# Influence of time variable geopotential models on precise orbits of altimetry satellites and derived mean sea level

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# Introduction

- The purpose is to study the influence of three different geopotential models, namely, EIGEN-GL04S (Lemoine et al., 2007), time-variable EIGEN-6S (Förste et al., 2012) and a static version EIGEN-6S_static (at epoch 2000.0), on precise orbits of Envisat (from April 2002 to December 2010), TOPEX/Poseidon (from September 1992 till October 2005), ERS-1 (from August 1991 till July 1996) and ERS-2 (from May 1995 till July 2003) and mean sea level trends computed using these orbits
- Precise orbits of these satellites were computed in the same for all satellites ITRF2008 terrestrial reference frame using the same consistent models 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.
- The RMS fits of SLR, altimetry crossover and DORIS observations, orbital arc overlaps in radial direction, as well as global and regional mean sea level trends have been inter-compared

# The main models and input data used for precise orbit determination

| | |
|---|---|
| Terrestrial Reference Frame | ITRF2008 (Altamimi et al., 2011), SLRF2008 (Pavlis, 2009) and DPOD2008 (Willis, 2011) are used for stations missing in ITRF2008 |
| Polar motion and UT1 | IERS EOP 08 C04 (IAU2000A) series with IERS daily and sub-daily corrections |
| Precession and Nutation model | IERS Conventions (2010) |
| Gravity field models (static) | EIGEN-GL04S versus time-variable EIGEN-6S and EIGEN-6S static (at epoch 2000.0), up to n=m=90 |
| Gravity field (time varying) | Annual and semi-annual variation for degree 2-50, $C_{n,m}$dot for degree 2-50 for EIGEN-6S, $C_{2,0}$dot for EIGEN-6S_static model, $\Delta C_{2,0}$ periodic terms for EIGEN-6S* models |
| Solid Earth tides | IERS Conventions (2010) |
| Pole tide | IERS Conventions (2010) |
| Ocean tides | EOT10A (Savcenko and Bosch, 2010), all constituents up to degree and order 50 |
| Atmospheric tides | Biancale and Bode (2006) |
| Atmospheric gravity | ECMWF 6-hourly fields up to degree and order 50 (Flechtner, 2007) |
| Third bodies | Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto (DE-421) (Folkner et al., 2009) |

# 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 |
| Drifts of coefficients | no | For degree 2-50 terms | Only $C_{2,0}$ |
| Annual and semi-annual variations | For degree 2-50 terms | For degree 2-50 terms | For degree 2-50 terms |
| Reference epoch | MJD 1460.5 (01.01.2004) | MJD 1826.5 (01.01.2005) | MJD -0.5 (01.01.2000) |
| GM value [m3/s2] | 3.986004415 E+14 | 3.986004415 E+14 | 3.986004415 E+14 |
| Semi major axis [m] | 6378136.46 | 6378136.46 | 6378136.46 |
| $C_{2,0}$ | -0.484165281 E-03 | -0.484165300 E-03 | -0.484165316 E-03 |
| $C_{2,0}$dot | 0.0 | 3.182710000 E-12 | 3.18271000 E-12 |
| $\Delta C_{2,0}$ | 0.0 | see next slide | see next slide |

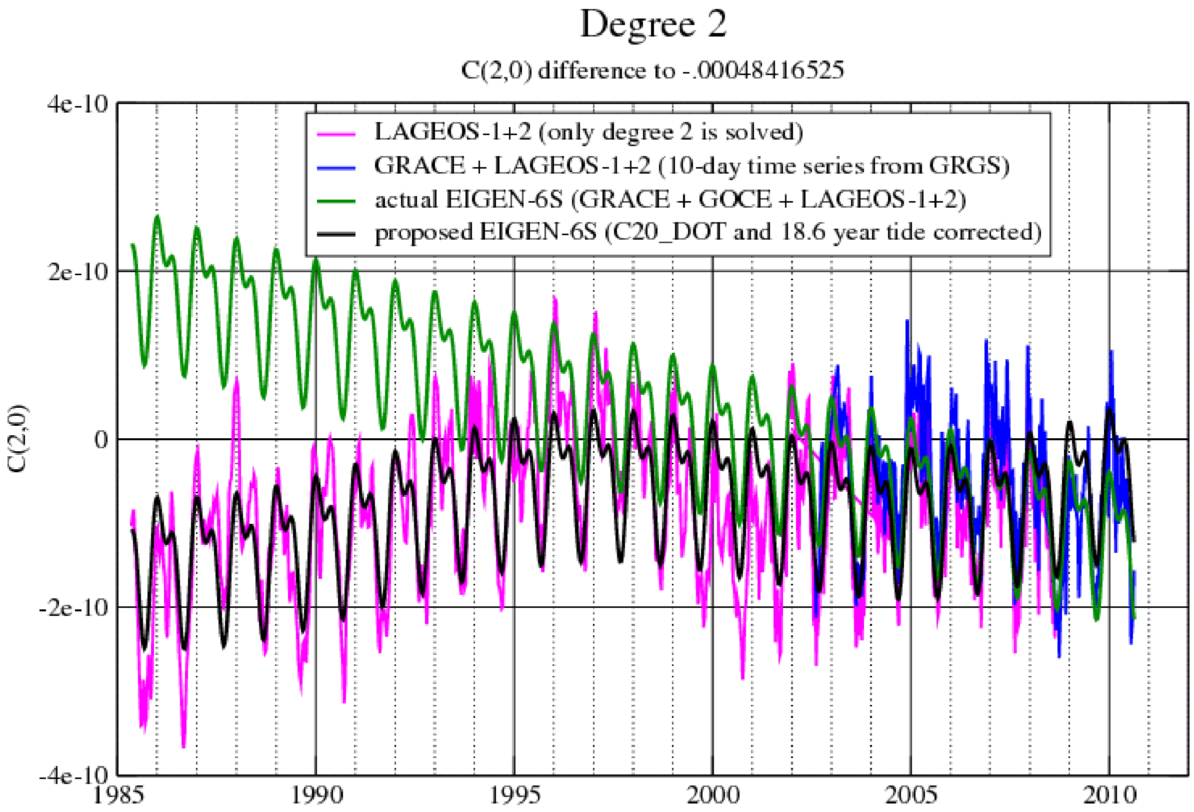
# Coefficient $C_{2,0}$ in EIGEN-6S_correct and EIGEN-6S_static models

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

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

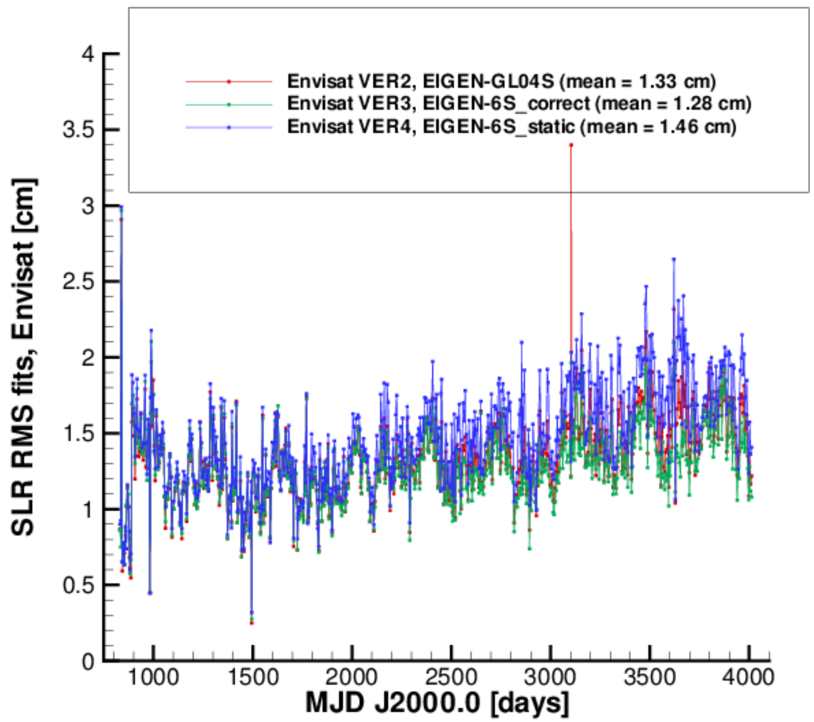
$\Delta C_{2,0}$ = a1*sin(2*π*(t-2005)/18.6129)+a2*cos(2*π*(t-2005)/18.6129),

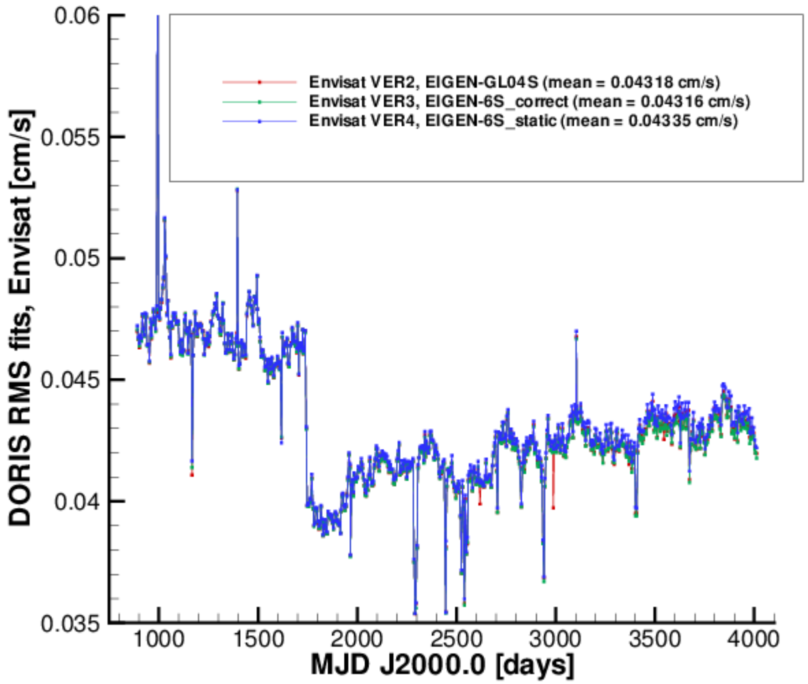
a1 = -9.01895E-12, a2= -3.47674E-11




Courtesy Jean-Michel Lemoine (GRGS/CNES)

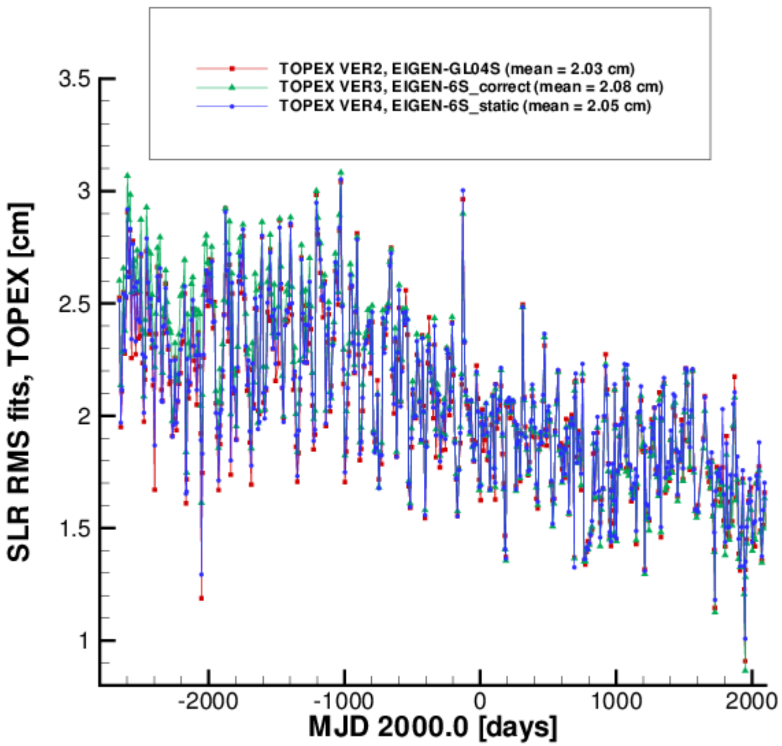
# Influence on SLR and DORIS observation RMS fits for Envisat (April 2002 – December 2010)

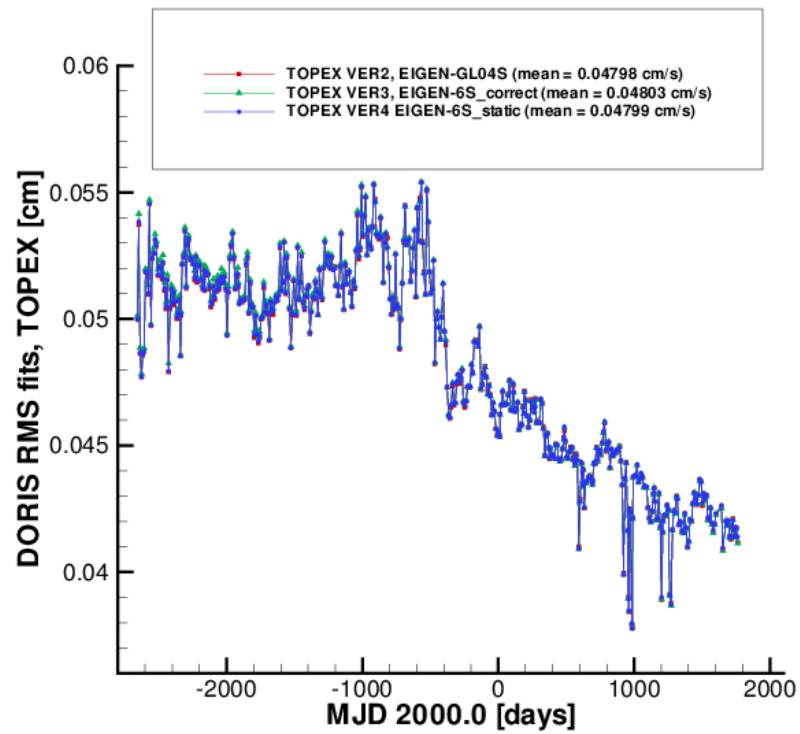



- SLR RMS fits: improvement by 0.5 mm (3.8%) from 1.33 to 1.28 cm using time-variable EIGEN-6S_correct model, as compared to EIGEN-GL04S one, especially for years 2007 – 2010;
- DORIS RMS fits: minor influence of the gravity field model used, however, time-variable EIGEN-6S_correct model brings some small improvement for years 2007 - 2010

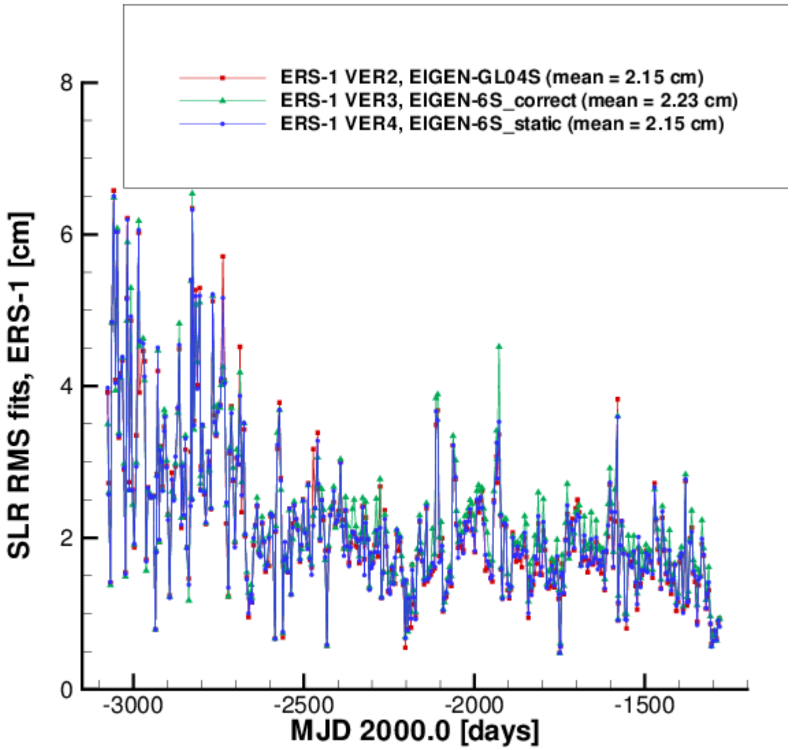
# Influence on SLR and DORIS observation RMS fits for TOPEX/Poseidon (September 1992 – October 2005)

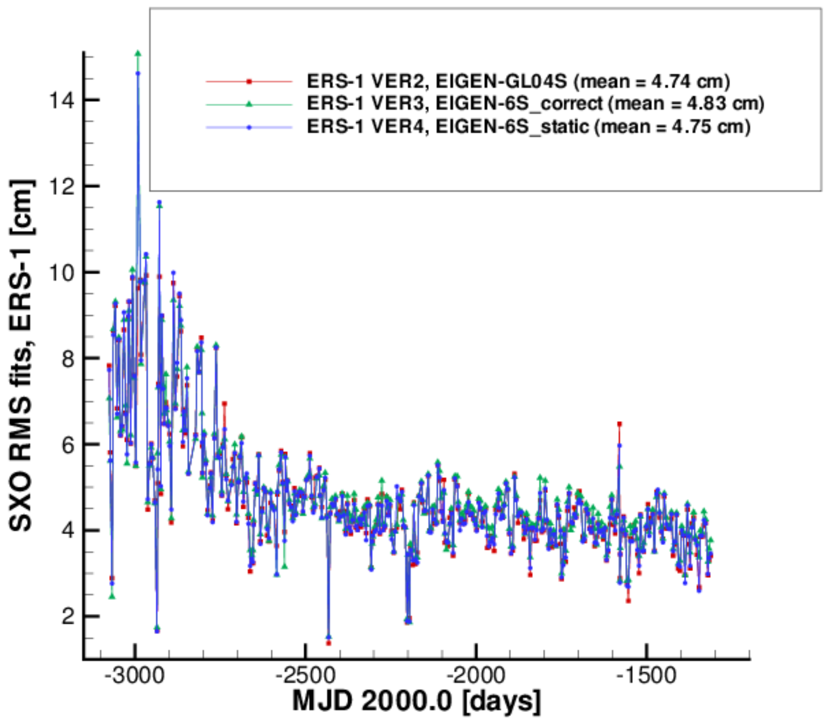



- SLR RMS fits: use of EIGEN-GL04S geopotential model gives the smallest fits, use of time-variable EIGEN-6S model leads to the increase of fits by 0.5 mm (2.5%) from 2.03 to 2.08 cm, especially for years 1992 – 1997;
- DORIS RMS fits: minor influence of the gravity field model used, however, use of time-variable EIGEN-6S model increases fits slightly (0.00005 cm/s, i.e. about 0.1%), especially for years 1992 – 1997

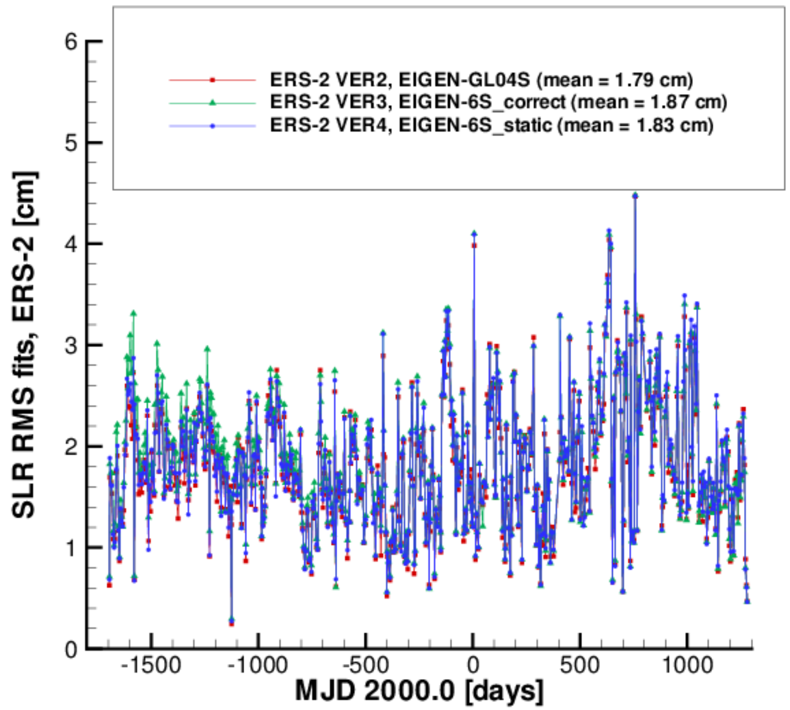
# Influence on SLR and altimeter crossover (SXO) observation RMS fits for ERS-1 (August 1991 – July 1996)

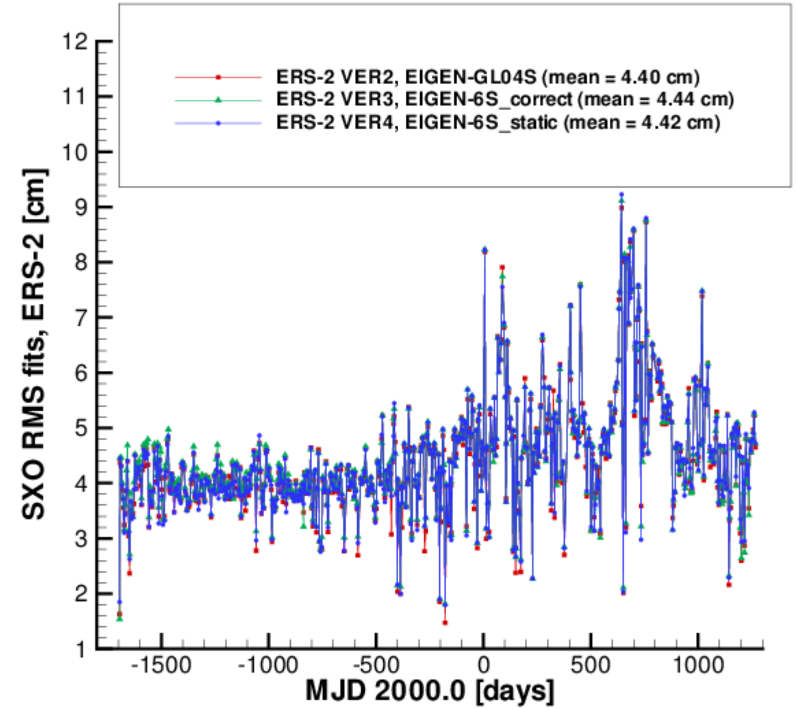



- SLR RMS fits: EIGEN-GL04S and EIGEN-6S static geopotential models perform similar, use of time-variable EIGEN-6S_correct model increases fits by 0.8 mm (3.7%) from 2.15 to 2.23 cm;
- SXO RMS fits: EIGEN-GL04S and EIGEN-6S static geopotential models perform similar, EIGEN-GL04S provide the smallest fits, use of time-variable EIGEN-6S_correct model increases fits by 0.9 mm (1.9%) from 4.74 to 4.83 cm;

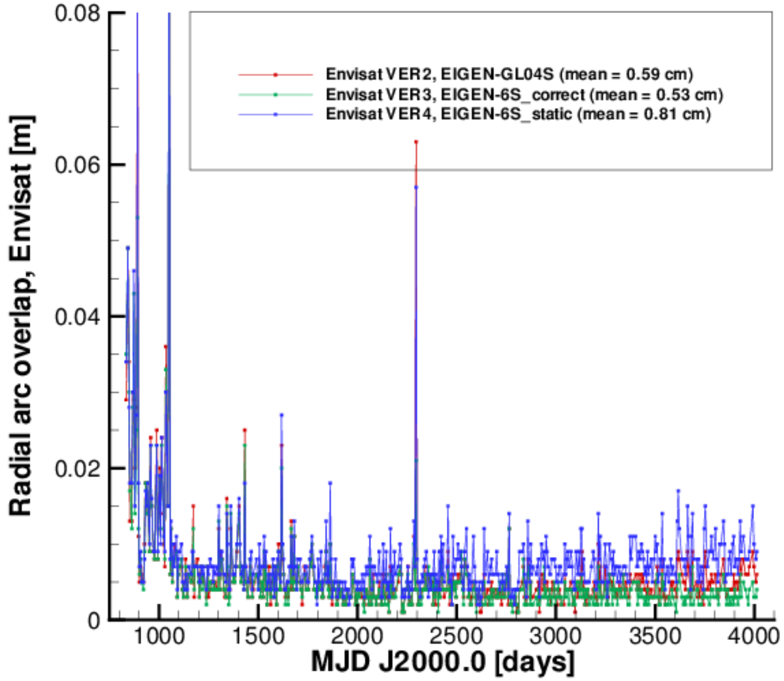
# Influence on SLR and altimeter crossover (SXO) observation RMS fits for ERS-2 (May 1995 – July 2003)

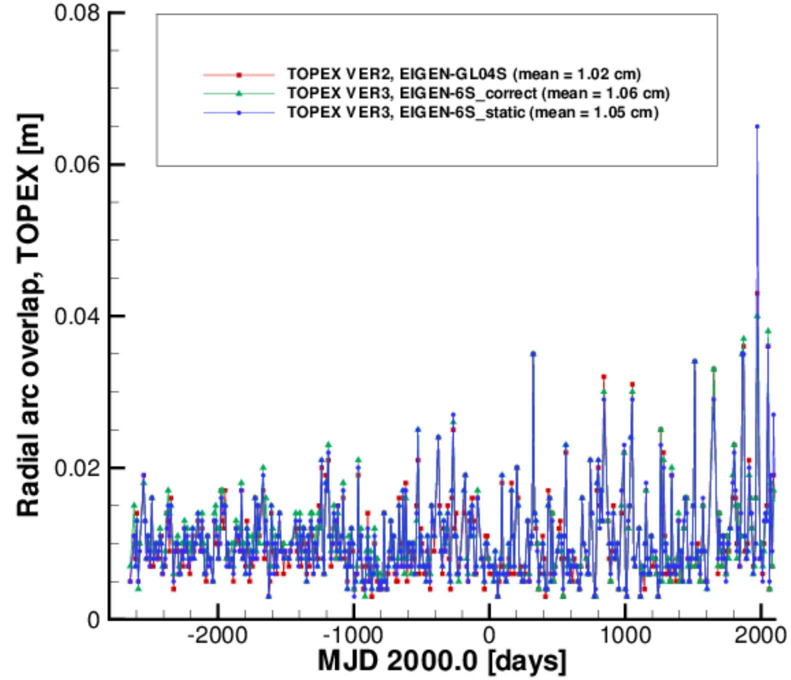



- SLR RMS fits: EIGEN-GL04S geopotential model provides the smallest fits followed by EIGEN-6S static geopotential model; use of time-variable EIGEN-6S model increases fits by 0.8 mm (4.5%) from 1.79 to 1.83 cm;
- SXO RMS fits: EIGEN-GL04S geopotential model provides the smallest fits followed by EIGEN-6S static geopotential model; use of time-variable EIGEN-6S model increases fits by 0.4 mm (0.9%) from 4.40 to 4.44 cm;

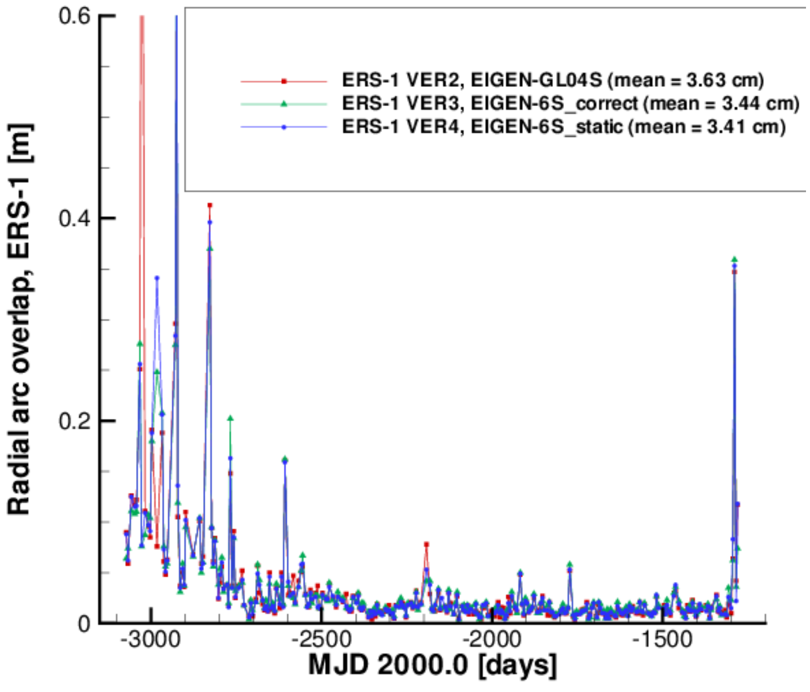
# Influence on the orbital arc radial 2-day overlaps for Envisat (April 2002 – December 2010) and TOPEX/Poseidon (September 1992 – October 2005)

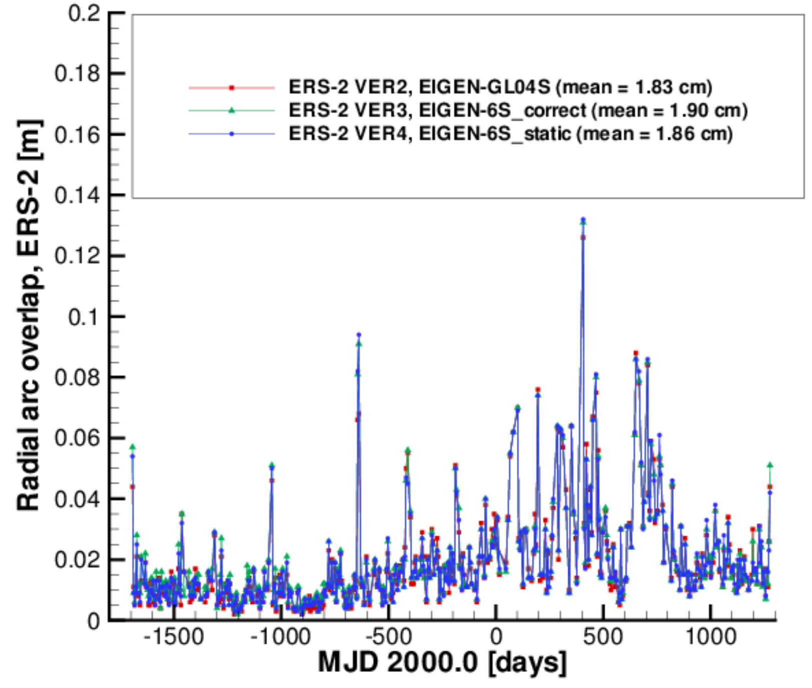



- Minor influence of the gravity field models used on the radial overlaps for TOPEX/Poseidon, however, EIGEN-GL04S model provides the smallest ones;
- More notable influence for Envisat: time-variable EIGEN-6S_correct model provides the smallest ones, while use of static EIGEN-6S model increases arc overlaps

# Influence on the orbital arc radial 2-day overlaps for ERS-1 (August 1991 – July 1996) and ERS-2 (May 1995 – July 2003)




- ERS-1: static EIGEN-6S model provides the smallest radial overlaps, followed by time-variable EIGEN-6S_correct model; orbital arcs with few observations are sensitive to the geopotential model used resulting sometimes in outliers;
- ERS-2: more stable situation, since additionally PRARE data were used; EIGEN-GL04S gives smallest overlaps, followed by the static EIGEN-6S model

# Influence on the RMS and mean of altimeter crossover differences

RMS and mean of crossover differences determined over crossovers with the time differences of less than 5 days for the orbit solutions tested

| ERS-1 orbits (from August 1, 1991 till May 30, 1996) | RMS of crossover differences [cm] | Mean of crossover differences [cm] |
|---|---|---|
| VER2 (CCI04) EIGEN-GL04S | 7.12 | 0.28 |
| VER3 (CCI10) EIGEN-6S_correct | 7.18 | 0.26 |
| VER4 (CCI12) EIGEN-6S_static (2000.0) | 7.15 | 0.28 |

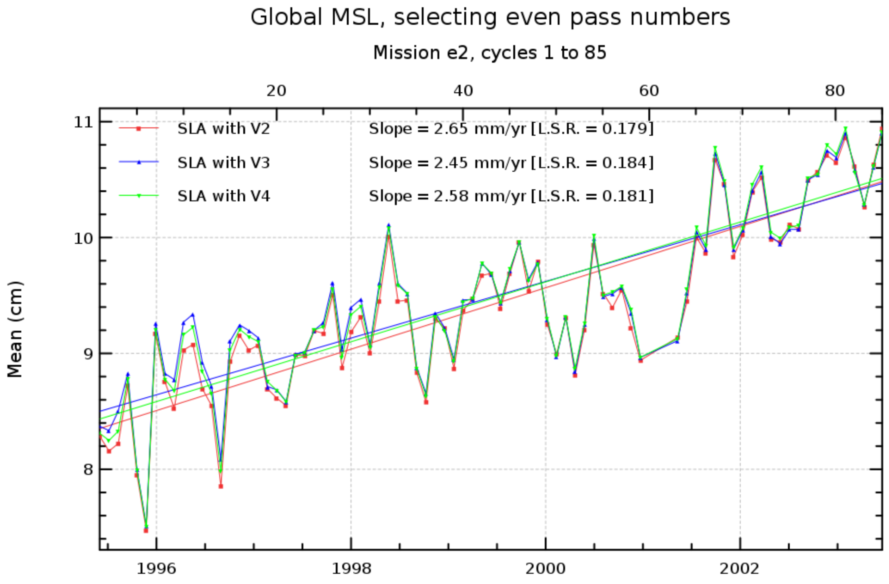
| ERS-2 orbits (from May 15, 1995 till June 16, 2003) | RMS of crossover differences [cm] | Mean of crossover differences [cm] |
|---|---|---|
| VER2 (CCI04) EIGEN-GL04S | 6.51 | 0.04 |
| VER3 (CCI10) EIGEN-6S_correct | 6.53 | 0.02 |
| VER4 (CCI12) EIGEN-6S_static (2000.0) | 6.53 | 0.03 |

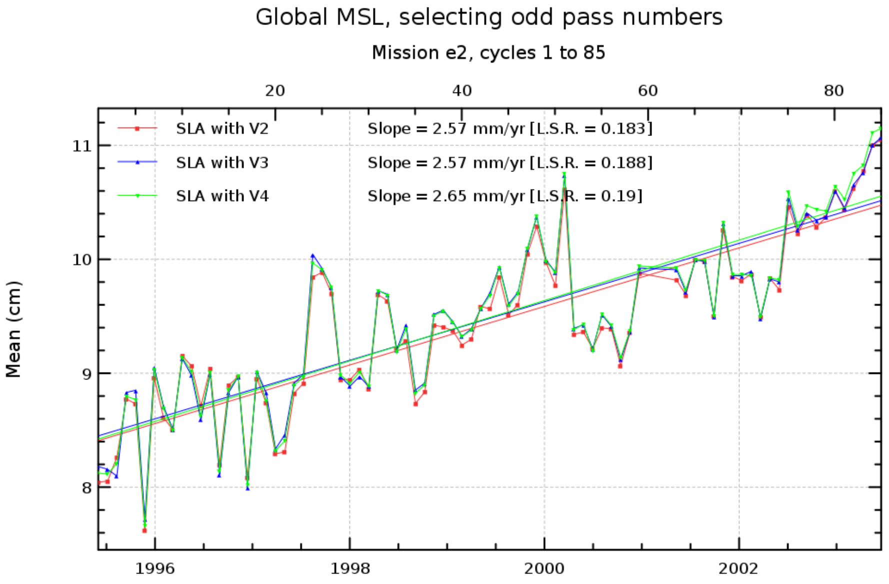
| Envisat orbits (from May 14, 2002 till December 28, 2010) | RMS of crossover differences [cm] | Mean of crossover differences [cm] |
|---|---|---|
| VER2 (CCI07) EIGEN-GL04S | 5.97 | 0.41 |
| VER3 (CCI11) EIGEN-6S_correct | 5.94 | 0.38 |
| VER4 (CCI12) EIGEN-6S_static (2000.0) | 5.99 | 0.48 |

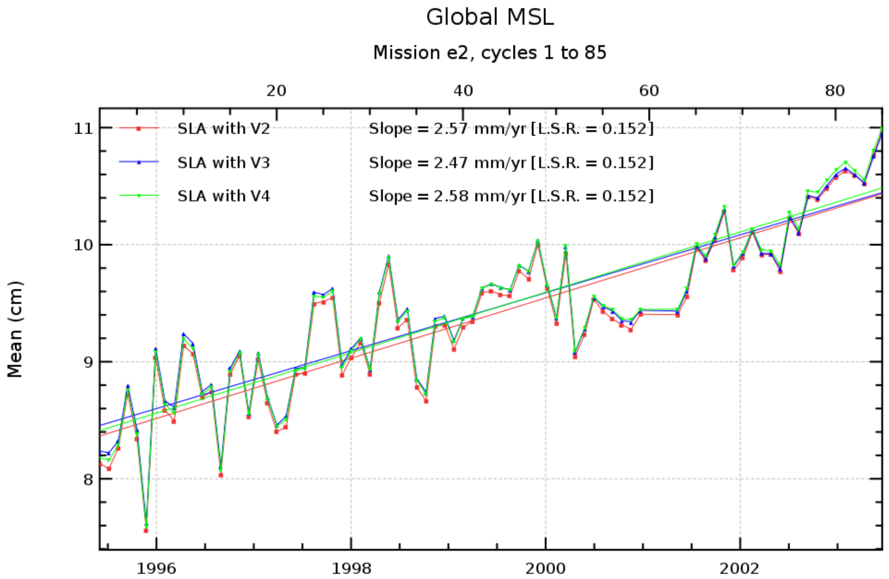
| TOPEX/Poseidon orbits (from April 9, 1993 till September 30, 2005) | RMS of crossover differences [cm] | Mean of crossover differences [cm] |
|---|---|---|
| VER2 (CCI01) EIGEN-GL04S | 5.32 | -0.34 |
| VER3 (CCI02) EIGEN-6S_correct | 5.35 | -0.09 |
| VER4 (CCI03) EIGEN-6S_static (2000.0) | 5.35 | -0.07 |

Rather small influence of these gravity field models on the mean values of RMS of crossover differences. However, ERS-1, ERS-2 and TOPEX/Poseidon orbits based on EIGEN-GL04S model give smallest RMS, while for Envisat the orbit based on the time-variable EIGEN-6S_correct model performs better

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

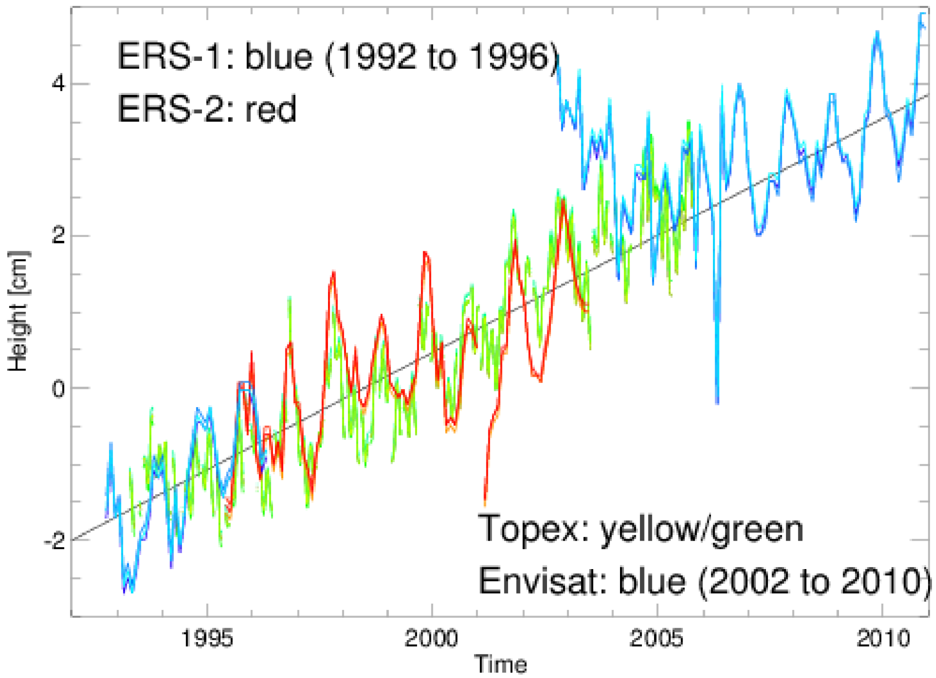



- Rather small (below 0.1 mm/yr) influence on the global MSL trend,
- The MSL trend values computed using ascending and descending parts of the orbits are homogenous (differences below 0.1-0.2 mm/yr)
- No impact on annual and semi-annual signals was detected

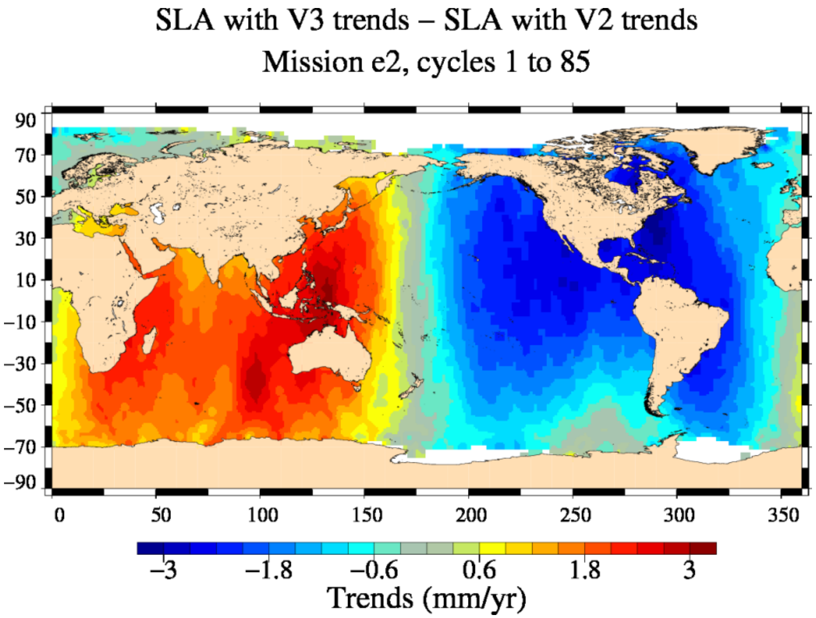
# Impact on the global Mean Sea Level (MSL) for all four satellites

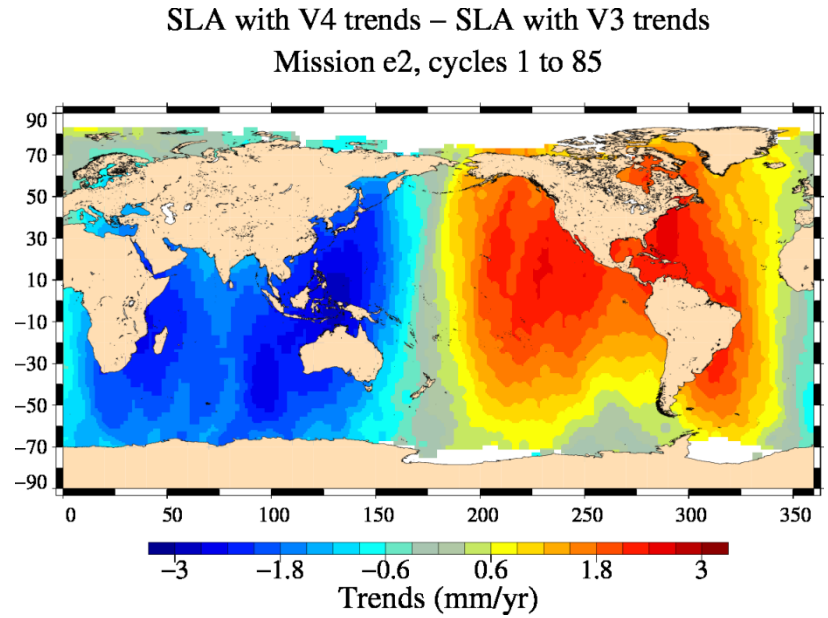


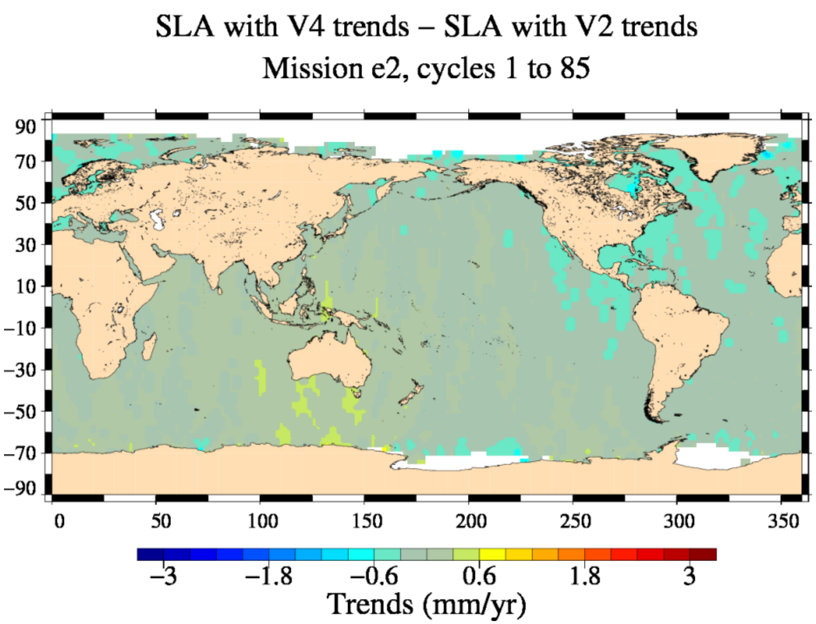

- Global MSL trends and their formal errors (mm/yr) computed using ERS-1, ERS-2, Envisat and TOPEX orbits derived various geopotential models are shown in the table below
- Rather small (0.1-0.2 mm/yr) influence of the geopotential models used on the global MSL trend for all four satellites
- Orbits based on EIGEN-6S_correct model seem to give 0.1 mm/yr smaller global MSL trend then others

| Earth gravity field model | ERS-1 | ERS-2 | TOPEX | Envisat | Four satellites |
|---|---|---|---|---|---|
| EIGEN-GL04S | 5.4 ± 0.4 | 2.5 ± 0.2 | 3.4 ± 0.1 | 1.0 ± 0.3 | 3.2 ± 0.3 |
| EIGEN-6S_correct | 5.2 ± 0.5 | 2.3 ± 0.3 | 3.5 ± 0.1 | 0.8 ± 0.3 | 3.1 ± 0.3 |
| EIGEN-6S_static | 5.3 ± 0.5 | 2.5 ± 0.3 | 3.4 ± 0.1 | 1.0 ± 0.3 | 3.2 ± 0.3 |

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




- Regional MSL trends computed using V3 orbit based on time-variable 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
- Regional MSL trends computed using V2 and V4 orbits based on static gravity field models are homogenous

# Conclusions

- Influence of EIGEN-GL04S, time-variable EIGEN-6S_correct and a static version EIGEN-6S_static (at epoch 2000.0) geopotential models on precise orbits of Envisat, TOPEX/Poseidon, ERS-1 and ERS-2 and mean sea level trend computed using these orbits was studied
- Time-variable EIGEN-6S_correct geopotential model brings improvement for Envisat orbit (2002-2010)
- EIGEN-GL04S and in some cases EIGEN-6S static (at epoch 2000.0) geopotential models perform better for ERS-1 (1991-1996), ERS-2 (1995-2003) and TOPEX/Poseidon (1992-2005) orbits at the time intervals given
- It seems, that some drift terms of degree and order 2-50 of the EIGEN-6S geopotential model determined using GRACE data at the time interval 2003-2008 might cause an error, when to be used outside this time interval
- Rather small (0.1-0.2 mm/yr) influence of the geopotential models tested on the global mean sea level trend for all four satellites was found
- Strong East/West differences (up to 3 mm/yr) were found in the regional mean sea level trends, while using time-variable EIGEN-6S_correct geopotential model, as compared to EIGEN-GL04S and EIGEN-6S_static ones
- Further improvement of time-variable geopotential models at the time span from 1991 till 2003 is still desirable

## Acknowledgements

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Thank you for your attention!