# Atmospheric

# Extreme

# Events

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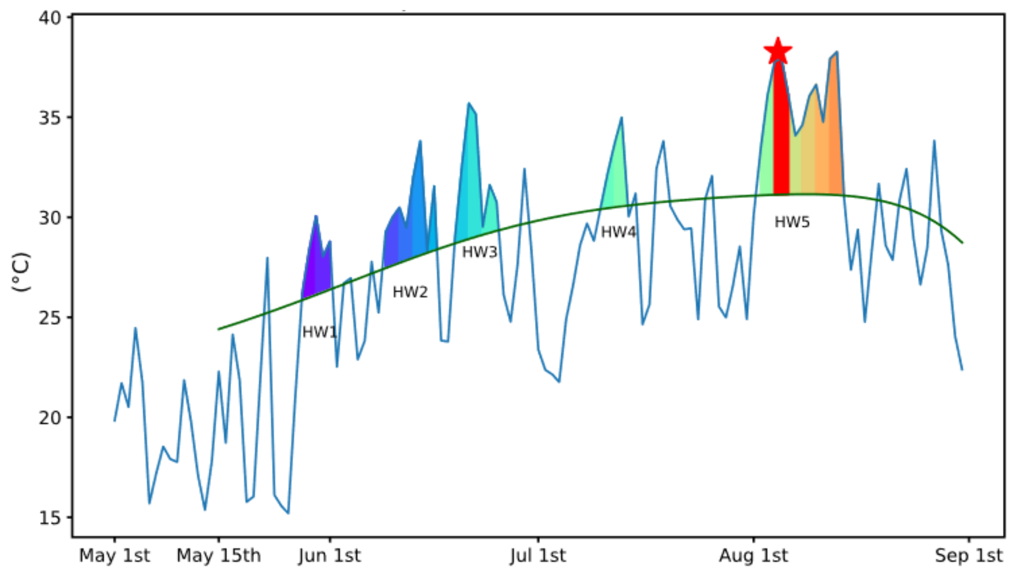
# What is an extreme event?

*Single-event perspective*

An event is considered extreme if the value of a ***variable exceeds (or lies below) a certain threshold***: e.g. 90th or higher percentile of maximum daily temperature for the calendar day over a base period

***Temperature at 2m height***




*(**Prodhomme et al., 2021**)*

*More complex approach*

The description of extreme events in a single-event perspective is **NOT** sufficient given the complexity of the system we are dealing with. We need to shift to the more complex approach of **Compounds Events**:

- *Preconditioned events*

  a weather-driven or climate-driven precondition aggravates the impacts of a climatic impact-driver

- *Multivariate events*

  multiple drivers and/or climatic impact-drivers lead to an impact

- *Temporally compounding events*

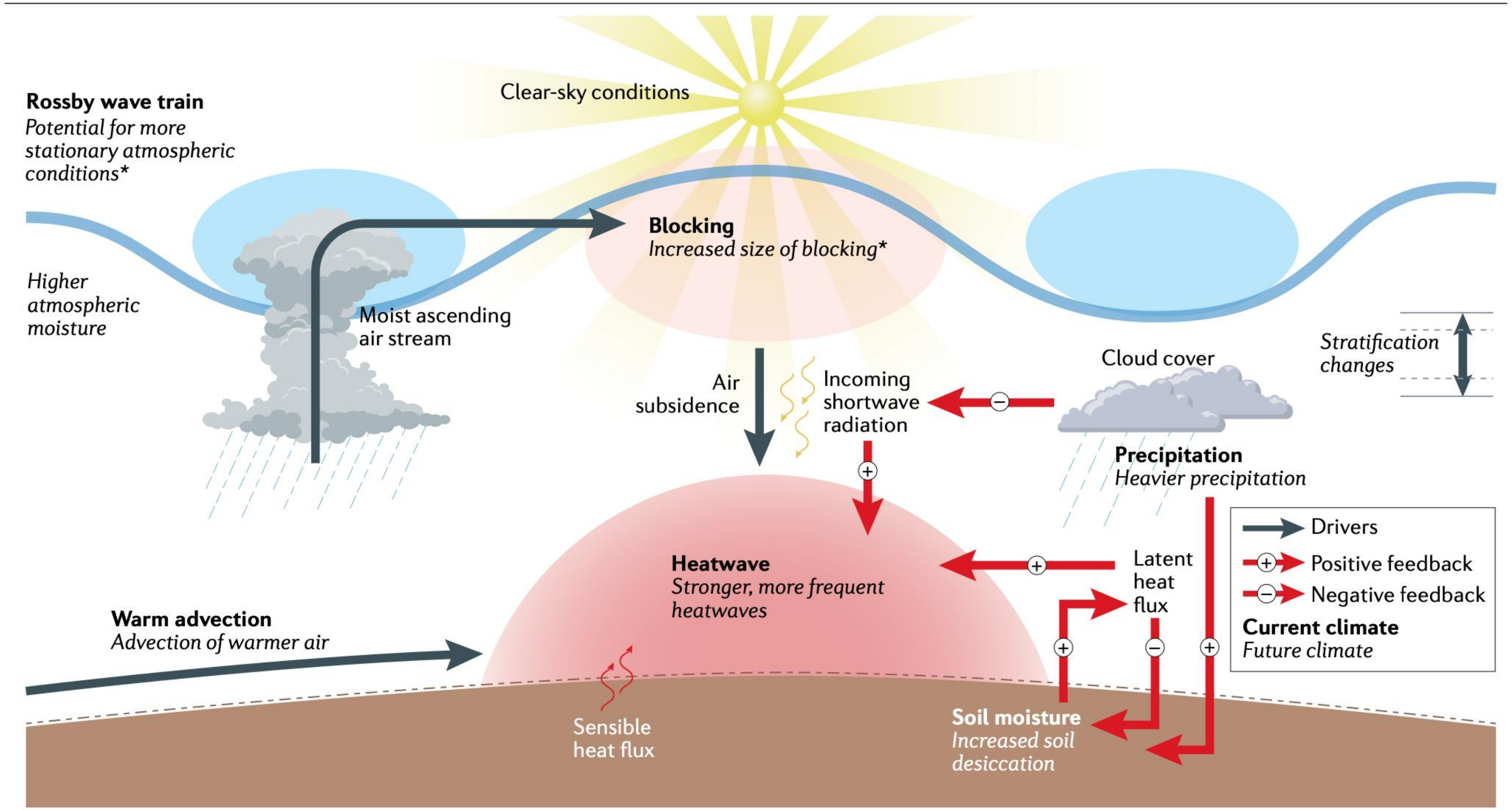
  a succession of hazards leads to an impact

- *Spatially compounding events*

  hazards in multiple connected locations cause an aggregated impact

# What is an extreme event?

*More complex approach*




Domeisen et al. Nature reviews 2023

# High-impact weather phenomena

- Extreme events such as **floods, storms, heatwaves** or **droughts** have strong socio-economic impacts on our lives, affect food and water supplies and damage terrestrial ecosystems and infrastructure

- "Globally between 2000 and 2019 over **475.000 people lost their lives** as a result of more than **11.000 extreme weather events**, with economic losses for **US$ 2.56T**." (*Global Climate Risk Index 2021*)

*Flooding in Limone (CN) after the storm Alex, Oct 2020*

*Fallen trees after the storm Vaia, Trentino, Oct 2018*

# High-impact phenomena: natural vs weather-related

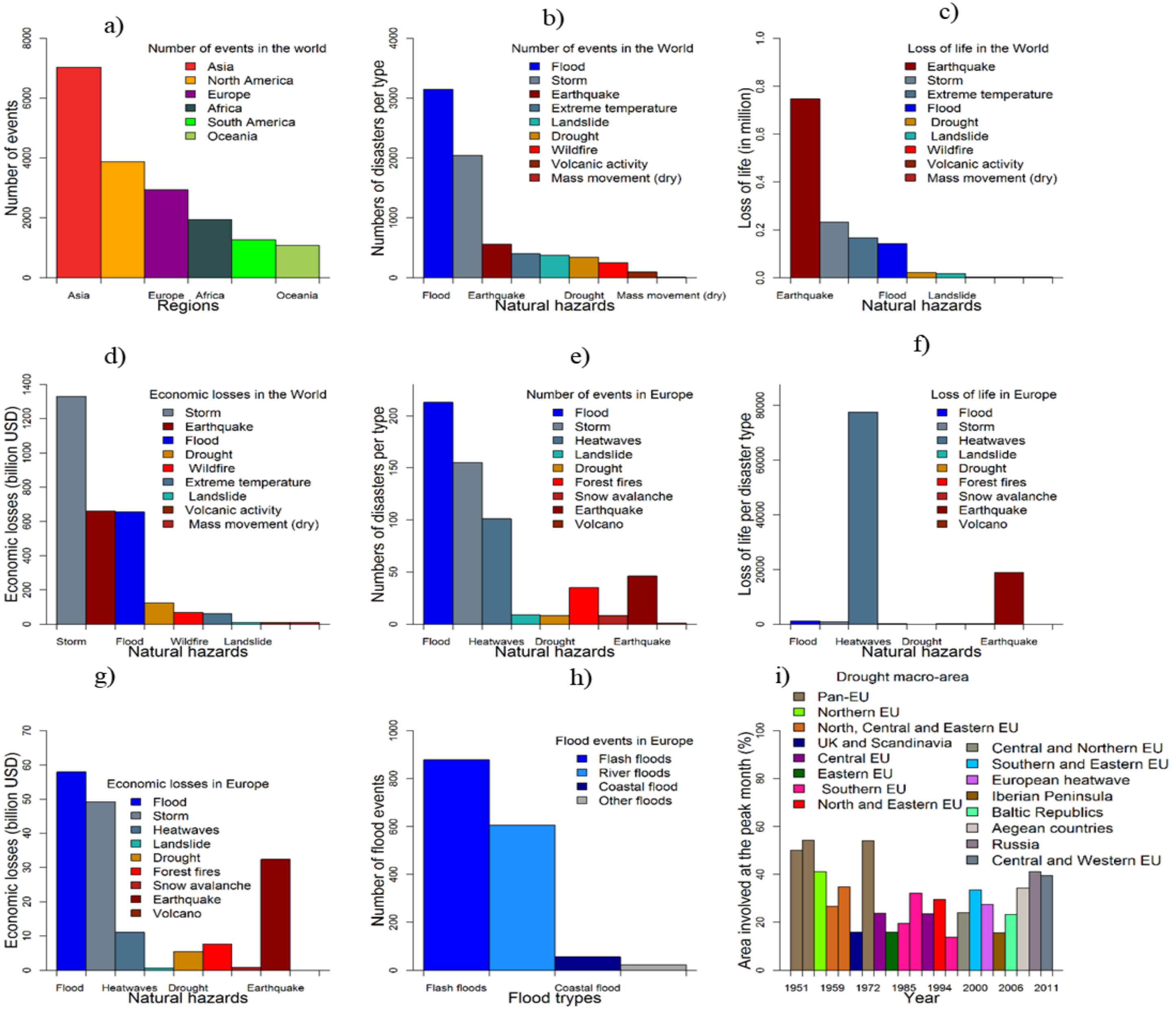



Fig. 2. (a) **Numbers of events during 1980–2018**;

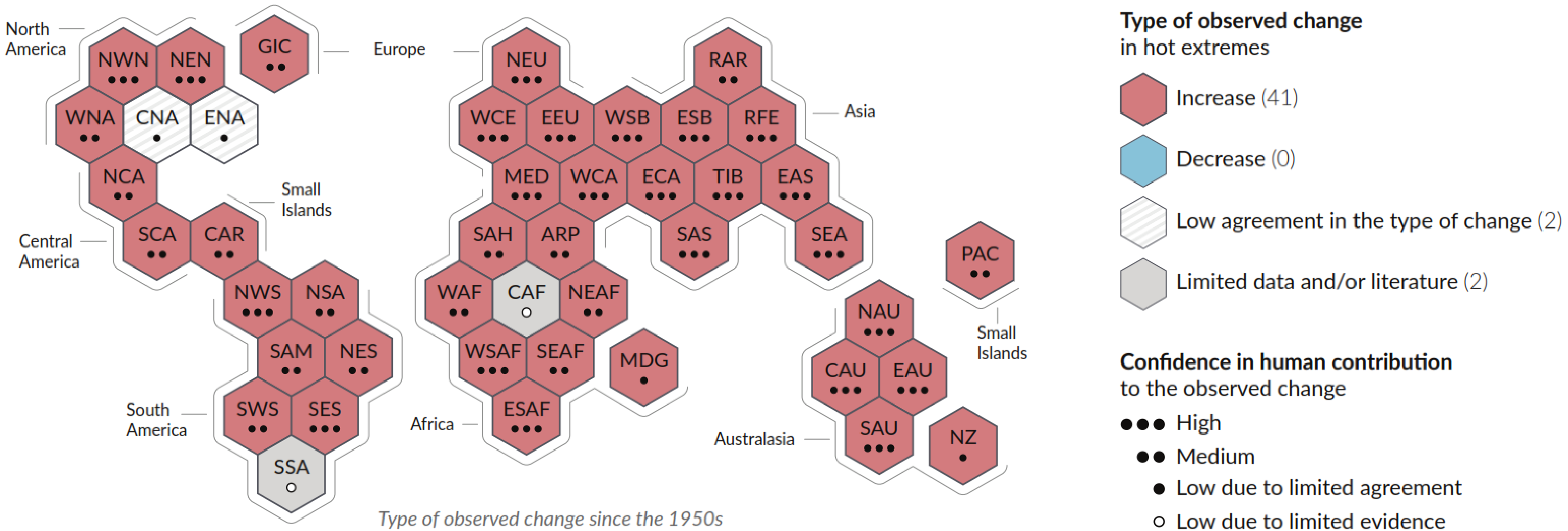
(i) **the 22 largest drought events (% of area involved) in Europe from 1950 to 2012.** The data used in figure a, b-d, e-g, h and i is taken from Munich. (2019), EM-DAT (2019), EEA (2019), Paprotny et al. (2018), and Spinoni et al. (2015), respectively.

S. Debele, P. Kumar , J. Sahani, B. Marti-Cardona, S B Mickovski, L. S. Leo, F. Porcù, F. Bertini, D. Montesi, Z. Vojinovic, S. Di Sabatino (2019). **Environmental Resarch, 179.**

OPERANDUM

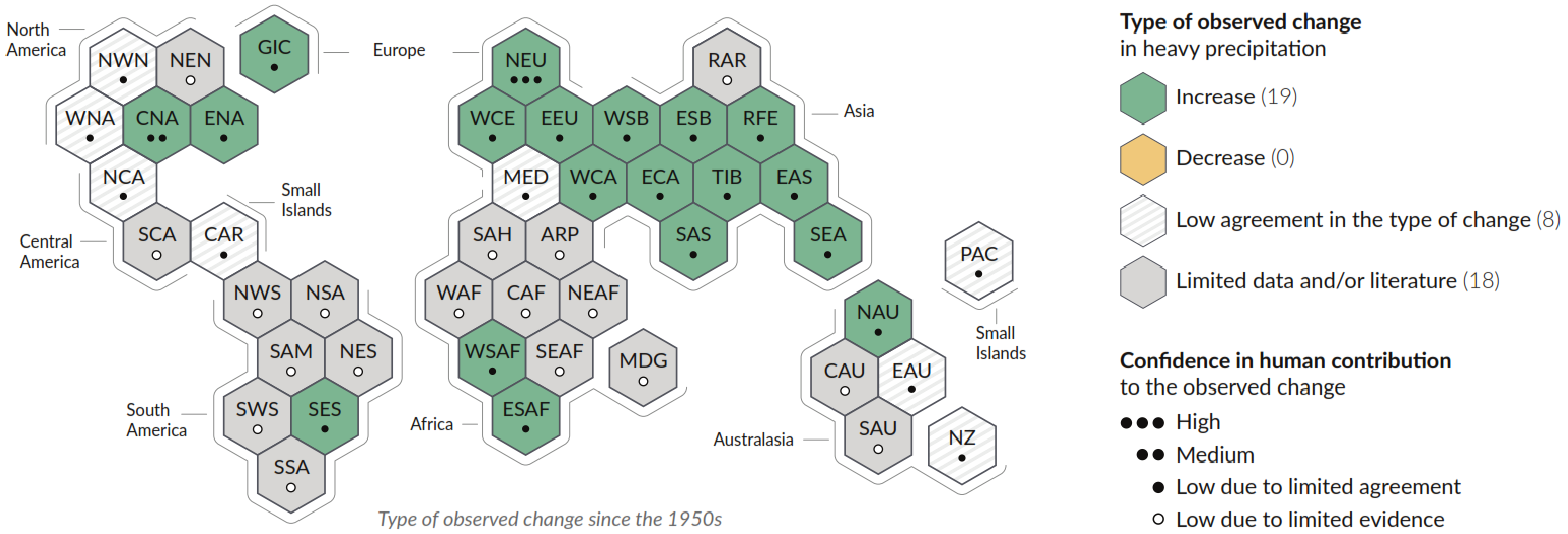
# IPCC Sixth Assessment Report

"It is *virtually certain* that **hot extremes** (including heatwaves) have become more frequent and more intense across most land regions since the 1950s […], with *high confidence* that human-induced climate change is the main driver of these changes"



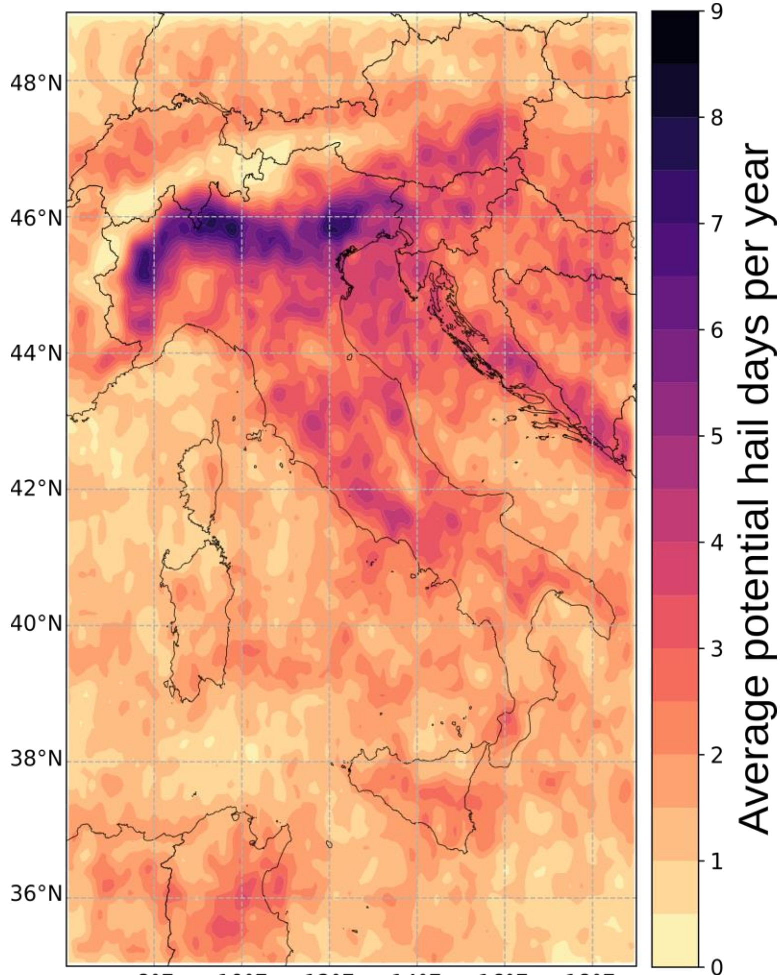
# IPCC Sixth Assessment Report

"The frequency and intensity of **heavy precipitation** events have increased since the 1950s over most land areas for which observational data are sufficient for trend analysis (*high confidence*), and human-caused climate change is *likely* the main driver "



# An italian example: impacts of extreme hailstorms

*Climatology of hailstorms*




*(**Giordani et al**. - under revision)*

The new European record of hailstone size was recorded in the Friuli Venezia Giulia region on 25 July 2023: about **19 cm** large hailstone.

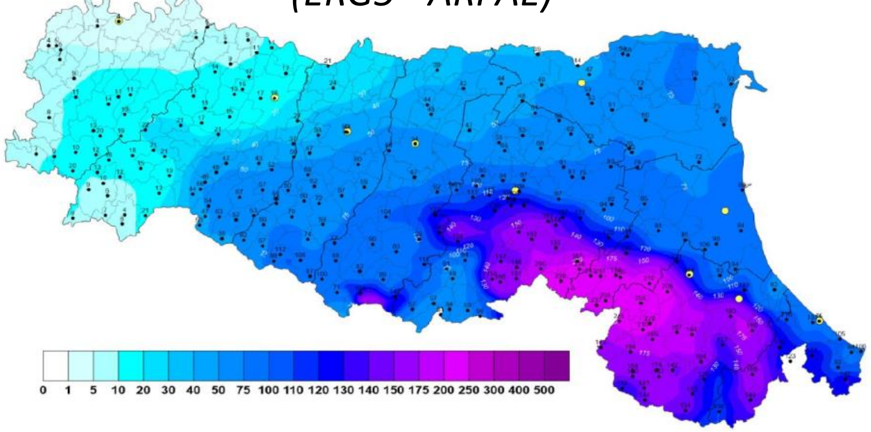


Local severe storms during July 2023 in Northern Italy caused about **4.0 billions € of losses**, **280 injuries** and **3 deaths**.

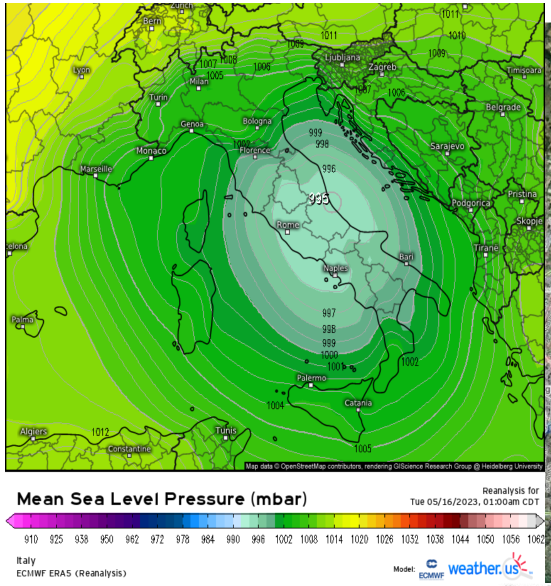
# Italian example: compound flood events

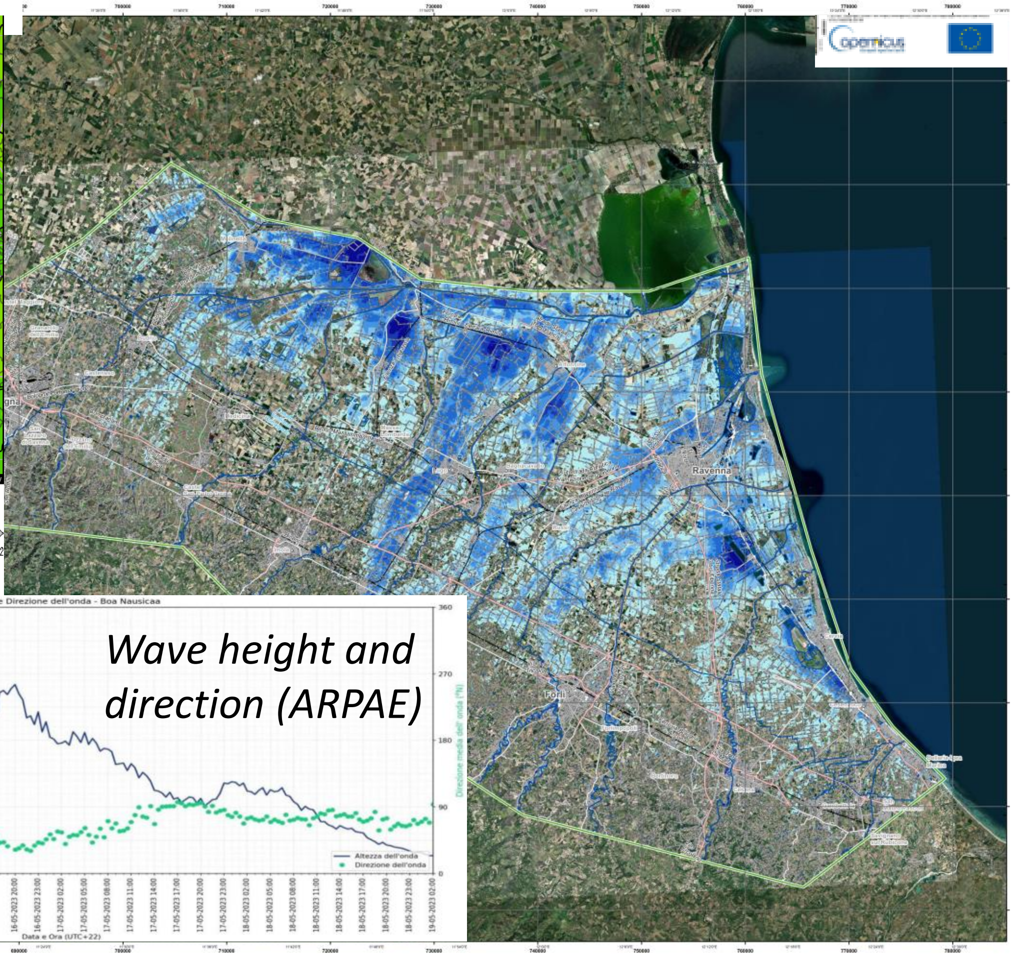
Coastal and inland floods in Emilia Romagna on 16-17 May 2023 caused by the co-occurrence of **high river discharges** and **storm surges**, due to **severe precipitation** and **wind gusts (Bora)**, driven by a **slowly-moving low-pressure system**

*Accumulated precipitation 16-17 May (ERG5 - ARPAE)*




*Sea-level pressure (16 May)*




*Wave height and direction (ARPAE)*

# Italian example: compound flood events

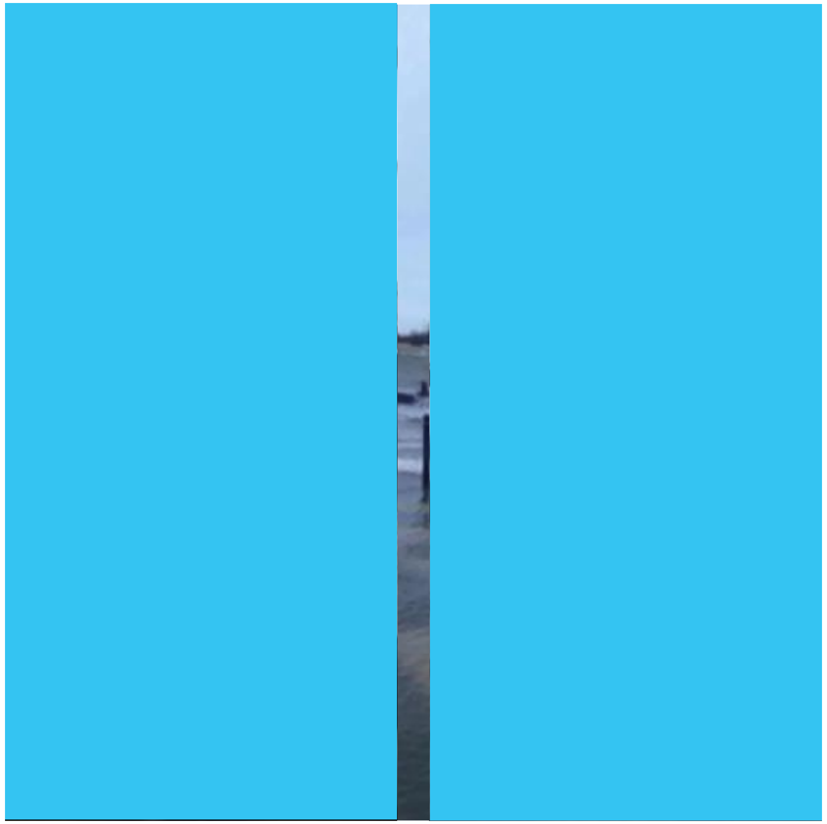
## STORM-SURGE (5-7 Feb 2015)

Defined by local authorities as the main event within the North Adriatic in the last decade, responsible of several damages to infrastructures, defences structures and bathing establishments along the whole northern Italian Coast.

| EXTREME RECORDS | |
|---|---|
| 1.21 m | Sea Level Porto Corsini |
| 4.31 m | Wave Height Nausicaa |

| OBSERVATION DATA | |
|---|---|
| 44°(NE) | Wave Direction |
| 516 $m^2h$ | Wave Energy |
| 74 h | Duration |
| Severe | Energetic Class |

OTHER DAMAGES: Beach Erosion and Marine Flooding



Credits lanuovaferrara.gelocal.it

Dolan & Davis (1992– classification scheme - severe

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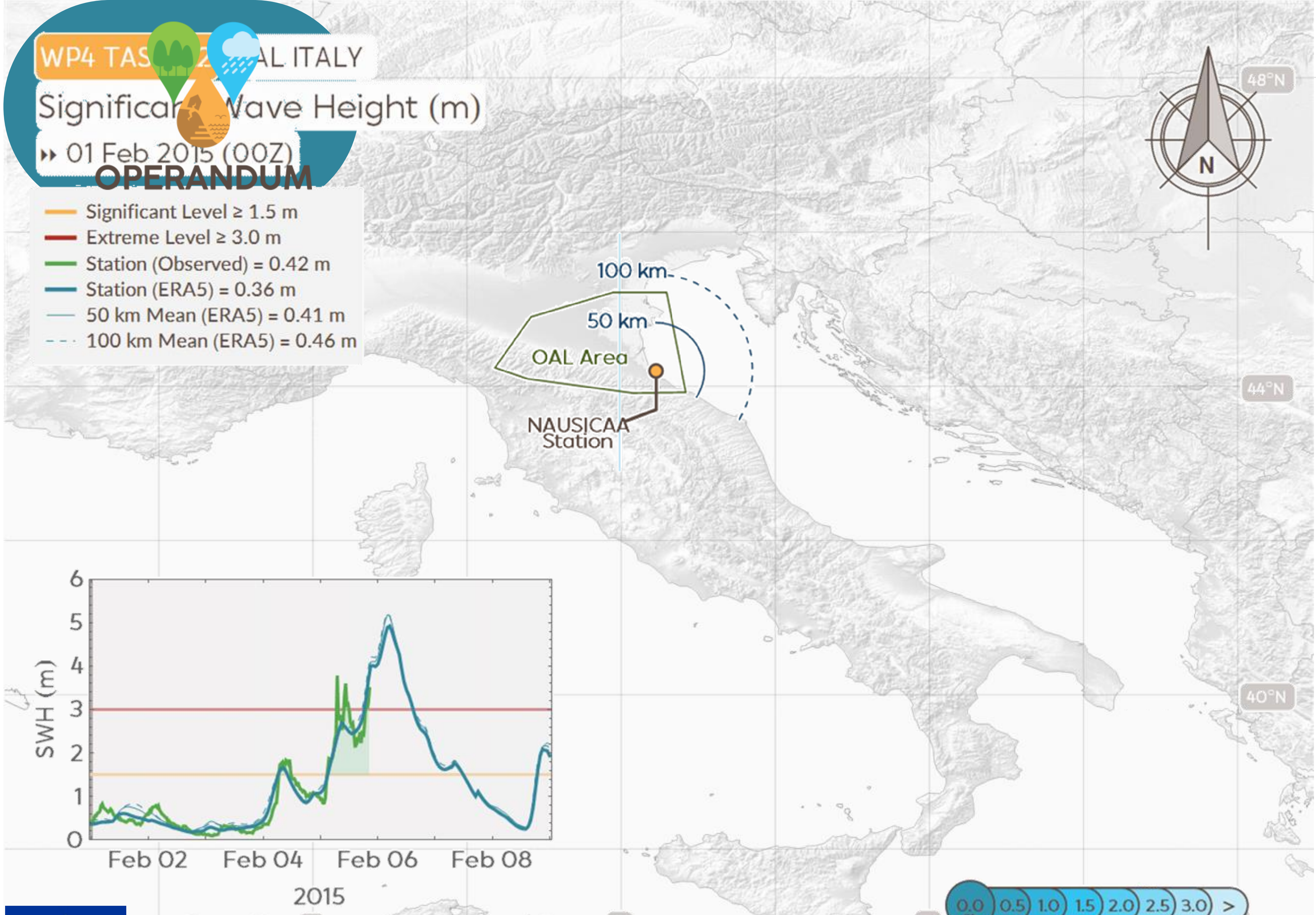
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776848

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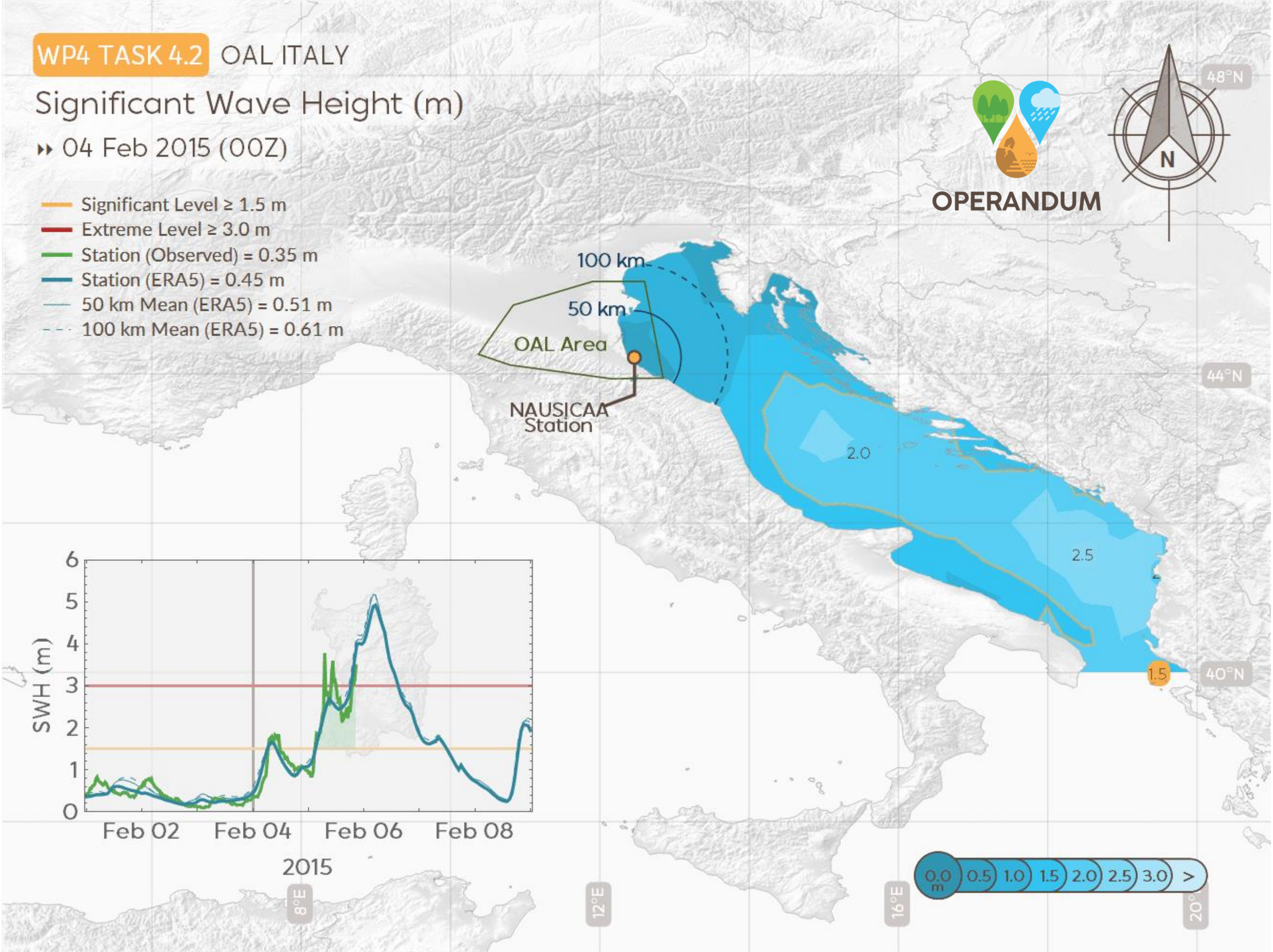
WP4 TASK 4.2
OAL ITALY
Significant Wave Height (m)
04 Feb 2015 (00Z)
Significant Level ≥ 1.5 m
Extreme Level ≥ 3.0 m
Station (Observed) = 0.35 m
Station (ERA5) = 0.45 m
50 km Mean (ERA5) = 0.51 m
100 km Mean (ERA5) = 0.61 m
OPERANDUM
N
48°N
44°N
40°N
8°E
12°E
16°E
20°E
100 km
50 km
OAL Area
NAUSICAA Station
2.0
2.5
1.5
SWH (m)
6
5
4
3
2
1
0
Feb 02
Feb 04
Feb 06
Feb 08
2015
0.0 m
0.5
1.0
1.5
2.0
2.5
3.0
>

# What are the current challenges?

1. Better understanding the **physical processes** driving and influencing extreme events, with a focus on the role of complex topography (orography, water bodies and urban land use)

2. Increase the **model prediction skill** of extreme events over different spatial and temporal scales

3. Improve the comprehension of unprecedented and plausible extreme events to prevent their **impacts** and elaborate effective **adaptation measures** (e.g. through large multi-model ensembles)

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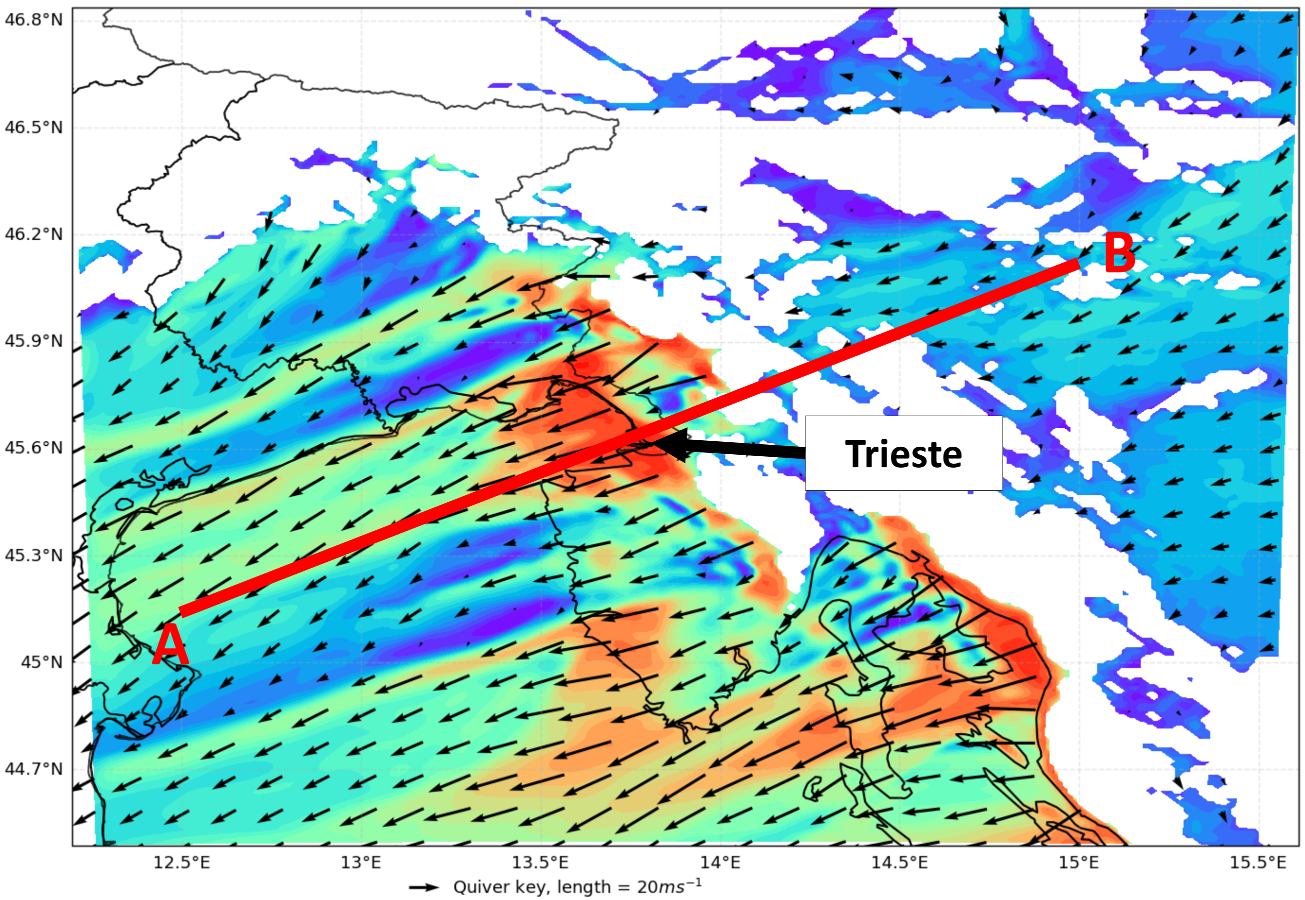
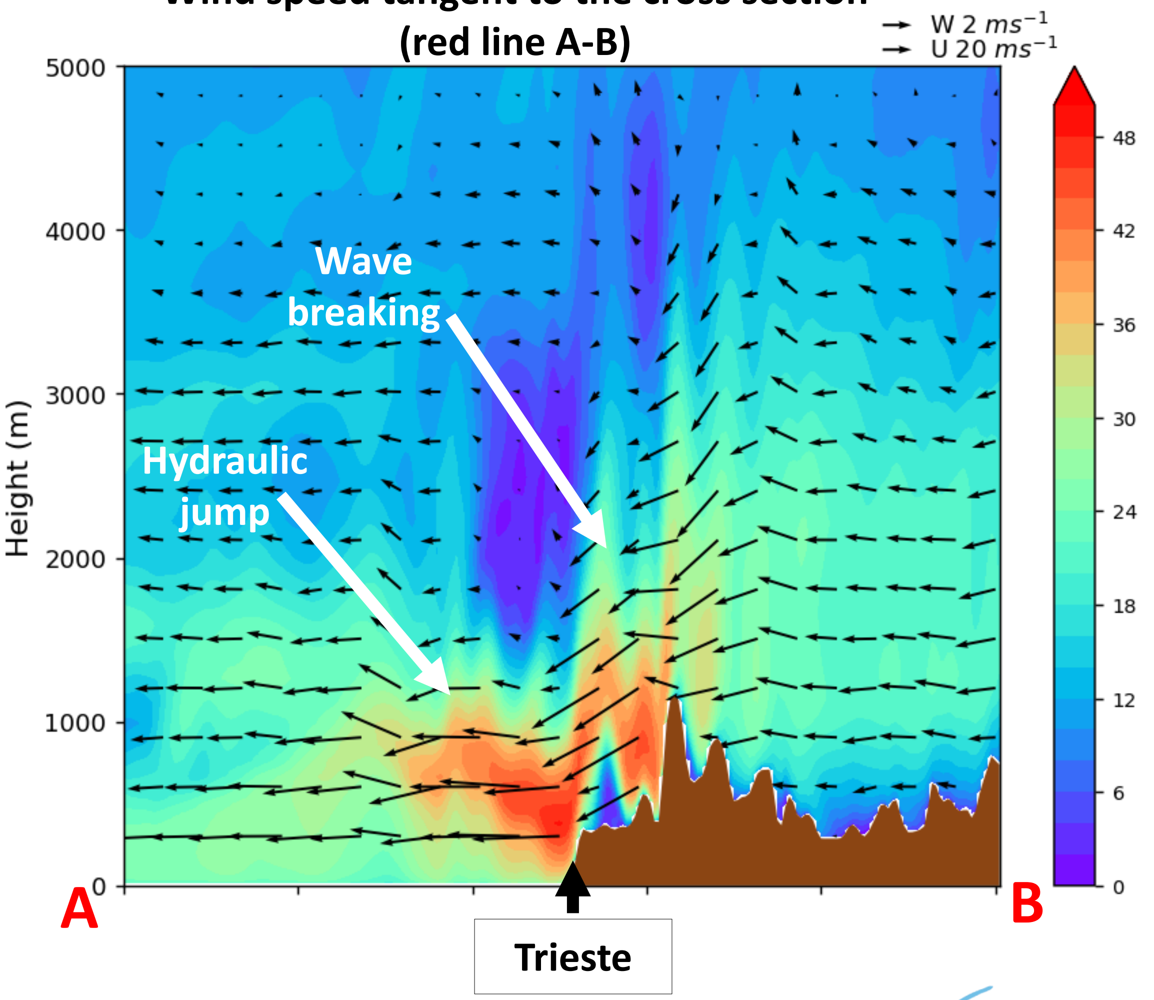
# Complex topography and extreme phenomena

## Downscaling of Bora winds (extreme event on 11 February 2012)

**Wind speed at 950 hPa over Northern Adriatic region**




**Wind speed tangent to the cross section (red line A-B)**




Dynamical downscaling of ERA5 with WRF up to 1 km of grid-spacing

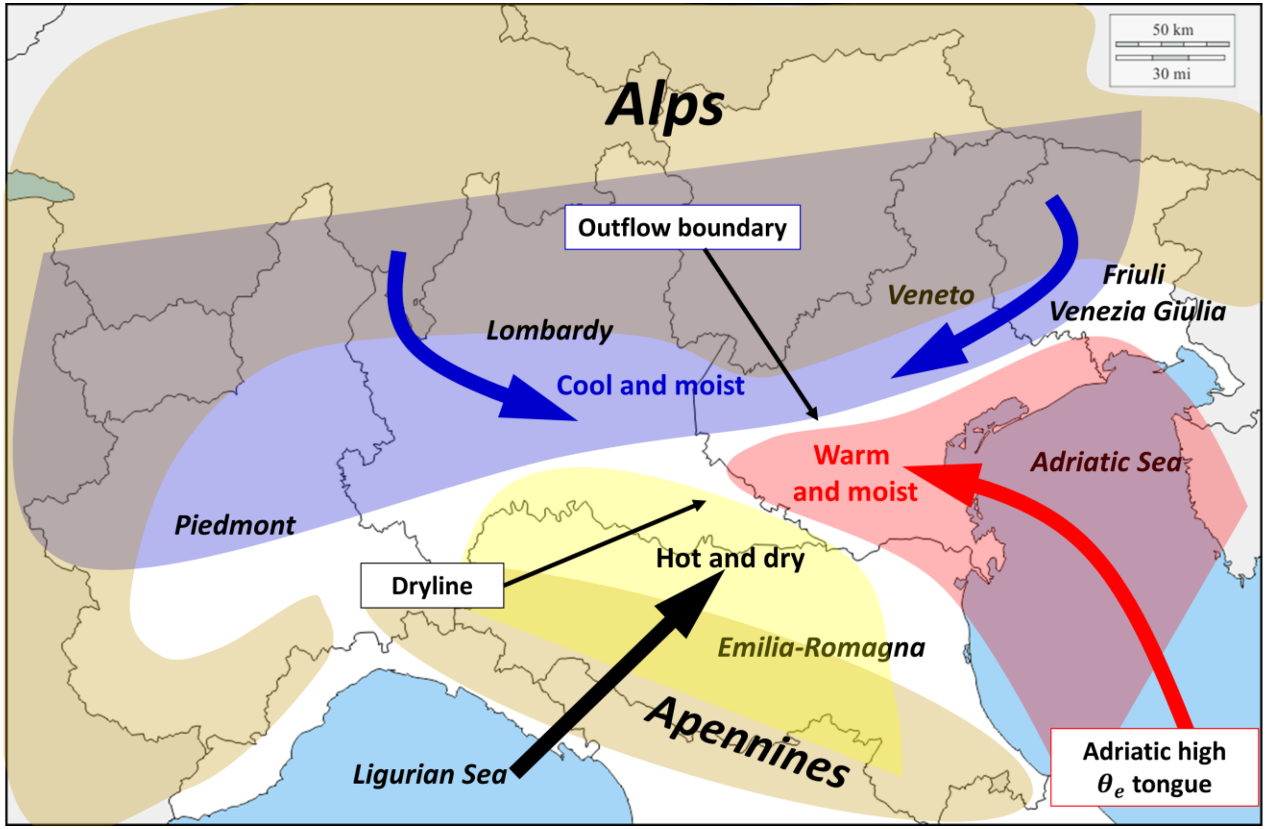
Bora winds are generated by the orographic waves breaking over the Carso plateu.

RISKADAPT
Modeling of Risks and Adaptation

1

# Complex topography and extreme phenomena

## Tornadoes and complex orography




*(De Martin et al., 2024)*

- Northern Italy is a hot-spot for tornadoes development in Europe. Why?
- Observations show during tornado occurrence in the region the presence of peculiar surface boundaries, generated by air flows induced by the local orography.
- Numerical simulations highlighted that along these surface boundaries the streamwise vorticity and potential instability is increased, favoring the development of tornadoes.

# Complex topography and extreme phenomena

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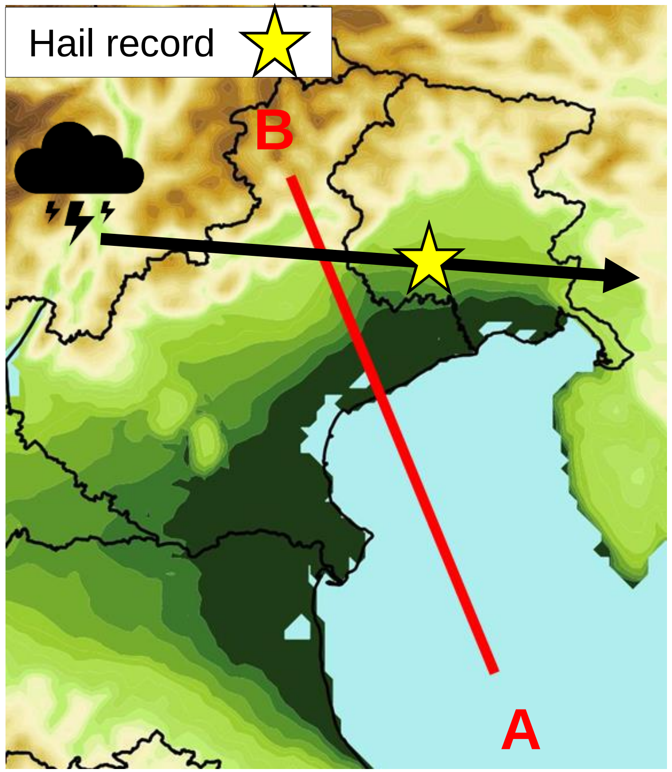
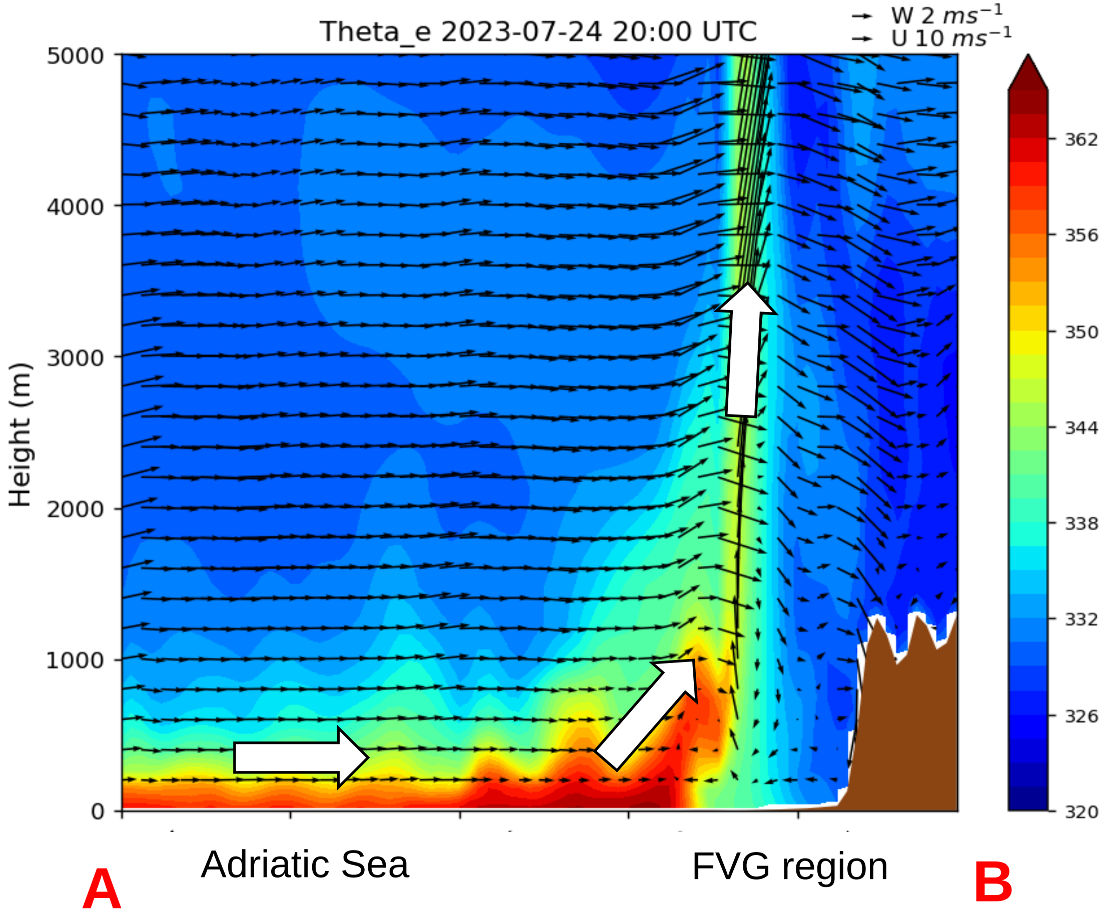
## Giant hailstones and the Adriatic Sea (24 July 2023 event in the FVG region)




Operational WRF simulation with 3.5 km grid-spacing and 45 vertical levels.




Equivalent potential temperature (theta-e) and wind tangent to the cross section (A-B) shown with a red line in the plot on the left.

***(De Martin et al., in preparation)***

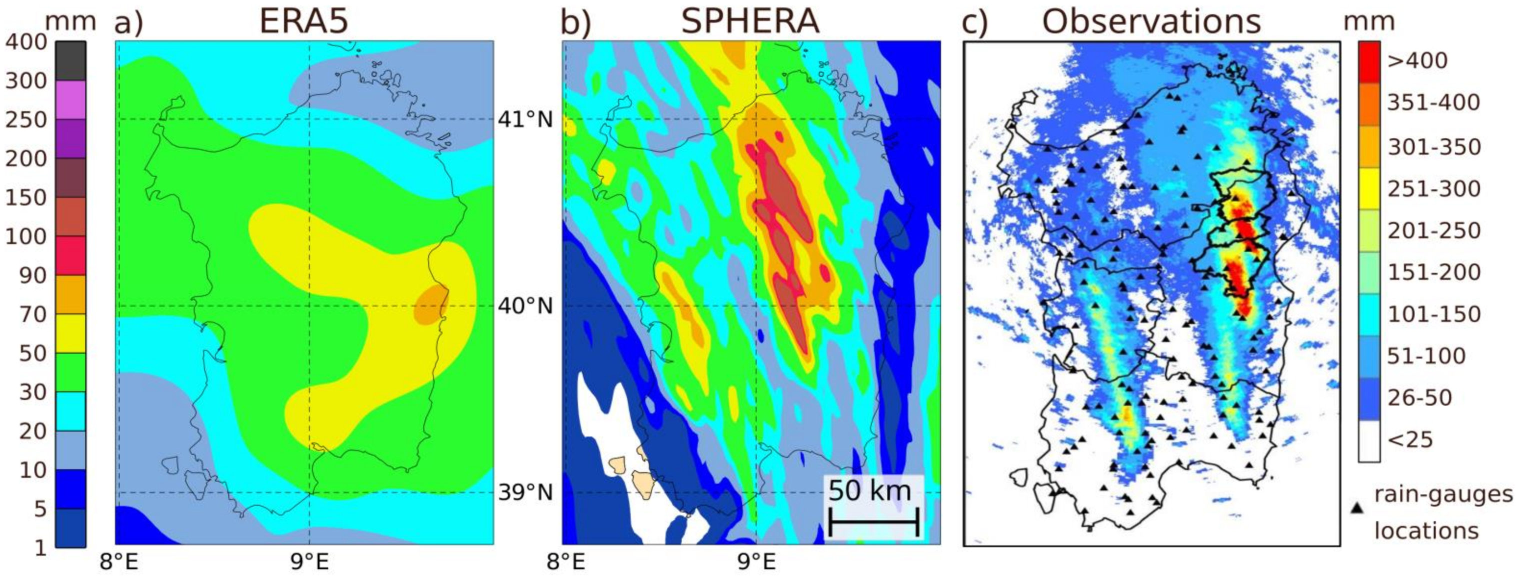
The presence of the Adriatic Sea was crucial for the hailstorm development, since it provided a source of moisture, necessary to generate the record-breaking hailstones.

# Complex topography and extreme phenomena

## Mesoscale Convective Systems (MCS) in Sardinia (18 November 2013)

Warm and moist advected air forced by the cyclone Cleopatra interacted with the Gennargentu massif causing persistent orographic lifting and the formation of multiple MCSs

Unprecedented record-breaking rainfall accumulations of **470mm/24h** and wind gusts >100 km/h



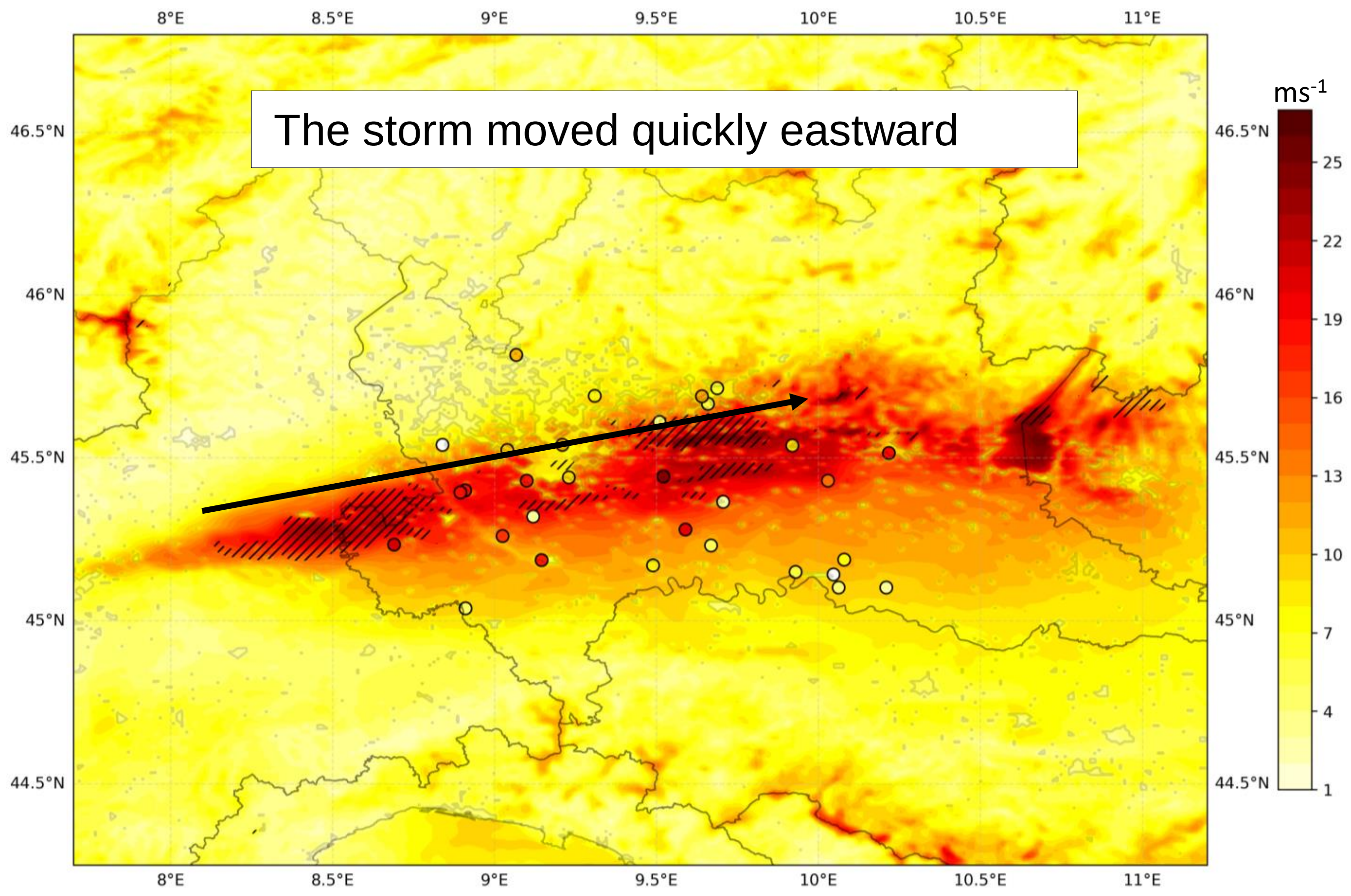

*(Giordani et al., 2023)*

Benefits of high-resolution "convection-permitting" modeling in representing the extreme precipitation bands

1

# Complex topography and extreme phenomena

## Convective windstorms and cities




Mean max wind gusts (colour shading) simulated by an ensemble of simulations, compared to observations (coloured dots).

During the night of 25 July 2023 a violent convective windstorm affected Milan, breaking down many trees and blocking the transports.

A mini-ensemble of six WRF simulations, initialized 6 hours before the storm development, with 1 km grid-spacing and 64 vertical levels, was obtained perturbing urban and boundary layer parametrization schemes.

# Complex topography and extreme phenomena

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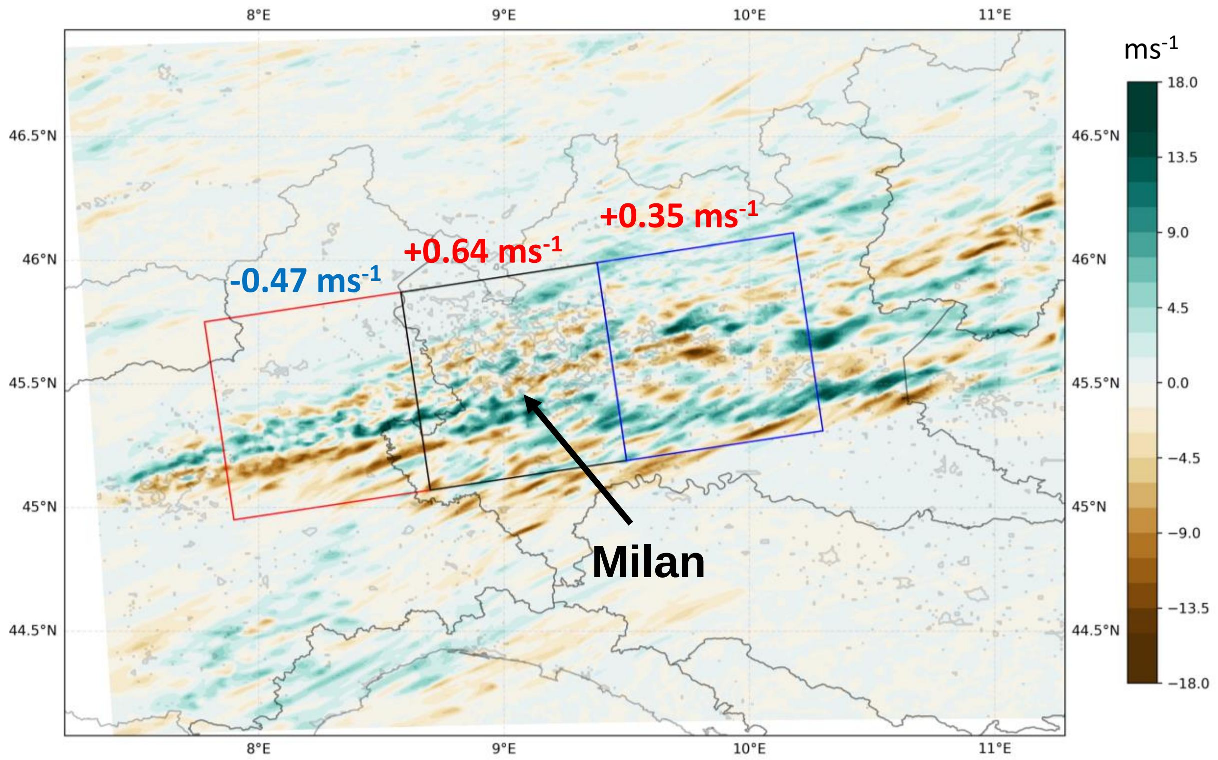
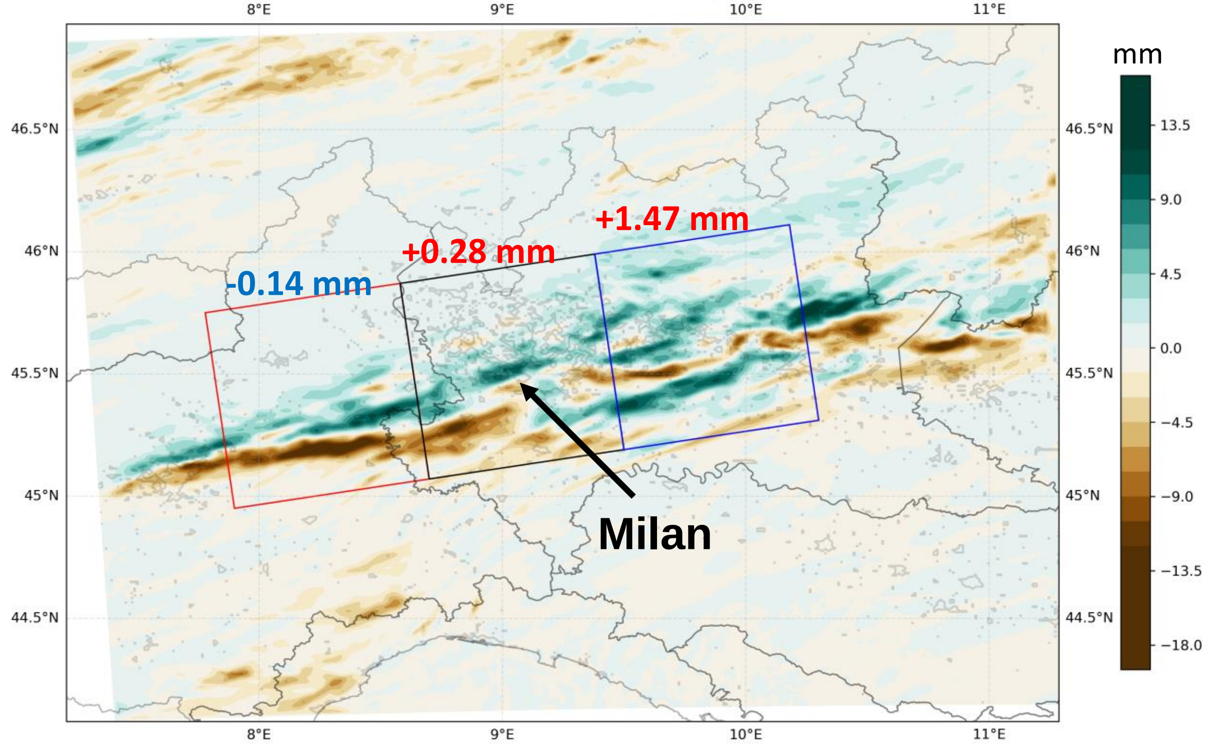
## Convective windstorms and cities

Max updraft speed *urban*-no urban***




Rainfalls *urban*-no urban***




*(De Martin et al., in preparation)*

The ensemble of the difference between "urban" simulations and "no-urban" simulations pointed out an intensification of the updrafts over the city and an intensification of the rainfalls downwind.

*with urban land use　　　　**with urban land use replaced by croplands

1

# Observation of intensified urban heat island during heatwaves

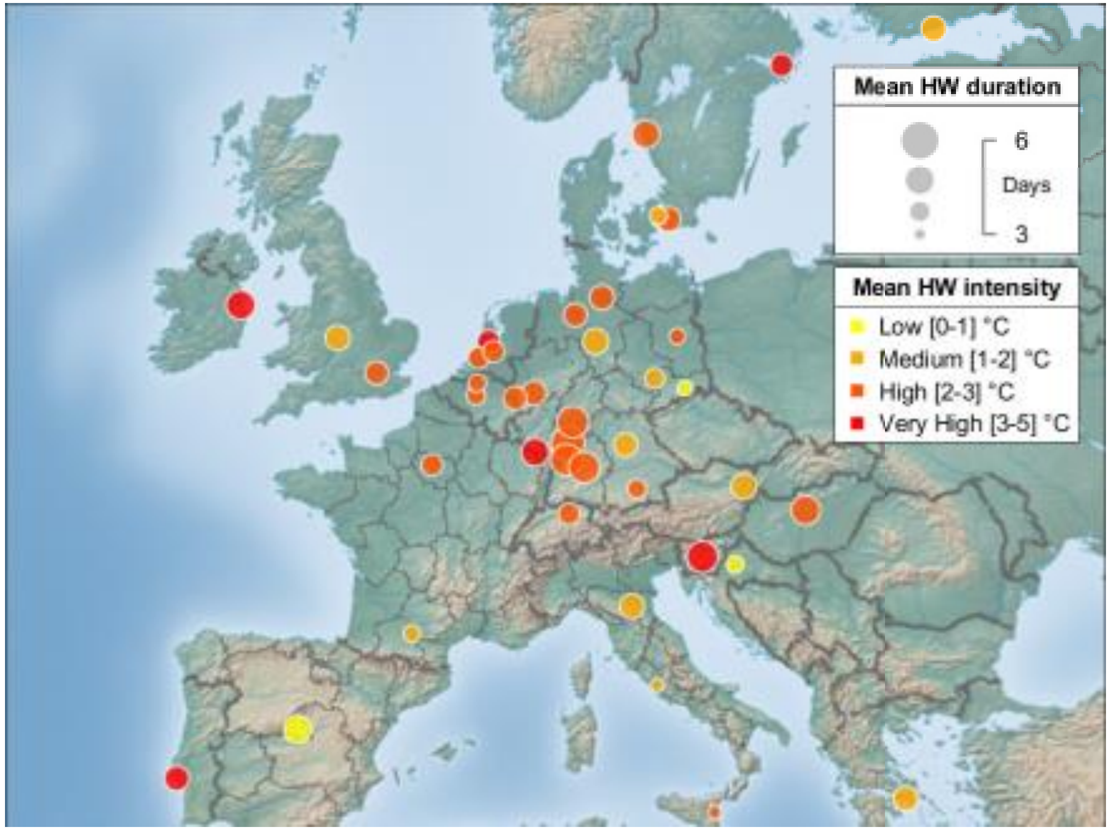



**Fig. 4**: HW characteristics: Point size indicates mean duration of HWs detected, while the color represents mean HW intensity

**Data:** in situ daily temperature measurements provided by European Climate Assessment & Dataset (ECA&D) and by World Meteorological Organization (WMO) network

**Period**: a time interval of 20 years (2000 - 2019) is selected, only boreal summers (June, July and August)

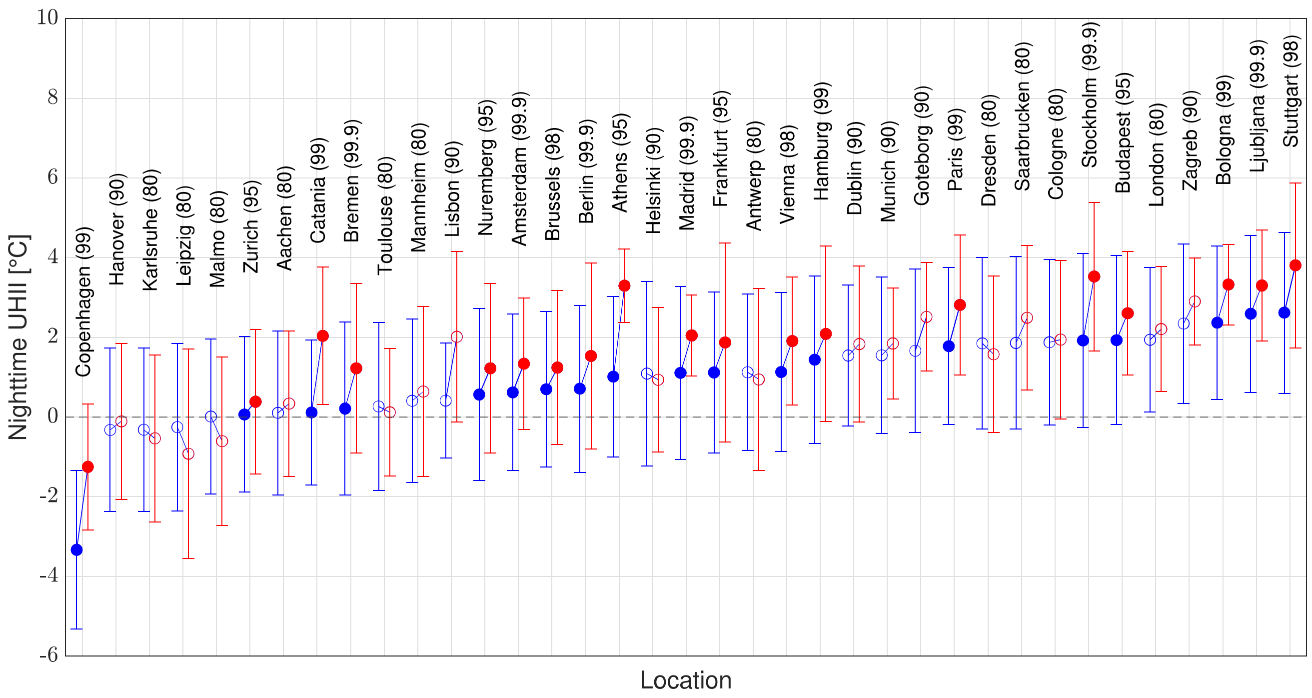
**Heatwave detection**: procedure similar to Stefanon et al. (2012)

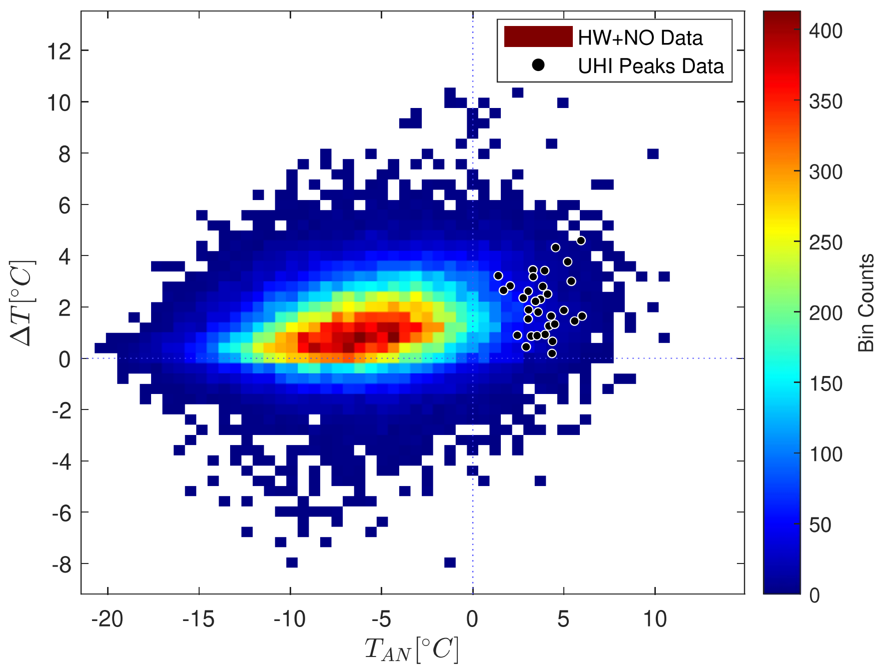
–→ daily temperature anomalies evaluated w.r.t. 20 years of ERA5 data for each city

**Possega et al. 2023, Environmental Research Letters, 17.12**

# Observation of intensified urban heat island during heatwaves

(a) Mean noctural UHII




Possega et al. 2023, Environmental Research Letters, 17.12

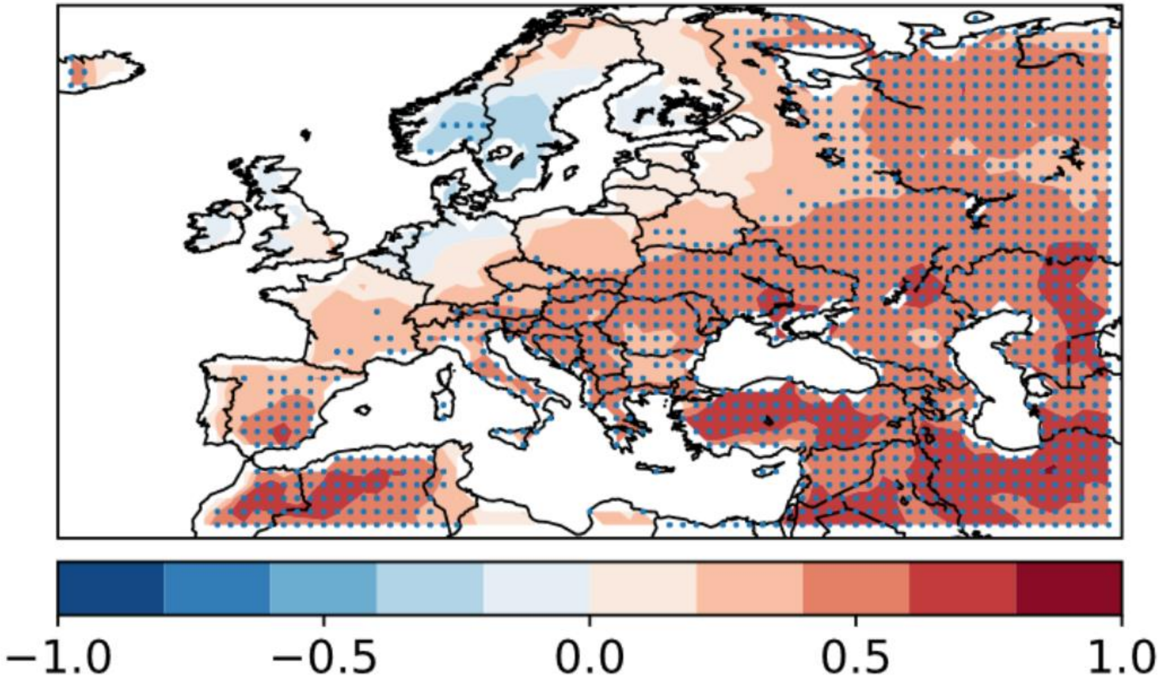
Robust increase of UHI intensity during heatwaves compared to climatological conditions.
On average 0.7 °C

2

# Prediction skills of summer extreme temperatures in Seasonal Forecast Systems

***Anomaly Correlation Coefficient (ACC)***

*ECMWF SEAS5 model – **TX90p index*** in MJJA*




*(Prodhomme et al., 2021)*

**TX90p index*:*
*n. of days with daily max T2m above 90th percentile*

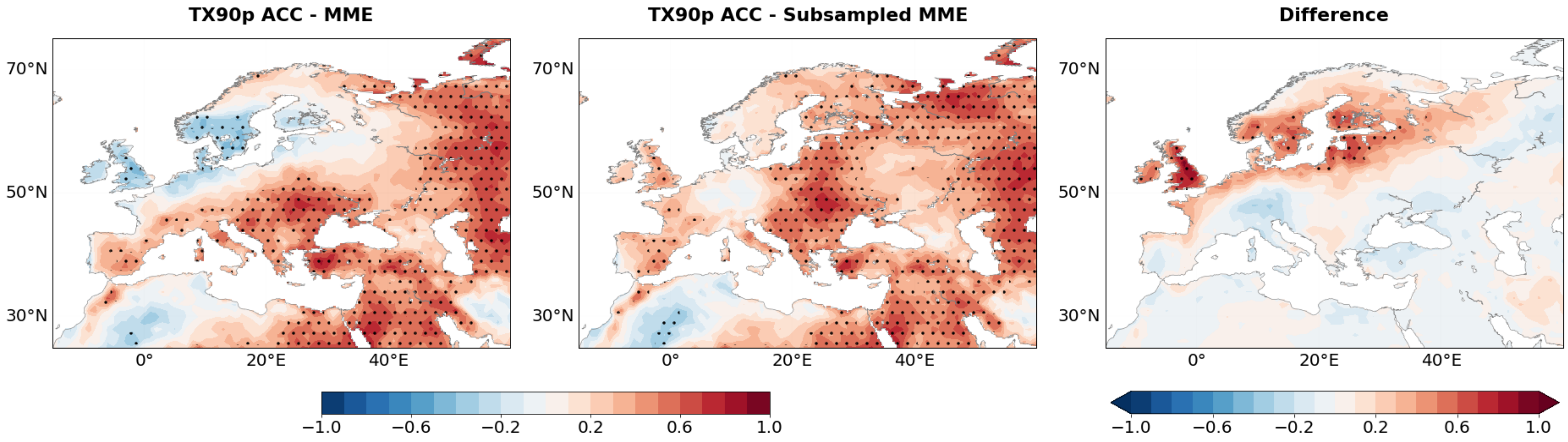
- **Good prediction skills** of summer extreme temperatures in state-of-the-art seasonal forecast systems over **southern/eastern regions**
- However, **low prediction skills** over **northern/continental regions**, affected by particularly hot summers in the past few years (e.g. France 2003 and UK 2022)

trigger

2

# Improved Prediction Skills through statistical post-processing techniques: sub-sampling

Prediction skills of extreme events occurrence can be improved by **sub-sampling the model ensemble**, that is by retaining only those ensemble members satisfying specific statistical conditions on the atmospheric state*.




*(Famooss Paolini et al.)*

* Prediction skills obtained by retaining only ensemble members that correctly represent the summer NAO phase.
The adopted seasonal prediction systems are available on Copernicus Data Store
Analysis have been performed for the hindcast time period 1993—2016

trigger

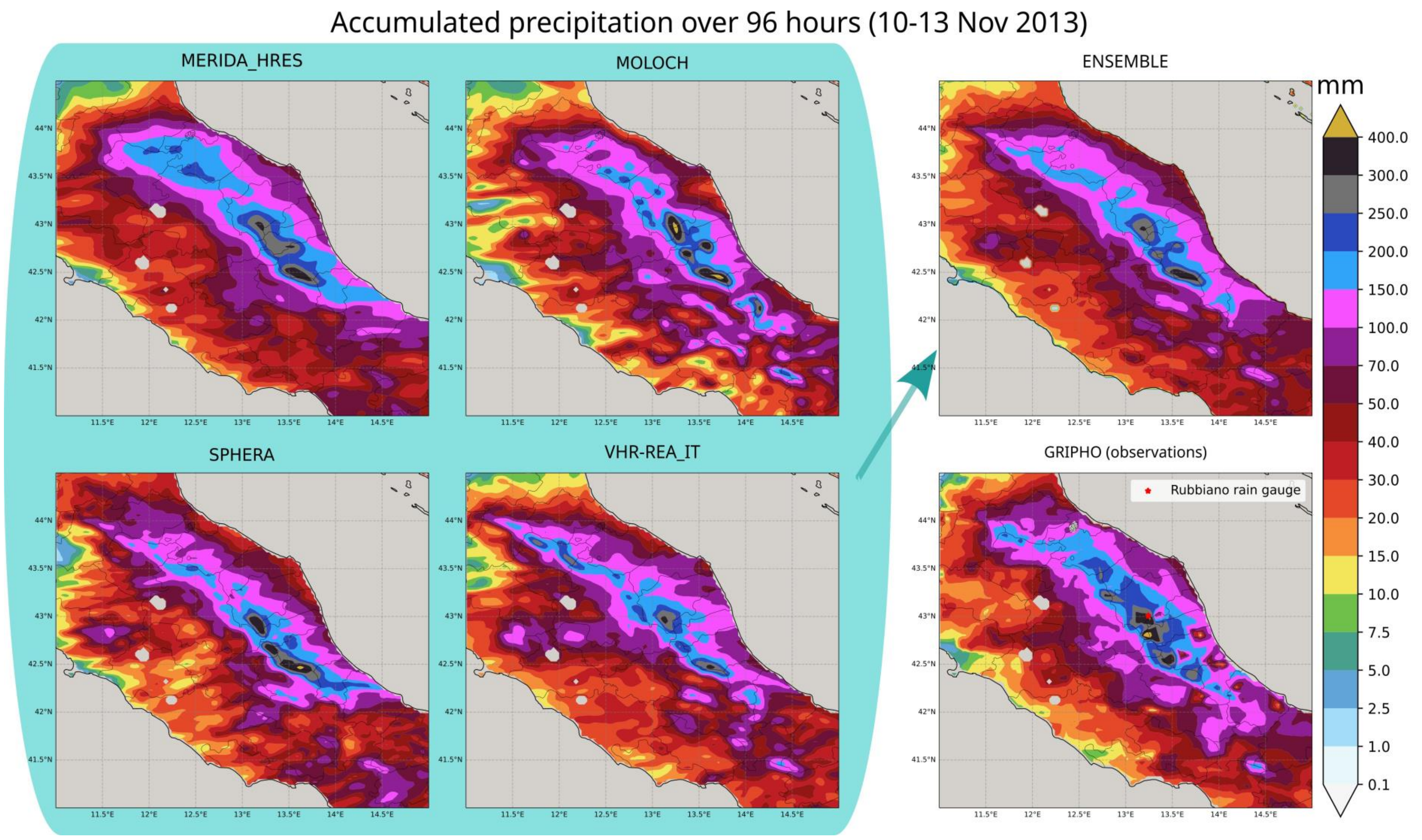
3

# Multi-model ensemble of past extreme rainfalls

## Flood in Marche region on 10-13 November 2013 due to persistent orographic rainfall

The ensemble aggregation of retrospective datasets improves the representation of extreme rainfalls and reduces the error associated with heavy daily rainfalls over Italy (including the Emilia Romagna region).

*(**Giordani et al.**, in preparation)*




ecosister

# Multi-model ensemble of past extreme rainfalls

3

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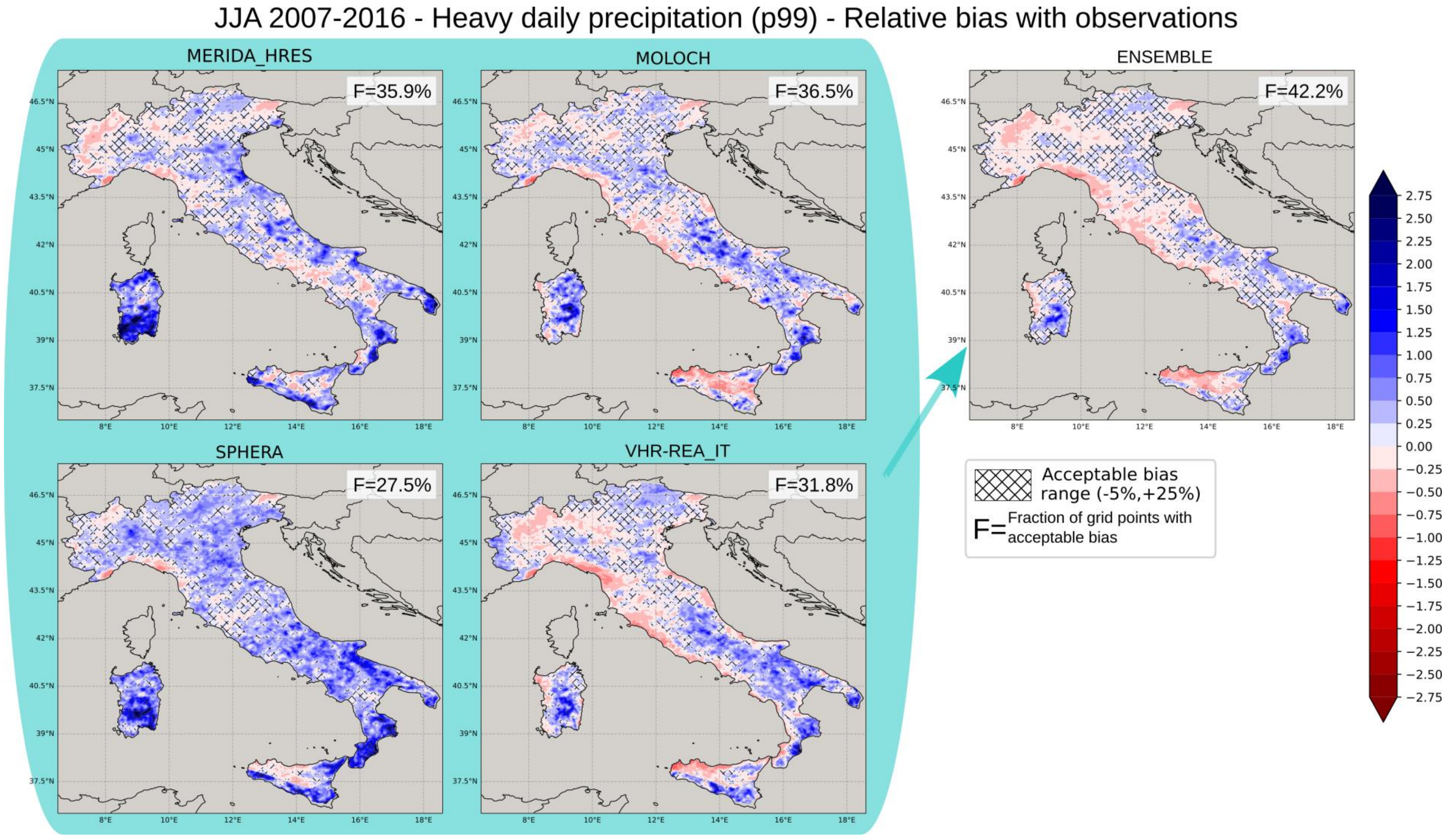


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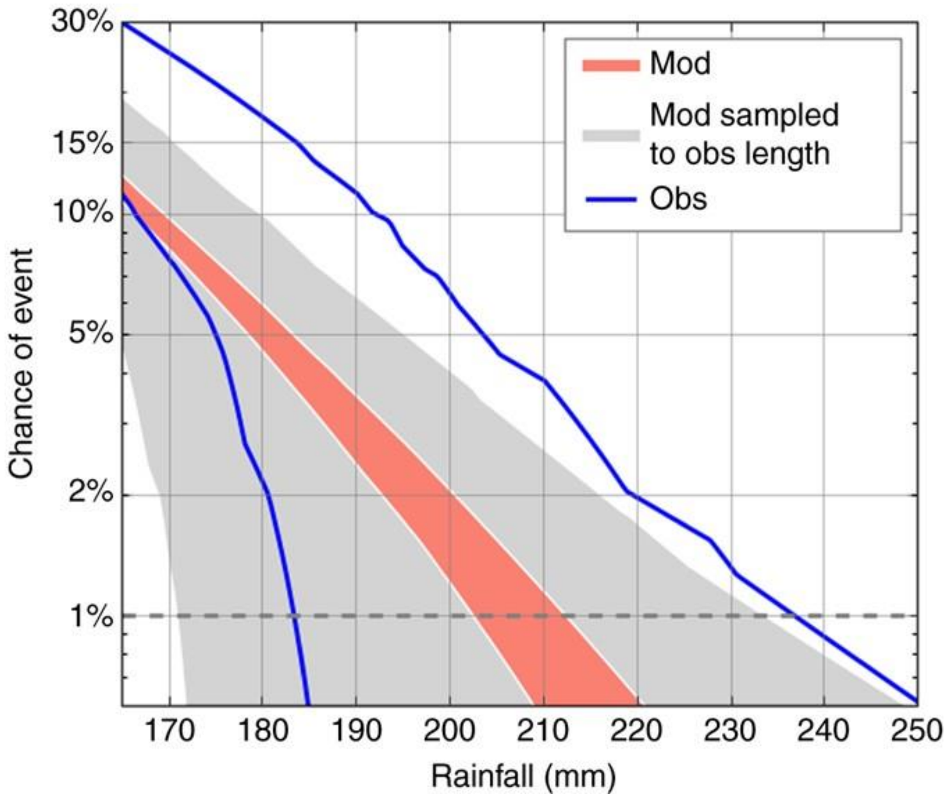
3

# Multi-model ensemble for future plausible and unprecedented rainfall extremes

*How to sistematically characterize future rare and high-impact weather events?*

→ **UNSEEN** approach (Thompson et al., 2017)
(**UN**precedented **S**imulated **E**xtremes using **EN**sembles)

- UNSEEN uses high-resolution large-ensemble forecasts to compute robust statistics for rare events which is challenging to compute from historical records
- With UNSEEN it could be possible to identify plausible – yet unseen – extreme events and to stress-test adaptation measures with maximum credible events




(Thompson et al., 2017)

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

**ALMACARES - SINTESI**
SInossi di eveNTi Estremi coStieri per l'adattamento climatIco in Emilia-Romagna

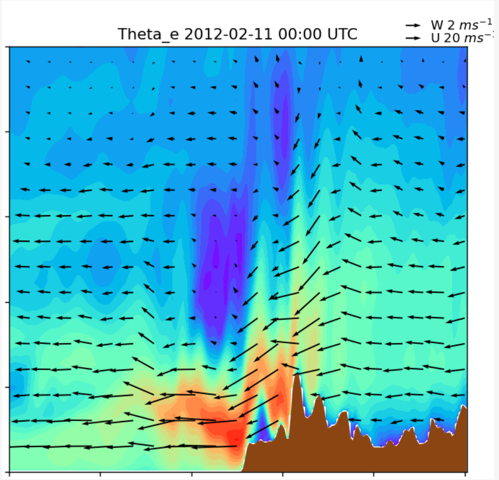
# Conclusions

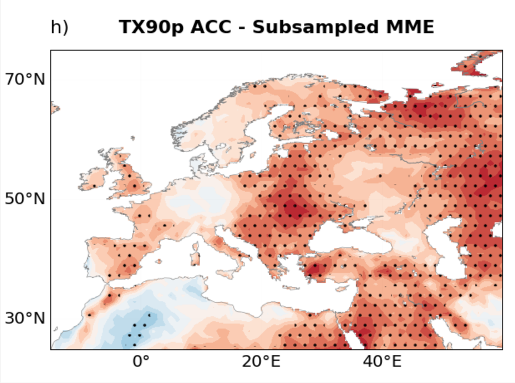
Weather and climate extremes are **high-impact** phenomena that require a **multi-scale** approach for their comprehensive understanding, especially in a warming climate.

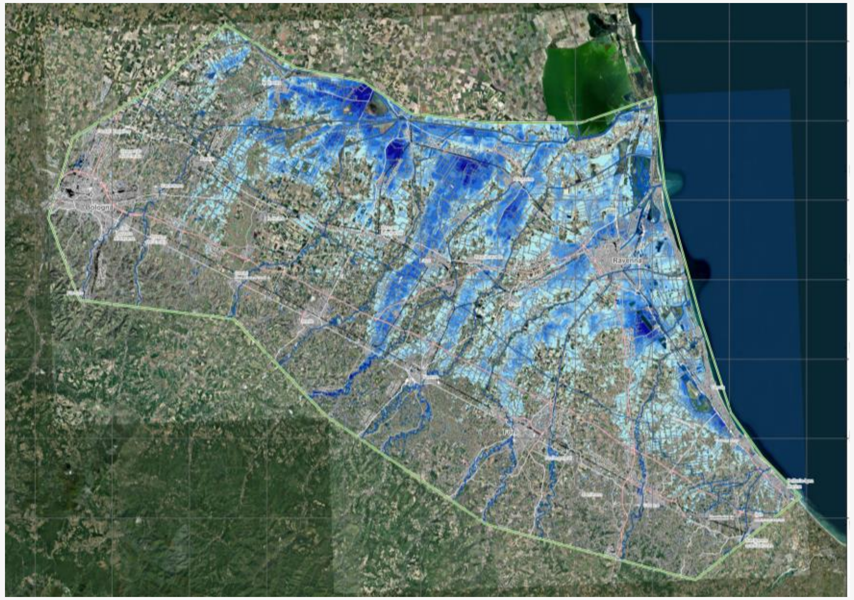
- High-resolution simulations pointed out **that extreme weather events are generated by physical processes not yet completely understood** considering the large range of time scales involved. Still models suffer from **missing an accurate representation of the near surface processes**. For example the role of urban areas on exacerbating the onset of extremes still requires attention. We are still far from seamless simulations.

- Positive points are that **the integration of more physics combined with statistical techniques** will be able to obtain some indication of seasonal behaviour especially for the variable "temperature".

- Studying plausible and unprecedented extreme events through large multi-model ensembles (UNSEEN approach) can help to compute robust statistics about rare events, which is necessary for the development of effective **adaptation** measures.


Theta_e 2012-02-11 00:00 UTC
W 2 $ms^{-1}$
U 20 $ms^{-1}$


h)
TX90p ACC - Subsampled MME
70°N
50°N
30°N
0°
20°E
40°E



# Thank you!