Recent Crustal Deformation of the Alps derived from GNSS observations

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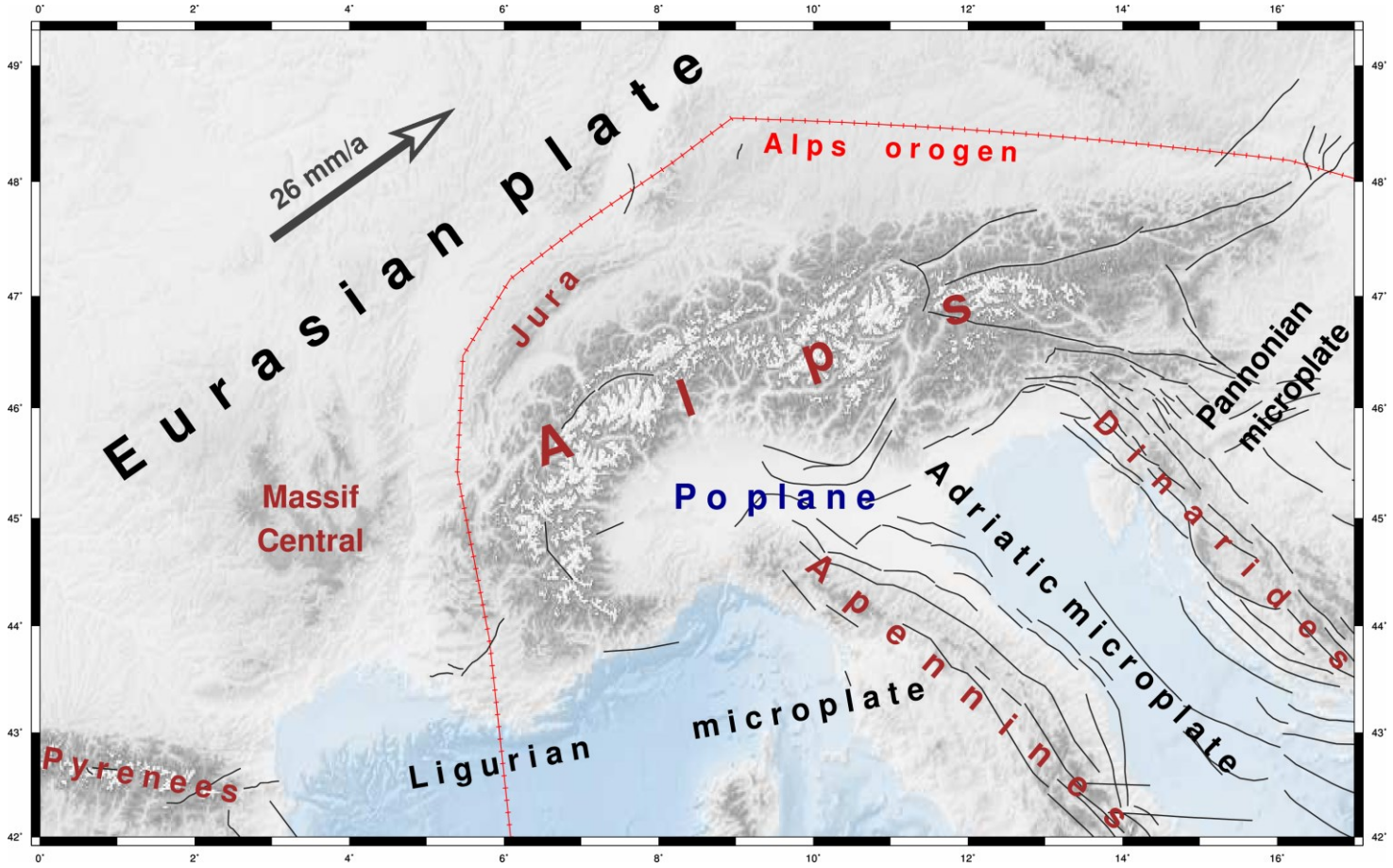
Initial Situation

- BADW and DGFI participated in the INTERREG IIIb Project *Alps-GPSQuakenet* in 2004 funded by the EU
- Participants were from France, Italy, Slovenia and Germany with several partners of each country
  - France (2): Institut Physique du Globe de Strasbourg, Laboratoire de Géophysique Interne et Tectonophysique (Grenoble)
  - Italy (7): Regional Authorities from Piedmont, Veneto, Bolzano, Liguria, Lombardy, Trento, and the Fondazione Montagna Sicura (private non-profit foundation), Dipartimento di Scienze della Terra (University Trieste)
  - Germany (2): Deutsche Geodätisches Forschungsinstitut (DGFI) and Bayerische Akademie der Wissenschaften (BEK)
  - Slovenia (1): Environmental Agency of the Republic of Sloveni (Slovenia)
- There were no partners from Switzerland and Austria due to the application procedure and available funds
- Between 2004 and 2006 approx. 30 CGNSS Stations have been build for this project
- During the duration of the project (3 years) only a small amount of data was available and not enough time to derive significant deformation information

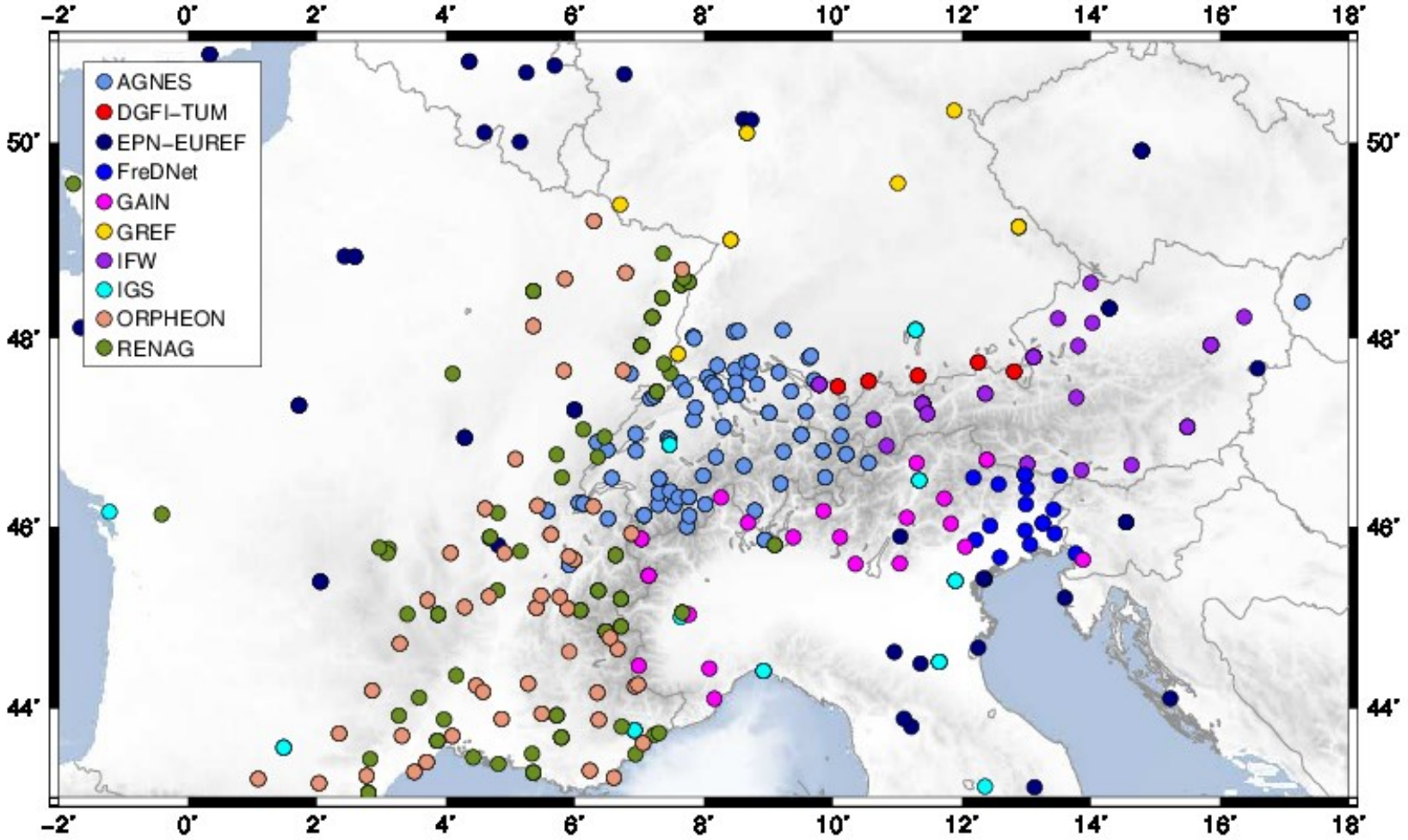
Data collection was continued over the past years!

Tectonic Setting

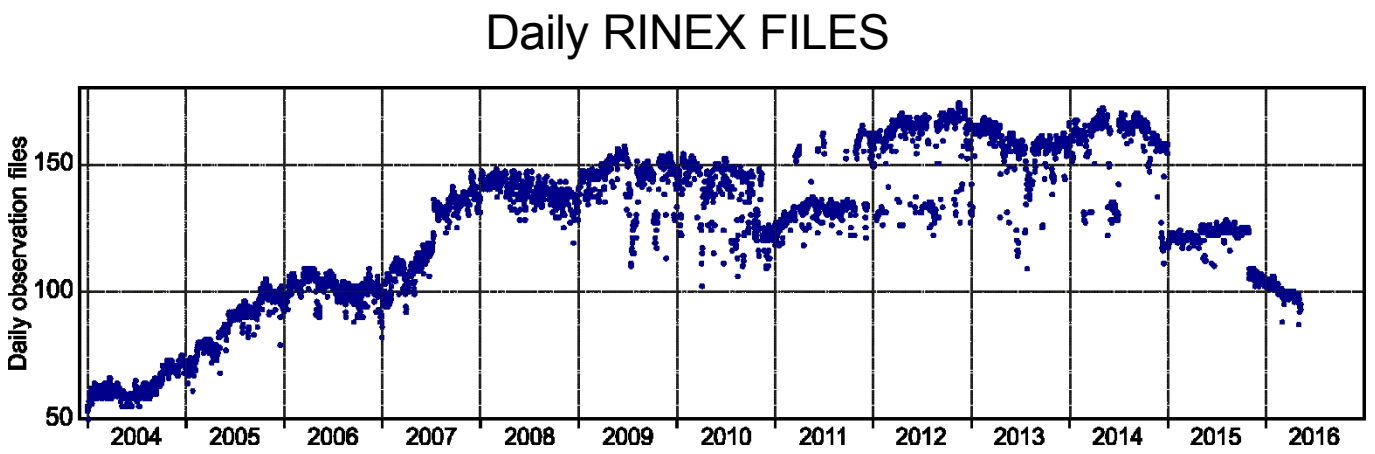


Tectonics of the Alpen region with their plates (i.e. Eurasian, Pannonian, Adriatic and Liguria). The red line represents the Alpen orogen (Bird, 2003). Black lines are the tectonic faults (Source: http://diss.rm.ingv.it/share-edsf/).
The topography is taken from the ETOPO1 model (Amante and Eakins, 2009. Source: https://www.ngdc.noaa.gov/mgg/global/global.html).

CGNSS Stations with freely avail. Data



Amount of Data available in Time

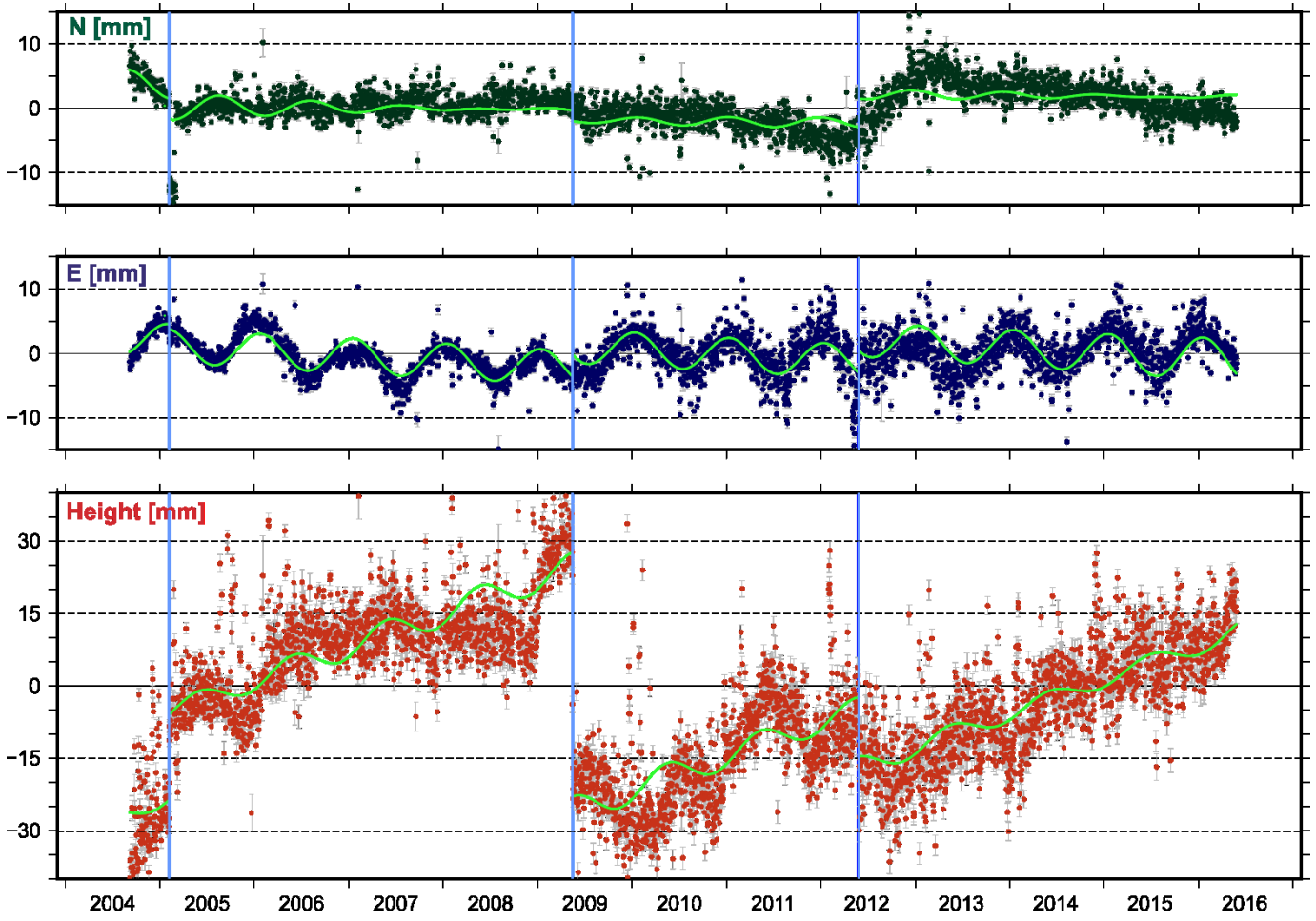


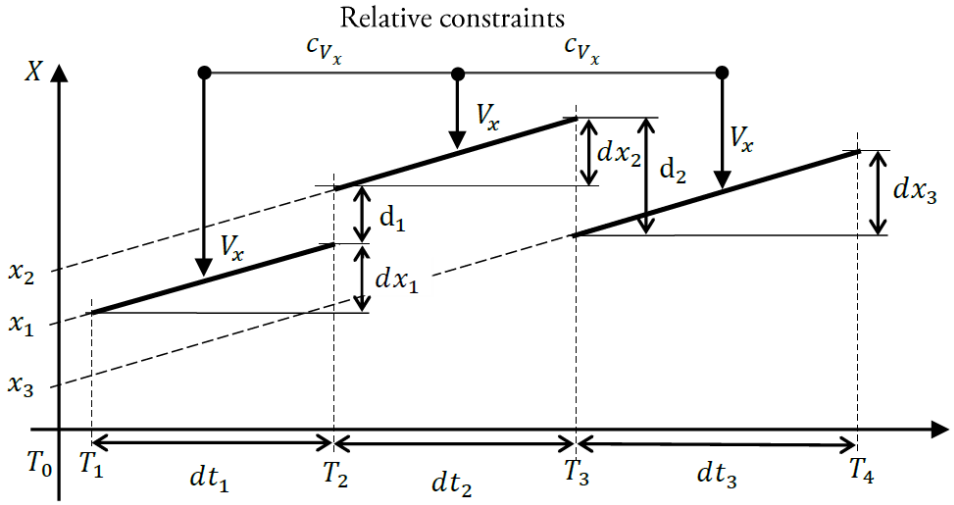
- Data analysed span the period between 1.1.2004 until 30.5.2016
- 194 GNSS sites were included in the network
- 570.000 daily RINEX observation files were processed
- Between 2012 and 2015 almost 180 daily RINEX files were processed for each day

Analysis of the GNSS Data

- Data from the systems GPS and GLONASS have been processed (sampling 30s)
- Implementation in the reference frame IGb08
- The data were processed with BERNESE 5.2
  - Type mean antenna calibrations models were (igs08.atx) used
  - CODE final orbits: reprocessed (2004-2013) & final/operational (2014-1016))
  - Tropospheric zenith delays based on the global mapping function (GMF)
  - Ocean tide loading is estimated with the FES2004 model
  - Linear velocity estimation using ADDNEQ2 (at least 3 years of data have to be available)
  - Analysis of the position time series for the detection of outliers and sudden jumps

Analysis of Position Time Series (BOLG)





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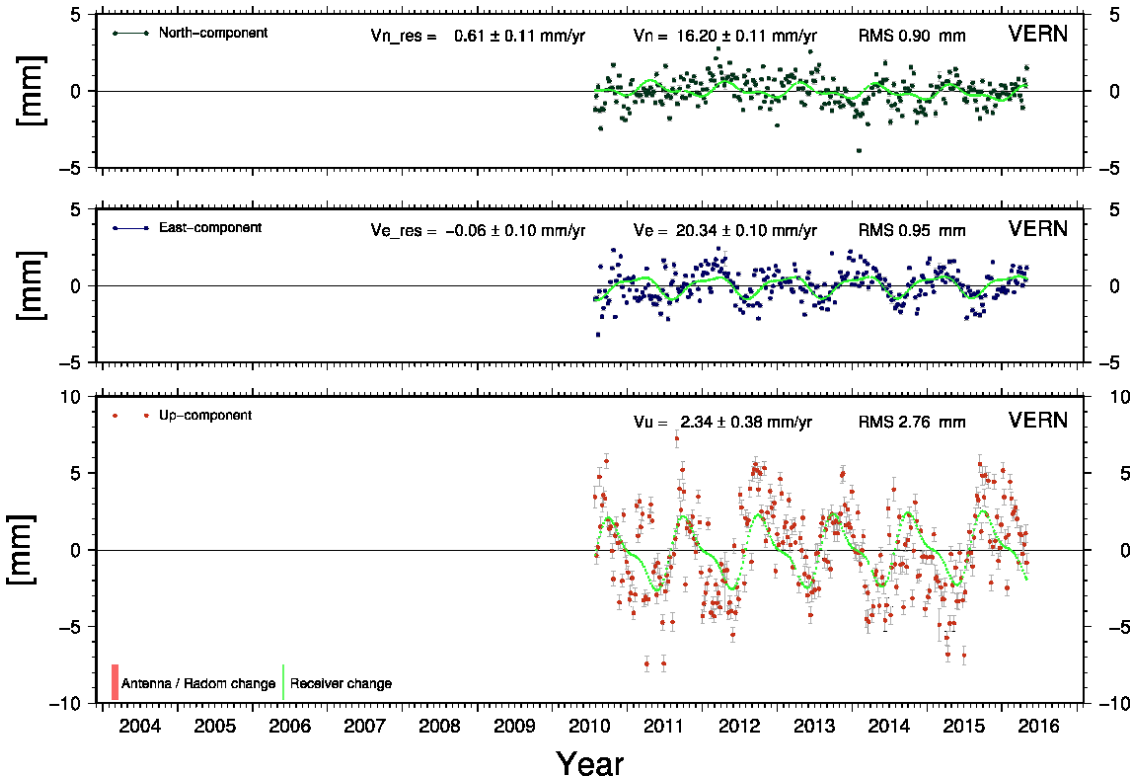
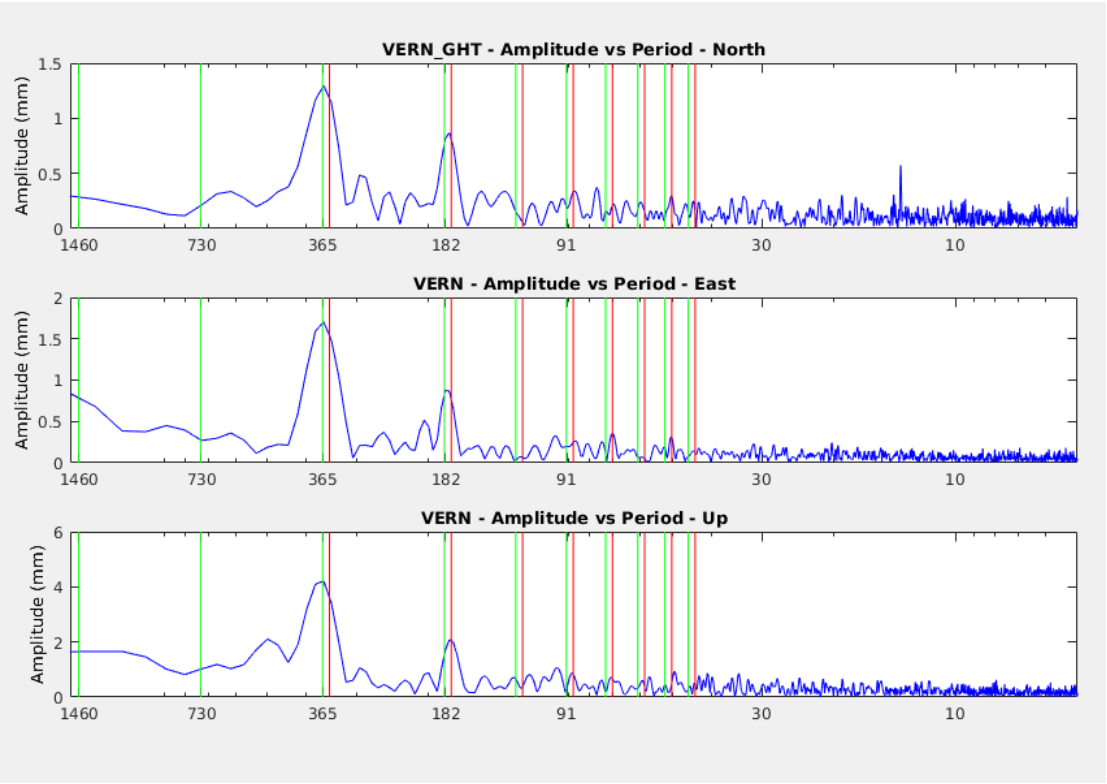
Analysis of Position Time Series (VERN)





VERN	V_{North}	V_{East}	V_{Height}	S_{north}	S_{east}	S_{height}
	[mm/a]			[mm]		
Linear	16.06	20.38	2.25	2.39	2.20	5.85
Lin.+a+1/2a(Ampl.)	16.04	20.37	2.29	2.01	1.67	5.03

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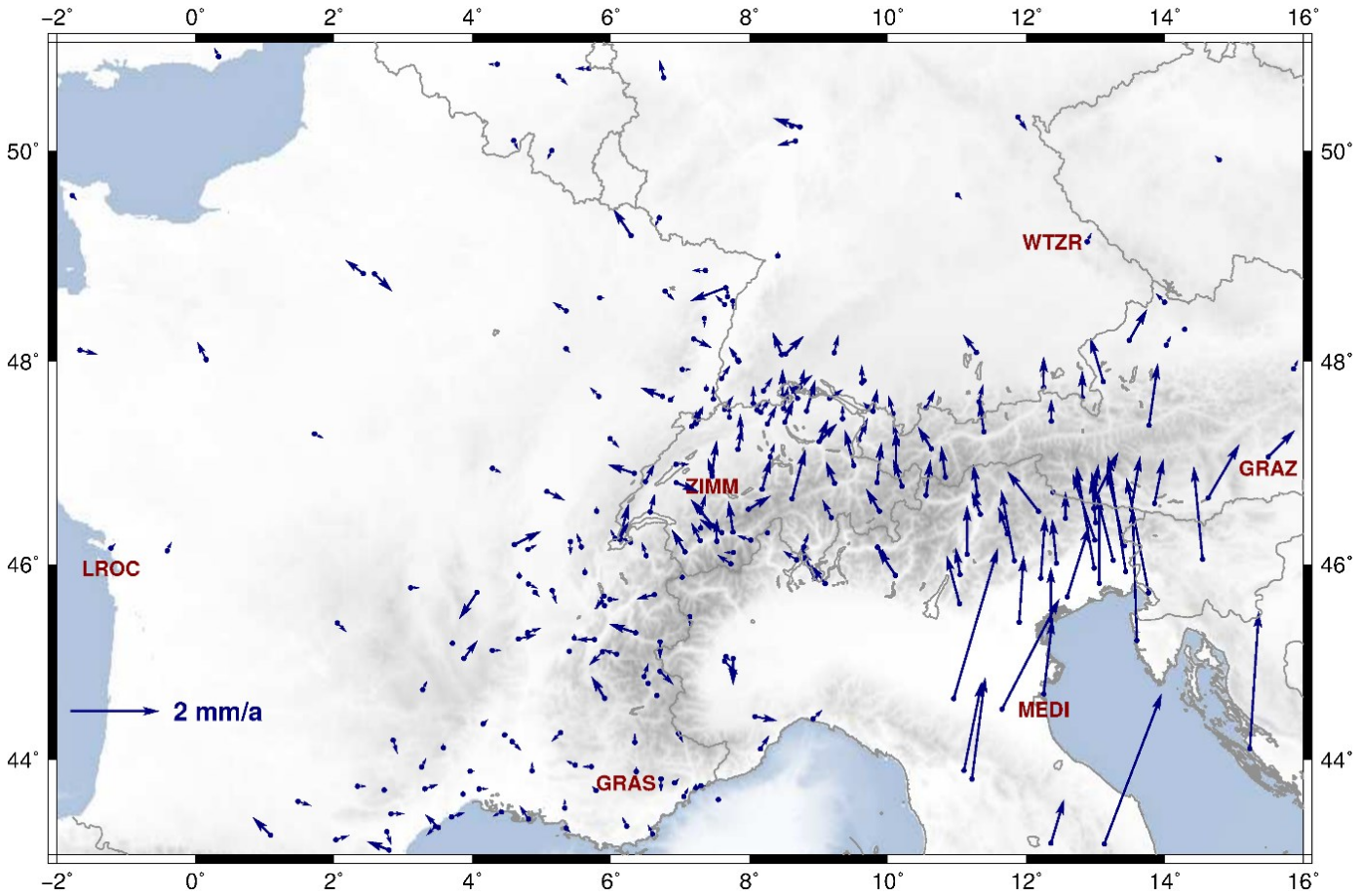
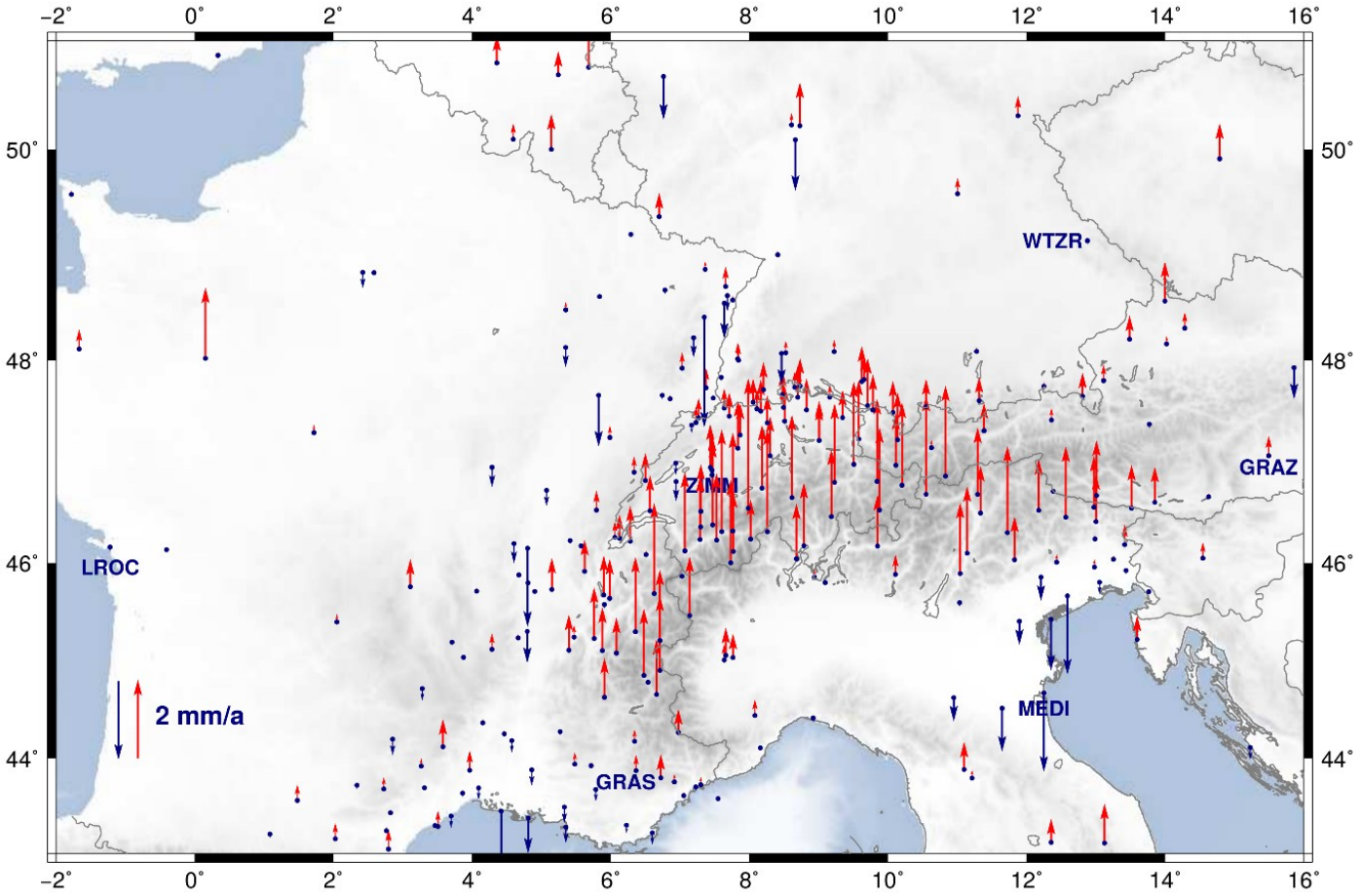
Horizontal Velocities (ETRF 2000)



Standard deviation of the horizontal components: ~ 0.2 mm/a

Plus velocities from **SWISSTOPO**

Vertical Velocities



Standard deviation of the vertical components: ~ 0.4 mm/a

Plus velocities from **SWISSTOPO**

Velocity Comparison with other Groups

Project	Common Sites	MEAN_N [mm/a)	SDEV_N [mm/a]	MEAN_E [mm/a]	SDEV_E [mm/a]	MEAN_U [mm/a]	SDEV_H [mm/a]
AlpArray Init. (alp08)	114	-0.15	0.20	-0.37	0.18	-0.47	0.58
EPN Densifi-cation (epnd14)	108	0.05	0.20	-0.05	0.28	0.39	0.66
CEGRIN 14 (cgn14)	78	-0.08	0.21	-0.01	0.33	-0.14	0.73
Swisstopo 16 (ch16)	50	-0.05	0.14	-0.16	0.19	-0.17	0.41
EPN14	47	-0.02	0.19	-0.07	0.19	0.20	0.41
ITRF14	18	0.04	0.24	0.02	0.14	0.38	0.37

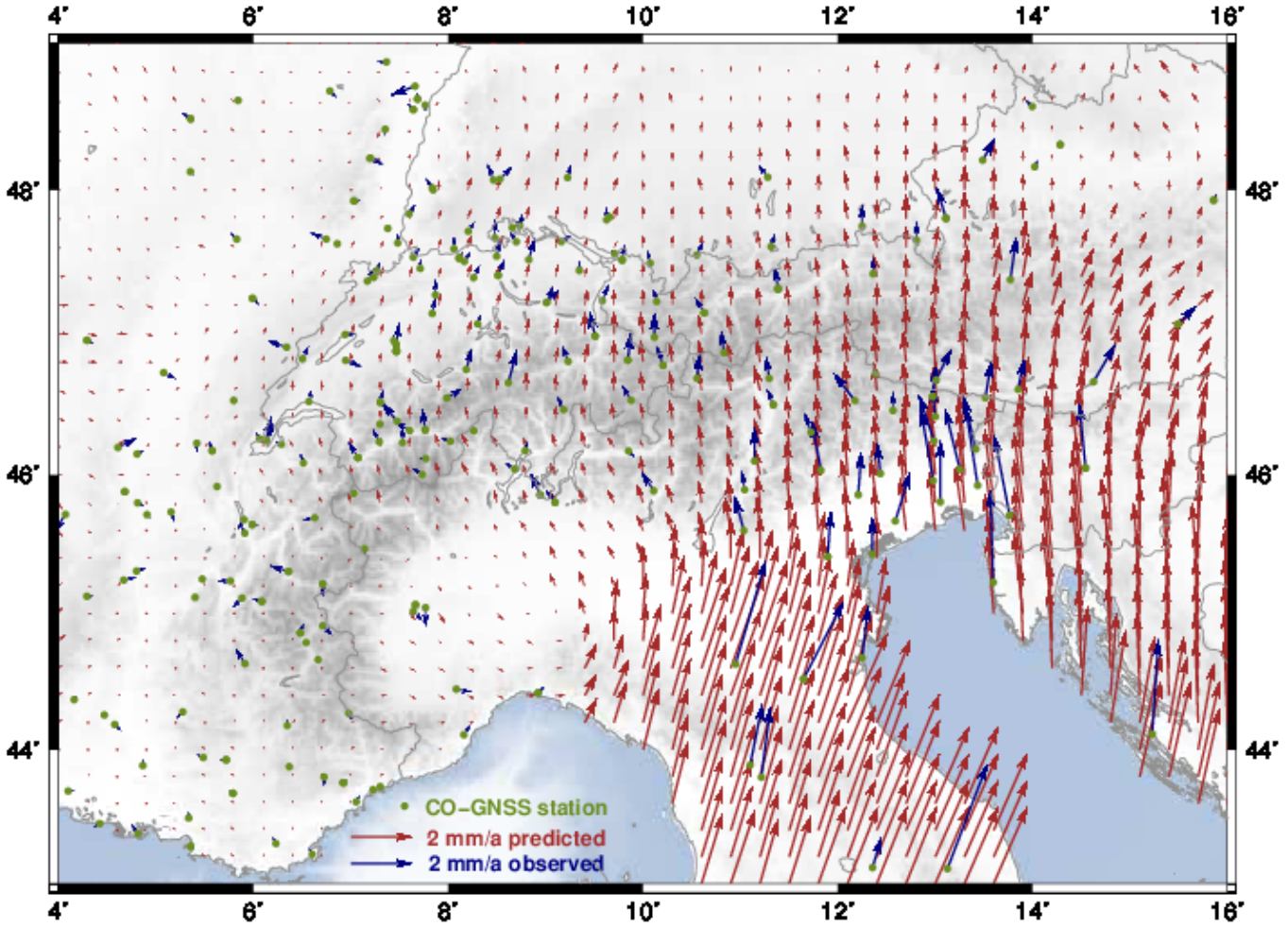
Source: EUREF Working Group on European Dense Velocity

http://pnac.swisstopo.admin.ch/divers/dens_vel

Deformation Models

- Separation between horizontal and vertical movements in two models
- Mean standard deviation for horizontal velocities 0.2 mm/a and 0.4 mm/a for vertical movement respectively
- Velocity components are derived for a grid (25 km x 25 km) via least-squares collocation (LSC)
  - Grid width corresponds to average station distance
  - Correlation length d ~ 100 km
- Separation of the trend (horizontal plate movement) required in advance
- Deviations in the velocity of a single station of more than 0.5 mm/a from surrounding stations were interpreted as local effects and were removed in the collocation

Horizontal Deformation Model of the Alps



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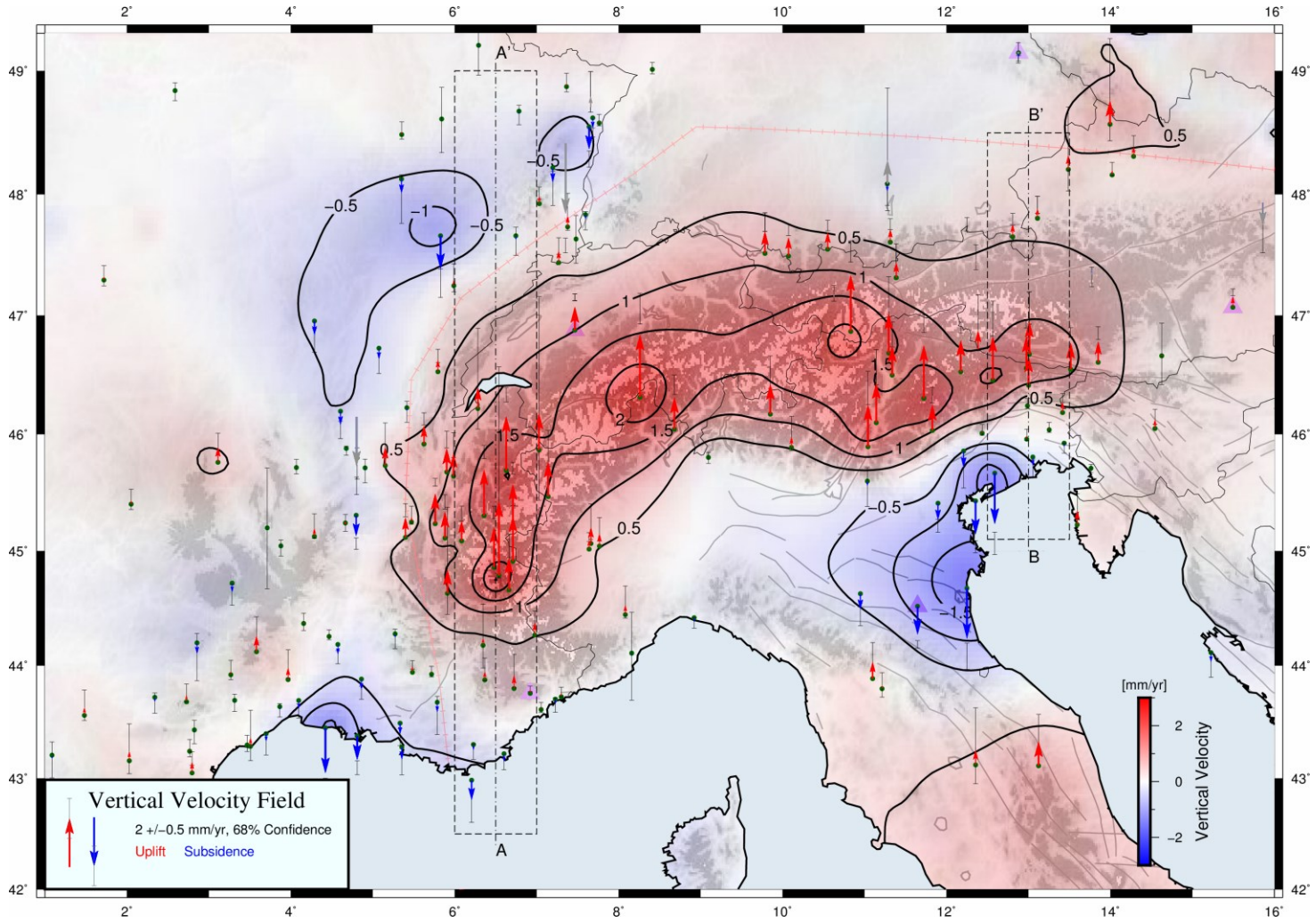
Vertical Deformation Model of the Alps



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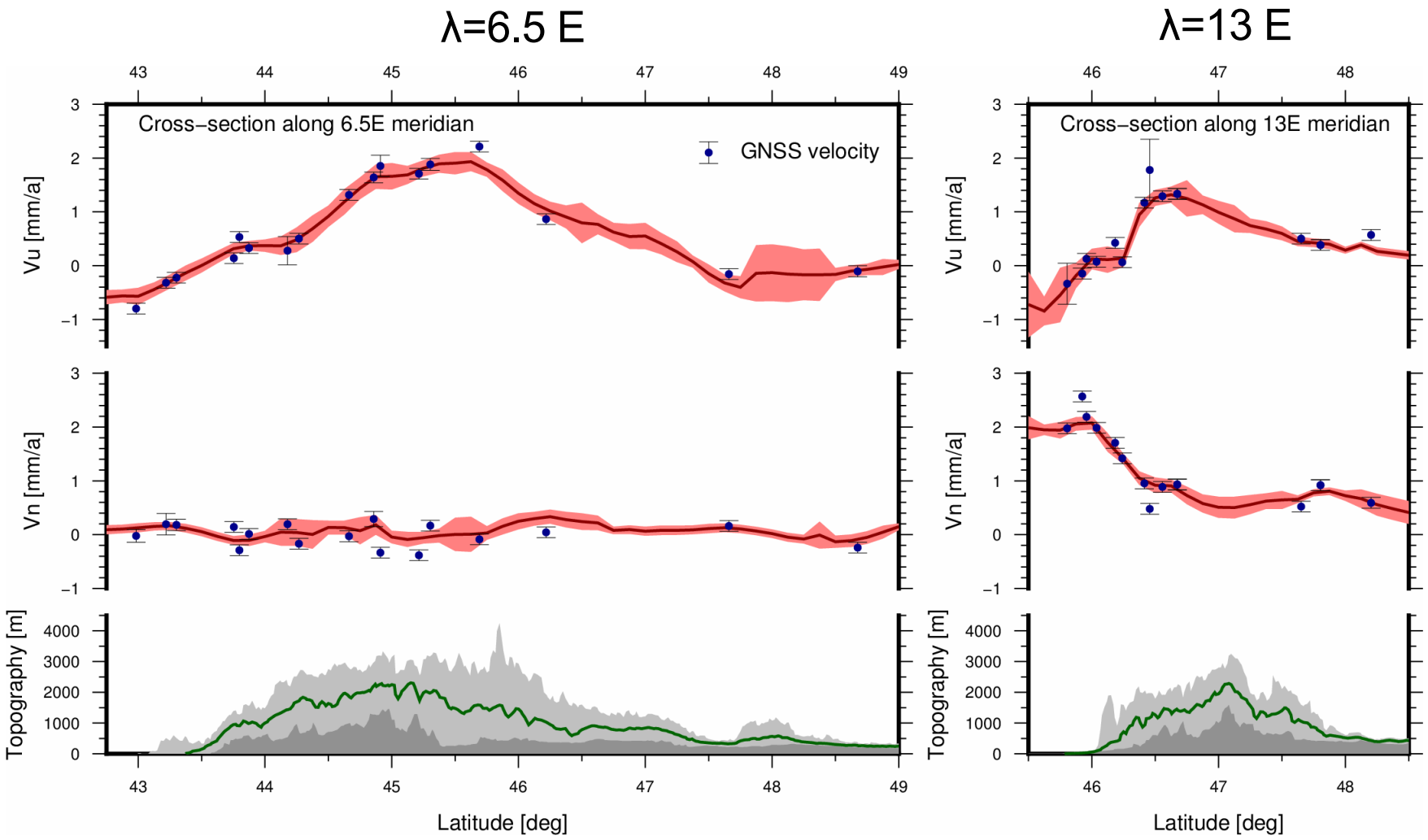
Velocity Profiles in North-South-Directions



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Outlook

- The mean uplift rate of the Alps is 1.8 mm/a, with largest rates of 2.5 mm/a in the central are of the Western and the Southern Alps
- Subsidence can be found in the Upper Rhine Graben, the Bresse Graben and the Venetian-Friuli Basin
- Analysis is completed for now - but collection of GNSS Data will be continue for the next years
- Reprocessed products available in the IGS14 will allow a re-analysis over a longer period of time
- Published in Earth System Science Data ESSD:
  - Sánchez, L., Völksen, C., Sokolov, A., Arenz, H., and Seitz, F .: Present-day surface deformation of the Alpine region inferred from geodetic techniques, Earth Syst. Sci. Data, 10, 1503-1526, https://doi.org/10.5194/essd-10-1503-2018, 2018
- Numerical results are available through the World Data Center *Pangaea*
  - https://doi.pangaea.de/10.1594/PANGAEA.886889