Current status and future perspectives of VLBI global solutions

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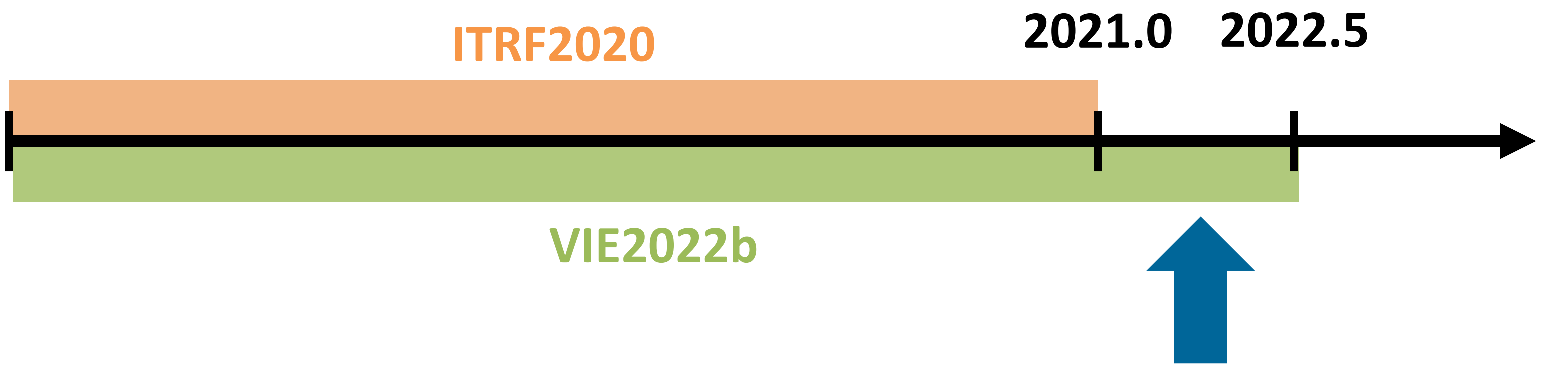
Lisa Kern • Hana Krásná • Johannes Böhm • Matthias Madzak
TU Wien, Austria

Motivation

- Very Long Baseline Interferometry
  - Crucial for determination of CRF, scale, EOP (UT1, nutation)

- Vienna IVS Analysis Center
  - Global solution (multi-session solution) on NEQ level
    → VLBI-only TRF + CRF solutions

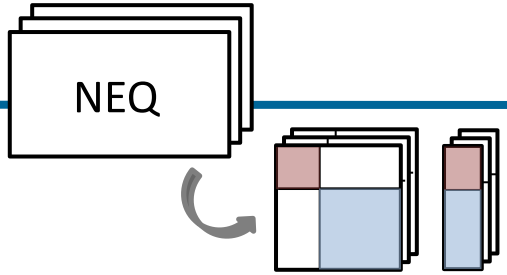
Vienna VLBI and Satellite Software



Benefit of +18 months of VLBI observations?

Global solution theory

e.g., Brockmann (1997), Angermann et al. (2004)



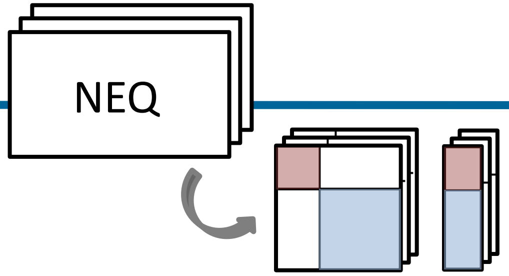
Processing steps

VLBI NEQs (Input)

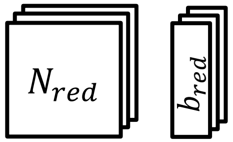
Global solution theory

e.g., Brockmann (1997), Angermann et al. (2004)

Processing steps



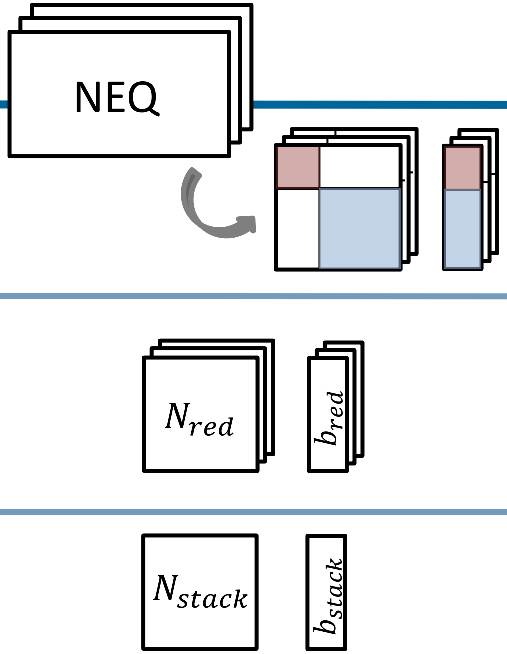
VLBI NEQs (Input)



Session-wise reduction of non-global parameters

Global solution theory

e.g., Brockmann (1997), Angermann et al. (2004)



Processing steps

VLBI NEQs (Input)

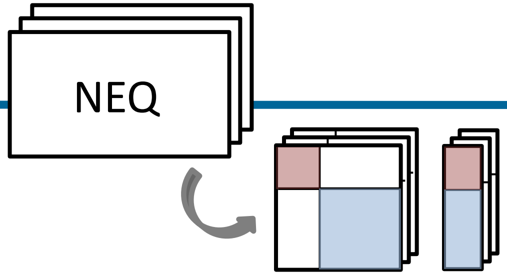
Session-wise reduction of non-global parameters

Stacking

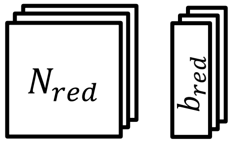
Global solution theory

e.g., Brockmann (1997), Angermann et al. (2004)

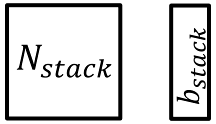
Processing steps



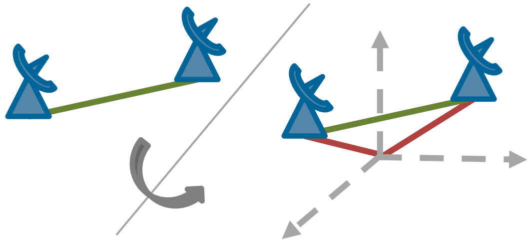
VLBI NEQs (Input)



Session-wise reduction of non-global parameters



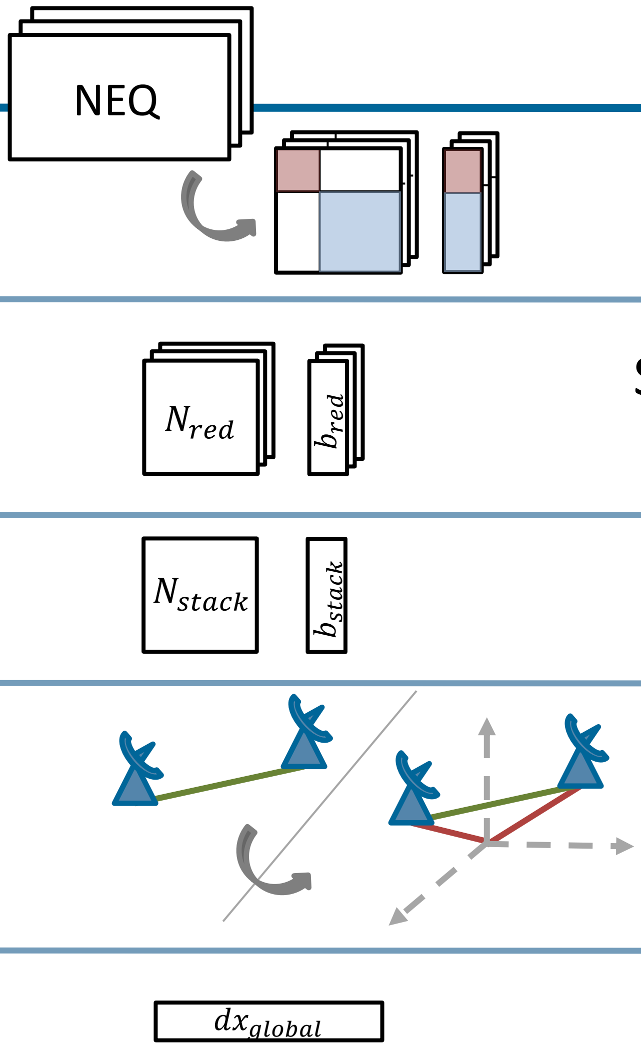
Stacking



Introduction of geodetic datum

Global solution theory

e.g., Brockmann (1997), Angermann et al. (2004)



Processing steps

VLBI NEQs (Input)

Session-wise reduction of non-global parameters

Stacking

Introduction of geodetic datum

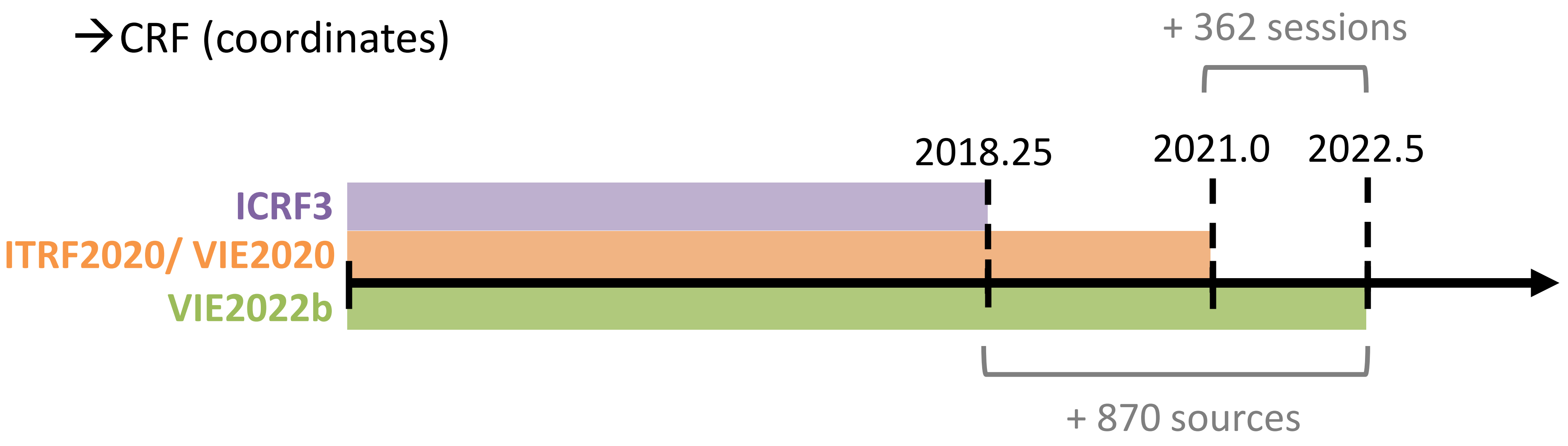
Global solution

Global solution at VIE AC – VIE2020

Krásná et al., 2023 – revision submitted

- VIE IVS Analysis Center participated in efforts of calculating **ITRF2020**

- VIE VLBI-only solutions: VIE2020 & VIE2022b
  - → TRF (coordinates + linear velocities)
  - → CRF (coordinates)



Global solution at VIE AC – VIE2020

Krásná et al., 2023 – revision submitted

Terrestrial reference frame

– **Transformation parameter** from ITRF2020 to VIE2020/ VIE2022b

	T_x [mm] $\dot{T}_x$ [mm/yr]	T_y [mm] $\dot{T}_y$ [mm/yr]	T_z [mm] $\dot{T}_z$ [mm/yr]	R_x [µas] $\dot{R}_x$ [µas/yr]	R_y [µas] $\dot{R}_y$ [µas/yr]	R_z [µas] $\dot{R}_z$ [µas/yr]	scale s [ppb] ([mm]) $\dot{s}$ [ppb/yr] ([mm/yr])
VIE2020	−0.8 ± 1.7 0.0 ± 0.0	−3.4 ± 1.7 −0.2 ± 0.0	−2.0 ± 1.7 0.0 ± 0.0	60.5 ± 69.2 6.0 ± 1.7	21.6 ± 68.5 0.8 ± 1.8	−5.4 ± 54.2 4.4 ± 1.5	0.56 ± 0.26 (3.6 ± 1.7) 0.02 ± 0.01 (0.1 ± 0.0)
VIE2022b	1.9 ± 0.7 0.2 ± 0.0	−1.0 ± 0.7 −0.2 ± 0.0	−2.3 ± 0.7 −0.2 ± 0.0	35.4 ± 29.4 5.6 ± 0.7	36.2 ± 29.0 4.3 ± 0.7	21.4 ± 23.2 1.8 ± 0.6	0.59 ± 0.11 (3.7 ± 0.7) 0.03 ± 0.00 (0.2 ± 0.0)

→ Good agreement between ITRF and VLBI-only VIE TRF solution

Global solution at VIE AC – VIE2020

Krásná et al., 2023 – revision submitted

Terrestrial reference frame

– **Transformation parameter** from ITRF2020 to VIE2020/ VIE2022b

	T_x [mm] $\dot{T}_x$ [mm/yr]	T_y [mm] $\dot{T}_y$ [mm/yr]	T_z [mm] $\dot{T}_z$ [mm/yr]	R_x [µas] $\dot{R}_x$ [µas/yr]	R_y [µas] $\dot{R}_y$ [µas/yr]	R_z [µas] $\dot{R}_z$ [µas/yr]	scale s [ppb] ([mm]) $\dot{s}$ [ppb/yr] ([mm/yr])
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→ Good agreement between ITRF and VLBI-only VIE TRF solution

– Scale difference

- Trend after 2014

→ VLBI working group established

Global solution at VIE AC – VIE2020

Krásná et al., 2023 – revision submitted

Terrestrial reference frame

- **Antenna height**

VIE2022b vs. ITRF2020:

→ estimated heights are higher in VIE2022b (scale difference)

→ lower height error

VIE2022b vs. VIE2020:

→ lower height error

antenna	$\Delta h \pm m_{\Delta h}$ [mm]	m_h [mm] VIE2022b (VIE2020)	m_h [mm] ITRF2020
FD-VLBA	1.6 ± 1.4	0.2 (0.2)	1.4
GGAO12M	7.7 ± 3.5	0.7 (1.3)	3.4
GGAO7108	−77.3 ± 30.6	10.6 (10.7)	28.7
HRAS_085	33.0 ± 17.4	17.1 (17.1)	3.3
KOKEE	−0.8 ± 1.2	0.2 (0.2)	1.2
KOKEE12M	−1.6 ± 3.6	0.4 (0.6)	3.5
MACGO12M	16.3 ± 11.2	0.4 (x.x)	11.2
NYALE13S	−2.2 ± 27.3	0.8 (2.1)	27.3
NYALES20	4.7 ± 1.1	0.2 (0.2)	1.1
ONSA13NE	2.6 ± 3.1	0.2 (0.4)	3.1
ONSA13SW	4.2 ± 4.0	0.3 (0.5)	4.0
ONSALA60	1.4 ± 1.0	0.2 (0.2)	1.0
RAEGSMAR	−21.7 ± 390.9	8.6 (x.x)	390.8
RAEGYEB	9.9 ± 2.0	0.4 (0.5)	1.9
WETTZ13N	3.2 ± 1.1	0.2 (0.2)	1.1
WETTZ13S	4.0 ± 1.5	0.3 (0.4)	1.5
WETTZELL	4.2 ± 0.9	0.1 (0.1)	0.9
YEBES40M	2.2 ± 1.3	0.2 (0.2)	1.3

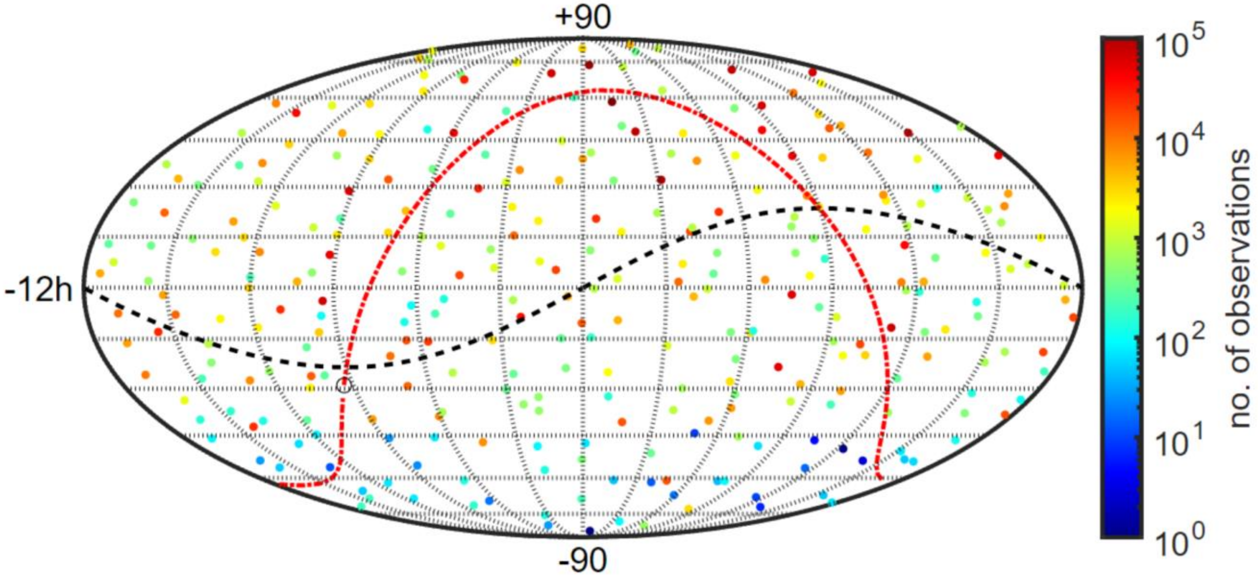
Antenna height differences and formal errors

Global solution at VIE AC – VIE2020

Krásná et al., 2023 – revision submitted

Celestial reference frame

- **VIE2022b**-*sx* (5407 sources = ICRF3 + 870 sources)
- Unweighted NNR on 301 ICRF3 defining sources



Number of observations of **ICRF3 defining sources** from ICRF3 cutoff date (MAR 2018) – VIE2022b cutoff date (JUN 2022)

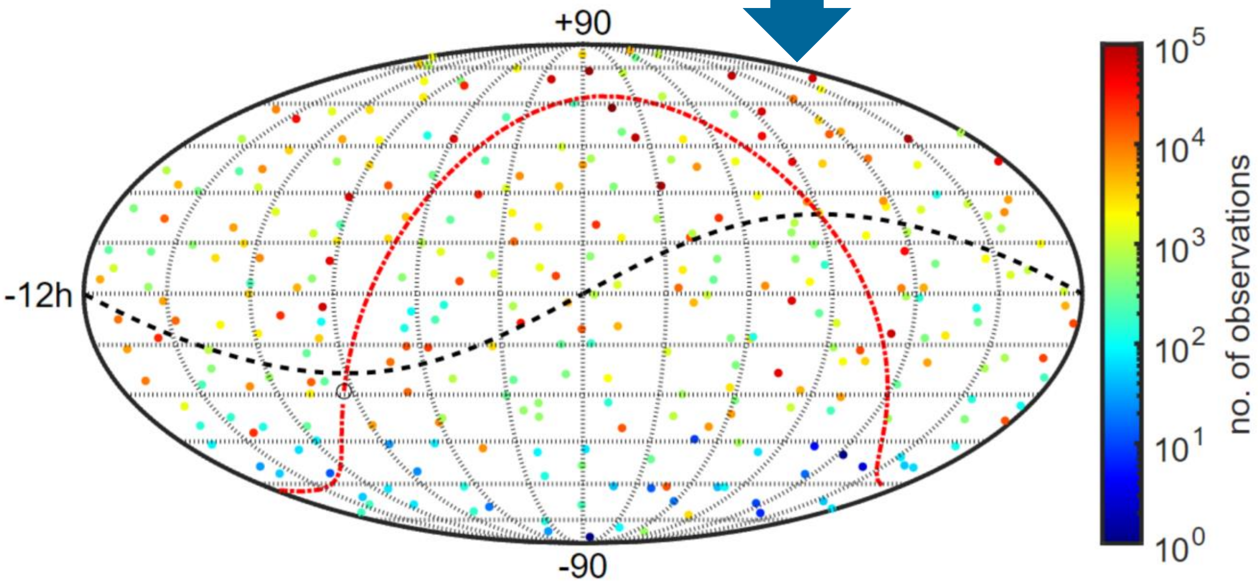
Global solution at VIE AC – VIE2020

Krásná et al., 2023 – revision submitted

Celestial reference frame

- VIE2022b-*sx* (5407 sources = ICRF3 + 870 sources)
- Unweighted NNR on 301 ICRF3 defining sources

Despite great international effort*
→ increase in $\#observations$ slower for southern defining sources



Number of observations of **ICRF3 defining sources** from ICRF3 cutoff date (MAR 2018) – VIE2022b cutoff date (JUN 2022)

*IVS-CRDS (de Witt et al. 2019);
AOV (McCallum et al. 2019);
AUS mixed-mode program (McCallum et al. 2022)

Global solution at VIE AC – VIE2020

Krásná et al., 2023 – revision submitted

Celestial reference frame

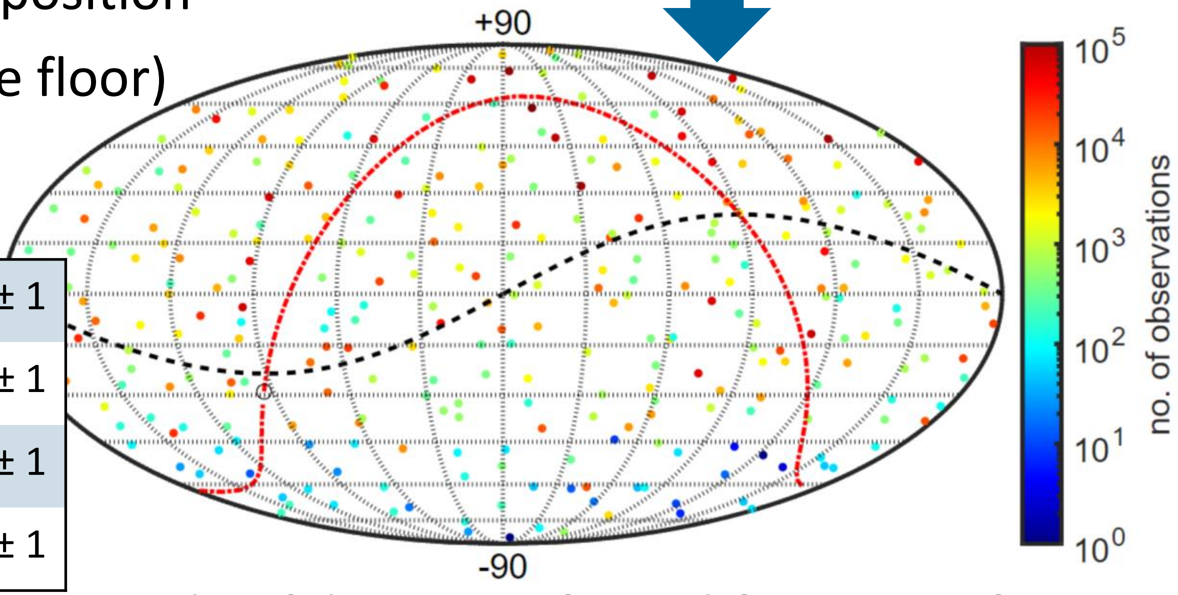
- **VIE2022b**-*sx* (5407 sources = ICRF3 + 870 sources)
- Unweighted NNR on 301 ICRF3 defining sources
- Vector spherical harmonics decomposition

→ Differences $< 30\ \mu as$ (below noise floor)

Despite great international effort*
→ increase in $\#observations$ slower for southern defining sources

VSH parameters $[\mu as]$

R_1	9 ± 2	$a^{e}_{2,0}$	20 ± 3	$a^{e,Re}_{2,2}$	0 ± 1
R_2	-9 ± 2	$a^{m}_{2,0}$	6 ± 2	$a^{e,Im}_{2,2}$	-4 ± 1
R_3	-13 ± 2	$a^{e,Re}_{2,1}$	-3 ± 3	$a^{m,Re}_{2,2}$	4 ± 1
D_1	1 ± 2	$a^{e,Im}_{2,1}$	1 ± 3	$a^{m,Im}_{2,2}$	1 ± 1
D_2	-6 ± 2	$a^{m,Re}_{2,1}$	-2 ± 3		
D_3	-25 ± 2	$a^{m,Im}_{2,1}$	3 ± 3		



Number of observations of **ICRF3 defining sources** from ICRF3 cutoff date (MAR 2018) – VIE2022b cutoff date (JUN 2022)

Global solution – TRF datum definition

- Motivation:
  - Development of a new **state-of-the-art/ stand-alone** Python software for intra-/ inter- technique combination on NEQ level
  - Input: pre-reduced, datum-free NEQ (SINEX)

- Status:
  - VLBI Global solution on NEQ level

Global solution – TRF datum definition

- Methods of introducing NNT/ NNR conditions
  - *Conditions with infinite weight (Helmert rendering)*

e.g., Sillard and Boucher (2001)

$$N_c = \begin{bmatrix} N & B \\ B^T & 0 \end{bmatrix}$$

= forcing translations/ rotations w.r.t. reference frame to be zero

  - *Constraints with covariances*

e.g., Altamimi et al. (2002)

$$N_c = N + H^T \boldsymbol{P} H \text{ with } H = (B^T B)^{-1} B^T$$

= loose constraints: lead to a "loose fit" of network within the datum definition

Global solution – TRF datum definition

- Methods of introducing NNT/ NNR conditions
  - *Conditions with infinite weight (Helmert rendering)*
  - *Constraints with covariances*

$$N_c = \begin{bmatrix} N & B \\ B^T & 0 \end{bmatrix}$$

$$N_c = N + H^T \boldsymbol{P} H \text{ with } H = (B^T B)^{-1} B^T$$

- Scaling of B
  - strict: B_{NNT} by $\sqrt{N}$ and B_{NNR} by $\sqrt{\sum_{i=1}^{N} x_{0,i}^2 + y_{0,i}^2 + z_{0,i}^2}$
  - common in VLBI community: B_{NNR} by R_E

→ No impact on estimates/ variances, but on fulfillment of conditions

Global solution – TRF datum definition

- Methods of introducing NNT/ NNR conditions
  - *Conditions with infinite weight (Helmert rendering)*
  - *Constraints with covariances*

$$N_c = \begin{bmatrix} N & B \\ B^T & 0 \end{bmatrix}$$

$$N_c = N + H^T \boldsymbol{P} H \text{ with } H = (B^T B)^{-1} B^T$$

- Weighting of constraints
  - Comparability of methods? What are „infinite weights“?

$$\boldsymbol{CONSwCOV}_{\boldsymbol{w=10^8}} \cong \boldsymbol{HR}$$

≡ formal error = 0.1 mm

Conclusion & Outlook

- Conclusion:
  - **VIE2020/ VIE2022b – ITRF2020**: good agreement,
    2022b crucial for new VGOS telescopes
  - **VIE2022b-sx – ICRF3**: differences in VSH parameters below noise floor

- Outlook:
  - Development of new state-of-the-art/ stand-alone Python software for intra-/ and inter-technique combination on NEQ level

References

Contact: *lisa.kern@tuwien.ac.at*

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