Hydrological and hydraulic modelling for flood map estimation: a case study

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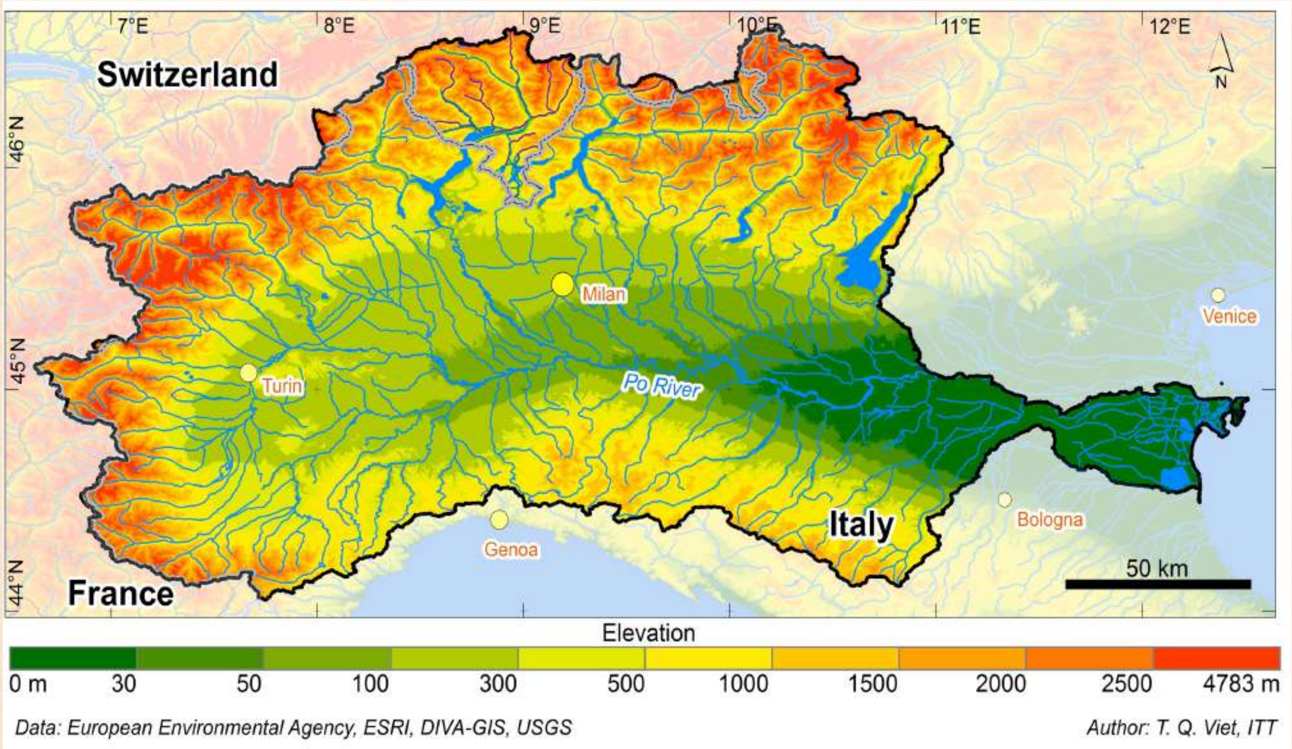
Application: The Po River



Purpose: to produce flood maps associated to different return periods.

- Example of concrete application to show a result that can be used by stakeholders;

- An integrated hydrological (CHyM) and hydraulic (CA2D) approach over the Po river basin (Italy);

- Production of flood hazard maps using observational and modeled data.

How do we model a flood?

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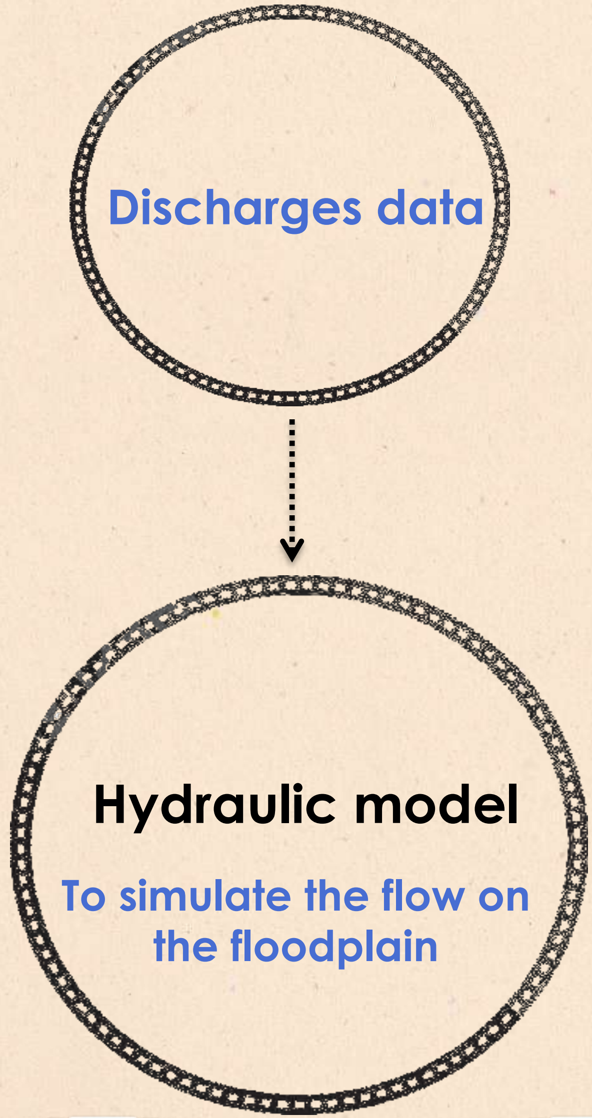

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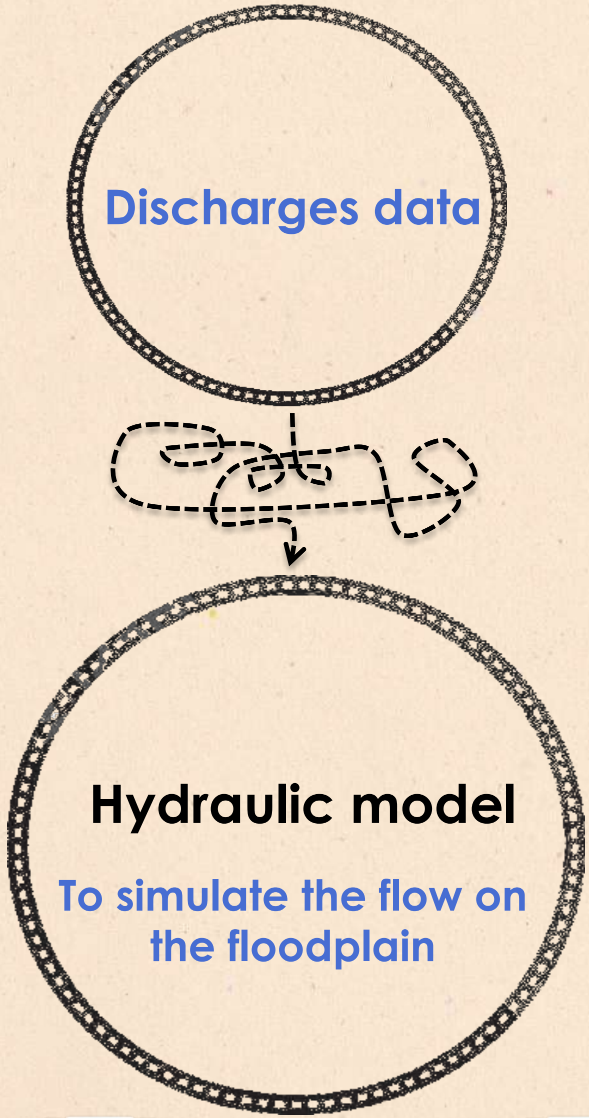
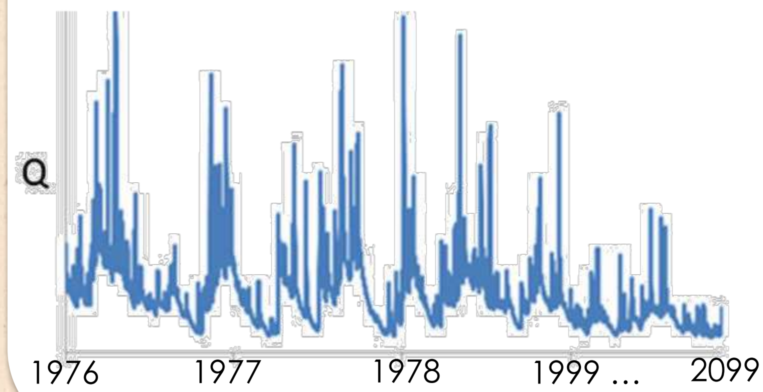


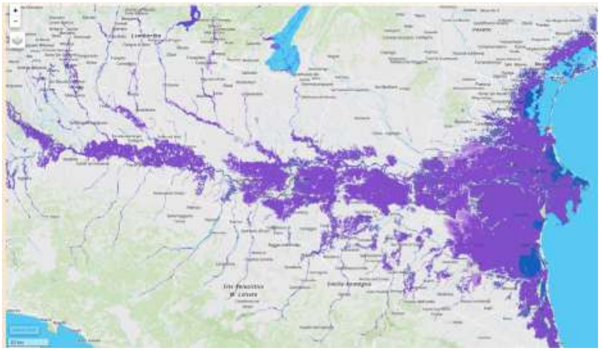
The method:

N-year discharge climatology



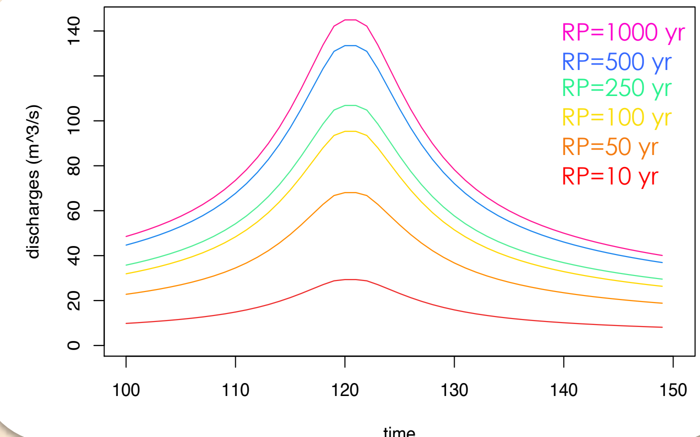
Statistical Flood Frequency analysis

Flood hazard maps



RP 250
RP 500

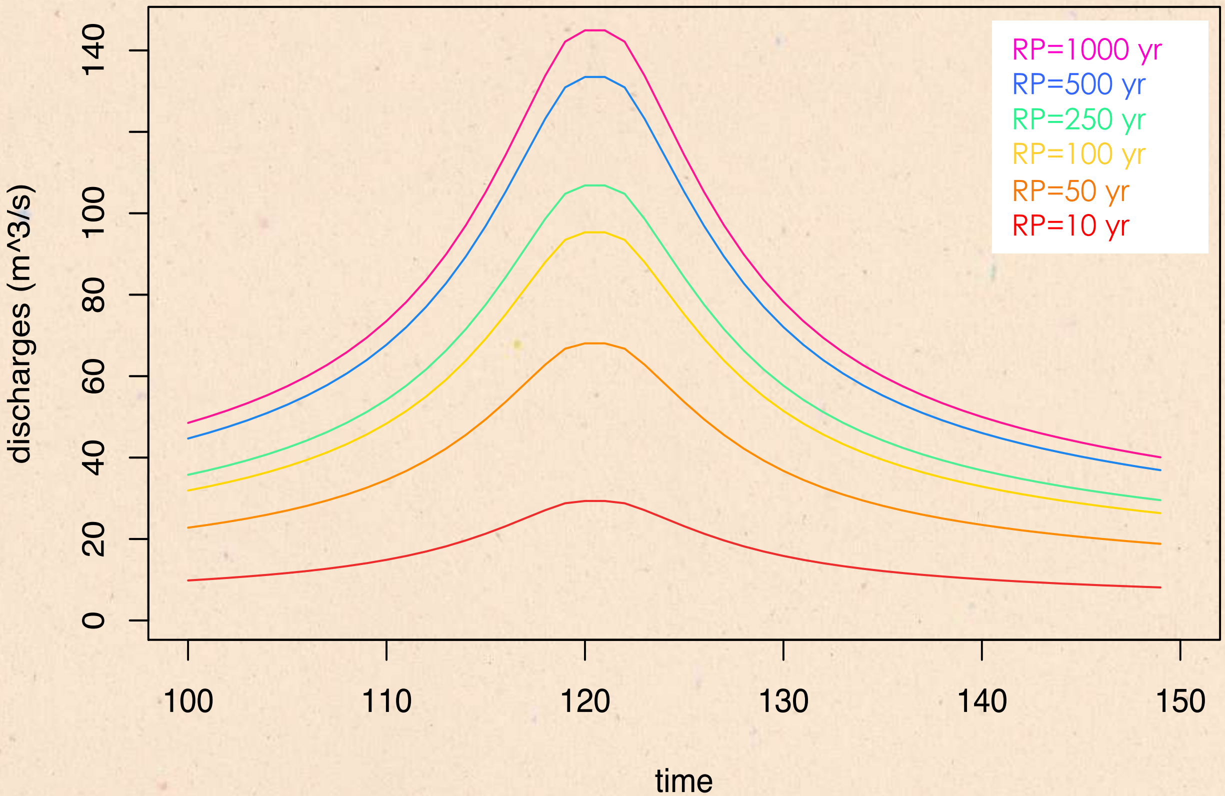
CA2D
hydraulic model
(Dottori et al., 2011)



Synthetic Design Hydrograph (SDH)
(Maione et al., 2003; Beirlant et al. 2004; Alfieri et al. 2015; ...)

What was the Return Period again?

It expresses the probability that events such as **floods** will occur. Defined as **the inverse of probability** and gives the **estimated time interval between events** of a similar size or intensity.

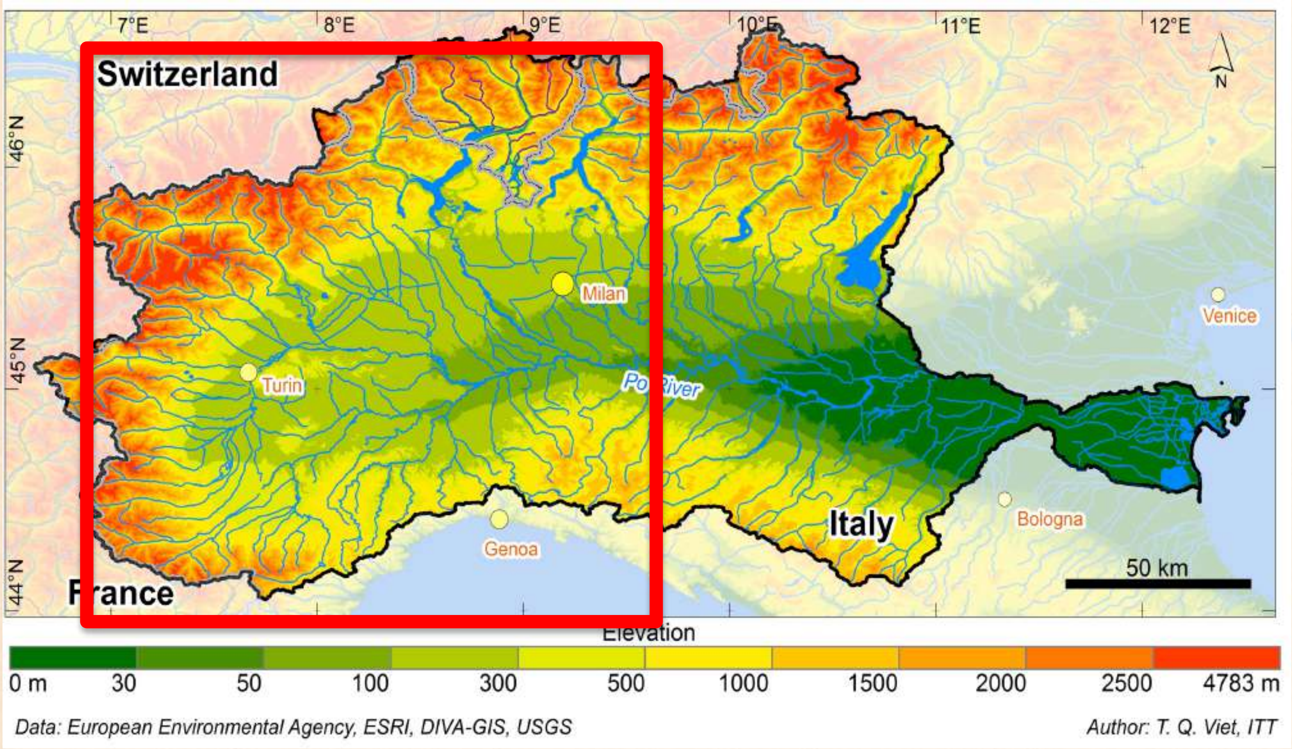


For example

The return period of a flood of **100 years**

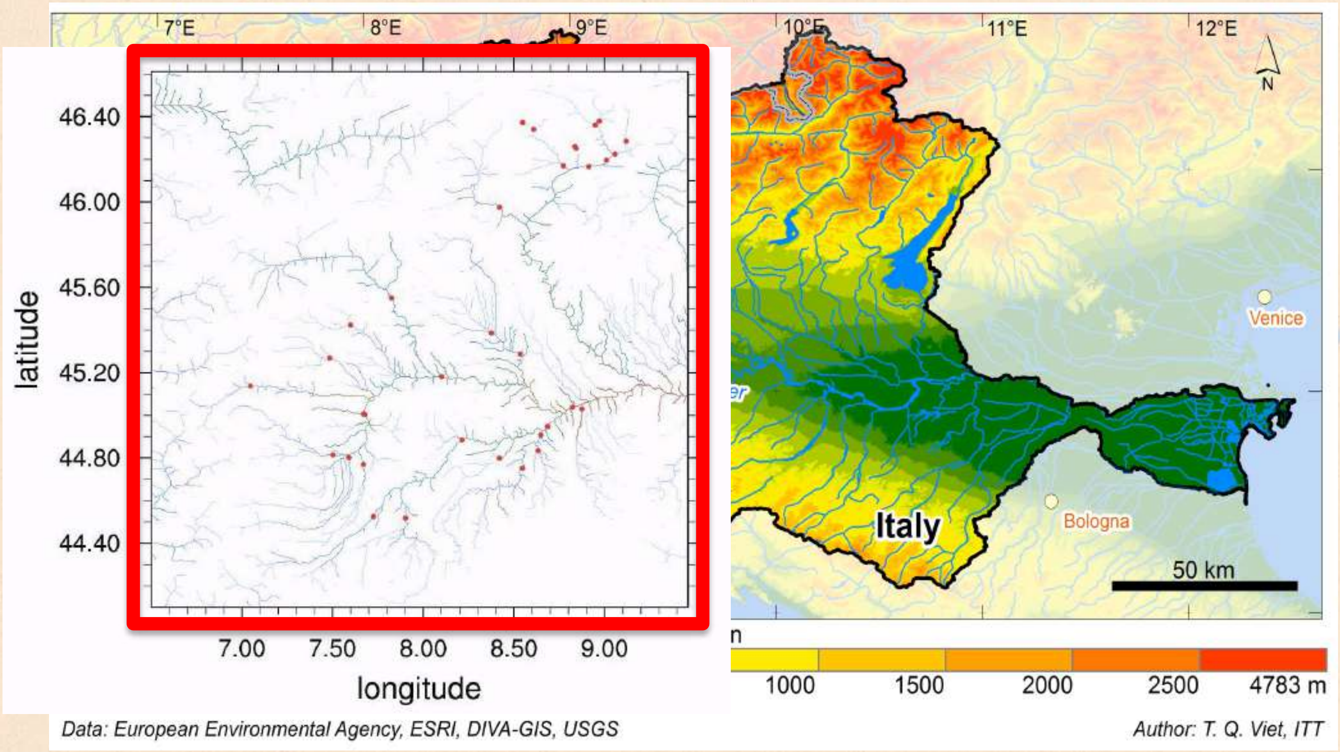
corresponds to **the probability of occurrence** of the event **equal to 1/100**, or 1% in any one year.

Application: The Po River



Purpose: to produce flood maps associated to different return periods.

Application: The Po River



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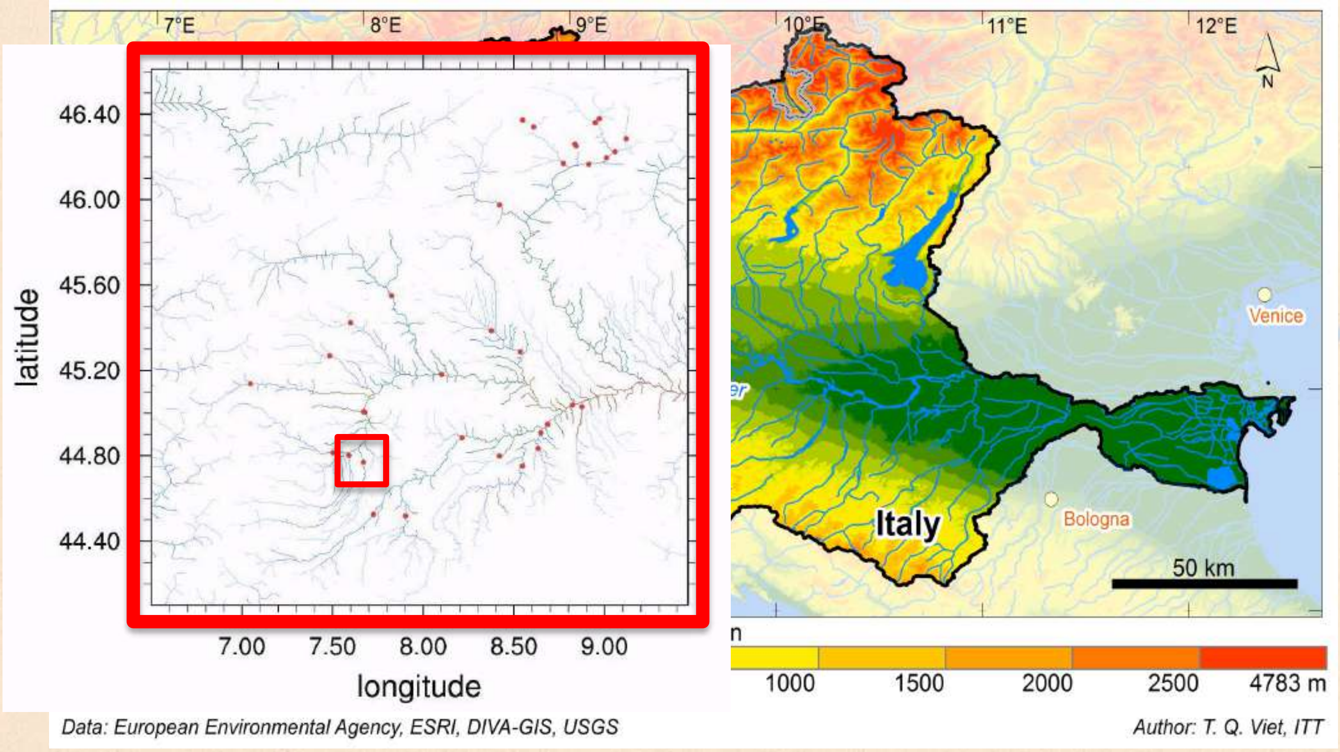
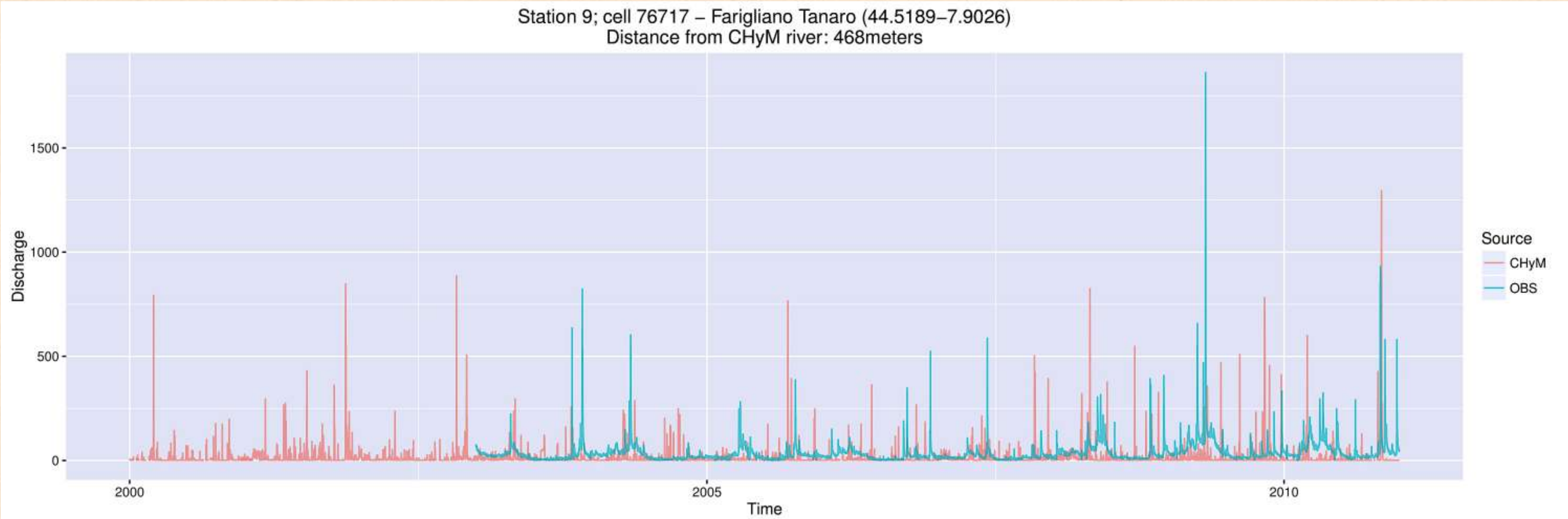
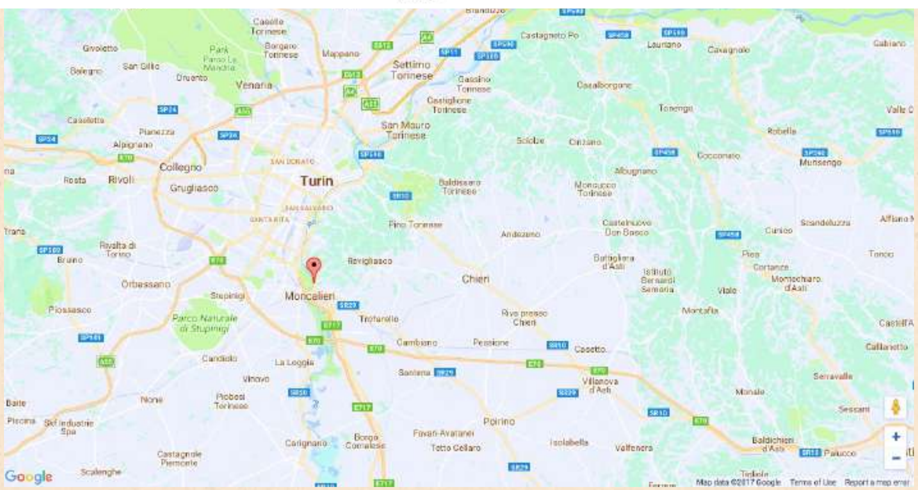


Purpose: to produce flood maps associated to different return periods.

Example: Moncalieri



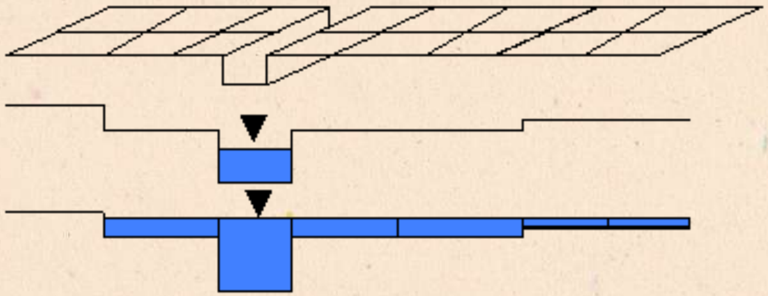


Hydraulic modelling over floodplains

- In order to simulate the flow on the floodplain we need an **hydraulic model**
- Flow is controlled by topography and friction
- Flow leads to complex spatial patterns of water depths

CA2D

Dottori, Francesco, and Ezio Todini. "Developments of a flood inundation model based on the cellular automata approach: testing different methods to improve model performance." *Physics and Chemistry of the Earth, Parts A/B/C* 36.7-8 (2011): 266-280.



Assumes that the flow between two cells is simply a function of the **free surface height difference** between those cells, the grid scale Manning's **friction coefficient** for the floodplain and **local water acceleration**.

Parallelized version (NEW!)

Inputs:

- **Synthetic Design Hydrographs (SDH)**
- **Digital Elevation Model**

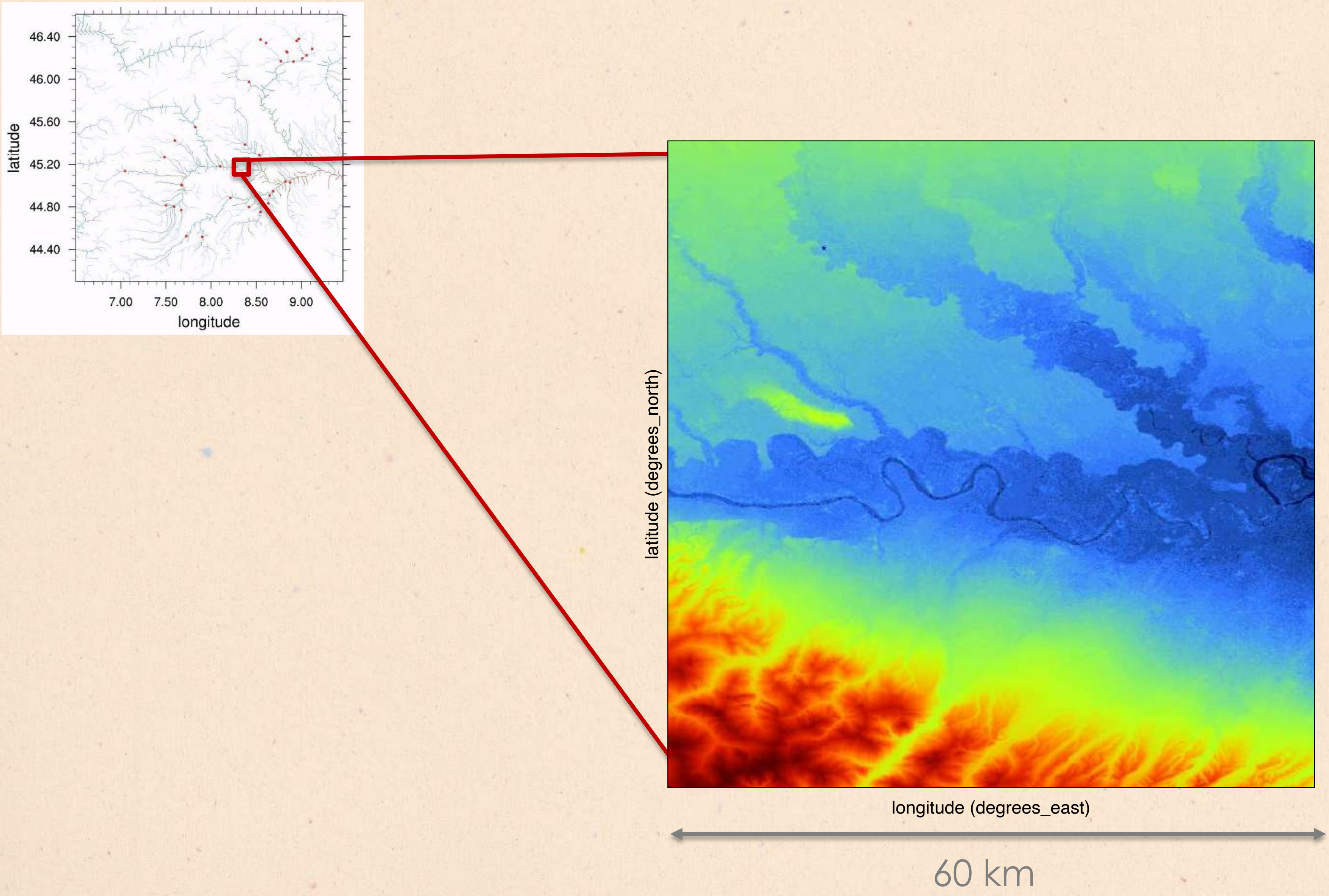
Digital Elevation Model

HydroSHEDS4 dataset
(Lehner et al., 2013; Lehner et al., 2008)

Based on NASA's **3 arc-second** (~90m) SRTM satellite-based elevation dataset

Particularly suited to the creation of a reliable **river network for the CHyM model** resulting in higher accuracy

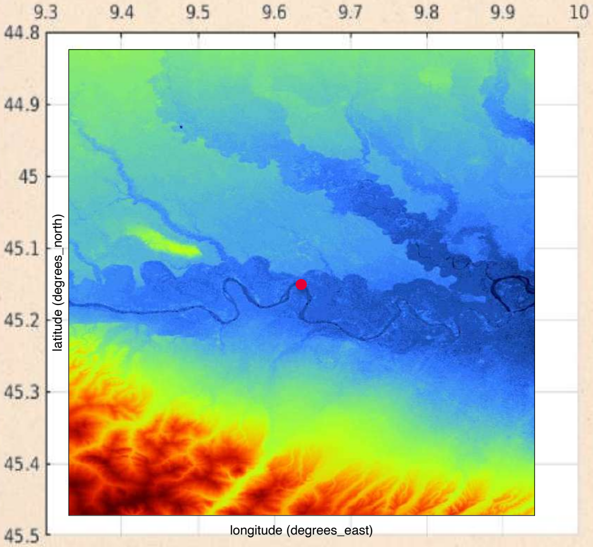
Extend the flood mapping procedure to **any area of the world**



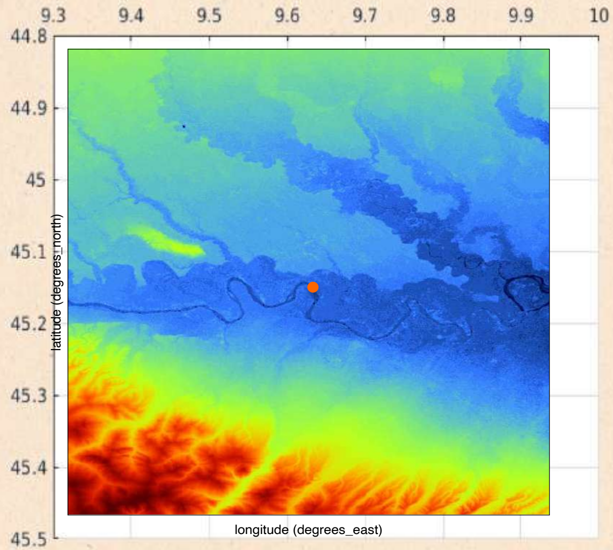
46.40
46.00
45.60
45.20
44.80
44.40
latitude
7.00
7.50
8.00
8.50
9.00
longitude
latitude (degrees_north)
longitude (degrees_east)
60 km

Is it so “easy”?

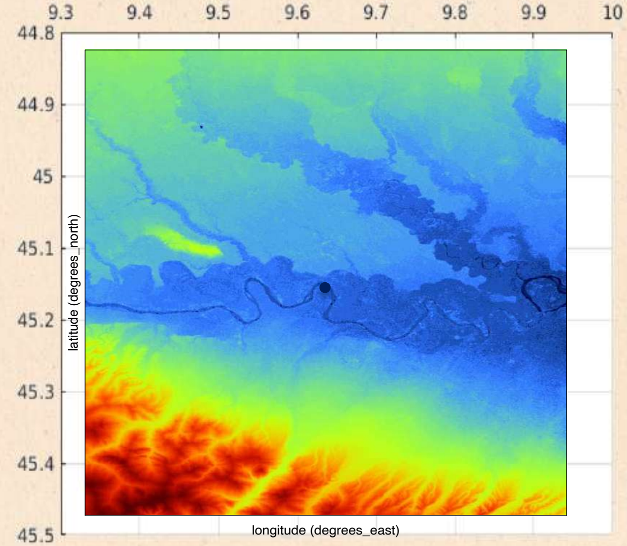
RP=1.5 years

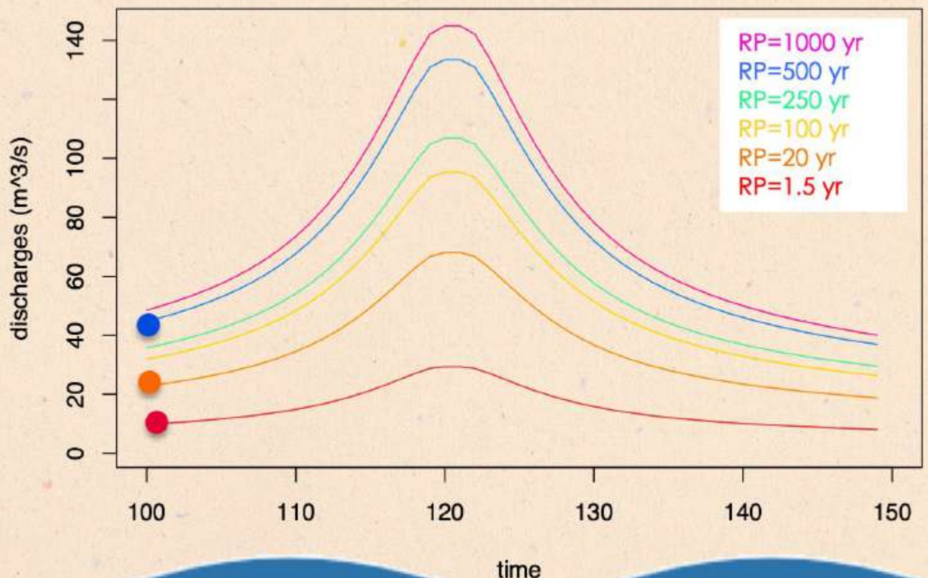


RP=20 years

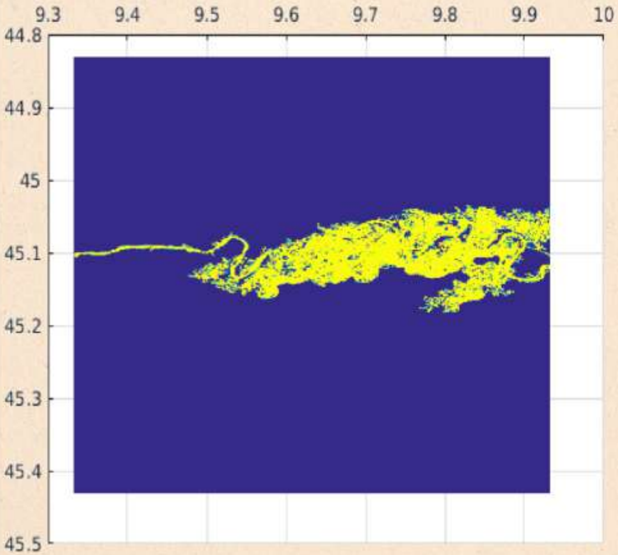


RP=500 years

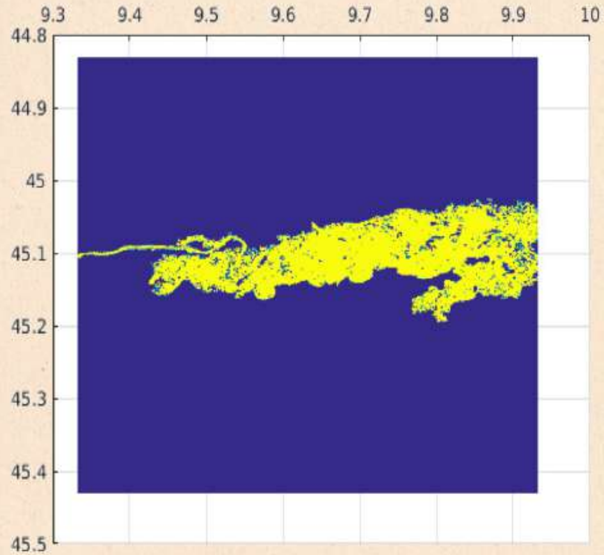




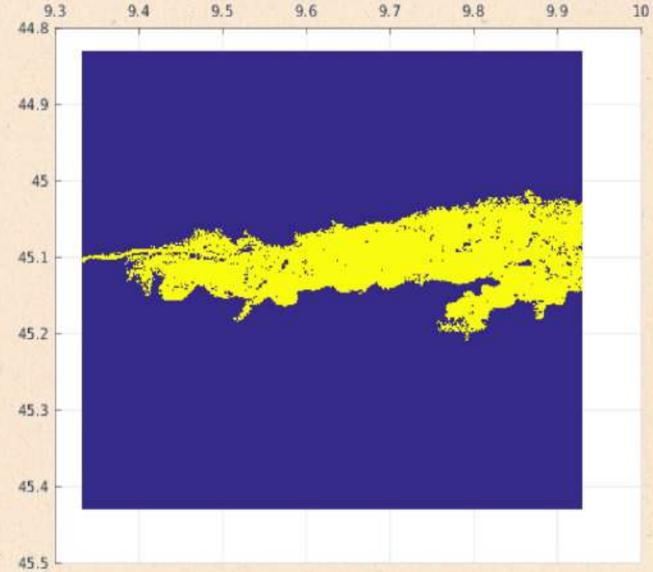
RP=1.5 years

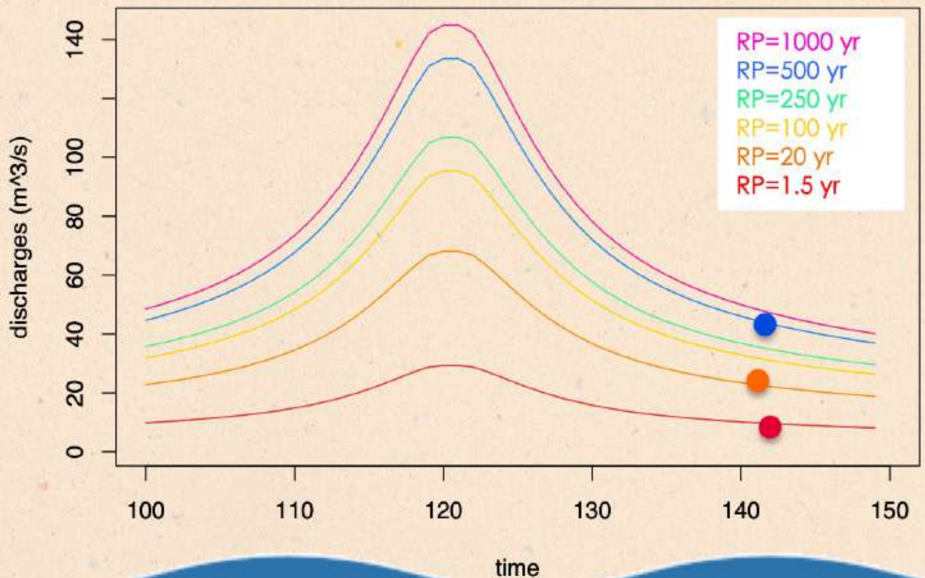


RP=20 years



RP=500 years





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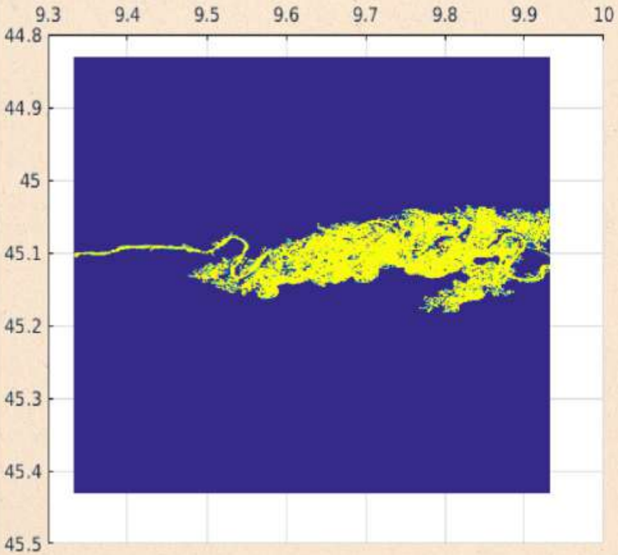
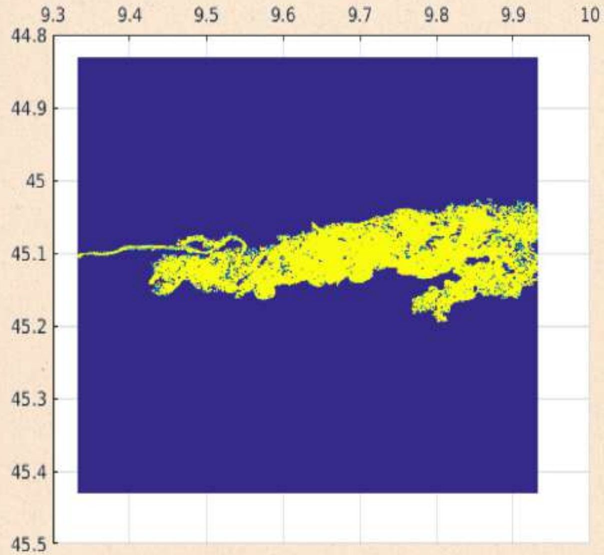
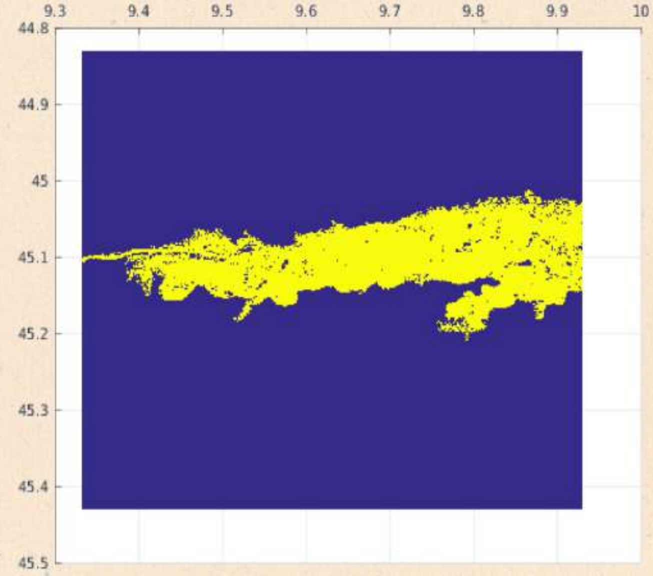
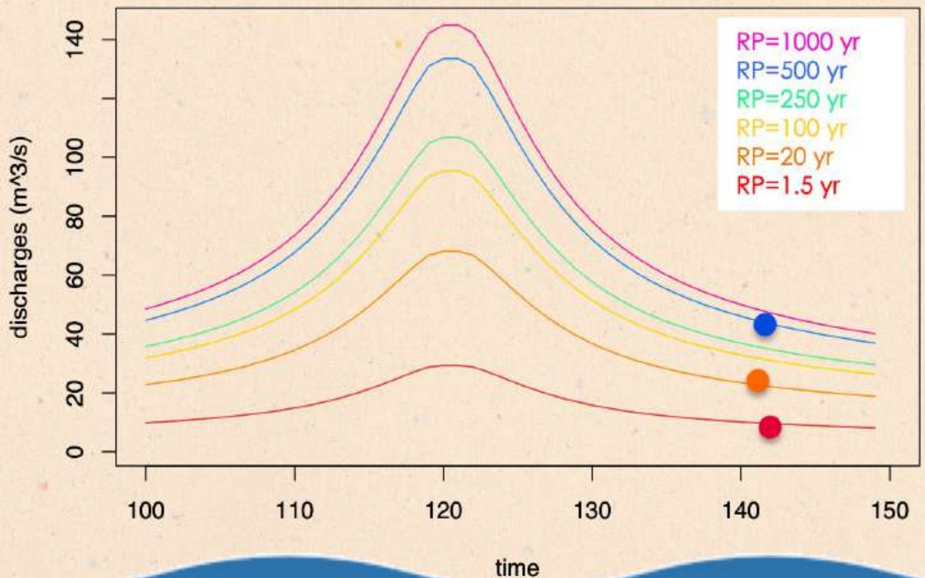


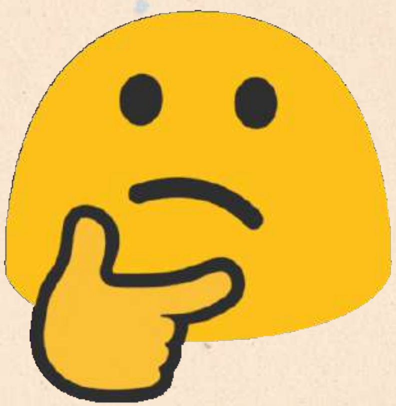
RP=20 years



RP=500 years







DEMs usually **do not contain** information about the **dams** and **river banks**.

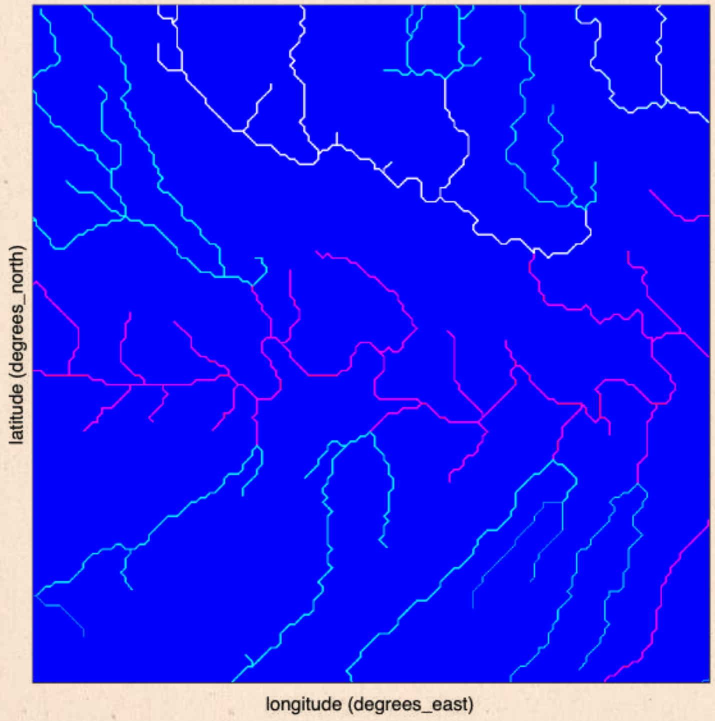
A solution is to *adapt* the DEM to the chosen domain.

How?

Using the **bankfull discharge** (RP=1.5 years) as a reference

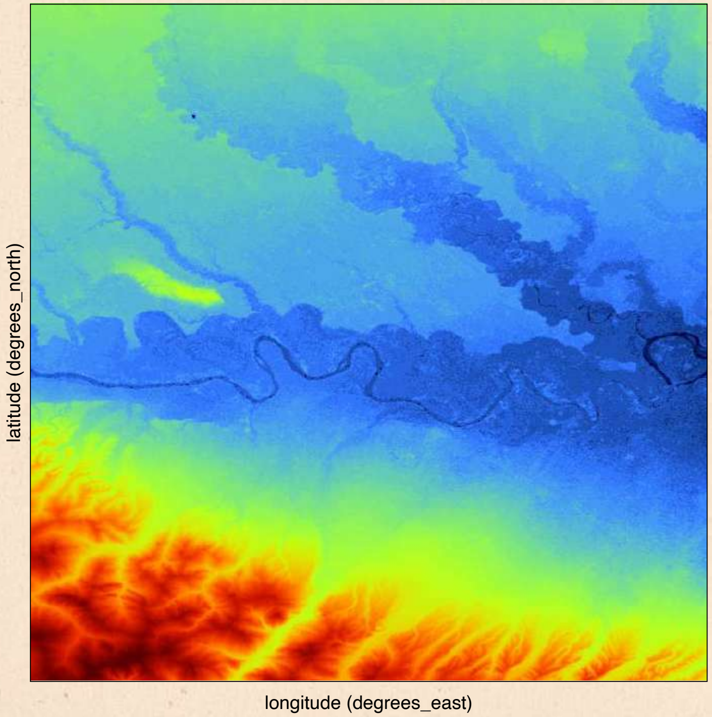
Digital Elevation Model

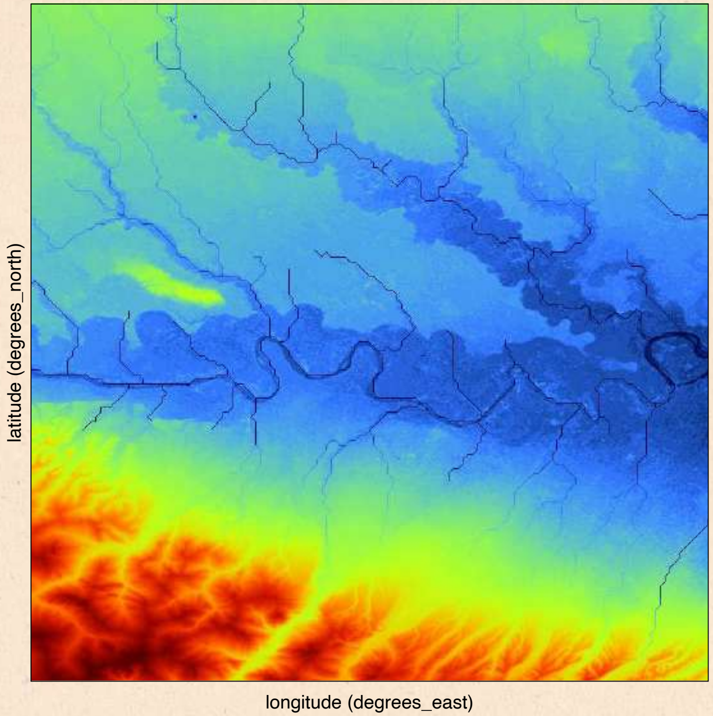
Available river widths and depths derived using HydroSHEDS DEM dataset (K. Andreadis et al 2013)



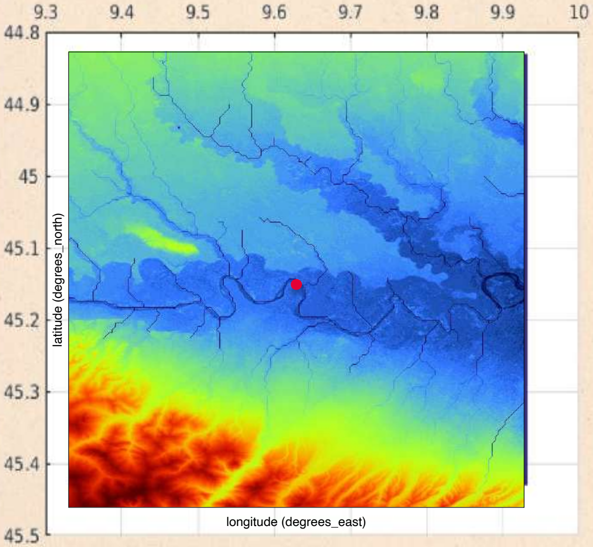
Digital Elevation Model

The idea is to “dig” the DEM until we are sure that the bankfull discharge (RP=1.5 years) is contained by the riverbed.

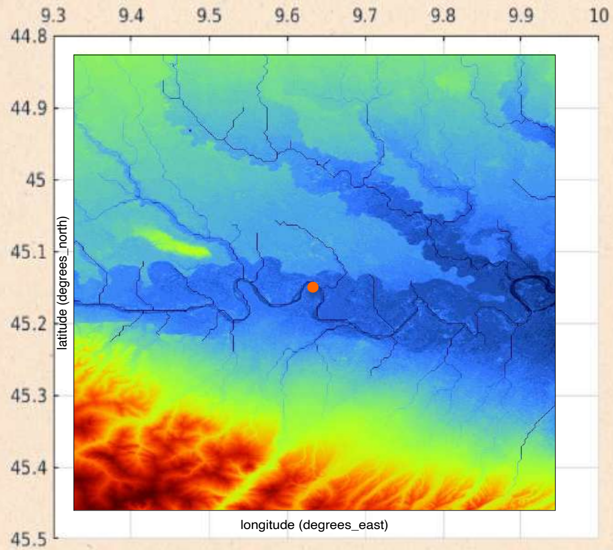




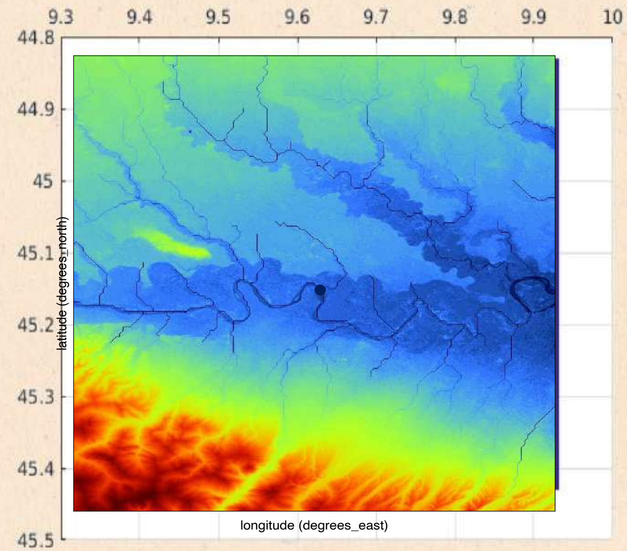
RP=1.5 years

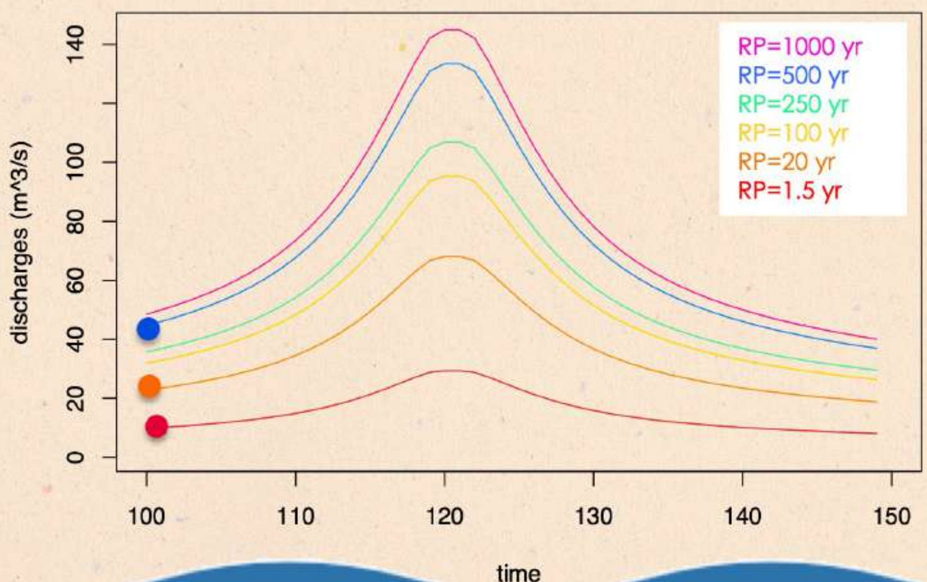


RP=20 years



RP=500 years





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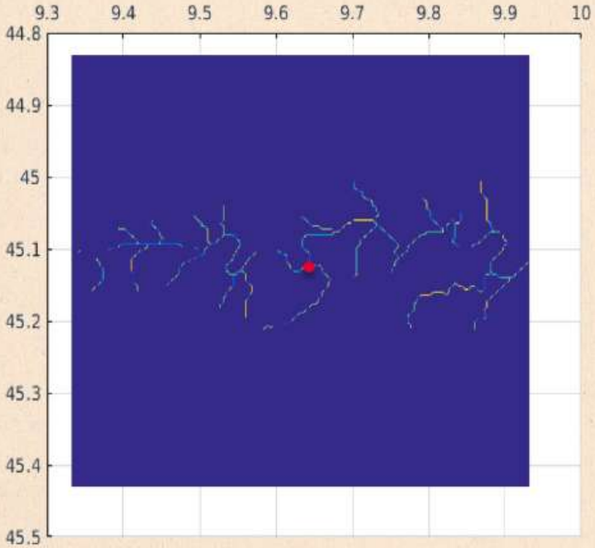

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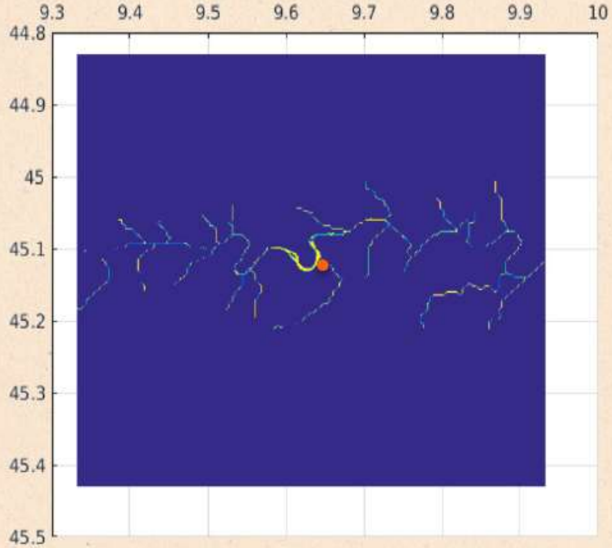

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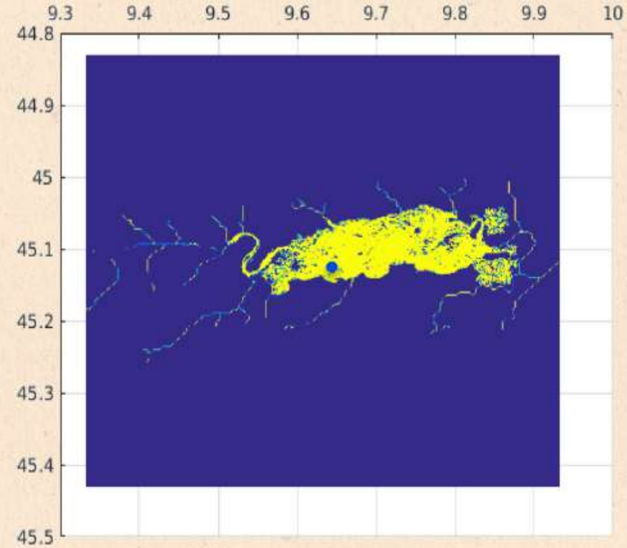
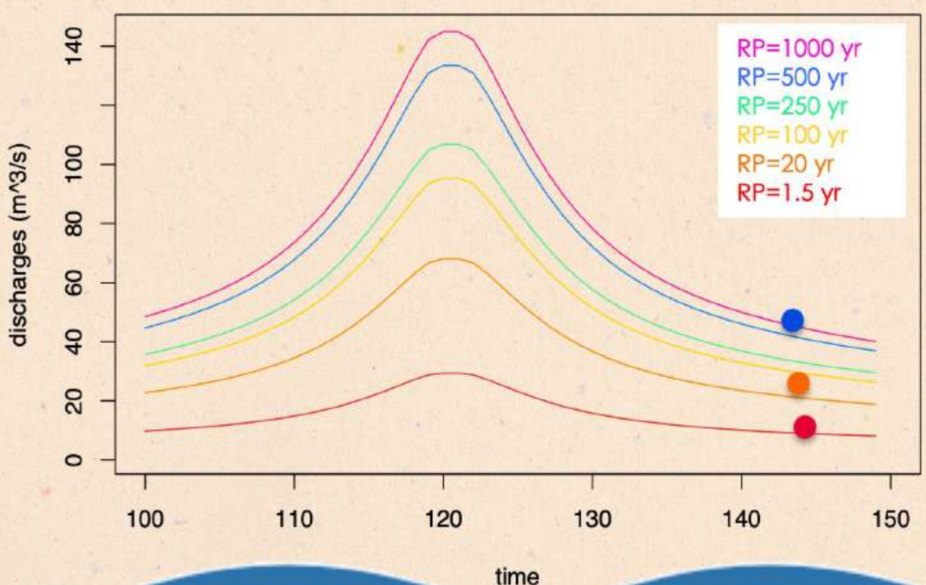
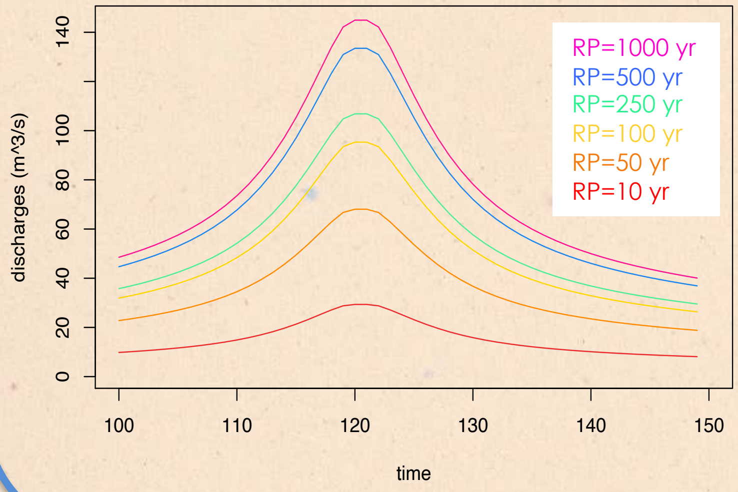
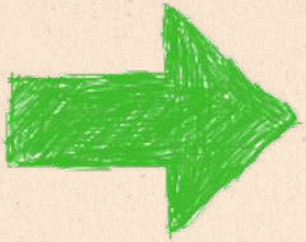




Synthetic Design Hydrograph





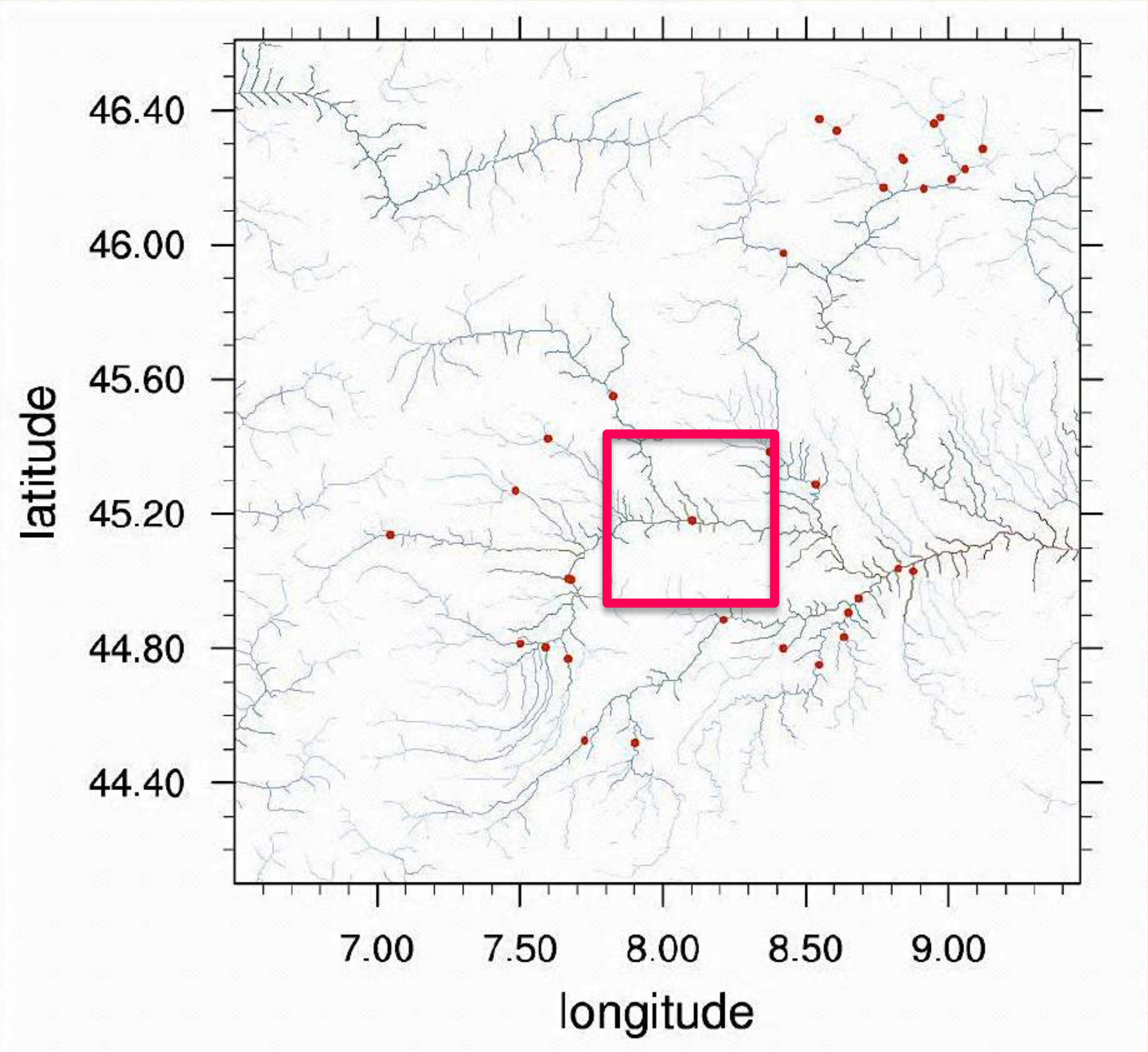
CA2D

HydroSHEDS vf DEM 90 m

B. Lehner et al (2008)

River depths

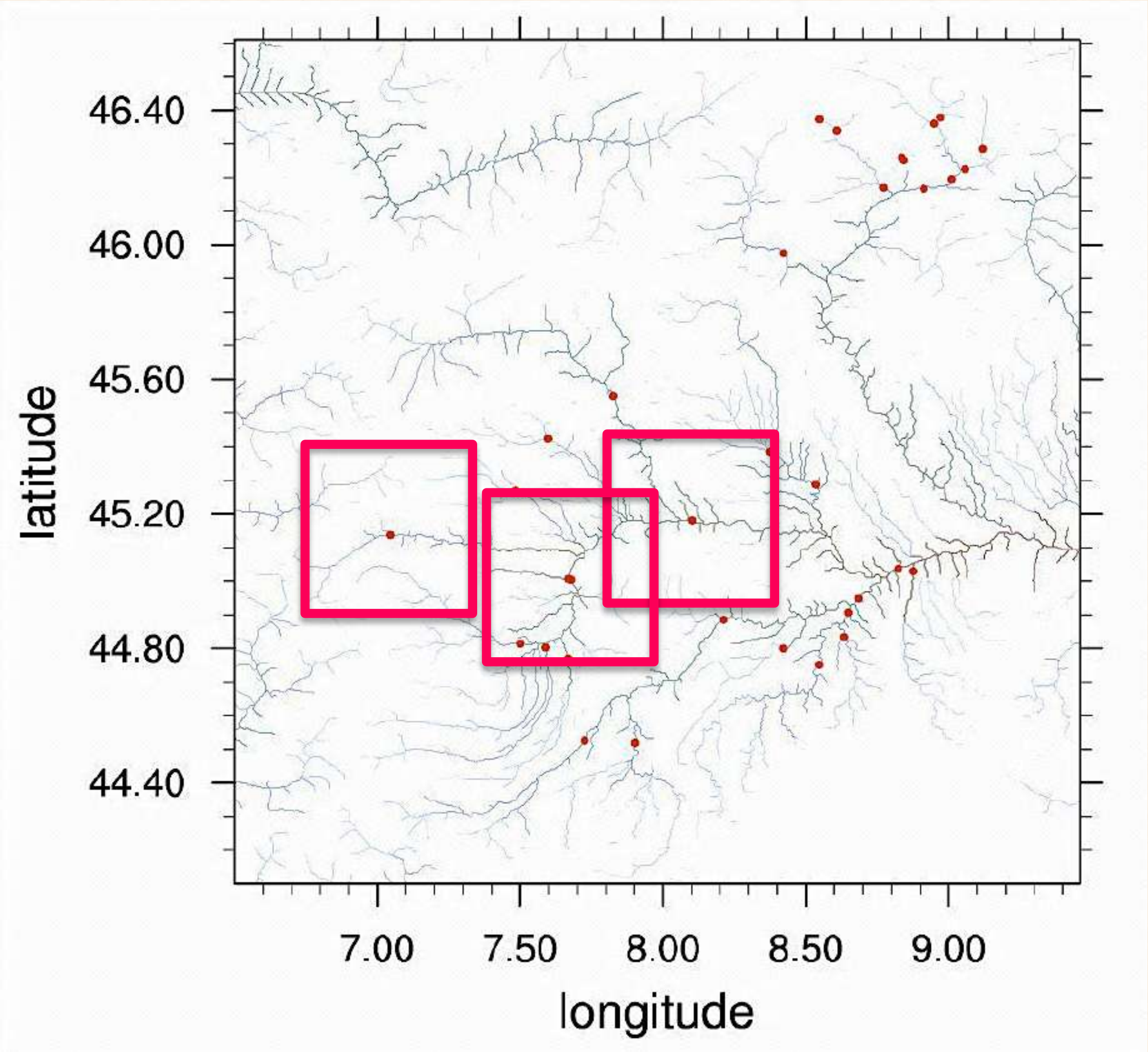
K. Andreadis et al (2013)



DEM ~90 m

34 stations of observed discharges data

34 simulations using CA2D



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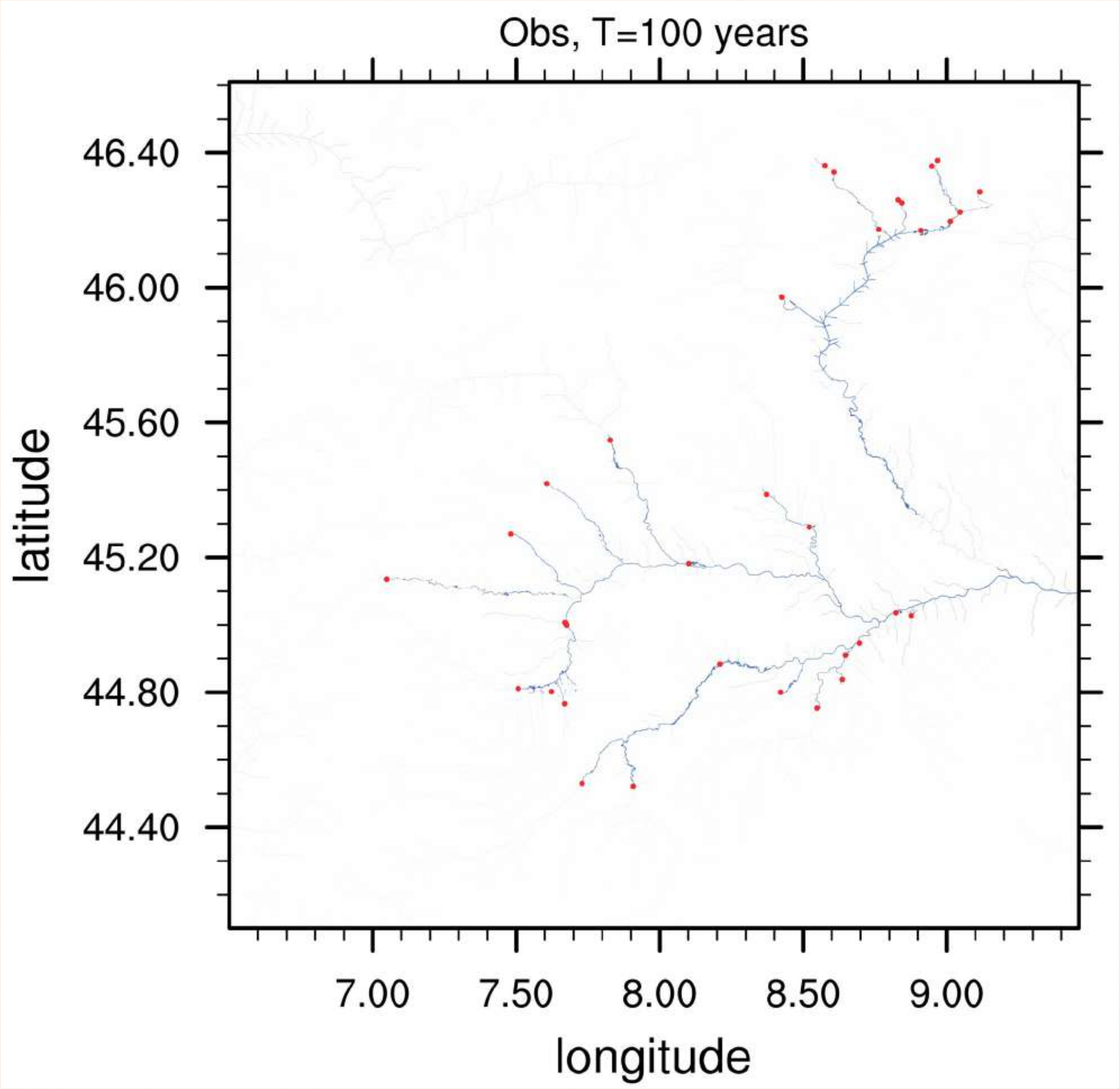
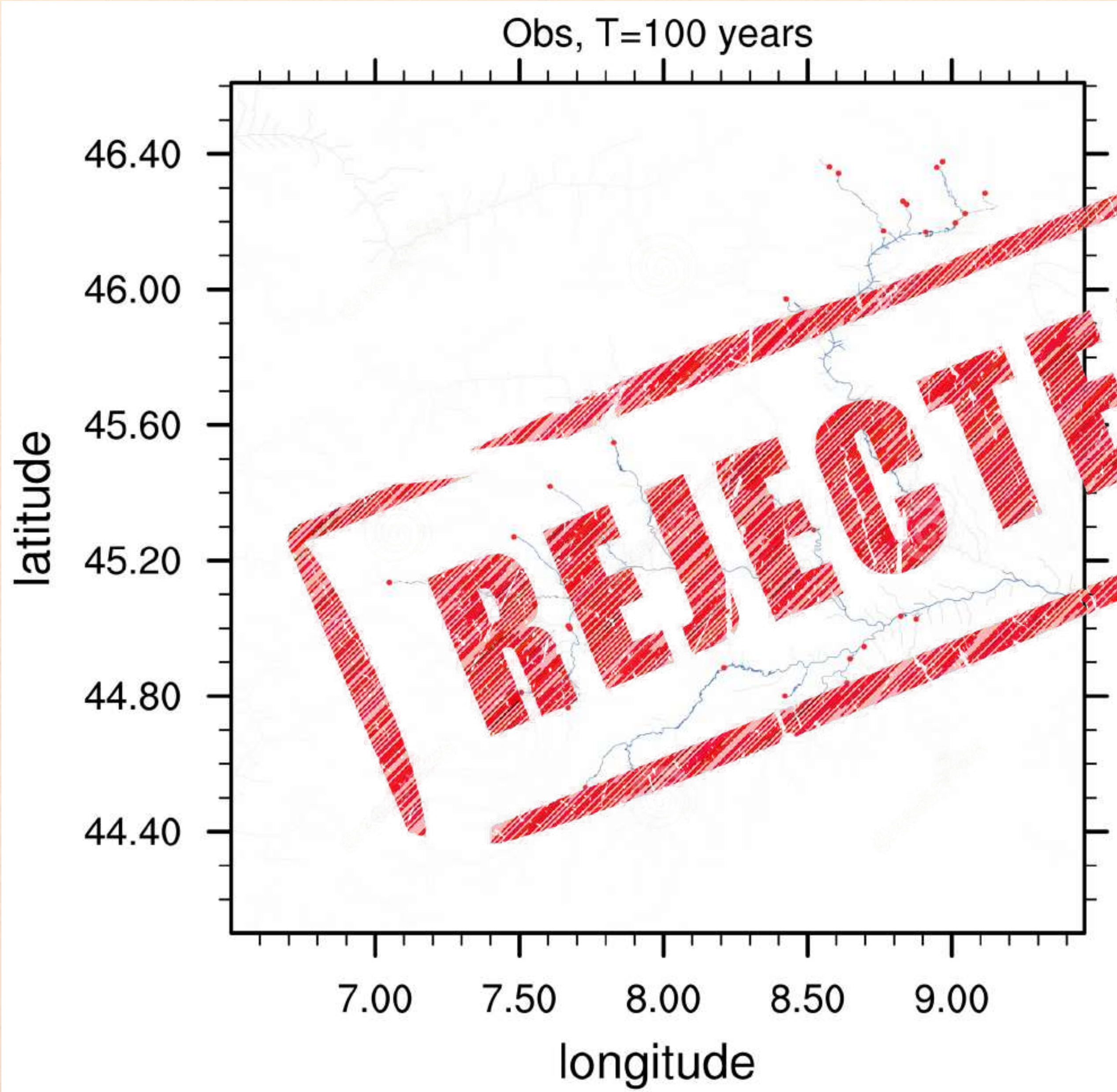


The network of the observational stations is not dense enough to simulate the river flow.

Observations are not sufficient to produce the flood maps.



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The method:

Precipitation data:

-observations

-climate modeling

Hydrological model CHyM

(Coppola et al 2003)

To estimate river discharges

Hydraulic model CA2D

(Dottori et al 2011)

To simulate the flow on the floodplain

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(A. Fantini 2019)

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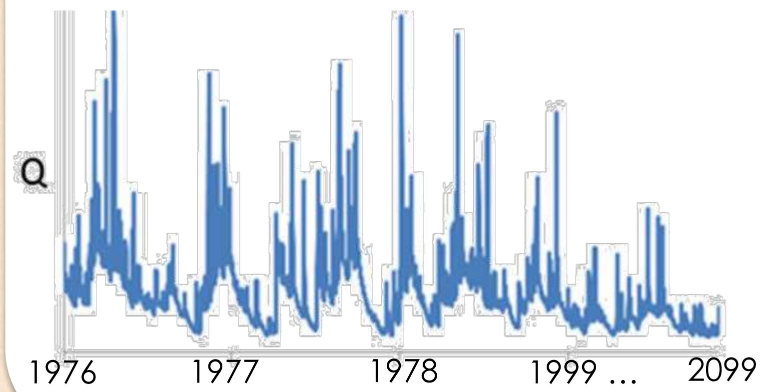
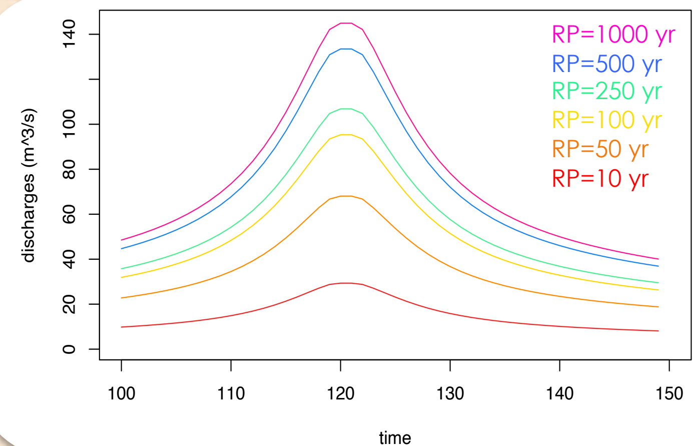


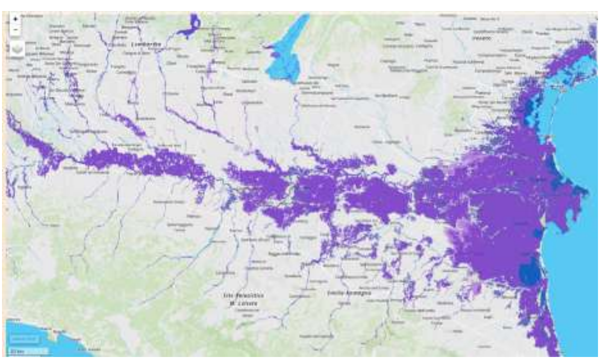
Statistical Flood Frequency analysis



Synthetic Design Hydrograph (SDH)
(Maione et al., 2003; Beirlant et al. 2004; Alfieri et al. 2015; ...)

CA2D hydraulic model
(Dottori et al., 2011)

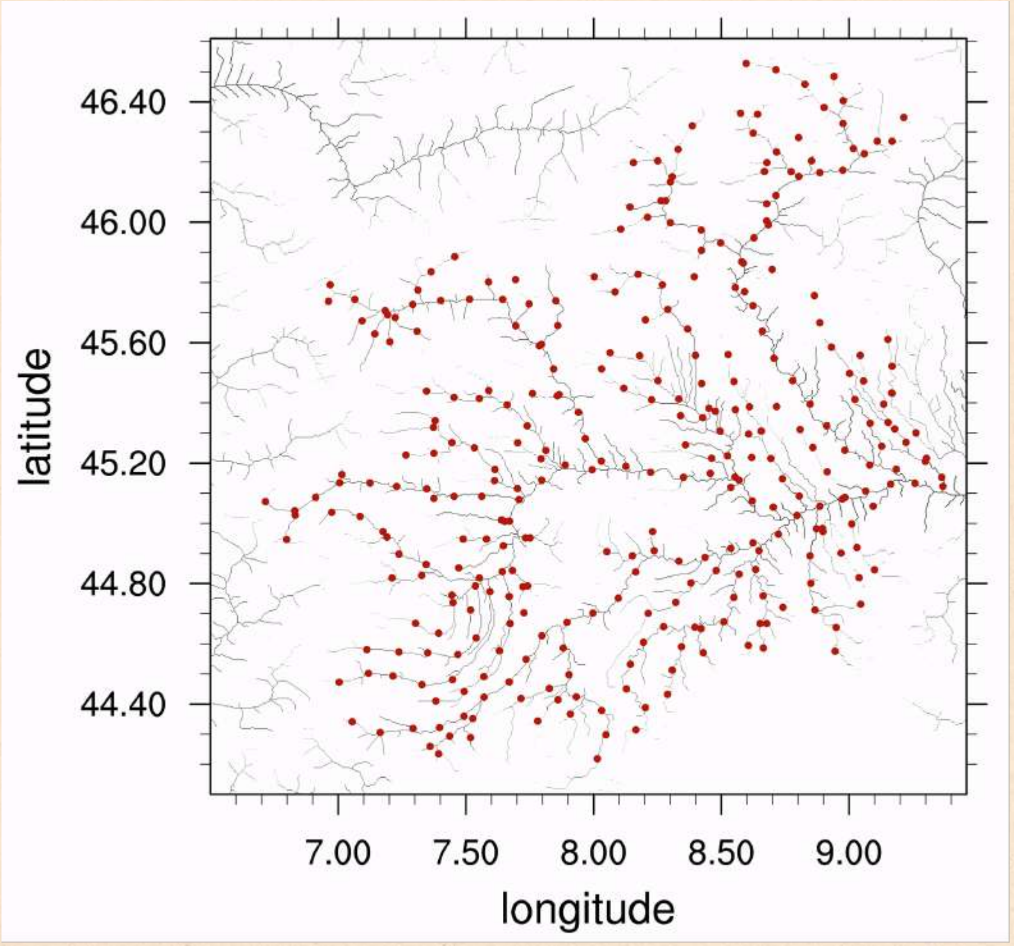
Flood hazard maps



RP=250
RP=500

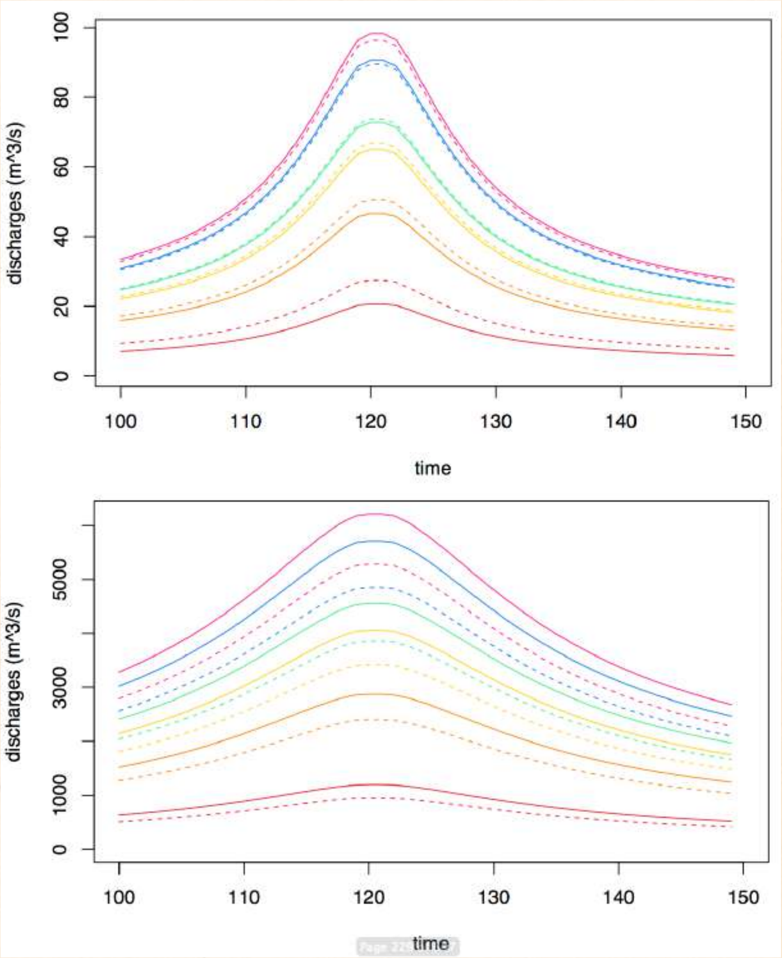
(R. Nogherotto et al 2022)

CHyM: the “virtual” stations



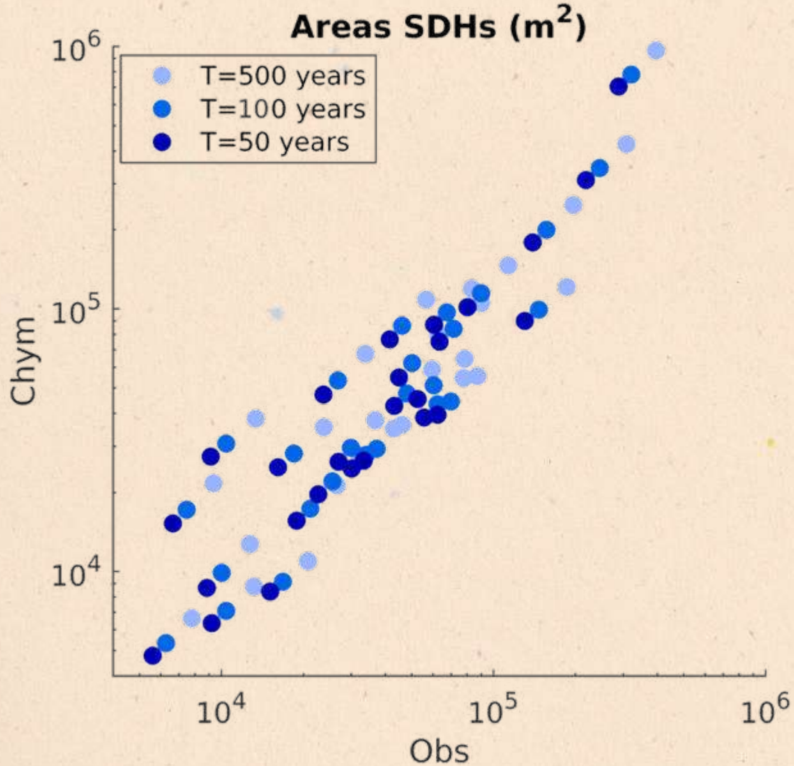
We have created a new set of virtual stations (one every 10 km) along the river network and run CA2D for each station with data from the hydrological model CHyM.

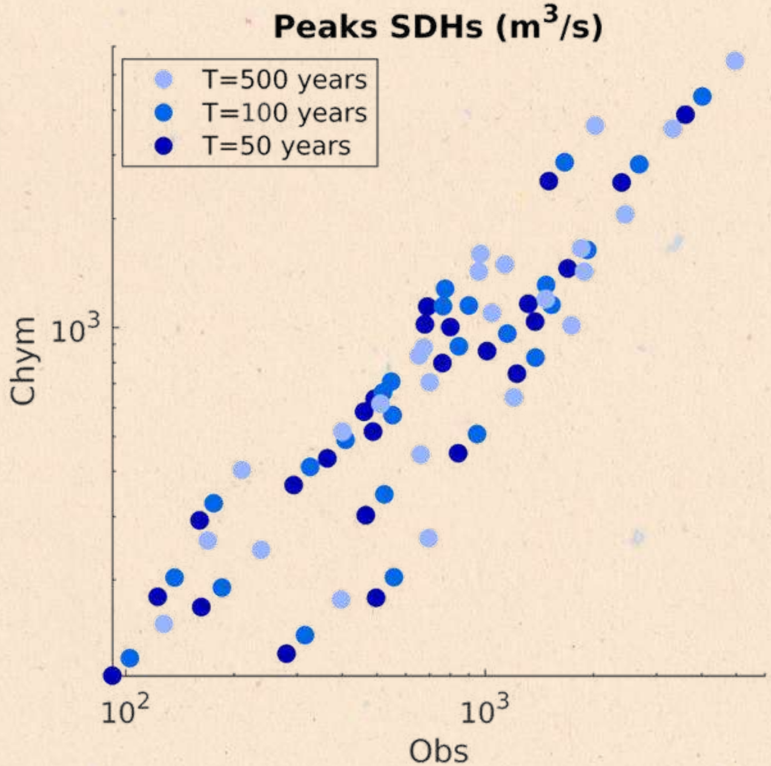
Example: observations vs model



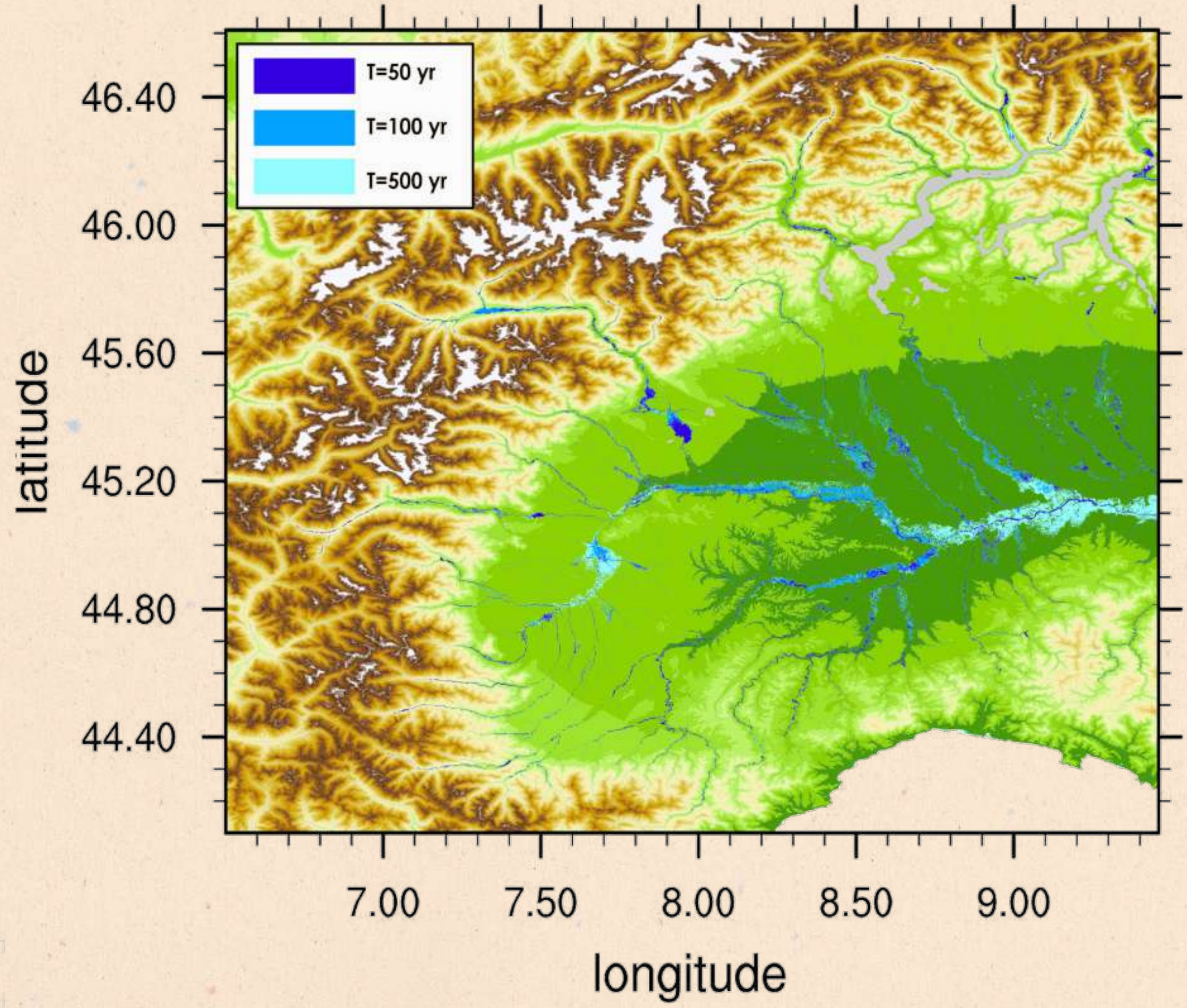
Observation
Model

Observations vs model





Map over the western Po



Maps validation

Comparison with observation

Maps validation

Comparison with observation.

Observation:

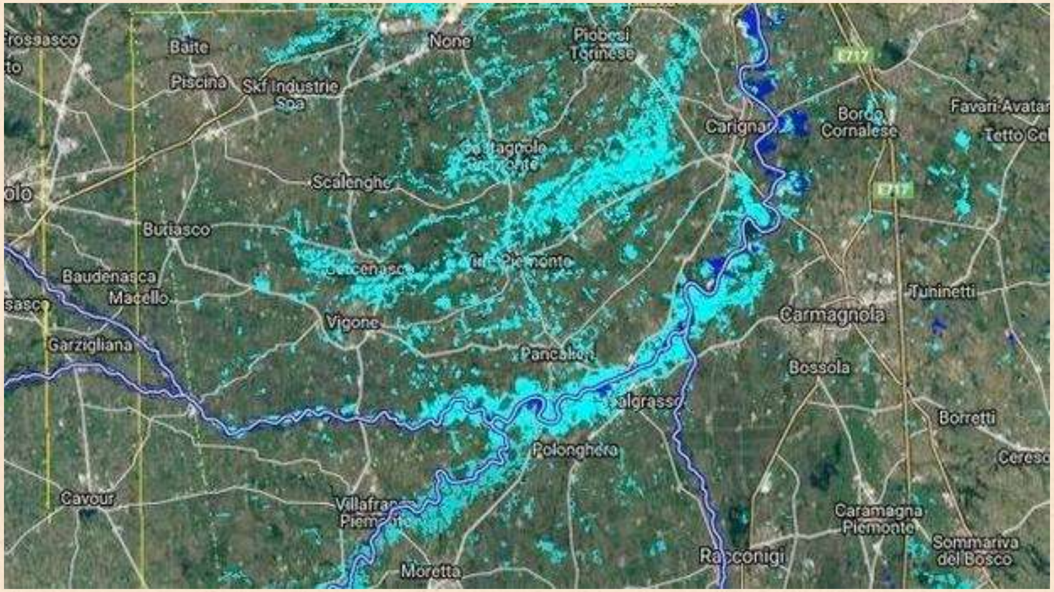
Maps validation

- Case studies

- Comparison with other available maps

Case study: Flood in November 2016

Observed flood from CosmoSkyMed satellite



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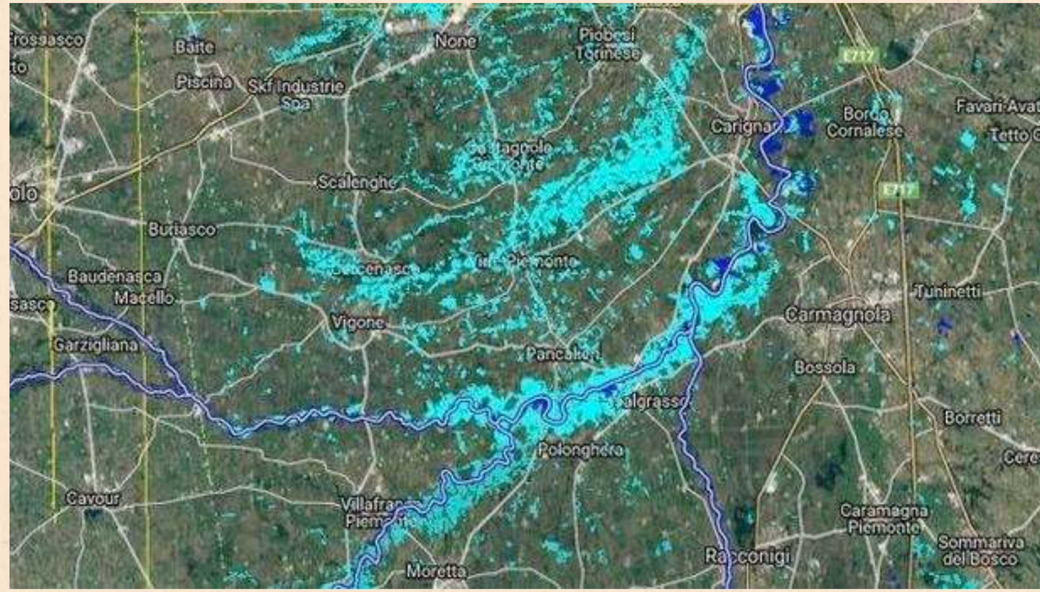
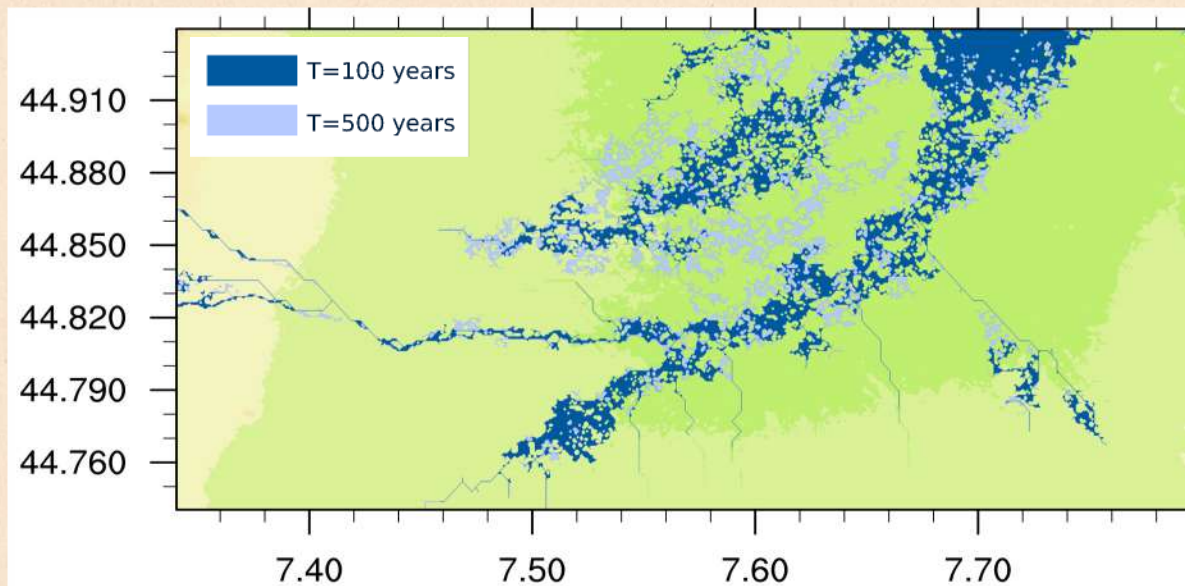


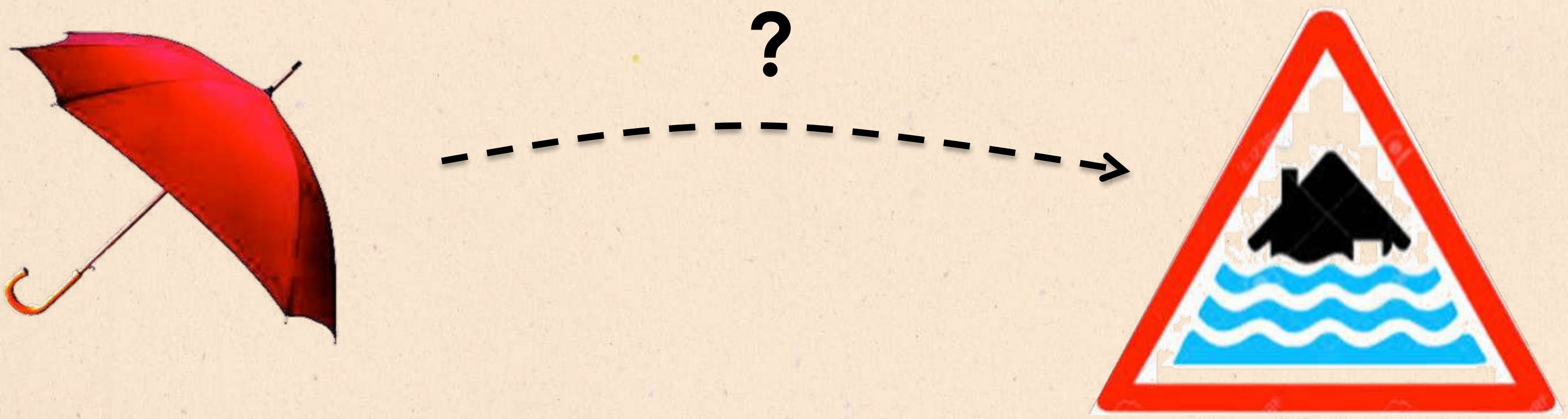
Modeled flood



(R. Nogherotto et al 2022)

And we can do more!

How do the projected changes in **precipitation and river discharges** affect the distribution of **floods**?



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To simulate the flow on the floodplain

Two RegCM 4.6.1 12km EURO-CORDEX simulations run (A. Fantini 2019):

HadGEM driven **1979-2016** **historical simulation**

HadGEM driven **1971-2099** **scenario simulation** (RCP8.5)

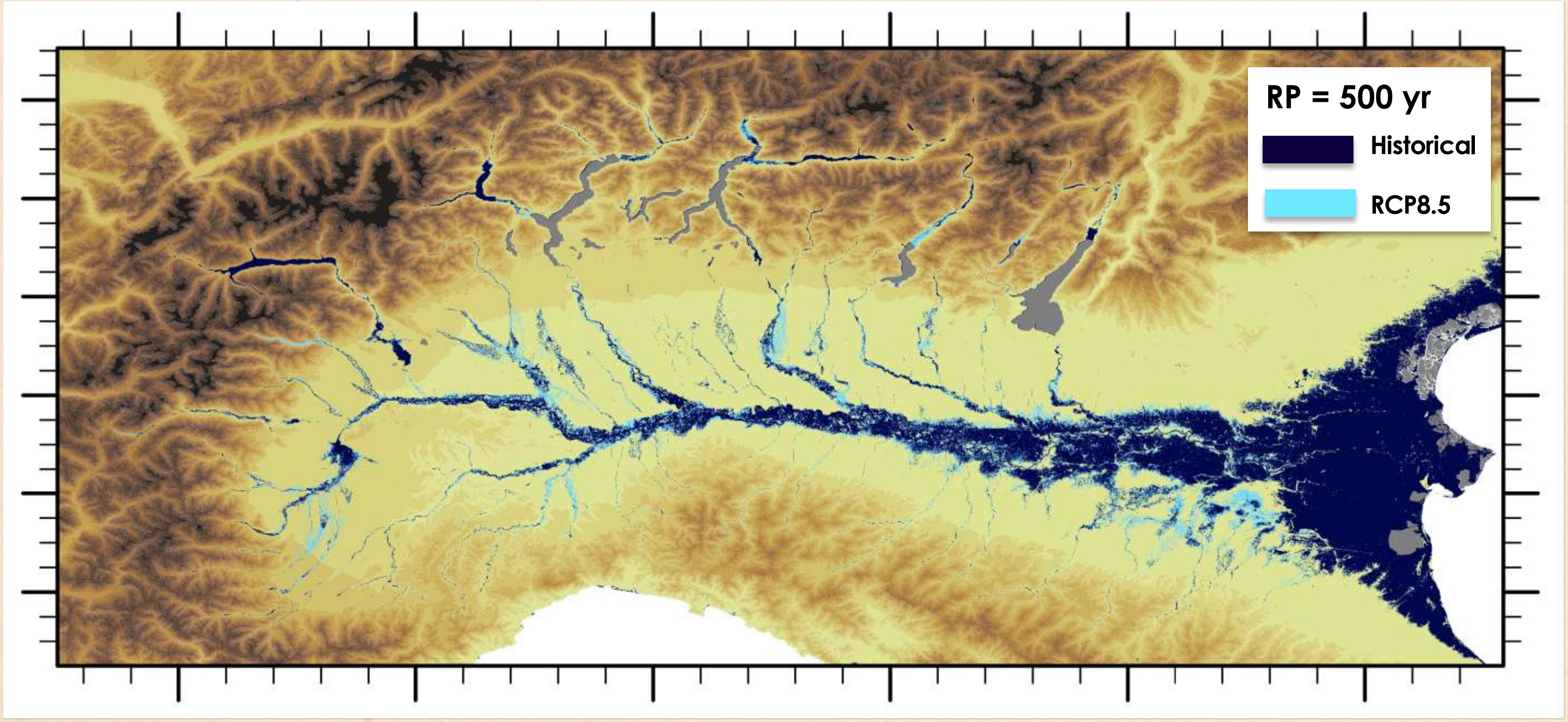
Precipitation change → **Discharges change**

CHyM

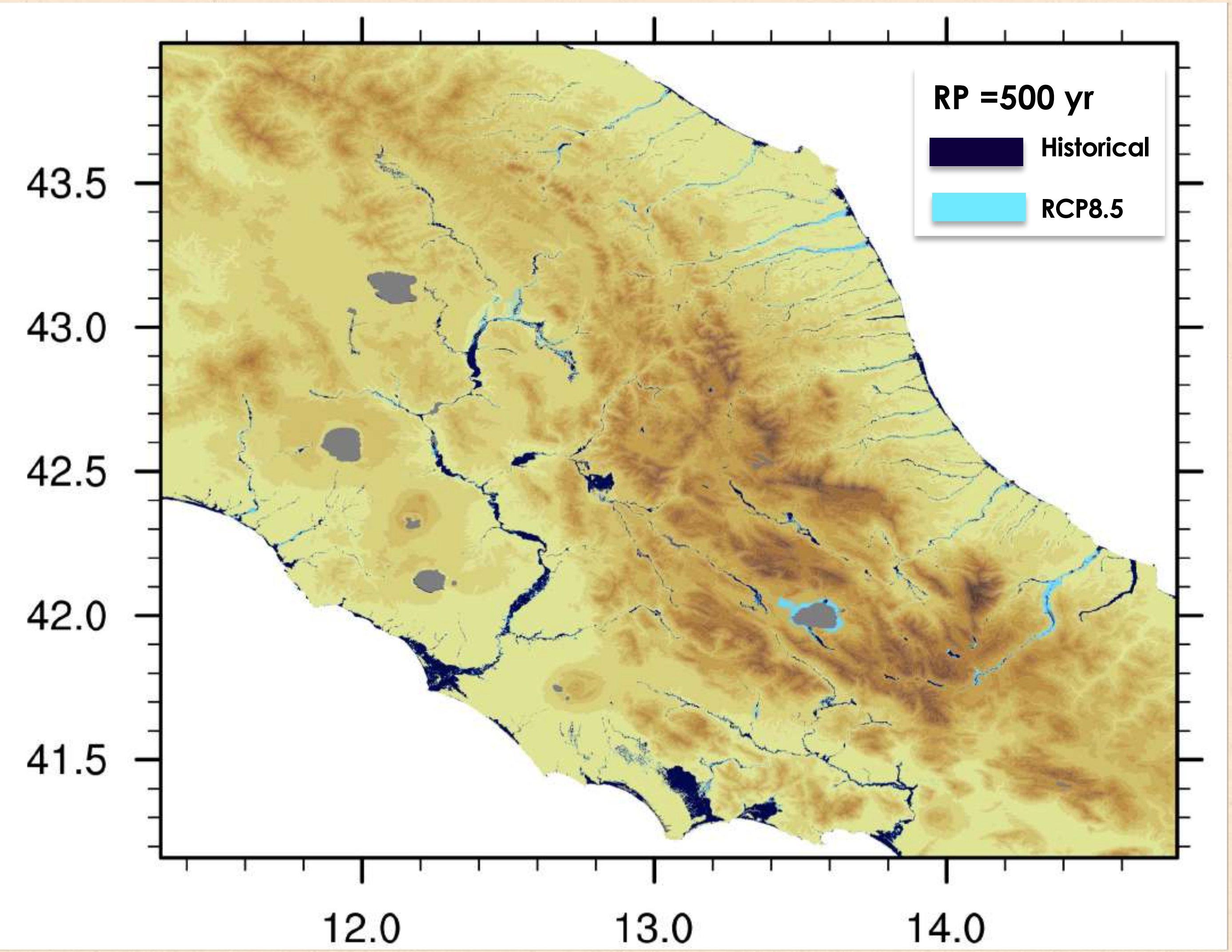
$R95_{ptot}$ change → **Mean annual maximum discharge change**

We performed the flood extent simulation for a range of return periods using both **historical** and **RCP8.5** data to estimate **the flood change**.

For **T=500 yr, flooded area increases by 18%** in the North of Italy.



Central Italian **flood extent will increase in the eastern coast**, in line with the increase of maximum discharges.



Concluding:

We can produce flood hazard maps via a model chain for the needed return period!

The methodology can be applied anywhere, at national or continental scale!

With different data (observed/modeled) according to what we want to study!

Perform ensemble analysis to assess uncertainty?

THANK YOU

rnoghero@ictp.it