GEO-KINEMATICS OF CENTRAL AND SUUTH-EAST EUROPE RESULTING FROM COMBINATION OF VARIOUS REGIONAL GPS VELOCITY FIELDS

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Motivation

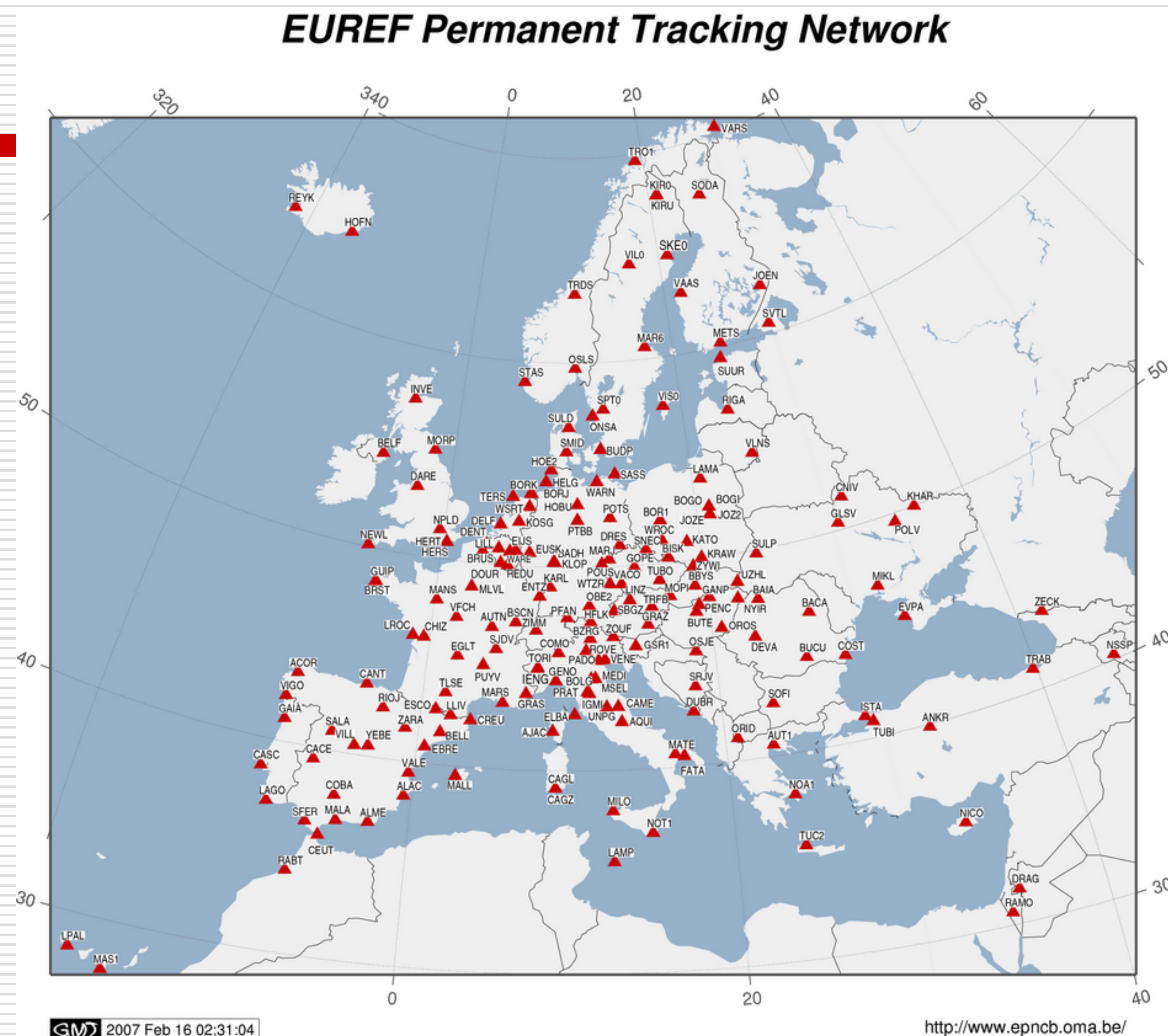
- Countries in Central Europe and Balkan Peninsula are covered by several regional and national permanent and/or epoch GPS networks related to geokinematical investigations.
- The history, purpose, observing schedule, instrumentation, etc. of these networks are variable, dependent on scientific intents, methodology, financial ability, etc.
- These networks are processed and analyzed completely independently and are yielding to regional or local velocity fields
- Simple combination of various individual velocity fields into unique system is not straightforward because of different realizations of reference frames, different sets of reference sites, different epochs and various accuracy and quality of the input data.

Content

- Examples of velocity fields from permanent and epoch GPS network in Central and south-east Europe suitable for combination
- Method applied for combination of velocities into unique velocity field
- Information about individual velocity fields resulting from combination procedure
- Horizontal velocities for Central and south-east Europe and the geokinematical implications

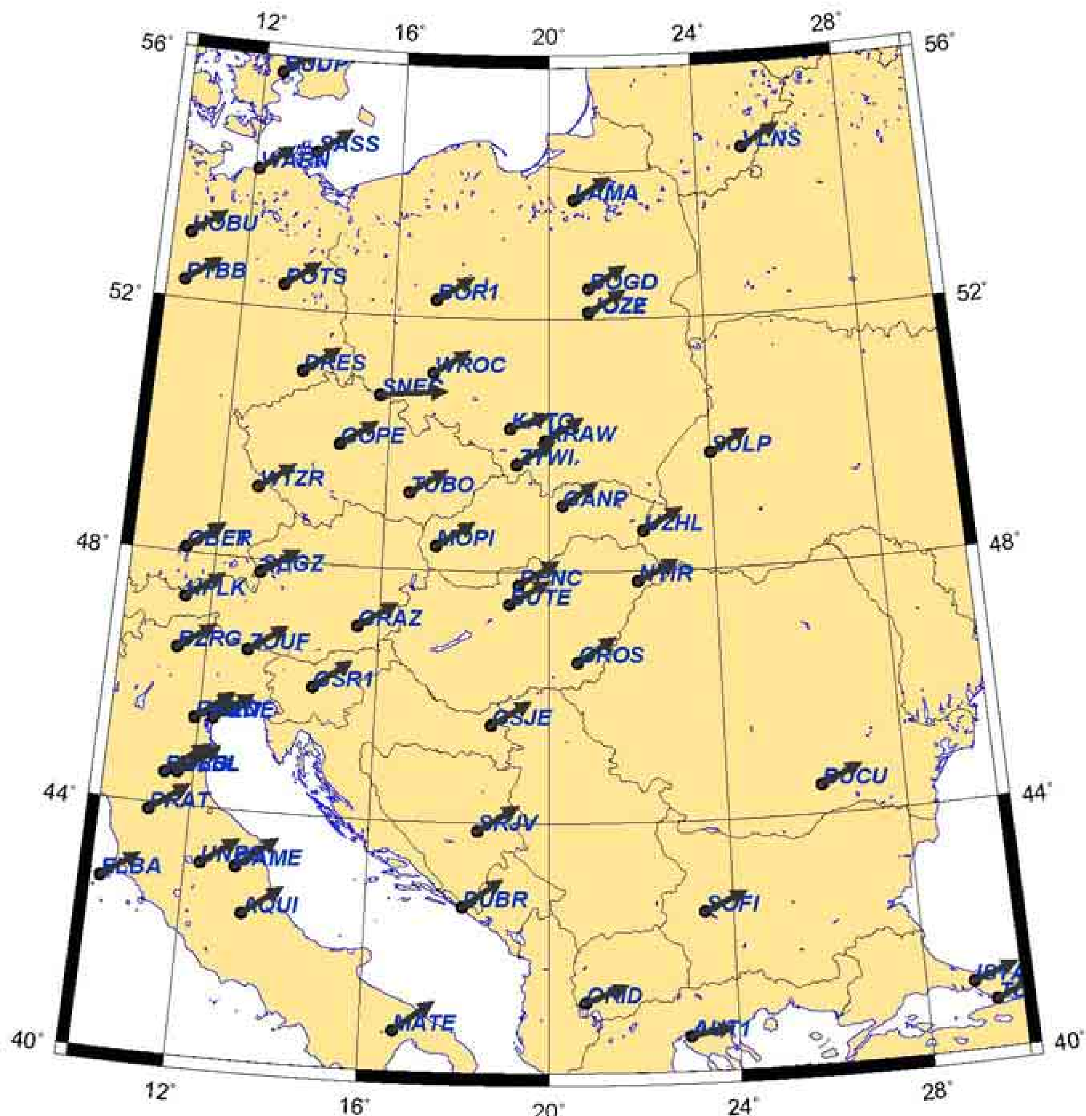
EUREF Permanent Network

- ❑Basis for definition of velocity filed in our area of interest
- ❑Observations since 1996, in 2007 nearly 200 sites
- ❑Available velocities from 1-11 years of permanent GPS tracking
- ❑Velocities related to ITRF2000, epoch 1997



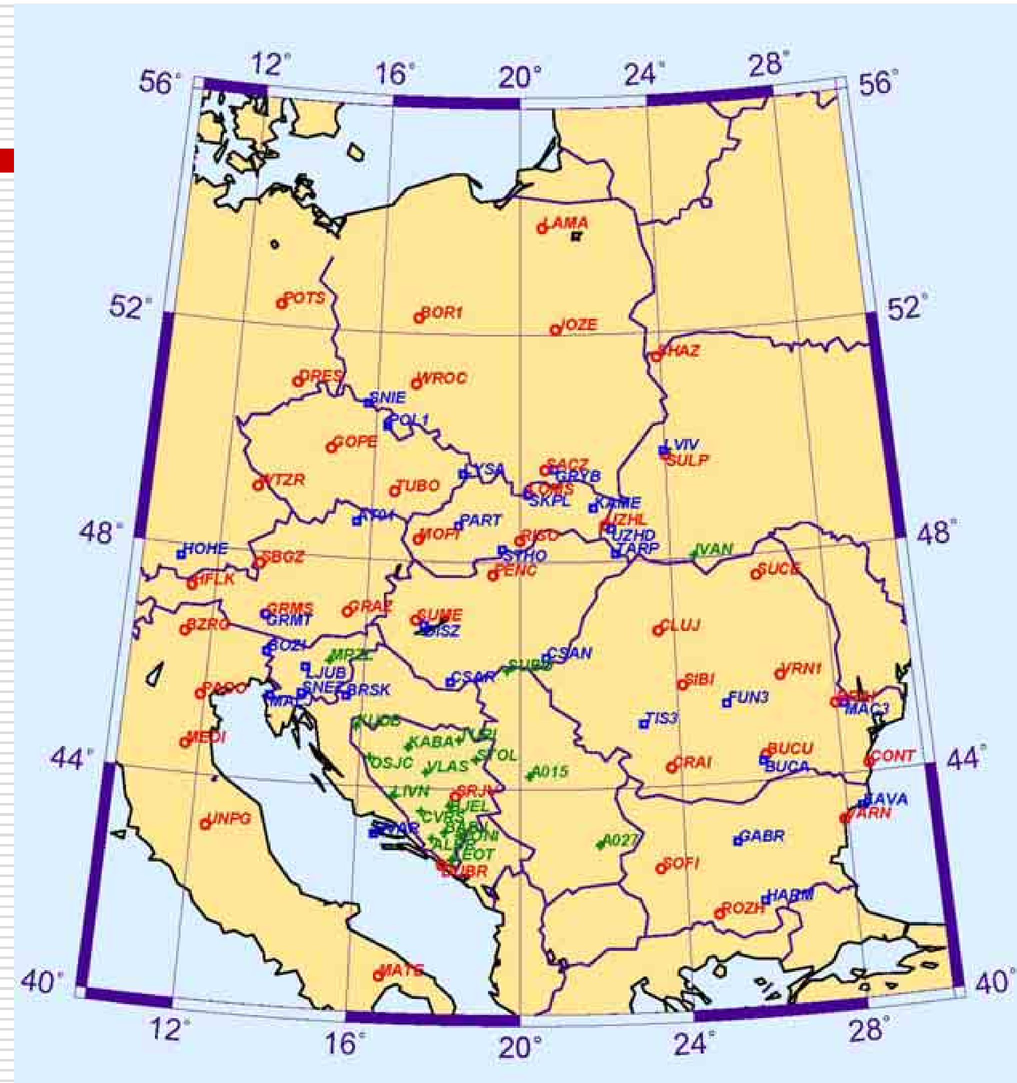
EUREF Permanent Network velocity field

- There are about 45 EPN stations in the region with relevant velocities available
- Their distribution is non-regular and large gaps are in Balkan region
- Unreliable estimates of uncertainties of velocities (about 0.01 mm/year)



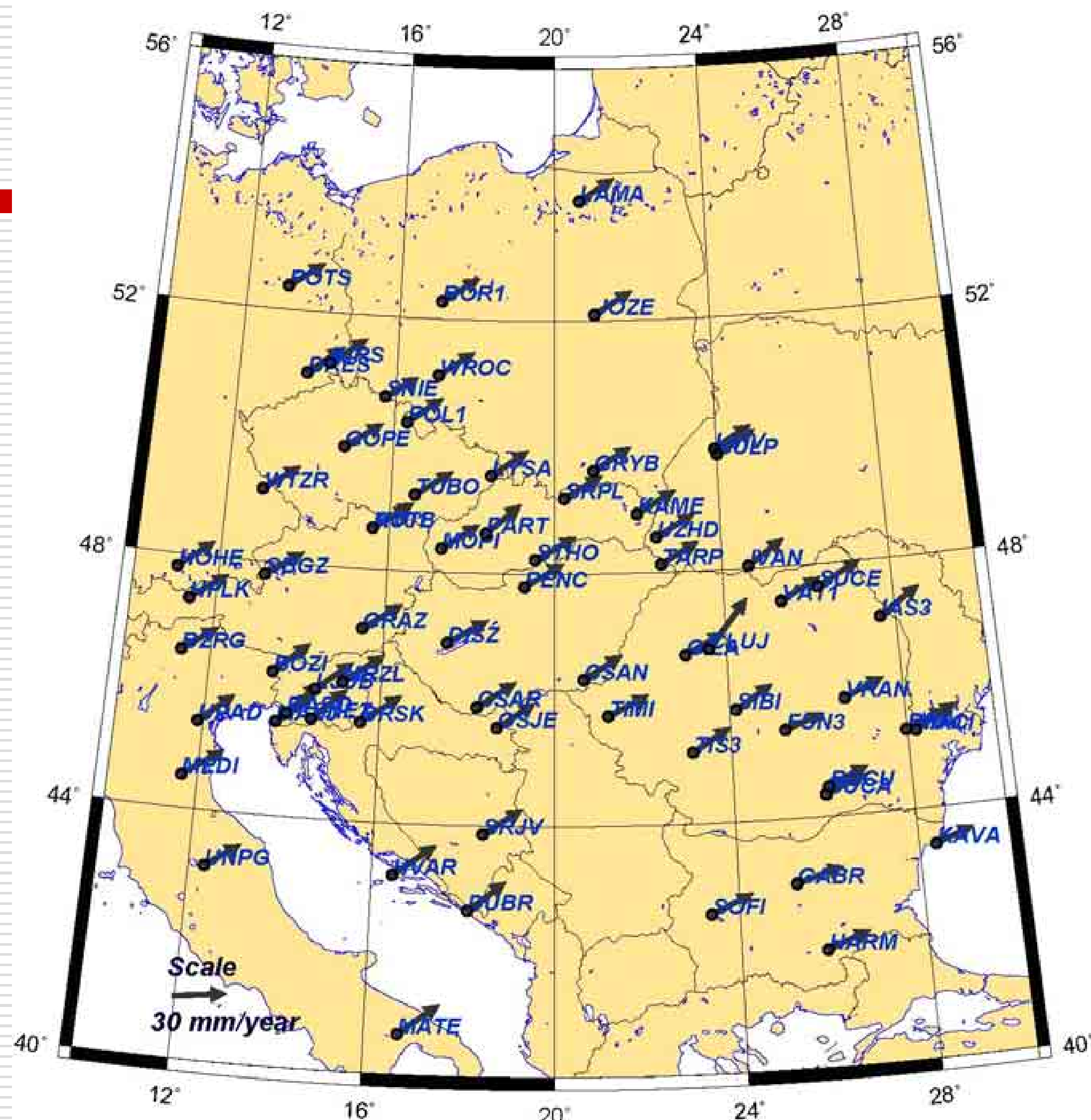
CEGRN Epoch Network

- Epoch network observed since 1994
- Status in 2005 – 90 stations
- Permanent stations (mostly EPN)
- Epoch stations
- New ‘candidate’ stations



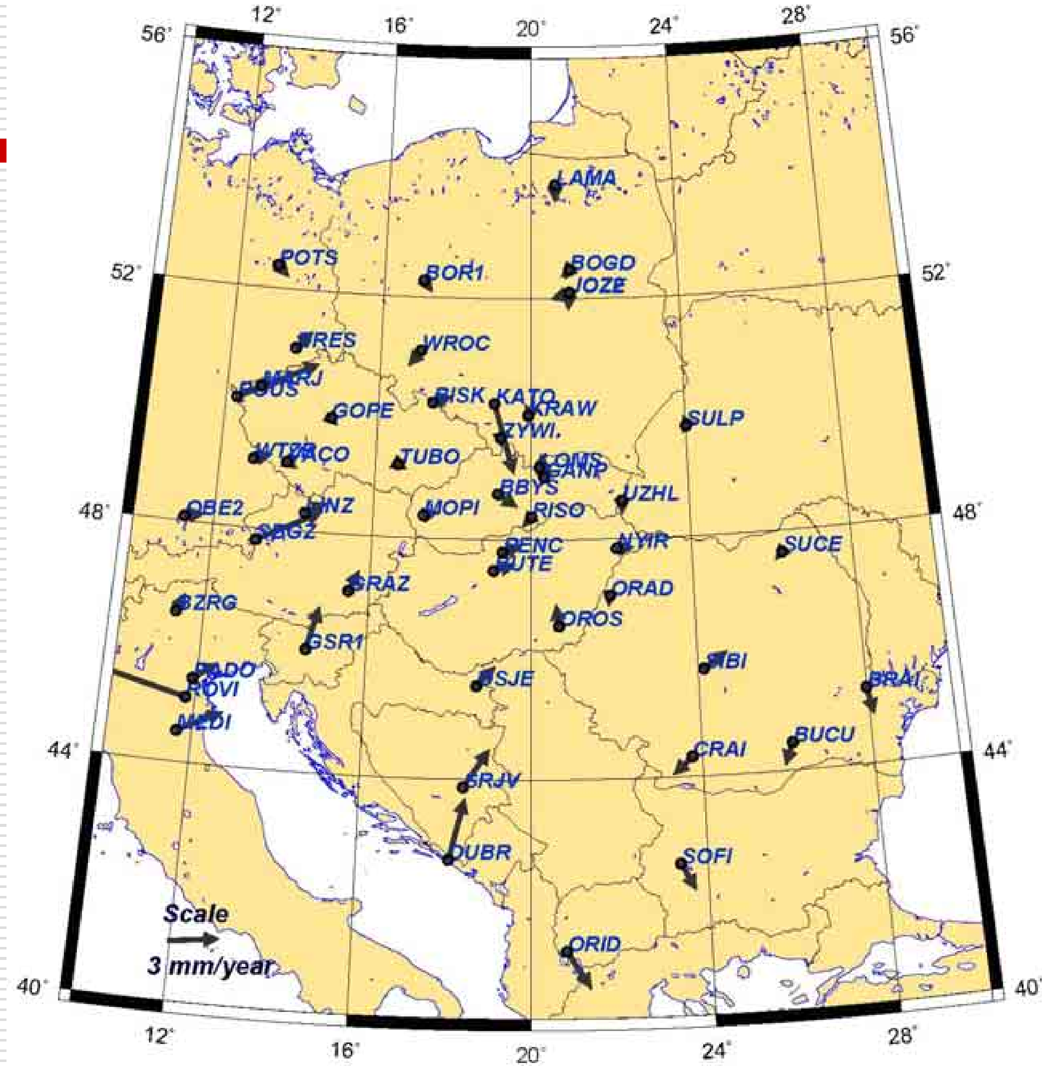
CEGRN epoch network velocity field

- Velocities based on 2-12 year span of observations
- Available are velocities for 60 stations with full covariance matrix
- Velocities are referred to ITFR2000, epoch 1997.0



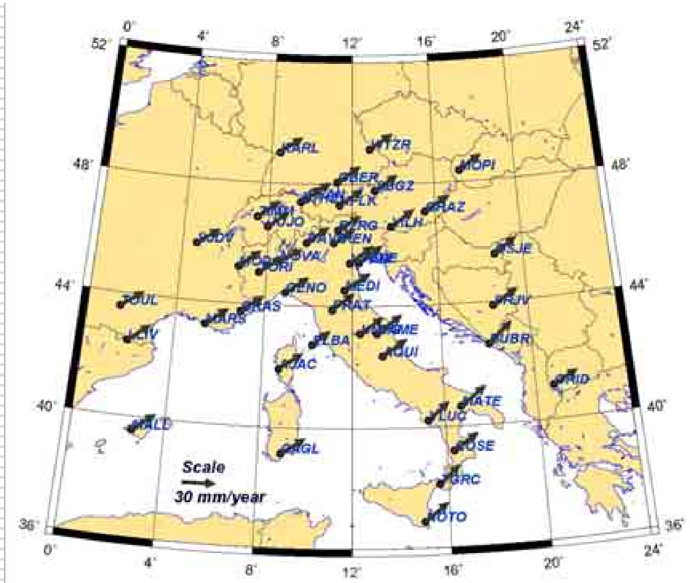
Network of permanent stations in Central Europe and Balkan Peninsula

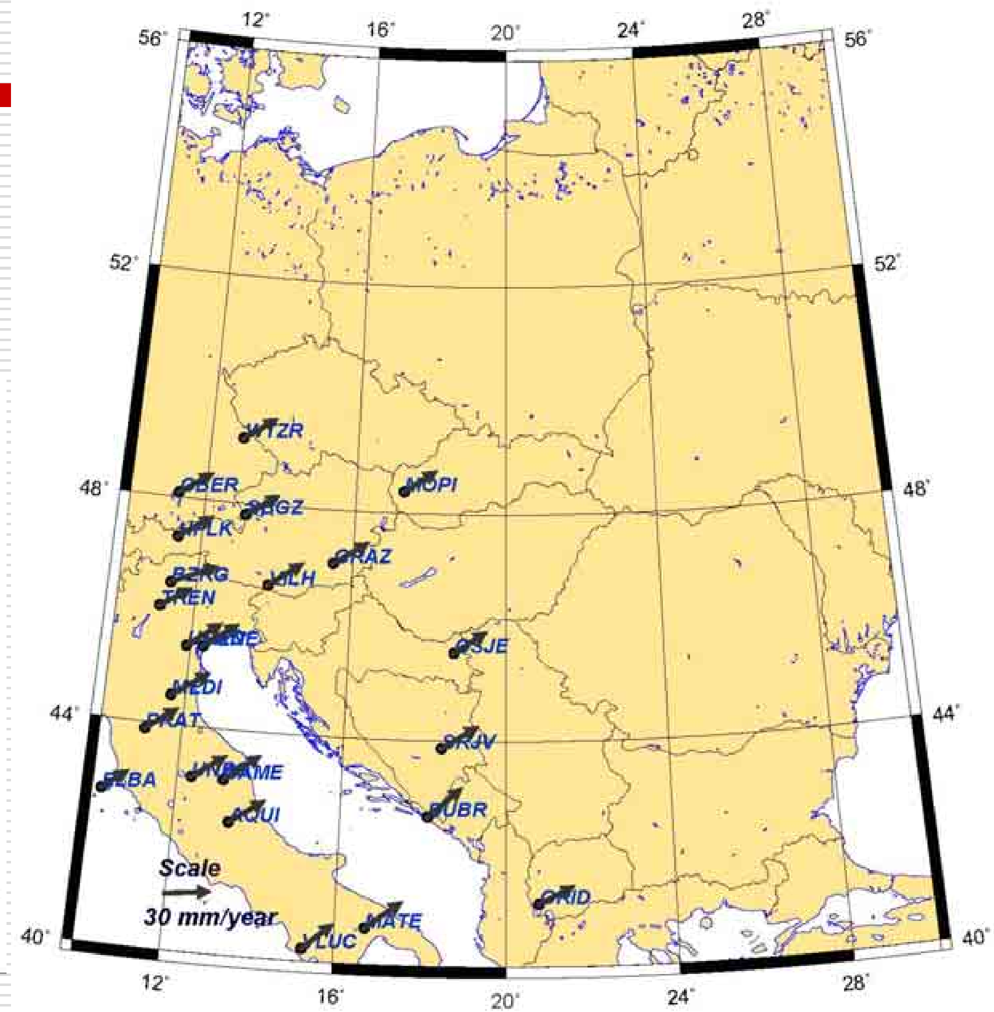
- EPN stations in region and 10 non-EPN permanent stations
- Velocities based on 1-4 year span of observations
- Analysis procedure results in relative velocity field with global EURA motion removed (intraplate velocities)



Network of permanent stations in Italy and close regions

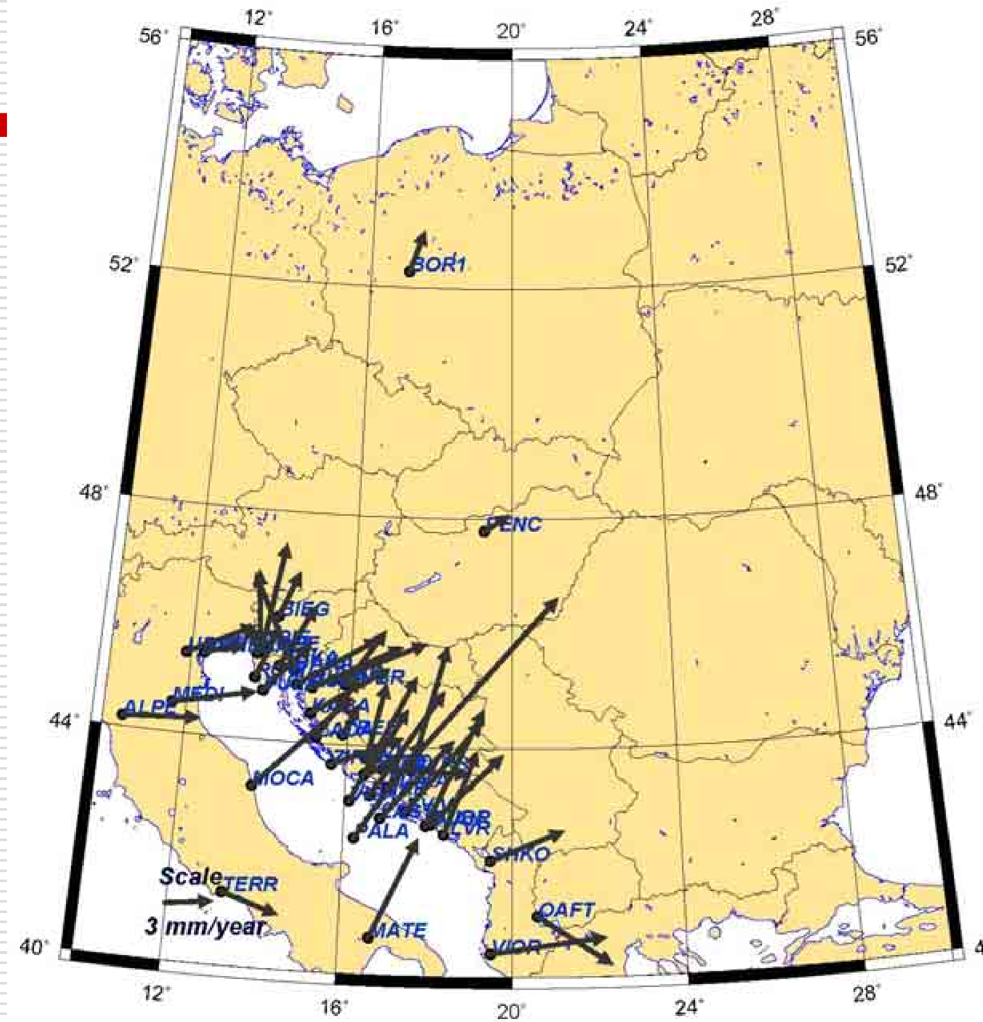
- Up to 50 permanent EPN and non-EPN stations used for geodynamic investigation of Apennine region (Caporali et al.)





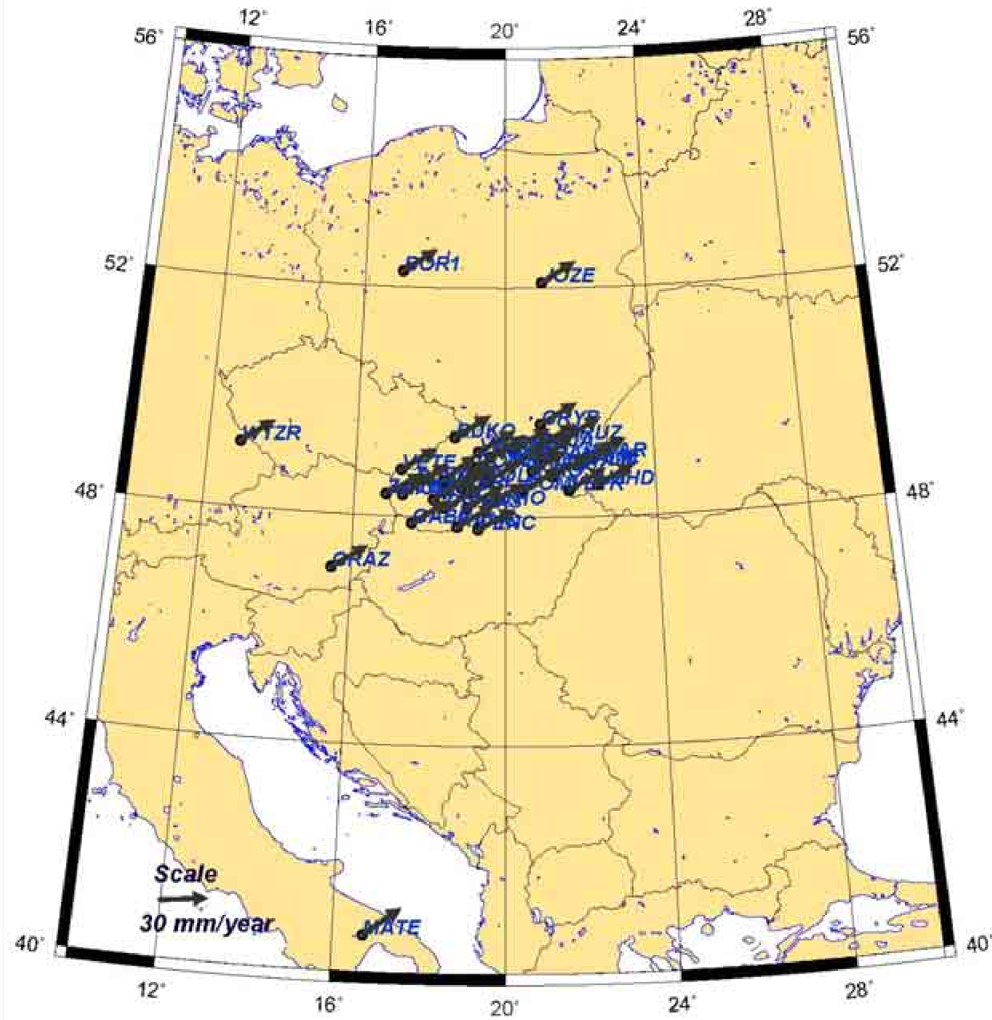
Epoch network in Adria region

- Velocities based on observations from 2 – 3 epochs within the project CRODYN (1994, 1996 and 1998) , Altiner et al.
- Velocities are related to ITRF96 and subequently reduced for motion of EURA
- Only formal accuracies available



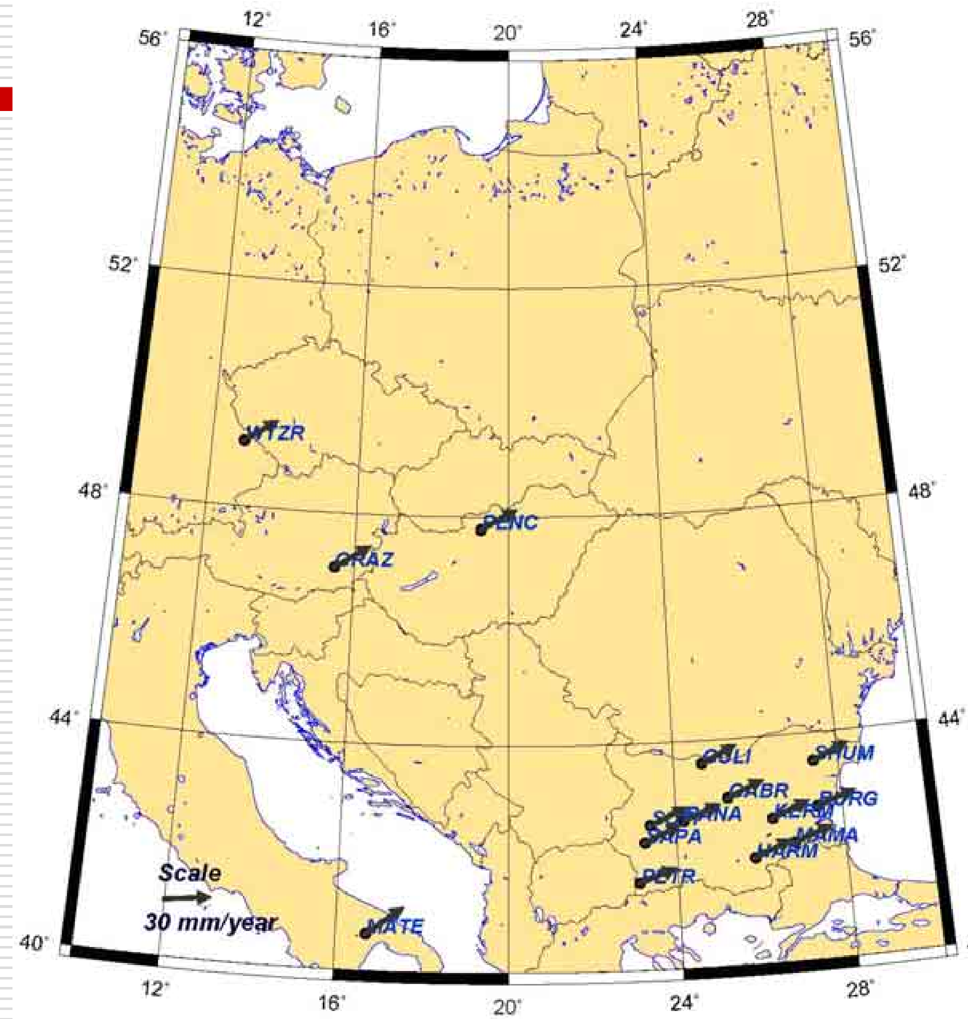
Epoch network in Slovakia (Slovak geodynamic reference network)

- Slovak national geodynamic reference network
- Epoch observations since 1993 to 2003 (8 campaigns)
- 40 epoch sites in Slovakia and 9 EPN permanent stations
- Velocities in ITRF2000 and full covariance matrix are available

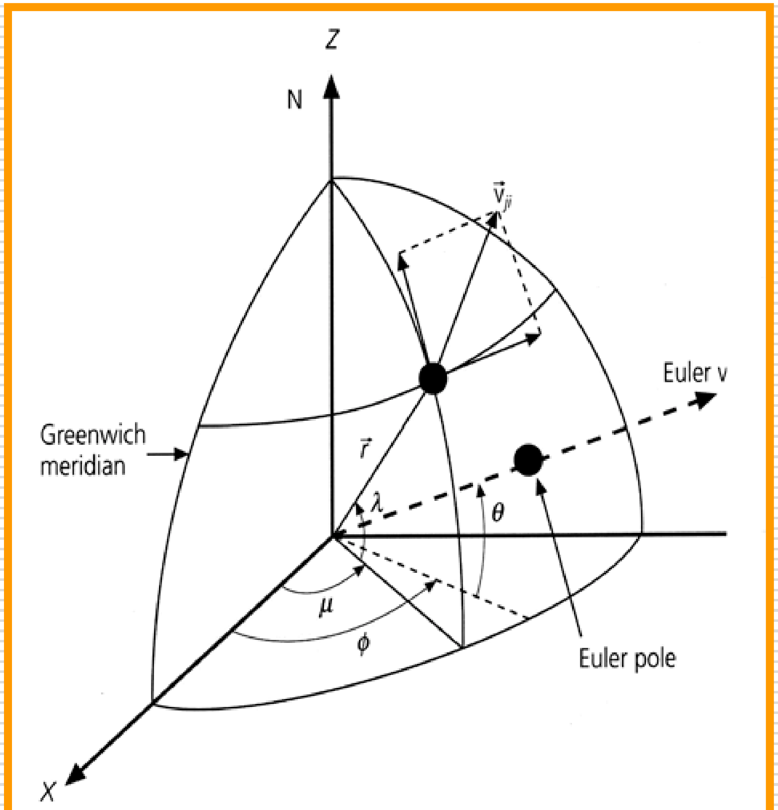


GPS epoch network in Bulgaria

- BULREF stations – 15 sites observed in 1993 and 2003, velocities in ITRF2000 available for 10 stations (Milev, Vassileva et al.)
- 5 EPN stations included
- No redundant observations available, only formal accuracies for velocities



Method of referencing the velocities into common reference



- **If the horizontal velocities describe movement of homogeneous, compact area on spherical surface they can be described as rotation around the Euler pole**
- **The same principle for differences of velocities: Differences of two velocity fields can be evaluated as the rotation around Euler pole**
- **The position of Euler pole and velocity of rotation can be estimated if sufficient number of identical points is available**

Method of referencing the velocities into common reference

$$v_n = \omega \sin(\lambda - \lambda_E) \cos\varphi_E$$
$$v_e = \omega[\cos\varphi_E \sin\varphi \cos(\lambda - \lambda_E) - \sin\varphi_E \cos\varphi]$$

$$\delta v_n = \delta\omega \sin(\lambda - \lambda_E) \cos\varphi_E$$
$$\delta v_e = \delta\omega[\cos\varphi_E \sin\varphi \cos(\lambda - \lambda_E) - \sin\varphi_E \cos\varphi]$$

Rotation of Eurasia according to APKIM 2000

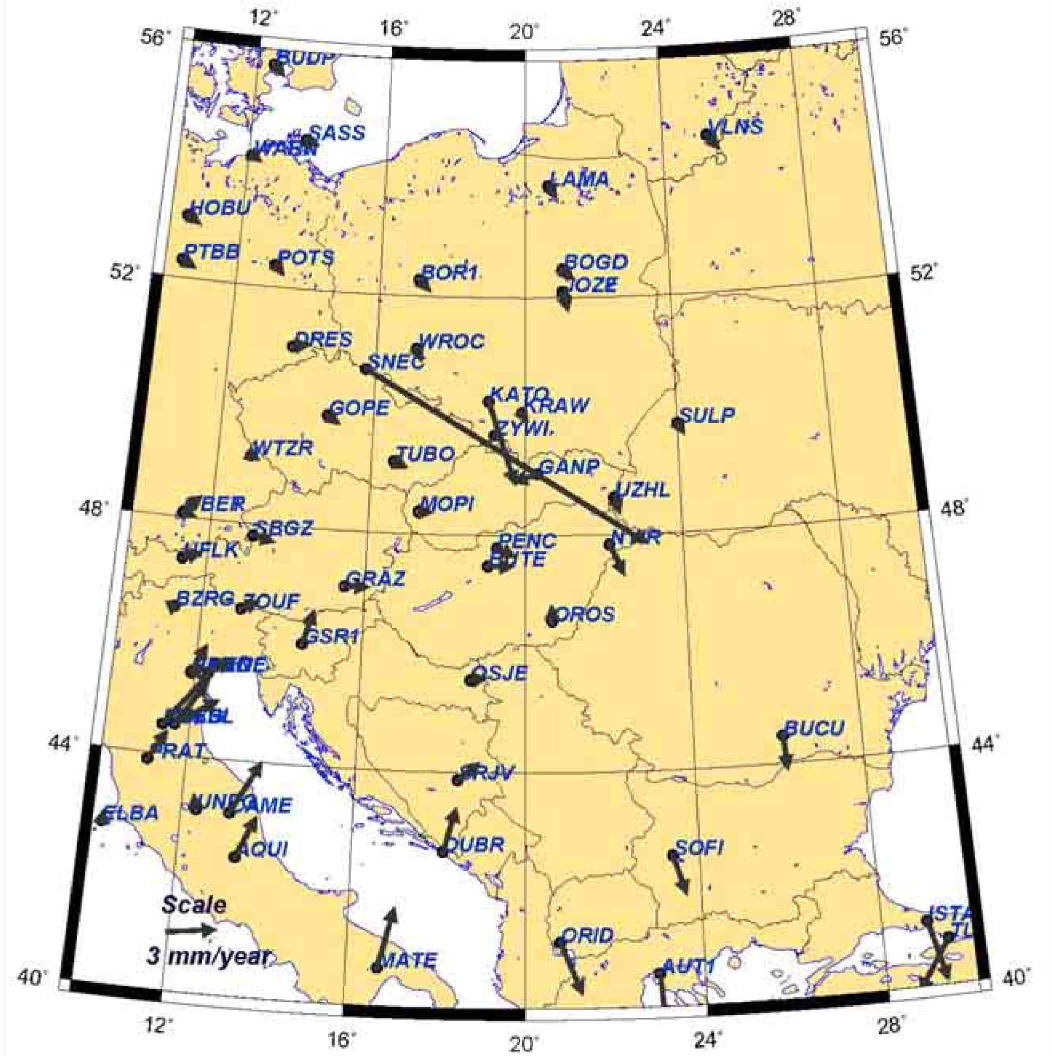
$$\varphi_E = 57.9°, \lambda_E = -97.1°$$
$$\omega = 28.8\, mm / year$$

- **Principle: Estimation of geographical coordinates φ_E, λ_E of Euler pole and rotation velocity ω on the basis of horizontal velocities**
- **Application: estimation of φ_E, λ_E and $\delta\omega$ on the basis of differences of velocities δv_n and δv_e evaluated in two systems**
- **Reduction of individual velocities according to estimated parameters of rotation of the velocity field into ITRF2000**
- **Reduction of ITRF velocities for APKIM 2000 model**

EUREF Permanent Network intraplate velocity field

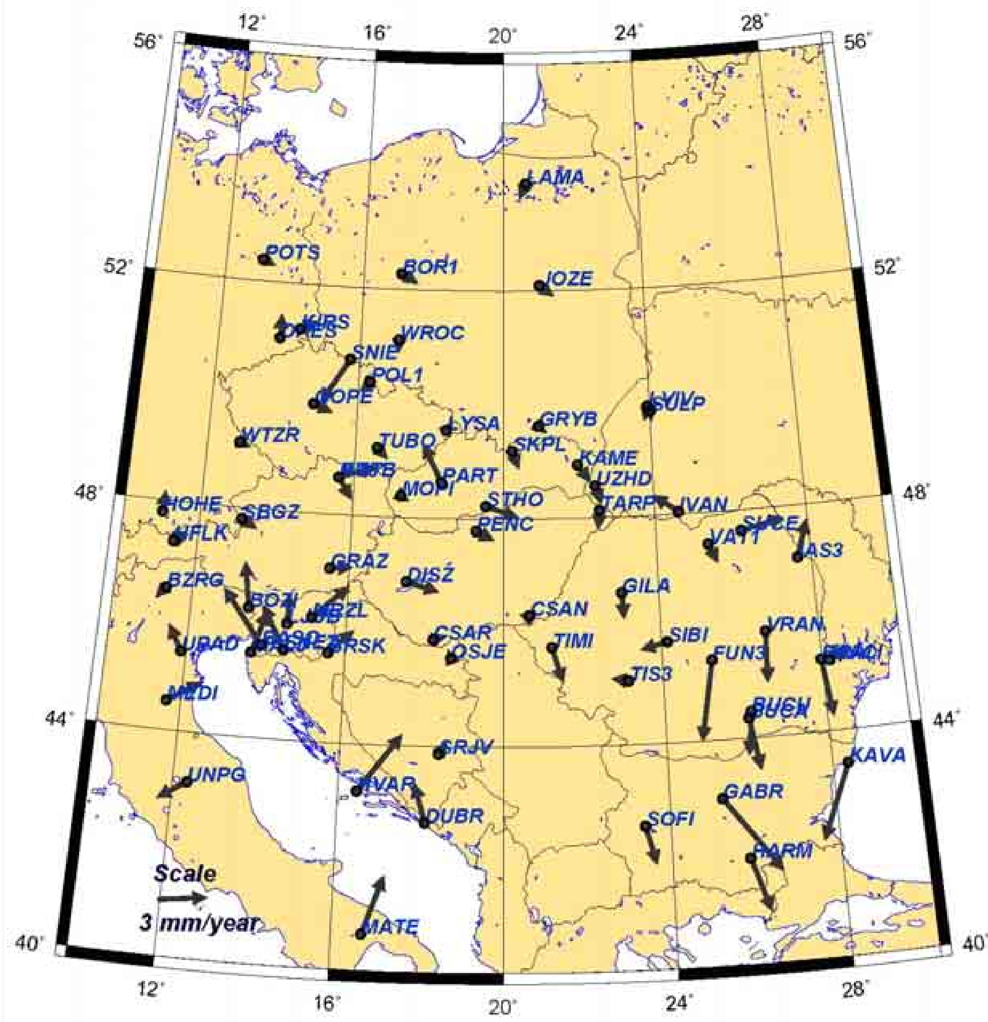
- Intraplate velocities are from 0 to 5 mm/year with structured behaviour in Adria and Balkan region
- Exceptions SNEC and KATO
- Euler pole and rotation from 169 sites on European part of EURA

$\varphi_E=54.7$, $\lambda_E=-94.8$ $\omega=27.7$ mm/year (1 mm/year less than APKIM)



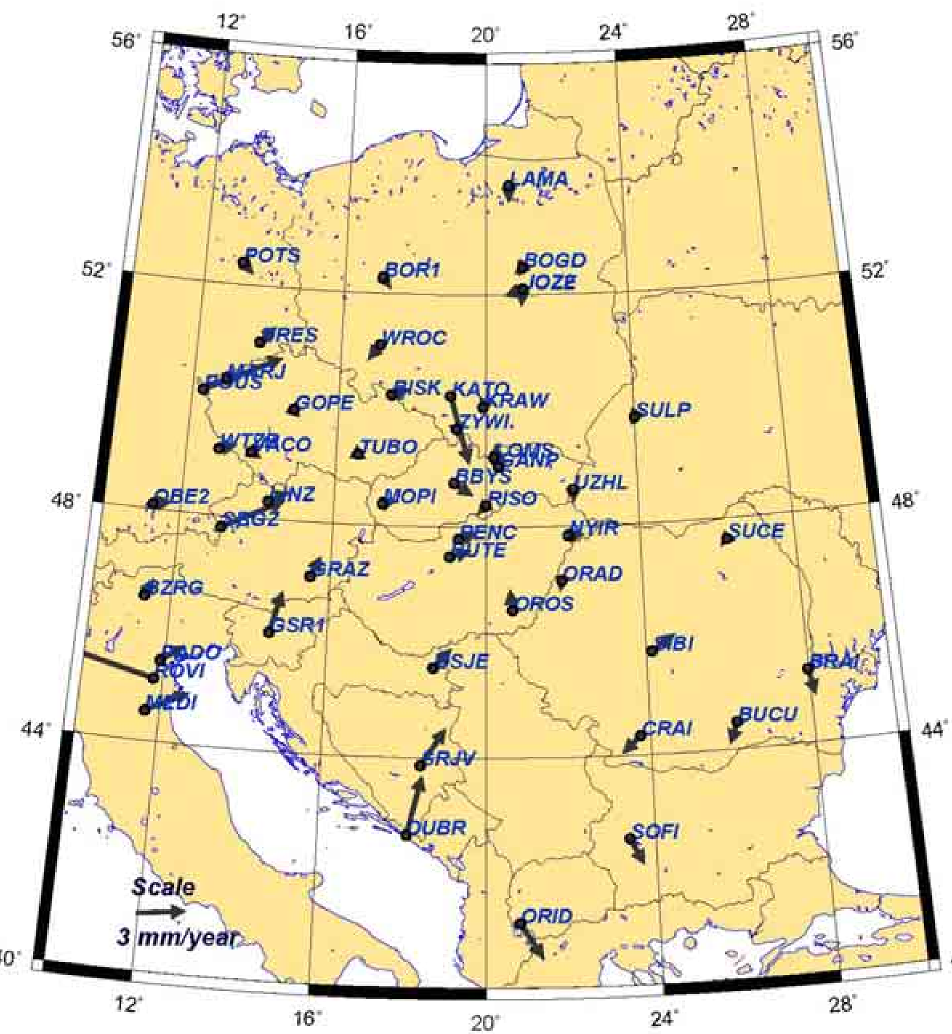
CEGRN epoch network intraplate velocity field

- Epoch velocities evaluated from 2 to 9 observing campaigns
- Good coverage of Romania, however these velocities are derived from few epochs (2-5)
- 29 identical sites with EPN, rotation to EPN ω=-0.8 mm/year
- Probably local phenomena: SNIE and PART



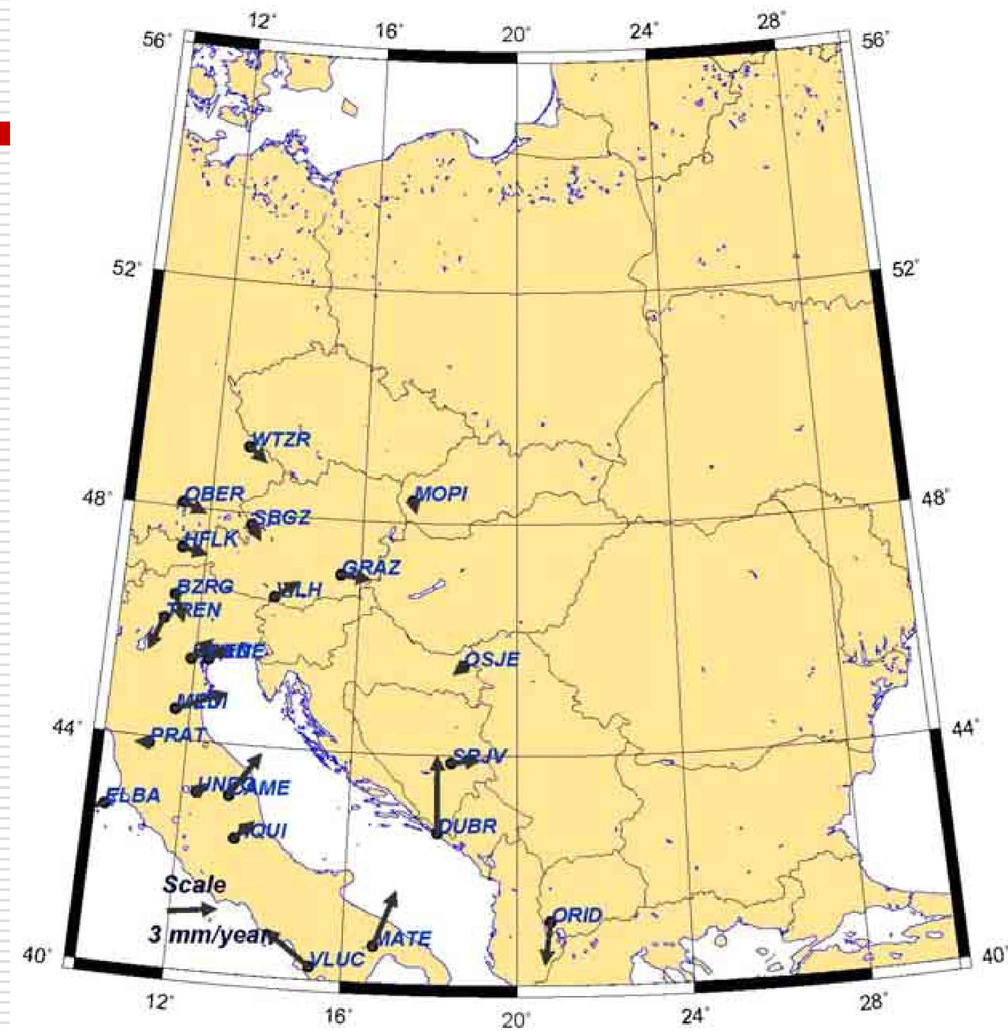
Intraplate velocities from network of permanent stations in Central Europe and Balkan Peninsula

- 37 identical sites with EPN, consistency at level 0.6 mm/year
- Anomalous behavior ROVI, KATO, POUS
- Rotation relative to EPN ω=0.4 mm/year



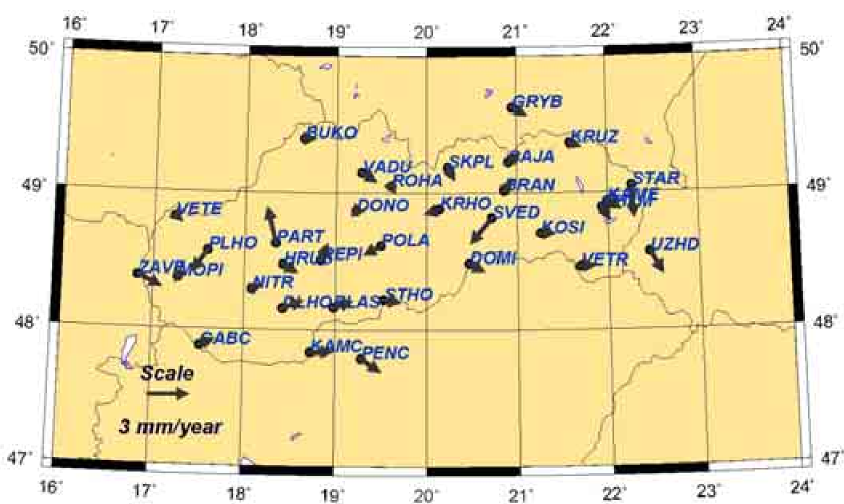
Intraplate velocities from network of permanent stations in Italy and close regions

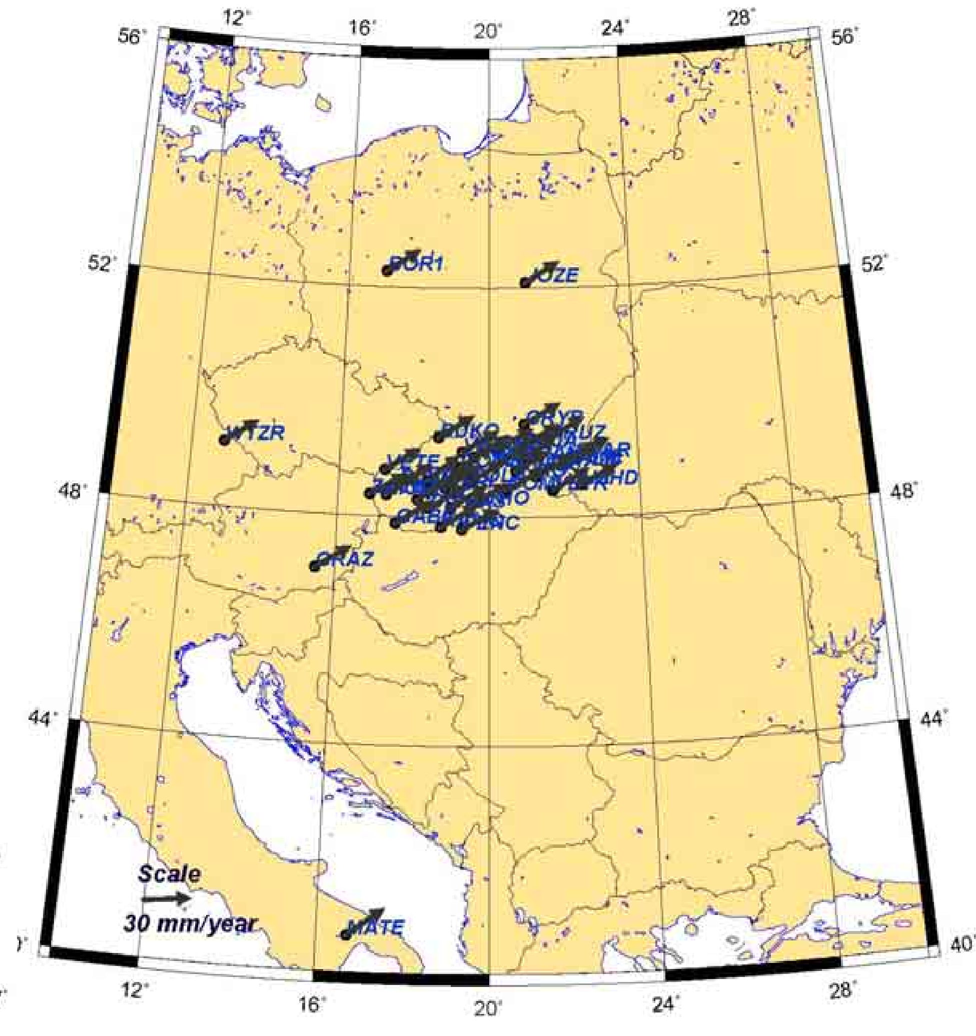
- 35 stations identical with EPN (in the whole region)
- 8 non-EPN sttaions
- Obervations 1-6 years
- Consistency with EPN 1 mm/year, rotation to EPN ω=1.7 mm/year



Intraplate velocities from Slovak geodynamic reference network

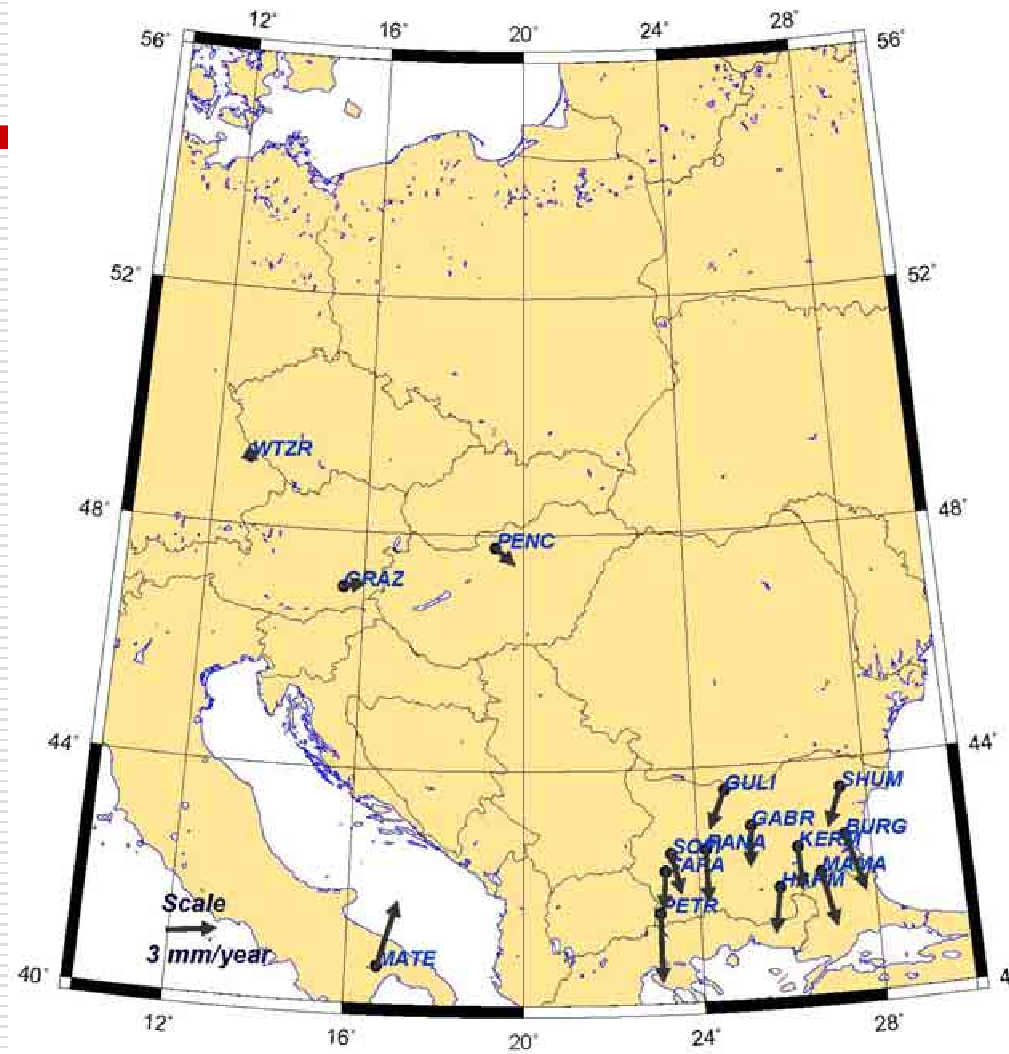
- Intraplate velocities mostly 0-2 mm/year, only 3 stations 3mm/year
- 11 stations identical with EPN, consistency 0.3 mm/year, no rotation to EPN





Intraplate velocities for GPS epoch network in Bulgaria

- All stations in Bulgaria have trend 3 mm/year oriented to south
- 6 stations identical with EPN, consistency at level 0.3 mm/year



Combination of velocities into one common velocity field

- 300 intraplate velocities of about 200 sites, referred to the same reference are available
- The accuracy of data is very heterogeneous because of various origin (epoch/permanent), various observation history (from 1 year (permanent) to 12 years (epoch)), various approach to processing
- Evaluation of relevant and comparable characteristics is complicated and only a first estimate is available now
- The velocity field in regular intervals is computed using the least squares collocation approach

Interpolation of velocity field into regular grid

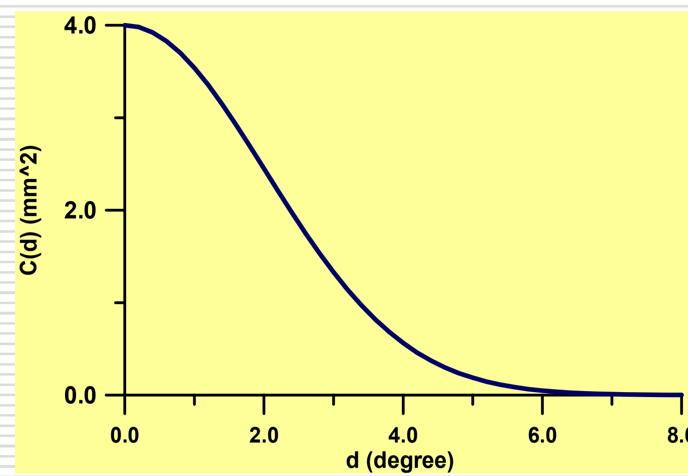
Prediction of velocities using LSC

$$\mathbf{v}_{pred} = \mathbf{C}_S \mathbf{C}_v^{-1} \mathbf{v}_{obs}$$

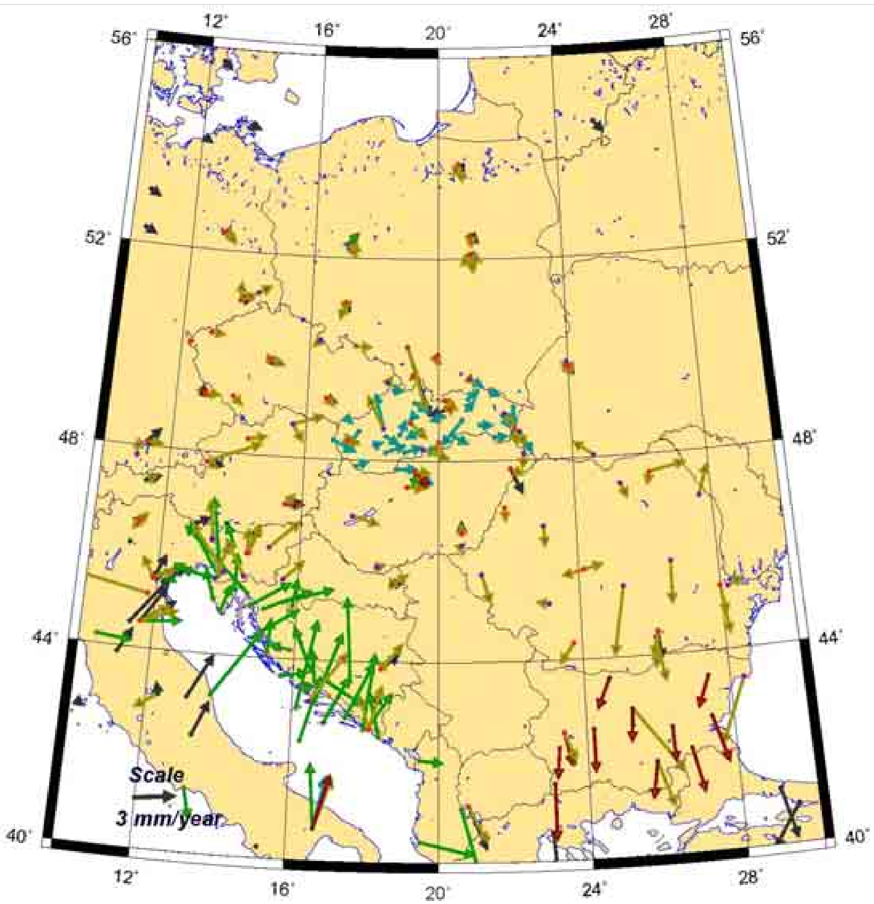
V_{pred} – predicted velocities
C_s - covariance matrix of signal
C_v - covariance matrix of observed velocities
V_{obs} - observed velocities

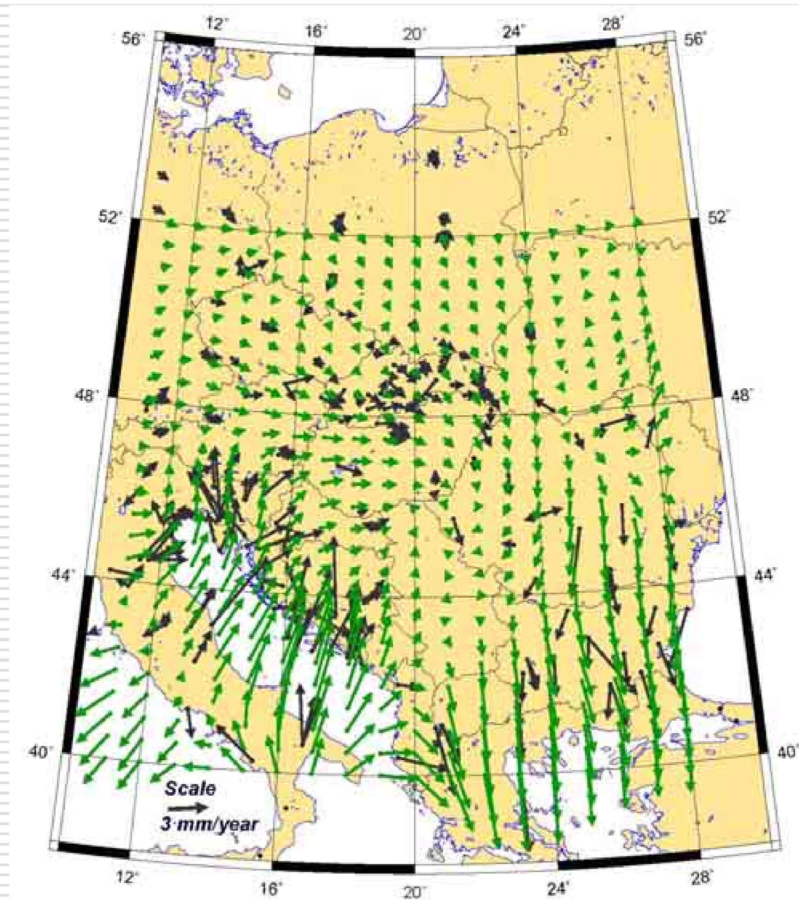
Covariance matrix of predicted signal

$$C(d) = \sigma_{0s}^2 \exp\left(-c^2 d^2\right)$$



OBSERVED AND INTERPOLATED VELOCITIES (1.0 x 0.5 deg grid)



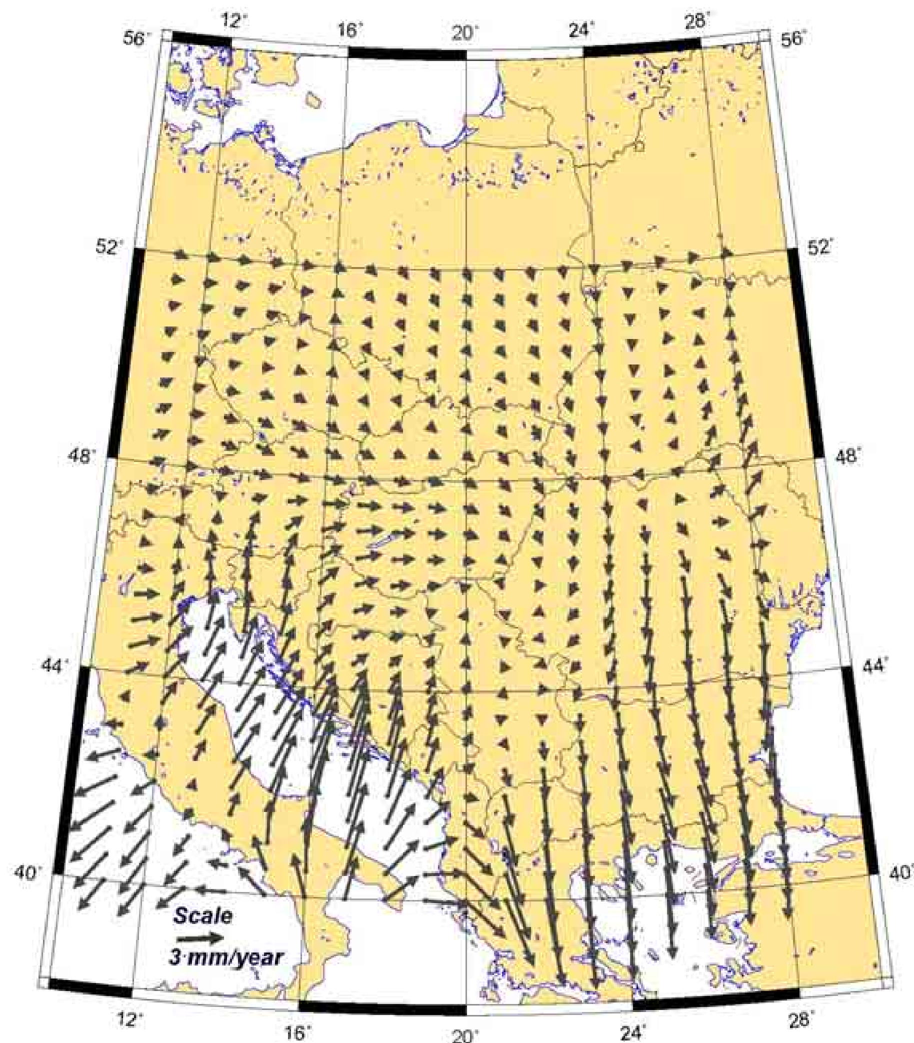


INTERPOLATED INTRAPLATE VELOCITIES (1.0 x 0.5 deg grid)

Main geo-kinematics features of the region:

- Regional patterns from EPN are supported by local networks. Northern part of CE part is relative stable (about 1 mm/year), eastward orientation of velocities in Panonian Basin, rotation of Adria (Adria microplate?), divergence of velocities in Italian Peninsula and

East Carpathian

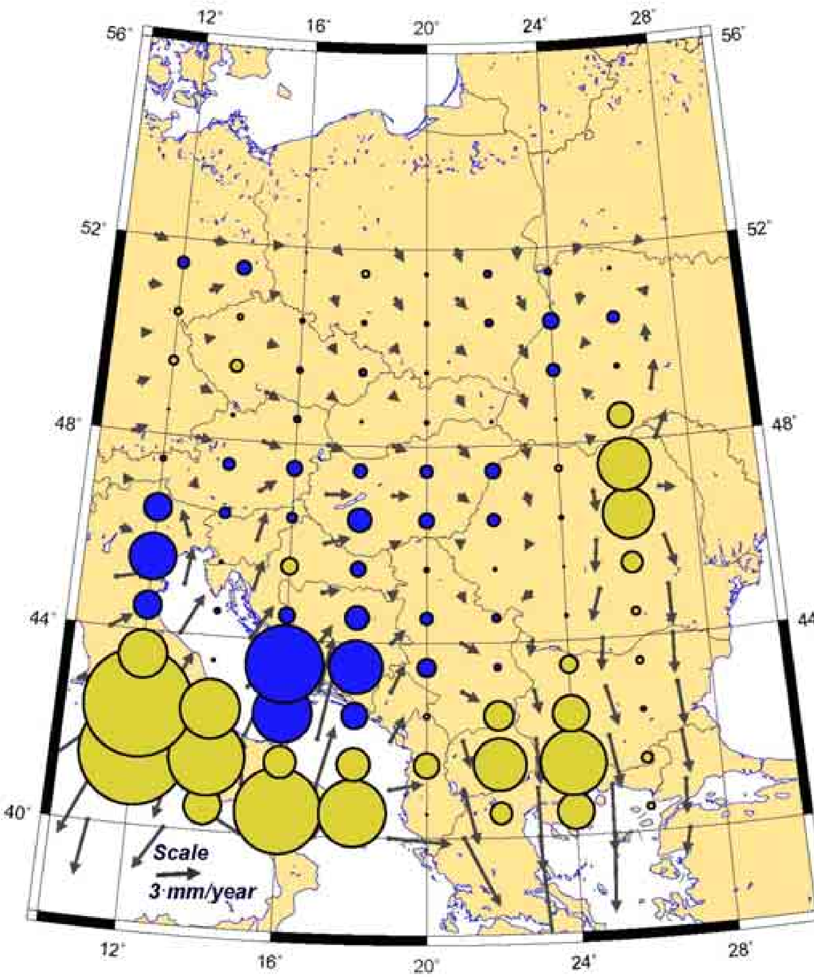


SURVACE DEFORMATIONS INFERRED FROM INTERPOLATED INTRAPLATE VELOCITIES (example)

Surface dilatation

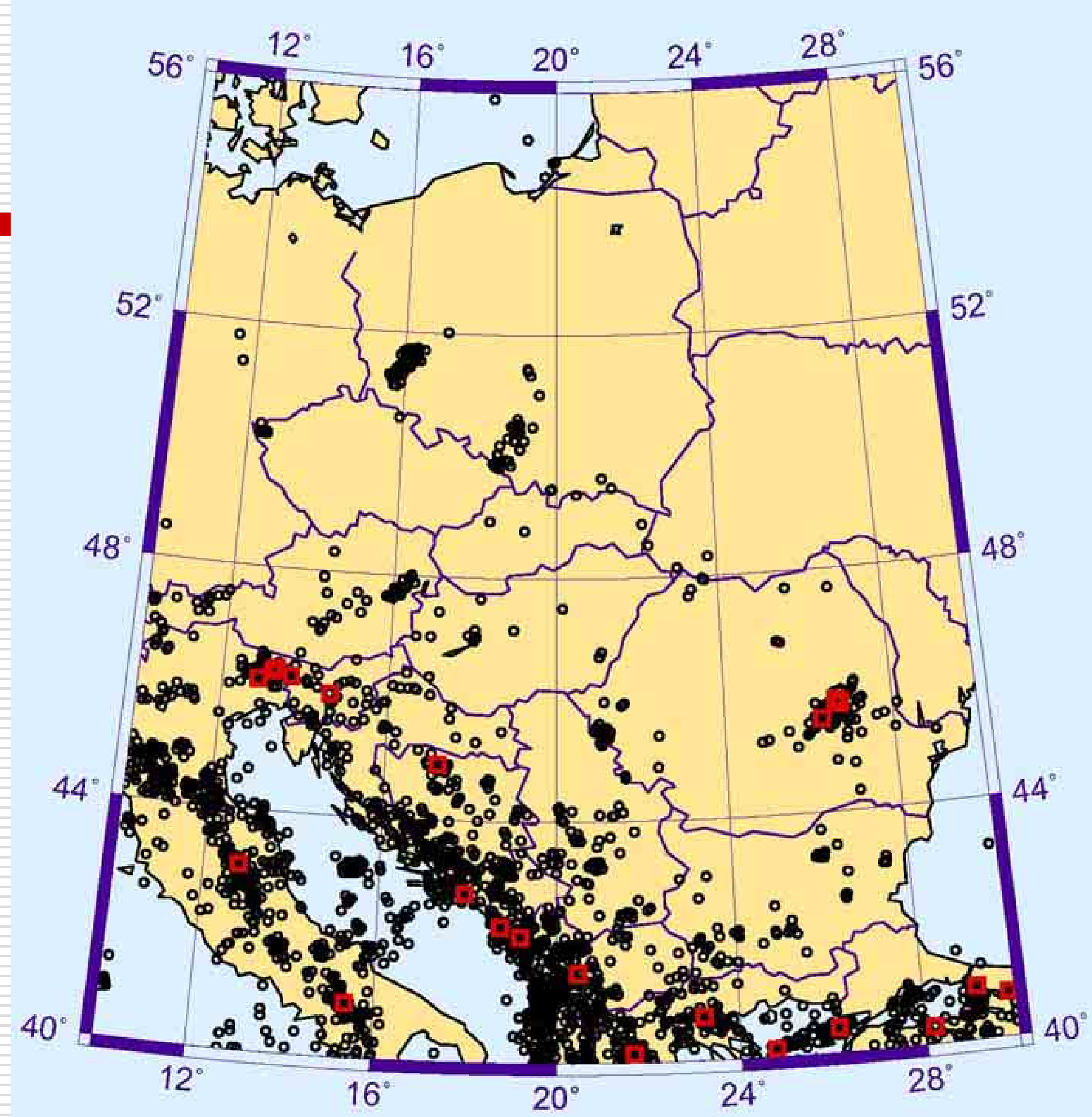
Surface depression

Range: 0 – 20 nanostrain/year



EARTHQUAKES IN CENTRAL AND SOUTHEAST EUROPE

- Earthquakes in period 1963-2006
- Magnitude > 4.0
- Magnitude > 6.0
- Intraplate velocities over 3 mm/year and large velocity gradients are mainly in active seismic region



Outlook

- There are more national or regional velocity fields in Central Europe and Balkan region reported in the literature. However the data are not published in numerical form or there are no velocities of sites which can enable the referencing.
- As example we can mention the GPS networks in west Greece, Black Sea region, Romania, Hungary, etc.
- The main problem of combination of heterogeneous data is correct modeling of velocity uncertainties. The next step in the combination will be a model for global covariance matrix respecting the real accuracies of velocities.

Conclusions

- The presented study was a start to complex modeling of velocity field in Central and south-east Europe using velocity fields from various databases
- The main problem is besides the availability of relevant velocity fields the correct stochastic modeling
- After compilation of more regional and local velocity fields the deformation modeling will follow