On the determination of a Kalman filter celestial reference frame and its application in VLBI analysis

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Introduction

In this study, we use **Kalman filtering** for the creation of a **celestial reference frame** (CRF). Having time series of radio source coordinates instead of temporally constant coordinates is beneficial for radio sources that exhibit temporal variations, for example, caused by source structure effects. However, the vast majority of radio sources has been observed on only very few occasions. For these sources, the constant coordinate model is sufficient and considerably more efficient to compute. Therefore, **we compute our CRF in two steps**; First, we estimate a **constant** frame of more than 4000 radio sources and then feed the residuals of about 800 selected sources into our Kalman filter to compute a **time series** frame.

We evaluate the CRF solutions by applying them in the **VLBI analysis** and comparing the estimated Earth orientation parameters (EOP) and radio source coordinates among each other as well as to external data sets.

Methodology

Two-level approach:

Constant frame	Time series frame
• Least-squares adjustment • Input: normal equations	• Kalman filter • Input: residuals based on constant frame

1. Single-session analysis to create normal equations (VieVS)
2. Computation of constant frame (global solution)
3. Apply constant frame in single-session analysis to estimate residuals
4. Feed residuals into Kalman filter and smoother to create time series frame

Advantages:

Most radio sources have been observed less than five times → constant model computationally very efficient

Some radio sources with excellent observational history but irregular behavior (e.g., source structure) → time series able to capture these non-linear effects

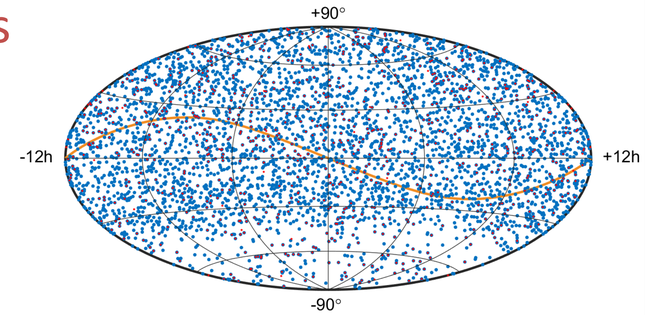
Constant + time series approach allows for a **complete** CRF, taking into account **non-linearity** of selected sources

VLBI CRF solutions

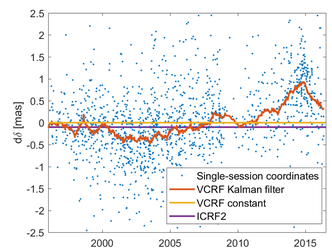
1980 – 2016.5
5446 IVS-VLBI sessions

Nothnagel et al., 2015

Constant frame: 4097 radio sources
Time series frame: 822 radio sources
295 used for datum definition

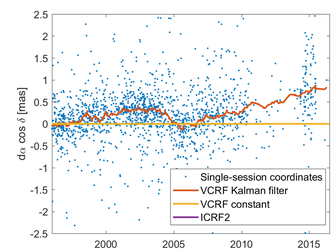


0119+115, declination



ICRF2 defining source

4C 39.25, right ascension

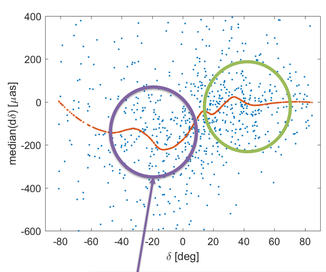


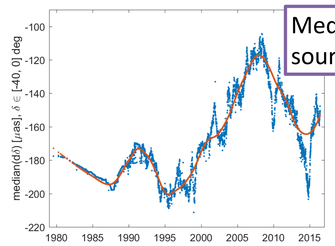
ICRF2 special handling source

Source coordinates evaluation

Mayer et al., 2017

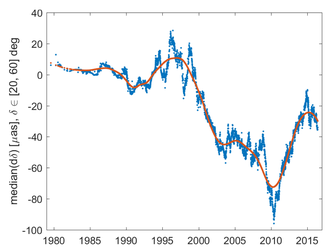
Investigating a temporal evolution of the "declination bias"





Median difference of southern sources over time

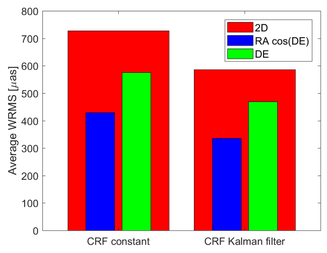
Bias for southern sources in CRF solutions using recent VLBI data when compared to ICRF2



For comparison, the same for northern sources

Source coordinates in VLBI analysis

WRMS [µas]	RA cos(DE)	DE	2D
CRF constant	429	576	728
CRF Kalman filter	336	470	586
Δ(KF – constant)	-22%	-18%	-20%



estimated offsets

$$\tilde{x} = x_0 + \Delta x$$

overall coordinates

a priori coordinates (from CRF)

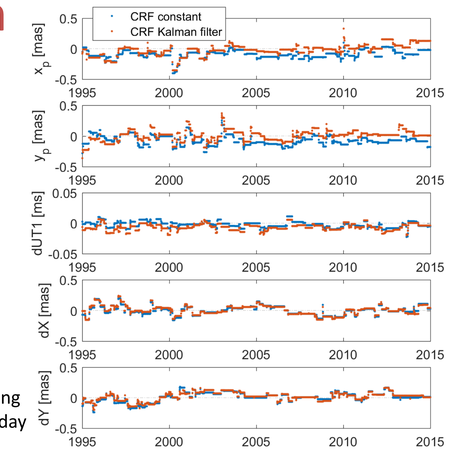
„repeatability"

WRMS [µas]	RA cos(DE)	DE	2D
CRF constant	452	586	753
CRF Kalman filter	462	599	769
Δ(KF – constant)	+2%	+2%	+2%

References:
Nothnagel et al., 2015: The IVS data input to ITRF2014. International VLBI Service for Geodesy and Astrometry, GFZ Data Services. http://doi.org/10.5880/GFZ.1.1.2015.002
Mayer et al., 2017: Tropospheric delay modelling and the celestial reference frame at radio wavelengths. Astronomy & Astrophysics, 606:A143

EOP evaluation

- Differences of EOP estimated in VLBI analysis w.r.t. IERS 14 C04 (plot & tables) and DTRF2014 EOP (tables)
- Similar results for EOP from ITRF2014 and JTRF2014 (not shown here)



Plotted: moving medians (30-day window)

Reference: IERS 14 C04

WRMS [µas]	x_P	y_P	dUT1	dX	dY
CRF constant	225	243	221	208	195
CRF Kalman filter	223	216	237	211	197
Δ(KF – constant)	-1%	-11%	+7%	+1%	+1%

WRMS [µas]	x_P	y_P	dUT1	dX	dY
CRF constant	209	211	217	208	194
CRF Kalman filter	214	215	222	211	196
Δ(KF – constant)	+2%	+2%	+2%	+1%	+1%

after subtracting trend

Reference: DTRF2014 EOP

WRMS [µas]	x_P	y_P	dUT1	dX	dY
CRF constant	221	216	690	377	377
CRF Kalman filter	225	221	691	377	380
Δ(KF – constant)	+2%	+2%	+0%	0%	+1%

WRMS [µas]	x_P	y_P	dUT1	dX	dY
CRF constant	243	240	691	378	378
CRF Kalman filter	226	219	693	377	380
Δ(KF – constant)	-7%	-9%	+0%	-0%	+1%

Summary

- **2-level** CRF: **complete** constant frame, consistent with **time series** frame of well-observed sources (taking into account **non-linear** coordinate variations)
- Time series allows to study **time dependence of declination bias**
- **Performance in VLBI analysis:** estimated coordinate offsets 20% smaller for Kalman filter CRF; repeatabilities of coordinates and EOP within a few percent

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