

Velocity and strain field estimation using permanent GNSS stations in the region of the EnCeladus Hellenic Supersite

Dimitrios Anastasiou¹, Xanthos Papanikolaou¹, Maria Tsakiri¹, Spyros Lalechos²

¹Dionysos Satellite Observatory, School of Rural Surveying and Geoinformatics Engineering
National Technical University of Athens

²Earthquake Planning and Protection Organization



<http://dionysos.survey.ntua.gr/>

danastasiou@mail.ntua.gr

IUGG BERLIN 2023
THE 28TH GENERAL ASSEMBLY

11-20 . 07 . 2023



Presentation Structure

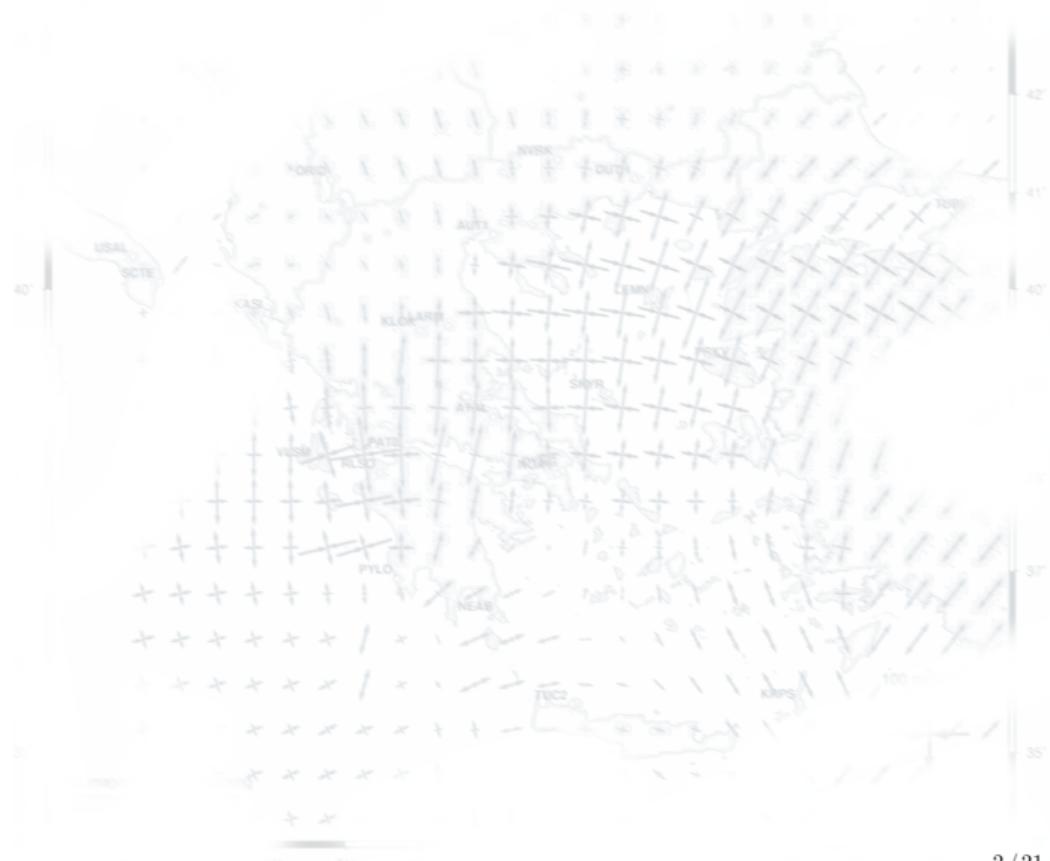
Introduction

Data set and processing scheme

Processing

Results & Outputs

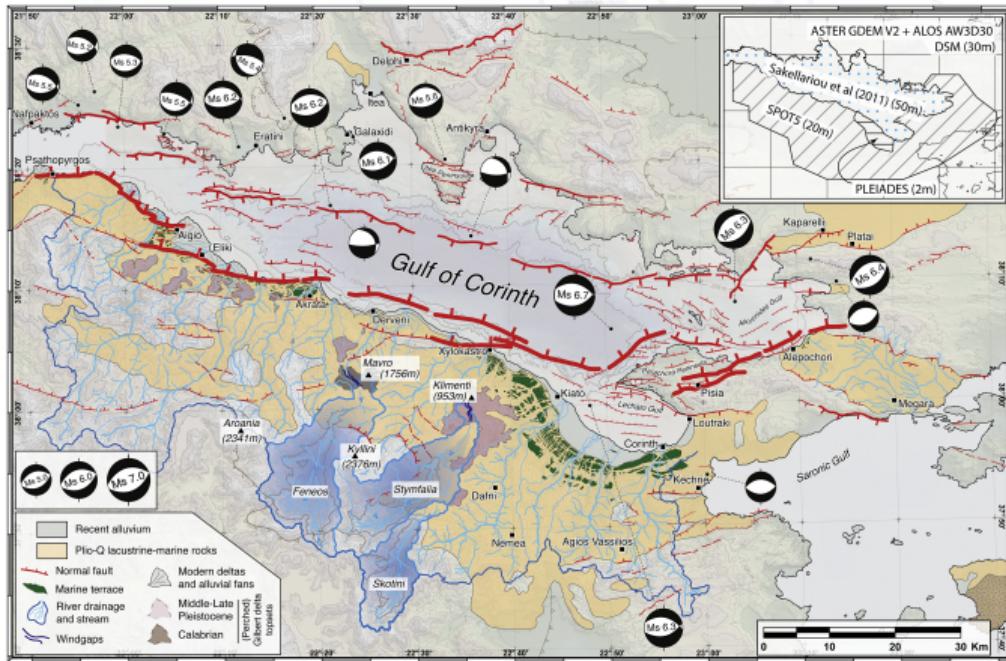
Discussion / Conclusions



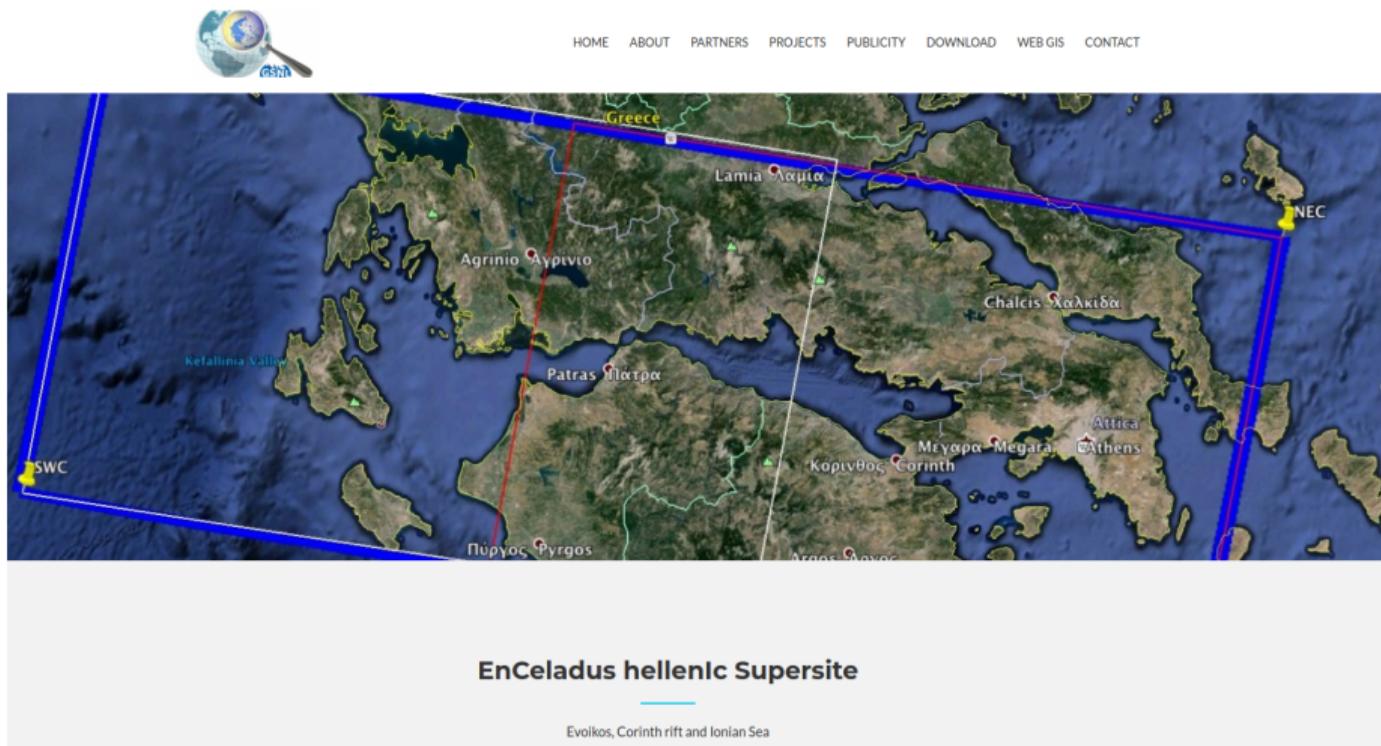
Corinth Rift

Geotectonic background

- Narrowest and fastest extending continental region.
- one of the highest seismicity rates in the Euro-Mediterranean region.



EnCeladus Hellenic Supersite



<https://greeksupersite.eu/>

DSO Recent Activity and motivation

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.

As part of the operation of the EnCeladus Hellenic Supersite, DSO undertook the monitoring of the Corinth Gulf area through GPS/GNSS stations and the development of a multidisciplinary platform. 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,
- improve our academic services (NTUA is a University)

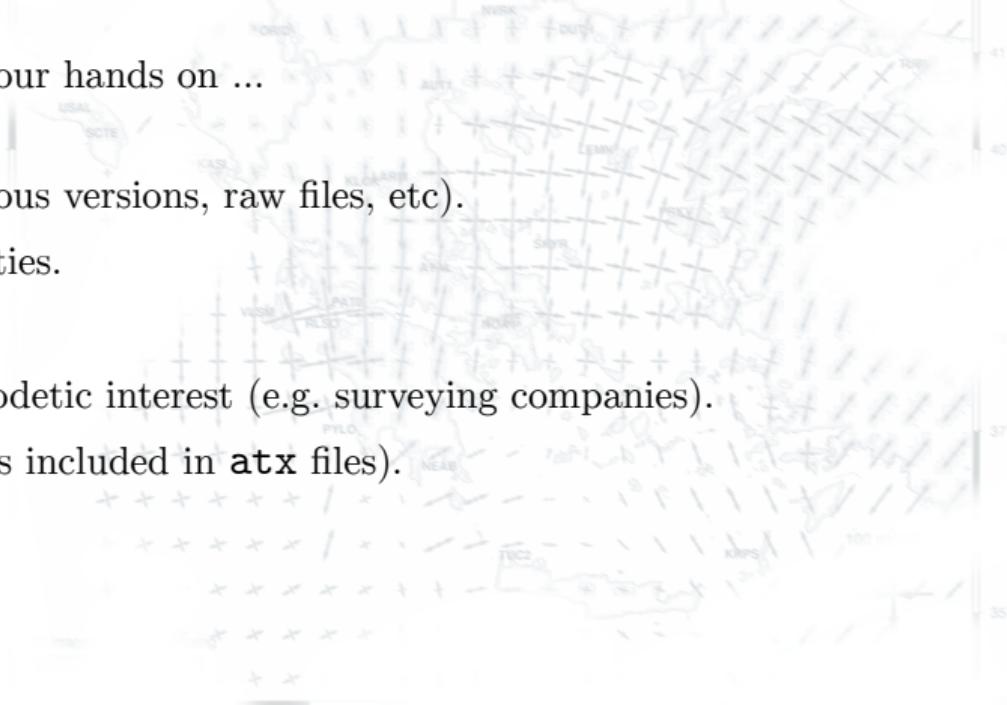
The Data Set

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:

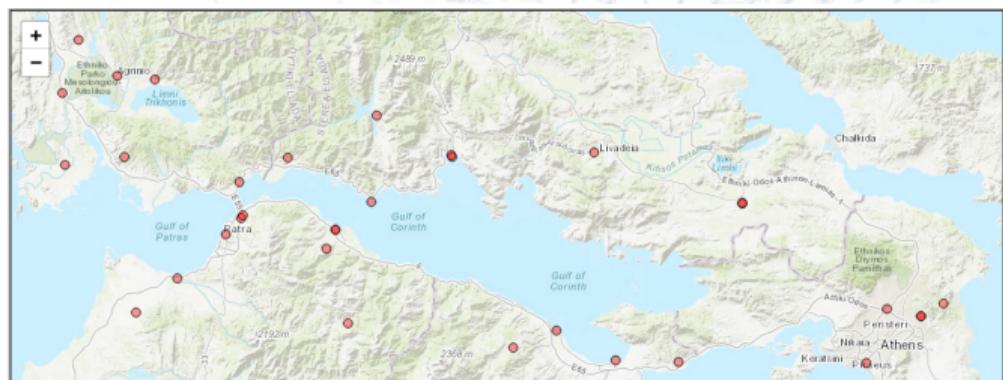
- Inhomogenous dataset (**RINEX** of various versions, raw files, etc).
- Various maintainers, different mentalities.
- Different acquisition methods/rates.
- No log files for maintainers with no geodetic interest (e.g. surveying companies).
- Wide variety of equipment (not always included in **atx**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



Network EnCeladus

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



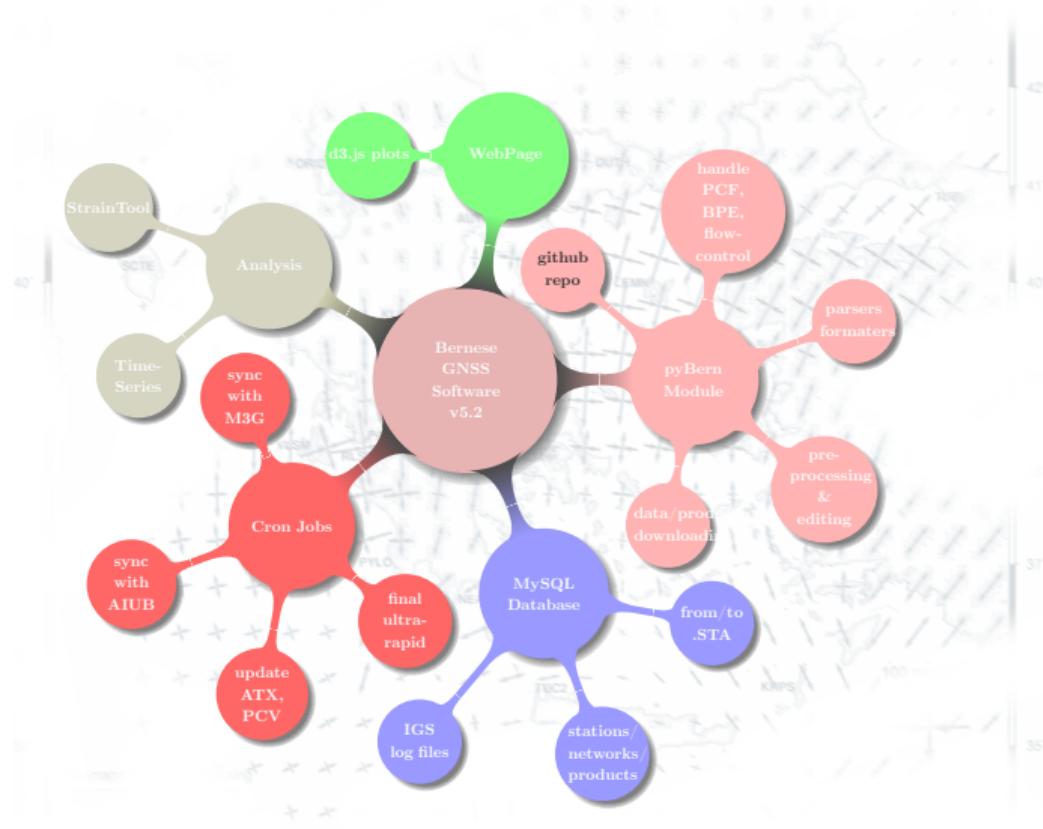
-» Network EnCeladus

The Scheme

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

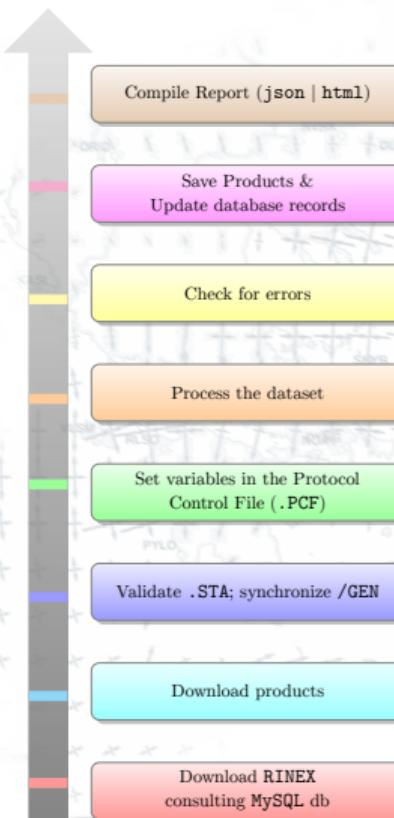
Integration with

- **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
```

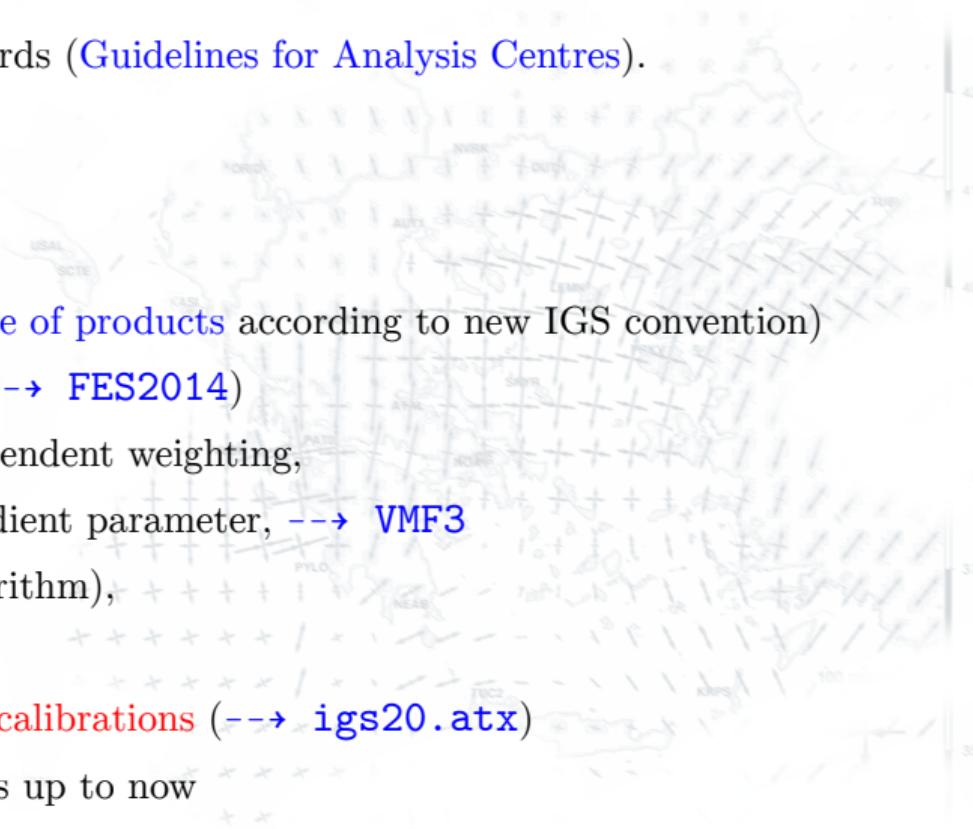


Compliance wrt EUREF standards and upgrade planning

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

- SINEX with required info/blocks,
- Reference frame **IGb14**,(→ [IGS20](#))
- IERS Conventions 2010,
- IGS/CODE products, (→ [Long filename of products](#) according to new IGS convention)
- ocean loading corrections (**FES2004**),(→ [FES2014](#))
- 3° elevation cut-off angle; elevation dependent weighting,
- GMF and/or **VMF1**; Chen-Herring gradient parameter, → [VMF3](#)
- ambiguities fixed (length-dependent algorithm),
- use GLONASS obs (when available)
- use ATX files (**epn_14.atx**) - **individual calibrations** (→ [igs20.atx](#))

⇒ 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

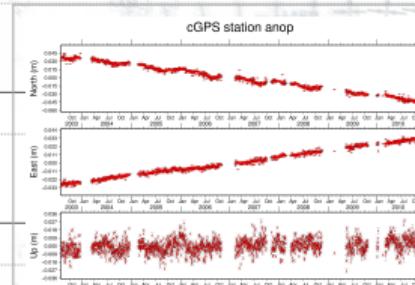
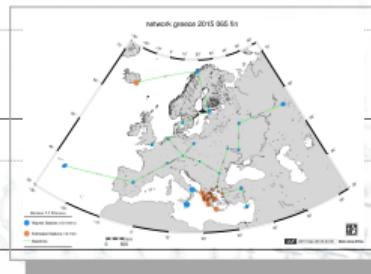
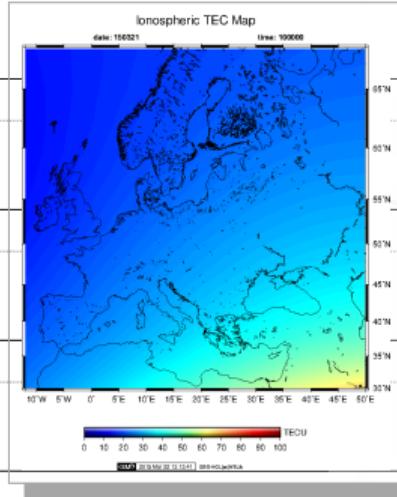
Array of Objects

[expand](#)

8. Ambiguity Resolution Summary

Array of Objects

Baseline	sta1	sta2	length (km)	Method	N. of Amb.	Percentage	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

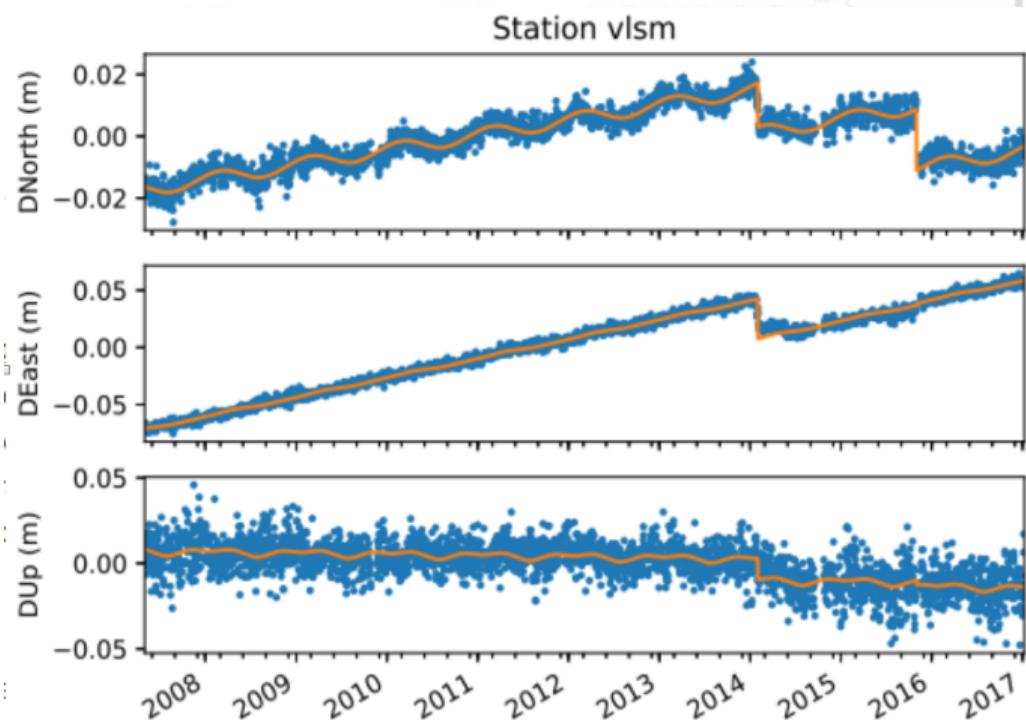


Coordinate estimates - Time series analysis

We analyze time-series using Hector Package

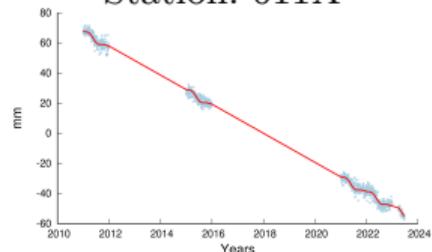
(Bos et al., 2012), to estimate:

- 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 (annual, semi-annual),
- velocity changes (e.g. inflation of Santorini isl.),
- post-seismic decay (not used)

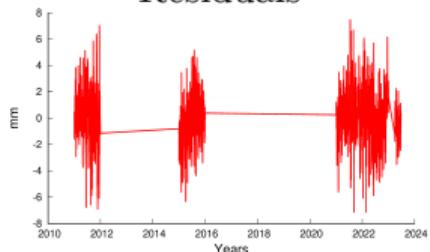


Time series analysis

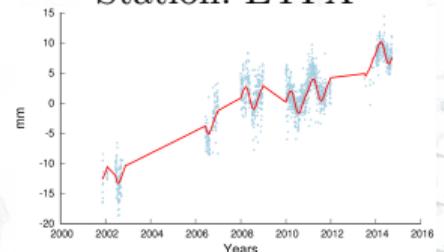
Station: 011A



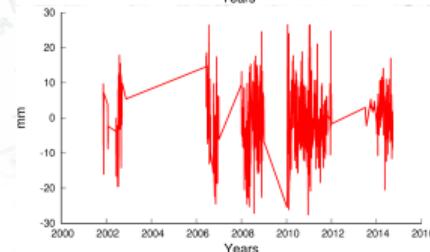
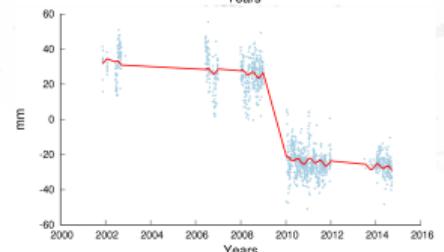
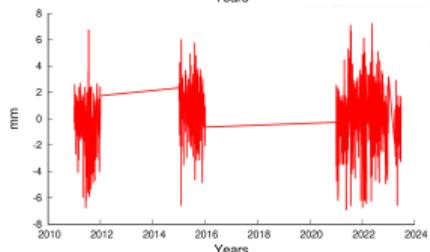
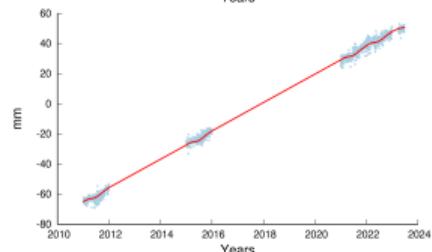
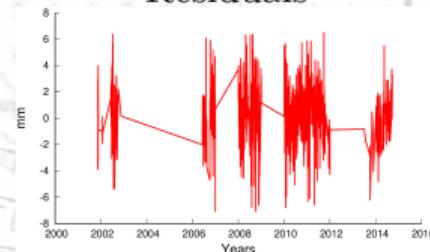
Residuals



Station: EYPA

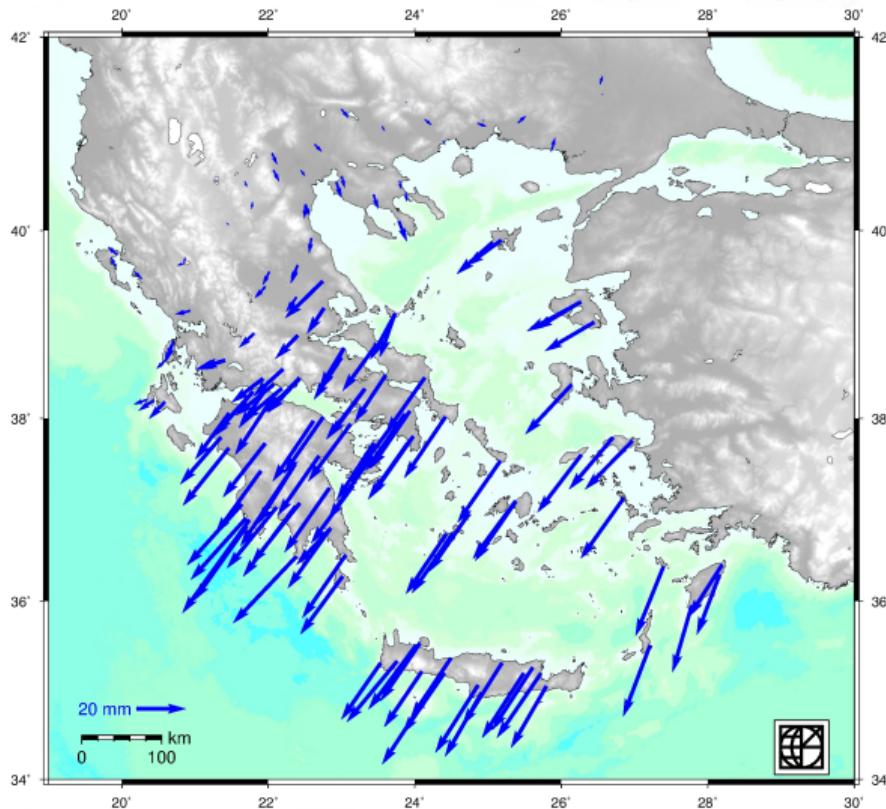
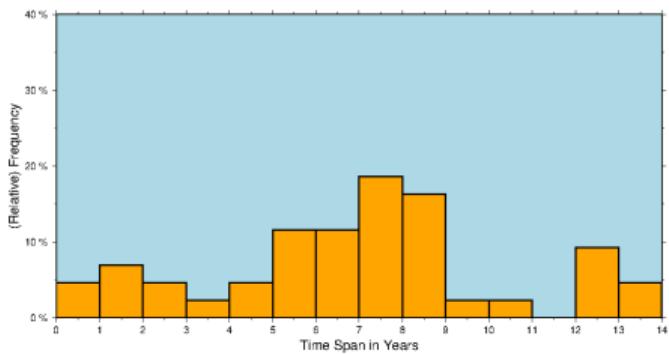


Residuals

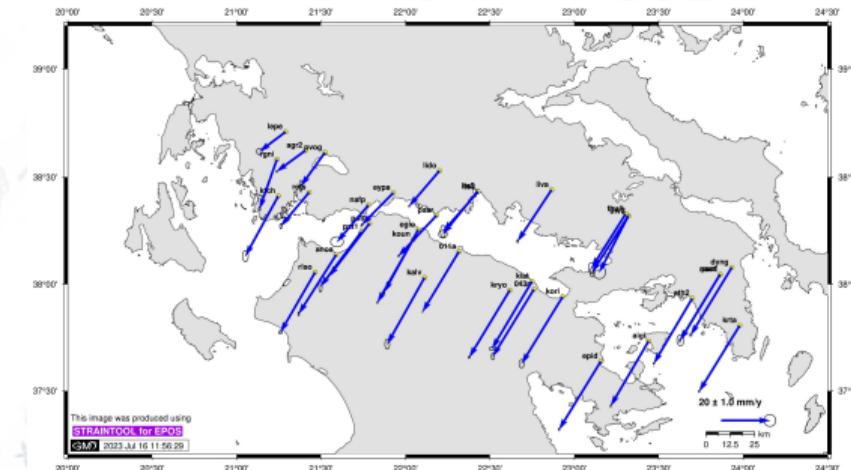
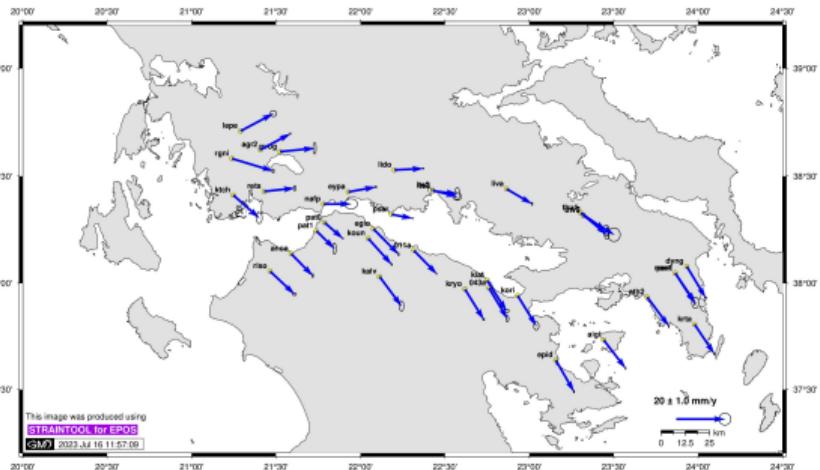


Velocity field in Greece wrt a stable Europe

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



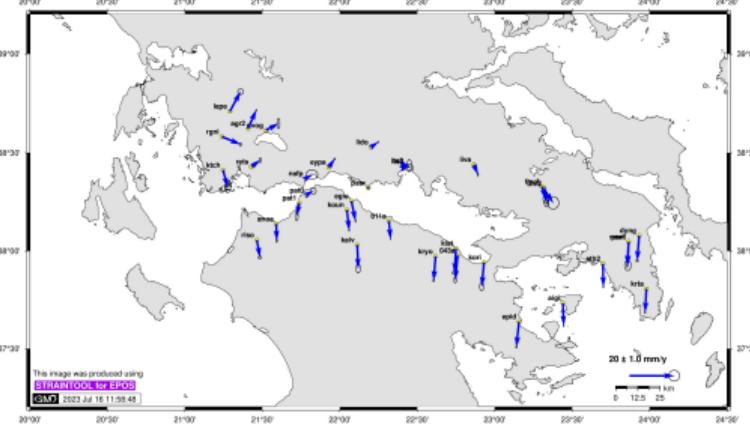
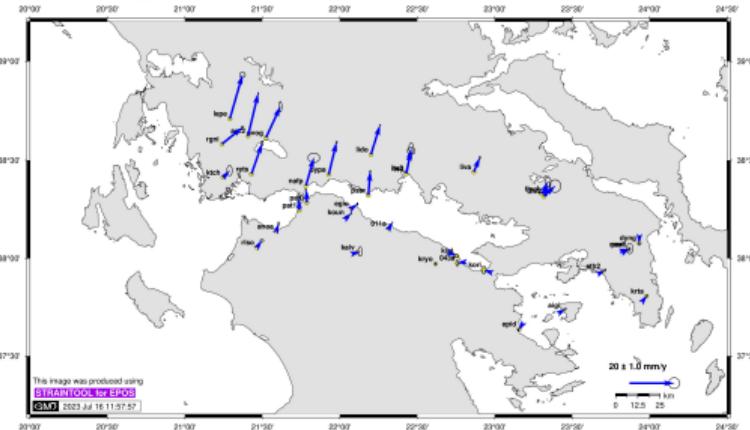
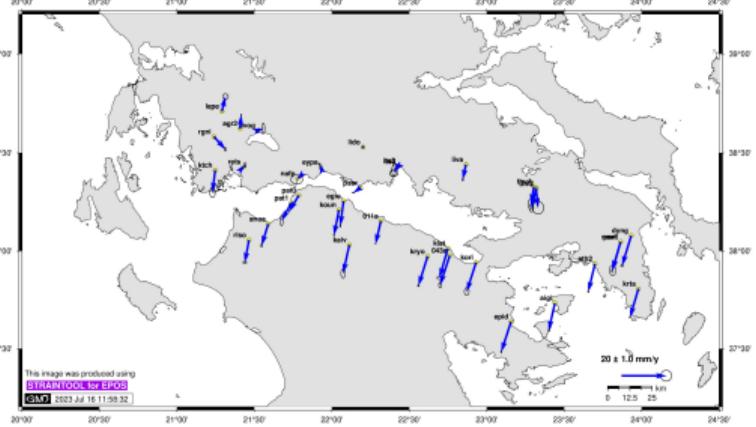
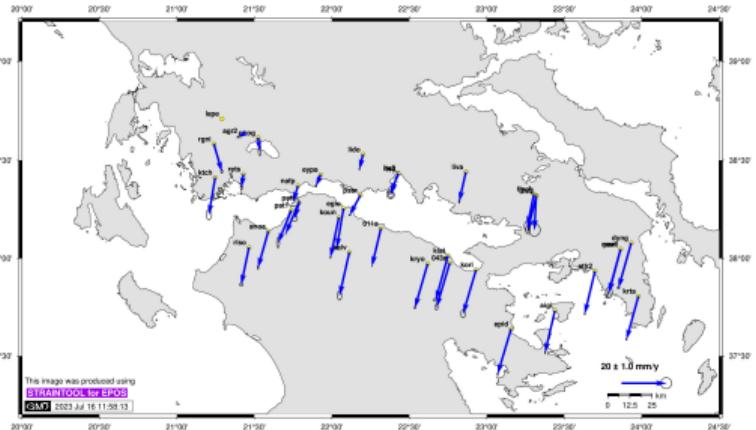
Corinth Gulf
IGb14 || Stable Europe



(mm/yr)	N	E	U
min	-13.0	7.5	-9.0
max	7.2	17.0	5.0

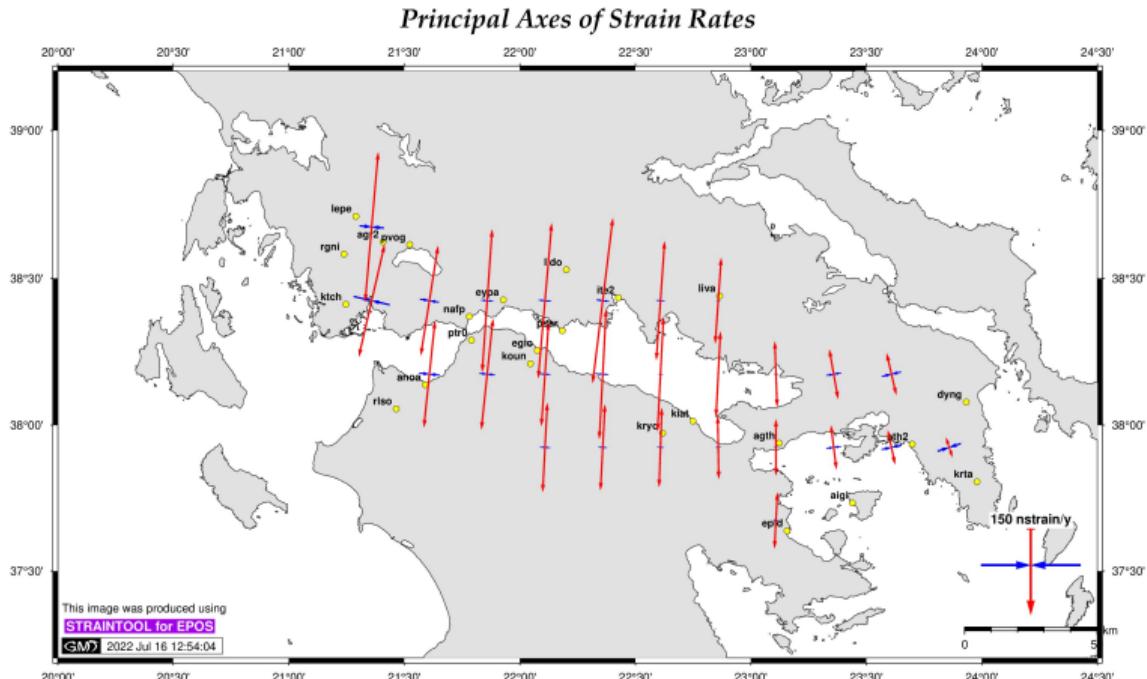
(mm/yr)	N	E	U
min	-8.1	-7.2	9.0
max	-28.0	-17.7	5.0

Kinematic fields - fixed stations



Strain rates

- **StrainTool** software used to estimate strain tensor parameters ([Anastasiou et al., 2021](#))
- 25 Permanent GNSS Station
- grd step 0.25°



Online platform

 Dionysos
Satellite
Observatory

Home Gallery Laboratory ▾ GNSS Analysis ▾

English ▾

EnCeladus Supersite | GNSS Analysis

Corinth Rift, is an ideal natural laboratory to investigate rift deformation mechanisms.

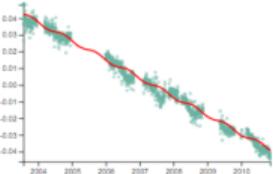
DSO and EPPO manage to establish an automatic processing engine for all available permanent GNSS stations established in the region.

Station Time-Series

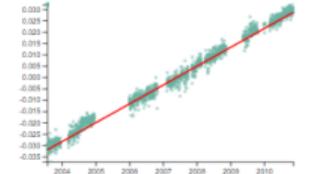
For details on how DSO analyzes GPS/GNSS data, refer to [GNSS Analysis](#). You can also find information on time-series stacking and parameter estimation.

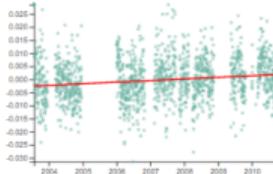
Note that sites that belong to private networks may not be presented here; if you are interested though, you can [contact DSO](#) or the respective station owner.

Show Outliers



Show Model





North		East		Up	
velocity	Reference Epoch	velocity	Reference Epoch	velocity	Reference Epoch
-11.1 mm/yr	2007-04-20	8.3 mm/yr	2007-04-20	0.6 mm/yr	2007-04-20

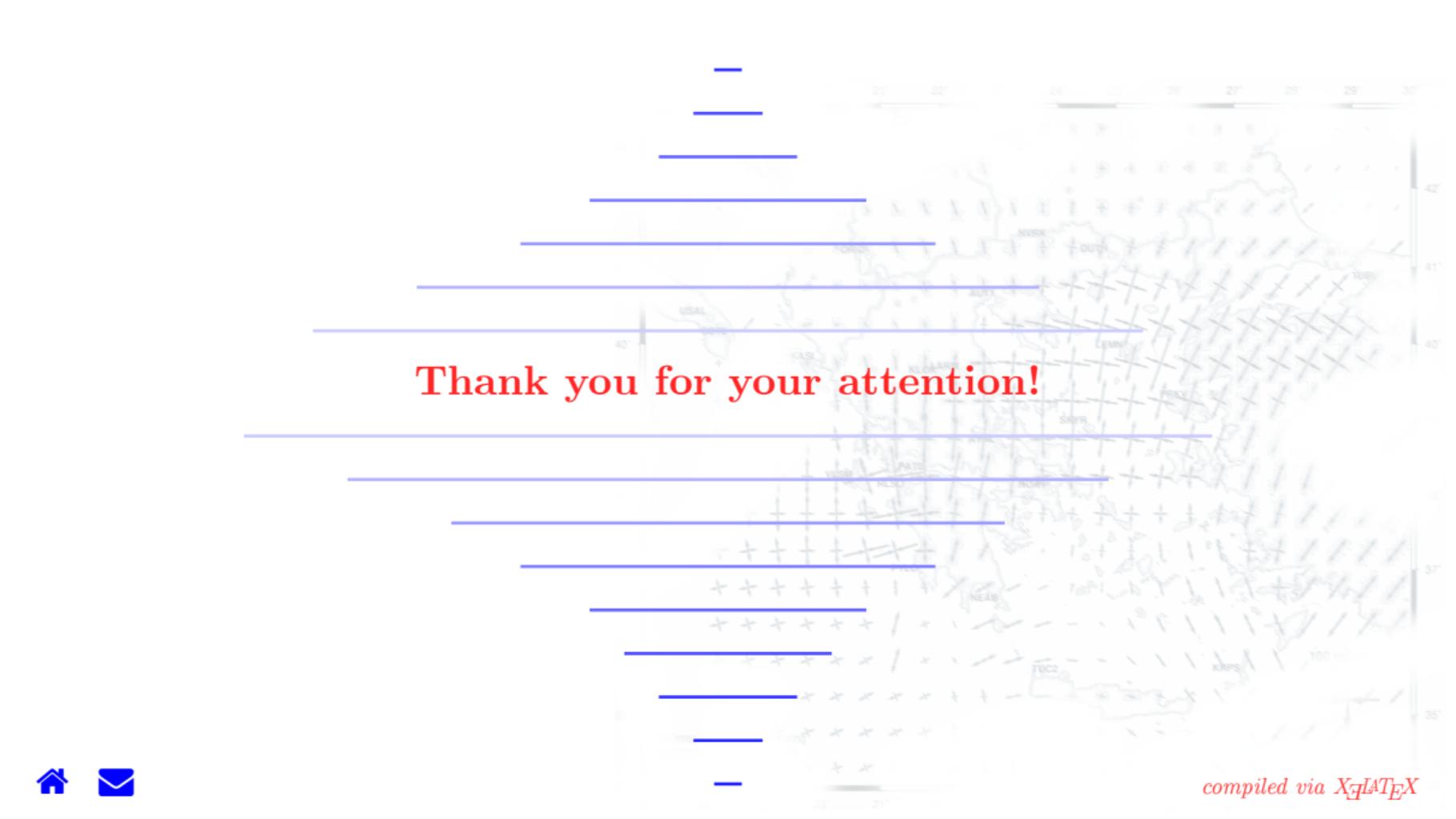
Harmonic Signals

In-Phase (mm)	Out-Of-Phase (mm)
0.0	-0.1, T = 367.7 days
0.4	0.9, T = 174.8 days

<http://dionysos.survey.ntua.gr/dso/enceladus/>

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.
- A dense velocity field for accurate estimation of ground/tectonic motions in the region will help to develop a better understanding of complex kinematic field.
- 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 support monitoring in an operational manner..



Thank you for your attention!

References I

- 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. 17).
- 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. 12).
- Dach, R., U. Hugentobler, P. Fridez, and M. Meindl (2007). *Bernese GPS Software Version 5.0*. Astronomical Institute, University of Bern (cit. on p. 8).
- Fernández-Blanco, David, Gino de Gelder, Robin Lacassin, and Rolando Armijo (Dec. 2019). "A new crustal fault formed the modern Corinth Rift". In: *Earth-Science Reviews* 199, p. 102919. doi: [10.1016/j.earscirev.2019.102919](https://doi.org/10.1016/j.earscirev.2019.102919) (cit. on p. 3).
- 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. 14).