from GPS, GLONASS, and SLR data Earth's oblateness changes

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Table of contents

GPS+GLONASS (GNSS) solutions:

- Sensitivity to low-degree Earth's gravity field coefficients
- Solution set-up
- C_{20} and correlation with dynamical orbit parameters

SLR solutions

- Solution set-up
- C₂₀ from LAGEOS-only and multi-SLR solutions
- Alternative C_{20} recovery from surface load displacements

Impact on Earth Rotation Parameters (ERPs)

- Pole coordinates
- Length-of-day

Conclusions





Sensitivity of GNSS solutions to low-degree gravity coeff.





GNSS solutions



List of estimated parameters & solution set-up

	Estimated parameters		GNSS solutions		
ssia			up to 32 GPS and 24 GLONASS satellites	We processed 10 years of GPS	
0th COSPAR Scientific Assembly 2014. 2–10 August 2014, Moscow, Russia	Orbits	Osculating elements	a, e, i, Ω , ω , u ₀ (1 set per 3 days)	and GLONASS data using the standard orbit modeling as from CODE with two major exceptions:	
		Dynamical parameters	D ₀ , Y ₀ , X ₀ , X _S , X _C – unconstrained D _S , D _C , Y _S , Y _C – constrained at 10^{-12} (1 set per 3 days)		
		Pseudo-stochastic pulses	R, S, W (constrained, estimated every 12 ^h)	• 7-day solutions are generated instead of the 3-day long-arc solutions as for the IGS.	
	Earth rotation parameters		X _P , Y _P , UT1-UTC (Piecewise linear, 1 set per day)	 The Earth's gravity field coefficients up to degree/order 4/4 and 	
Asser	parameters Geocenter coordinates Forth gravity field		1 set per 7 days	geocenter coordinates are	
:OSPAR Scientific Assembly 2014. 2–10 August 2014	Earth gravity field		Estimated up to d/o 4/4 (1 set per 7 days)	simultaneously estimated along with other parameters.	
AR So	Station coordinates		1 set per 7 days		
Oth COSP	Other parameters		Troposphere ZD (2h), gradients (24h) and ZTD biases		

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GNSS orbit modeling



GNSS dynamic orbit parameters estimated in standard CODE solutions (reduced ECOM model):

$$\begin{pmatrix} D\\Y\\X \end{pmatrix} = \begin{pmatrix} D_0\\Y_0\\X_0 + X_S \sin u + X_C \cos u \end{pmatrix}$$

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C₂₀ from GPS+GLONASS



GNSS dynamic orbit parameters : Do, Yo, Xo, Xs, Xc



GNSS dynamic orbit parameters : Do, Yo, Xo, Xs, Xc





C_{21} , S_{21} , C_{30} from GPS+GLONASS



GNSS-derived gravity field parameters agree quite well with the CSR RL05 results (median difference of 8.2.10⁻¹¹), but:

- GNSS-derived parameters show both: the seasonal signals as well as draconitic periods,
- C₂₀ is correlated with orbit parameters in the X direction.

Gravity coefficients benefit from the contribution of GLONASS (after 2008, when the station coverage improves).

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SLR solutions



List of estimated parameters & solution set-up

		SLR solutions	
Esti	imated parameters	LAGEOS-1/2, Starlatta Stalla AUSAI	
		Stanette, Stena, AJISAI	
	Osculating elements	a, e, i, Ω , ω , u ₀ (1 set per 7 days)	
Orbits	Dynamical parameters	LAGEOS-1/2 : S_0 , S_S , S_C (1 set per 7 days) Sta/Ste/AJI : C_D , S_C , S_S , W_C , W_S (1 set per day)	
	Pseudo-stochastic pulses	LAGEOS-1/2 : no pulses Sta/Ste/AJI : once-per-revolution in along-track only	
	Earth rotation parameters	X _P , Y _P , UT1-UTC (Piecewise linear, 1 set per day)	
Geo	center coordinates	1 set per 7 days	
E	arth gravity field	Estimated up to d/o 4/4 (1 set per 7 days)	
St	ation coordinates	1 set per 7 days	
0	ther parameters	Range biases for selected SLR stations	

We processed 10 years of SLR data to 5 geodetic satellites: LAGEOS-1/2, Starlette, Stella, and AJISAI.

Orbit modeling of low orbiting satellites (LEO) comprises more estimated parameters due to their higher sensitivity to non-gravitational perturbations (atmospheric drag, albedo, direct radiation pressure).



Once-per-revolution empirical parameters in out-of-plane are not estimated for LAGEOS, because they are directly correlated with C_{20} .

GLONASS, and SLR data. 2014, Moscow, Russia Sośnica et al.: Earth's oblateness changes from GPS, 40th COSPAR Scientific Assembly 2014. 2–10 August -10 August COSPAR Scientific Assembly 2014.

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LAGEOS-1

C₂₀ from LAGEOS-only and multi-SLR



Variations of C₂₀ from the LAGEOS-only solution are slightly overestimated due to correlations with other estimated parameters, e.g.:

- other gravity field coefficients (e.g., C₄₀),
- Length-of-day,
- Orbit parameters (e.g., ascending node),
- Empirical orbit parameters (S₀, S_C, S_S).

The multi-SLR solution with five high and low orbiting SLR satellites is thus more robust.



C₂₀ from multi-SLR with and without AOD



- When applying the time variable atmosphere and ocean gravity dealiasing products (AOD), the estimated signal is changed, the annual signal is decreased, whereas the semiannual signal is increased w.r.t. the solution without AOD.
- A full consistency between products must be kept when comparing different gravity field solutions (e.g., GRACE and SLR).



C₂₀ from surface load



Variations of C₂₀ can alternatively be recovered from surface load density variations, but this method is limited due to the inhomogeneous distribution of SLR stations. The correlation coefficients between "classical" C₂₀ determination and C₂₀ from station load displacements is 0.26 (and 0.53 for the Z geocenter coordinate).

Earth Rotation Parameters



Three pillars of satellite geodesy



Current status:

IGS/ILRS provide products related to Geometry and Rotation, but not yet to temporal variations in the Earth's Gravity field.



Parameters related to all three pillars are simultaneously estimated, because they are strongly dependent on each other.

How much affected are the GNSS/SLR-derived parameters by neglecting the temporal gravity field variations?



GNSS solutions - polar motion



For the X pole coordinate:

- the amplitude of the 7^{th} harmonic is reduced from 15.9 to 12.2 µas,
- the amplitude of the <u>annual signal</u> is reduced from 12.8 to 6.9 µas,
- the mean offset w.r.t. IERS-08-C04 is reduced from -10.5 to -9.9 µas,

for the solutions without and with estimating gravity field parameters, respectively.

A priori static gravity field is insufficient for current high-accurate GNSS products.

Temporal variations in gravity field should be considered.

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SLR solution with and without estimating gravity field



 $\begin{bmatrix} 50 \\ 40 \\ 30 \\ 0 \\ 0 \\ 10 \\ 10^1 \\ \log(days) \\ 10^2 \\ 10^3 \end{bmatrix} = \begin{bmatrix} 280 \\ 200 \\ 280 \\ 200 \\ 280 \\ 200 \\$

For LoD, the simultaneous estimation of the gravity field parameters:

- 1. reduces the offset of LoD estimates,
- 2. substantially reduces the a posteriori error of estimated LoD. The mean a posteriori error of LoD is 1.3, 16.9, 7.1, and 44.6 µs/day in the multi-SLR solution with gravity, multi-SLR solution without gravity, LAGEOS-1/2 solution without gravity, and SLR-LEO solution without gravity field parameters, respectively.
- 2. reduces peaks in the spectral analysis, which correspond, e.g., to orbit modeling deficiencies (peaks of 222 days, i.e., draconitic year of LAGEOS-2, 280 days, i.e., eclipsing period of LAGEOS-1),



Slide 17

Summary



The GNSS satellites are sufficiently sensitive to low-degree gravity field parameters (including C_{20}), to recover the temporal gravity field variations.



The empirical orbit parameters in the X direction are correlated with C_{20} , therefore the X-parameters partly absorb the C_{20} variations. However, not all the gravity variations are absorbed by empirical parameters.



Low orbiting SLR satellites improve the SLR solutions by reducing the correlations between estimated parameters. Mutli-SLR solutions with high and low orbiting SLR satellites is preferable as compared to LAGEOS-only.



The simultaneous estimation of gravity field parameters along with ERPs, station coordinates, and other parameters is feasible and it is beneficial, e.g., for estimated pole coordinates and length-of-day.



Temporal gravity field variations should be taken into account in both, the SLR and GNSS solutions.





Thank you for your attention

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