

Vertical crustal deformations and climate variability through PCA and SVD

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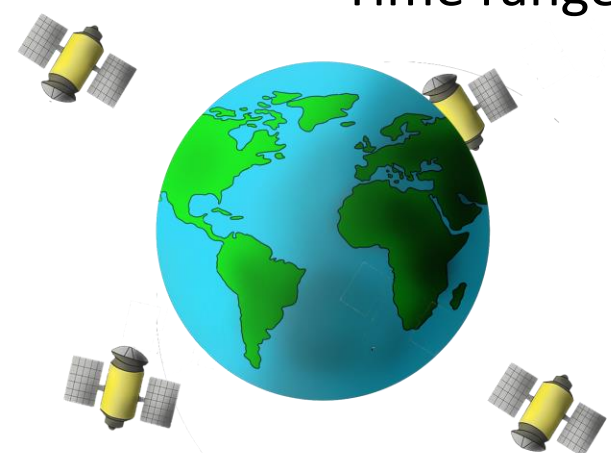
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Data

114 time series

Region: **Europe and Mediterranean area**

Time range: **2010-2018**

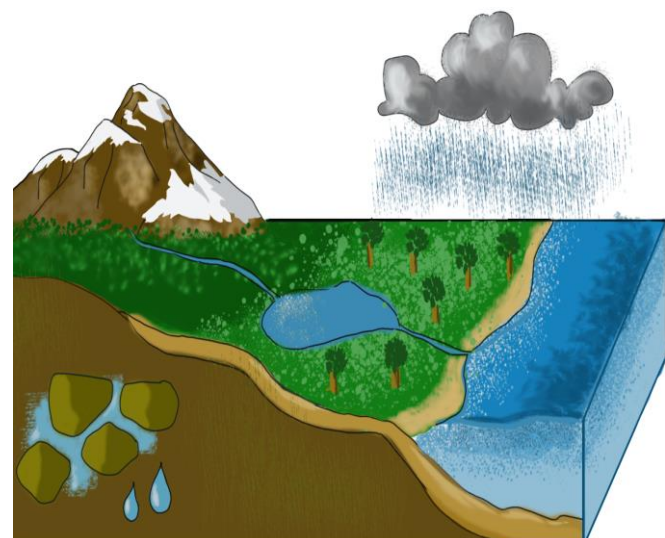


Surface pressure (SP)

GPS Height



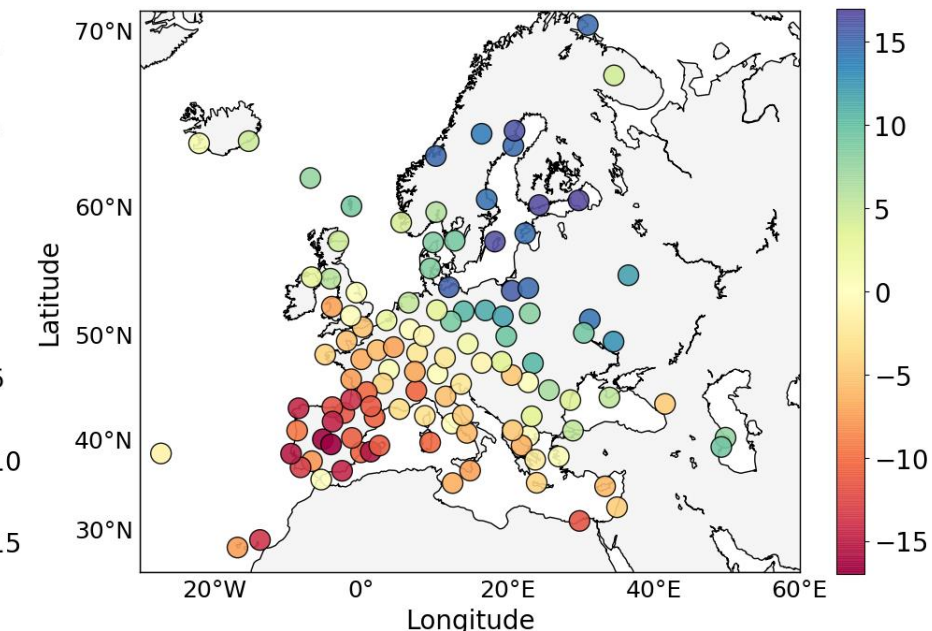
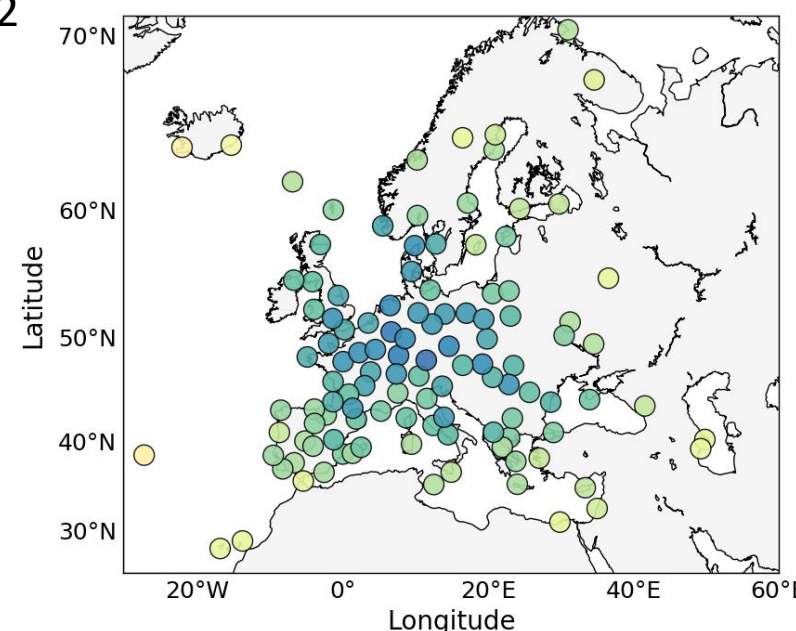
Terrestrial Water Storage (TWS)



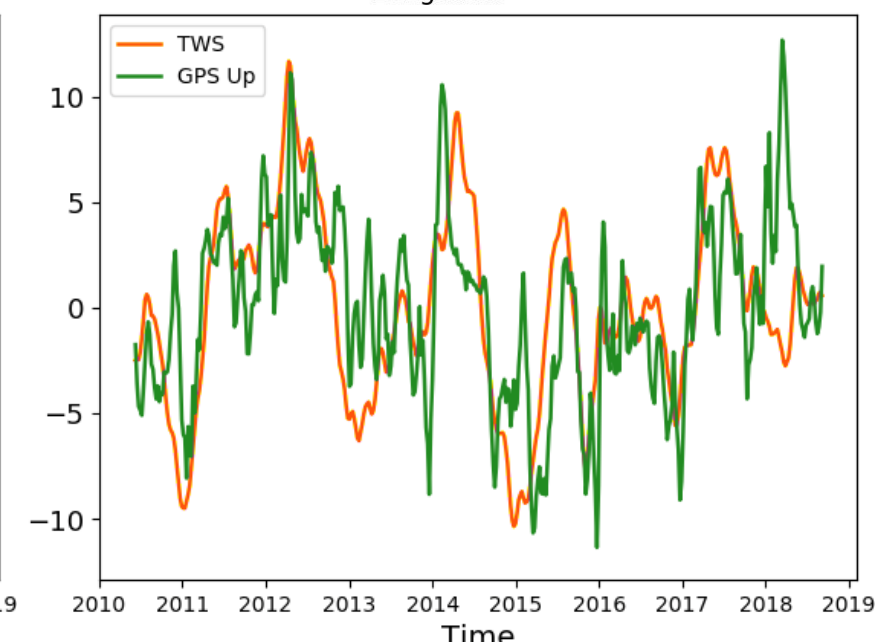
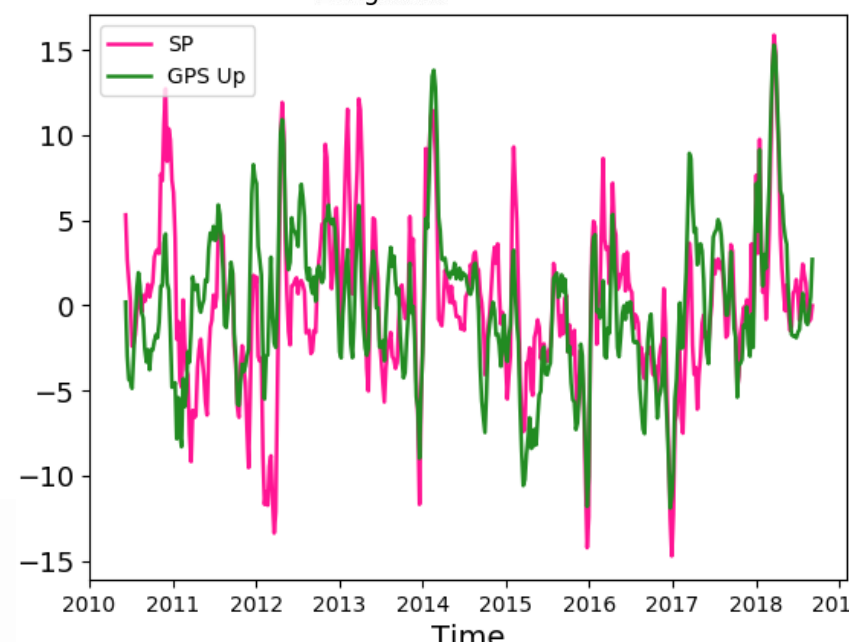
PCA

SVD

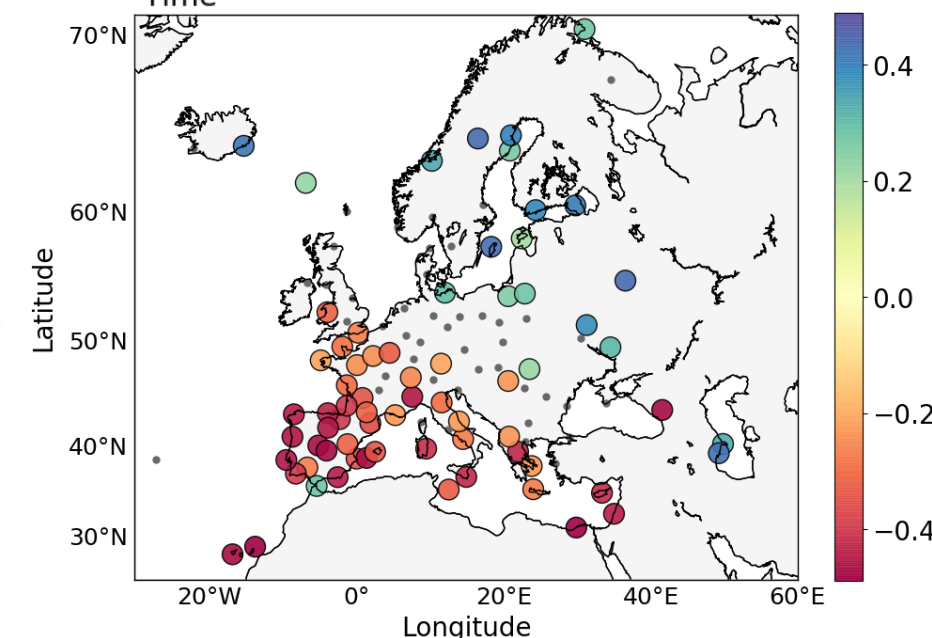
Correlation with MEI



First (left) and second (right) spatial pattern of the weekly GPS Height residuals



First time components of the SVD pairs SP-GPS H (left) and TWS-GPS H (right)



Spatial distribution of the correlation coefficients between the MEI and the GPS Height time series.

Interannual Variability of GPS Heights and Environmental Parameters over Europe and the Mediterranean Area by Elia L., Zerbini S. and Raicich F. Published on Remote Sensing 2021, 13(8), 1554.
<https://doi.org/10.3390/rs13081554>

Objective

- ☐ To identify and analyse principal modes of variability of
 - GPS height
 - Environmental parameters

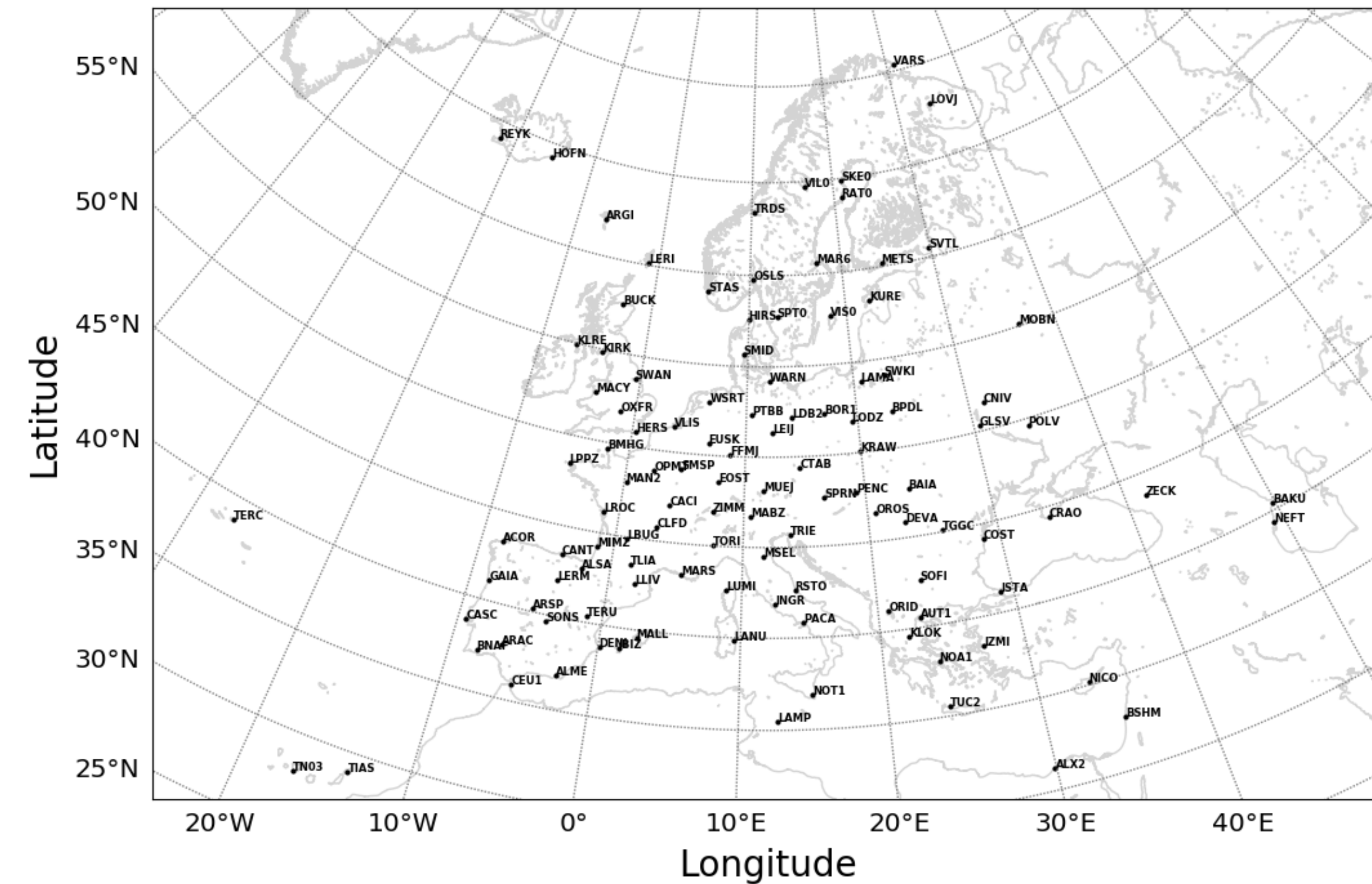
and

- ☐ To study the coupled variability of these parameters

Parameters

- GPS height
- Surface atmospheric pressure (SP)
- Terrestrial Water Storage (TWS)
- Multivariate ENSO Index

Study area and GPS stations



114 GPS stations selected
according to

- Length of the time series of the daily coordinates
- Completeness of the time series
- Spatially uniform coverage

Datasets

Daily time series covering the period

June 9, 2010 – September 5, 2018

- GPS height
(Nevada Geodetic Laboratory, <http://geodesy.unr.edu/>)
- SP
(National Center for Environmental Prediction,
<https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.html>)
- TWS
(NASA Data and Information Services Center, <https://disc.gsfc.nasa.gov/>)

Data pre-processing

- Detrending
- Deseasoning
- Estimate of weekly mean values
- Standardization
- Spatial interpolation in the case of SP and TWS

Principal Components Analysis (PCA)

To identify principal modes of variability of a dataset



Principal Component Analysis (PCA):
modes of variability



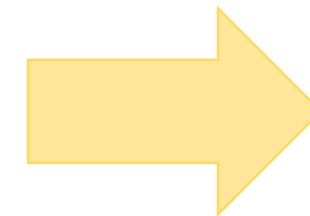
spatial pattern



time component

PCA theory

$$F_{ij} = \begin{bmatrix} f(t_1, x_1) & \cdots & f(t_1, x_p) \\ \vdots & \ddots & \vdots \\ f(t_n, x_1) & \cdots & f(t_n, x_p) \end{bmatrix}$$



$$R = \frac{F^T F}{n-1}$$

- eigenvector c_i of $R \rightarrow$ spatial pattern of the i -th mode
- vector $a_i = F c_i \rightarrow$ time component of the i -th mode
- eigenvalue l_i of $R \rightarrow$ variance explained by the i -th mode

Vertical crustal deformations and climate variability through PCA and SVD

Each PCA mode explains part of the total variability of the dataset

Variance (%)			
Modes	GPS height	SP	TWS
1	32.77	46.54	29.67
2	11.55	22.22	12.08
3	5.58	11.82	10.39
4	4.13	5.64	7.78

Singular Value Decomposition (SVD)

To identify common modes of variability between pairs of variables



Singular Value Decomposition (SVD)
common modes of variability



2 spatial patterns



2 time components

Pair of variables studied:

- GPS height-AP → first 4 modes = 85% of total covariance
- GPS height-TWS → first 3 modes = 51% of total covariance

SVD theory

F_1 and F_2 : matrices of the two variables

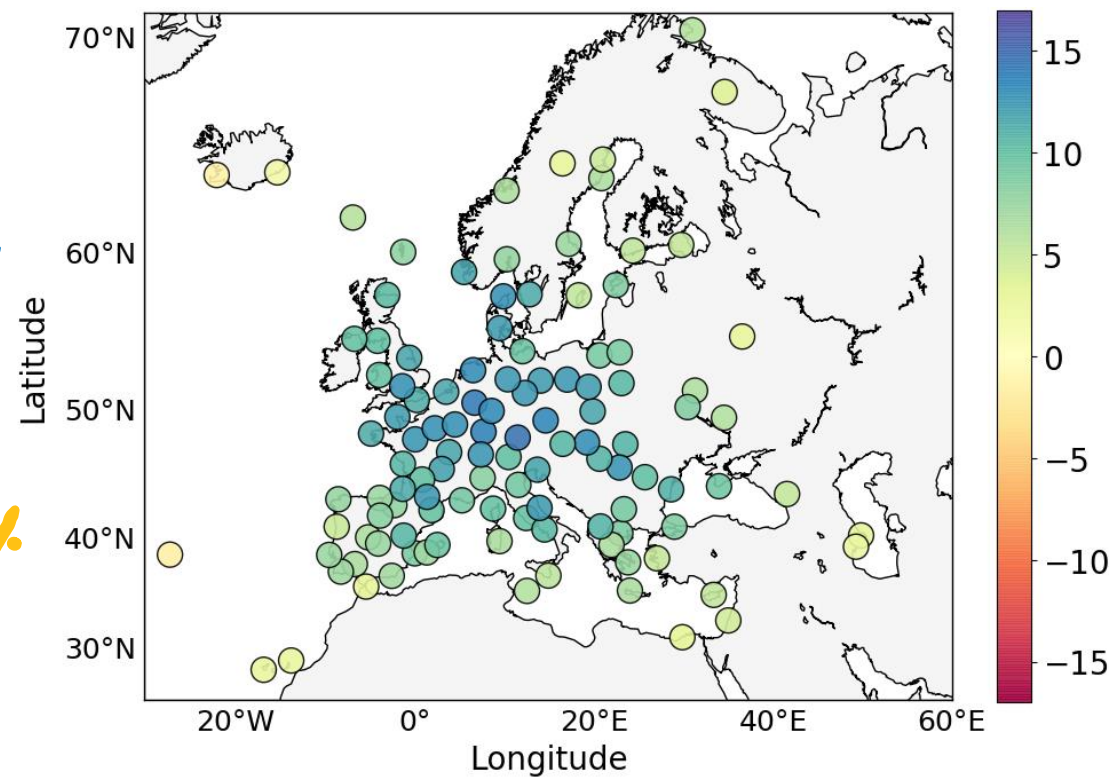
$$R_{cross} = F_1^T F_2 = ULV^T$$

- Columns u_i of U and v_i of V → spatial pattern of the i -th mode of covariability of F_1 and F_2
- Vectors $a_i = F_1 u_i$ and $b_i = F_2 v_i$ → time component of the i -th mode of covariability of F_1 and F_2
- Values l_i of L → covariance explained by the i -th mode

Vertical crustal deformations and climate variability through PCA and SVD

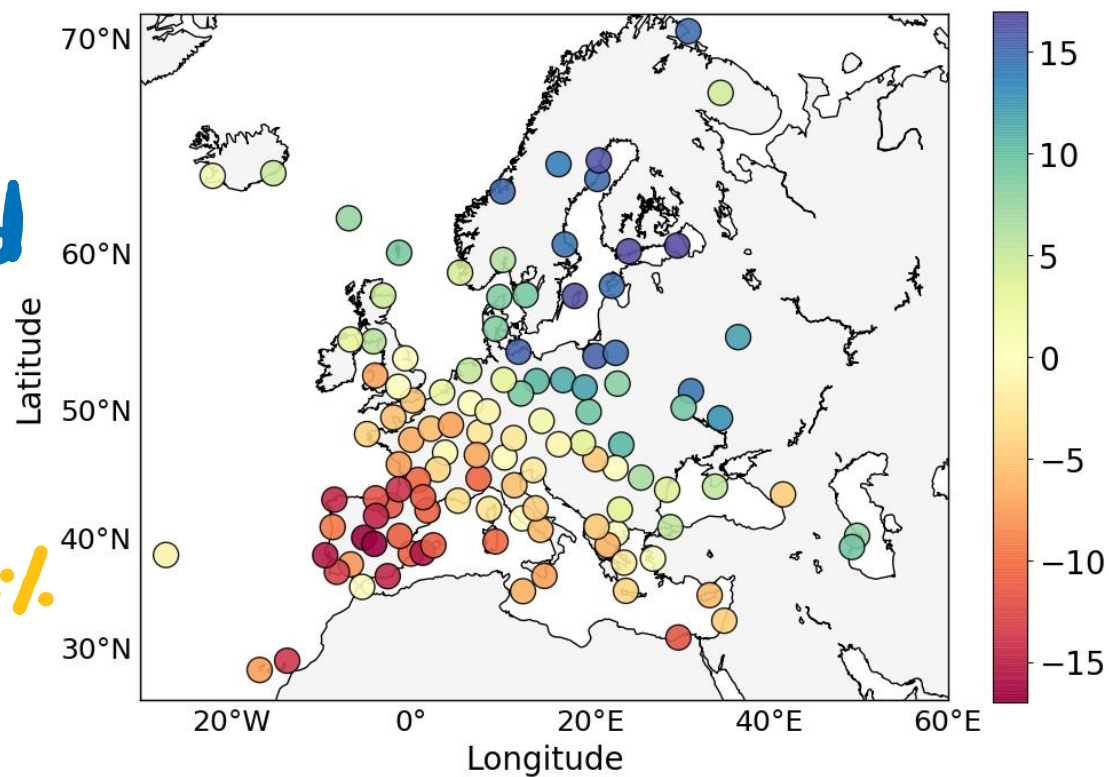
GPS height: 1st and 2nd PCA modes

1st
32.77%

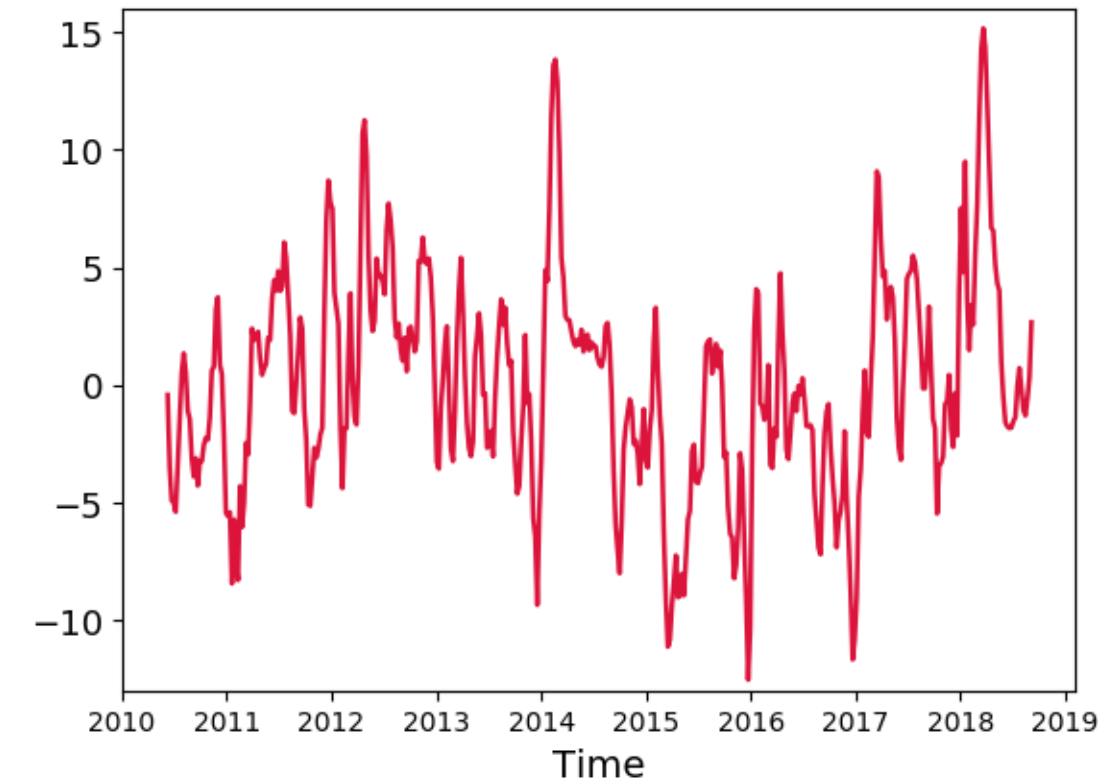


- Coherent behaviour over Europe and the Mediterranean area

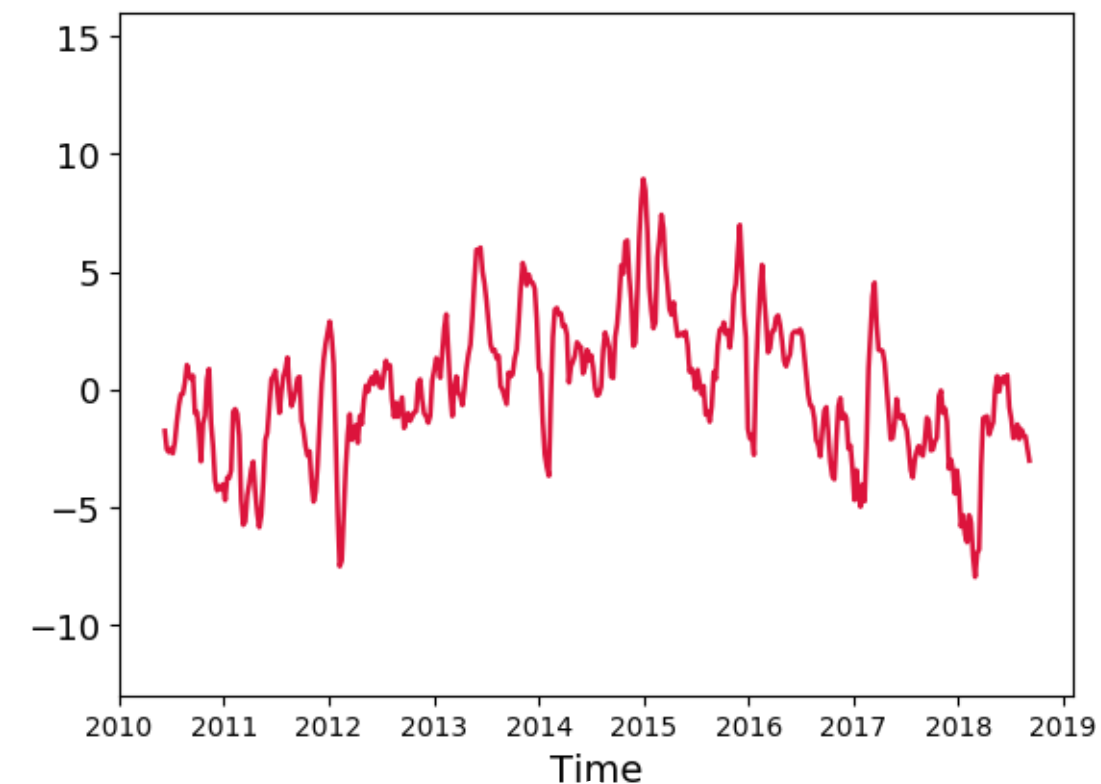
2nd
11.55%



- South-north gradient



- Large oscillations loading variations due to essential climate variables
- 5y oscillation might be associated with a sequence of severe droughts

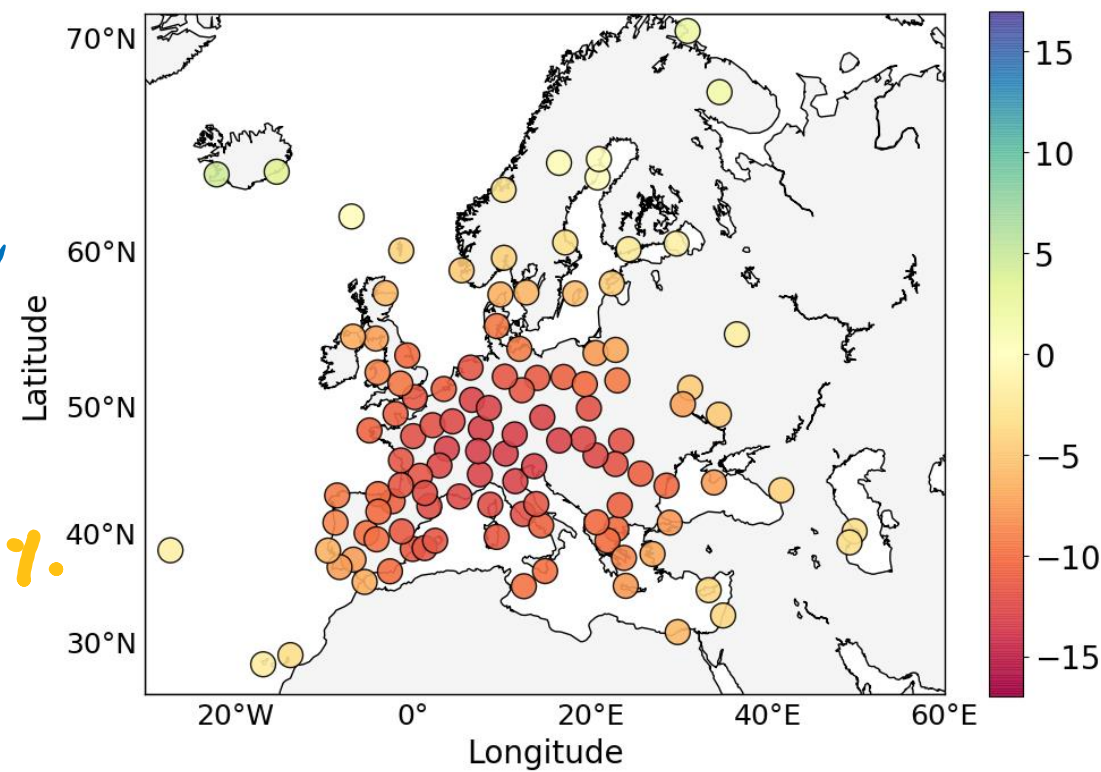


- Decadal oscillation
- ENSO phenomenon impact

Vertical crustal deformations and climate variability through PCA and SVD

SP: 1st and 2nd PCA modes

1st
46.54%



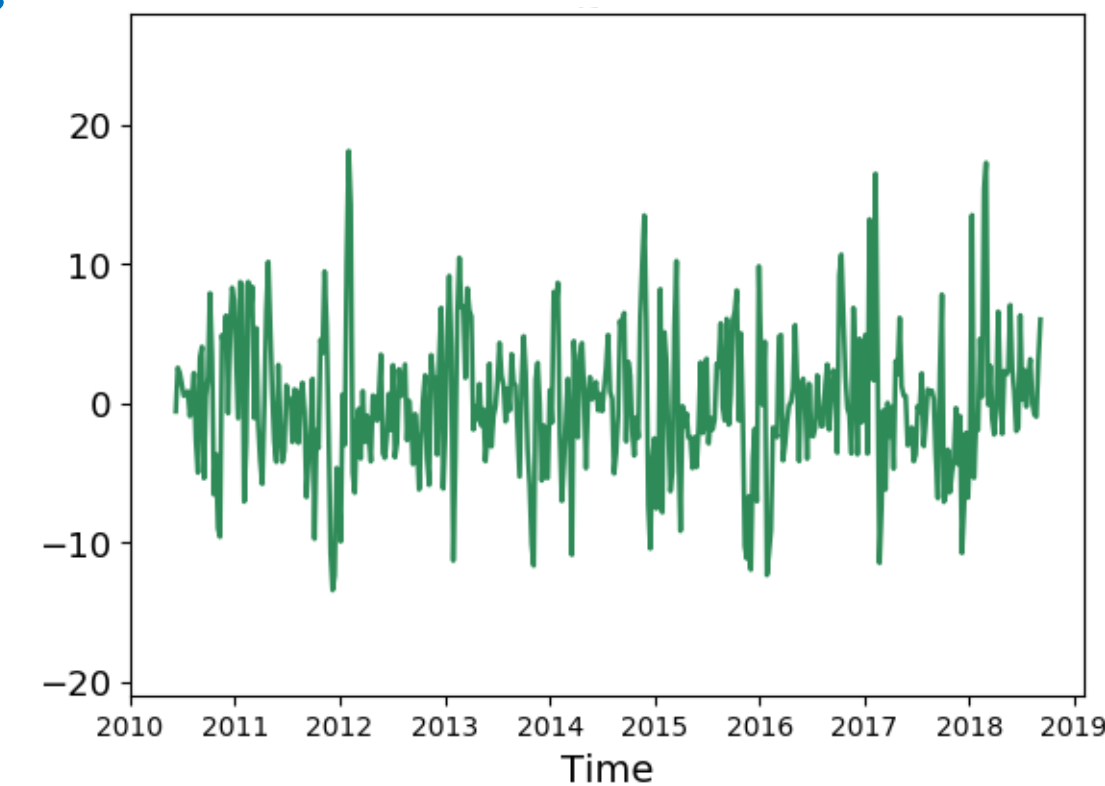
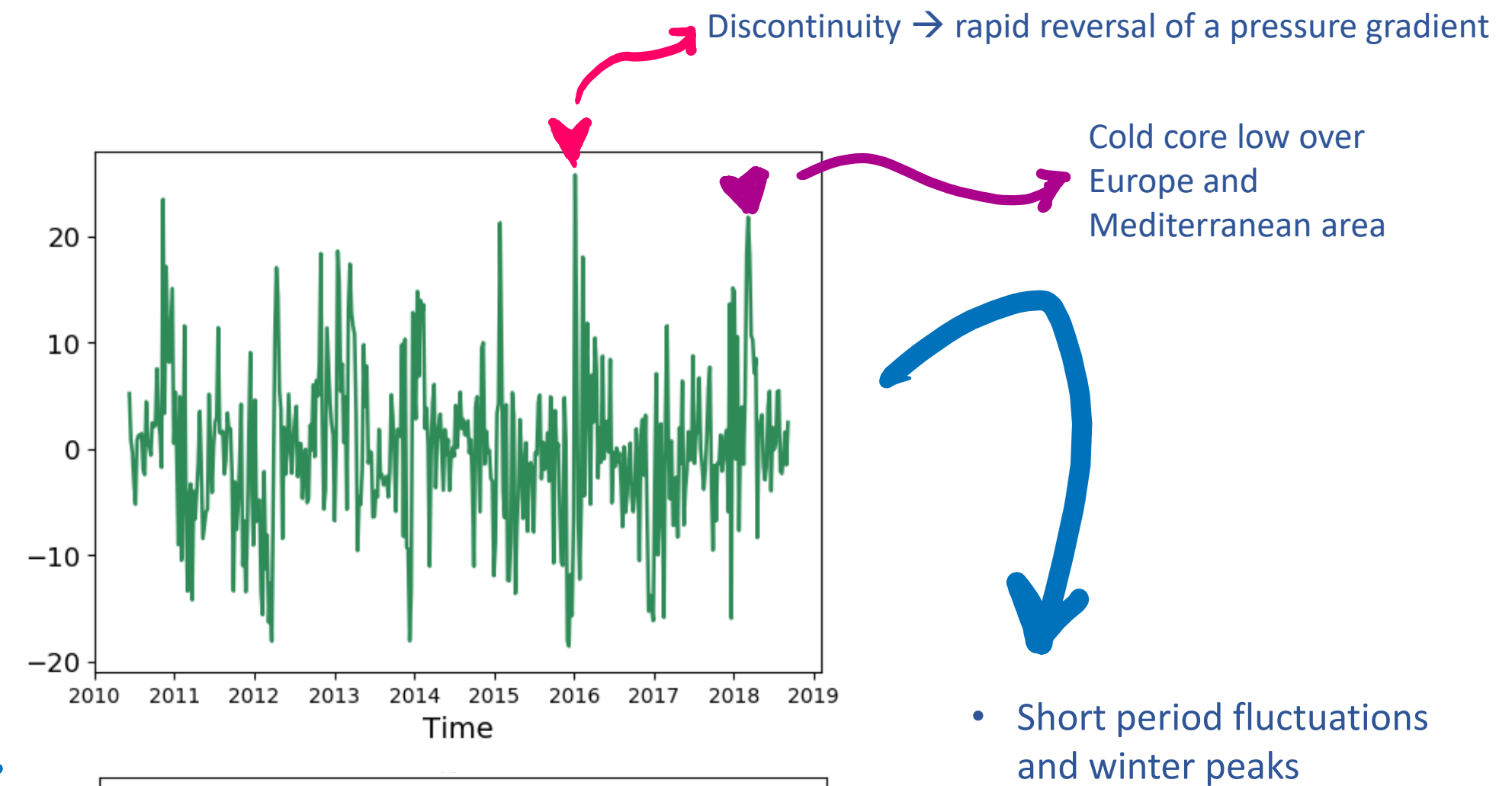
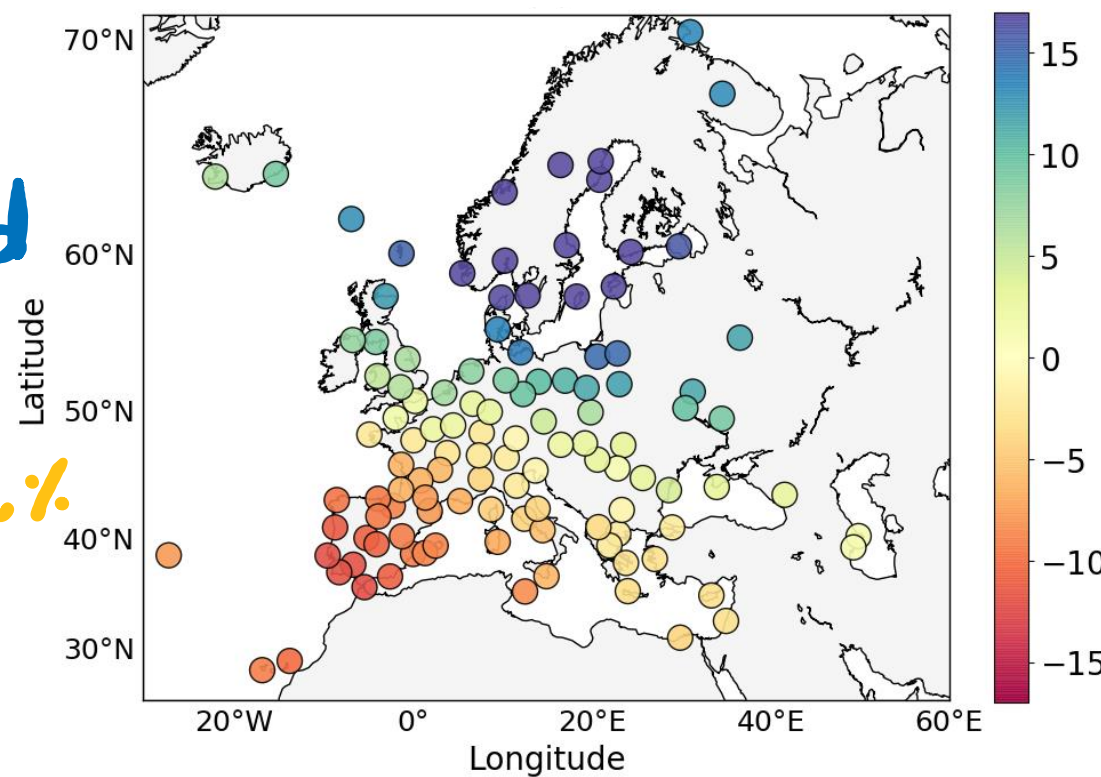
- Coherent behaviour over Europe and the Mediterranean area
- Atlantic side:
 - Icelandic Low (coeff. > 0)
 - and
 - Azores anticyclone (coeff. < 0)



NORTH ATLANTIC OSCILLATION

- South-north gradient

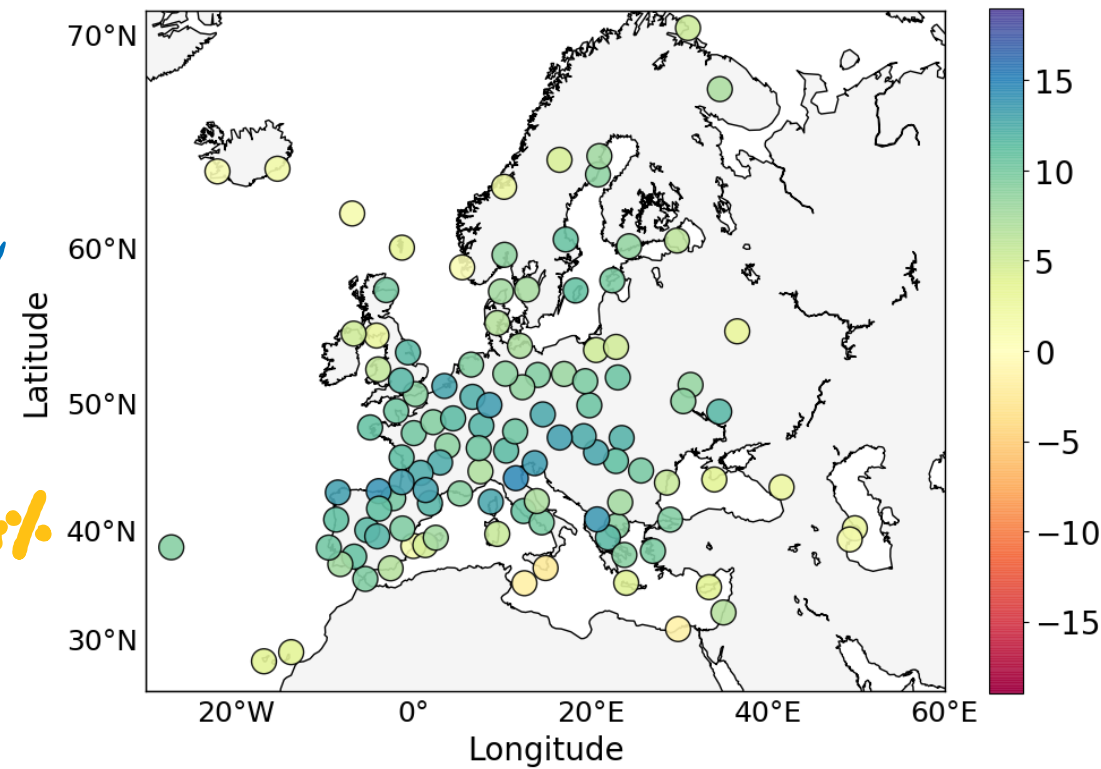
2nd
21.22%



Vertical crustal deformations and climate variability through PCA and SVD

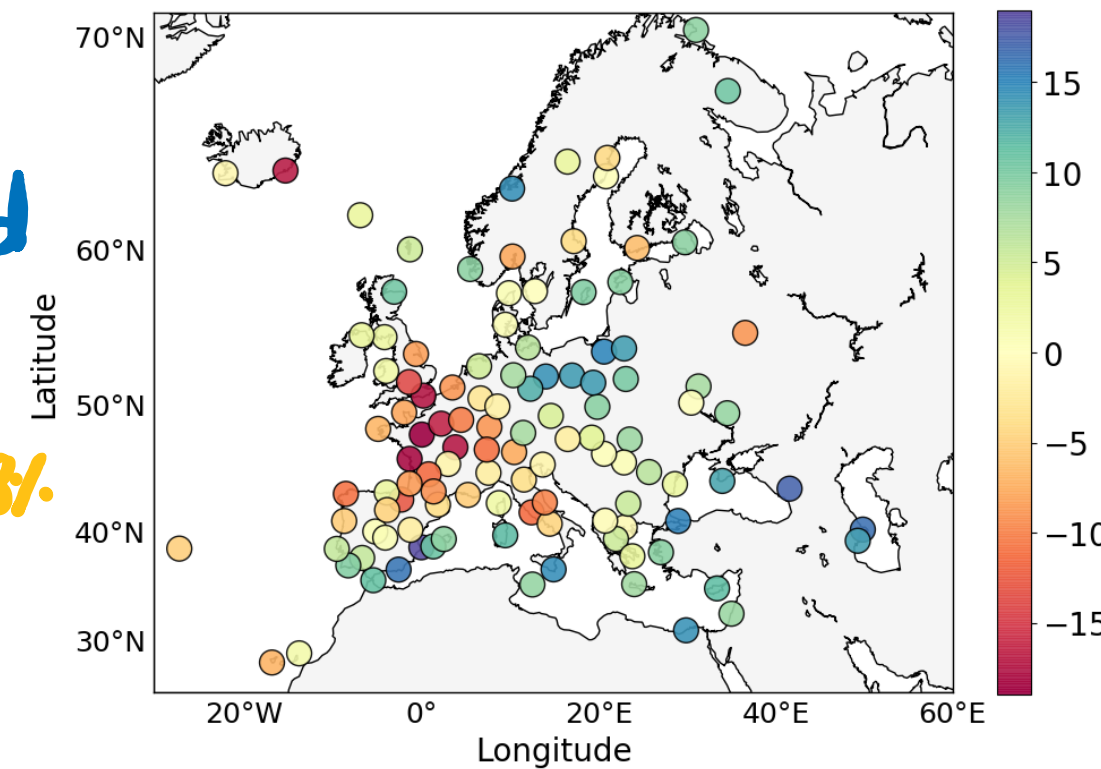
TWS: 1st and 2nd PCA modes

1st
29.67%



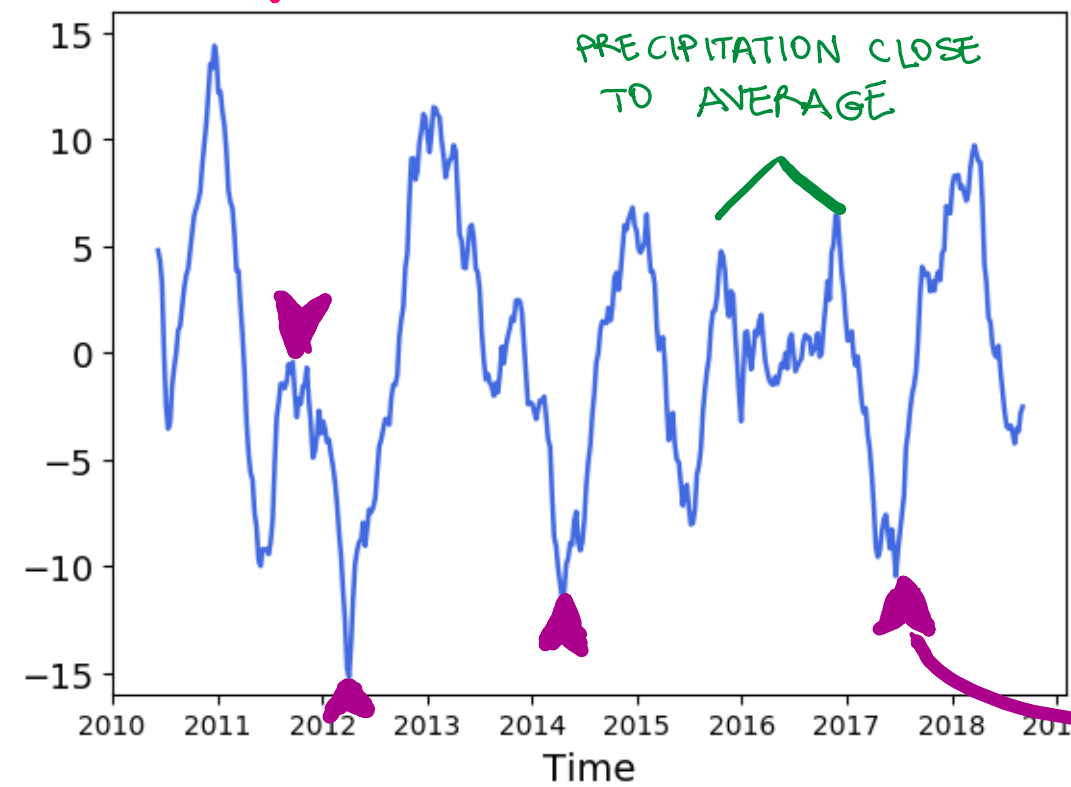
- Coherent behaviour over Europe and the Mediterranean area

2nd
12.08%

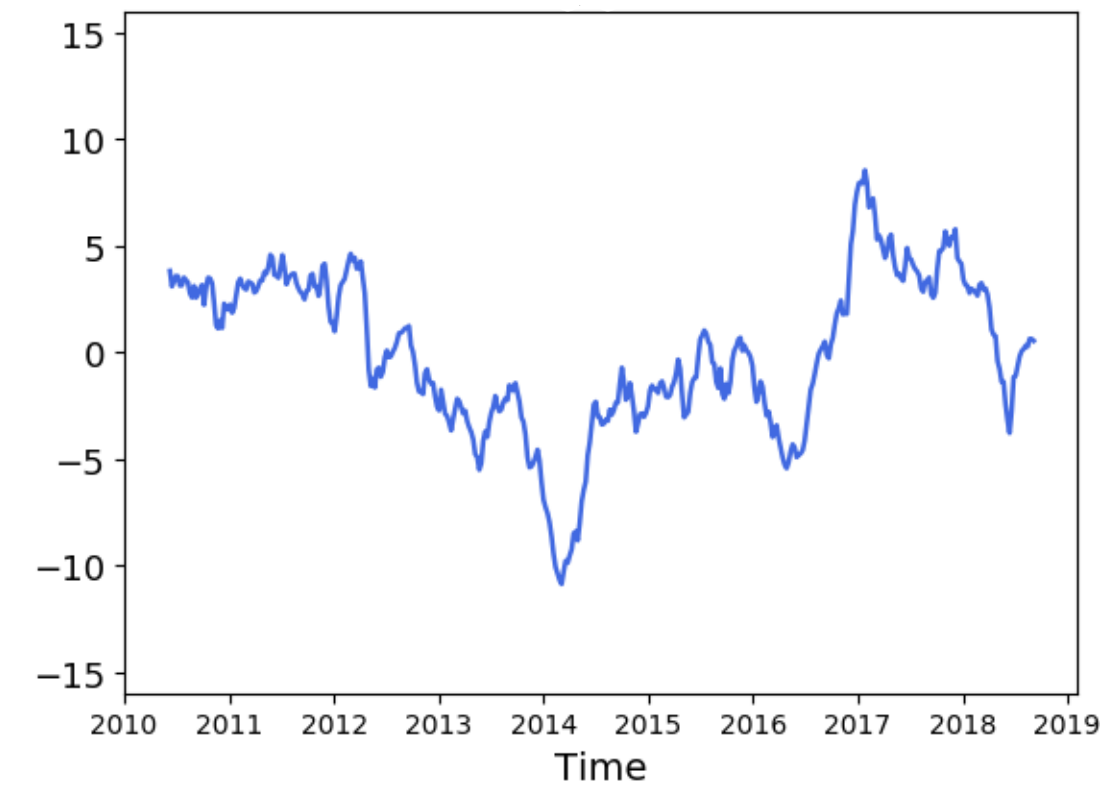


- Coherent behaviour in Central Europe

2010: very wet



- Large oscillations with period of 2y

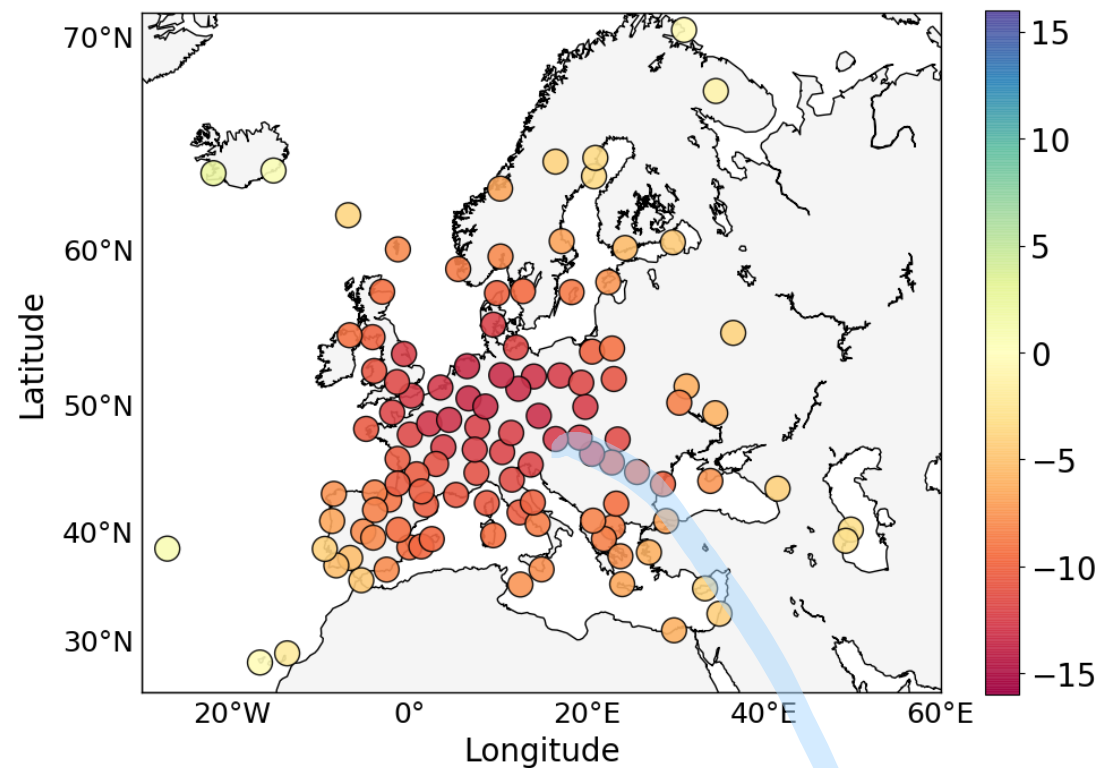


- Decadal period
- Minimum in 2014

Vertical crustal deformations and climate variability through PCA and SVD

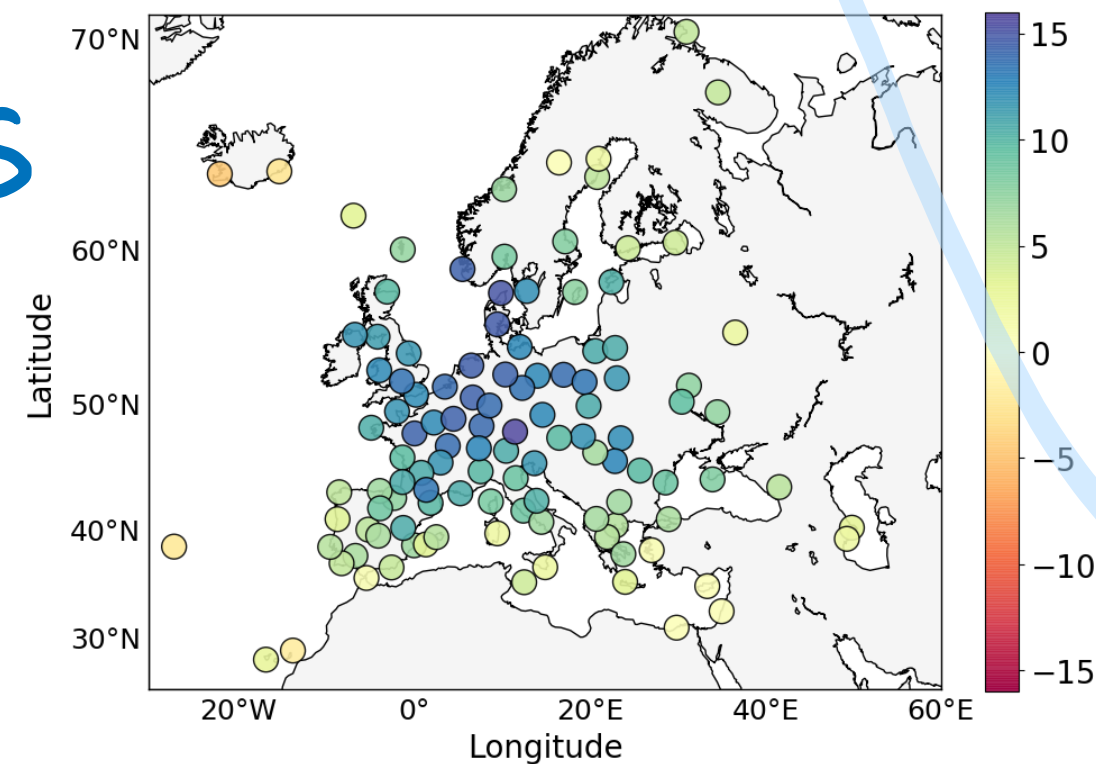
SP-GPS height: 1st SVD mode (52.03%)

SP



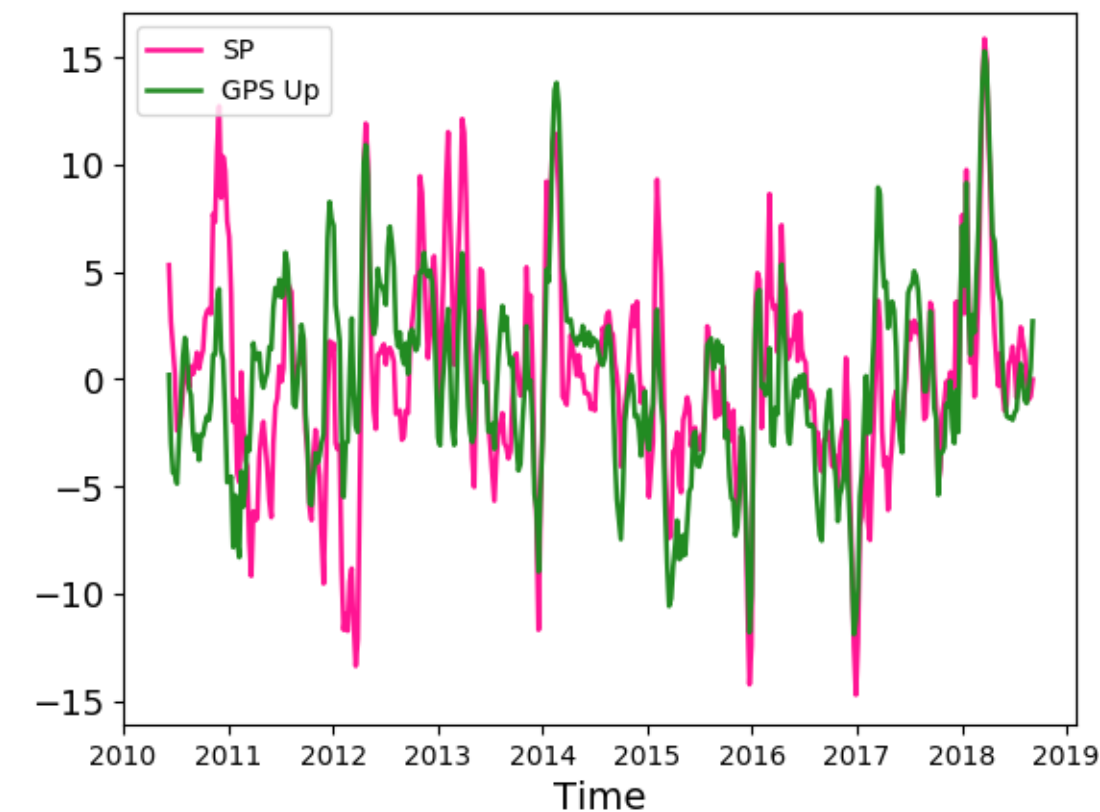
- Anticorrelation between the two spatial patterns
- GPS height: larger positive values in Central Europe than those in coastal areas

GPS



Different response of coastal and inland sites to the same pressure forcing

Larger values inland, as expected*

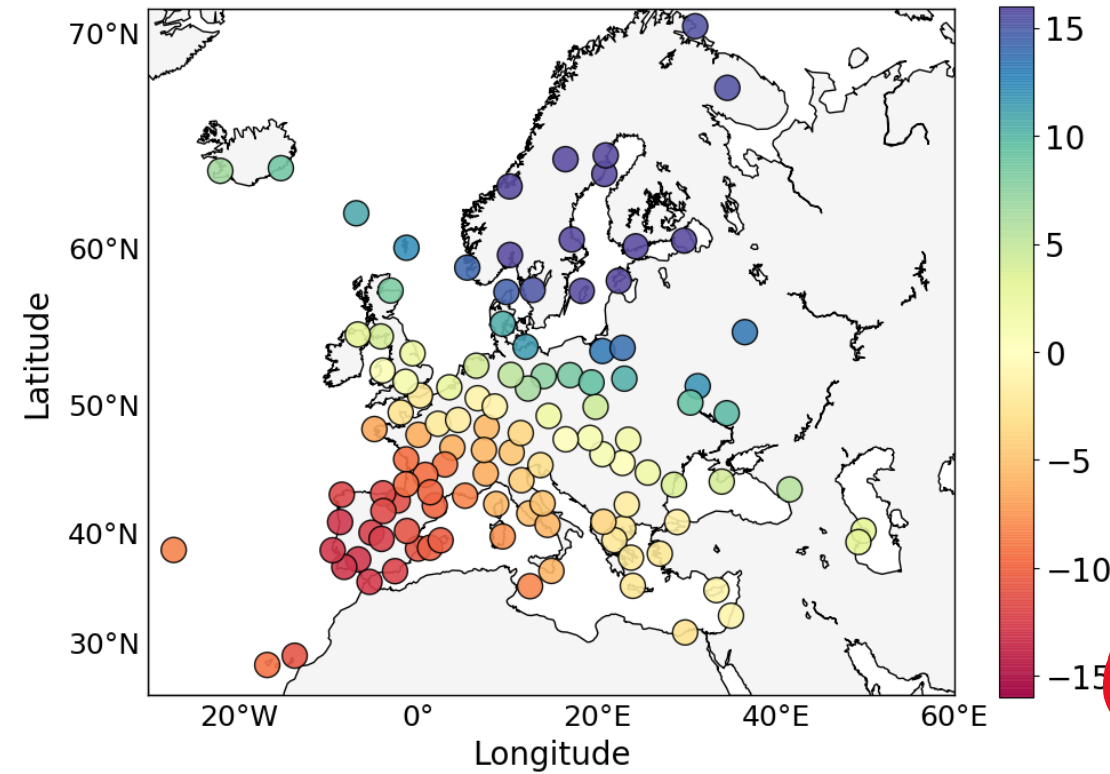


- 5y oscillation

Vertical crustal deformations and climate variability through PCA and SVD

SP-GPS height: 2nd SVD mode (19.43%)

SP



• S-N gradient

Difference between:

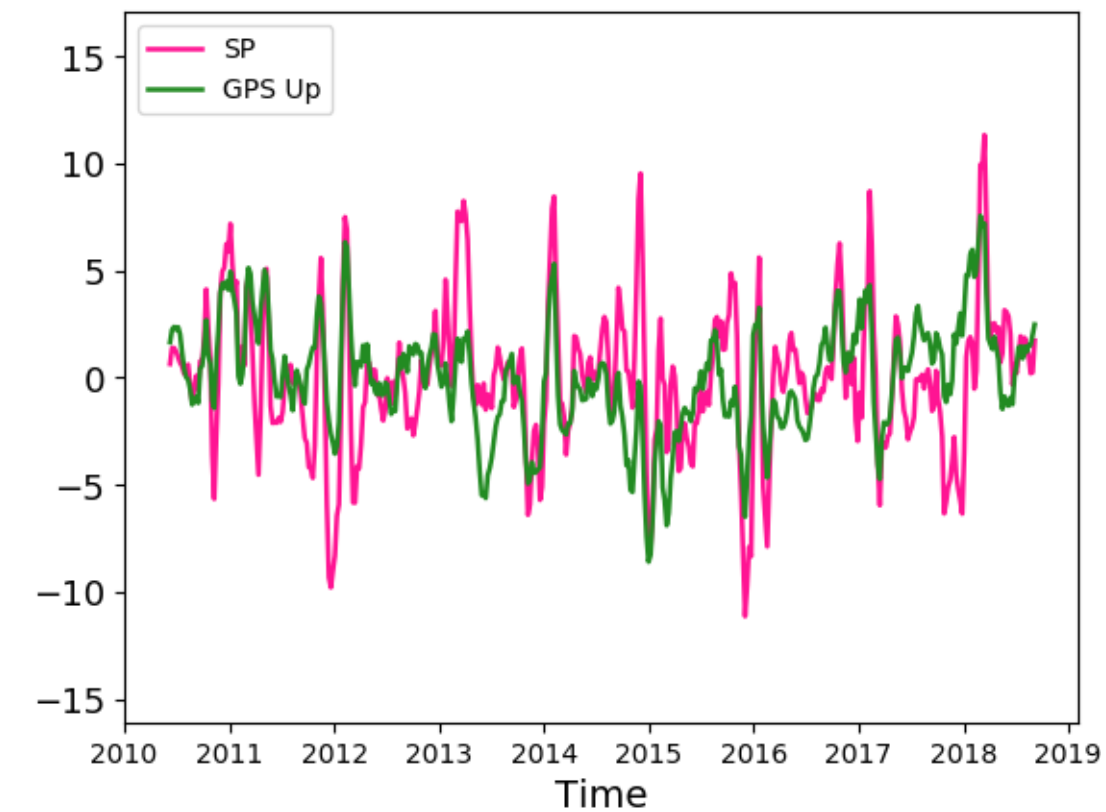
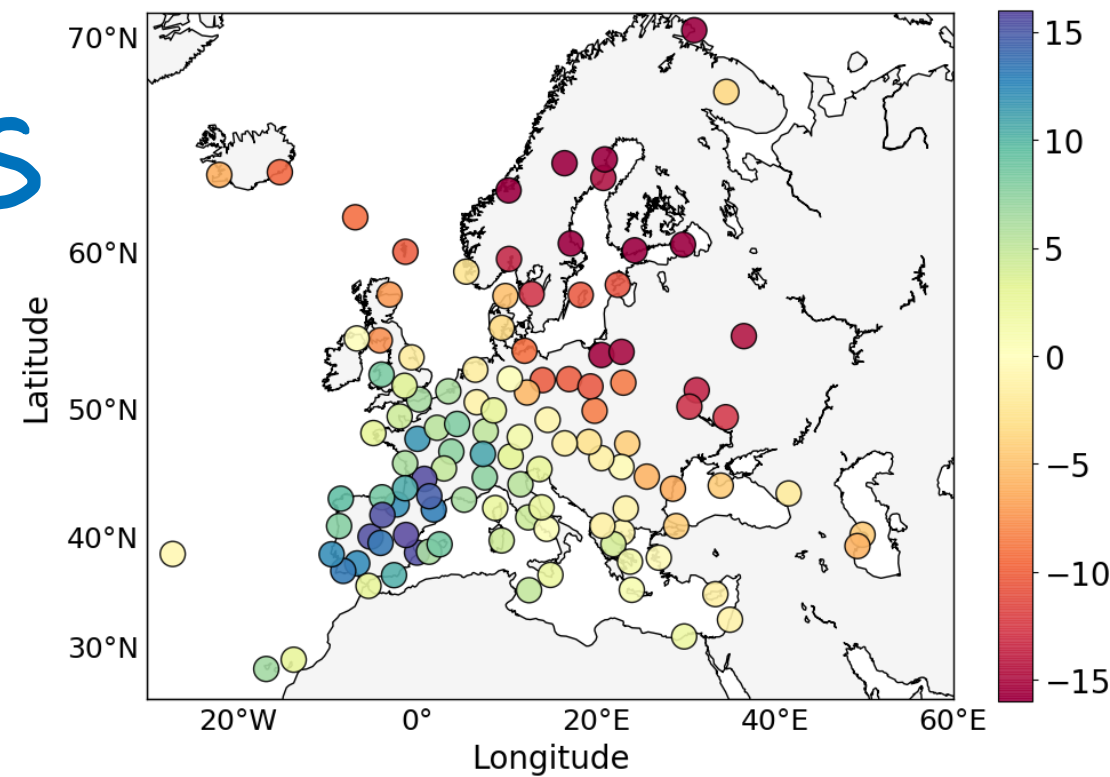
southern warmer regions
(high SP)

&

northern cooler regions
(low SP)

• Anticorrelation

GPS

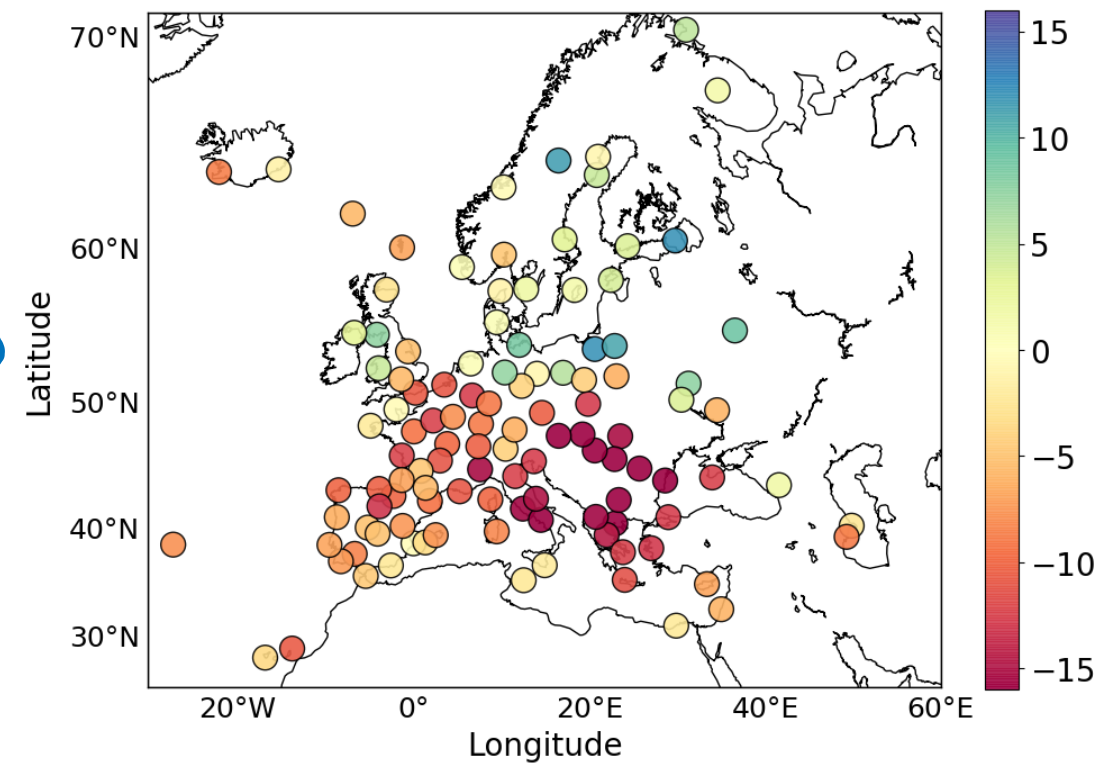


• Short period variability

Vertical crustal deformations and climate variability through PCA and SVD

TWS-GPS height: 1st SVD mode (20.20%)

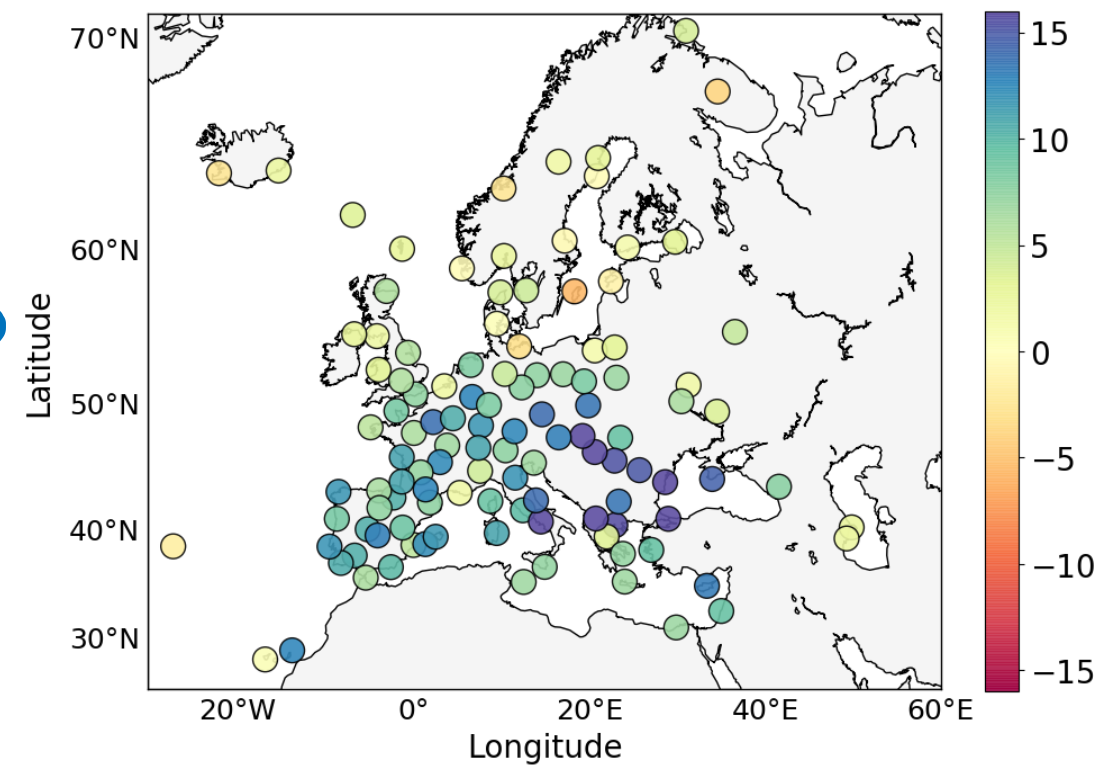
TWS



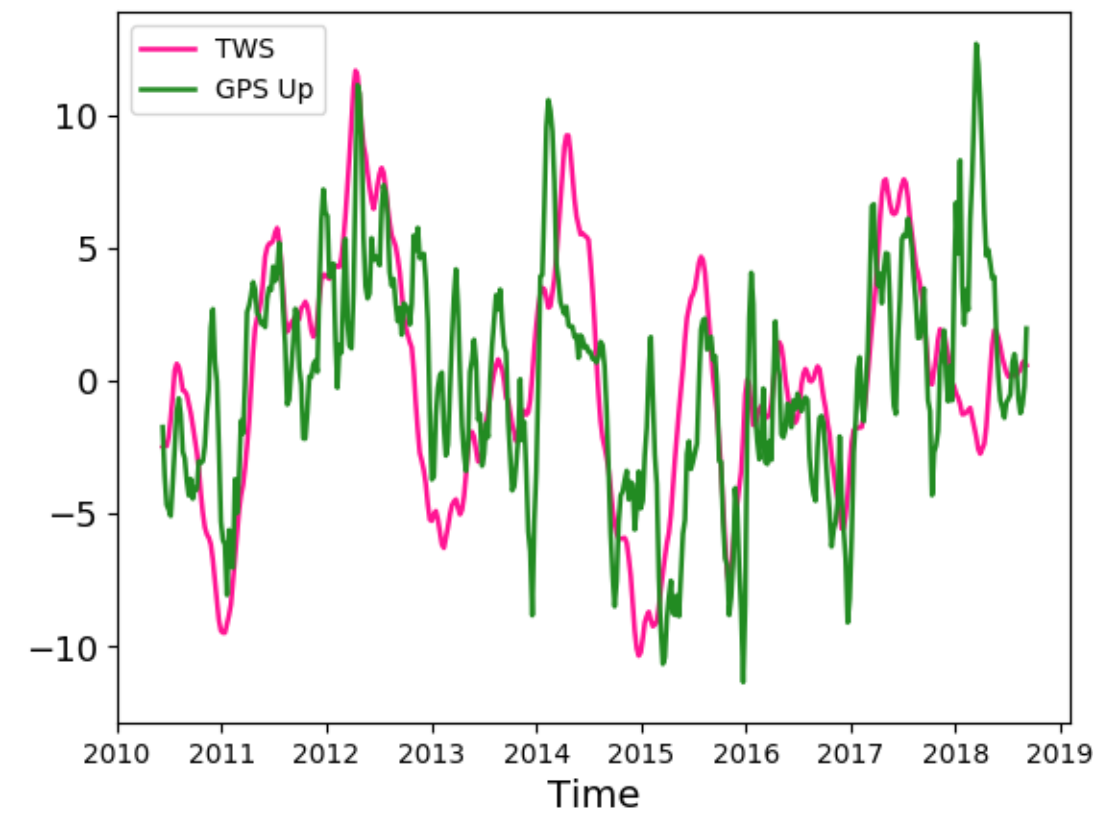
- Anticorrelation between the two spatial patterns



GPS



This mode is likely representative of the **vertical deformation** induced by the **TWS loading** on the Earth's crust

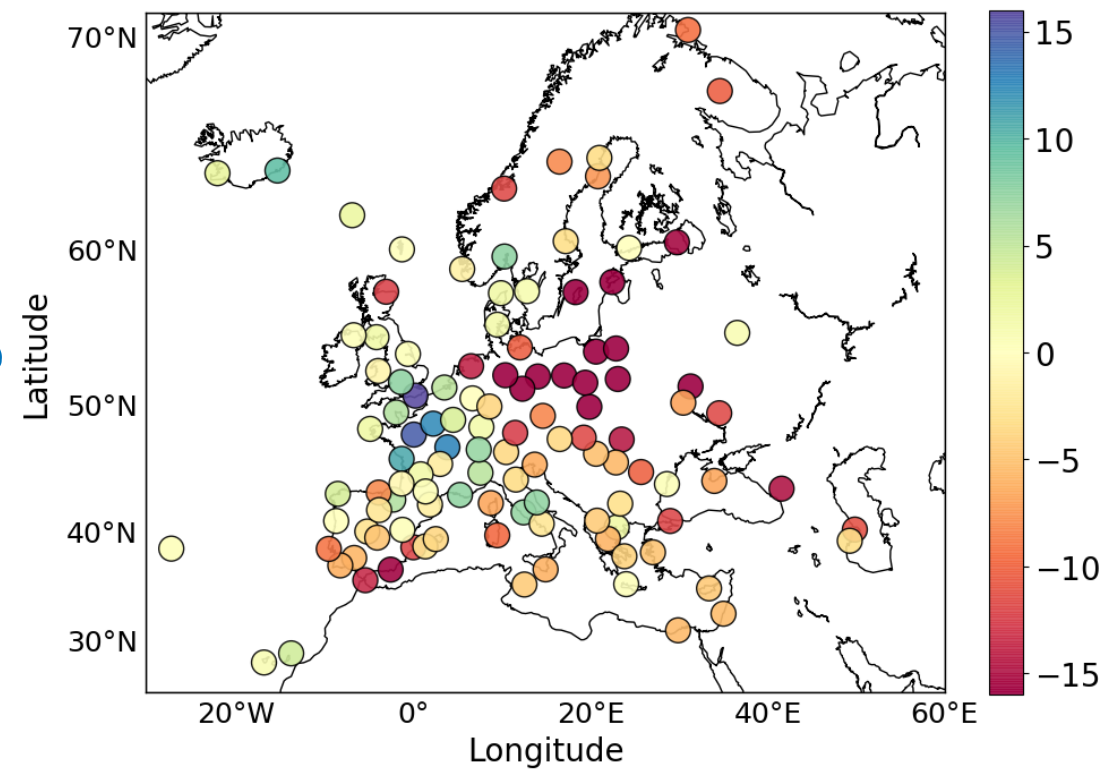


- 5y oscillation

Vertical crustal deformations and climate variability through PCA and SVD

TWS-GPS height: 2nd SVD mode (14.98%)

TWS

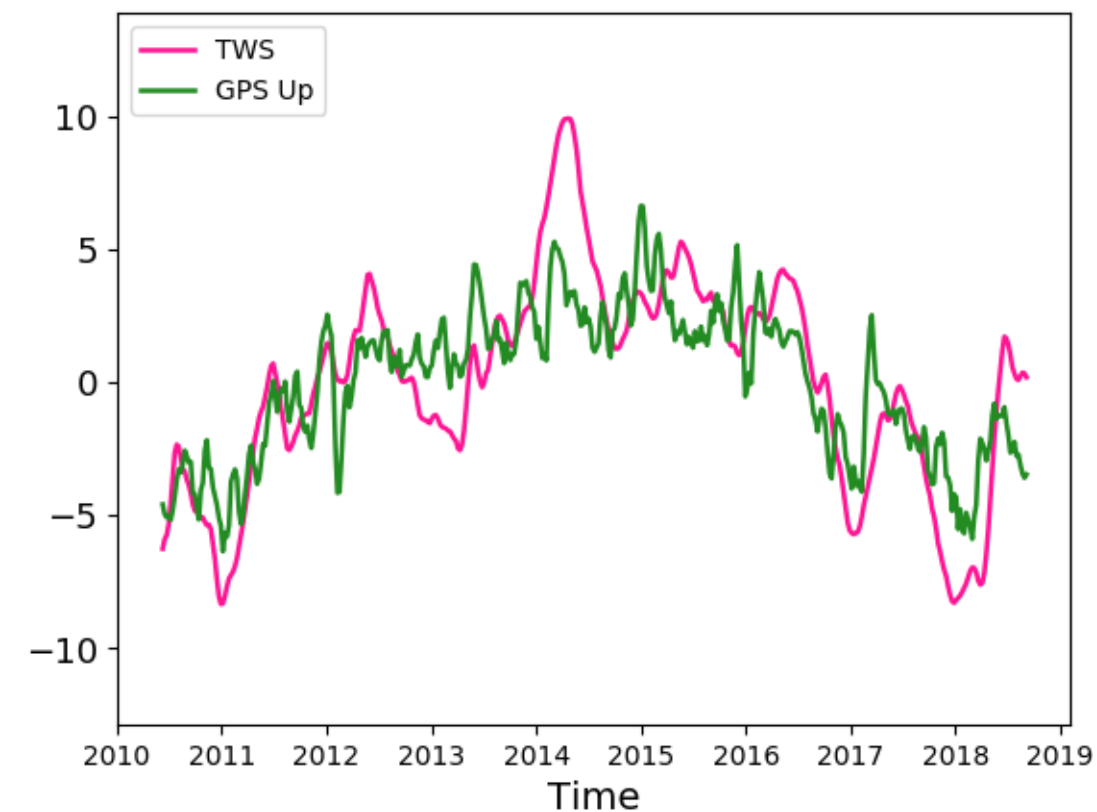
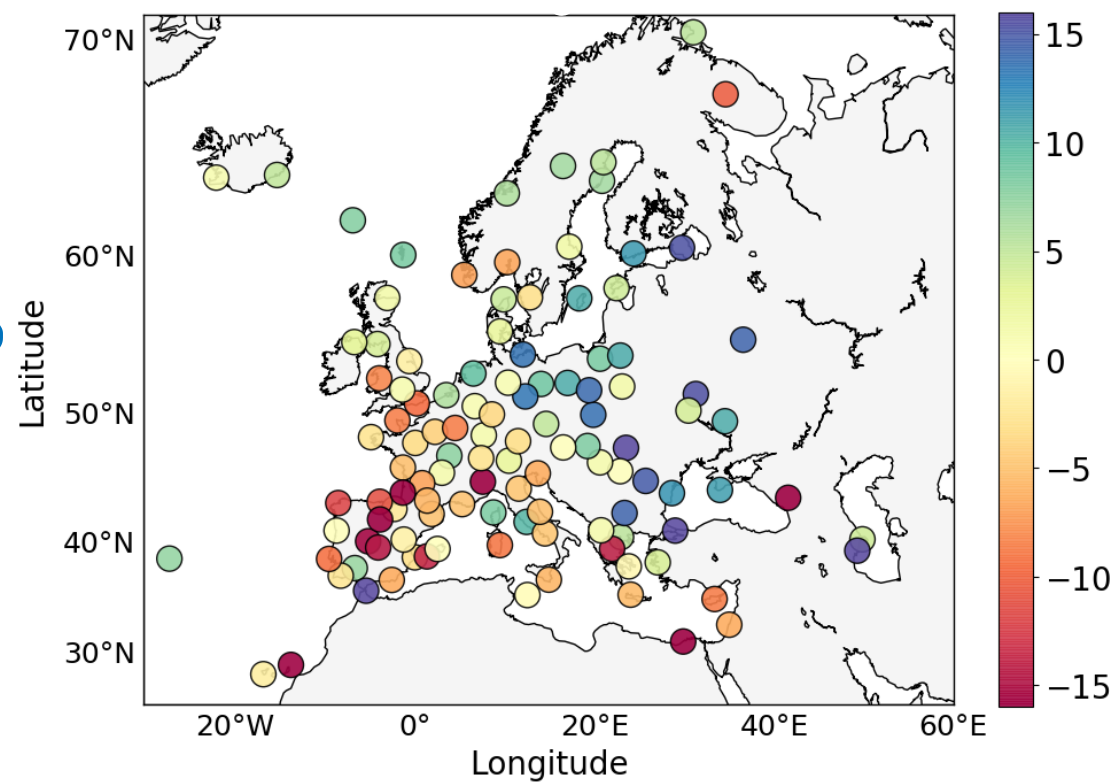


- Anticorrelation between the two spatial patterns



TWS loading mechanism

GPS



- Decadal oscillation
- This long-period oscillation of similar shape does not appear in the SVDs SP-GPS Height

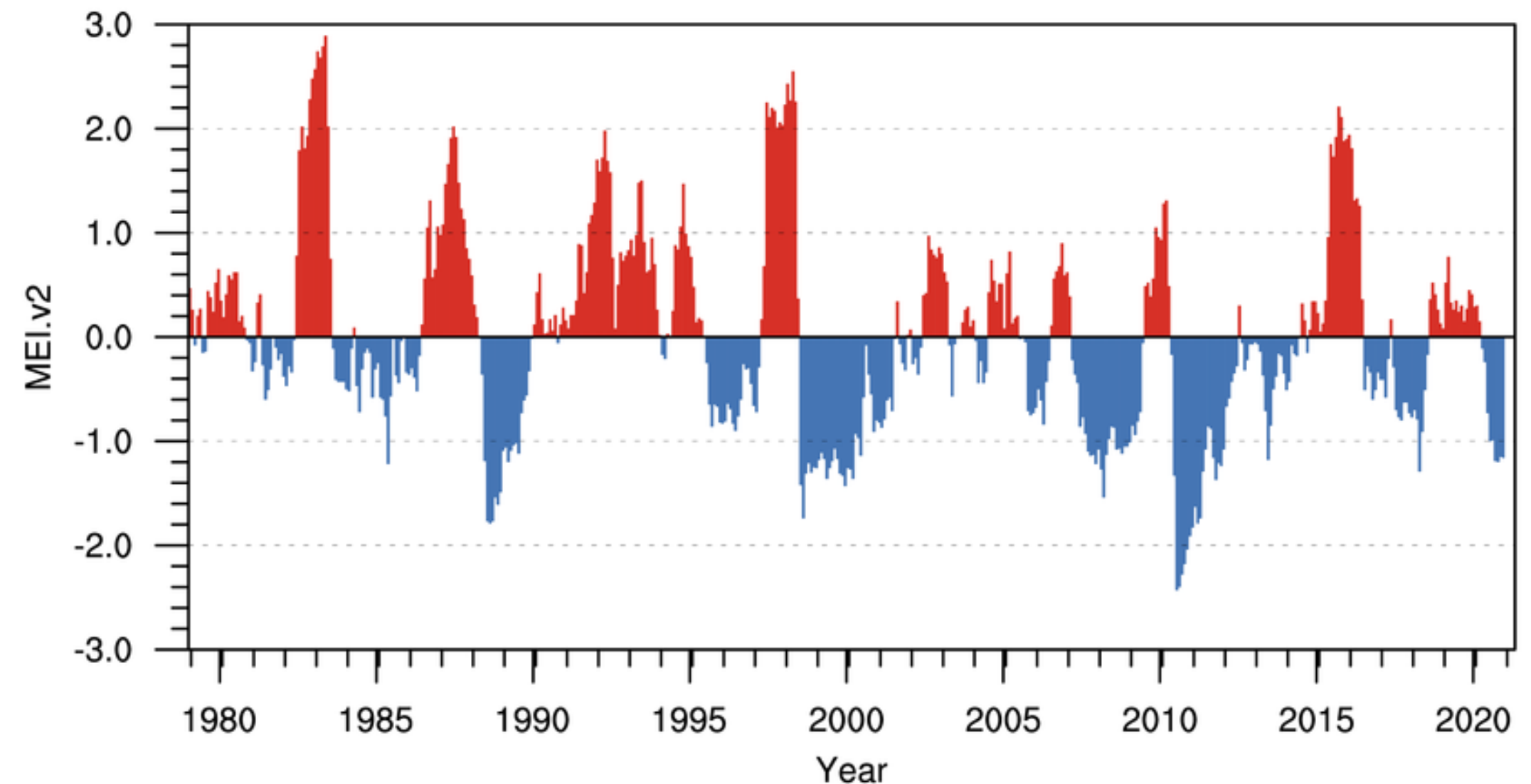


The behaviour is mostly due to TWS impact

Multivariate ENSO Index

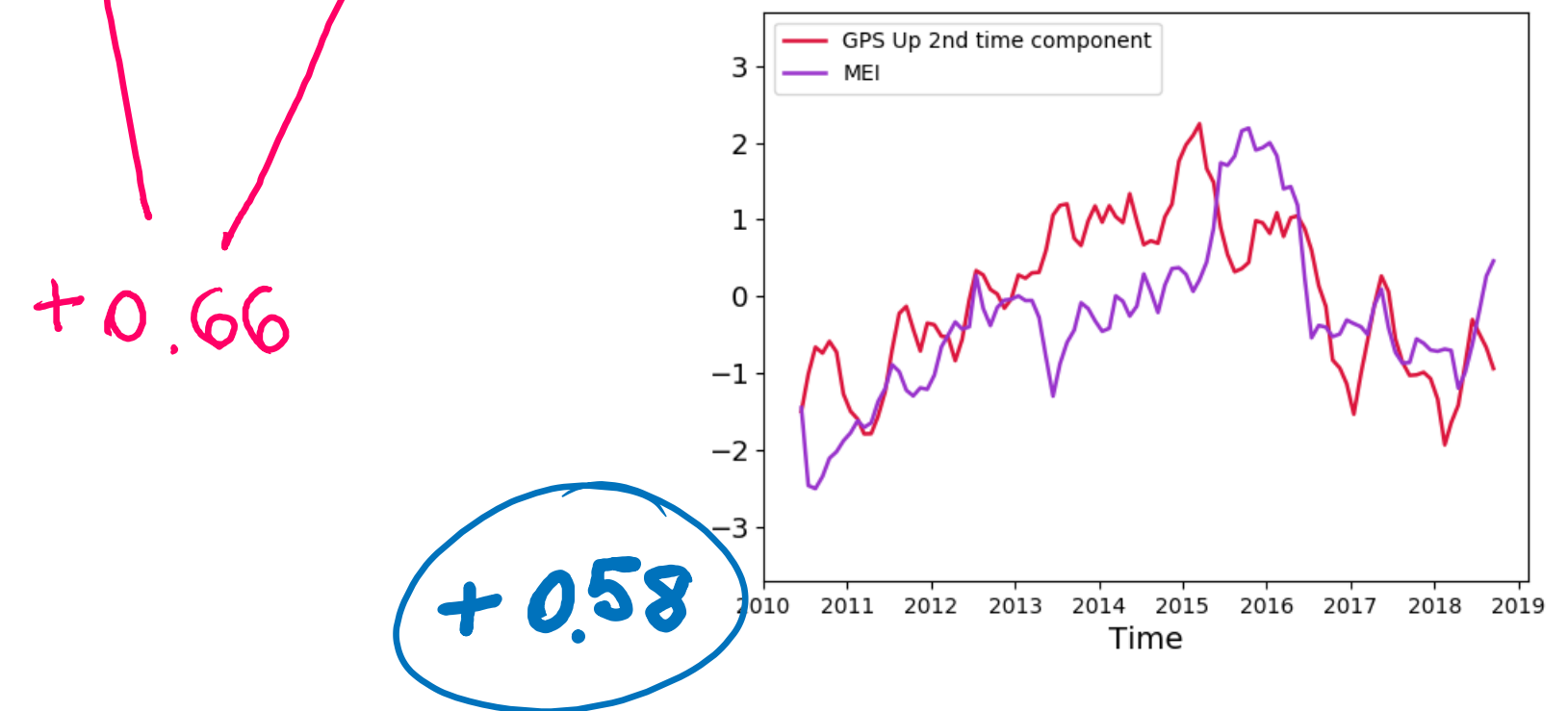
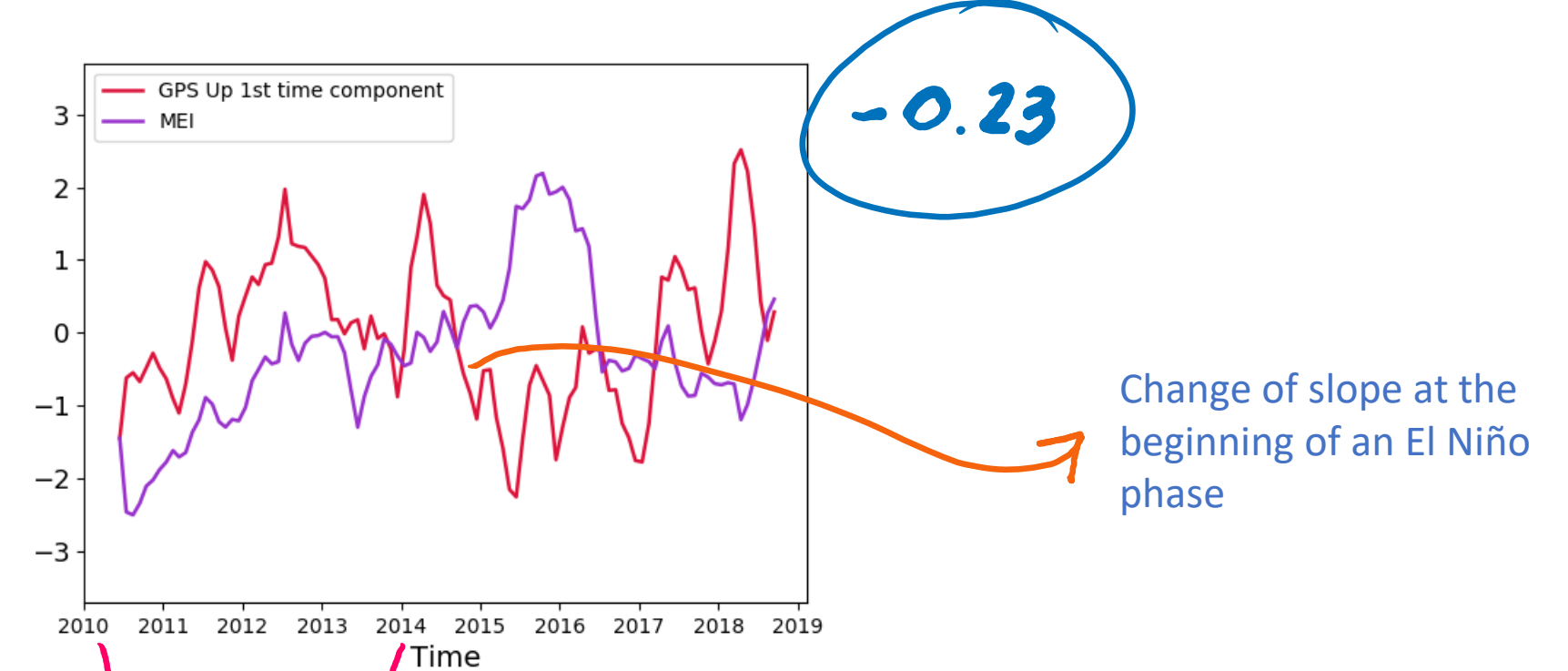
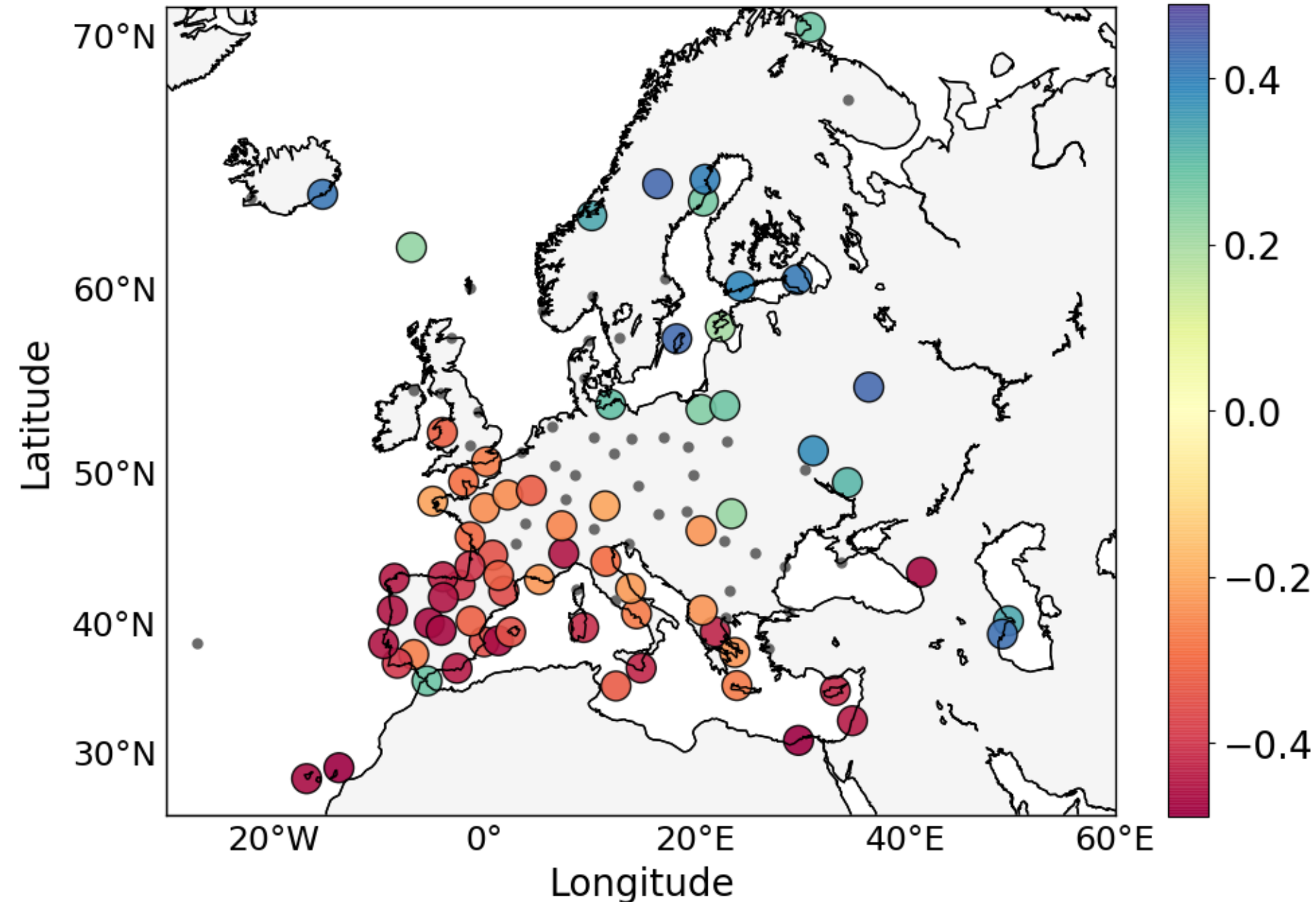
MEI provides an assessment of the **El Niño Southern Oscillation** and is based on 5 main variables related to the Equatorial Pacific:

- Sea level pressure
- Sea surface temperature
- Zonal and meridional components of the surface winds
- Outgoing longwave radiation



<https://psl.noaa.gov/enso/mei/>

Correlation map MEI-GPS height



Conclusions

PCA

- Principal modes of variability of GPS height, SP, TWS
- Relationship with climatic events

SVD

- Common modes of variability between the pairs GPS height-SP and GPS height-TWS
- Loading mechanism at continental scale

COMPARISON
WITH MEI

- Relationship between MEI and vertical deformation of Earth crust at continental scale

