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

\[ \tau = -\frac{1}{c} b WSNP k \]
O’Higgins (9 m)

Wettzell (20 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
Leaps in EUREF-GNSS coordinate time series caused by imposing different a priori TRF datum

GNSS station WTZR at Wettzell in Germany

ITRF94  ITRF96  ITRF97  ITRF2000  ITRF05
## Comparisons of velocities of VLBI stations between IVS solutions

<table>
<thead>
<tr>
<th>VLBI sites contributing IVS sessions in Europe</th>
<th>VieVS solution – IGG Special AC case1</th>
<th>VieVS solution - IGG case2</th>
<th>VieVS solution - IGG case3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$v_{\text{north}}$, cm/year</td>
<td>$v_{\text{east}}$, cm/year</td>
<td>$v_{\text{radial}}$, cm/year</td>
</tr>
<tr>
<td>Wettzell (Germany)</td>
<td>fixed</td>
<td>fixed</td>
<td>fixed</td>
</tr>
<tr>
<td>Nyales20 (Norway)</td>
<td>1.5</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Onsala60 (Sweden)</td>
<td>1.5</td>
<td>1.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Medicina (Italy)</td>
<td>1.8</td>
<td>2.2</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VLBI sites contributing IVS sessions in Europe</th>
<th>DOGS CS &lt;OCCAM DGFI operational AC</th>
<th>Calc/Solve BKG operational AC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$v_{\text{north}}$, cm/year</td>
<td>$v_{\text{east}}$, cm/year</td>
</tr>
<tr>
<td>Wettzell (Germany)</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Nyales20 (Norway)</td>
<td>1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Onsala60 (Sweden)</td>
<td>1.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Medicina (Italy)</td>
<td>1.7</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Comparisons of velocities of IVS-AC (DGFI) and EUREF solutions (VLBI and GNSS)

<table>
<thead>
<tr>
<th>Co-located sites in Europe</th>
<th>IVS-DGFI</th>
<th></th>
<th>EUREF</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$V_{\text{north}}$ (~time span) (cm/year)</td>
<td>$V_{\text{east}}$ (cm/year)</td>
<td>$V_{\text{radial}}$ (cm/year)</td>
<td>$V_{\text{north}}$</td>
</tr>
<tr>
<td>Wettzell (Germany)-WTZR</td>
<td>1.5 (~26)</td>
<td>2.0</td>
<td>-0.1</td>
<td>1.7 (~14)</td>
</tr>
<tr>
<td>Onsala60 (Sweden)-ONSA</td>
<td>1.4 (~26)</td>
<td>1.7</td>
<td>0.2</td>
<td>1.6 (~14)</td>
</tr>
<tr>
<td>Matera (Italy)-MATE</td>
<td>1.8 (~19)</td>
<td>2.4</td>
<td>-0.1</td>
<td>2.0 (~14)</td>
</tr>
<tr>
<td>Zelenchukskaya (Russia)-ZECK</td>
<td>0.8 (~4)</td>
<td>2.5</td>
<td>0.4</td>
<td>1.3 (~13)</td>
</tr>
<tr>
<td>Medicina (Italy)-MEDI</td>
<td>1.7 (~22)</td>
<td>2.2</td>
<td>-0.3</td>
<td>2.1 (~14)</td>
</tr>
</tbody>
</table>
radial velocity vectors from EUREF solution.
Subsidence is red
uplift is black
radial velocity vectors from IVS-Europe sessions
VieVS solution (case2)
subsidence is red
uplift is black
global horizontal velocity vectors from EUREF solutions
global horizontal velocity vectors from IVS-Europe sessions
ViéVS solution (case2)
relative horizontal velocity vectors w.r.t. Europe plate (intra-plate motions)

$v_{\text{mean (east)}}: 2.1 \text{ cm/year}$
$v_{\text{mean (north)}}: 1.9 \text{ cm/year}$
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 Medicina

IVS BKG MEDICINA

Amplitude in mm

10 years  1 year  6 months

Frequency$^{-1}$ in years

IVS DGFI MEDICINA

Amplitude in mm

10 years  1 year  6 months

Frequency$^{-1}$ in years

EUREF MEDI

Amplitude in mm

10 years  1 year  6 months

Frequency$^{-1}$ in years

IVS GSFC MEDICINA

Amplitude in mm

10 years  1 year  6 months

Frequency$^{-1}$ in years
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
<table>
<thead>
<tr>
<th>antenna</th>
<th>solution</th>
<th>total epochs</th>
<th>time span (year)</th>
<th>Mean sampling interval (day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wettzell WTZR</td>
<td>DGFI</td>
<td>2406 736</td>
<td>26.09 14.12</td>
<td>3.96 weekly</td>
</tr>
<tr>
<td>Nyales20</td>
<td>DGFI</td>
<td>905</td>
<td>15.39</td>
<td>6.22</td>
</tr>
<tr>
<td>Svetloe SVTL</td>
<td>DGFI</td>
<td>292 690</td>
<td>6.69 13.68</td>
<td>8.39 weekly</td>
</tr>
<tr>
<td>Onsala60 ONSA</td>
<td>DGFI</td>
<td>531 737</td>
<td>26.07 14.12</td>
<td>17.96 weekly</td>
</tr>
<tr>
<td>Medicina MEDI</td>
<td>DGFI</td>
<td>318 726</td>
<td>22.22 14.12</td>
<td>25.60 weekly</td>
</tr>
<tr>
<td>Zelenchk ZECK</td>
<td>DGFI</td>
<td>204 610</td>
<td>4.18 12.80</td>
<td>7.51 weekly</td>
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<tr>
<td>Matera MATE</td>
<td>DGFI</td>
<td>602 735</td>
<td>19.18 14.12</td>
<td>11.65 weekly</td>
</tr>
<tr>
<td>Noto NOT1</td>
<td>DGFI</td>
<td>121 514</td>
<td>20.63 9.87</td>
<td>62.79 weekly</td>
</tr>
</tbody>
</table>
**Question:** $X(t_{0})^{\text{TRF}} \rightarrow ? \rightarrow X(t_{0})^{\text{TRF}}$

**Answer:**

$$X(t_{0})^{\text{TRF}} = X(t_{0})^{\text{TRF}} + T_{XY}^{\text{t}}(t_{1}) + (t_{0} - t_{1}) T_{rXY}^{\text{t}}(t_{1})$$

$$+ X(t_{0})^{\text{TRF}} \cdot [D_{XY}^{\text{t}}(t_{1}) + (t_{0} - t_{1}) D_{rXY}^{\text{t}}(t_{1})]$$

$$+ X(t_{0})^{\text{TRF}} \cdot [R_{XY}^{\text{t}}(t_{1}) + (t_{0} - t_{1}) R_{rXY}^{\text{t}}(t_{1})]$$

$T_{XY}^{\text{t}}(t_{1})$: Translation vector from TRFX to TRFY at epoch $t_{1}$.

$T_{rXY}^{\text{t}}(t_{1})$: Translation rates from TRFX to TRFY at epoch $t_{1}$.

$D$ and $R$ denote to scale factor and rotations.
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.
Co-located site Matera

I. VS BKG MATERA

Amplitude in mm

Frequency in years

-10 years - 1 year - 6 months

EUREF MATE

Amplitude in mm

Frequency in years

-10 years - 1 year - 6 months

IVS DGFI MATERA

Amplitude in mm

Frequency in years

-10 years - 1 year - 6 months

IVS GSFC MATERA

Amplitude in mm

Frequency in years

-10 years - 1 year - 6 months
Co-located site Zelenchukskava

IVS BKG ZELENCHK

Amplitude in mm

10 years  1 year  6 months

Frequency\(^{-1}\) in years

EUREF ZECK

Amplitude in mm

10 years  1 year  6 months

Frequency\(^{-1}\) in years

IVS DGFI ZELENCHK

Amplitude in mm

10 years  1 year  6 months

Frequency\(^{-1}\) in years

IVS GSFC ZELENCHK

Amplitude in mm

10 years  1 year  6 months

Frequency\(^{-1}\) in years
Co-located site Zelenchukskava

IVS BKG ZELENCHK

Amplitude in mm

10 years  1 year  6 months

Frequency\(^{-1}\) in years
EUREF ZECK

Amplitude in mm

10 years  1 year  6 months

Frequency\(^{-1}\) in years
IVS GSFC ZELENCHK
Co-located site Svetloe
Co-located site NOTO

I. VS BKG NOTO

II. VS DGFI NOTO

EUREF NOT1

IV. VS GSFC NOTO