Assessment of the orbit related sea level errors for TOPEX altimetry at seasonal to decadal time scales

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Objectives

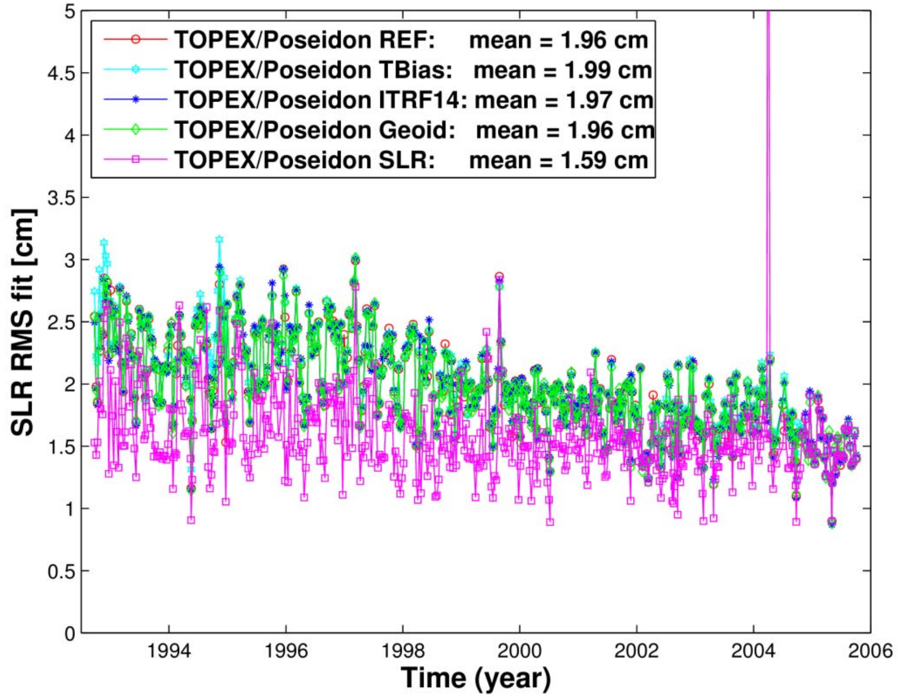
- Assessment of the radial orbit error for the TOPEX/Poseidon mission (1993-2004)
- Upper bound orbit errors from gridded radial orbit differences for global mean and regional sea level
- We use three state-of-the-art orbits derived in ITRF2008 and five test orbits
  - Reference: GFZ VER11 (Rudenko et al., 2017) = REF
  - External orbits: GSFC std1504 and GRGS
  - Impact of the tracking data: SLR-only, DORIS-only, TBias (no DORIS system time bias estimated)
  - Impact of the terrestrial reference frame: ITRF2014 instead of ITRF2008 (ITRF14 orbit)
  - Impact of Earth's time variable gravity field model: EIGEN-6S2 instead of EIGEN-6S4 (Geoid orbit)
- Time scales: seasonal = annual (365.25 days), interannual (5 years), decadal (here: 11 years)

The main models used for the GFZ REF, GSFC std1504 and GRGS orbits

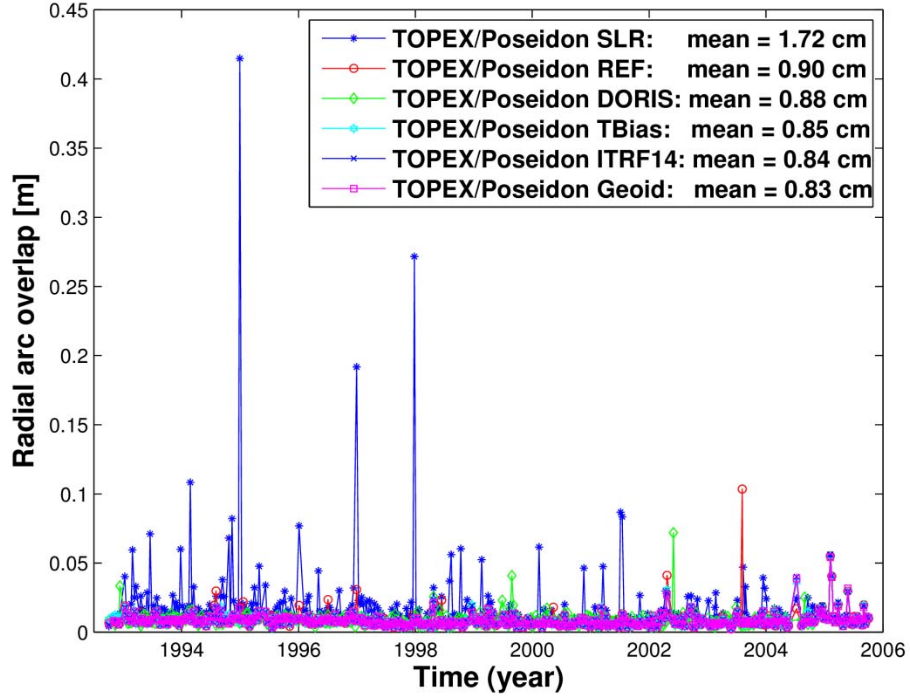
Parameter	GFZ REF	GSFC std1504	GRGS
Terrestrial reference frame	ITRF2008, SLRF2008, DPOD2008	ITRF2008, SLRF2008, DPOD2008	ITRF2008, SLRF2008, DPOD2008
Static Earth‘s gravity field model	EIGEN-6S4	GOCO2S (> n=m=5)	EIGEN-6S2
Time-variable Earth‘s gravity field model	EIGEN-6S4 up to n=m=80	Updated harmonic piece-wise fit to 5x5 weekly solutions	EIGEN-6S2 up to n=m=50
Solid Earth tide model	IERS Conventions (2010)	IERS Conventions (2003)	IERS Conventions (2010)
Ocean tide model	EOT11a	GOT4.10	FES2012
Non-tidal atmospheric and oceanic gravity	GFZ AOD1B RL05 based on ECMWF 6-h fields up to n=m=100	ECMWF 6-h fields up to n=m=50	3-h ERA-interim/ECMWF up to n=m=50 / TUGO R12 up to n=m=50
Non-tidal atmospheric loading effect on stations	Based on ECMWF ERA-Interim data	none	none
Ocean loading effect on stations	FES2004	GOT4.10	FES2012
Annual geocenter motion on stations	Not explicitly modelled	Ries (2013)	none

TOPEX / Poseidon orbit accuracy

SLR observations RMS fits



2-day radial arc overlaps

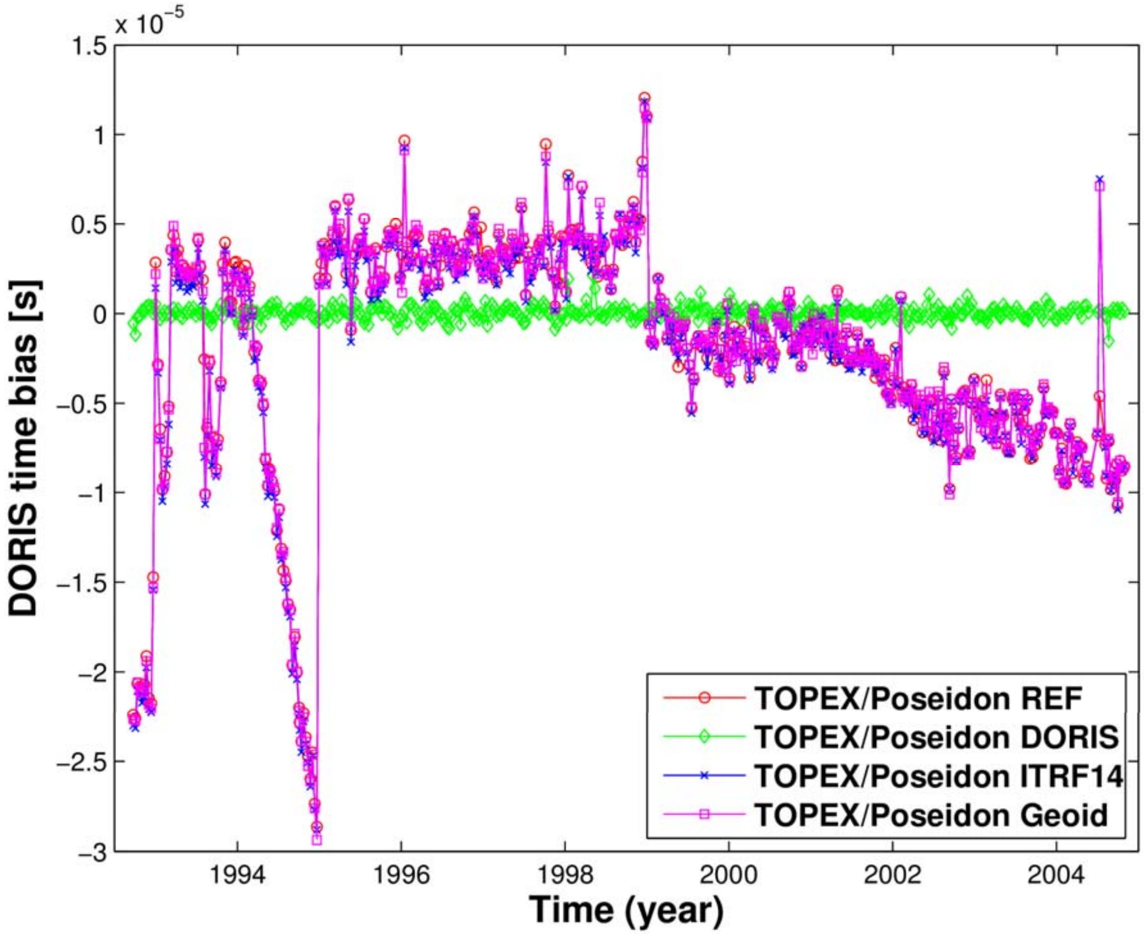


⇒ SLR RMS fits: for SLR and DORIS data orbits: 1.96-1.97 cm; for SLR-only orbit: 1.59 cm (related to weighting: SLR 3 cm, DORIS: 0.05 cm/s)

⇒ Radial arc overlap: smallest for EIGEN-6S2 /Geoid orbit (0.83 cm)

⇒ Using just SLR observations (instead of SLR and DORIS) increases radial arc overlap from 0.90 to 1.72 cm (in 1.9 times)

DORIS system time bias of various TOPEX/Poseidon orbits



⇒ Variations from -29 µs to +13 µs.

⇒ Very similar behaviour for the REF, ITRF14 and Geoid orbits

⇒ Close to zero for the DORIS orbit.

Median of the time series of global mean height differences and RMS values at crossover points (April 1993 – November 2004, lapses of 5 days)

	REF	GSFC	GRGS	SLR	DORIS	ITRF14	Geoid
Mean [mm]	-3.1	**-1.6**	-2.9	-2.6	**-4.7**	-3.1	-2.1
RMS [mm]	49.8	**49.5**	**51.3**	51.1	50.7	49.8	49.7

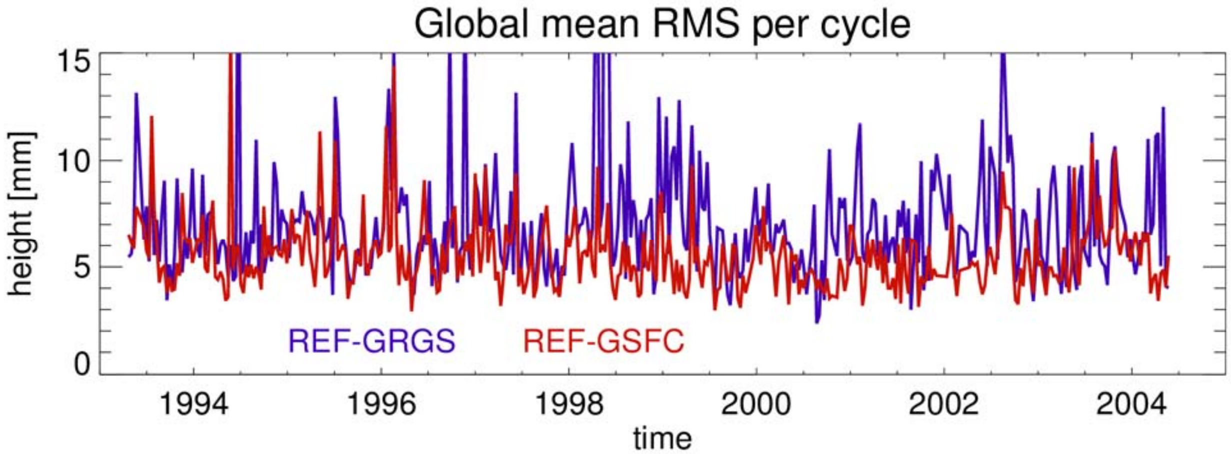
⇒ The smallest (best) absolute mean (1.6 mm) is obtained for the GSFC orbit, the largest one (4.7 mm) – for the DORIS-only orbit.

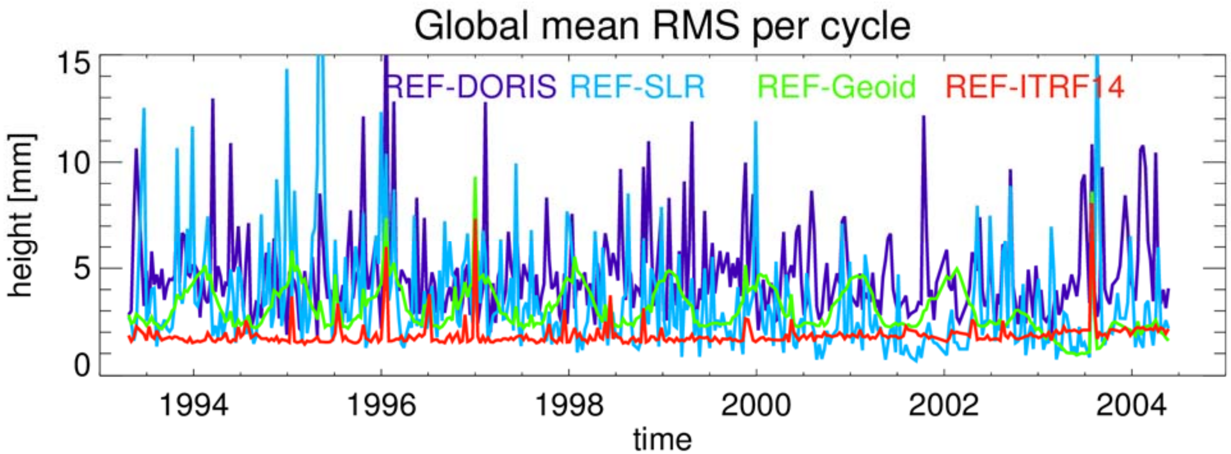
⇒ The smallest (best) RMS value (49.5 mm) is obtained for the GSFC orbit, the largest one (51.3 mm) among orbits tested – for the GRGS orbit.

⇒ Using both SLR and DORIS data (REF orbit) gives smaller RMS of crossover differences than just using SLR or DORIS data separately.

⇒ Geoid orbit performs a bit better than the REF orbit.

Global mean RMS of gridded radial orbit differences per cycles over the oceans for different orbit configurations (REF – test)



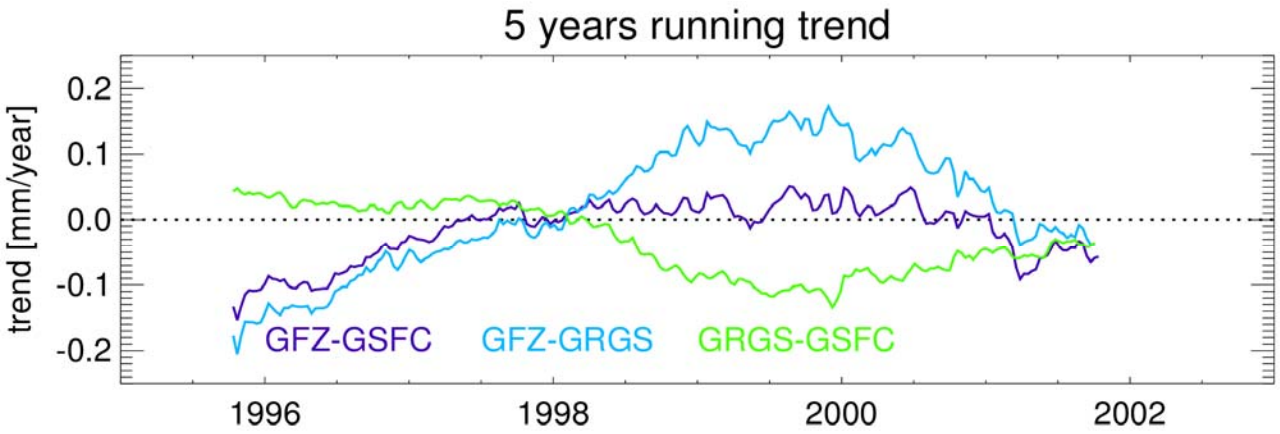


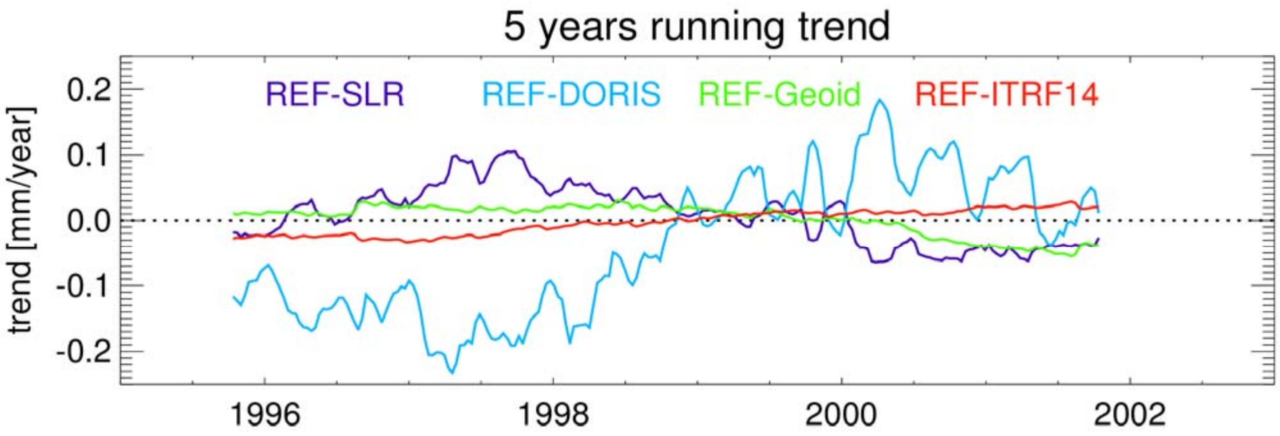
Global mean RMS of the radial orbit differences:
REF-GRGS: 7.0 mm,
REF-GSFC: 5.4 mm,
REF-DORIS: 5.1 mm,
REF-SLR: 4.2 mm,
REF-Geoid: 2.0 mm,
REF-ITRF14: 1.1 mm

Most orbit differences are dominated by sub-seasonal variability.

Seasonal cycle found for the Geoid, GSFC and GRGS orbit differences w.r.t. to the REF orbit.

5-year running trends for the global mean radial orbit differences over the ocean for different orbit configurations





⇒ All curves range within ±0.2 mm/year

⇒ Before 1998: GSFC and GRGS orbits suggest stronger trends than REF orbit.

⇒ After 1998: GRGS orbit suggests smaller sea level trends then GSFC and REF orbits.

⇒ Inconsistencies of the tracking stations sub-networks explain large portions of the observed global mean interannual variability.

⇒ Very small impact of the Earth‘s gravity field model and TRF realization replacement

Global mean errors over the oceans related to the POD configuration (ascending, descending tracks)

	SLR	DORIS	ITRF14	GEOID	GSFC	GRGS
RMS [mm]	4.2	5.1	1.1	2.0	5.4	7.0
Interannual trend [mm/year]	0.04 (0.3,0.3)	0.10 (0.5, 0.4)	0.02	0.02	0.05	0.10 (0.4,0.3)
Decadal trend [mm/year]	0.01 (-0.07,0.07)	0.05 (0.2,-0.3)	0.00	0.00	0.04	0.02 (0.3,-0.3)

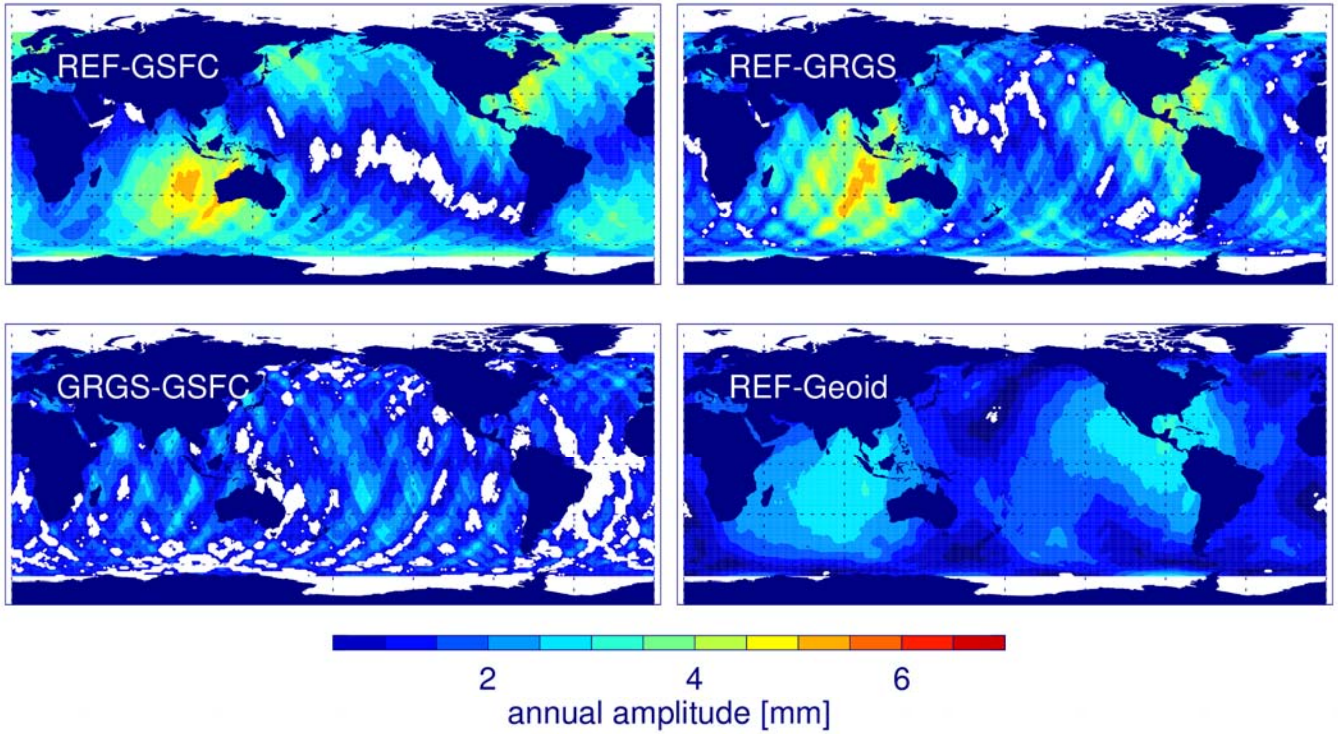
⇒ The global mean RMS radial orbit errors are of the order of 7 mm.

⇒ The global mean annual (seasonal) component of the radial error can be neglected.

⇒ The interannual (5-year time scale) trend is maximum 0.1 mm/yr (20% of total sea level value)

⇒ The orbit-related errors of the decadal trends are less than 0.05 mm/yr.

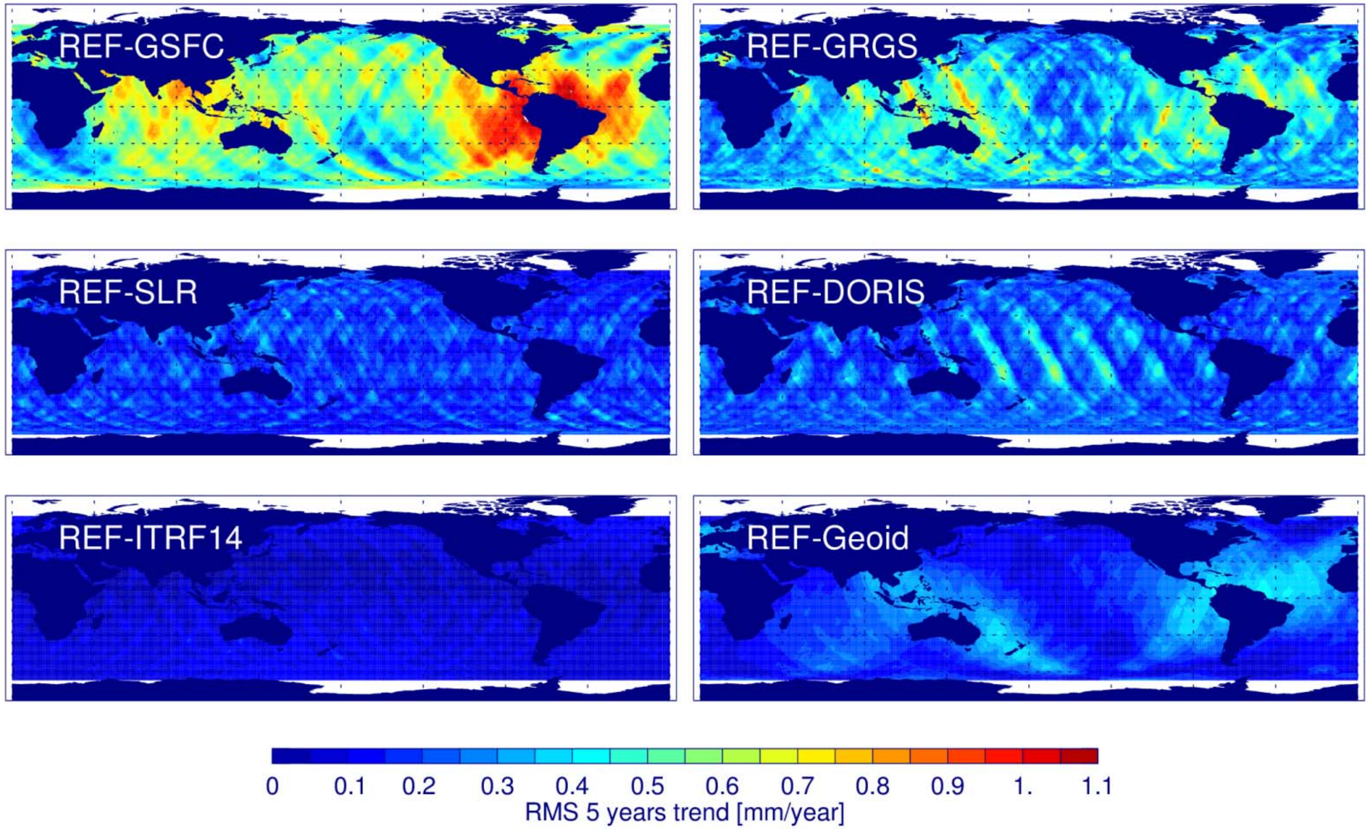
Annual amplitude of the radial orbit differences



The most prominents annual amplitudes:
REF-GRGS: 5.6 mm,
REF-GSFC: 5.4 mm,
REF-Geoid: 3.2 mm.

The plausible sources: differences in the Earth‘s time variable models, non-tidal atmospheric loading corrections and geocenter motion modelling.

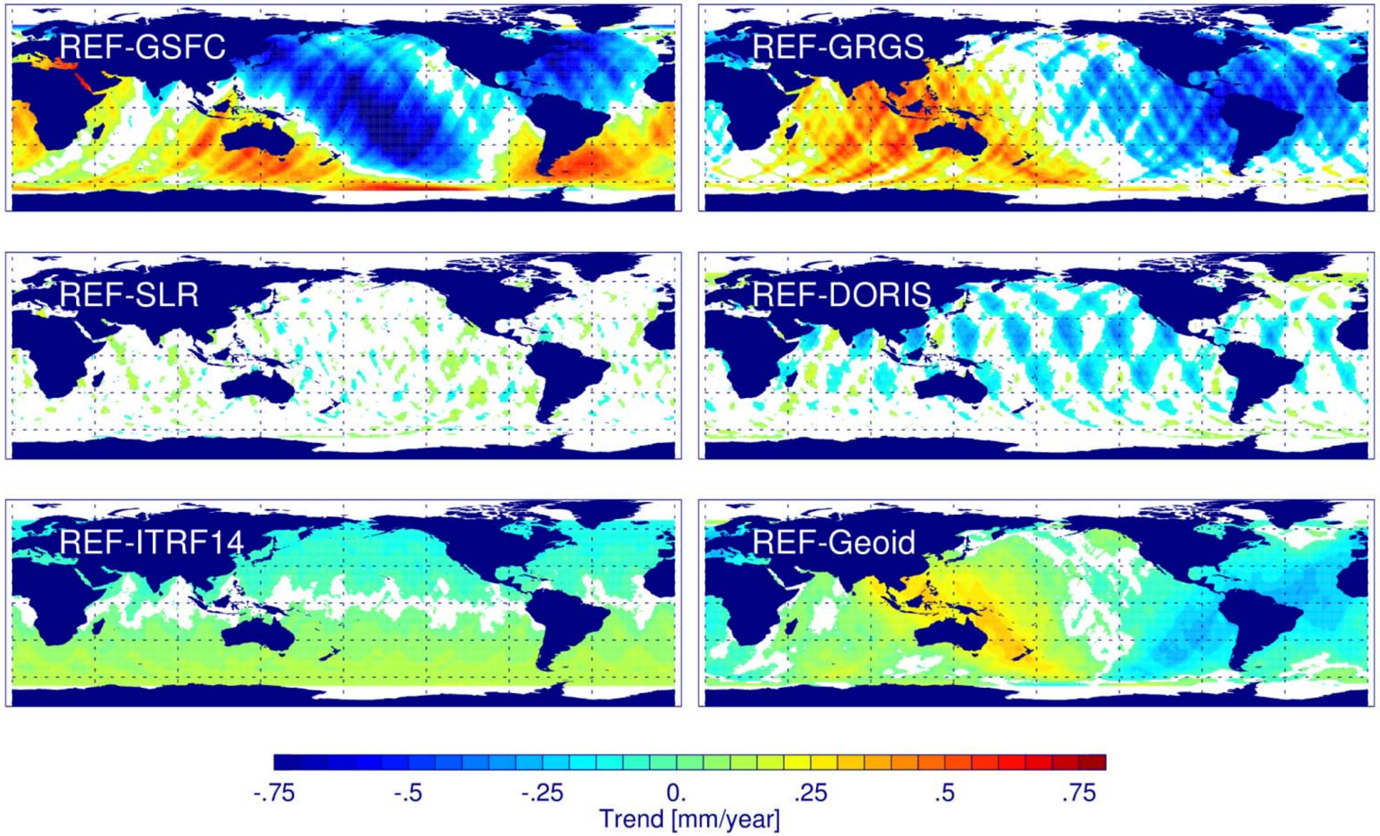
RMS of 5-year running trend differences (REF – test) for all orbit configurations tested (April 1993 – June 2004)



The trends of the interannual regional variability - up 1.2 (0.9) mm/year for the GSFC (GRGS) orbits, w.s.t. the GFZ REF orbit.
The maxima - in the regions around South America and Australia.

Similar features are found for the Geoid orbit, but with smaller amplitude.

Regional decadal trend differences (April 1993 – June 2004)



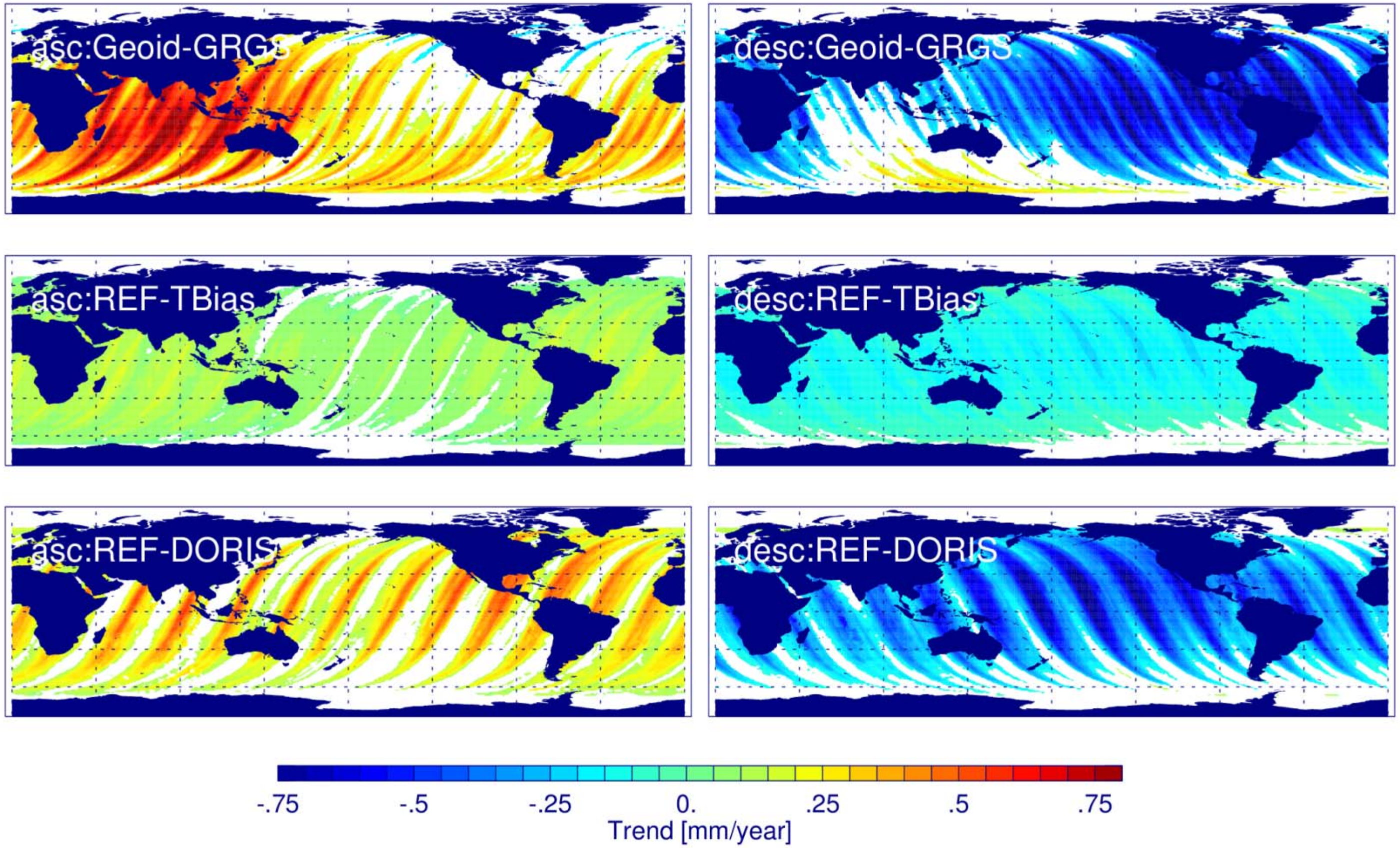
REF-GSFC: 1.0 mm/yr,
REF-GRGS: 0.7 mm/yr,
REF-Geoid: 0.4 mm/yr,
REF-DORIS: 0.4 mm/yr,
REF-ITRF14: 0.2 mm/yr,
REF-SLR: 0.2 mm/yr.

Regional upper bound errors related to the POD configuration

	REF-SLR	REF-DORIS	REF-ITRF14	REF-GEOID	REF-GSFC	REF-GRGS
RMS [mm]	7.2	9.3	2.4	3.5	7.4	10.7
Annual amplitude [mm]	1.4	2.1	0.4	3.2	5.4	5.6
Interannual trend [mm/year]	0.5	0.6	0.2	0.4	1.2	0.9
Decadal trend [mm/year]	0.2	0.4	0.2	0.4	1.0	0.7

The RMS of the regional upper bound radial orbit error is more than 10 mm.
The annual amplitude of this error is up to 6 mm.
The interannual trend reaches 1.2 mm/year at the 5-year time scale.
The orbit-related regional error of the decadal trend reaches 1.0 mm/year.

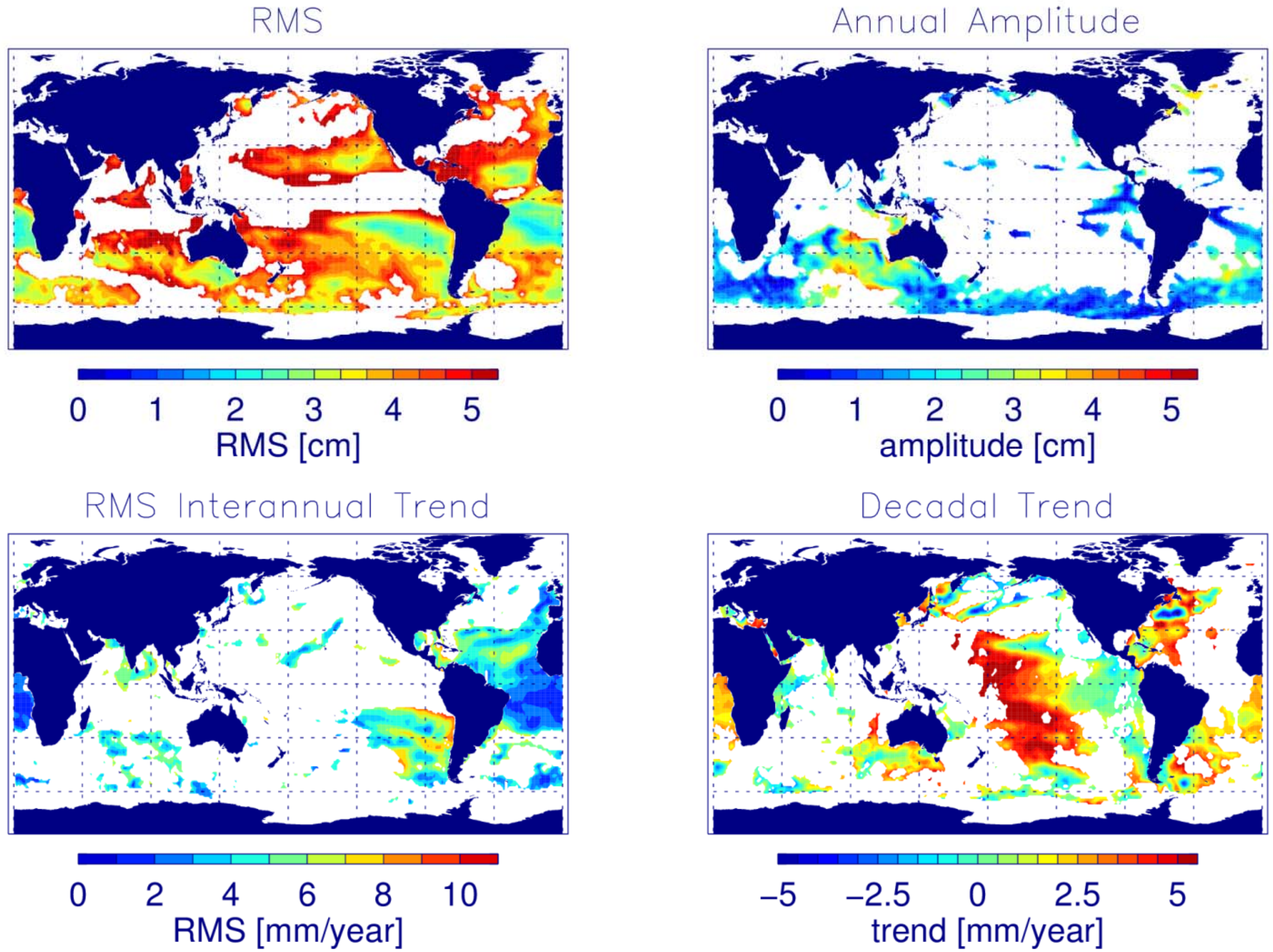
Radial orbit trend differences for ascending (left) and descending (right) tracks



Decadal trend differences, anti-correlated between ascending and descending tracks.
Same effect for global mean values.
Seems to be related to parameterisation of DORIS data.
DORIS system time bias can explain part of the effect.
Effect cancels for merged data, critical for regional studies involving along-track data (calibration sites).

RMS of sea level, annual amplitude, RMS of interannual trend and decadal trend from TOPEX altimeter data (February 1993 – October 2005)

Regions where orbit error is more than 10% of the local sea level value (TOPEX CCI).



Total variability: calm oceanic regions, about half the ocean.
Seasonal signal: mainly Southern Ocean.
Interannual variability: Tropical and Subtropical Atlantic, south-eastern Pacific.
Decadal scales: South Atlantic, western North Atlantic, central Pacific, and south-eastern Indian Ocean, but also several marginal seas (Mediterranean, Red Sea, Yellow Sea and Sea of Japan).

Conclusions I

Global mean radial orbit errors over the ocean:
RMS: up to ~ 7 mm, *seasonal* negligible,
interannual < 0.1mm/year, *decadal* < 0.05 mm/year

Regional upper bound radial orbit errors:
RMS <11 mm, strong sub-seasonal signal;
Seasonal: up to 6 mm, sources: Earth’s time variable gravity field, stability of tracking station sub-networks, AOD gravity modelling, geocenter motion correction;
Interannual (5 years): up to 1.2 mm/year, sources: z-component of the reference system, Earth’s time variable gravity field
Decadal: up to 1.0 mm/year (~interannual variabilty), sources: Earth’s time variable gravity field model, reference systems only secondary

Conclusions II

Potential impact of radial orbit errors on large scale oceanic signals:

- no significant artificial signals in global mean sea level from POD on annual to decadal timescales

- significant artificial signals in global mean sea level from POD on interannual timescales

- regional radial orbit errors still reach more than
1 mm/year on interannual to decadal scales.

Therefore, further improvement of the orbit quality for altimetry missions is necessary to meet the requirements of the sea level product users!

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