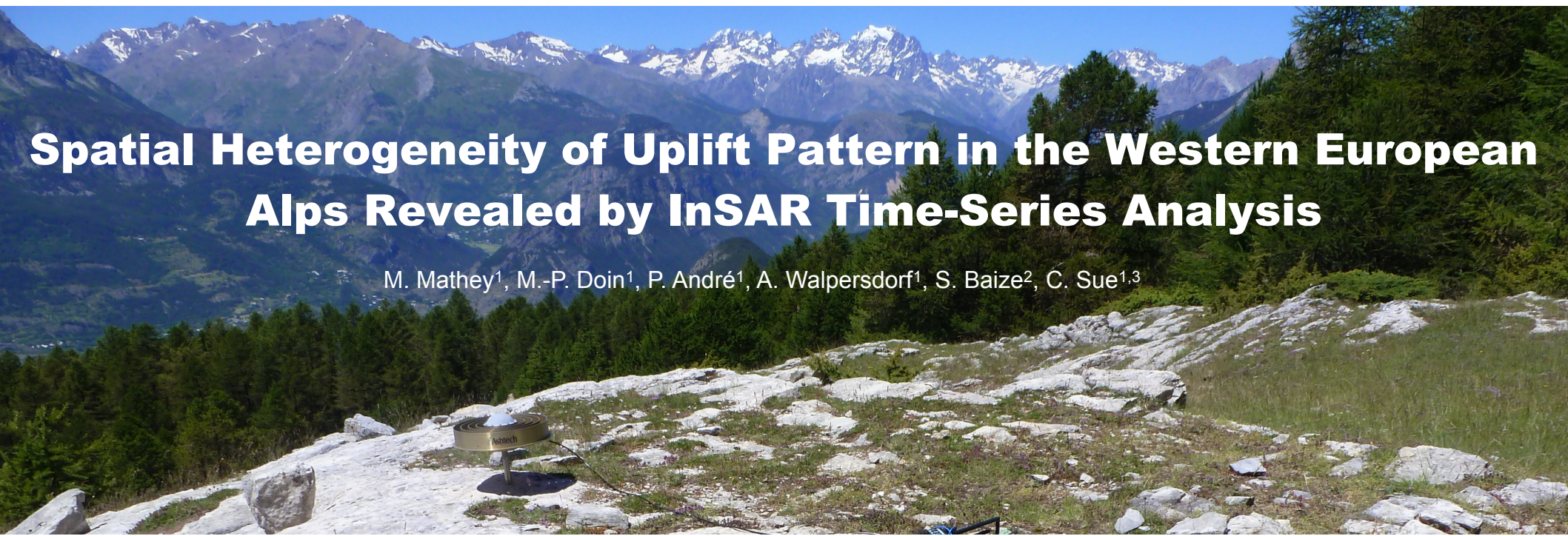




Spatial Heterogeneity of Uplift Pattern in the Western European Alps Revealed by InSAR Time-Series Analysis

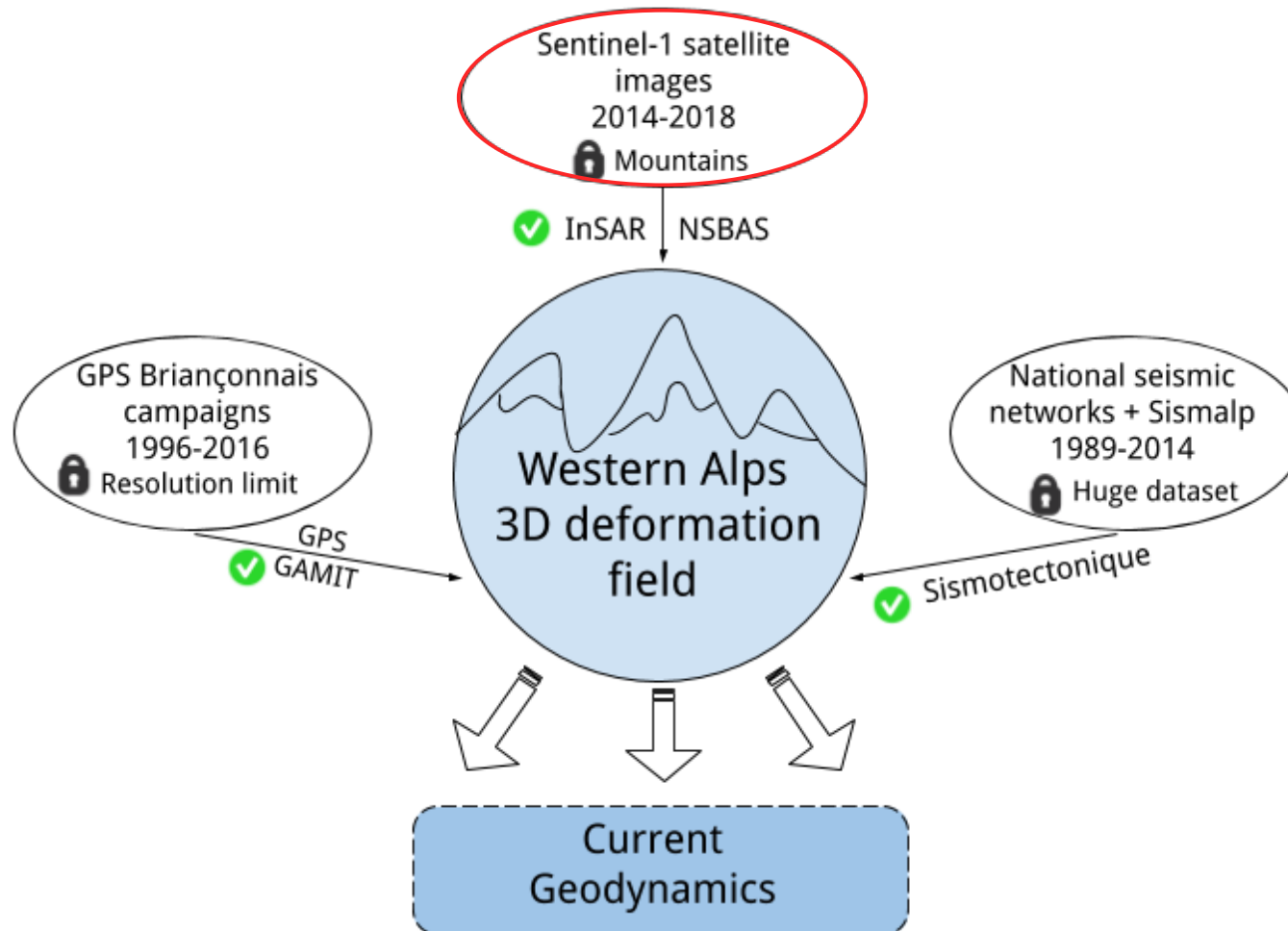
M. Mathey¹, M.-P. Doin¹, P. André¹, A. Walpersdorf¹, S. Baize², C. Sue^{1,3}

¹University Grenoble Alpes, University Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, Grenoble, 38000, France.

²IRSN, PSE-ENV/SCAN/BERSSIN, BP 17, Fontenay-aux-roses, F-92262, France.

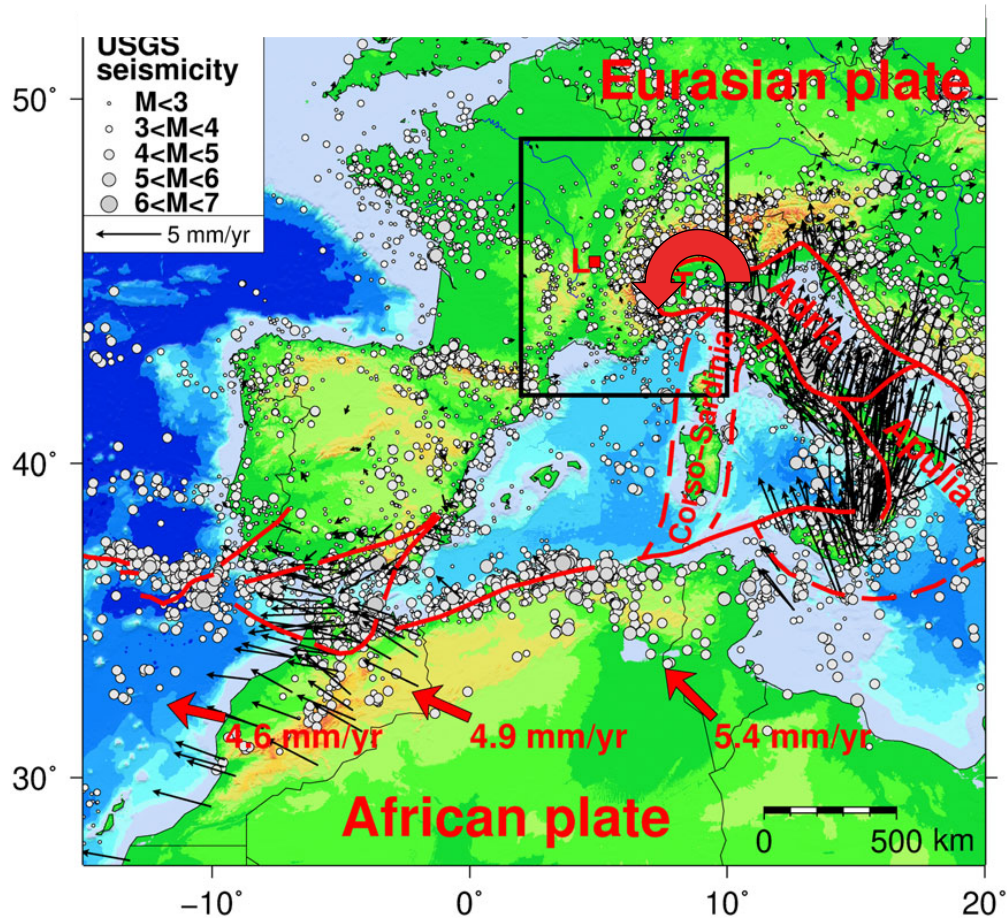
³Chrono-Environnement Besançon, OSU THETA, University Bourgogne-Franche-Comté, Besançon, 25000, France.

→ Up to 25 years of complementary data records and methods enhancement



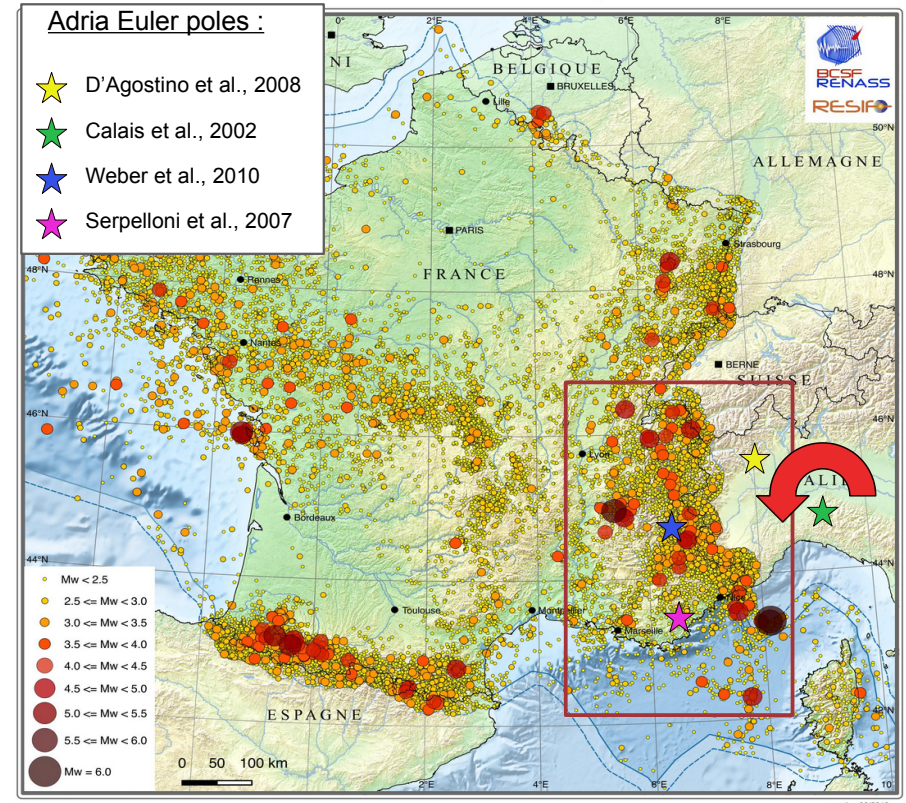
Seismotectonic context

Present-day kinematics of the Mediterranean region



- low horizontal deformation rates
- low to moderate seismicity

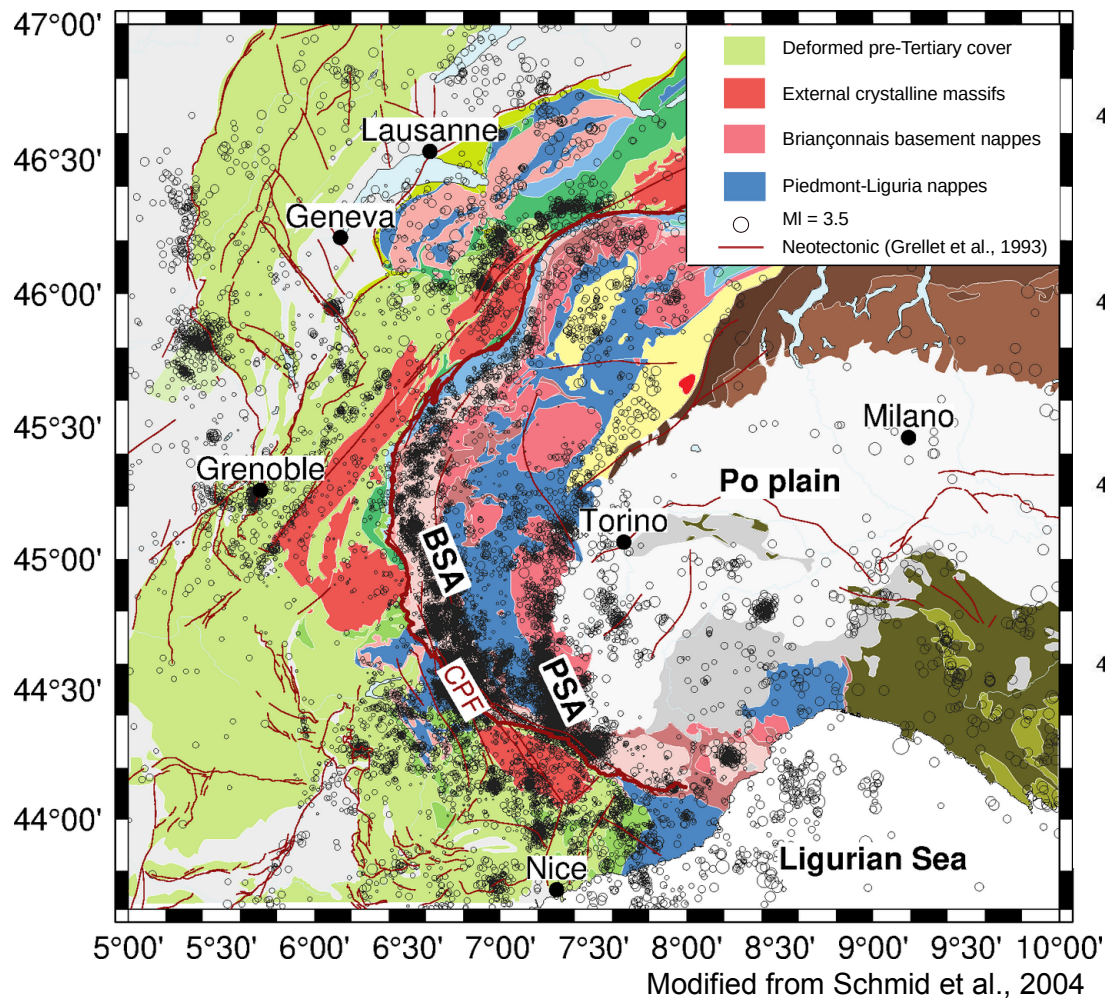
Instrumental seismicity of the Western Alps



Epicentres des séismes d'origine naturelle dans la zone SI-Hex (France métropolitaine et zone économique exclusive en mer (ZEE), avec élargissement de 20 km). Catalogues de sismicité utilisés : sur la période 1962-2009 le catalogue issu du projet SI-Hex (Cara et al. 2015, <http://www.franceseisme.fr>), sur la période 2010-2018 le catalogue BCSF-ReNaSS, pour lequel la magnitude MI a été convertie en Mw.

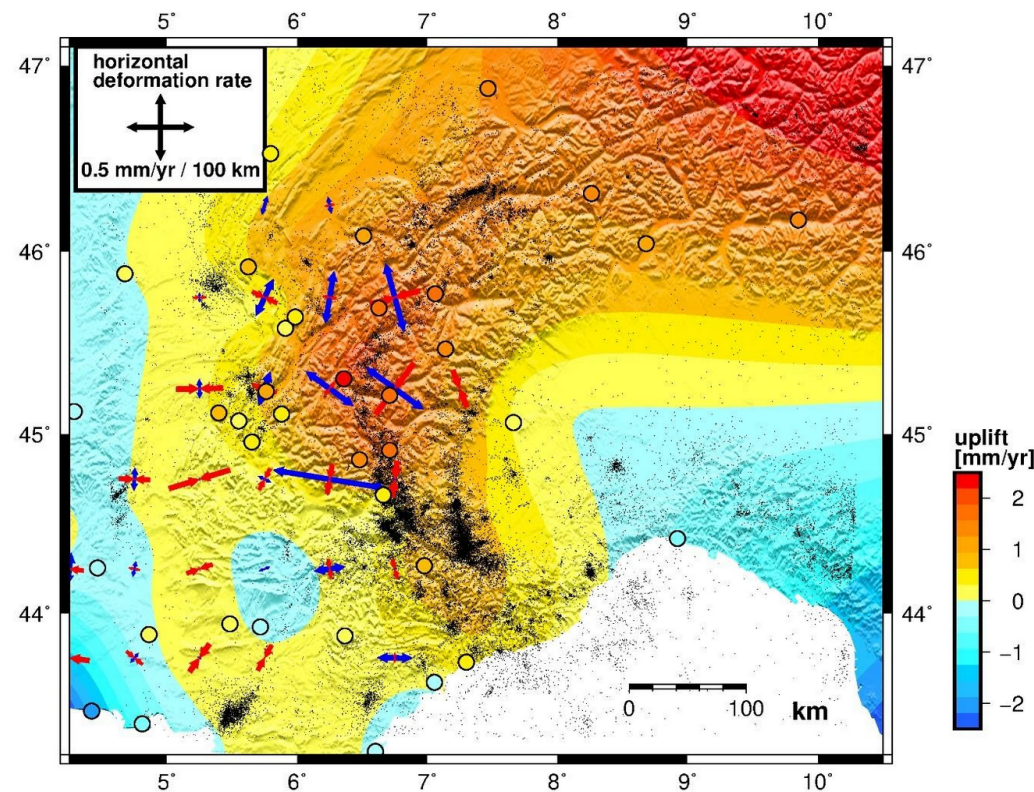
Cara et al., 2015

Geological settings and seismicity



- 2 main seismic arcs
- PF dividing internal and external zones

Geodetic context : uplift and extension



Walpersdorf et al., 2018

⇒ What is the spatial variability of the uplift ?

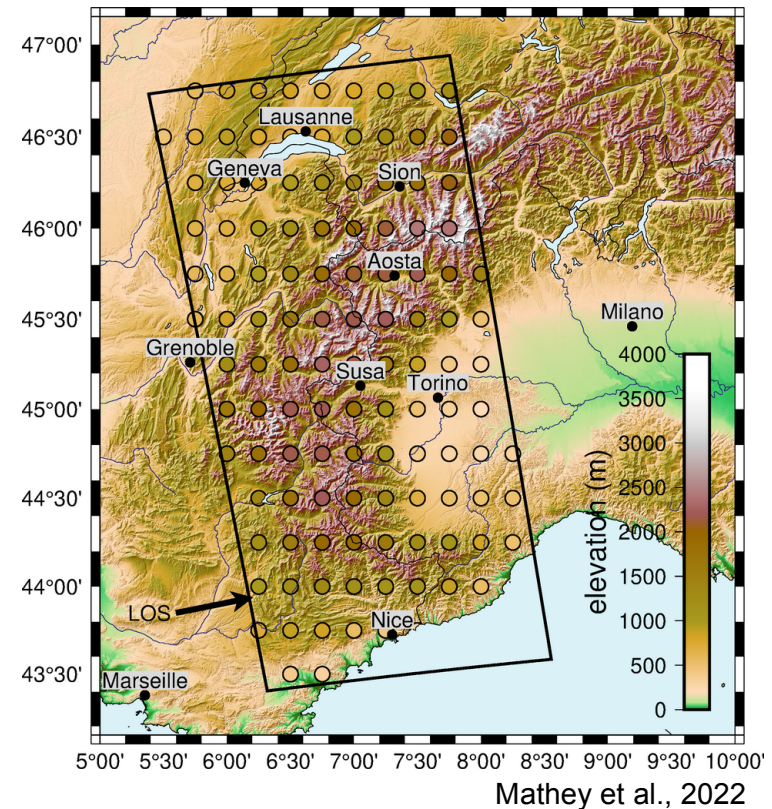
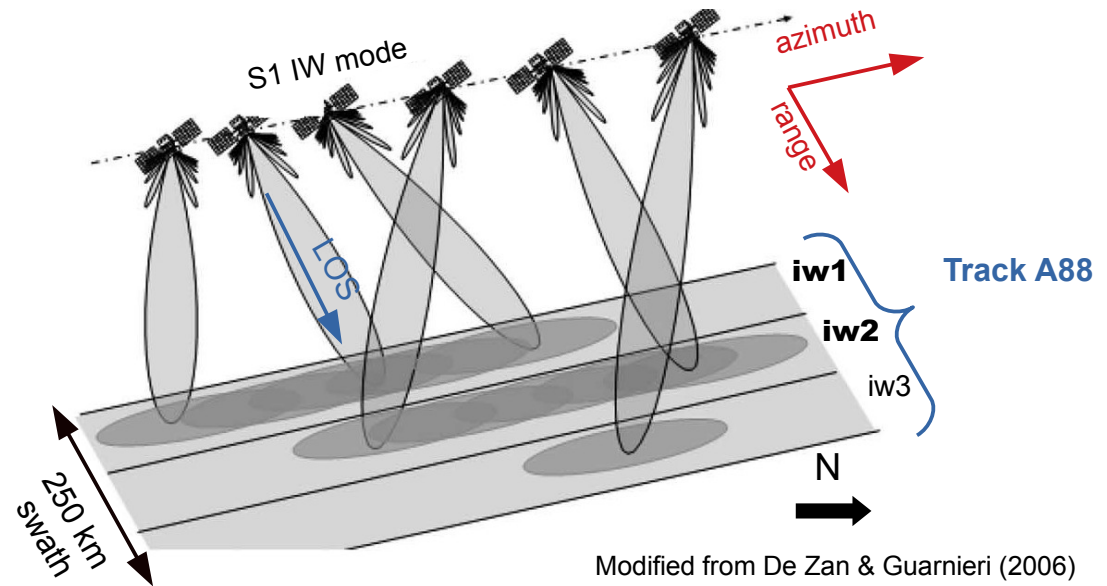
Interferometric Synthetic Aperture Radar

- Sentinel-1 satellite
- 173 acquisitions during 2014-2018 :
Sentinel 1-A launched 2014
Sentinel 1-B launched 2016
} 1 acquisition / week
- **small baseline** approach (NSBAS, Doin et al., 2011)
- time serie inversion procedure
- Interferometric phase requiring corrections :

$$\varphi = \varphi_{\text{orb}} + \varphi_{\text{topo}} + \varphi_{\text{def}} + \varphi_{\text{APS}} + \varphi_{\text{bruit}}$$

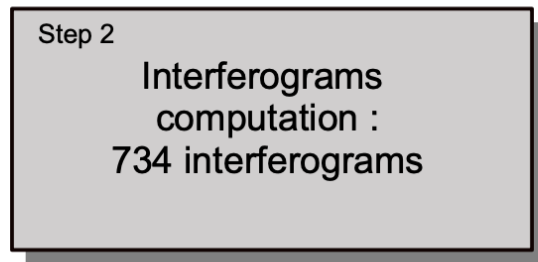
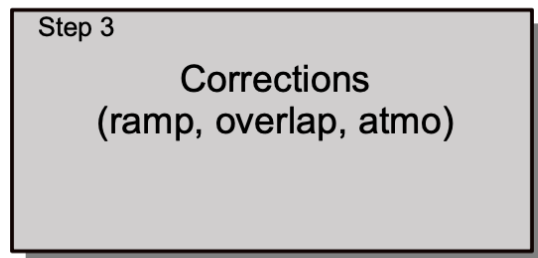
φ_{def} → ~1-2 mm/yr
 φ_{APS} → ~10-20 mm/yr
 φ_{bruit} → snow, vegetation

⇒ **challenging area**

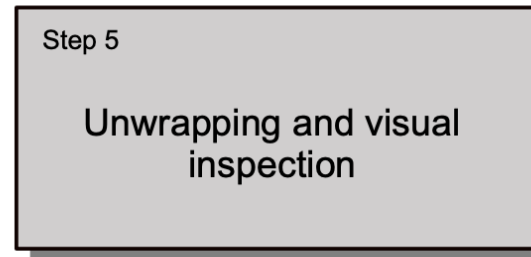
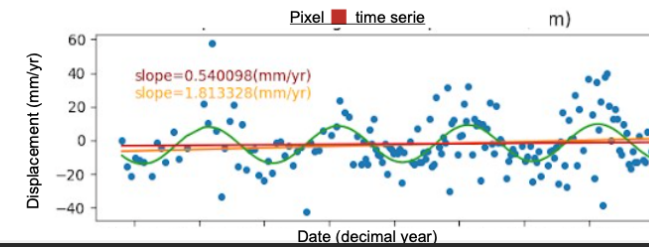


NSBAS workflow

2014/11/04 - 2014/11/28

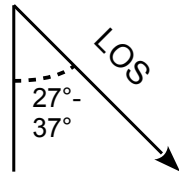
2014/11/04 - 2014/11/28
ERA5

ERA5_filtSW

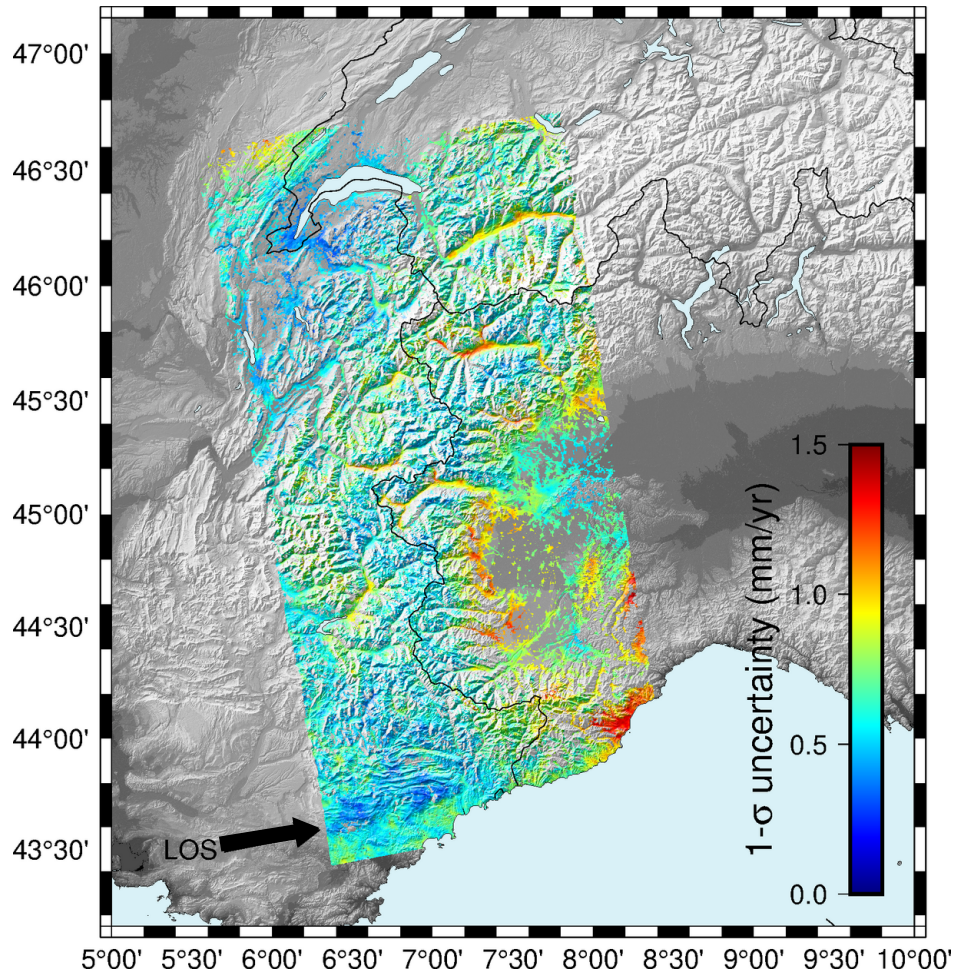
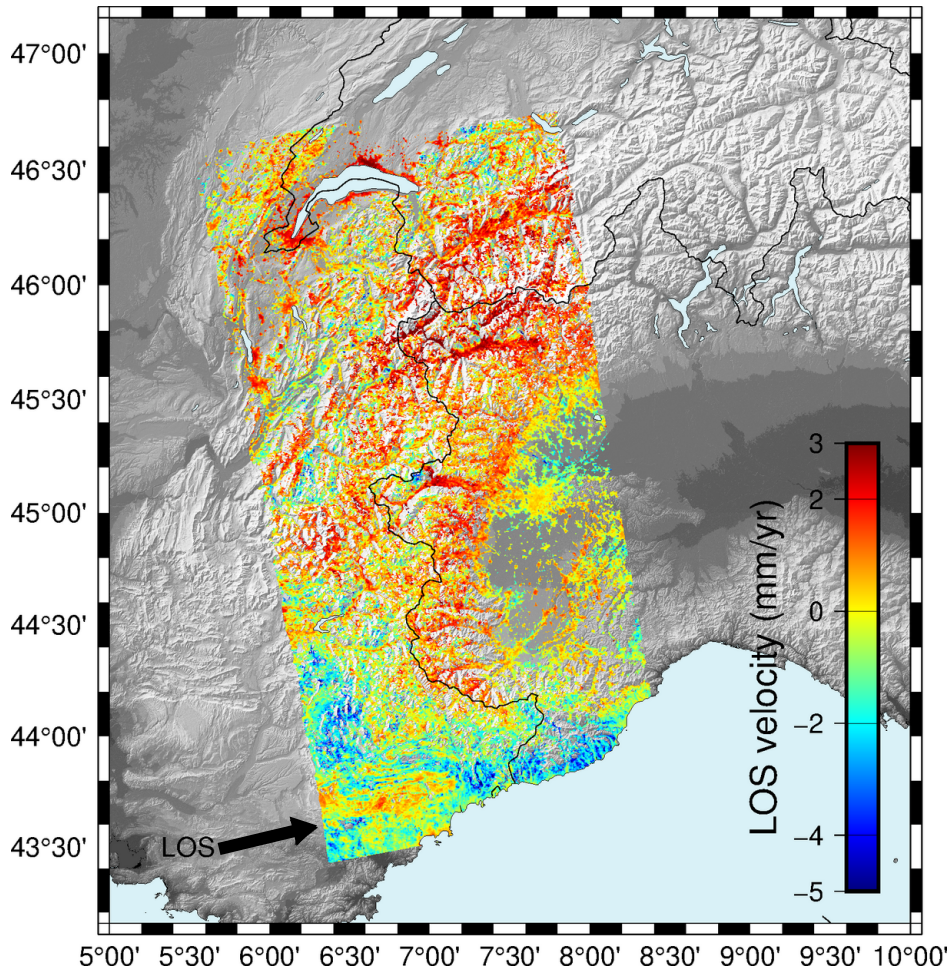
2014/11/04-2014/11/28
ERA5_filtSW_corr

Velocity estimates

Velocity map in line of sight



Velocity uncertainty map

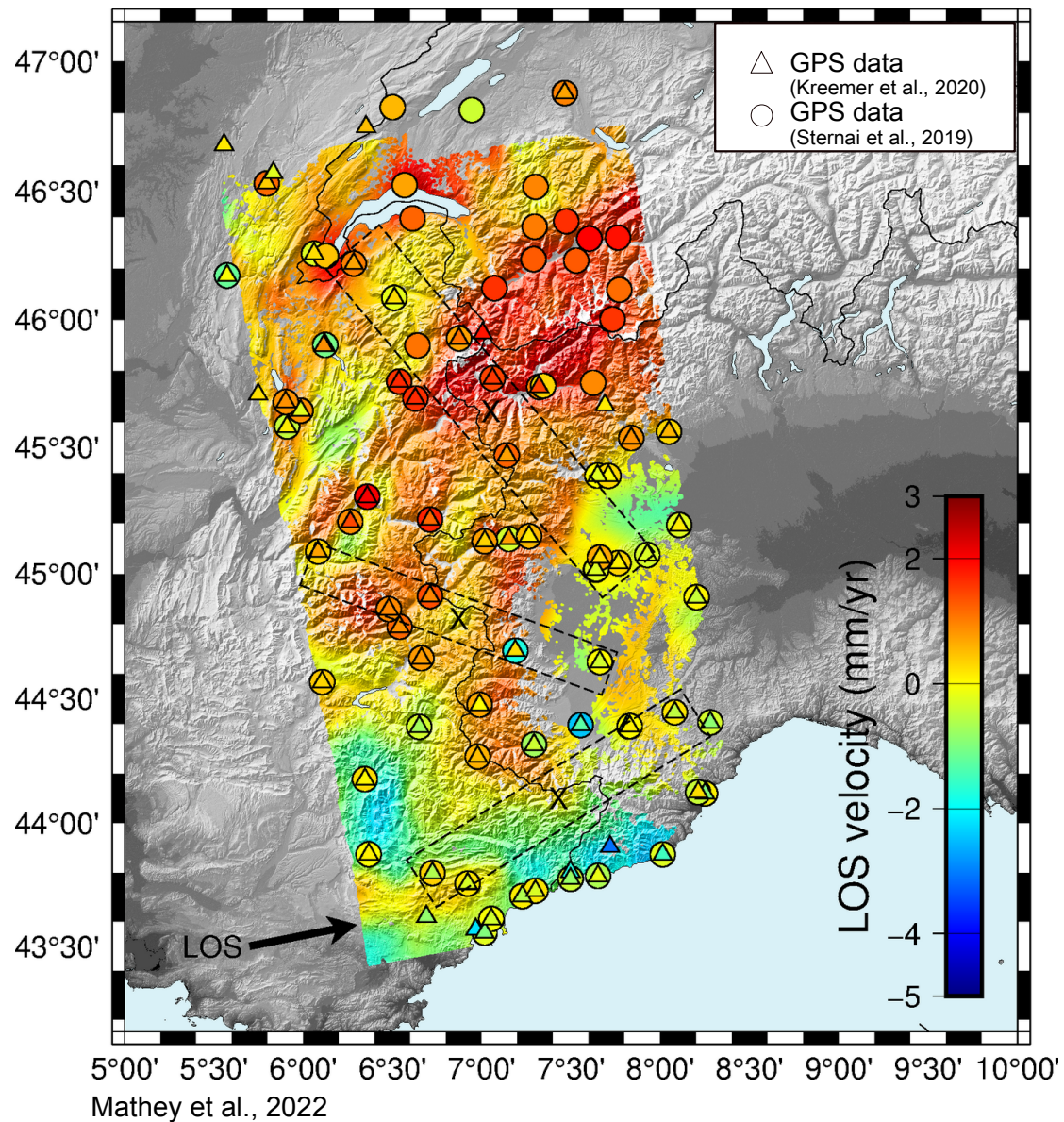


Mathey et al., 2022

- Pixels masked according to criteria and DSGSD map (André 2020)
- red/blue areas (moving toward/away from the satellite) interpreted as uplift and subsidence motions
- Higher uncertainties : deep valleys (atmospheric residuals) and Po plain (seasonal loading)

Velocity estimates

Comparison with GPS data in LOS



- Smoothed velocity map :

Pixels with $\sigma > 0.8$ mm/yr masked

spatial smoothing = 20 km width gaussian filter

- Global pattern :

Uplift in the core of the belt

Subsidence at the coast and in the Po plain

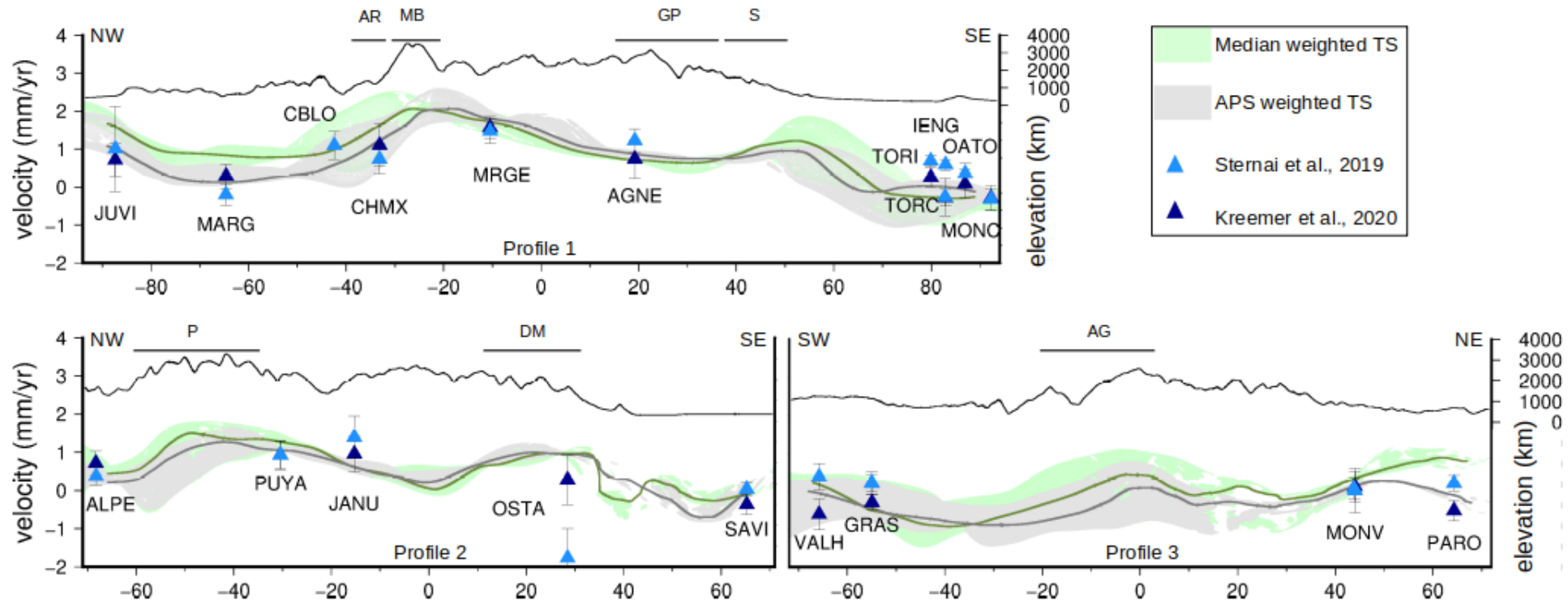
Good overall agreement ($cc \sim 0.65$)



Sharing is encouraged

Velocity estimates

Comparison with GPS data in LOS



Mathey et al., 2022

Global pattern :

Uplift in the core of the belt

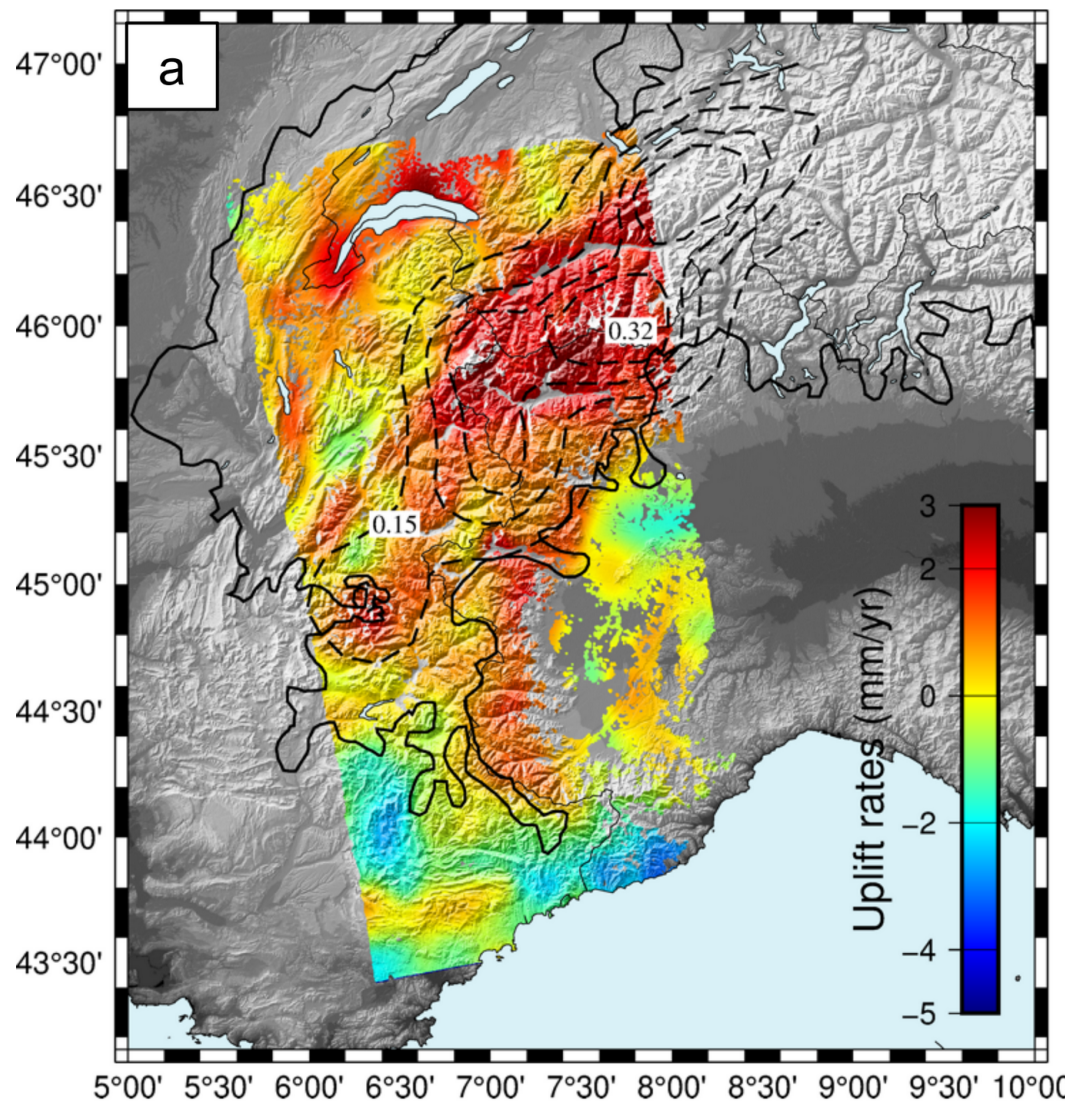
Subsidence at the coast and in the Po plain

Good overall agreement ($cc \sim 0.65$)

Velocity estimates

Comparison with ice unloading models

- Uplift maximum in the higher elevation areas (northern W. Alps)
→ within LGM extent
- Short wavelength spatial variations of the uplift pattern
→ not explained by LGM rebound
→ spatially correlated to LIA and present-day glacier shrinkage rebound models but amplitude too low

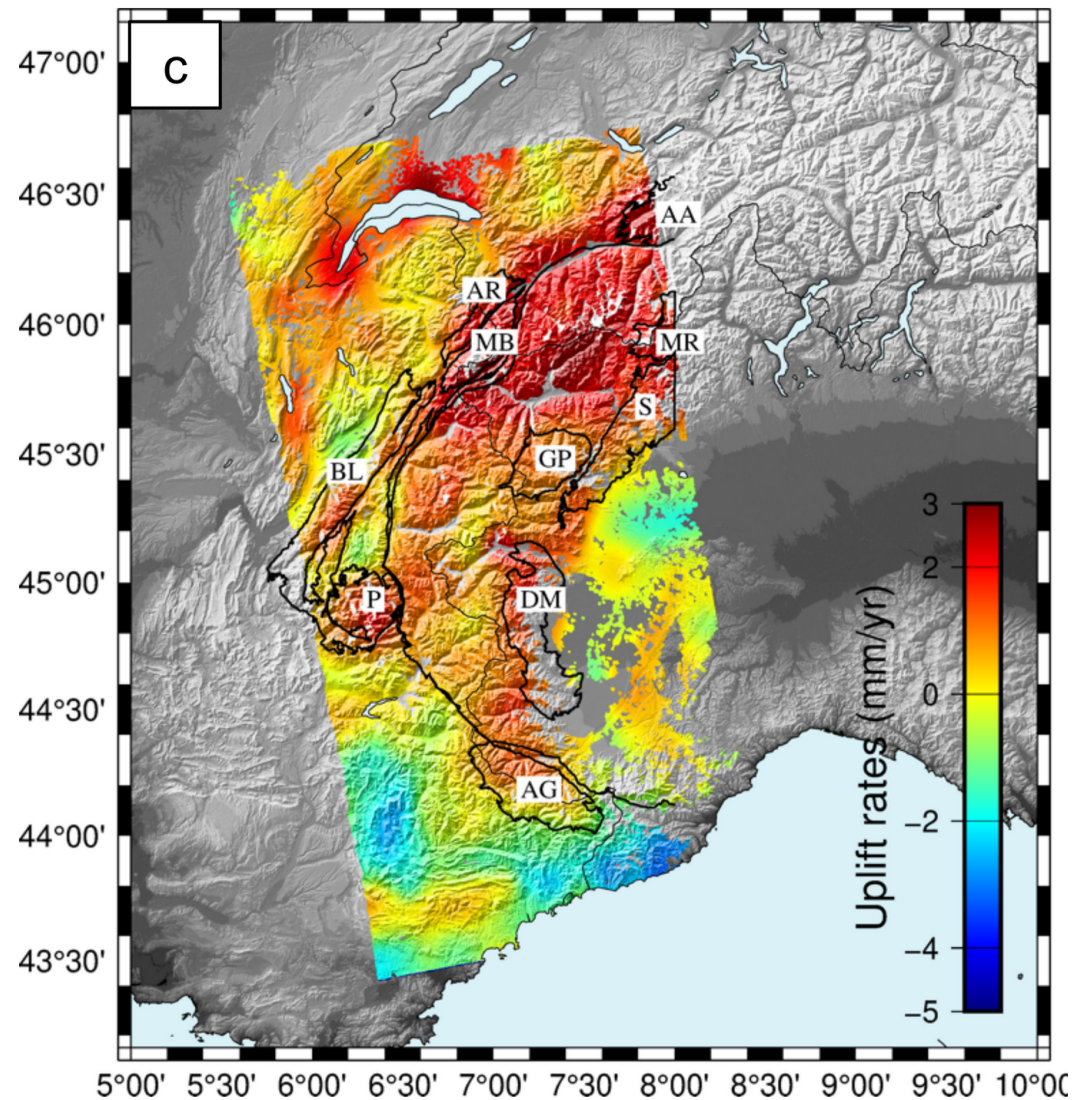


Mathey et al., 2022

Velocity estimates

Comparison with geological features

- Uplift maximum in the higher elevation areas (northern W. Alps)
→ within LGM extent
- Short wavelength spatial variations of the uplift pattern
→ not explained by LGM rebound
→ spatially correlated to LIA and present-day glacier shrinkage rebound models but amplitude too low
- Differential uplift in the external crystalline massifs wrt surroundings : Pelvoux (P), Belledonne (BL), Mont-blanc (MB) and Aiguilles rouges (AR) massifs



Mathey et al., 2022



Sharing is encouraged

Velocity estimates

- **Thermochronometric ages** derived from apatite fission tracks (AFT) and inverted **exhumation rates** (Fox et al., 2015)
- Younger ages correspond to higher exhumation rates
- Exhumation rates higher on the **external massifs**

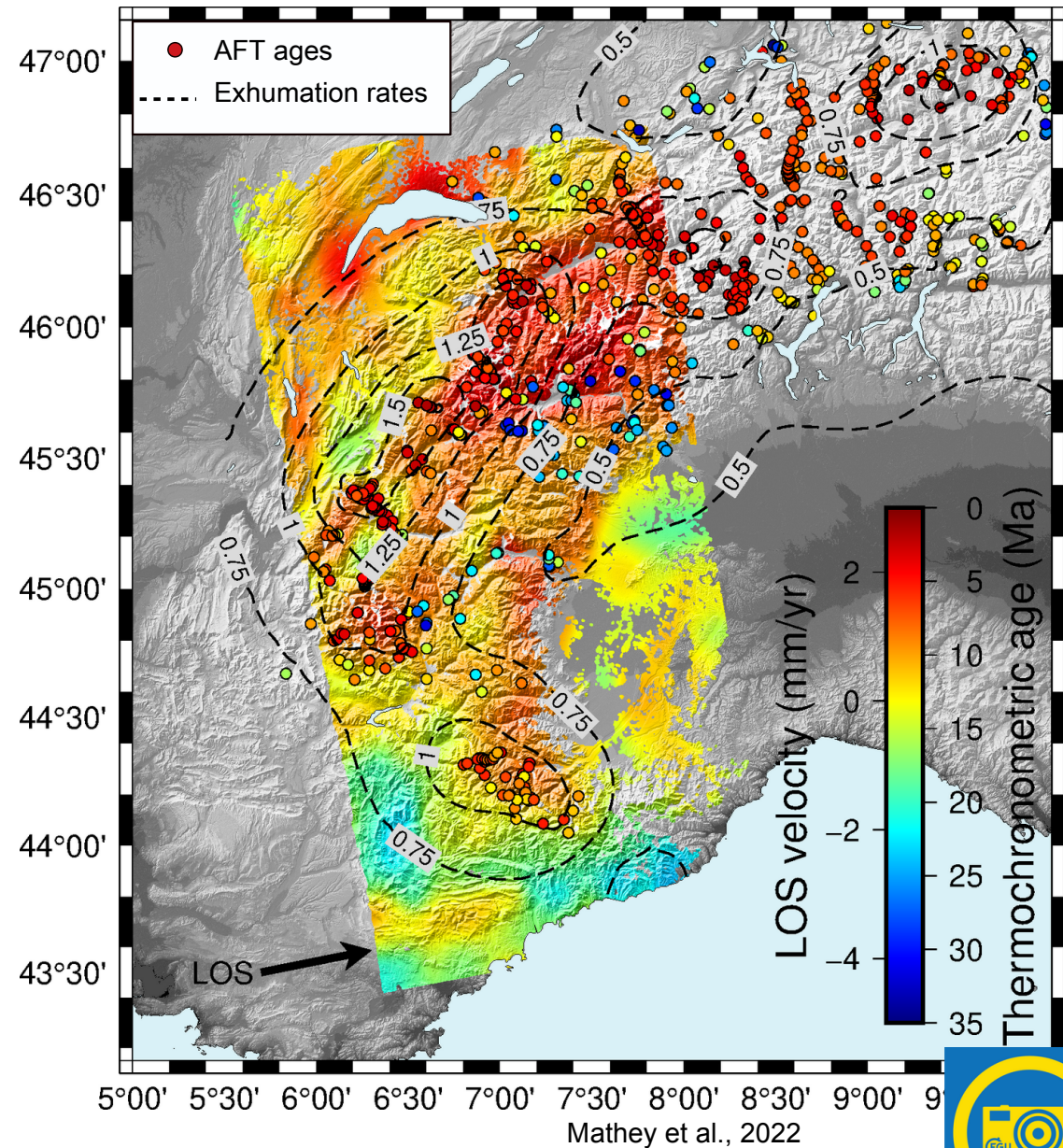
→ what is the spatial variability of the uplift ?

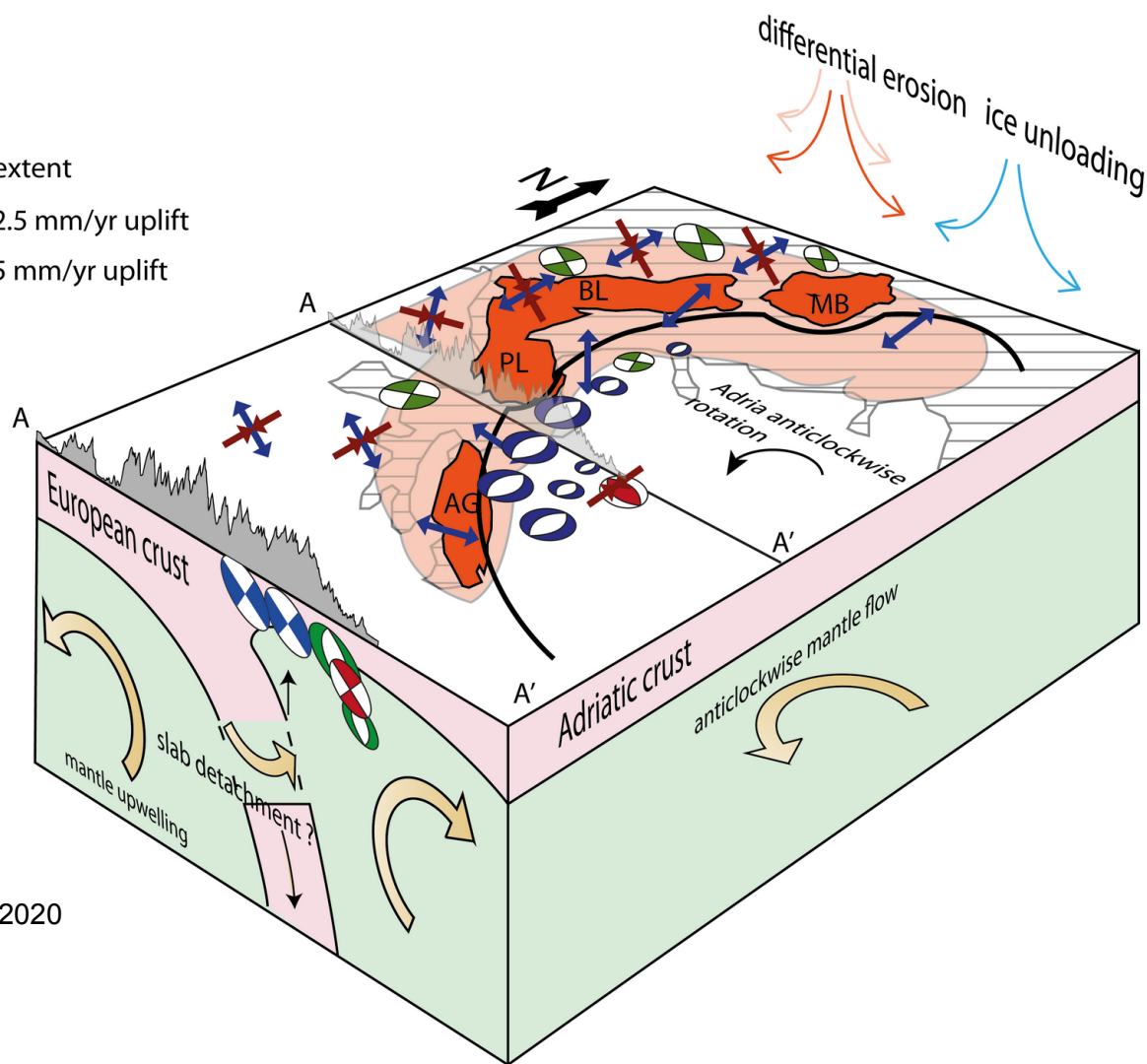
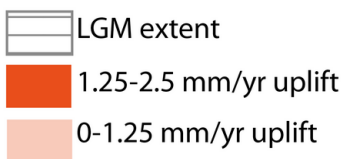
⇒ Localized velocities

⇒ Differential surficial response

⇒ Suggests heterogeneous rheologies

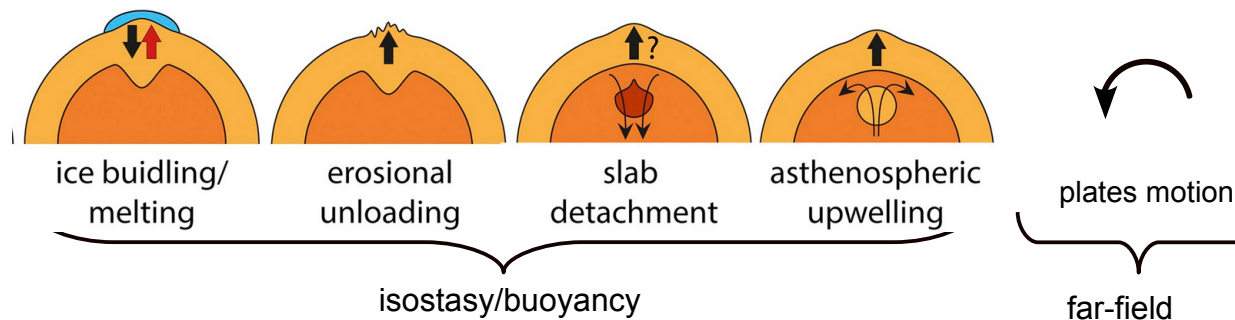
Comparison with exhumation rates (< 2Ma)





Mathey, 2020

Sternai et al., 2019



Geodynamic conclusions

→ what is the spatial variability of the uplift ?

- Long wavelength moderate uplift rates field
- Short wavelength high uplift rates field

⇒ uplift and extension localized but spatially decorrelated

⇒ Differential surficial response = rheological control

⇒ Overlay of $\neq \lambda$ processes



Further readings

Mathey M., Doin M.P., André P., Walpersdorf A., Baize S., Sue C., (in press), Spatial heterogeneity of uplift pattern in the Western European Alps revealed by InSAR time series analysis. *Geophysical Research Letters*. <https://doi.org/10.1002/essoar.10507009.1>

Mathey M., Walpersdorf A., Sue C., Baize S., Deprez, A. (2020). Seismogenic potential of the High Durance Fault constrained by 20 yr of GNSS measurements in the Western European Alps. *Geophysical Journal International*, 222(3). doi.org/10.1093/gji/ggaa292

Mathey M., Pagani C., Sue C., Baize S., Walpersdorf A., Bodin T., Husson L., Hannouz E., Potin B., Present-day geodynamics of the Western Alps: new insights from earthquake mechanisms. *Solid Earth*. doi.org/10.5194/se-12-1661-2021