Celestial reference frame determined from very long baseline interferometry experiments conducted at K-band (24 GHz) over the past 20 years

Hana Krásná[1], David Gordon[2], Aletha de Witt[3], Christopher S. Jacobs[4]

[1]Technische Universität Wien, [2]United States Naval Observatory,
[3]South African Radio Astronomy Observatory, [4]Jet Propulsion Laboratory, California Institute of Technology

Abstract

The current third realization of the international celestial reference frame (ICRF3) was adopted in August 2018 and includes positions of extragalactic objects at three frequencies: 8.4 GHz, 24 GHz and 32 GHz. In this paper we present an update of the celestial reference frame (CRF) estimated from very long baseline interferometry measurements at K-band (24 GHz) including data until June 2022. The observations of the radio sources are conducted with the Very Long Baseline Array from the U.S. territory and the celestial frame is densified in the southern hemisphere with the HartRAO – Hobart26m single baseline observations.

The data set starts in May 2002 and currently consists of more than 120 24h observing sessions performed over the past 20 years. Since the publication of ICRF3, the additional observations of the sources during the last four years allow maintenance of the celestial reference frame and more than 200 additional radio sources ensure an expansion of the frame. We determine the updated K-CRF with two independent analysis software packages (VieVS and Calc/Solve) and describe the differences in the solution strategy. We compare the updated K-CRF to ICRF3k using the so-called vector spherical harmonics providing information about systematic differences between two astrometric catalogs.

VLBI data (24 GHz)

Sessions
124 24h observing sessions: 05/2002 – 06/2022
87 VLBA sessions
37 single baseline sessions Ho-Hh (+ Ti, T6)

Data rates
2002-2010: 128-256 Mbps
2015-10/2019: 2048 Mbps (VLBA)
11/2019 – present: 4096 Mbps (VLBA)

Setup of the solutions

USNO-k-220705
- CALC/SOLVE
- group delay + delay rates
- ionosphere from 2 hour average JPL GPS ionosphere maps
- baseline dependent weighting
- trop. mapping functions: VMF1 (h+w)
- DAO trop. gradients with constraints of 0.5 mm (offset) and 2.0 mm/day (rate)

VIE-k-220919
- VieVS 3.2
- NGS cards until 2019, Version 4 vgosDB since 2019
- group delays
- ionosphere until 2019: JPL GPS maps
- ionosphere since 2019: CODE ionex map with 1 hour spacing www.aiub.unibe.ch/download/CODE/
- elevation dependent weighting (Gipson et al., 2008)
- trop. mapping functions: VMF3 (h+w)
- zero trop. gradients a priori with absolute constraints of 1 mm and 0.5 mm after 6 hours

Parametrisation of the solutions

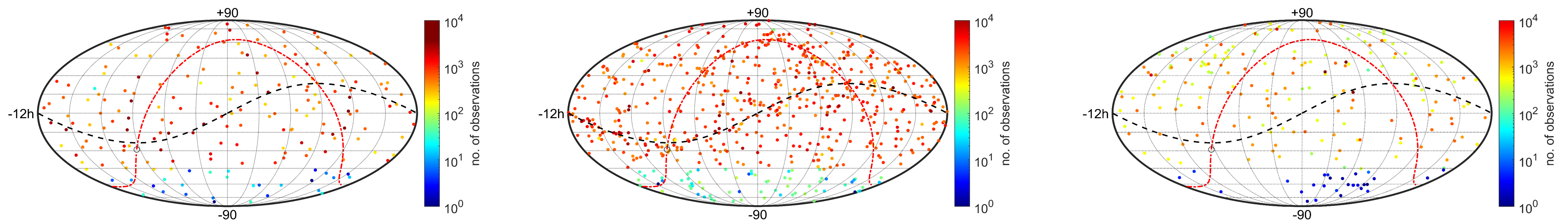
Global solution – datum definition (USNO-k-220705)
- NNT/NNR w.r.t. recent USNO S/X solution on VLBA antennas
- uniform weighted NNR w.r.t. ICRF3sx (Charlot et al., 2020) on 272 defining sources

Global solution – datum definition (VIE-k-220919)
- NNT/NNR w.r.t. ITRF2020 (Altamimi et al., 2022) VLBA antennas except MK-VLBA
- unweighted NNR w.r.t. ICRF3k (Charlot et al., 2020) on 193 defining sources

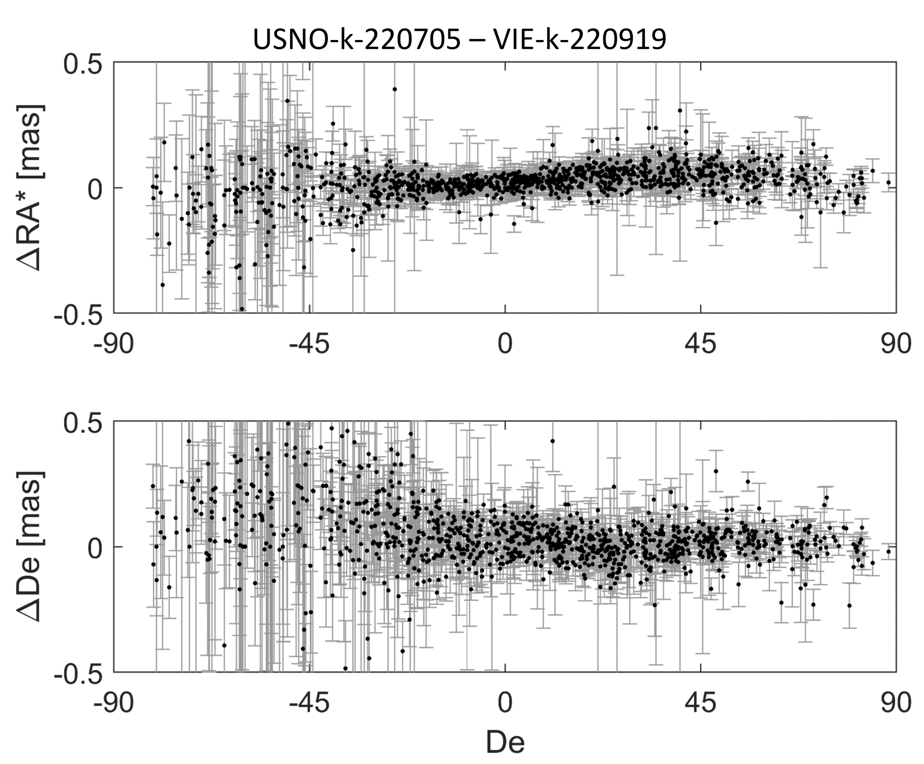
clocks – 60 min estimation interval
zenith wet delay – pwlo in 30 min
troposphere gradients – pwlo in 6 hours
EOP from VLBA sessions – pwlo (vie) or offset and rate (usno) at midnights for pole coordinates and UT1-UTC, one offset for nutation

Earth Orientation parameters (see Poster II Krásná et al., REFAG2022)

Increase of observations since ICRF3k release

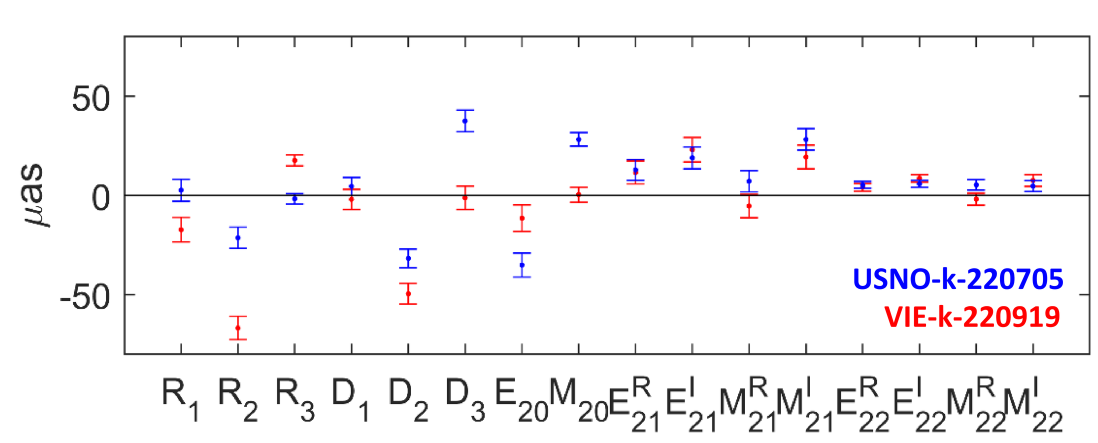


Difference between USNO-k-220705 and VIE-k-220919



VSH	[µas]
R_1	-20 +/- 3
R_2	-47 +/- 3
R_3	22 +/- 1
D_1	-10 +/- 2
D_2	-18 +/- 2
D_3	-39 +/- 3
M_{20}	-30 +/- 2
E_{20}	27 +/- 3
E_{21} real	-1 +/- 3
E_{21} imag.	2 +/- 3
M_{21} real	-11 +/- 3
M_{21} imag.	-11 +/- 3
E_{22} real	-2 +/- 1
E_{22} imag.	3 +/- 1
M_{22} real	-9 +/- 1
M_{22} imag.	2 +/- 2

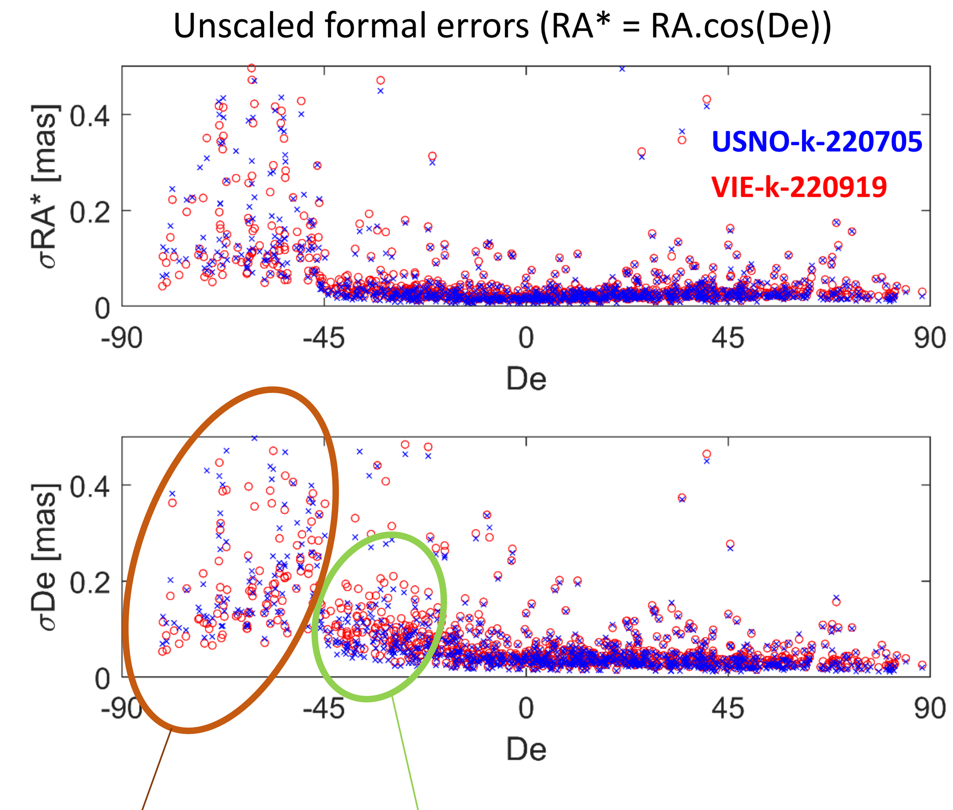
Parameters of Vector Spherical Harmonics w.r.t. ICRF3k
(Mignard & Klioner, 2012; Titov & Lambert, 2013)



R – rotation
D – dipole
E, M – quadrupole harmonics (electric and magnetic type)

Formal errors of estimated source coordinates

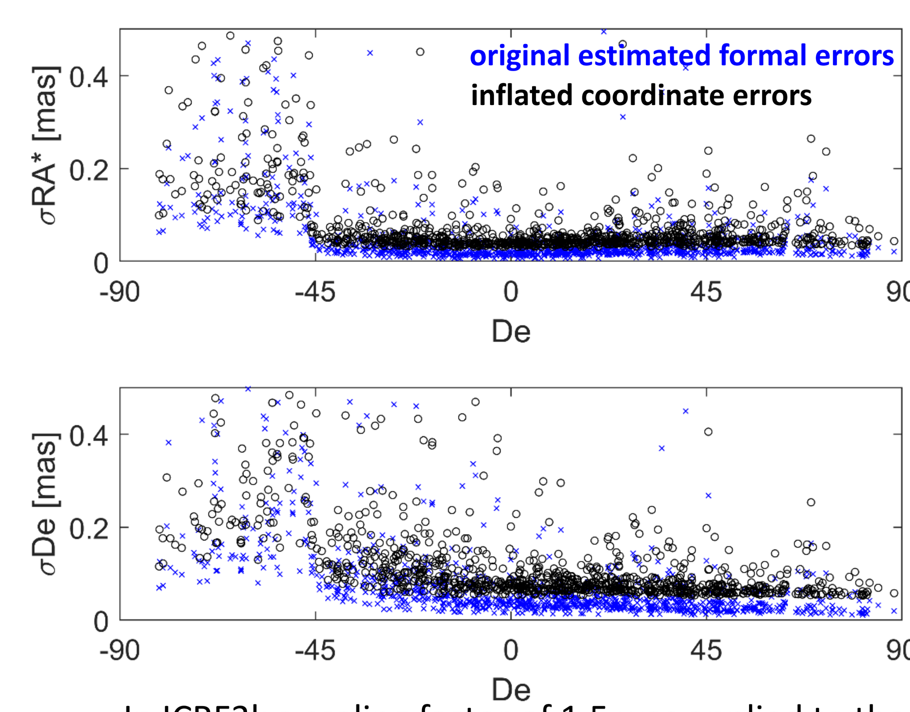
Unscaled formal errors (RA* = RA.cos(De))



sources observed in **single baseline sessions, low number of observations** in total

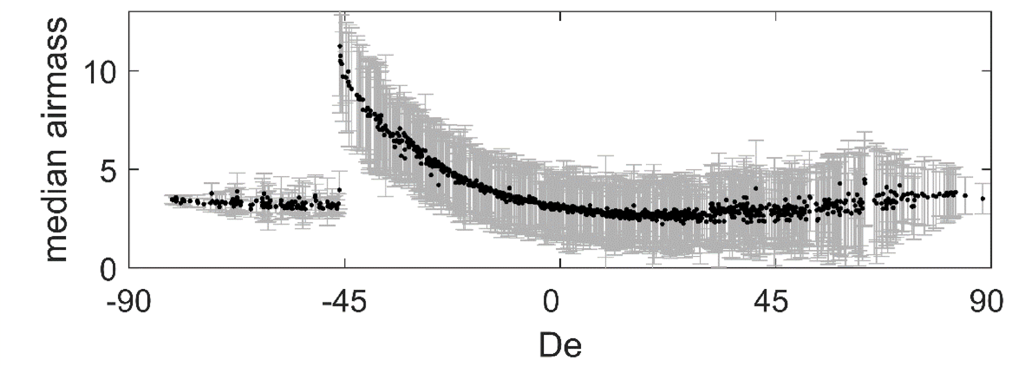
high median airmass (above 4) for sources with declination between -45° and -15°

Formal errors in USNO-k-220705



In ICRF3k a scaling factor of 1.5 was applied to the estimated source coordinate uncertainties and a noise floor of 30 µas and 50 µas was adopted for RA and De, respectively. We show the **original** and **inflated** formal errors for USNO-k-220705.

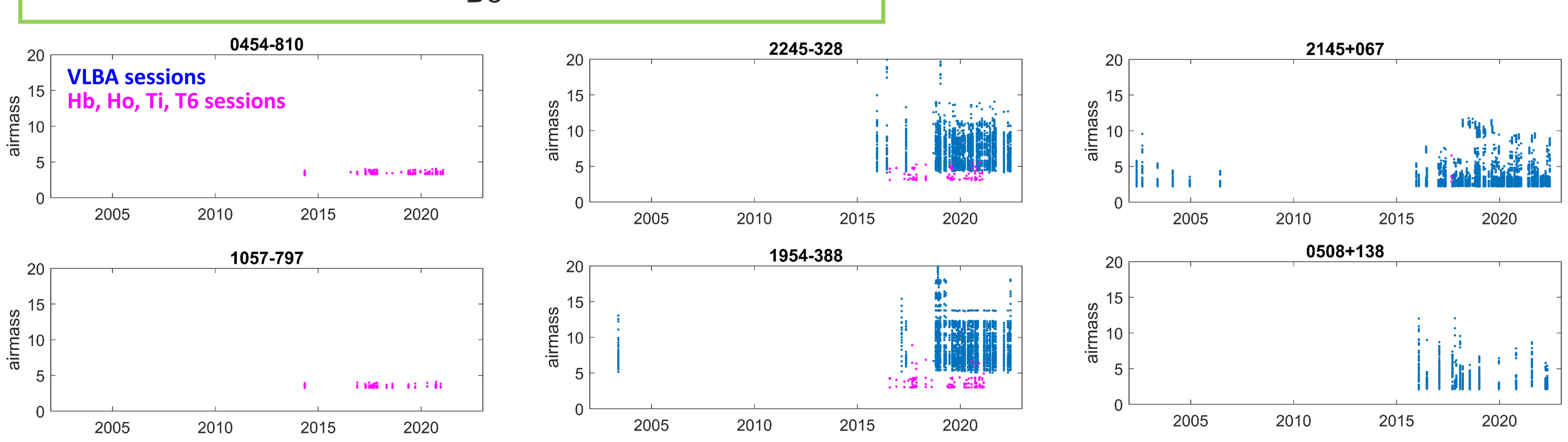
median formal error [µas]	RA*	De
VIE-k-220919	27.6	46.2
USNO-k-220705 (original errors)	25.2	43.6
USNO-k-220705 (inflated errors)	48.4	82.3



Airmass that a source is observed at during one observation

$$airmass = \frac{1}{\sin el_1} + \frac{1}{\sin el_2}$$

errorbars = standard deviation over all values for the respective source



Summary
- 211 new sources since ICRF3k release
- Deep south sources (De < -45°) are observed in single baseline (HartRAO-Hobart26m) sessions only -> high formal errors
- Susceptibility to troposphere modeling errors for sources with De <-45°;-15°> because of median airmass higher than 4
- Difference between USNO-k-220705 and VIE-k-220919 is small (wrms ΔRA* = 43 µas , ΔDe = 70 µas) but systematic in rotation -> further investigation on NNR condition is needed
- Further investigation on tropospheric modelling is foreseen

References
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