Benefits of SLR in epoch reference frames

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Outline

- Motivation
- Datum definition
- Terrestrial reference frames (TRFs)
- Earth orientations parameters (EOPs)
- Gravity field parameters (SH-coefficients up to d/o 2)
- Conclusions

Motivation

Due to the linear station velocities, multi-year reference frames (ITRF2008, DTRF2008) do not consider

- periodic signals (e.g. seasonal)
- seismic and post-seismic signals (e.g. Peru 2001 / Chile 2010 / Japan 2011)
- other non-linear signals (e.g. antenna change).

These signals could be considered by

- approximate them with mathematical functions (e.g. sine/cosine, splines)
- applying loading models (e.g. atmosphere, hydrosphere)
- estimate **epoch reference frames**.

Motivation

daily (TUM) | 7day/28day (DGFI) | 24h session-wise (DGFI/IGG)

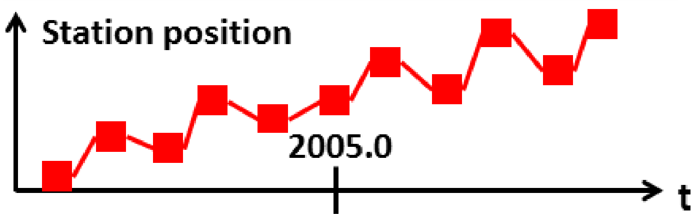
GPS-NEQ | SLR-NEQ | VLBI-NEQ | DORIS-NEQ

- time resolution: daily, weekly, …
- time span: 1994.0 to 2007.0
- different parameterization (EOP)

Analysis of time series

- Homogenization of time resolution
- Homogenization of EOP parameterization
- Selection and introduction of local ties (LTs)
- Realization of the geodetic datum
- Estimation of variance factors

epoch reference frames (7day/28day interval)



+ EOPs & SH coefficients up to d/o 2

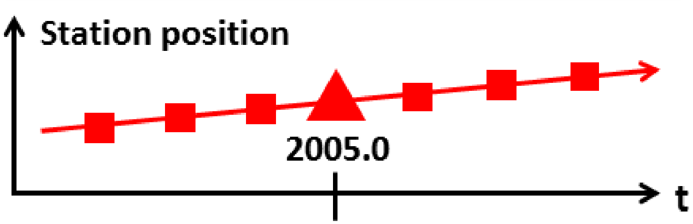
Analysis of time series

- Introduction of station velocities
- Homogenization of EOP parameterization
- Accumulation of technique-specific NEQs

GPS-TRF | SLR-TRF | VLBI-TRF | DORIS-TRF

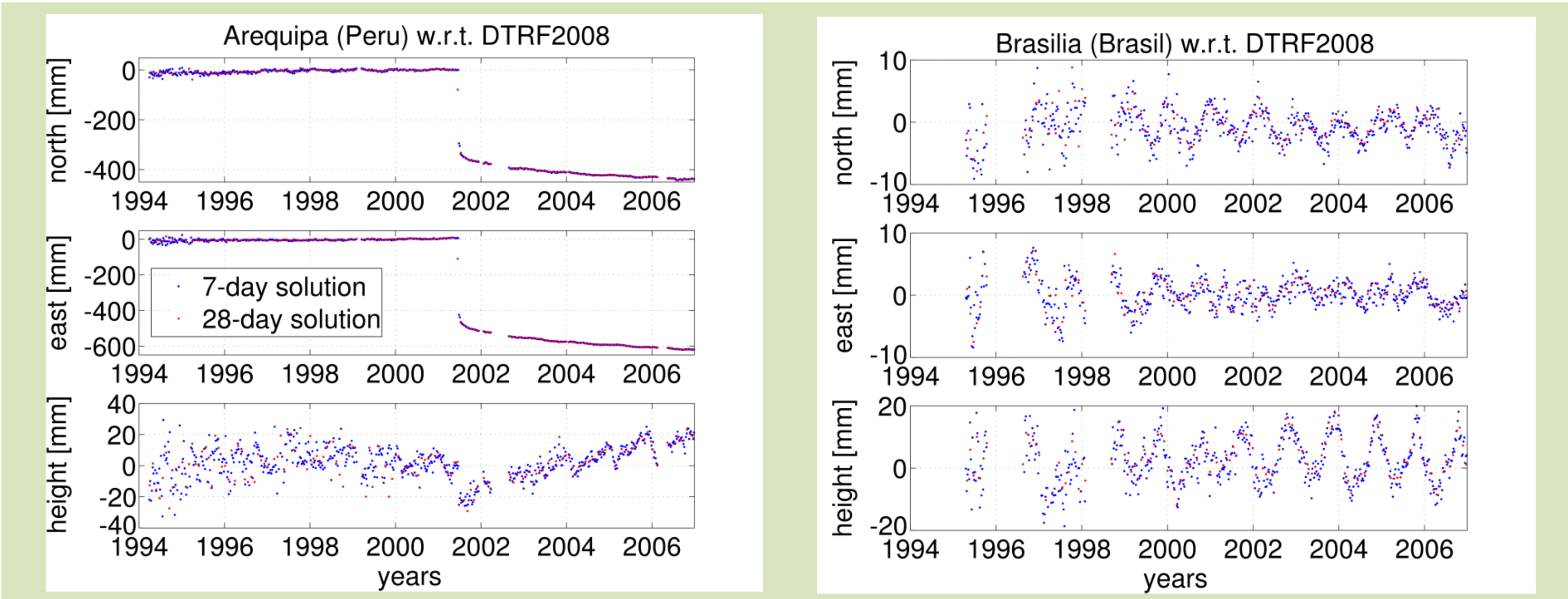
- Selection and introduction of local ties (LTs)
- Combination of station velocities
- Realization of the geodetic datum
- Estimation of variance factors

DTRF2008



+ EOPs

Motivation (7d/28d w.r.t. DTRF2008)



- significant jumps in north (**-29 cm**) and east (**-42 cm**) component
- change of the linear velocity in height component
- non-linear post-seismic behaviour
- seasonal signal in all three components (height: **2 cm**)
- amplitude not constant over time

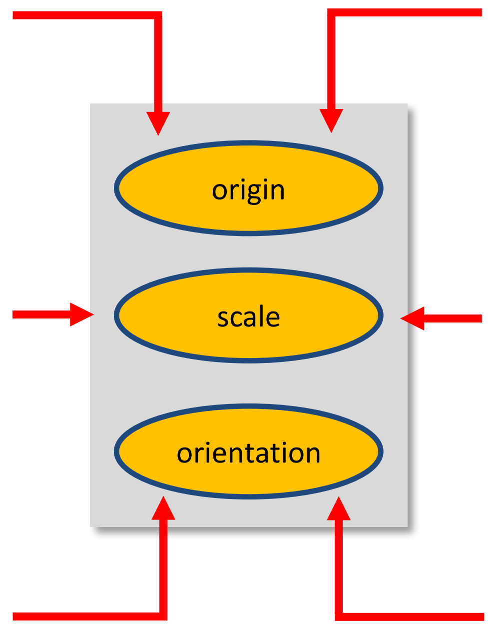
Datum definition

Epoch reference frames

SLR origin (C_{10}, C_{11}, S_{11})=0 via local ties to GPS & VLBI

combined **SLR**/VLBI scale via local ties to GPS

NNR condition over a subset of GPS sites via local ties to SLR & VLBI



IERS Conventions 2010 (Petit et al.)

no translations/translation rates w.r.t. SLR.

no scale factor /scale rate w.r.t. mean scale/scale rate of VLBI & SLR.

no rotations /rotation rates between ITRF2008 & ITRF2005 for a subset of sites.

Datum definition

How could we validate the datum of the estimated epoch reference frames?

TRF (t) ⟷ **DTRF2008 (2005.0)**

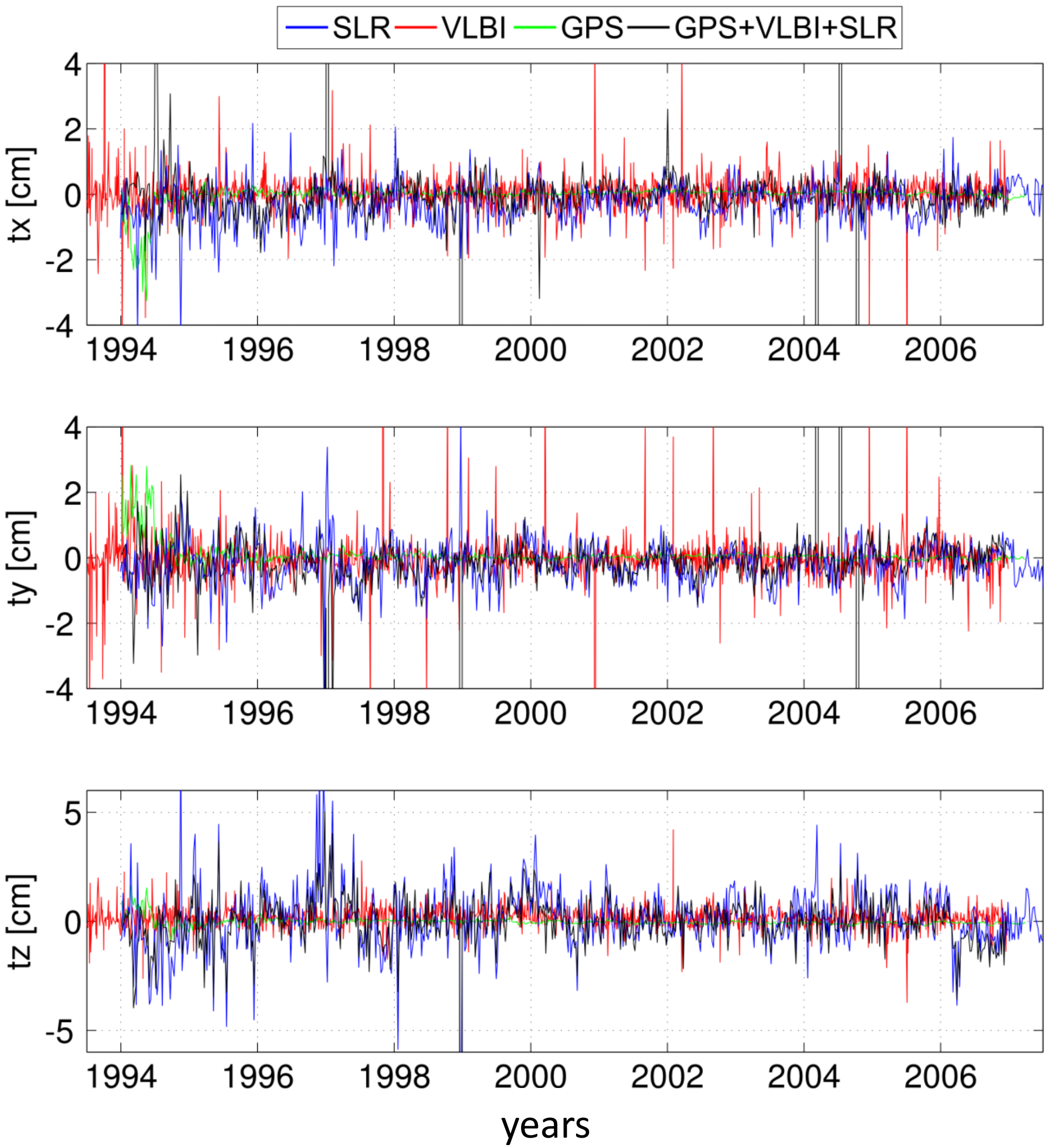
ITRF2008 (2005.0)

- Validation of the external accuracy of the TRFs by an epoch-wise 7P Helmert-Transformation of the estimated TRFs on the DTRF2008

origin	:	SLR / combination (GPS-/VLBI-part) → DTRF2008
scale	:	SLR / VLBI / combination (GPS-part) → DTRF2008
orientation	:	GPS / combination (SLR-/VLBI-part) → DTRF2008

origin

TRFs: translations w.r.t. DTRF2008



[cm]		SLR	comb. (GPS)	comb. (VLBI)
tx	Mean	-0.293	-0.055	-0.023
	WRMS	0.511	0.470	0.613
ty	Mean	-0.173	-0.142	-0.428
	WRMS	0.547	0.472	0.573
tz	Mean	0.093	0.095	-0.085
	WRMS	1.124	0.920	0.999

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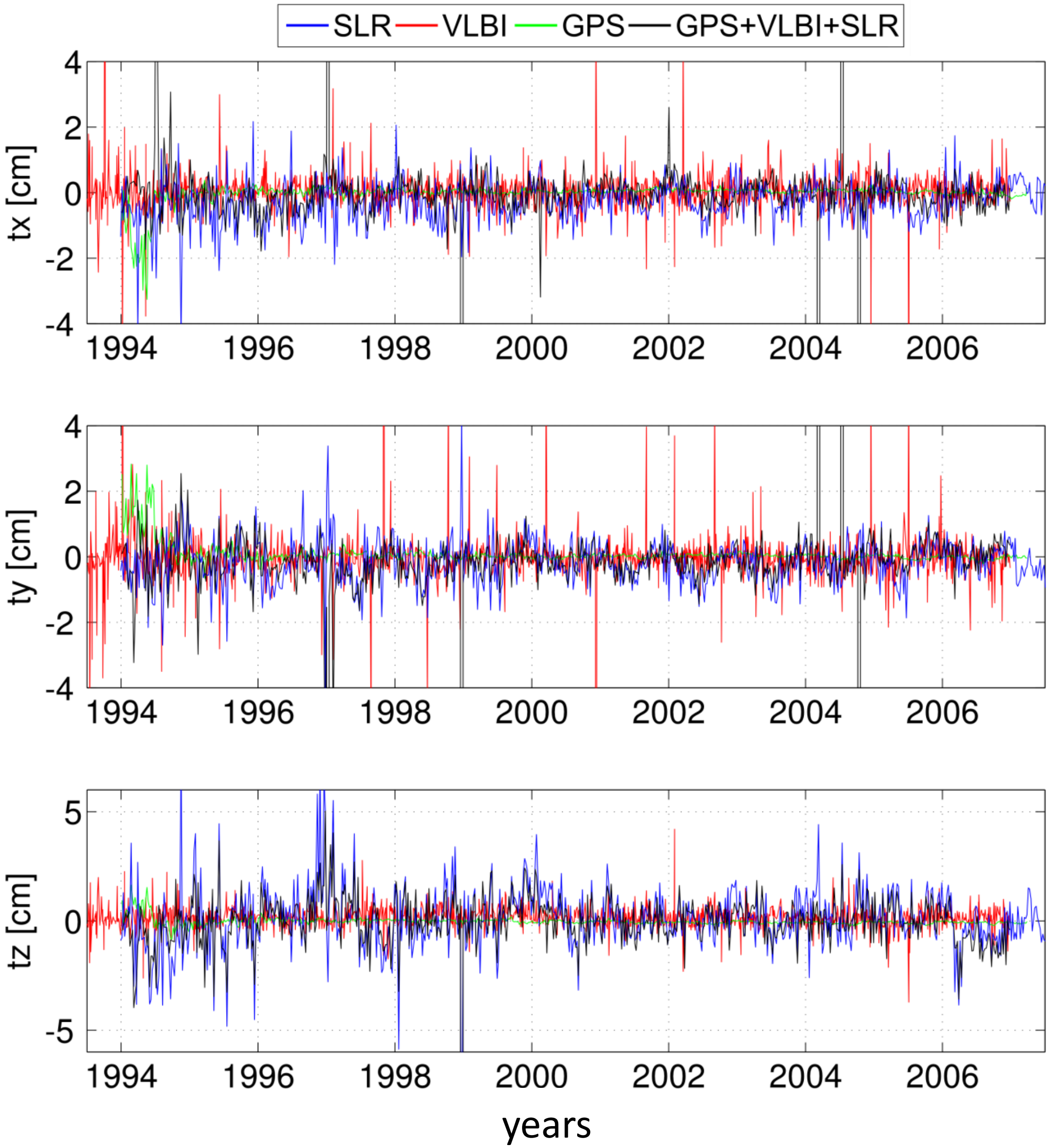
DGFI

TRFs: translations w.r.t. DTRF2008



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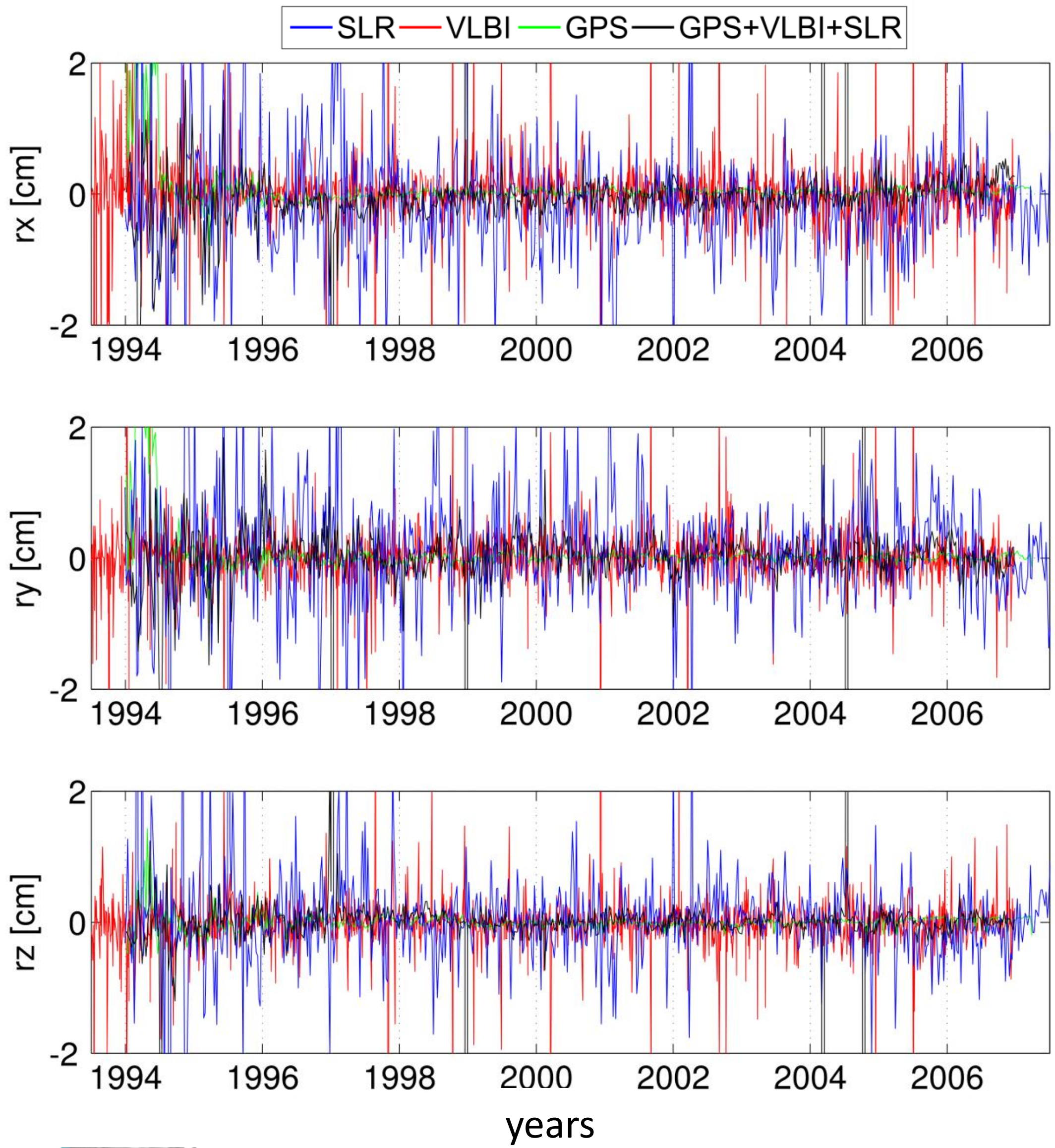
Combination show good agreement with DTRF2008

VLBI-part of the combination shows an offset in the y-comp. of the origin.

orientation

TRFs: rotations w.r.t. DTRF2008



[cm]	GPS	comb. (SLR)	comb. (VLBI)
Mean	0.083	-0.090	-0.312
WRMS	0.140	0.426	0.337
Mean	0.066	0.174	-0002
WRMS	0.131	0.484	0.423
Mean	-0.008	-0.032	0.243
WRMS	0.073	0.473	0.362

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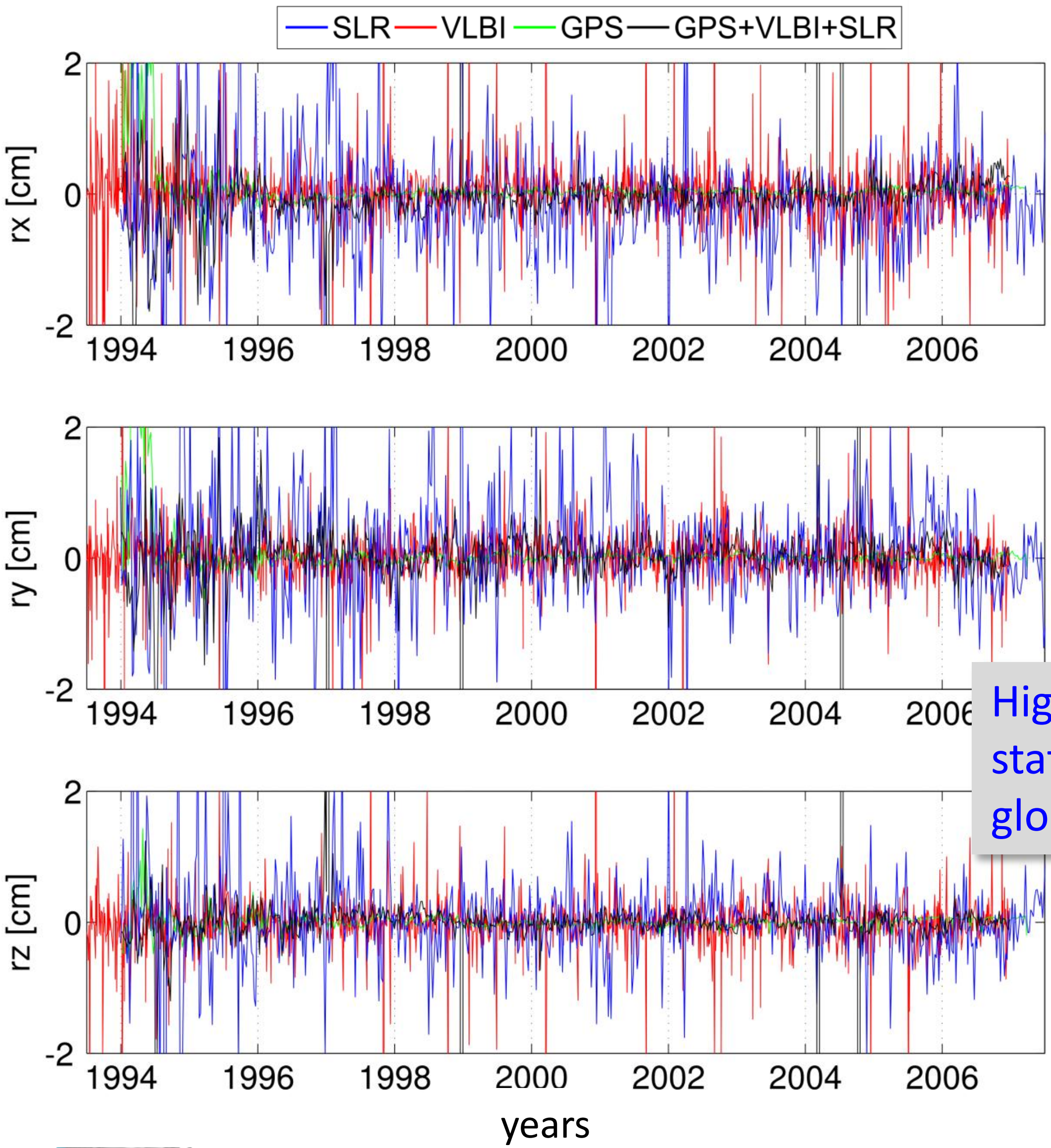
TRFs: rotations w.r.t. DTRF2008



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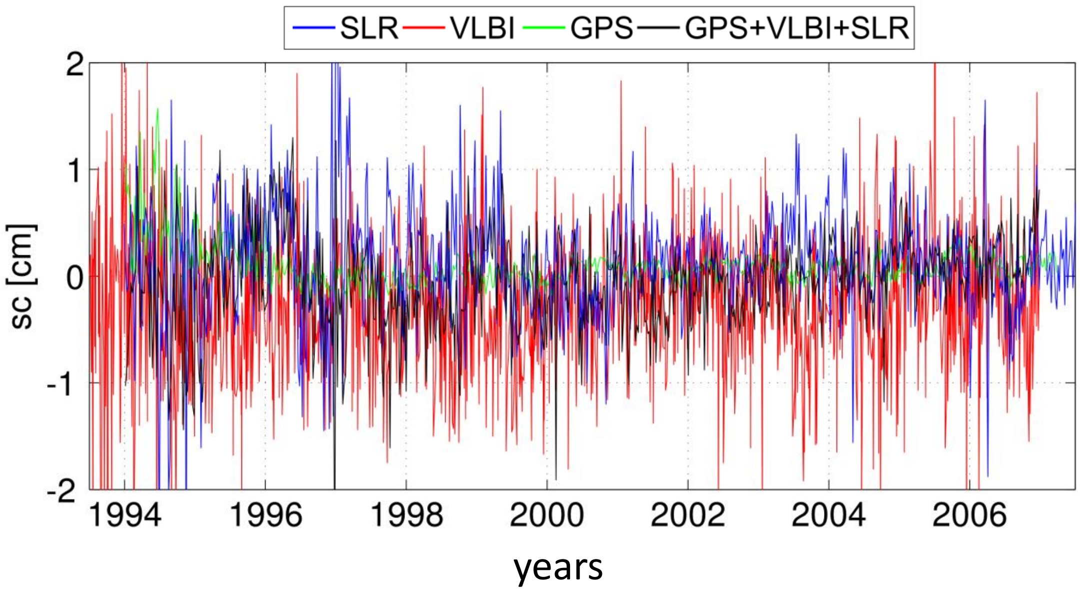
Mean	-0.008	-0.032	0.243
WRMS	0.073	0.473	0.362

Higher scatter due to inhomogeneous station distribution and accuracy/ global distribution of the used LTs

scale

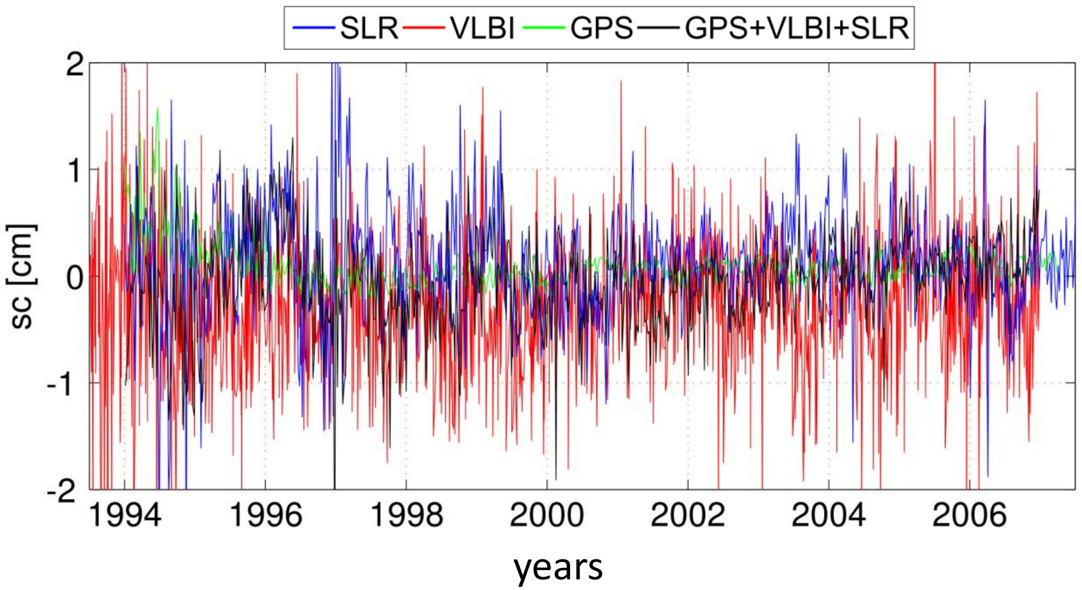
TRFs: scale factors w.r.t. DTRF2008



[cm]	SLR	VLBI	comb. (GPS)
Mean	0.138	-0.274	-0.081
WRMS	0.420	0.527	0.403

scale

TRFs: scale factors w.r.t. DTRF2008



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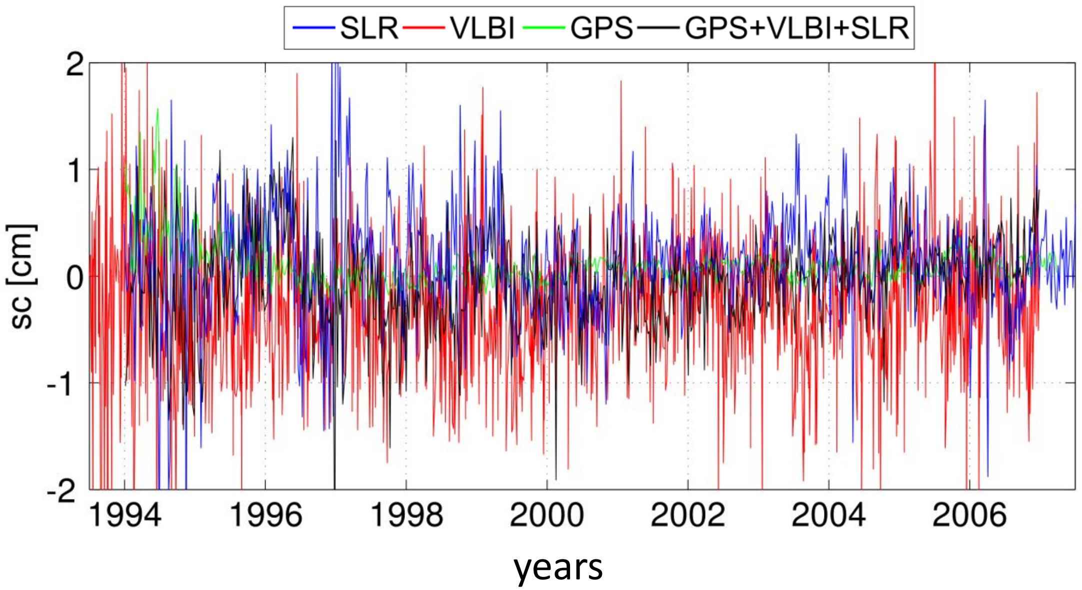
Mean	0.138	-0.274	-0.081
WRMS	0.420	0.527	0.403

Combination gets mean scale factor of SLR & VLBI.

scale

TRFs: scale factors w.r.t. DTRF2008



[cm]	SLR	VLBI	comb. (GPS)
Mean	0.138	-0.274	-0.081
WRMS	0.420	0.527	0.403

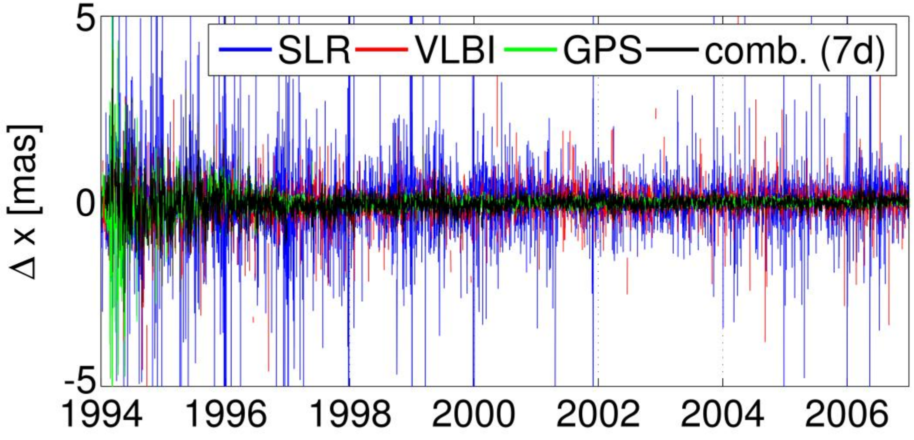
Combination gets mean scale factor of SLR & VLBI.

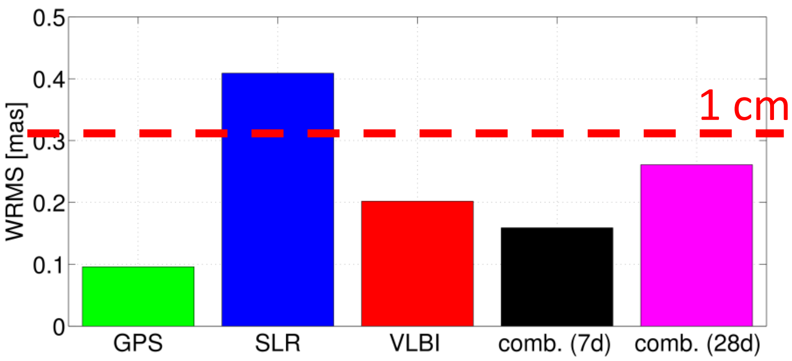
origin — The mean accuracy of the x- & y-component is about 5 mm, the accuracy of the z-component is about 1 cm (including annual signal)

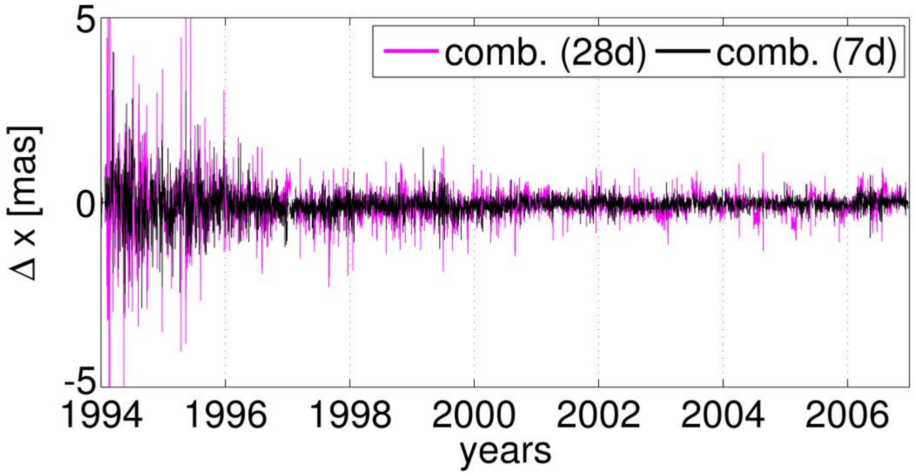
scale — The scale factor of the combination is the mean of the SLR- & VLBI-scale factor. The scale difference between SLR & VLBI is 4 mm.

orientation — The accuracy of the transferred orientation from GPS to SLR & VLBI is about 5 mm (due to station distribution and local ties).

EOPs: terrestrial pole (x) w.r.t. IERS 08 C04

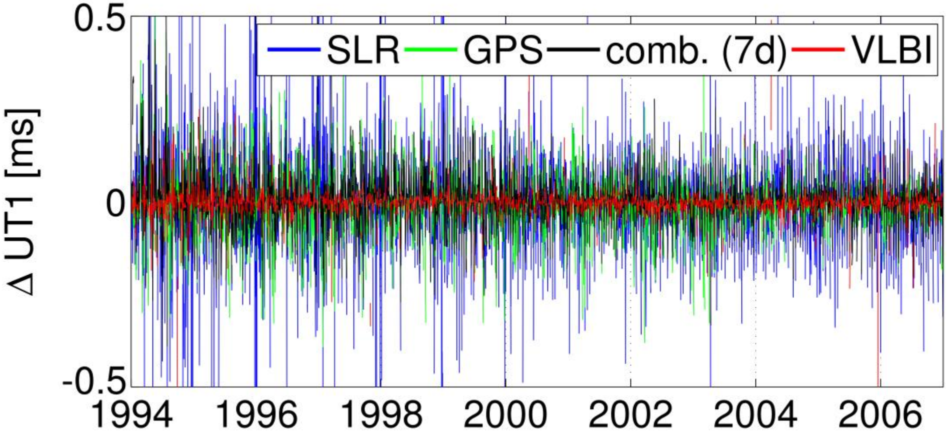


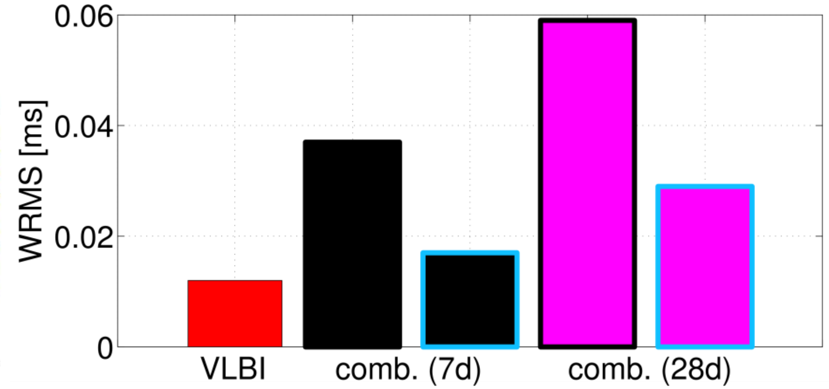


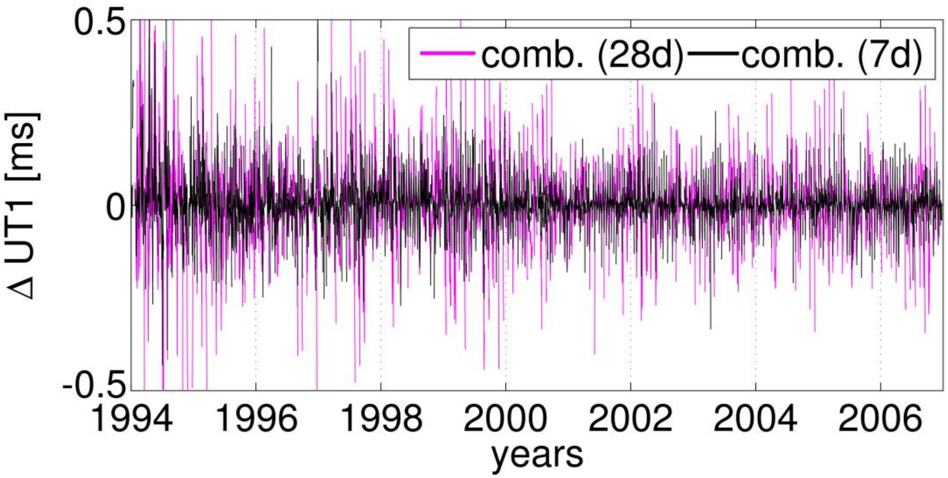


- The WRMS of SLR is higher than the WRMS of GPS & VLBI
- The pole coordinates of SLR at the borders of the used arc are not well estimated
- The WRMS of both combinations is less than 1 cm

EOPs: UT1 w.r.t. IERS 08 C04



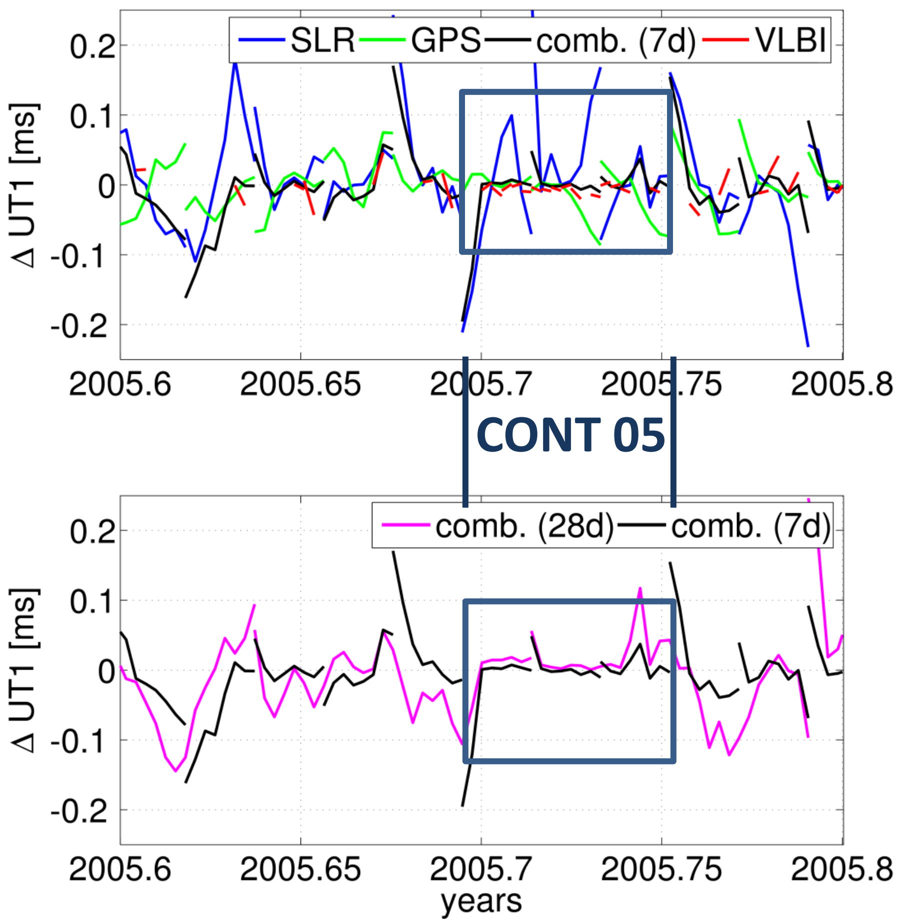




all epochs — combined solution with only SLR & GPS contributing to it

VLBI epochs — combined solution with all three techniques contributing to it

EOPs: UT1 w.r.t. IERS 08 C04



GPS/SLR provide a LOD which is

- affected by deficiencies in the orbit modeling
- correlated with Earth oblateness & rate of ascending node

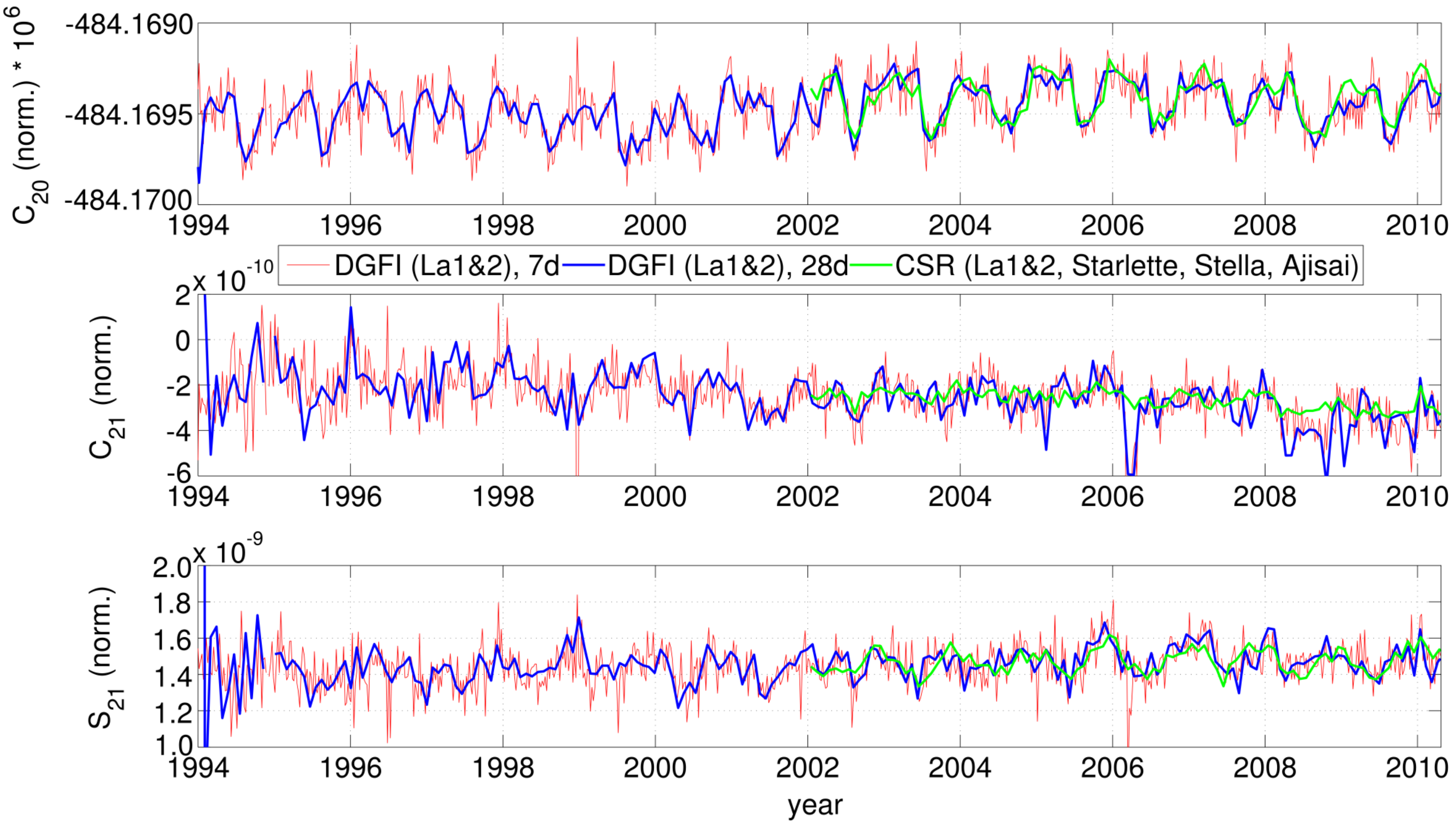
→ UT1 shows systematic drift w.r.t. VLBI

VLBI observes UT1 directly but not continuously (24h sessions only on Monday on Thursday)

The combination of GPS & SLR show drift in UT1, whereas combination of all three techniques shows no drift (e.g. CONT05, blue box)

More information on the poster: "Adjustment of EOP and gravity field parameter from SLR observations"

SH coefficients d/o 2: C_{20}, C_{21} & S_{21}



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Conclusions

Terrestrial reference frame:

- SLR is the primary technique to provide information about origin and scale for global TRFs; therefor SLR is essential for the combination
- The accuracy of the datum realization depends strongly on the selection and accuracy of the used local ties

Earth orientation parameters:

- SLR pole coordinates have a WRMS of about 0.5 mas (much more than VLBI/GPS)
- SLR provides an UT1 which is affected by orbit systematics (see poster)

Gravity field parameter:

- Coefficients of d/o 2 show good agreement with CSR results although the CSR solution contains much more satellites

Thank you for your attention!

Adjustment of EOP and gravity field parameter from SLR observations

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Motivation

Satellite Laser Ranging (SLR) is the primary technique to estimate consistently station positions, Earth Orientation Parameters (EOP) and orbit parameters of the satellites together with the spherical harmonics of low degree and order of the Earth gravity field. The big effort of the common adjustment of these parameters is the high correlation of the orbit parameters (e.g. Kepler elements, empirical accelerations), length of day (LOD) as the first derivative of Universal Time (UT) and the gravity field parameter C_{20}. The relation between these parameters is given in equation (1).

$$\dot{\Omega}\Big|_{secular} = \frac{3}{2}\sqrt{\frac{GM}{a_e^3}}\left(\frac{a_e}{a}\right)^{\frac{7}{2}}\frac{C_{20}\cos i}{(1-e^2)^2}, \quad (1)$$

where $\dot{\Omega}$ is the rate of change of the ascending node, a_e is the major axis of the Earth, GM is the gravity constant multiplied by the mass of the Earth and a, e, i are the major axis, the eccentricity and the inclination of a satellite.
In this study we discuss different solutions (7-day and 28-day arc, one-satellite and multi-satellite constellation) and evaluate the correlations and the stability of the estimated parameters.

Solution types

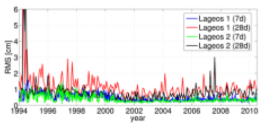

Fig 1:Fits of the 7-day/28-day orbits of Lageos 1 and 2. Only observations from official core stations of the International Laser Ranging Service (ILRS) are considered.

	Lageos 1	Lageos 2
7-day arc	0.46	0.38
28-day arc	1.04	0.75

Tab. 1: Mean RMS values [cm] of the orbit fits shown in Fig. 1.

Fig. 1 shows the different fits of the satellite orbits of Lageos 1 and 2. The mean RMS values are given in Tab. 1. The accuracy of the 7-day arcs is at the level of five millimeters whereas the accuracy of the 28-day arcs is at the level of one centimeter. Fig. 2 points out that a reduction of the correlation of C_{20} and Ω could be achieved using longer arcs or including more than one satellite. The most uncorrelated parameters could be estimated in solutions containing two satellites with an arc length of 28 days.

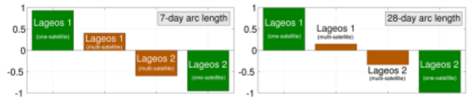

Fig. 2: Mean correlations of C_{20} and Ω for one-satellite solutions (green-coloured) and multi-satellite solutions (orange-coloured). In the left part of Fig. 2 the mean correlations of solutions with an arc length of 7 days are shown, whereas the right part illustrates the same situation for a 28-day arc.

Earth Orientation Parameters (1)

The parameterization of UT1 and LOD is the same in all solutions. Since SLR is not able to determine UT1, the offsets are extrapolated with LOD to 0h epochs of a piecewise linear polygon. At the mid-epoch of the arc, one UT1 value is fixed to a priori (IERS 08 C04).
Because of the high correlations expressed in equation (1), errors or non-modelled perturbations of the satellites systematically affect the estimated LOD and the UT1 values respectively (Fig. 3).

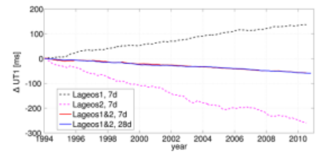

Fig. 3: Accumulated differences of UT1 w.r.t. IERS 08 C04 over a time span of 16.5 years. The individual solutions of Lageos 1 and 2 with an arc length of 28 days are not displayed (see Tab. 2).

Fig. 3 shows a systematic drift for UT1 w.r.t. the IERS 08 C04 time series. Tab. 2 summarizes the different mean drifts for each solution.

	Lageos 1	Lageos 2	Lageos 1&2
7-day arc	8.23	-17.57	-3.63
28-day arc	-38.02	-26.93	-3.97

Tab. 2: Mean drifts of UT1 [ms/y] w.r.t. IERS 08 C04 for the different solutions.

The spurious drifts of the 7-day arc one-satellite solution have an opposite sign and a nearly constant ratio which could be explained with equation (1). Since all parameters except the inclination of Lageos 1 and 2 are approximately the same, the sign and ratio depends on the $\cos i$ term of equation (1). The one-satellite solution with a 28-day arc doesn't show this characteristics. Although the mean correlation of C_{20} and Ω is reduced by using a 28-day arc multi-satellite solution (Fig. 2), there still remains a systematic drift in Fig. 3.

Gravity field parameter

The estimated gravity field coefficients of the solutions with the data of two satellites show a very good agreement with a solution of the Center for Space Research (CSR) although the CSR solution contains observations to three more satellites than the DGFI solutions (Fig. 4).

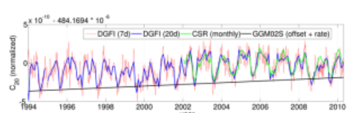

Fig. 4: Estimated normalized C_{20} coefs. The DGFI solutions contain only data from Lageos 1 and 2 whereas the solution of CSR includes in addition data from Stella, Starlette and Ajisai.

Earth Orientation Parameters (2)

The estimated gravity field coefficients of the multi-satellite solutions (Fig. 4) are then, in a second iteration step, set up as a priori values for C_{20} to reduce the drift of the UT1 values resulting from a slightly wrong C_{20}. The results are summarized in Fig. 5 and Tab. 3. The one-satellite solutions benefit tremendously in this second iteration step. The mean correlation of C_{20} and Ω is reduced to 0.05 for all solution types.

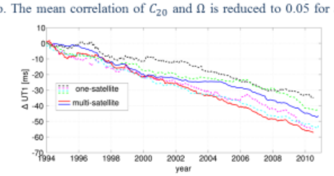

Fig. 5: Accumulated differences of UT1 w.r.t. IERS 08 C04 over a time span of 16.5 years. All solutions of the second iteration show a systematic drift in the order of -2.8 to -3.9 ms/y (Tab. 3).

Nevertheless, Fig. 5 and Tab. 3 show that all solutions contain a spurious drift w.r.t. IERS 08 C04. This could be due to the fact that an offset of LOD could also be caused by a periodically occurring perturbation perpendicular to the orbit plane of the satellite (cross track direction).

	Lageos 1	Lageos 2	Lageos 1&2
7-day arc	-2.78	-3.23	-3.62
28-day arc	-3.55	-3.87	-3.70

Tab. 3: *Mean drifts of UT1 [ms/y] w.r.t. IERS 08 C04 for the different solutions.*

Conclusions & Future Work

The main part of the UT1 drifts in Fig. 3 are induced by the fact that the a priori C_{20} values of the first iteration step (here GGM02S, see Fig. 4) leads to a wrong $\dot{\Omega}$ and as a consequence of this to a wrong LOD. If we use the C_{20} values of a multi-satellite solution (see also Fig. 4) instead of that we get much lower drifts (Fig. 5). These remaining drifts have the same sign and therefor couldn't be excited by a wrong C_{20}.
The next step would be to study the relationship between perturbations offending the satellite in cross track direction. To improve the solution furthermore we want to introduce other geodetic satellites like Etalon 1 and 2, Stella, Starlette and Ajisai. We also want to estimate variance factors in the combination of different satellites in order to improve the relative weighting.

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