Consistent estimation of Earth rotation, geometry and gravity with DGFI's multi-satellite SLR solution

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International Laser Ranging Service

CGE
Centrum für Geodätische Erdsystemforschung

DGFI

18th International Workshop on Laser Ranging, 11.-15. November 2013, Fujiyoshida, Japan

GGOS aims

Geometry

- measuring the geometric shape of the Earth's surface and its kinematics & variations

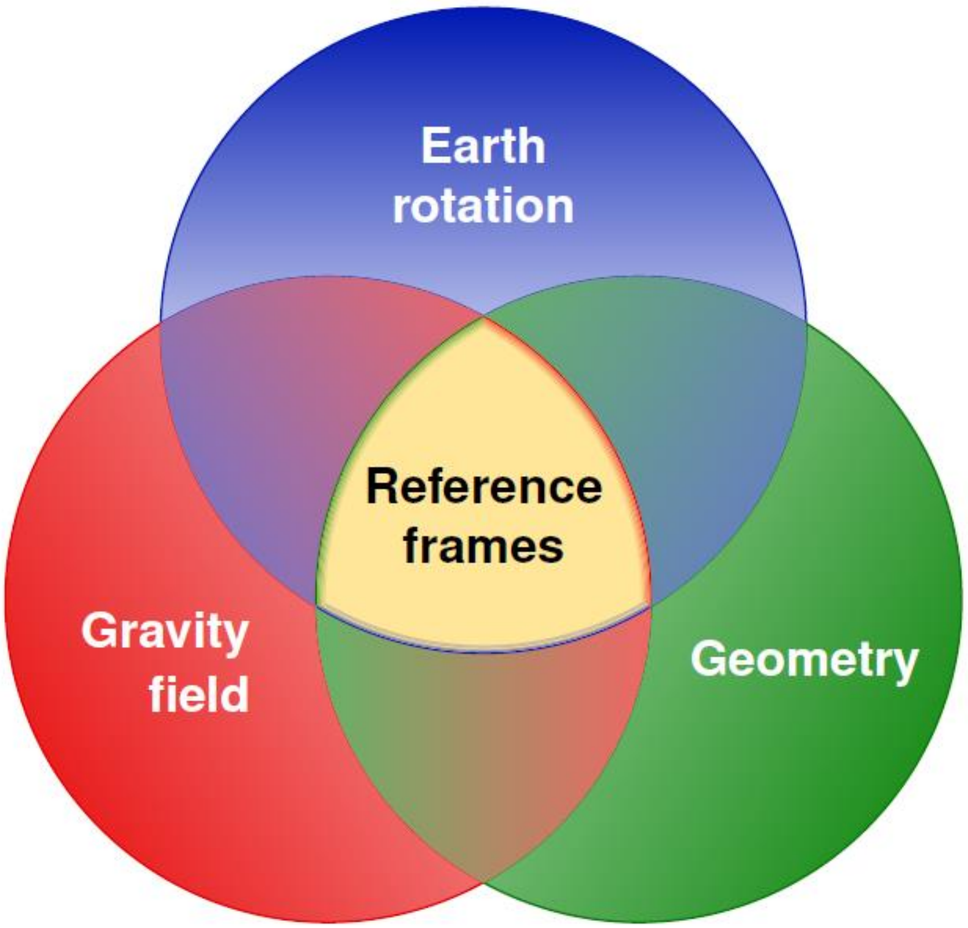
Earth rotation

- monitoring the variations of the Earth's rotation as indicator of angular momentum and torques

Gravity field

- determining and monitoring the Earth's gravity field

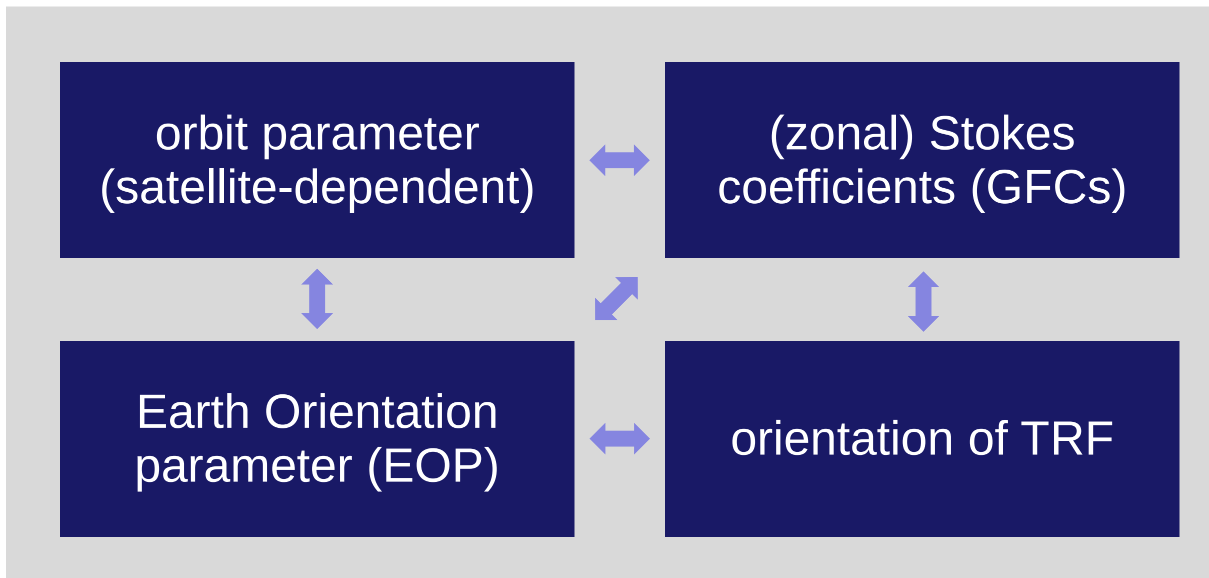
➢ Highly-accurate and consistent **reference frames** are required to integrate the three pillars.



[acc. to Plag & Pearlman, 2009]

Interaction between the "pillars"

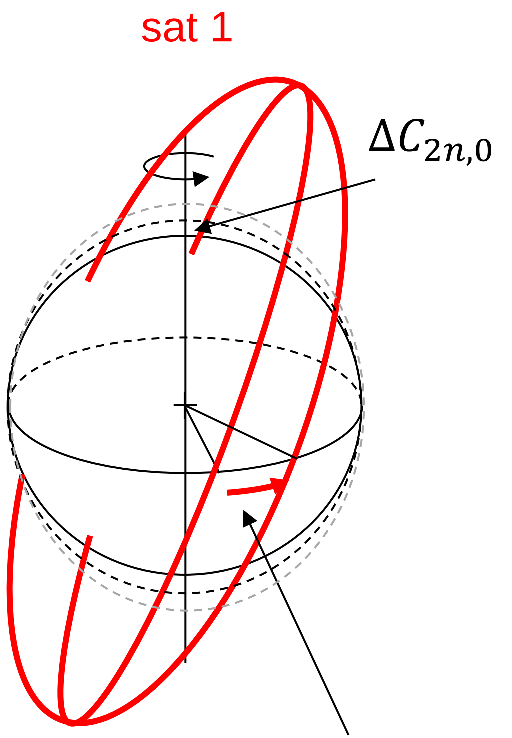
- **GGOS goal**: Consistent estimation of the Earth's geometry, the Earth's orientation and the Earth's gravity field and its temporal variations
- **problem**: High interaction between different parameter groups in a common adjustment (also complementary parameters!)



- **inter-technique solution:** Combination of observation techniques with different advantages (e.g. GNSS, SLR, VLBI, DORIS, GRACE, GOCE, …)
- **intra-technique solution**: Combination of SLR observations to satellites with different orbit characteristics

Correlations I

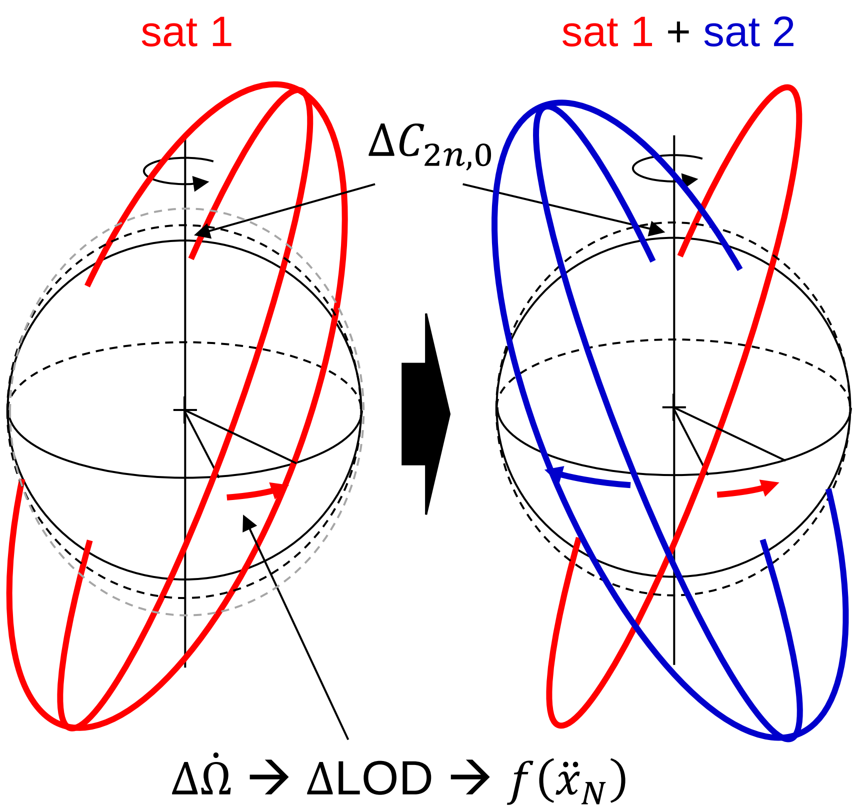
- **sat 1**: high correlations between Earth gravity field, nodal precession, empirical cross-track accelerations and Earth rotation



$\Delta\dot{\Omega} \rightarrow \Delta\text{LOD} \rightarrow f(\ddot{x}_N)$

Correlations II

- **sat 1**: high correlations between Earth gravity field, nodal precession, empirical cross-track accelerations and Earth rotation
- **sat 1** + **sat 2**: mixed inclinations are important to decorrelate Earth gravity field, satellite orbit and Earth rotation
- optimal mix would be the **butterfly configuration** $(I_1 - 90° = 90° - I_2)$
  → precession of nodes in opposite direction with the same velocity



Correlations III

- **sat 1**: high correlations between Earth gravity field, nodal precession, empirical cross-track accelerations and Earth rotation
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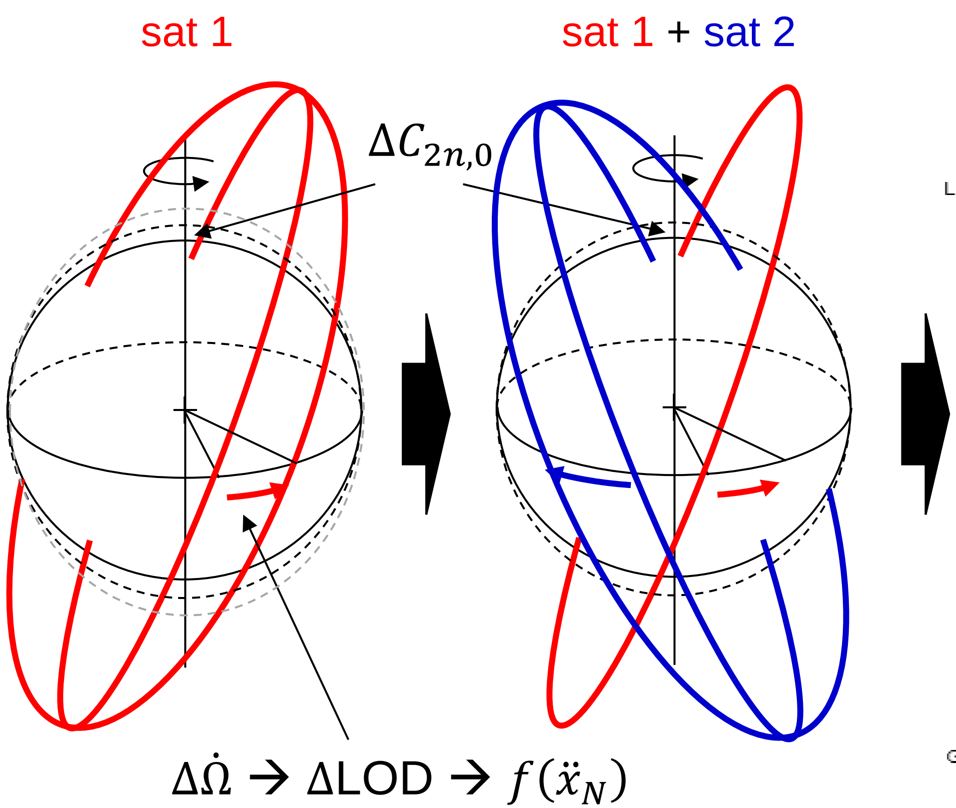
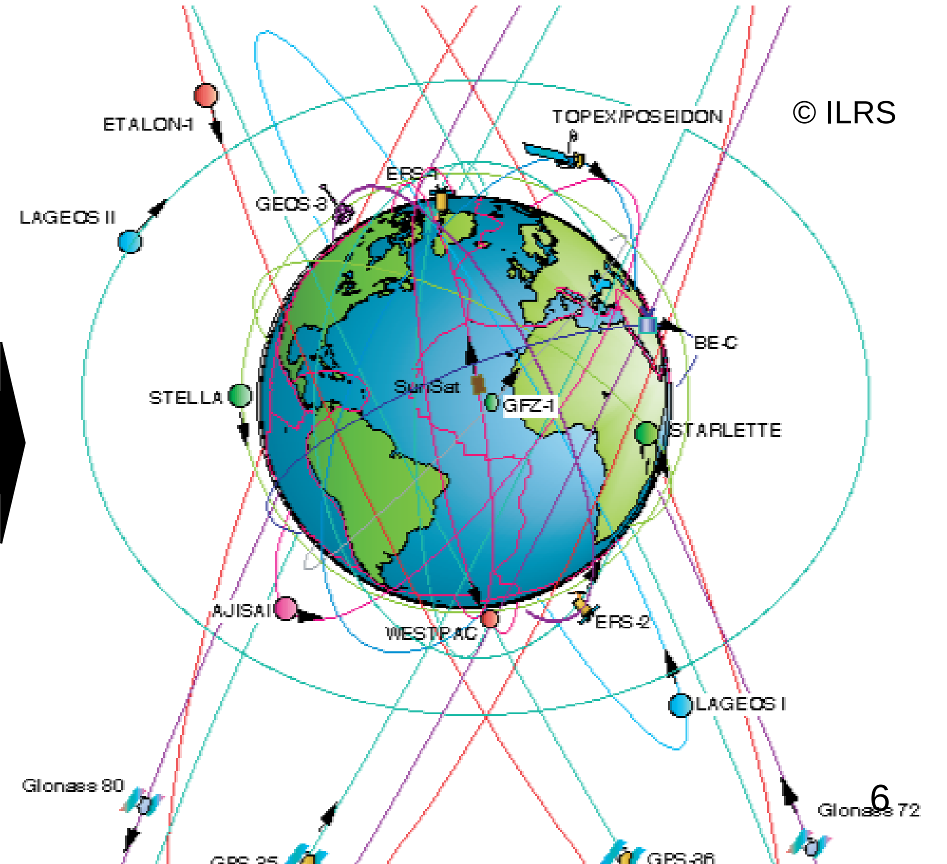
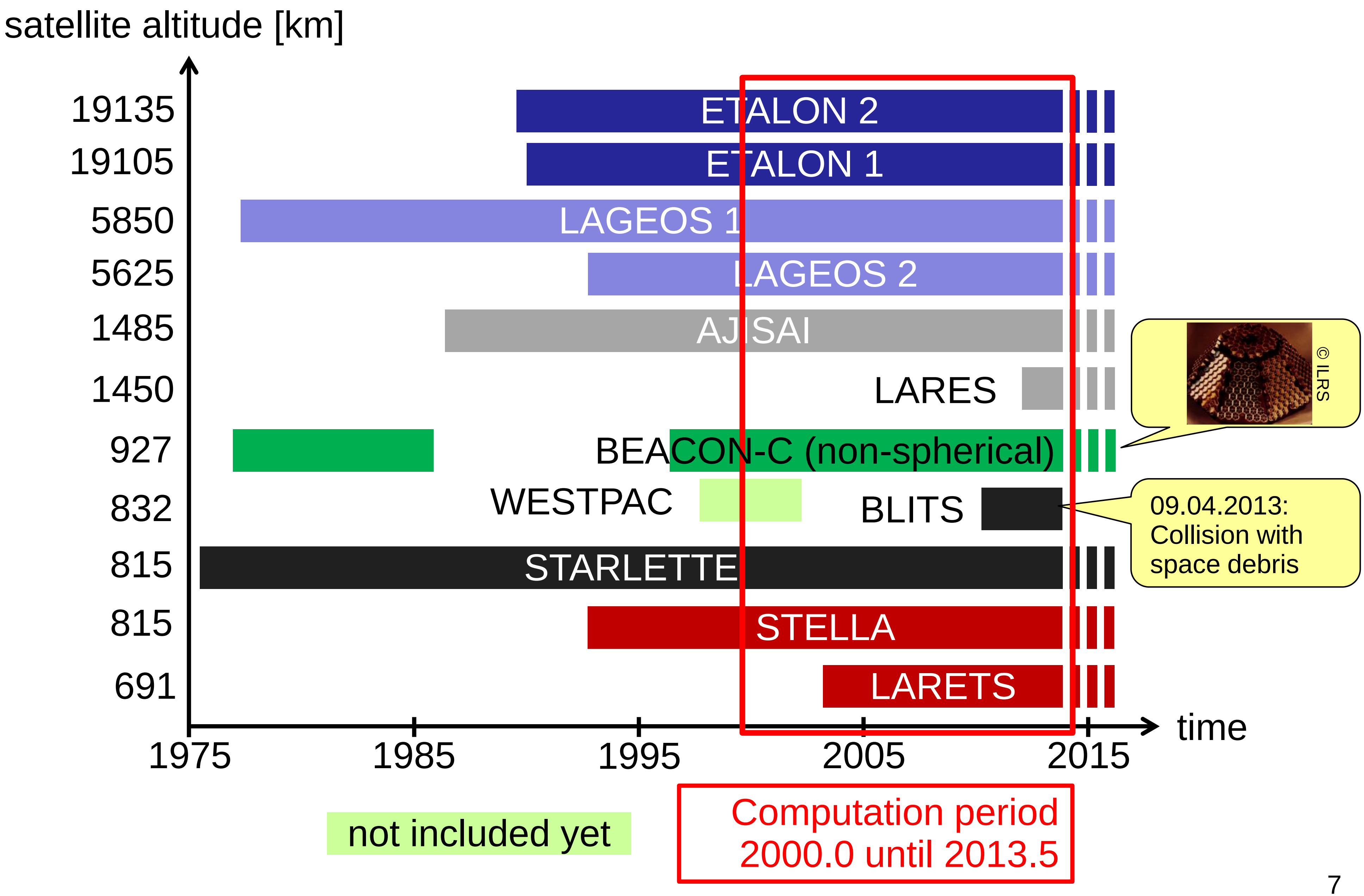


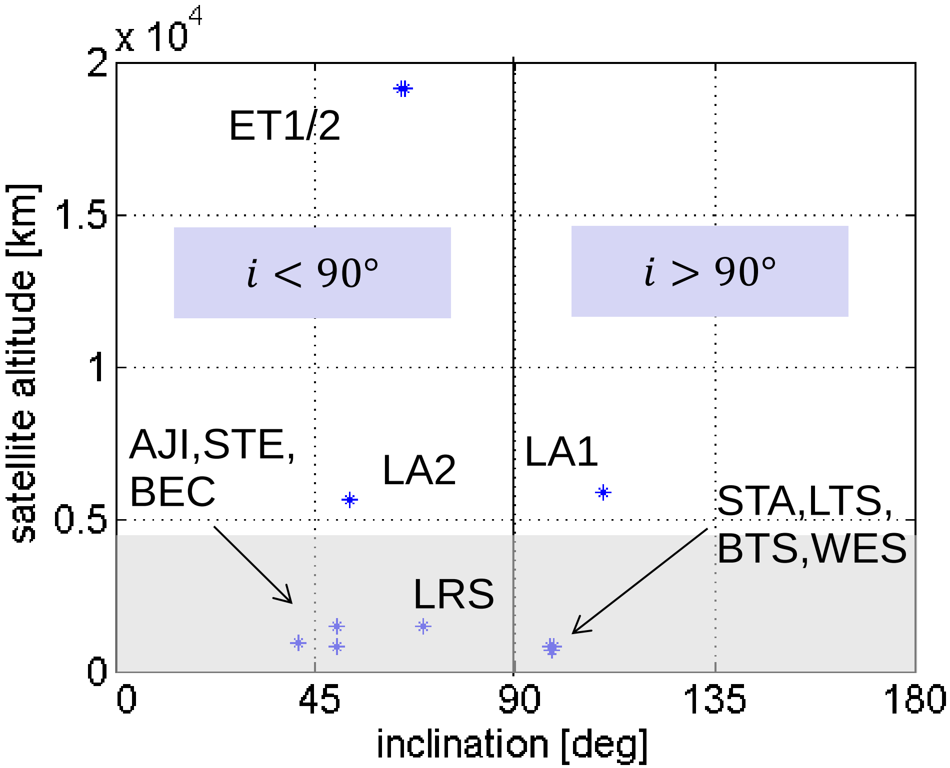


Data I



satellite altitude [km]
19135
19105
5850
5625
1485
1450
927
832
815
815
691
ETALON 2
ETALON 1
LAGEOS 1
LAGEOS 2
AJISAI
LARES
BEACON-C (non-spherical)
WESTPAC
BLITS
STARLETTE
STELLA
LARETS
© ILRS
09.04.2013: Collision with space debris
1975
1985
1995
2005
2015
time
not included yet
Computation period 2000.0 until 2013.5

Data II



satellite	mass [kg]	diameter [m]	rev.-period [h]
LAGEOS1	406.97	0.60	3.76
LAGEOS2	405.38	0.60	3.76
ETALON1	1415.0	1.294	11.26
ETALON2	1415.0	1.294	11.26
STELLA	47.3	0.24	1.74
STARLETTE	47.0	0.24	1.69
AJISAI	685.0	2.15	1.93
LARETS	23.28	0.21	1.64
LARES	386.8	0.364	1.91
BLITS	7.53	0.17	1.68
BEACONC	52.6	non-sph.	1.80

- Observations are combined on the NEQ-level
- Weighting of NEQs is done via VCE
- LARETS, BLITS, BEACONC and STELLA get lower weights

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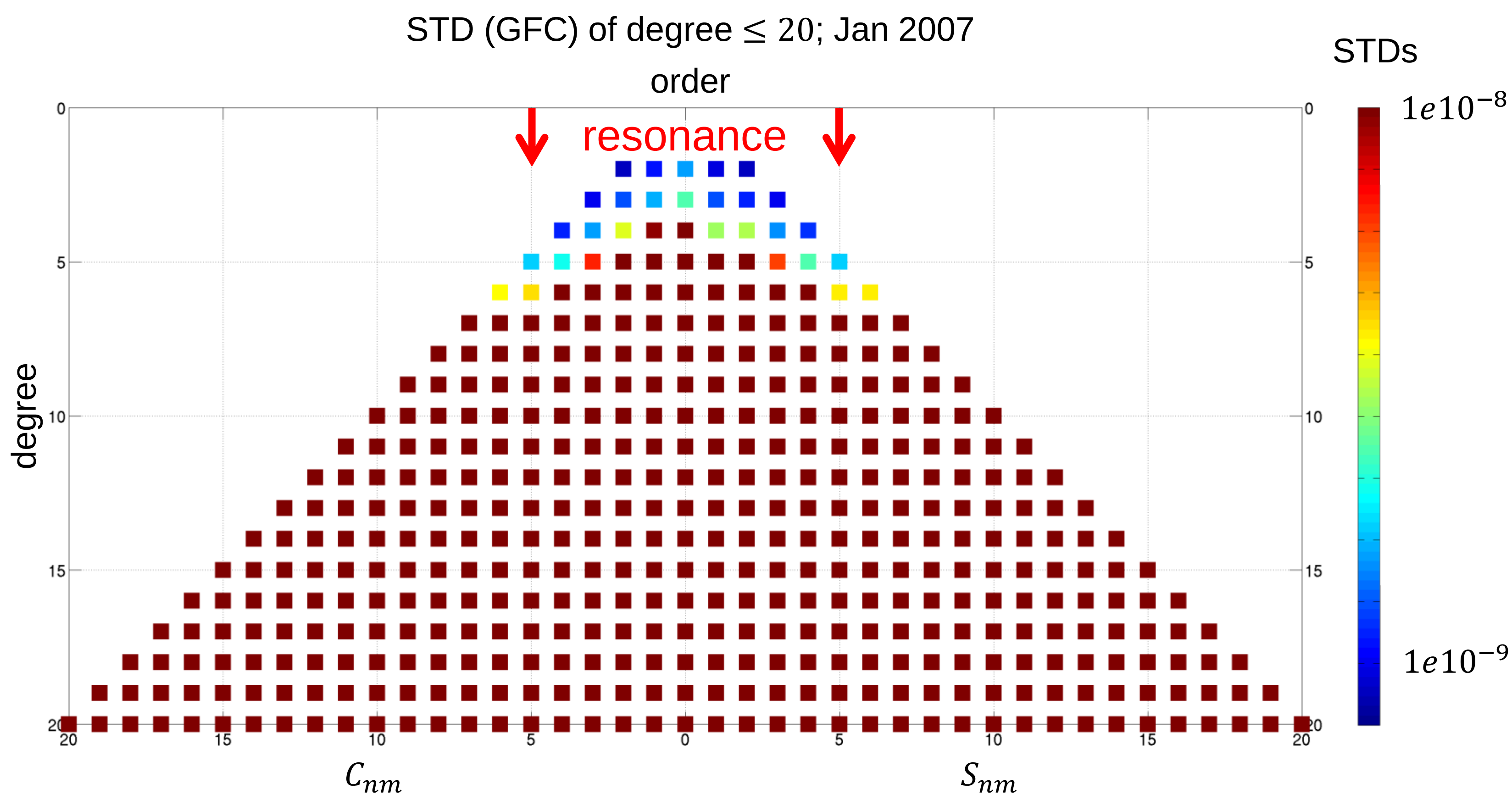
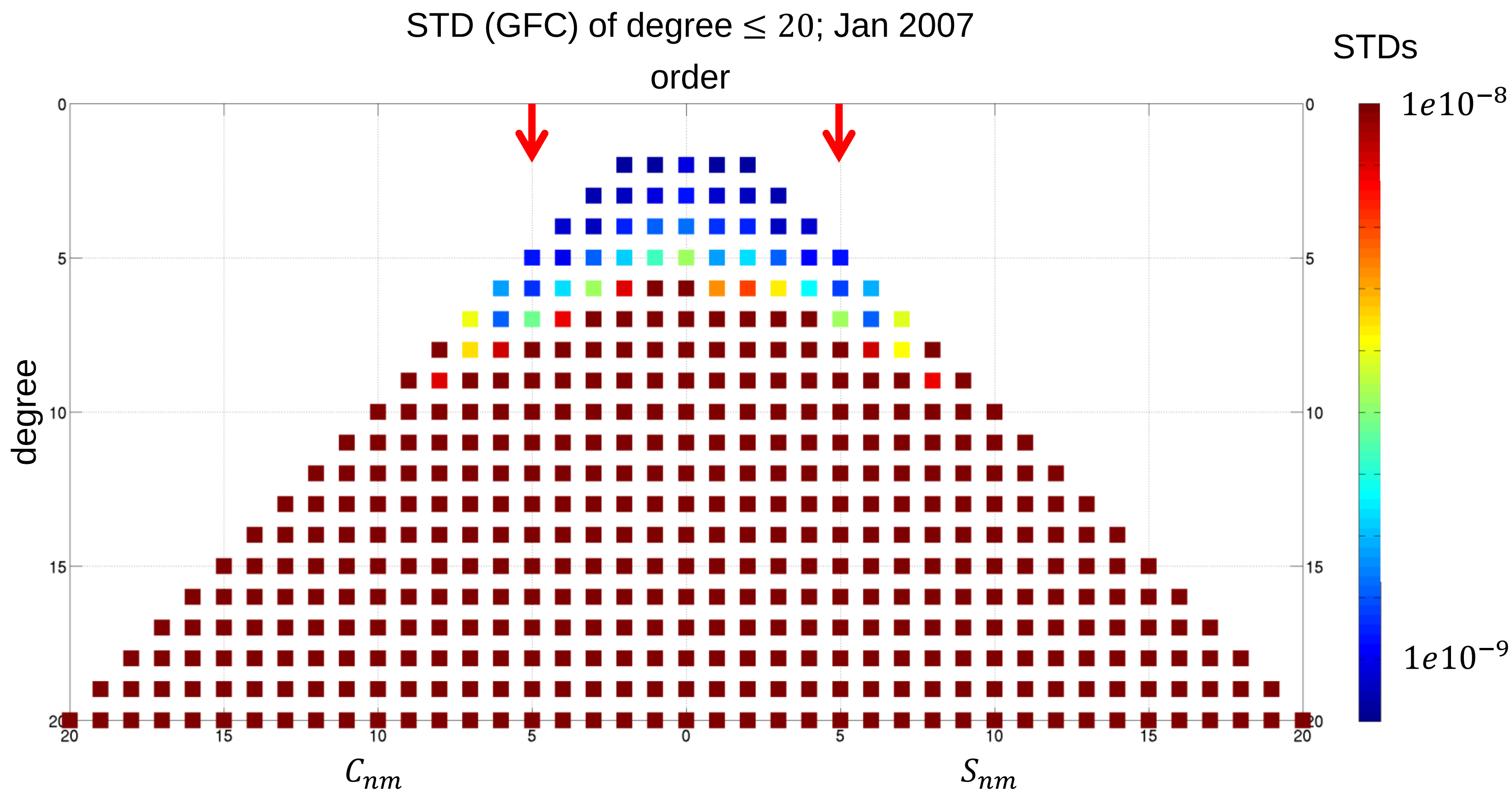
Earth gravity field I



LAGEOS1

- low sensitivity on GFCs of degree > 3
- high correlations of low-degree GFCs with satellite orbit

Earth gravity field II



LAGEOS1/2

- stable estimation of GFCs of degree ≤ 4
- decorrelation of low-degree GFCs with satellite orbits due to mixed inclinations

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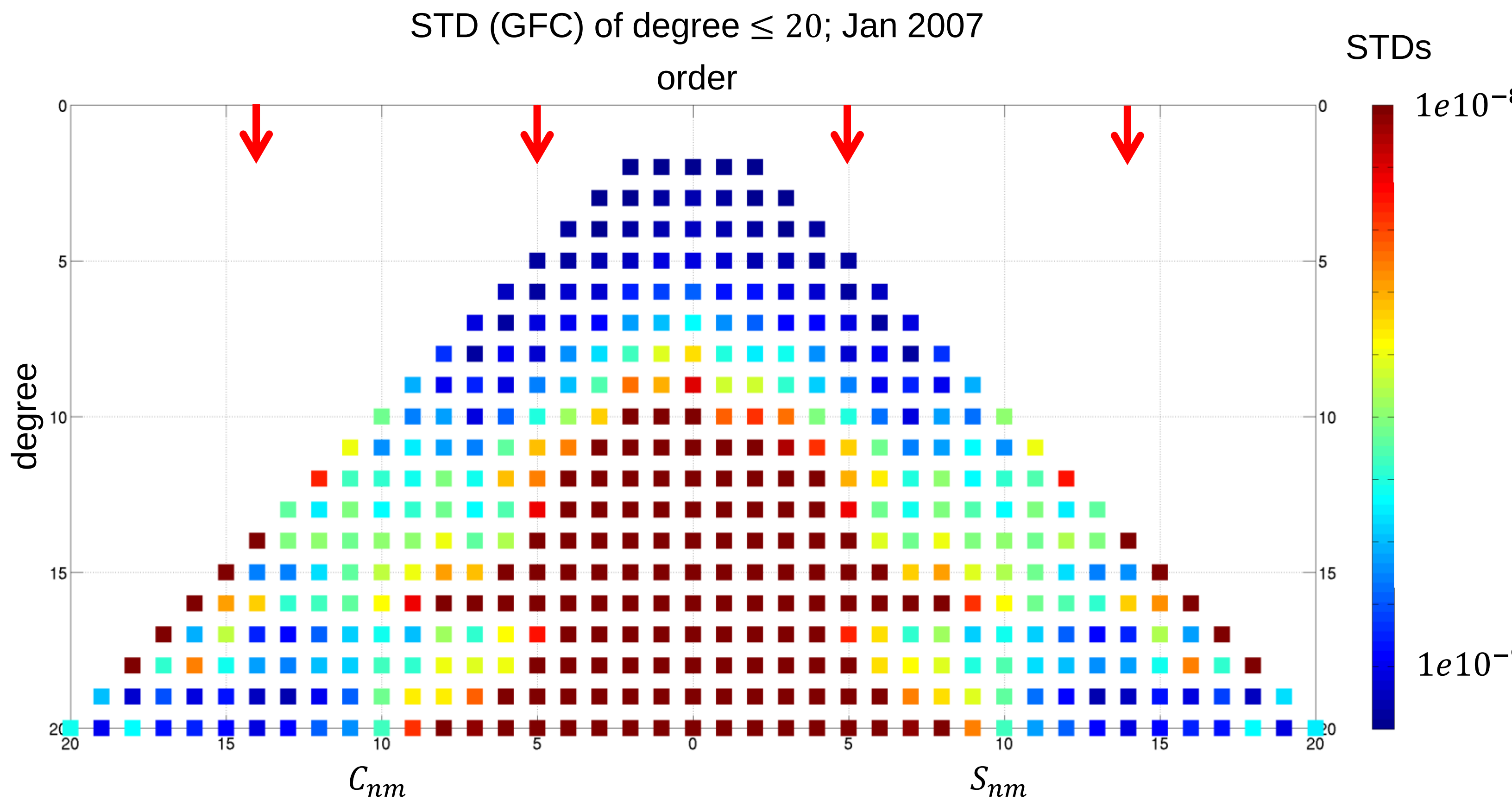
Earth gravity field III



LAGEOS1/2 + STARLETTE

- stable estimation of GFCs of degree ≤ 6
- decrease of STD of tesseral GFCs
- STARLETTE has slightly lower λ than LAGEOS1/2 → high impact on GFC estimation

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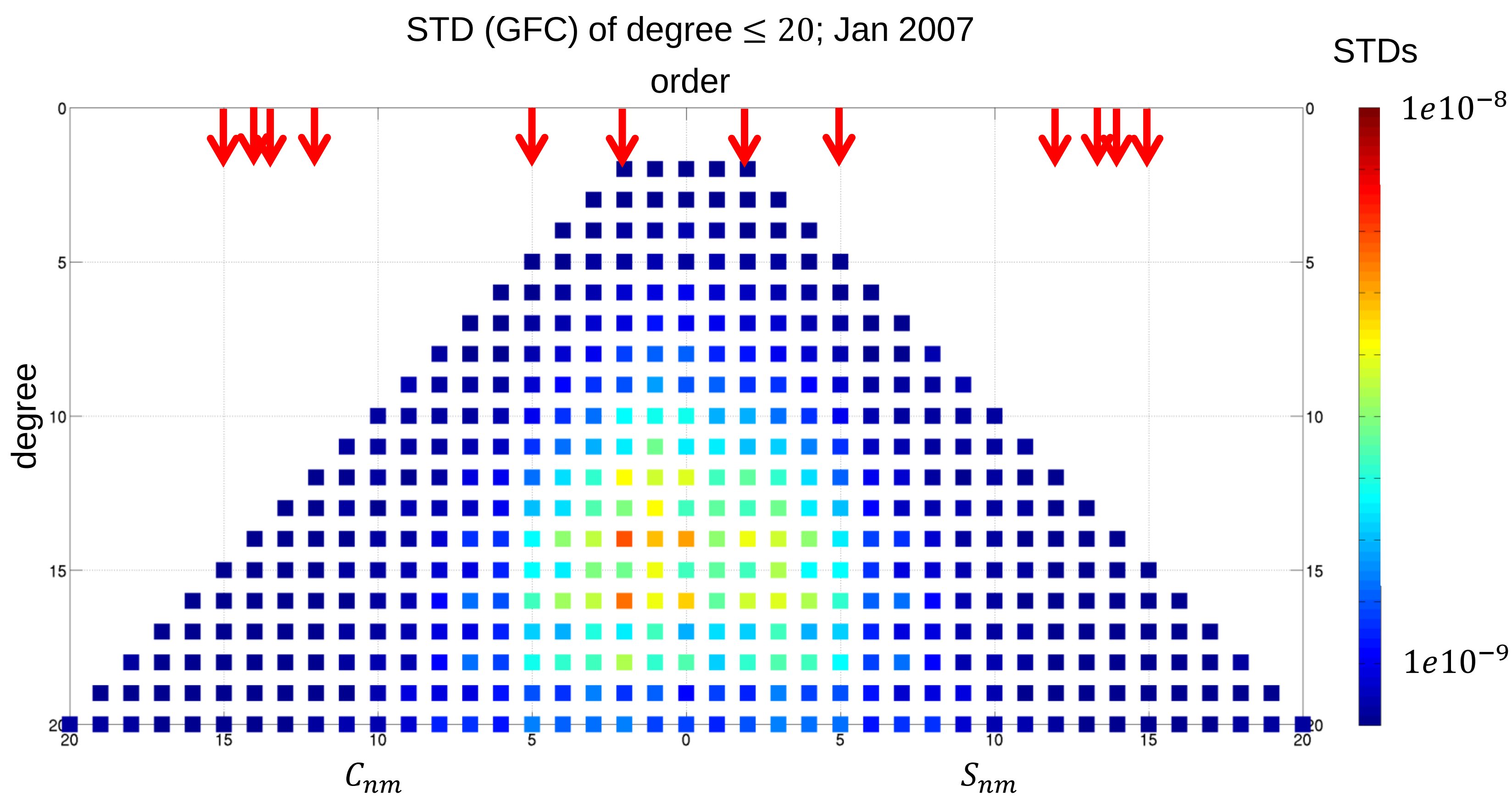
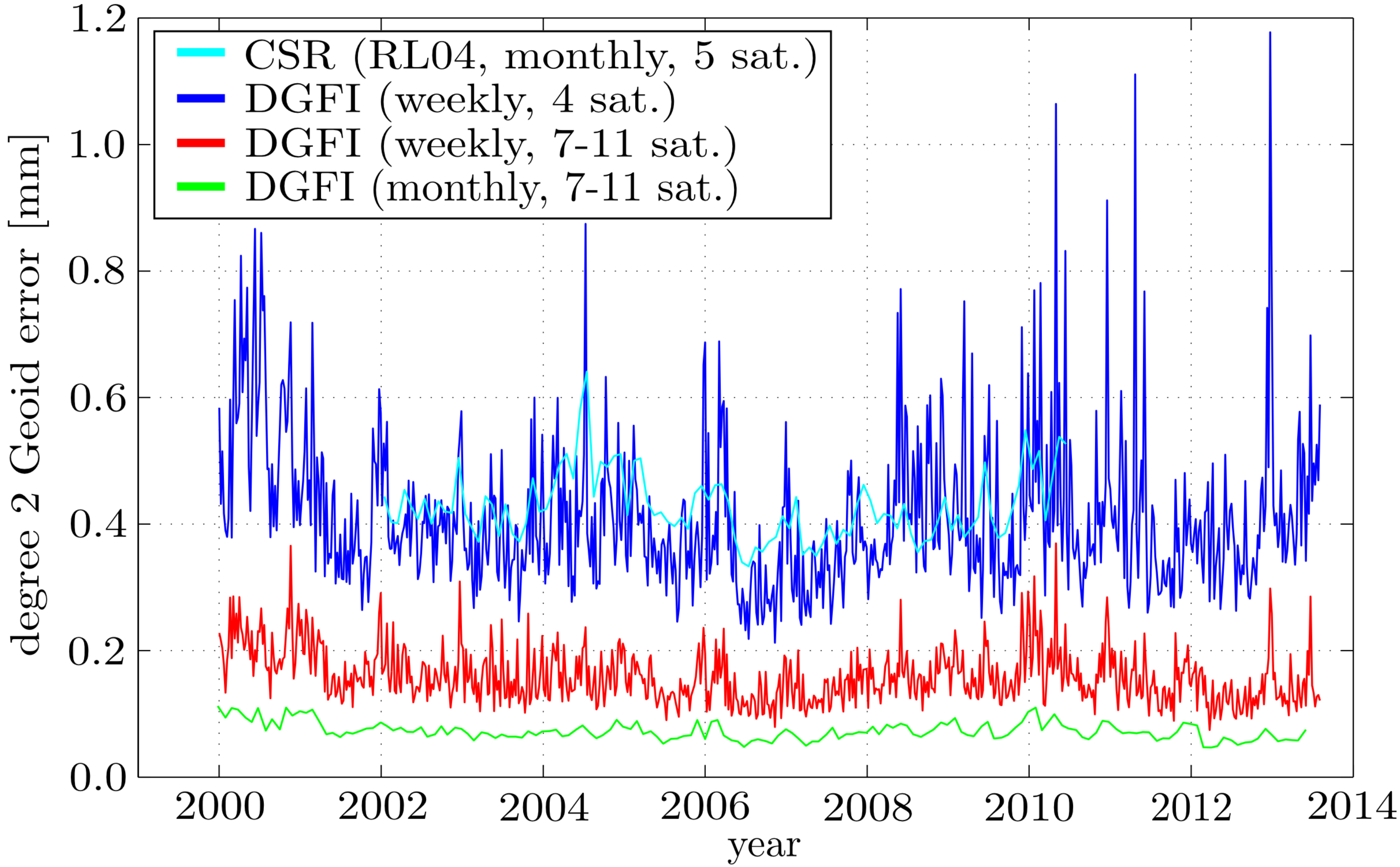
Earth gravity field IV



LAGEOS1/2 + ETALON1/2 + LARETS + STARLETTE + STELLA + AJISAI

- small STD of sectoral/tesseral GFCs up to degree ≤ 20
- zonal GFCs have higher STDs
- resonances of LEOs allow to estimate GFCs of high degree

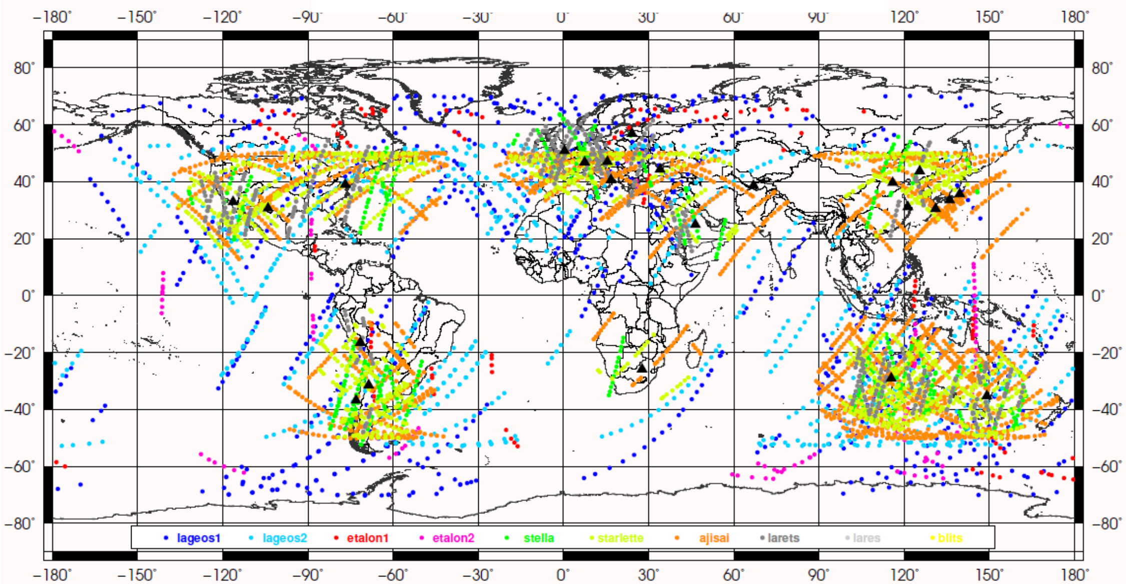
Earth gravity field V



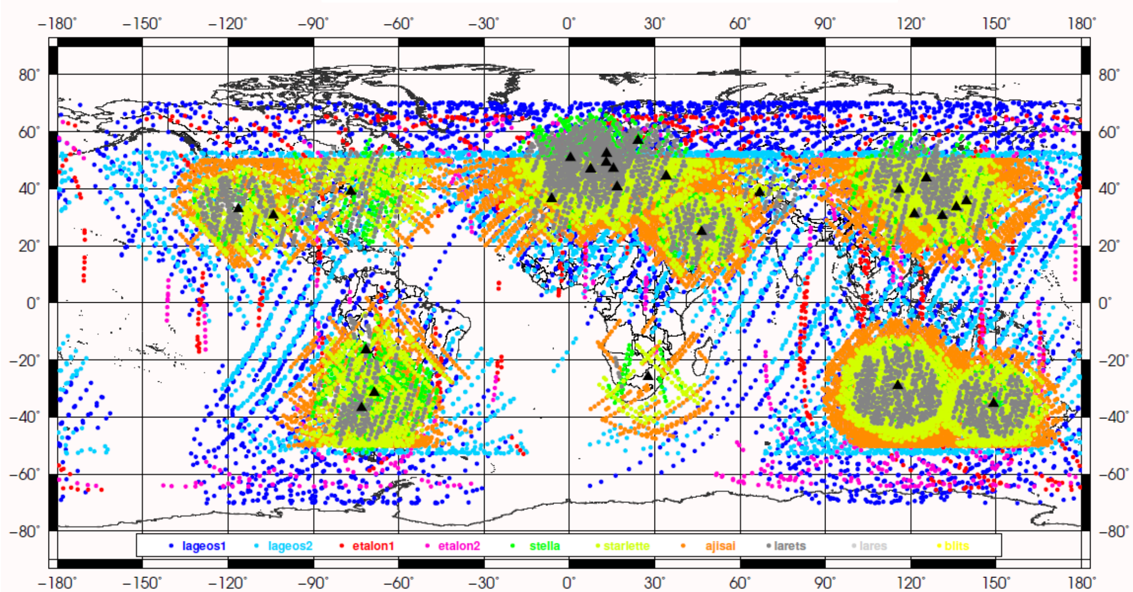
- weekly $\sigma^2(c_2)$ of DGFI (11 sat.) is smaller than monthly $\sigma^2(c_2)$ of CSR!

weekly / monthly global observation coverage

31.12.2006 – 07.01.2007



January 2007



weekly solution

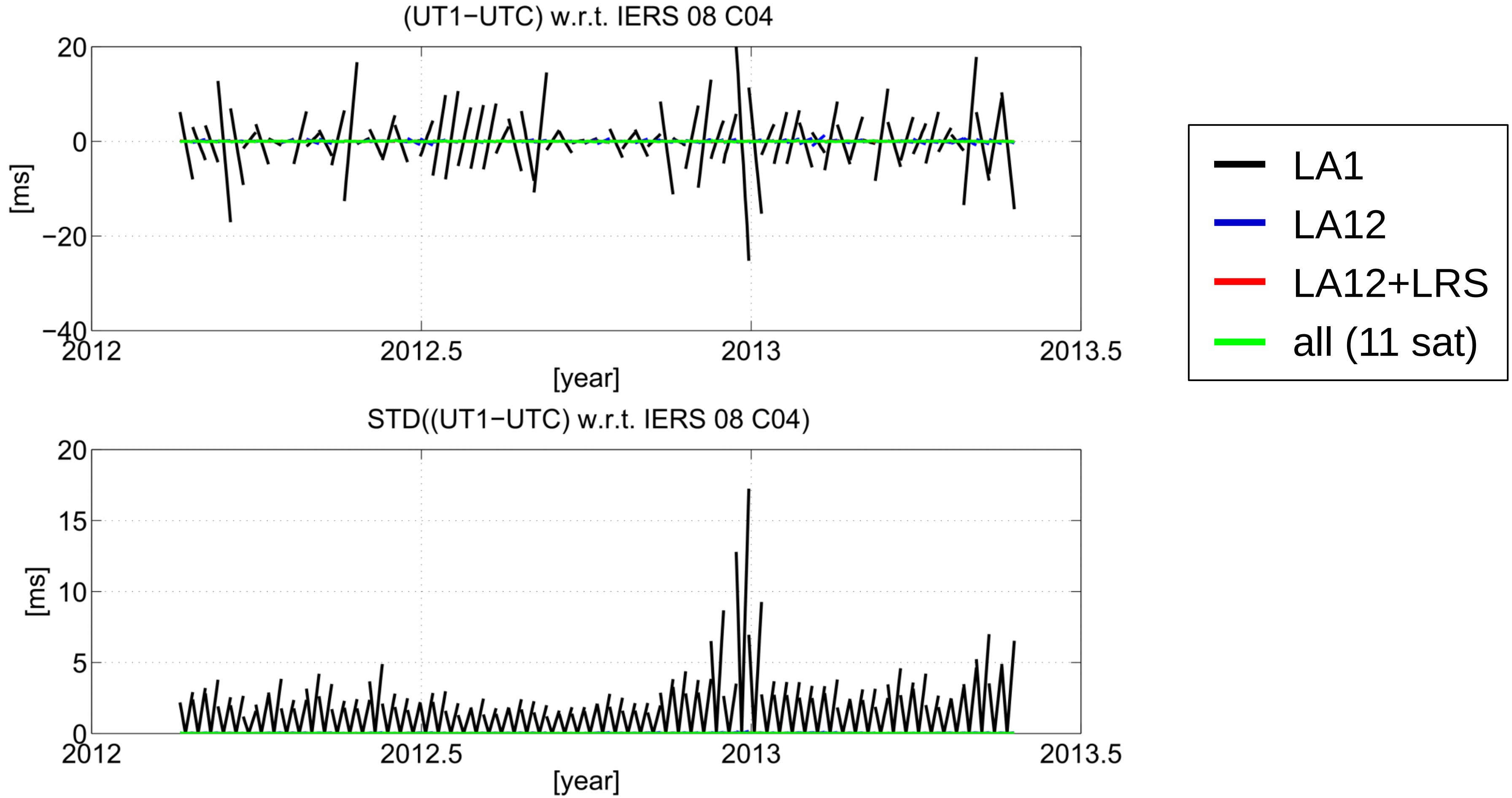
- poor observation distribution
- sometimes bad observation geometry due to station outage
- high weekly variability

monthly solution

- dense observation distribution
- good network geometry
- low monthly variability

Earth Orientation Parameter I

weekly solution between Feb. 2012 and May 2013 (LARES period)



RMS Δ x-pole [μas]	39.2			
RMS Δ y-pole [μas]	50.0			

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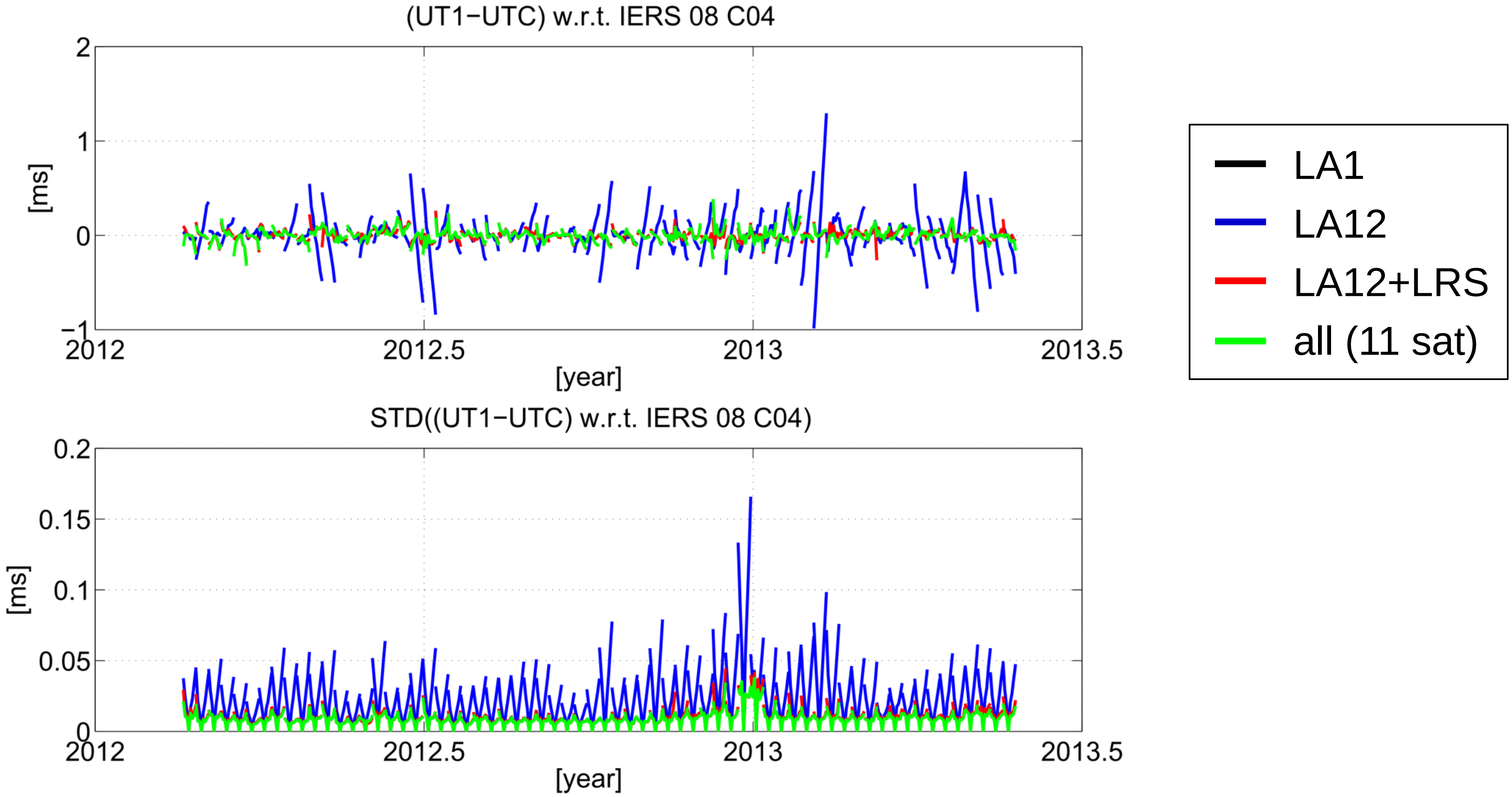
Earth Orientation Parameter II

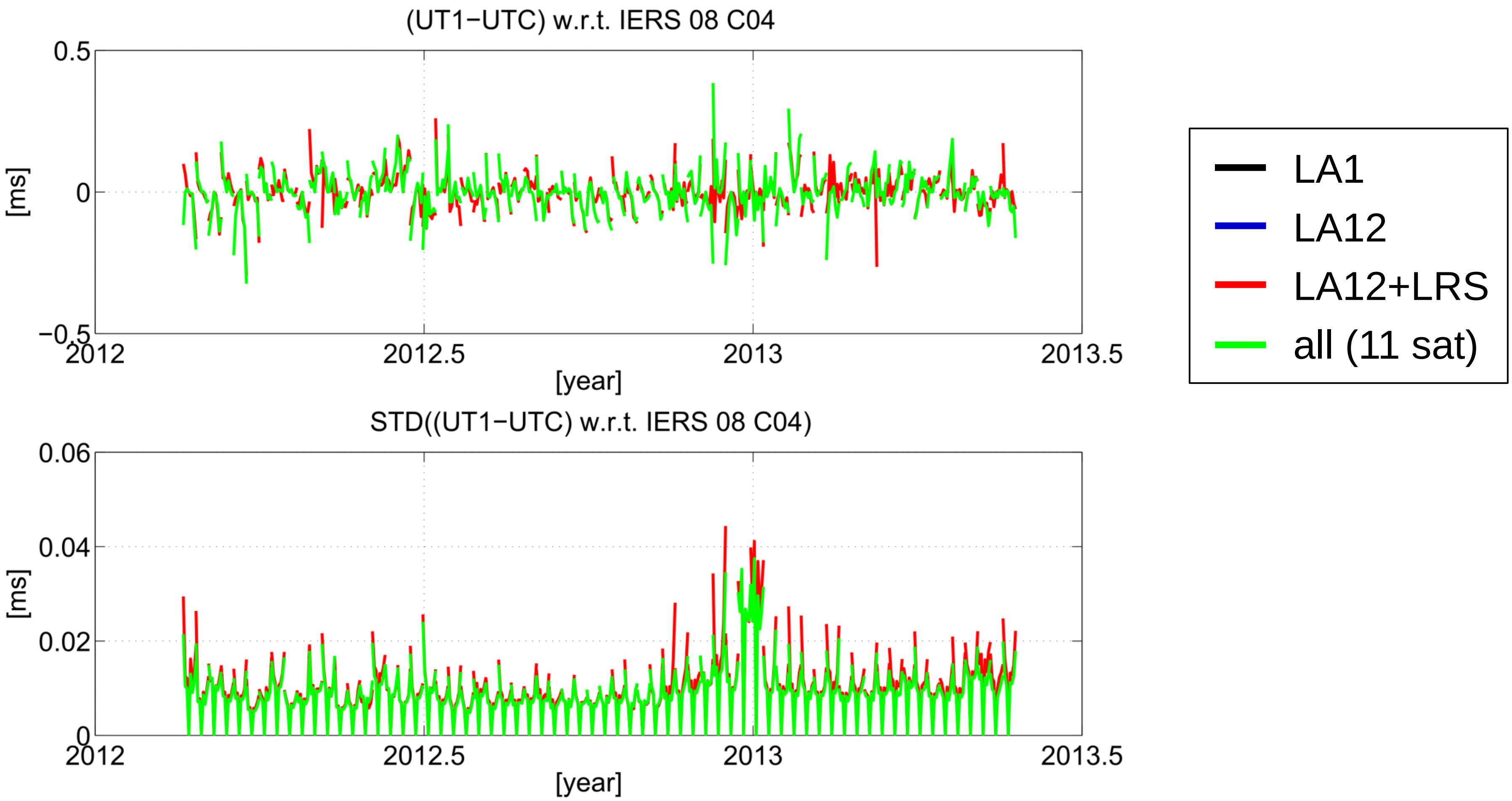
weekly solution between Feb. 2012 and May 2013 (LARES period)



RMS Δ x-pole [μas]	39.2	15.1		
RMS Δ y-pole [μas]	50.0	16.1		

Earth Orientation Parameter III

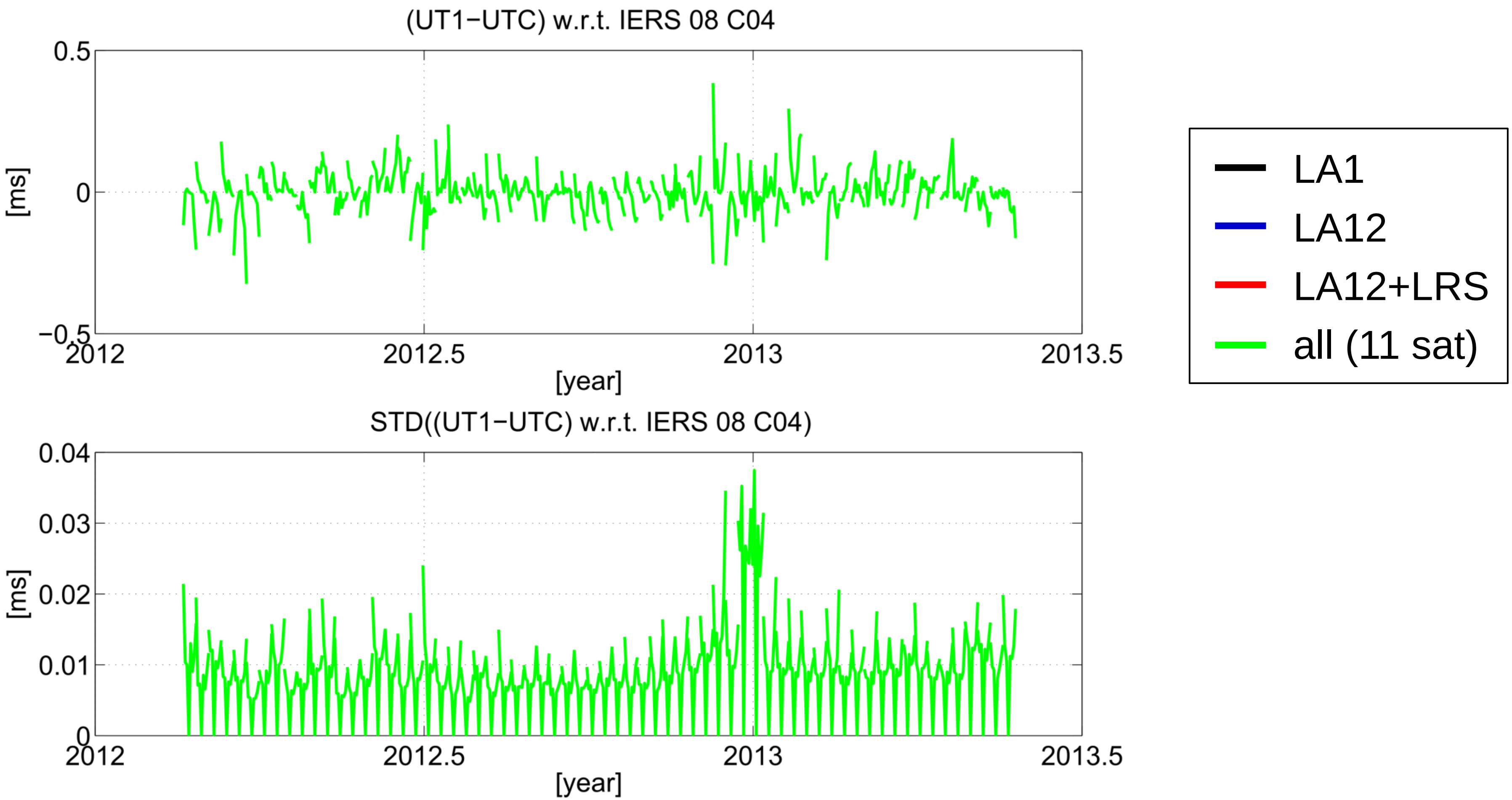
weekly solution between Feb. 2012 and May 2013 (LARES period)



RMS Δ x-pole [μas]	39.2	15.1	15.3	
RMS Δ y-pole [μas]	50.0	16.1	15.8	

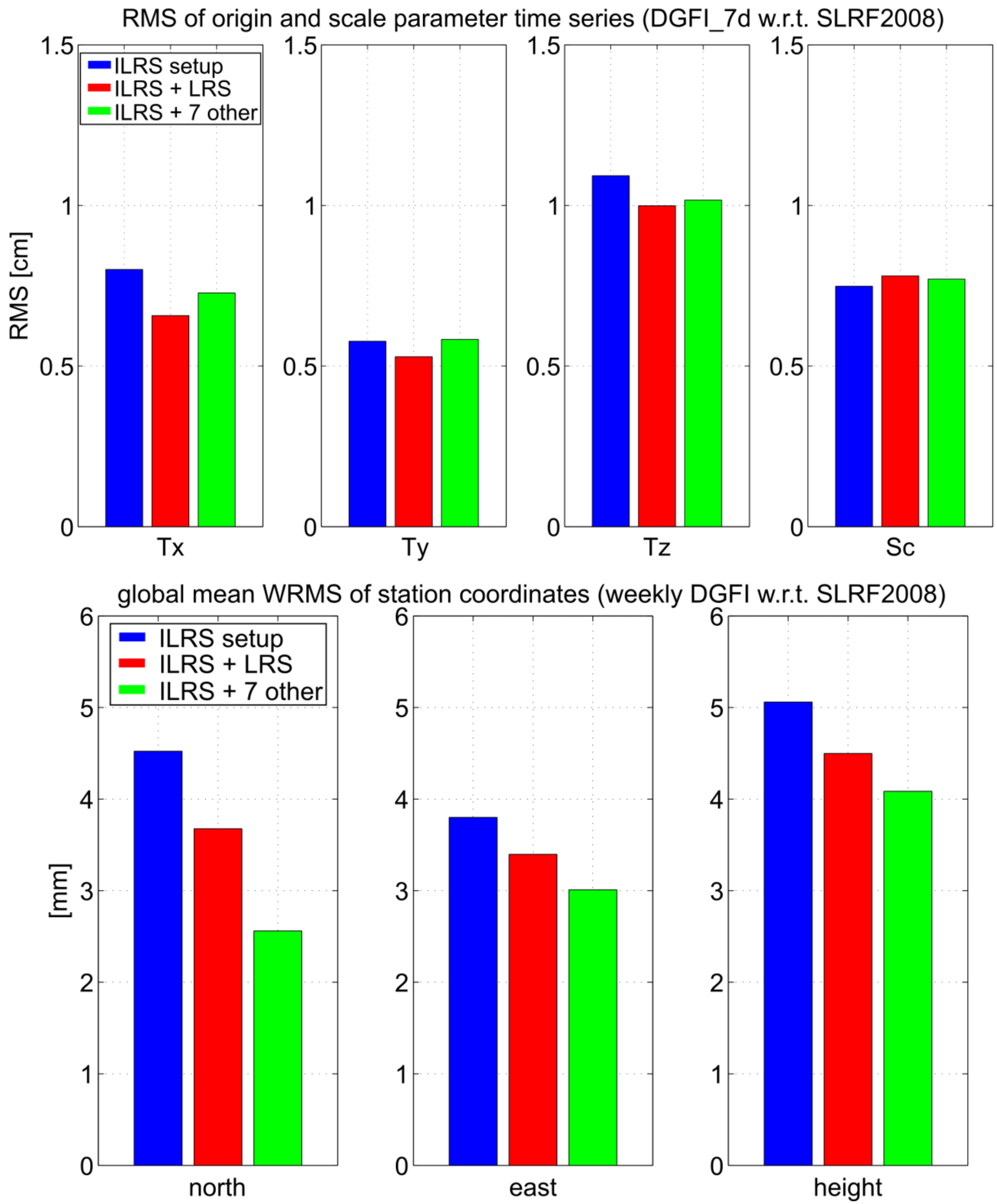
Earth Orientation Parameter IV

weekly solution between Feb. 2012 and May 2013 (LARES period)



RMS Δ x-pole [μas]	39.2	15.1	15.3	14.6
RMS Δ y-pole [μas]	50.0	16.1	15.8	14.7

Terrestrial Reference Frame



RMS of translation / scale parameter w.r.t. SLRF2008

- Tx: -14 % (ILRS+LRS)
  - 7 % (11 sat)
- Ty: -6 % (ILRS+LRS)
- Tz: -7 % (ILRS+LRS)
  -6 % (11 sat)
- Sc: +4 % (ILRS+LRS)
  +3 % (11 sat)

global mean coordinate WRMS

- north: -14 % (ILRS+LRS)
  -40 % (11 sat)
- east: -5 % (ILRS+LRS)
  -17 % (11 sat)
- height: -10 % (ILRS+LRS)
  -18 % (11 sat)

Summary

- **Earth gravity field:**
  - mix of different satellite heights and resonances allows to estimate stable GFCs together with orbit parameters, TRF and EOPs
  - the longer the arc length is, the smaller are the STDs of the esti-mated GFCs (well-determined GFCs up to d/o 20 with monthly (4 weeks stacked) solutions!)
- **EOP:**
  - mix of different satellite inclinations allows to reduce the (UT1-UTC) systematics (decorrelation of gravity, orbit and ΔLOD)
  - The more satellites are combined, the smaller is the scatter of the pole coordinates
- **TRF:**
  - LARES helps to reduce the scatter of the transformation parameters & the global WRMS of the coordinates
  - with 11 satellites, the global WRMS is reduced by about 20-40 % w.r.t. the ILRS (LA1/2, ET1/2) solution

Bloßfeld M., Müller H., Gerstl M., Stefka V., Bouman J. (2013)
Improved monthly Earth's gravity field solutions using multi-satellite SLR,
J Geophys Res, submitted soon

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Relative weighting of satellites

- relative weighting using a variance component estimation (VCE) based on normal equations

$$N_c = \lambda_1 N_1 + \lambda_2 N_2 + \cdots + \lambda_{10} N_{10} \quad \text{with} \quad \lambda_i = \frac{1}{\sigma_i^2}$$

satellite	σ_0^2 (TRF+EOP+GFC)
LA1	3.8
LA2	2.2
ET1	8.6
ET2	7.0
STE	34.6
STA	13.3
AJI	12.9
LTS	46.2
LRS	12.9
BTS	52.2
BEC	163.0

- ➢ Estimation of TRF+EOP+GFC in one combined adjustment
- ➢ STE: sun-synchronus orbit
- ➢ LTS: very poor AMR
- ➢ BTS: new reflector type, low weight
- ➢ BEC: non-spherical shape appr. With spherical model