The contribution of Satellite Laser Ranging to the very long wavelengths of combined gravity field models

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Why SLR?

- long time series are available
- the spherical shape of geodetic satellites makes the modeling of non-gravitational forces easier
- implications of the satellites' high altitude
  - low atmospheric influence
  - sensititity of geodetic satellites to the Earth's gravity field is limited to the long wavelengths (i.e., low degrees) → advantageous for the separation of coefficients
  - largest orbit perturbation is caused by the Earth's oblateness, i.e., the C_{20} term
- degree-2 terms can not be accurately determined with space gravimetry
- satellite gravimetry is insensitive to geocenter motion

Principle of parameter estimation

- software tools used for orbit determination and parameter estimation: GEODYN II, SOLVE

least-squares adjustment according to $\hat{x} = (A^T P A)^{-1} A P^T y$

- satellite state vector at initial epoch and perturbing forces → computed range (ϱ_c)
- 2-way time-of-flight measurement → observed range (ϱ_o)
- vector of observations: $y = \varrho_c - \varrho_o$
- vector of unknown parameters (x)
  - arc parameters (e.g. state vector, atmospheric drag coefficient)
  - global parameters (e.g. geopotential coefficients, station coordinates)
- design matrix A contains the partial derivatives of y with respect to x

Satellite data (1)

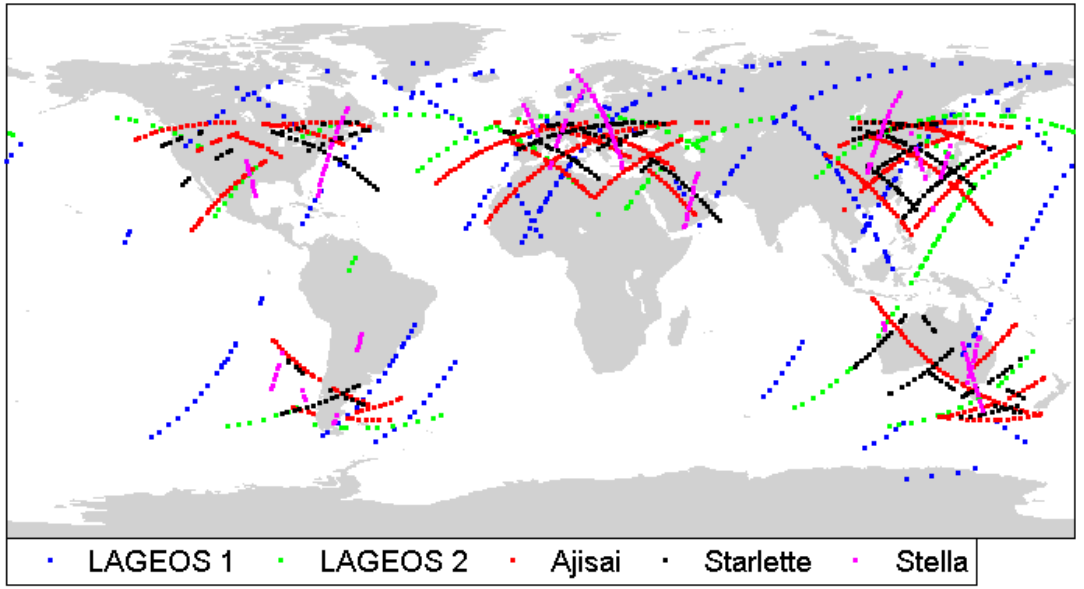
- considered satellites and some of their characteristics:

	LAGEOS 1	LAGEOS 2	Ajisai	Starlette	Stella
Launch date	1976	1992	1986	1975	1993
Inclination [°]	110	53	50	50	99
Altitude [km]	5850	5625	1485	800	815

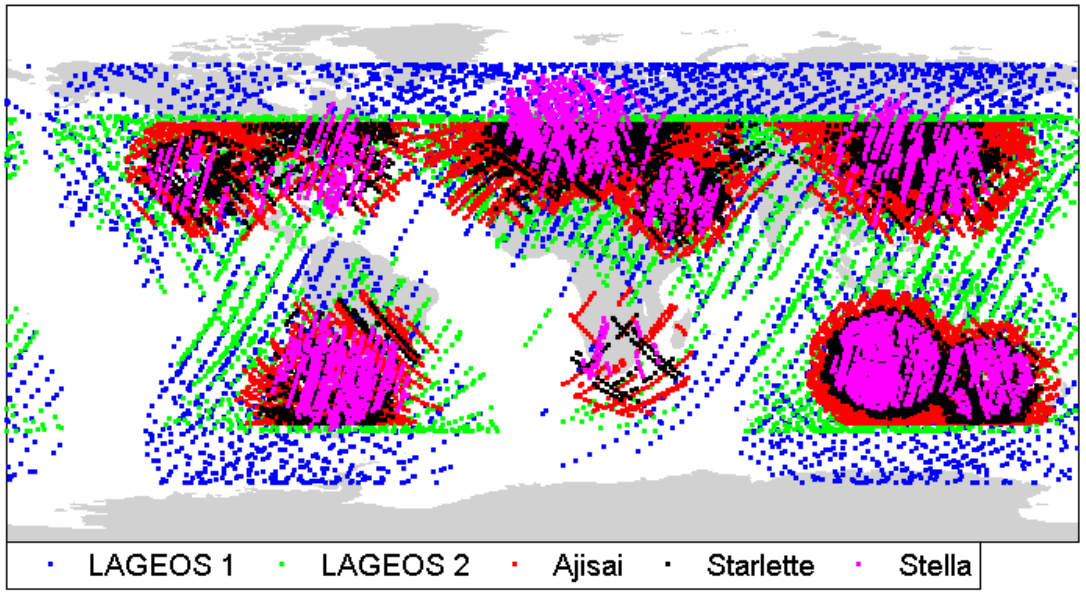
- the same satellites are used for simulation studies and real data analysis BUT the investigation period varies
  - period for simulation studies: Jan 2007 to Dec 2007 (1 year)
  - period for real data analysis: Jan 2006 to Dec 2010 (5 years)

Satellite data (2)

- 1-day spatial coverage



- 30-day spatial coverage

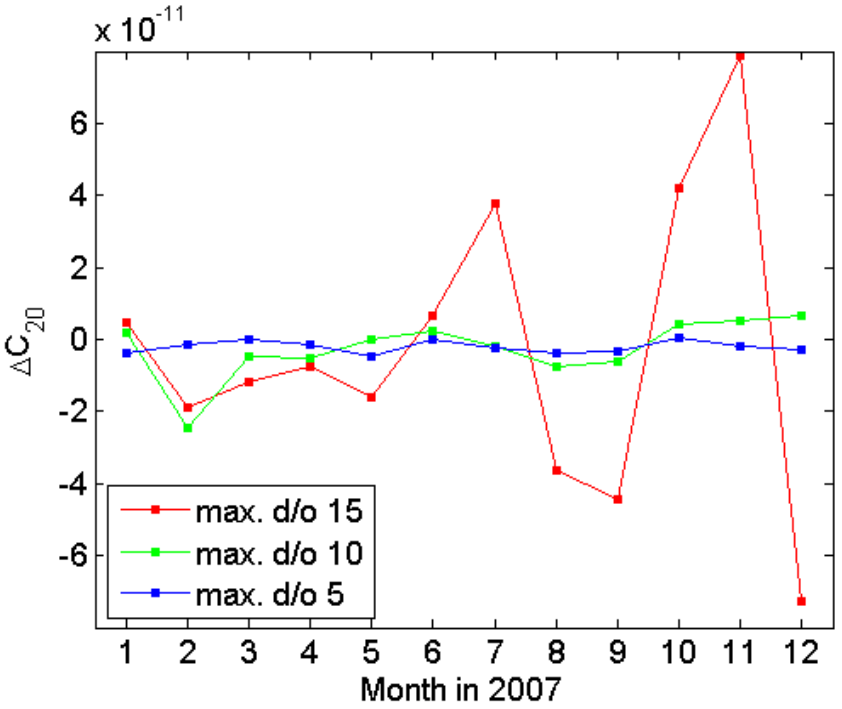


Simulation setup

- question to be answered: ‚Up to which degree and order (d/o) can gravity field coefficients be estimated from monthly data sets?‘
- simulation of 2-way ranges
  - to five satellites
  - from stations that provided real data in 2007
  - number of simulated ranges per month: 5000 to LAGEOS 1 and LAGEOS 2, 10000 to Ajisai, 3000 to Stella, and 6000 to Starlette
  - Gaussian noise used as station-specific error model
- estimation of monthly sets of spherical harmonic coefficients up to d/o 5, d/o 10, and d/o 15
- no time-variable effects were simulated → monthly sets should be
  - identical and
  - the differences between estimated coefficients and ‚true‘ coefficients should be zero

Simulation results

- differences between estimated and ‚true' gravity field coefficients:



- estimating coefficients up to d/o 10 and d/o 15 results in exceedingly ill-posed normal equation systems → set maximum d/o to 5

Real data analysis setup

- one normal equation system (NES) per satellite and month has been generated by adopting GOCE standards

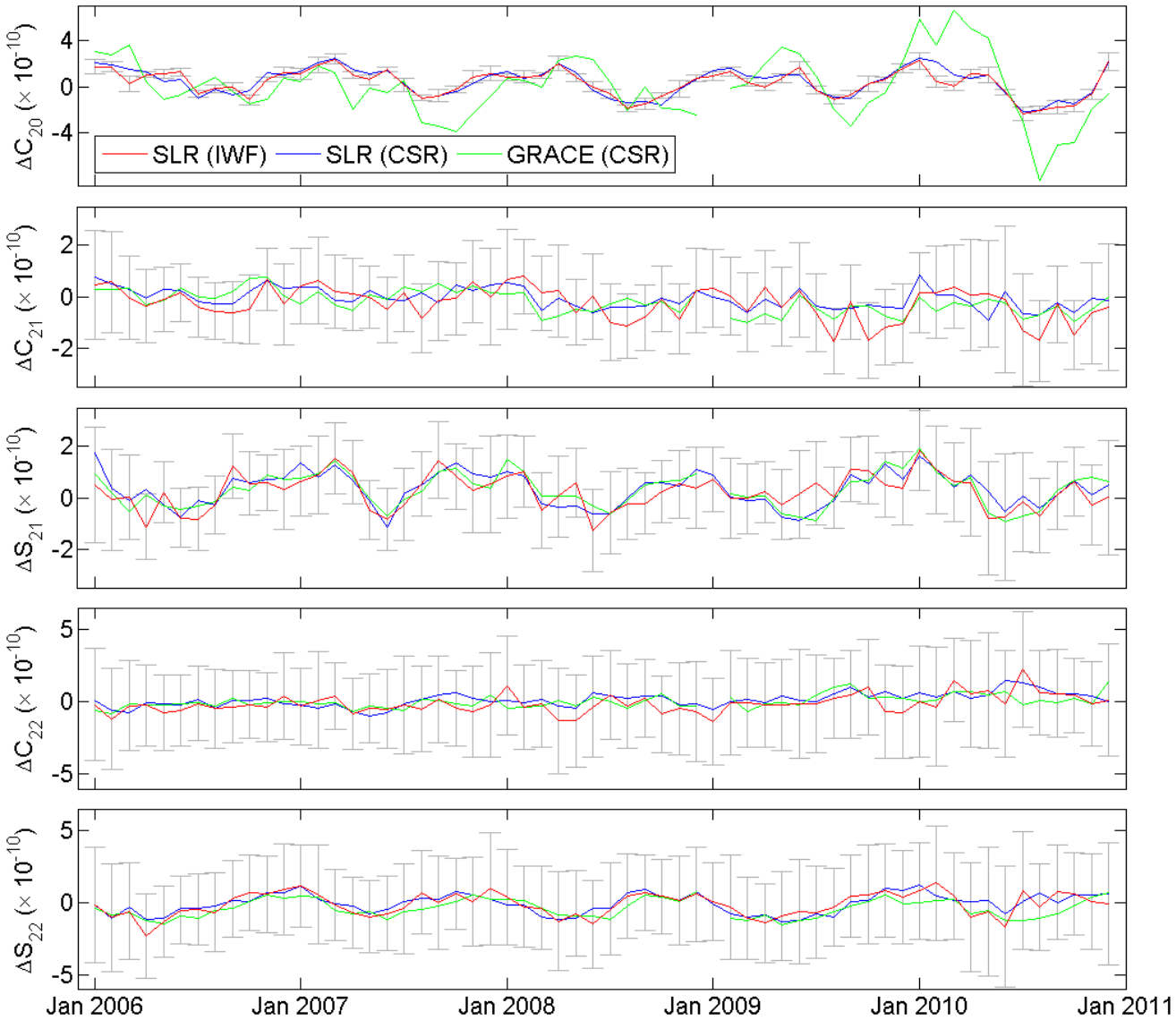
- combination of NESs:
  - by month, i.e., 5 satellite-dependent NESs form 1 combined NES

    → time-variable gravity field coefficients; advantageous for comparison with results from other research groups
  - over all months and all satellites

    → static gravity field coefficients as input for a static combined gravity field model

Results – time-variable coefficients

- time-variable gravity field coefficients of degree 2

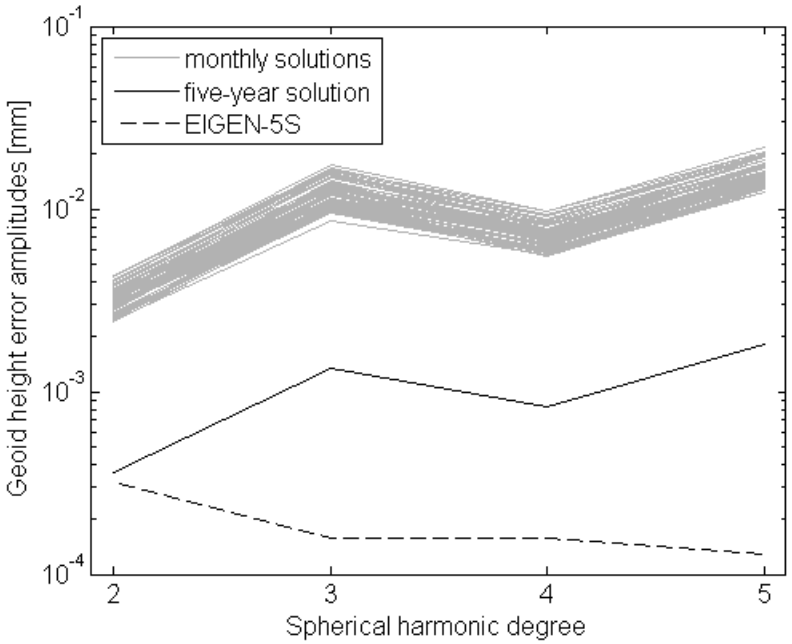


Discussion – temporal change in C_{20}

- between 2006 and 2010, C_{20} has decreased, i.e., the Earth's oblateness has increased
- large-scale mass transport from high to low latitudes must have taken place
- average geoid change per latitude band from zonal coefficients:

Results – static coefficients

- the static solution comprises all monthly arcs to all satellites
- error amplitudes in terms of geoid height:



- the NES of the static solution serves as input for the satellite-only gravity field model GOCO02S

GOCO02S

- data used in the combination process:

Data type	Resolution in maximum d/o	Time span
ITG-Grace2010s	180	7 years
GOCE SST	110	12 months
GOCE SGG	250	8 months
CHAMP	120	8 years
SLR	5	5 years

- combination by means of variance component estimation
- available at: *http://icgem.gfz-potsdam.de/ICGEM/*