VLBI-based assessment of the consistency of the conventional EOP series and the terrestrial reference frames

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MOTIVATION

GGOS
Global Geodetic
Observing System

GOALS for CRF and TRF:

- **Accuracy**: $1\ mm\ \ (\mathbf{30}\ \boldsymbol{\mu as})$
- **Stability**: $1\ mm/\mathrm{year}\ (\mathbf{30}\ \boldsymbol{\mu as/year})$

TRFs

The ITRF is based on the **combination of solutions** from the **four space geodetic techniques**, with each new release incorporating **updated** data and models.

EOPs

The current conventional EOP series, **IERS 14 C04**, is based on a **monthly combination** of the EOP estimates obtained by the analysis centers of each space geodetic technique.

OBJECTIVES

Assess the consistency among the conventional **TRF** and **EOP** through the analysis of **VLBI data**, taking **different TRF** as alternative settings in the analysis.

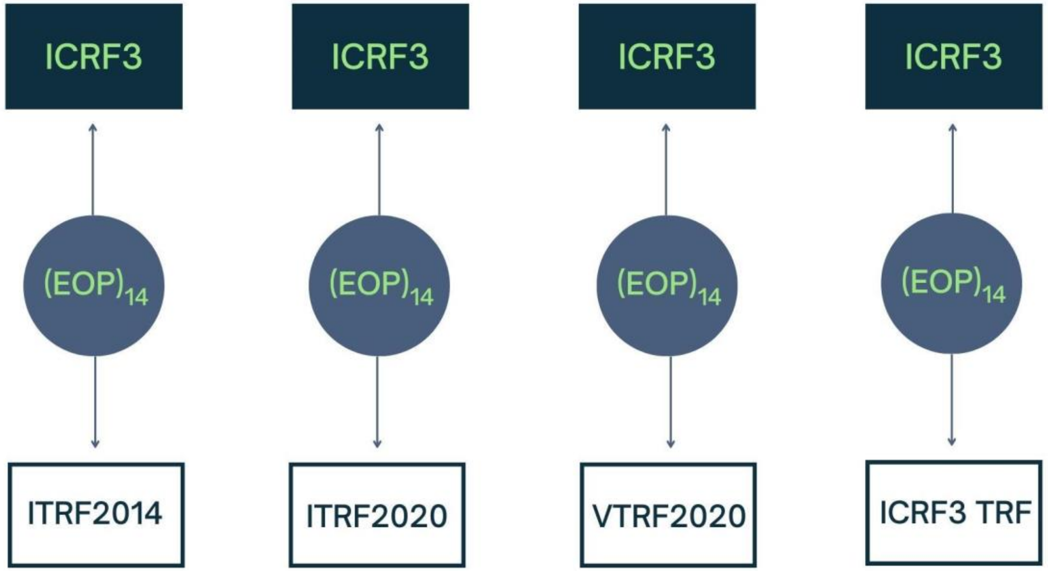
This study **evaluates** if the **TRF** selection has a **significant impact** on the **consistency of the estimated EOP** and assesses its **agreement** with the conventional EOP series.

TRF	Reference	Comment
ITRF2014	[1]	Data until 2014
ITRF2020	[2] [3]	Data until 2020
VTRF2020	[4] [5]	Data until 2020, VLBI-only frame, contains the same VLBI data as it was provided to ITRF2020
ICRF3 TRF	[6]	Data until 2014, station positions and velocities consistent with ITRF2014

Table 1: Different TRFs used in this study

Current study is an extension and continuation of the work developed by Belda, S. et al. "On the consistency of the current conventional EOP series and the celestial and terrestrial reference frames", in Journal of Geodesy (2017), Heinkelmann at al. "The consistency of the current conventional celestial and terrestrial reference frames and the conventional EOP series" (2014), and Heinkelmann at al. "How consistent are the current conventional celestial and terrestrial reference frames and the conventional Earth Orientation Parameters?", in *REFAG 2014 Springer* (2015)

DATA ANALYSIS



Case study	Comments
Case A	Impact of using different Terrestrial Reference Frames (TRFs) to compute EOP solutions. Assessed by fixing the station coordinates to their a priori values.

Table 2: Case study

PROCESSING PARAMETERS

TRF	ITRF2014	ITRF2020	VTRF2020	ICRF3 TRF
Sessions type	R1/R4			
Sessions period	2002 – 2021			
Sessions number	2053			
Analysis Software	VieVS VLBI v3.2			
ICRF	ICRF3			
EOP estimation	1 offset per day			
EOP apriori	IERS 14 C04			
Precession/Nutation modelling	IAU 2006/2000A			
TROP estimation	ZWD and gradients as pice-wise linear functions (1h and 6h interval lengths, respectively)			
TROP modelling	VMF1			
Quality check	Discard VLBI sessions with a posteriori sigma of unit weight larger than 5			
Parameters	Fixed stations coordinates Fixed source coordinates			

Table 3: Processing parameters used in this study

RESULTS

CASE A: TERRESTRIAL REFERENCE FRAMES

	Δx_{pol} (µas)			Δy_{pol} (µas)			ΔdUT1 (µs)			ΔX (µas)			ΔY (µas)		
Fixed	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS
ITRF2014	-51.4 ± 5.7	5.0 ± 0.4	2.92	5.3 ± 5.1	-2.9 ± 0.4	2.65	2.1 ± 0.4	-0.3 ± 0.04	4.61	-48.5 ± 3.2	3.4 ± 0.2	1.94	17.6 ± 3.3	-0.9 ± 0.3	1.98
ITRF2020	-56.6 ± 5.0	4.0 ± 0.4	2.58	2.4 ± 5.0	-0.7 ± 0.4	2.67	0.2 ± 0.4	-0.3 ± 0.03	4.53	-46.6 ± 3.2	3.1 ± 0.2	1.97	13.1 ± 3.3	-0.3 ± 0.2	1.98
ICRF3 TRF	-146.8 ± 27.0	9.9 ± 1.9	11.10	-91.7 ± 18.0	12.3 ± 1.3	7.65	1.9 ± 1.9	-2.3 ± 0.15	18.22	-55.4 ± 4.8	3.3 ± 0.3	2.39	17.3 ± 4.9	-0.8 ± 0.4	2.41
VTRF2020	-1068.8 ± 101.4	184.5 ± 7.3	18.55	2025.7 ± 79.6	-146.0 ± 5.9	15.19	-16.4 ± 5.2	1.1 ± 0.45	24.33	-73.1 ± 15.1	1.6 ± 1.1	3.37	-63.1 ± 16.1	4.7 ± 1.2	3.54

Table 4: EOP residuals (µas or µs for ΔdUT1) w.r.t. IERS 14 C04 between solutions using different TRFs for the computation of EOP. Note: Shift (referred to epoch J2000.0) and linear trend (year^{-1}) estimated by WLS

ITRF2014 & ITRF2020:

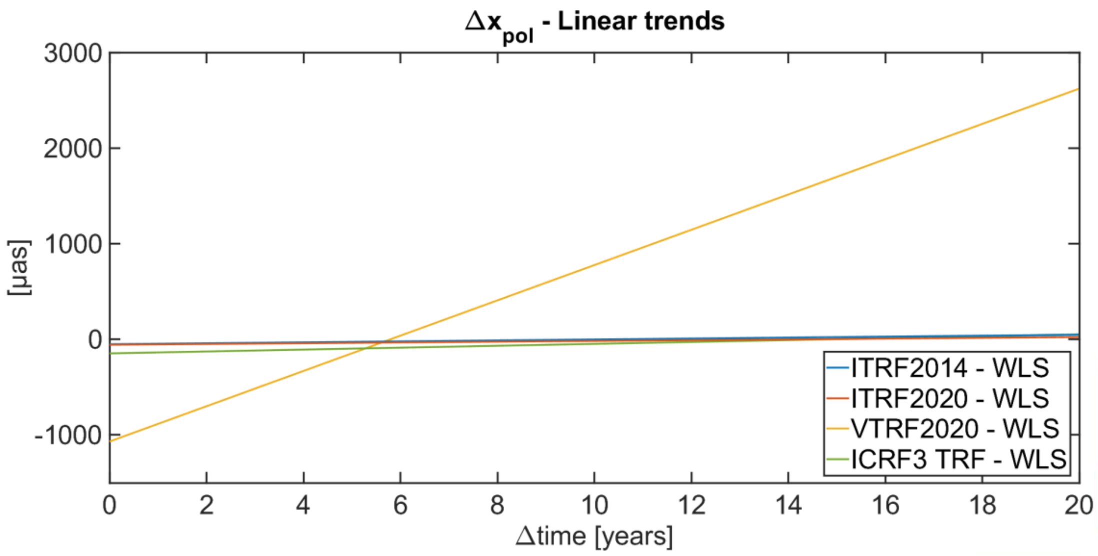
- Solutions are **consistent** and **similar** between each other.
- **ITRF2020** results have **improved** comparing with **ITRF2014** ones.

VTRF2020

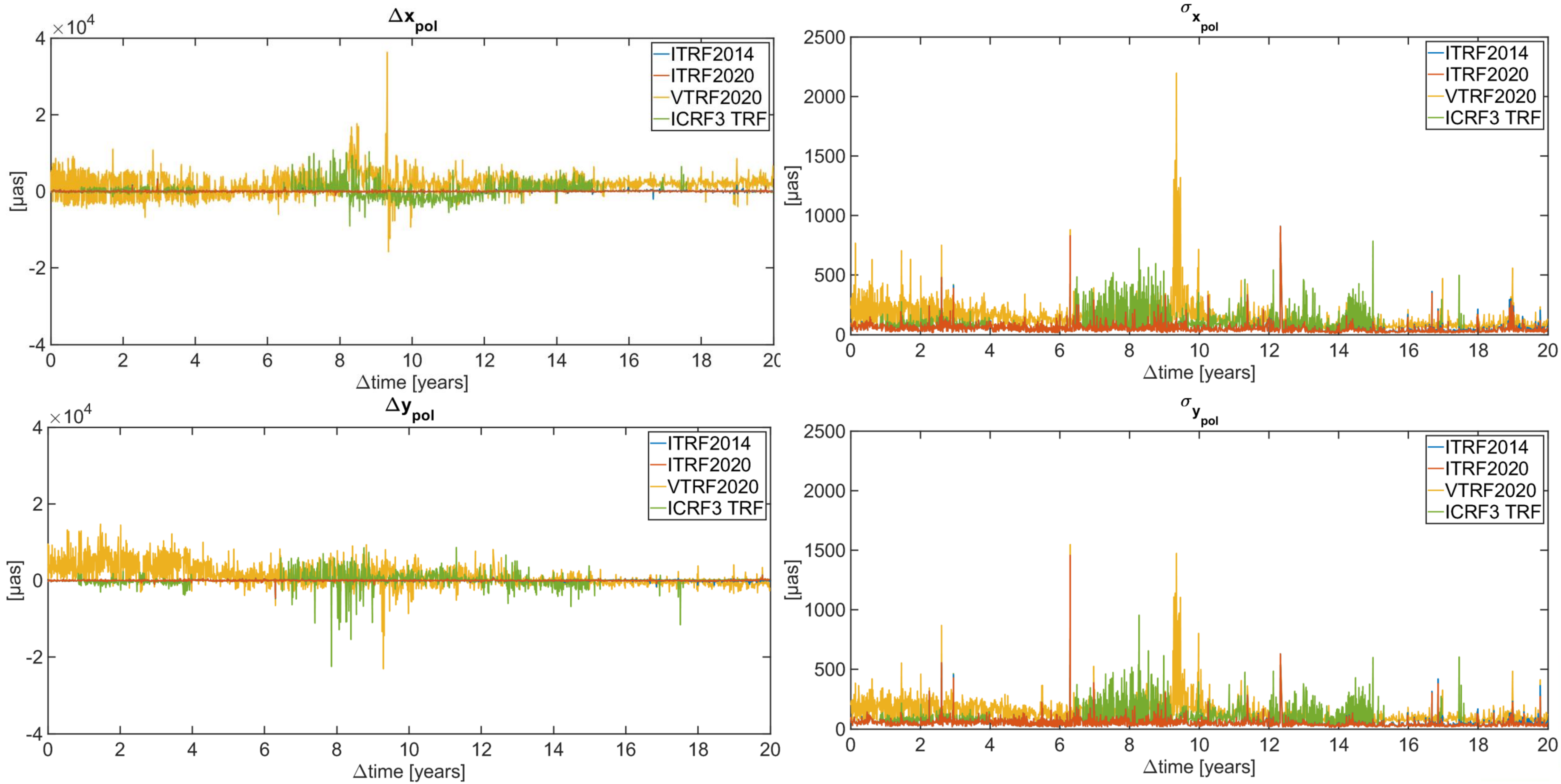
- Exhibit **considerable shifts and drifts** results for the all EOP set.
- Registering for the $\boldsymbol{\Delta x_{pol}}$ and $\boldsymbol{\Delta y_{pol}}$ drifts of $\mathbf{184.5}\ \boldsymbol{\mu as}/\mathbf{year}$ and $-\mathbf{146}\ \boldsymbol{\mu as/year}$, respectively.

ICRF3 TRF

- Second **highest results** are observed in this TRF.
- Particularly for the $\boldsymbol{\Delta x_{pol}}$ and $\boldsymbol{\Delta y_{pol}}$ drifts of $\mathbf{9.9}\ \boldsymbol{\mu as}/\mathbf{year}$ and $\mathbf{12.3}\ \boldsymbol{\mu as/year}$, respectively.



EOP residuals and uncertainties



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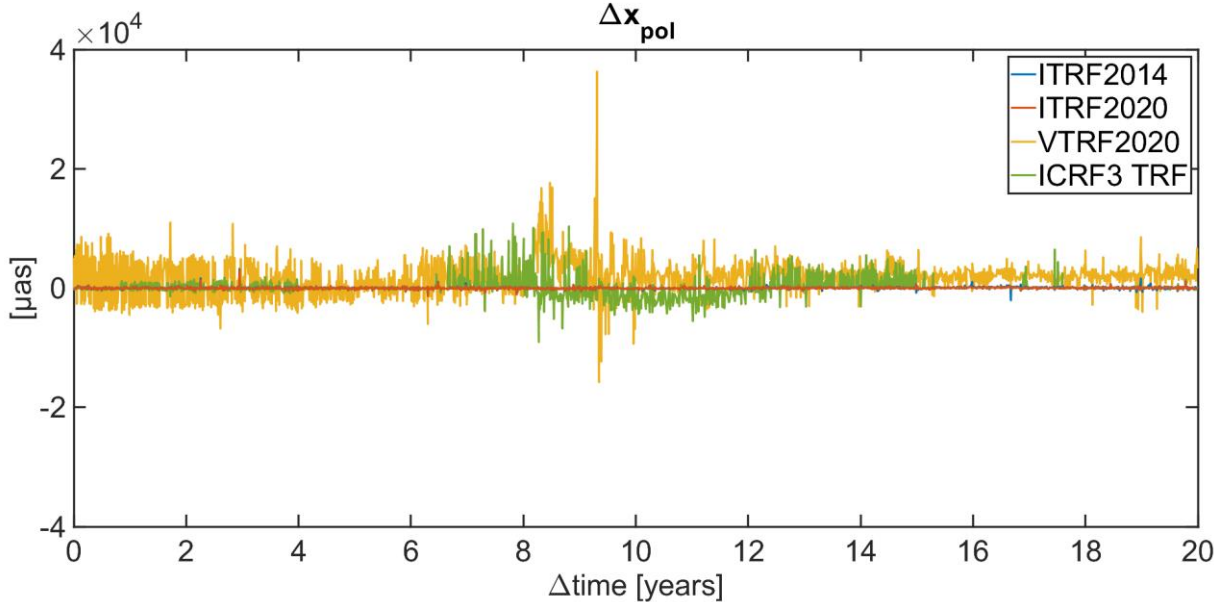
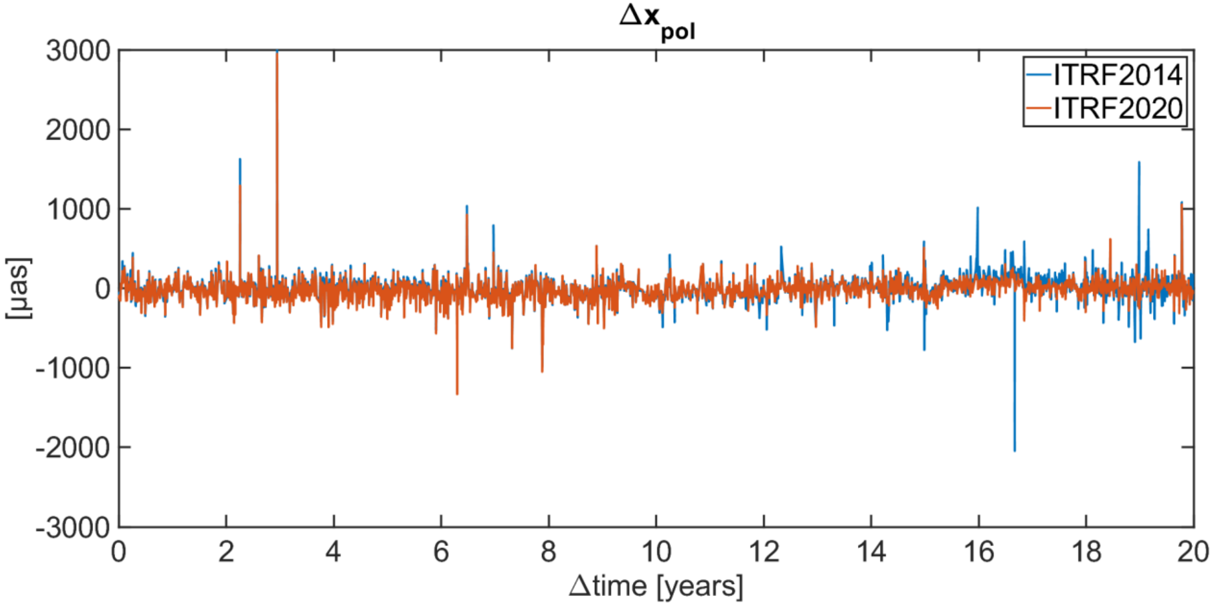




ITRF2014 and ITRF2020:

- **Similar** and **consistent** results

VTRF2020:

- **Large residuals** and **uncertainties** when compared with the other TRFs results.
- **High residuals in 2011** can be related with the discontinuities present in some stations due to the **Tohoku event.**
- The source for the general **high order of magnitude** of the results **could not be found and further analyzed**.
- VTRF2020 results were **removed** from further plots, for the sake of clarity.

ICRF3 TRF:

- Presents periods of **non-negligible residuals** and **uncertainties**, specifically between 2008-2017.
- Further analysis on the cause of these behavior was pursued.

CASE STUDIES

- **ITRF2014** and **ITRF2020**: Present **high quality** data

- **TSUKUB32** and **KASHIM34** stations were among most of the sessions that presented high poor quality. Both stations **presented discontinuities** within its coordinates defined by the TRF.

- Considering the stations discontinuities, **three case studies** were defined (Tab. 6)

	ITRF2014		ITRF2020		VTRF2020		ICRF3 TRF	
Excluded stations: TSUKUB32 KASHIM34	—	x	—	x	—	x	—	x
$0 < chi^2 < 5$	2019	1999	2019	2000	128	214	1399	1668
$chi^2 > 5$	0	19	0	18	1891	1804	620	350
NaN	0	1	0	1	0	1	0	1
#Sessions	2019	2019	2019	2019	2019	2019	2019	2019

Table 5: Number of sessions in function of residuals values and processing parameters. Note: OPT files were optimized for ITRF2014 and ITRF2020. Stations KASHIM34 and TSUKUB32 were not included due to discontinuity issues in ICRF3 TRF. Sessions with $chi^2 > 10$ were not used in further computations, hence the final processing list had a total of 1951 sessions.

Case studies	Sub-case studies	Comments
Case A: TRFs	Case 1	No stations previously excluded.
	Case 2	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
	Case 3	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.

Table 6: Case A: Sub-case studies

SHIFT AND DRIFT

CASE 2

Sub-case studies	Comments
Case 1	No stations previously excluded.
Case 2 - - ->	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
Case 3	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.

Case 2	Δx_{pol} (µas)			Δy_{pol} (µas)			ΔdUT1 (µs)			ΔX (µas)			ΔY (µas)		
Fixed	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS
ITRF2014	-40.9 ± 6.4	4.6 ± 0.5	2.83	6.6 ± 5.6	-3.1 ± 0.4	2.56	1.6 ± 0.4	-0.3 ± 0.04	4.15	-46.1 ± 3.5	3.3 ± 0.3	1.96	6.7 ± 3.5	-0.3 ± 0.3	1.94
ITRF2020	-45.9 ± 5.6	3.4 ± 0.4	2.49	0.1 ± 5.5	-0.6 ± 0.4	2.58	-0.5 ± 0.4	-0.3 ± 0.03	4.04	-44.5 ± 3.5	3.0 ± 0.3	1.97	2.6 ± 3.5	0.3 ± 0.3	1.94
ICRF3 TRF	-241.6 ± 25.6	14.7 ± 1.8	9.66	-19.7 ± 11.4	7.7 ± 0.8	4.56	3.5 ± 0.9	-2.6 ± 0.07	7.38	-48.5 ± 4.8	3.1 ± 0.3	2.27	10.2 ± 5.0	-0.4 ± 0.4	2.35
VTRF20	-690.0 ± 108.1	168.1 ± 7.6	17.94	1875.4 ± 88.0	-131.6 ± 6.4	16.00	-21.0 ± 5.9	2.2 ± 0.48	22.90	-91.6 ± 15.9	2.5 ± 1.2	3.50	-79.8 ± 16.9	5.8 ± 1.2	3.61

Table 7: Case 2: EOP residuals (µas or µs for ΔdUT1) w.r.t. IERS 14 C04 between solutions using different TRFs for the computation of EOP. Note: Shift (referred to epoch J2000.0) and linear trend (year^{-1}) estimated by WLS. Stations KASHIM34 and TSUKUB32 were not included due to discontinuity issues in ICRF3 TRF.

ITRF2014 & ITRF2020:

- Solutions are **consistent** and **similar** between each other.
- As in case 1, **ITRF2020** results have **improved** comparing with **ITRF2014** ones.

ICRF3 TRF

- **Drift decreased** for Δy_{pol}, ΔX, and ΔY of 4.6 μas/year, 0.2 μas/year and 0.4 μas/year, respectively.
- **WRMS decreased** for the all EOP set.

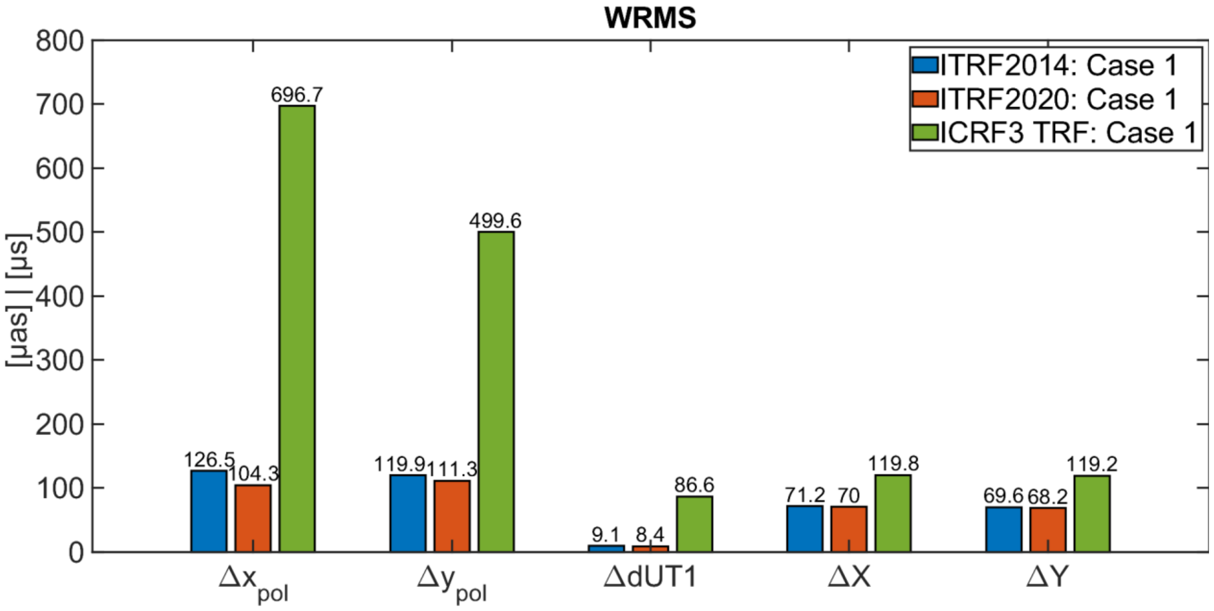
VTRF2020

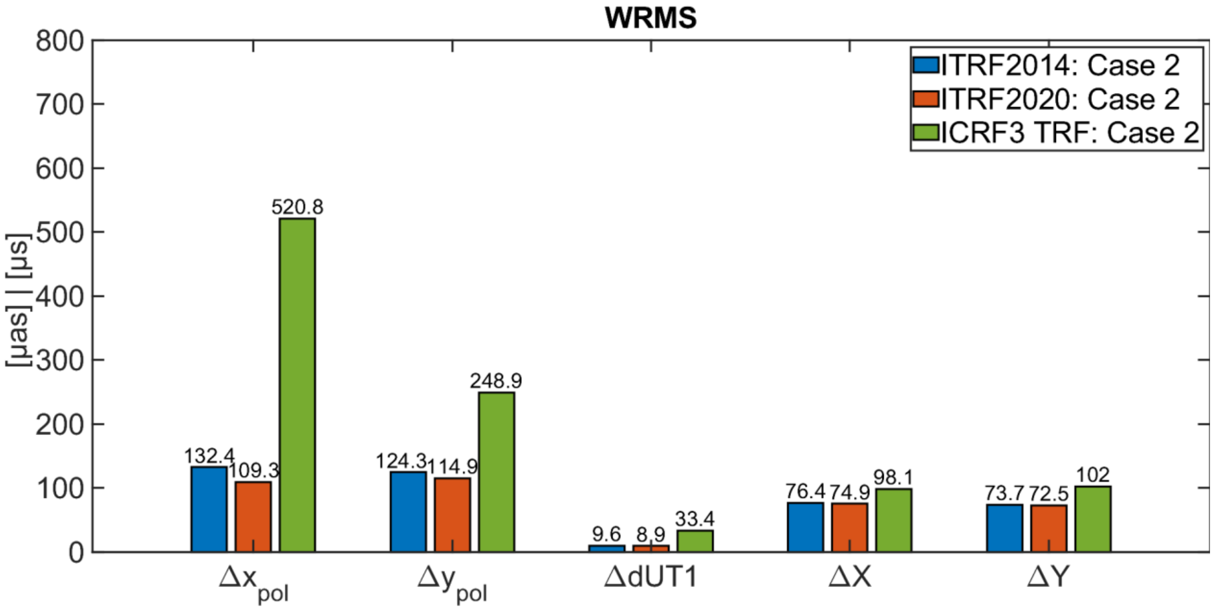
- EOP residuals w.r.t. IERS 14 C04 remained **significant** and **non-negligible.**

WRMS

EOP estimated vs IERS 14 C04

Sub-case studies	Comments
Case 1	No stations previously excluded.
Case 2	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
Case 3	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.



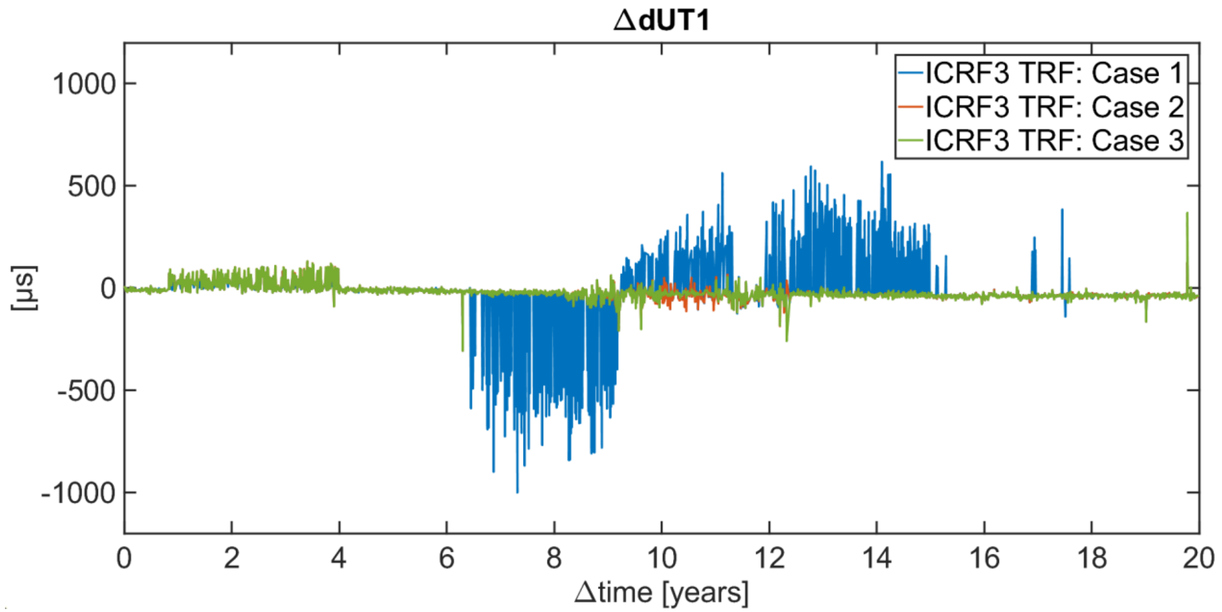


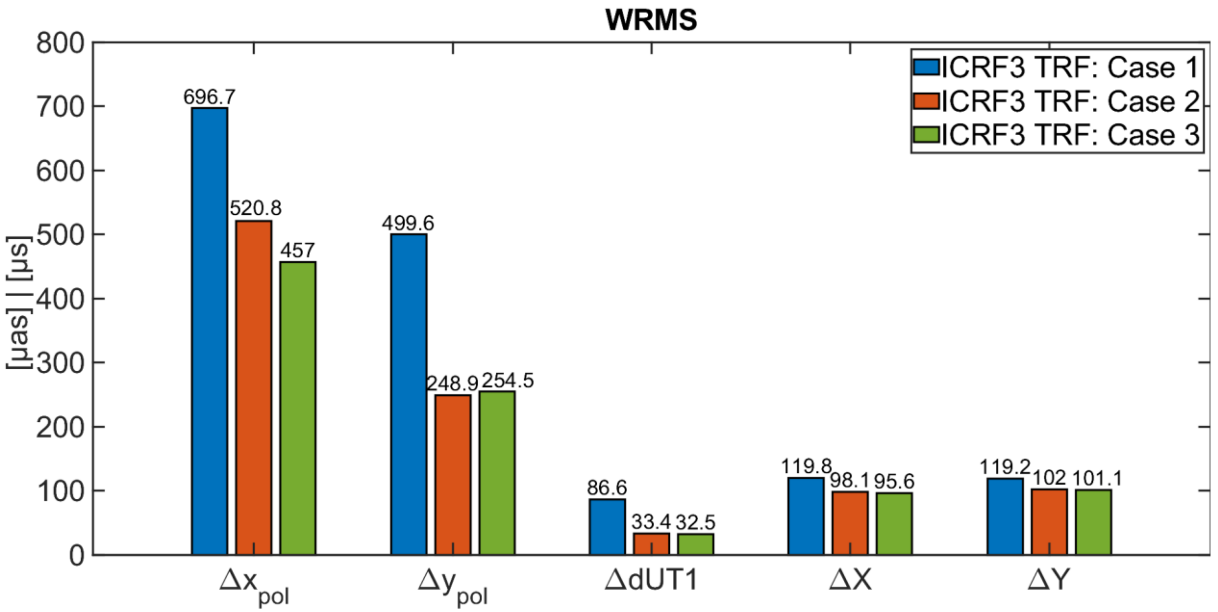
- ITRF2020 has the **smallest WRMS** for all EOP set, **independently** of the case study.
- ITRF2014 and ITRF2020 have considerable differences for $\boldsymbol{\Delta x_{pol}}$ and $\boldsymbol{\Delta y_{pol}}$ with $\mathbf{22.2}\ \boldsymbol{\mu as}$ and $\mathbf{8.6}\ \boldsymbol{\mu as}$, respectively.
- **WRMS** are **bigger** for ITRF2014 and ITRF2020 in Case **2**.
- **WRMS** much **smaller** for ICRF3 TRF in Case 2, more specifically for Δx_{pol} and Δy_{pol}.

EOP residuals and uncertainties

CASE 3: ICRF3 TRF

Sub-case studies	Comments
Case 1	No stations previously excluded.
Case 2	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
Case 3 - - ->	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.





Stations with discontinuities in the **ICRF3 TRF** removed. 25 stations were excluded.

CASE 1 vs CASE 2:

- Significant **decrease** in the WRMS for **ICRF3 TRF** can be observed, specially for Δx_{pol}, Δy_{pol}

CASE 2 vs CASE 3:

- **Only** for Δx_{pol} a considerable **improvement** is achieved in the WRMS ($63.8\ \mu as$).

FINAL REMARKS

ITRF2014 and ITRF2020

- Solutions are **consistent and similar** between each other.
- Majority of the results are consistent with the **GGOS goals**
- ITRF2020 results have **improved** comparing with ITRF2014 ones.
- WRMS improvement of **17%** and **7%** was attained for Δx_{pol} and Δy_{pol}, respectively.

ICRF3 TRF

- Existence of **discontinuities** that affect the results is clear.
- WRMS reduction of **25%** and **50%** was reached for Δx_{pol} and Δy_{pol}, respectively, between Case 1 and Case 2.
- Benefits of removing all 25 stations with discontinuities is not evident.
- The **degradation of the network** surpasses the improvement of removing the problematic stations.

"Why achieve the same EOP using different ITRF was not possible?"

- **Poor** ITRF **network**
- Insufficient number of suitable radio sources (VLBI)
- Incompleteness of the **theory/models**
- Inconsistency between techniques
- Different **Time domain** of data
  - ICRF3 <2015
  - ITRF2014 <2014
  - ITRF2020 <2020

FUTURE STEPS

- **Extend the analysis** for years prior to 2002.
- Compare the **similarity transformation vs VLBI ERP differences**.
    - To assess if the EOP differences determined in Case A can be attributed to the differences in **orientation of each frame.**
- Cooperate with BKG team, that provided the VTRF2020, to **further analyse VTRF2020** results.

THANK YOU

For your attention!

| REFAG 2022 |

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REFERENCES

[1] Zuheir Altamimi et al. "ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions". In: *Journal of geophysical research: solid earth* 121.8 (2016), pp. 6109–6131.

[2] *ITRF2020*. 2022. URL: https://itrf.ign.fr/en/solutions/itrf2020.

[3] Zuheir Altamimi. *The International Terrestrial Reference Frame: an update.*

[4] H Hellmers et al. *The IVS contribution to ITRF2020.*

[5] Hendrik Hellmers et al. "Combined IVS contribution to the ITRF2020". In: *EGU General Assembly Conference*. 2021.

[6] P Charlot et al. "The third realization of the International Celestial Reference Frame by very long baseline interferometry". In: *Astronomy & Astrophysics* 644 (2020), A159.

[7] S. Belda et al. "On the consistency of the current conventional EOP series and the celestial and terrestrial reference frames". In: *Journal of Geodesy* (2017).

[8] Robert Heinkelmann et al. "The consistency of the current conventional celestial and terrestrial reference frames and the conventional EOP series". In: *Proc Journ* (2014), pp. 224–225.

[9] Robert Heinkelmann et al. "How Consistent are The Current Conventional Celestial and Terrestrial Reference Frames and The Conventional Earth Orientation Parameters?" In: *REFAG 2014*. Springer, 2015, pp. 183–189.

ANNEX

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ANALYSIS STRATEGY

WEIGTHED ROOT MEAN SQUARE (WRMS) and WM

- Analise the EOP estimated with different TRFs using IERS 14 C04 as the EOP apriori

$$\mathrm{WM} = \frac{\sum_{i=1}^{N} \frac{\tilde{x}_{\mathrm{eop1},i} - \tilde{x}_{\mathrm{eop2},i}}{\sigma^2_{\mathrm{eop1},i} + \sigma^2_{\mathrm{eop2},i}}}{\sum_{i=1}^{N} \frac{1}{\sigma^2_{\mathrm{eop1},i} + \sigma^2_{\mathrm{eop2},i}}}$$

$$\mathrm{WRMS} = \sqrt{\frac{\sum_{i=1}^{N} \frac{(\tilde{x}_{\mathrm{eop1},i} - \tilde{x}_{\mathrm{eop2},i} - \mathrm{WM})^2}{\sigma^2_{\mathrm{eop1},i} + \sigma^2_{\mathrm{eop2},i}}}{\sum_{i=1}^{N} \frac{1}{\sigma^2_{\mathrm{eop1},i} + \sigma^2_{\mathrm{eop2},i}}}}$$

- $eop1$: EOP from the VLBI analysis using the different settings
- $eop2$: EOP apriori
- $\bar{x}$: EOP values
- N: their number
- σ: formal uncertainty

WEIGHTED LEAST SQUARE (WLS)

SHIFT AND DRIFT

- Analise the EOP residuals w.r.t. IERS 14 C04 between solutions using different TRFs for the computation of EOP
- Values adjusted to a Linear Trend, computed by WLS:
  - Shift (referred to epoch J2000.0)
  - Drift
  - Error of fit assessed by the WRMS

SHIFT AND DRIFT

Case 1	Δx_{pol} (µas)			Δy_{pol} (µas)			ΔdUT1 (µs)			ΔX (µas)			ΔY (µas)		
Fixed	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS
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Table 4: Case 1: EOP residuals (µas or µs for ΔdUT1) w.r.t. IERS 14 C04 between solutions using different TRFs for the computation of EOP. Note: Shift (referred to epoch J2000.0) and linear trend (year^{-1}) estimated by WLS

Case 2	Δx_{pol} (µas)			Δy_{pol} (µas)			ΔdUT1 (µs)			ΔX (µas)			ΔY (µas)		
Fixed	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS	Shift	Drift	WRMS
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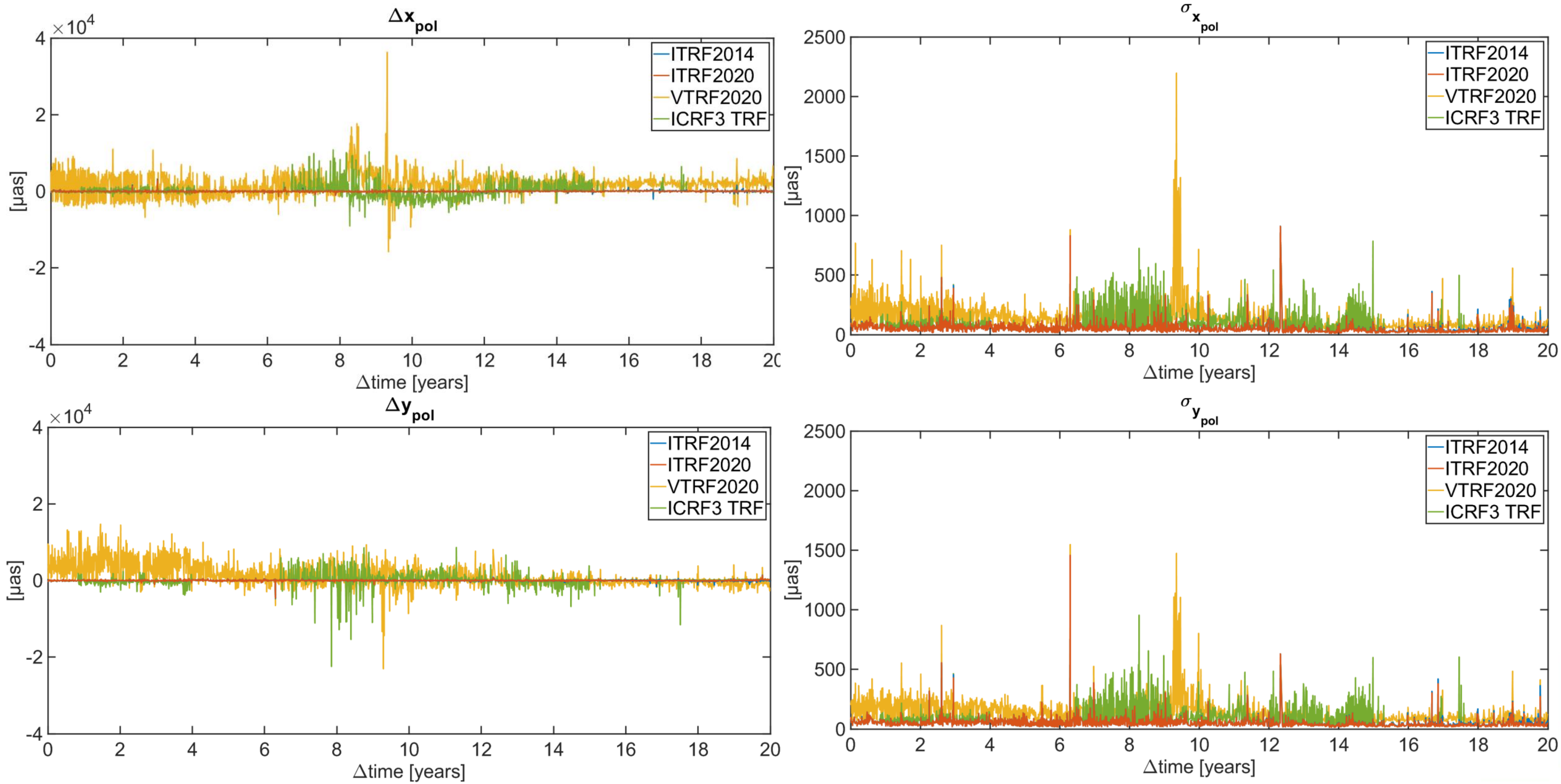
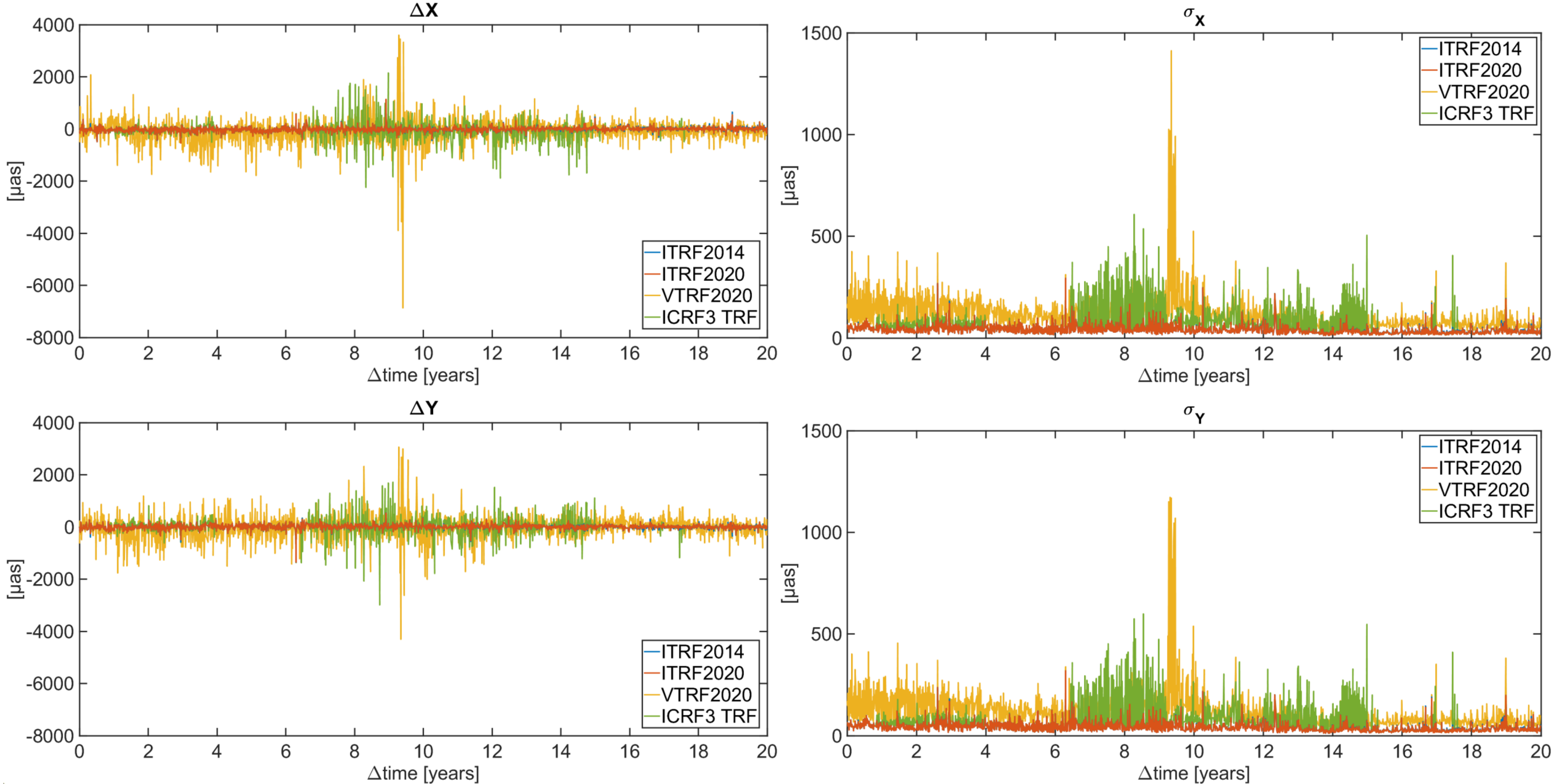
Table 7: Case 2: EOP residuals (µas or µs for ΔdUT1) w.r.t. IERS 14 C04 between solutions using different TRFs for the computation of EOP. Note: Shift (referred to epoch J2000.0) and linear trend (year^{-1}) estimated by WLS. Stations KASHIM34 and TSUKUB32 were not included due to discontinuity issues in ICRF3 TRF.

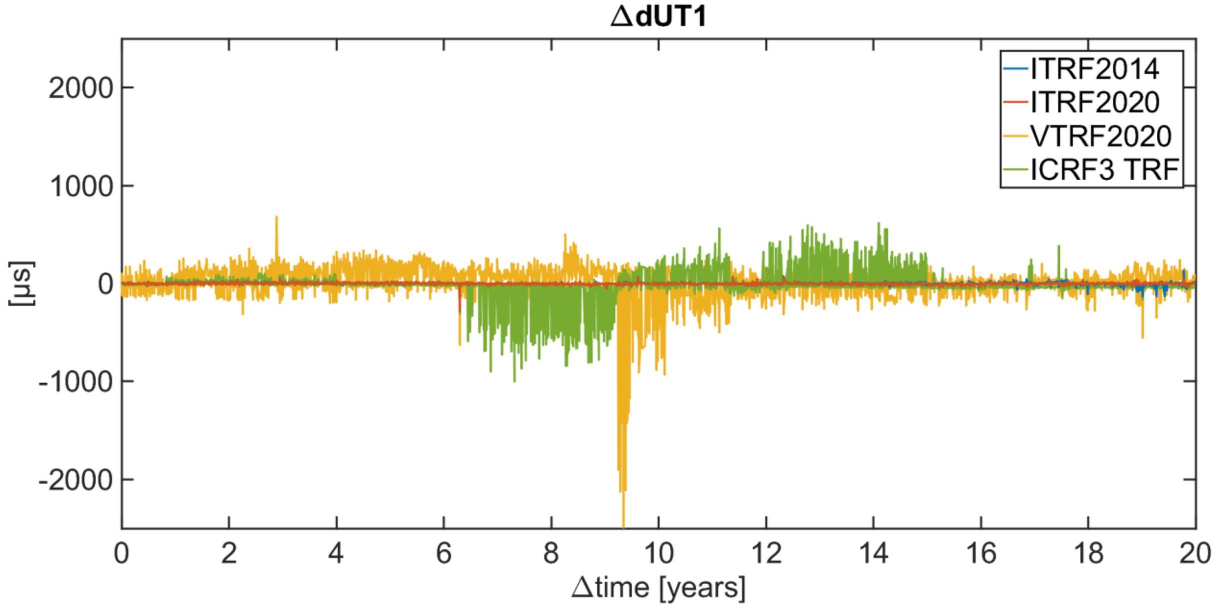
EOP residuals and uncertainties

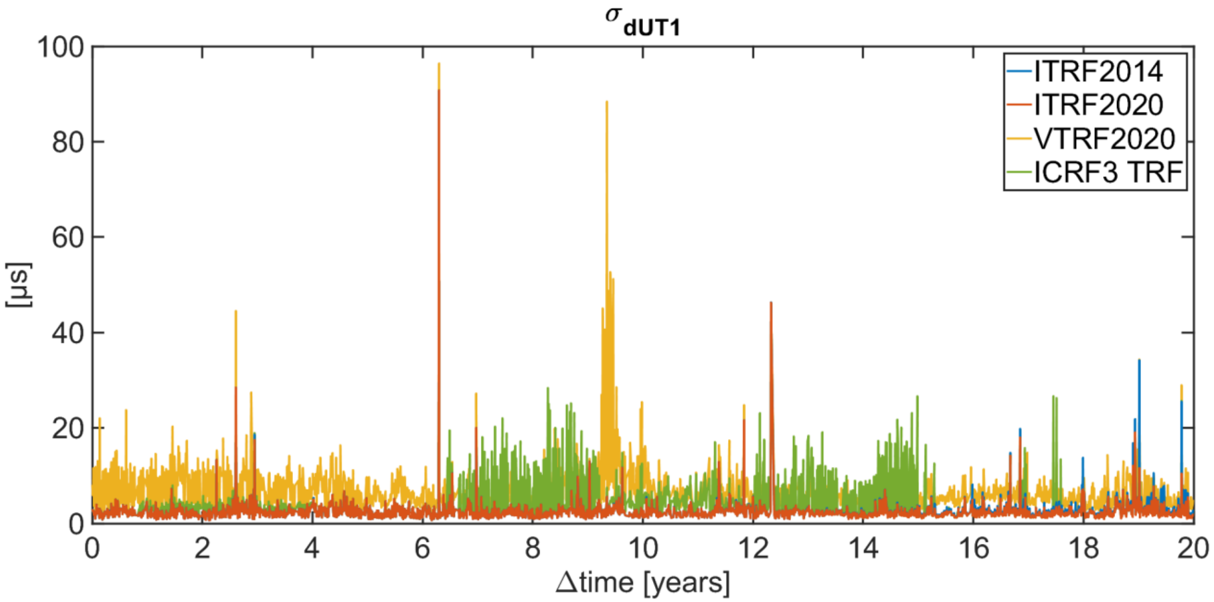


EOP residuals and uncertainties



EOP residuals and uncertainties





ITRF2014 and ITRF2020:

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VTRF2020:

- **Large residuals** and **uncertainties** when compared with the other TRFs results.
- **High residuals in 2011** can be related with the discontinuities present in some stations due to the **Tohoku event.**
- The source for the general **high order of magnitude** of the results **could not be found and further analyzed**.
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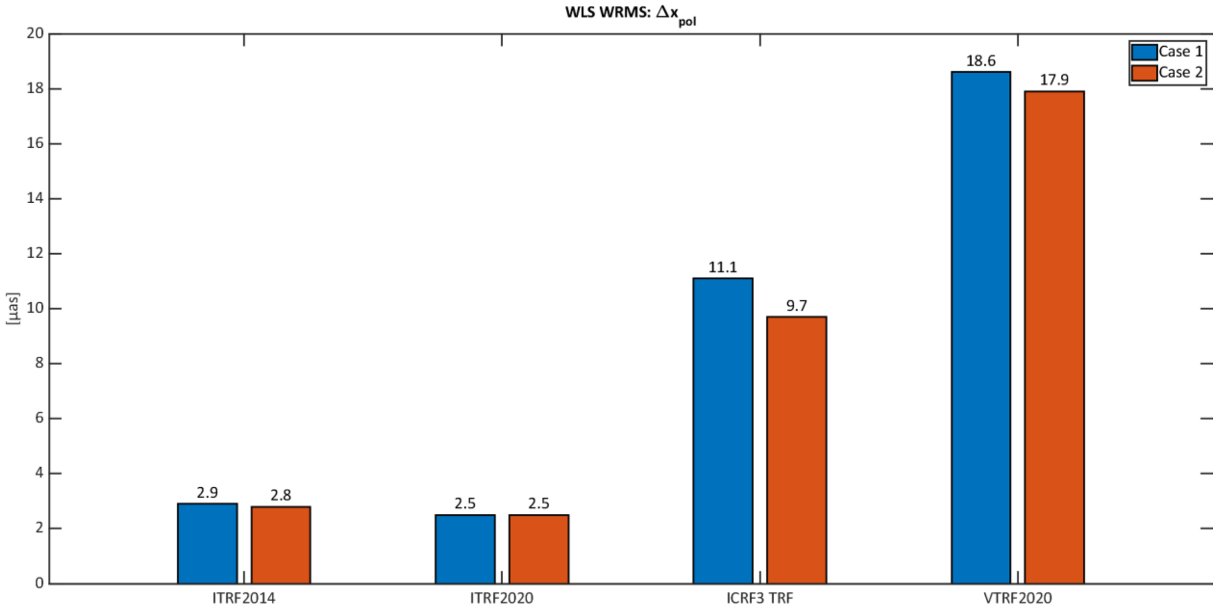
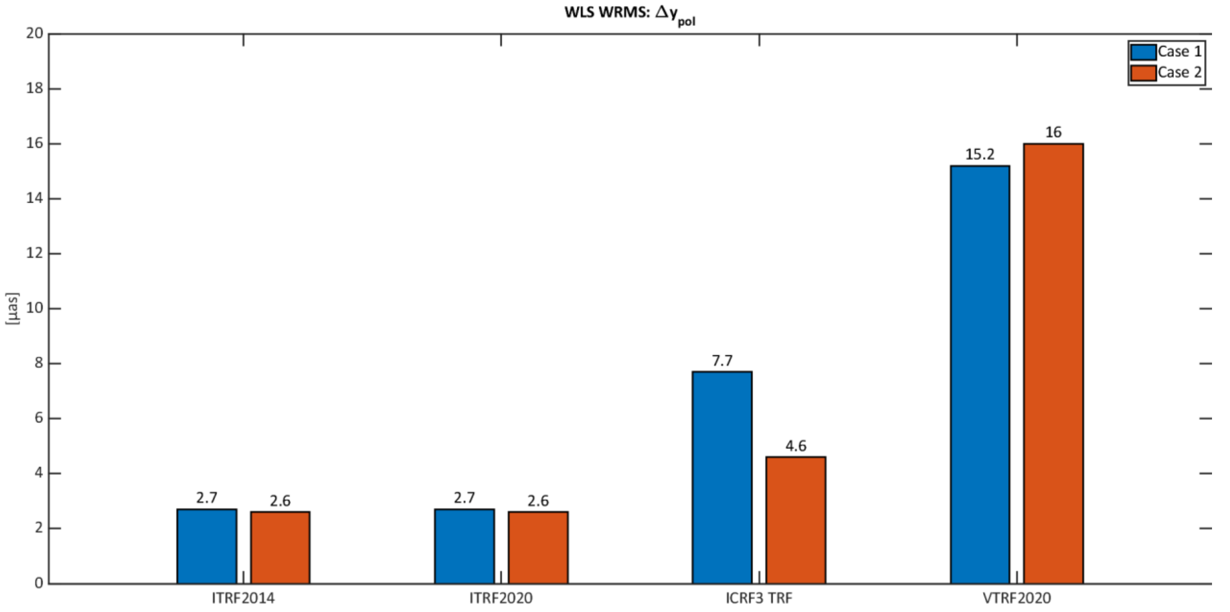
ICRF3 TRF:

- Presents periods of **non-negligible residuals** and **uncertainties**, specifically between 2008-2017.
- Further analysis on the cause of these behavior was pursued.

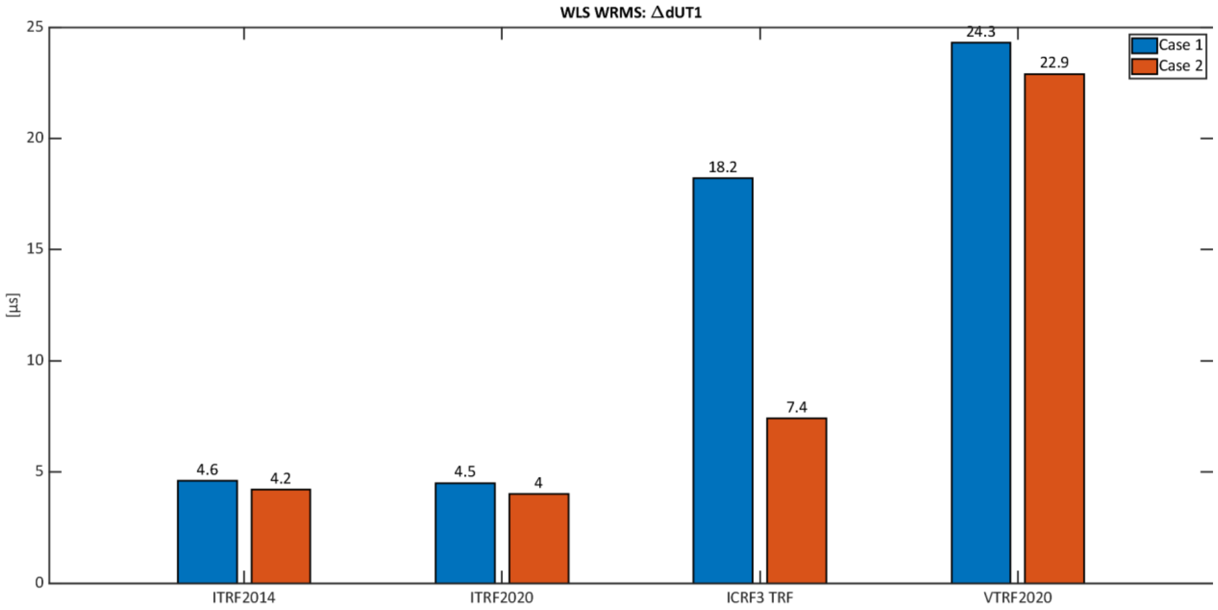
WLS WRMS



WLS WRMS: Δx_{pol}
[µas]
Case 1
Case 2
2.9
2.8
2.5
2.5
11.1
9.7
18.6
17.9
ITRF2014
ITRF2020
ICRF3 TRF
VTRF2020

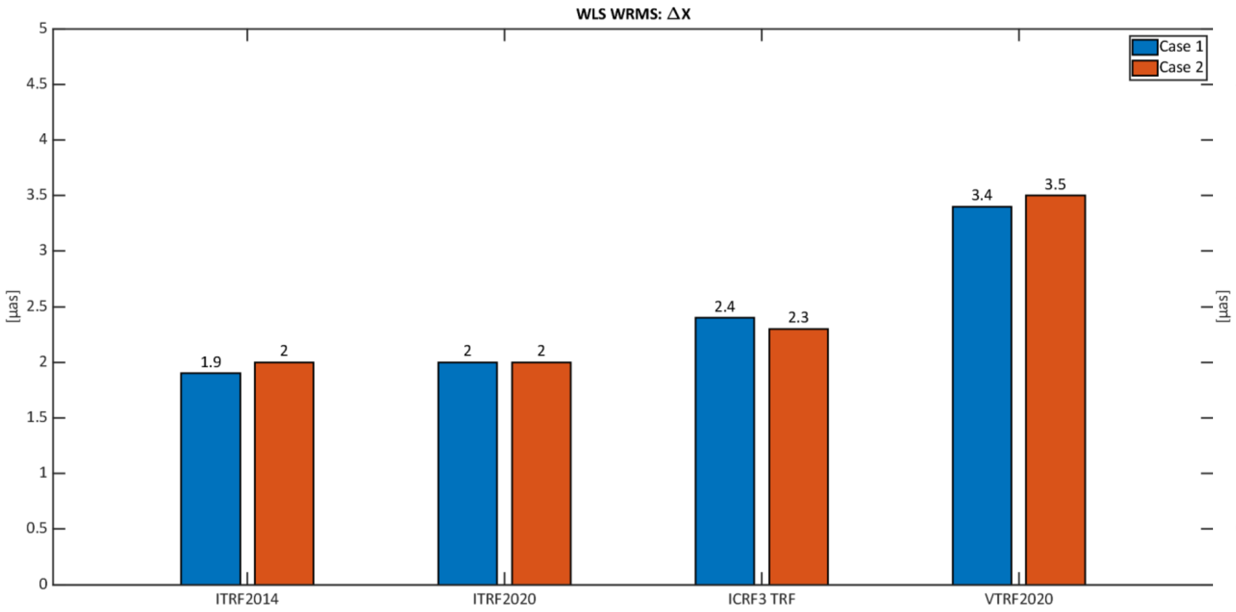


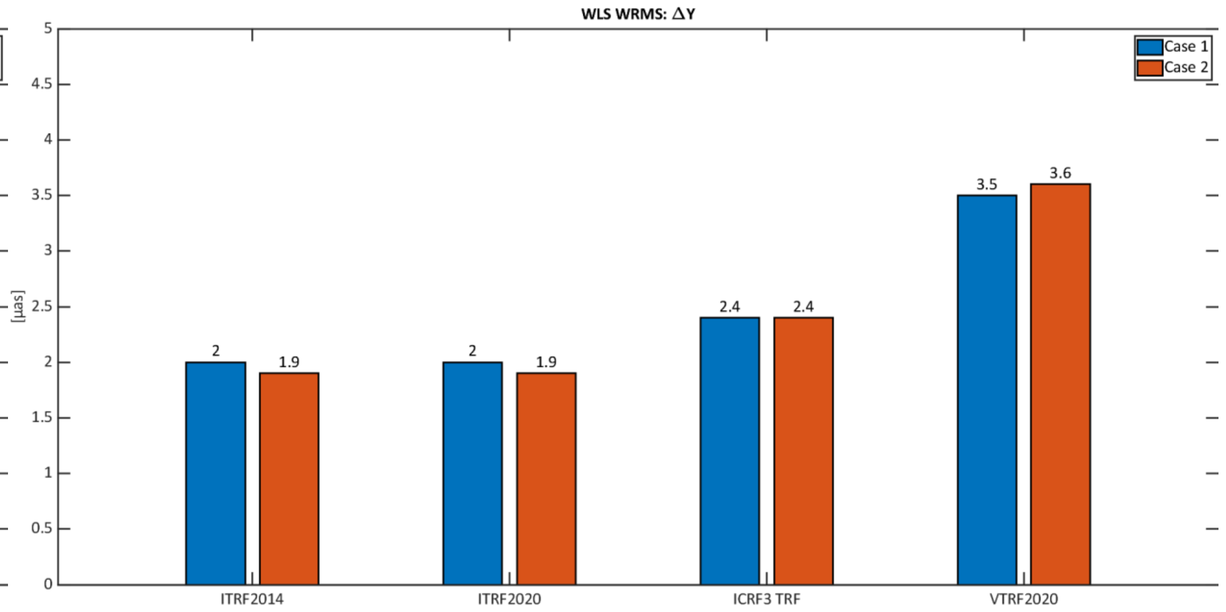
WLS WRMS: Δy_{pol}
[µas]
Case 1
Case 2
2.7
2.6
2.7
2.6
7.7
4.6
15.2
16
ITRF2014
ITRF2020
ICRF3 TRF
VTRF2020



WLS WRMS: ΔdUT1
[µs]
Case 1
Case 2
4.6
4.2
4.5
4
18.2
7.4
24.3
22.9
ITRF2014
ITRF2020
ICRF3 TRF
VTRF2020

WLS WRMS





- VTRF2020 has the biggest WRMS values of all TRFs tested
- Second highest values are observed for ICRF3 TRF
- ITRF2014 and ITRF2020 present the smallest values

WRMS and WM:

EOP estimated vs IERS 14 C04

- ITRF2020 has the smallest WRMS for all EOP set, independently of the case study.
- ITRF2014 and ITRF2020 have considerable differences for Δx_{pol} and Δy_{pol} with $22.2\ \mu as$ and $8.6\ \mu as$, respectively.
- WRMS are bigger for ITRF2014 and ITRF2020 in Case 2.
- WRMS much smaller for ICRF3 TRF in Case 2, more specifically for Δx_{pol} and Δy_{pol}.

Case 1	$\Delta x_{\rm pol}$ (µas)		$\Delta y_{\rm pol}$ (µas)		ΔdUT1 (µs)		ΔX (µas)		ΔY (µas)	
Fixed	WM	WRMS	WM	WRMS	WM	WRMS	WM	WRMS	WM	WRMS
ITRF2014	9.7	126.5	-33.3	119.9	-0.5	9.1	-12.6	71.2	7.3	69.6
ITRF2020	-6.2	104.3	-1.3	111.3	-2.1	8.4	-13.5	70.0	9.2	68.2
ICRF3 TRF	-21.4	696.7	79.3	499.6	-8.6	86.6	-22.2	119.8	7.6	119.2
VTRF2020	1483.7	2035.4	242.2	1717.2	-1.3	125.0	-57.9	293.0	-5.0	305.4

Table 8: WM and WRMS differences between EOP estimated with a priori EOP (IERS 14 C04) and different TRF.

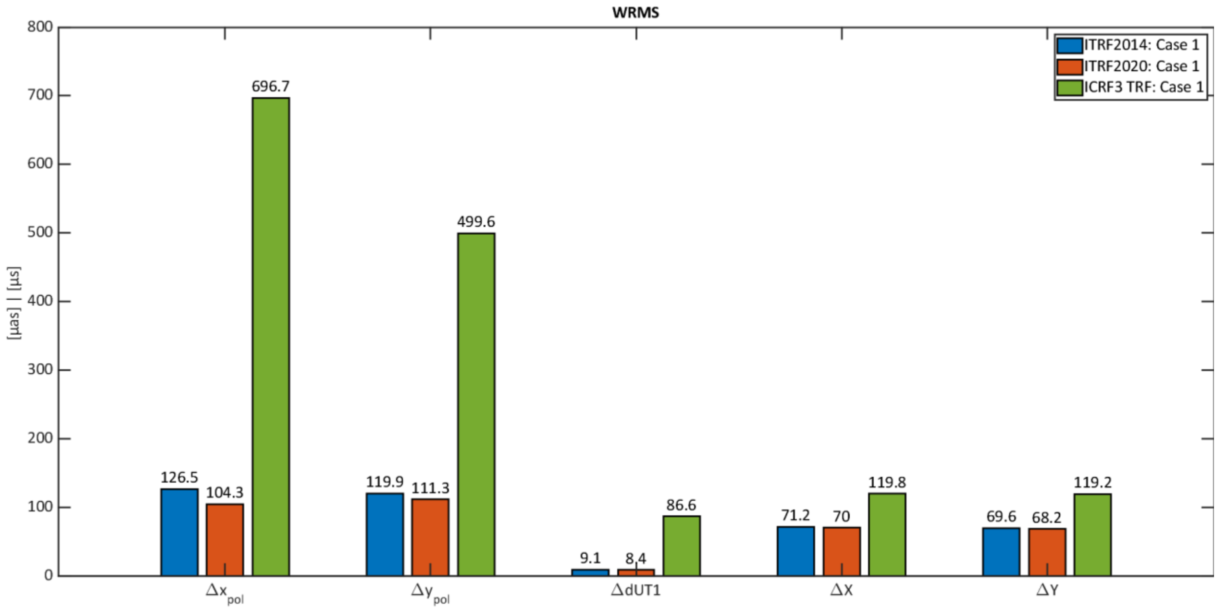
Case 2	$\Delta x_{\rm pol}$ (µas)		$\Delta y_{\rm pol}$ (µas)		ΔdUT1 (µs)		ΔX (µas)		ΔY (µas)	
Fixed	WM	WRMS	WM	WRMS	WM	WRMS	WM	WRMS	WM	WRMS
ITRF2014	13.8	132.4	-35.3	124.3	-0.6	9.6	-11.2	76.4	3.3	73.7
ITRF2020	-3.6	109.3	-1.1	114.9	-2.4	8.9	-12.3	74.9	5.1	72.5
ICRF3 TRF	-93.6	520.8	96.3	248.9	-12.4	33.4	-14.4	98.1	4.2	102.0
VTRF20	1660.8	1995.8	275.8	1774.9	2.0	131.6	-66.5	306.7	-8.5	314.9

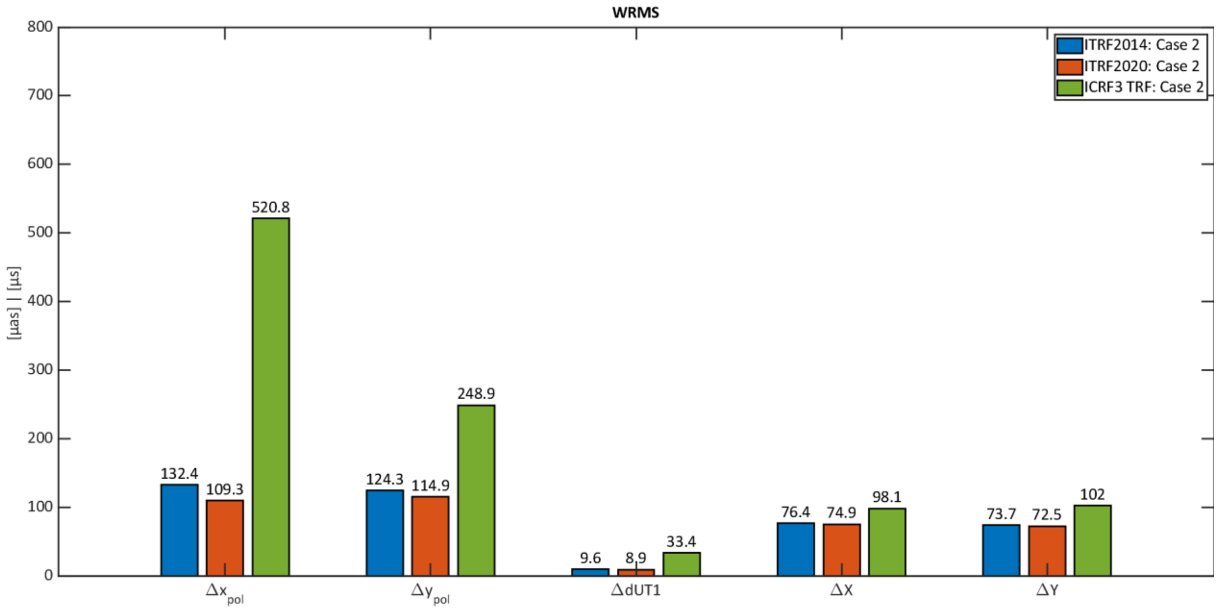
Table 9: WM and WRMS differences between EOP estimated with a priori EOP (IERS 14 C04) and different TRF. Note: stations KASHIM34 and TSUKUB32 were not included due to discontinuity issues in ICRF3 TRF.

WRMS

EOP estimated vs IERS 14 C04

Sub-case studies	Comments
Case 1	No stations previously excluded.
Case 2	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
Case 3	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.





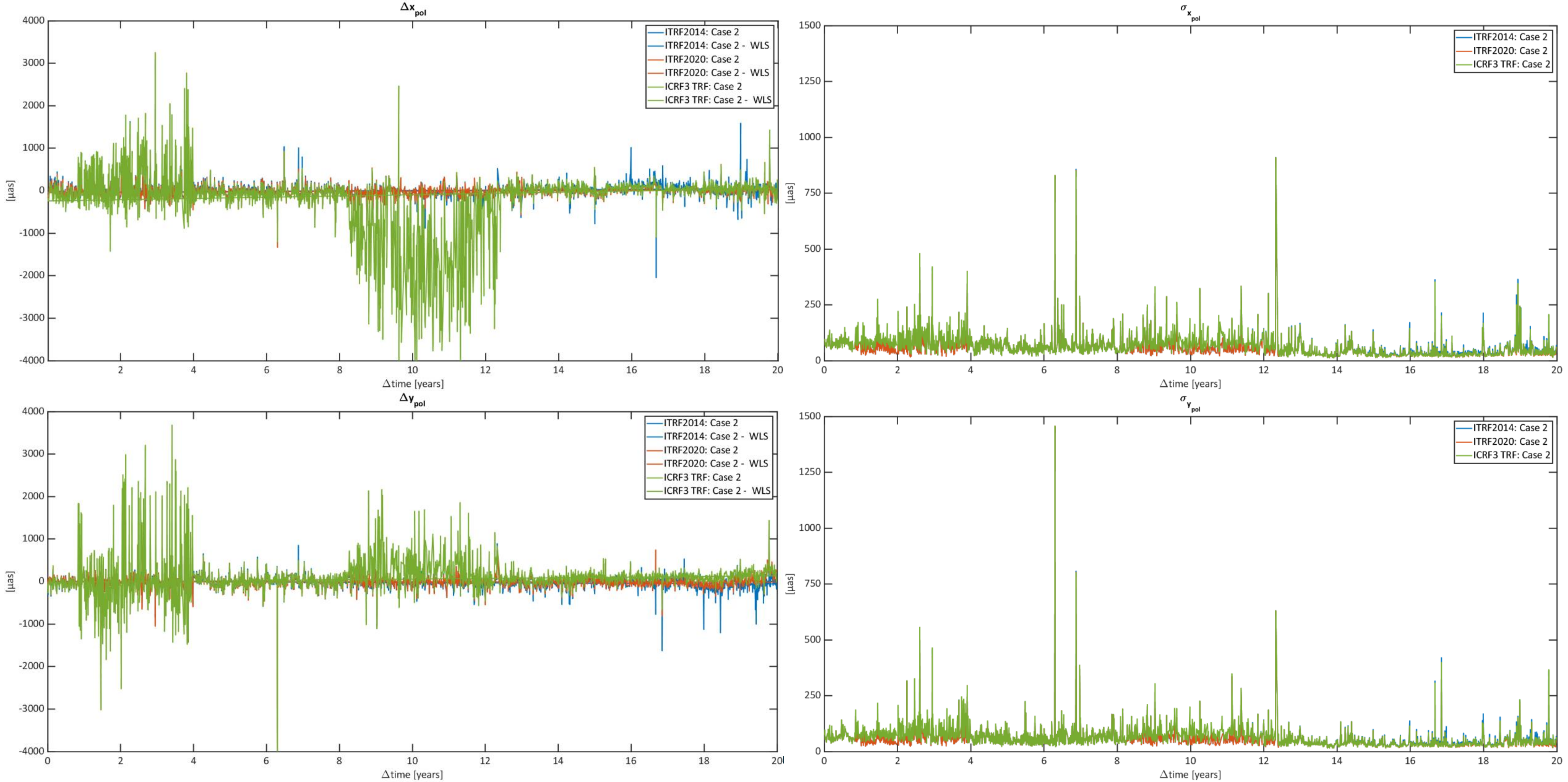
- ITRF2020 has the smallest WRMS for all EOP set, independently of the case study.
- ITRF2014 and ITRF2020 have considerable differences for Δx_{pol} and Δy_{pol} with 22.2 μas and 8.6 μas, respectively.
- WRMS are bigger for ITRF2014 and ITRF2020 in Case 2.
- WRMS much smaller for ICRF3 TRF in Case 2, more specifically for Δx_{pol} and Δy_{pol}.

$\Delta WRMS$	Δ Case 2, Case 1		Δ ITRF2014,ITRF2020	
	ITRF2014	ITRF2020	Case 1	Case 2
Δx_{pol} (µas)	5.9	5	**22.2**	23.1
Δy_{pol} (µas)	4.4	3.6	**8.6**	9.4
ΔdUT1 (µs)	0.5	0.5	**0.7**	0.7
ΔX (µas)	5.2	4.9	**1.2**	1.5
ΔY (µas)	4.1	4.3	**1.4**	1.2

Table 10: WRMS differences between Case 1 and Case 2, and between ITRF2014 and ITRF2020.

EOP residuals and uncertainties
CASE 2

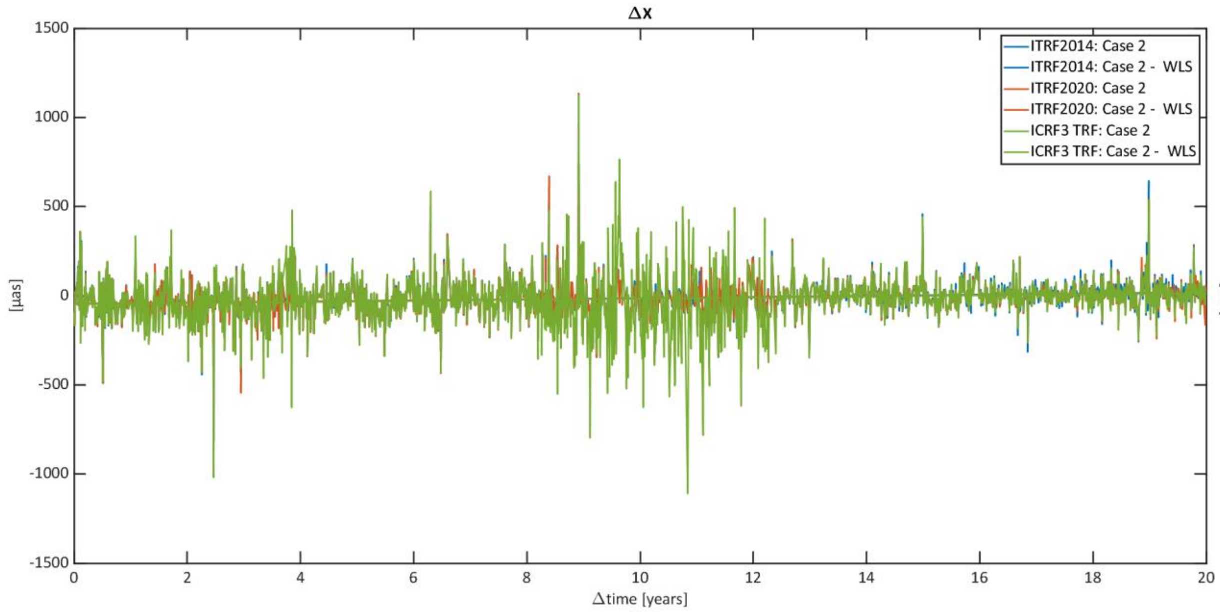
Sub-case studies	Comments
Case 1	No stations previously excluded.
Case 2	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
Case 3	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.

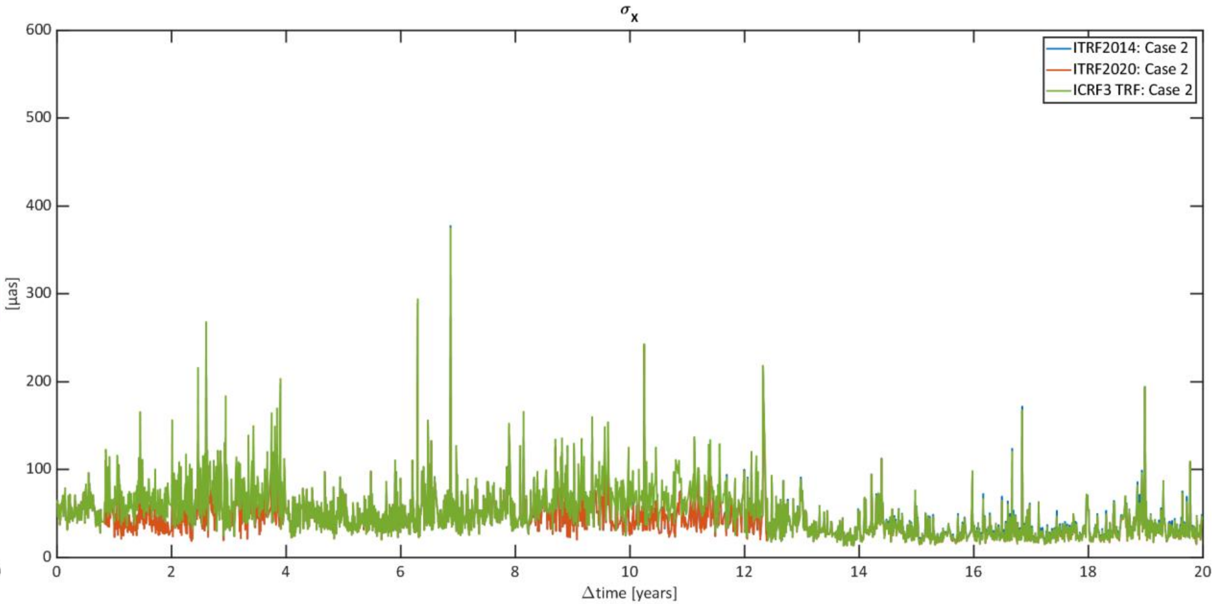


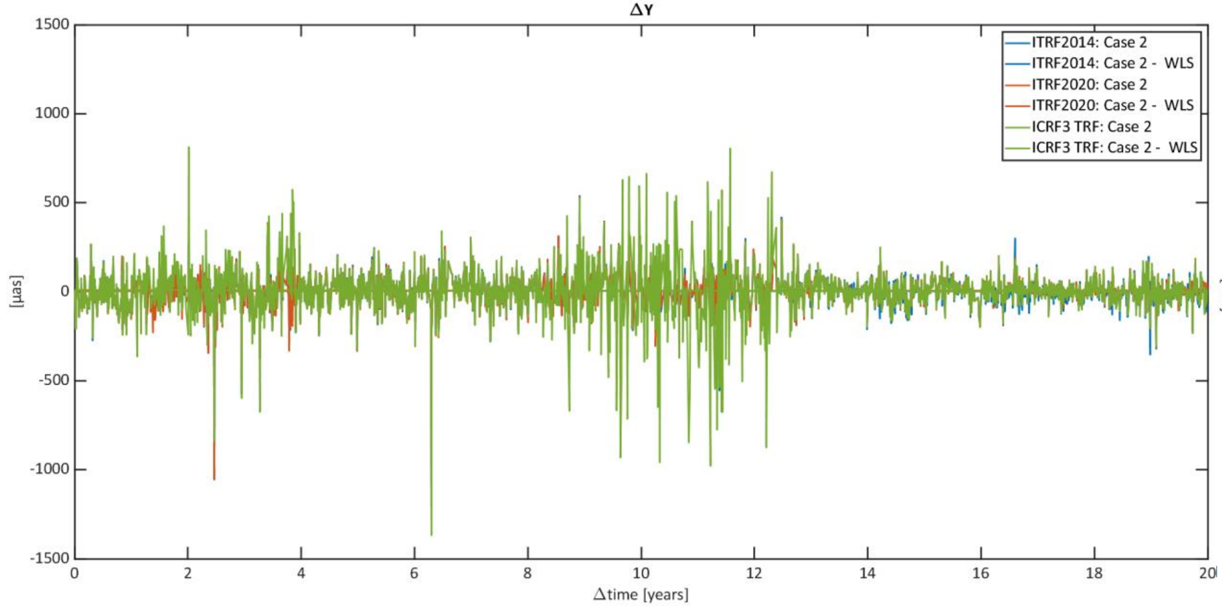
EOP residuals and uncertainties

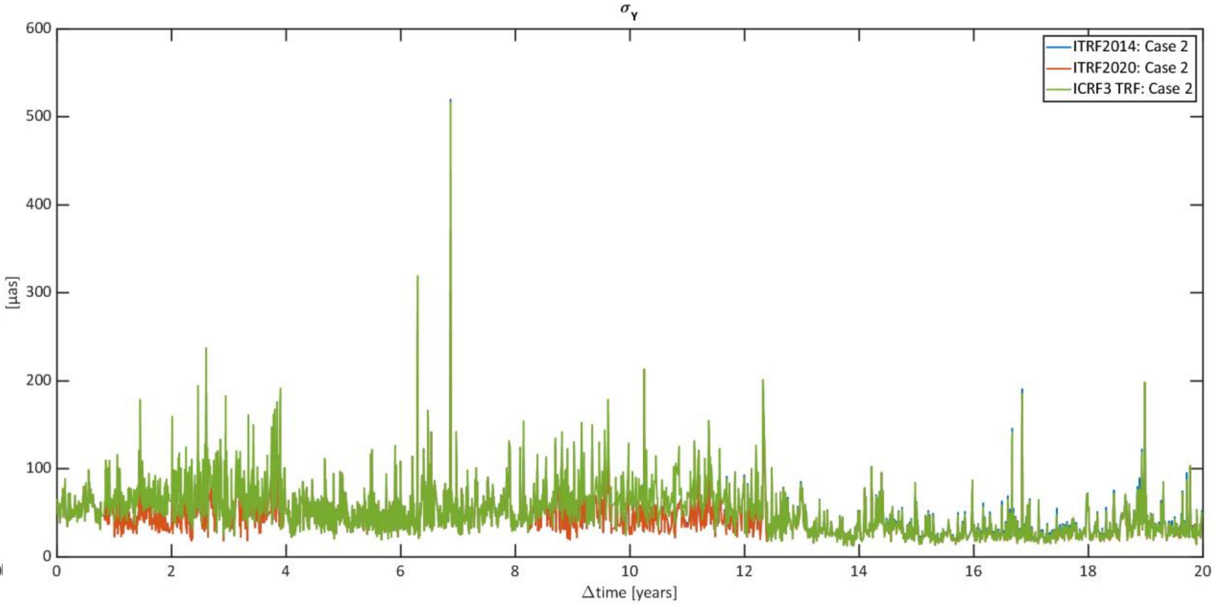
CASE 2

Sub-case studies	Comments
Case 1	No stations previously excluded.
Case 2	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
Case 3	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.



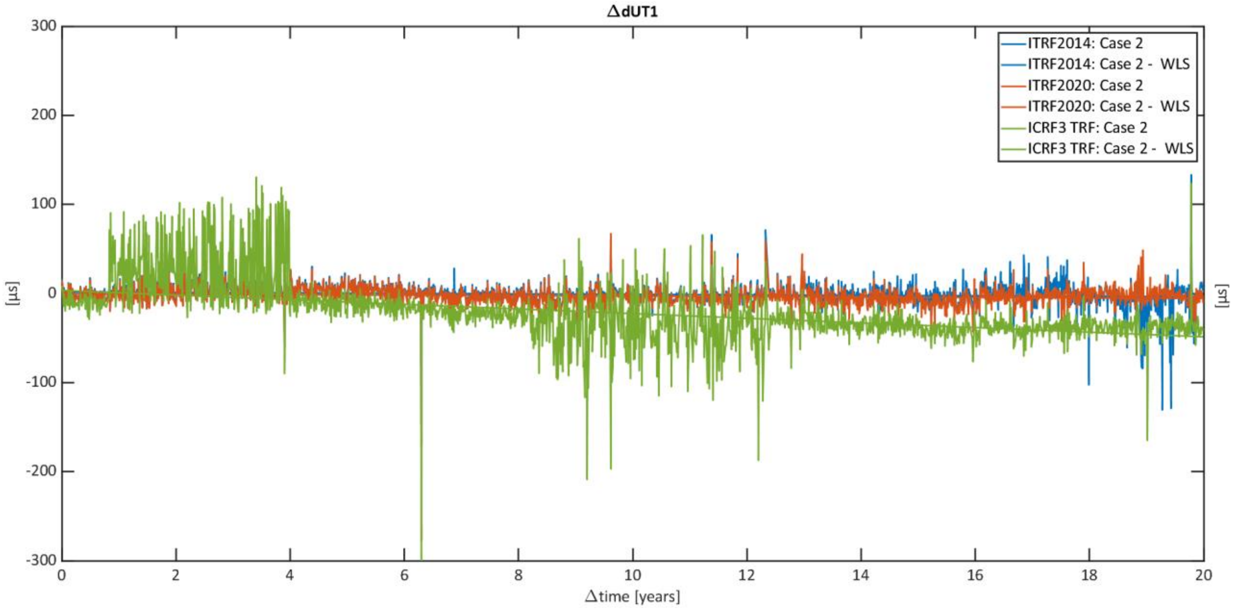


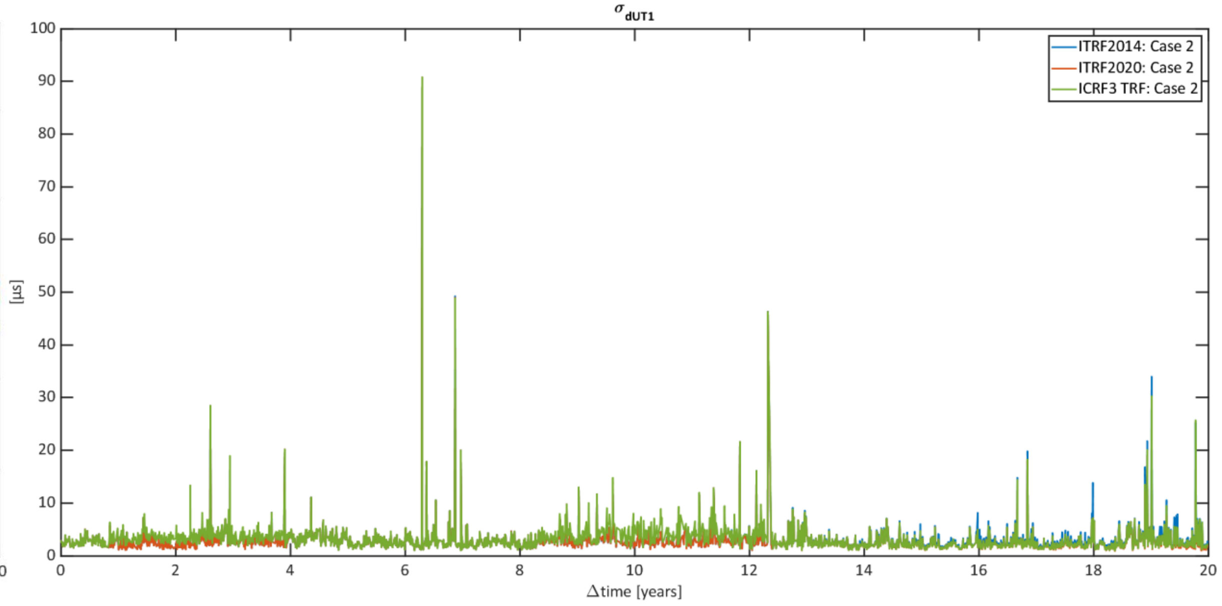




EOP residuals and uncertainties
CASE 2

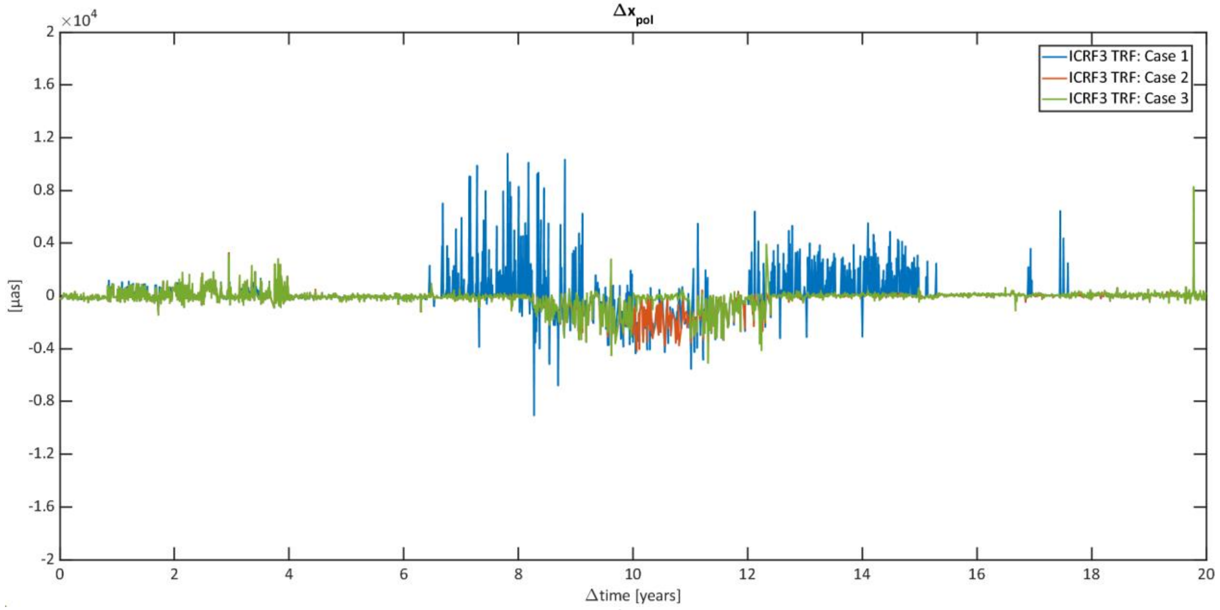
Sub-case studies	Comments
Case 1	No stations previously excluded.
Case 2	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
Case 3	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.

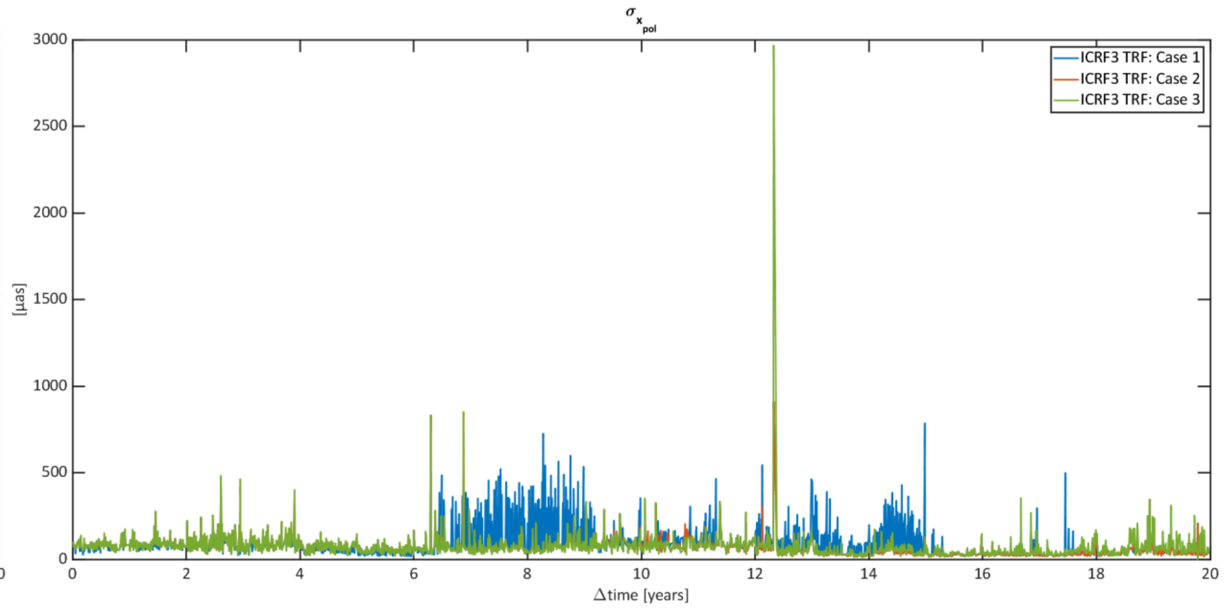


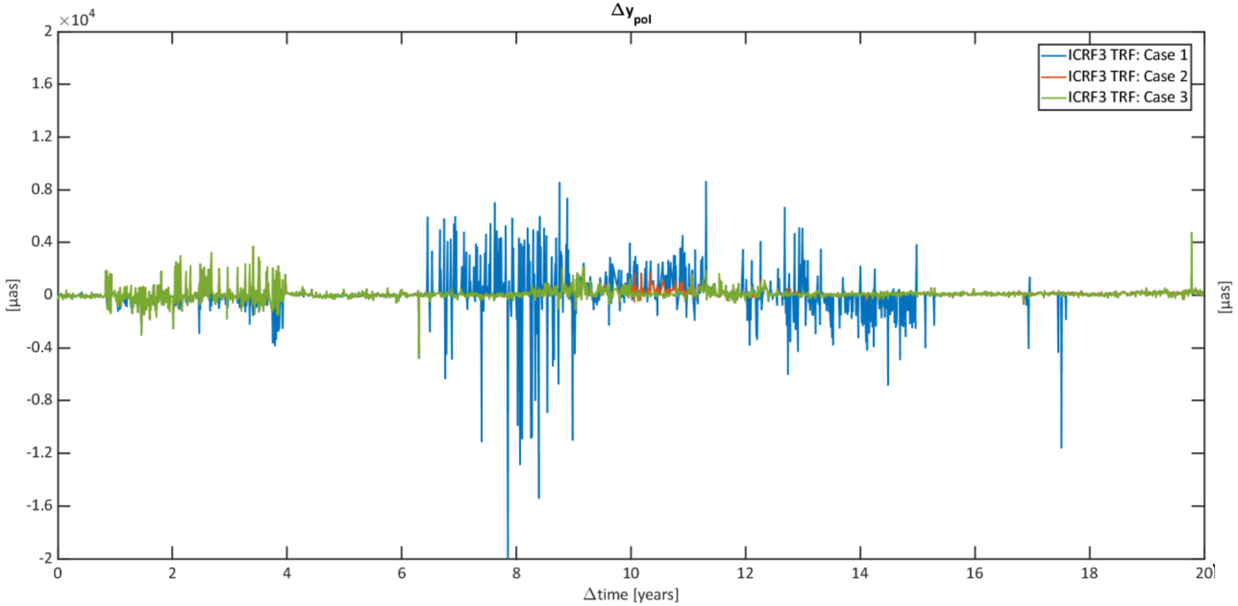


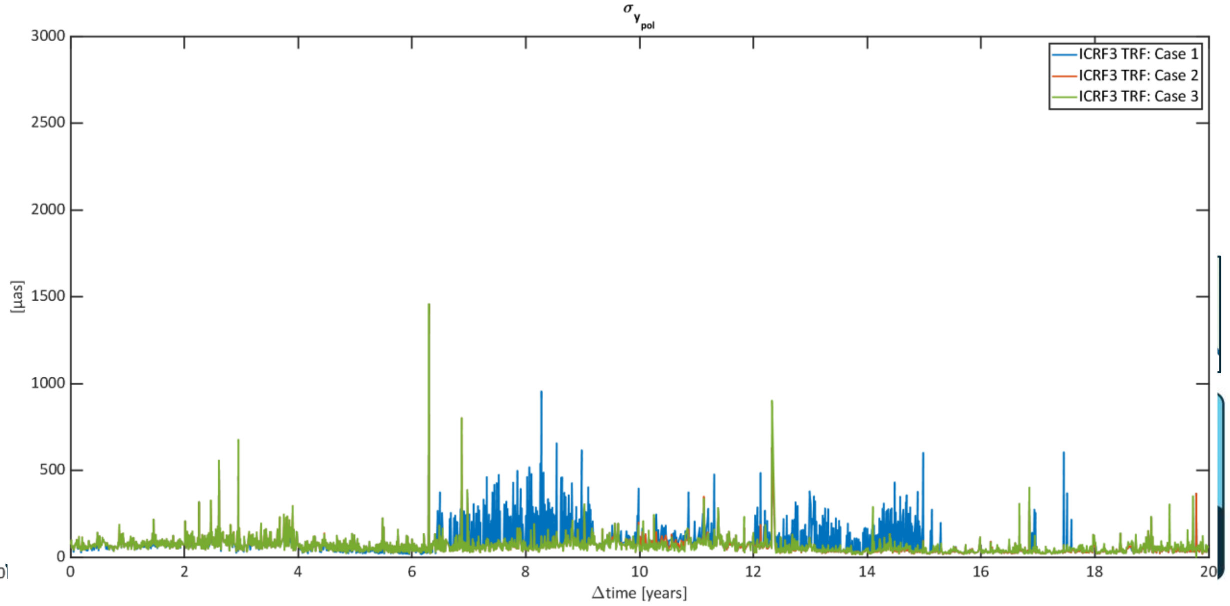
EOP residuals and uncertainties
CASE 3: ICRF3 TRF

Sub-case studies	Comments
Case 1	No stations previously excluded.
Case 2	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
Case 3	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.



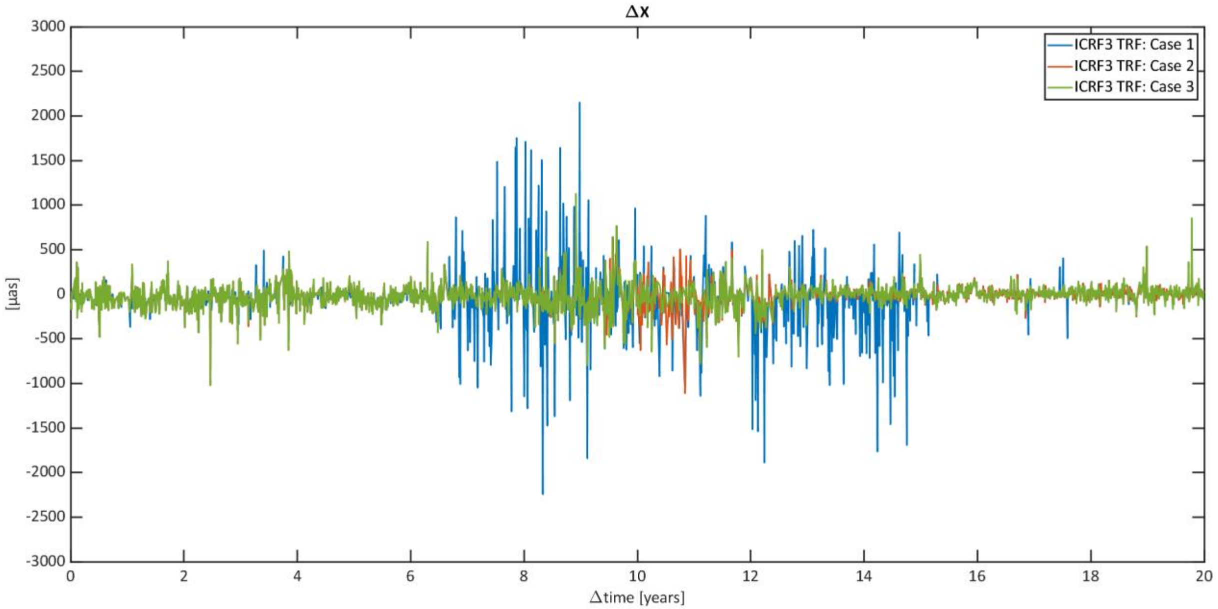


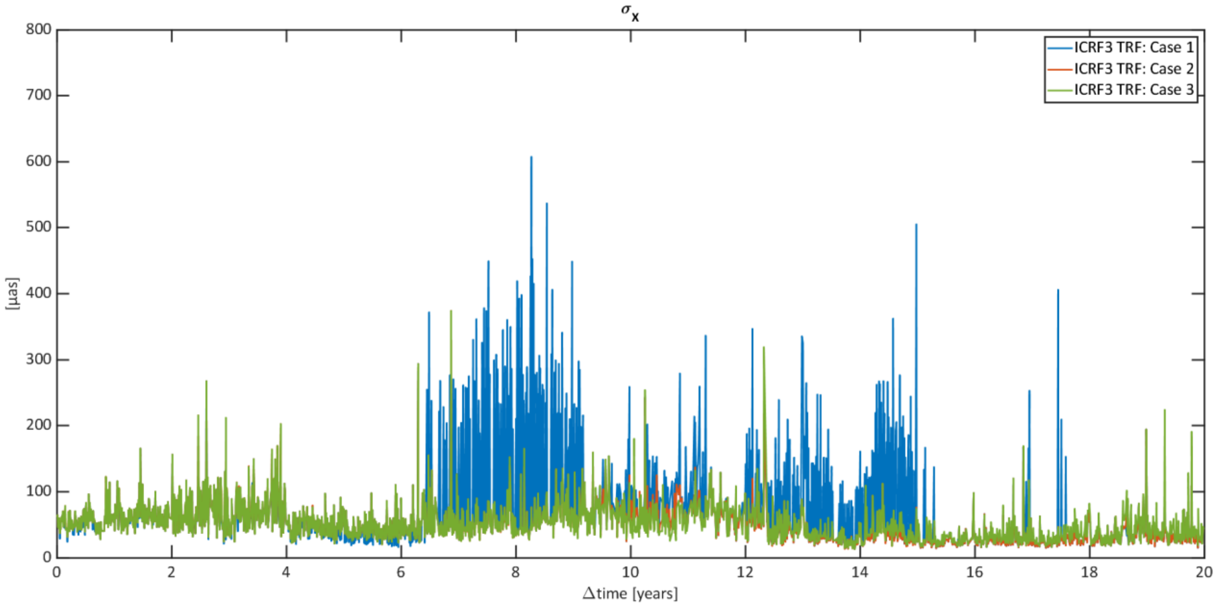


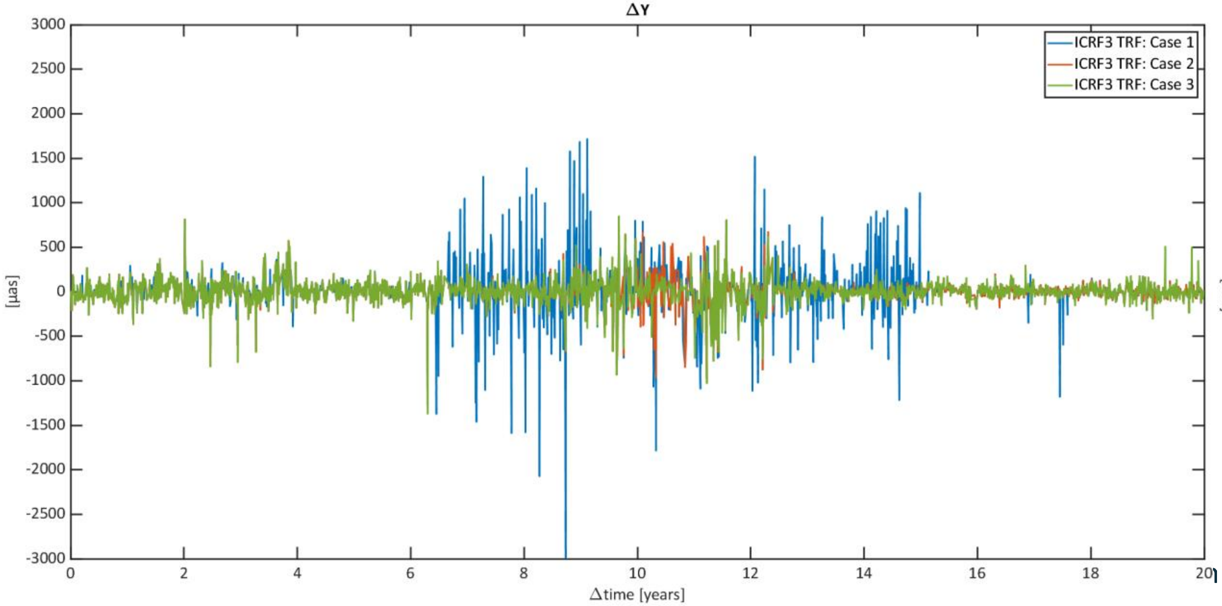


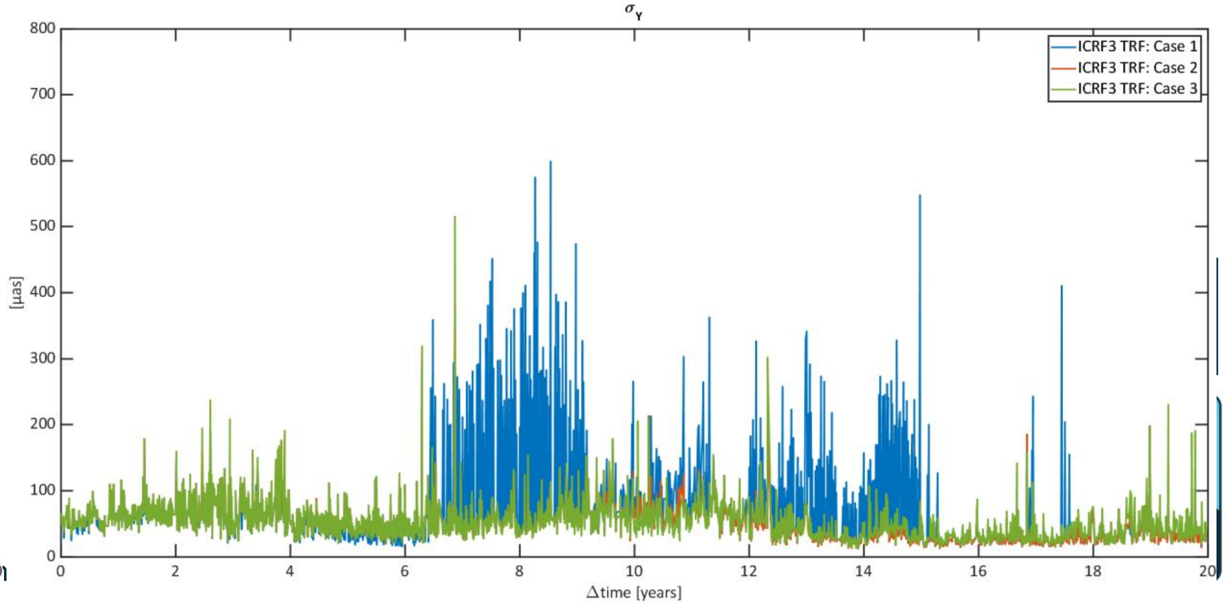
EOP residuals and uncertainties
CASE 3: ICRF3 TRF

Sub-case studies	Comments
Case 1	No stations previously excluded.
Case 2	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
Case 3	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.





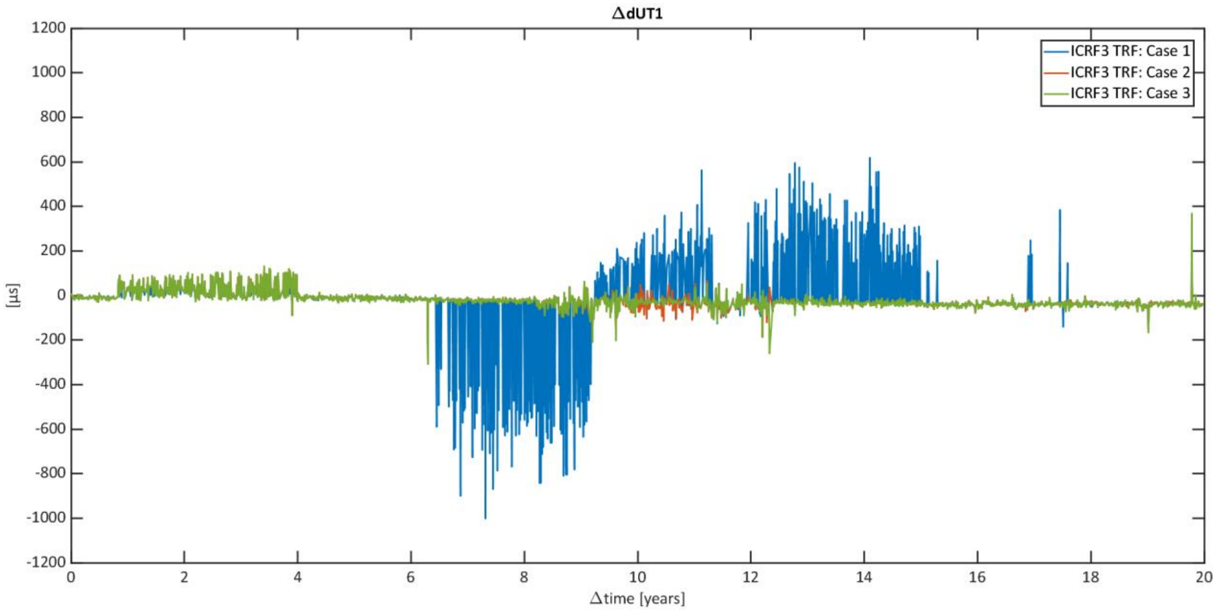


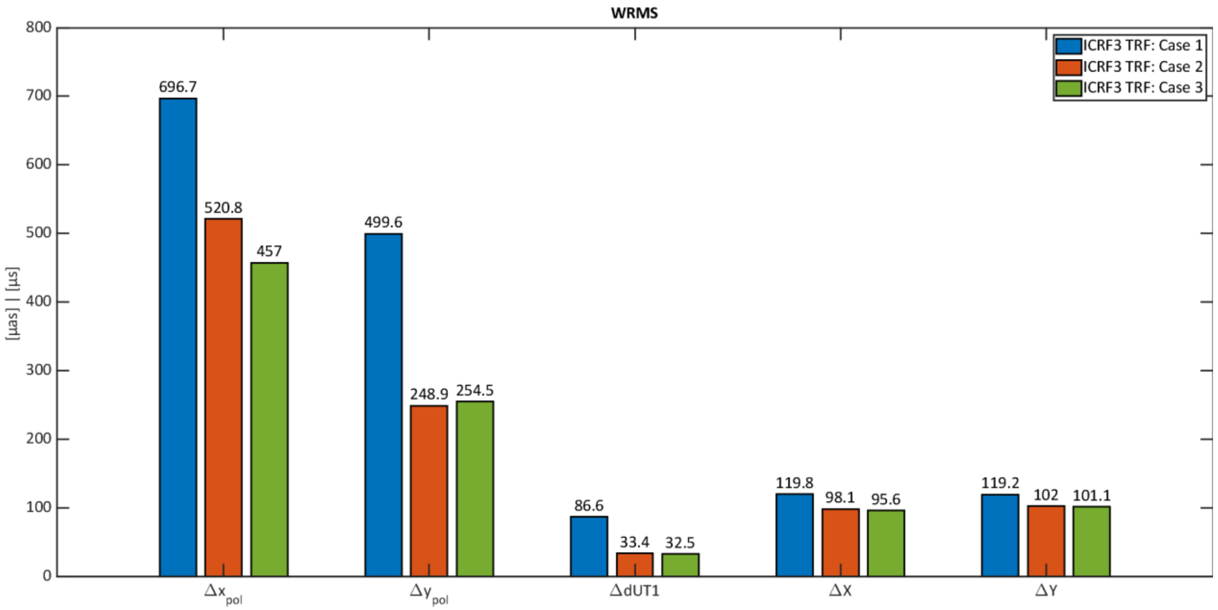


EOP residuals and uncertainties

CASE 3: ICRF3 TRF

Sub-case studies	Comments
Case 1	No stations previously excluded.
Case 2	Stations KASHIM34 and TSUKUB32 were previously excluded due to discontinuity issues in ICRF3 TRF.
Case 3	All stations with discontinuity issues in ICRF3 TRF were previously excluded. Furthermore YARRA12 was also excluded.





- Stations with discontinuities in the ICRF3 TRF removed. 25 stations were excluded.
- Case 1 vs Case 2: Significant decrease in the WRMS for ICRF3 TRF can be observed, specially for Δx_{pol}, Δy_{pol}
- Case 2 vs Case 3: only for Δx_{pol} a considerable improvement is achieved in the WRMS (63.8 μas).

SPACE GEODETIC TECHNIQUES

| PRODUCTS |

Parameter	VLBI	GNSS	DORIS	SLR	LLR	Altimetry
ICRF (quasars)	X					
Nutation	X	(X)		(X)	X	
Polar motion	X	X	X	X	X	
UT1	X					
Length of day	(X)	X	X	X	X	
ITRF (stations)	X	X	X	X	X	(X)
Geocenter		X	X	X		X
Gravity field		X	X	X	(X)	X
Orbits		X	X	X	X	X
LEO orbits		X	X	X		X
Ionosphere	X	X	X			X
Troposphere	X	X	X			X
Time/frequency	(X)	X		(X)		

[Ref] H. Schuh, D. Behrend, “VLBI: A Fascinating Technique for Geodesy and Astrometry”, 2012