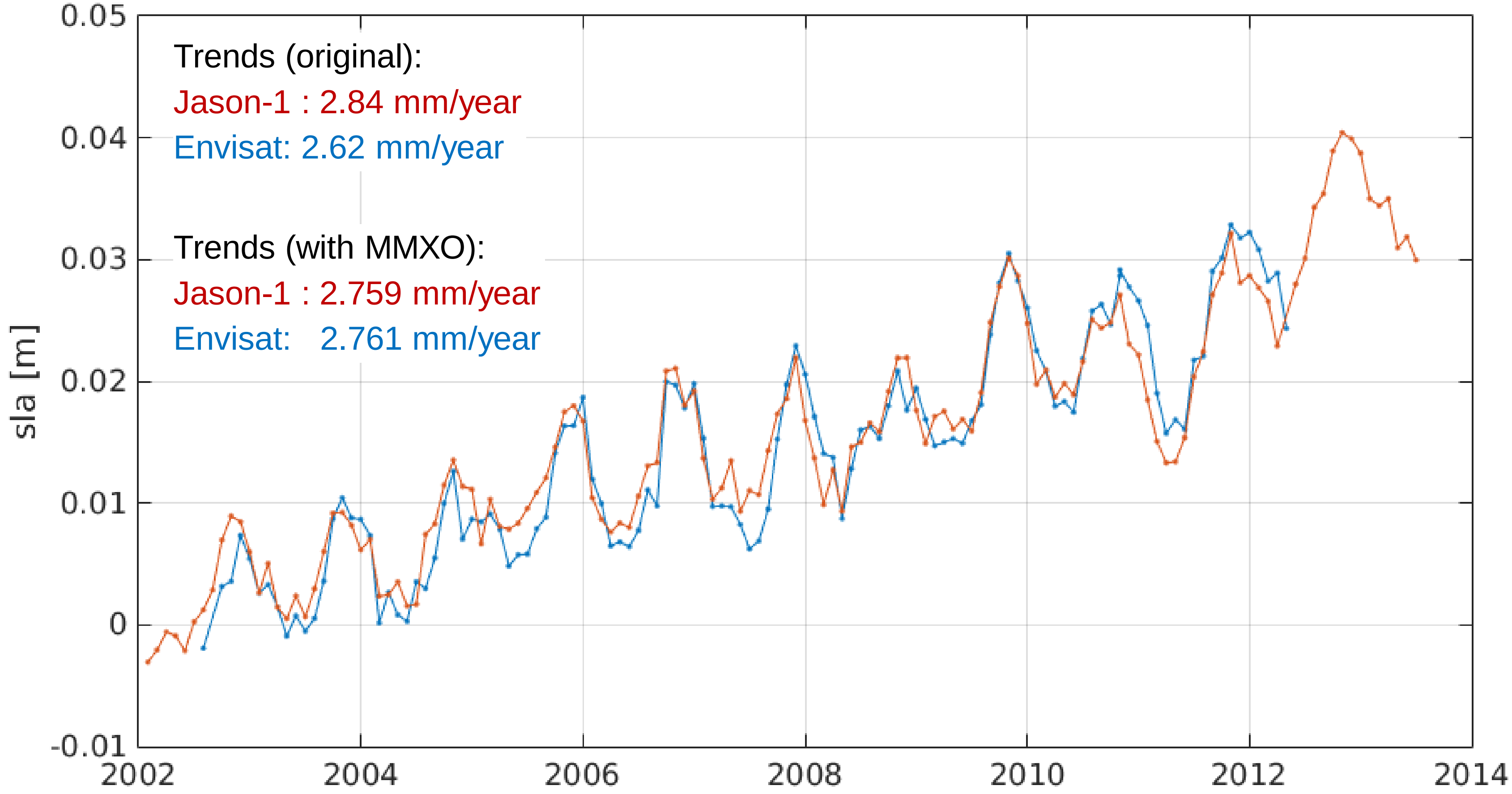


⇒ improved inter-mission consistency
⇒ annual signal becomes clearer

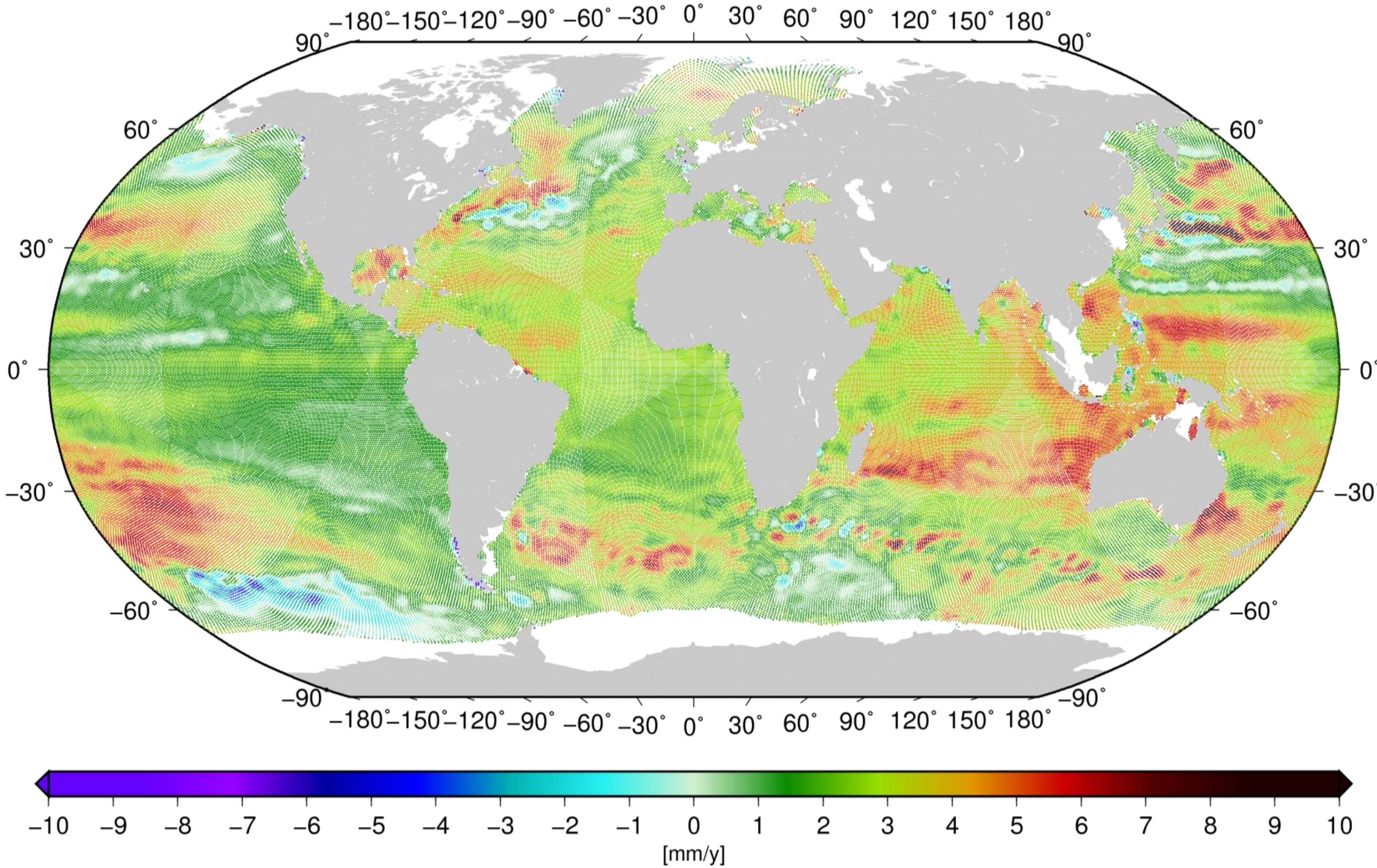
Global sea level change (without MMXO)



Global sea level change



Regional sea level change (1992-2016)



Conclusion

- Multi-mission altimetry provides the basis for a long-term monitoring of global and regional sea level behavior
- A careful calibration of the different missions is necessary in order to account for instrumental offsets and drifts, as well a for geographically correlated errors (e.g. due to orbit or model errors).
- The presented multi-mission crossover analysis is a perfect tool to establish a harmonized data base and to provide a reliable time series of global mean sea level usable for climate change studies.