# On possible alternatives for the realization of ETRS89 based on ITRF2014

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# Background for this presentation

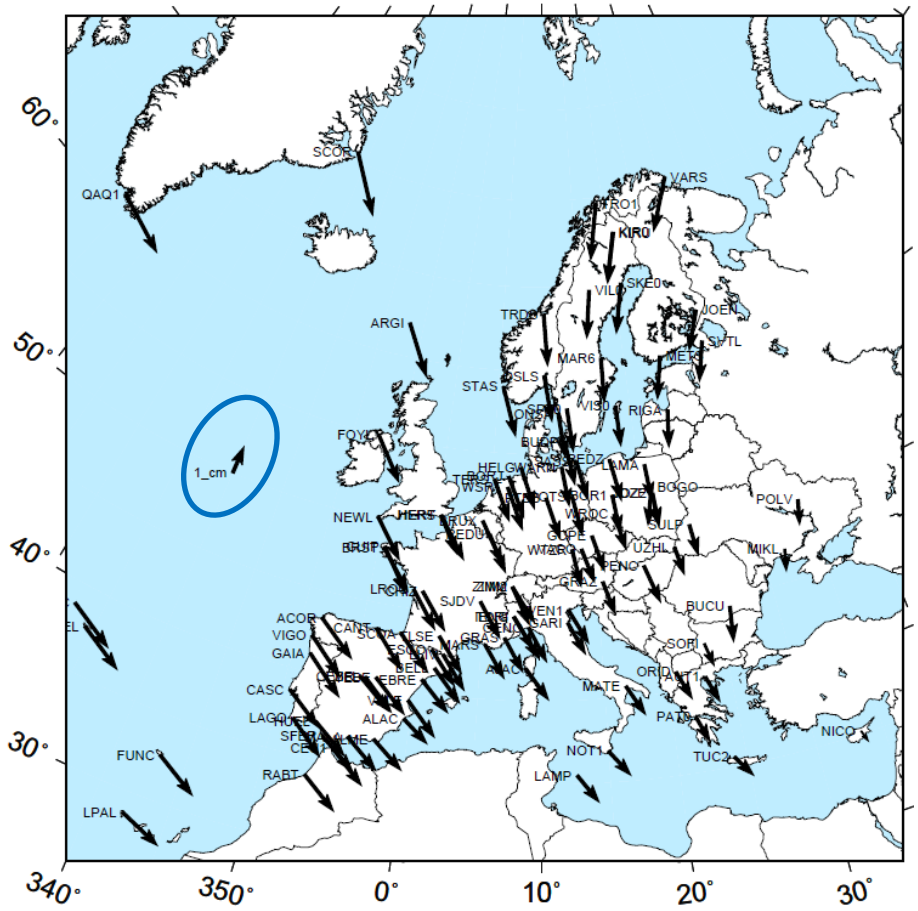
- It is assumed that it is beneficial to have good agreement at the co-ordinate level of realizations of ETRS89 based on different ETRFs
- Therefore: Would it be possible to slightly adjust an ETRF2014 in order to improve the agreement to realizations based on ETRF2000.
- It is assumed that current realizations of ETRF2000 are done from ~year 2000 up to now, so mid epoch ~2010.

- Some limitations in ETRF2000 are stressed (vertical velocities)
- And limitations in current procedure for ETRFs (vertical positions)

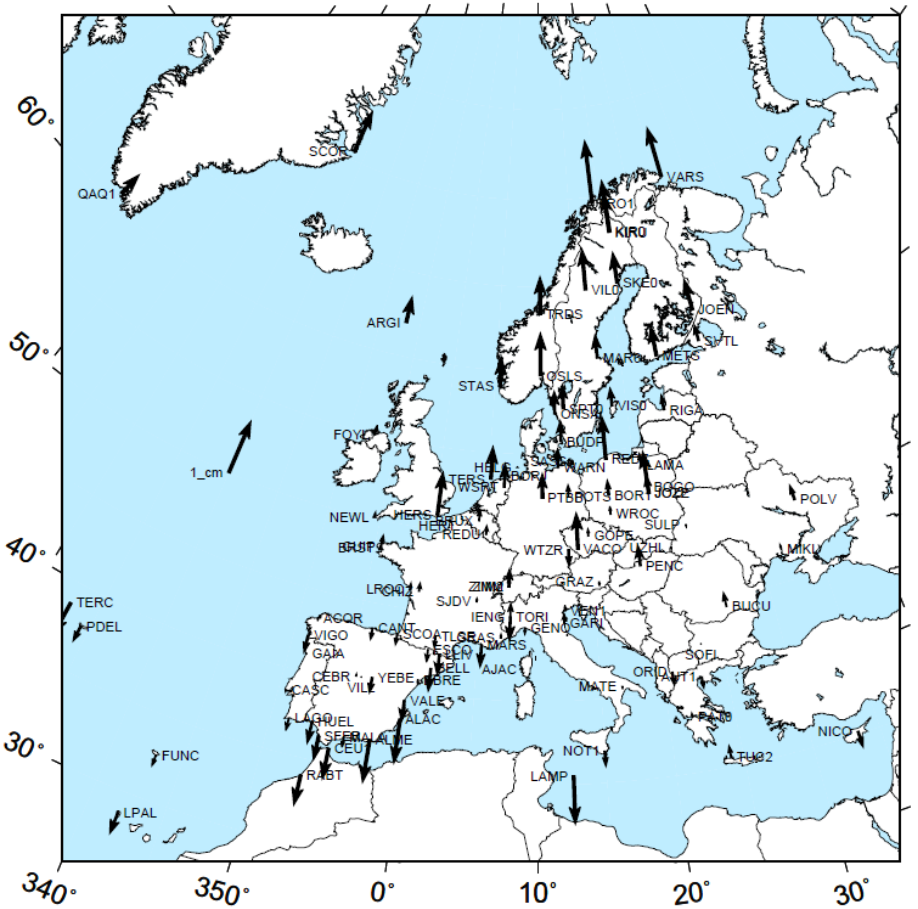
- Therefore some pragmatic alternatives are presented and discussed.

# Residual plots at epoch 2010 between:
# - The preliminary option ETRF2014(P) from ITRF2014
# - EPN_A_ETRF2000_C1920.SSC

## Horizontal




## Vertical




| Sites: 105 | dn (mm) | de (mm) | du (mm) |
|---|---|---|---|
| Mean | -12.3 | 6.0 | 0.9 |
| RMS | 12.7 | 8.4 | 4.1 |

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# Recapitulate ETRF2014P from presentation in San Sebastian (by Z Altamimi)

Transformation parameters at epoch 2010.0 and their rates from ITRF2014 to ETRF2014(P)

| | Tx<br>mm<br>mm/yr | Ty<br>mm<br>mm/yr | Tz<br>mm<br>mm/yr | D<br>ppb<br>ppb/yr | Rx<br>mas<br>mas/yr | Ry<br>mas<br>mas/yr | Rz<br>mas<br>mas/yr |
|---|---|---|---|---|---|---|---|
| **From ITRF2014 to ETRF2014P** | 55.3 | 53.1 | -52.7 | 0.0 | 1.785 | 11.151 | -16.170 |
| **Rates** | 0.0 | 0.0 | 0.0 | 0.0 | 0.085 | 0.531 | -0.770 |

Could be determined slightly different in order to minimize bias to current ETRF2000 (well, maybe not allowed if we strictly follow the ETRS89 definition, but if we test anyway?)

Determined by the plate motion model (slight update from San Sebastian.)

# A modified 3-parameter fit (translations) to determine TX, Ty, TZ

Fit between:

- ITRF2014 solution, internal epoch 2010, rotated to 1989.0 using the plate rotation parameters (basically this is ETRF2014-G)
- Transform to EPN_A_ETRF2000_C1920.SSC at internal epoch 2010
- Need to handle solution numbers, which are not coincident between EPN and the ITRF2014. Only one solution used for each station.

Results:

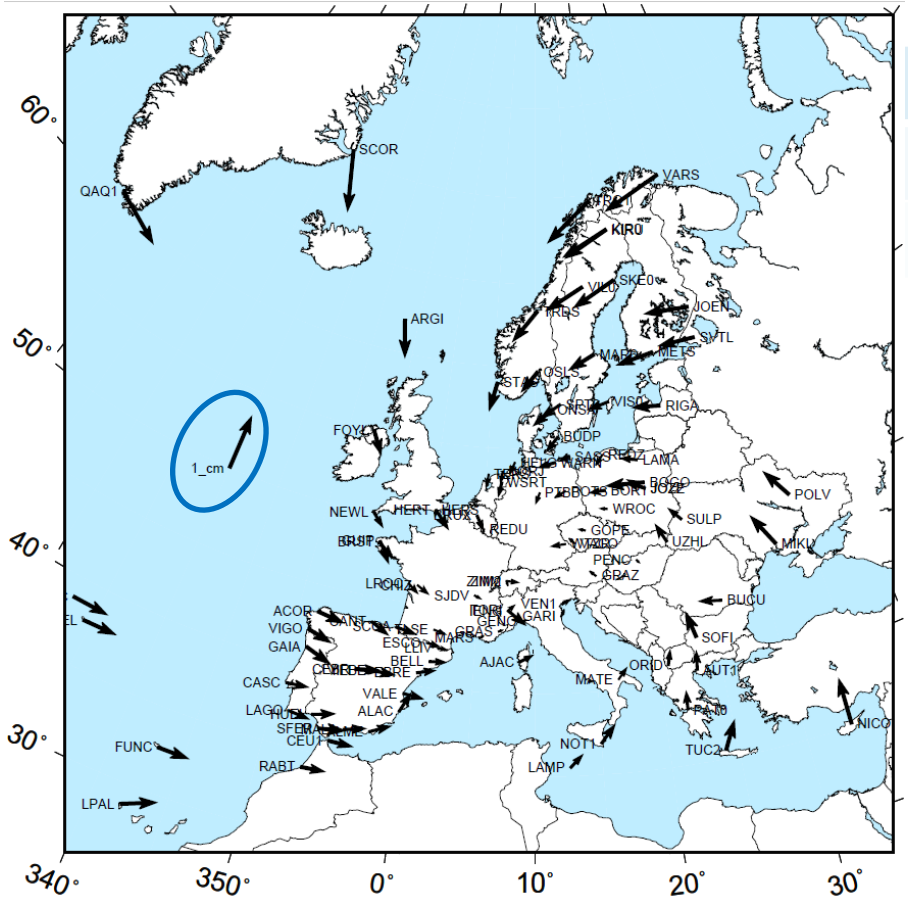
Uncertainty of a single observation

```
# Number of common sites : 105
#
# TX =     45.75 +/-  0.54  ,  s0X :   5.53 (mm)
# TY =     45.61 +/-  0.34  ,  s0Y :   3.50 (mm)
# TZ =    -45.87 +/-  0.34  ,  s0Z :  3.52 (mm)
```

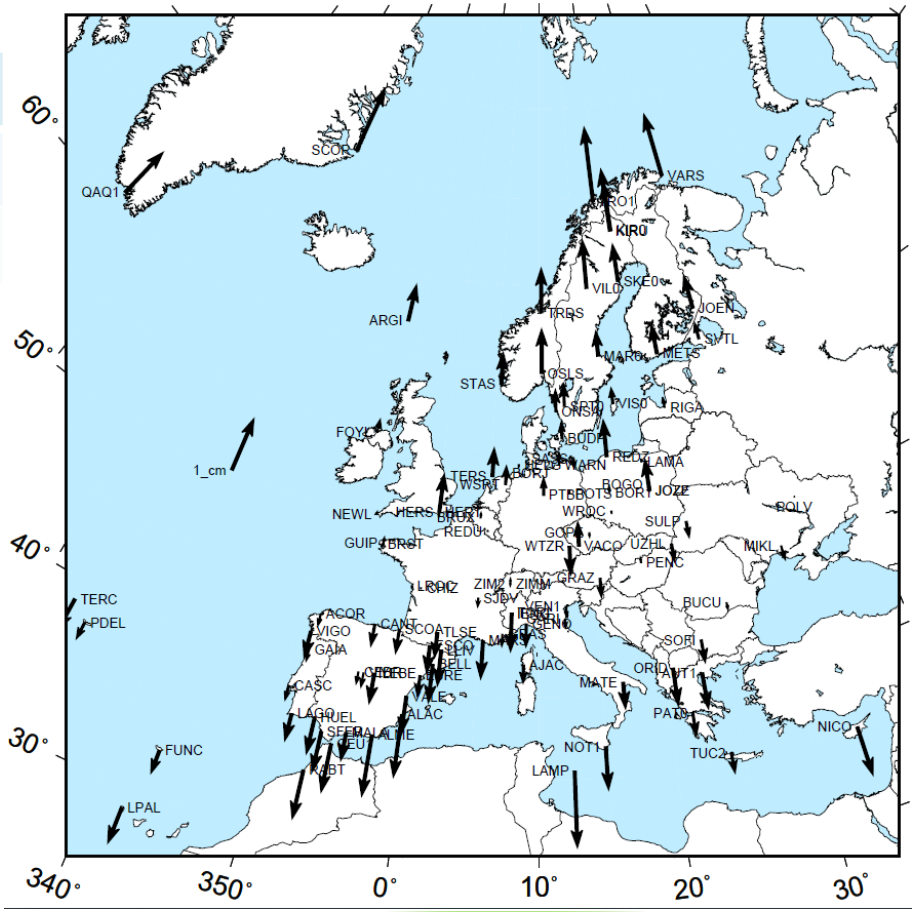
Rejected as outliers: DYNG, ISTA, KARL, MALL, MDVJ, REYK, UNPG

# Residual plots at epoch 2010 between:
# - ITRF2014 transformed to the modified ETRF2014M
# - EPN_A_ETRF2000_C1920.SSC

## Horizontal




## Vertical




| Sites: 105 | dn (mm) | de (mm) | du (mm) |
|---|---|---|---|
| Mean | -0.3 | 0.2 | -0.8 |
| RMS | 2.9 | 3.8 | 5.6 |

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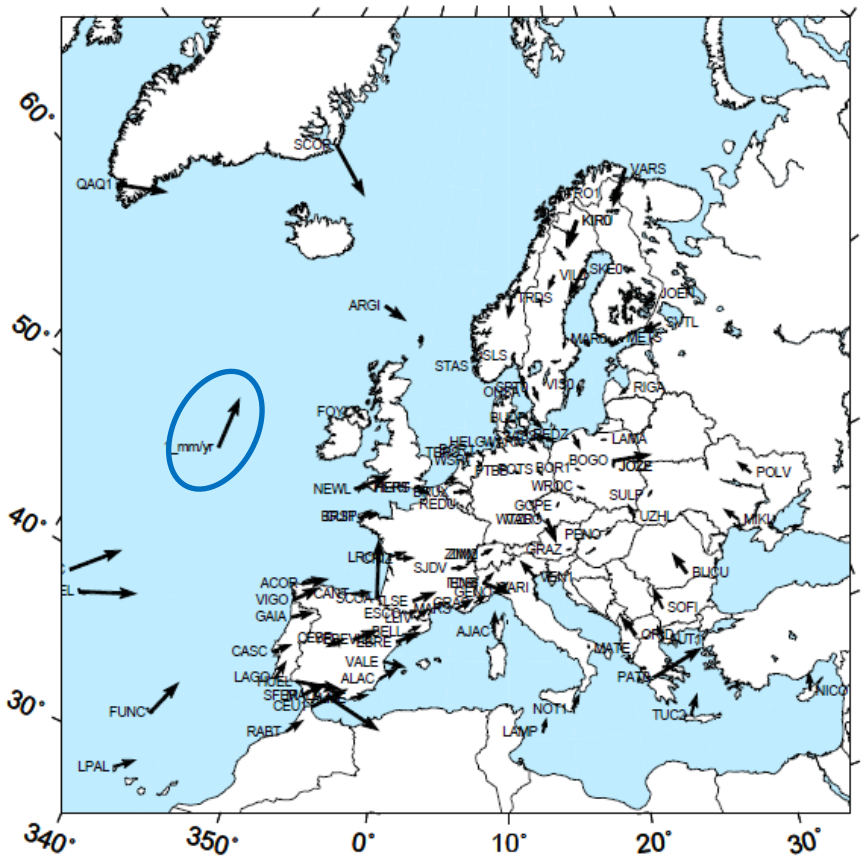
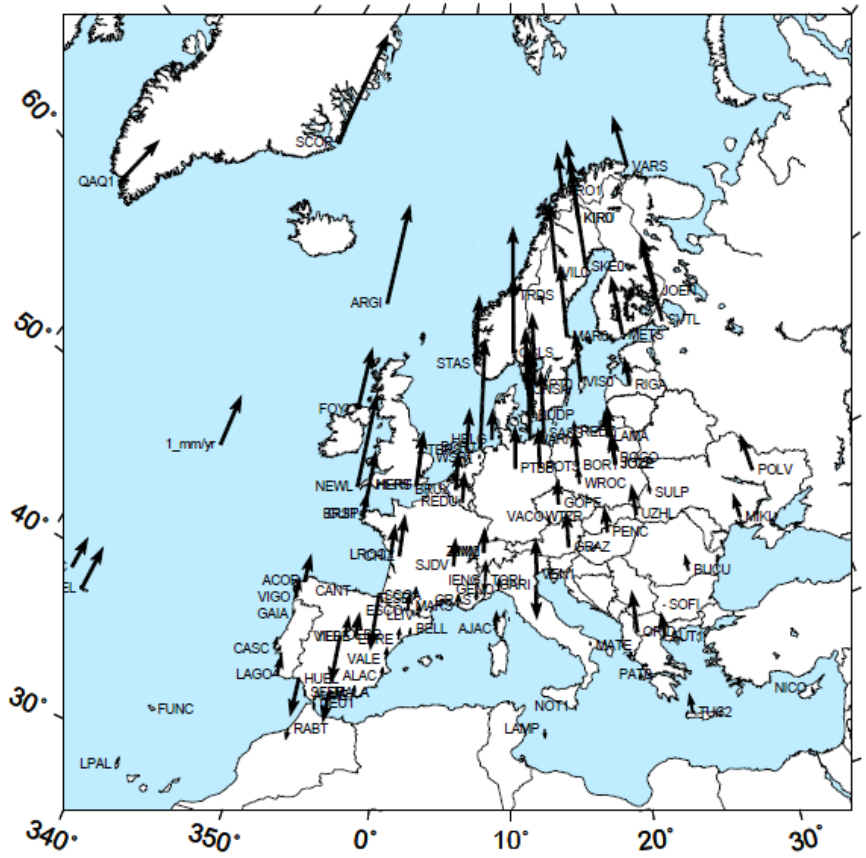
# Velocity differences between ITRF2014 rotated to Eurasia and EPN_A_ETRF2000_C1920.SSC

(Difference in vertical velocity is a sincere problem with ETRF2000)

Horizontal




Vertical




| Sites: 105 | dvn (mm/yr) | dve (mm/yr) | dvu (mm/yr) |
|---|---|---|---|
| Mean | 0.07 | 0.16 | 0.55 |
| RMS | 0.29 | 0.33 | 0.83 |

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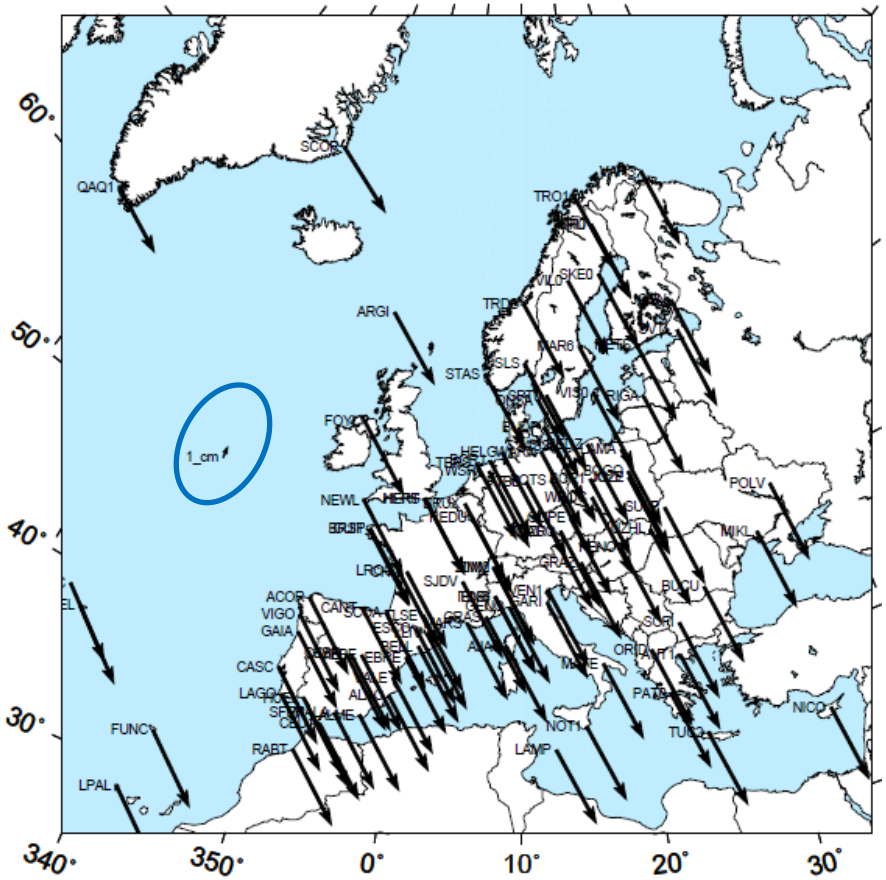
# Some considerations

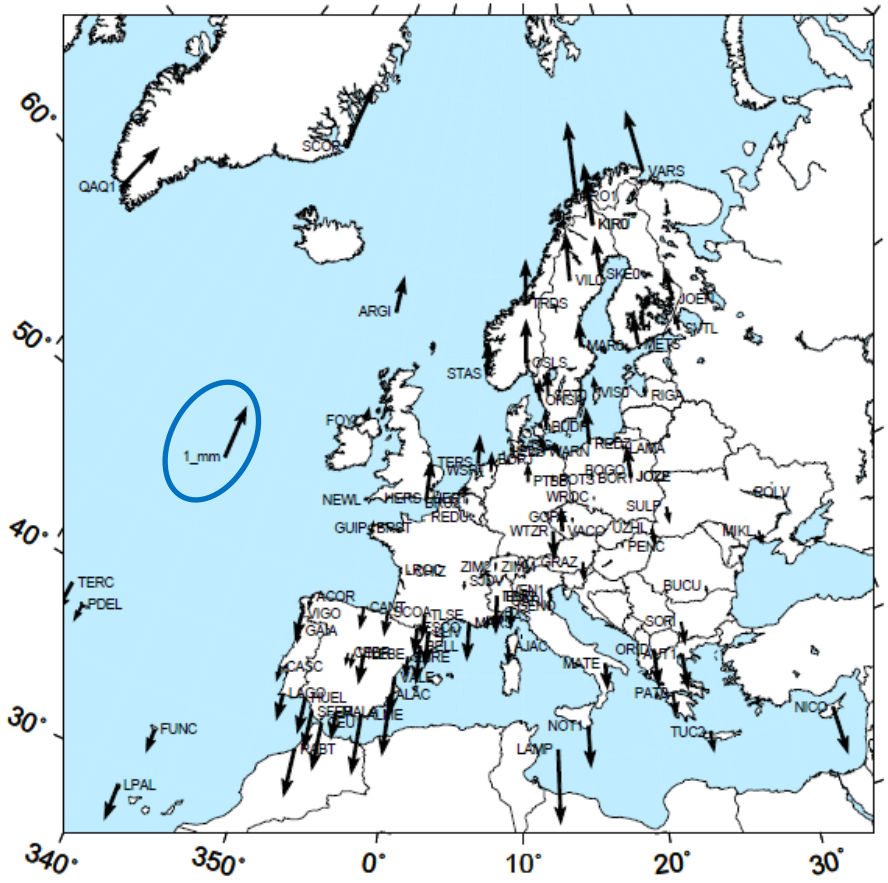
- We (EUREF) have promoted the adoption and use of ETRF2000 since the release of ITRF2000 (Memo no 5, 12-04-2001)
- A "pragmatic ETRF2014" is derived and compared to official ETRF2000 from EPN. It agrees well (small bias and RMS at 5 mm level) for the time period when ETRF2000 have been in use
  - For central Europe the agreement is even better
- When we introduce an ETRF2014 with minor bias to ETRF2000, we show that consecutive ETRFs agree well and that our realizations are stable.
- Since ITRFs seems very mature, also future ETRFs will agree very well after the introduction of ETRF2014 (argument for not keeping ETRF2000).

# Position differences between ITRF2014 (rotated to 1989.0 using the plate rotation for Eurasia) and the modified option for ETRF2014M at epoch 2010.0

## Horizontal




## Vertical




| Sites: 105 | dn (mm) | de (mm) | du (mm) |
|---|---|---|---|
| Mean | -67 | 37 | -0.8 |
| RMS | 8.1 | 12.3 | 11.3 |

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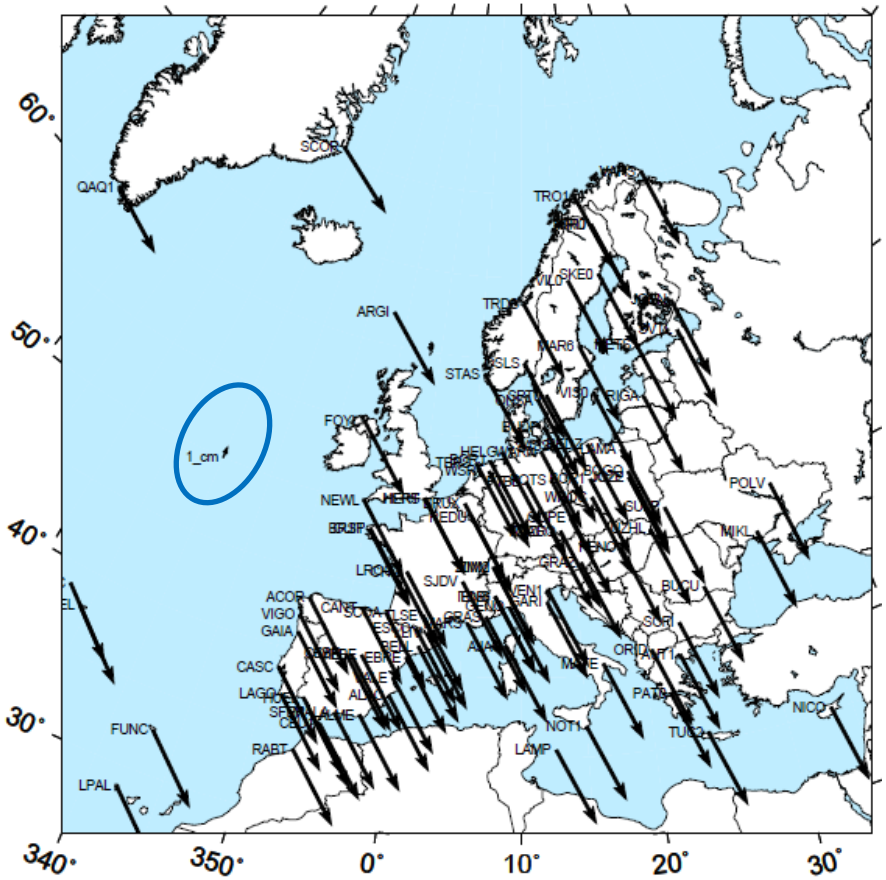
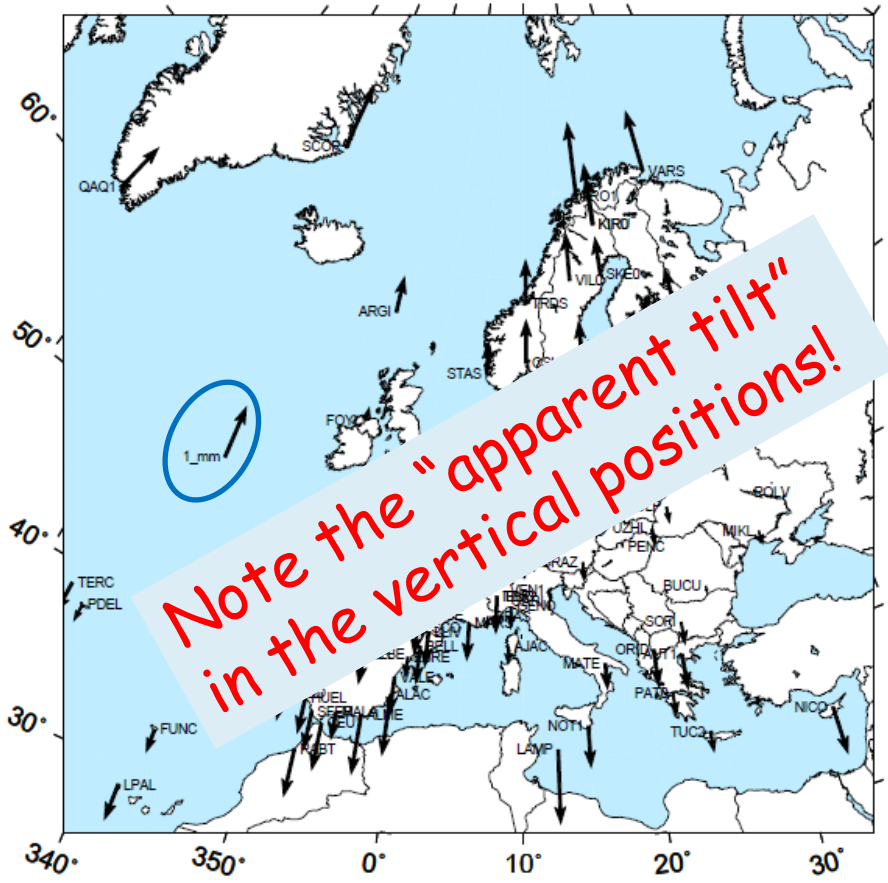
# Position differences between ITRF2014 (rotated to 1989.0 using the plate rotation for Eurasia) and the modified option for ETRF2014M at epoch 2010.0

## Horizontal




## Vertical




| Sites: 105 | dn (mm) | de (mm) | du (mm) |
|---|---|---|---|
| Mean | -67 | 37 | -0.8 |
| RMS | 8.1 | 12.3 | 11.3 |

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# Limitations in proposed alternatives for ETRF2014 and possible other options?

- ETRF2000:
  - \+ Fulfil the requirement of small changes at the coordinate level
  - – Differences in vertical velocity compared to ITRF
  - – Show an "apparent tilt" in vertical position compared to ITRFs
- ETRF2014 (Preliminary version, and Modified translation option)
  - \+ Identical vertical velocity as ITRF2014
  - – Show an "apparent tilt" in vertical position compared to ITRF2014
- ETRF2014G (geocentric option)
  - \+ Identical vertical velocity as ITRF2014
  - \+ Identical vertical position compared to ITRF2014
  - – But very large (7 cm level) changes in coordinates to ETRF2000

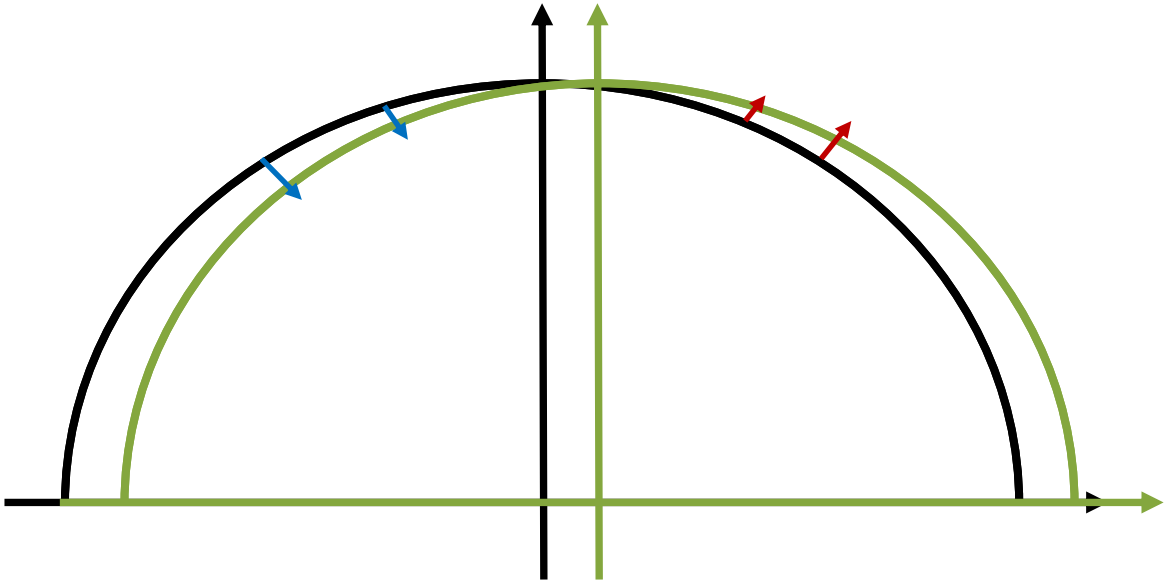
➢An alternative version of ETRF2014G with minor coordinate changes to ETRF2000 would be beneficial!

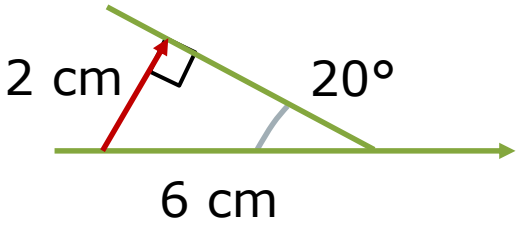
# On ETRS89 and its realizations in the perspective of geoid models and IHRS

(International Height Reference System)

- The "apparent tilt" in ETRF2000 and ETRF2014P,M compared to ITRFxx is annoying in the perspective of geoid modelling over large areas. E.g. while comparing the geoid model to "GPS-levelling", (i.e. ETRS89-EVRS and its realizations)
  - Should we use GNSS vertical positions in ETRFxx or in ITRFxx together with EVRS for geoid work in Europe?
- This issue may be even more pronounced in the near future in the perspective on the IHRS and its realizations, where the relation between our realizations of EVRS and the future IHRF will be determined using GNSS and global geopotential modes (including local gravity etc)
- Therefore, identical vertical positions in ETRFs and ITRFs would be beneficial.
  - And consecutive ITRFs seems to be mature and stable in this respect

# The translation in the transformation from ITRF to ETRF cause an apparent ”tilt” in the vertical





# Transformation formula from ITRF to ETRF
## (Boucher&Altamimi Memo v8, chapter 3)

$$X^E(t_c) = X^I_{YY}(t_c) + T_{yy} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times X^I_{YY}(t_c) \cdot (t_c - 1989.0)$$

- The rotation rates are used to compute the rotations of the Eurasian plate between two epochs, epoch of observation, tc, and 1989.0, when the system ETRS89 was fixed to the Eurasian plate.
- Applying these rotations means that the axes are rotated back to their estimated directions at 1989.0
- The knowledge about the rotation of the Eurasian plate has been improved during the years, therefore the used values have also changed
- The translation vector accounts for the difference between the origin of ITRFyy and the origin of ITRF89
- This translation vector is a computational effect due to different stations, observations, techniques, models, etc. between the different realizations of ITRS

# We explore an alternative to estimate translations to minimize bias to ETRF2000 - and apply a static Euler pole rotation

$$X^E(t_c) = X^I_{YY}(t_c) + T_{yy} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times X^I_{YY}(t_c) \cdot (t_c - 1989.0)$$

# We explore an alternative to estimate translations to minimize bias to ETRF2000 - and apply a static Euler pole rotation

$$X^E(t_c) = X^I_{YY}(t_c) + \cancel{T_{YY}} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times X^I_{YY}(t_c) \cdot (t_c - 1989.0)$$

# We explore an alternative to estimate translations to minimize bias to ETRF2000 - and apply a static Euler pole rotation

$$X^E(t_c) = X^I_{YY}(t_c) + \cancel{T_{YY}} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times X^I_{YY}(t_c) \cdot (t_c - 1989.0)$$

$$X^E(t_c) = X^I_{YY}(t_c) + \boxed{R_{E14} \times X^I_{YY}(t_c)} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times X^I_{YY}(t_c) \cdot (t_c - 1989.0)$$

Where: $R_{E14} \times X^I_{YY}(t_c) = \begin{pmatrix} 0 & -R3_{E14} & R2_{E14} \\ R3_{E14} & 0 & -R1_{E14} \\ -R2_{E14} & R1_{E14} & 0 \end{pmatrix} \times X^I_{YY}(t_c)$

- The static rotation only effects the horizontal positions and leave the vertical position unchanged.

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# We explore an alternative to estimate translations to minimize bias to ETRF2000 - and apply a static Euler pole rotation

$$X^E(t_c) = X^I_{YY}(t_c) + \cancel{T_{YY}} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times X^I_{YY}(t_c) \cdot (t_c - 1989.0)$$

$$X^E(t_c) = X^I_{YY}(t_c) + R_{E14} \times X^I_{YY}(t_c) + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times X^I_{YY}(t_c) \cdot (t_c - 1989.0)$$

Where: $R_{E14} \times X^I_{YY}(t_c) = \begin{pmatrix} 0 & -R3_{E14} & R2_{E14} \\ R3_{E14} & 0 & -R1_{E14} \\ -R2_{E14} & R1_{E14} & 0 \end{pmatrix} \times X^I_{YY}(t_c)$

- The static rotation only effects the horizontal positions and leave the vertical position unchanged.
- To derive ETRF2014 this way is different in practice, but no change principles – we just adapt the new ETRF to previous conventional frame in order to minimize the changes at the coordinate level.

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# Testing the static Euler pole for ETRF2014E
# Resolving the rotation parameters

Fit between:

- ITRF2014 solution, internal epoch 2010, rotated to 1989.0 using the plate rotation parameters (basically this is ETRF2014G)
- EPN_A_ETRF2000_C1920.SSC at internal epoch 2010

Results:

```
# Number of common sites : 105
# RX =  -1.5041 mas ,    sRX =   0.0387 mas  (~1 mm)
# RY =   2.0317 mas ,    sRY =   0.0142 mas  (~½mm)
# RX =   0.5508 mas ,    sRZ =   0.0440 mas  (~1 mm)
# Statistics of residuals for the common points:
# m_dn =  0.57 mm , RMS_dn =   4.1 mm
# m_de = -0.22 mm , RMS_de =   4.1 mm
# m_du = -0.03 mm , RMS_du =  16.1 mm
```

Uncertainty in transformation parameters

Uncertainty of a single observation

Bias in vertical positions between ITRF2014 and ETRF2000 is ~zero!

Due to the apparent tilt

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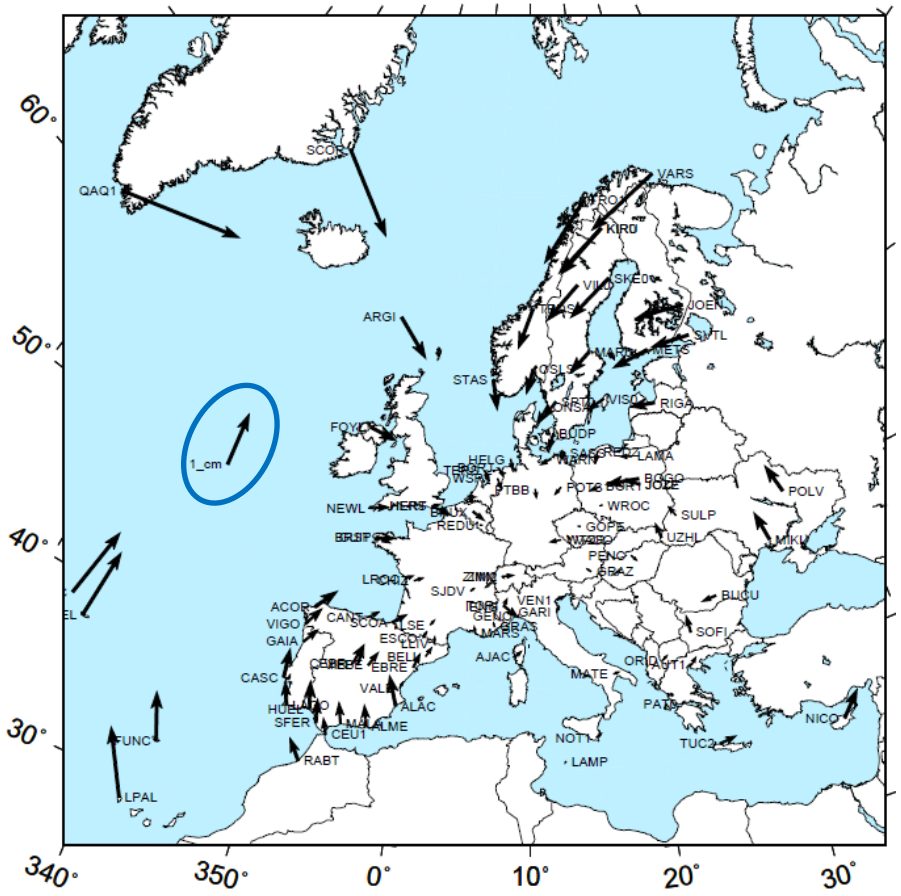
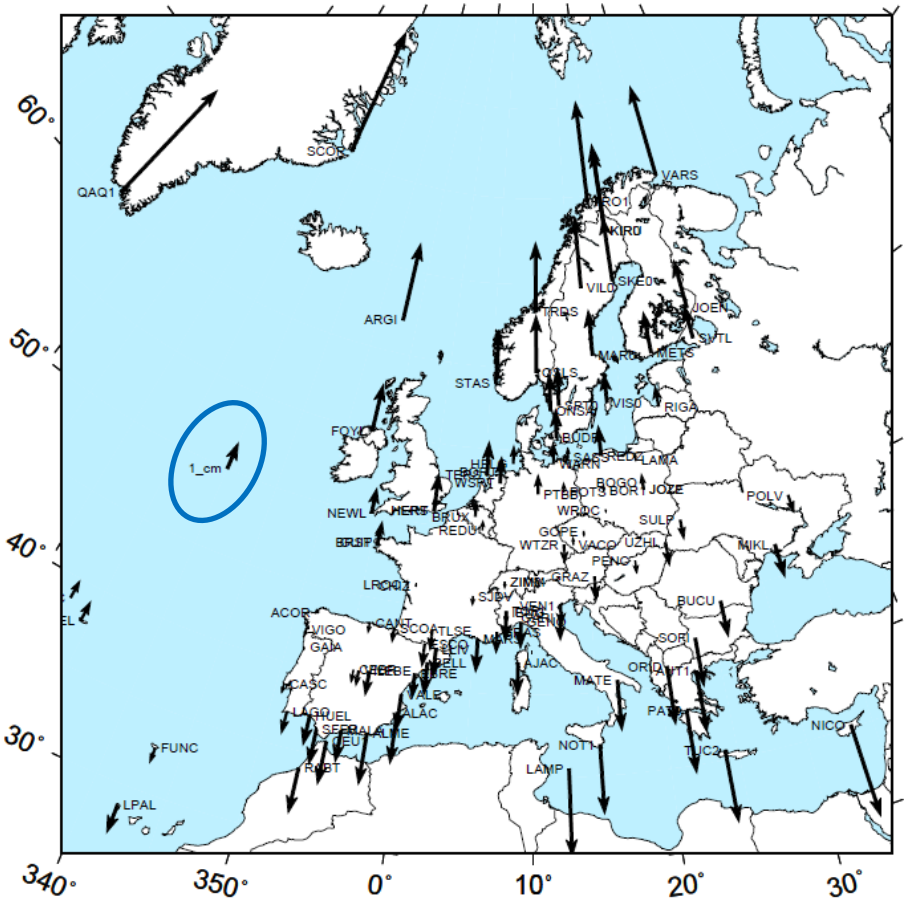
# Residual plots at epoch 2010 between:
# - ITRF2014 transformed to the rotation option ETRF2014E
# - EPN_A_ETRF2000_C1920.SSC

## Horizontal




## Vertical




| Sites: 105 | dn (mm) | de (mm) | du (mm) |
|---|---|---|---|
| Mean | 0.6 | -0.2 | 0.0 |
| RMS | 4.1 | 4.1 | 16.1 |

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# Summary of options for the realization of ETRS89 from ITRF2014

- ETRF2000:
  - \+ Fulfil the requirement of small changes at the coordinate level
  - – Differences in vertical velocity compared to ITRF
  - – Show an "apparent tilt" in vertical position compared to ITRFs
- ETRF2014 (Preliminary version, and Modified translation option)
  - \+ Identical vertical velocity as ITRF2014
  - – ETRF2014P show ~2 cm bias to ETRF2000
  - – Show an "apparent tilt" in vertical position compared to ITRF2014
- ETRF2014G (geocentric version)
  - \+ Identical vertical velocity as ITRF2014
  - \+ Identical vertical position compared to ITRF2014
  - – But very large (7 cm level) changes in coordinates to ETRF2000
- ETRF2014E (Euler pole option)
  - \+ Identical vertical velocity as ITRF2014
  - \+ Identical vertical position compared to ITRF2014
  - \+ Horizontal positions agree reasonable well to ETRF2000
  - – But introduce rotations