LAGEOS based Earth system parameter determination and GRACE

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LAGEOS-1 / -2

- NASA / NASA/ASI mission
- LAGEOS = Laser GEOdynamics Satellite
- GFZ is ILRS Analysis Center
- Mission parameters:
  - Launch 04-MAY-1976 / 22-OCT-1992
  - Altitude 5,900 km
  - Inclination 109.8° / 52.6°
  - Nearly circular
  - Lifetime 50 years nominal

Courtesy NASA

Original Motivation to do LAGEOS

- GFZ's position and EOP solutions from LAGEOS-1/-2

  > AC contribution to ILRS pos&eop daily and weekly products

  > ILRS intra-technique combination

  > inter-technique combination for ITRF2008

  > re-processing done for the period since 1983

- Adopt up-to-date GRACE standards (..., AOD, …)
- Solve for the low degree harmonics
  - Direct comparison with GRACE results
  - Rigorous combination with GRACE
  - Long-term meteorological/hydrological analysis
  - Long-term background model analysis
  - Reference frame analysis

Models and Data

- 15-d arcs from LAGEOS-1 for JAN 1983 to DEC 1992
- Weekly arcs from LAGEOS-1 and -2 for JAN 1993 to DEC 2006
- GRACE RL04 standards
  - EIGEN-GL04C
  - AOD1B
  - Ocean tides FES2004
  - Atmospheric tides Bode&Biancale2003
  - Ocean tide loading (Bos&Scherneck web site)
- Parameters (1m a priori σ)
  - Station coordinates and velocities per 15-d / 7-d
  - EOPs (polar motion, LOD) per 1-d
  - Global gravity field coefficients degree 0 - 10
  - Selected ocean tide waves
  - Geocenter bias per 1-a, 1/a, 2/a

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Atmosphere and Ocean Dealiasing

- AOD products cover the non-tidal atmospheric and oceanic mass variations

- Invented for GRACE, available now back to 1976 from

  http://isdc.gfz-potsdam.de

- 1976 to 2001 OMCT based on ERA-40 (ECMWF reanalysis over 40 a)
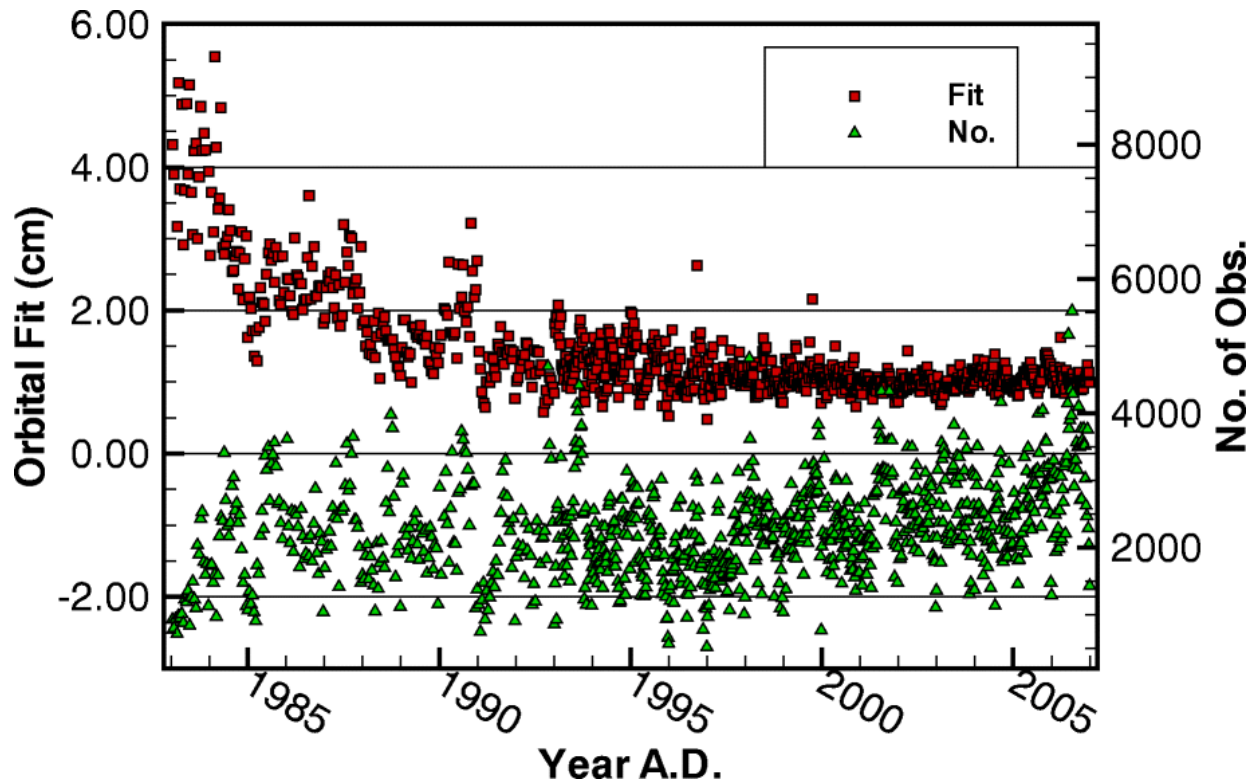
- 2001 to date OMCT based on ECMWF operational data

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Atmosphere and Ocean Dealiasing

- Impact on LAGEOS derived C_{20}
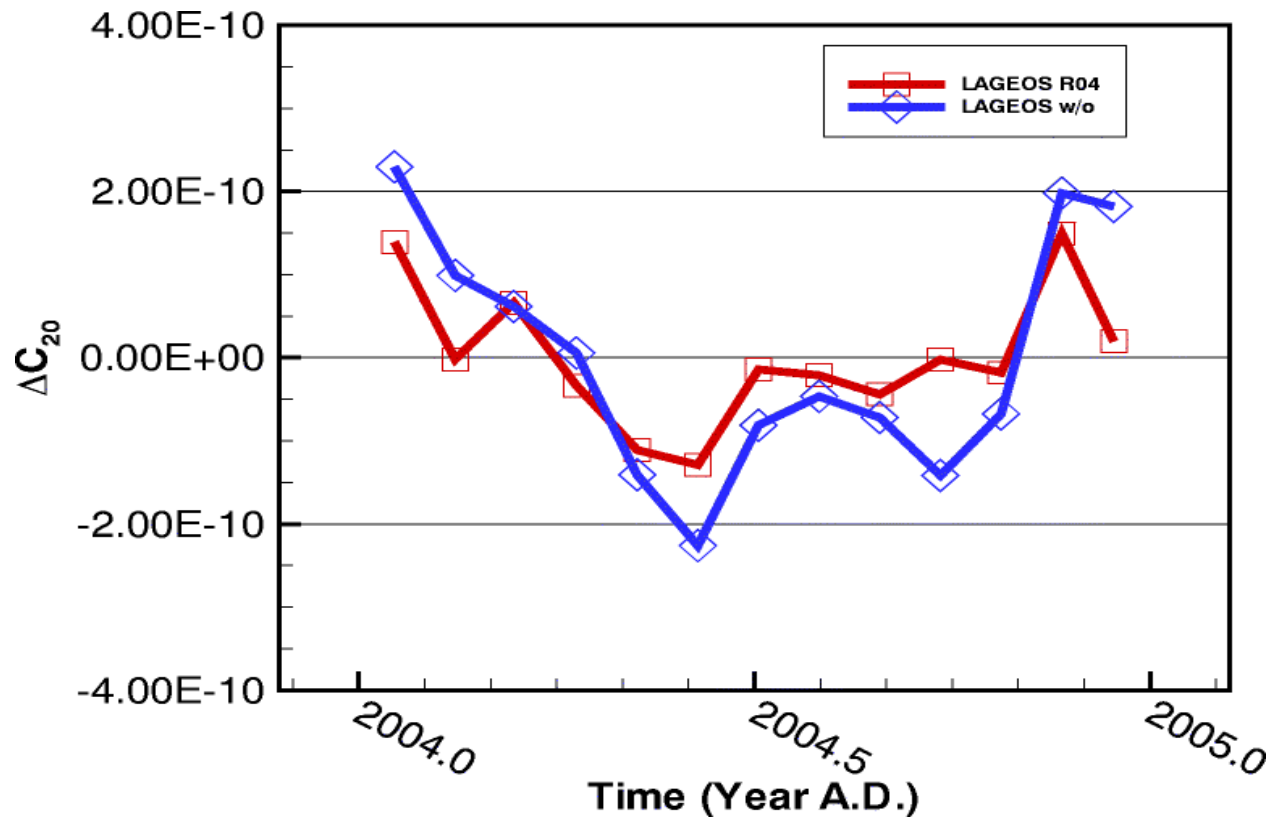
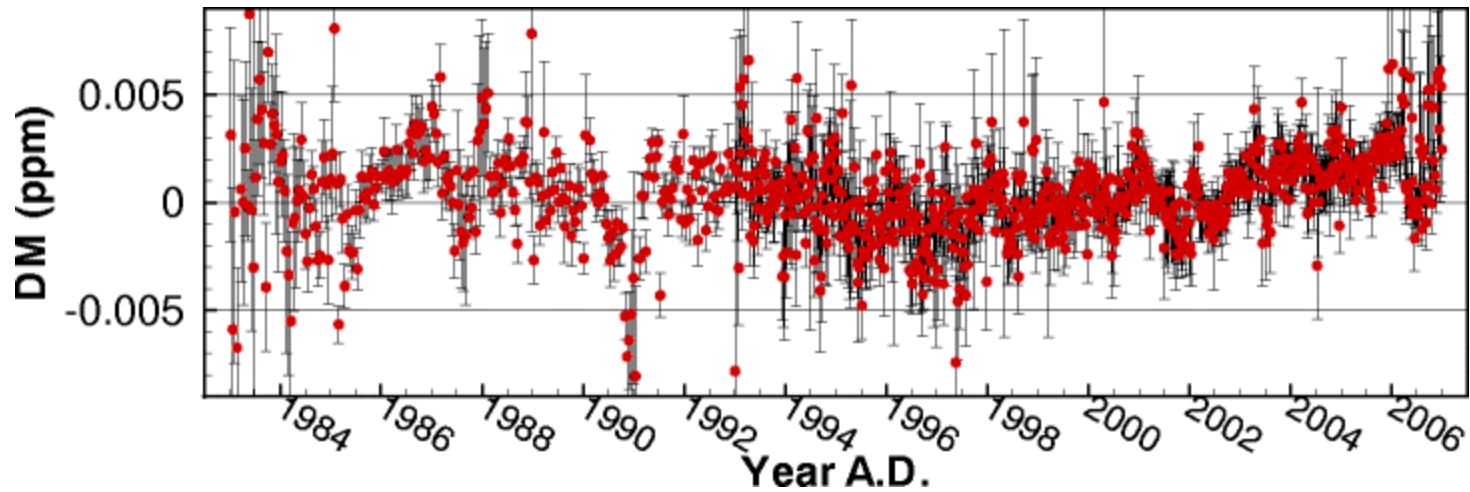# Reference Frame Solution

- Orbital fit
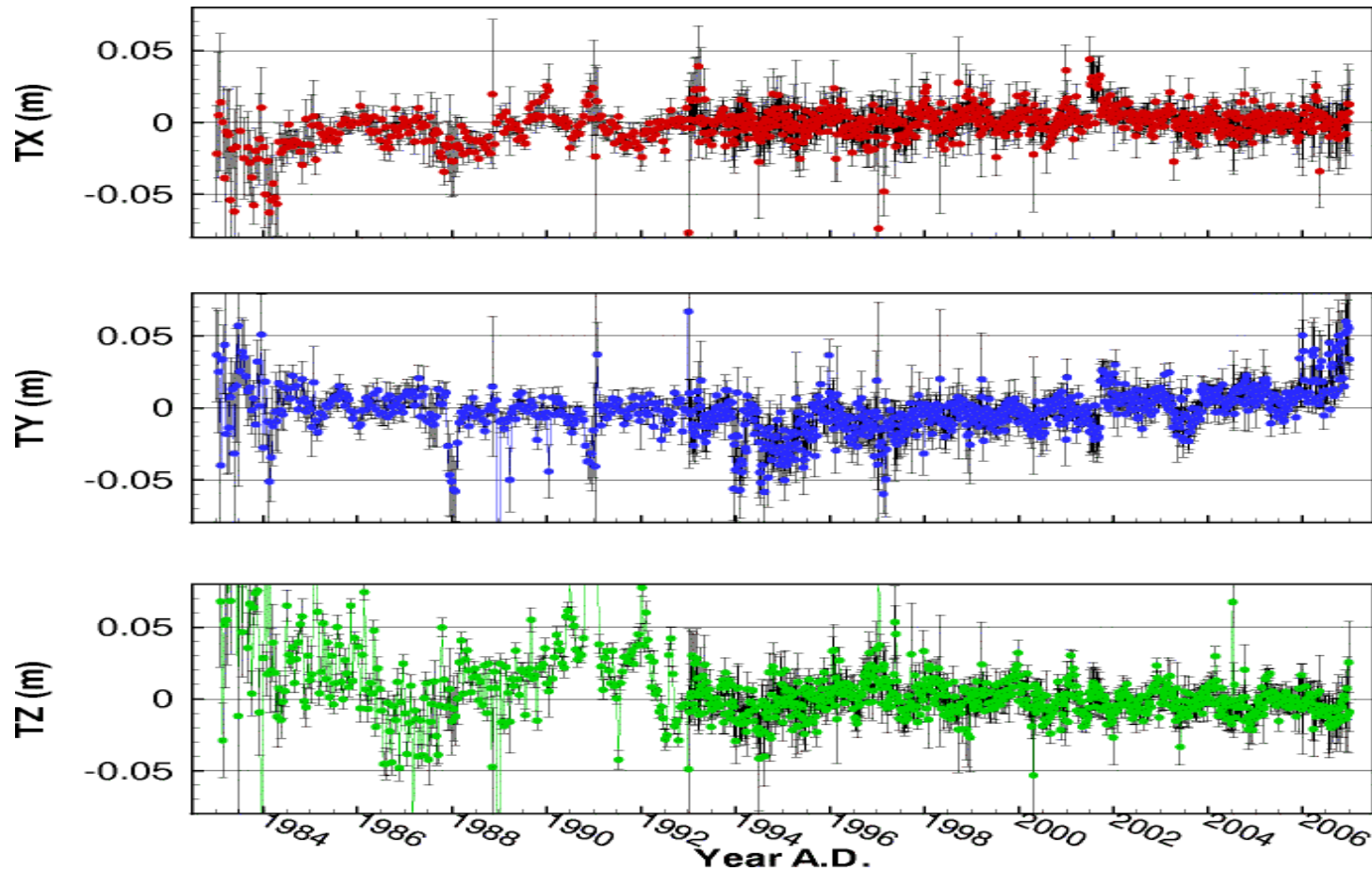 - Overall RMS 1.1 cm for 1,731,008 observations since 1993

Reference Frame Solution

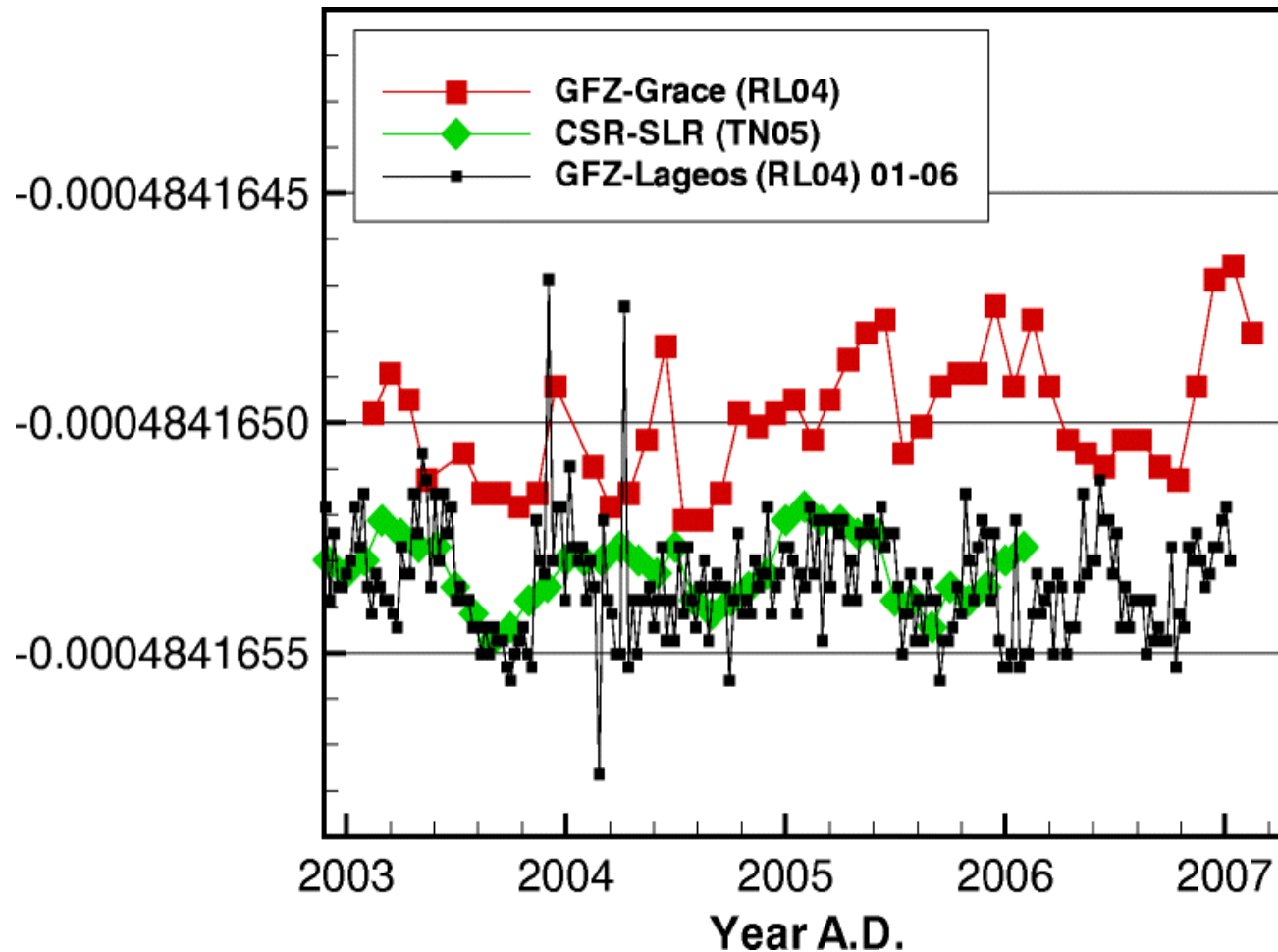- Scale vs. SLRF2005
  - Overall RMS 2.2 ppb

Reference Frame Solution

- Translation vs. SLRF2005
   - Overall RMS 1.6 / 1.8 / 3.1 cm in X, Y, Z

Earth Oblateness C_{20}

- Bias between LAGEOS and GRACE

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1st Int. LARES Science Workshop, Rome, Italy, 3-4 July 2009

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GRACE

- NASA/DLR gravity mission
- GRACE = Gravity Recovery And Climate Experiment
- GFZ is part of the SDS (Science Data System)
- Mission parameters:
  - Launch 17-MAR-2002
  - Altitude 500 km
  - Inclination 89.0°
  - Nearly circular
  - Lifetime 5 years nominal

Courtesy Astrium
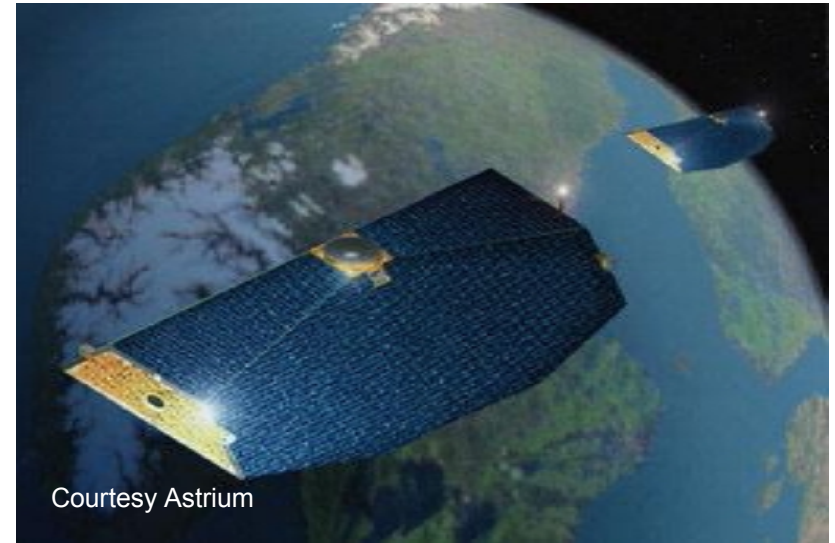
Evolution of GFZ's EIGEN-GRACE0xS Series

- EIGEN = European Improved Gravity field of the Earth by New techniques
  - 0x = solution number
  - S = Satellite-only solutions

- Statistics:

|	Mean	Time-variable (monthly/weekly sol.)
EIGEN-GRACE01S	39 days	
EIGEN-GRACE02S	110 days	9 (04/2002-11/2003) / none
EIGEN-GRACE03S	376 days	16 (02/2003-07/2004) / none
EIGEN-GRACE04S	430 days	46 (02/2003-12/2006) / none
EIGEN-GRACE05S	4 years	73 (08/2002-03/2009) / 281

Evolution of GFZ's EIGEN-GRACE0xS Series

- Statistics cont'd

	Arc length [d]	AOD1B	GPS-Amb. Ground
EIGEN-GRACE01S	1.5	ECMWF, PPHA	real
EIGEN-GRACE02S	1.5	ECMWF, PPHA	real
EIGEN-GRACE03S	1.5	ECMWF, PPHA	real
EIGEN-GRACE04S	1.0	ECMWF, OMCT	integer
EIGEN-GRACE05S	1.0	ECMWF, OMCT	integer

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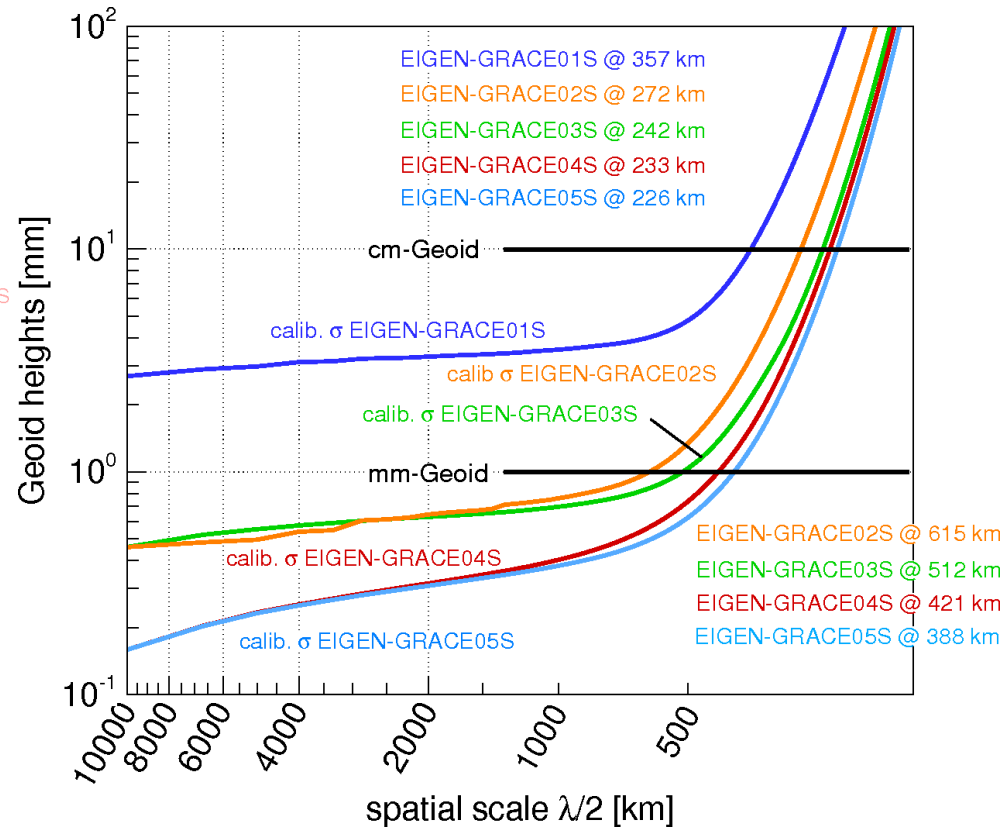Helmholtz Centre
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EIGEN-GRACE0xS

- Gain in spectral accuracy


Degree Variances
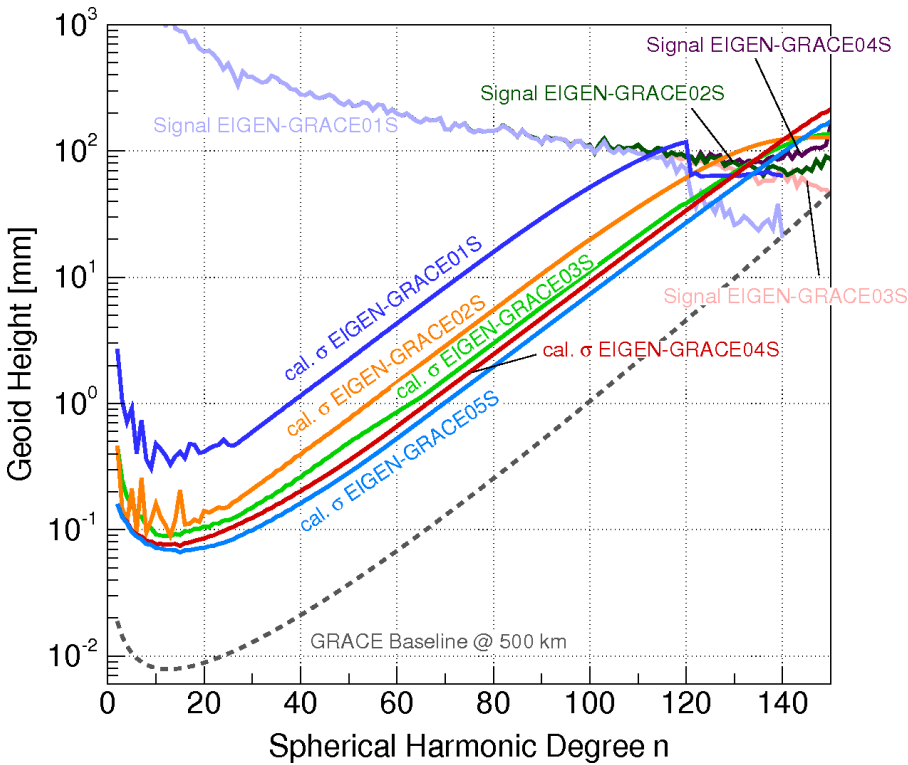
Accumulated Error

EIGEN-GRACE0xS

- Further planning towards EIGEN-GRACE06S
  - Improved pre-processing of level-1B data (less loss of data, …)
  - Improved GPS constellation (absolute phase center corrections, phase wind-up, shadow crossing, noon-turns, attitude model, …)
  - Improved GPS antennae phase corrections masks
  - Shorter GRACE arc length (6h)
  - EIGEN05C as background model
  - Improved ocean tide model EOT08a: empirical corrections to FES2004
  - Usage of trend of annnual and semi-annual variations derived from EIGEN-GRACE05S
  - ….

EIGEN-GRACE06S

- **Improved pre-processing of level-1B data**
    - Large impact at low degrees
    - Errors improve towards baseline
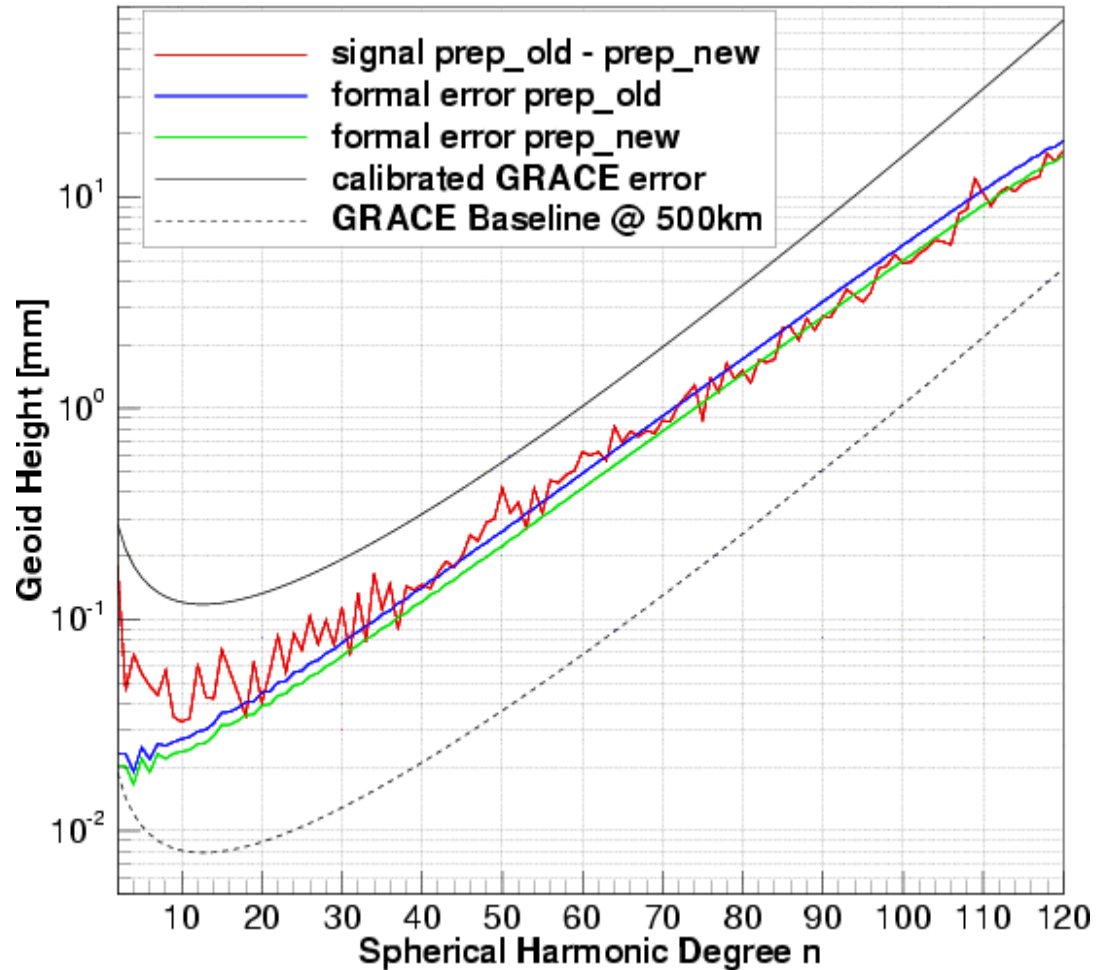
EIGEN Combinations

- Outcome of a long-time cooperation between GFZ and GRGS Toulouse

- Spherical harmonic coefficients up to degree/order 360 (~50 km resolution)

- Satellite data:
  - Evaluation of satellite orbit perturbations (SLR from ground, GPS on-board)
  - Inter-satellite range and range-rate observations
  - Gradiometry

- Surface data:
  - Ground gravity measurements (land, ship, airborne)
  - Geoid height measurements (satellite altimetry)

- Combination of satellite data and satellite and surface data on the normal equation level

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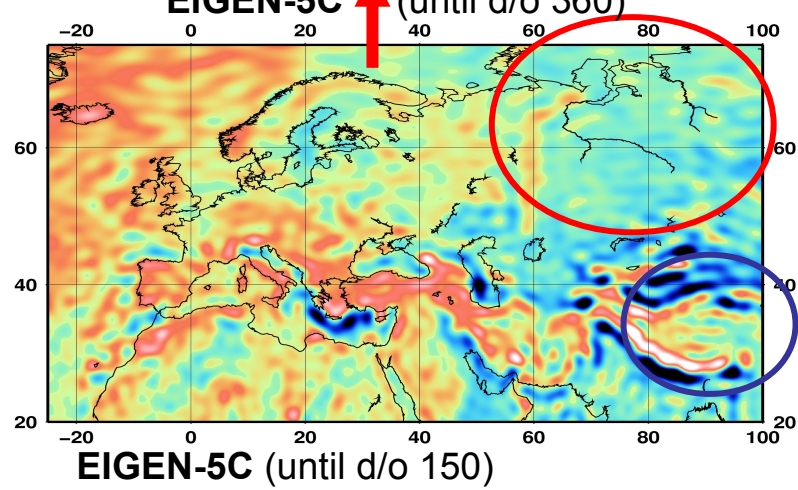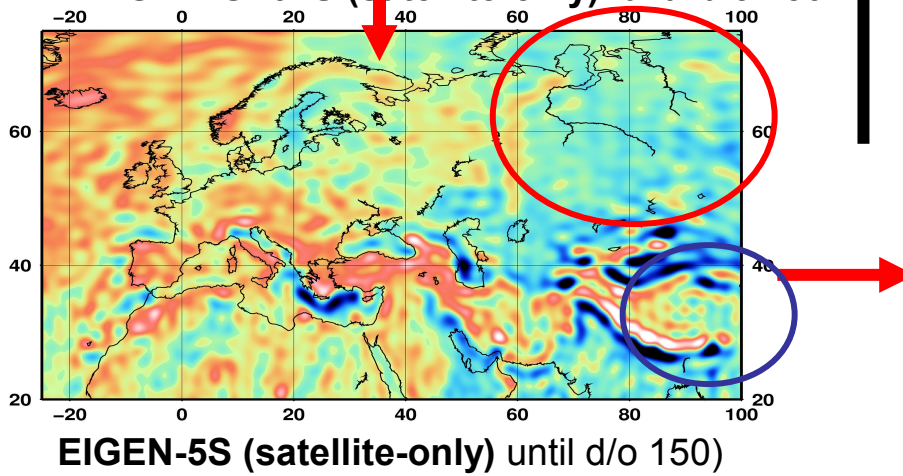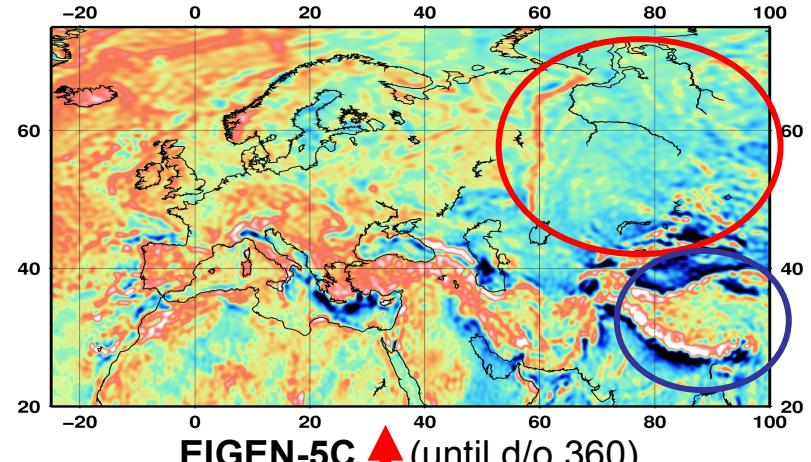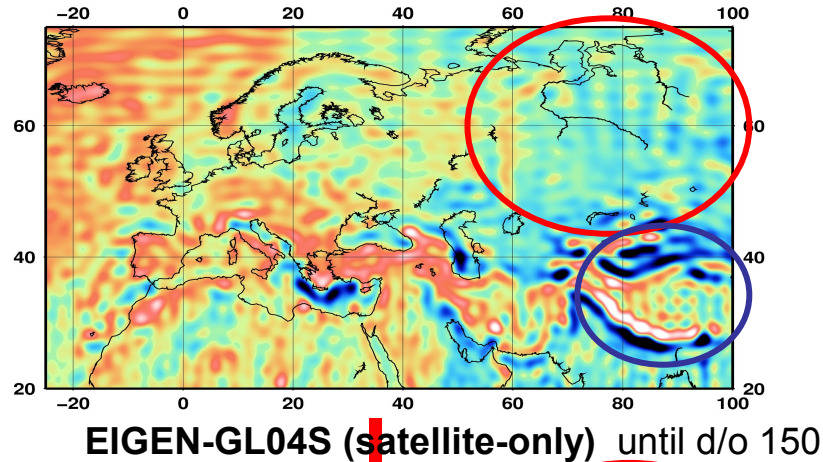Helmholtz Centre
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EIGEN Combinations

- EIGEN-GL04C (2006)
  - GL = GRACE + LAGEOS
  - 0x = solution number
  - C = Combination

- EIGEN-5C (= EIGEN-GL05C) (2008)

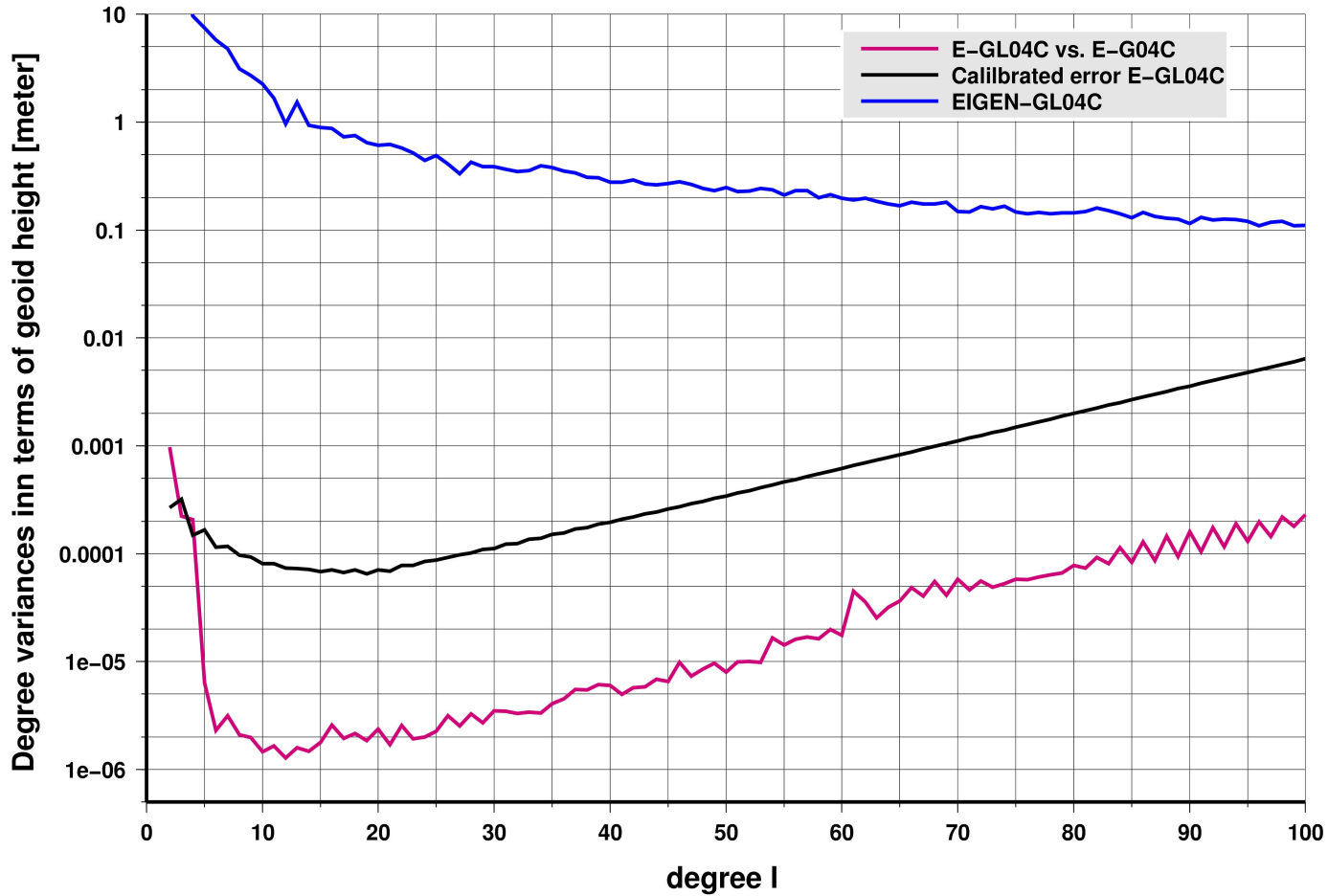|	EIGEN-GL04C	EIGEN-5C
LAGEOS	24 months 2/2003 - 2/2005	72 months 01/2001 - 12/2006
GRACE	30 months 2/2003 - 7/2005	54 months 8/2002 - 1/2007
Surface	- Various gravity anomaly sets for the continents and the North Polar region, 30'x30'. - Altimetry geoid undulations over the oceans, 2'x2'	

EIGEN Improvement

- From EIGEN-GL04 to EIGEN-5

EIGEN-GL04S (satellite-only) until d/o 150

EIGEN-5S (satellite-only) until d/o 150)

EIGEN-5C (until d/o 360)

EIGEN-5C (until d/o 150)

Gravity anomaly mGal

−140 −120 −100 −80 −60 −40 −20 0 20 40 60 80 100 120 140

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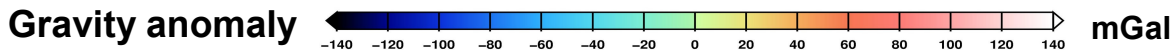
EIGEN-GL

- Impact of LAGEOS

Degree variances EIGEN–G04C (without LAGEOS) vs. EIGEN–GL04C

GOCE

- ESA gravity mission
- GOCE = Gravity field and steady-state Ocean Circulation Explorer
- GFZ is part of the HPF (High level Processing Facility)
- Mission parameters:
  - Launch 17-MAR-2009
  - Altitude 270 km
  - Inclination 96.5° (sun-synchronous)
  - Nearly circular
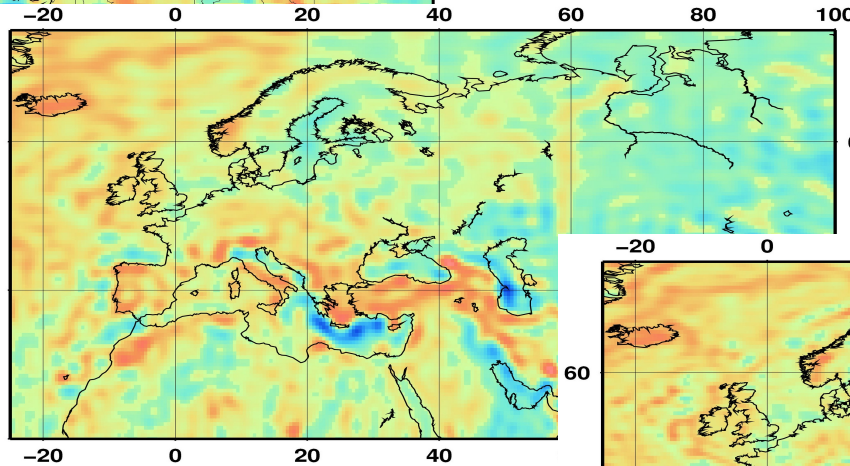 - Lifetime 18 months

Courtesy ESA

Impact of GOCE

Enhancement of the spatial resolution in <u>satellite-only</u> Earth gravity field models
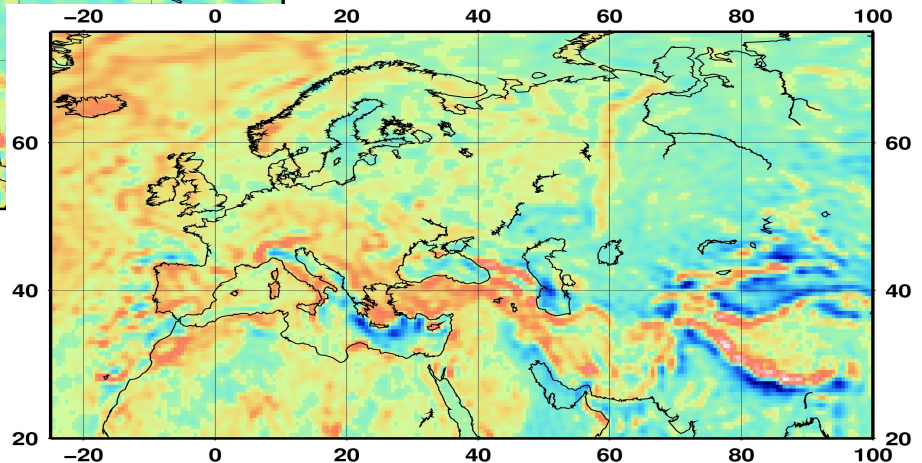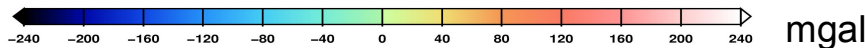
Example: Gravity anomalies for Europe
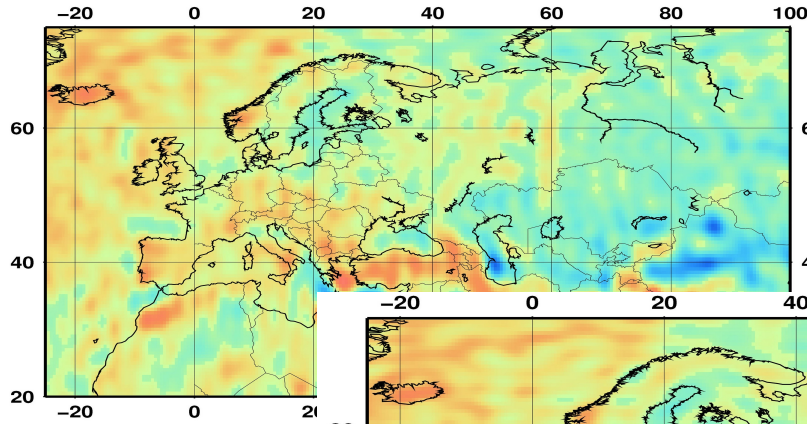
CHAMP (6 years, 2002…2008, EIGEN-CHAMP05S)
Gravity field estimation from orbit perturbations
Spatial resolution ~ 300 km

GRACE (6 years, 2002…2008
EIGEN-GRACE05S)
Orbit perturbations + K-band measurements
Spatial resolution ~ 150 km

Expected resolution for GOCE:
Gradiometry (+ orbit perturbations)
~ 80 km

mgal

−240 −200 −160 −120 −80 −40 0 40 80 120 160 200 240

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Conclusions

- LAGEOS data since 1983 have been processed with GRACE RL04 standards, measurement model according ILRS AWG
  - 25 year long reference frame solution for geocenter and scale
- EIGEN GRACE-only gravity models
  - Improvements towards baseline scheduled with RL06 (also C_{20})
  - Better de-correlation of the lower degrees
- EIGEN combination models
  - LAGEOS impact on degrees 2 to 4
  - Probably not much to expected from GOCE to the lower degrees

Acknowledgement