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Consistent Realization of CRF, TRF, and EOP

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Introduction

The ICRF and ITRF are the realizations of the ICRS and ITRS, respectively. The EOP are the parameters linking these two frames, and they are common parameters between the space geodetic techniques whose observations are used to estimate the ICRF and ITRF. Both realizations have been computed separately based on different data sets and by fixing parameters corresponding to the other frame, respectively. This causes inconsistencies between the frames themselves but also between the EOP series resulting from the two computations even though they should be the same. To gain consistency between the two reference frames, a common adjustment is performed. This implies the usage of homogeneously processed input data, a consistent parameterization and that no parameters are fixed. The realizations benefit in many ways: consistency of the frames and EOP is reached, poorly estimated parameters of one technique could be strengthened by information from the other techniques and consequently the quasar coordinates are improved. In this study, we simultaneously estimate the celestial and terrestrial reference frames together with the full set of EOP based on homogeneously processed GNSS, VLBI, and SLR data over a time period of 11 years (2005.0-2016.0). We present the impact of various combination setups for the EOP and for the local tie handling and discuss the benefits of a simultaneous estimation.

Input data & parameters

Table 1. Input data

	GNSS	SLR	VLBI
Software	Bernese (CODE)	DOGS-OC (DGFI-TUM)	OCCAM (DGFI-TUM)
Resolution	daily	weekly	session-wise
Time span	January 2005 - December 2015		

Table 2. Estimated parameters

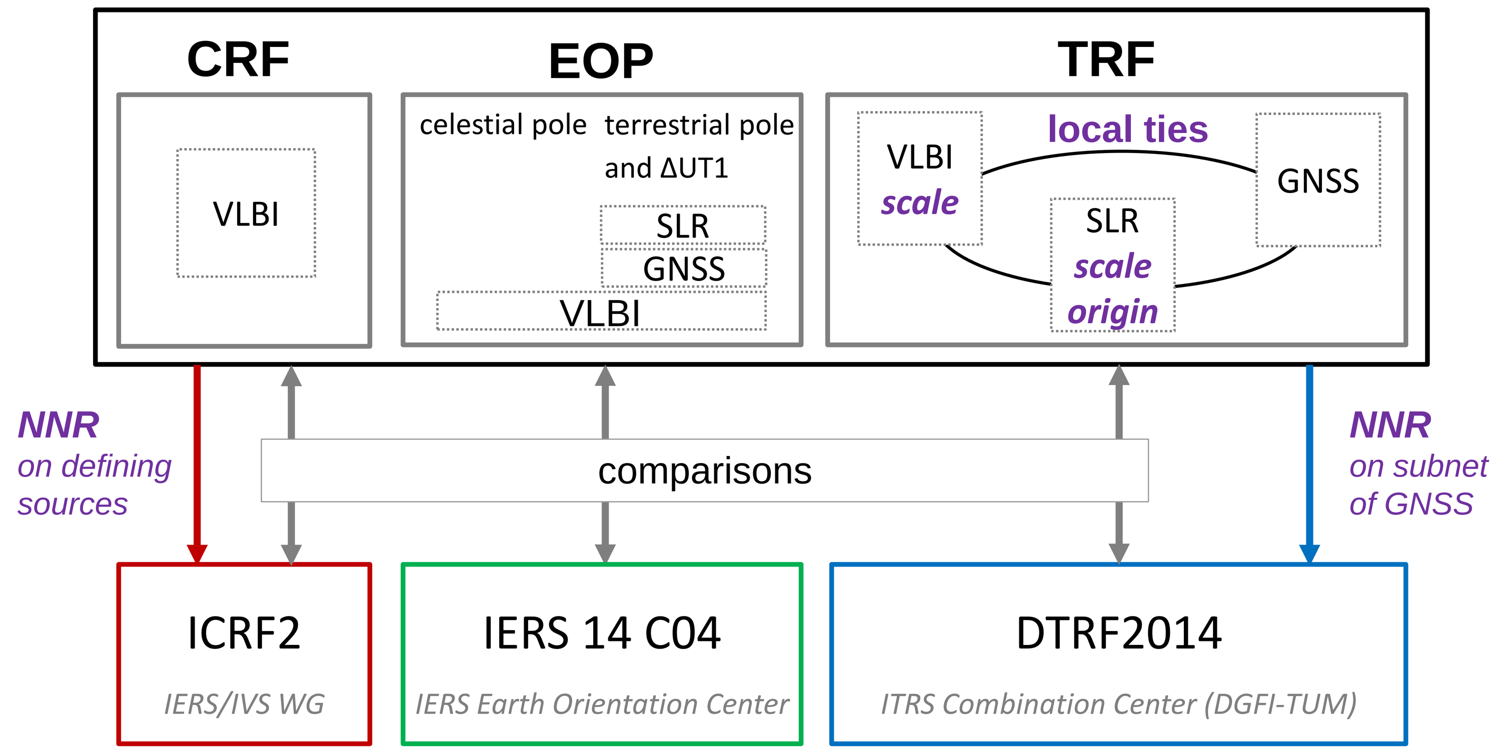
	GNSS	SLR	VLBI	Combination
Station coordinates & velocities	X	X	X	X
Source coordinates			X	X
Terrestrial x-/y-pole	X	X	X	X
UT1-UTC	(X)	(X)	X	X
Celestial X-/Y-pole			X	X

Abbreviation list

EOP: Earth Orientation Parameters
GNSS: Global Navigation Satellite System
IERS: International Earth Rotation and Reference Systems Service
ICRF/ITRF: International Celestial/Terrestrial Reference Frame
ICRS/ITRS: International Celestial/Terrestrial Reference System
IVS: International VLBI Service for Geodesy and Astrometry
LT: Local tie
SLR: Satellite Laser Ranging
VCS: VLBA Calibrator Survey
VLBA: Very Long Baseline Array
VLBI: Very Long Baseline interferometry

Combination

Consistent combination at the normal equation level



The origin is realized in the SLR-only solutions, and the scale is realized in the SLR-only and VLBI-only solutions intrinsically.

Combination setups

- **Selections of LT and velocity equality**

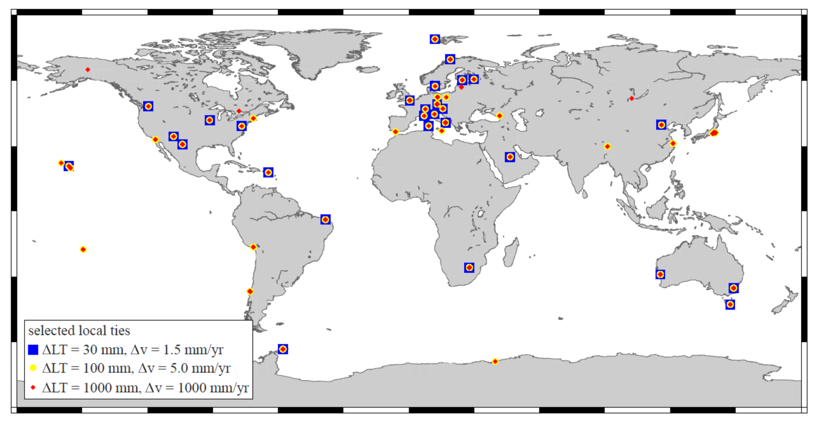


Fig 1. Selected co-located sites

$\Delta LT = |\mathbf{LT}(t_{LT}) - (\mathbf{X}_1(t_{LT}) - \mathbf{X}_2(t_{LT}))|$

The reference point difference vectors between single-technique multi-year solutions $(\mathbf{X}_1(t_{LT}) - \mathbf{X}_2(t_{LT}))$ are compared with ITRF2014 LTs ($\mathbf{LT}(t_{LT})$). If ΔLT is smaller than the defined values (Table 3) , the LT is introduced in the combination. The same holds for the velocities. The full set of EOP is included in these combinations.

Table 3. Solution setups for different LT selections and number of introduced LTs

Sol.	ΔLT [mm] / Δv [mm/yr]	GNSS/ GNSS	VLBI/ VLBI	GNSS/ VLBI	GNSS/ SLR	SLR/ VLBI	Total
A	30 / 1.5	32	-	23	30	4	89
B	100 / 5.0	44	2	55	60	7	167
C	1000 / 1000	47	4	135	82	14	282

- **EOP combination setups**

Four different EOP combination setups are tested to check the influence of combined EOP on the CRS realization. For these combination, the identical LTs are introduced following the condition of Solution **A**, i.e. $\Delta LT < 30$ mm and $\Delta v < 1.5$ mm/yr.

Table 4. Solution setups for different EOP combination

Sol.	Which EOP are combined?
A-C	all
D	none
E	ΔUT1 only
F	x/y-pole only

Main Results

Impact of LT selections

- TRF: SLR and VLBI is more sensitive on LT selections than GNSS. SLR and VLBI scale agrees well for solution **A** (Fig 2).
- CRF: The CRF components (Eq. 1) have most impacts when $\Delta LT < 1000$ mm is used.
- EOP: The EOP are less sensitive to different LT selections

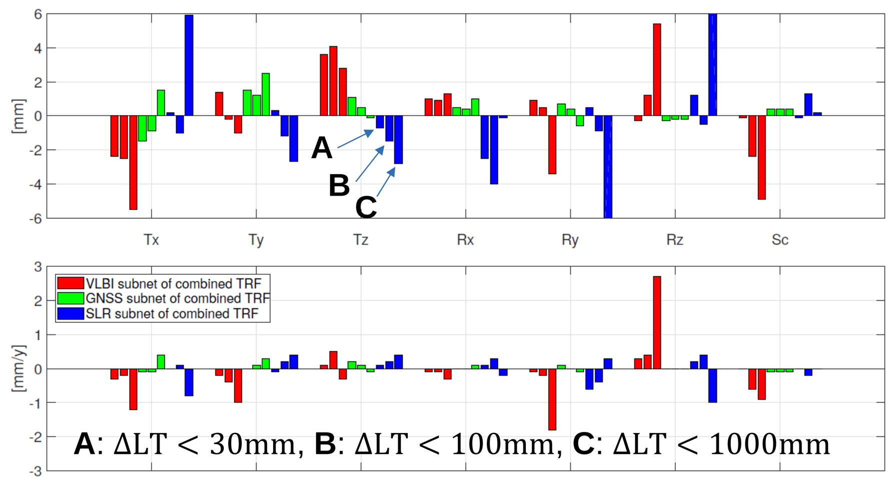
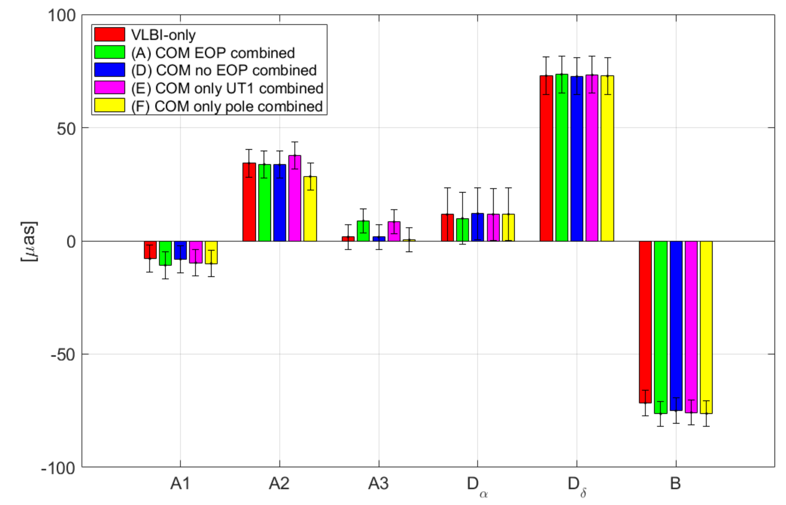


Fig 2. Estimated offsets (upper) and rates (lower) of the Helmert transformation parameters (the technique-specific subnets of the combined TRF solution w.r.t. single-technique multi-year solutions).

Impact of EOP combination setups



$$\Delta\alpha = A_1\, tan\delta\, cos\alpha + A_2\, tan\delta\, sin\alpha - A_3 + D_\alpha(\delta - \delta_0)$$

$$\Delta\delta = -A_1\, sin\alpha + A_2\, cos\alpha + D_\delta(\delta - \delta_0) + B_\delta$$

[Eq. 1]

3 rotations, 2 slopes and 1 bias

Fig 3. Transformation parameters w.r.t ICRF2 (Eq. 1).

- If *no EOP are combined* (**D**), the CRF is hardly influenced by the combination.
- *The combination of the terrestrial pole coordinates only* (**F**) improves the agreement with ICRF2 (A2 and A3 components agree better than the VLBI-only solution).
- *The combination* (**A** and **E**) *of ΔUT1* mainly affects the CRF z-rotation.
- After combination, the standard deviations of the source coordinates are improved, especially for VCS sources and newly added sources (not included in ICRF2 but mostly observed in the VCS-II campaign).

Conclusion

- A consistent realization of CRF, TRF, and EOP by combining VLBI, SLR and GNSS data (2005-2015) is performed.
- LT selection mostly affects the TRF (best results for LT-threshold of 3 mm and 1.5 mm/yr for velocities); minor effects on CRF and EOP.
- The estimated CRF benefits from combining terrestrial pole coordinates, whereas the combination of ΔUT1 causes a rotation around the z-axis.
- The standard deviations of the estimated CRF benefit from the combination (in comparison with the VLBI-only solution)
- **Further detailed investigations can be found in Kwak et al. (2018):**

Kwak, Y., Bloßfeld, M., Schmid, R. et al. (2018) Consistent realization of Celestial and Terrestrial Reference Frames. J Geod. https://doi.org/10.1007/s00190-018-1130-6