TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

Pulkovo Observatory

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Impact of seasonal station displacement models on radio source positions

Krásná H.[1], Z. Malkin[2], J. Böhm[1]

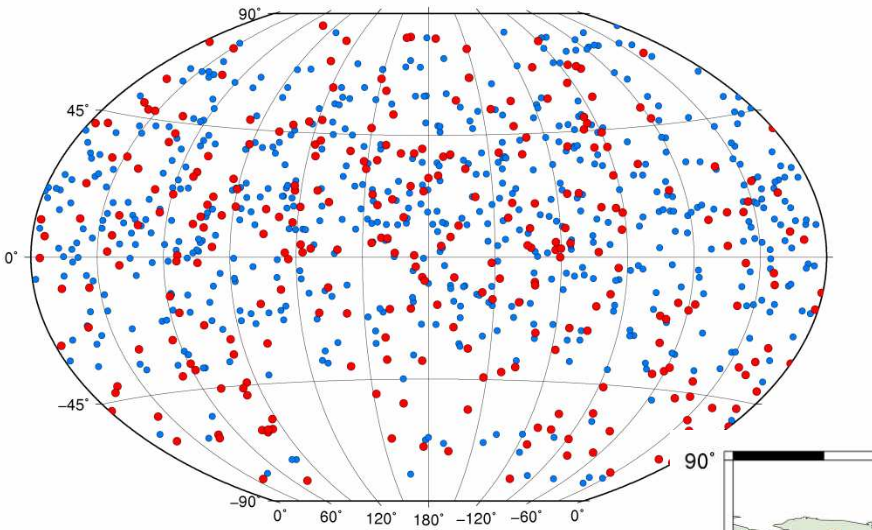
[1] TU Vienna, Austria;
[2] Pulkovo Observatory and St. Petersburg University, Russia

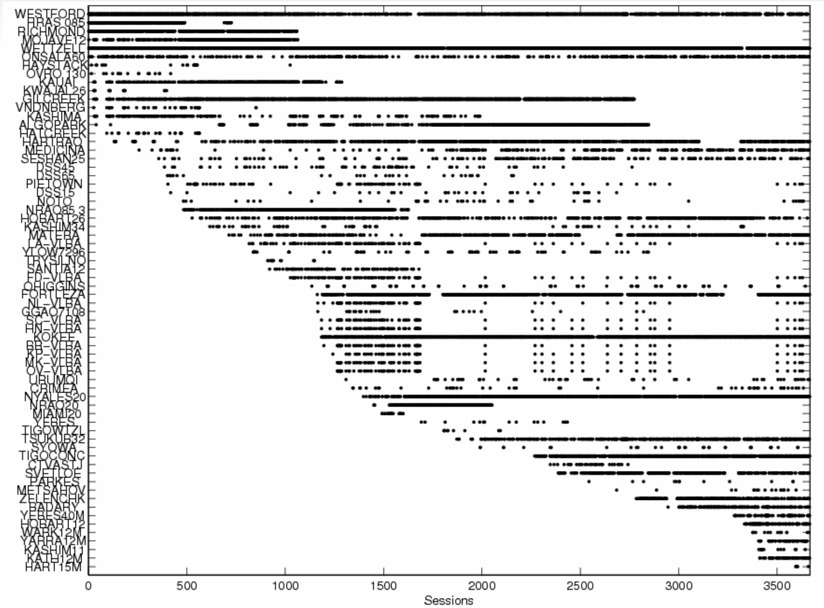
Outline

- new reference frames VieTRF13b and VieCRF13b
- models of neglected seasonal station motions
  - harmonic model (annual + semi-annual period)
  - mean annual model
- comparison of estimated celestial reference frames

VieTRF13b and VieCRF13b

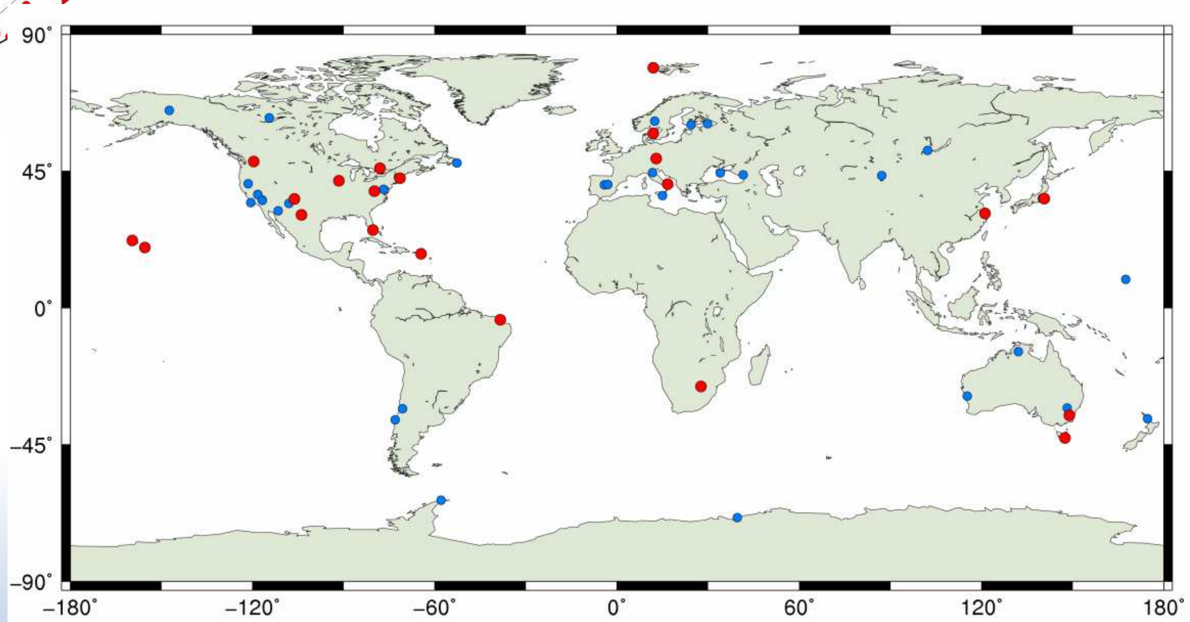
~3700 sessions (1984.0 – 2013.3)
5.6 Mio observations





66 stations
(22 datum stations)

871 radio sources
(285 datum sources)



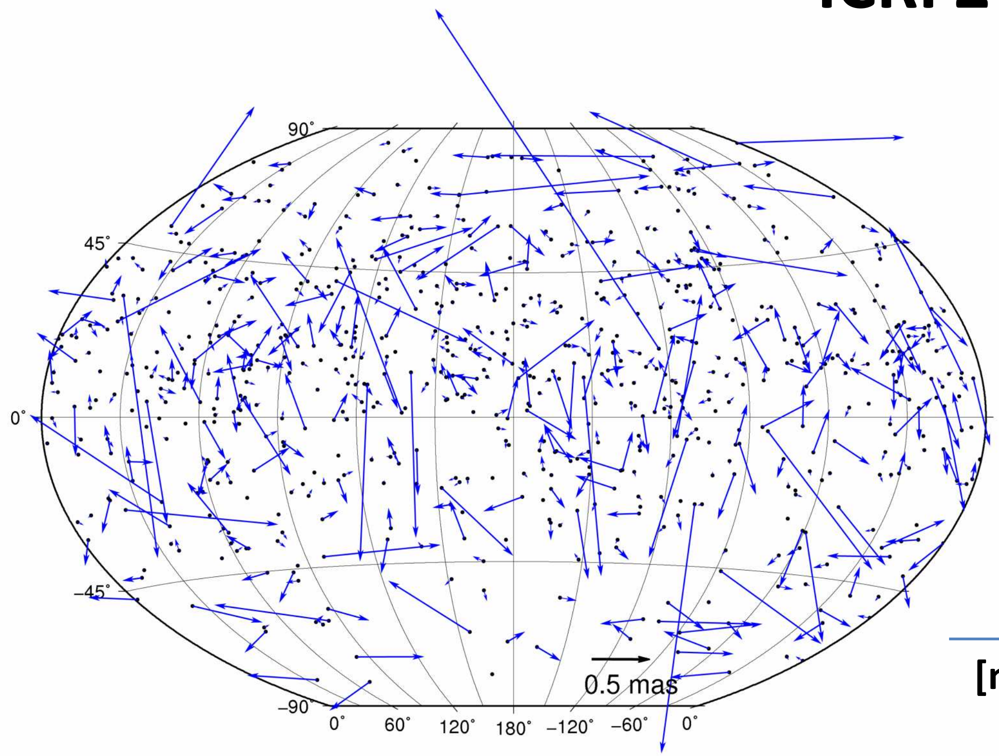
Comparison of VieTRF13b w.r.t. VTRF2008 at epoch 2000.0

	m_{xyz} < 0.5 cm	all stations
Tx [mm]	2.40 ± 0.69	2.53 ± 0.82
Ty [mm]	-0.95 ± 0.71	-0.88 ± 0.84
Tz [mm]	0.04 ± 0.66	-0.07 ± 0.79
Rx [microas]	15.89 ± 27.46	15.75 ± 32.24
Ry [microas]	25.01 ± 26.53	27.31 ± 31.23
Rz [microas]	53.21 ± 21.86	52.89 ± 25.97
Scale [ppb]	0.02 ± 0.10	-0.02 ± 0.12

$$m_{xyz} = \sqrt{\frac{\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2}{3}}$$

- 14 parameter Helmert transformation (variation of the parameters is not shown here)
- coordinates and velocities are weighted according to the formal errors derived in the new global solution
- except of Tx and Rz all parameters are within their formal errors

Comparison of VieCRF13b w.r.t. ICRF2



only sources with m_{RADe} < 1 mas

$$m_{RADe} = \sqrt{\frac{\sigma_{RA}^2 + \sigma_{De}^2}{2}}$$

rotation parameters (A1, A2, A3) were weighted according to the formal errors derived in the global solution

[microas]	m_{RADe} < 1 mas (720 sources)	all sources
A1	0.01 ± 0.68	-0.25 ± 1.12
A2	0.04 ± 0.68	-0.09 ± 1.16
A3	-0.06 ± 0.65	-0.02 ± 0.84

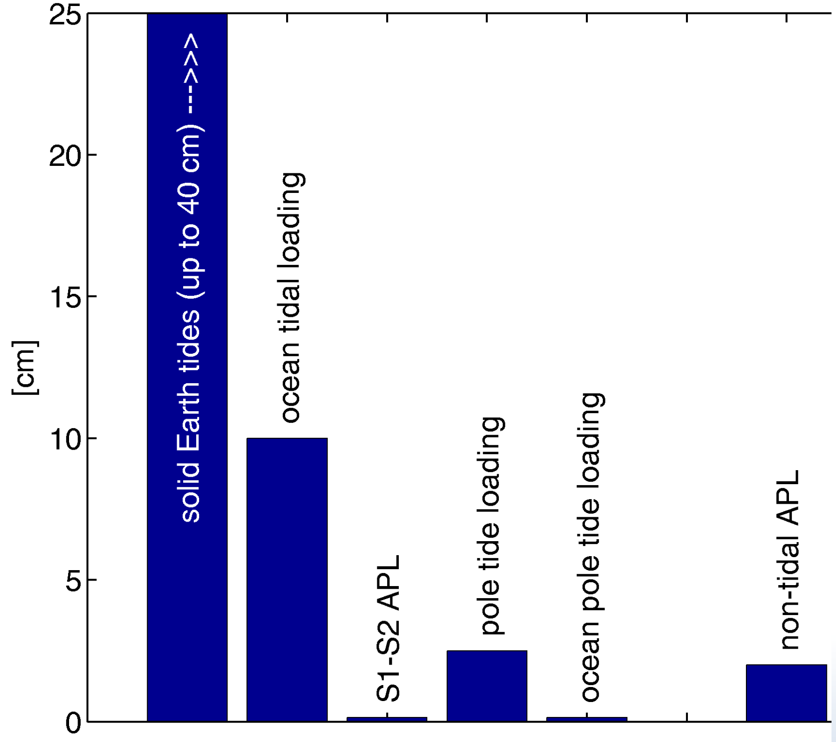
weighted mean difference
RA: -0.18 microas
De: -0.49 microas

WRMS
RA: 15.82 microas
De: 15.45 microas

Conventional displacement of stations

- International Terrestrial Reference Frame considers the position at a reference epoch plus a linear velocity term for station coordinates
- the actual station movement also includes several tidal and non-tidal correction

- for VieTRF13b we applied
  - solid Earth tides (IERS Conv. 2010)
  - ocean tidal loading (FES2004)
  - atmospheric pressure loading (GSFC Group) (tidal and non-tidal part – usual practice in VLBI analysis)
  - pole tide loading (IERS Conv. 2010)
  - ocean pole tide loading (Desai 2002)



Unmodelled non-linear displacements
(neglected seasonal station motions)

- the increasing accuracy of VLBI observations and the growing time span of available data allow the determination of seasonal signals in station positions which still remain unmodelled in the conventional analysis approach

- we create empirical **harmonic models** for selected stations

AND

- **mean annual models** by stacking yearly time series of station positions

Annual and semi-annual signal in TRF

- harmonic functions
- sine and cosine amplitudes are derived from the topocentric station displacement with zero a priori values
- estimated in a global adjustment as additional parameters to the default solution

$$\Delta d_{\mathrm{REN}} = Ac_{\mathrm{REN}} \cdot \sin\left(\frac{mjd - mjd_0}{P} 2\pi\right) + As_{\mathrm{REN}} \cdot \cos\left(\frac{mjd - mjd_0}{P} 2\pi\right)$$

P – period of station movement (365.25 days, 182.625 days)
mjd_0 – reference epoch set to J2000.0
mjd – time of observation

amplitude

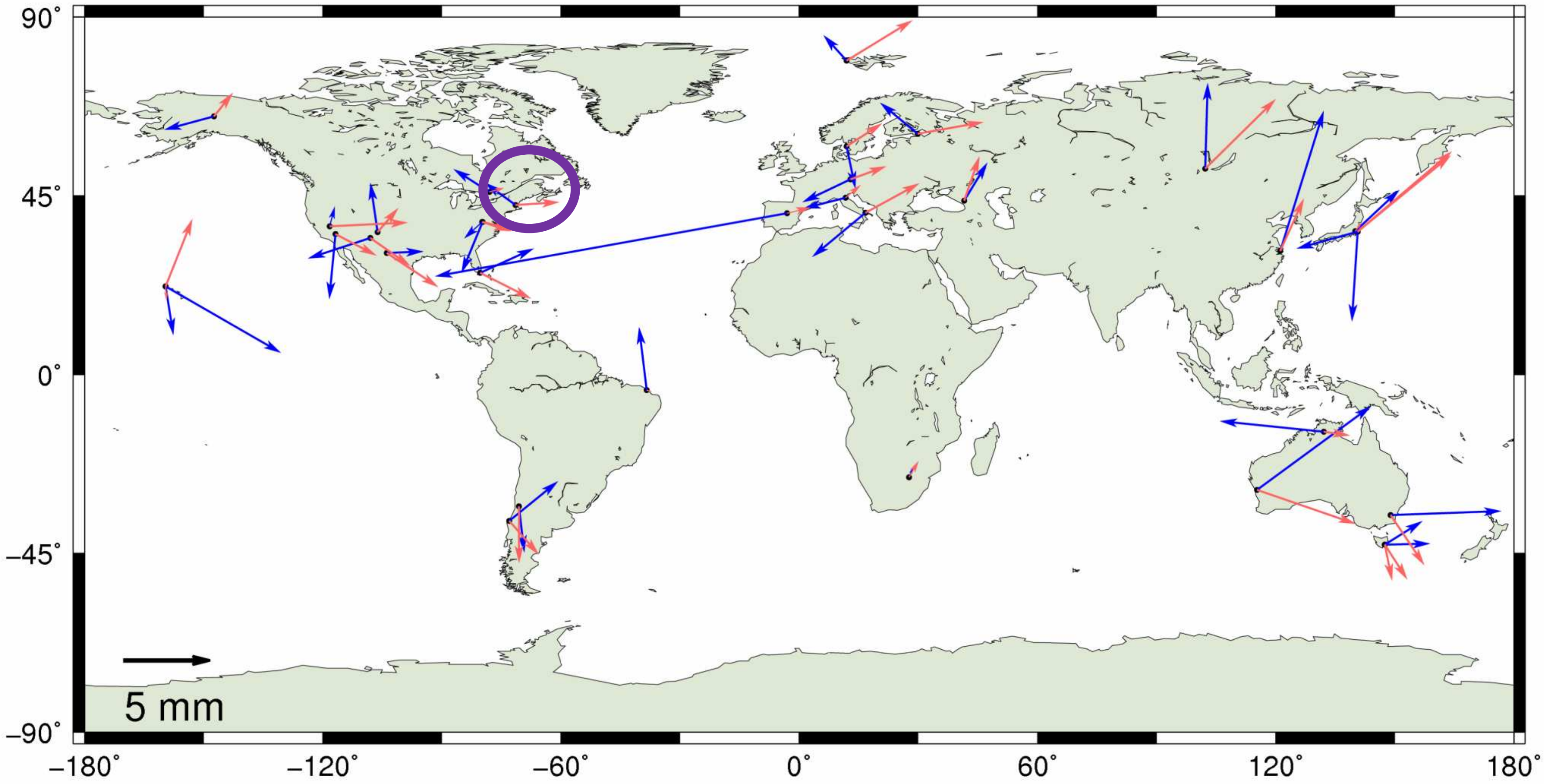
$$A_{REN} = \sqrt{Ac_{REN}^2 + As_{REN}^2}$$

phase

$$\Phi_{REN} = \arctan\left(\frac{As_{REN}}{Ac_{REN}}\right)$$

vertical amplitude of annual and semi-annual harmonic signal estimated within a global solution

estimated only for stations which participated in more than 50 sessions

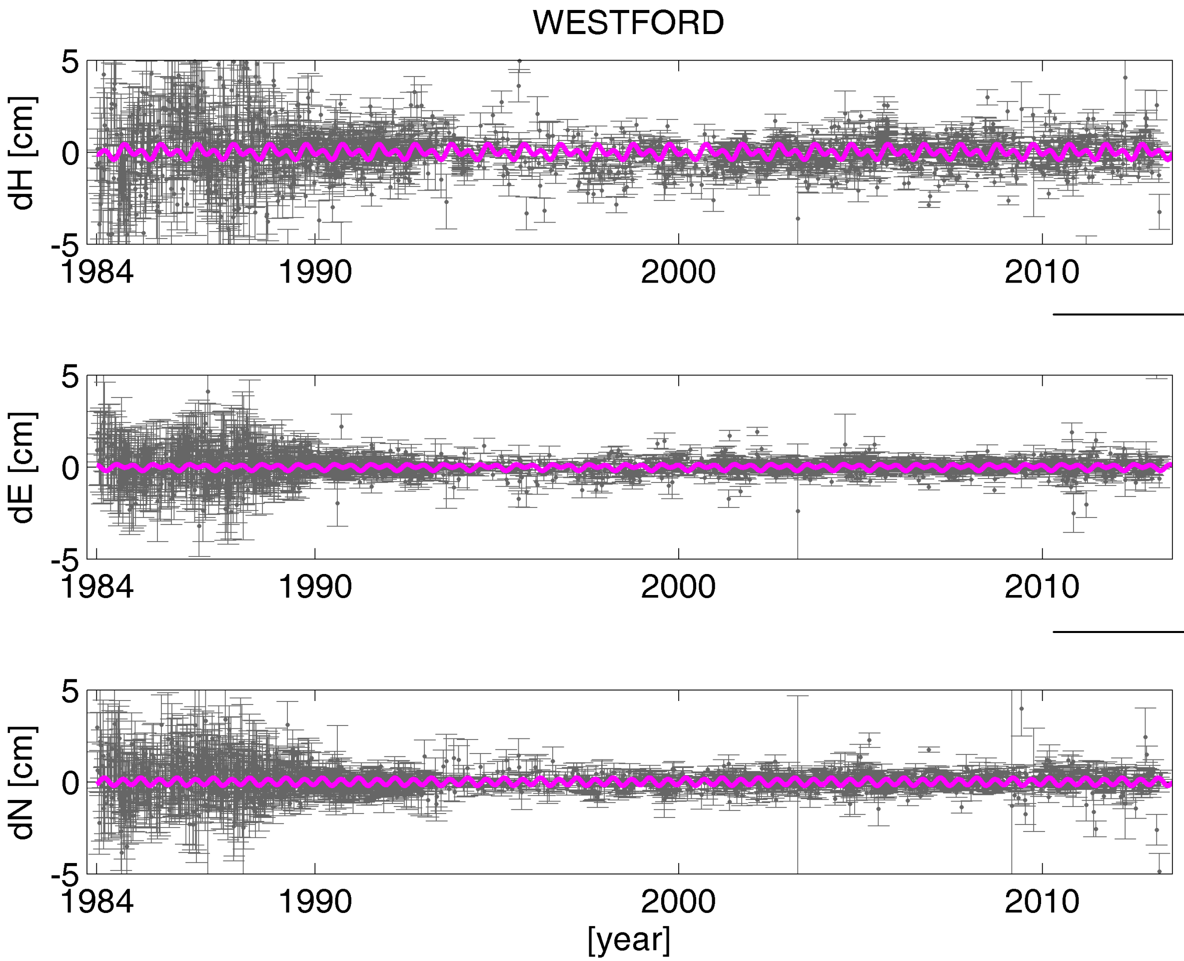


arrow pointing towards north depicts that the maximum appears in January (it continues clock-wise further)

Time series for station Westford

estimated harmonic model at annual (1)
and semi-annual period (2)

$$x = \sum_{i=1}^{2} A_i \cdot \sin\left(\frac{mjd - mjd_0}{P_i} 2\pi + \Phi_i\right)$$



A_1 = 0.22 ± 0.04 cm
ϕ_1 = 144.1 ± 11.2 deg

A_2 = 0.26 ± 0.04 cm
ϕ_2 = 97.5 ± 9.1 deg

A_1 = 0.09 ± 0.03 cm
ϕ_1 = 187.4 ± 14.6 deg

A_2 = 0.12 ± 0.03 cm
ϕ_2 = 80.6 ± 11.0 deg

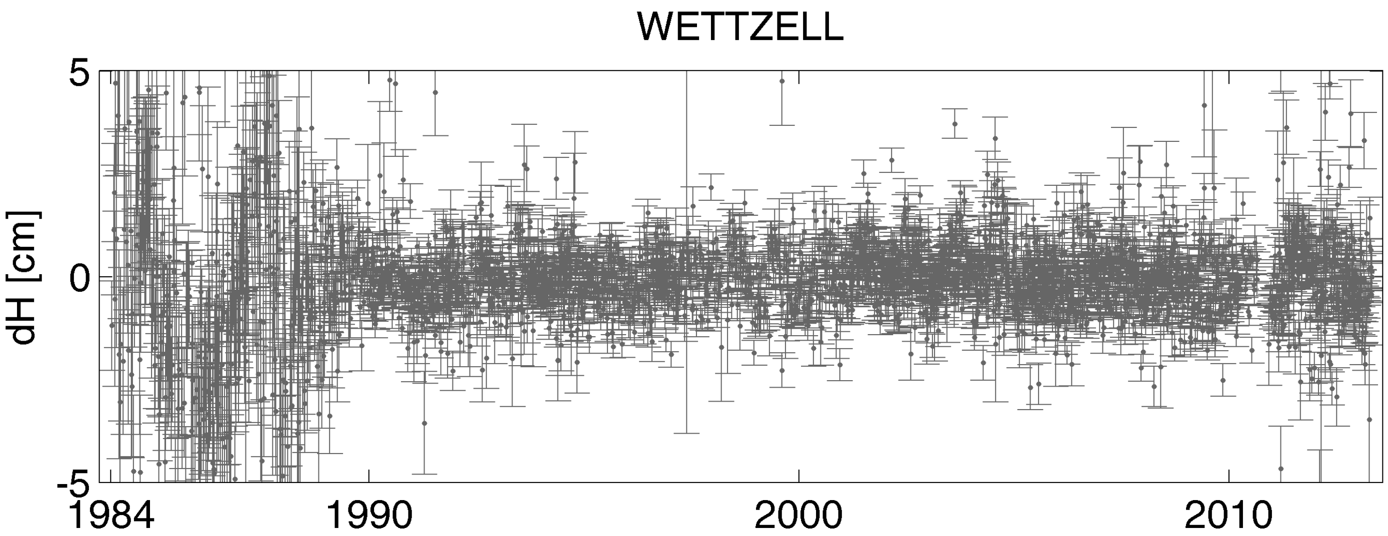
A_1 = 0.04 ± 0.03 cm
ϕ_1 = 43.2 ± 35.0 deg

A_2 = 0.18 ± 0.03 cm
ϕ_2 = 120.2± 7.8 deg

Mean annual models (non-harmonic)

we follow Tesmer et al. (2009)

- we estimate session-wise stations coordinates w.r.t. the new VieTRF13b reference frame
- weighted mean value for each year was removed from the time series
- all estimates were stacked into one mean year (in local VEN system)
- smoothing of the mean annual signal with a „smoothing spline“ predefined in MatLab, as weights the formal errors of the estimated coordinates were used



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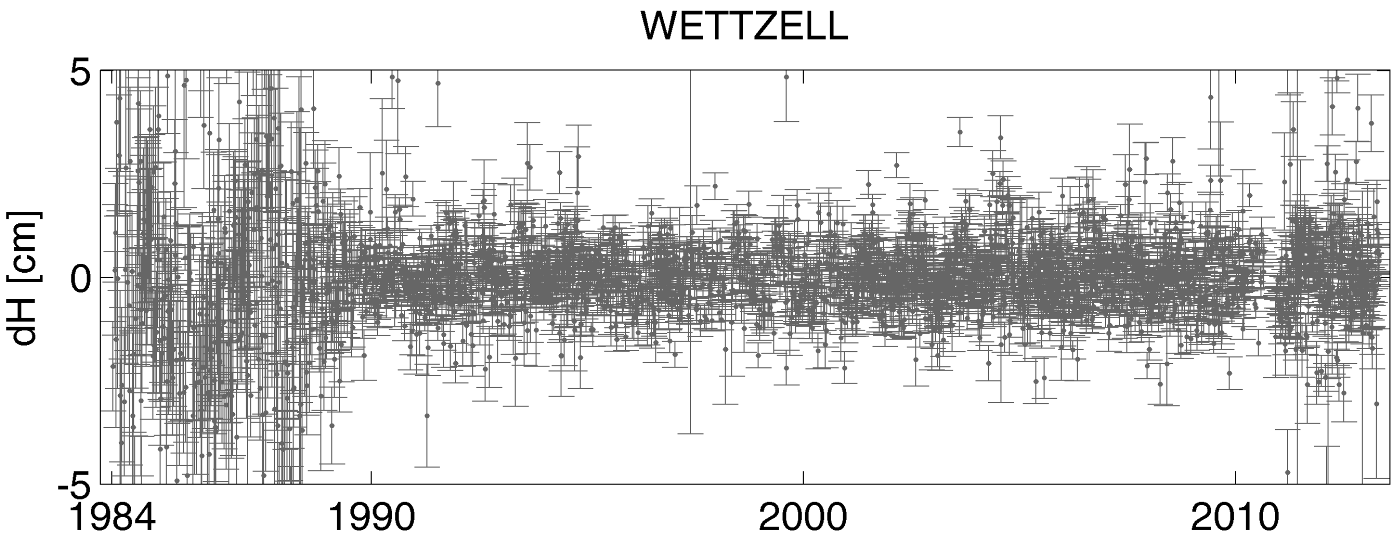

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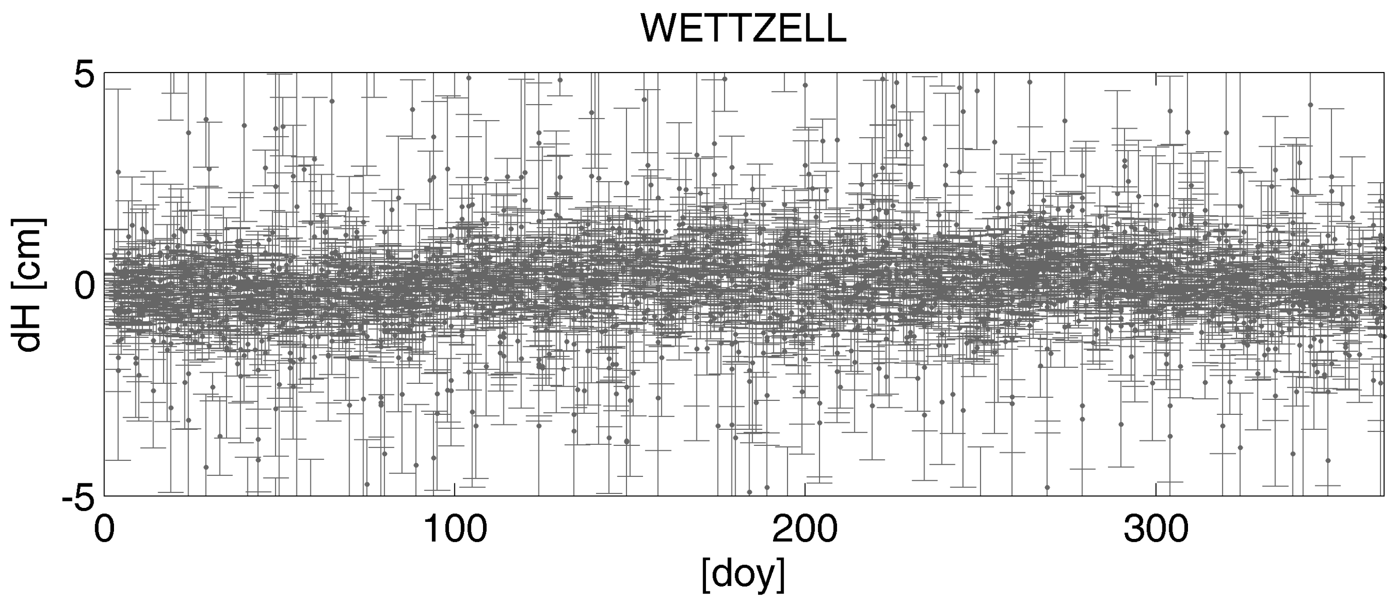

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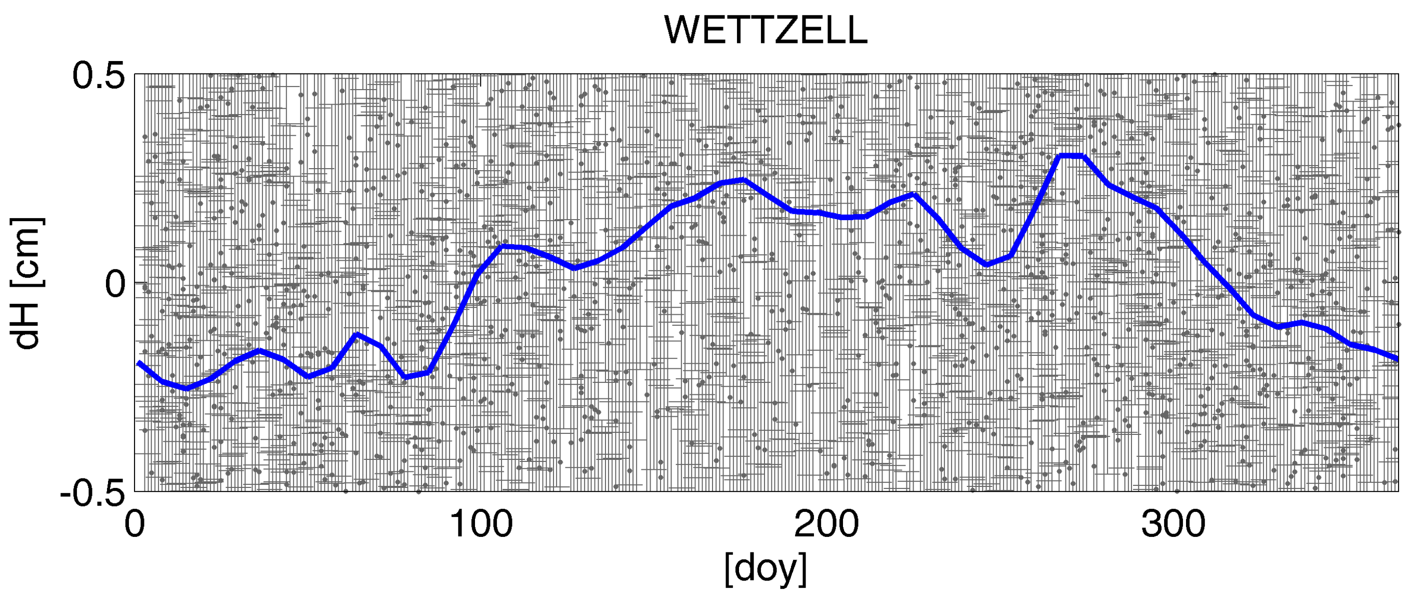
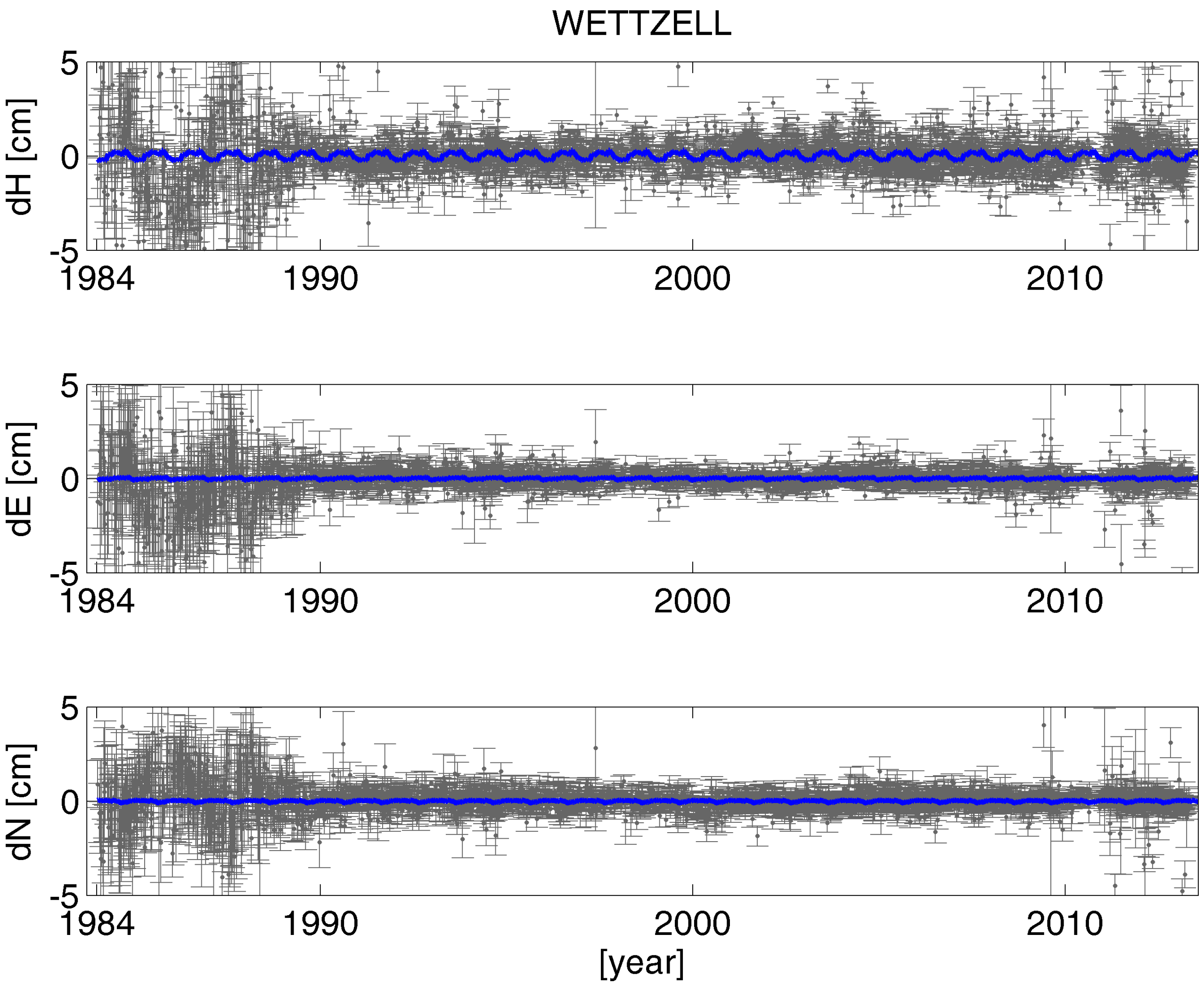


Time series for station Wettzell

Estimated mean annual non-harmonic model



max: 0.30 cm
min: -0.26 cm

max: 0.08 cm
min: -0.09 cm

max: 0.05 cm
min: -0.10 cm

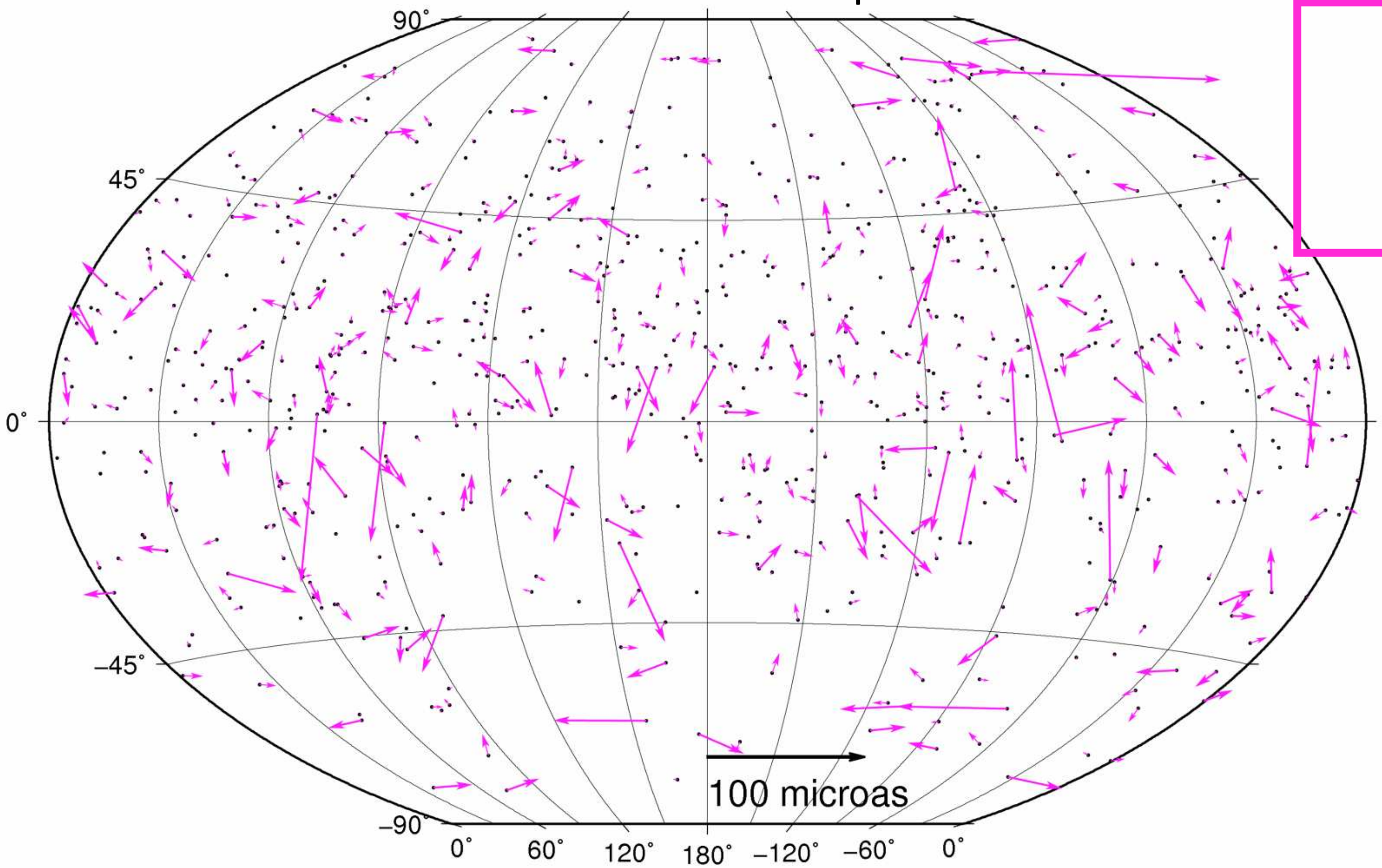
Comparison of celestial reference frames

in each global solution TRF+CRF+EOP were estimated

Solution 1 – reference parameterization

Solution 2 – harmonic model of station displacement (annual and semiannual) was applied a priori on station coordinates

differences in source positions



weighted mean difference w.r.t. S1

RA: 0.038 microas

De: -0.030 microas

only sources with m_{RADe} < 1 mas

Comparison of celestial reference frames

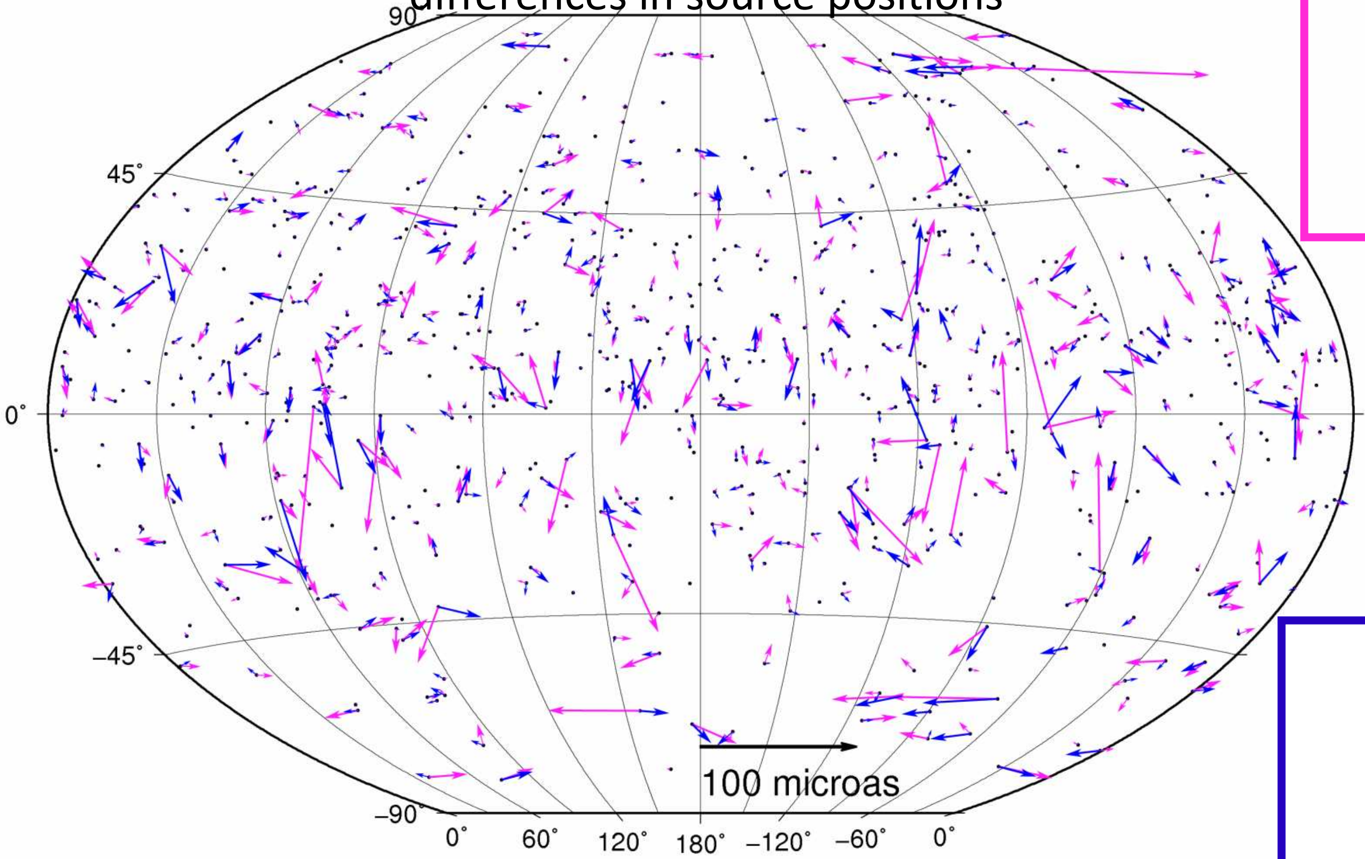
in each global solution TRF+CRF+EOP were estimated

Solution 1 – reference parameterization

Solution 2 – harmonic model of station displacement (annual and semiannual) was applied a priori on station coordinates

Solution 3 – mean annual non-harmonic model applied a priori on station coordinates

differences in source positions



only sources with m_{RADe} < 1 mas

weighted mean difference w.r.t. S1
RA: 0.038 microas
De: -0.030 microas

weighted mean difference w.r.t. S1
RA: 0.004 microas
De: -0.022 microas

Comparison of celestial reference frames

in each global solution TRF+CRF+EOP were estimated

Solution 1 – reference parameterization
Solution 2 – harmonic model of station displacement (annual and semiannual) was applied a priori on station coordinates
Solution 3 – mean annual non-harmonic model applied a priori on station coordinates

Comparison of WRMS over the differences for the RA and De component w.r.t. VieCRF13b

WRMS [microas]	**RA**	**De**
Solution 1	15.825	15.460
Solution 2	15.811	15.471
Solution 3	15.830	15.487

Weighted rotational parameters

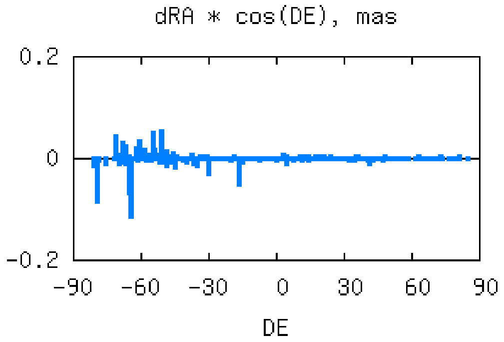
	S2 – S1	**S3 – S1**	**S3 – S2**
A1 [microas]	0.11 ± 0.12	0.04 ± 0.08	-0.07± 0.10
A2 [microas]	-0.07 ± 0.12	0.01 ± 0.08	0.08 ± 0.10
A3 [microas]	-0.02 ± 0.12	-0.00 ± 0.08	0.02 ± 0.10

only sources with m_{RADe} < 1 mas

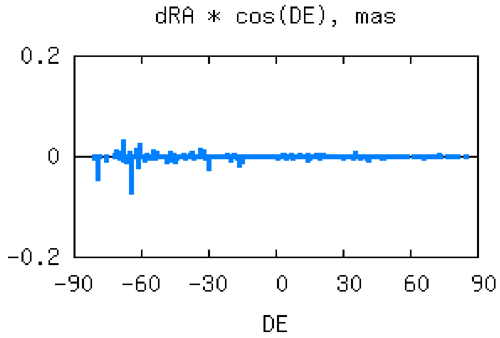
Comparison of celestial reference frames

between common **defining sources**

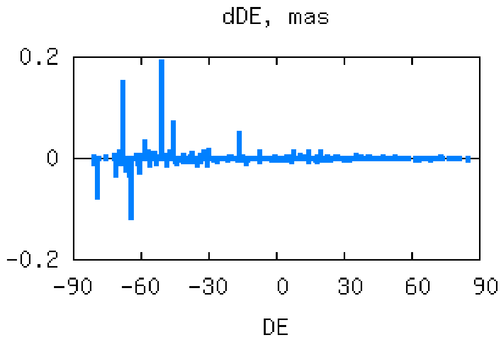
S1 – S2

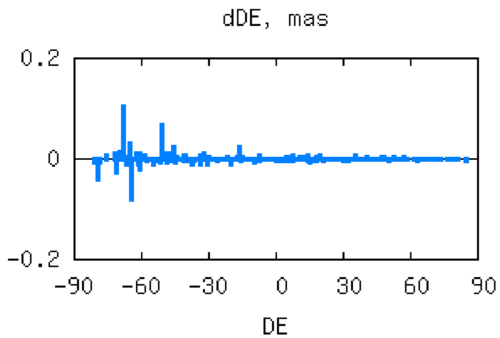


S1 – S3

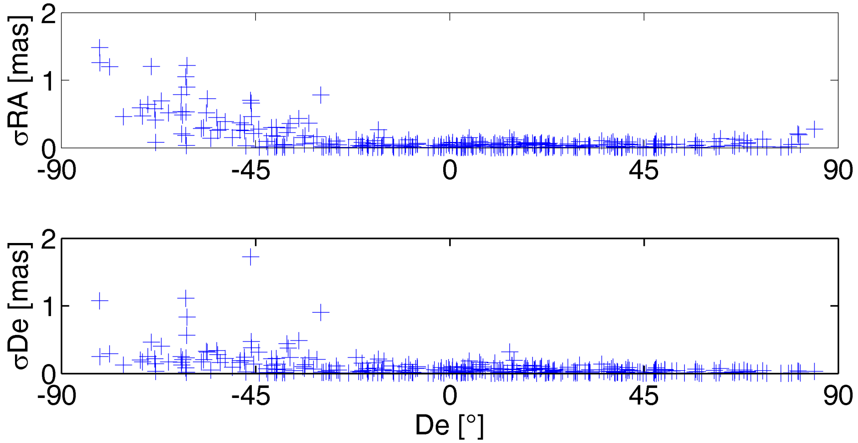


differences in RA





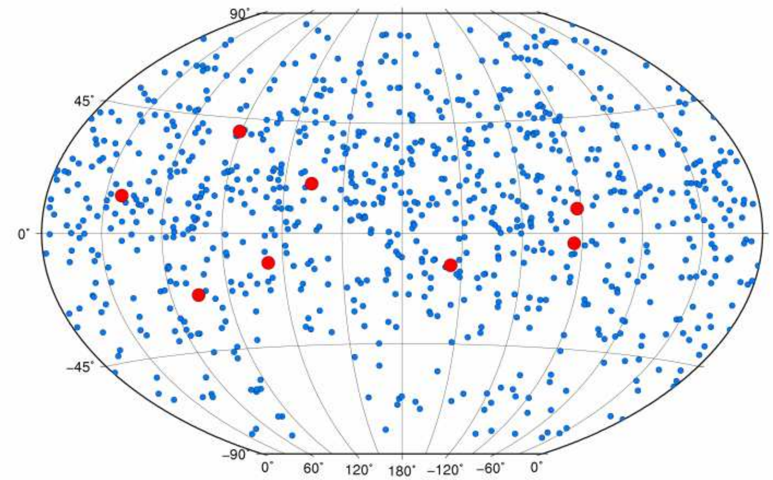
differences in De



formal errors of
the estimated coordinates

Comparison of time series of selected sources

8 most observed sources



0552+398, 1741-038, 0727-115, 0851+202,
1749+096, 1334-127, 0454-234, 0229+131

- each of the 3 global solutions was computed again
- the coordinates of the 8 most observed sources were session-wise reduced (together with the 39 special handling sources)
- they were estimated as „arc parameters“ within a back solution

session-wise normal equation systems

$$\begin{bmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$$

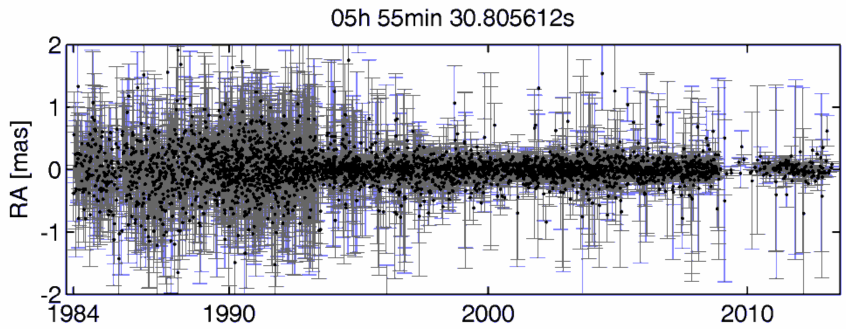
globally estimated p.

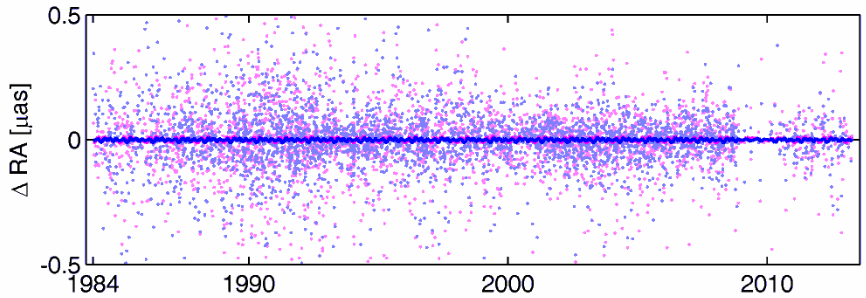
reduced p.

after the global adjustment we know the vector x_1 (global parameters); the vector x_2 we get from a so-called back solution for each session:

$$x_2 = N_{22}^{-1} \cdot b_2 - N_{22}^{-1} \cdot N_{21} \cdot x_1$$

Comparison of the time series of 0552+398 – the most observed source



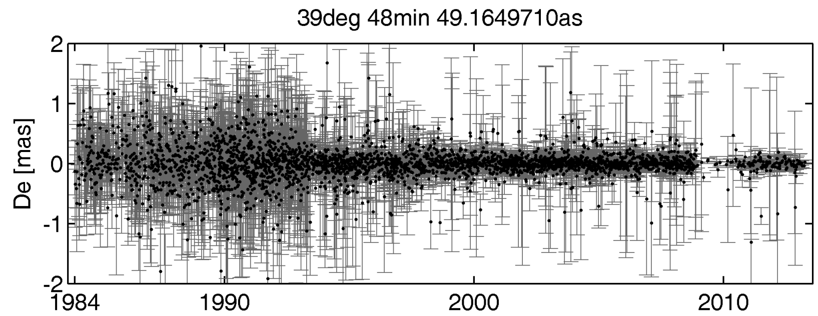


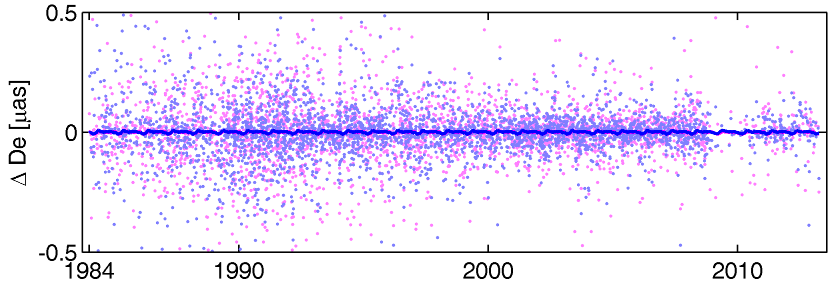
WRMS of the difference in RA w.r.t. VieCRF13b

Solution 1: 109.28 microas

Solution 2: 109.05 microas

Solution 3: 109.14 microas





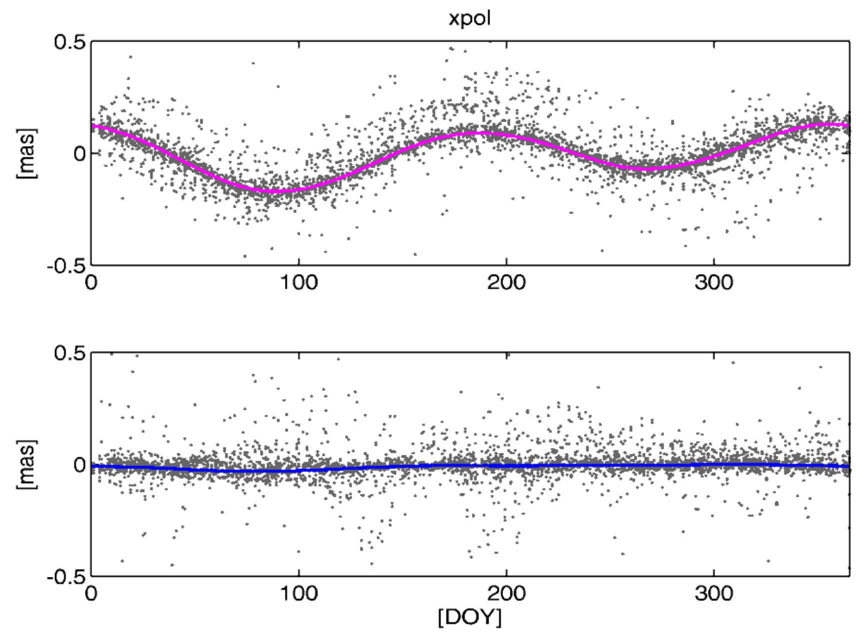
WRMS of the difference in De w.r.t. VieCRF13b

Solution 1: 91.27 microas

Solution 2: 91.25 microas

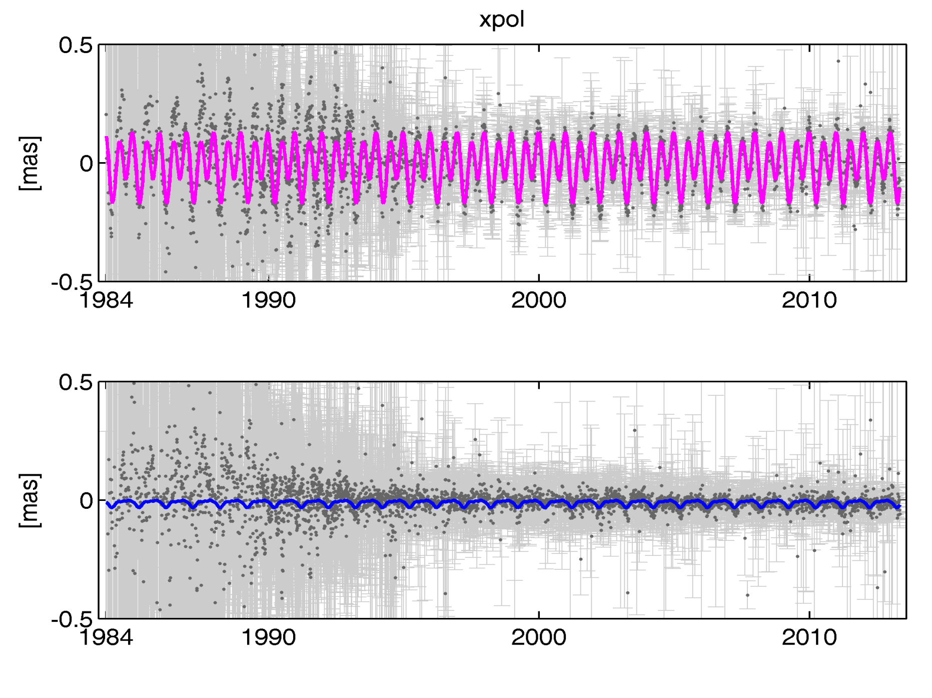
Solution 3: 91.30 microas

EOP: x-pole



S2 – S1

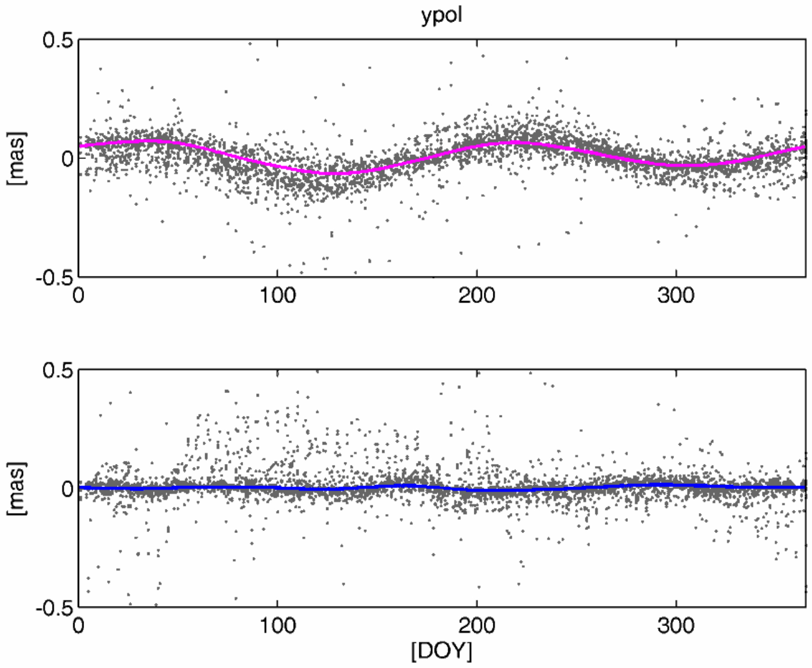
max: 133.8 microas
min: -171.0 microas



S3 – S1

max: -0.7 microas
min: -32.5 microas

EOP: y-pole

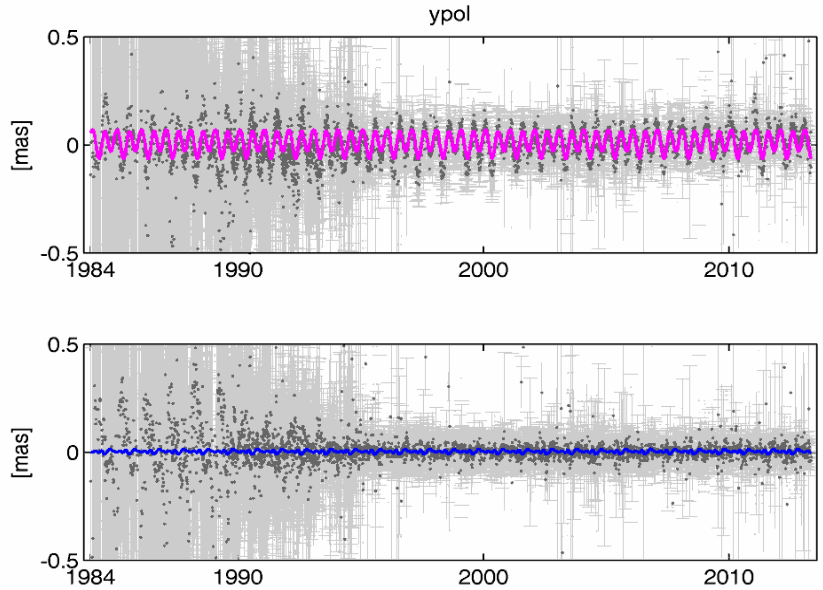


S2 – S1

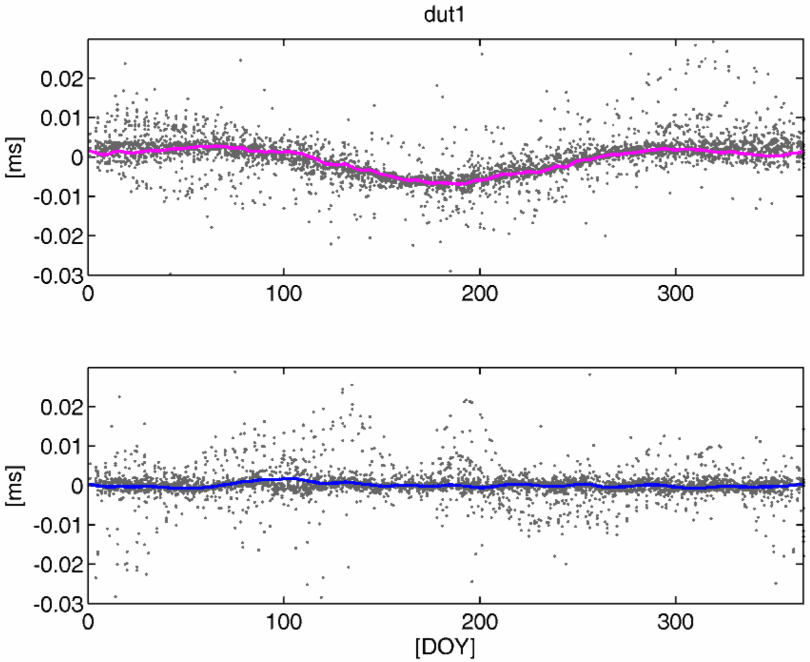
max: 71.5 microas
min: -65.3 microas

S3 – S1

max: 15.3 microas
min: -9.8 microas

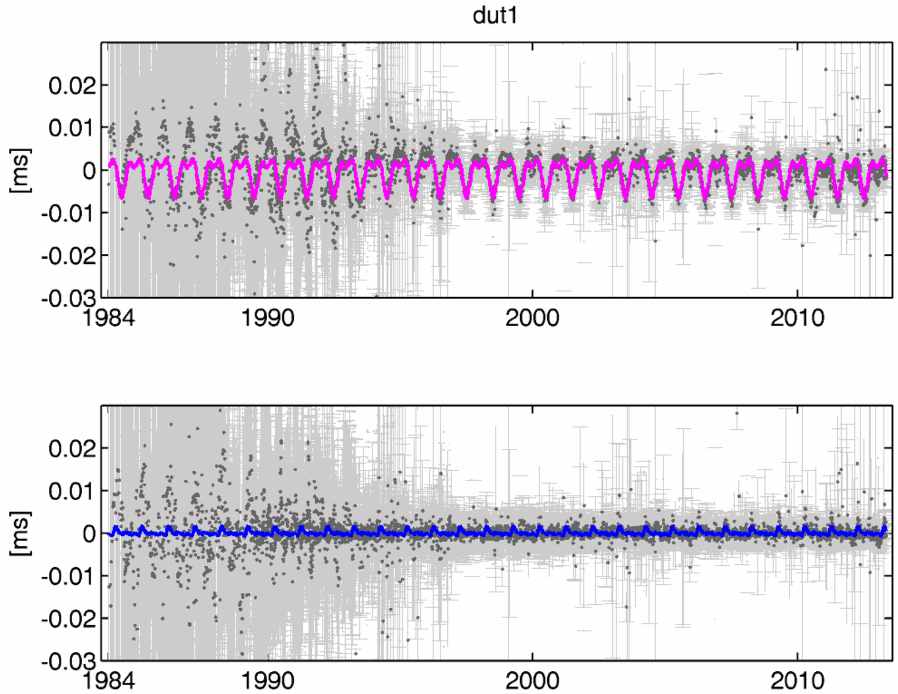


EOP: dUT1



S2 – S1

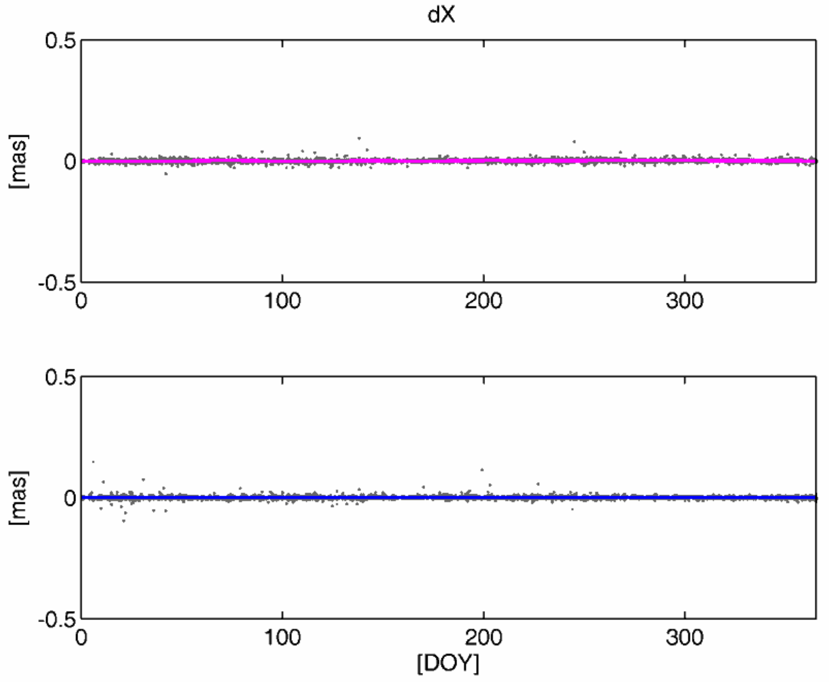
max: 2.8 micros
min: -6.9 micros



S3 – S1

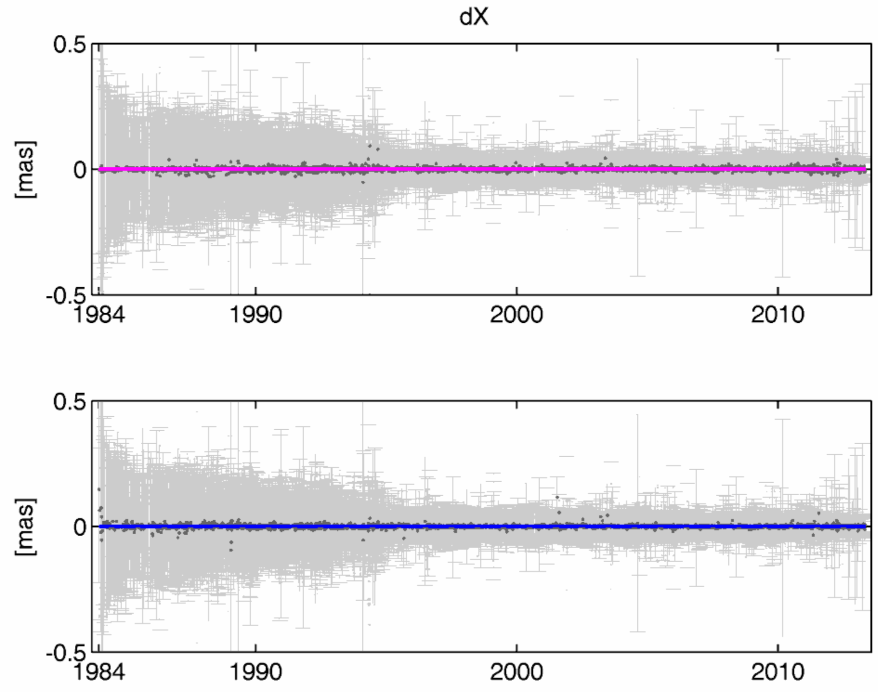
max: 1.7 micros
min: -0.7 micros

EOP: dX



S2 – S1

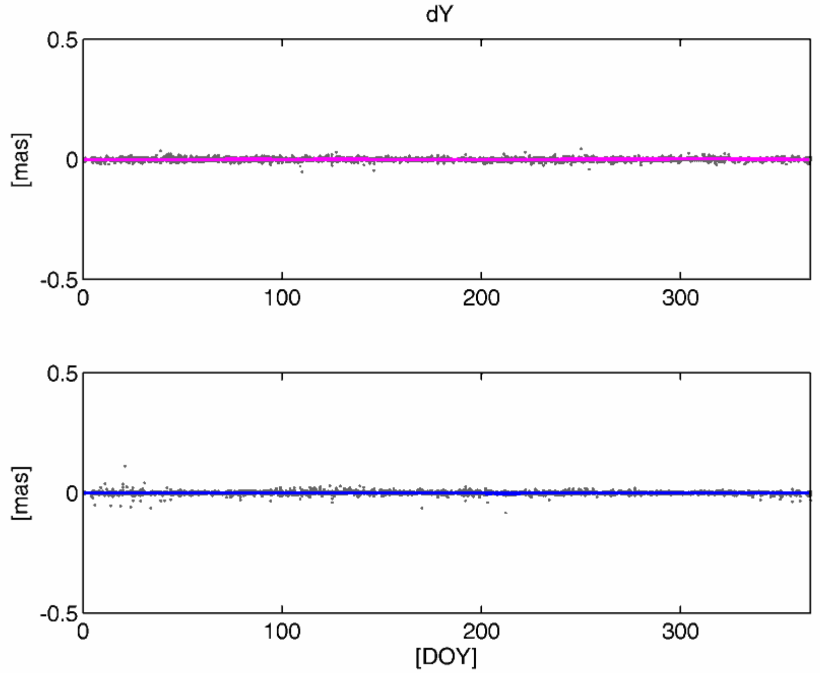
max: 1.5 micros
min: -1.4 micros



S3 – S1

max: 1.4 microas
min: -1.1 microas

EOP: dY

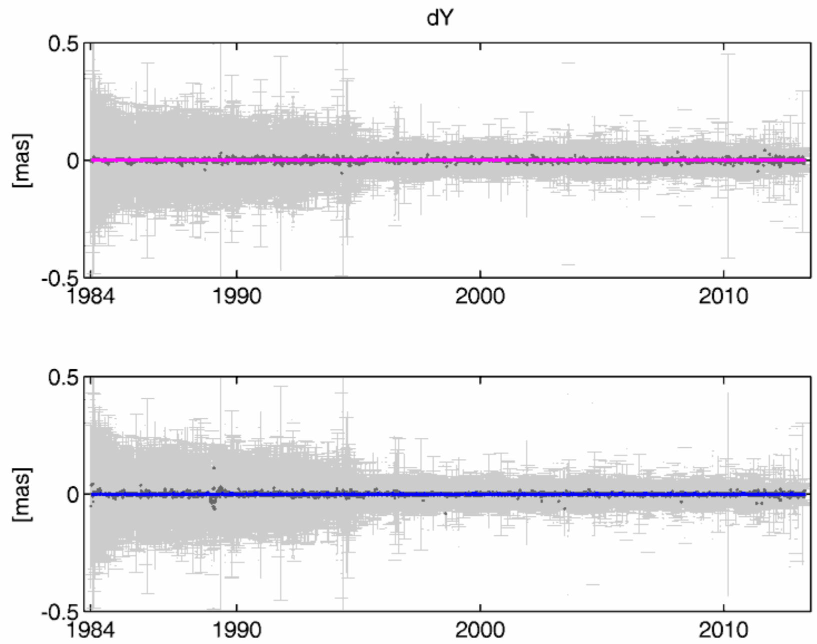


S2 – S1

max: 1.5 micros
min: -1.6 micros

S3 – S1

max: 0.5 microas
min: -1.0 microas



Conclusions

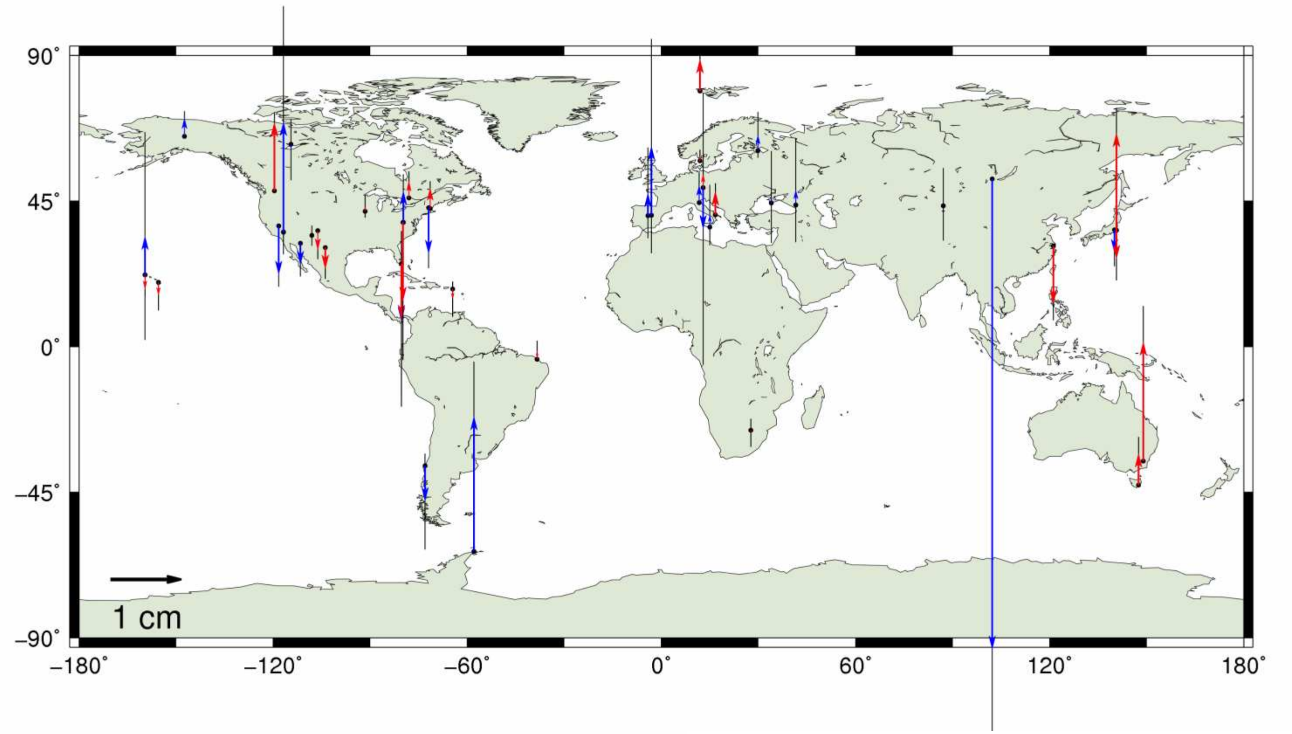
- New terrestrial and celestial reference frames (called VieTRF13b and VieCRF13b, covering the time span 1984.0 – 2013.3) were introduced.
- Two kinds of models for remaining long-period signal in station coordinates were created. One of them being the harmonic model at annual and semi-annual periods, the second one a non-harmonic mean annual model.
- Seasonal station movements do not yield any significant systematic effect on the CRF but can cause a significant change in position of radio sources with small number of sessions non-evenly distributed over the year fraction.
- A strong influence of estimated ERP (polar motion and UT1) is seen between the standard solution S1 and solution S2 which applies the harmonic annual and semi-annual model of the remaining signal at station coordinates.

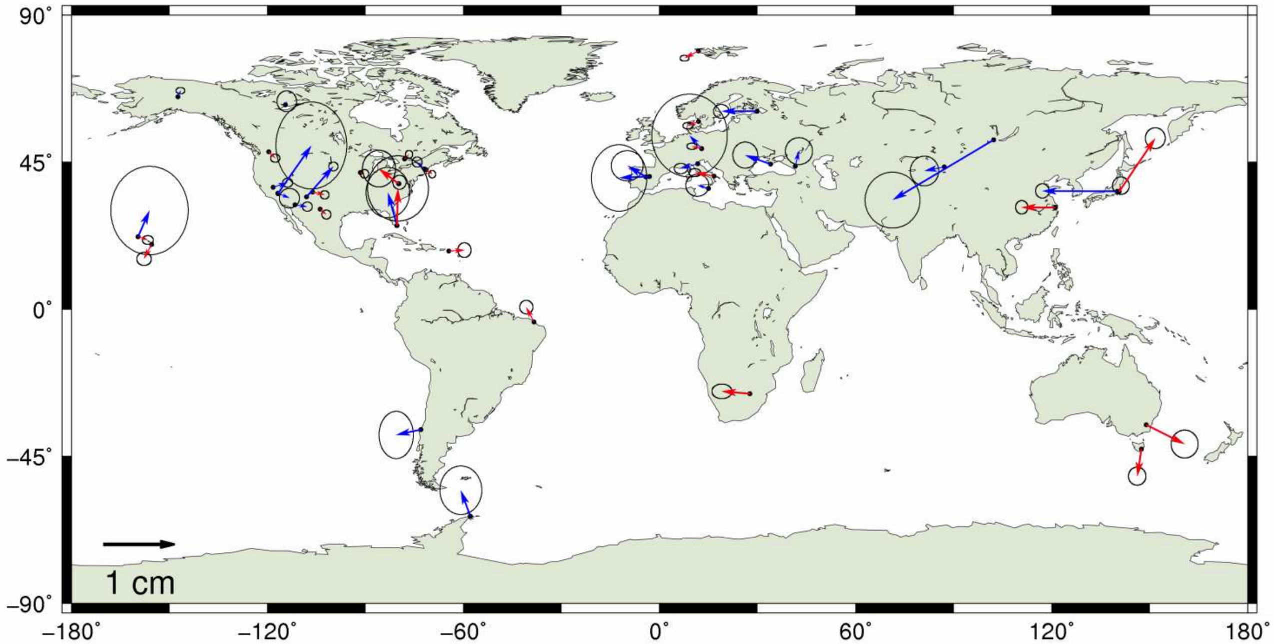
JOURNÉES 2013
Systèmes de Référence Spatio-Temporels

Thank you for your attention!

Hana Krásná works within FWF-Project
P23-143-N21 „Integrated VLBI“.

Comparison of VieTRF13b w.r.t. VTRF2008 at epoch 2000.0





stations with mean coordinate error m_{xyz} < 0.5 cm

$$m_{xyz} = \sqrt{\frac{\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2}{3}}$$

- Treatment of discontinuities

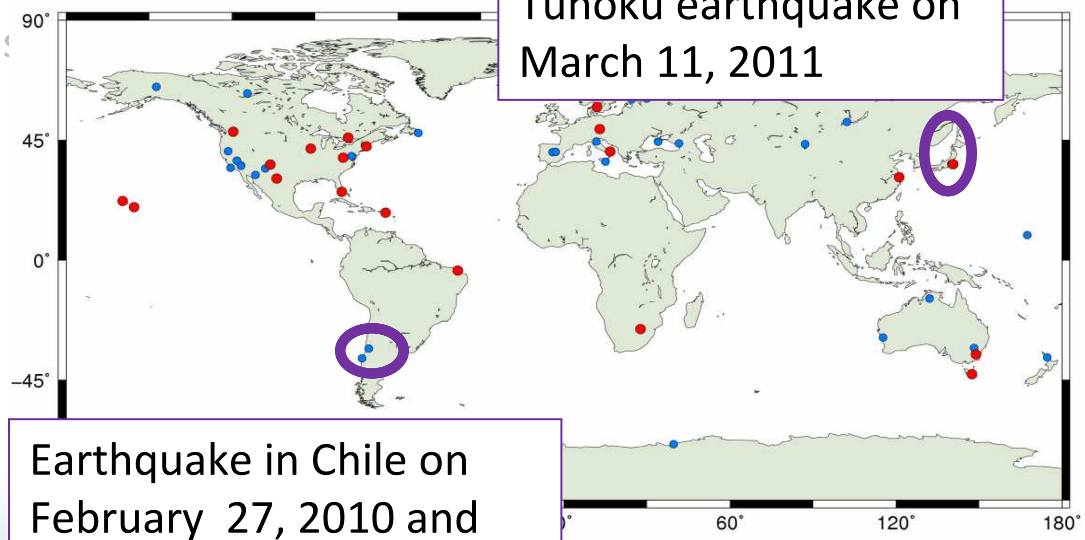
  VLBI-DISCONT.txt (prepared by the NASA GSFC, VLBI analysis group)

  in case of an antenna repair - independent coordinates before and after the event are estimated, velocity is constrained to be constant

  in case of an Earthquake - independent coordinates together with linear velocity are estimated before and after the event

Recent large Earthquakes:

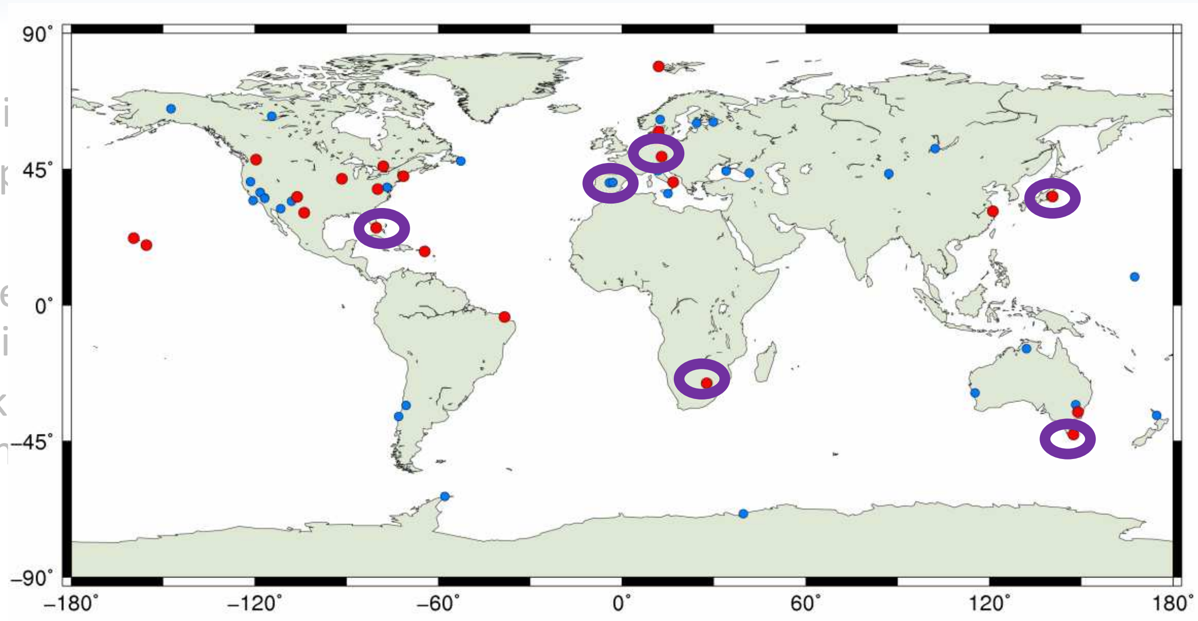
- Constraining of velocity for
  - Richmond – Miami20
  - Wettzell – Tigowtzl
  - Yebes – Yebes40m
  - Kashima – Kashima34
  - Hobart26 – Hobart12
  - HartRAO – Hart15m



- Treatment of discontinui
  VLBI-DISCONT.txt (prep

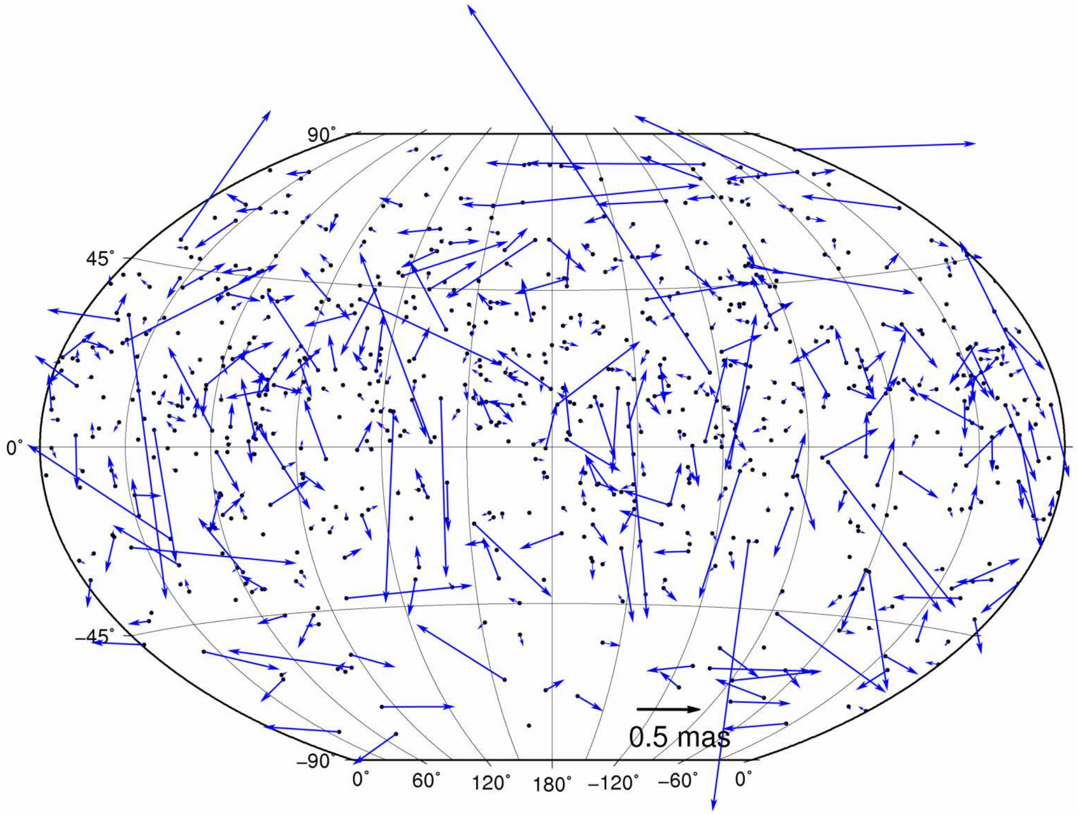
  in case of an antenna re
  estimated, velocity i

  in case of an Earthquak
  estimated before an



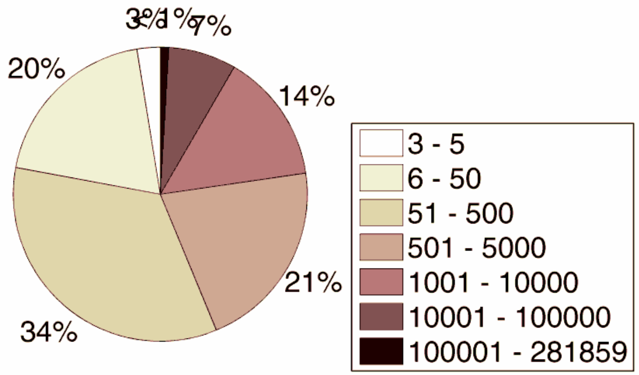
- Constraining of velocity for stations in the same area
  - Richmond – Miami20
  - Wettzell – Tigowtzl
  - Yebes – Yebes40m
  - Kashima – Kashima34
  - Hobart26 – Hobart12
  - HartRAO – Hart15m

Comparison of VieCRF13b w.r.t. ICRF2

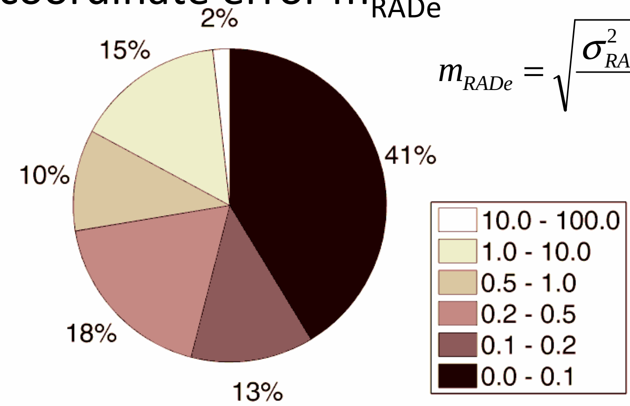


only sources with m_{RADe} < 1 mas

number of observations per source



distribution of the mean coordinate error m_{RADe}



$$m_{RADe} = \sqrt{\frac{\sigma_{RA}^2 + \sigma_{De}^2}{2}}$$

[mas]

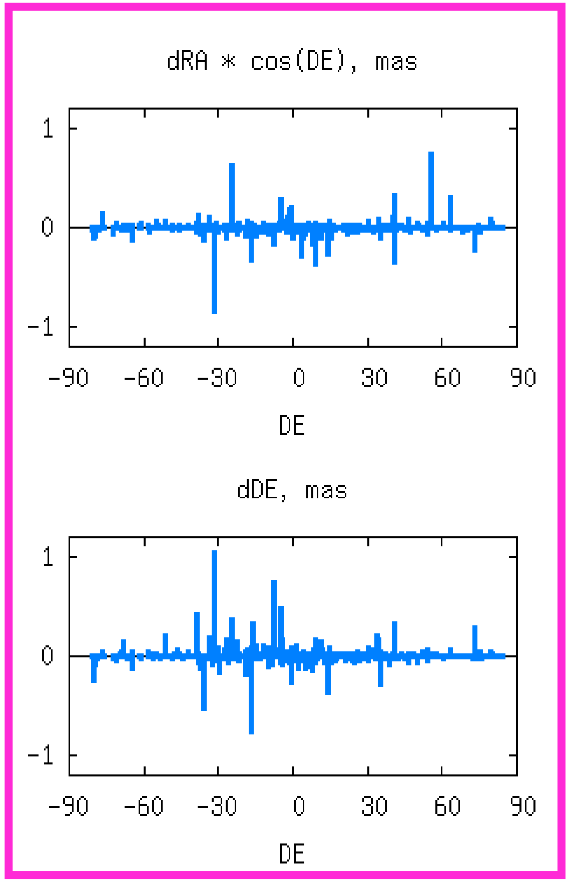
weighted mean difference
RA: -0.18 microas
De: -0.49 microas

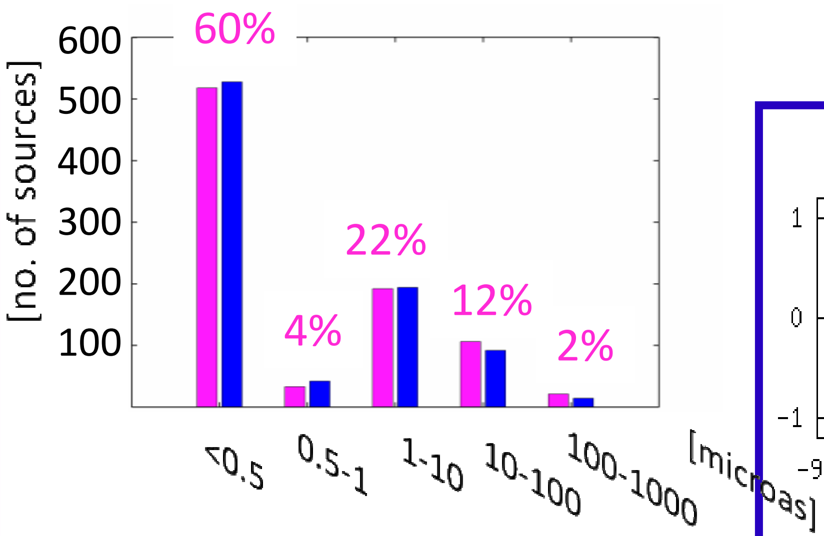
WRMS
RA: 15.82 microas
De: 15.45 microas

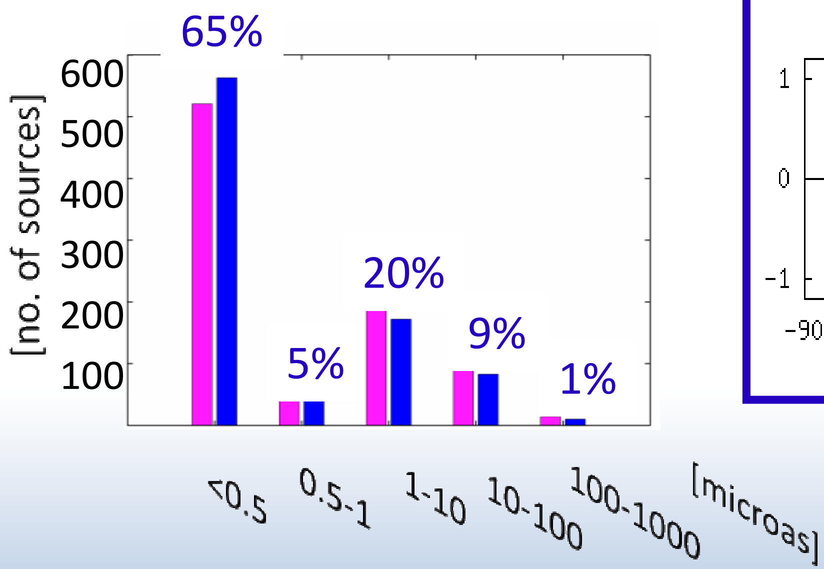
Comparison of all common sources

differences in source positions

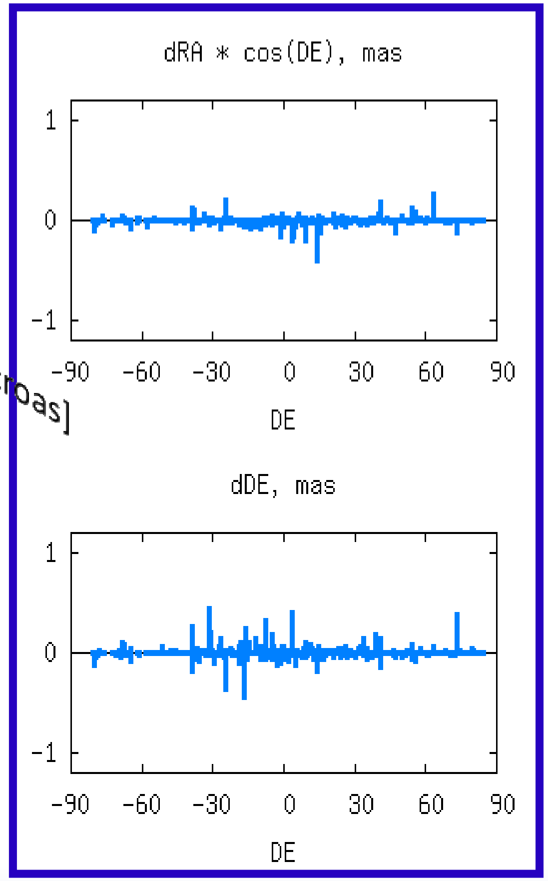
S1 – S2



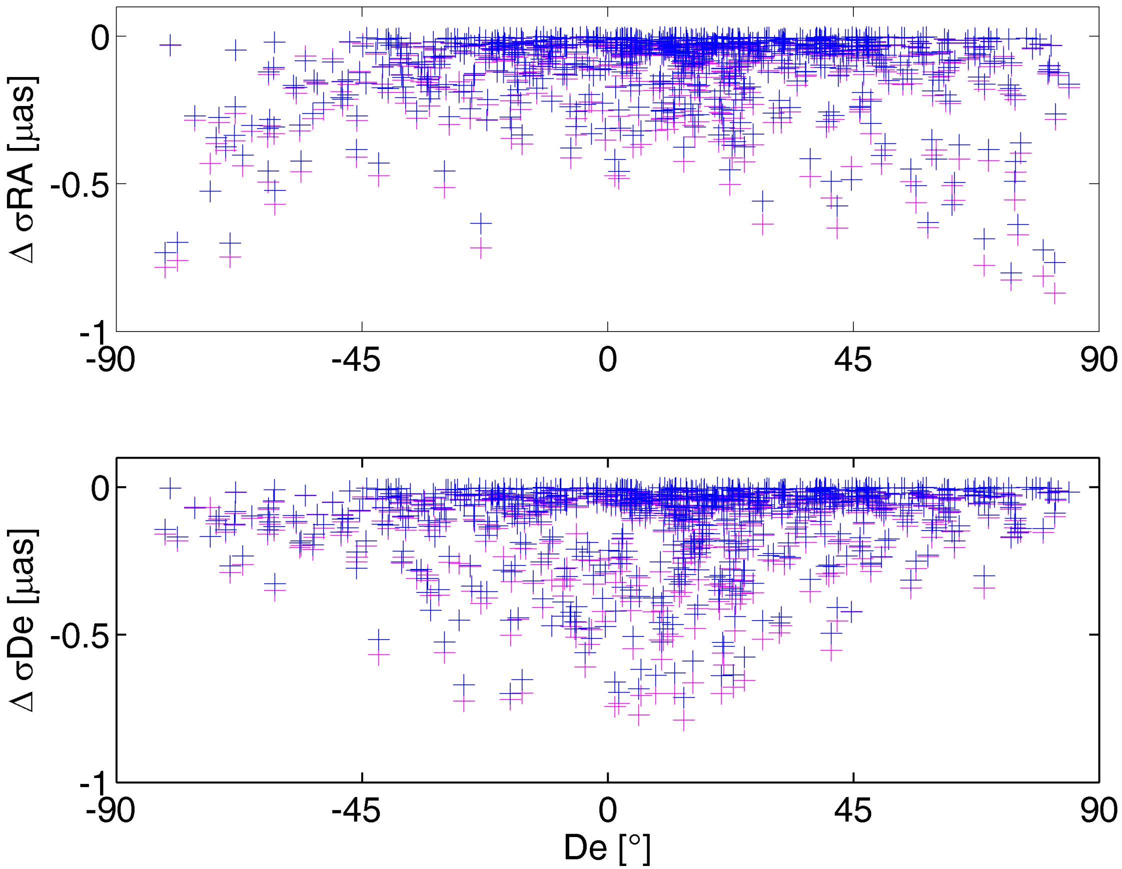




S1 – S3



Comparison of formal errors of the CRF



mean difference
of the formal errors

RA

S2 – S1: -0.114 microas

S3 – S1: -0.107 microas

De

S2 – S1: -0.125 microas

S3 – S1: -0.118 microas

only sources with m_{RADe} < 1 mas