

DSO contribution to EUREF Densification and a dense velocity field for Greece

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Presentation Structure

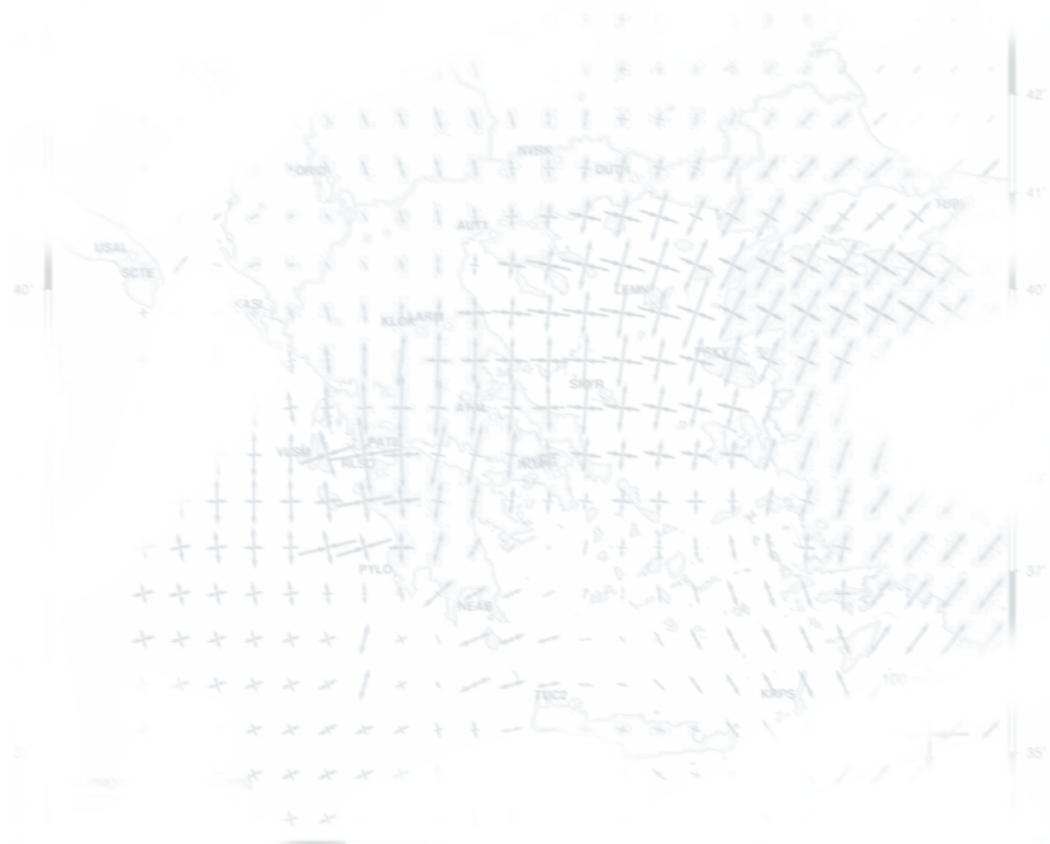
Introduction

GPS/GNSS Networks in Greece

Processing

Results & Outputs

Discussion / Conclusions



DSO Recent Activity

Dionysos Satellite Observatory (DSO) of the National Technical University of Athens (NTUA), has developed and maintains an automated processing scheme to accommodate the routine analysis of all available continuous GNSS stations in Greece.

This daily analysis process is implemented for over ten years now (not always continuous though due to various problems), yielding results which help us further understand the complicated tectonic setting of Greece and nearby regions.

Important results, include:

- the recent volcanic activity in *Santorini* (e.g. [Papoutsis et al., 2013](#)),
- the 2014 *Kefallonia* earthquakes (e.g. [Anastasiou, Chouliaras, et al., 2014](#))

Motivation

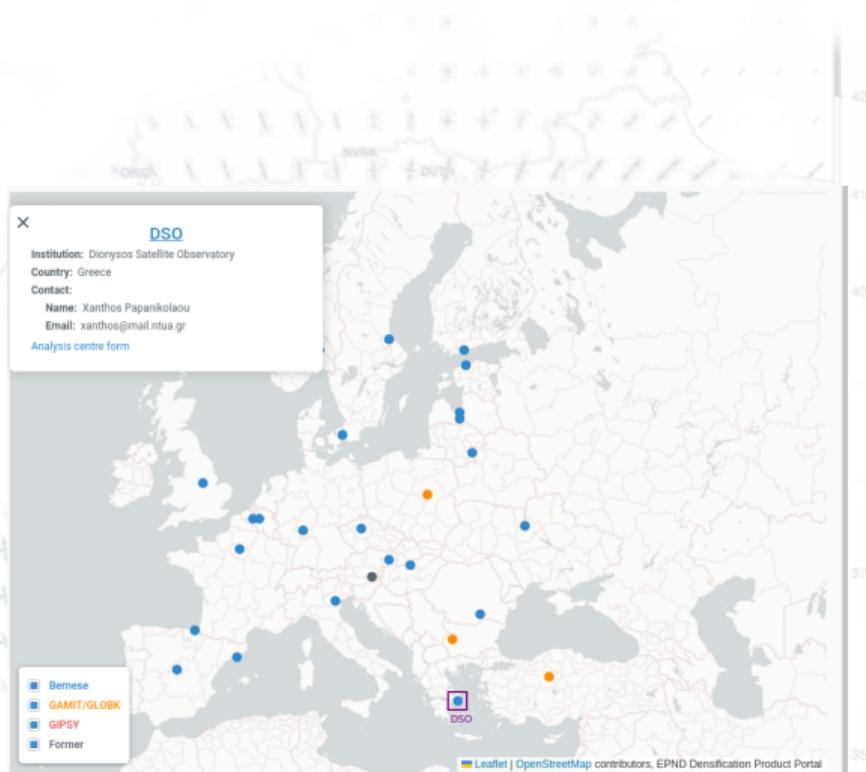
Routine GNSS processing and site/network monitoring is crucial, because:

- Greece lies in a region of utmost tectonic and volcanic unrest (e.g. active volcano in Santorini isl.),
- results & products are important to a series of fields spanning the whole range of Geosciences,
- helps us follow and apply state-of-the-art technologies in GNSS analysis & Satellite Geodesy and expand & modernize our research activity,
- contribute to the GNSS/EUREF community and be involved in ongoing/future projects,
- improve our academic services (NTUA is a University)

Throughout the last years, routine processing & monitoring has helped us gain a more thorough view of the complex tectonic and volcanic setting of Greece.

Contribution to EPN Densification up to now

- Start our contribution from 2016
- Processing and upload daily SINEX files including 78 station
- Data processing from GPS week 1400 up to 2238 on IGb14



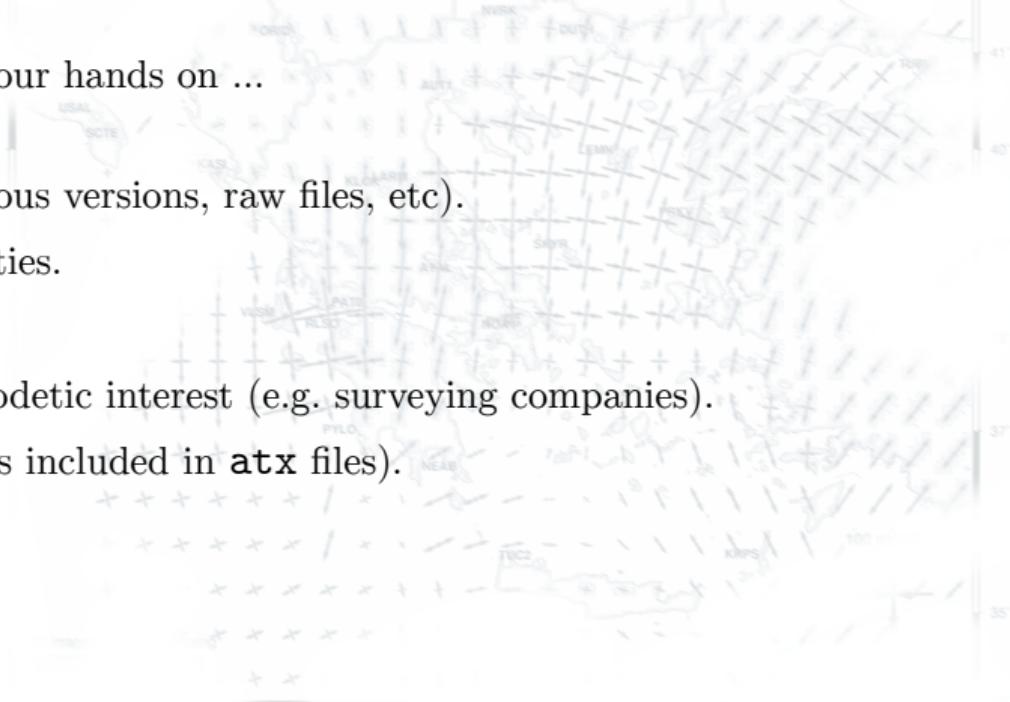
The Data Set

Routine processing for precise positioning, assumes a well established, credible dataset (metadata). This has proven to be rather challenging! Lately, the introduction of M3G has provided assistance.

Currently we process whatever we can get our hands on ...

Problems:

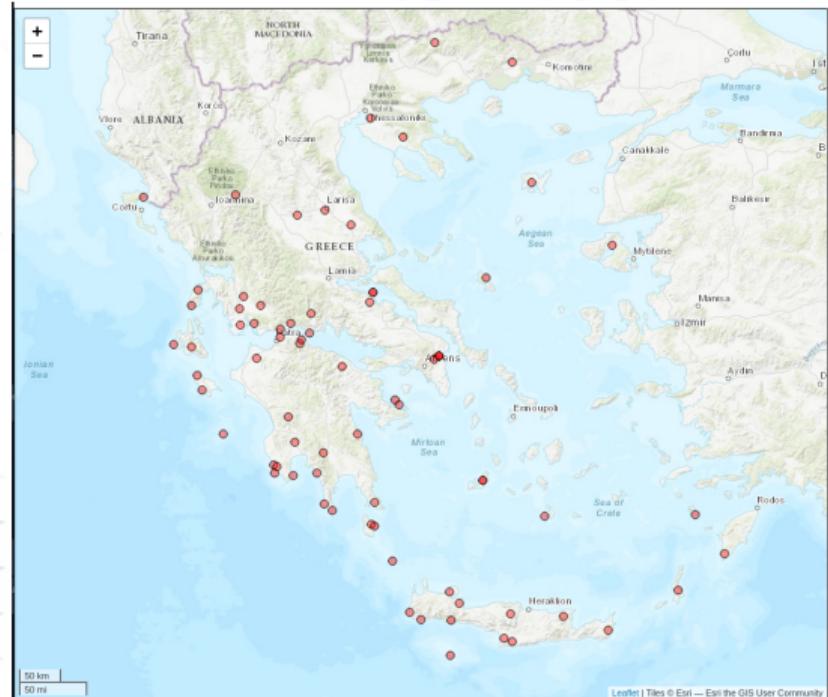
- Inhomogenous dataset (**RINEX** of various versions, raw files, etc).
- Various maintainers, different mentalities.
- Different acquisition methods/rates.
- No log files for maintainers with no geodetic interest (e.g. surveying companies).
- Wide variety of equipment (not always included in **atx** files).



Network GREECE

Network **Greece** includes the majority of the available sites (≈ 100) but not all of them are (always/currently) active. Various providers but all with geodetic interest & equipment.

- covers all of Greece
- different (geodetic type) equipment
- credible time-span (early 2004 - now)
- all free available GNSS data
- large data gaps & inactive stations

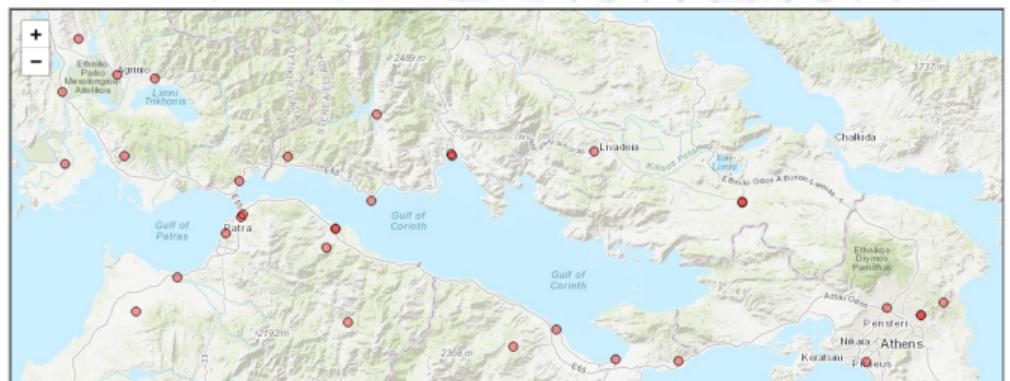


-» Network GREECE

Local Networks

The **Corinth Rift** network is centered around the Corinth Gulf, a region of special tectonic interest. Larger site density compared to the rest of Greece.

- credible time-span
- only covers the Corinth Rift
- different providers (including surveying & cadastral services)
- no log files & equipment changes



-» Network EnCeladus

The Scheme

The core tool/software is **Bernese GNSS Software v5.2**(Dach et al., 2007).

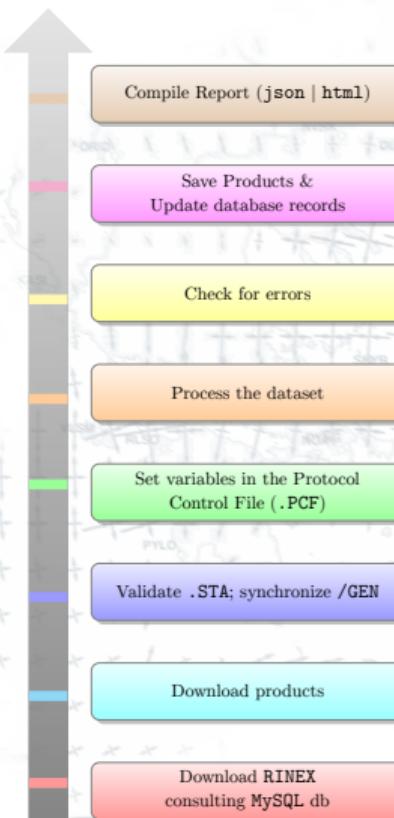
Integration with

- **MySQL database,**
- **Python module** (product/data downloading, pre-processing, driving cron jobs, etc)
<https://github.com/DS0lab/autobern>
- **Time-series** analysis (integrated in routine processing on regular intervals)
- **Strain Rates** via StrainTool (on user demand)



Workflow

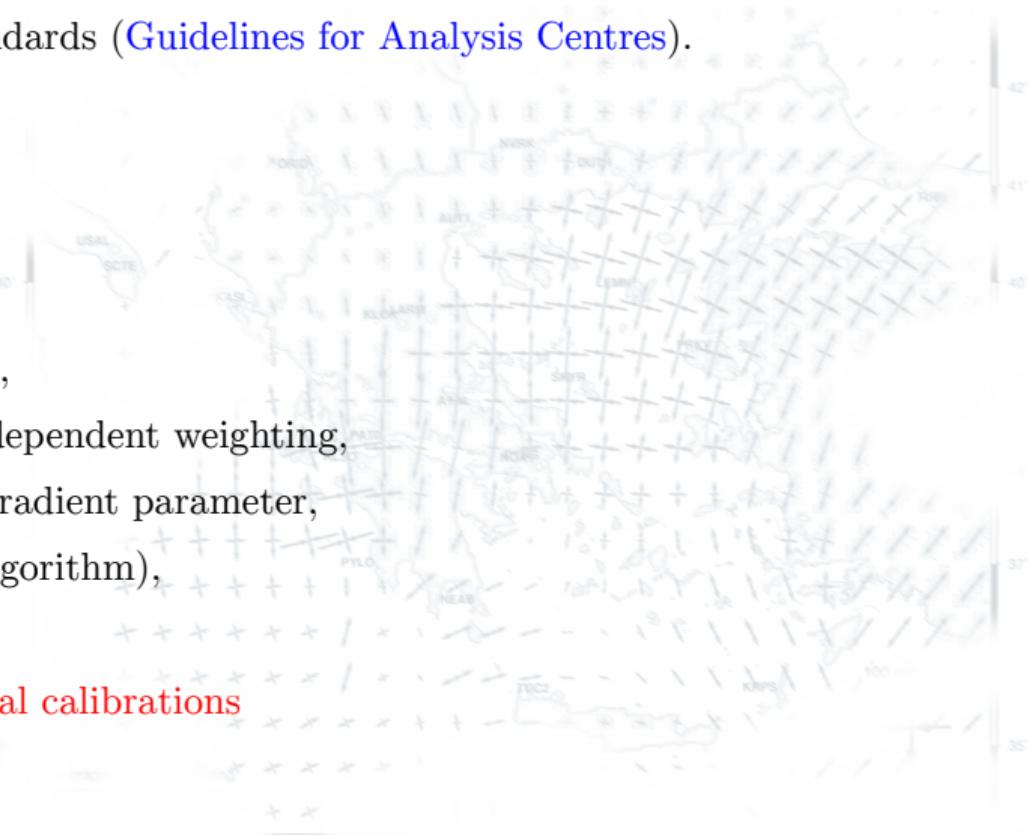
```
$>ddrun.sh --year= --doy= --session=
--bern-loadgps= --campaign=
--satellite-system= --solution-id=
--save-dir= --analysis-center=
--use-ntua-products=
--append-suffix= --elevation-angle=
--update= --pcv=
--apply-exclude-list
```



Compliance wrt EUREF standards

Processing is consistent with EUREF standards ([Guidelines for Analysis Centres](#)).

- SINEX with required info/blocks,
- Reference frame **IGb14**,
- IERS Conventions 2010,
- IGS/CODE products,
- ocean loading corrections (**FES2004**),
- 3° elevation cut-off angle; elevation dependent weighting,
- GMF and/or **VMF1**; Chen-Herring gradient parameter,
- ambiguities fixed (length-dependent algorithm),
- use GLONASS obs (when available)
- use ATX files (**epn_14.atx**) - individual calibrations



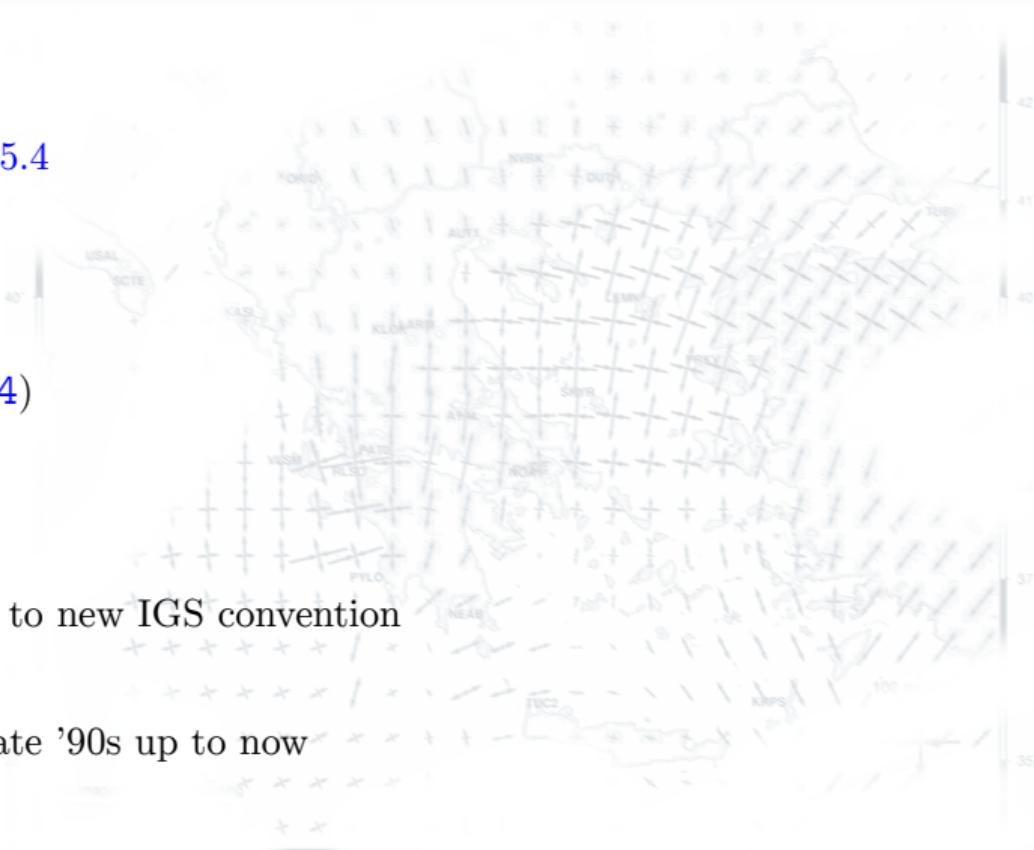
Upgrade planning - switch to IGS20

⇒ New release Bernese GNSS Software **v5.4**

New values on processing options:

- Reference frame **IGS20**
- Oceans loading corrections (**FES2014**)
- **VMF3** for tropospheric modeling
- ATX file: **igs20.atx**
- Long filename of products according to new IGS convention

⇒ ⇒ Reprocess all available data from late '90s up to now



Results & Output

4. Solution Identifiers

Array of Objects

[expand](#)

5. PCF Variables

Array of Objects

[expand](#)

6. Saved products

Array of Objects

[expand](#)

7. Warnings

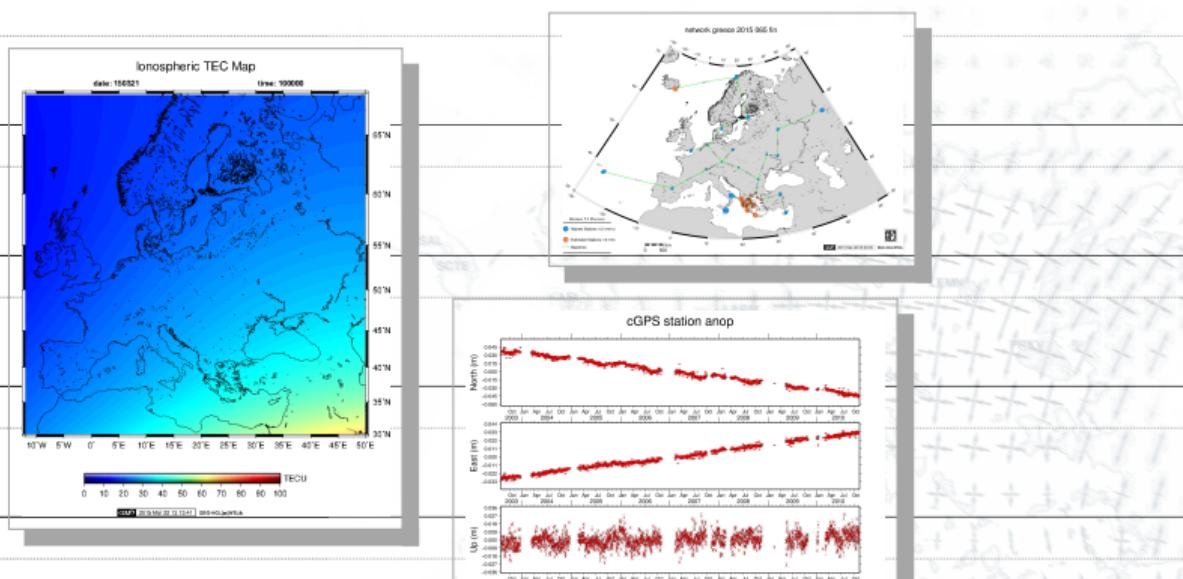
Array of Objects

[expand](#)

8. Ambiguity Resolution Summary

Array of Objects

Baseline	sta1	sta2	length (km)	Method	N. of Amb.	Perce. tance	Satellite system
AUKL	AUT1	KLOK	139.7	pbnl	74	54.1	GPS
AULE	AUT1	LEMN	199.6	pbnl	60	55	GPS
KCTL	KATC	TILO	59	pbnl	50	90	GPS
KLRL	KLOK	RLSO	174.2	pbnl	74	41.9	GPS

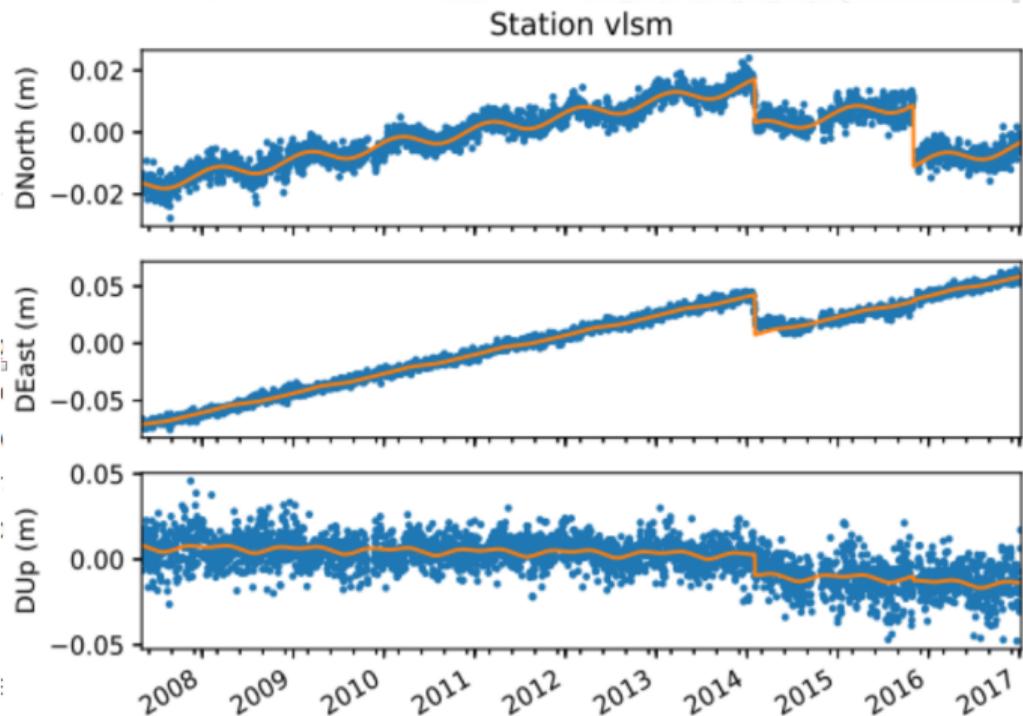


Coordinate estimates - Time series analysis

We analyze time-series using in-house software tools, to estimate:

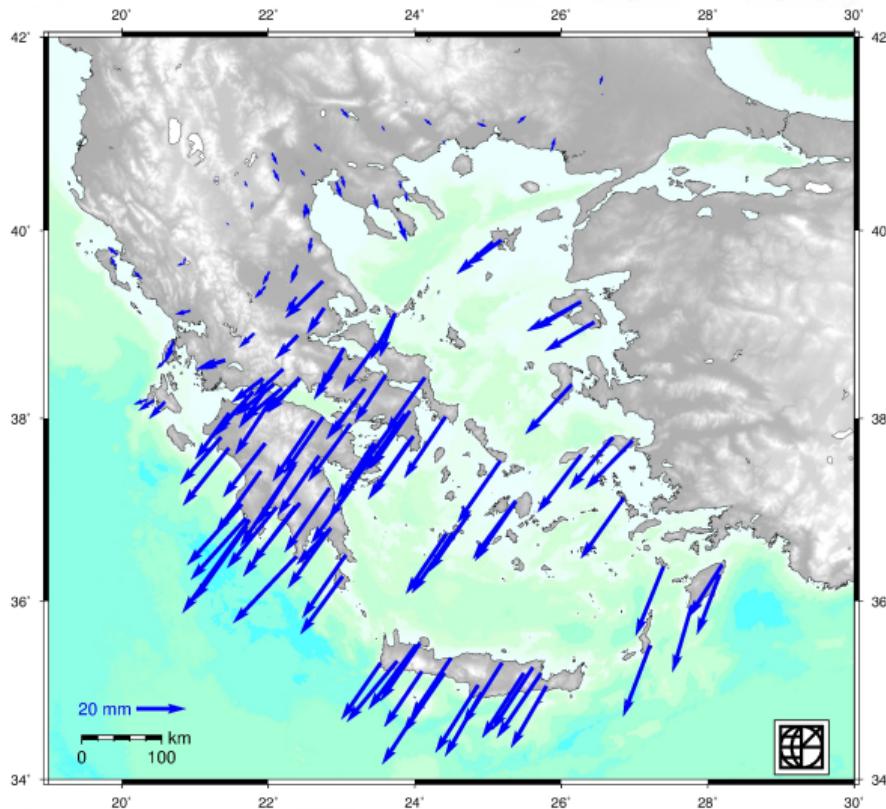
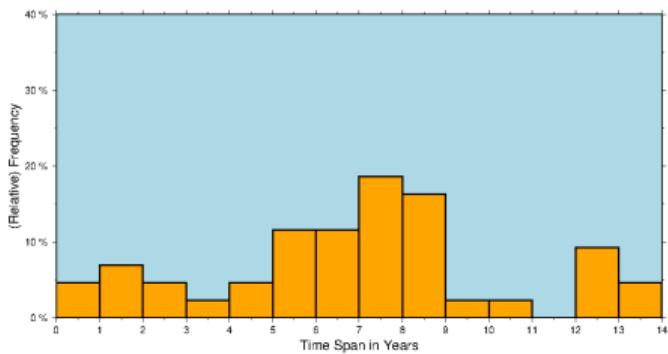
- tectonic velocities (linear trends),
- offsets/jumps due to miscellaneous reasons (e.g. instrumentation changes, earthquakes, etc); note that this step requires a-priori knowledge of such events (log-files, NOA earthquake catalogue)
- harmonics signals (using periodograms),
- velocity changes (e.g. inflation of Santorini isl.),
- post-seismic decay (still under development)

New time series analysis in progress using Hector Package ([Bos et al., 2012](#))

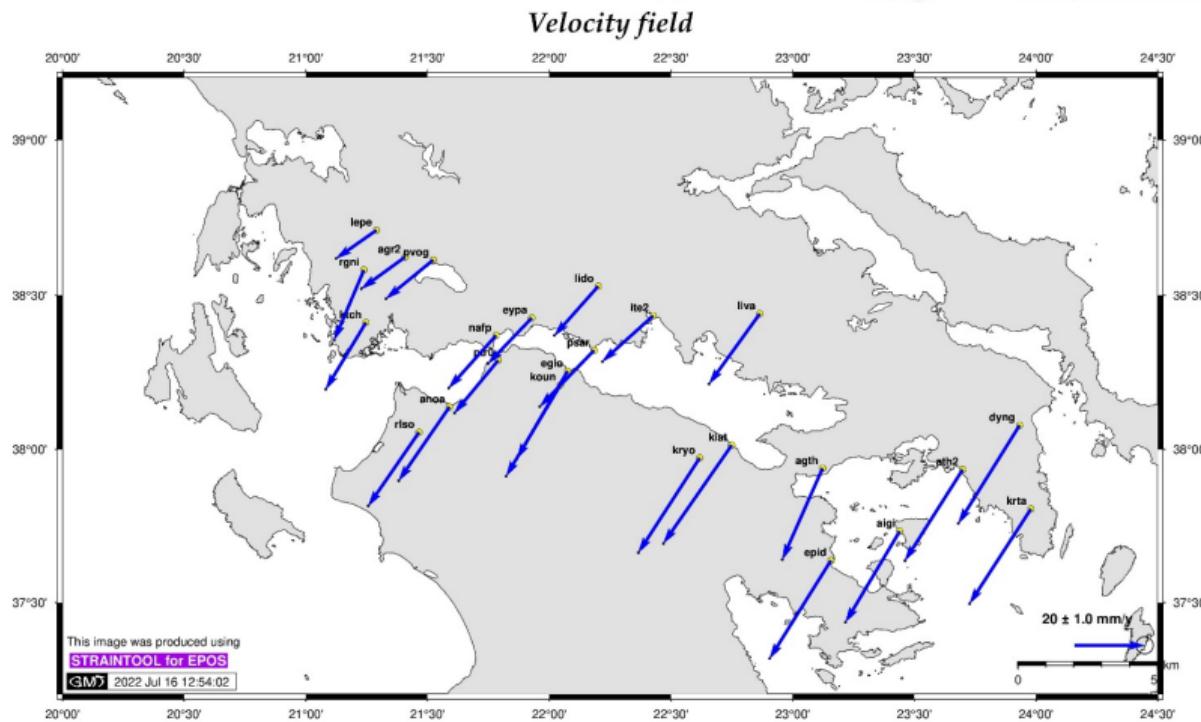


Velocity field in Greece wrt a stable Europe

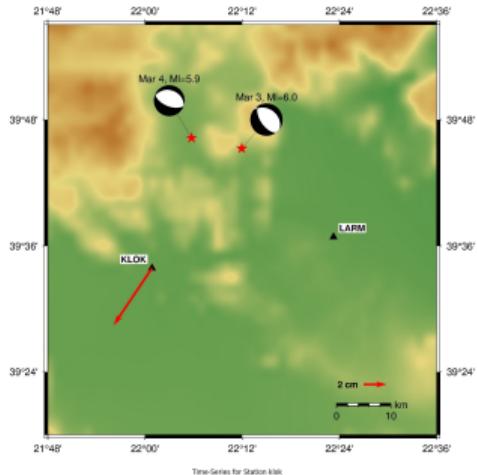
- 100 station
- data availability > 3 years
- Velocity field w.r.t. a stable Europe (Kreemer et al., 2014)



Focus on specific regions - Corinth Gulf

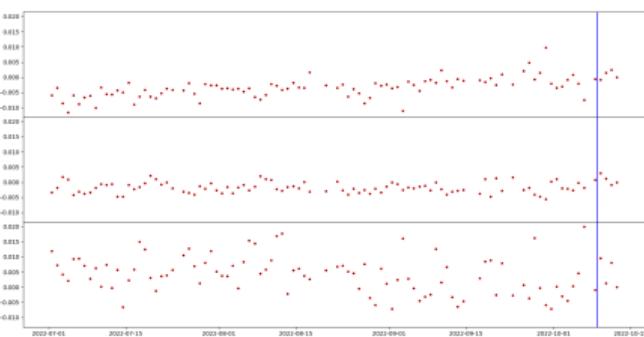
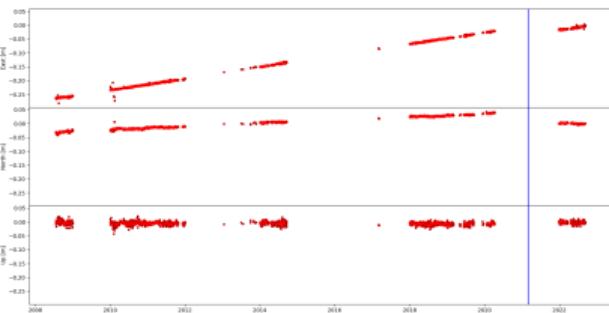
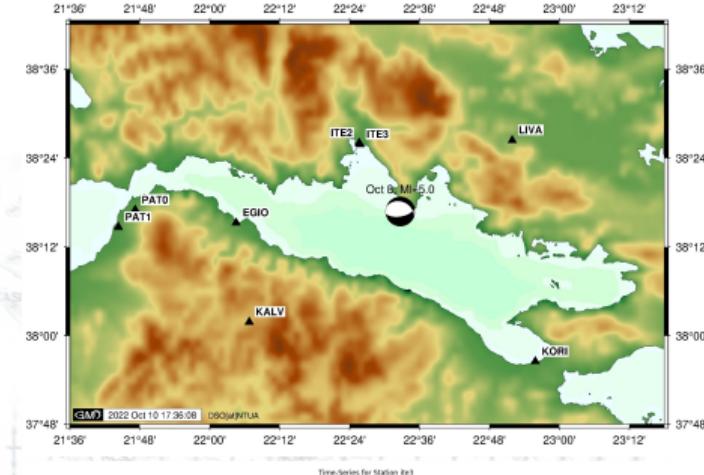


Thessaly 2021



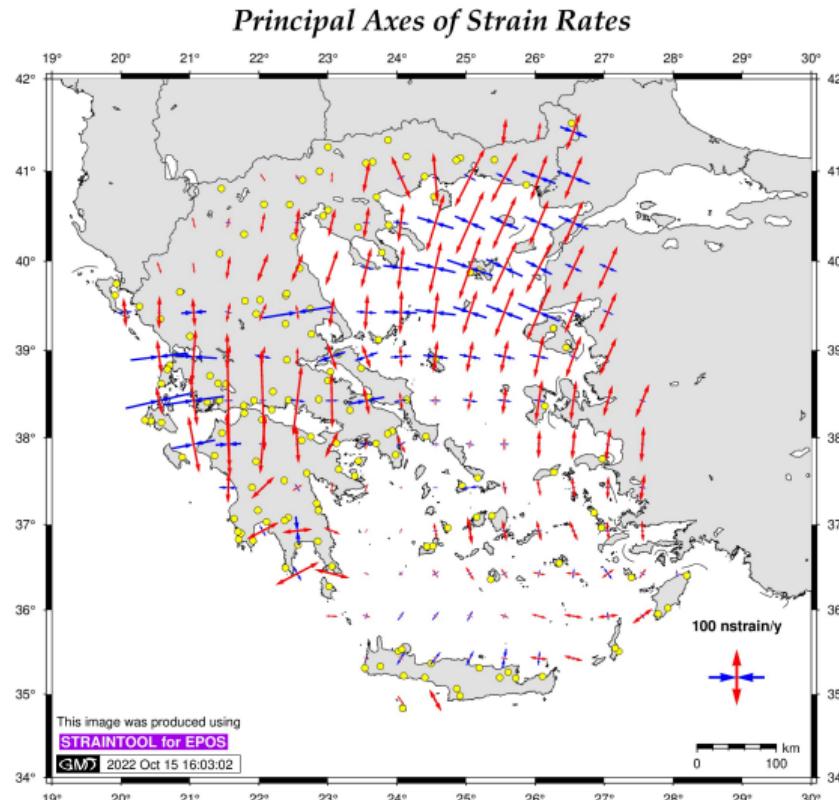
Recent Earthquakes

Itea 2022



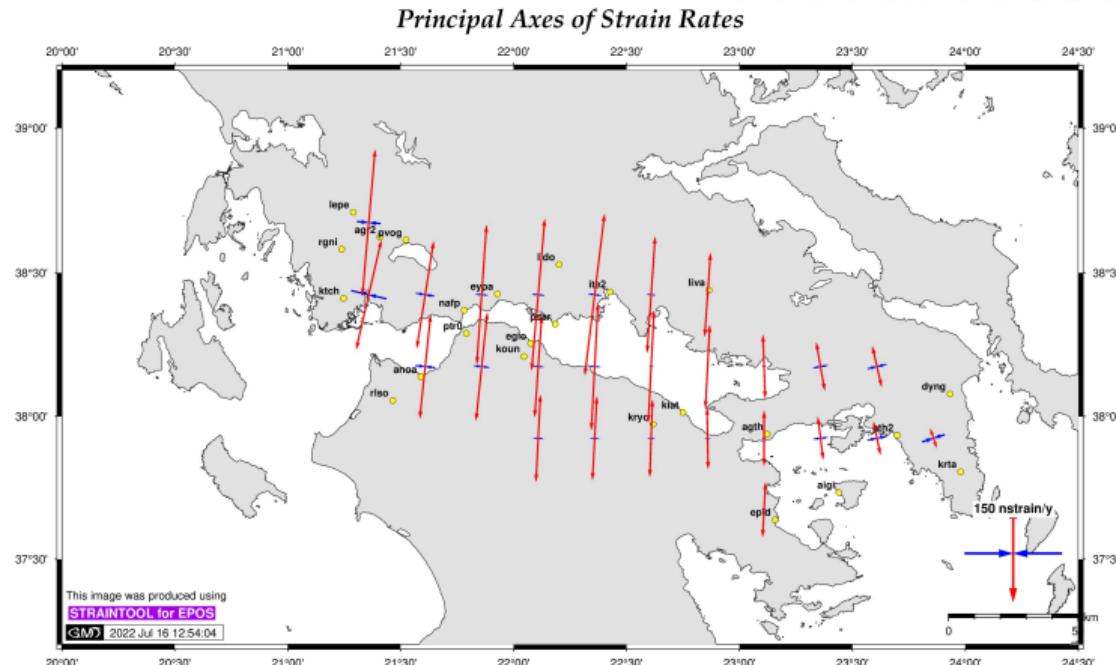
Strain rates

- **StrainTool** software used to estimate strain tensor parameters (Anastasiou, Papanikolaou, et al., 2021)
- grid step 0.5°



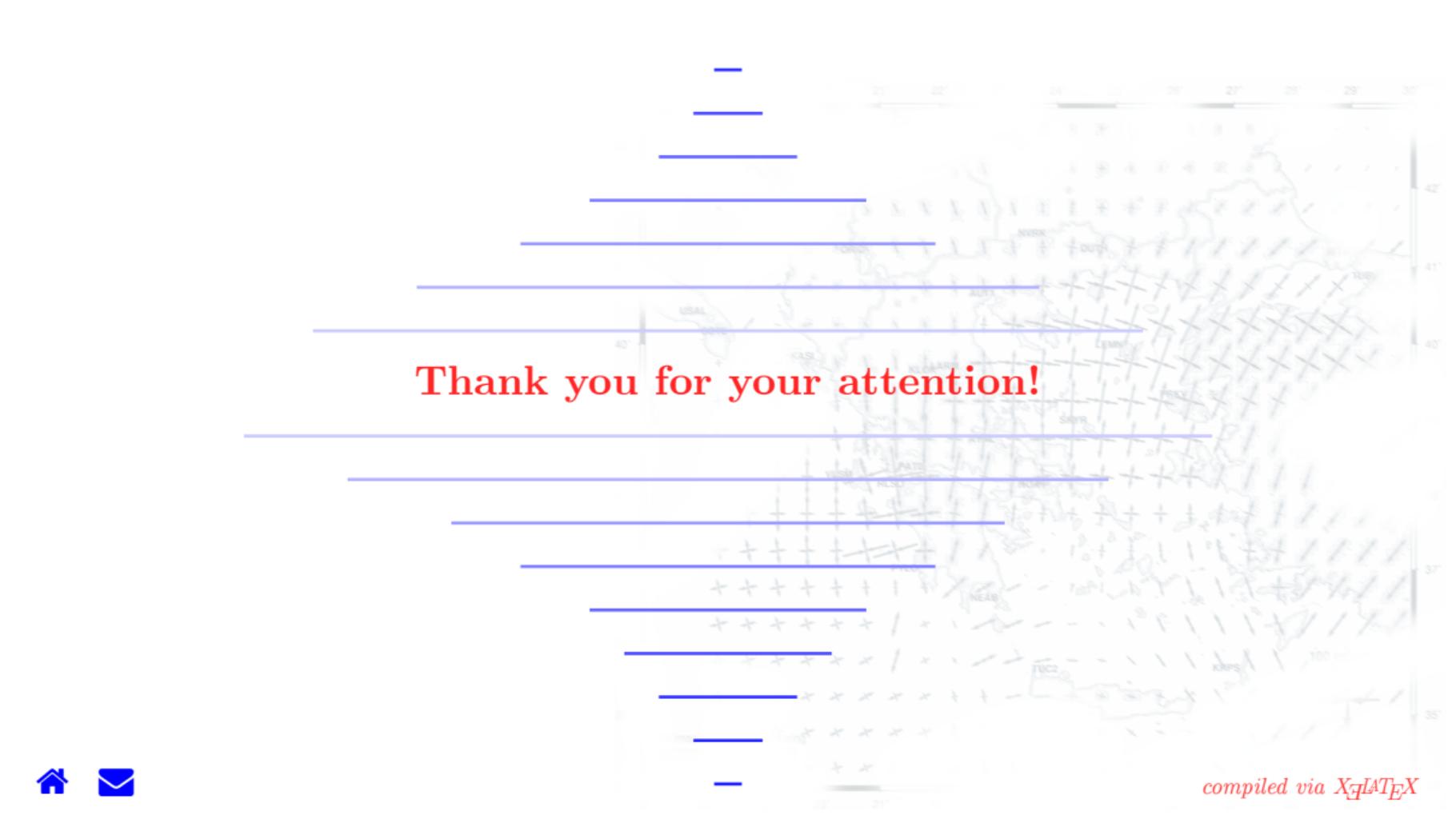
Strain rates - focus on specific region

- 25 Permanent GNSS Station
- grd step 0.25°



Discussion / Conclusions

- Greece is located in a complex tectonic background with many changes in the kinematics of the area.
- Routine processing and monitoring are very important and revealing for Greece; products are requested by and disseminated to a wide range of Geoscientists.
- Greece's crustal dynamics are evidently complex and inhomogenous; a difficult task to model by Reference Systems (especially non-dynamic, such as the ones currently in use).
- A dense velocity field for accurate estimation of ground/tectonic motions in the region will help to develop a stable local reference frame and the connection of the region with the global and European reference systems.
- The continuous monitoring of the networks gives useful results for the effect of strong earthquakes or other “abrupt” phenomena; small, dense networks are of great help (even with instrumentation of non-geodetic accuracy).
- Our plan: grow up our team and be more involved to the GNSS/EUREF community.



Thank you for your attention!

References I

- Anastasiou, D., G. Chouliaras, X. Papanikolaou, A. Marinou, V. Zacharis, J. Galanis, and G. Drakatos (2014). "Geodetic and seismological analysis of the January 26, 2014 Cephalonia Island earthquake sequence". In: *26th General Assembly of the IUGG, Prague, Czech Republic, 22/6 - 2/7*. (cit. on p. 3).
- Anastasiou, D., X. Papanikolaou, A. Ganas, and Paradissis .D (2021). "StrainTool: A software package to estimate strain tensor parameters (v1.0-r1)". In: *Zenodo*. doi: [10.5281/zenodo.1297565](https://doi.org/10.5281/zenodo.1297565). URL: <https://doi.org/10.5281/zenodo.1297565> (cit. on p. 18).
- Bos, M. S., R. M. S. Fernandes, S. D. P. Williams, and L. Bastos (Dec. 2012). "Fast error analysis of continuous GNSS observations with missing data". In: *Journal of Geodesy* 87.4, pp. 351–360. doi: [10.1007/s00190-012-0605-0](https://doi.org/10.1007/s00190-012-0605-0) (cit. on p. 14).
- Dach, R., U. Hugentobler, P. Fridez, and M. Meindl (2007). *Bernese GPS Software Version 5.0*. Astronomical Institute, University of Bern (cit. on p. 9).
- Kreemer, C., G. Blewitt, and E.C. Klein (2014). "A geodetic plate motion and Global Strain Rate Model". In: *Geochemistry, Geophysics, Geosystems* 15, pp. 3849–3889. doi: [10.1002/2014GC005407](https://doi.org/10.1002/2014GC005407). URL: <https://doi.org/10.1002/2014GC0054075> (cit. on p. 15).
- Papoutsis, I., X. Papanikolaou, M. Floyd, K. H. Ji, C. Kontoes, D. Paradissis, and V. Zacharis (2013). "Mapping inflation at Santorini volcano, Greece, using GPS and InSAR". In: *Geophysical Research Letters* 40.2, pp. 267–272. issn: 1944-8007. doi: [10.1029/2012GL054137](https://doi.org/10.1029/2012GL054137). URL: <http://dx.doi.org/10.1029/2012GL054137> (cit. on p. 3).