Impact of recent time variable geopotential models on precise orbits of altimetry satellites, global and regional mean sea level trends

Sergei Rudenko (1,2), Denise Dettmering (3), Saskia Esselborn (1), Tilo Schöne (1), Christoph Förste (1), Jean-Michel Lemoine (4), Michaël Ablain (5), David Alexandre (5) and Karl-Hans Neumayer (1)

(1) Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Potsdam Germany

(2) Technical University Berlin, Germany (E-mail address: rudenko@gfz-potsdam.de)

(3) Deutsches Geodätisches Forschungsinstitut (DGFI), Munich, Germany

(4) CNES/GRGS, Toulouse, France

(5) Collecte Localisation Satellites (C.L.S.), Toulouse, France

Ocean Surface Topography Science Team (OSTST) meeting,
October 8-11, 2013, Boulder, Colorado, USA

Introduction

- The purpose of this study is to investigate the impact of recent time variable geopotential models on precise orbits of altimetry satellites ERS-1 (August 1991 till July1996), TOPEX/Poseidon (September 1992 till October 2005), ERS-2 (May 1995 till February 2006) and Envisat (April 2002 to January 2011) at the time spans given, global and regional mean sea level trends
- Geopotential models investigated: EIGEN-GL04S (Lemoine et al., 2007), EIGEN-6S (Förste et al., 2012), EIGEN-6S_static (at epoch 2000.0), new time variable geopotential models: EIGEN-6S2, EIGEN-6S2A and EIGEN-6S2B
- Precise orbits of all satellites were computed at GFZ in the same for all satellites ITRF2008 terrestrial reference frame using the same consistent SLCCI project Orbit Standards based mainly on the IERS Conventions (2010)
- The orbits are computed using the Earth Parameter and Orbit System - Orbit Computation (EPOS-OC) software for precise orbit determination and the Altimeter Database and Processing System (ADS) both developed at GFZ for altimetry crossover data computation and altimetry analysis of the orbits
- SLR and altimeter crossover data were used for ERS-1, additionally PRARE measurements were utilized for ERS-2 and SLR and DORIS observations were applied for Envisat and TOPEX/Poseidon precise orbit determination

The main models used for precise orbit determination

Parameter	REAPER project	SLCCI project (this study)
Terrestrial Reference Frame	ITRF2005	ITRF2008
Polar motion and UT1	IERS EOP 05 C04 (IAU2000A)	IERS EOP 08 C04 (IAU2000A)
Precession and nutation model	IERS Conventions 2003	IERS Conventions 2010
Gravity field model (static)	EIGEN-GL04S	EIGEN-GL04S, EIGEN-6S, EIGEN-6S_static, EIGEN-6S2, EIGEN-6S2A, EIGEN-6S2B
Gravity field model (time varying)	EIGEN-GL04S-ANNUAL	EIGEN-GL04S-ANNUAL, EIGEN-6S, EIGEN-6S_static, EIGEN-6S2, EIGEN-6S2A, EIGEN-6S2B
Solid Earth tides	IERS Conventions 2003	IERS Conventions 2010
Pole tide	IERS Conventions 2003	IERS Conventions 2010
Ocean tides	FES2004	EOT10A
Atmospheric tides	Biancale and Bode (2006)	Biancale and Bode (2006)
Atmospheric gravity	ECMWF 6-hourly fields up to degree and order 50	ECMWF 6-hourly fields up to degree and order 50
Third bodies	Sun, Moon, Venus, Mars, Jupiter (DE-405)	Sun, Moon, all 8 major planets (DE-421)

The main parameters of the geopotential models used

Parameter	EIGEN-GL04S (VER2)	EIGEN-6S_correct (VER3)	EIGEN-6S_static (at 2000.0) (VER4)
Maximal degree and order	150	240	240
Truncation level	90	90	90
Reference epoch	MJD 1460.5 (01.01.2004)	MJD 1826.5 (01.01.2005)	MJD -0.5 (01.01.2000)
$C_{2,0}$	-0.484165281 E-03	-0.484165300 E-03	-0.484165316 E-03
Drifts of coefficients	No	Constant drift for degree 2-50 terms	Constant drift only for $C_{2,0}$ term
$C_{2,0}$dot	0.0	3.182710000 E-12	3.18271000 E-12
$\Delta C_{2,0}$ correction to EIGEN-6S model	0.0	A periodic term (1), see Slide 6	A periodic term (1), see Slide 6

The main parameters of the geopotential models used (continue)

Parameter	EIGEN-6S2 (VER5)	EIGEN-6S2A (VER6)	EIGEN-6S2B (VER7)
Maximal degree and order	260	260	260
Truncation level	90	90	90
Reference epoch	Coefficient specific	Coefficient specific	Coefficient specific
$C_{2,0}$	Time dependant	Time dependant	Time dependant
$C_{2,0}$dot (1950-1985)	0.0	0.0	0.0
$C_{2,0}$dot (1985-2012)	A yearly time series	A yearly time series	A yearly time series
$C_{2,0}$dot (2012-2050)	0.0	0.0	0.0
$C_{3,0}$dot - $S_{50,50}$dot (1950-2003)	constant	0.0	constant
$C_{3,0}$dot - $S_{50,50}$dot (2003-2012)	constant	A yearly time series	A yearly time series
$C_{3,0}$dot - $S_{50,50}$dot (2012-2050)	constant	0.0	constant

Coefficient $C_{2,0}$ in EIGEN-6S_correct and EIGEN-6S_static models

$C_{2,0}(t) = C_{2,0} + C_{2,0}dot*(t-2005) + \Delta C_{2,0}$,

where $C_{2,0}$ = -4.8416529995630E-04, $C_{2,0}dot$ = 3.18271E-12,

$\Delta C_{2,0} = a1*\sin(2*\pi*(t-2005)/18.6129)+a2*\cos(2*\pi*(t-2005)/18.6129)$, (1)

a1 = -9.01895E-12, a2= -3.47674E-11

Representation of the coefficient drifts in EIGEN-6S2A and EIGEN-6S2B models

Note 1. EIGEN-6S2A model is based on the EIGEN-6S2 model and provides yearly time series of drifts for degree 2-50 geopotential terms obtained from GRGS GRACE RL02 solution, but zero drifts for degree 3-50 terms outside of the GRACE period (2003-2012).

Note 2. EIGEN-6S2B model is based on EIGEN-6S2 model and provides yearly time series of drifts for degree 2-50 geopotential terms obtained from GRGS GRACE RL02 solution and constant drifts for degree 3-50 terms outside of the GRACE period (2003-2012).

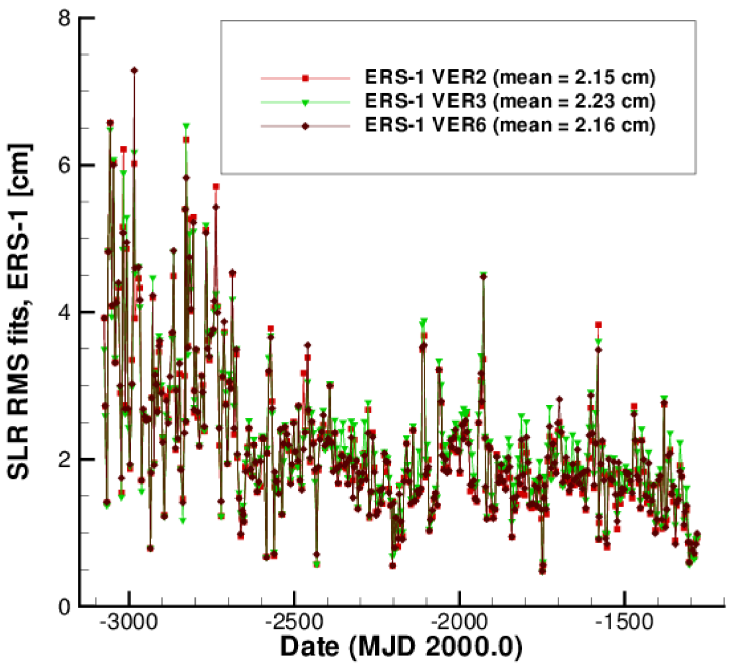
For all six geopotential models:

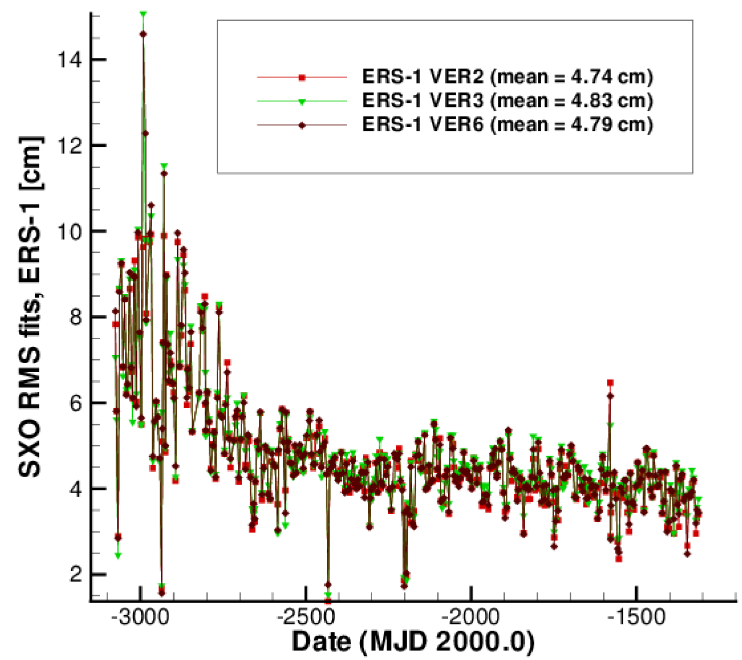
Geocentric gravitational constant GM = 3.986004415 E+14 m3/s2

Semi major axis = 6378136.46 m

Annual and semi-annual variations are provided for degree 2-50 terms

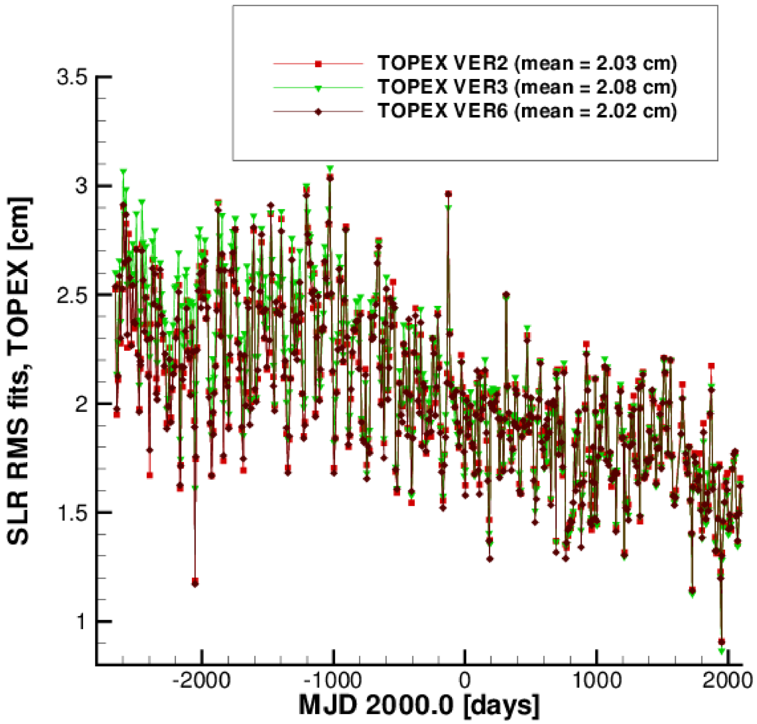
Impact on SLR and altimeter crossover (SXO) observation RMS fits for ERS-1 (August 1991 – July 1996)

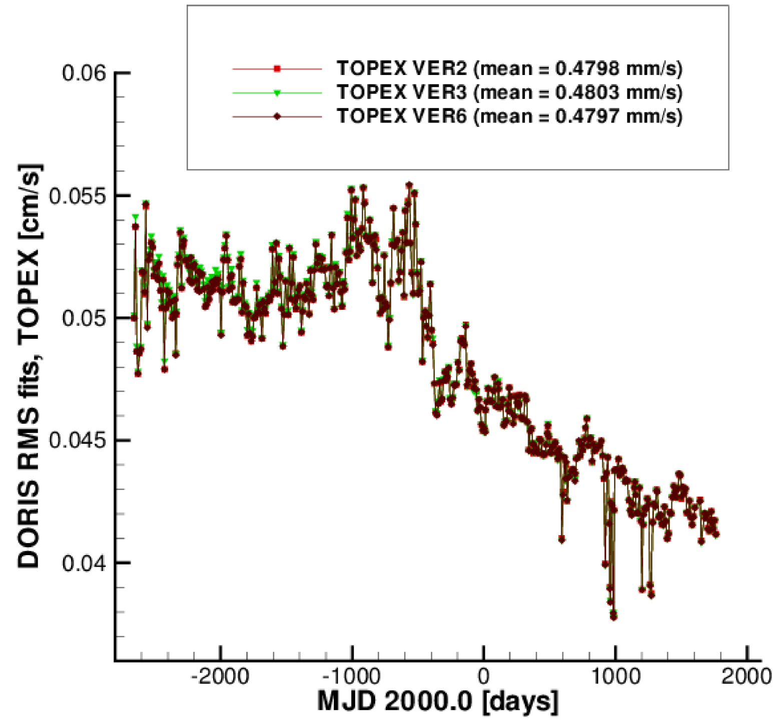




- The smallest RMS fits of SLR and SXO observations are obtained using EIGEN-GL04S gravity model (VER2 orbit)
- Use of the EIGEN-6S model (VER3 orbit) at the time spans before 2002 increases RMS fits of SLR and SXO observations => use of the geopotential drift terms of the GRACE-derived gravity models at the time before 2002 degrades orbit quality!

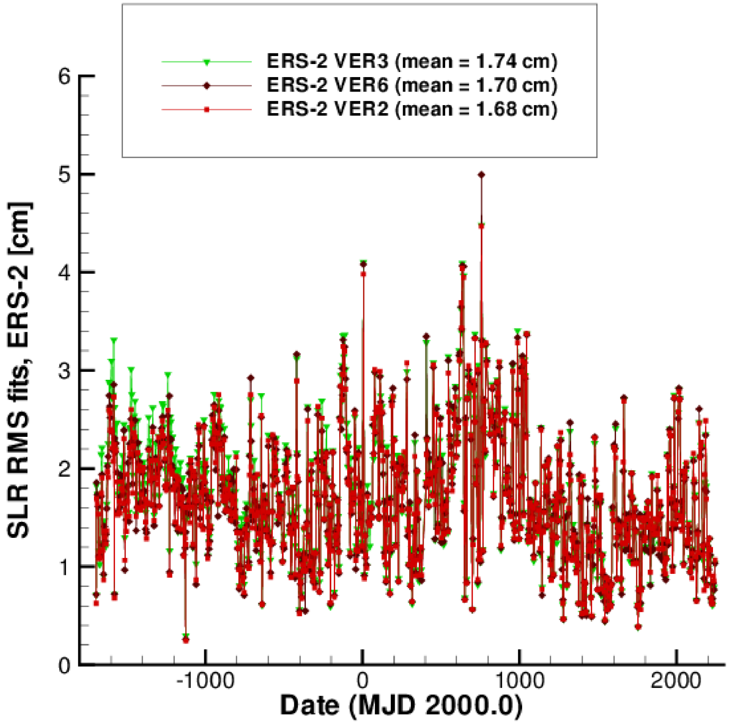
Impact on SLR and DORIS observation RMS fits for TOPEX/Poseidon (September 1992 – October 2005)

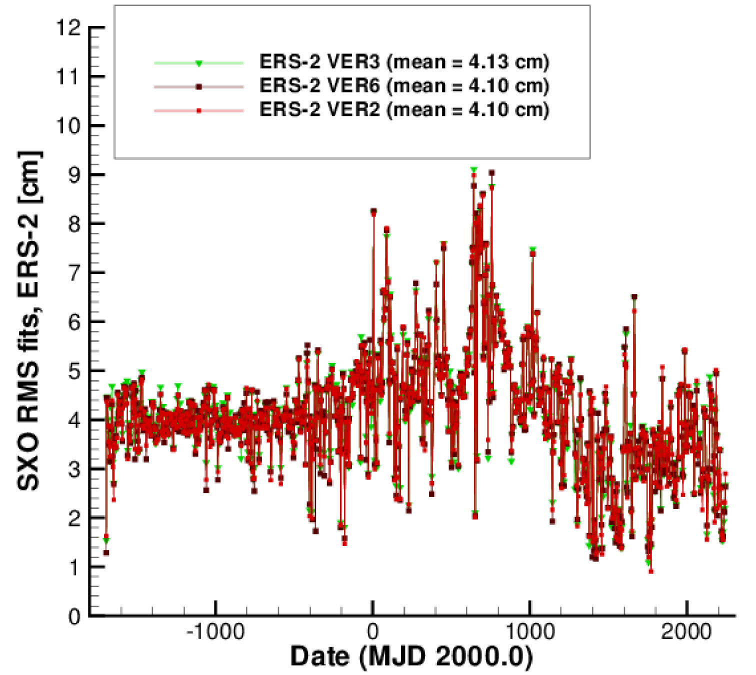




- SLR RMS fits: use of time-variable EIGEN-6S2A geopotential model (VER6 orbit) gives the smallest fits, use of EIGEN-6S model leads to the increase of fits by 0.5 mm (2.5%) from 2.03 to 2.08 cm, especially for years 1992 – 1997;
- DORIS RMS fits: minor influence of the gravity field model used, however, use of EIGEN-6S2A model gives smallest fits, while EIGEN-6S model increases fits slightly (0.00005 cm/s, i.e. about 0.1%), especially for years 1992 – 1997

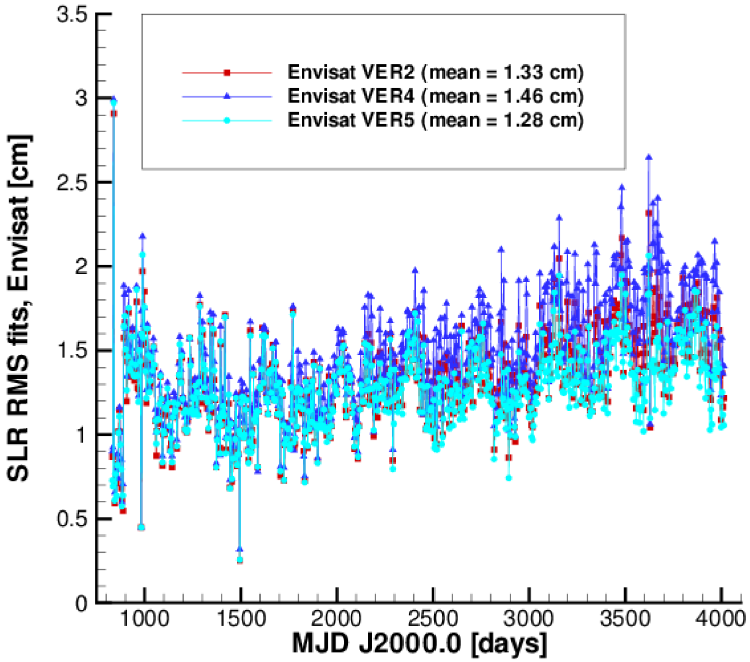
Impact on SLR and altimeter crossover (SXO) observation RMS fits for ERS-2 (May 1995 – February 2006)

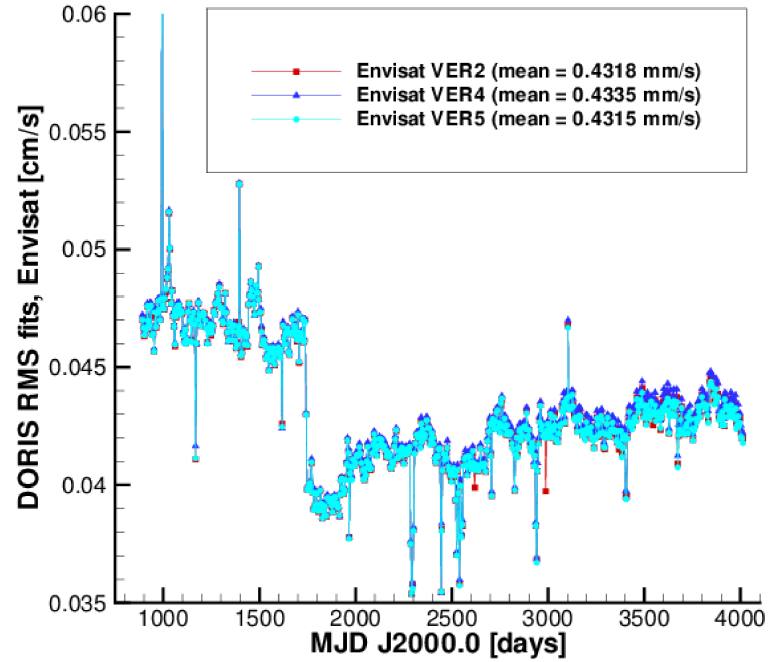




- The smallest RMS fits of SLR and SXO observations are obtained using EIGEN-GL04S and EIGEN-6S2A gravity models (VER2 and VER6 orbits)
- Use of the EIGEN-6S model (VER3 orbit) at the time spans before 2002 increases RMS fits of SLR and SXO observations => use of the geopotential drift terms of the GRACE-derived gravity models at the time before 2002 degrades orbit quality!

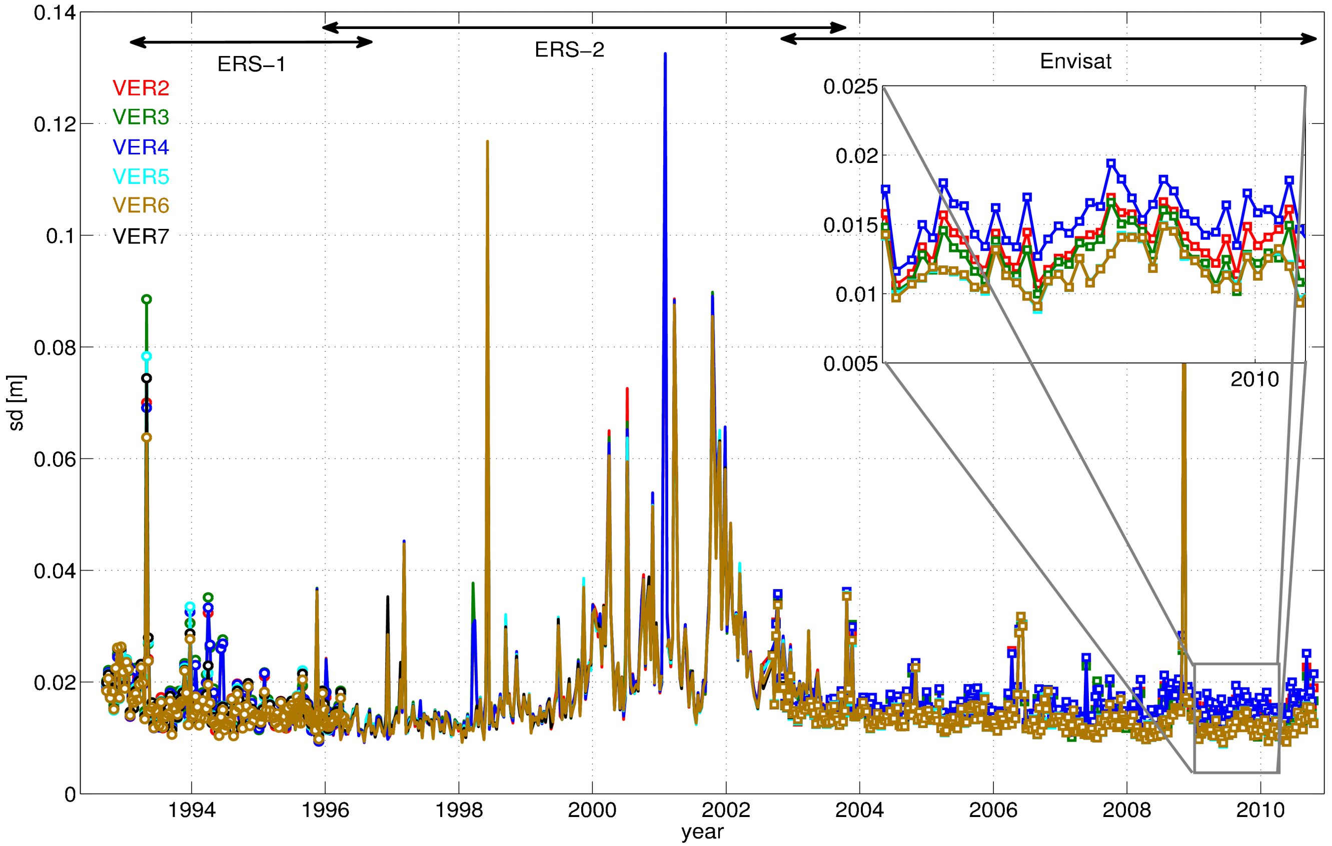
Impact on SLR and DORIS observation RMS fits for Envisat (April 2002 – December 2010)





- SLR RMS fits: improvement by 0.5 mm (3.8%) from 1.33 to 1.28 cm using time-variable EIGEN-6S2 and EIGEN-6S2A models (VER5 and VER6 orbits), as compared to EIGEN-GL04S model (VER2 orbit), especially for years 2007 – 2010;
- DORIS RMS fits: minor influence of the gravity field models used, however, time-variable EIGEN-6S2, EIGEN-6S2A and EIGEN-6S2B models (VER5, VER6, VER7 orbits) bring some small improvement for years 2007 – 2010

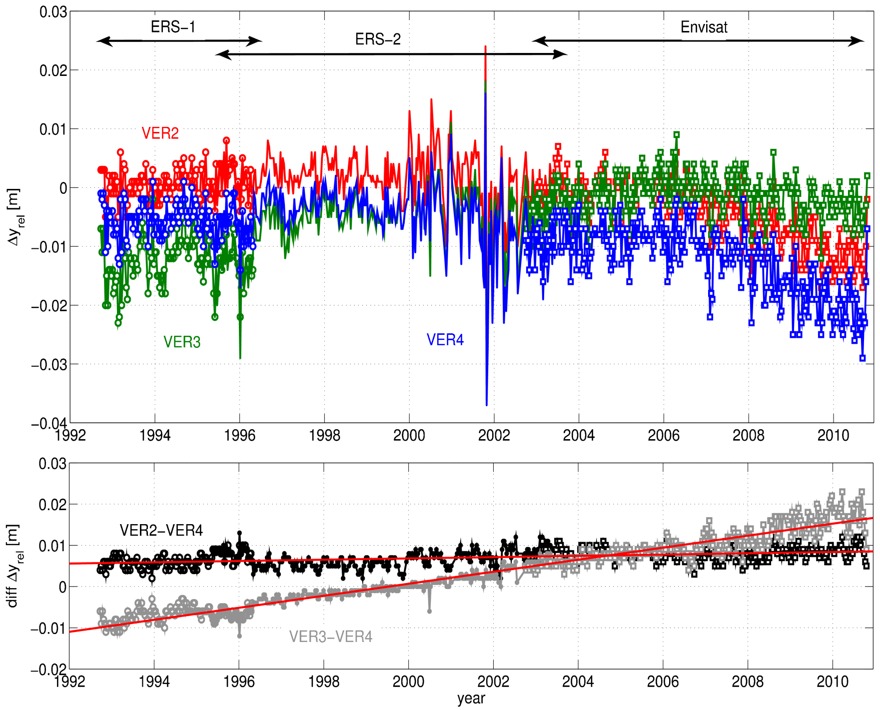
Standard deviation of radial errors for ERS-1, ERS-2 and Envisat

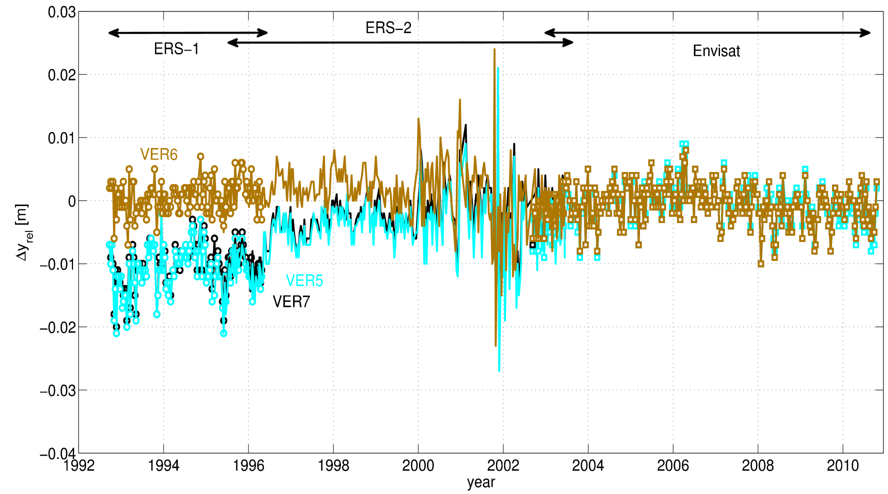


	VER2	VER3	VER4	VER5	VER6	VER7
ERS-1	1.68	1.75	1.69	1.63	**1.57**	1.64
ERS-2	2.11	2.12	2.11	2.03	**2.02**	2.03
Envisat	1.55	1.52	1.65	**1.40**	1.41	1.41

- EIGEN-6S2, EIGEN-6S2A and EIGEN-6S2B models (VER5 – VER7 orbits) show better results than three older models (VER2 – VER4 orbits), especially for Envisat,
- The mean standard deviation of the radial errors for the whole mission lifetime for the best orbit version reaches 1.6 cm for ERS-1 (VER6 orbit), 2.0 cm for ERS-2 (VER6 orbit) and 1.4 cm for Envisat (VER5 orbit)

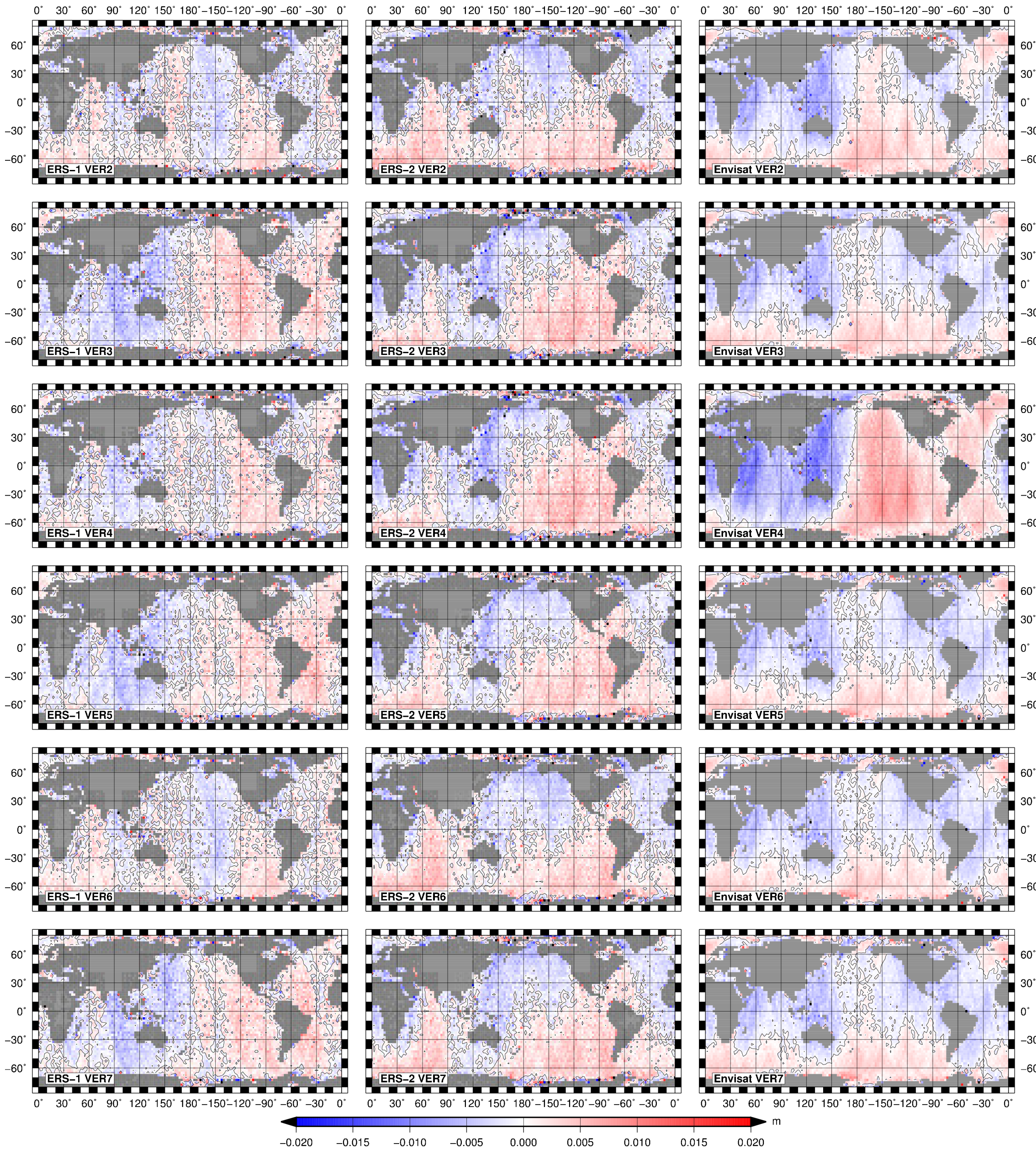
Relative center-of-origin shifts (y-component) with respect to reference missions of ERS-1, ERS-2 and Envisat using VER2, VER3, VER4 (all left side) and VER5, VER6 and VER7 (all right side) orbit solutions





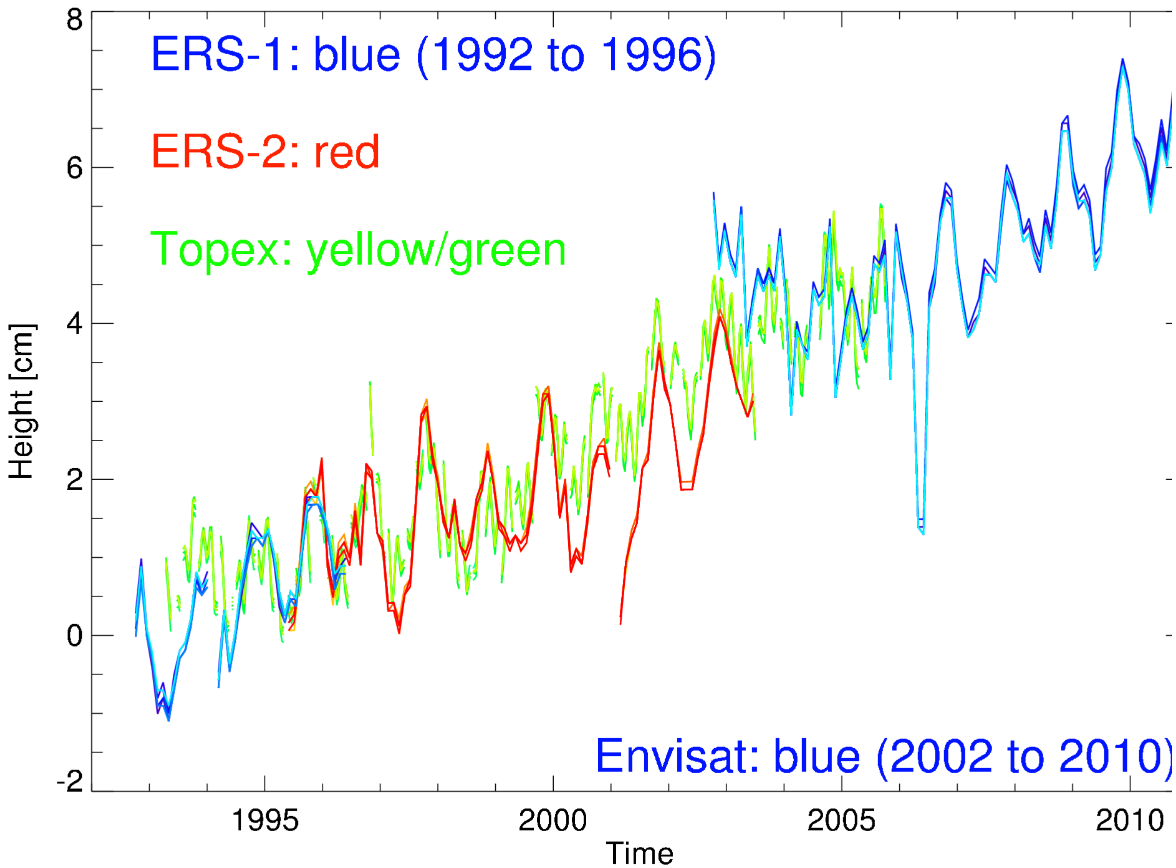
- Relative center-of-origin shift in y-component computed using VER2, VER3, VER4, VER5 and VER7 orbit solutions show drifts at different time spans
- Only VER6 orbit based on EIGEN-6S2A model gives a time series without significant drift and provides good results for all three missions

Geographically correlated errors (GCE) for ERS-1 (left), ERS-2 (middle) and Envisat (right) based on VER2 – VER7 orbit solutions (from top)



- All GCE remain smaller than about 2 cm
- The RMS values of GCE range between 2.8 and 5.0 mm
- The best results reached for ERS-1 with VER6 orbit (2.8 mm RMS), for ERS-2 with VER5, VER6 and VER7 orbits (3.6 mm RMS), for Envisat with VER3, VER5, VER6 and VER7 orbits (2.9 mm RMS)
- VER6 orbit solution based on EIGEN-6S2A geopotential model ensures minimal GCE without systematic effects for all three missions.

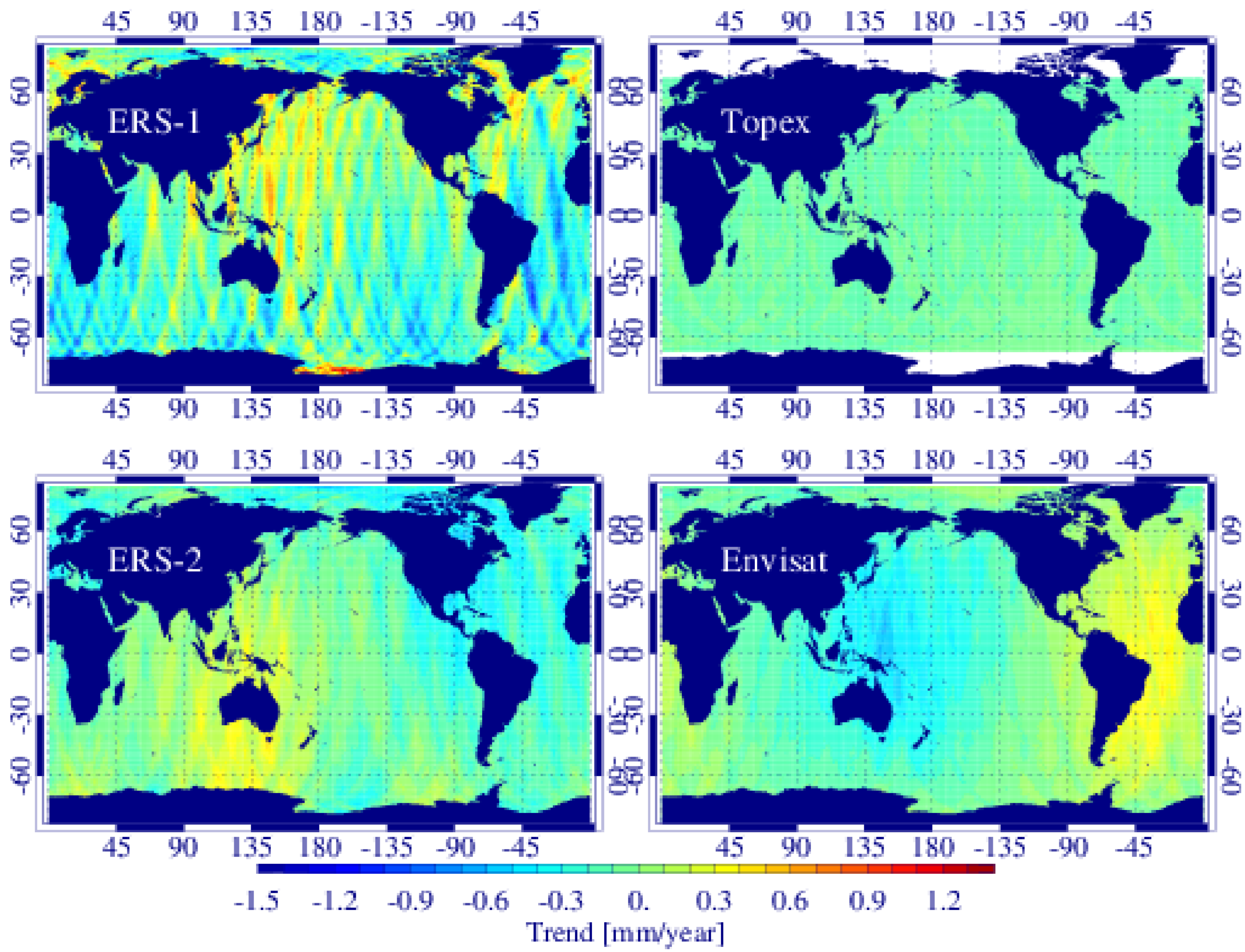
Impact on the global Mean Sea Level (MSL) for all four satellites



- Global MSL trends and their formal errors (mm/yr) computed using ERS-1, TOPEX, ERS-2 and Envisat orbits derived various geopotential models are shown in the table below
- Rather small (0.1-0.2 mm/yr) influence of the geopotential models used on the global MSL trend for all four satellites

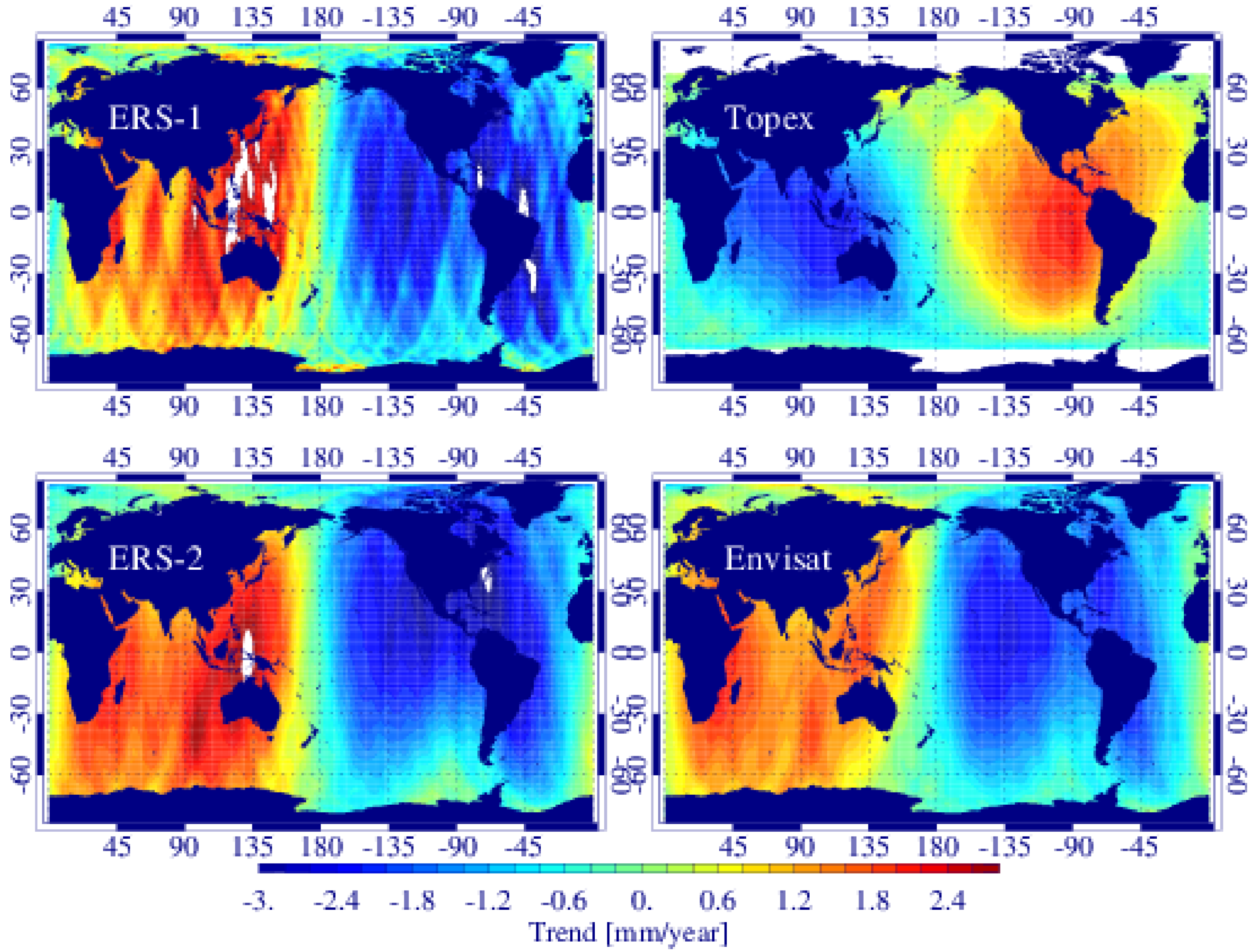
ERS-1	ERS-2	TOPEX	Envisat
5.3 – 5.5 (±0.4)	2.5 – 2.7 (±0.2)	3.4 – 3.5 (±0.1)	2.9 – 3.1 (±0.4)

Impact on the regional Mean Sea Level for ERS-1, ERS-2, TOPEX and Envisat: EIGEN-6S_static (VER4) minus EIGEN-GL04S (VER2)



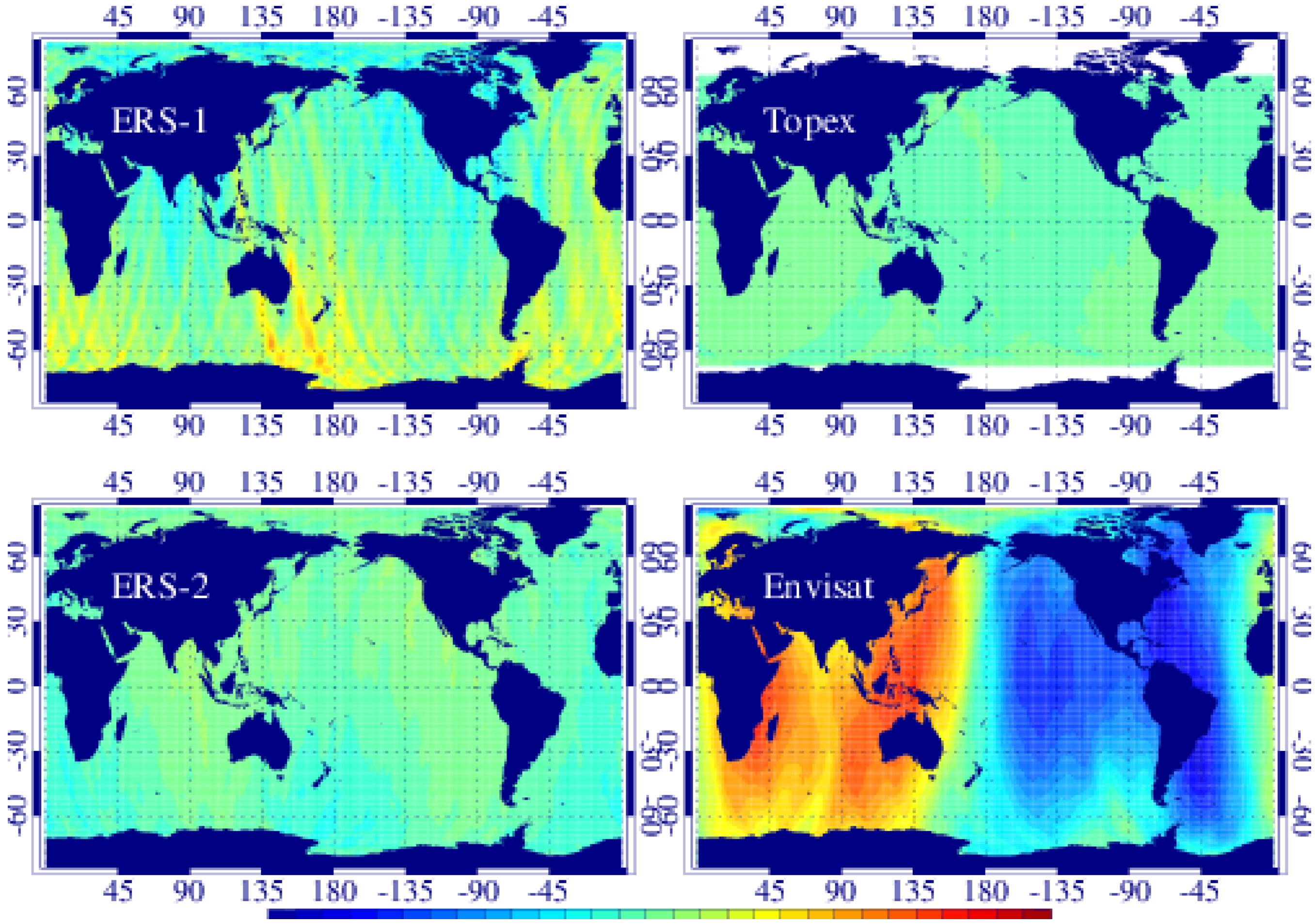
Rather small differences (up to 0.3-0.5 mm/yr) in the regional MSL trends computed using the VER4 and VER2 orbits based on static (EIGEN-6S_static and EIGEN-GL04S) geopotential models

Impact on the regional Mean Sea Level for ERS-1, ERS-2, TOPEX and Envisat: EIGEN-6S_correct (VER3) minus EIGEN-GL04S (VER2)



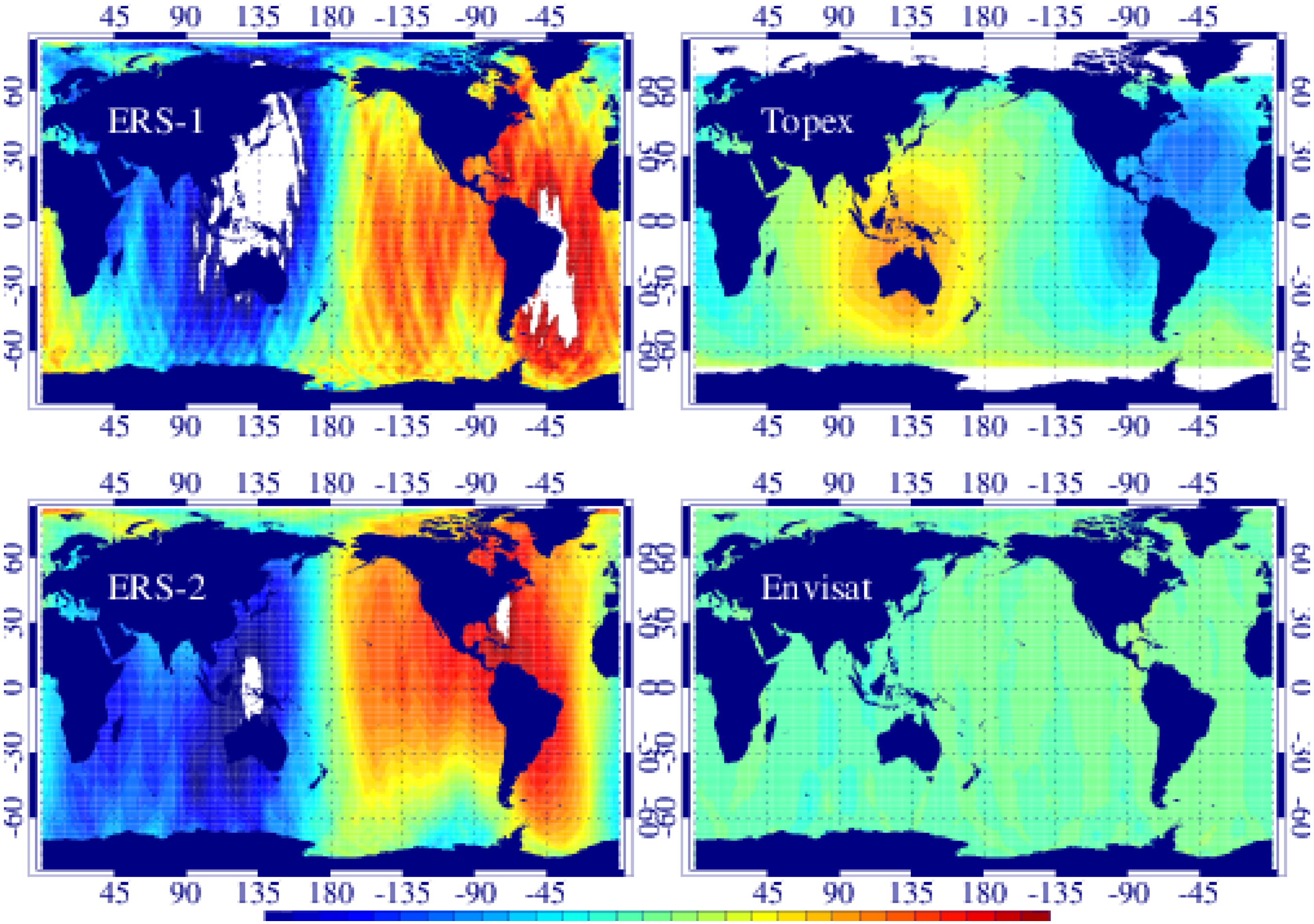
East-West differences up to 3 mm/yr in the regional MSL trends computed using the VER3 and VER2 orbits based on the time-variable (EIGEN-6S_correct) and static (EIGEN-GL04S) geopotential models

Impact on the regional Mean Sea Level for ERS-1, ERS-2, TOPEX and Envisat: EIGEN-6S2A (VER6) minus EIGEN-GL04S (VER2)



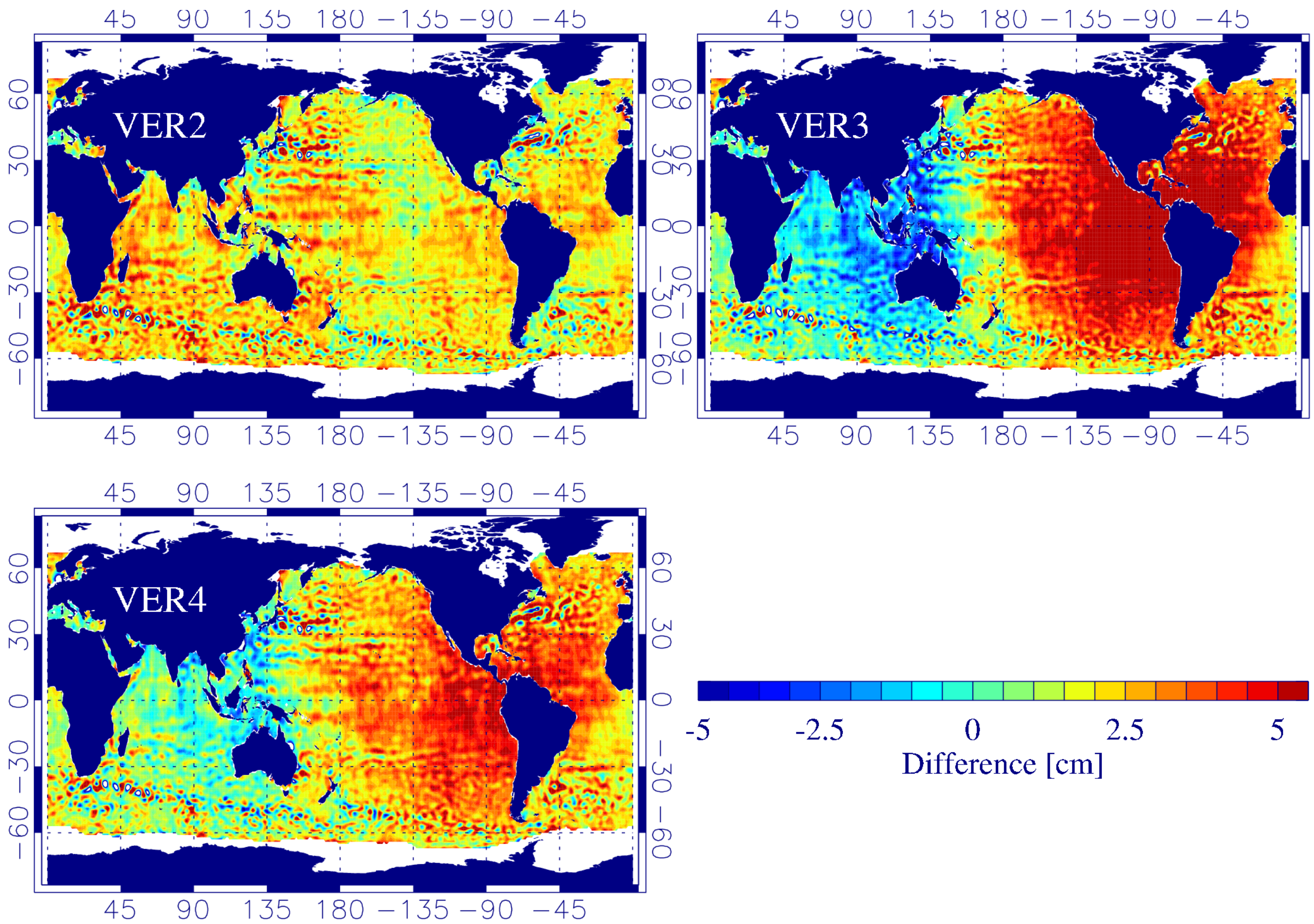
Rather small differences (up to 0.2-0.3 mm/yr) in the regional MSL trends computed using the VER6 and VER2 orbits for ERS-2 and TOPEX, medium differences (up 0.5 mm/yr) for ERS-1 and large differences (up to 2.5 mm/yr) for Envisat

Impact on the regional Mean Sea Level for ERS-1, ERS-2, TOPEX and Envisat: EIGEN-6S2A (VER6) minus EIGEN-6S2 (VER5)



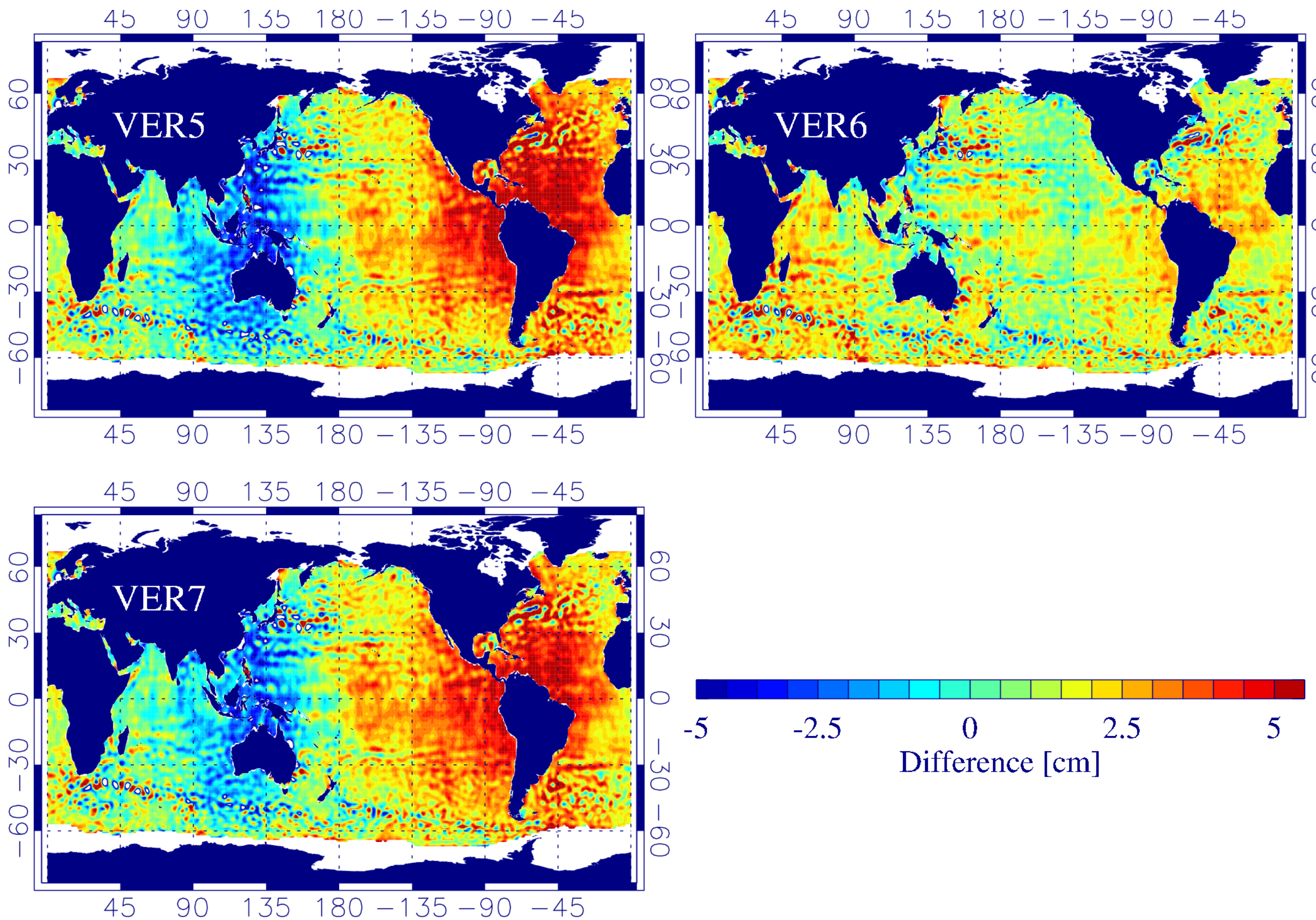
Rather small differences (up to 0.1-0.2 mm/yr) for Envisat, medium size (up to 1.5 mm/yr) differences for TOPEX and large (up to 3 mm/yr) East-West differences for ERS-1 and ERS-2 using EIGEN-6S2A and EIGEN-6S2 gravity models

Differences of the mean sea level calculated from ERS-2 and TOPEX for VER2, VER3 and VER4 orbit solutions (June 1995 – June 1996)



A clear dipole pattern with extrema of ±5 cm visible for ERS-2 and TOPEX sea level differences for VER3 and VER4 orbit solutions, but not for VER2 orbit solution

Differences of the mean sea level calculated from ERS-2 and TOPEX for VER5, VER6 and VER7 orbit solutions (June 1995 – June 1996)



A clear dipole pattern with extrema of ±5 cm visible for ERS-2 and TOPEX sea level differences for VER5 and VER7 orbit solutions, but not for VER6 orbit solution

Conclusions and outlook

- The influence of two static (EIGEN-GL04S and EIGEN-6S_static) and four time variable (EIGEN-6S_correct, EIGEN-6S2, EIGEN-6S2A and EIGEN-6S2B) geopotential models on precise orbits of ERS-1 (1991 – 1996), TOPEX/Poseidon (1992 – 2005), ERS-2 (1995 – 2006) and Envisat (2002 - 2010) and on global and regional mean sea level trends computed using these orbits was studied at the time spans given
- The best geopotential models from the analysis of the observations residuals and orbital arc overlaps are EIGEN-6S2 and EIGEN-6S2A for Envisat, EIGEN-6S2A for TOPEX/Poseidon, EIGEN-6S_static for ERS-1 and EIGEN-GL04S and EIGEN-S2A for ERS-2
- The multi-mission crossover analysis indicates that EIGEN-6S2A geopotential model provides the most consistent results for all four satellite missions
- The differences in the global mean sea level (MSL) trends computed using these six geopotential models are below 0.1-0.2 mm/yr, i.e. almost no influence on the global MSL trend was found
- However, significant East/West differences (up to 3 mm/yr) are found in the regional mean sea level trends, while using different static and time-variable geopotential models
- The final conclusion over all tests for all four satellites used: EIGEN-6S2A time variable geopotential model performs best among the models studied
- A more refined time variable geopotential model at the time span from 1985 till 2003 should bring even better results. Such a model could be probably derived by using SLR measurements to LAGEOS-1,-2, Stella, Starlette and DORIS measurements to TOPEX/Poseidon and some other satellites

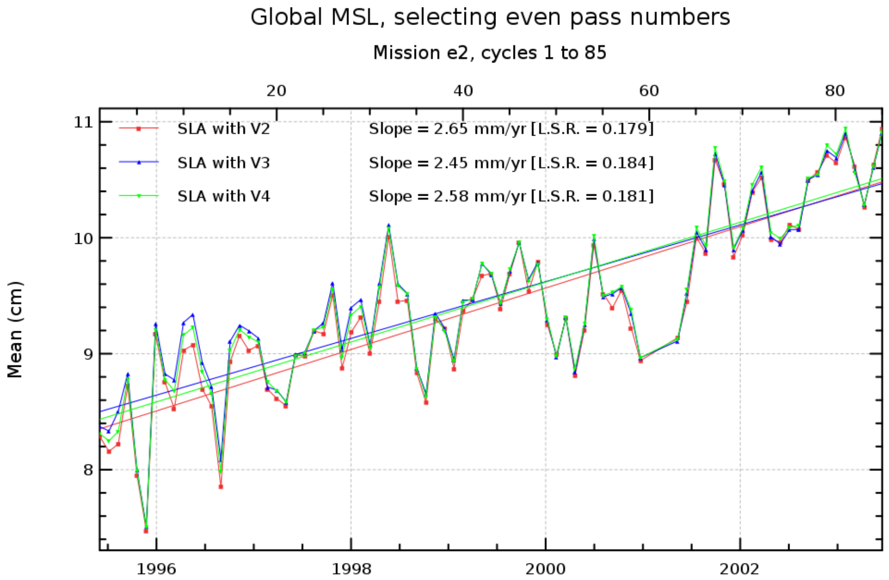
Acknowledgements

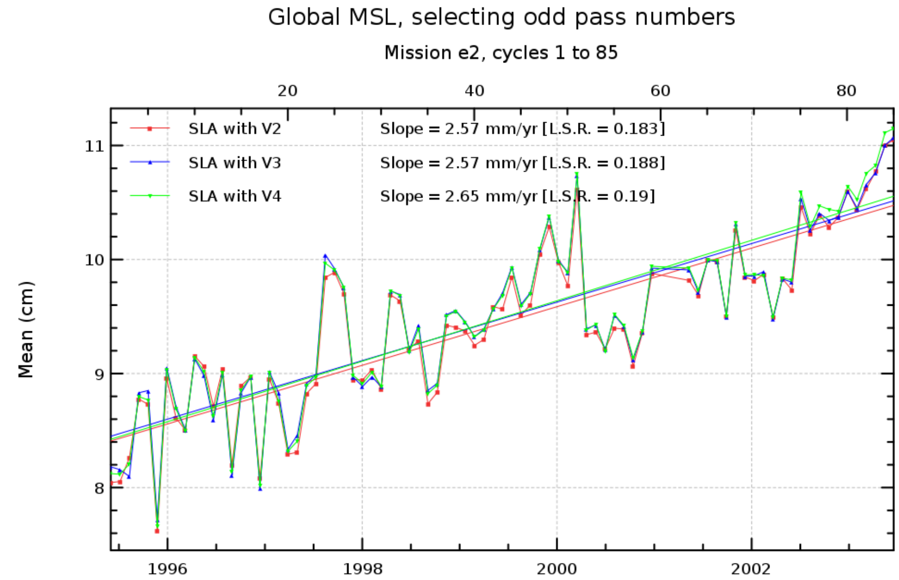
- SLR, DORIS and PRARE data available from the ILRS, IDS and ESA were used in this research
- Observation data from altimeter missions are provided by ADS and OpenADB based on data from ESA and CNES/NASA
- We thank all institutions in charge of mission operation, maintenance, processing and distribution of data used in this study
- This investigation was partly supported by the European Space Agency within the REAPER and Climate Change Initiative Sea Level Project
- The GOCE data preprocessing for EIGEN-6S and EIGEN-6S2 models was partly financed through ESA contract no. 18308/04/NL/MM

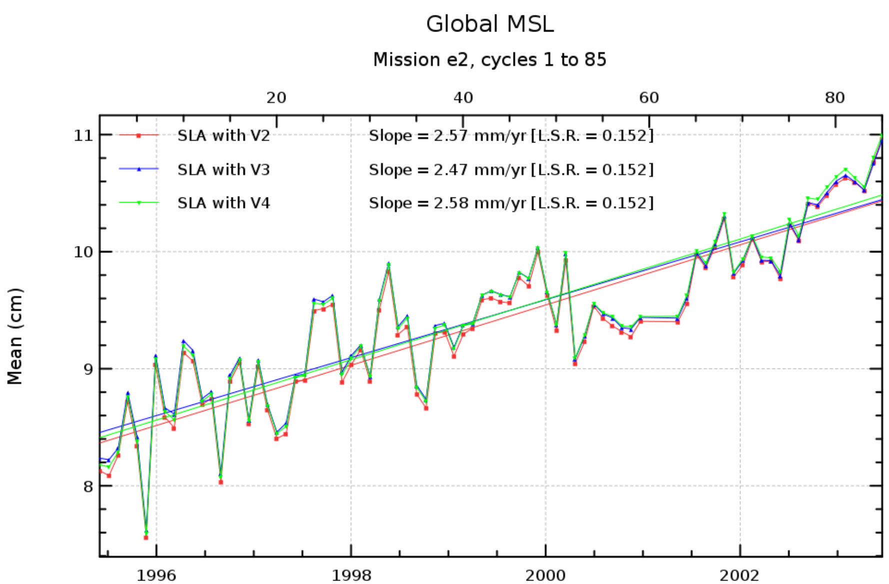
Thank you for your attention!

Appendix

Impact on the global Mean Sea Level (MSL) – an example for ERS-2



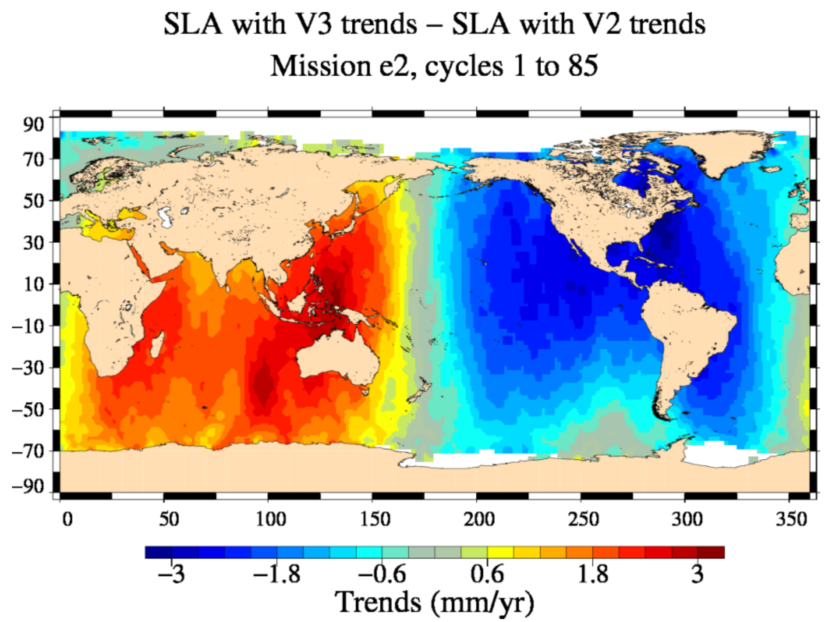


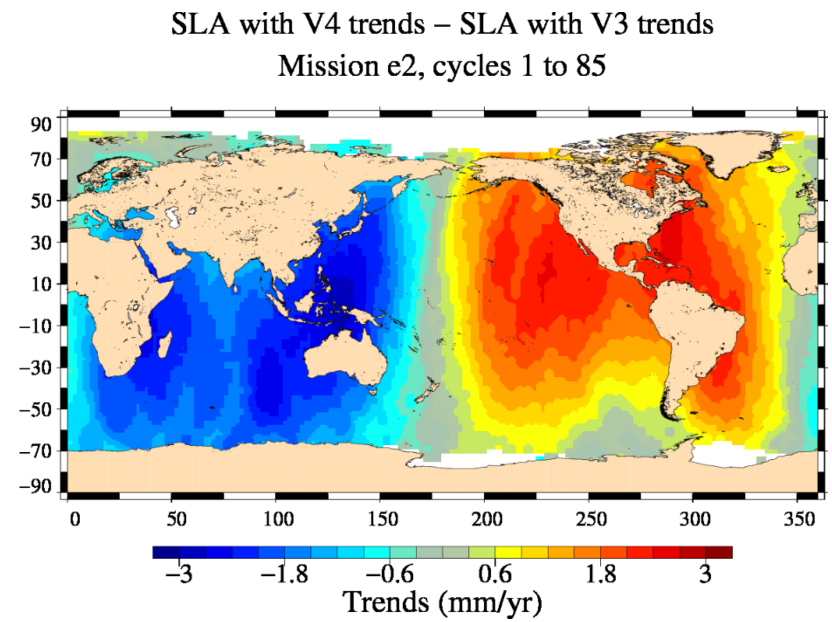


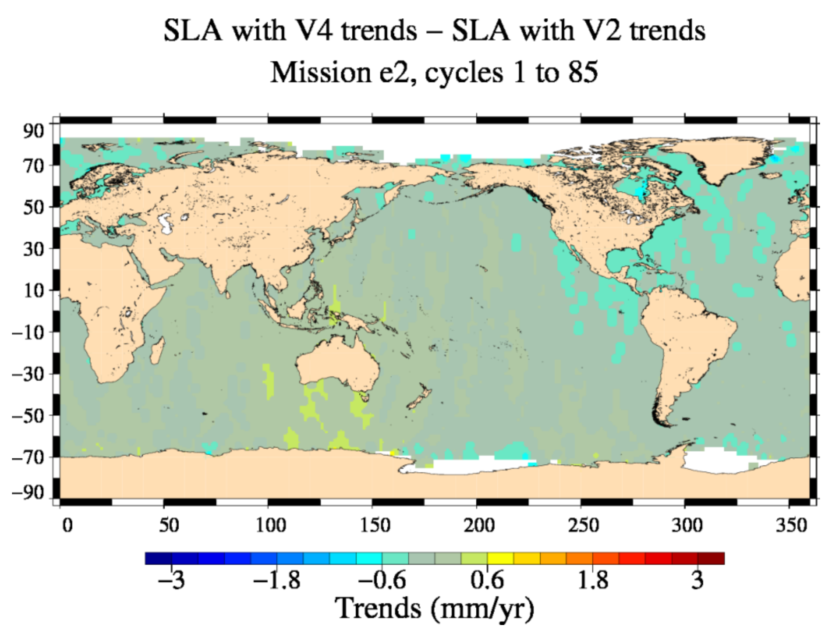
- Rather small (below 0.1 mm/yr) influence on the global MSL trend,
- The MSL trend values computed using ascending and descending parts of the orbits are homogenous (differences below 0.1-0.2 mm/yr)
- No impact on annual and semi-annual signals was detected

(Rudenko et al. Influence of time variable geopotential models..., 2013)

Impact on the regional Mean Sea Level – an example for ERS-2

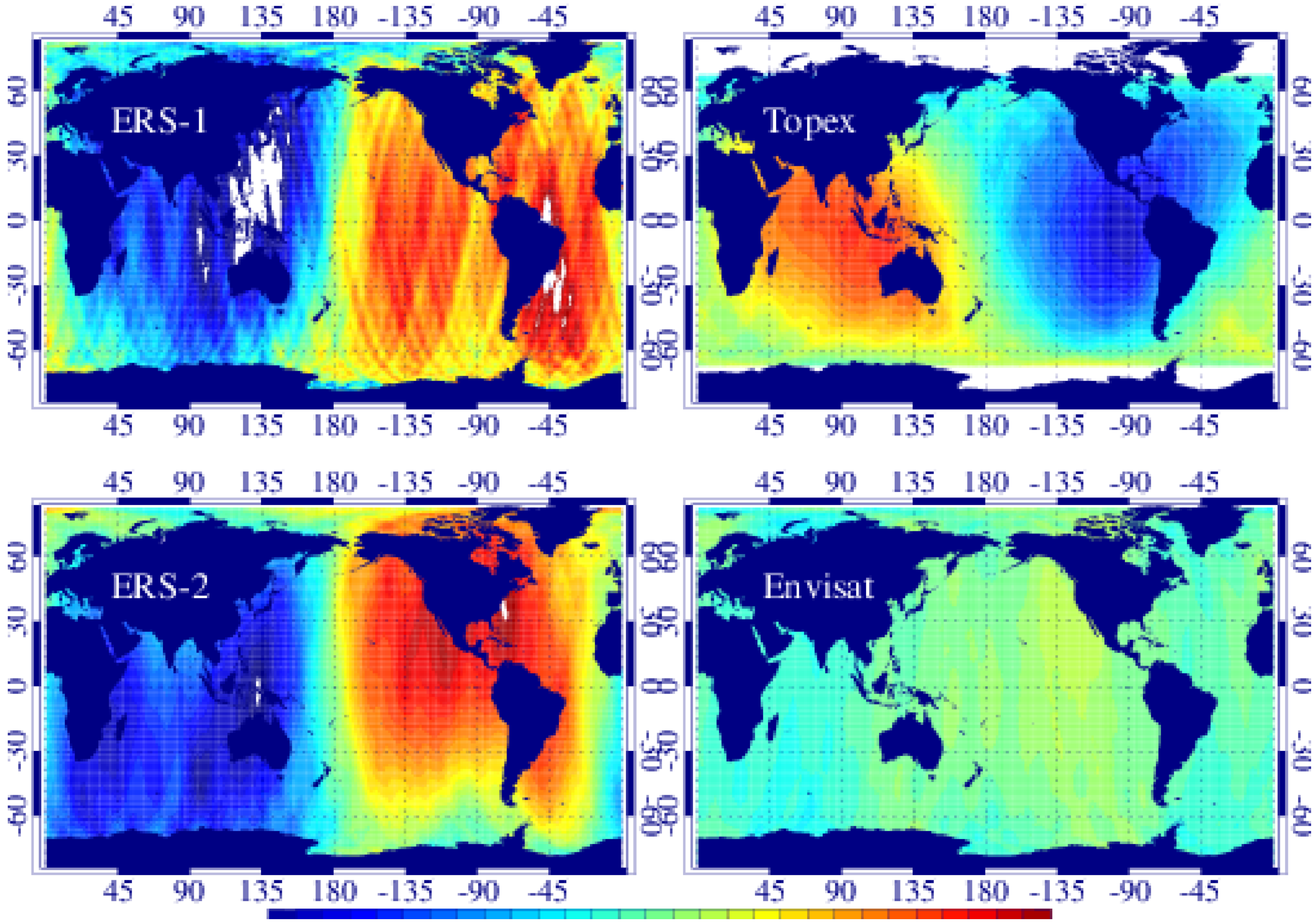






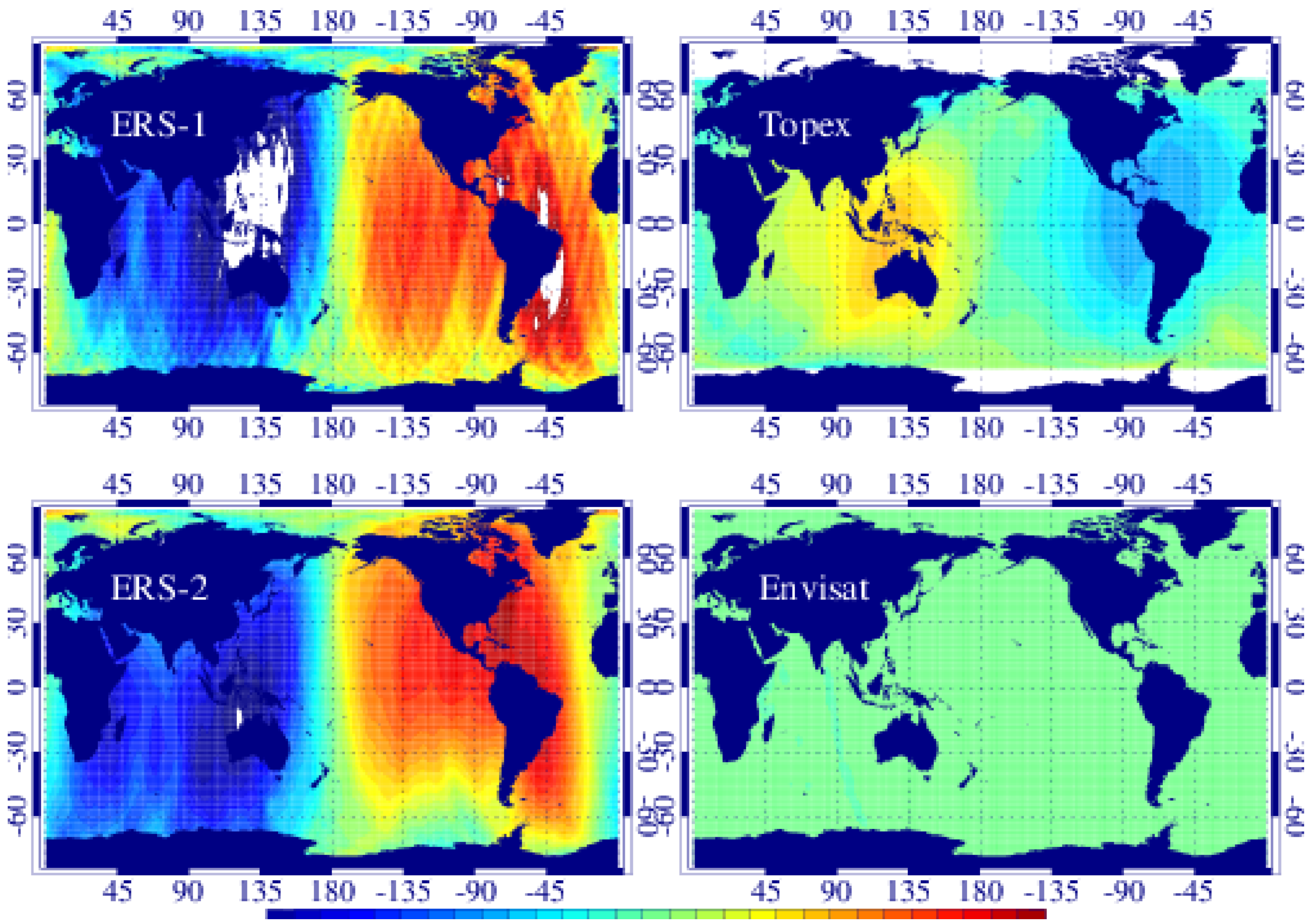
- Regional MSL trends computed using V3 orbit based on the time-variable EIGEN-6S_correct gravity field model show strong East/West differences (up to 3 mm/yr), as compared to those computed using V2 and V4 orbits based on static gravity field models (EIGEN-GL04S and EIGEN-6S_static)
- Regional MSL trends computed using V2 and V4 orbits based on static gravity field models are homogenous

Impact on the regional Mean Sea Level for ERS-1, ERS-2, TOPEX and Envisat: EIGEN-6S2A (VER6) minus EIGEN-6S (VER3)



Rather small differences (up to 0.5 mm/yr) in the regional MSL trends for Envisat and large (up to 3 mm/yr) East-West differences for ERS-1, ERS-2 and TOPEX using the VER6 and VER3 orbits based on EIGEN-6S2A and EIGEN-6S geopotential models

Impact on the regional Mean Sea Level for ERS-1, ERS-2, TOPEX and Envisat: EIGEN-6S2A (VER6) minus EIGEN-6S2B (VER7)



Rather small differences (up to 0.1-0.2 mm/yr) for Envisat, medium size (up to 1.5 mm/yr) differences for TOPEX and large (up to 3 mm/yr) East-West differences for ERS-1 and ERS-2 using EIGEN-6S2A and EIGEN-6S2B models