The European Commission's science and knowledge service

Joint Research Centre

Hydrological and flood modelling at JRC

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*(**thanks to** Lorenzo Alfieri, Luc Feyen, Valerio Lorini, Ad de Roo, Peter Salamon)*

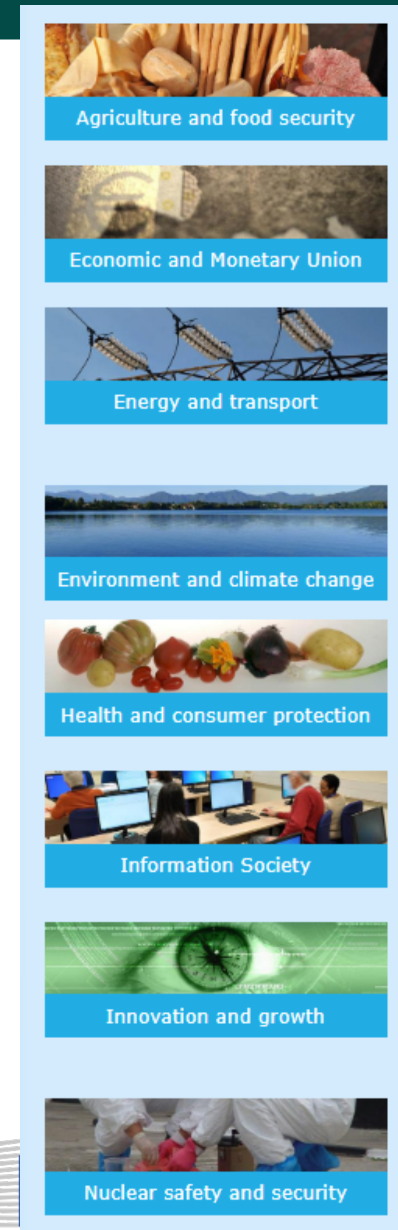
European Commission

Outline

- The Joint research Centre
- Hydrological modelling: LISFLOOD
- Forecasting and monitoring system for droughts and floods
- Flood (inundation) modelling: LISFLOOD-FP - CA2D
- Flood modelling at local scale
- Flood modelling at continental and global scale

The Joint Research Centre

- The Joint Research Centre (JRC) is the European Commission's science and knowledge service
- JRC supports EU policies with independent scientific evidence throughout the whole policy cycle
- JRC manage and make sense of knowledge and develop innovative tools and make them available to policy makers
- Research areas: environment and climate change, economy, energy and transport, consumer health and safety and more...



Hydrological and flood modelling at JRC

Why?

- JRC supports the design and implementation of climate and water related policies
  - disaster risk management
  - influence of policy and land use changes on water resources
  - climate change impacts on water resources and hydrological extremes

Hydrological and flood modelling at JRC

Why?

- JRC supports the design and implementation of climate and water related policies
  - disaster risk management for Europe and the World (e.g. emergency response)
  - influence of policy and land use changes on water resources
  - climate change impacts on water resources and hydrological extremes

How?

- We develop monitoring and forecasting systems for hydrological extremes

- We produce analyses of hydrological processes under present and future climate and socio-economic conditions

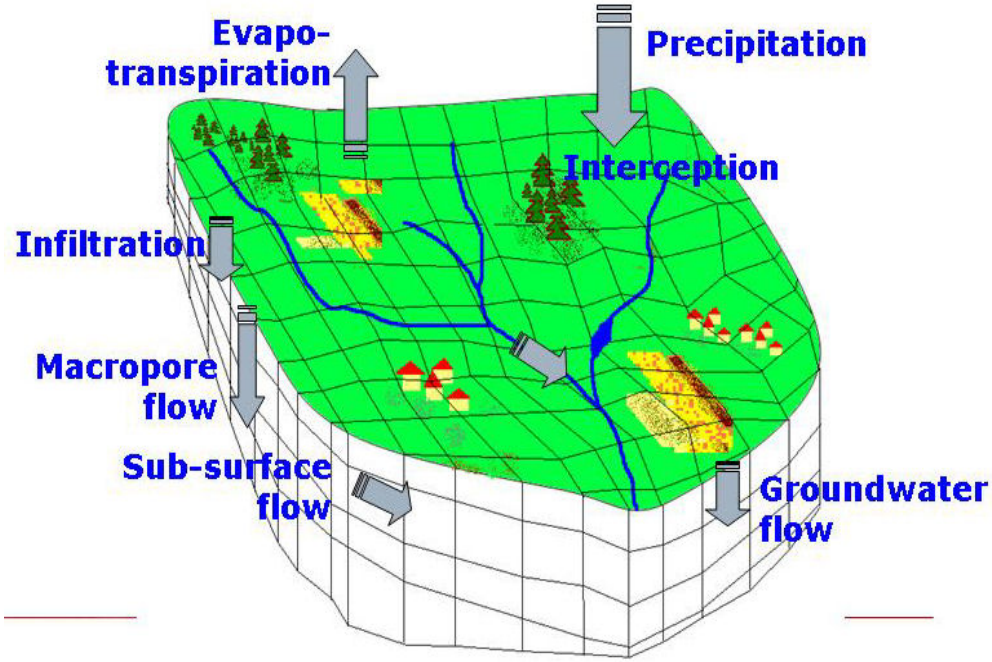
Hydrological and flood models at JRC

- We need models suitable to work at large scale (Europe or global)
- We need to provide information useful for our end users (policy makers, national authorities, emergency responders etc)
- We both use existing models and develop in-house models
- Hydrological modelling**: LISFLOOD**
- Flood (inundation) modelling: **LISFLOOD-FP - CA2D**

The LISFLOOD model

LISFLOOD is a hydrological model developed at JRC for research and policy support:

- disaster risk management (EFAS, EDO etc)
- water resources (climate impacts)
- the water-energy-food-environment nexus (WEFE)



Versions:

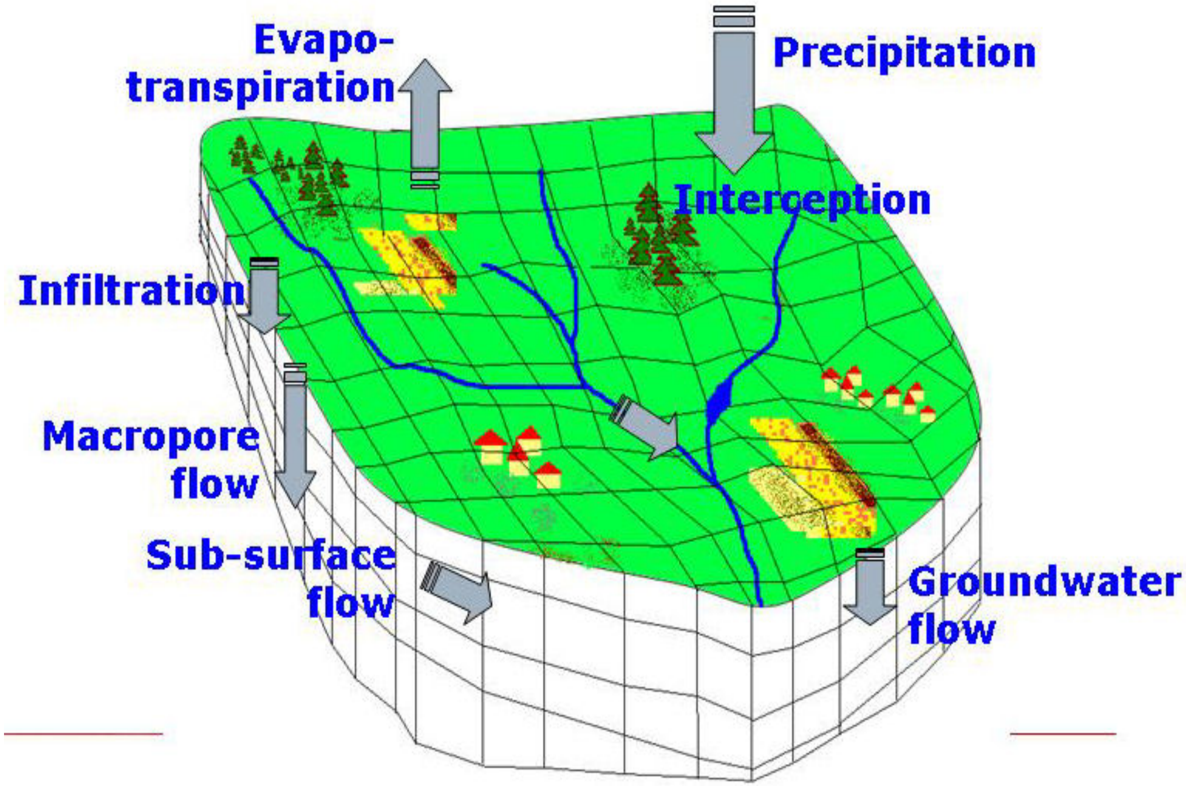
5km Europe
- EFAS - floods
- EDO - droughts

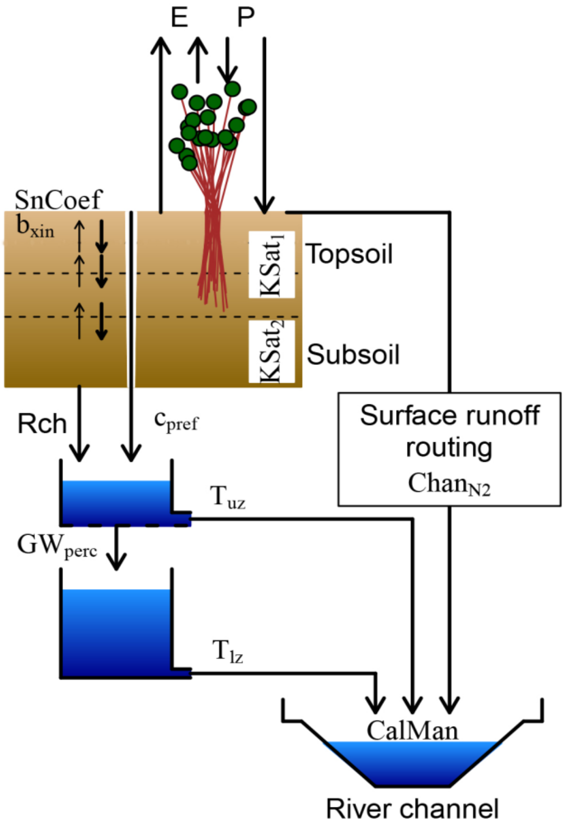
0.1° Global
- GloFAS – floods
- E2O Tier1&2

0.083° Africa
- JRC nexus studies

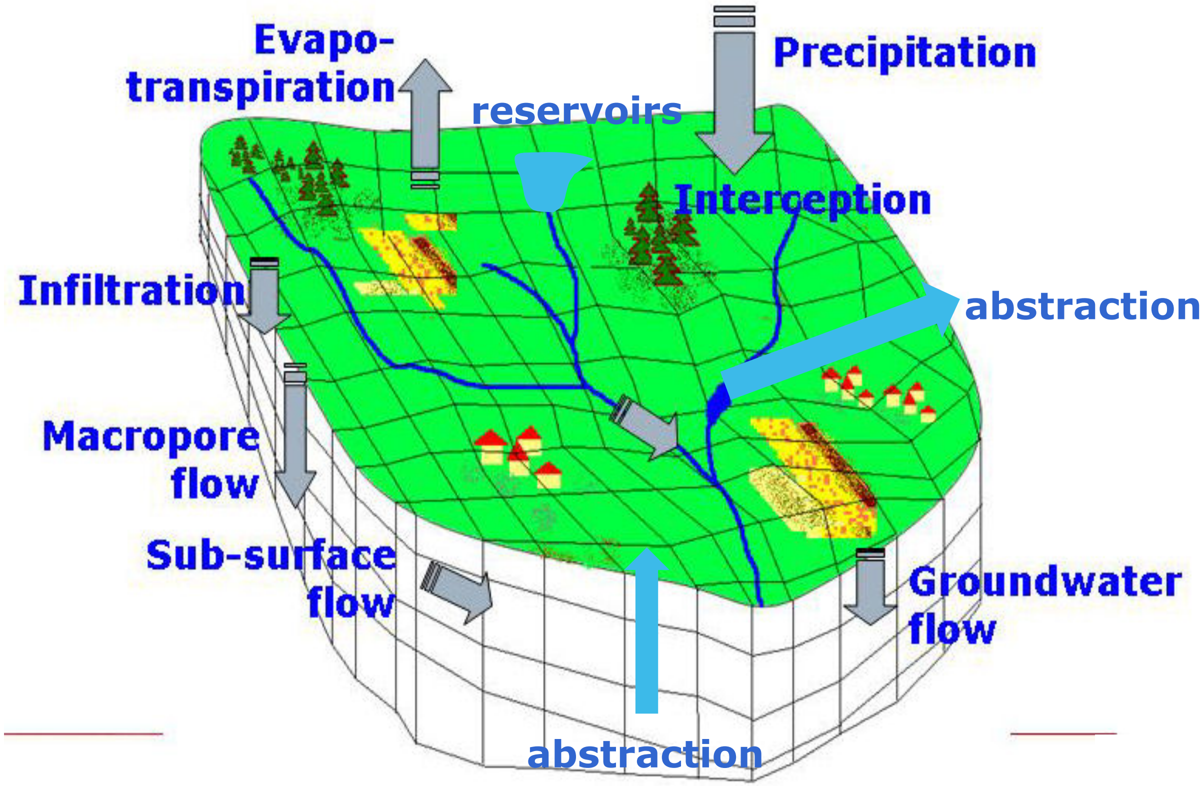
0.5° Global
- HELIX

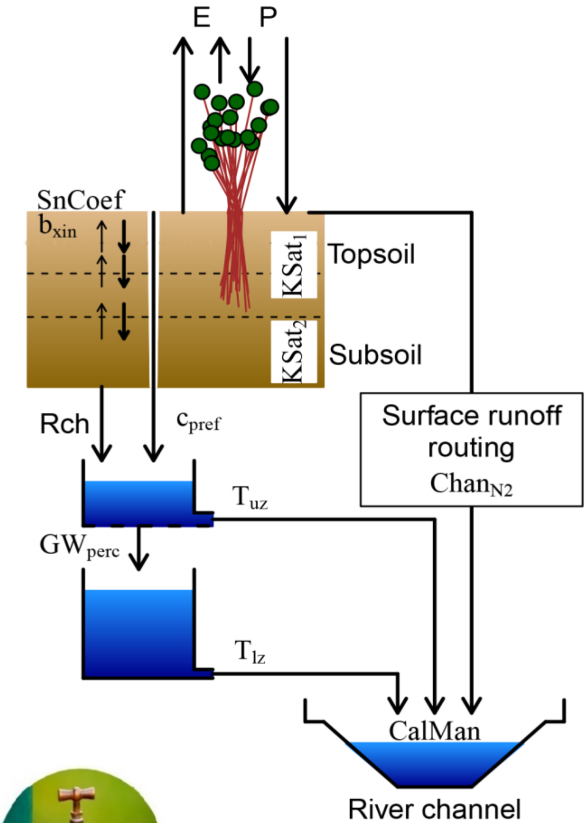
The LISFLOOD model





The LISFLOOD model





- Reservoirs (+ energy)
- Lakes
- Embedded irrigation demand (+yield)
- Surface water abstractions
- Groundwater storage / abstraction
- Rainfed agriculture crop yield

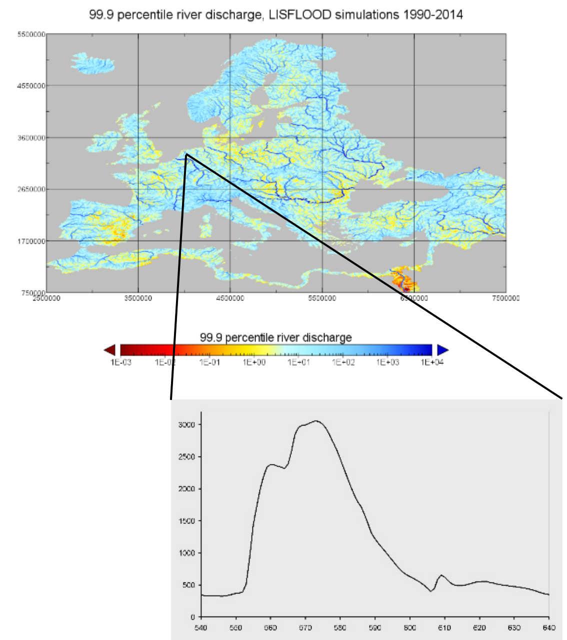
The LISFLOOD model

- Tailored for modelling water balance AND **peak flows (floods)**
- Can simulate with observed weather or **climate scenarios**
- **Specific datasets** for applications in Europe (reservoirs, land use, water demand, agriculture, urban areas)
- Simulates **water availability vs demand**
- Takes **env. flow threshold** into account (temporarily stopping abstractions)
- Simulates **lakes &** (**hydropower) reservoirs** (v3: energy)
- Embedded **irrigation water demand** estimation (v3: crop yield)

LISFLOOD: outputs

Variables:

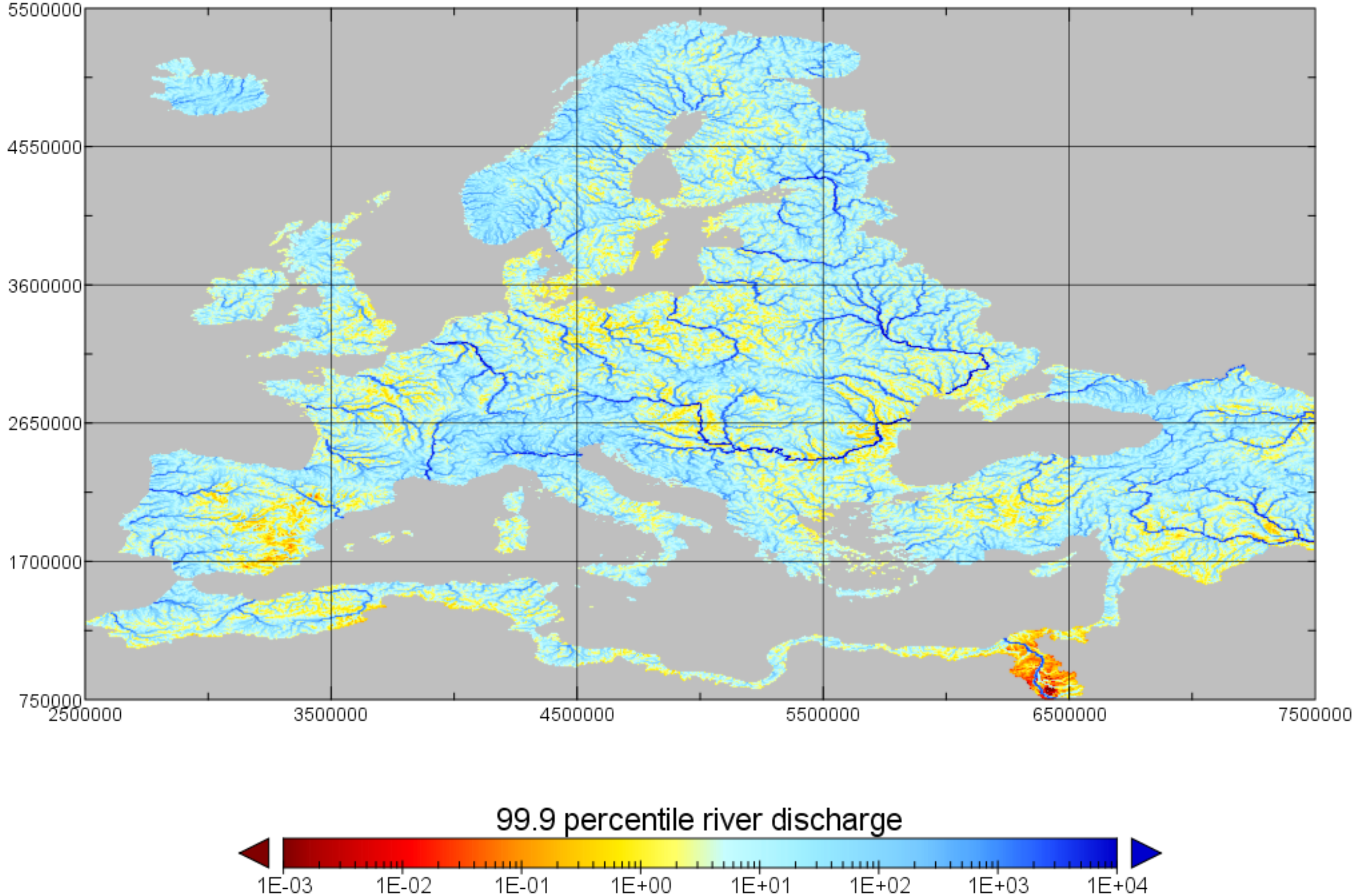
- River discharge + flow return periods
- Soil moisture
- Lake and reservoir volume dynamics
- Groundwater recharge
- Reservoir outflow
- Energy produced (anomalies)
- Crop yield (anomalies)

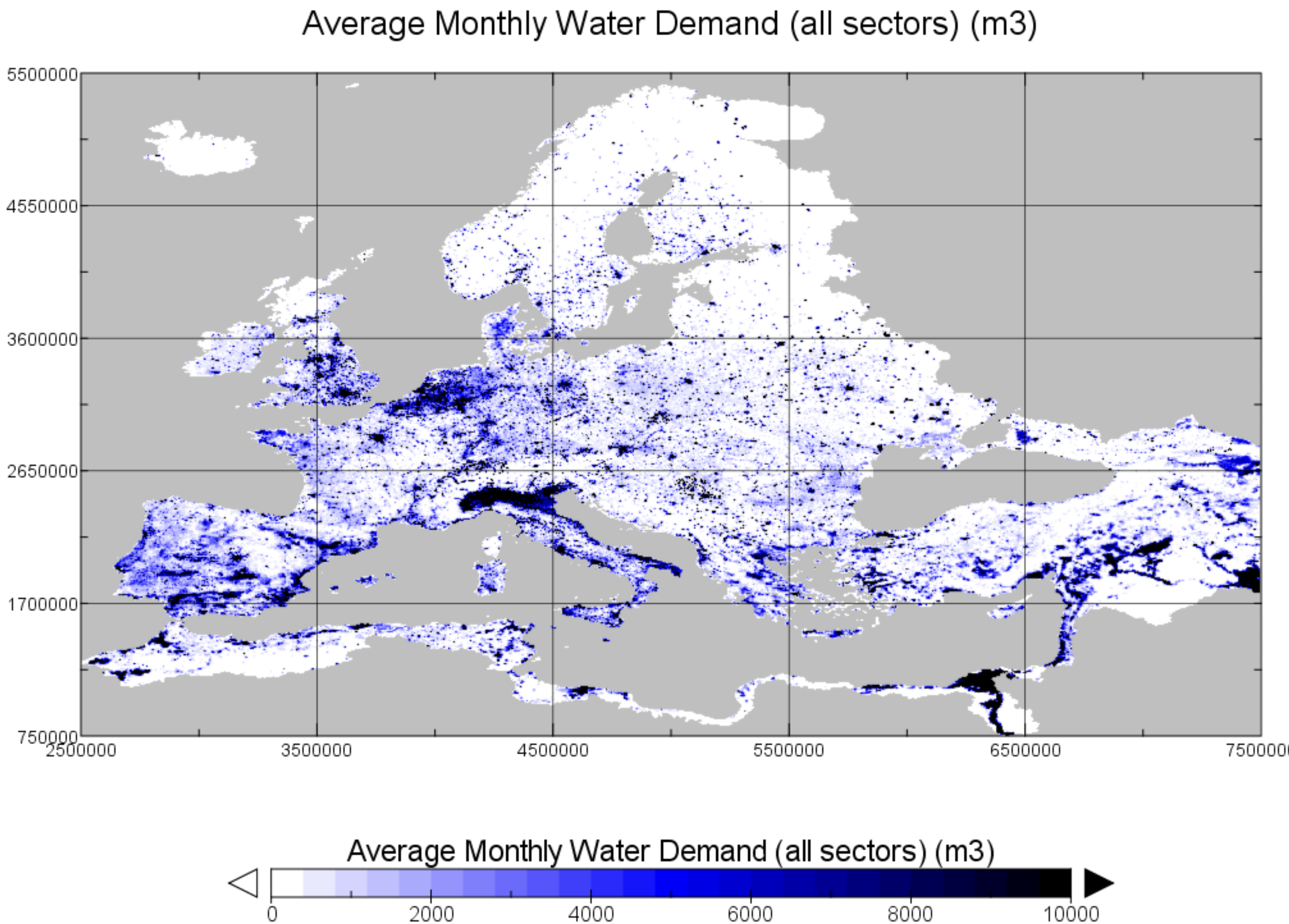


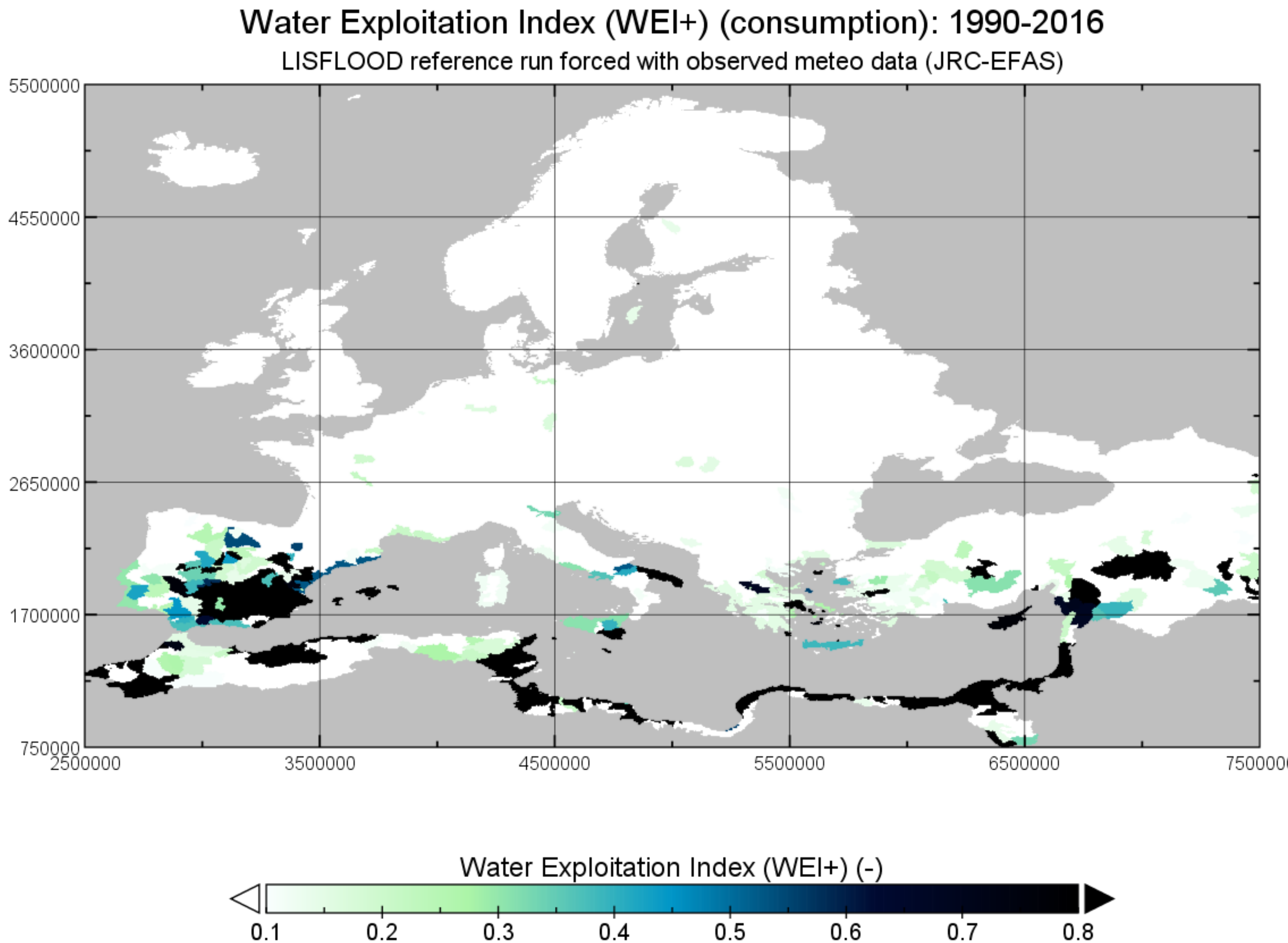
Indicators:

- Vegetation/Crop growth stress (RWS)
- Water Exploitation Index (consumption vs availability)
- Falkenmark Indices (water per capita)
- Water dependency (upstream dep.)
- Flood & drought indicators

99.9 percentile river discharge, LISFLOOD simulations 1990-2014




Average Monthly Water Demand (all sectors) (m3)
5500000
4550000
3600000
2650000
1700000
750000
2500000
3500000
4500000
5500000
6500000
7500000
Average Monthly Water Demand (all sectors) (m3)
0
2000
4000
6000
8000
10000



Water Exploitation Index (WEI+) (consumption): 1990-2016
LISFLOOD reference run forced with observed meteo data (JRC-EFAS)
5500000
4550000
3600000
2650000
1700000
750000
2500000
3500000
4500000
5500000
6500000
7500000
Water Exploitation Index (WEI+) (-)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

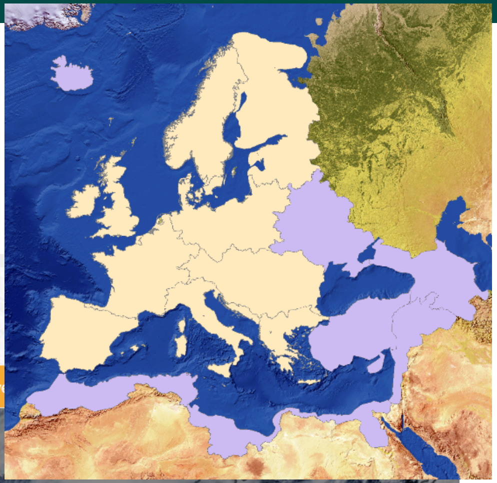
LISFLOOD applications: hydrological extremes

LISFLOOD is at the core of JRC monitoring and forecasting systems

- Flood – **EFAS** and **GloFAS**
- Drought – **EDO** and **GDO**

European Flood Awareness System (EFAS)

- Early warning information for the major European and Mediterranean rivers
- based on deterministic and ensemble weather forecasts and hydrological modelling
- 10-day streamflow and flash flooding forecasts updated twice per day
- Forecasts available EFAS partners (e.g. hydrological services, civil protection)



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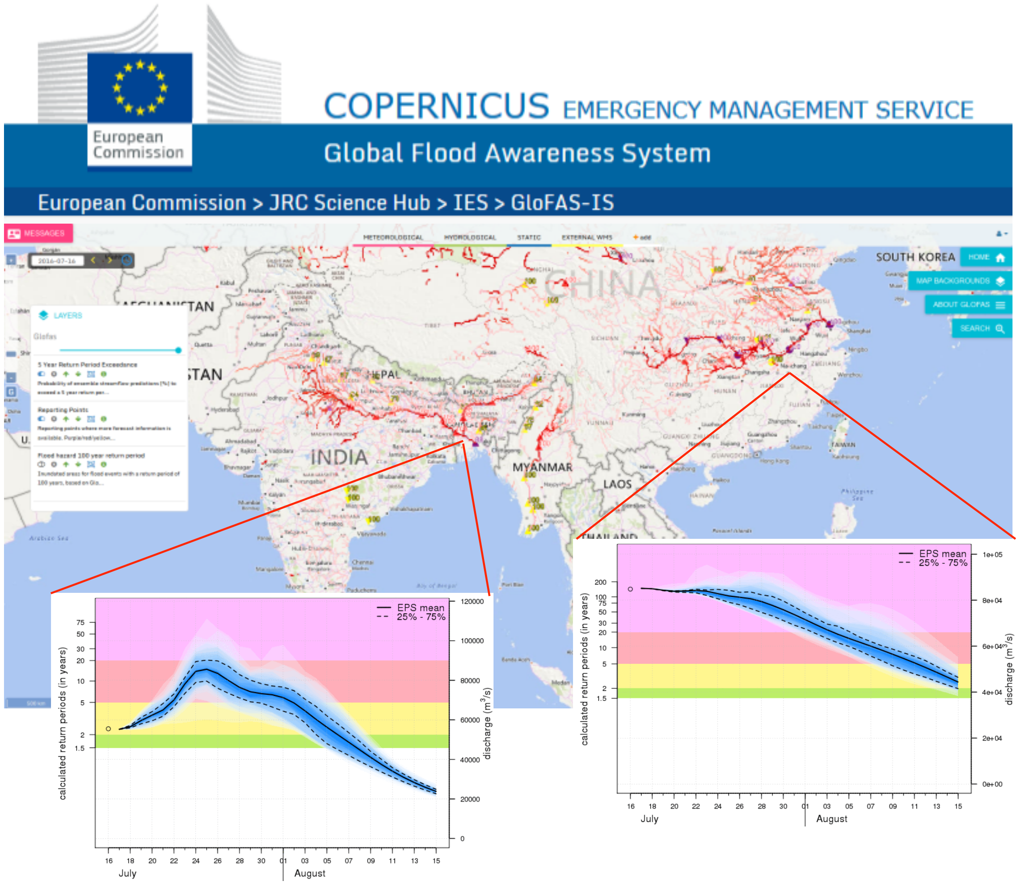
Global Flood Awareness System (GloFAS)

- Operational flood predictions for the major global rivers
- Based on combined hydrological models (H-TESSEL + LISFLOOD) running at 0.1°resolution with ensemble weather forecasts from ECMWF

- 30-day streamflow forecasts updated once per day

- Early warning information available to registered users (National Hydrological Services, Red Cross, humanitarian organizations, researchers)

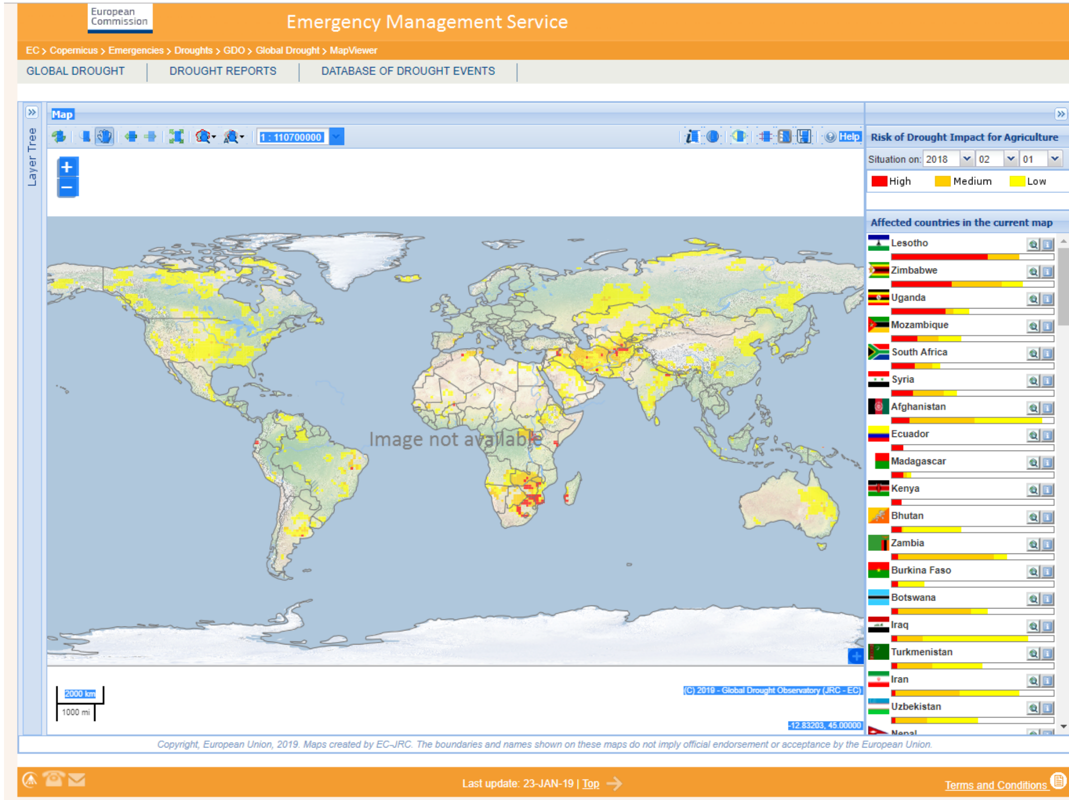


www.globalfloods.eu

European Commission

European and Global Drought Observatory

- The Europe (EDO) and Global (GDO) Drought Observatory provide drought-relevant information and early-warnings
- Different indicators of drought conditions and impacts
- Short analytical reports (Drought News) are published in case of imminent droughts.
- connect drought data providers and users from global to regional levels.



https://emergency.copernicus.eu/

European Commission

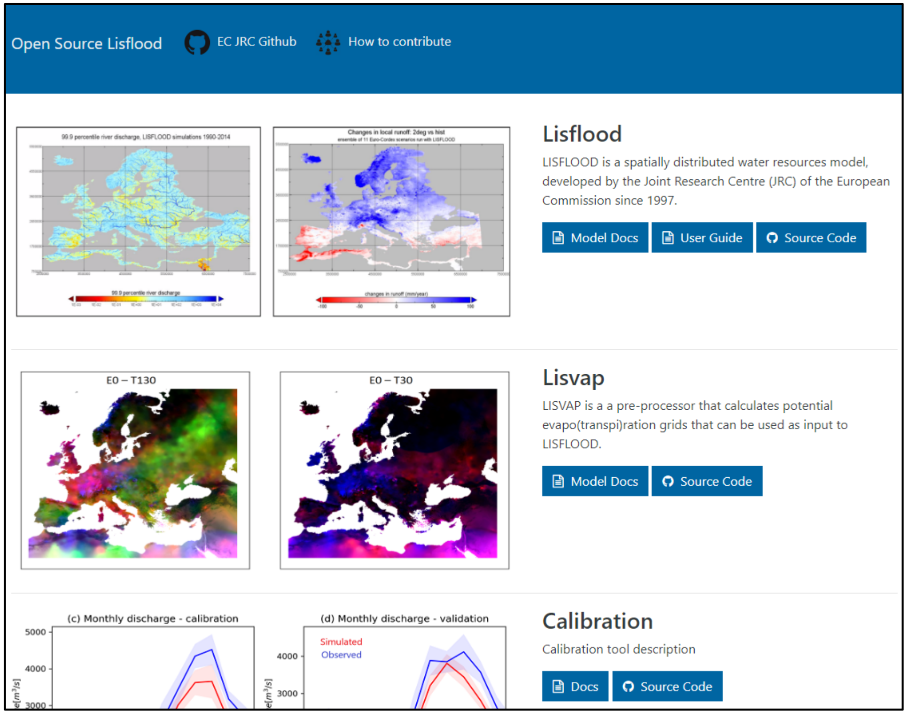
LISFLOOD goes open source

Aim:

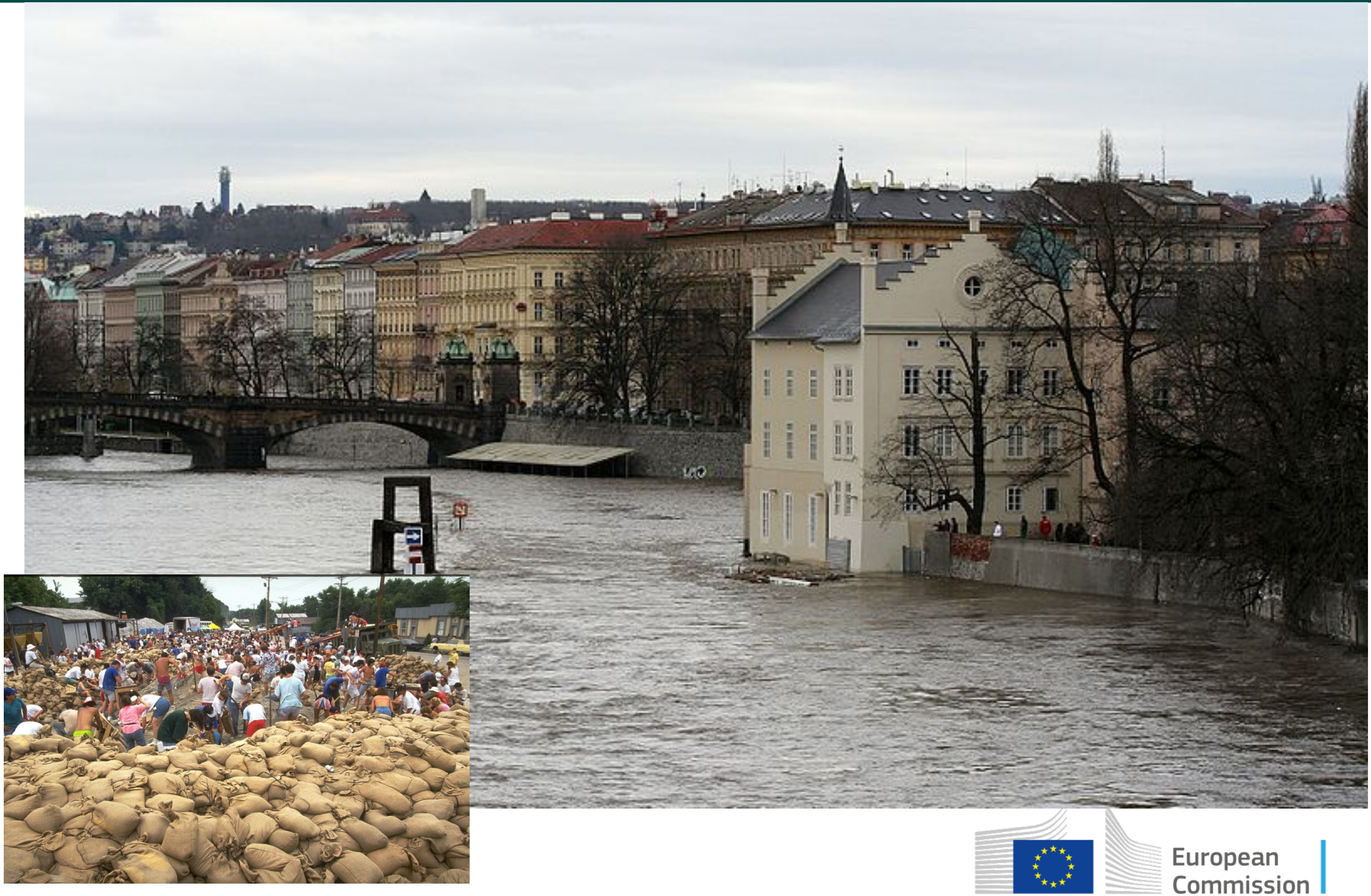
- increase the transparency of the model and its results for all users
- engage a large community of developers to further improve LISFLOOD.

https://ec-jrc.github.io/lisflood/

- LISFLOOD source code
- LISFLOOD manuals and user documentation
- Use cases with data (example river basin)
- Auxiliary tools (calibration, netCDF utilities)



Flood modelling



Flood modelling

- Flood models are used when water overflows drainage network
- Flow dynamics is complex due to terrain altimetry and interactions with embankments, dikes etc.
- River channel models (1D models generally used in hydrological models) cannot reproduce well flood dynamics especially in large-scale events
- Two-dimensional (2D) models are nowadays widely applied to model flood processes

Channel flow conditions

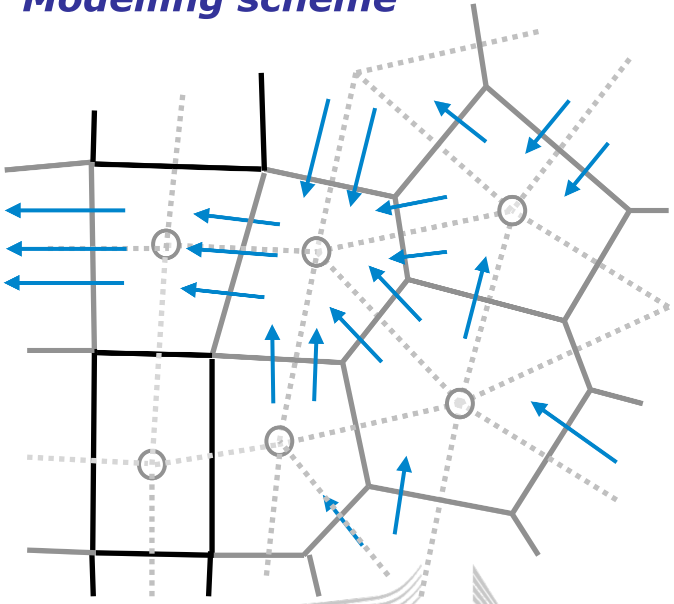
Flooding conditions

What is a 2D hydraulic model?

- Hydraulic model: a mathematical model that describes water flow by solving governing flow equations with a numerical scheme
- Two-dimensional (2D) model: during most flood events, water flows essentially on a XY grid
- flow equations are integrated over the vertical component → Shallow Water Equations (SWE)

Real event

Modelling scheme



Simplified 2D models

- Shallow water equations (SWE) are complex to solve. Models based on the complete SWE are generally used for limited areas

$$\frac{\partial(\rho\eta)}{\partial t} + \frac{\partial(\rho\eta u)}{\partial x} + \frac{\partial(\rho\eta v)}{\partial y} = 0,$$

$$\frac{\partial(\rho\eta u)}{\partial t} + \frac{\partial}{\partial x}\left(\rho\eta u^2 + \frac{1}{2}\rho g\eta^2\right) + \frac{\partial(\rho\eta uv)}{\partial y} = 0,$$

$$\frac{\partial(\rho\eta v)}{\partial t} + \frac{\partial(\rho\eta uv)}{\partial x} + \frac{\partial}{\partial y}\left(\rho\eta v^2 + \frac{1}{2}\rho g\eta^2\right) = 0.$$

Simplified 2D models

- Shallow water equations (SWE) complex to solve. Models based the complete SWE are generally used for limited areas

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$$\frac{\partial(\rho\eta v)}{\partial t} + \frac{\partial(\rho\eta uv)}{\partial x} + \frac{\partial}{\partial y}\left(\rho\eta v^2 + \frac{1}{2}\rho g\eta^2\right) = 0.$$

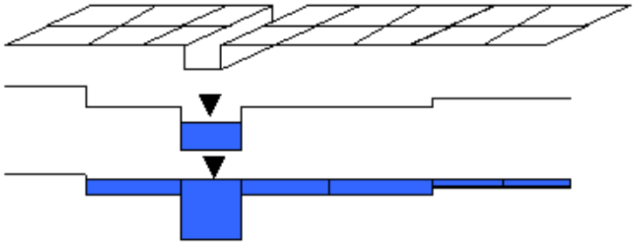
- However, nowadays approximated SWE integrated over regular grids can be applied up to continental and global scales

$$\Delta V_{i,t+\Delta t} = \Delta t \cdot \sum_{j=1}^{m} Q_{i,j}$$
$$Q_{i,j} = b\frac{q_0 - gh_{flow}\Delta t\frac{(H_i - H_j)}{\Delta x}}{1 + gh_{flow}\Delta t n^2 q_0 / h_{flow}^{10/3}}$$

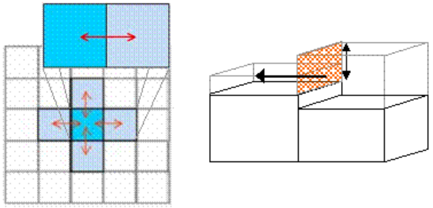
- Several 2D models make use of simplified SWE

LISFLOOD-FP model

- **LISFLOOD-FP** is a 2D hydrodynamic model designed to simulate floodplain inundation over complex topography
- Developed by the University of Bristol in 2000



- Current version of the model includes
  - Different solvers of flow equations
    over regular (square) grids
  - 1D-2D flows and hydraulic structures
  - Simulation of hydrological processes etc)
  - parallel computing for improved code efficiency



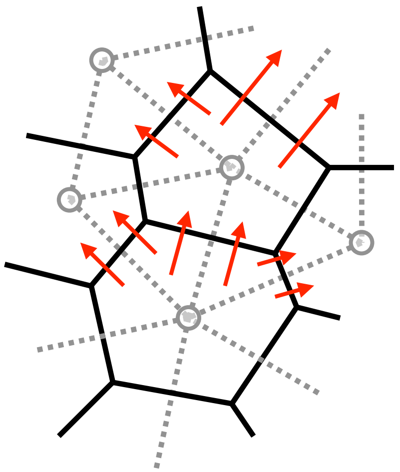
- Applications for river, pluvial and coastal flooding

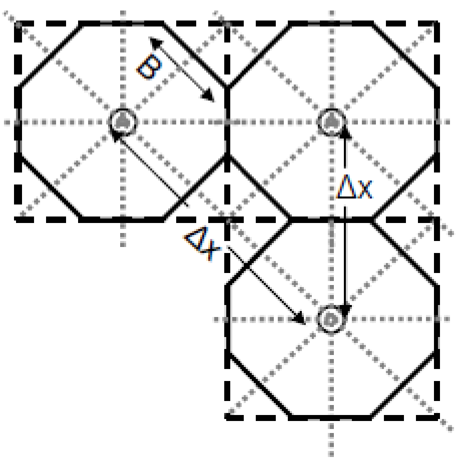
- Freely available for research purposes (under request)
  http://www.bristol.ac.uk/geography/research/hydrology/models/lisflood/

CA2D model

- **CA2D** is a 2D hydrodynamic model by the University of Bologna in 2010
- Similar to LISFLOOD-FP
  - Same set of flow equations
  - 1D-2D flows and hydraulic structures
  - Simulation of hydrological processes
  - Different grid structure (unstructured)

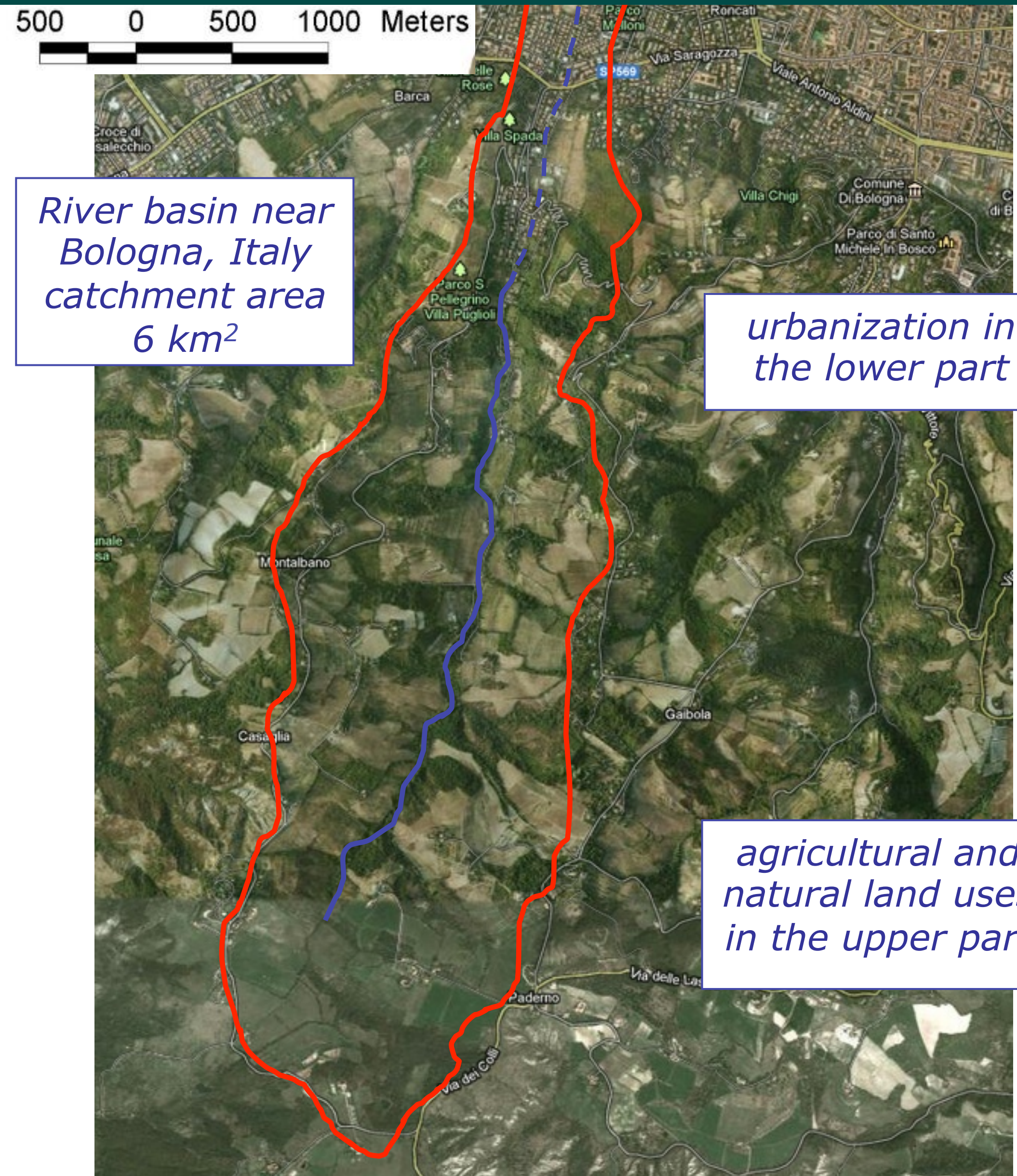
- Applications for river and pluvial flooding
- Applications from local test areas to global scale





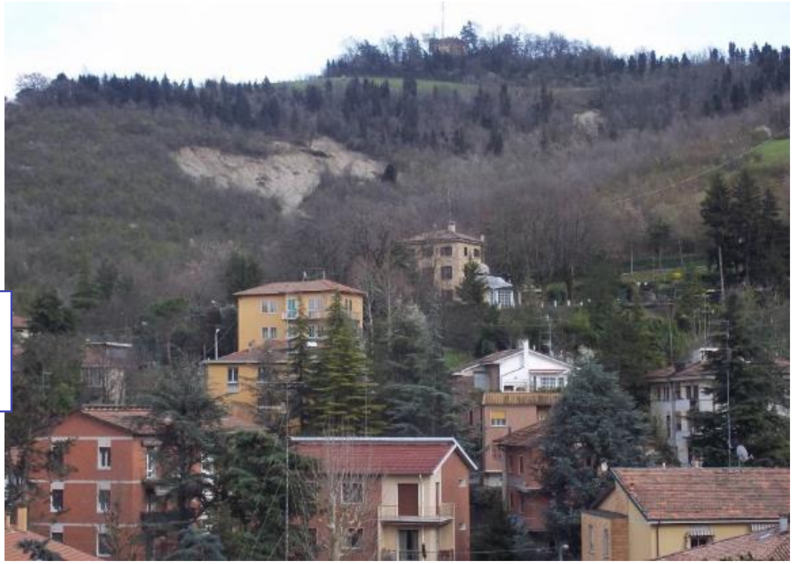
Applications : local scale

Applications of CA2D: local scale



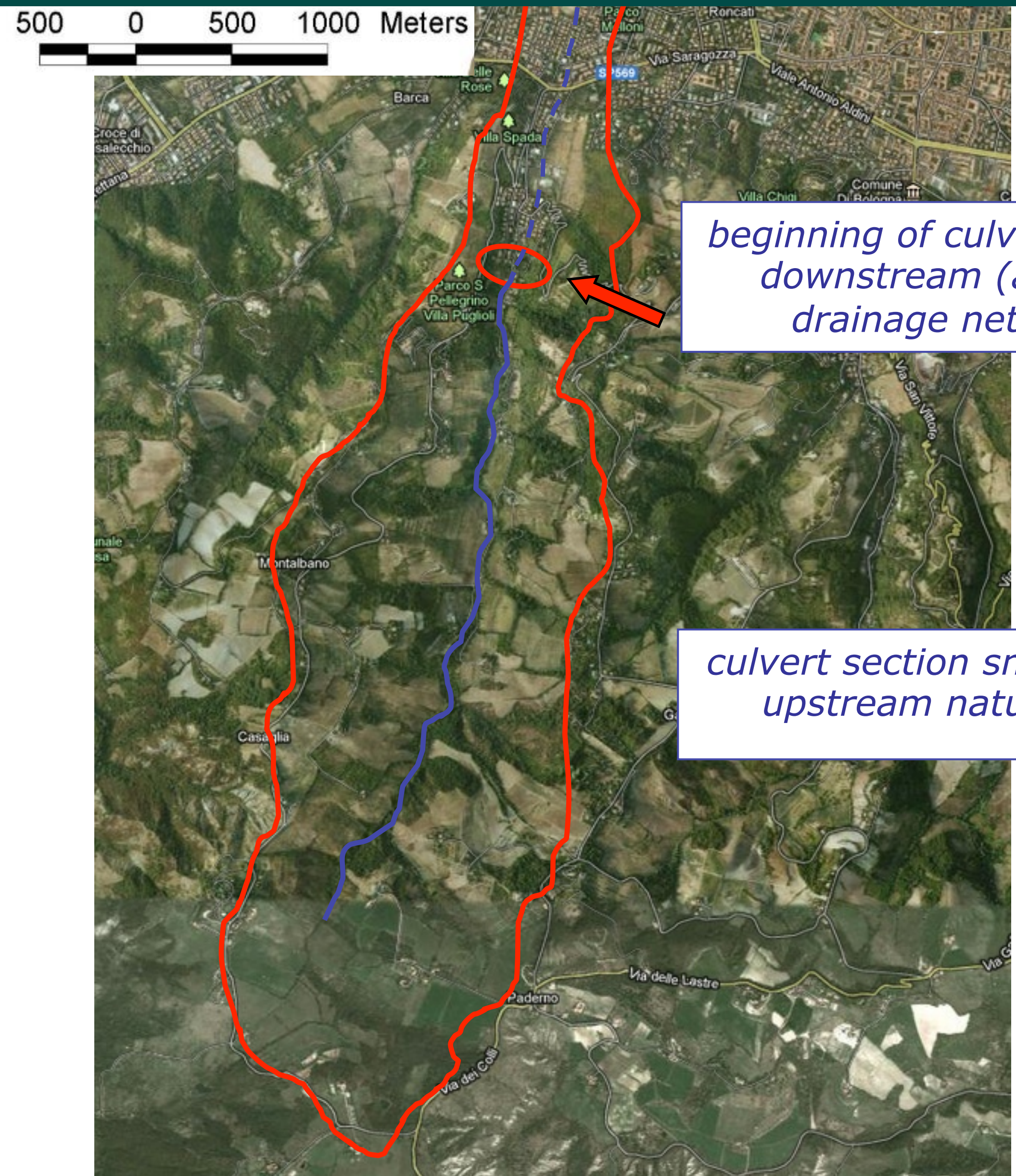
River basin near Bologna, Italy catchment area 6 km²

urbanization in the lower part



agricultural and natural land uses in the upper part

Applications of CA2D: local scale



beginning of culvert section downstream (artificial drainage network)

culvert section smaller than upstream natural bed

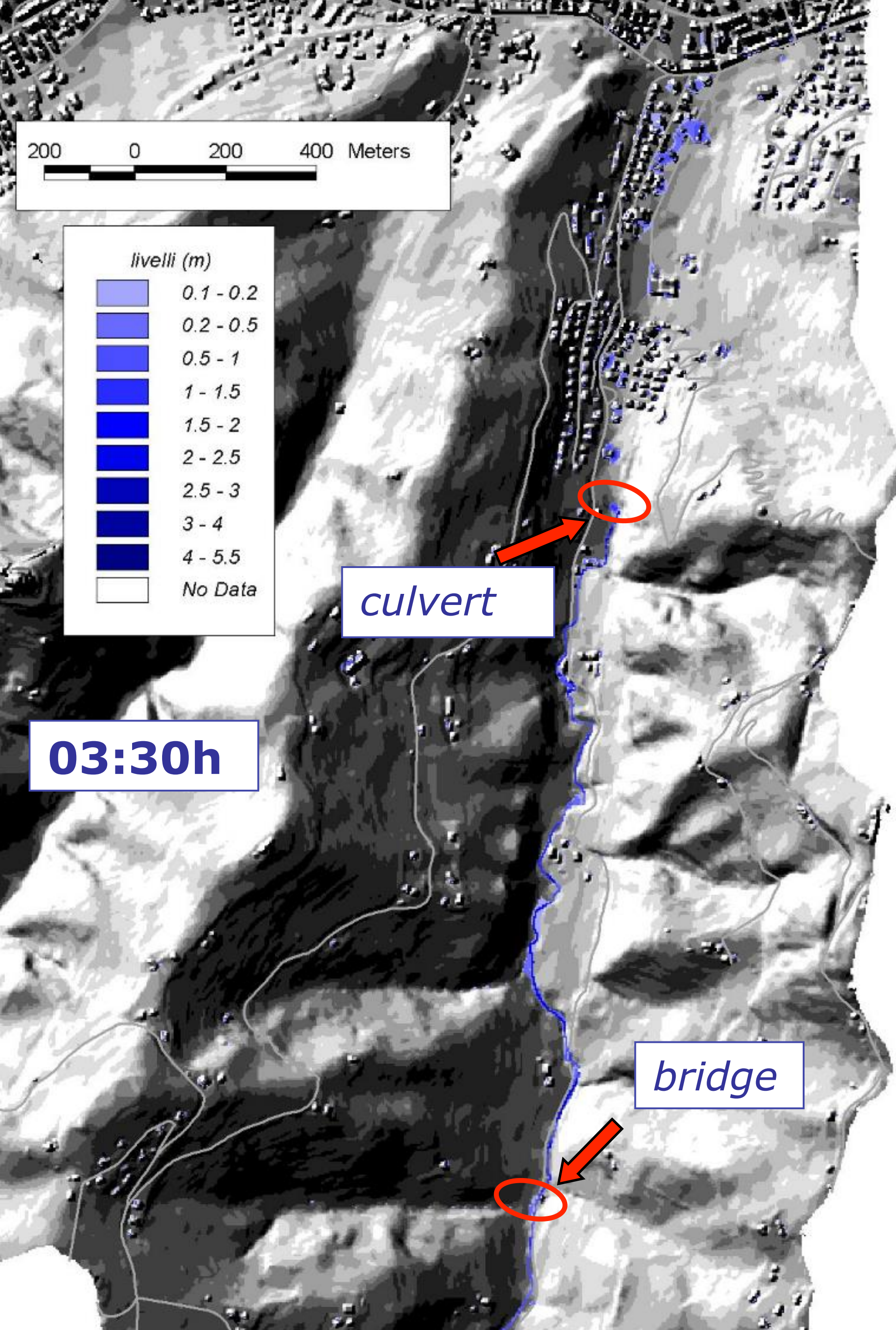
Applications of CA2D: local scale

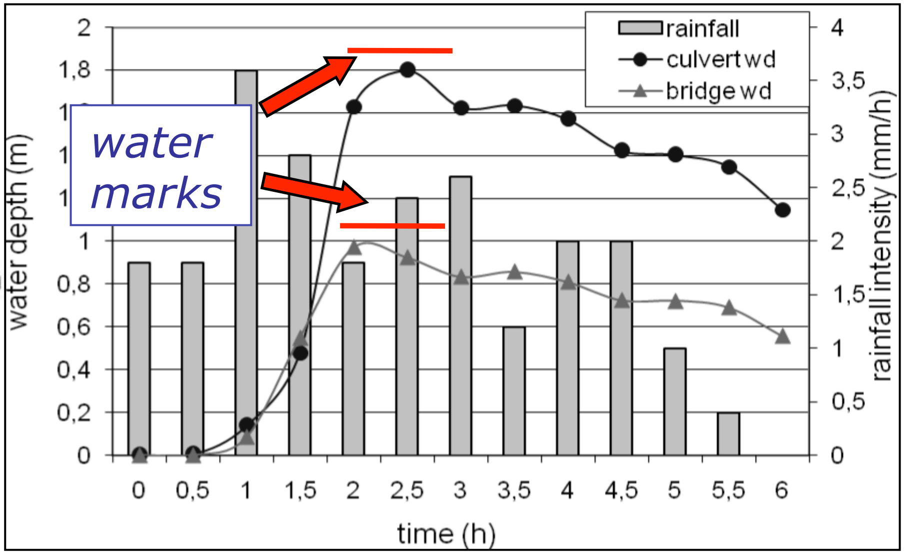
- CA2D applied to reproduce rainfall-runoff, channel flow and flooding processes at catchment scale

- Simulation of real events and hypothetical scenarios:
  → ordinary event (validation): rainfall observed on 5/4/2013
  → extreme event: scenario based on extreme values of historical series (return period ~ 50 years)

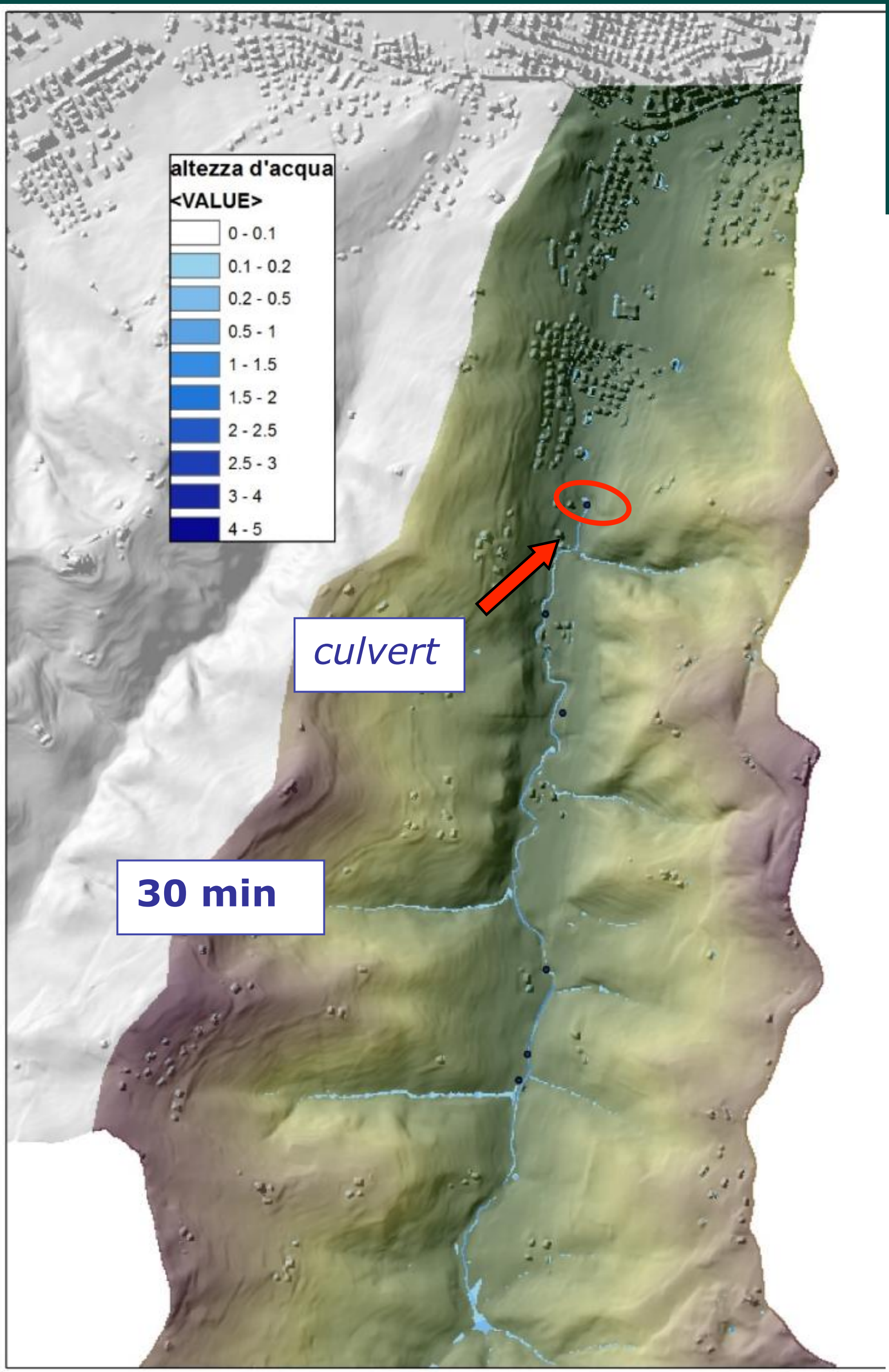
- Ordinary event: **24mm/6h**
- Extreme event: **70mm/2h**

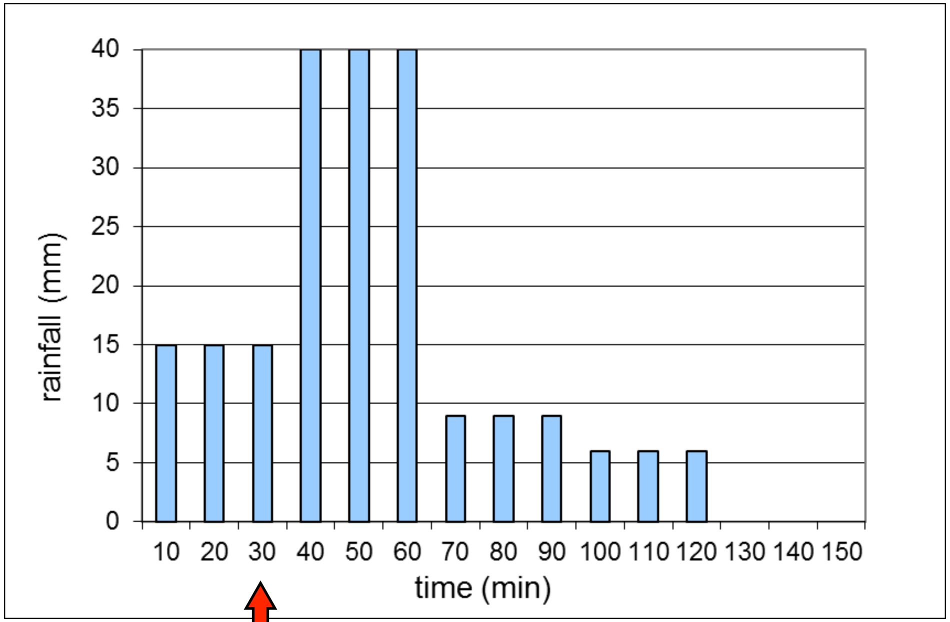
Results: ordinary event



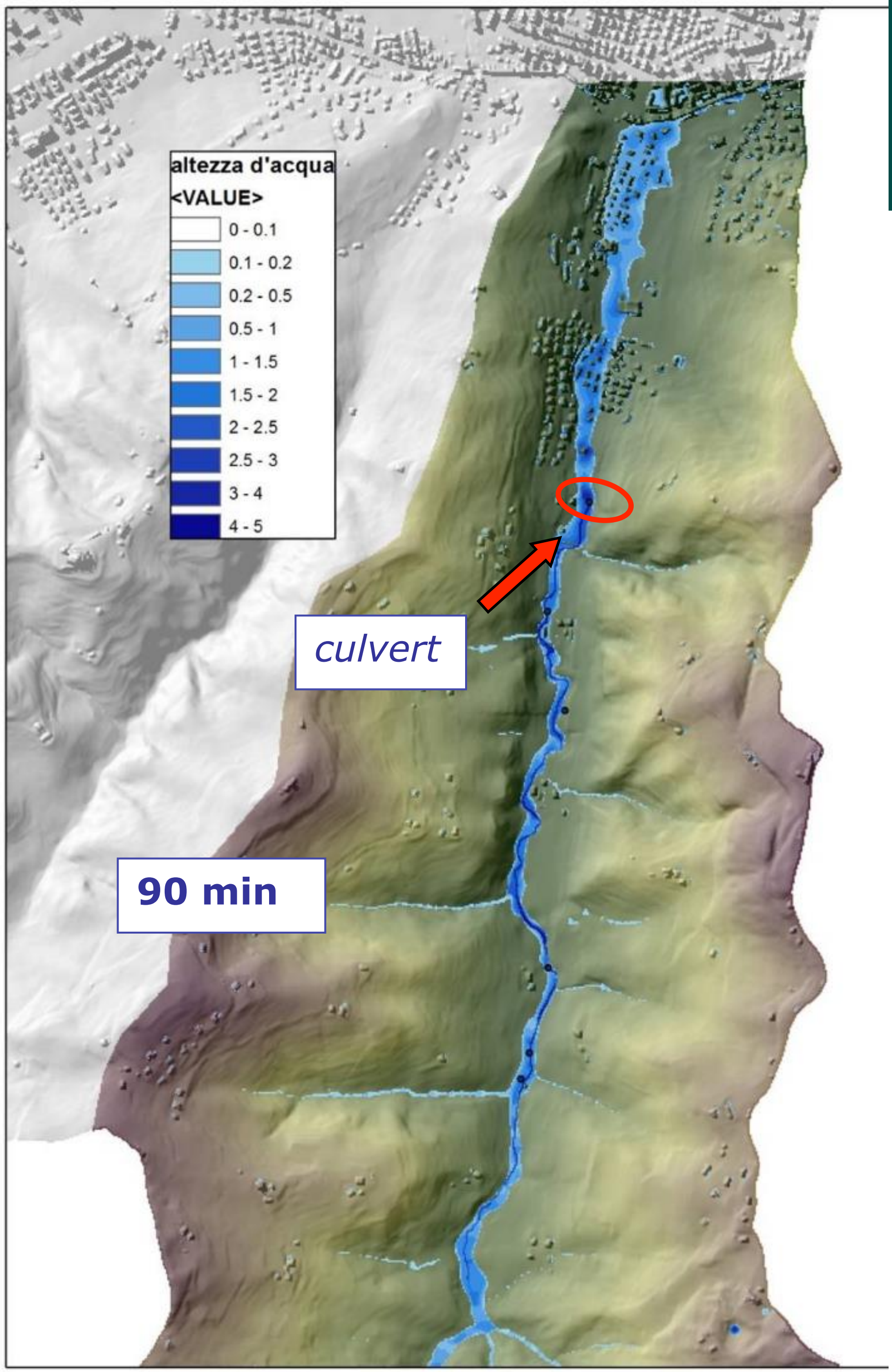


Results: extreme event

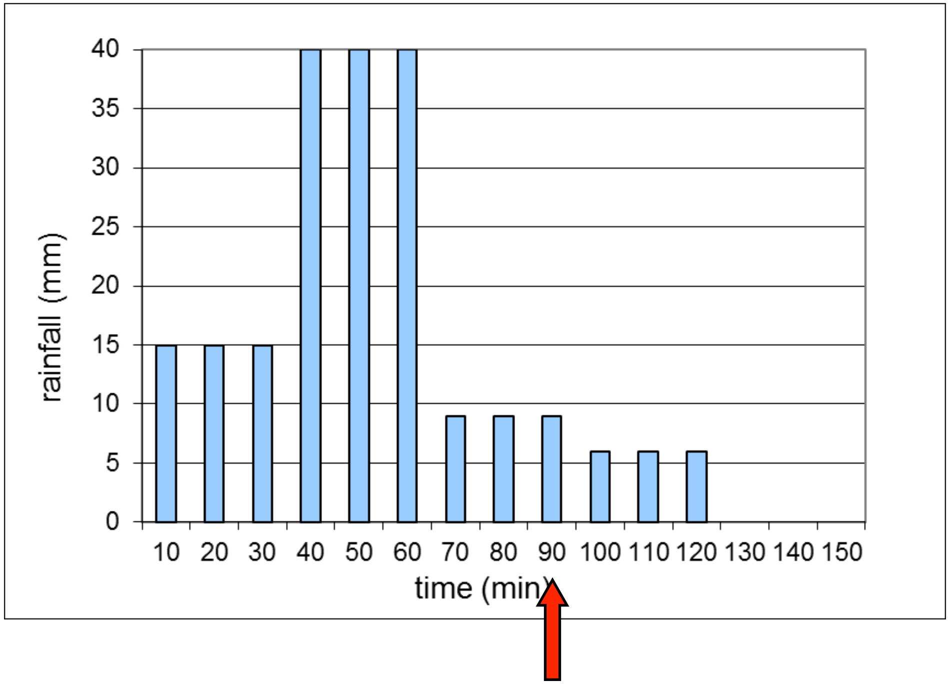




→ dischrge still low, the culvert section is still able to drain the inflow



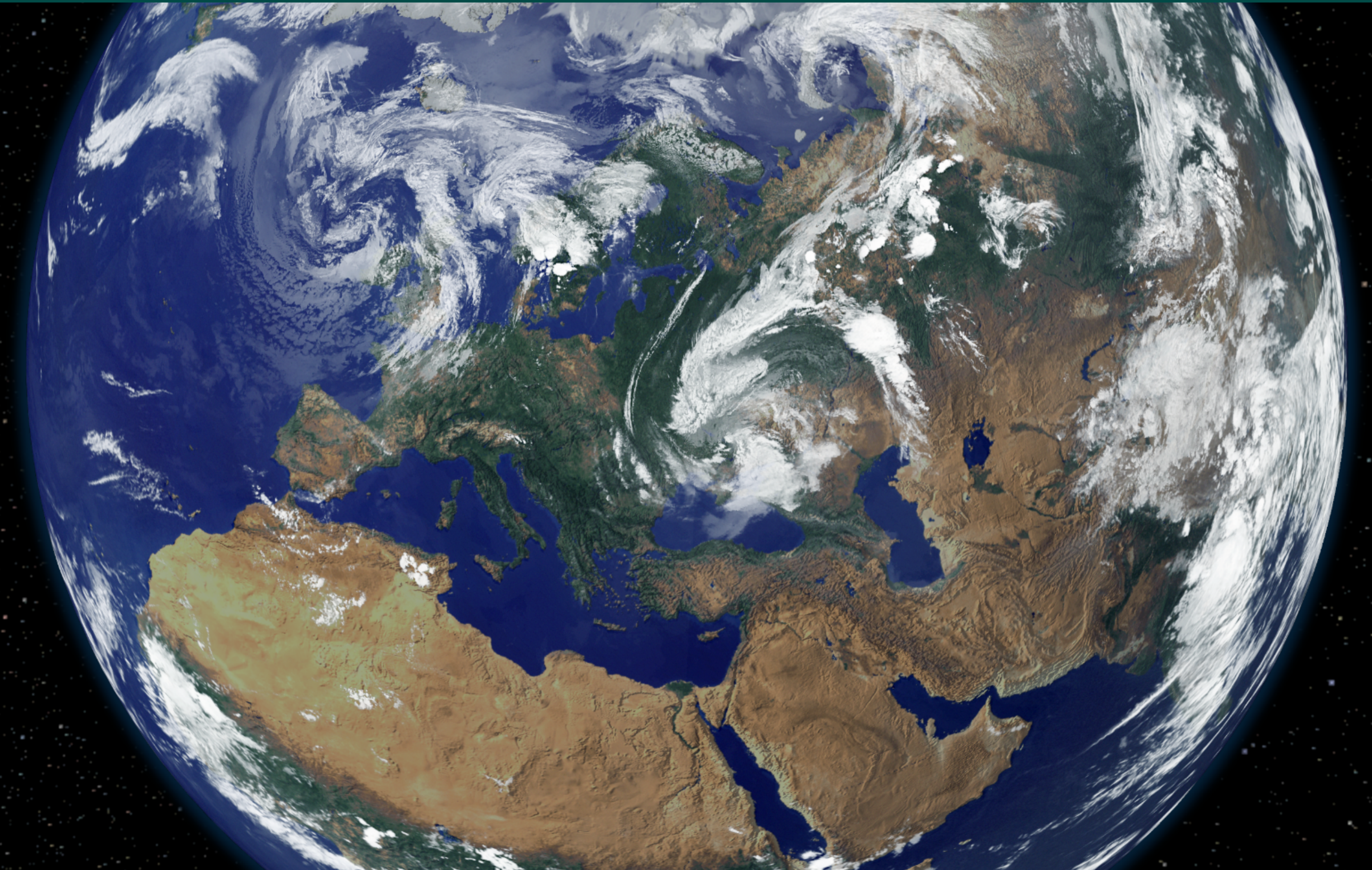
Results: extreme event



→ culvert section not sufficient to drain incoming discharge (> 20 m^3/s)

→ water in excess starts flooding the urban area, water depths up to 1.5m.

Applications: large scale



Applications of LISFLOOD-FP: European flood hazard map database

- Hydrological input: EFAS streamflow climatology (23 years)
- Simulations with a 2D hydrodynamic model (Lisflood-FP) run for each section of the major European river network
- Catalogue of flood hazard maps at 100m resolution, for return periods from 10 to 500 years
- Envelope of maps to derive pan-European hazard maps

Flood hazard maps for Europe, return period 100 years (Alfieri et al., 2014)

- Freely available for download at

http://data.jrc.ec.europa.eu/collection/floods

European Commission

Use of flood maps in EFAS: rapid flood mapping and impact assessment

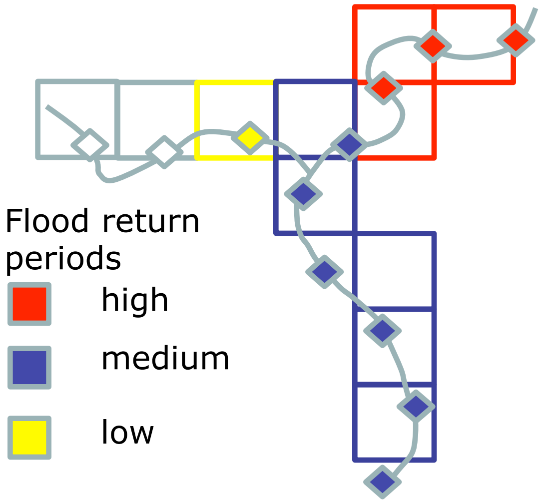
Mississippi and Missouri river floods of 1993. Andrea Booher - FEMA

Estimating flood prone areas and potential impacts due to a forecasted flood event is crucial in the preparedness phase:

- to plan emergency responses (e.g. reinforcing dykes, evacuating people)
- to support the planning and allocation of rescue assets,
- to get a first estimate of the forecasted flood event's potential socio-economic consequences.

Use of flood maps in EFAS: rapid flood mapping

For any forecasted event we identify
- river sections affected
- local flood magnitude (return period)

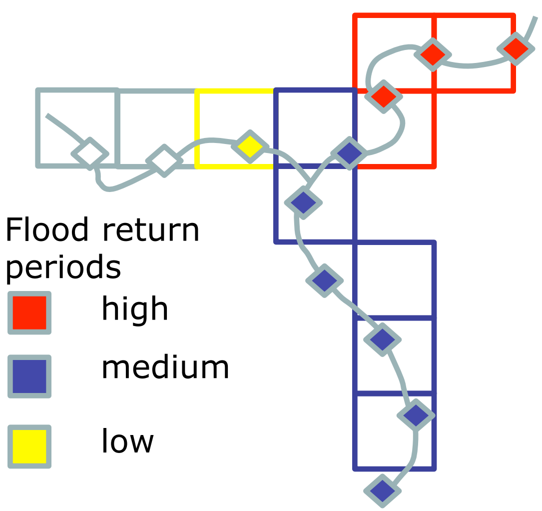


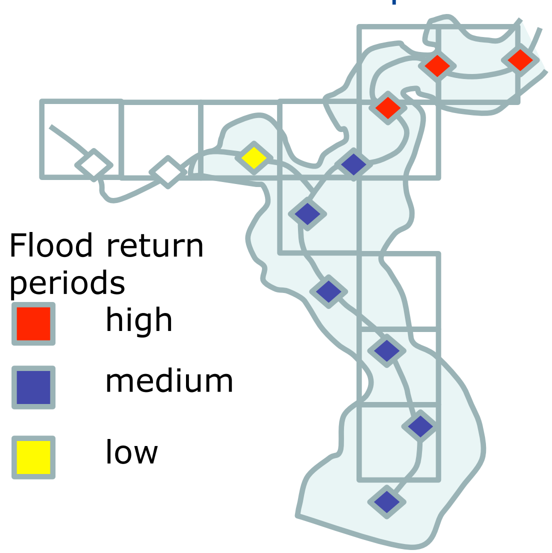
Dottori et al., 2017 - NHESS

Use of flood maps in EFAS: rapid flood mapping

For any forecasted event we identify
- river sections affected
- local flood magnitude (return period)

Location and magnitude are used with the flood map library and flood protection maps to derive event-based hazard maps





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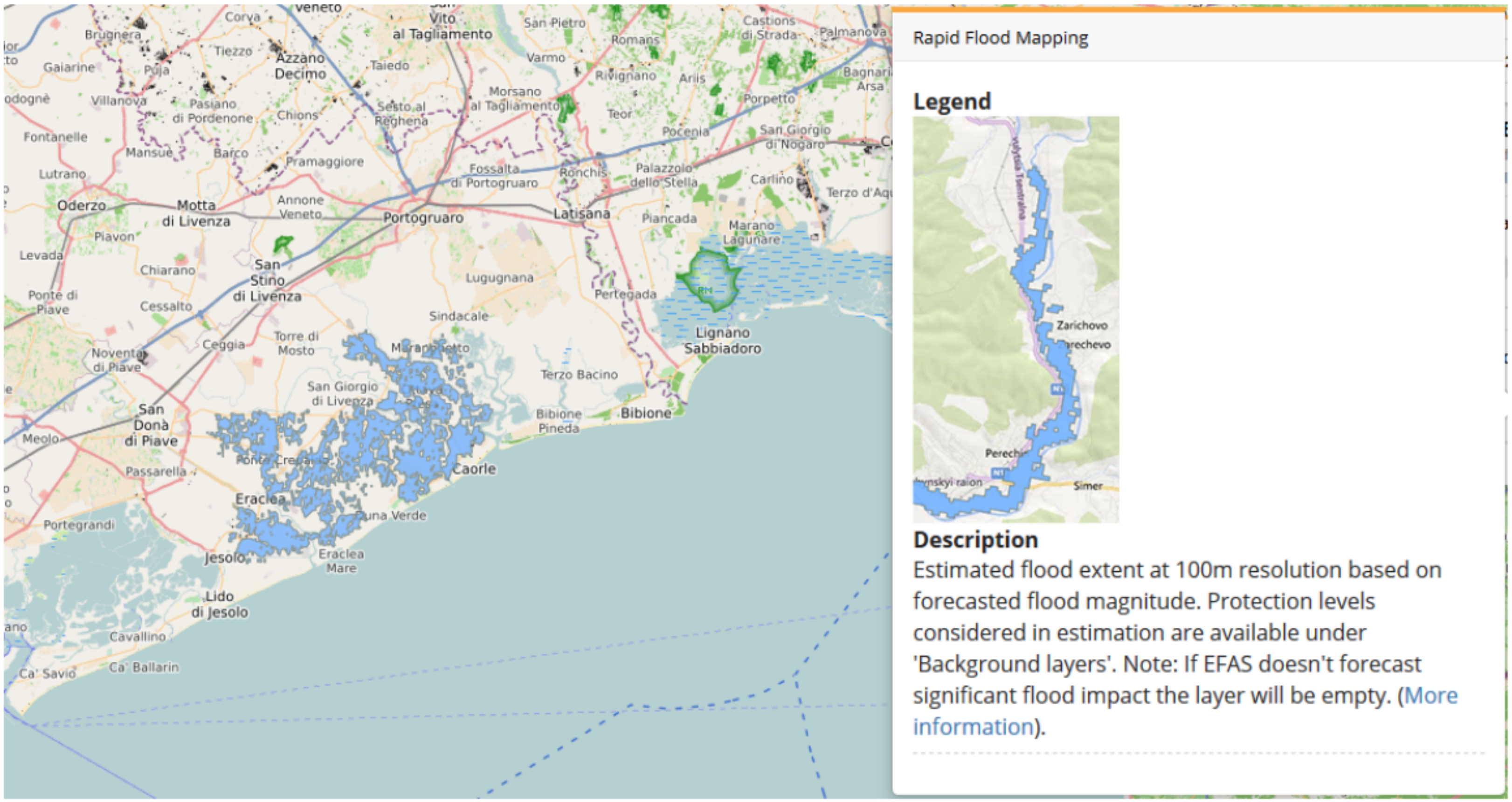
Use of flood maps in EFAS: rapid flood mapping

Display of the event-based flood extent map at 100m in EFAS



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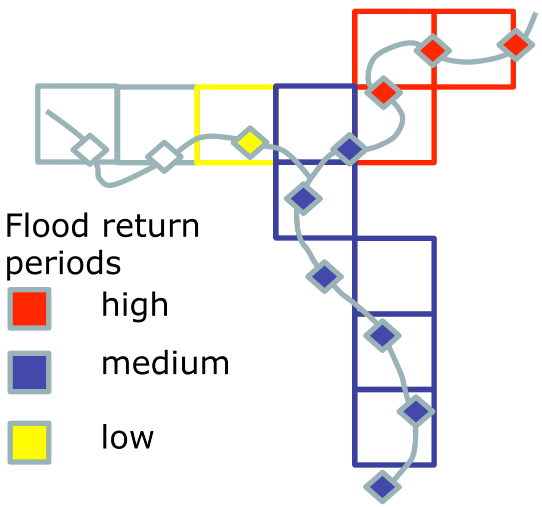
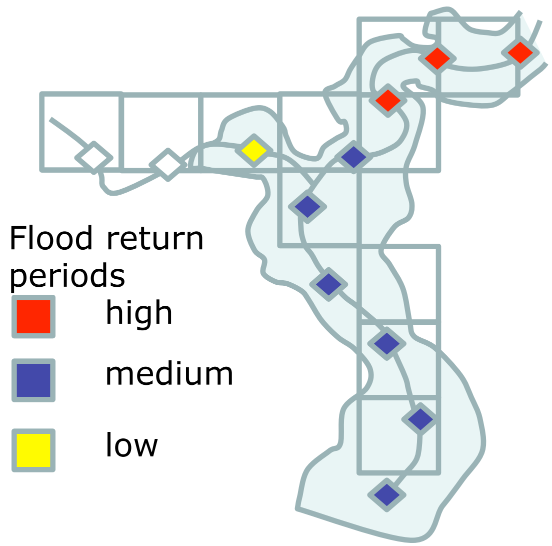
Use of flood maps in EFAS: Impact assessment

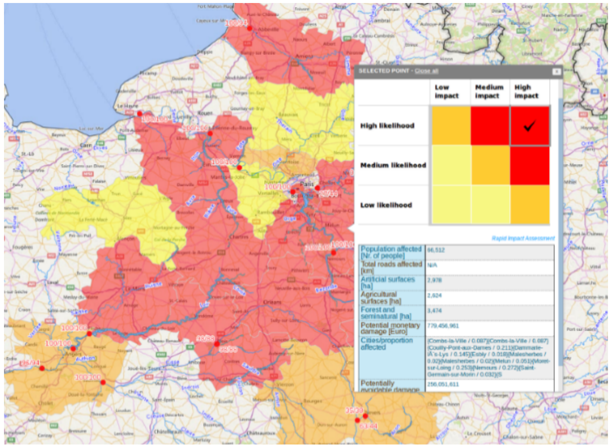
For any forecasted event we identify
- river sections affected
- local flood magnitude (return period)

Location and magnitude are used with the flood map library and flood protection maps to derive event-based hazard maps

combine flood maps with exposure and vulnerability information to assess potential impacts







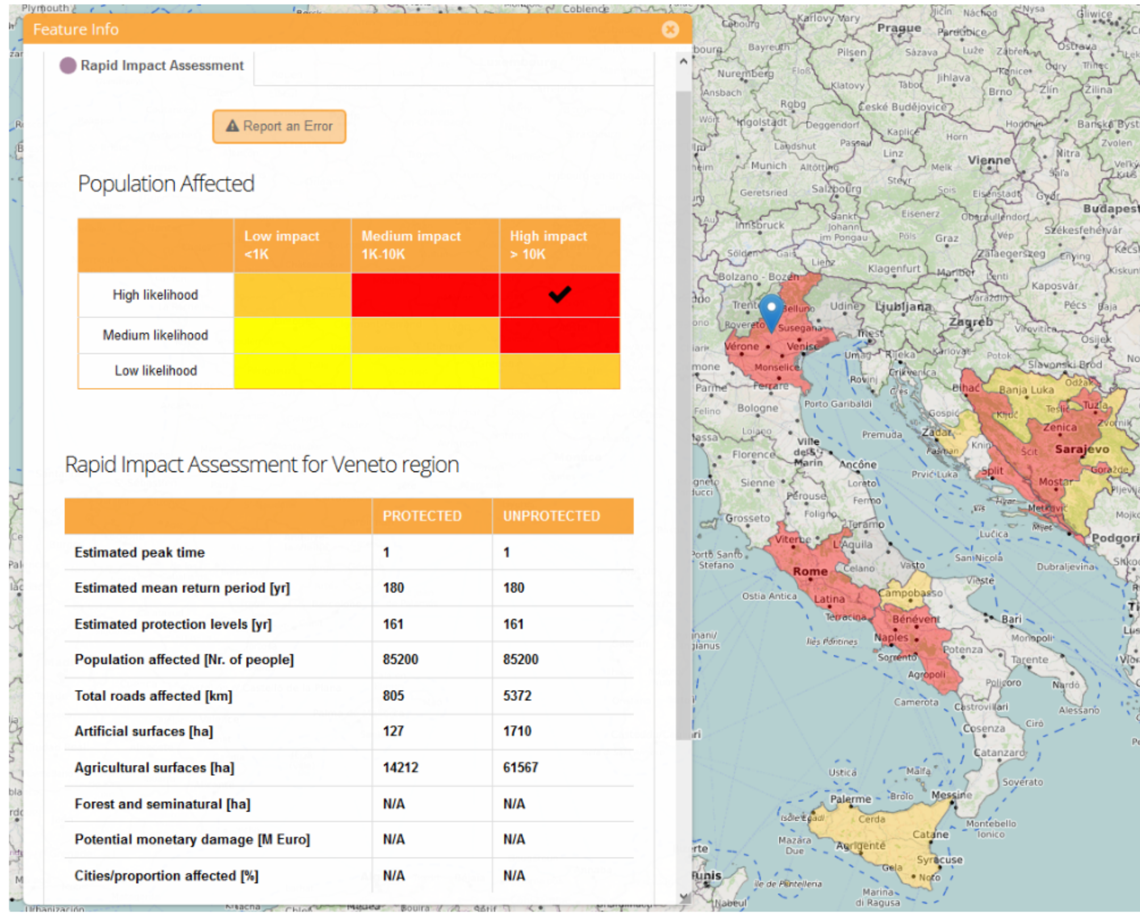
Dottori et al., 2017 - NHESS

Use of flood maps in EFAS: Impact assessment

Display of forecasted impacts on the EFAS interface:

- land use types affected
- Population affected
- Urban areas at risk
- Potential economic damage

Protected and unprotected scenarios



Dottori et al., 2017 - NHESS

Applications of CA2D: global flood hazard maps

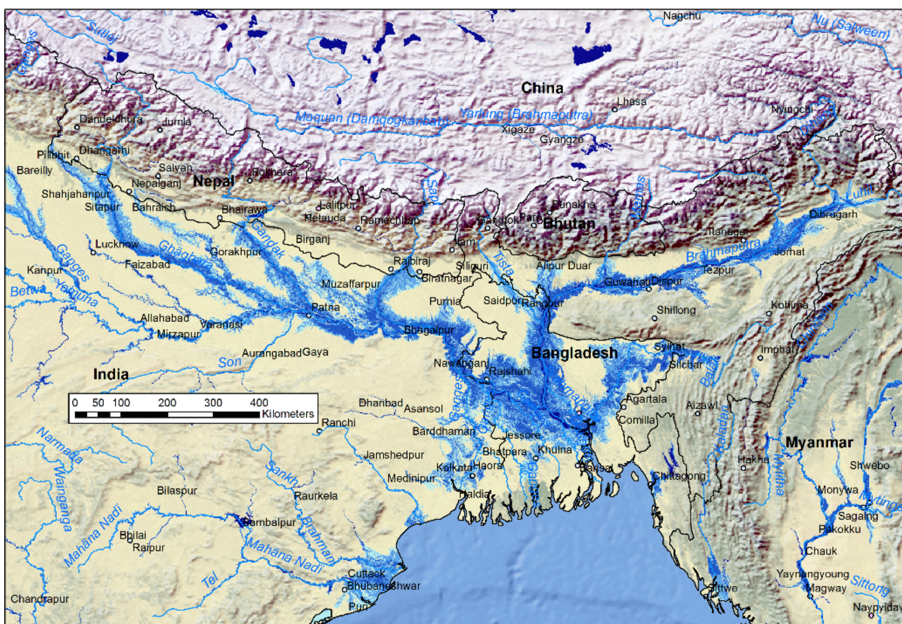
Objectives

- Develop a consistent set of flood hazard maps at global scale
- Provide a valuable tool to increase preparedness and reduce flood impacts in developing countries and data-scarce regions
- Integrate flood maps in the GloFAS forecasting system

Global flood hazard maps

- Hydrological input: GloFAS streamflow climatology (ERA-Interim)
- Based on 2D hydrodynamic modelling and freely available data
- 30'' resolution (~1km)
- return periods from 10 to 500 years

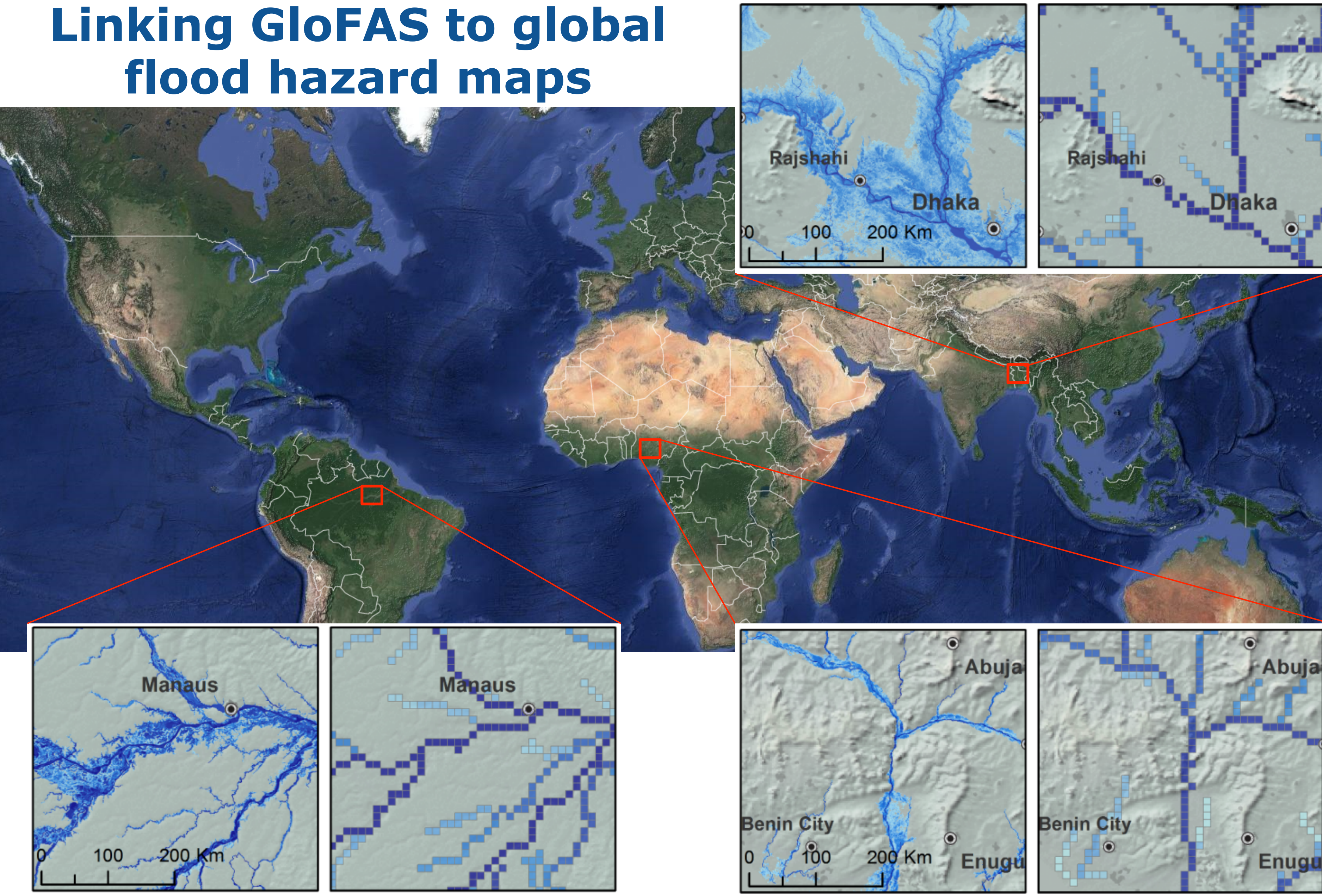
Flood hazard map for the Amazon River, return period 100 years (Dottori et. al, AWR 2016)



Flood hazard map for the Ganges-Brahmaputra rivers, return period 100 years (Dottori et. al, AWR 2016)

- Freely available for download at http://data.jrc.ec.europa.eu/collection/floods

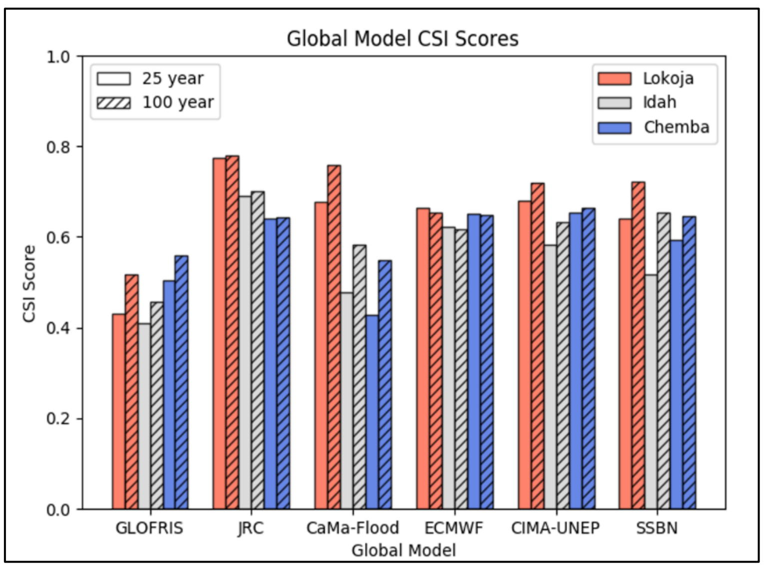
Linking GloFAS to global flood hazard maps

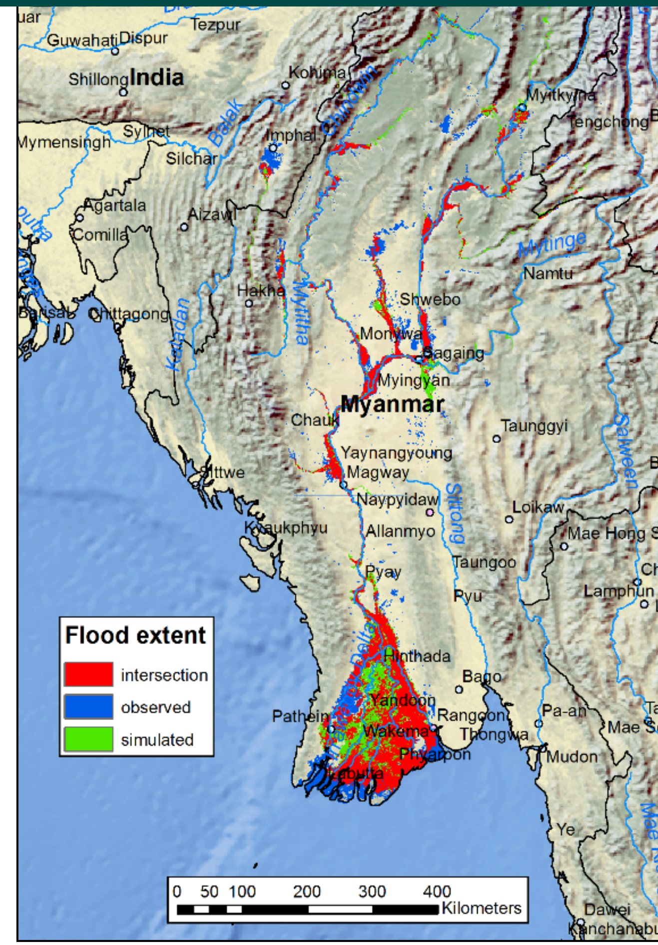


Global flood hazard maps: evaluation

- Validation with official flood hazard maps (Europe)
- Comparison with flooded areas from satellite images (South-America, Asia, Africa)
- Comparison with existing global flood models

Validation against satellite observations and other global flood models (Bernhofen et al., ERL 2018)





Simulated flood hazard maps and detected flood footprint for the period 2000-2013 in Myanmar (Dottori et al., 2016)

Thank you!