The consistency of the current conventional celestial and terrestrial reference frames and the conventional EOP series

Robert Heinkelmann[1], Santiago Belda-Palazón[2,1] , José M. Ferrándiz[2] , Harald Schuh[1]

1: Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Potsdam, Germany, heinkelmann@gfz-potsdam.de

2: University of Alicante, Departamento de Matemática Aplicada, Alicante, Spain

1. MOTIVATION

For applications in Earth sciences, navigation, and astronomy the celestial (ICRF) and terrestrial (ITRF) reference frames as well as the transformations among them (EOP) have to be consistent.

The current conventional frames and EOP are

- ITRF2008 based on VLBI, SLR, GNSS and DORIS data until 2008
- ICRF2 based on VLBI data until 2009
- IERS 08 C04 until 2008 consistent with ITRF2008, then extended using a weighted combination of EOP solutions and combinations

A complication for the assessment of the consistency among frames and EOP is that the frames are global parameters, while the EOP are determined as local parameters.

2. APPROACH

Various consistency studies are carried out. First of all, the effect of unmodeled geophysical signals in the regularized coordinates of ITRF2008 is assessed: fixing ("FIXED") and not fixing ("FREE") station coordinates on catalogue values. Next, the EOP are determined using the same VLBI data but fixing different TRFs. Global rotations (from similarity transformations) among frames are compared with the mean EOP differences. Finally, the consistency is evaluated using different a priori EOPs and celestial reference frames.

- Software: VieVS with adaptations (GFZ internal version)
- Data: geometrically stable sessions of the GFZ VLBI solution (ITRF2013 contribution) from 1984-07-09 to 2013-12-31

TRF	Reference	Comment
ITRF2000	Altamimi et al., 2002	Data until 2000
ITRF2005	Altamimi et al., 2007	Data until 2005
ITRF2008	Altamimi et al., 2011	Data until 2008
VTRF2008	Böckmann et al., 2010	Data until 2008, VLBI-only frame
DTRF2008	Seitz et al., 2012	Data until 2008, different combination approach

Table 1. Different TRFs used in this study

3. UNMODELED GEOPHYSICAL SIGNALS

The differences of the TRFs are assessed by fixing station coordinates on catalogue values. Since station coordinates are usually estimated in VLBI analyses we first assess the effect of this approach. Comparing FIXED vs. FREE w.r.t IERS 08 C04 results in

- strong decrease of the **correlation** and **large rms** for x_{pol}, y_{pol} and slightly for dUT1 (table 2)
- **drifts** show similar values using FIXED or FREE approach (exception: y_{pol})
- celestial pole coordinate ΔY shows a small drift (table 2).

EOP	ITRF2008 FIXED			ITRF2008 FREE			FIXED vs FREE
	shift	drift	rms	shift	drift	rms	correlation
Δx_{pol}(μas)	-17.4	-2.5 ± 0.5	289.5	-28.2	-2.5 ± 0.5	430.8	0.49
Δy_{pol}(μas)	-0.6	1.2 ± 0.4	238.4	-34.1	4.1 ± 0.5	420.3	0.44
ΔdUT1(μs)	5.7	-0.2 ± 0.03	16.6	6.0	-0.2 ± 0.03	26.0	0.61
ΔX(μas)	-1.2	0.6 ± 0.2	124.5	0.7	0.4 ± 0.2	127.5	0.95
ΔY(μas)	14.5	-3.2 ± 0.2	133.0	15.2	-3.3 ± 0.2	132.7	0.94

Table 2. EOP residuals (μas or μs for UT1) w.r.t. IERS 08 C04 between solutions using fixed and free ITRF2008 coordinates. Shift (referred at epoch 2000.0) and linear trends (yr^{-1}) are estimated by WLS. Correlation between both series is also shown.

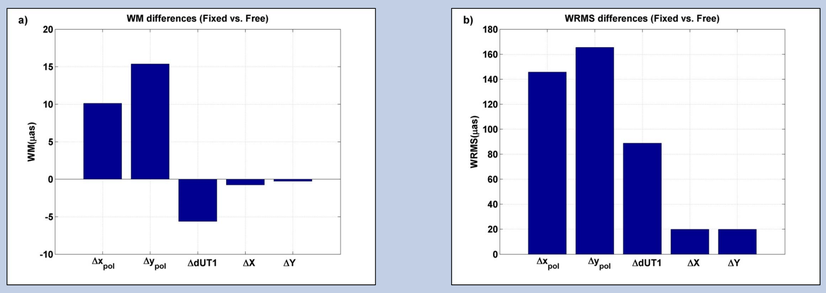

Figure 1. (a) WM and (b) WRMS differences between EOP estimated using fixed and free ITRF2008 coordinates

Weighted Mean (WM): Fixation of ITRF catalogue values causes insignificant weighted mean differences of the EOP.

Weighted Root Mean Squared (WRMS): Fixation of ITRF catalogue values causes scatter of about 150 μas on the terrestrial pole coordinates (x_{pol} and y_{pol}), 90 μas on dUT1, and 20 μas on the celestial pole coordinates.

4. EOP DIFFERENCES USING DIFFERENT TRF

ITRF2000: large WM, WRMS and shifts (x_{pol}, y_{pol} and dUT1) w.r.t. ITRF2008

VTRF2008: large WM (140 μas), WRMS (120 μas), and drift (-18.6 μas yr^{-1}) for y_{pol} (single-technique vs. multi-technique)

DTRF2008: large WM (160 μas) for dUT1, what is remarkable because both TRF are based on the same data

Celestial pole coordinates do not show significant effects (WM and WRMS about 5 μas and 10 μas respectively)

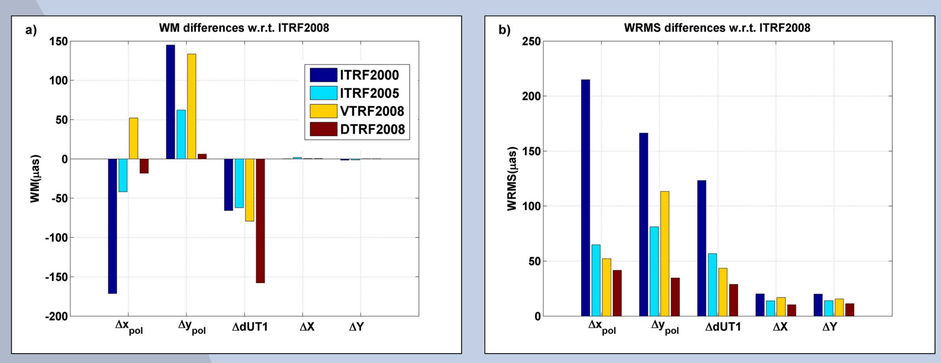

Figure 2. (a) WM and (b) WRMS differences between EOP estimated by different TRFs w.r.t ITRF2008

Table 3. Differences in EOP (μas or μs for UT1) between solutions using different TRFs w.r.t. ITRF2008. Shift (referred at epoch 2000.0) and linear trends (yr^{-1}) are estimated by least squared (LS).

TRF	Δx_{pol} (μas)			Δy_{pol} (μas)			ΔdUT1 (μs)			ΔX (μas)			ΔY (μas)		
	shift	drift	rms	shift	drift	rms	shift	drift	rms	shift	drift	rms	shift	drift	rms
$ITRF2005_{fixed}$	10.9	4.8 ± 0.3	129.7	-33.2	-7.6 ± 0.3	143.1	6.8	-0.4± 0.01	6.6	-2.5	0.1 ± 0.1	30.6	1.2	0.01 ± 0.1	35.9
$ITRF2000_{fixed}$	92.1	16.7 ± 0.9	344.9	-143.5	-7.4 ± 1.2	460.4	5.5	-0.2 ± 0.05	18.5	-1.1	0.1 ± 0.1	31.6	0.9	0.1 ± 0.1	38.9
$VTRF2008_{fixed}$	-28.2	-5.1 ± 0.3	124.4	-38.8	-18.6± 0.2	92.8	6.1	-0.2 ± 0.01	5.3	-1.0	0.1 ± 0.1	36.0	0.4	-0.2 ± 0.1	40.3
$DTRF2008_{fixed}$	39.3	-4.3 ± 0.3	101.1	-4.5	0.9 ± 0.2	76.0	11.3	-0.1 ± 0.01	4.3	-0.5	0.1 ± 0.1	28.4	0.5	-0.1 ± 0.1	34.4

5. GLOBAL ROTATIONS (SIMILARITY TRANSFORMATION): ITRF2005 W.R.T. ITRF2008

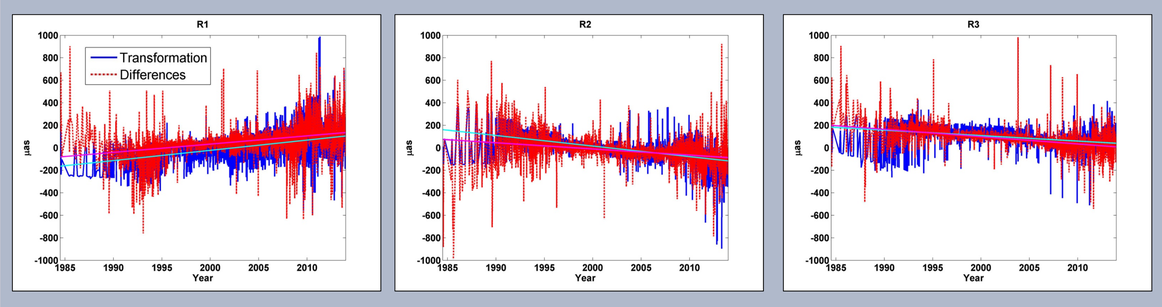

Figure 3 and table 4. Global rotations (R1, R2, R3) for each VLBI session from similarity transformation versus ERP differences between ITRF2005 w.r.t. ITRF2008. Shift (referred at epoch 2000.0) and drift (yr^{-1}) are shown.

	Transf. (μas)		Differ. (μas)		Comparison
	shift	drift	shift	drift	std (μas)
R1	-22.4	9.1±0.3	33.0	7.3±0.3	132.6
R2	15.6	-9.4±0.2	-10.1	-5.5±0.3	118.4
R3	108.6	-4.9±0.2	99.3	-6.5±0.2	95.3

6. EOP DIFFERENCES USING DIFFERENT A PRIORI EOP

ICRF2 ITRF2008

- **Case1:** IERS 08 C04
- **Case 2:** ERP: IERS 08 C04, IAU 2000/2006 (no FCN model)
- **Case3:** USNO FINALS

EOP	Case 2 vs. Case 1			Case 3 vs. Case 1		
	shift	drift	rms	shift	drift	rms
Δx_{pol}	2.2	-0.3±0.2	66.0	2.0	-0.3±0.2	90.7
Δy_{pol}	-2.7	0.3±0.1	52.8	-3.7	0.5±0.2	77.4
ΔdUT1	0.0	0.0±0.01	3.2	-0.1	0.0±0.01	7.0
ΔX	-36.1	-1.9±0.5	174.7	2.3	-0.3±0.2	61.4
ΔY	92.5	-0.5±0.5	180.7	-1.8	0.3±0.1	64.4

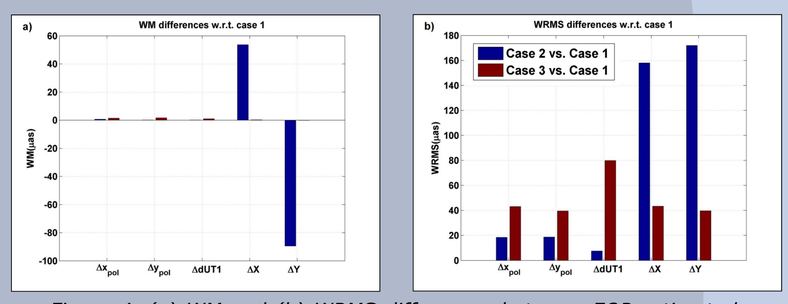

Figure 4. (a) WM and (b) WRMS differences between EOP estimated with different a priori EOP.

Table 5. Differences in EOP (μas or μs for UT1) between solutions using different a priori EOP series. Shift (referred at epoch 2000.0) and linear trends (yr^{-1}) are estimated by LS.

7. ICRF2 vs. ICRF1-ext.2

ICRF2 — **ICRF1 ext.2** → **ITRF2008 IERS 08 C04**

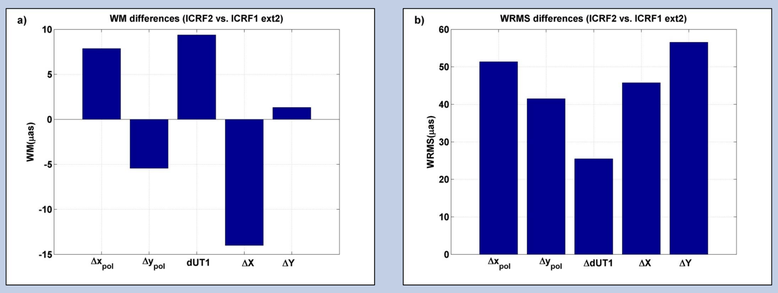

Figure 5. (a) WM and (b) WRMS differences between EOP estimated with ICRF2 and ICRF1 ext. 2.

EOP	ICRF2			ICRF1		
	shift	drift	rms	shift	drift	rms
Δx_{pol}	-17.0	-2.6±0.5	312.4	-22.3	-2.9±0.5	316.3
Δy_{pol}	-0.4	1.2±0.4	263.1	8.0	0.6±0.5	268.8
ΔdUT1	5.8	-0.2±0.03	18.5	4.7	-0.2±0.03	19.1
ΔX	-1.2	0.7±0.3	135.6	8.7	1.3±0.3	147.4
ΔY	14.5	-3.1±0.3	145.9	10.0	-2.1±0.3	162.9

Table 6. Differences in EOP (μas or μs for UT1) between solutions using ICRF2 and ICRF1 ext. 2 w.r.t. IERS 08 C04 series. Shift (referred at epoch 2000.0) and linear trends (yr^{-1}) are estimated by WLS.

8. CONCLUSIONS

- When fixing station coordinates ERP are significantly affected by unmodeled geophysical signals. Some approaches to cope with this problem are:
  - Usage of epoch reference frames
  - Considering more geophysical signals in the data analysis
  - Extending the TRF coordinate model to seasonal signals
- Remarkable EOP differences compared to ITRF2008 are:
  - VTRF2008 y_{pol} : WM ~140 μas, WRMS ~120 μas and drift ~-18.6 μas yr^{-1} (ICRF2 is consistent with VTRF2008!)
  - DTRF2008 in dUT1: WM ~160 μas (based on the same data!)
- Impact of CRFs on the EOP is about at the level of the given axes stability of ICRF2 (10 μas) and in general very small except for the small ΔY drift.
- Impact of TRFs on the EOP is general larger than the given level of the axes stability of ITRF2008 (80 μas ± 80 μas yr^{-1} at 2005.0). The multi-technique combination has a large effect on ERP.
- To achieve consistent CRF, TRF, and EOP, those have to be determined from a single combined solution.

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