EGU General Assembly 2020
Sharing Geoscience Online

PCA study of the interannual variability of GPS heights and environmental parameters

Letizia Elia[1], Susanna Zerbini[1], Fabio Raicich[2]

1 Department of Physics and Astronomy, University of Bologna, Italy

2 CNR Institute of Marine Sciences, Trieste, Italy

CNR
Consiglio Nazionale delle Ricerche

ISMAR
Istituto di Scienze Marine

Objective

- To identify and analyze principal modes of variability of
  - GPS heights
  - Environmental parameters

and

- To study the coupled variability of these parameters

Parameters

- GPS heights
- Surface atmospheric pressure (AP)
- Terrestrial water storage (TWS)
- Climate indices (NAO, EA, SCAND, AO, TNA, MEI)

Study area and GPS stations

107 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** heights (Nevada Geodetic Laboratory, http://geodesy.unr.edu/)
- **AP** (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 AP and TWS

Principal Component Analysis (PCA)

To identify principal modes of variability of a dataset

Principal Component Analysis (PCA):

modes of variability

spatial patterns

time components

PCA theory

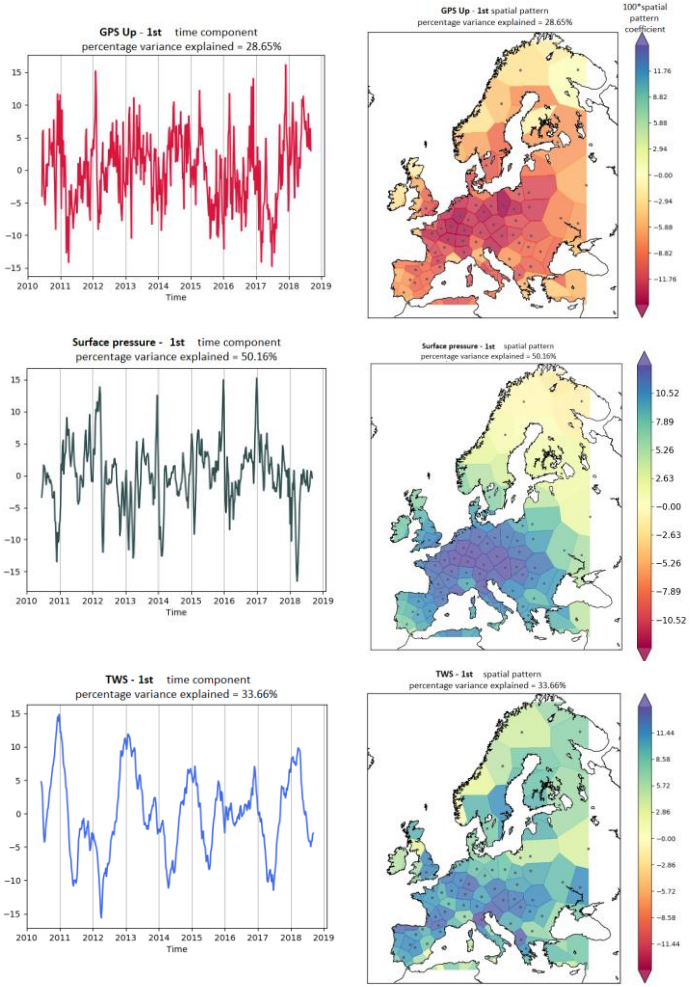
$$F_{ij} = \begin{bmatrix} f(t_1, x_1) & \cdots & f(t_1, x_p) \\ \vdots & \ddots & \vdots \\ f(t_n, x_1) & \cdots & f(t_n, x_p) \end{bmatrix} \rightarrow R = \frac{F^T F}{n-1}$$

- eigenvector c_i of R → spatial pattern of the *i*-th mode
- vector $a_i = Fc_i$ → time component of the *i*-th mode
- eigenvalue l_i of R → variance explained by the *i*-th mode

Each mode explains part of the total variability of the dataset

Percentage of variance explained			
Mode	GPS Height (%)	AP (%)	TWS (%)
1	28.65	50.16	33.66
2	11.60	21.86	12.91
3	9.07	10.80	11.04
4	4.17	4.67	7.19
Total	~ 50	~ 90	~ 65

Example: 1st mode of variability



- Change of slope between the end of 2010 and the beginning of 2011
- Change of slope at the beginning of 2018

- Heavy rainfalls characterized the second half of 2010 over Europe
- A drought period started in spring of 2011
- Anomalous cold and low pressure characterized the beginning of 2018

All 3 parameters are spatially coherent

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 3 modes = 70% of total covariance
- GPS height-TWS → first 3 modes = 50% of total covariance

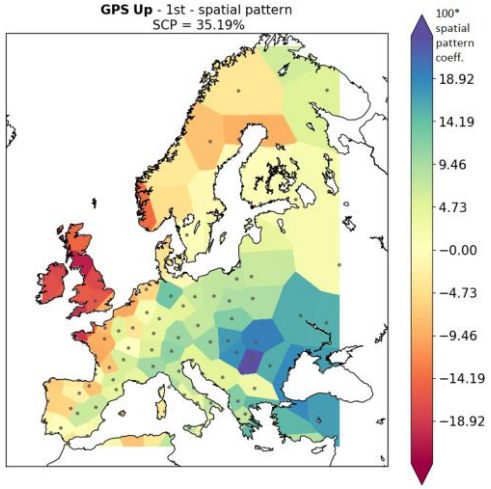
SVD theory

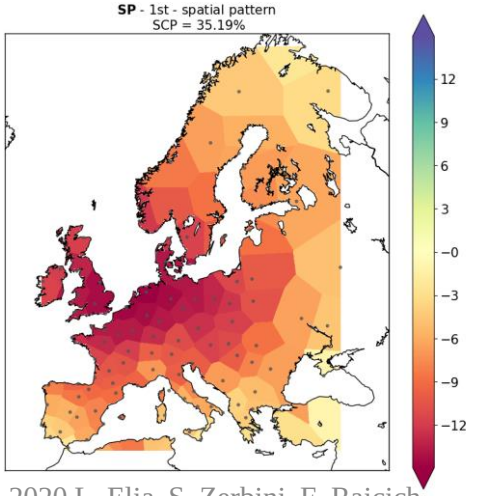
F_1 and F_2 : matrices of the two variables

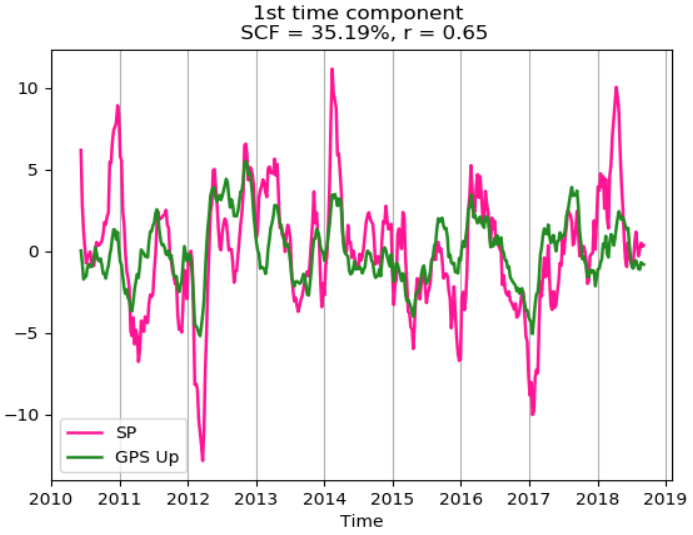
$$R_{cross} = F_1^T F_2 = ULV^T$$

- 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

SVD GPS height-AP



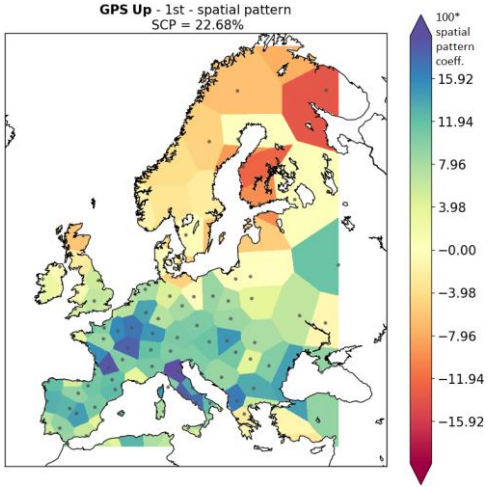


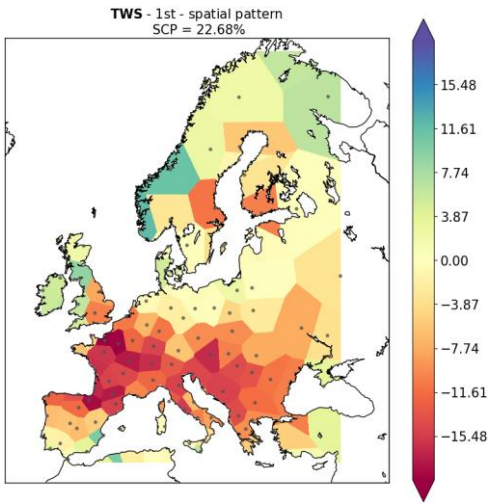


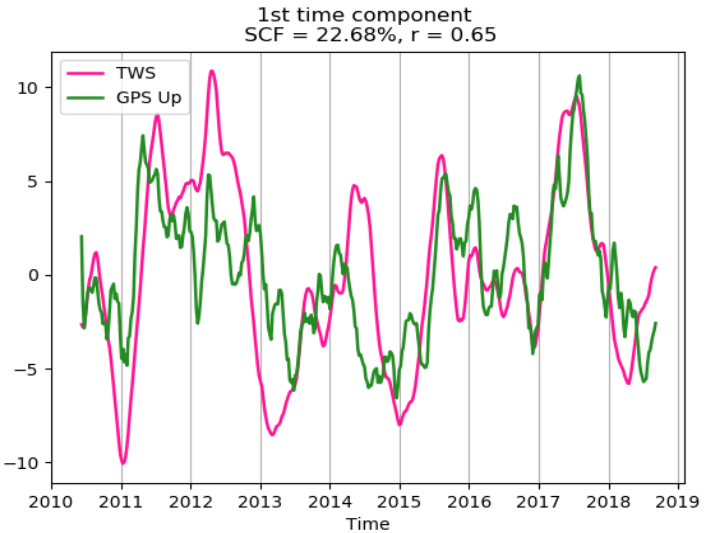
First mode of covariability:

- ~ 35% covariance
- AP: spatial pattern coherent over Europe and the Mediterranean area
- GPS height: spatial pattern coherent, except for the British Isles
- General anticorrelation of the spatial patterns → **loading mechanism**

SVD GPS height-TWS







First mode of covariability:

- ~ 23% covariance
- General anticorrelation of the spatial patterns of GPS height and TWS → **loading mechanism**

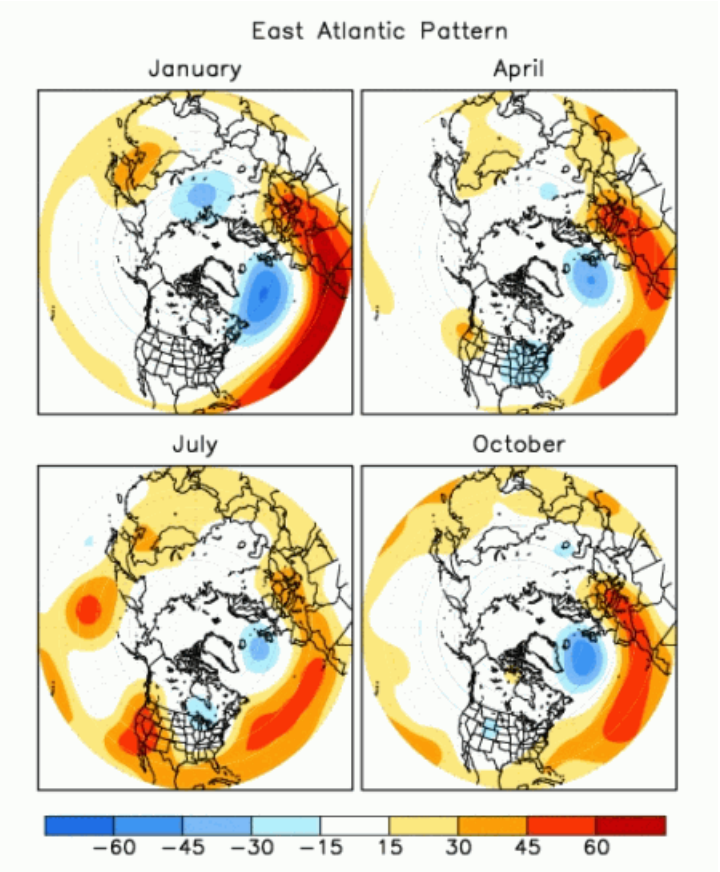
Climate indices

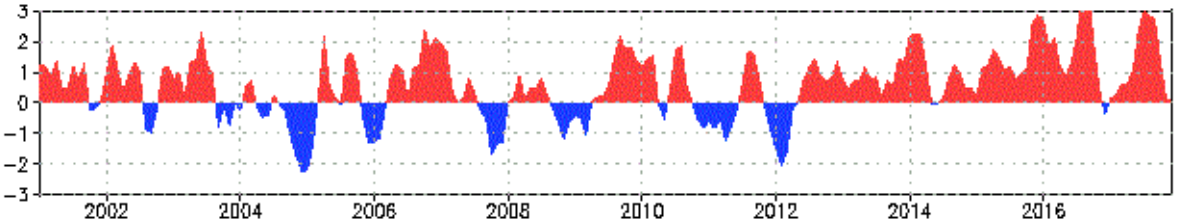
Climate indices NAO, EA, SCAND, AO, TNA, MEI

compared to

- Monthly means of the first four time components of the GPS height
- Monthly means of the "*dimensionality reduced*" time series of the GPS height

East Atlantic (EA)

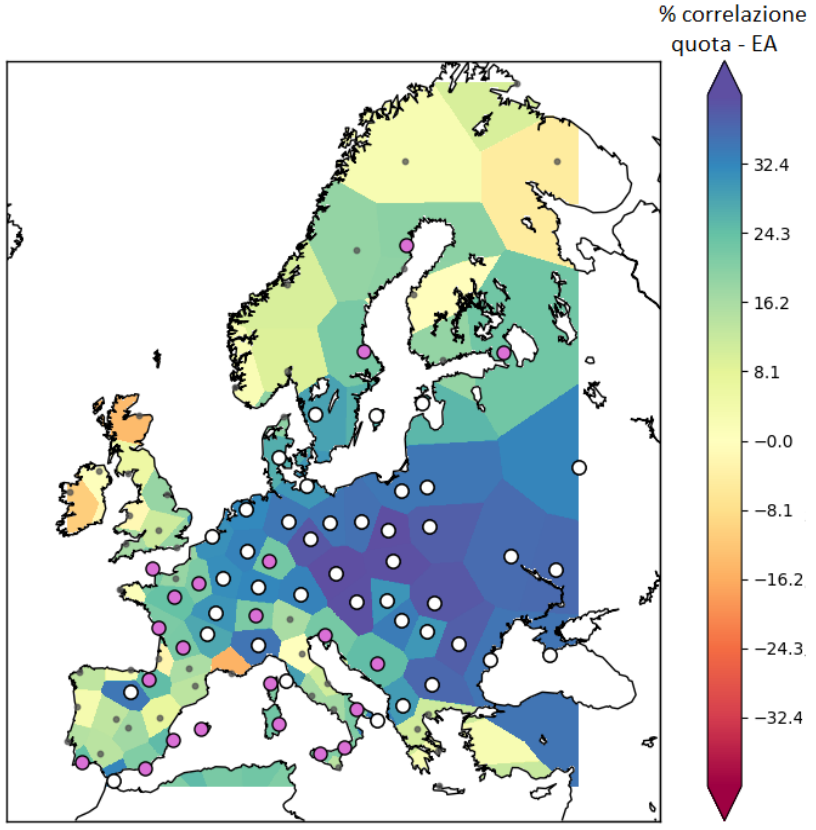


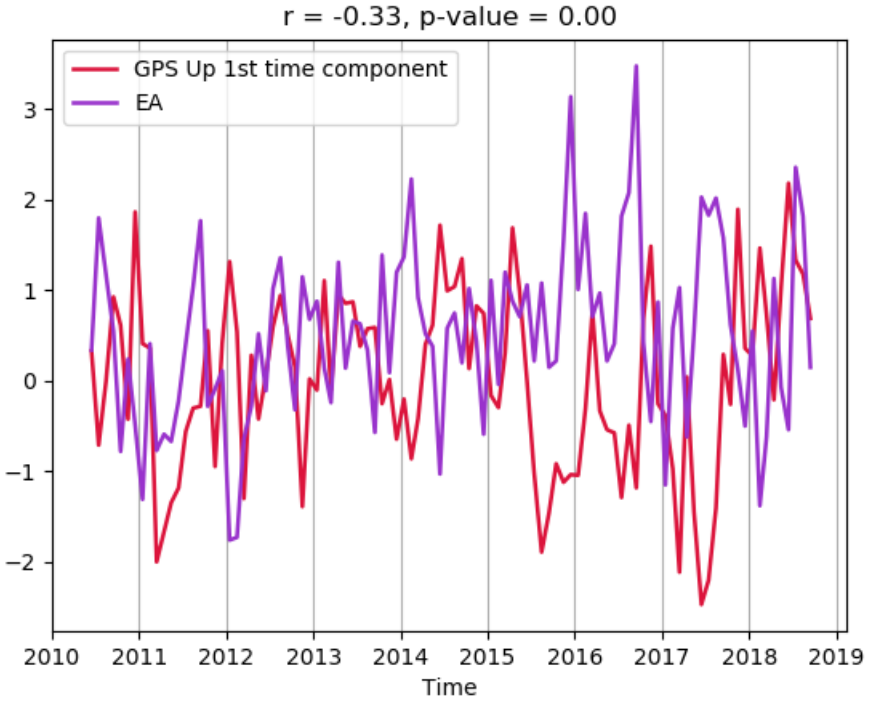


Features of the positive phase

- Above-average precipitations in Northern Europe and Scandinavia
- Below-average precipitations in Southern Europe

Correlation map EA-GPS height





Variance explained by the 1st mode 28.65%

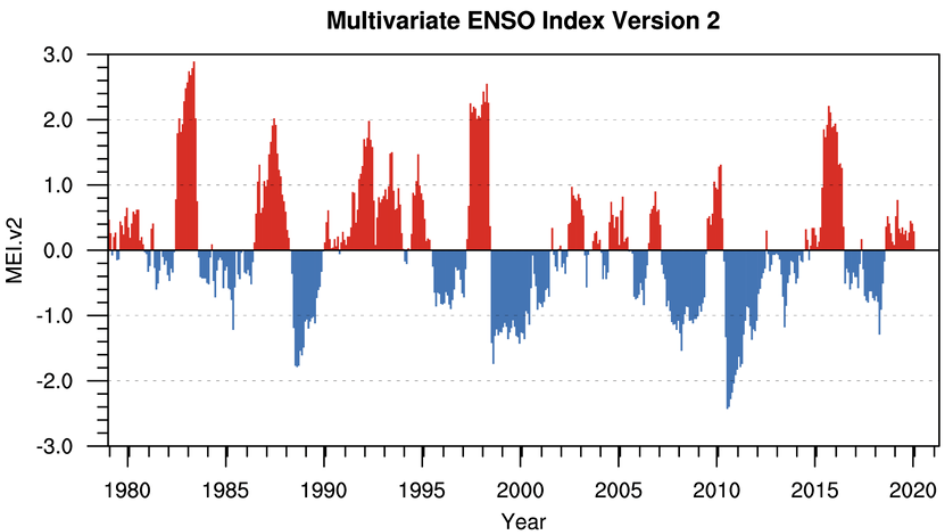
Lilac points: GPS site showing correlation with EA index larger than 10% and significance level larger than 95%

White points: GPS sites showing correlation with EA index larger than 10% and significance level larger than 99%

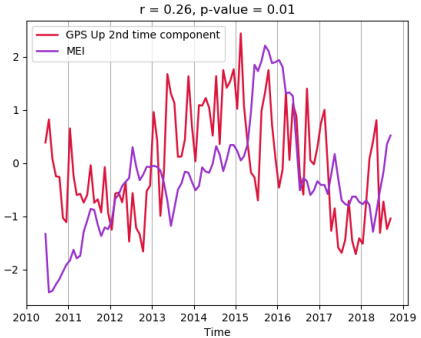
Multivariate ENSO Index

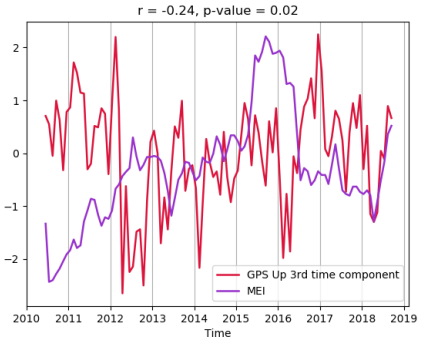
MEI provides an assessment of the El Niño Southern Oscillation and is based on 5 main variables related to the Equatorial Pacific:

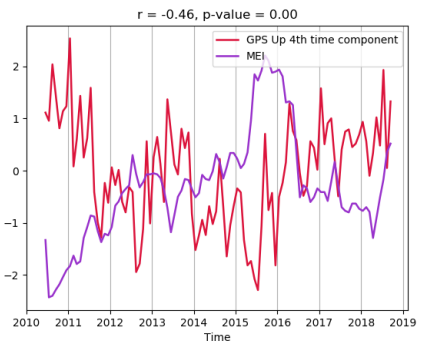
- Sea level pressure
- Sea surface temperature
- Zonal and meridional components of the surface winds
- Outgoing longwave radiation



Correlation map MEI-GPS height

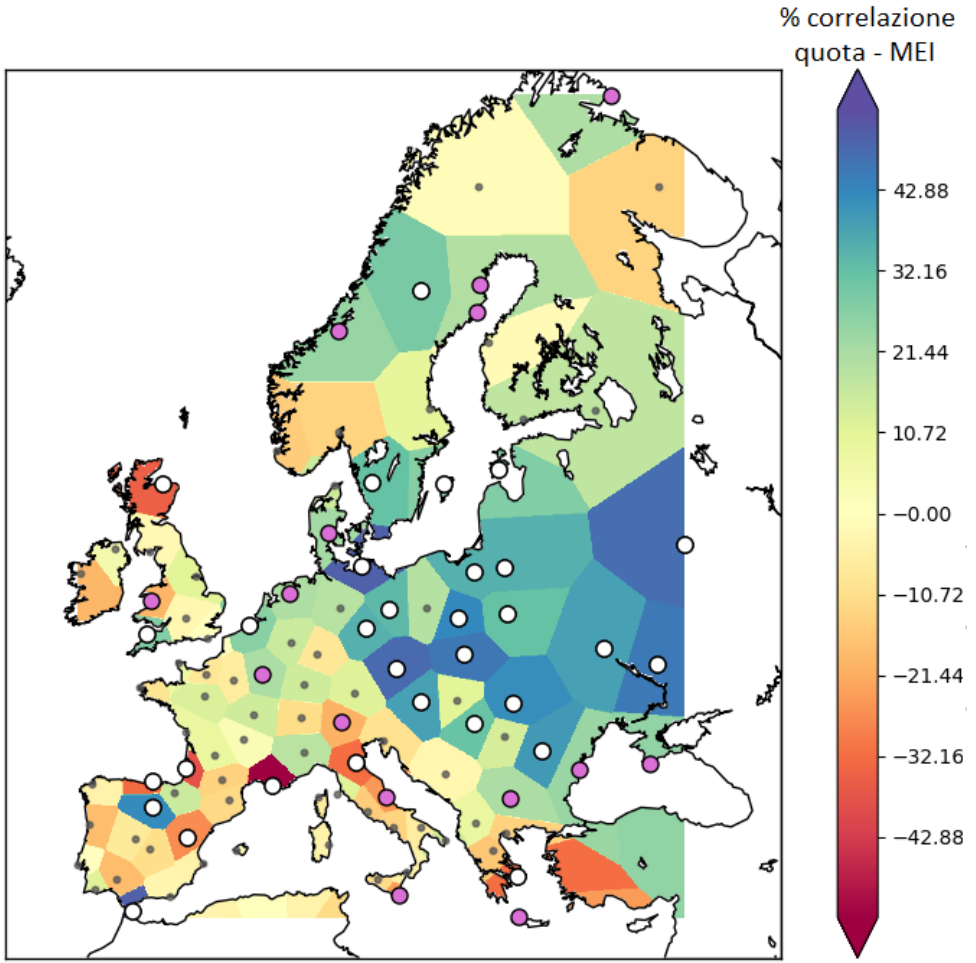






Variance explained by:

- 2nd mode 11.60 %
- 3rd mode 9.07 %
- 4th mode 4.17%



Lilac points: GPS sites showing correlation with MEI index larger than 10% and significance level larger than 95%

White points: GPS sites showing correlation with MEI index larger than 10% and significance level larger than 99%

Conclusions

PCA analysis

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

SVD analysis

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

Climate indices comparison

- Relationship between climate patterns and vertical deformation of the Earth crust at continental scale

Outlook

- Tracing fingerprints of climatic events
- Extension of the investigated time period