Intra-Eurasia plate motions based on EUREF, IVS-Europe, and IVS-combined solutions

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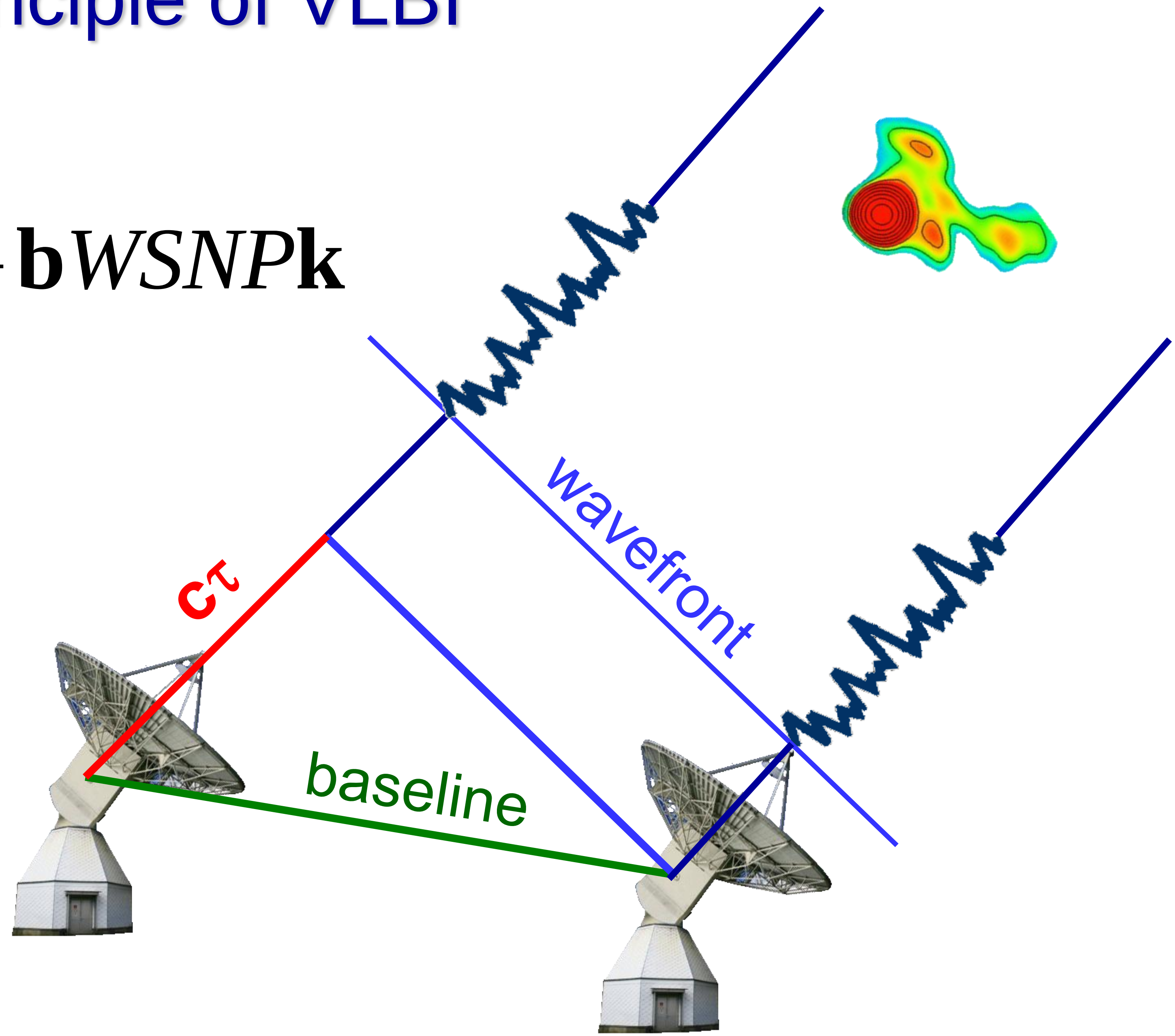
Motivation of this study

- Since the beginning of the 80ies several European VLBI stations have been observing and some data series cover about 30 years.
- VLBI antennas are providing very accurate and stable measurements (stable quasars e.g. Fey et al., IERS Technical Note 2009).
- Since 23rd of June 1989 every year several (6-12) IVS-Europe sessions have been carried out.
- Last complete solution of IVS-Europe sessions was done about 10 years ago (Campbell et al., 2002).
- Results of IVS-Europe sessions will be compared to those of the global VLBI sessions and to GNSS (EUREF).
- Different VLBI software will be compared in terms of the velocity estimates from their coordinate time series.
- Spectral analysis of VLBI and GNSS coordinate time series at co-located sites in Europe will be done in order to figure out harmonic variations of the station positions.

The principle of VLBI

$$\tau = -\frac{1}{c}\mathbf{b}WSNP\mathbf{k}$$



Wettzell (20 m)

O'Higgins (9 m)

Various VLBI solutions obtained by different IVS Analysis Centers were compared:

- Deutsches Geodaetisches Forschungsinstitut (DGFI) IVS-AC (Germany) solution.
- Bundesamt für Kartographie und Geodäsie (BKG) IVS-AC (Germany) solution.
- NASA , Goddard Space Flight Center (GSF) IVS-AC (USA) solution.
- TU Wien, Institut für Geodäsie und Geophysik (IGG) IVS-AC (Austria) solution.

Why?

Different software was used and different analysis option applied.

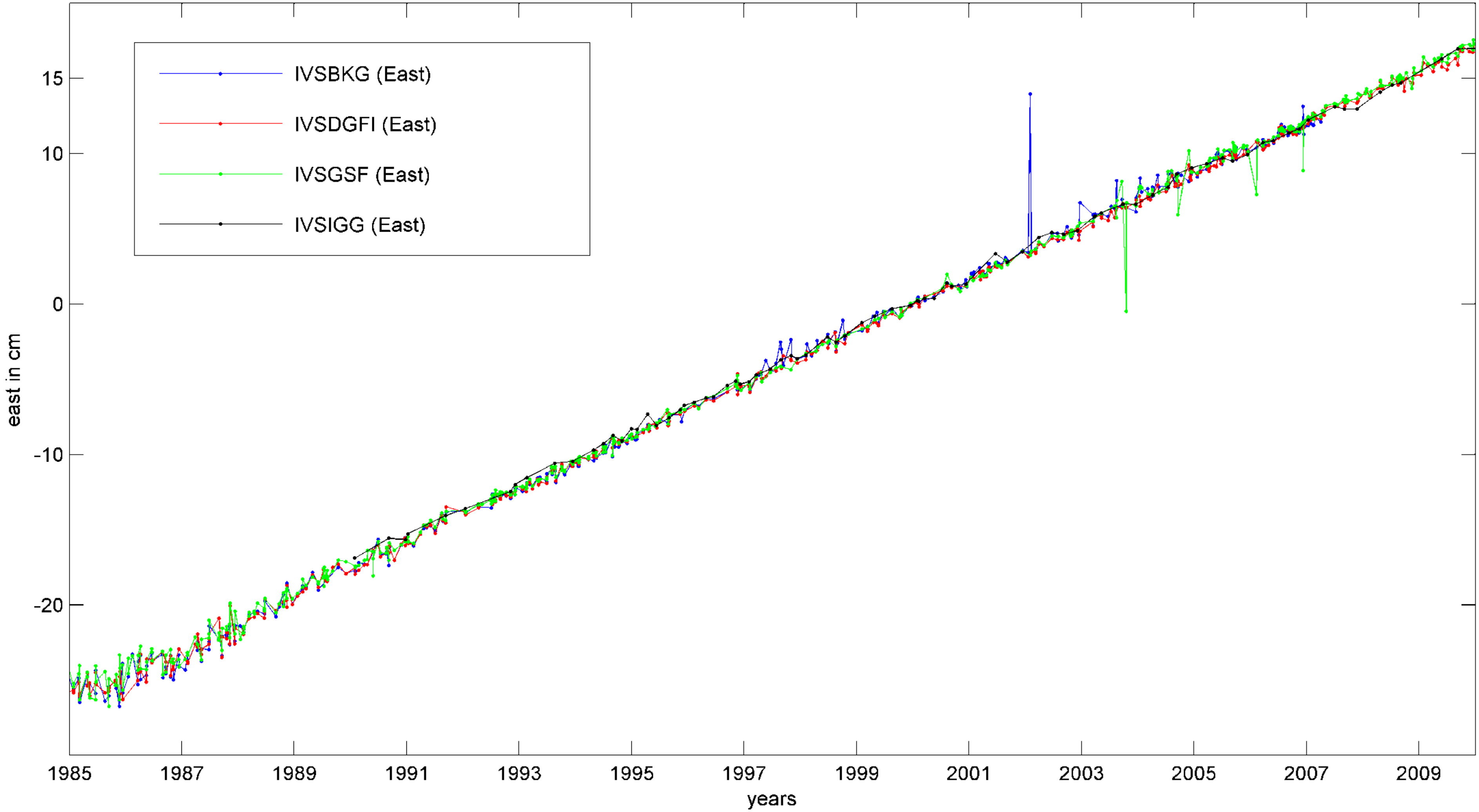
Some of the VLBI analysis options

- **A priori CRF.**
- **A priori TRF.**
- **Mapping function.**
- **Cut off elevation for observables.**
- **Elevation dependent weighting.**
- **Relative clock errors.**
- **Troposphere zenith delays and gradients.**
- **CRF, TRF, and EOP.**
- **Estimation intervals for each parameter group (station wise and global).**
- **Absolute and relative constraints between piece-wise linear offset estimates.**
- **Absolute datum constraints or NNT/NNR datum conditions on the estimated TRF.**
- **Models for station motion: solid Earth tides, ocean loading, tidal and non-tidal atmosphere loading, pole tides, and antenna thermal deformation.**
- **Models for EOP: IAU2000A precession-nutation, IERS C04 05 combined EOP series, high frequency oceanic tidal terms …**

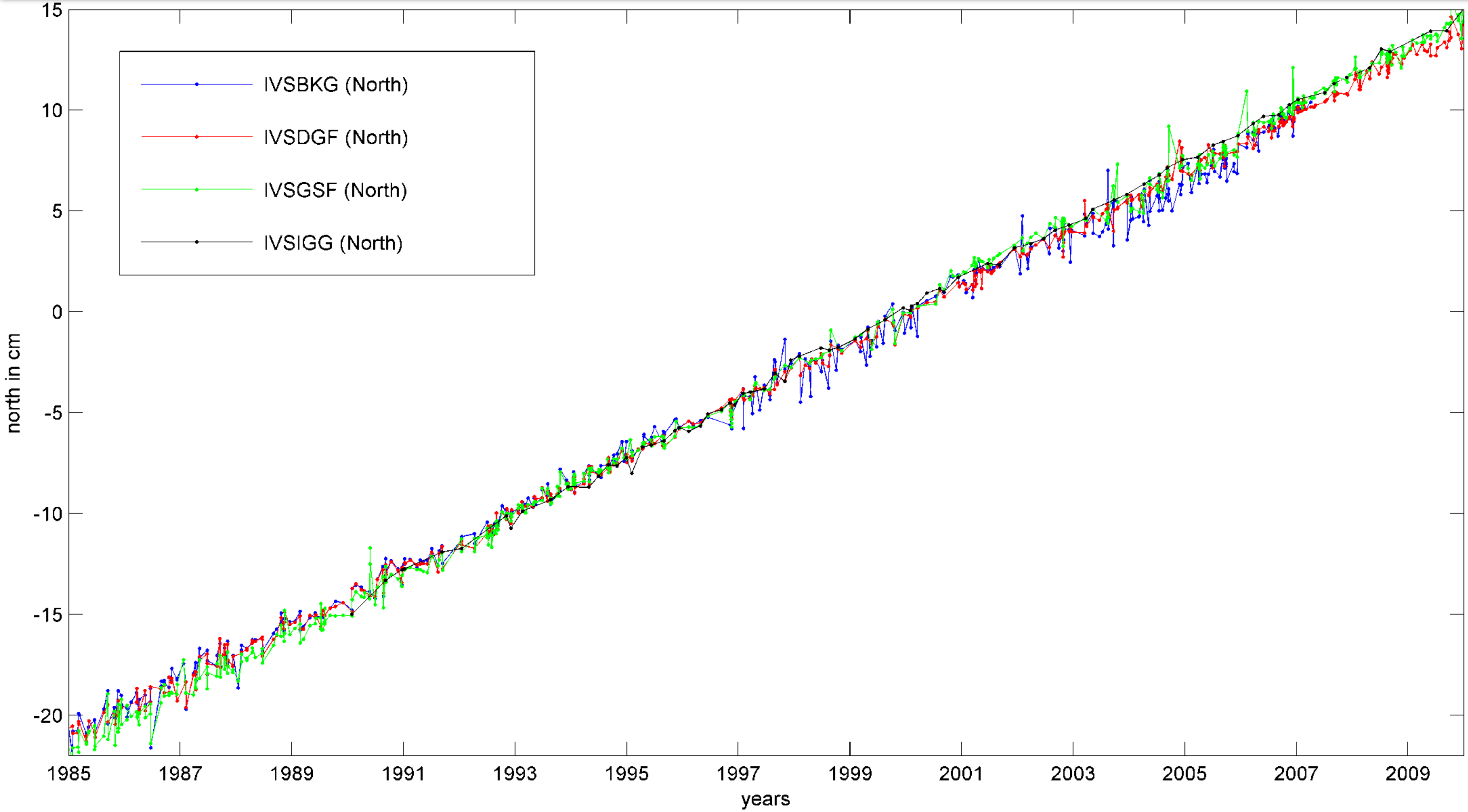
Vienna VLBI Software (VieVS) specific parameterization (TU-Wien, IGG-AC)

- **Case 1**
  - **All EOP fixed to their a priori values.**
  - **Wettzell (Germany) antenna fixed to a priori VTRF2008 coordinates.**
- **Case 2**
  - **ERPs are estimated.**
  - **Nutations fixed.**
  - **Conditions of NNT and NNR on VTRF2008.**
- **Case 3**
  - **All EOP fixed to their a priori values.**
  - **Conditions of NNT and NNR on VTRF2008.**

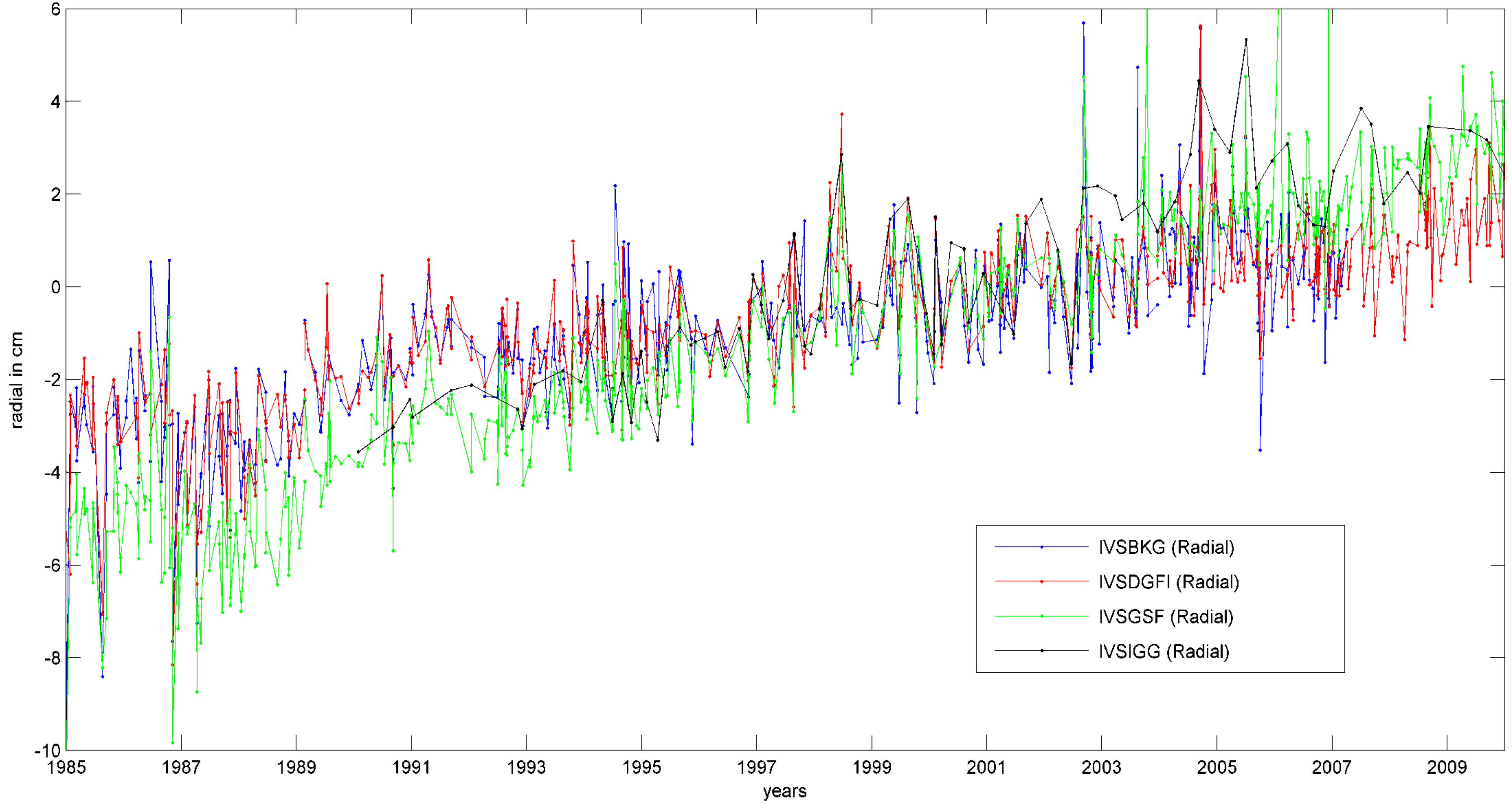
Onsala60 VLBI antenna east coordinate estimates from the solutions of different IVS-ACs

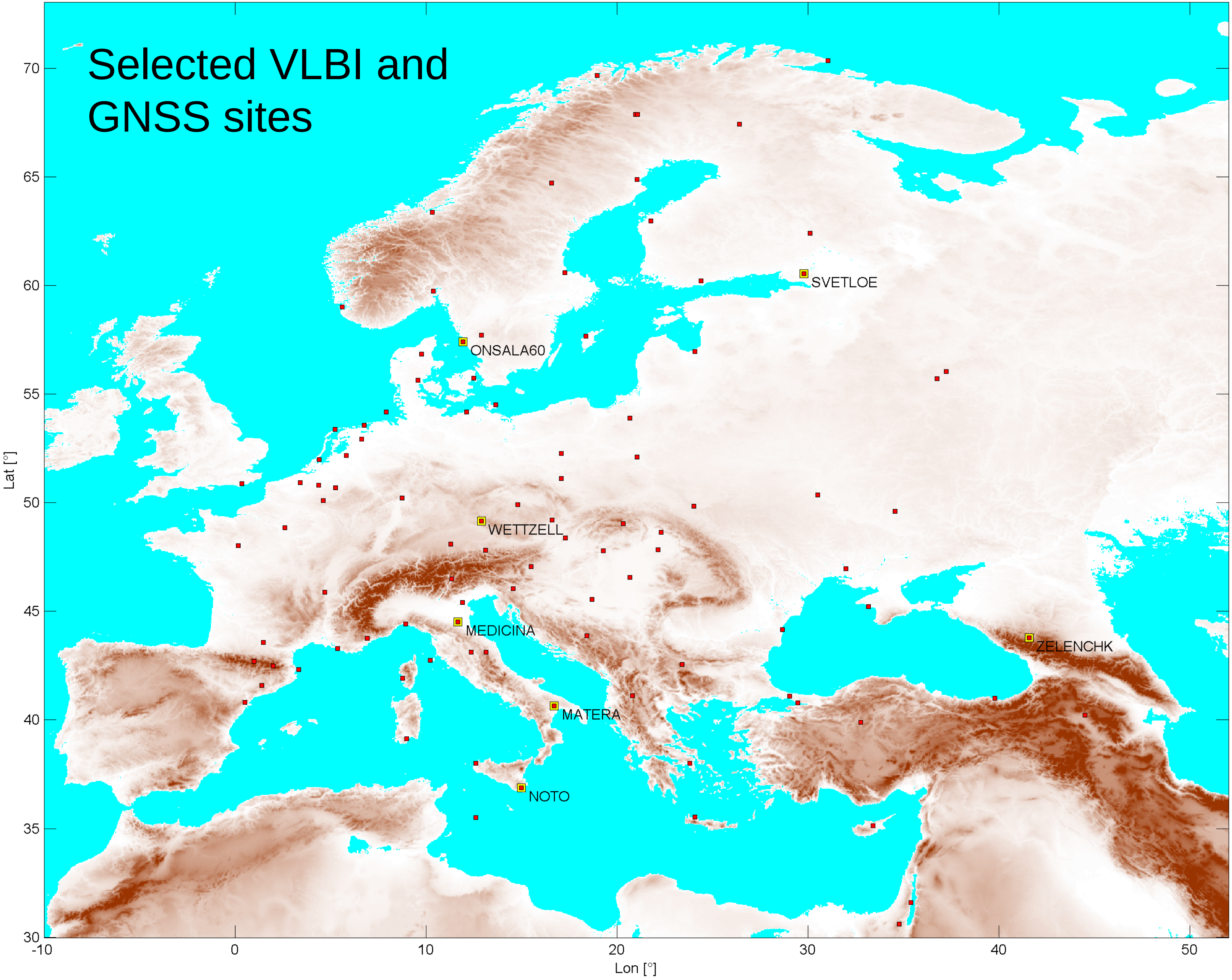


Onsala60 VLBI antenna north coordinate estimates from the solutions of different IVS-ACs

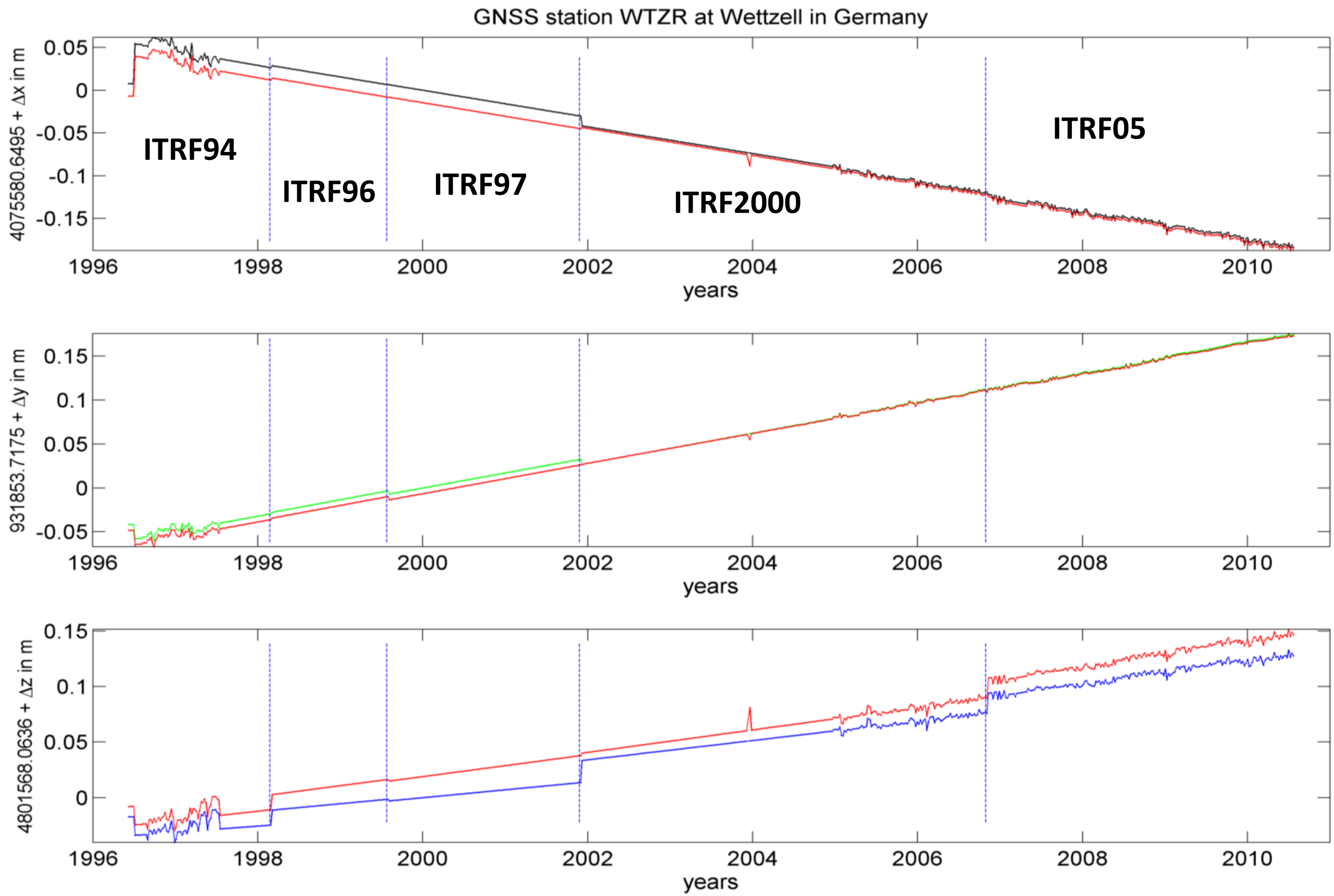


Onsala60 VLBI antenna radial coordinate estimates from the solutions of different IVS-ACs




Selected VLBI and GNSS sites
SVETLOE
ONSALA60
WETTZELL
MEDICINA
ZELENCHK
MATERA
NOTO
Lat [°]
Lon [°]
70
65
60
55
50
45
40
35
30
-10
0
10
20
30
40
50

Leaps in EUREF-GNSS coordinate time series caused by imposing different a priori TRF datum



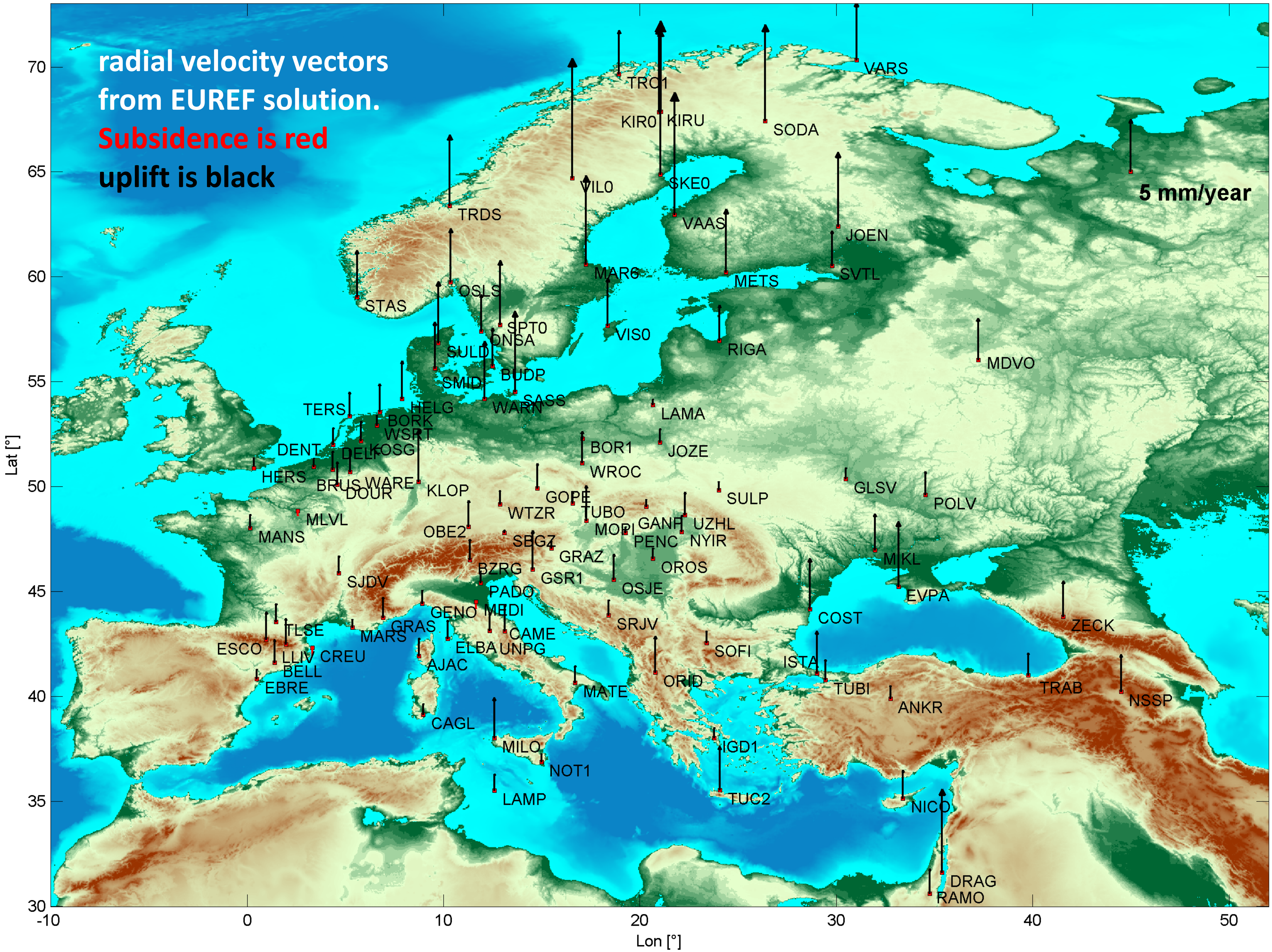
Comparisons of velocities of VLBI stations between IVS solutions

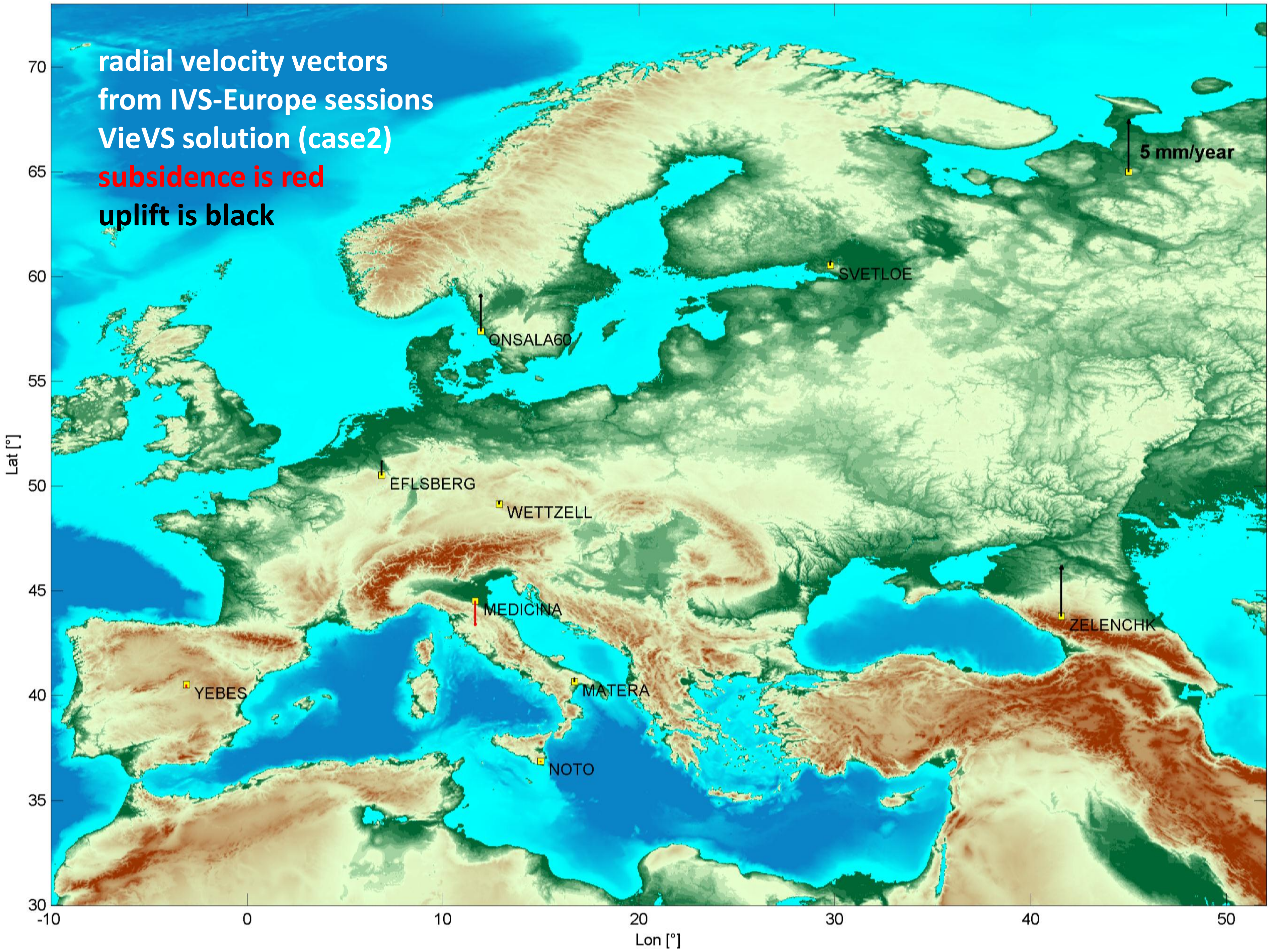
VLBI sites contributing IVS sessions in Europe	VieVS solution – IGG Special AC case1			VieVS solution - IGG case2			VieVS solution - IGG case3		
	v_{north} cm/year	v_{east} cm/year	v_{radial} cm/year	v_{north}	v_{east}	v_{radial}	v_{north}	v_{east}	v_{radial}
Wettzell (Germany)	fixed	fixed	fixed	1.5	2.0	0.0	1.5	2.0	0.0
Nyales20 (Norway)	1.5	1.0	0.6	1.4	1.0	0.8	1.4	1.0	0.8
Onsala60 (Sweden)	1.5	1.7	0.3	1.5	1.7	0.4	1.5	1.7	0.3
Medicina (Italy)	1.8	2.2	-0.2	1.8	2.2	-0.2	1.8	2.2	-0.2

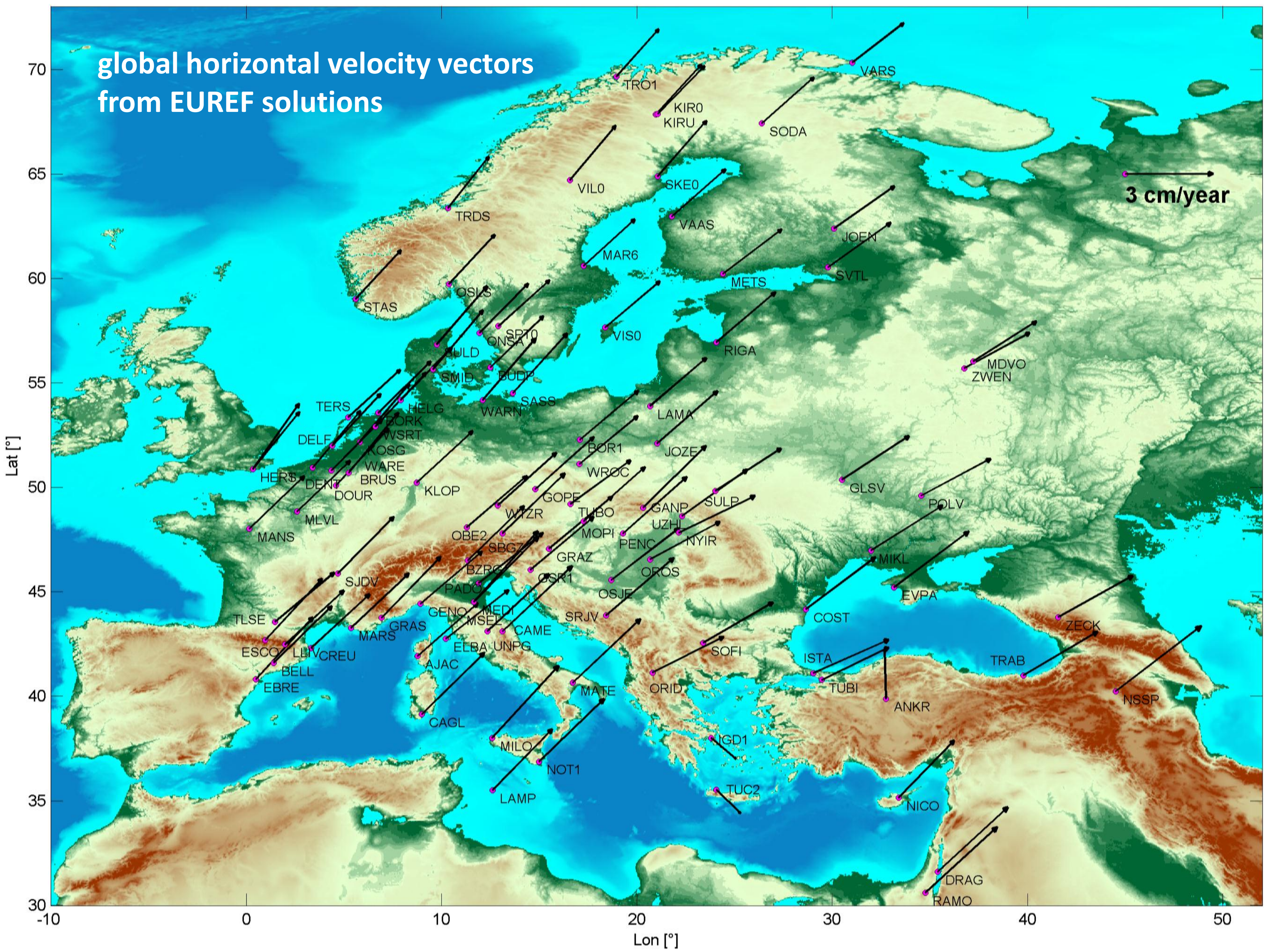
VLBI sites contributing IVS sessions in Europe	DOGS CS <OCCAM DGFI operational AC			Calc/Solve BKG operational AC		
	v_{north}	v_{east}	v_{radial}	v_{north}	v_{east}	v_{radial}
Wettzell (Germany)	1.5	2.0	-0.1	1.4	2.1	-0.1
Nyales20 (Norway)	1.4	1.1	0.6	1.4	1.1	0.5
Onsala60 (Sweden)	1.4	1.7	0.2	1.4	1.8	0.2
Medicina (Italy)	1.7	2.2	-0.3	1.7	2.3	-0.3

Comparisons of velocities of IVS-AC (DGFI) and EUREF solutions (VLBI and GNSS)

Co-located sites in Europe	IVS-DGFI			EUREF		
	V_{north} (~time span) (cm/year)	v_{east} (cm/year)	V_{radial} (cm/year)	v_{north}	v_{east}	v_{radial}
Wettzell (Germany)-WTZR	1.5 (~26)	2.0	-0.1	1.7 (~14)	2.0	0.1
Onsala60 (Sweden)-ONSA	1.4 (~26)	1.7	0.2	1.6 (~14)	1.7	0.3
Matera (Italy)-MATE	1.8 (~19)	2.4	-0.1	2.0 (~14)	2.3	0.2
Zelenchukskaya (Russia)-ZECK	0.8 (~4)	2.5	0.4	1.3 (~13)	2.5	0.3
Medicina (Italy)-MEDI	1.7 (~22)	2.2	-0.3	2.1 (~14)	2.2	-0.1


radial velocity vectors
from EUREF solution.
Subsidence is red
uplift is black
5 mm/year
Lat [°]
Lon [°]
VARS
TRO1
KIR0
KIRU
SODA
VIL0
SKE0
TRDS
VAAS
JOEN
MAR6
METS
SVTL
STAS
OSLS
SPT0
ONSA
VIS0
RIGA
MDVO
SULD
SMID
BUDP
SASS
WARN
HELG
TERS
BORK
WSRT
LAMA
DENT
DELF
KOSG
BOR1
JOZE
HERS
BRUS
WARE
DOUR
KLOP
WROC
GLSV
SULP
POLV
GOPE
WTZR
TUBO
MLVL
MANS
OBE2
MOPI
GANP
UZHL
PENC
NYIR
SBGZ
GRAZ
MIKL
BZRG
OROS
GSR1
SJDV
PADO
OSJE
EVPA
GENO
MEDI
COST
ZECK
SRJV
GRAS
TLSE
MARS
CAME
ESCO
ELBA
UNPG
SOFI
LLIV
CREU
AJAC
ISTA
BELL
ORID
TUBI
TRAB
EBRE
MATE
ANKR
NSSP
CAGL
MILO
IGD1
NOT1
LAMP
TUC2
NICO
DRAG
RAMO


radial velocity vectors
from IVS-Europe sessions
VieVS solution (case2)
subsidence is red
uplift is black
5 mm/year
SVETLOE
ONSALA60
EFLSBERG
WETTZELL
MEDICINA
ZELENCHK
YEBES
MATERA
NOTO
Lat [°]
Lon [°]
70
65
60
55
50
45
40
35
30
-10
0
10
20
30
40
50


global horizontal velocity vectors
from EUREF solutions
3 cm/year
Lat [°]
Lon [°]
70
65
60
55
50
45
40
35
30
-10
0
10
20
30
40
50
TRO1
VARS
KIR0
KIRU
SODA
VIL0
SKE0
TRDS
VAAS
JOEN
MAR6
METS
SVTL
STAS
OSLS
SPT0
ONSA
VIS0
RIGA
SULD
SMID
BUDP
MDVO
ZWEN
TERS
HELG
WARN
SASS
LAMA
BORK
WSRT
DELF
KOSG
BOR1
JOZE
WARE
BRUS
HERS
DENT
DOUR
WROC
KLOP
GLSV
GOPE
MLVL
TUBO
SULP
WTZR
POLV
GANP
UZHL
MANS
MOPI
OBE2
PENC
NYIR
SBGZ
GRAZ
MIKL
BZRG
OROS
SJDV
GSR1
PADO
OSJE
EVPA
GENO
MEDI
TLSE
SRJV
COST
MSEL
ZECK
MARS
GRAS
CAME
ESCO
LLIV
CREU
ELBA
UNPG
ISTA
SOFI
TRAB
BELL
AJAC
EBRE
ORID
TUBI
MATE
ANKR
NSSP
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TUC2
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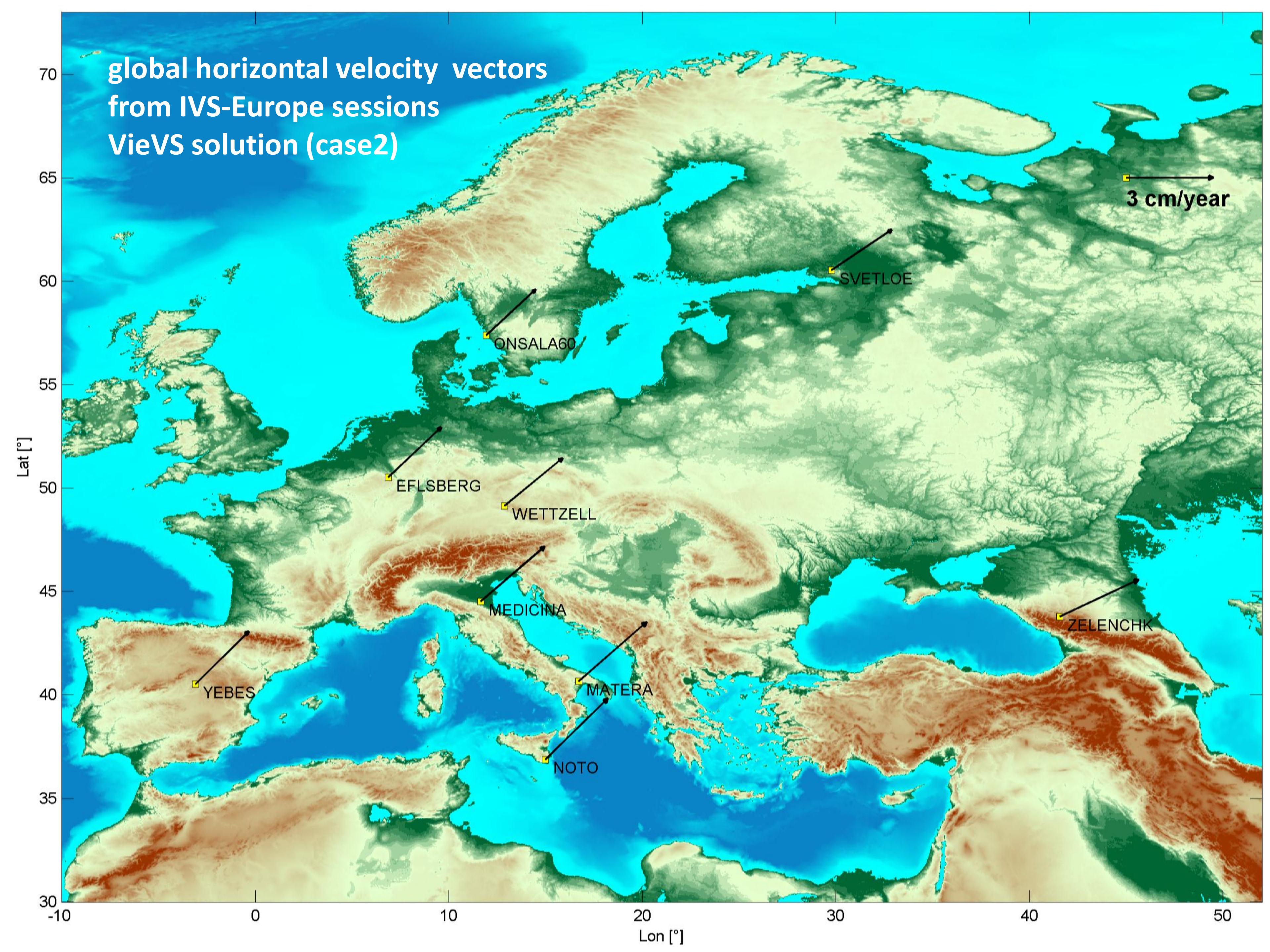
RAMO



global horizontal velocity vectors
from IVS-Europe sessions
VieVS solution (case2)
3 cm/year
SVETLOE
ONSALA60
EFLSBERG
WETTZELL
MEDICINA
ZELENCHK
YEBES
MATERA
NOTO
Lat [°]
Lon [°]
70
65
60
55
50
45
40
35
30
-10
0
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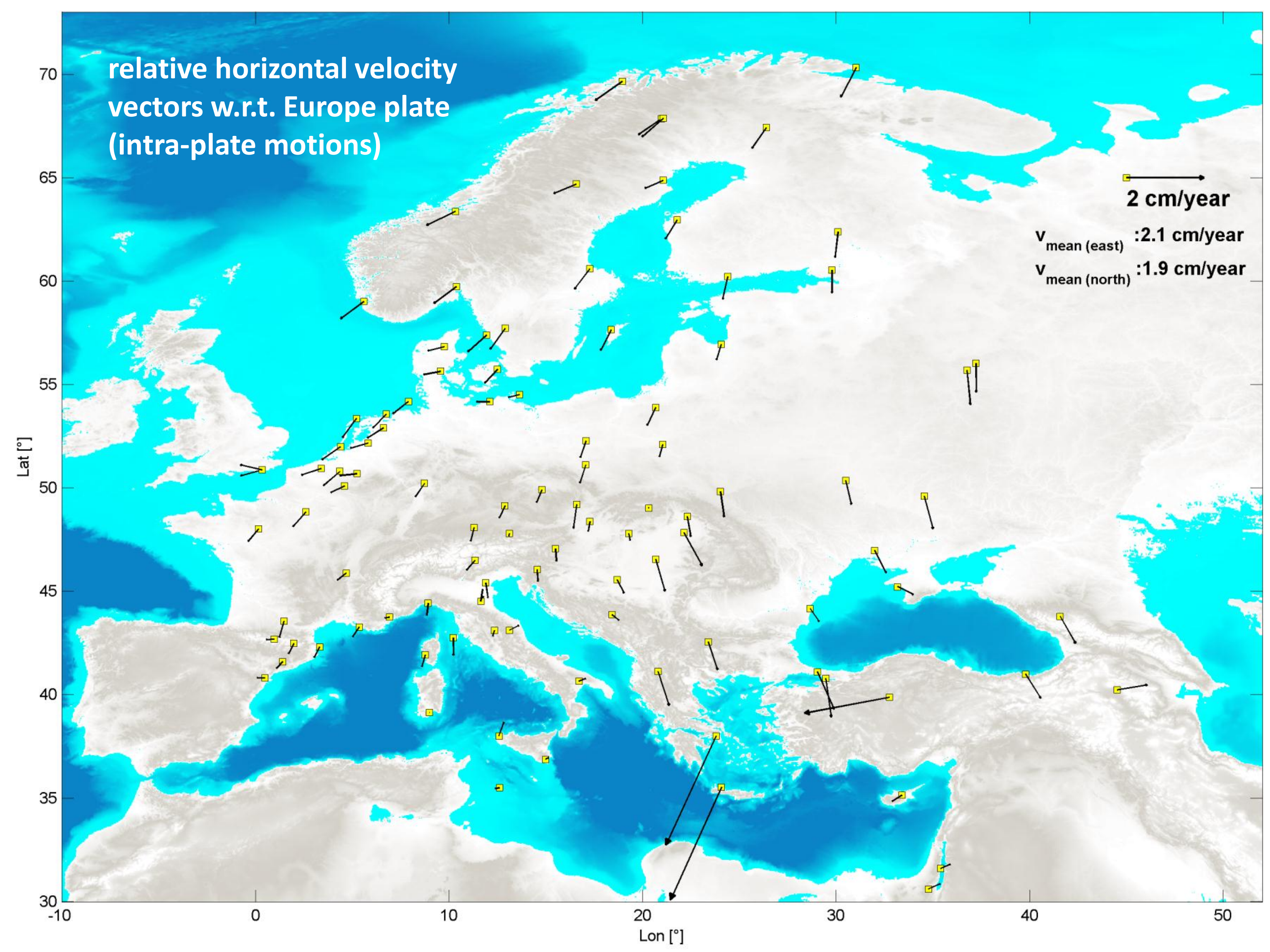
20
30
40
50

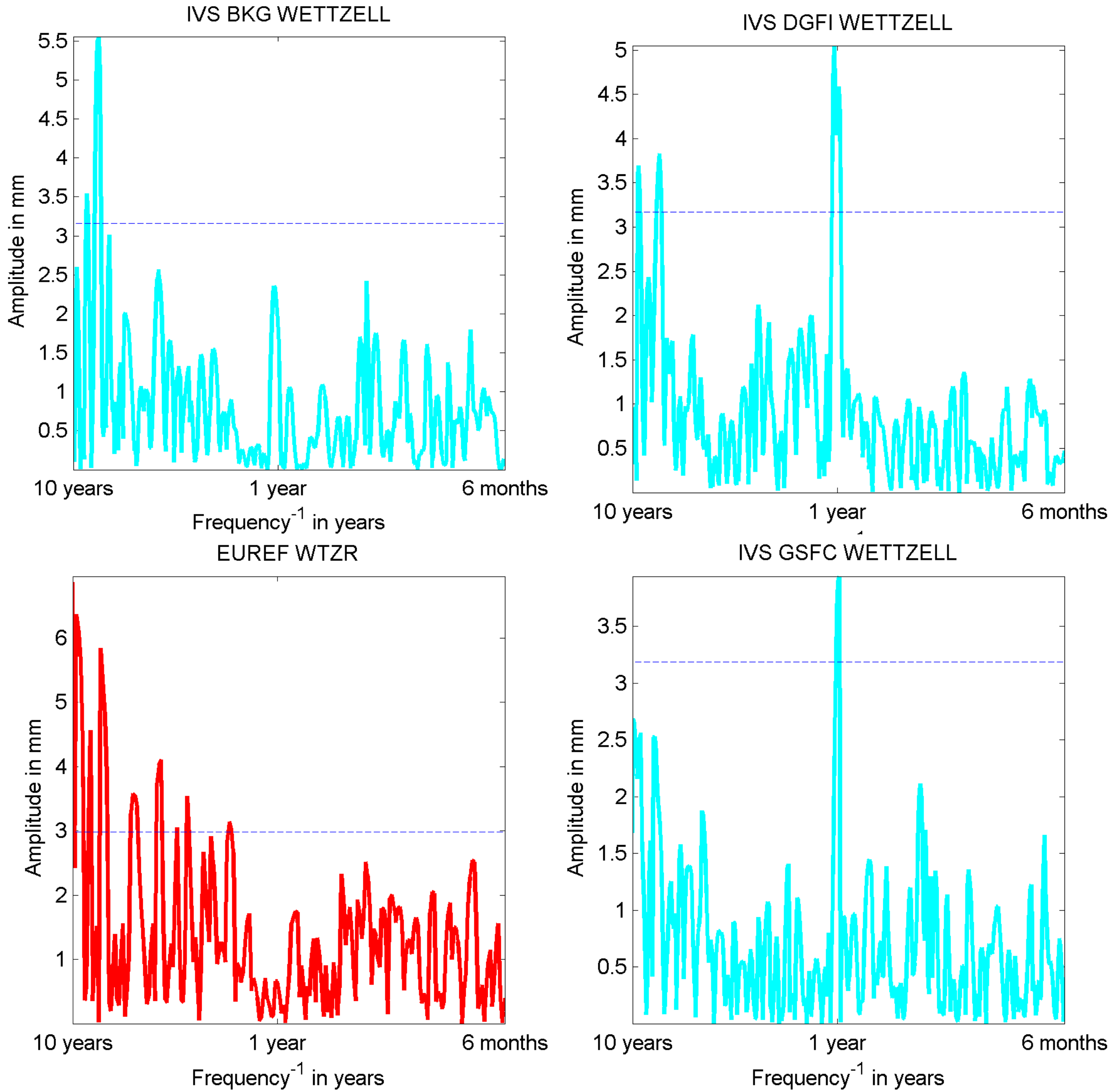


relative horizontal velocity
vectors w.r.t. Europe plate
(intra-plate motions)
2 cm/year
$v_{mean\ (east)}$:2.1 cm/year
$v_{mean\ (north)}$:1.9 cm/year
Lat [°]
Lon [°]
70
65
60
55
50
45
40
35
30
-10
0
10
20
30
40
50

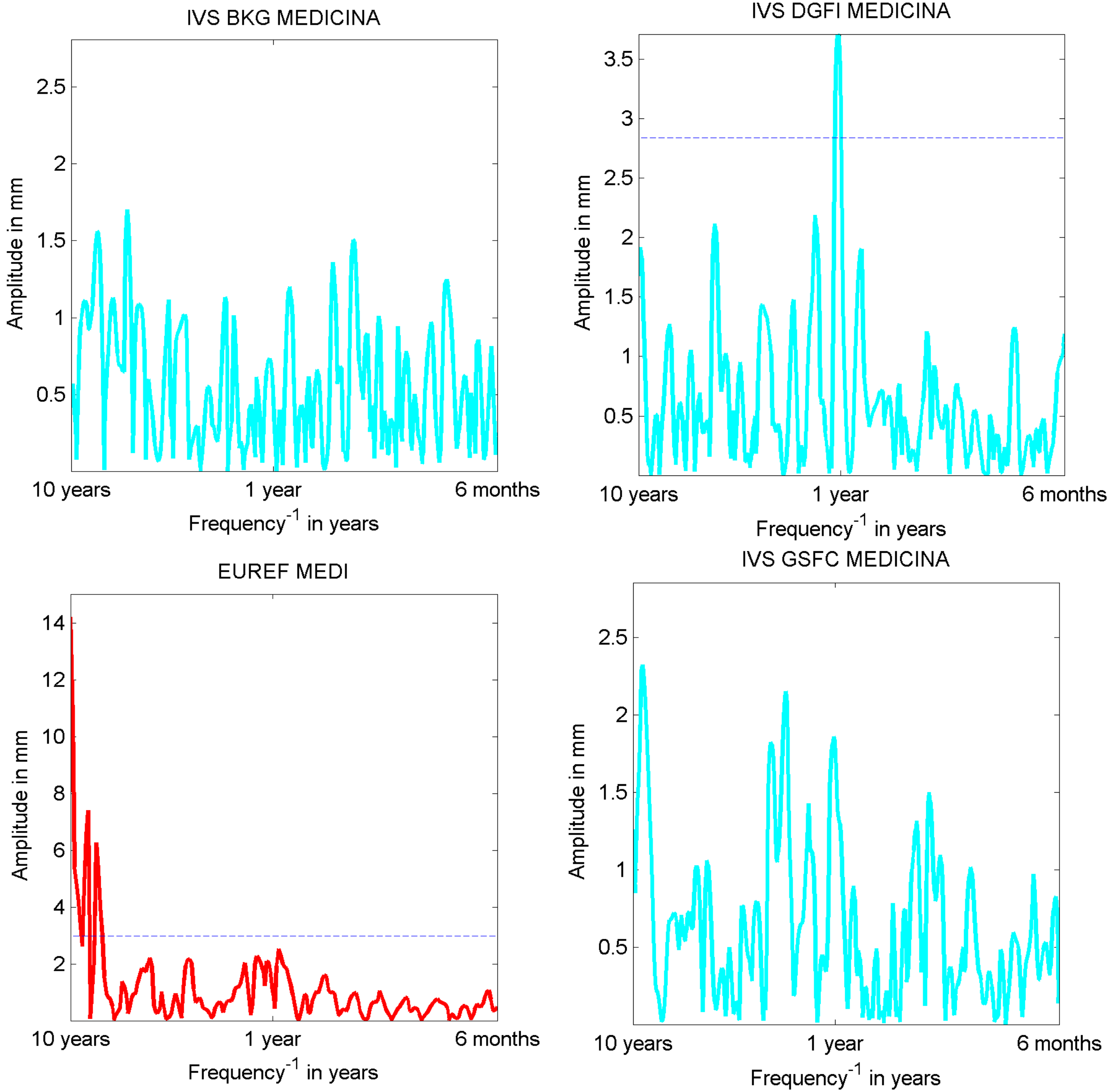
What is the goal of determining the spectra? (Motivation)

- After reducing the offsets and rates from the series, low frequency harmonic variations were investigated. Because
  - the estimated TRF coordinates of space geodetic techniques should be tide free according to the IERS Conventions.
  - The corrections to the station coordinates before the parameter estimation (e.g. solid Earth tides, ocean loading) were not perfect what could cause harmonic variations on the station position time series,
  - Geophysical models of station motions may be totally neglected (e.g. atmosphere loading, thermal deformation of the VLBI antenna).

Co-located site Wettzell



Co-located site Medicina



Conclusions

- The **IVS-ACs (DGFI, BKG, GSF and IGG)** solutions, and EUREF weekly solutions show us (for network covering Europe):
  - Estimating EOP or fixing to priori models did not cause significant differences on the velocity estimates in VLBI analysis for regional networks.
  - The horizontal and radial velocity estimates of IVS and EUREF solutions agree at co-located sites within a few millimeters/year level.
  - At some VLBI sites significant low frequency spectra (annual and decadal) were detected. This may be due to not reducing atmosphere loading effect or correcting thermal deformation a priori to the adjustment from the observations
  - EUREF GNSS coordinate time series often have leaps and spectra with larger amplitudes relatively to VLBI antennas at co-located sites.

vielen dank!

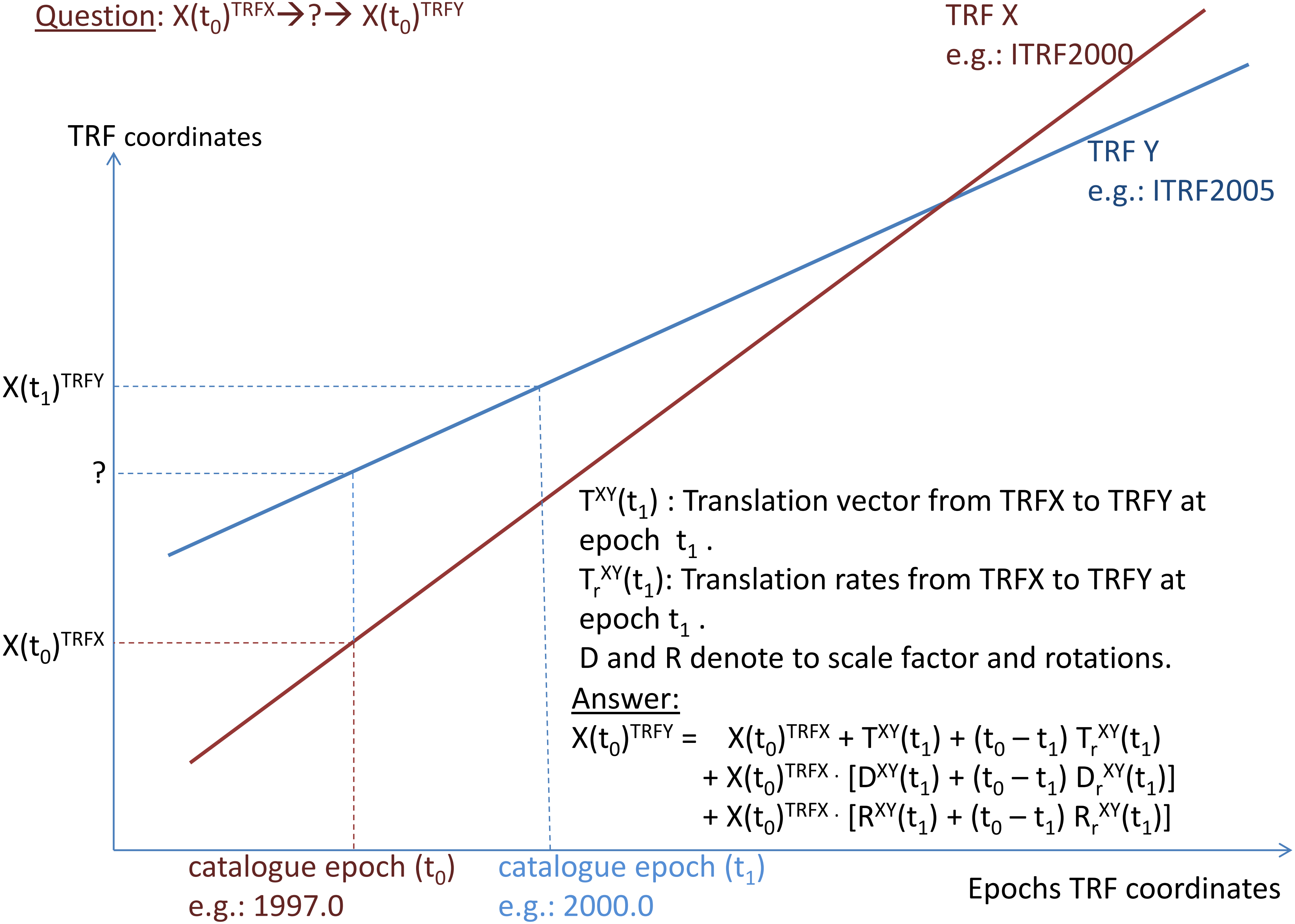
many thanks for your attention!

Appendices

Co-located VLBI and GNSS sites in Europe related to this study

antenna	solution	total epochs	time span (year)	Mean sampling interval (day)
Wettzell WTZR	DGFI EUREF	2406 736	26.09 14.12	3.96 weekly
Nyales20	DGFI	905	15.39	6.22
Svetloe SVTL	DGFI EUREF	292 690	6.69 13.68	8.39 weekly
Onsala60 ONSA	DGFI EUREF	531 737	26.07 14.12	17.96 weekly
Medicina MEDI	DGFI EUREF	318 726	22.22 14.12	25.60 weekly
Zelenchk ZECK	DGFI EUREF	204 610	4.18 12.80	7.51 weekly
Matera MATE	DGFI EUREF	602 735	19.18 14.12	11.65 weekly
Noto NOT1	DGFI EUREF	121 514	20.63 9.87	62.79 weekly

Question: $X(t_0)^{TRFX} \rightarrow ? \rightarrow X(t_0)^{TRFY}$



$T^{XY}(t_1)$: Translation vector from TRFX to TRFY at epoch t_1 .

$T_r^{XY}(t_1)$: Translation rates from TRFX to TRFY at epoch t_1 .

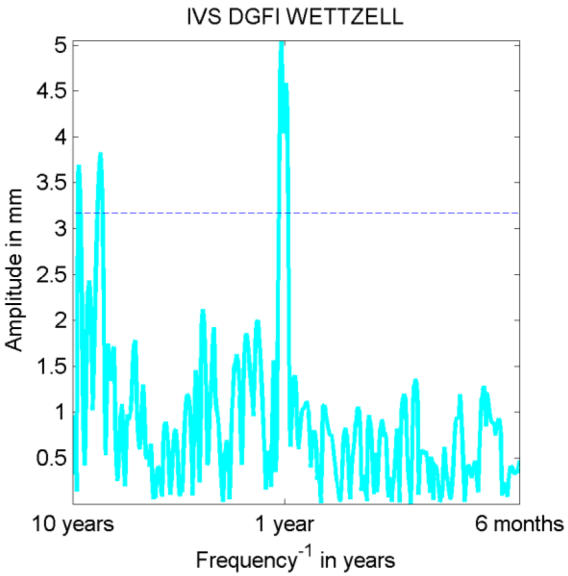
D and R denote to scale factor and rotations.

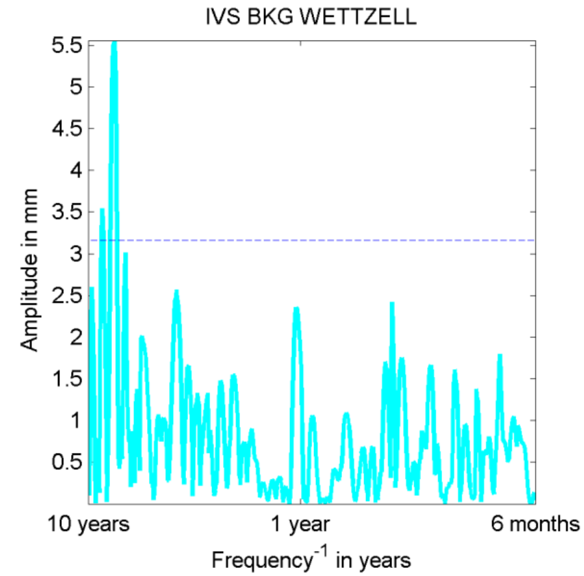
Answer:

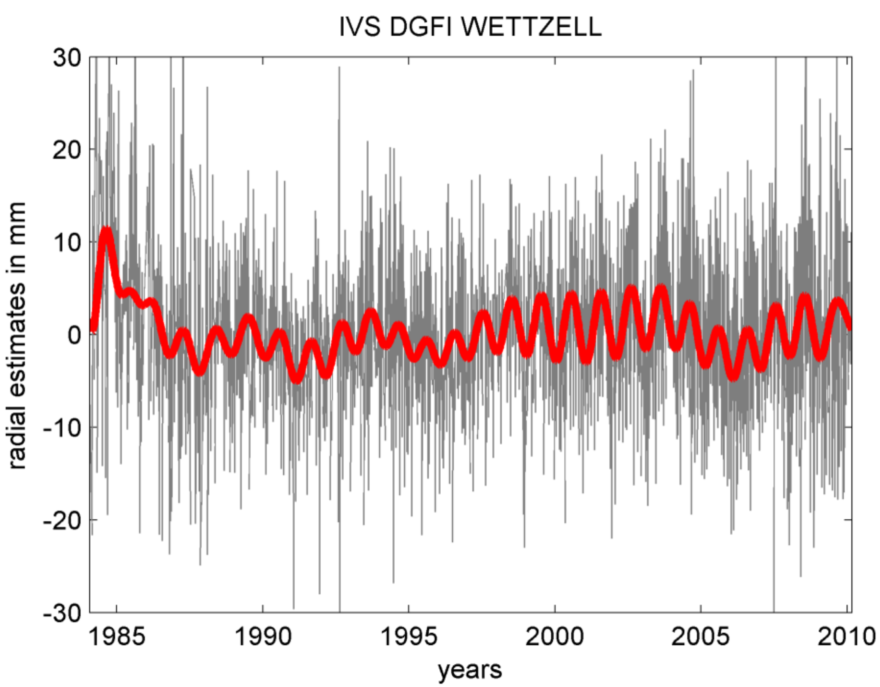
$$
\begin{aligned}
X(t_0)^{TRFY} = \; & X(t_0)^{TRFX} + T^{XY}(t_1) + (t_0 - t_1)\, T_r^{XY}(t_1) \\
& + X(t_0)^{TRFX} \cdot [D^{XY}(t_1) + (t_0 - t_1)\, D_r^{XY}(t_1)] \\
& + X(t_0)^{TRFX} \cdot [R^{XY}(t_1) + (t_0 - t_1)\, R_r^{XY}(t_1)]
\end{aligned}
$$

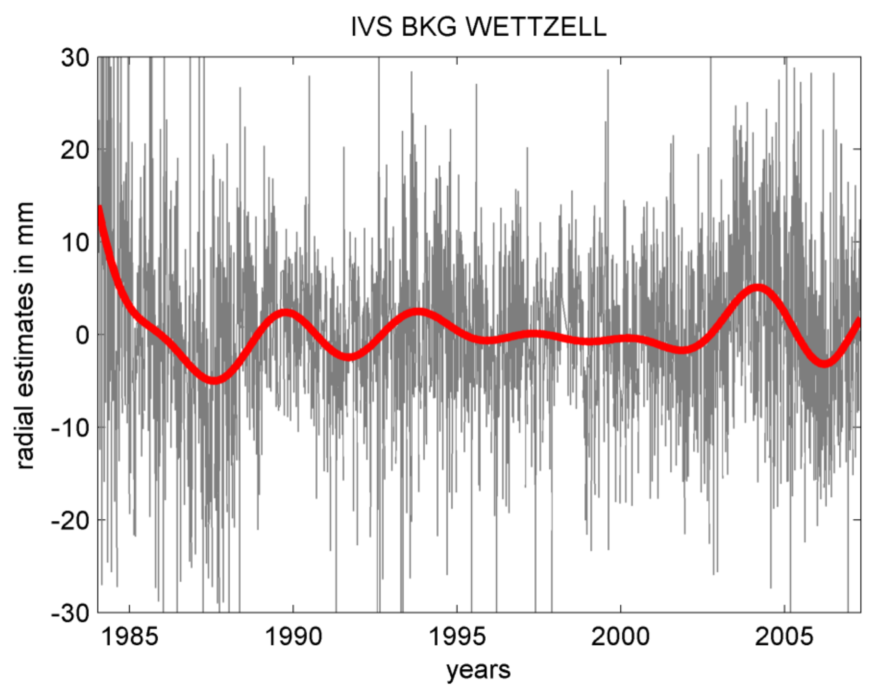
The harmonic function LS fit to the radial position estimates of different ACs. The frequencies included in the function were derived from the significant spectral peaks of Lomb-Scargle periodogram.

IVS SPECIAL SESSIONS FOR EOP and TRF estimation



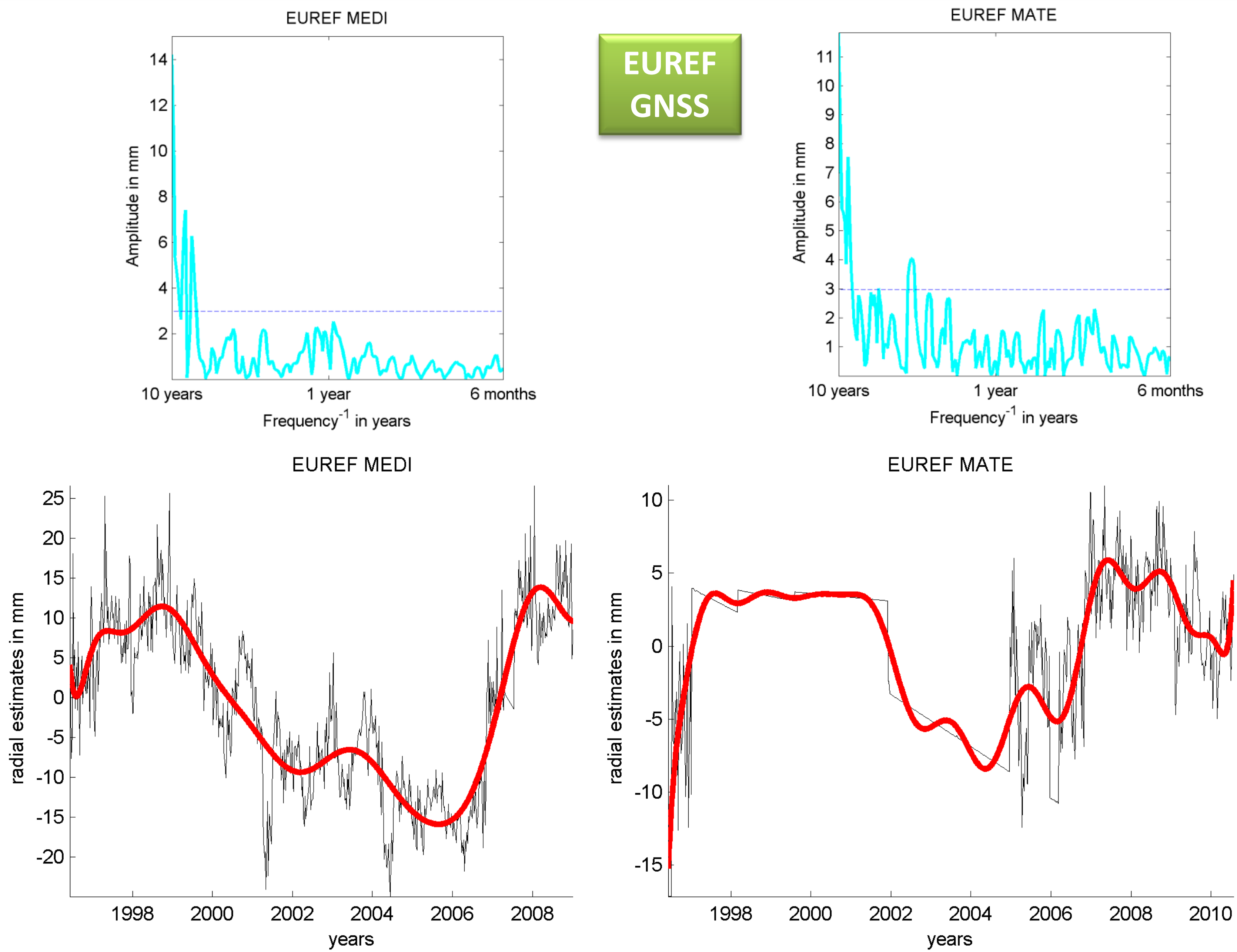




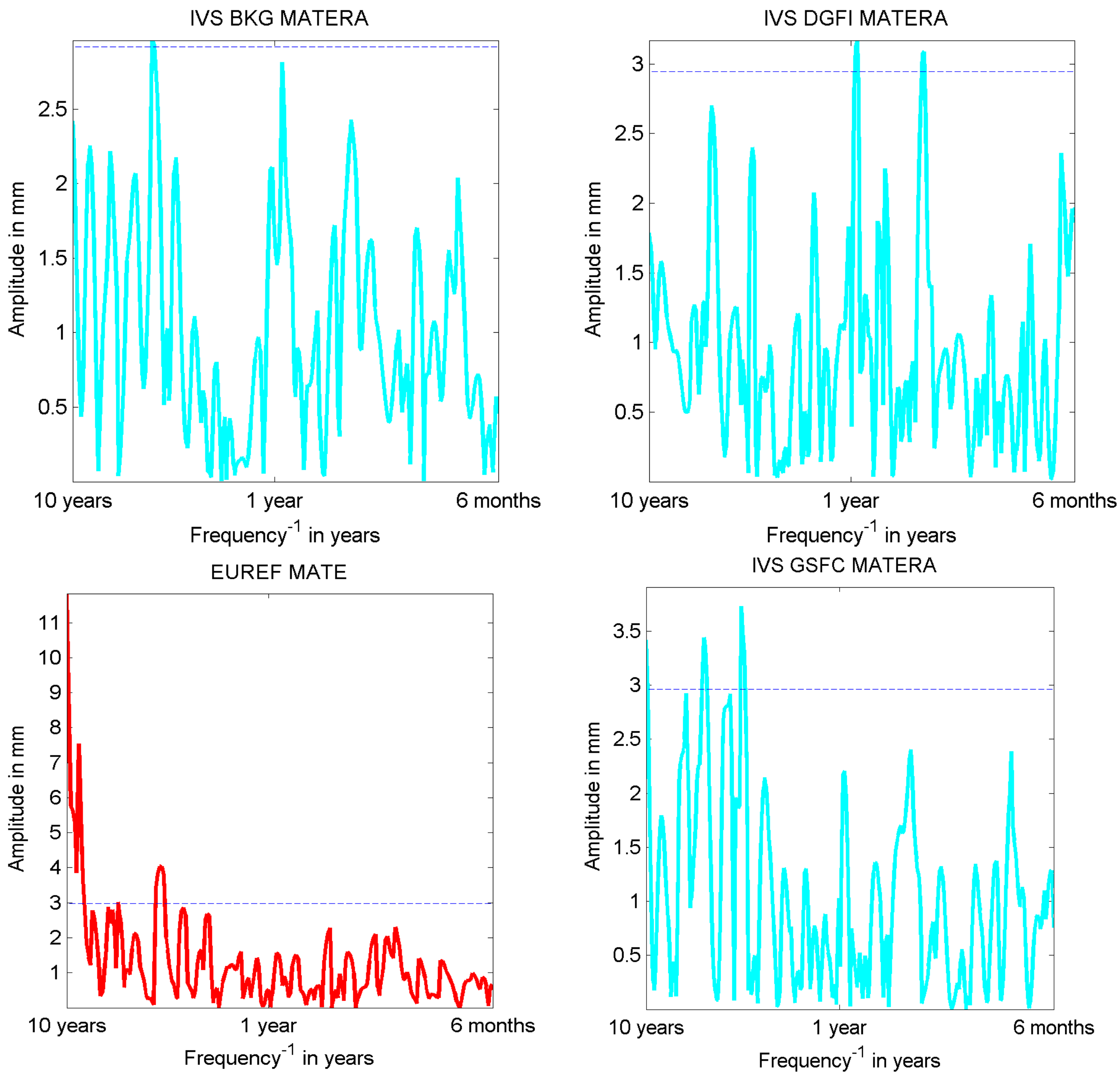


The harmonic function LS fit to the radial position estimates of different ACs. The frequencies included in the function were derived from the significant spectral peaks of Lomb-Scargle periodogram.

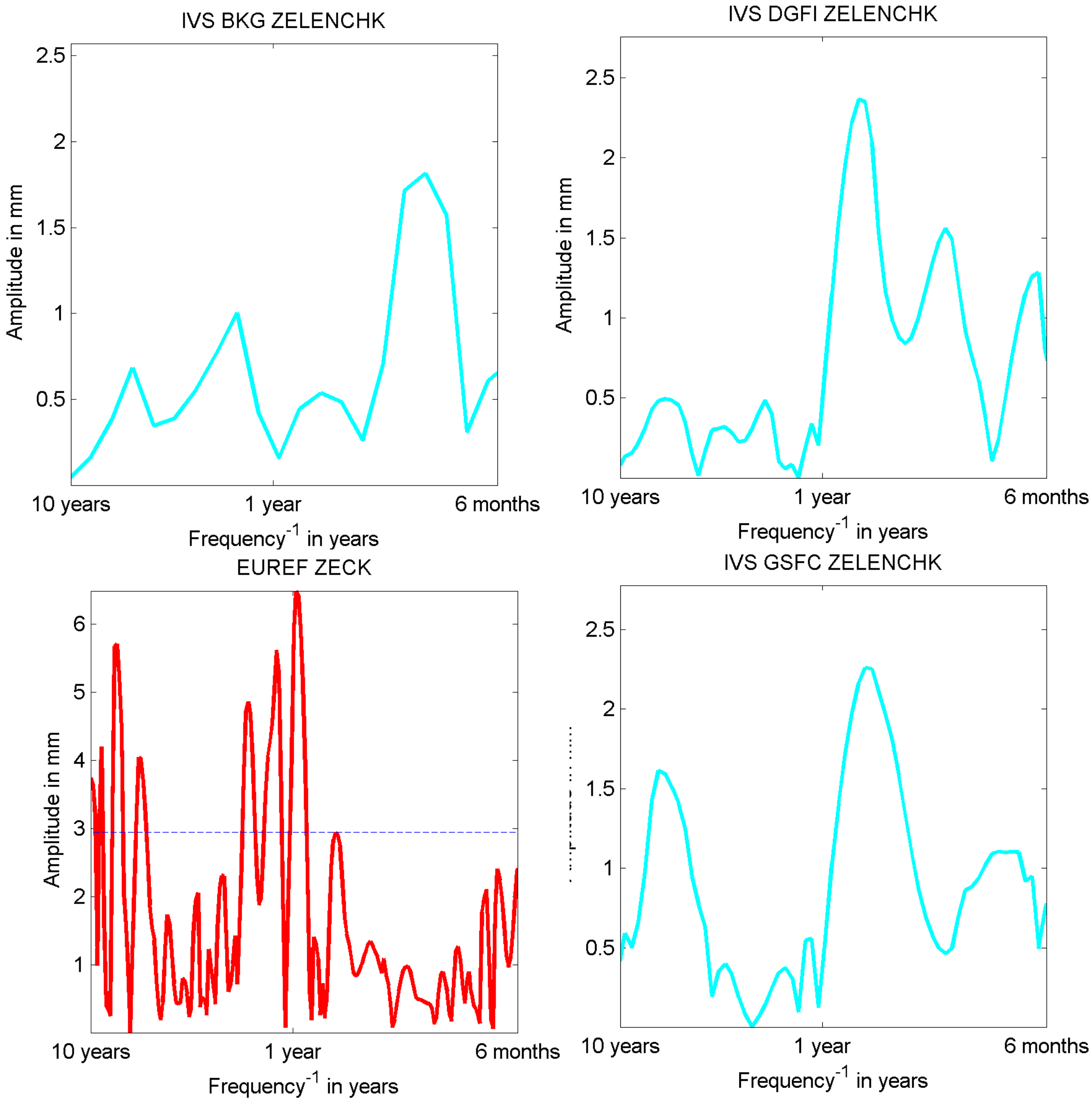
EUREF GNSS



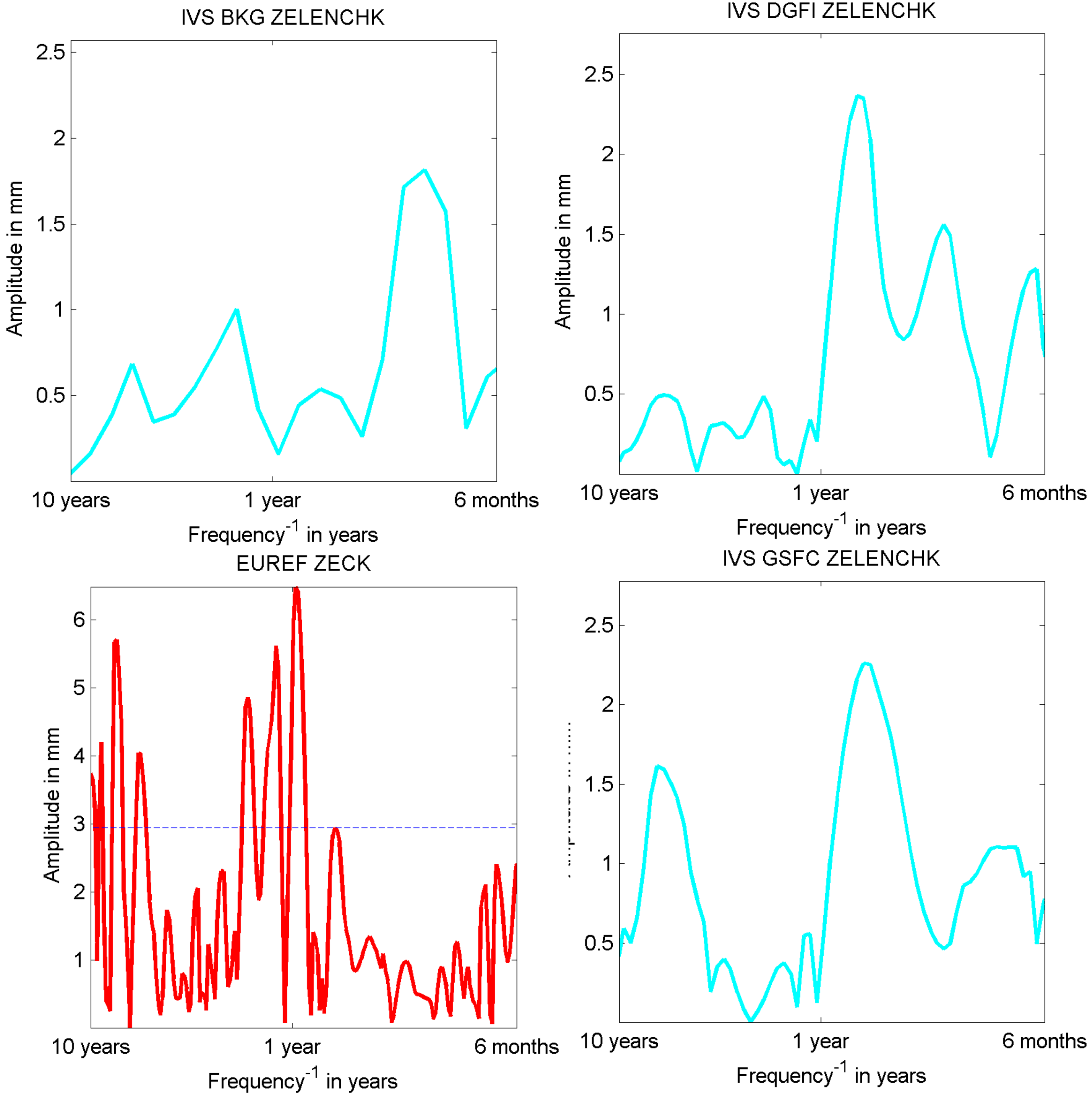
Co-located site Matera



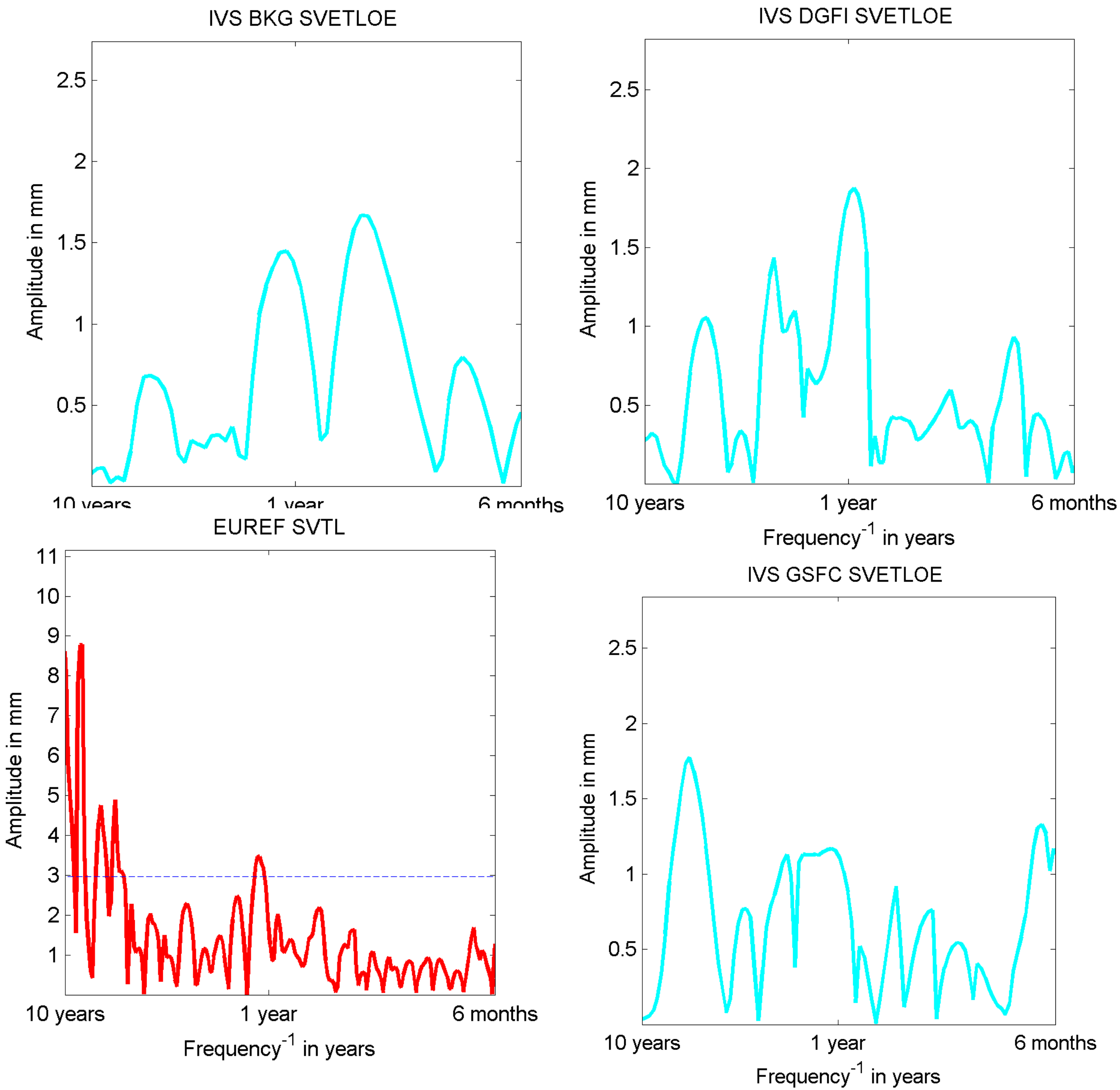
Co-located site Zelenchukskava



Co-located site Zelenchukskava



Co-located site Svetloe



Co-located site NOTO