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Assessment of flood hazard on European scale: concepts and methods

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This project is funded by the European Union

Presentation plan

- Objectives of TU Delft's primary contribution in RAIN Work Package 2.
- Probabilistic modelling of river floods in Europe
- Probabilistic modelling of storm surges in Europe
- Assessment of flood defences' vulnerability

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Primary work objectives

- Pan-European gridded data sets of the extreme weather probability in the present and projected climate scenarios for coastal and river floods.
- European flood risk map of damages to flood defence systems.

To do that we would need to:

- Prepare river and coastal flood scenarios, i.e. river discharges and storm surges' heights with given return periods…
- Prepare the scenarios both for historical periods and for the future, under different scenarios of climate change…
- Calculate the extent of floods, water levels and depth…
- Assess the impact of those floods on the flood defence systems…

…for all Europe

Is that possible?

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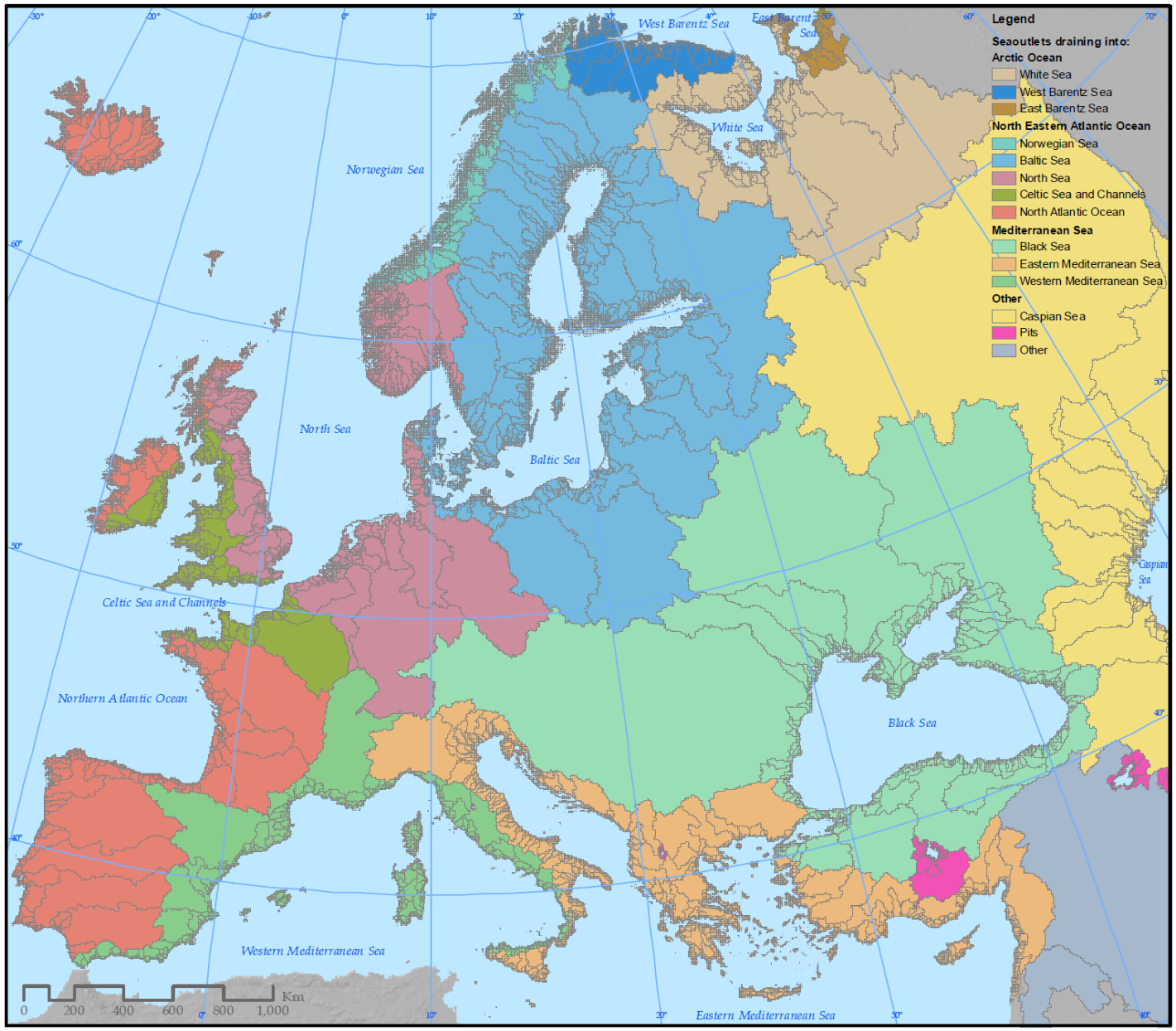
Rivers



Highest-order river catchments (sea outlets) in Europe

Vogt et al. (2010) "Main Rivers of Europe", available at http://ccm.jrc.ec.europa.eu/

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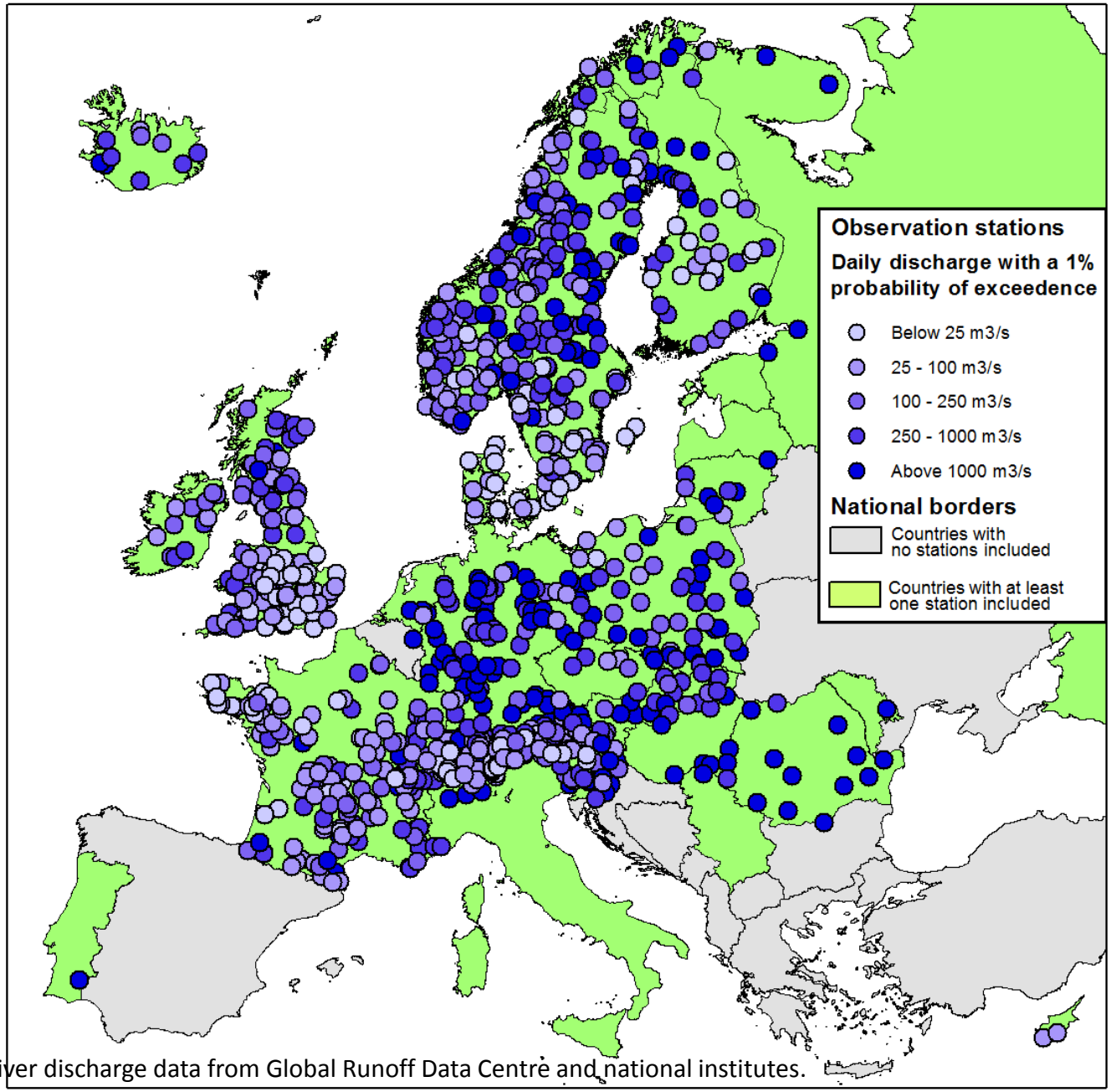
River discharges



River discharge data from Global Runoff Data Centre and national institutes.

Stations with at least three full decades of continuous records (1951-2000)

Country	Stations
France	163
Sweden	142
United Kingdom	136
Germany	125
Norway	101
Switzerland	75
Other	277
Total	**1019**

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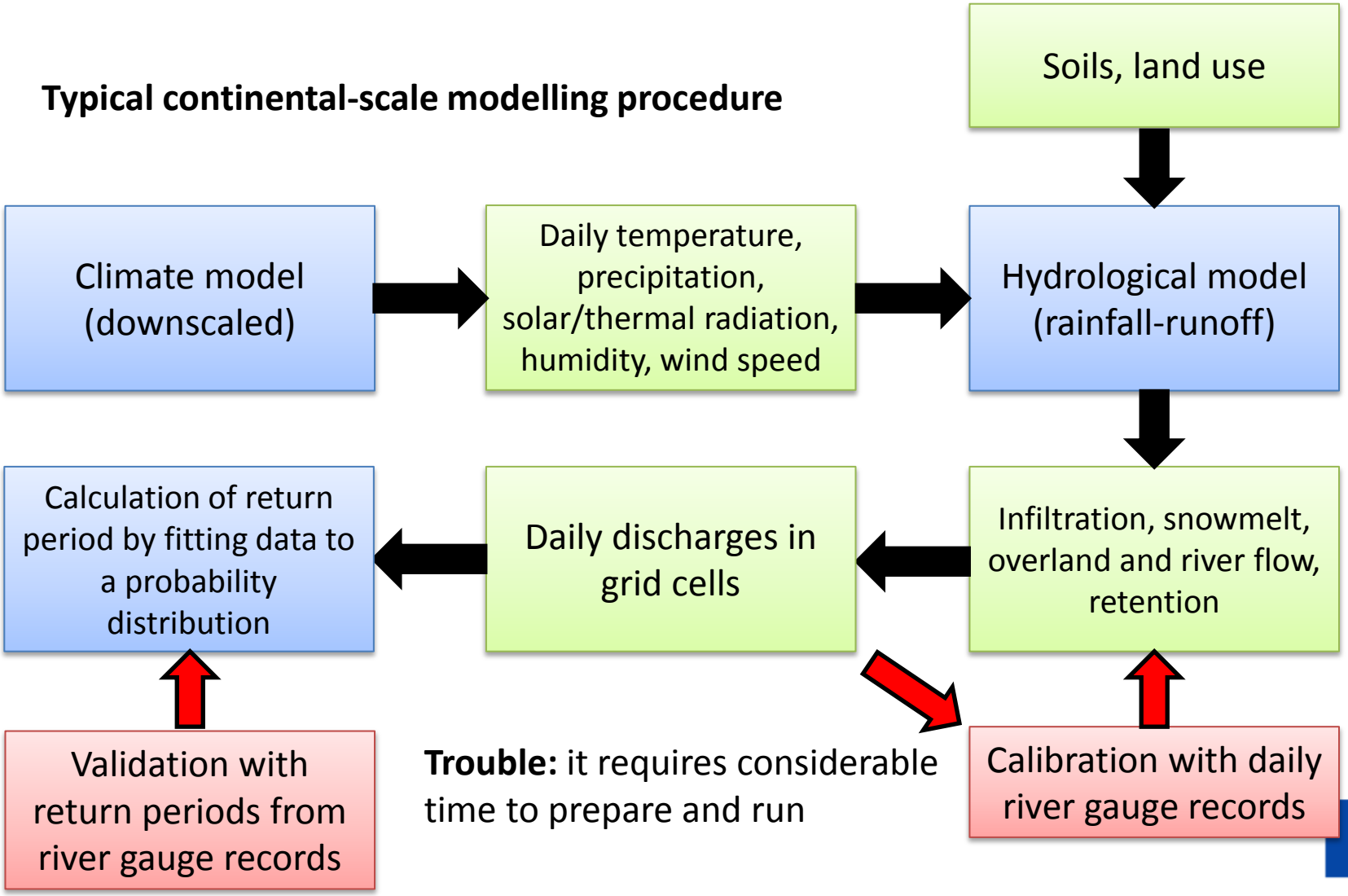
River discharges

Typical continental-scale modelling procedure



Trouble: it requires considerable time to prepare and run

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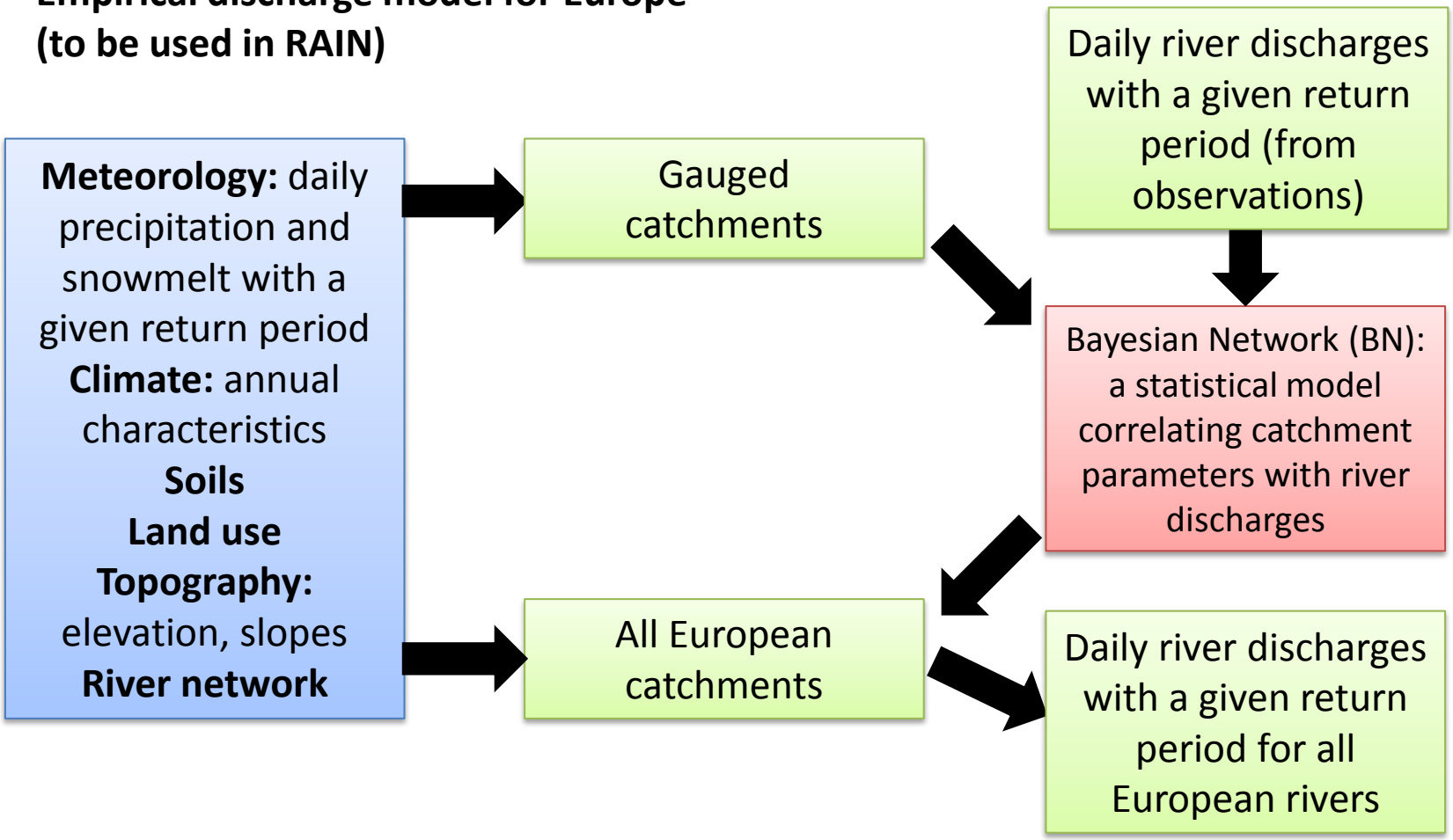
River discharges

Empirical discharge model for Europe (to be used in RAIN)



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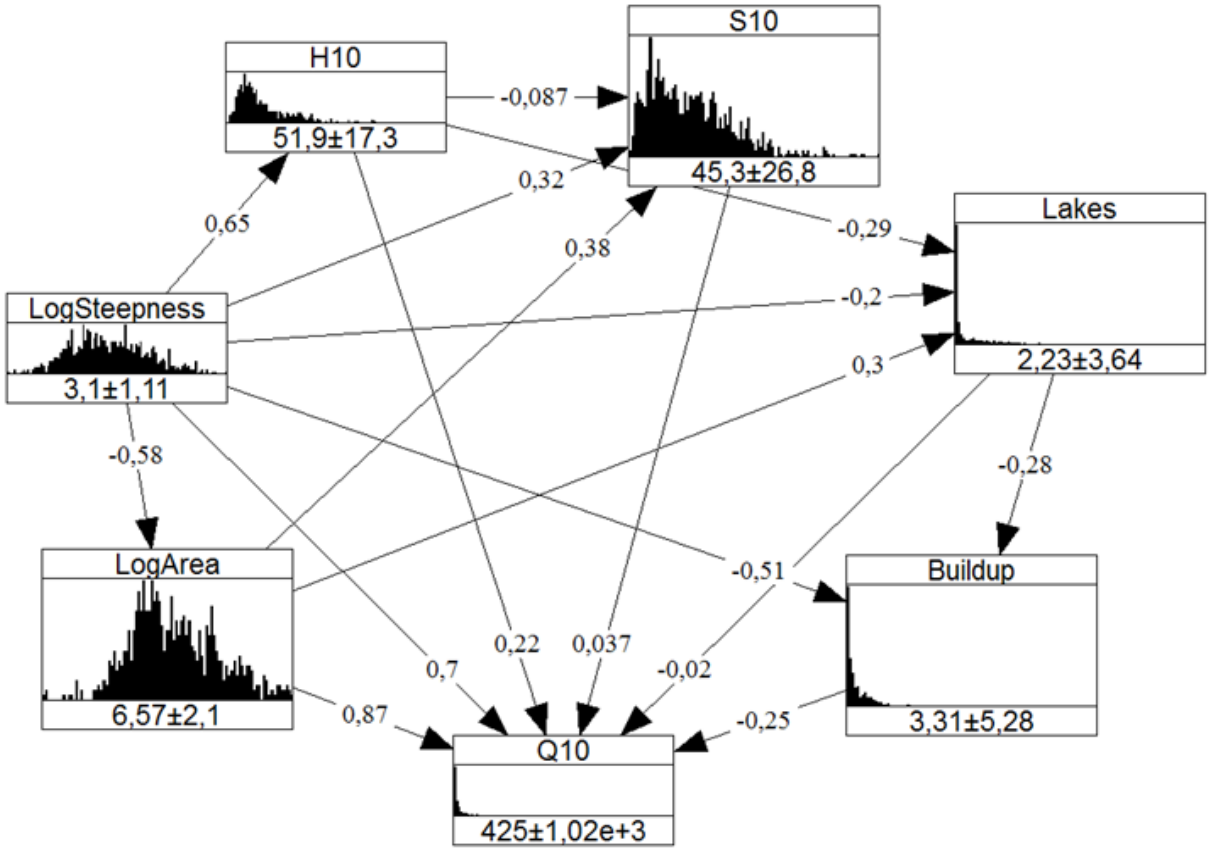
River discharges



Bayesian network for daily river discharges in Europe with a 10-year return period

Q10 – river discharge, 10-year return period;
LogArea – logarithm of catchment area;
LogSteepness - logarithm of catchment steepness;
H10 – rainfall, 10-year r. p.;
S10 – snowmelt, 10-year r. p.;
Lakes – lake coverage;
Build-up – build-up areas coverage.

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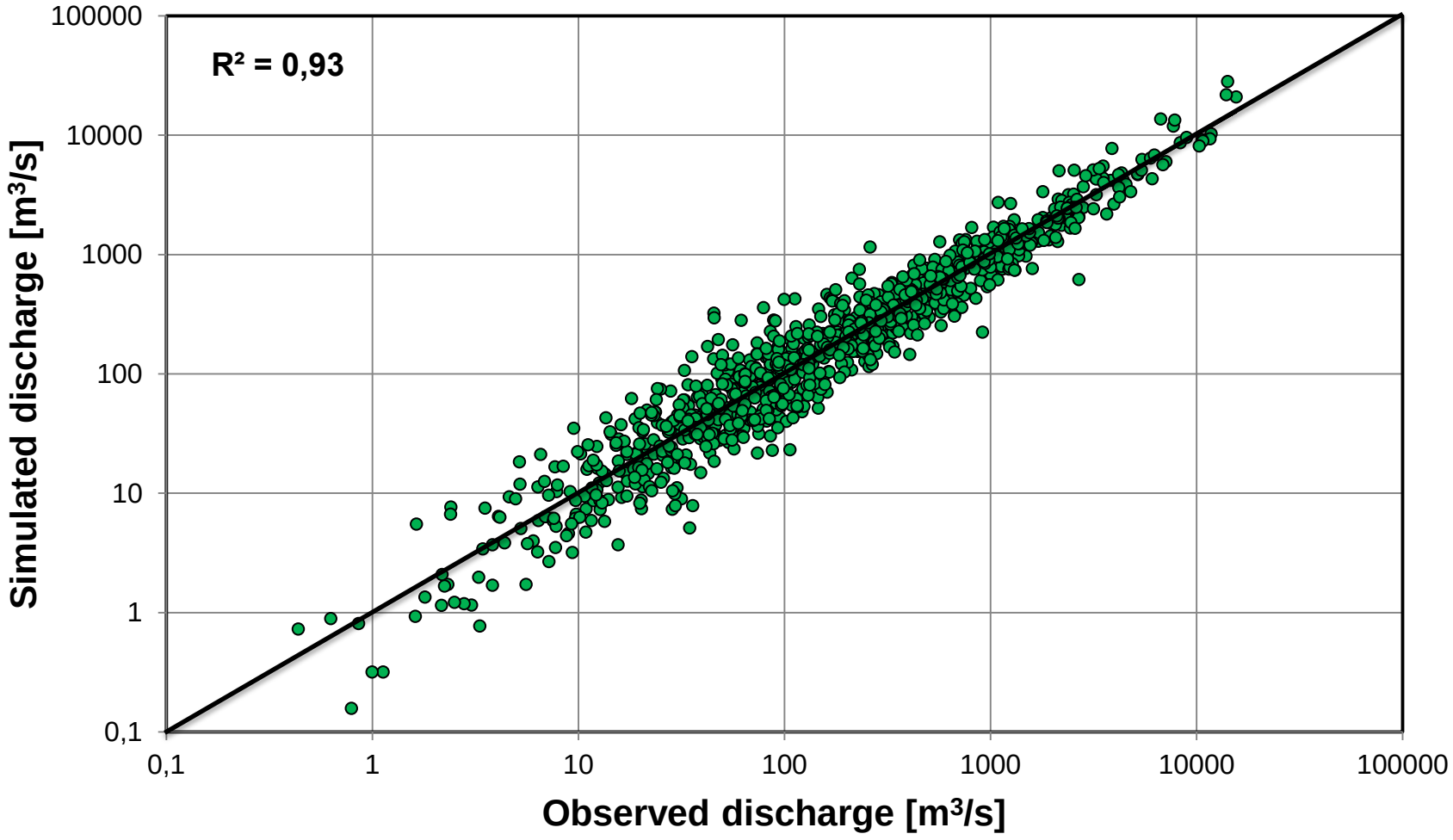
River discharges



Daily river discharges in Europe with a 100-year return period:
Simulated using a BN and calculated from river gauge observations

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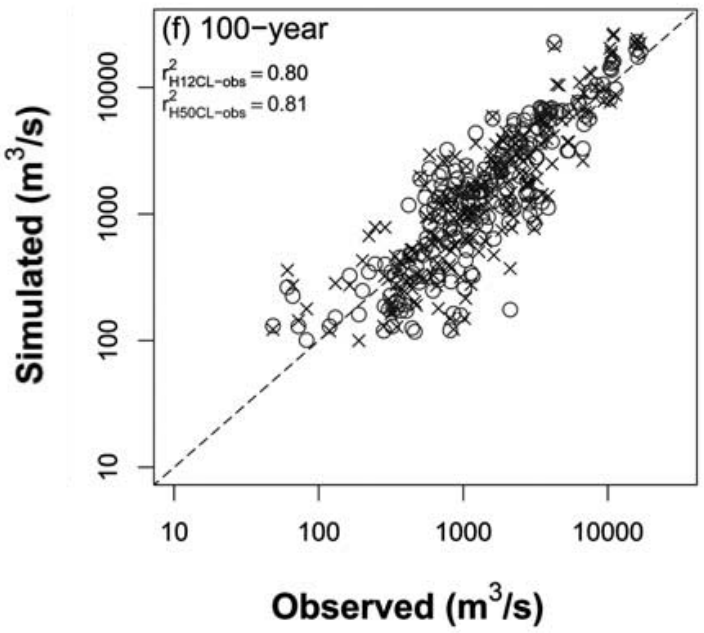
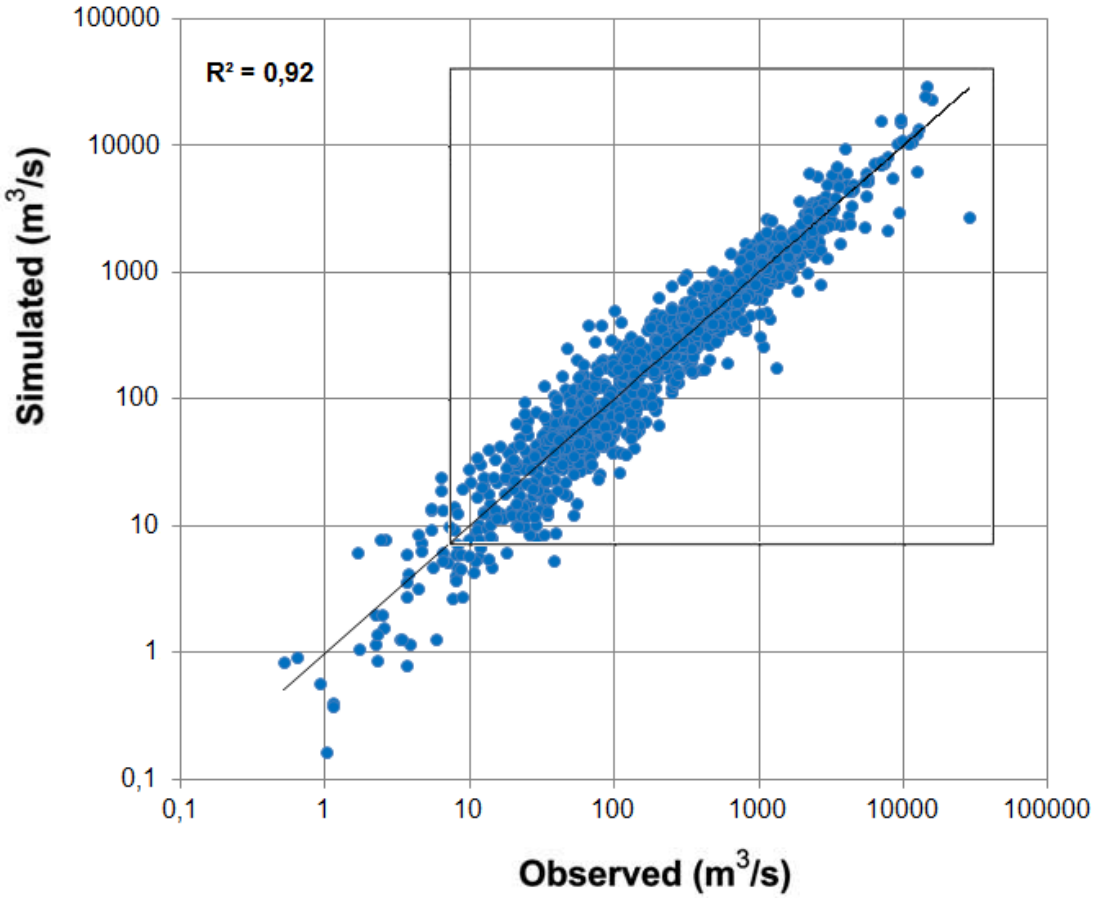
River discharges

Observed vs simulated discharges at European stations, 1% probability, GEV distribution

Dankers and Feyen (2008):
Hydrologic model validated at 219 stations for 1961-1990 or 1971-2000



My work (in progress):
Bayesian Network validated against 1013 stations for 1961-1990 or 1971-2000



Dankers and Feyen (2008) J Geophys Res 113:D19105. doi:10.1029/2007JD009719

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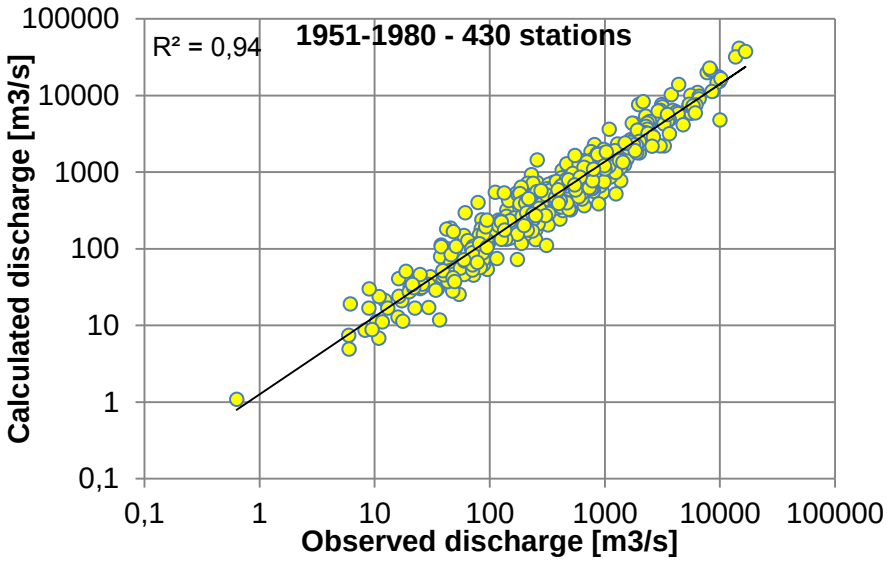
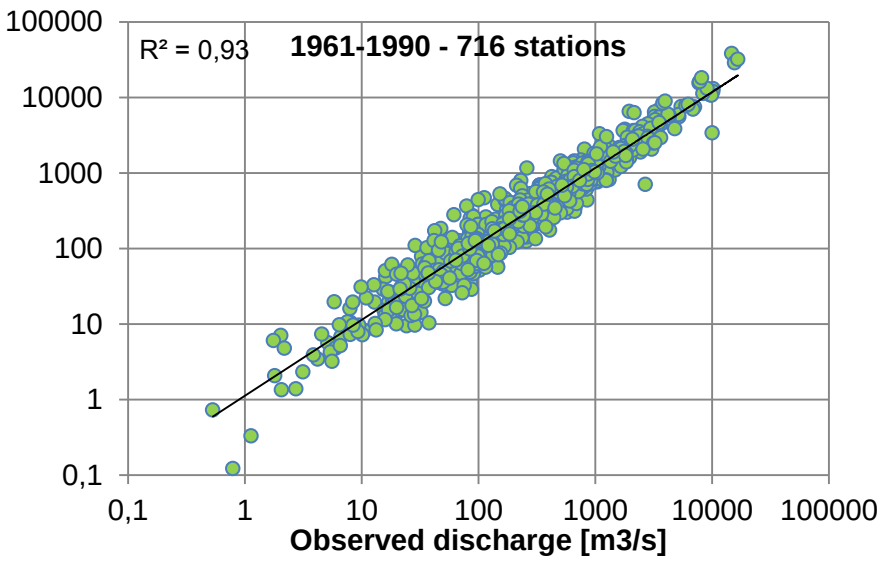
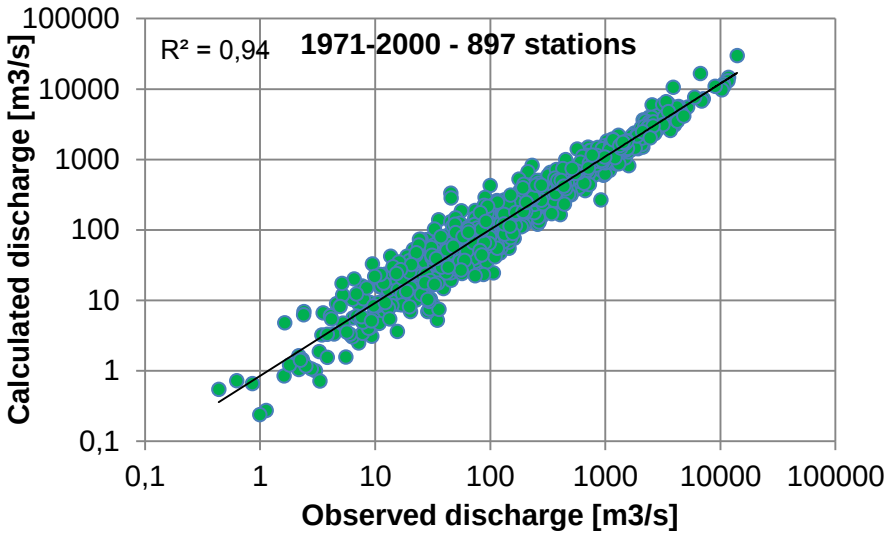
River discharges







Daily river discharges in Europe with a 100-year return period:
Calculated using a BN and observed from river gauge observations

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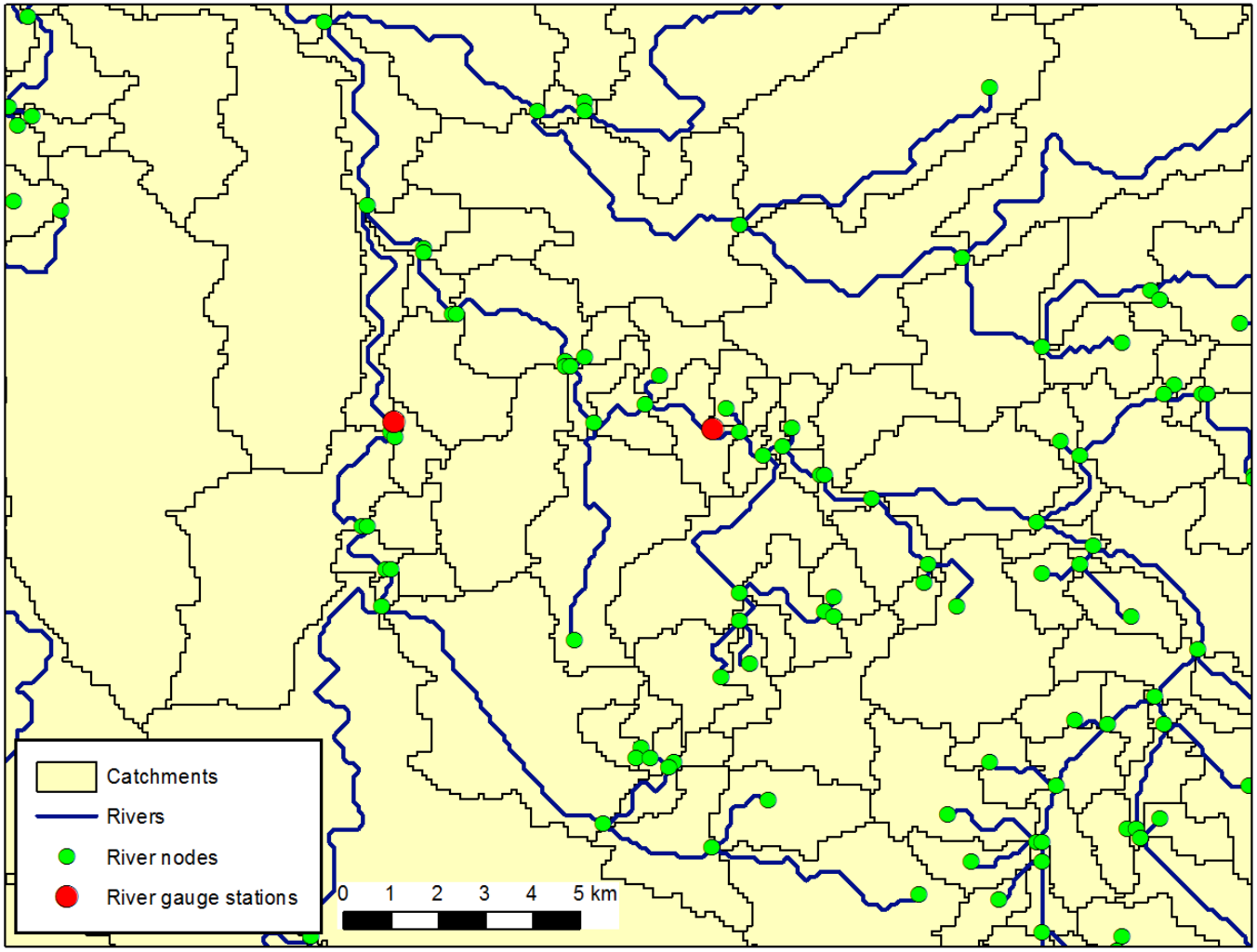
Flood extent



Discharges can be transformed into flood extents using a combination of GIS techniques with empirical methods or hydrodynamic models.

CCM2 database available at http://ccm.jrc.ec.europa.eu/

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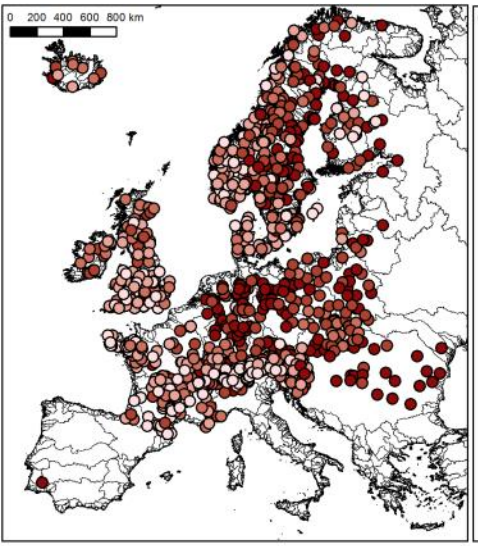
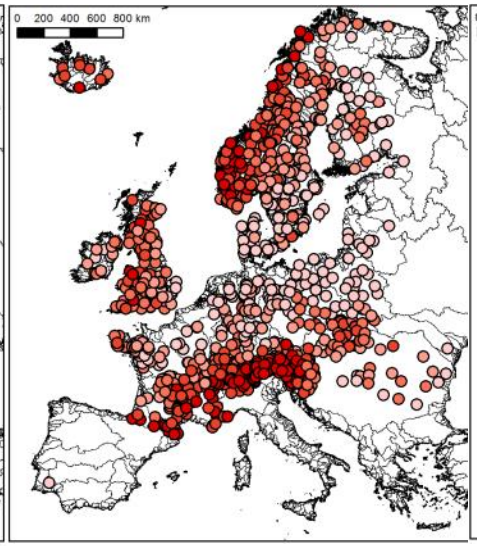
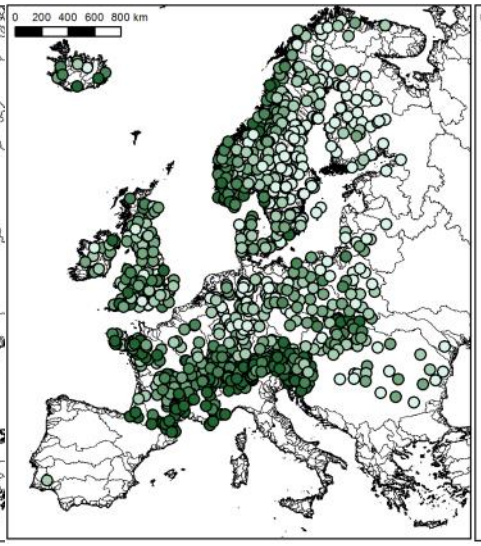
River discharges



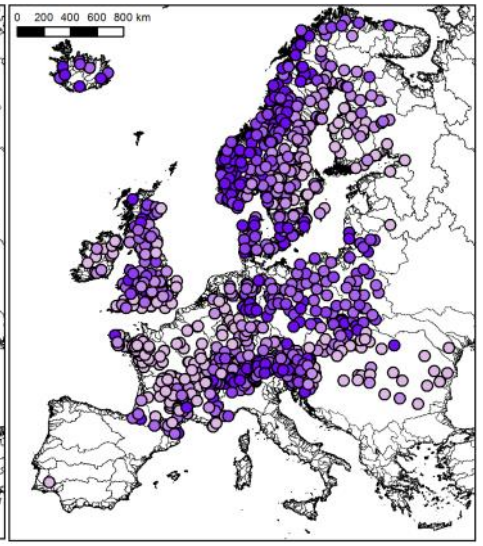
Catchment area



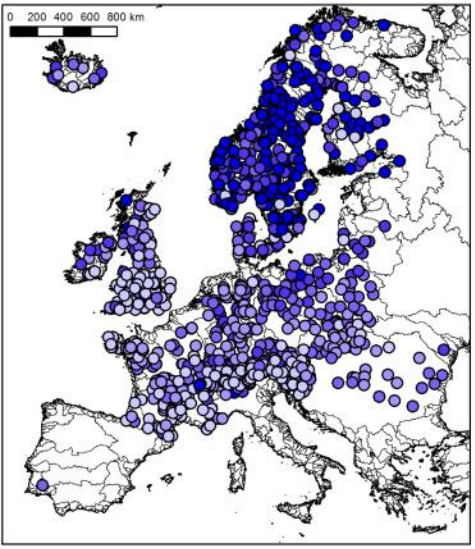
Catchment steepness



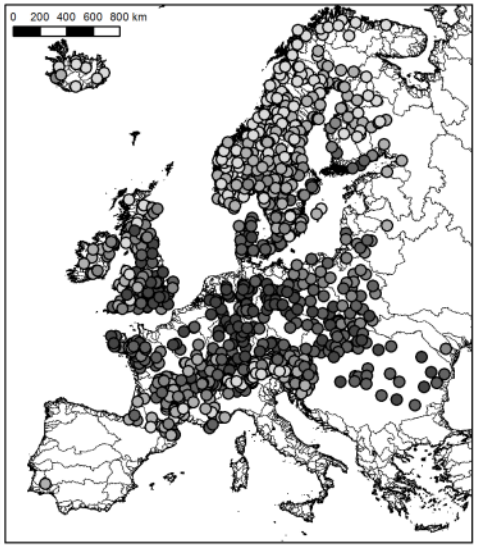
Extreme rainfall



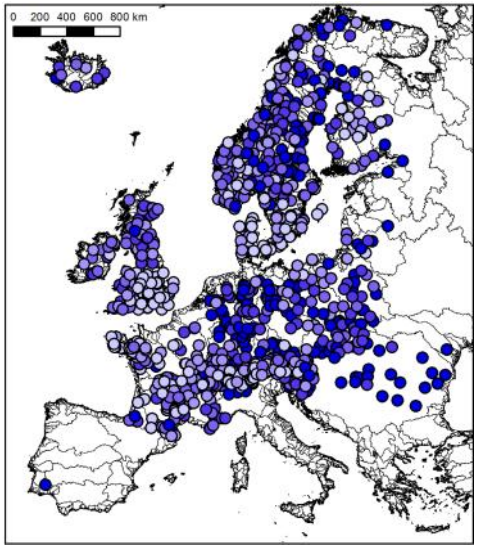
Extreme snowmelt



Lakes



Build-up areas



Extreme discharge

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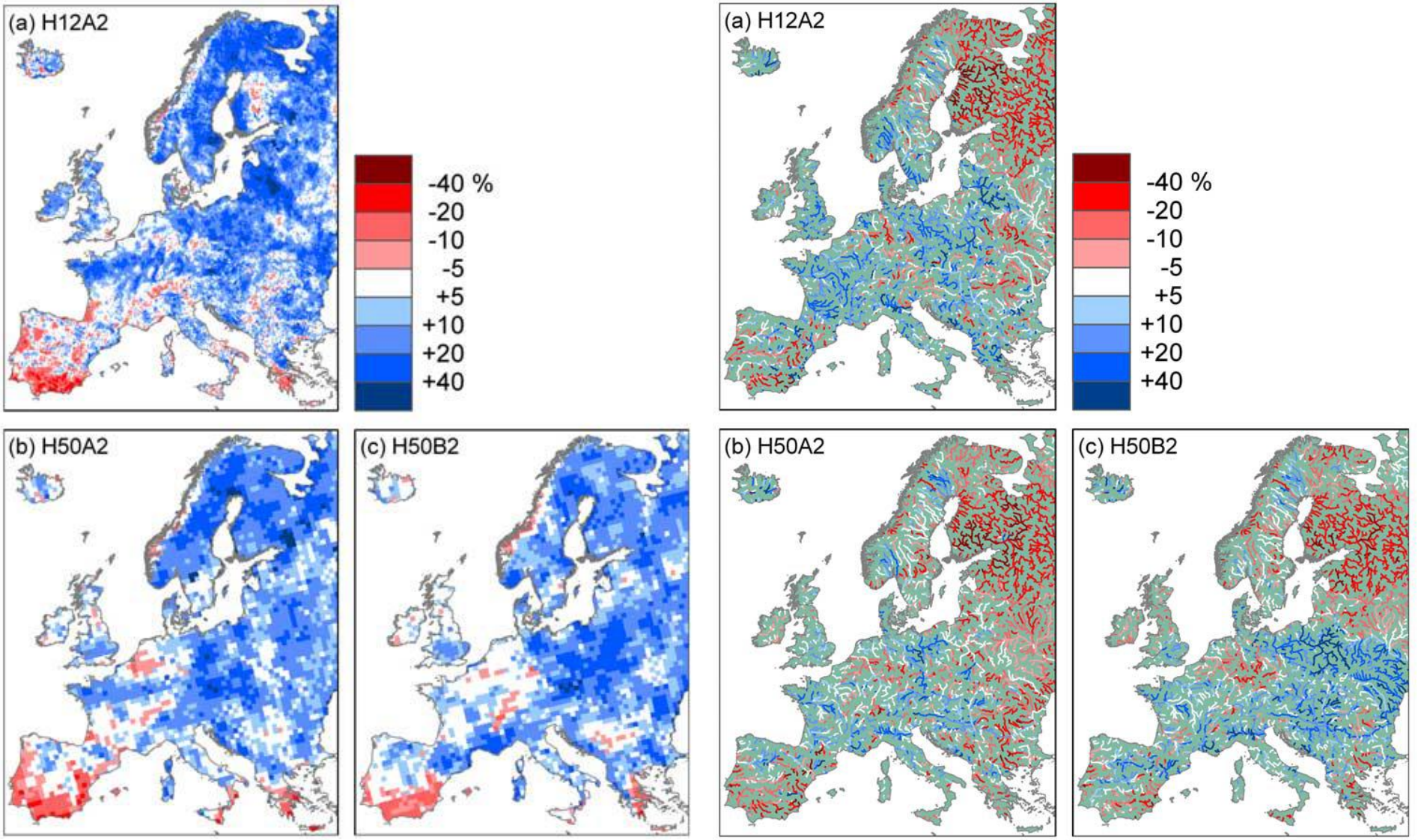
Climate change



Relative change of extreme precipitation (left) and discharge (right)

Projections by *Dankers and Feyen* (2008), 2071-2100 relative to 1961-1990

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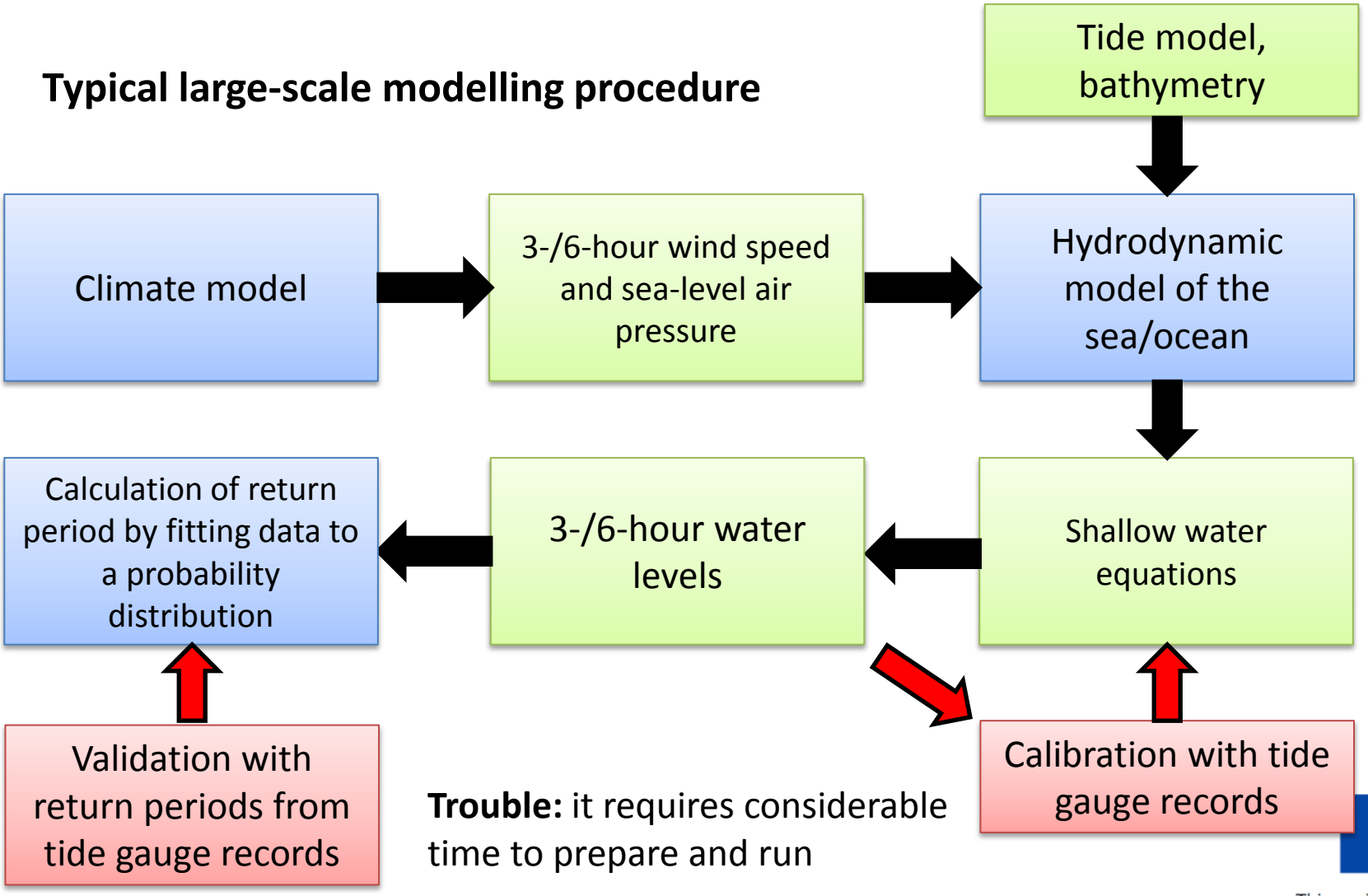
Storm surges

Typical large-scale modelling procedure



Trouble: it requires considerable time to prepare and run

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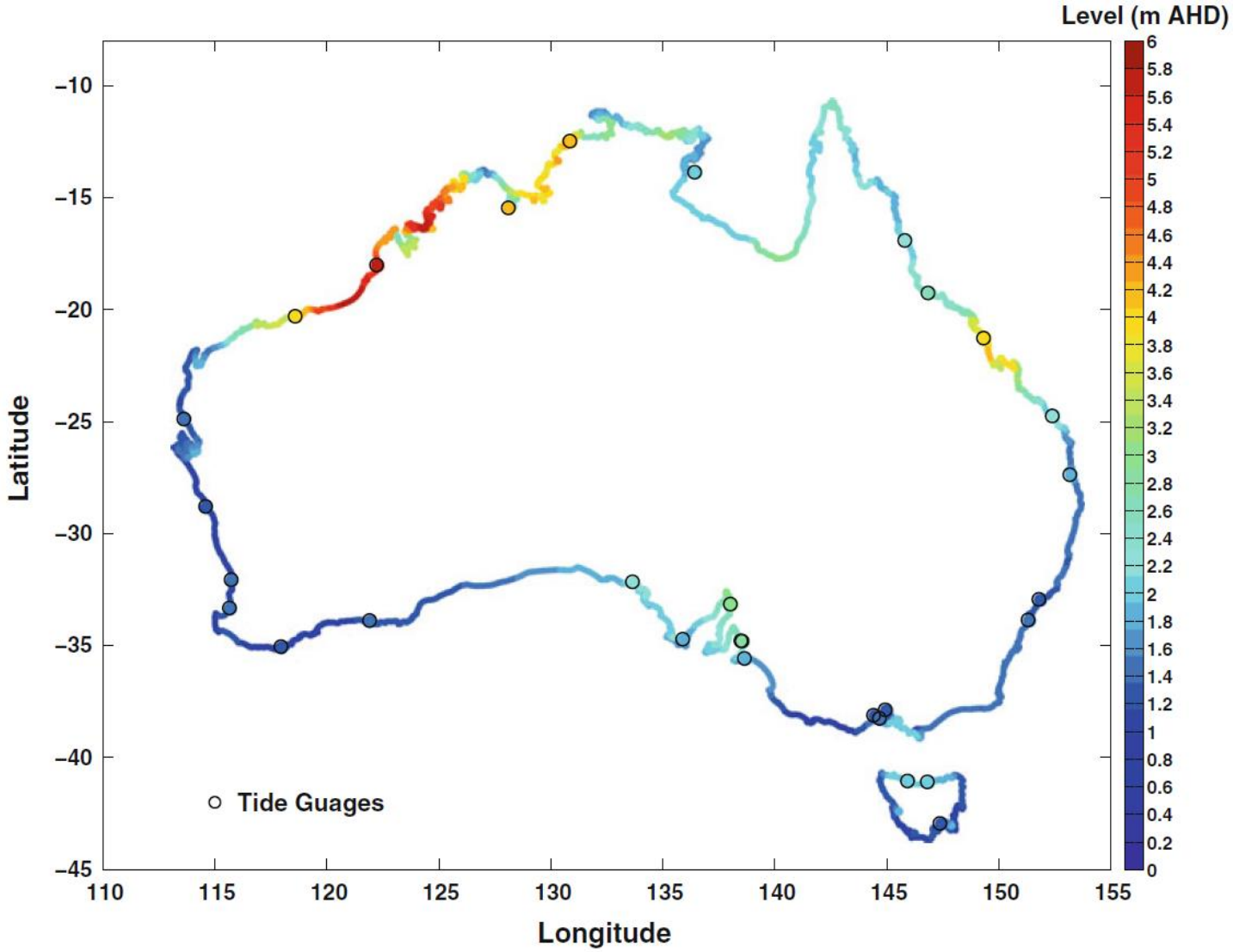
Storm surges



100-year storm surge heights on the coast of Australia
Calculated by a model of the ocean driven by wind and air pressure.
From *Haigh et al.* (2014).

Haigh et al. (2014) Clim Dyn 42:121–138. doi:10.1007/s00382-012-1652-1

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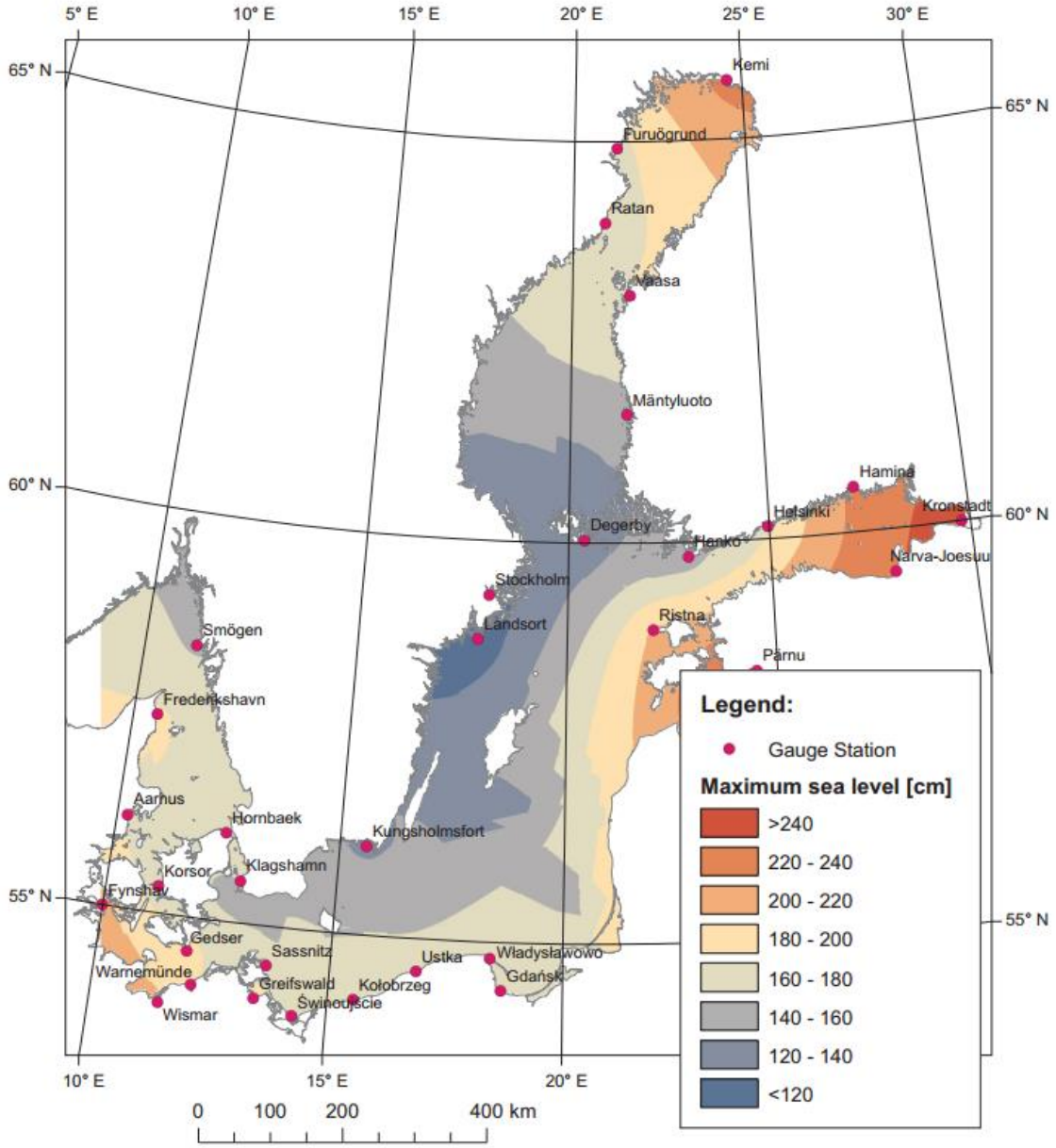
Storm surges



100-year storm surge heights in the Baltic Sea
Calculated by geostatistical interpolation of 50 years of data from 31 stations.
From *Wolski et al.* (2014).

Wolski et al. (2014) Oceanologia 56:259–290. doi:10.5697/oc.56-2.259

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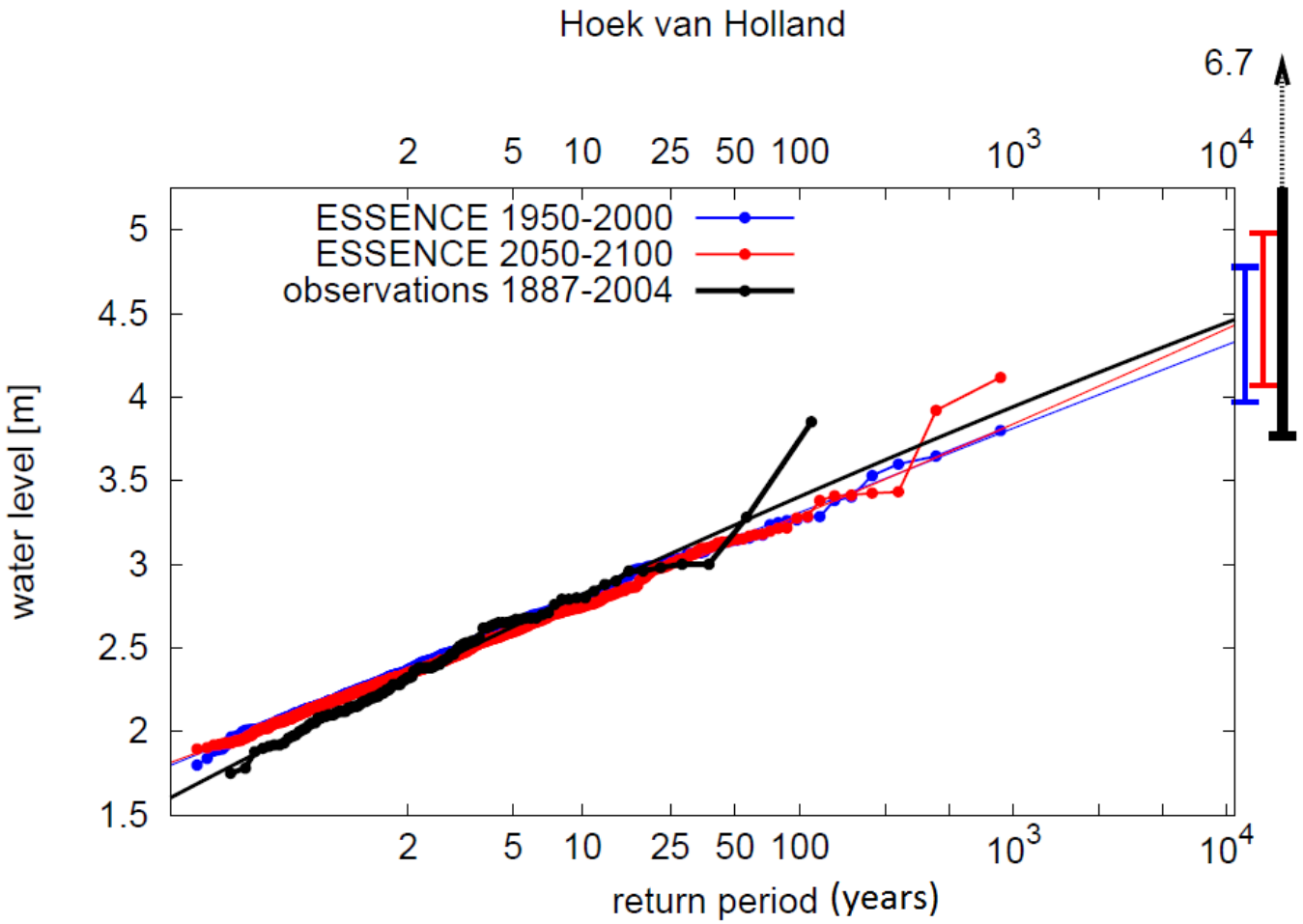
Storm surges



Storm surge heights in Hook of Holland (North Sea) under past and future climate (GEV distribution). From *Sterl et al.* (2009).

Sterl et al. (2009) Ocean Sci 5:369–378. doi:10.5194/os-5-369-2009

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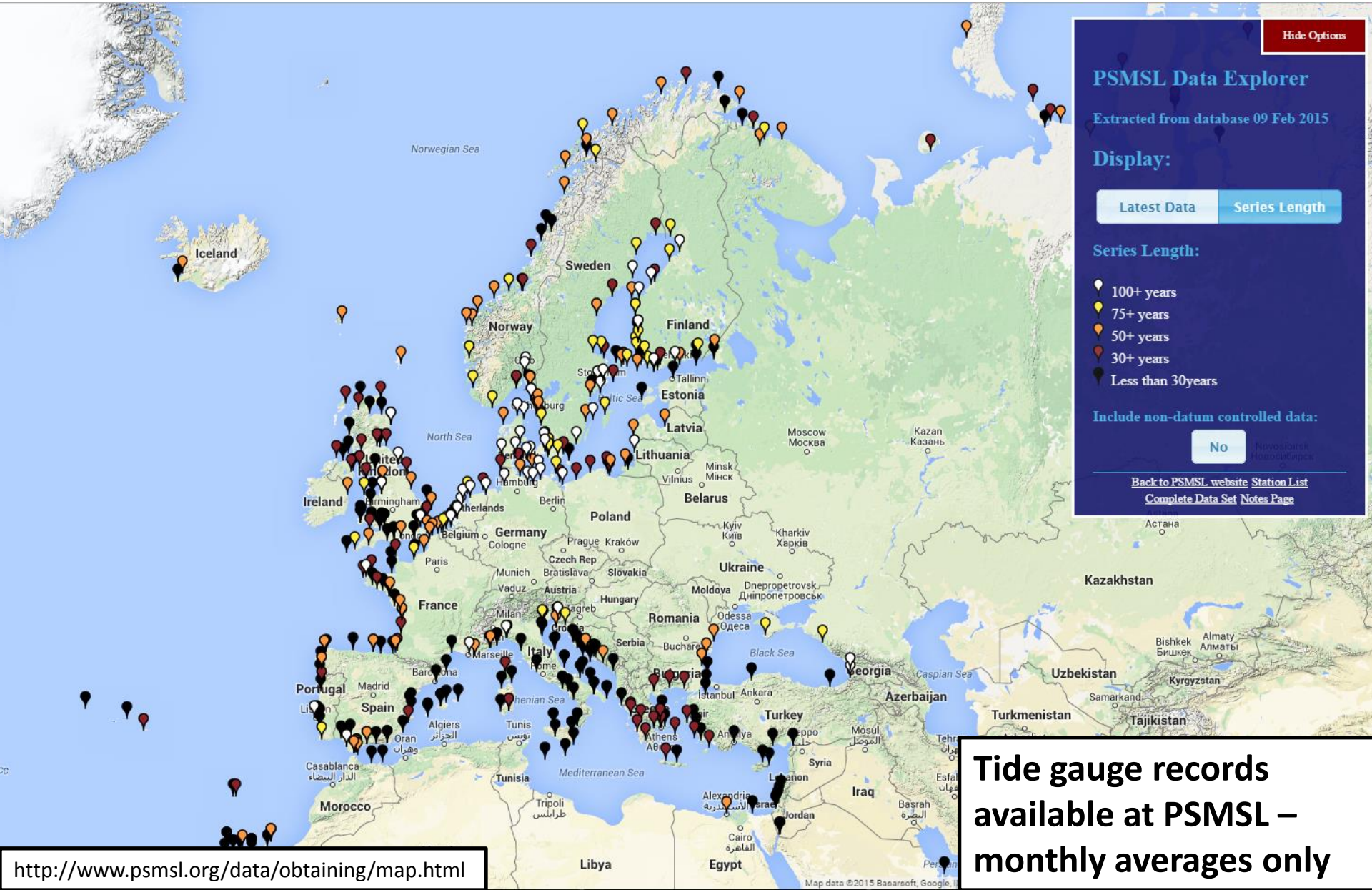
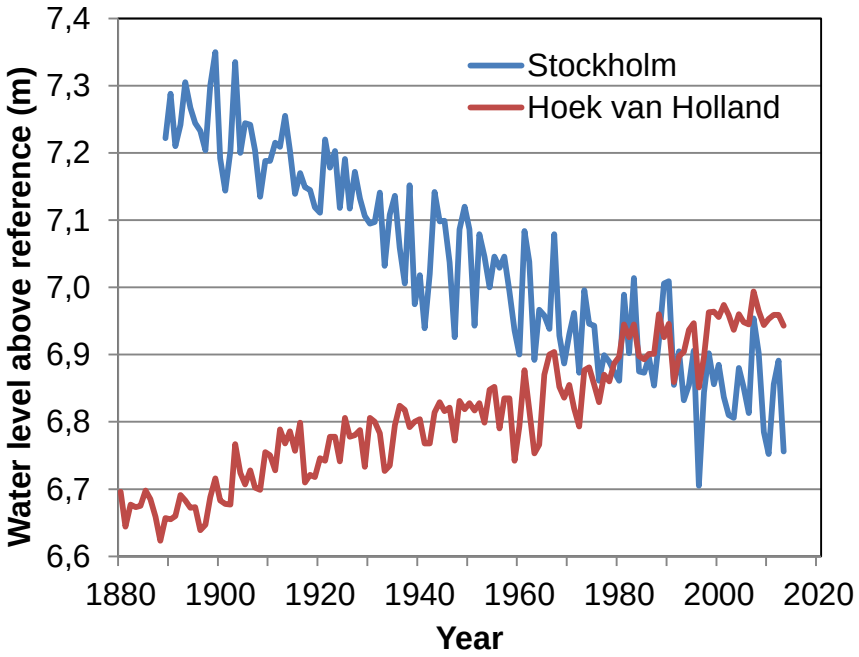
Sea level data



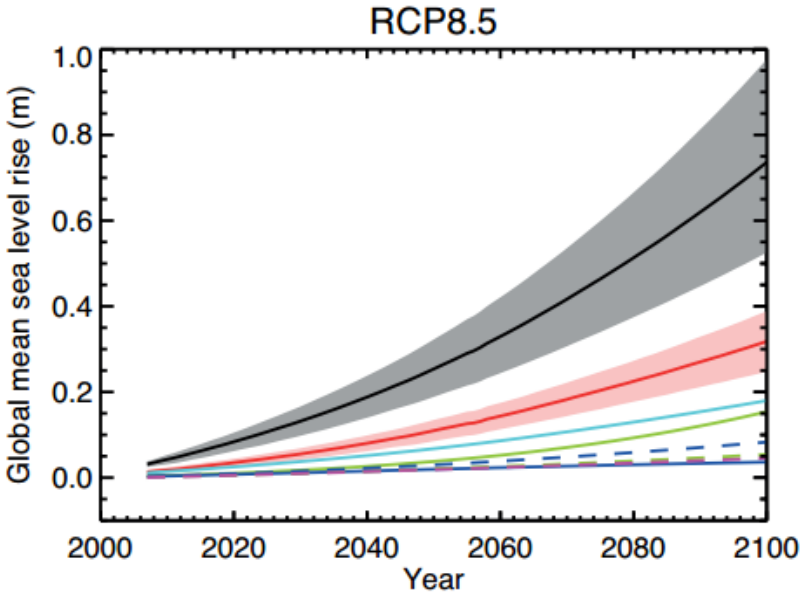
Tide gauge records available at PSMSL – monthly averages only

http://www.psmsl.org/data/obtaining/map.html

Climate change



Trends in mean sea level,1880-2013
Based on data from PSMSL.



Sea level rise up to 2100
IPCC projections by emission scenario.

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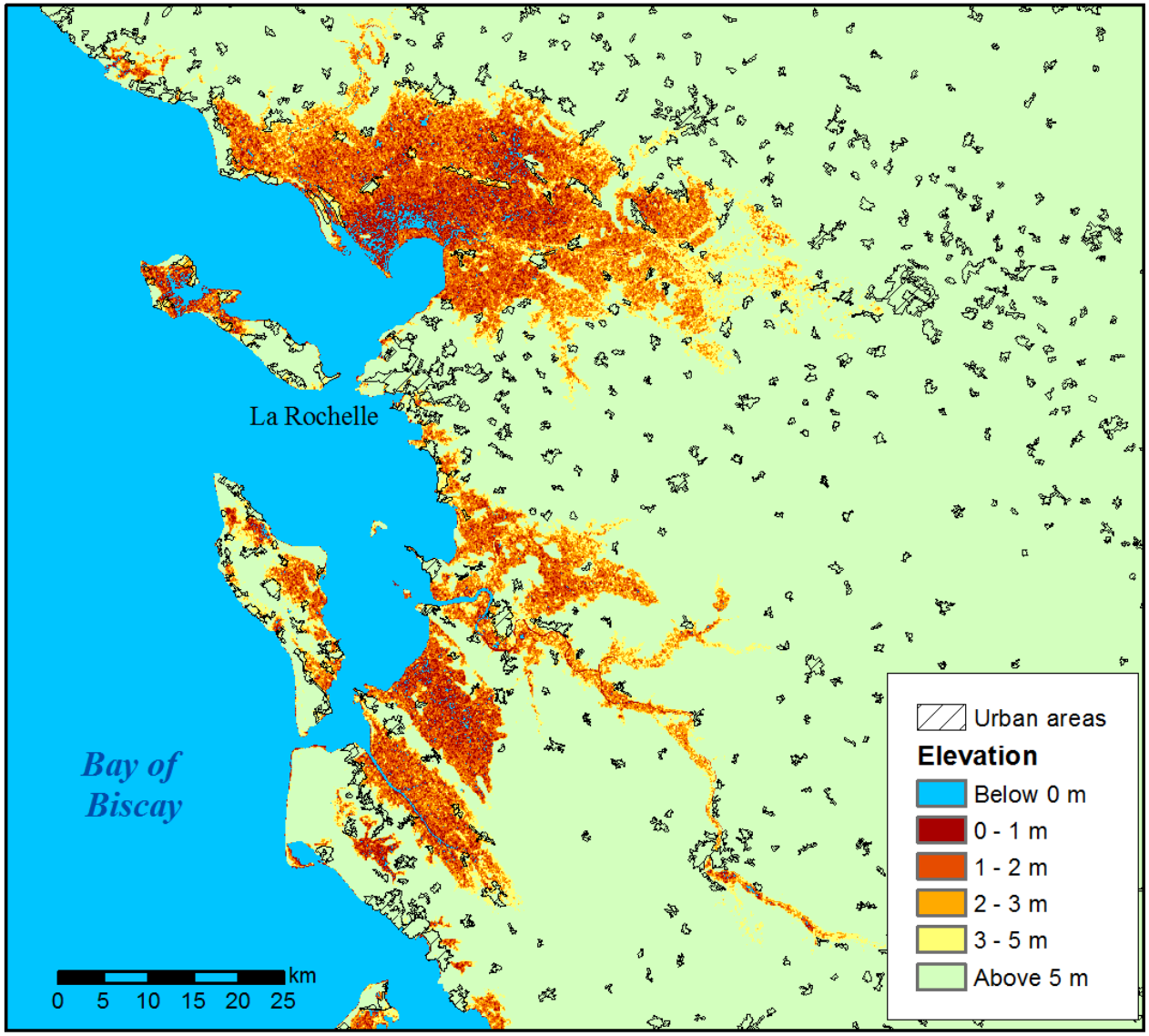
PSMSL, http://www.psmsl.org/data/obtaining/map.html; Church et al. (2013) “Sea Level Rise”, IPCC AR5

Coastal floods



"Bathtub fill" method: storm surge levels are intersected with the digital elevation model (DEM)

Trouble: the errors in elevation data from continental/global DEMs is often higher than the height of storm surges; Flood defences are mostly absent.

EU-DEM: http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/digital-elevation-model

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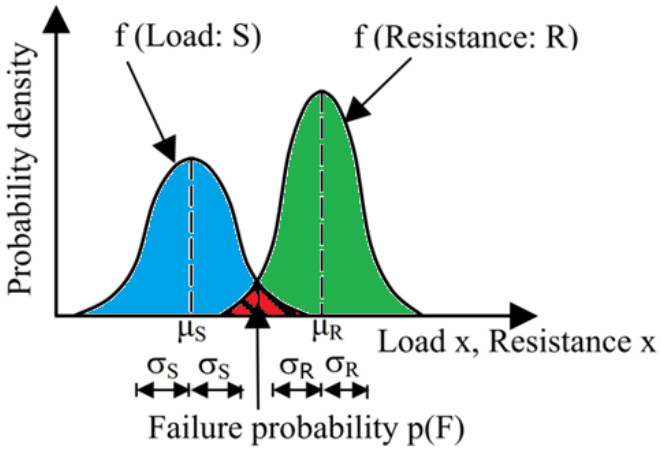
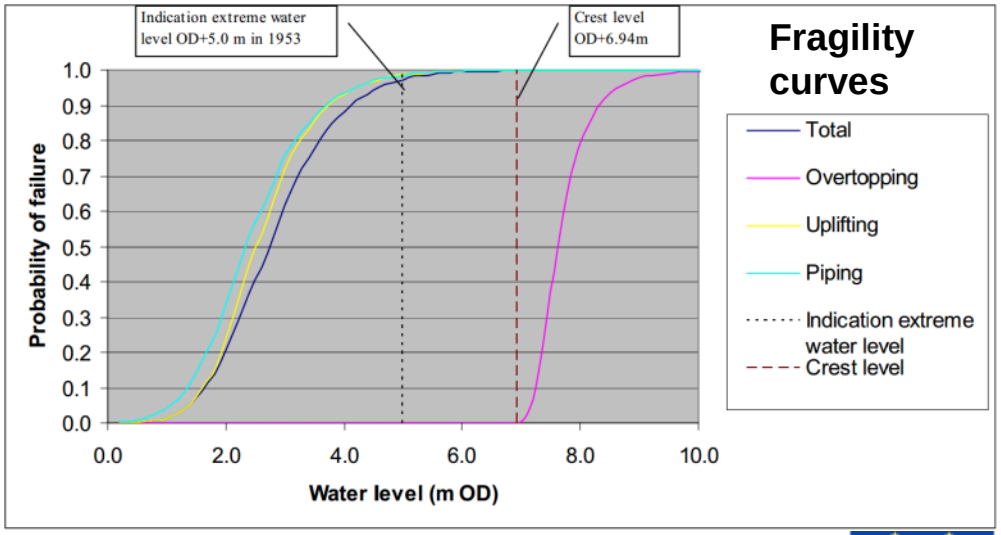
Flood defences

- Failure probability is the intersection of load and resistance.
- The most important load to flood defences is water level.
- Resistance is against overtopping, piping, heave, uplifting, erosion, instability and many others.
- Analysis of dike failure requires detailed knowledge of both.





Adapted from Möllmann and Vermeer (2007) "Reliability analysis of a dike failure", FLOODsite (2008) "Reliability Analysis of Flood Sea Defence Structures and Systems"

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Flood defences

Selected inventory of flood defences in Europe

Territory	Length of defences	Authority
England	11,000+ km of broadly defined flood defences	Mostly centralised in the Environment Agency
France	c. 10,000 km of broadly defined flood defences, incl. c. 1,300 km in the coast	Very scattered – mostly responsibility of landowners
Poland	8,482 km of river dikes	National and regional authorities
The Netherlands	3,500 km of primary and c. 14,000 km of secondary flood defences	Regional authorities

Data on flood defences locations and characteristics (crest height, width, slopes, soil type, etc.) are not available on European scale.

Environment Agency (2007) "Review of 2007 summer floods"; Kolen et al. (2013) J Flood Risk Management 6:261–278. doi:10.1111/jfr3.12011
Central Statistical Office (2015) "Rocznik Statystyczny Rolnictwa 2014"; Rijkswaterstaat (2006) Irrig Drain 55:S121–S132. doi:10.1002/ird.242

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Flood defences

A possible method of assessment of risk to flood defences in Europe

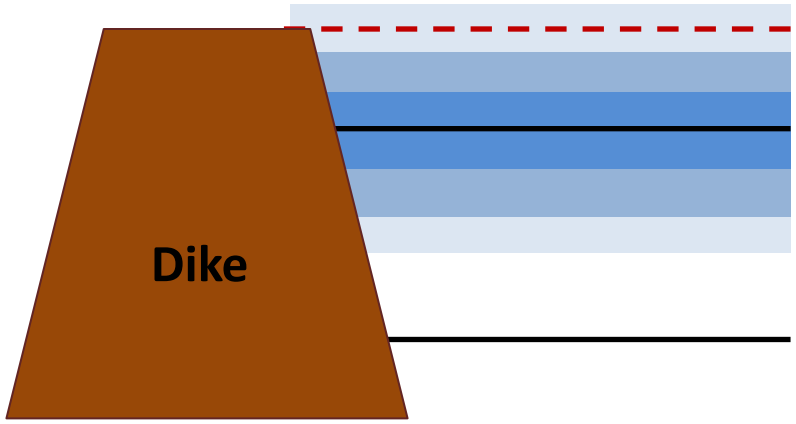
Assumed/desired/actual level of protection (crest height equal to a given water level return period + safety margin)

→

Climate change: increase/decrease of water levels with uncertainty bounds

→

Probability that the future water level will be higher than the dike's level of protection



Protection level 1/100 years + safety margin

Extreme water level (2071-2100) 1/100 years with uncertainty bounds

Extreme water level (1971-2000) 1/100 years

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Thank you

Photo credit: D.P.

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