Surface kinematics in the Alpine-Carpathian-Dinaric and Balkan region inferred from a new multi-network GPS combination solution

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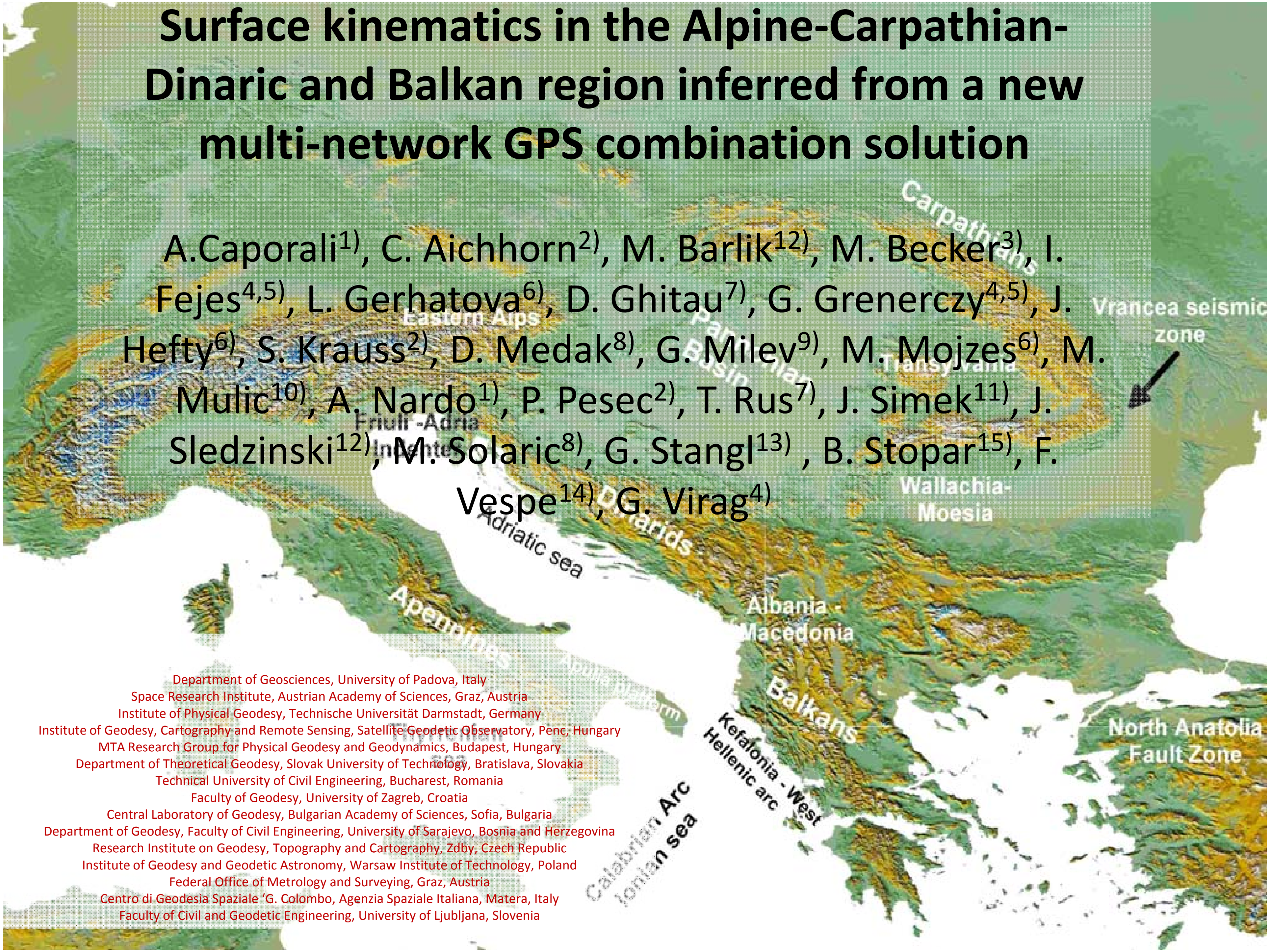


Some history

- CERGOP 2 Science Paper submitted to Journal of Geodynamics 19.12.2006
- Several Presentations at EUG (invited paper at CEI session), EUREF Symposium, WEGENER meeting and others
- Editor response on 23.05.2007: paper interesting, but too many things irrelevant to geodynamics;
- Discussions among us on what to do result in decision of extracting the purely geodynamic part leaving the more geodetic part to a separate paper
- AC circulates on 09.10.2007 a radically revised version. Enphasis on velocity flow and geokinematic interpretation.
- Invitation from Topoeurope on 02.10.2007 to submit a contributed paper on a special issue of Tectonophysics with deadline January 15, 2008
- Reasonable strategy: submit the CERGOP2 paper now; work on an improved paper including reprocessing, CEGRN06/07, other regional SINEX to submit to Tectonophysics
- 10.10.2007: Title ‘Geokinematics of Central Europe inferred from the CEGRN GPS network’ was submitted, with extended authors (Connie and Sandro) in time for deadline of Oct. 15.
- 10.01.2008: final acceptance of J of Geodyn CERGOP 2 paper
- 03.09.2008: Revision 1 submitted to Tectonophysics emphasis on combination/geodesy
- 04.04.2009: Revision 2 submitted to Tectonophysics: several references added
- 07.04.2009: informal communication of paper final acceptance

CEGRN Team and the scientific exploitation of geodetic data

CEGRN= Central European Geodynamic Research Network http://www.fomi.hu/CEGRN/

- Funded under the FP5
- **Geokinematics of Central Europe: New insights from the CERGOP-2/Environment Project**
  Journal of Geodynamics, Volume 45, Issues 4-5, May 2008, Pages 246-256
- **Surface kinematics in the Alpine-Carpathian-Dinaric and Balkan region inferred from a new multi-network GPS combination solution**
  ***Tectonophysics, In Press, Accepted Manuscript**, Available online 5 May 2009*
- *Active contribution to the EUREF/IAG Special project on Dense Velocity Fields*

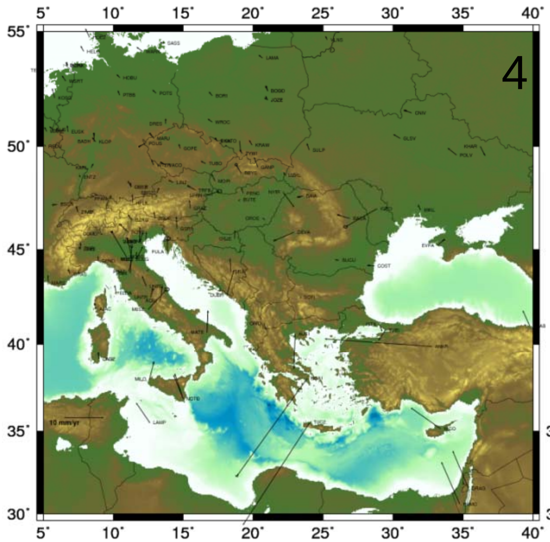
Key elements of the Tectonophysics/Topoeurope work (1/2)

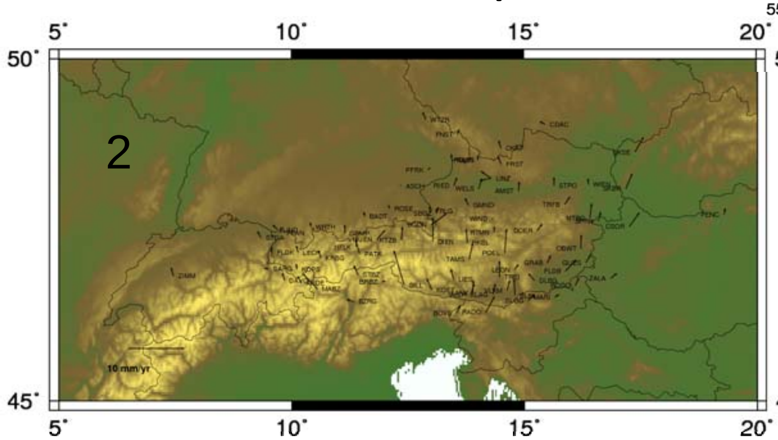
- CEGRN Campaigns Reprocessing!

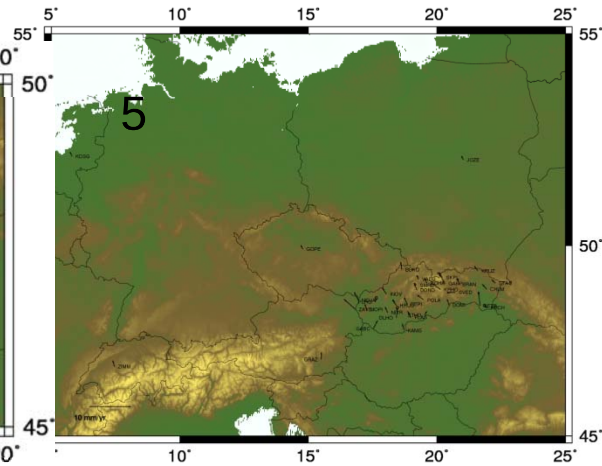
Software	Bernese 5.0
A priori coordinates	ITRF2005 coordinates and velocities
Datum definition	minimum constraints (no net translation) at the sites BOR1 GRAZ JOZE KOSG LAMA METS ONSA PENC ZIMM WTZR MATE GOPE
Absolute Phase Center Variations	individual values from EPN or mean values from Geo++ company, or igs05_1402.atx. Official .atx file
Elevation cutoff	5 degrees
Elevation dependent weighting	Applied
Station information file	from EPN, complemented with CEGRN stations
Ocean loading corrections	FES2004
Earth Orientation Parameters, Orbits and satellite information	Potsdam Munich Dresden reprocessing
Frame for orbits	IGS00b

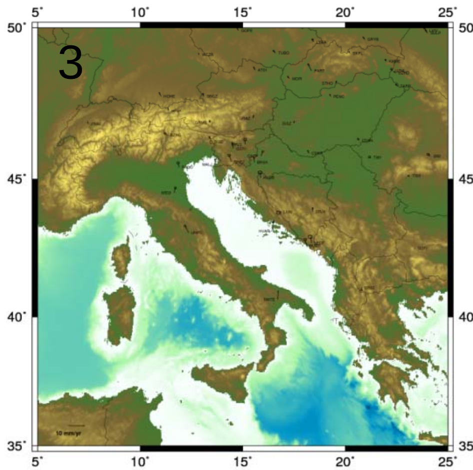
Key elements of the Tectonophysics/Topoeurope work (2/2)

- Combination of 7 networks in RV space

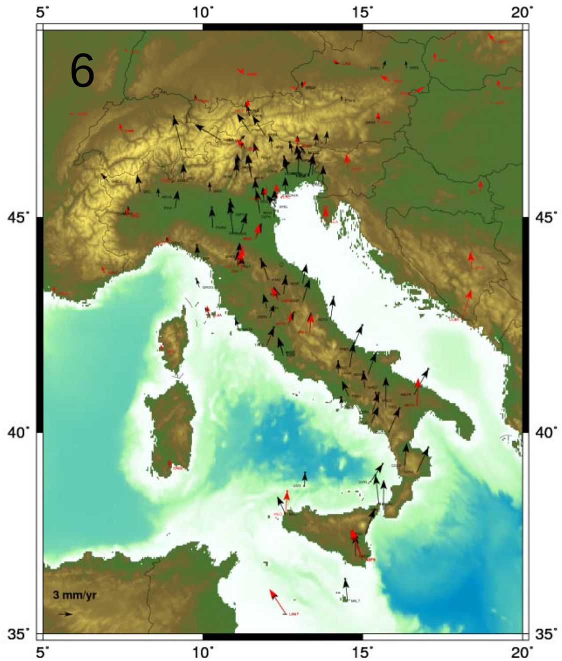


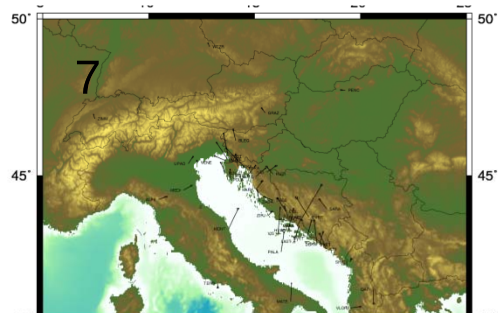


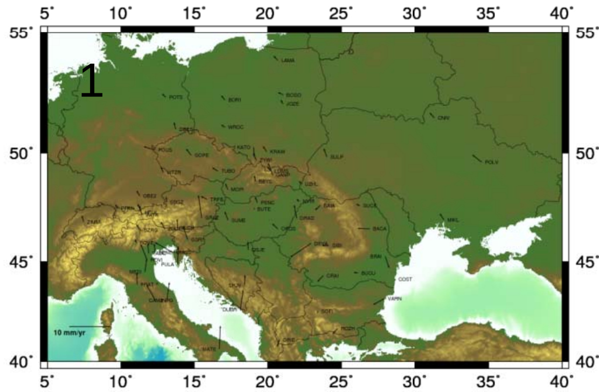




1. AMON
2. ARE
3. CEGRN
4. EUREF
5. SK
6. UPA
7. YUK







Issues on combining multi-year cumulative solutions in RV space

- Input SINEX are inhomogeneous as to:
  - Processing standards: different reference frames co-exist, absolute/relative antenna models, el-cutoff, ways to impose constraints, orbits/EOP’s…
  - Each combination group originating a RV SINEX may have made own choices as to soln’s
- As a conclusion, the slope (velocity) in time series are probably OK, but the coordinates may be inconsistent
- For the sake of geokinematics, velocities are really important, coordinates not so much
- Reprocessing would solve all the pending issues!

ADDNEQ2 combination of 7 normal equations results in 466 homogeneous velocities, same ITRF2005 frame

- SUMMARY OF RESULTS
- ------------------
- Number of parameters:
- --------------------
- Parameter type Adjusted explicitly / implicitly (pre-eliminated) Deleted Singular
- --
- Station coordinates / velocities 2905 2803 102 (before stacking) 0 6
- Site-specific troposphere parameters 522 0 522 (before stacking) 0 0
- --
- Previously pre-eliminated parameters 36081485 36081485
- --
- Total number 36084912 2803 36082109 0 6
- Statistics:
- ----------
- Total number of explicit parameters 2803
- Total number of implicit parameters 36082109
- Total number of adjusted parameters 36084912
- Total number of observations 277485158
- Degree of freedom (DOF) 241400246
- A posteriori RMS of unit weight 0.00272 m
- Chi**2/DOF 7.41
- Total number of observation files 44788
- Total number of stations 466
- Total number of satellites 0

Network	from	to
AMO	3/18/2001	7/6/2008
ARE	3/18/2001	7/6/2008
CEG	5/2/1994	6/23/2007
EUR	7/3/1996	3/28/2008
SK	8/30/1993	6/25/2007
UPA	1/31/1999	8/2/2008
YUK	6/8/1994	9/8/1998
Total	8/30/1993	8/2/2008

Network	rms (m)	Tx (m)	Ty (m)	Tz (m)	Rx (arcsec)	Ry (arcsec)	Rz (arcsec)	scale (ppm)
AMO	0.01335	0.1316	-0.0043	-0.1873	-0.0012	0.0063	-0.0006	0.00192
ARE	0.01615	-0.0139	-0.1171	-0.0632	0.0023	0.0003	-0.002	0.00682
CEGRN	0.0255	0.0556	-0.0895	-0.05	0.0013	0.0018	-0.0025	-0.00368
EUR	0.05372	0.0104	0.0176	-0.0314	-0.0004	0.0003	0.0017	0.0014
SK	0.01622	0.0922	0.0312	-0.0117	-0.0042	0.0012	-0.004	-0.01664
UPA	0.01906	-0.1244	0.1495	-0.0048	-0.0035	-0.0017	0.0027	0.00682
YUK	0.00731	-0.0263	-0.0653	-0.0698	0.0017	0.0002	0.0001	0.00432

Minimum constraints on coordinates ITRF2005; high constraints on ITRF2005 velocities

Interpolation of velocities by least squares collocation

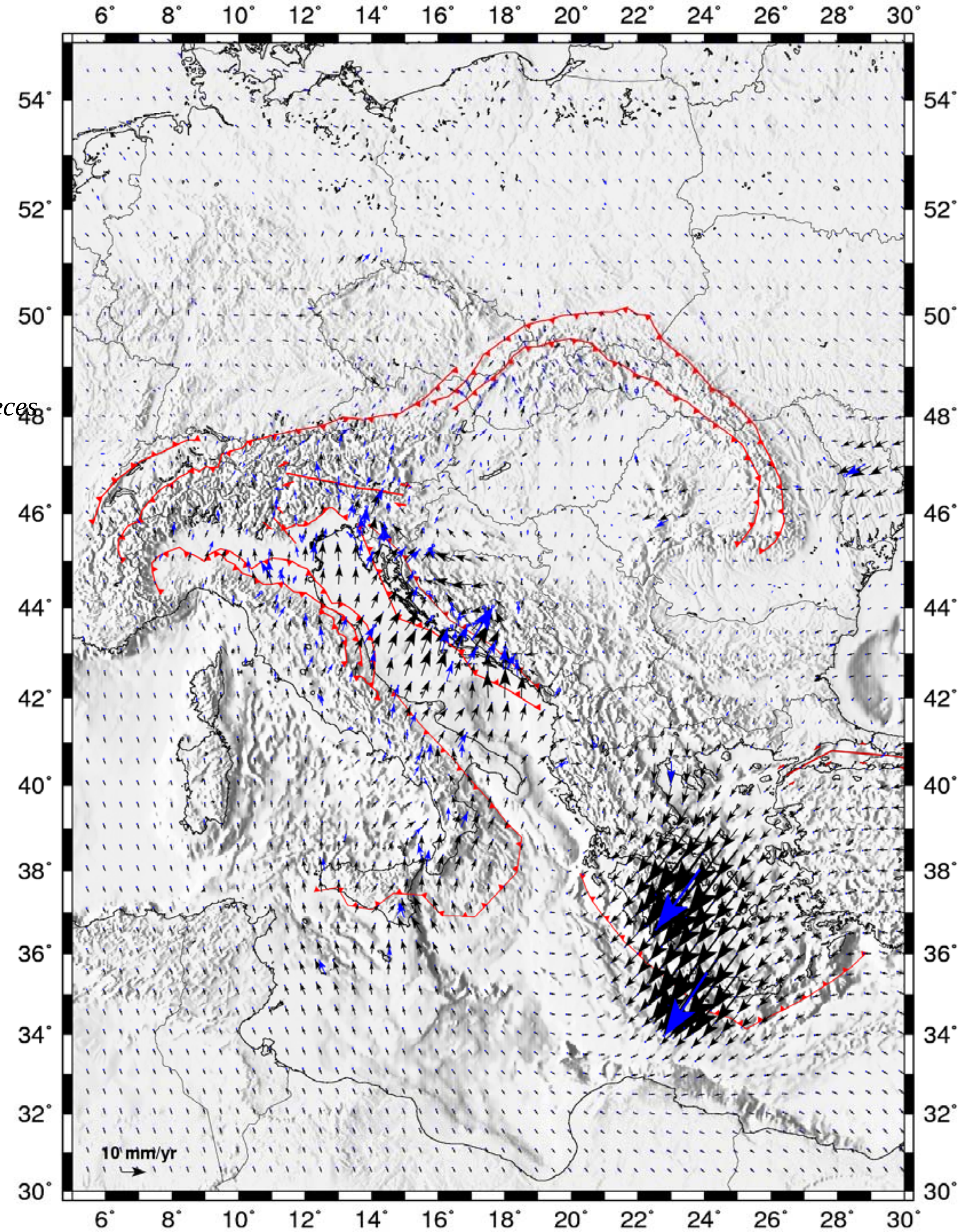
$$\begin{bmatrix} v_n \\ v_e \end{bmatrix}_P = \sum_s C(d_{P,s}) \sum_{s'} \left[C(d_{s,s'}) + W_{ss'} \right]^{-1} \cdot \begin{bmatrix} v_n \\ v_e \end{bmatrix}_{s'} \qquad s, s' = station \quad indeces$$

$$\begin{bmatrix} \sigma^2{}_n \\ \sigma^2{}_e \end{bmatrix}_P = I\sigma^2 - \sum_s C(d_{P,s}) \sum_{s'} \left[C(d_{s,s'}) + W_{ss'} \right]^{-1} C^T(d_{P,s'}) \cdot \begin{bmatrix} \sigma^2{}_n \\ \sigma^2{}_e \end{bmatrix}_{s'}$$

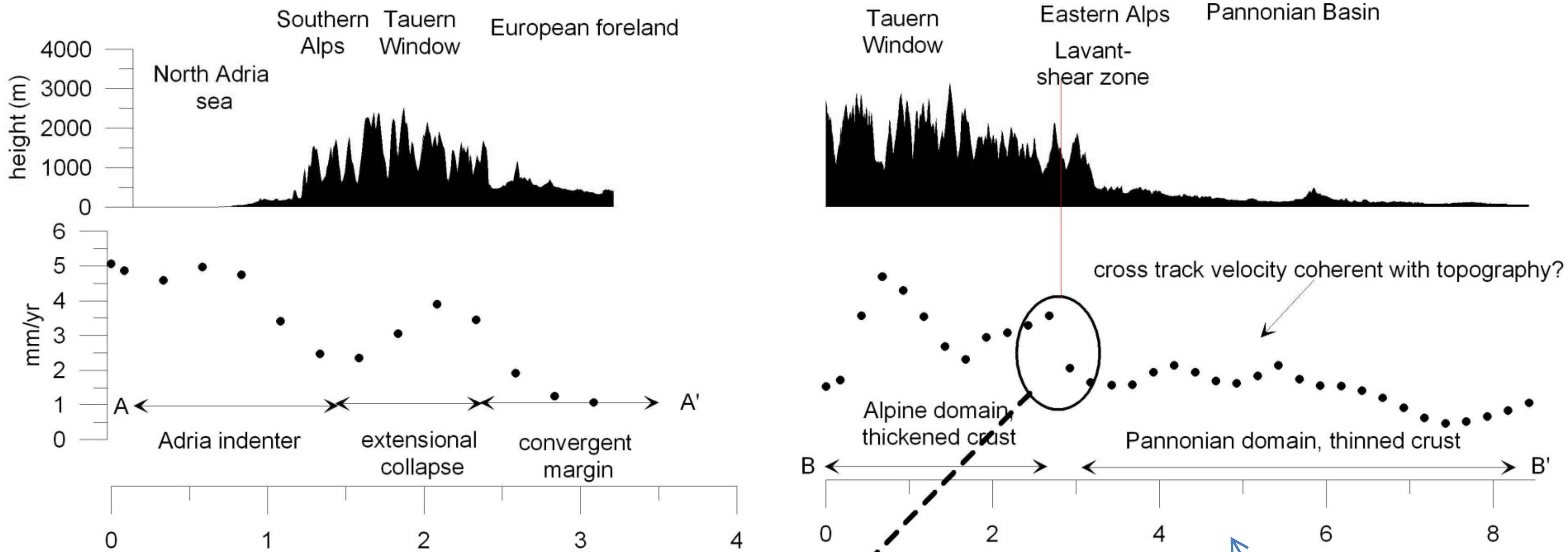
$$W_{ss'} = \frac{\frac{1}{\sigma^2{}_s}}{\sum_{s''} \frac{1}{\sigma^2{}_{s''}}} \delta_{ss'} \qquad\qquad C(d) = \frac{1}{1 + \left(\frac{d}{d_0} \right)^2}$$

Correlation distance 250-350 km, same order of magnitude of the flexural parameter of a semiinfinite elastic, isostatically supported halfspace of thickness 30 km

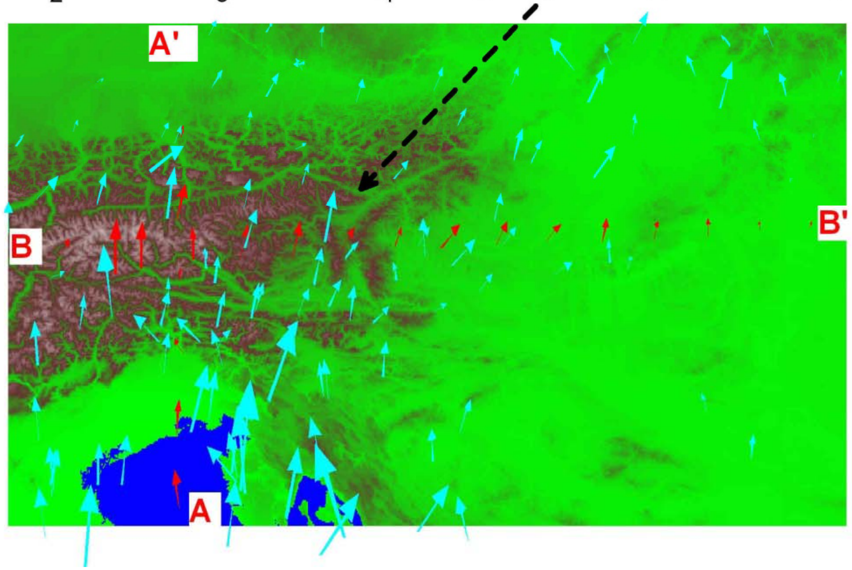
More details in Caporali, GJI 2003, Hefty, 2006



Velocity profiles: Eastern Alps Pannonian Basin



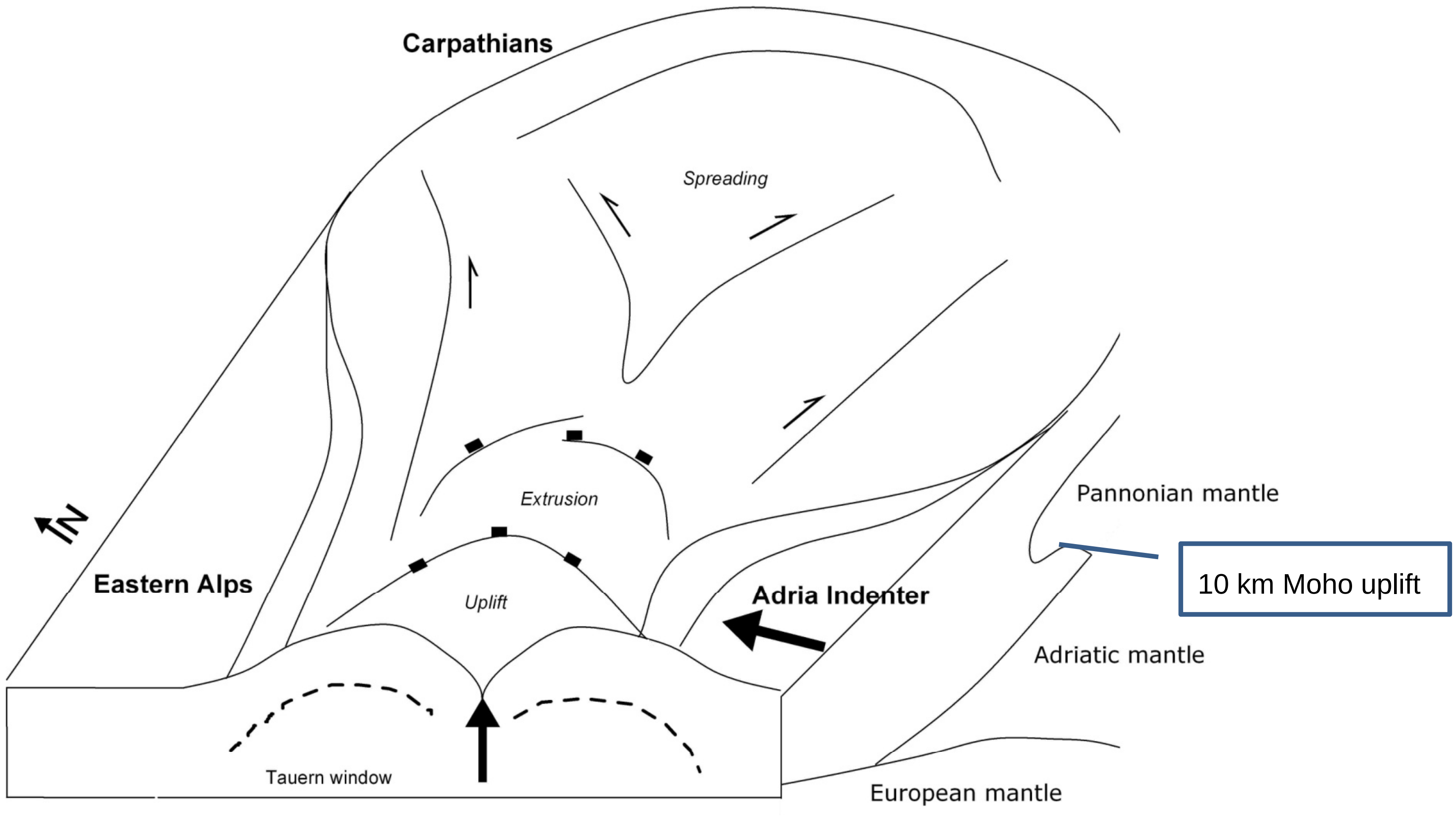
Blue: measured velocity



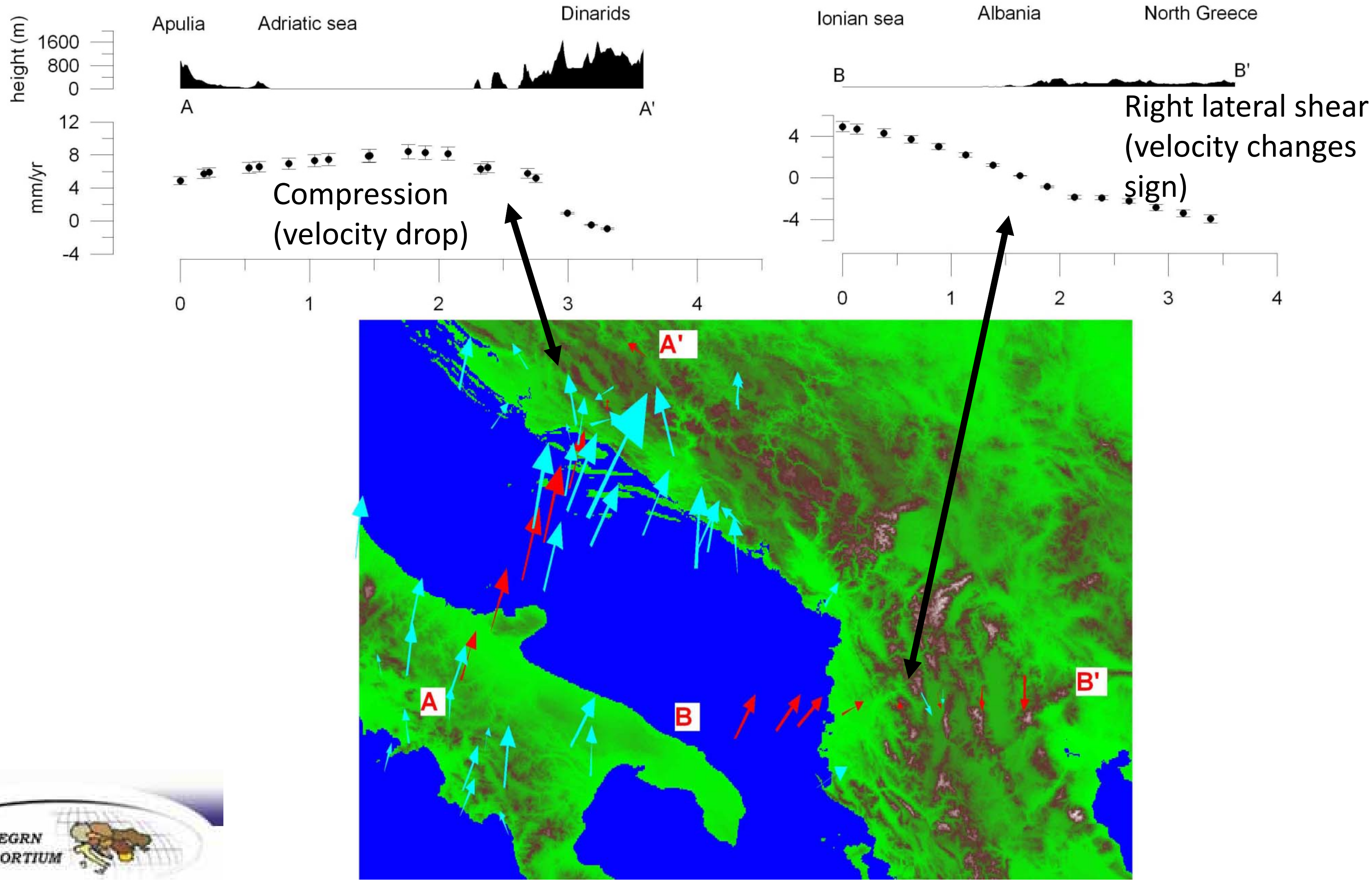
Scale axis x: 100 km

Red: velocities interpolated to the profile

Structural model of Ratschbacher et al.(1991): compression, uplift gravitational collapse and lateral extrusion in the Eastern Alps



Velocity profiles in the Adriatic and Albania

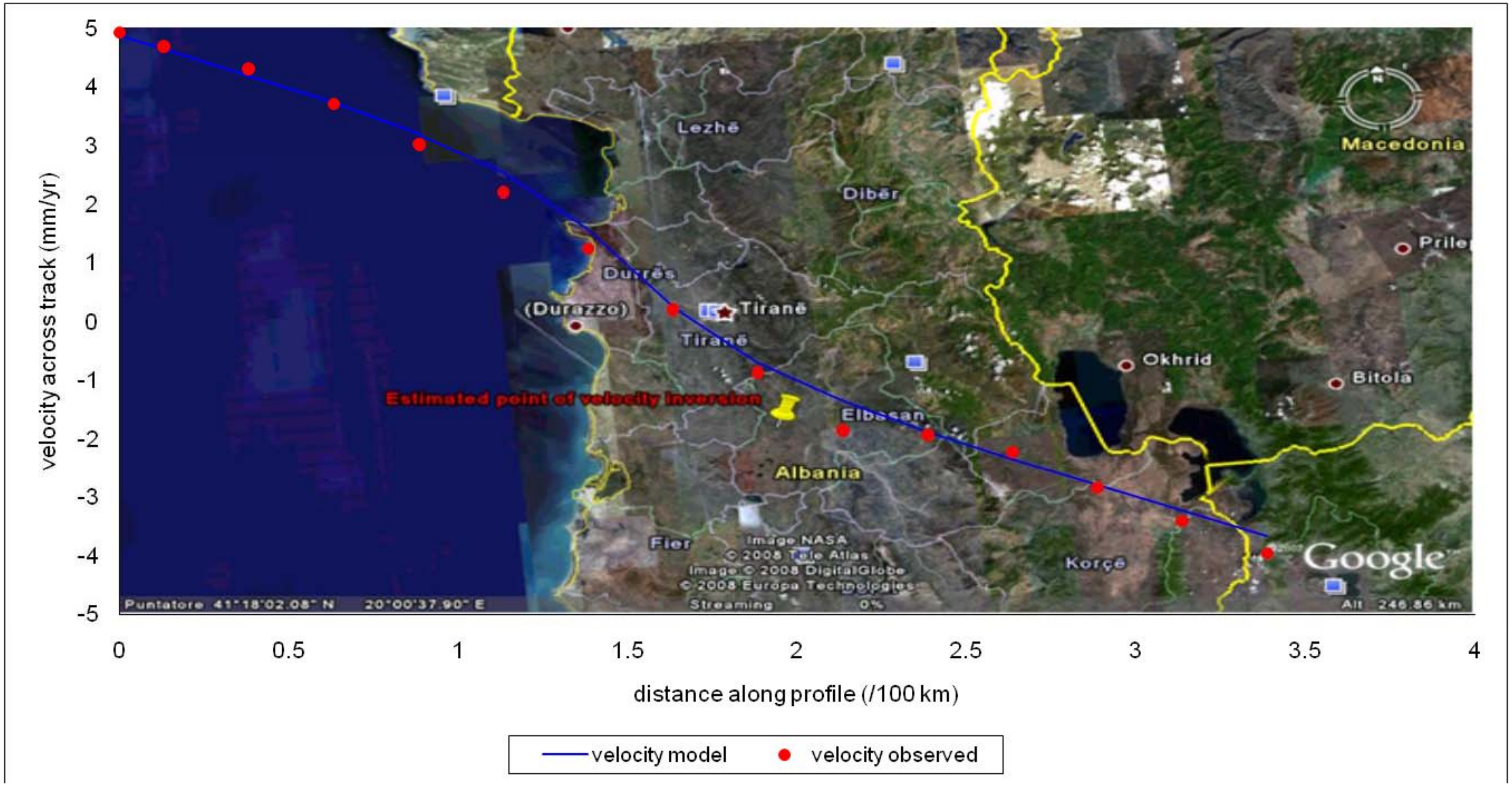


CEGRN CONSORTIUM

Modeling velocity inversion, locking depth 'a' and lithospheric thickness 'b' in a strike slip fault system

$$u(x) = \Delta u_0 \ln \frac{\sinh\frac{\pi(x-x_0)}{2b} + \left[\sinh^2\frac{\pi(x-x_0)}{2b} + \sin^2\frac{\pi a}{2b}\right]^{1/2}}{\sin\frac{\pi a}{2b}}$$

a=24 +/- 3 km
b=120 +/- 10 km

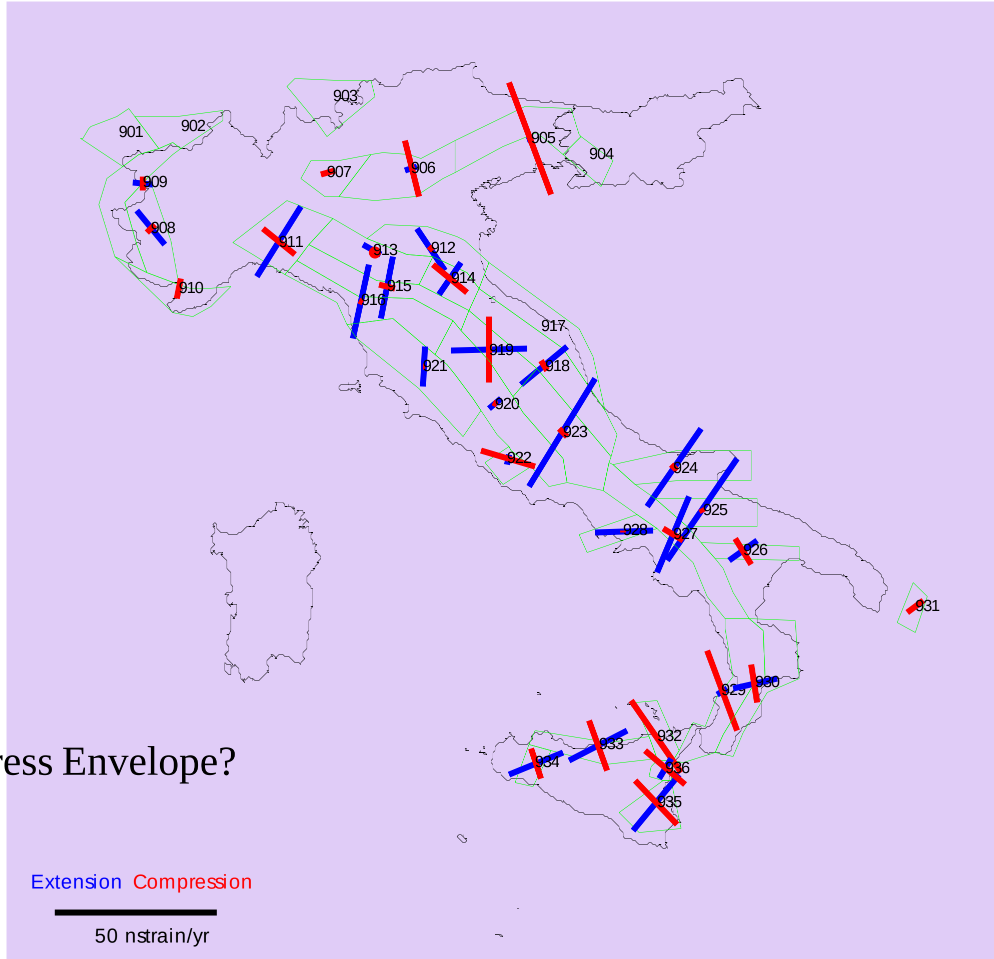


Conclusions

- First attempt to combine Multi-year solutions to estimate a dense velocity field
- Experience gained in the technical aspects and open questions in this new type of combination
- Improved velocity field across Europe through Least Squares Collocation
- Improved picture in known areas (eastern Alps), new results on several other areas (Pannonian basin, Adria-Balkans)
- Average strain rate in highly seismic zones computed with improved resolution

Conclusion: how can geodesy better integrate with seismology for mitigation of seismic hazard?

- Identify seismic zones: homogeneous geology , CMT's, historical catalogue
- Evaluate a and b of Gutenberg Richter law from catalogue for each zone
- Evaluate the seismic volume based on m, local Yield Stress Envelope
- Evaluate seismically released strain (Kostrov)
- Compare with geodesy and interpret discrepacies- review strength envelope of the lithosphere



$$\dot{\varepsilon}_{Kostrov} = \frac{1}{2\mu} \int_{m_{\min}}^{m_{\max}} \frac{M_0(m)N(m)}{h(m)A(m)} dm$$

$h =$ depth of seismogenic volume : requires Yield Stress Envelope?

$\mathrm{M}_0 =$ seismic moment released by individual event

$\mathrm{N} = \mathrm{a} + \mathrm{bm}$ Distribution of Gutenberg - Richter

$\mathrm{A} =$ slip area

$\mathrm{m} =$ magnitudo