WEATHER REGIMES AND EXTREME PRECIPITATION IN THE GREATER ALPINE REGION

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Clim2FlEx ISAC Consiglio Nazionale delle Ricerche

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This poster is part of Clim2FlEx project, with which we aim to build a end-to-end chain from global climate to river flood hydrology models, to relate climate and flood extremes in the Greater Alpine Region. To learn more, have a look to the posters of Anna Basso (PoliTo), Board X3.9; Vikas Kumar (UniTO), Board X3.10

GOAL OF THIS STUDY

Investigate the relation between Euro-Atlantic Weather Regimes and Extreme Precipitation Events in the Greater Alpine Region

DATA AND METHODOLOGY

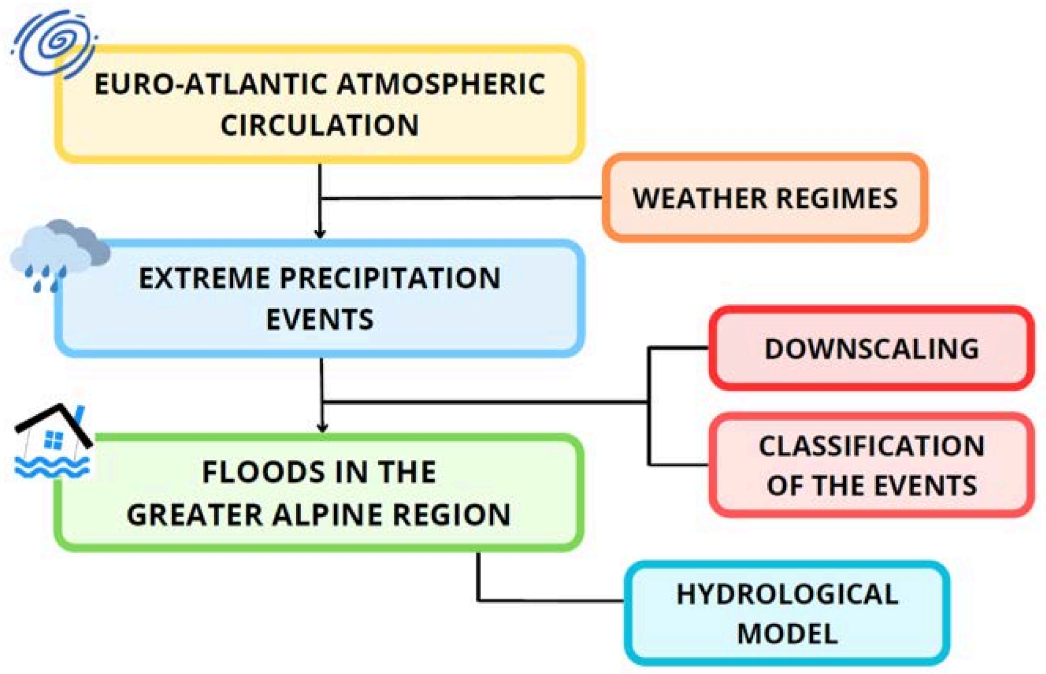
Weather Regimes (WRs)

~ ERA5 reanalysis, daily mean geopotential height at 500 hPa
~ Period 1940-01-01 to 2023-12-31
~ Domain **Euro-Atlantic (EAT)** (30°- 90°N; 80°W - 40°E)
~ Year- round classification from **Grams et. al. (2017)** and **Lee et. al. (2024)**

Extreme Precipitation (EPEs)

~ ERA5 reanalysis, daily mean total precipitation data
~ Period 1940-01-01 to 2023-12-31
~ Domain **Greater Alpine Region (GAR)** (43°- 49°N; 4°-19°E)
~ Extreme precipitation events extraction based on 95th quantile (Q95) considering wet days only (intensity > 1 mm/day)

Clim2FlEx PROJECT WORKFLOW



PROJECT GOAL

Linking river floods, climate extremes, and large-scale climate predictors.

WEBSITE

Euro-Atlantic Weather Regimes

Weather Regimes Patterns

7 Weather Regimes patterns plus "**No Regime**" condition (state closer to the reference climatology than to a WR), and relative frequencies over the period 1940 - 2023.
A Weather Regime Event is defined based on a minimum persistence of 2 days, otherwise it is classified as "**Transition Condition**"

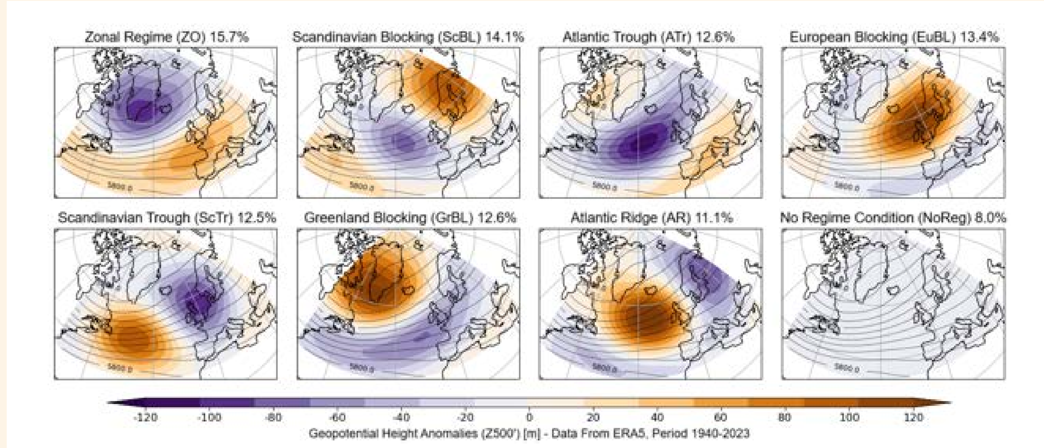


Fig. 1 Weather Regimes centroids (geopotential height anomalies) plus No Regime condition and relative average frequencies.

Interannual Variability and Seasonality

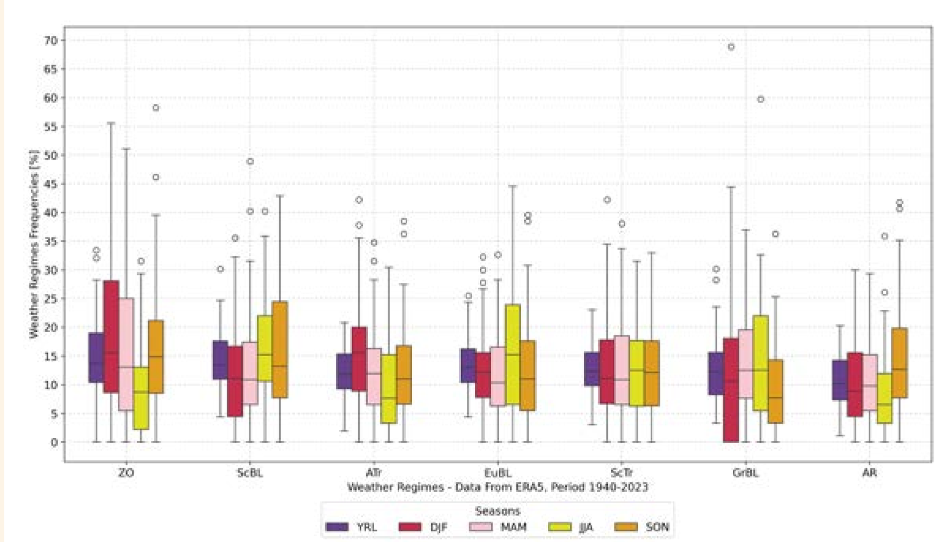


Fig. 2 Boxplot with the distribution of the WRs yearly frequencies (whole-year and different seasons).

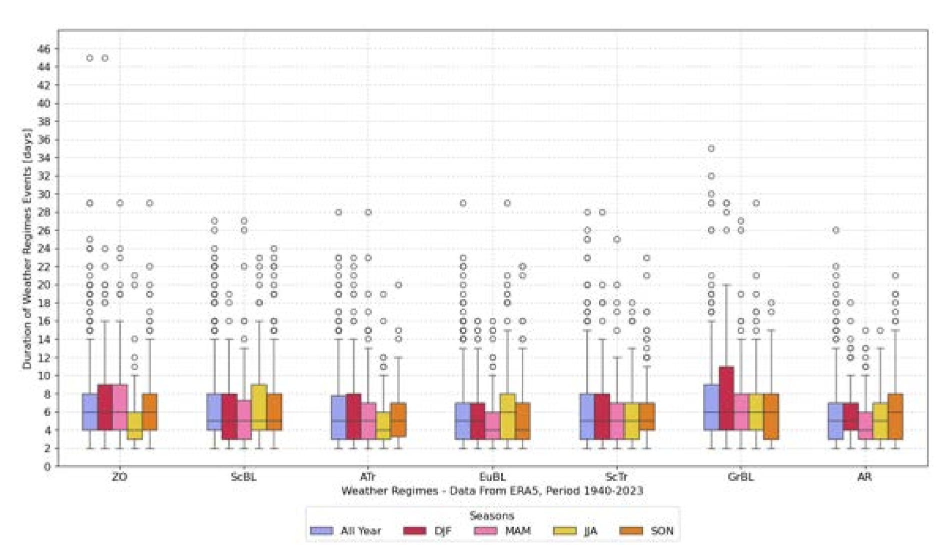


Fig. 3 Boxplot with the distribution of the WRs persistence (whole-year and different seasons).

Decadal and Multi-Decadal Variability

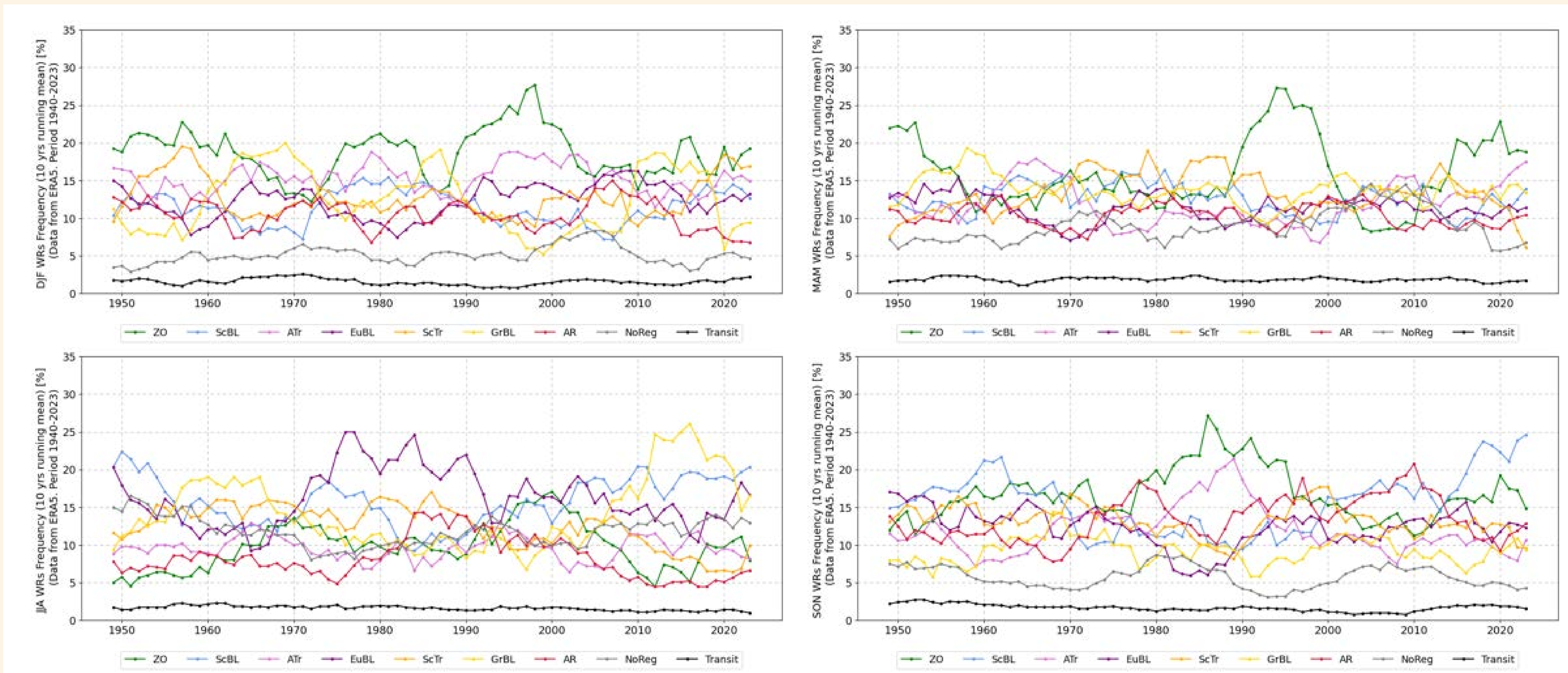


Fig. 4 Timesereries of ten years running mean of the yearly frequencies of the WRs divided by seasons.

Extreme Precipitation Events and Weather Regimes

Extreme Precipitation Threshold

For each gridpoint the Q95 of the distribution of the wet days is computed considering the whole period and the whole year. Then this threshold map is applied to each season separately.

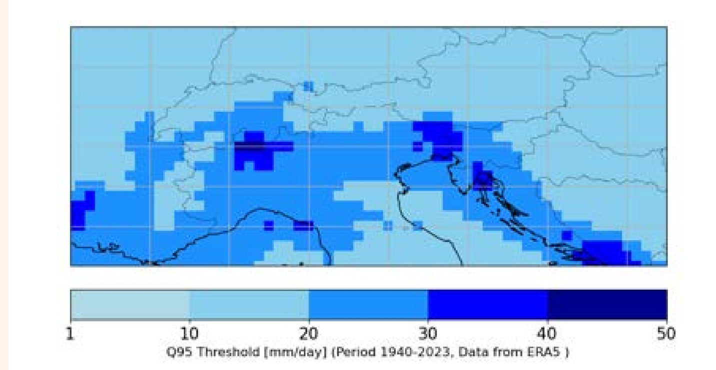


Fig. 5 Map of extreme precipitation threshold.

Extreme Precipitation Events During Different Seasons

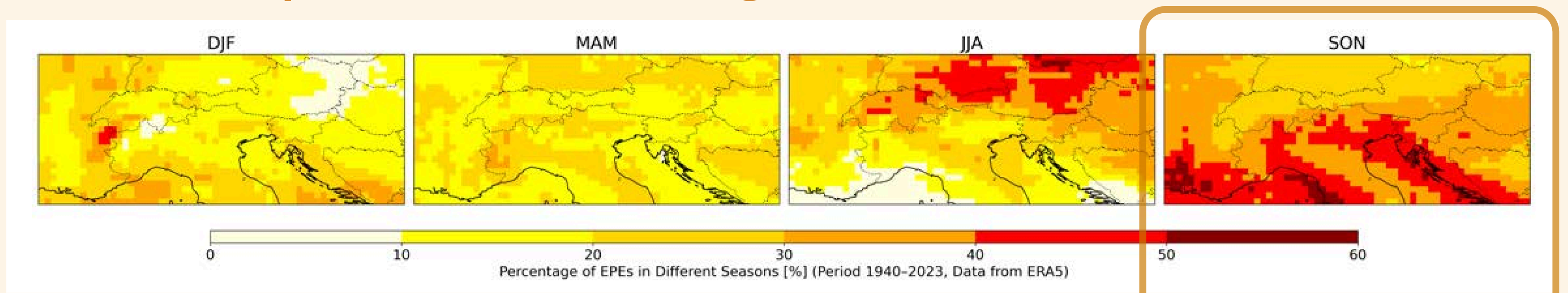
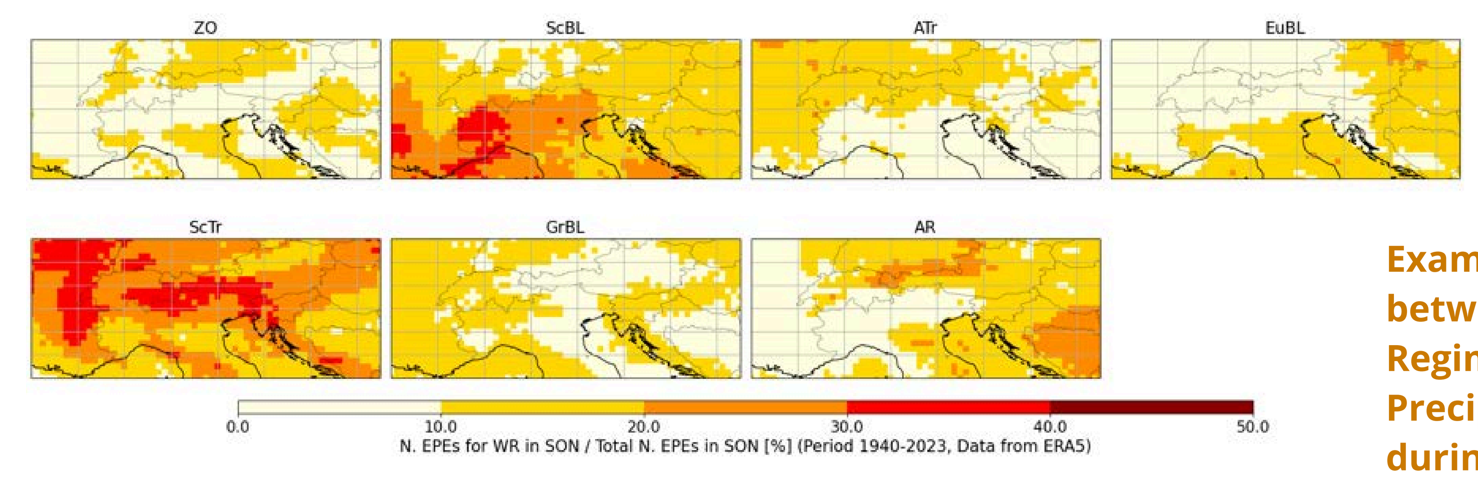


Fig. 6 Frequency of EPEs during different seasons.



Example of association between Weather Regimes and Extreme Precipitation Events during autumn (SON)

Fig. 7 Frequency of different WRs when EPEs occur during autumn (SON).

Predominant Weather Regimes During Extreme Precipitation Events

Method 1

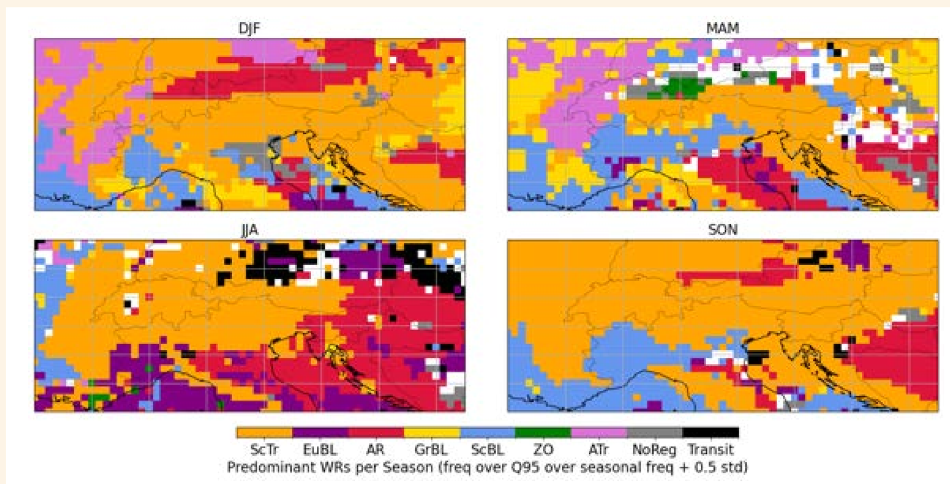


Fig. 8 Seasonal WR frequency during EPEs must be higher than the WR seasonal frequency + 0.5 standard deviation. Then, we choose the WR with the highest frequency.

Method 2

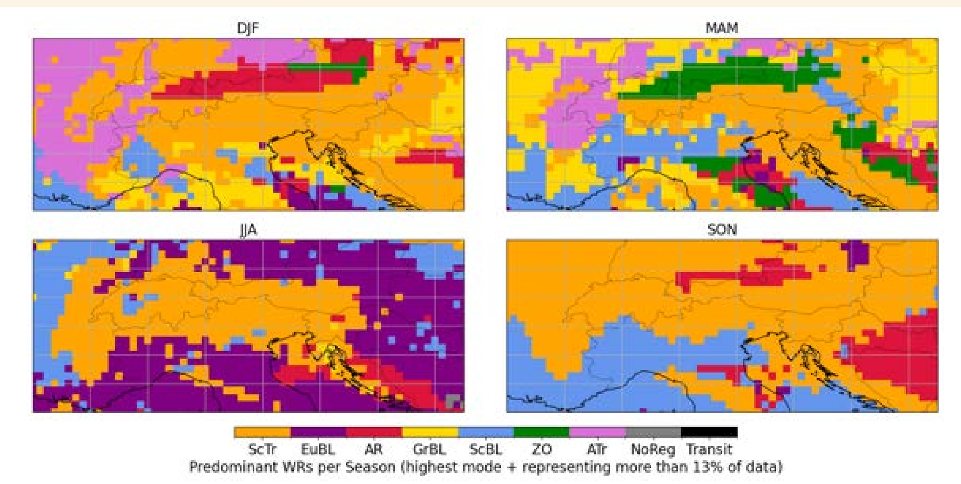


Fig. 9 We select the WR during EPEs that has the highest mode (weighted with the seasonal WR frequency), while representing at least the 13% of data.

CONCLUDING REMARKS AND FUTURE DEVELOPMENTS

~ Considering the natural variability of the atmospheric low-frequency circulation, we always **need to evaluate the contribution of the Weather Regimes to the Extreme Precipitation Events taking in account** the seasonal, interannual and decadal/multi-decadal **variations in the regimes frequencies**;

~ The relationship between the Euro-Atlantic WRs and EPEs in the GAR, may change during seasons and in different sub-regions of the analyzed domain. Although some **WRs** look **more linked to the EPEs**, such as: **Scandinavian Trough (ScTr)**, **Scandinavian Blocking (ScBL)**, **Atlantic Ridge (AR)** and **Atlantic Trough (ATr)**;

~ Considering the **goal of the Clim2FlEx project**, we aim to use the **WRs indexes and their link to EPEs** to provide valuable information on the dynamical conditions favouring **flood events** and their predictability;

~ We aspire to **apply the illustrated workflow to the future climate projections**, in order to increase our knowledge about the link between extreme events and climate change

REFERENCES: **Grams et. al. (2017)** Nature Clim Change 7, 557–562; **Lee et. al. (2024)** Geophysical Research Letters, 51

Catching the Floods: The Role of Catchment Classification and Precipitation

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INTRODUCTION

The link between climate extremes and river floods is complex and greatly affected by regional characteristics[a]. Particularly in mountainous regions, river discharges are highly dependent on elevation and size of catchment [b].

This study explores the **effects of spatio-temporal scales on the precipitation-discharge relationship in the Greater Alpine Region (GAR)**.

WHY DO SPATIO-TEMPORAL SCALES OF PRECIPITATION MATTER?

Resolution issue

DATA

River Discharge Data:

We have used the model river discharge output for this study from a modified TUW_GAR model (*). The simulations were performed @POLITO within the Clim2FlEx project.

Area of study - Piedmont Region: 1961-2020; GAR Region: 1998-2020

(*) More detailed information: https://sciendo.com/article/10.1515/johh-2015-0024

Climate Data:

ERA5 reanalysis (0.25° resolution):
Variables: TP (Total daily Precipitation), T2M (2m Temperature), SM (Soil Moisture), PET (Potential Evapotranspiration).
Period: 1960-01-01 to 2020-12-31
Region: Greater Alpine Region (GAR, 30°-90°N; 80°W-40°E)

ERA5_Land reanalysis (0.10°):
Variables: Precipitation (Total daily Precipitation)
Period: 1960-01-01 to 2020-12-31
Region: Greater Alpine Region (GAR, 30°-90°N; 80°W-40°E)

Regridding

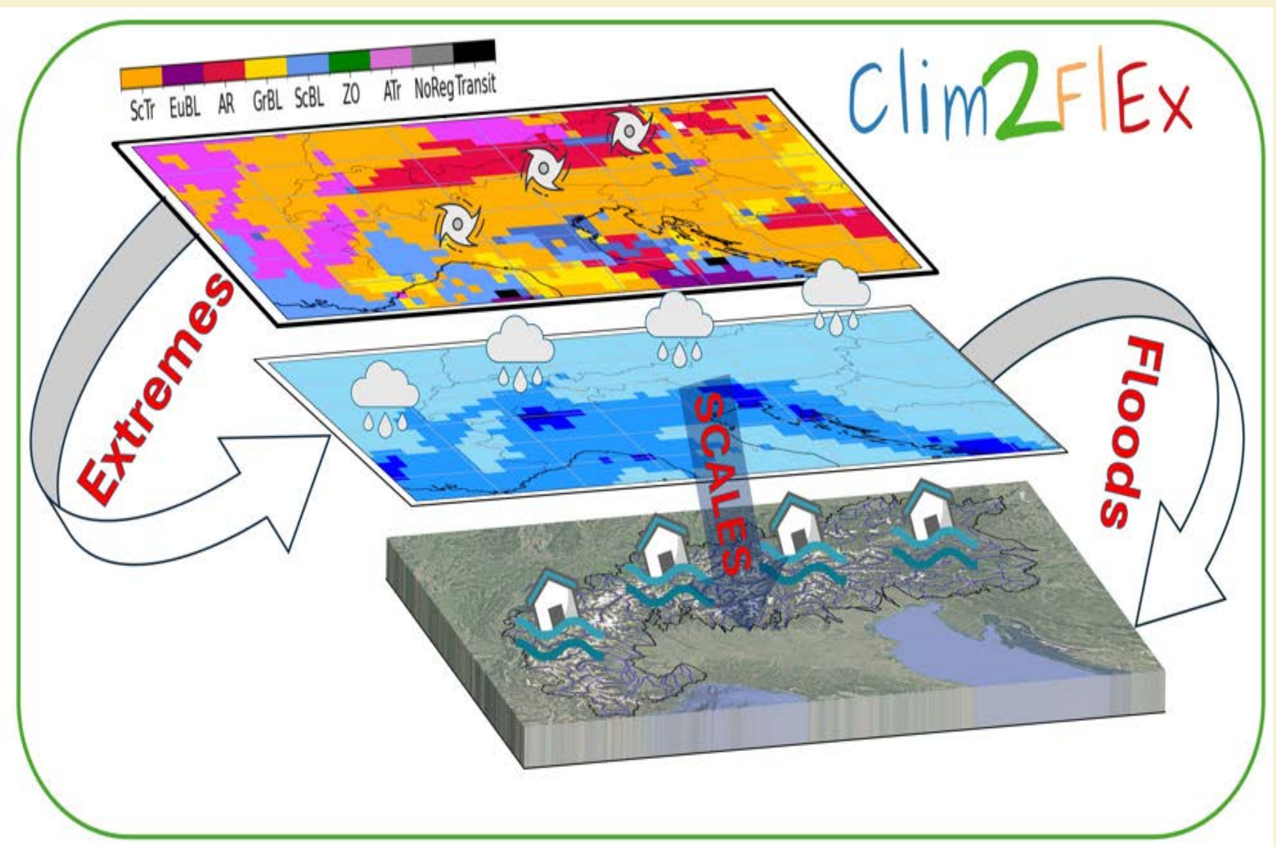
This poster is part of the **Clim2FlEx** project:-

- The main aim is to develop an end-to-end modelling chain from global climate models to river flood hydrology models.
- To better understand the relationship between climate and flood extremes in the Greater Alpine Region.

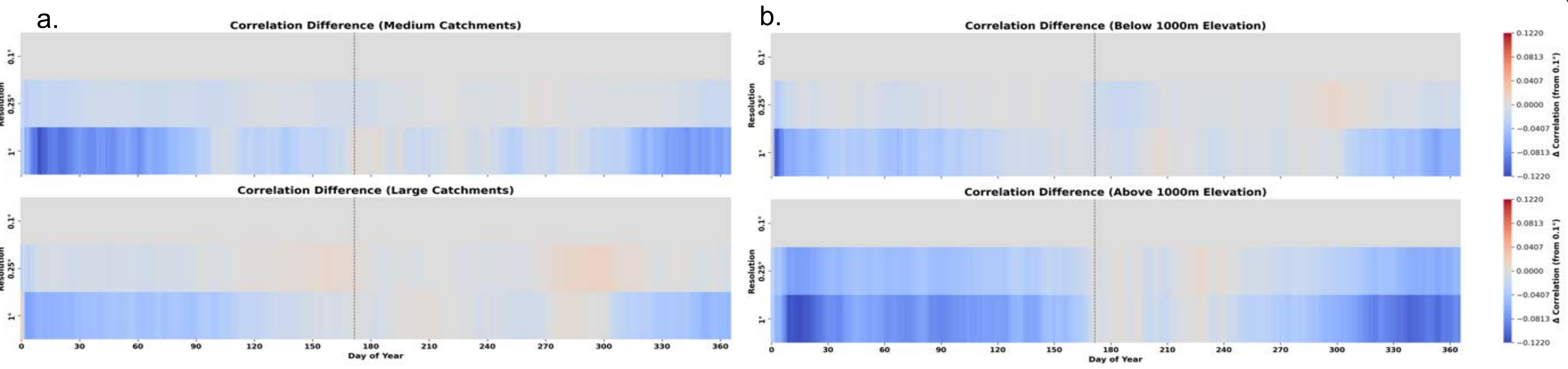
SCAN ME

To learn more, be sure to visit the posters by:

- **Anna Basso (Poster X3.9) - POLITO**
- **Ilaria Tessari (Poster X3.8) - CNR**



EFFECTS OF SPATIO-TEMPORAL SCALES



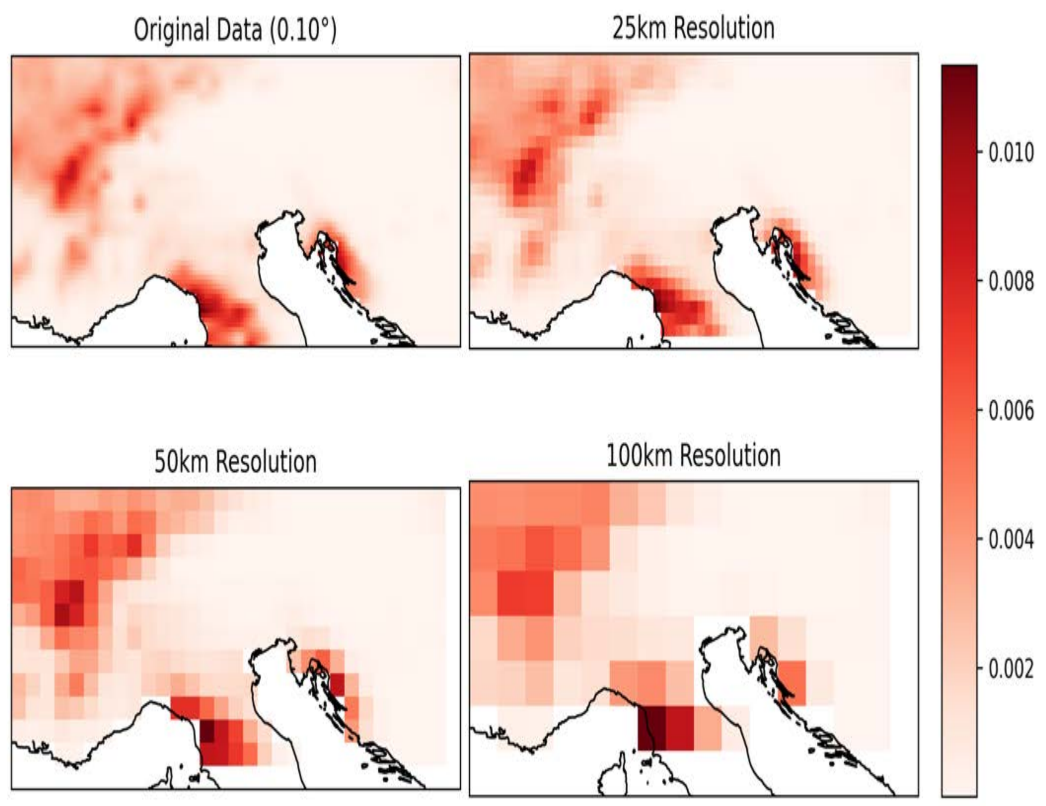


Figure 1. An example of regridded precipitation data (in meters) at different resolution using the ERA5_Land reanalysis dataset.

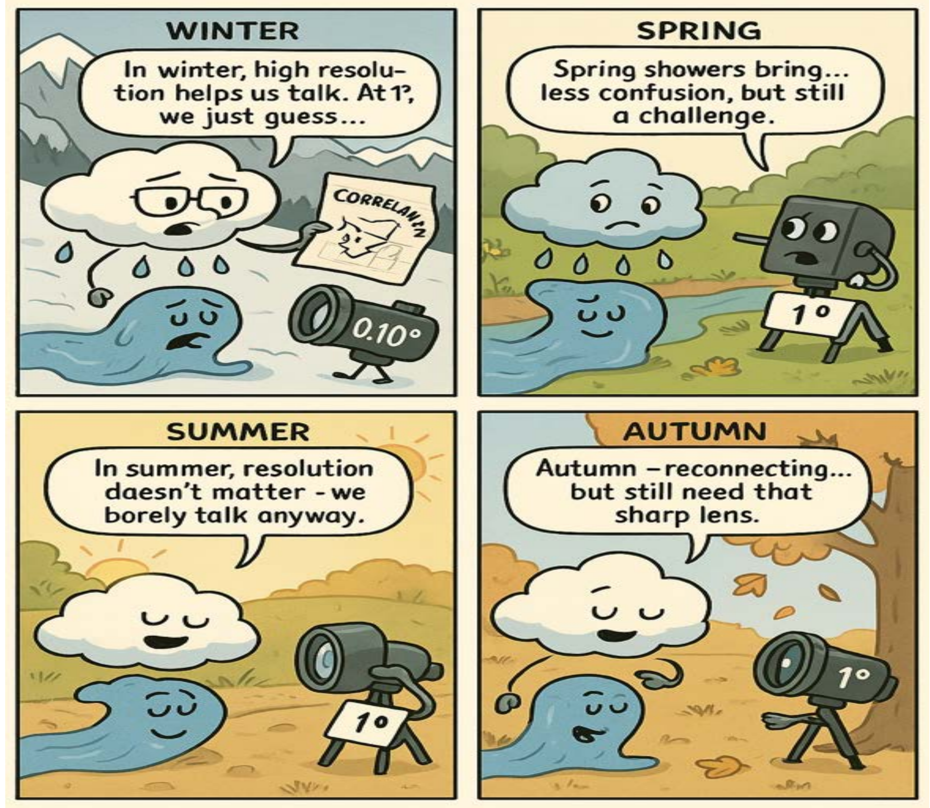
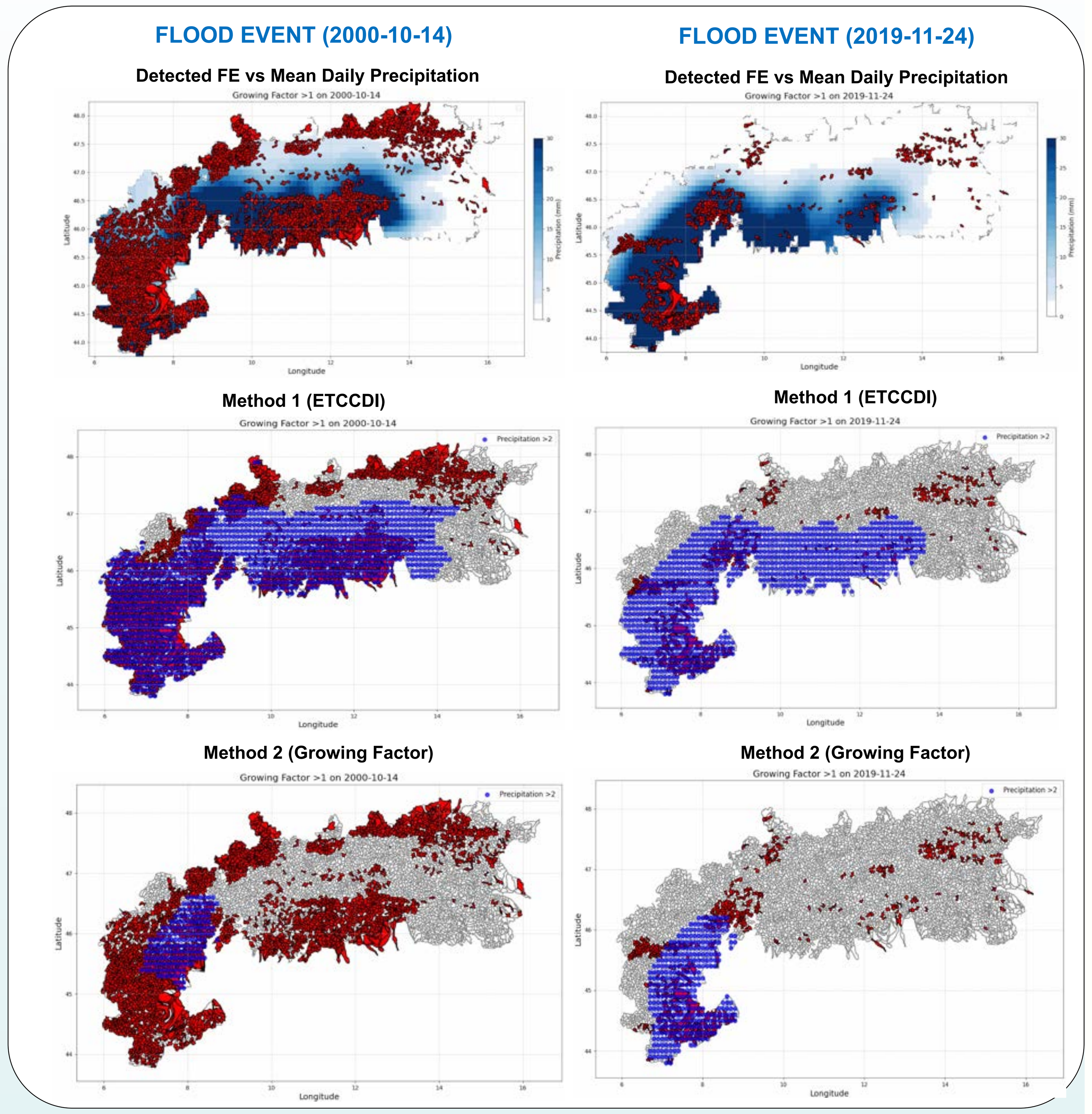


Figure 2. Change in correlation between precipitation and discharge for (a) Size, and (b) Elevation of the catchment at different resolution of precipitation data.

EXTREME PRECIPITATION EVENTS (EPEs)



Case studies of **flood events** on **2000-10-14** and **2019-11-24**

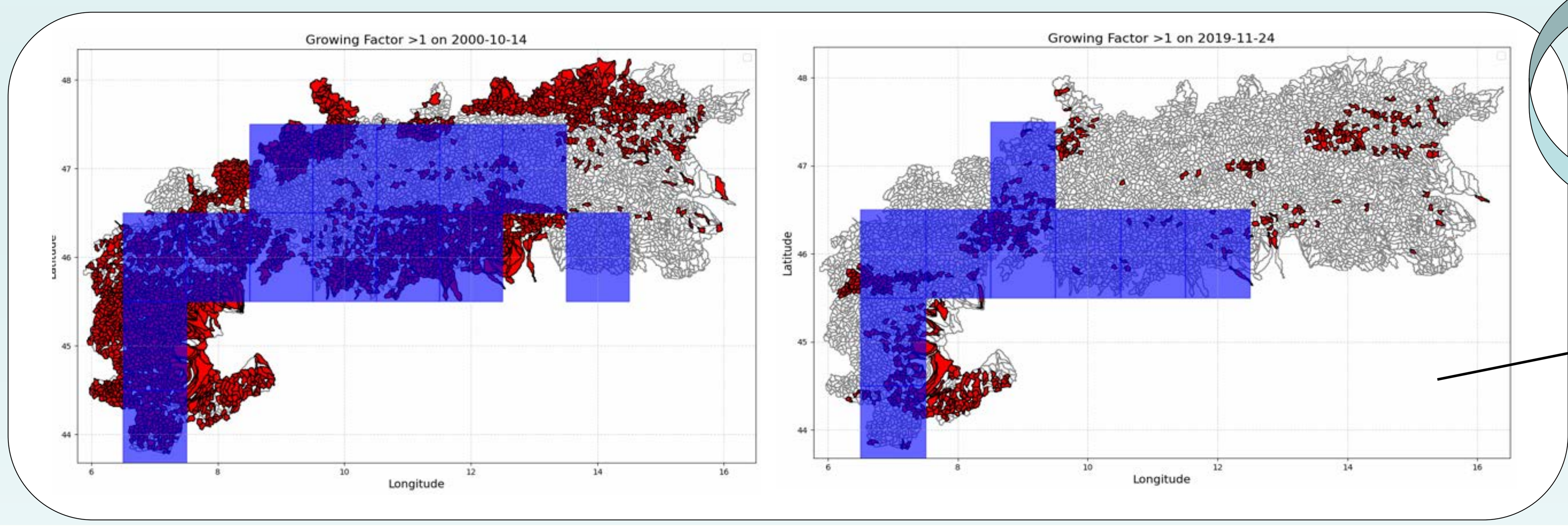
Detection methods for extreme precipitation related to Flood Extremes (FEs):

- **The Growing Factor (GF) method used in Hydrology for the detection of flood extremes**
- **ETCCDI indices of extreme precipitation (R10mm, R20mm, R99th, R95th)**

Both methods **detect an Extreme Precipitation Event (EPE)** during the flood event. However, the **spatial distribution is different**. We have verified with 7 large cases of Flood Extremes (FEs) and identified a similar pattern.

Which is the best method to detect an EPEs corresponding to FEs?

DETECTION OF EPEs AT LOW RESOLUTION (1°)



Case studies: **flood events** on **2000-10-14** and **2019-11-24**

Question: Is it possible to detect an EPEs corresponding to FEs at low resolution too? i.e., how well can we transfer this analysis to climate models?

We found that the detection of EPEs depends on the spatial scale and the season of occurrence of FEs (1998-2020). EPEs corresponding to major FEs occurred during the Autumn season (7 FEs) can be detected at low resolution.

CONCLUDING REMARKS

- A **strong dependency on data resolution** (ranging from 0.10° to 1°) is observed in the relationship between precipitation and river discharge.
- The impact of resolution varies by season, with **winter showing the greatest degradation in correlation, while summer remains least affected**.
- The relationship between flood extremes and precipitation extremes **depends on the method used for detecting precipitation extremes** (GF and ETCCDI) in the GAR region.
- Spatial variations exist in the flood-precipitation extremes relationship across the GAR region: while **floods in the western GAR are strongly driven by precipitation extremes**, those in the **northeastern GAR are primarily influenced by accumulated precipitation.**
- **Precipitation extremes responsible for floods can still be detected even with low-resolution data (1°).**

FUTURE WORK

- As part of Clim2FlEx, we will formulate an **approach to identify the Extreme Precipitation Events (EPEs) corresponding to each type of Flood Events (FEs) at the individual catchment scale.**
- This approach will then be applied to **future climate projections, with the aim of enhancing our understanding of the relationship between extreme flood events and climate change at catchment scale.**

REFERENCE:
a. Stein et al., (2021). Water Resour. https://doi.org/10.1029/2020WR028300
b. Bertola et al., (2020). Hydrol. Earth Syst. Sci. https://doi.org/10.5194/hess-25-1347-2021

SESSION: NH1.4 - MAPPING OF CLIMATE TO FLOOD EXTREMES

A DISTRIBUTED RAINFALL-RUNOFF MODEL TO EXPLORE THE CONNECTION BETWEEN FLOODS AND CLIMATE EXTREMES IN THE EUROPEAN ALPS

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THE RAINFALL-RUNOFF MODEL CALIBRATION REGIONALIZATION AND VALIDATION

The model used is a variation of the *TUWmodel* [1] that has been coupled with a *Nash-Cascade* (Fig. 1).
To calibrate the model the *weighted Nash-Sutcliffe* efficiency *wNSE* [2] function has been optimized, a variation of the commonly used *Nash-Sutcliffe* efficiency *NSE*, that gives additional weight on high flows.
To reach the goal of the proposed model, which aim to reproduce large scale regional events, a regionalization procedure has been performed based on the *HydroPASS* [3] algorithm, which utilizes a machine learning approach based on regression trees.
The regional model was finally validated both temporally and spatially using a training cluster of catchments and a test cluster of catchments (Fig. 2).

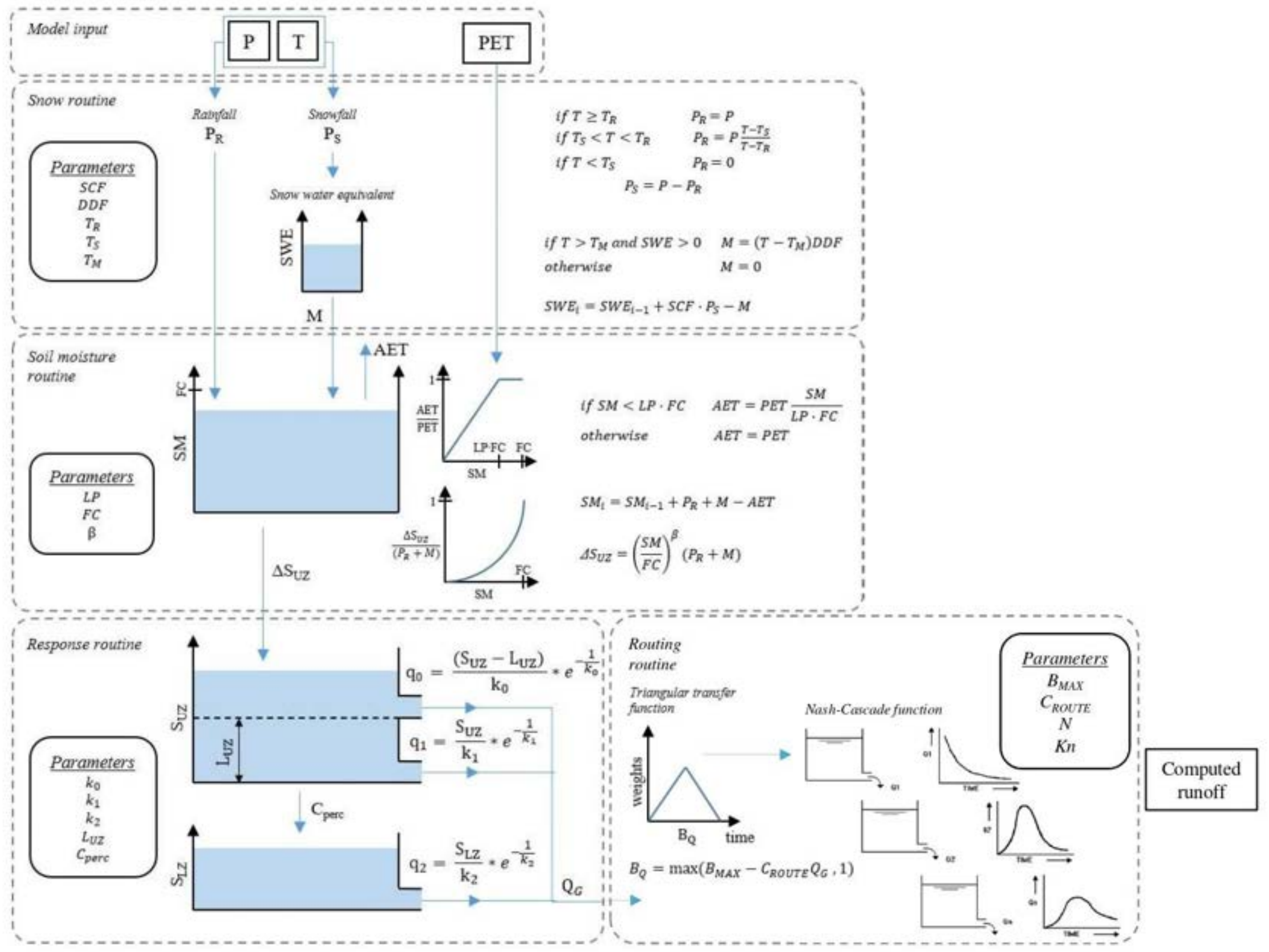


Fig. 1 - Schematic representation of the fully modified *TUWmodel*

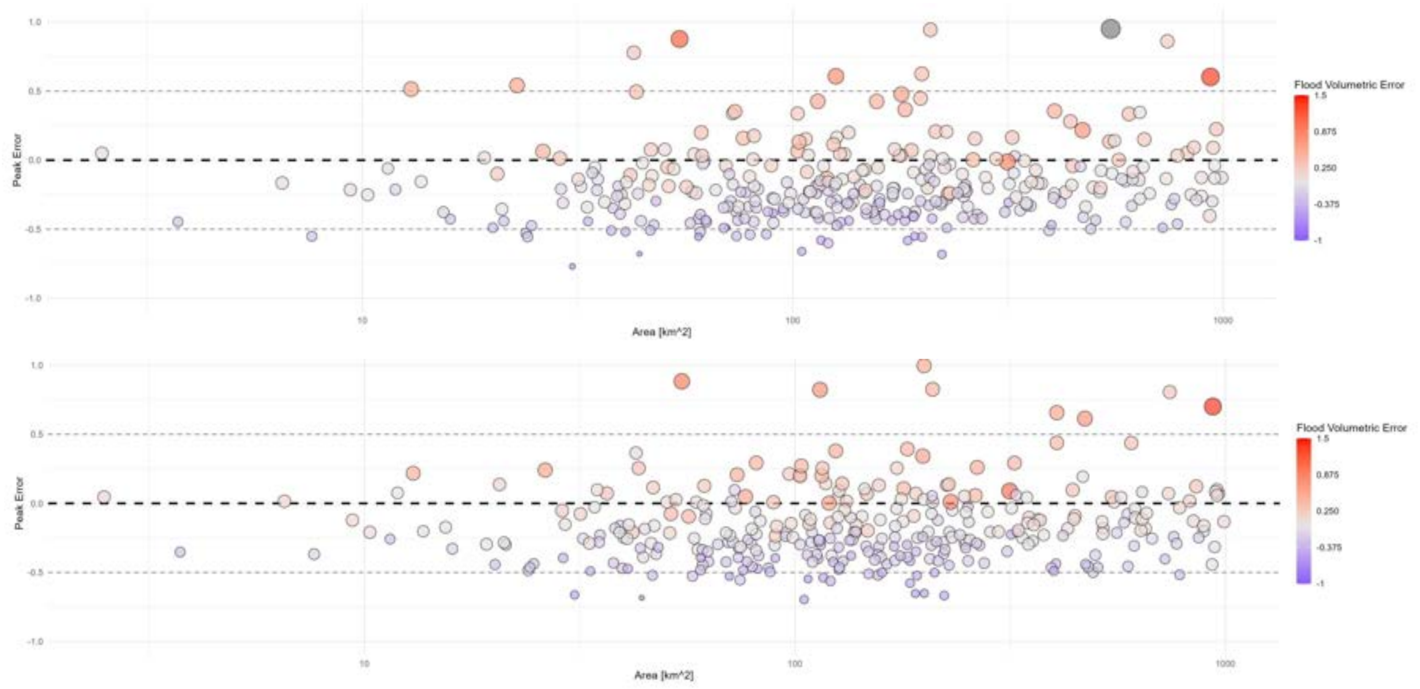


Fig. 2 - Regional model *weighted Nash-Sutcliffe* efficiency (above calibration period 2010 – 2020, below validation period 2000 – 2010)

SPATIO-TEMPORAL EVENT IDENTIFICATION

With *ERA5-Land* input data from 1951-2023 we simulate the discharge all around the *Greater Alpine Region*.
We identified events simultaneously in space and time calculating the *Growth Factor* for each day and each location (Fig. 3) and selecting as events all the situations above the threshold of *GF* equal to 2.

$$GF_{xy,di} = \frac{q_{xy,di}}{q_{mean\,xy,di}} \quad \text{where} \quad q_{mean\,xy,di} = \frac{\sum_1^n q_{xy,max91d}}{n_{years}}$$

Once we have detected events, we can classify them according to their extent, duration or intensity: we found that, even using different metrics, the most important events appear in each classification, which means that the method can be considered robust.

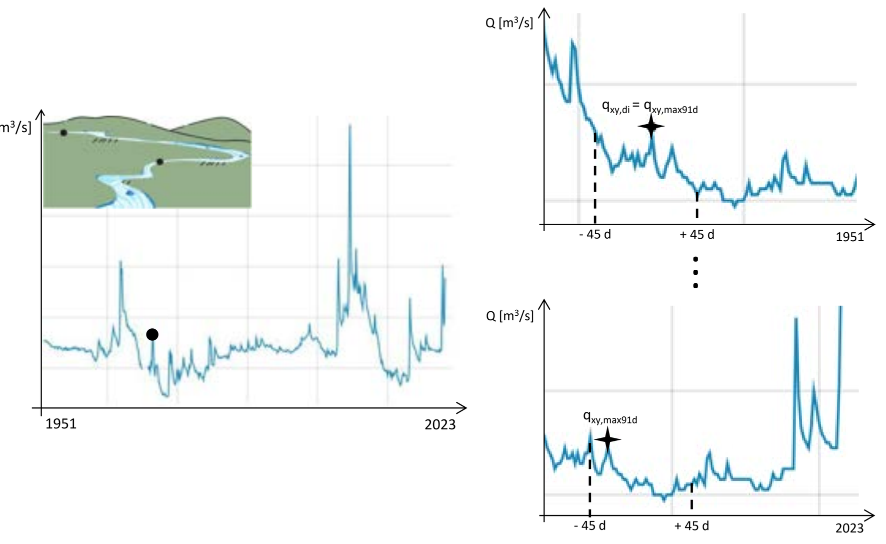


Fig. 3 – *Growth Factor* calculation

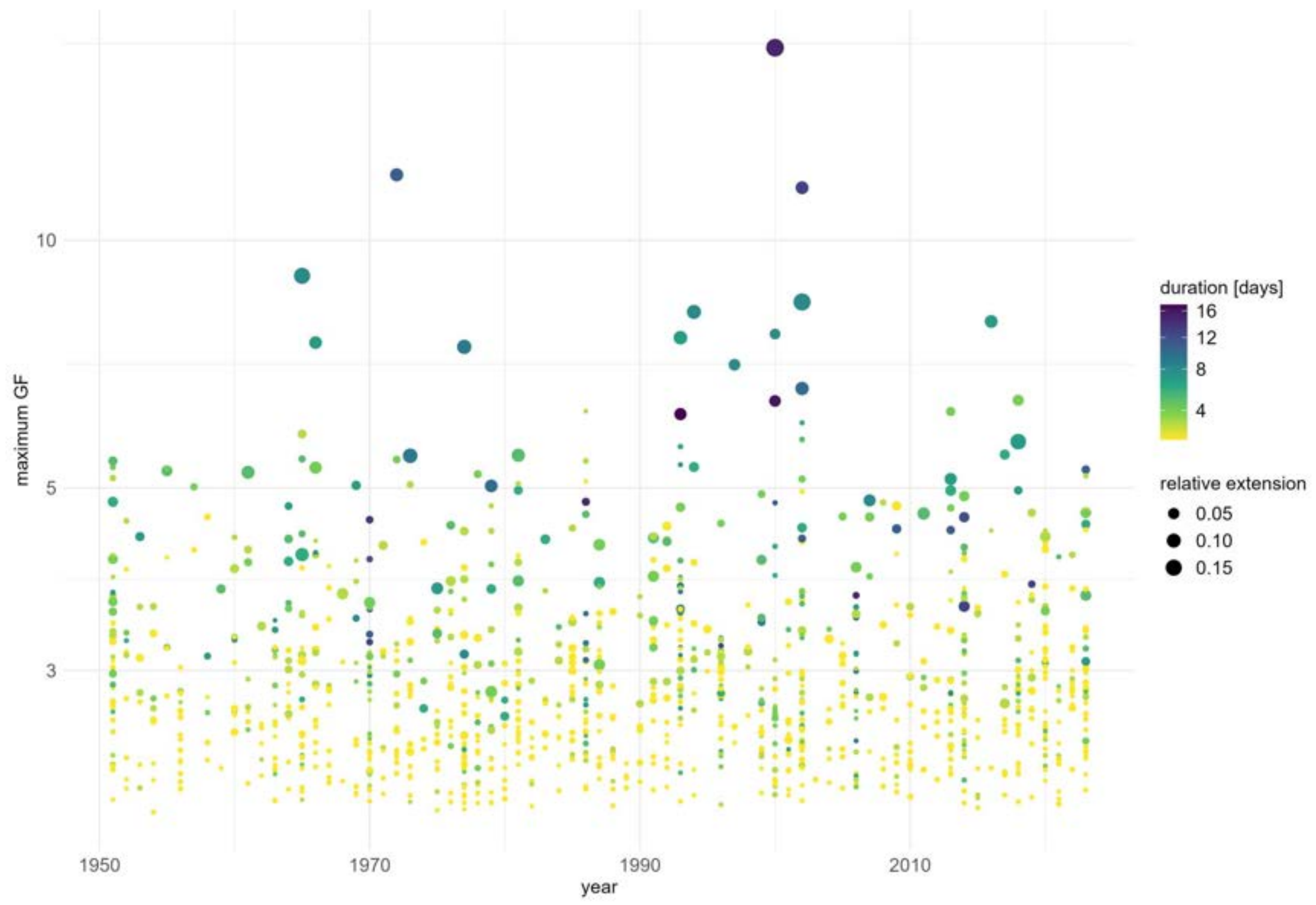


Fig. 4 - Flooding events detetcted in the *Greater Alpine Region* for the period 1951 – 2023 (in the legend relative extent means the extent of the event referred to the total extent of the *GAR*)

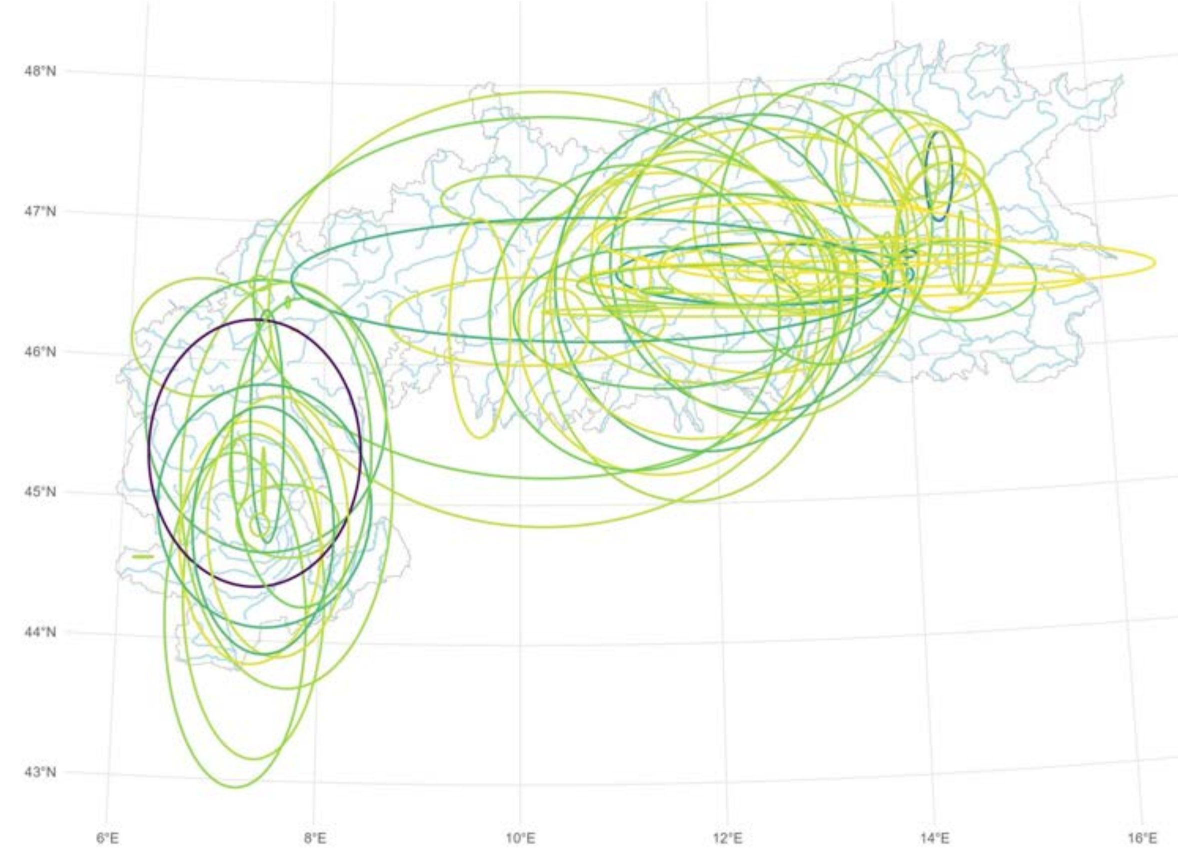


Fig. 5 - Interpolation ellipses of the 73 most important events identified in the *Greater Alpine Region* (a first version of ellipses has been reported in the figure, more effective representation methods are now being considered)

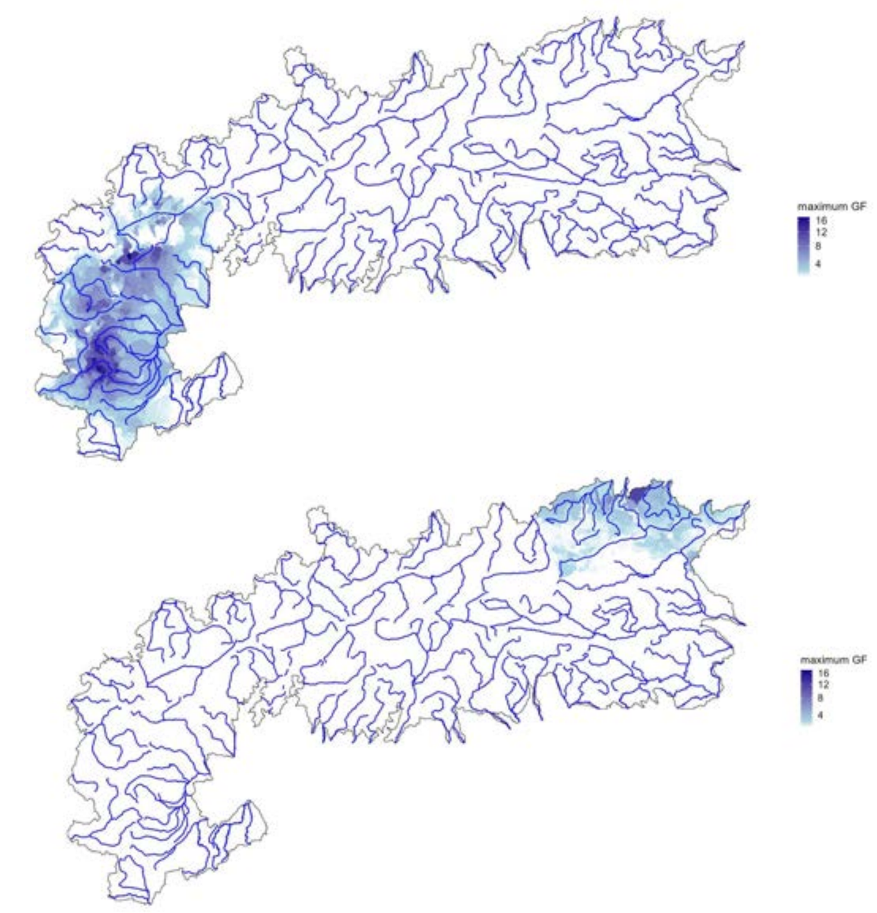


Fig. 6 - Two of the main events identified (above Piemonte in 2000, below Austria in 2002)

EVENT ANALYSIS

Events can be stratified into different classes [4], using the state variables from the model. The layers identified are: the seasonality, the meteorological nature and temporal organization of the triggering event and the antecedent soil moisture conditions. (Fig 7).

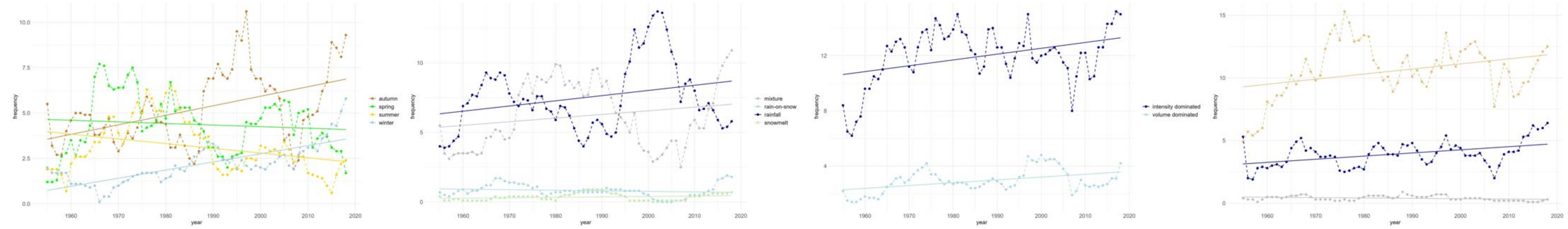
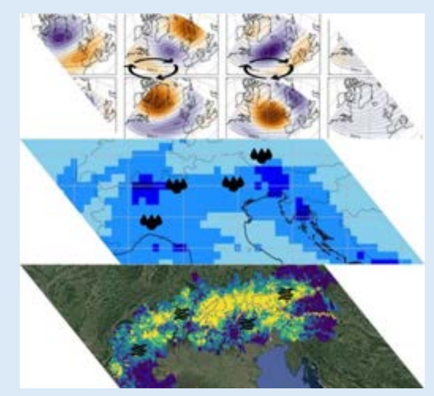


Fig. 7 - 10years moving mean of the annual frequency of the different event classes with their trends

Clim2FlEx

This poster is part of the *Clim2FlEx* project [5] which main objective is to build a end-to-end chain from global climate to river flood hydrology models to relate climate and flood extremes in the *Greater Alpine Region.*
To achieve this, the next phase of our work will attempt to communicate the events as defined from an hydrological and climatic point of view, so that possible links between them can be identified, also according to the different types of events and boundary conditions.
To know more see the work of Vikas Kumar (poster X3.10 - UniTo) and Ilaria Tessari (poster X3.8 - CNR).



MAIN REFERENCES: [1] Merz, R., Blöschl , G. (2004), Regionalisation of catchment model parameters. [2] Yeshewatesfa, H., Andràs, B. (2004), Modeling of the effect of land use changes on the runoff generation of a river basin through parameter regionalization of a watershed model. [3] Merz, R., Tarasova, L., & Basso, S. (2020), Parameter's controls of distributed catchment models - How much information is in conventional catchment descriptors? [4] Tarasova, L., Basso, S., Wendi, D., Viglione, A., Kumar, R., & Merz, R. (2020), A process-based framework to characterize and classify runoff events: The event typology of Germany. [5] http://www.idrologia.polito.it/web2/ricerca/valutazione-piene/clim2flex/