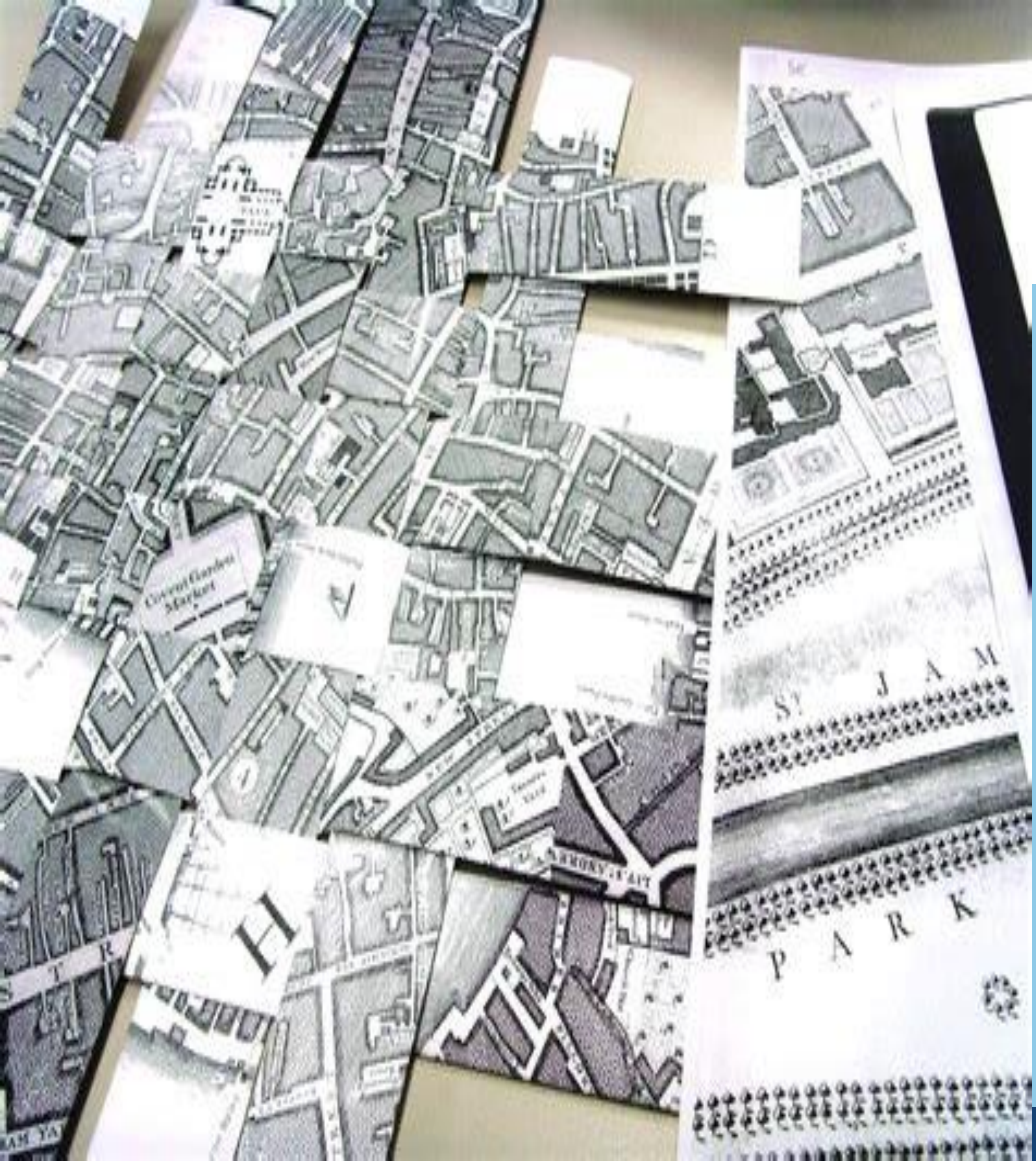
Lecture 2a



cost
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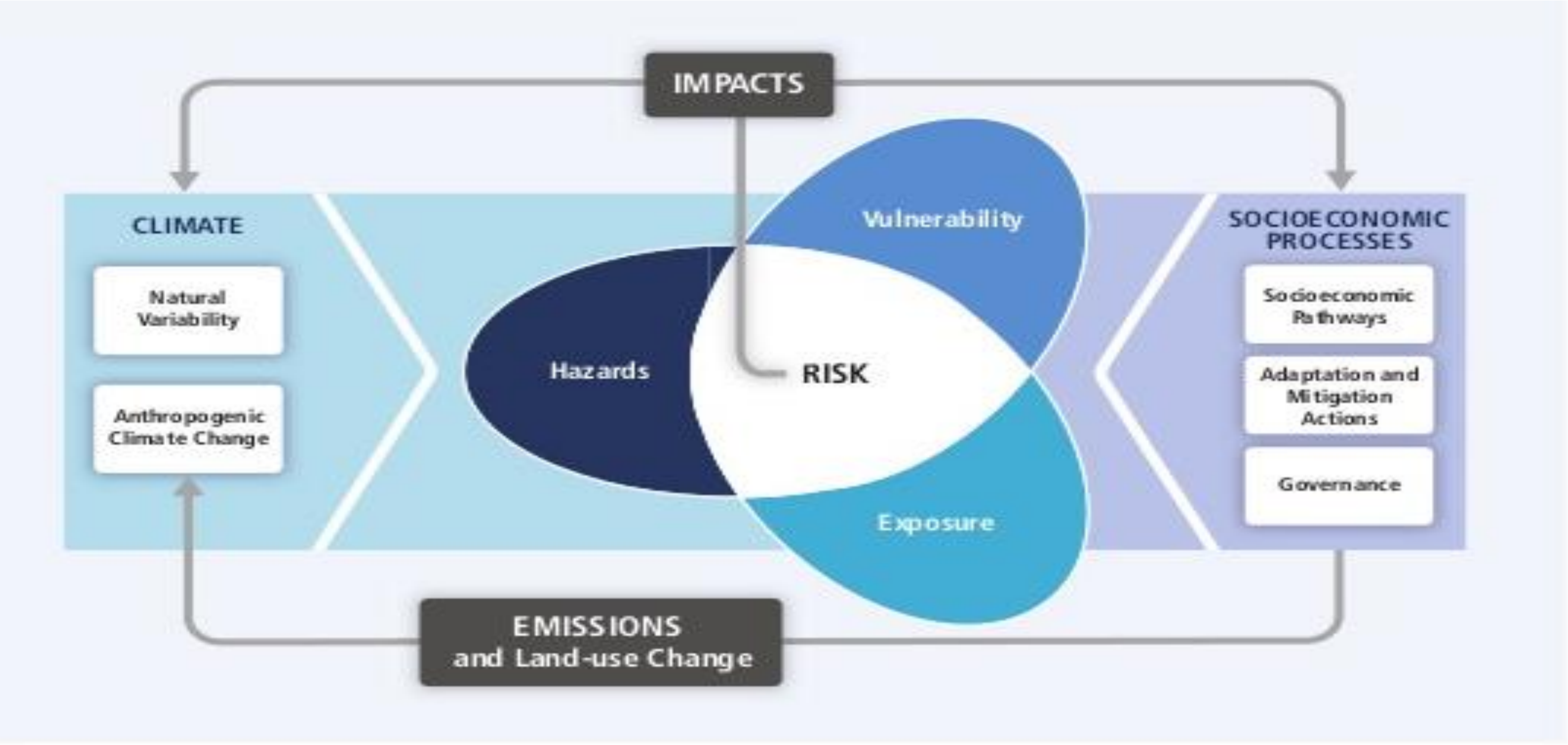
Compound weather and climate events:

Impacts

Bart van den Hurk (Deltares)

What causes extreme impacts?

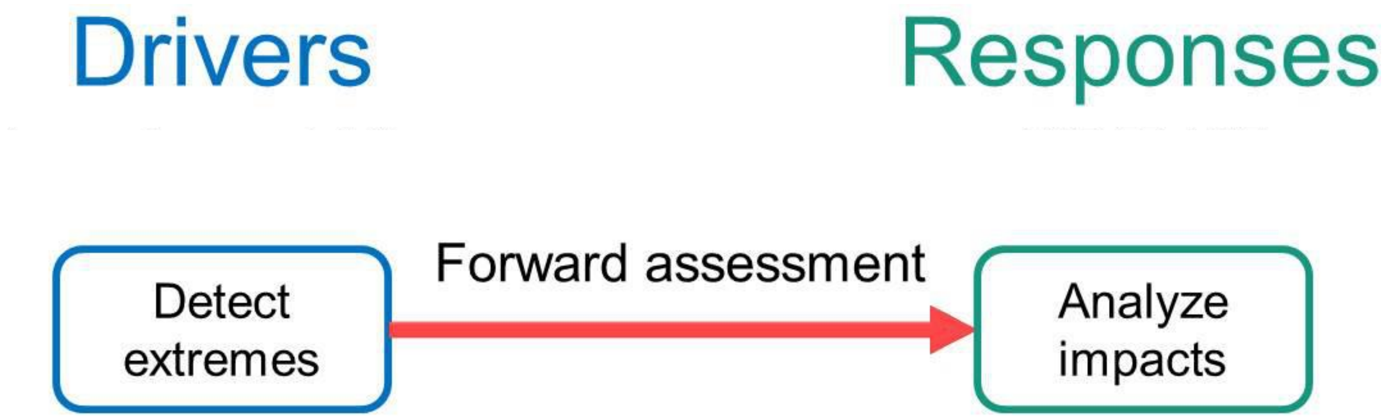
› Generally very difficult to determine



What causes extreme impacts?

- Generally very difficult to determine
- Typically multiple causes – what are the most important ones?
- Requires “backward assessment” / “bottom-up assessment”
- Very common in vulnerability assessment, e.g. when analyzing causes of individual disasters (“poor man’s analysis”)
- But: difficult to generalize from individual events
- how to derive general relationships?

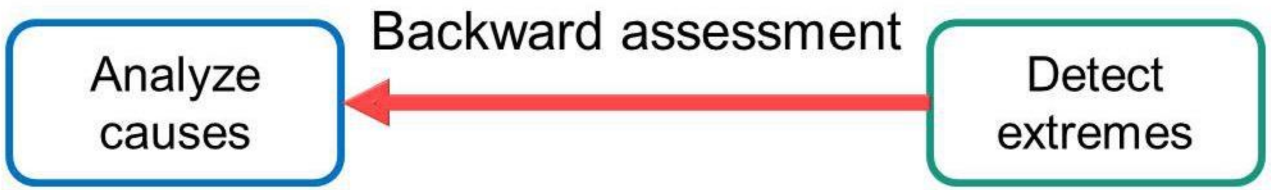
Forward and backward assessment



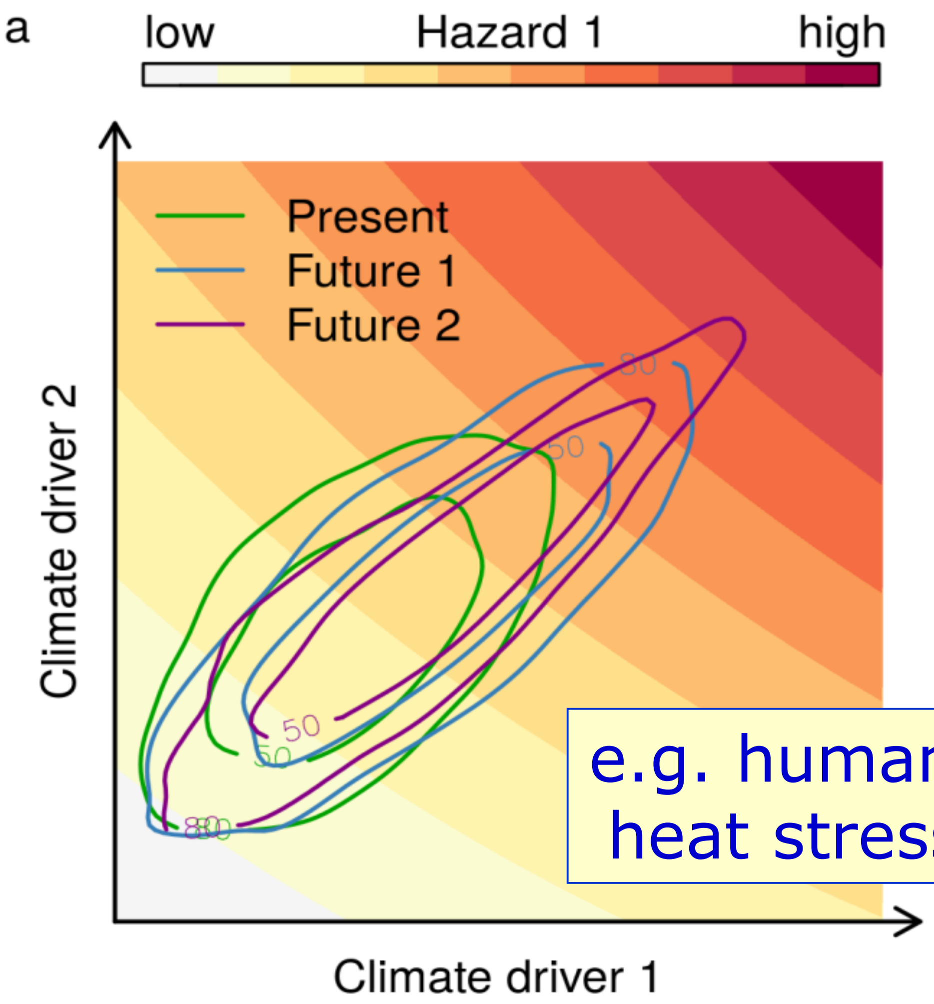
Zscheischler (2014) *PhD thesis*

Applicable methods

- Variable selection
- Compositing/Superposed Epoch Analysis (SEA)
- Classification
- Factorial model simulations
- ...

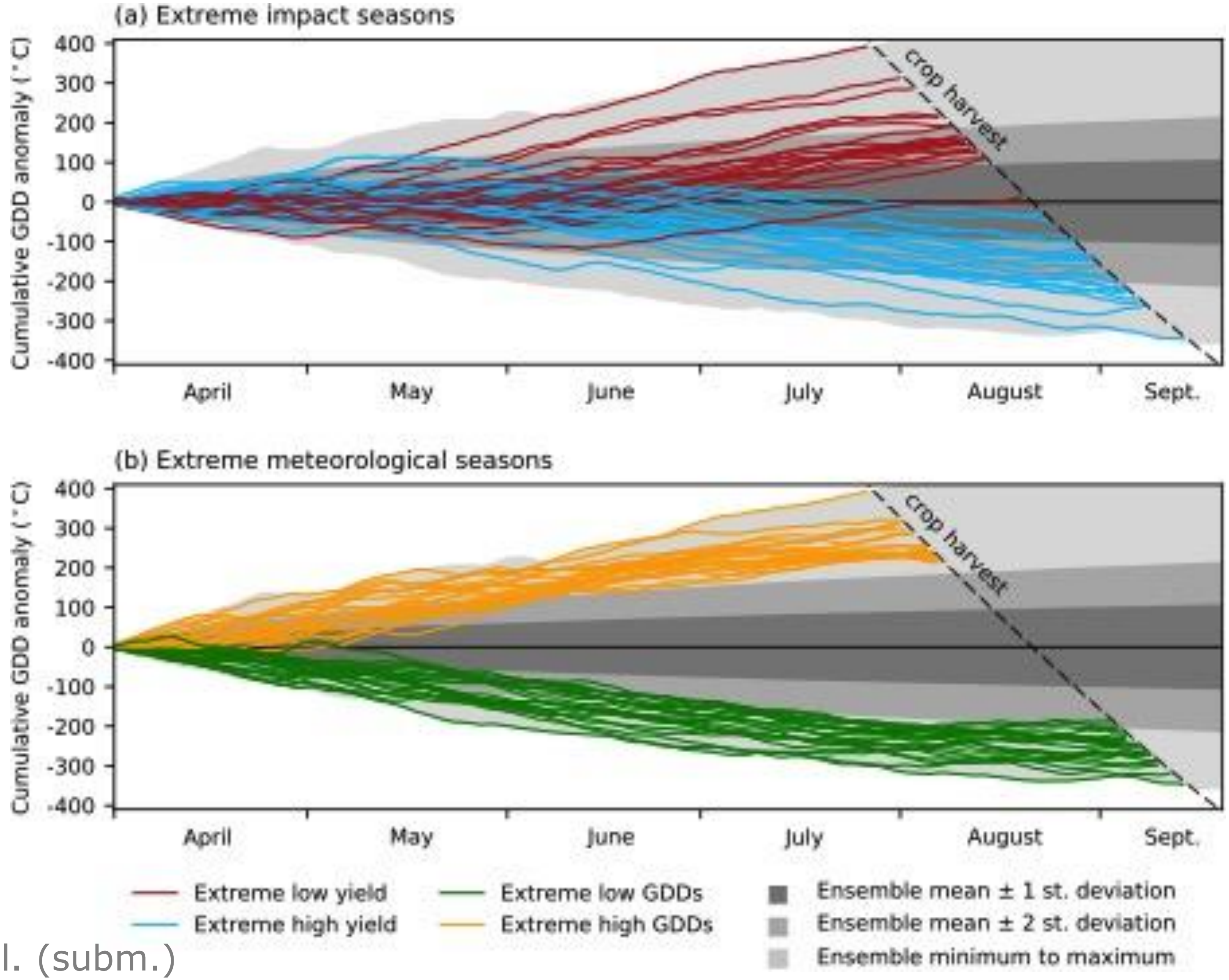


Impact varies with combination of drivers



e.g. human heat stress

Extreme drivers vs. extreme impacts

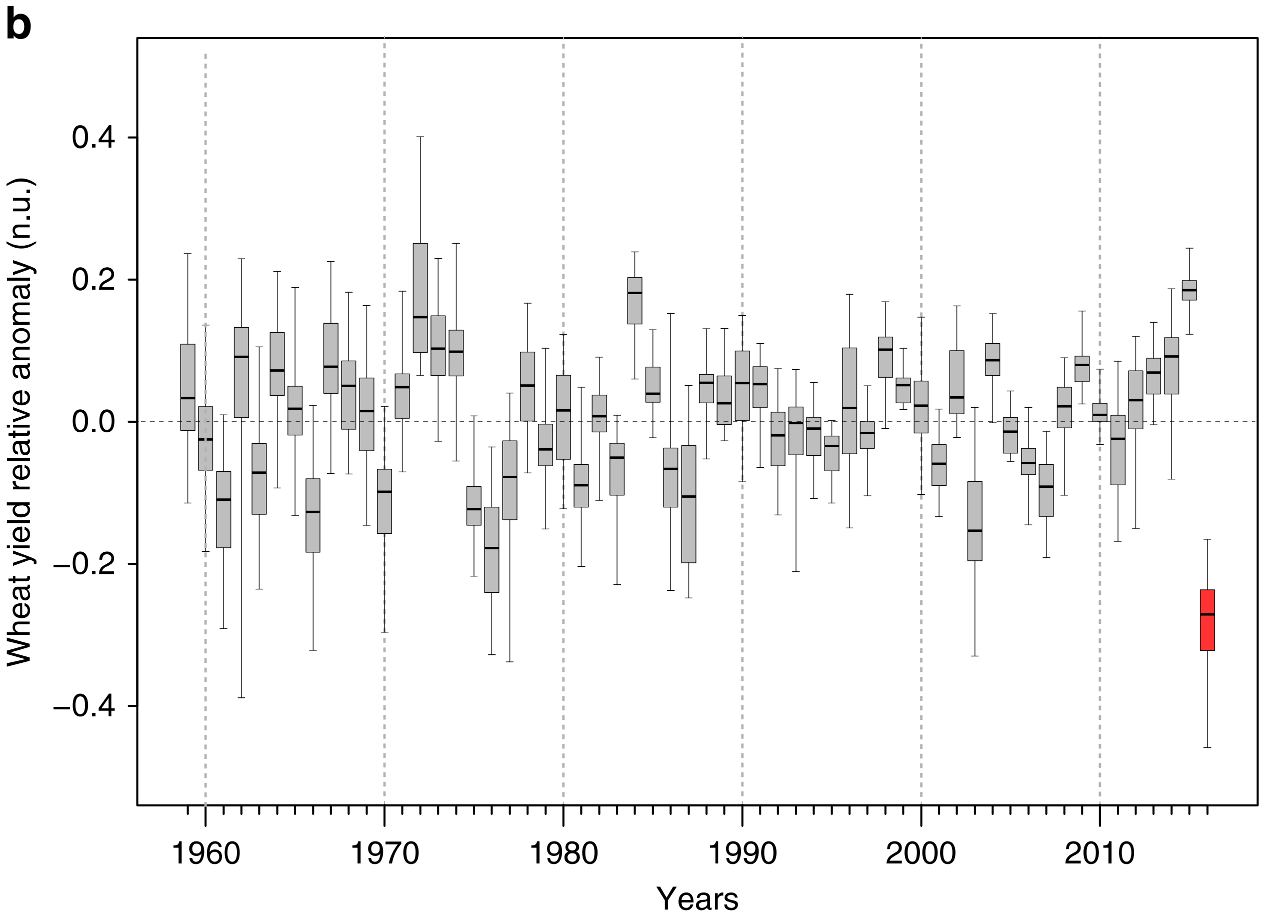


Van der Wiel et al. (subm.)

Examples

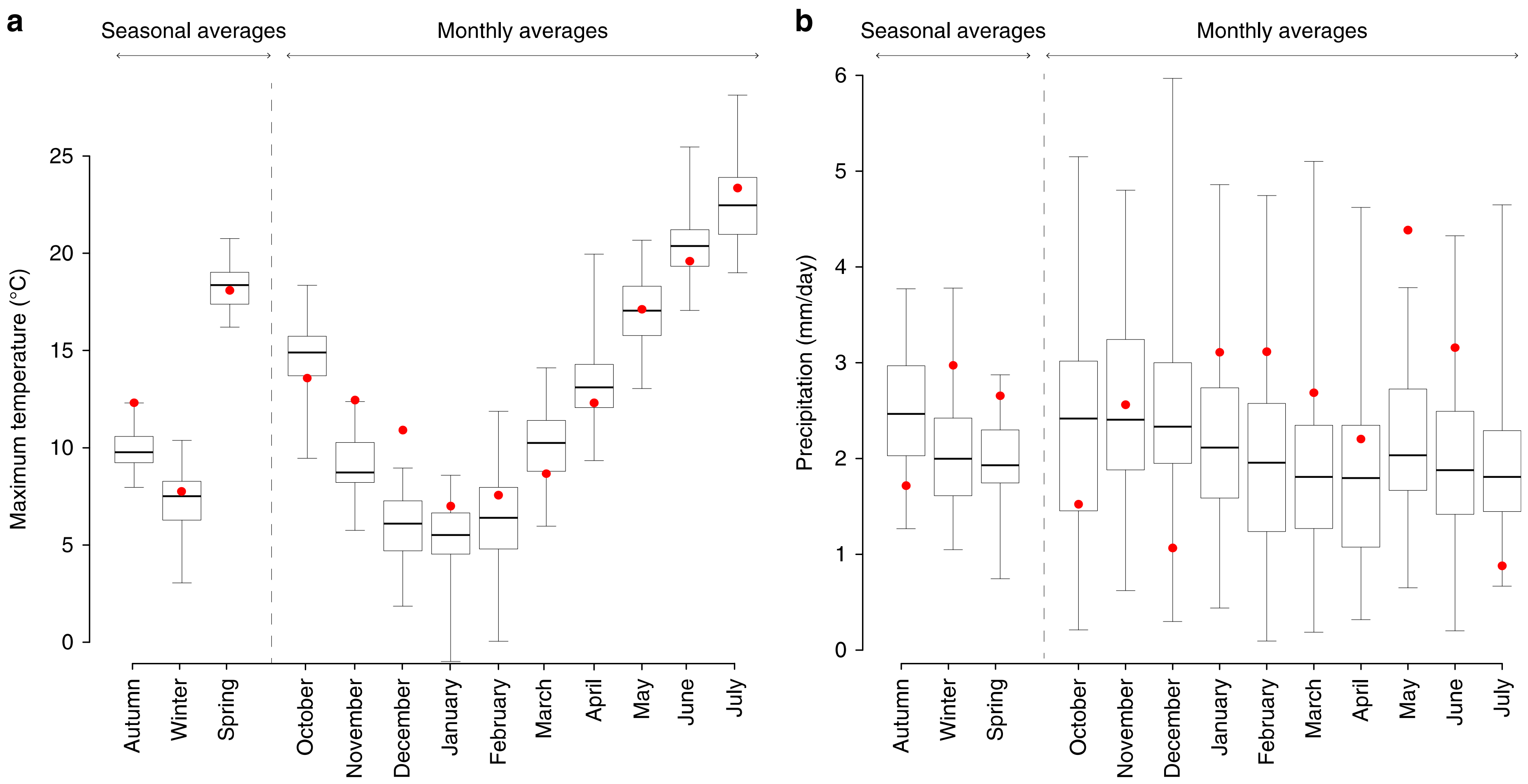
- Climate drivers of the 2016 yield failure in France

Yield anomalies in France



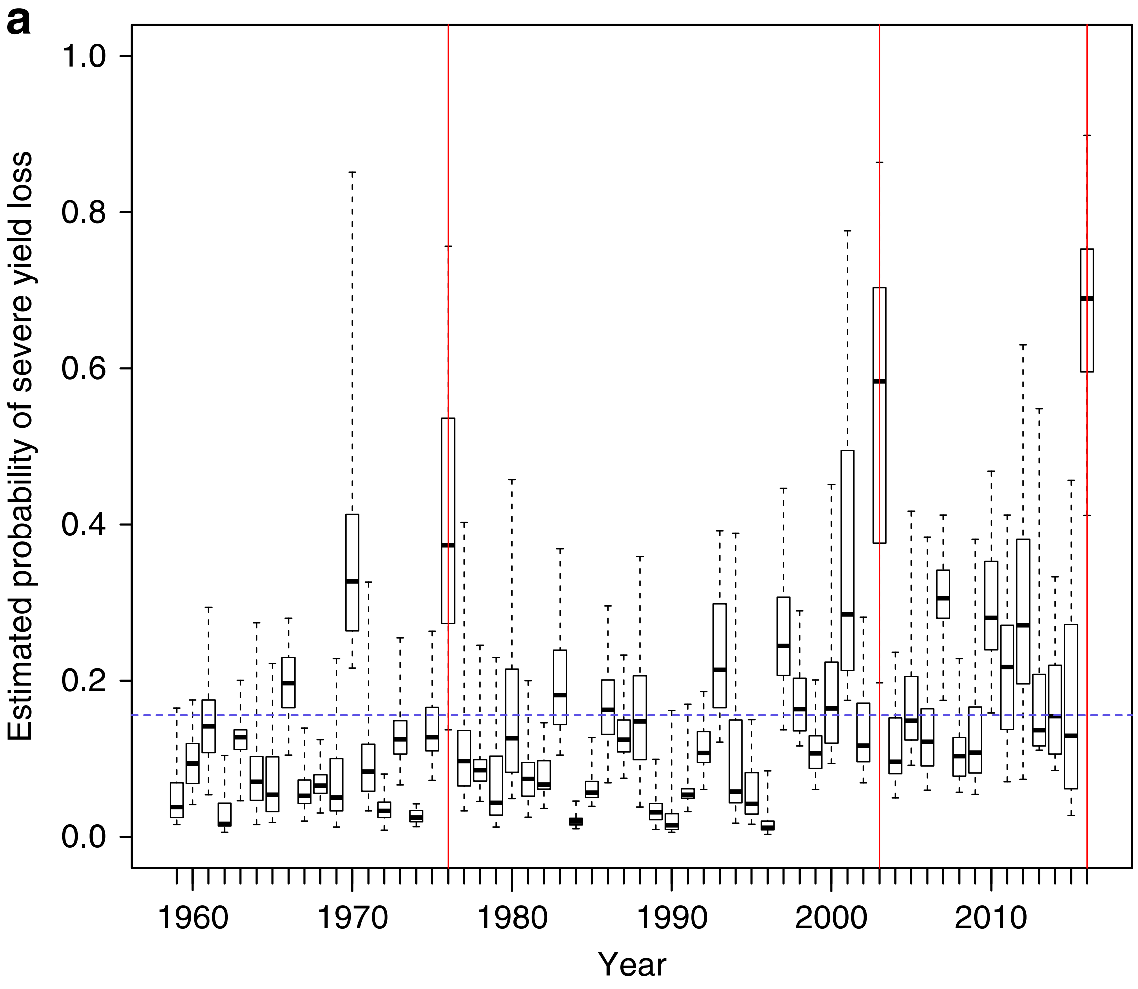
Ben-Ari et al. (2018) *Nature Communications*

Climate conditions in 2016



Ben-Ari et al. (2018) *Nature Communications*

Logistic regression



$$\text{logit}(p_i) = \beta_0 + \beta_1 x_i + \beta_2 x_i + \ \ldots$$

Selected best predictor variables:

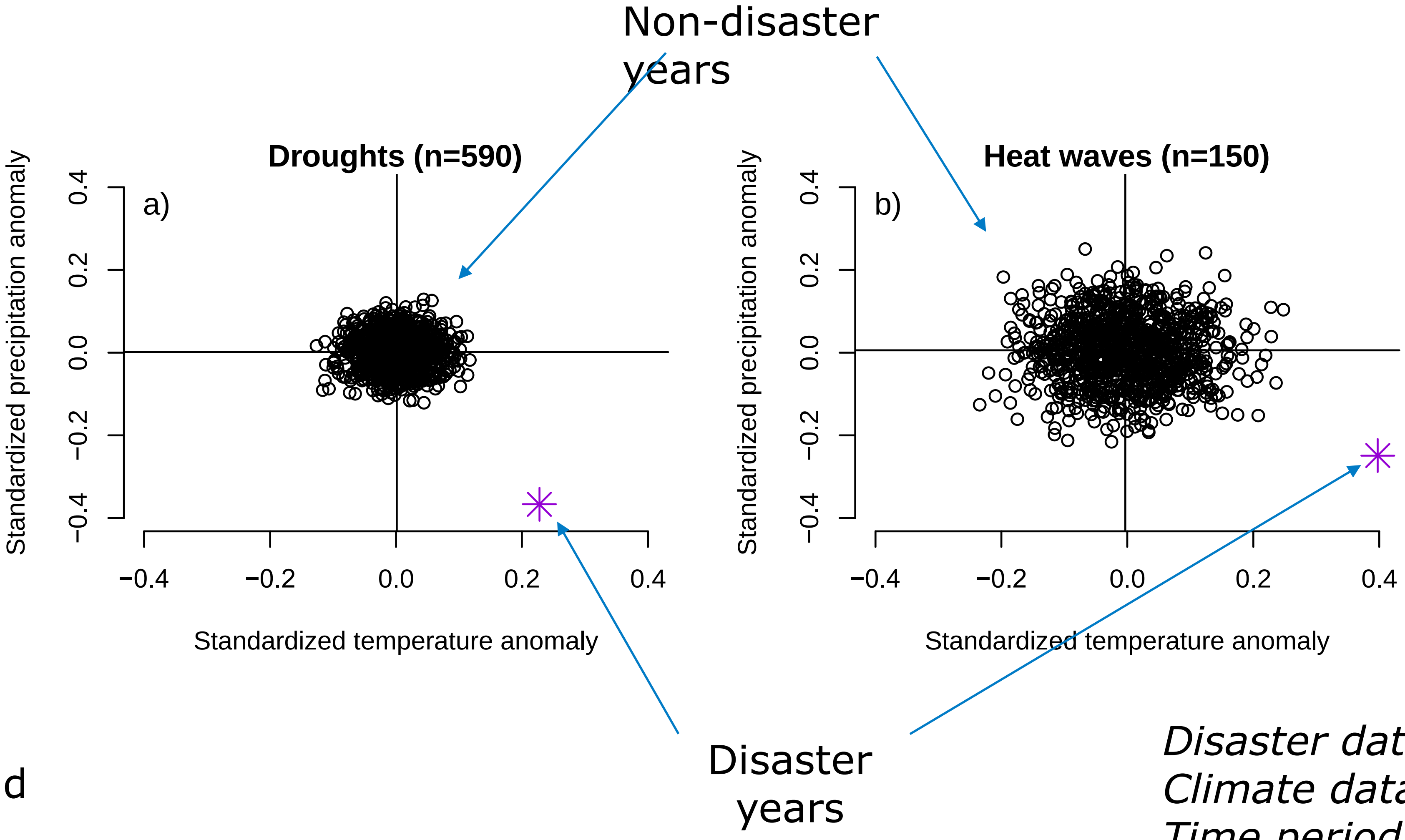
1) #days with Tmax between 0 and 10°C in December
2) November precipitation
3) Minimum June temperature
4) AMJJ precipitation
5) Interaction between 1) and 3)
6) Interaction between 3) and 4)

Ben-Ari et al. (2018) *Nature Communications*

Examples

- Climate drivers of the 2016 yield failure in France
- Drivers behind disasters

Bottom-up assessment of disasters



Averaged over entire years and countries.

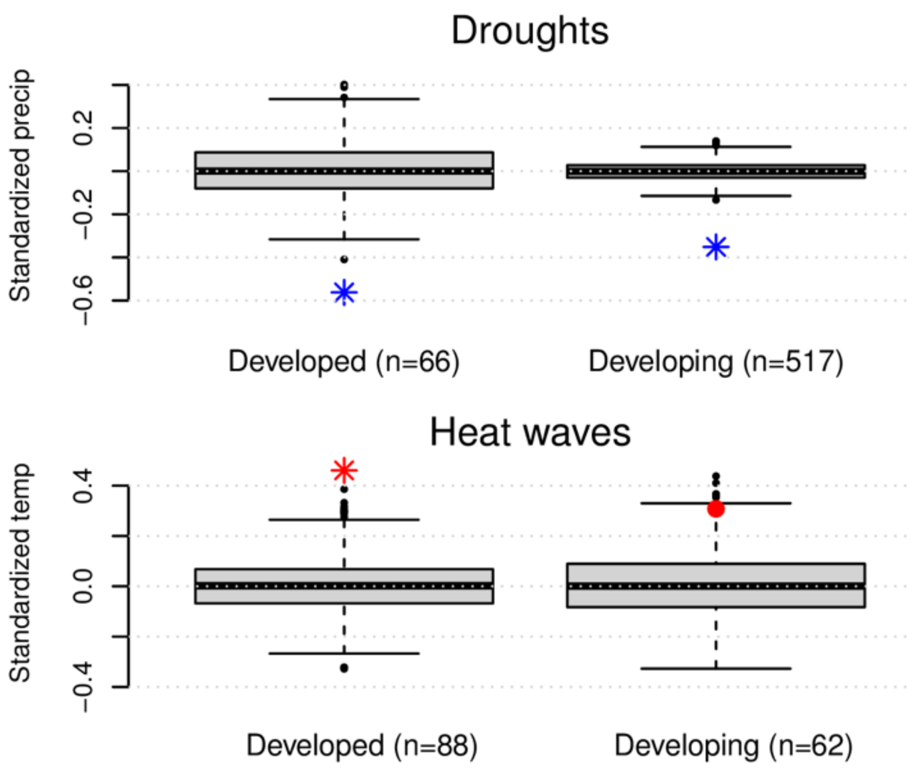
Disaster data: EM-DAT
Climate data: CRU
Time period: 1950-2015

Tschumi & Zscheischler (in press) *Climatic Change*

Relevance of vulnerability

- Climate anomalies during disaster years are larger in developed countries

- Climate anomalies in rich countries need to be very large to cause a disaster

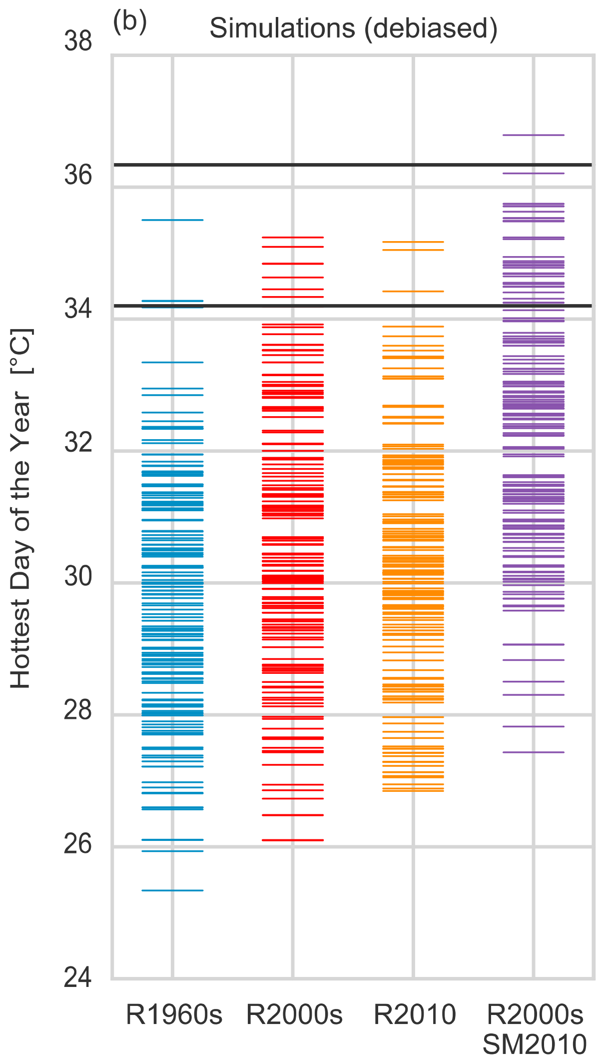


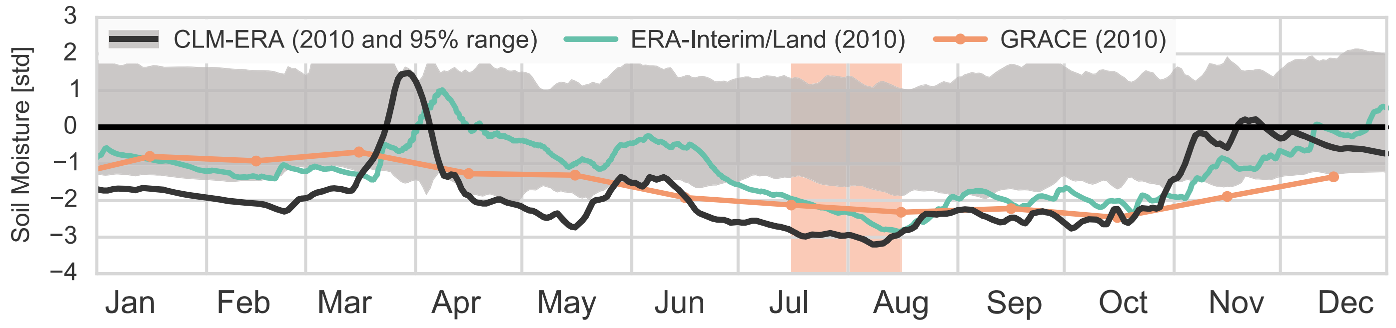
Tschumi & Zscheischler (2019) *Climatic Change*

Examples

- Climate drivers of the 2016 yield failure in France
- Drivers behind disasters
- Drivers of the 2010 Russian heatwave

Factorial model simulations



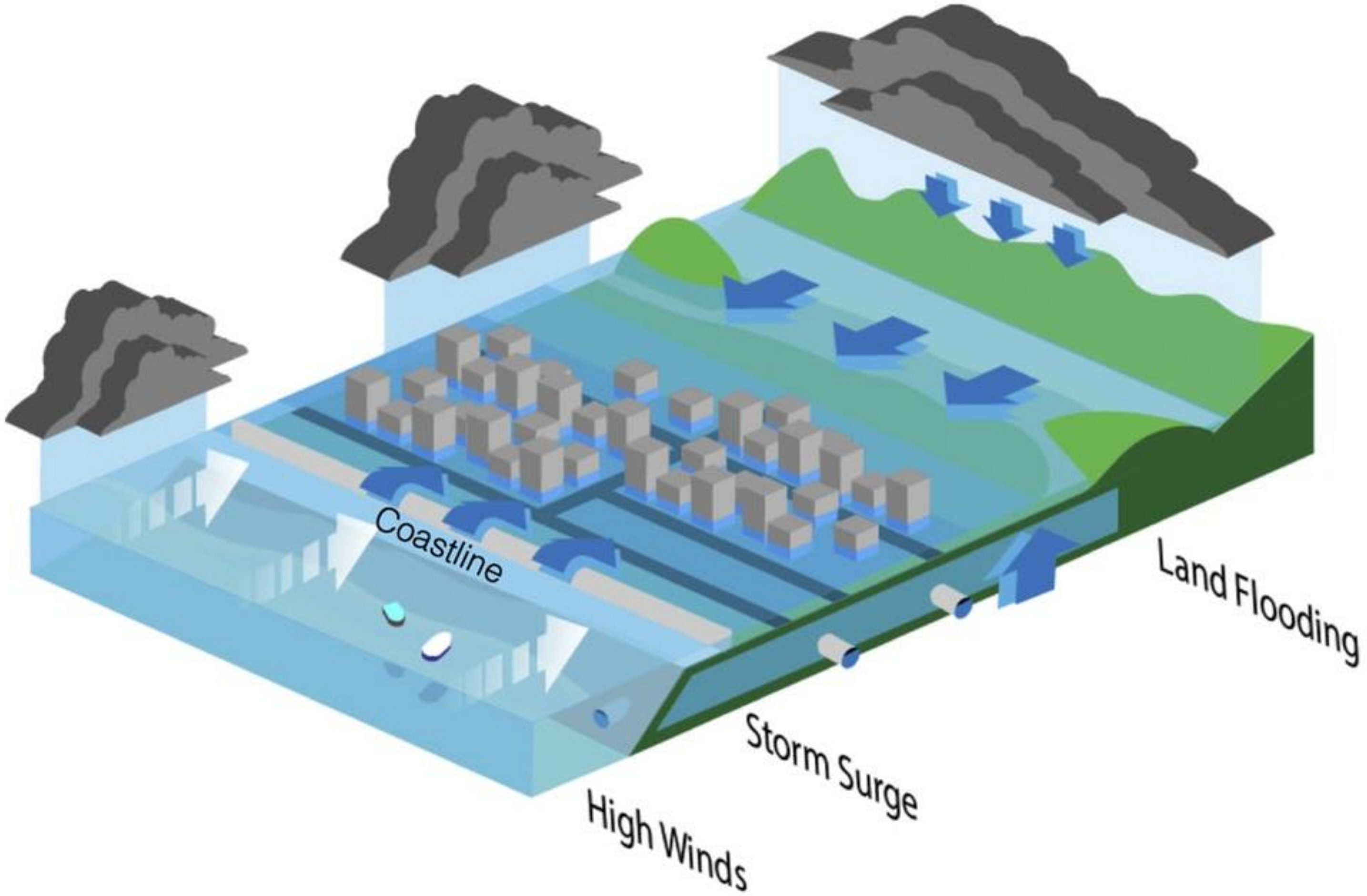


Hauser et al. (2016) *Earth's Future*

Examples

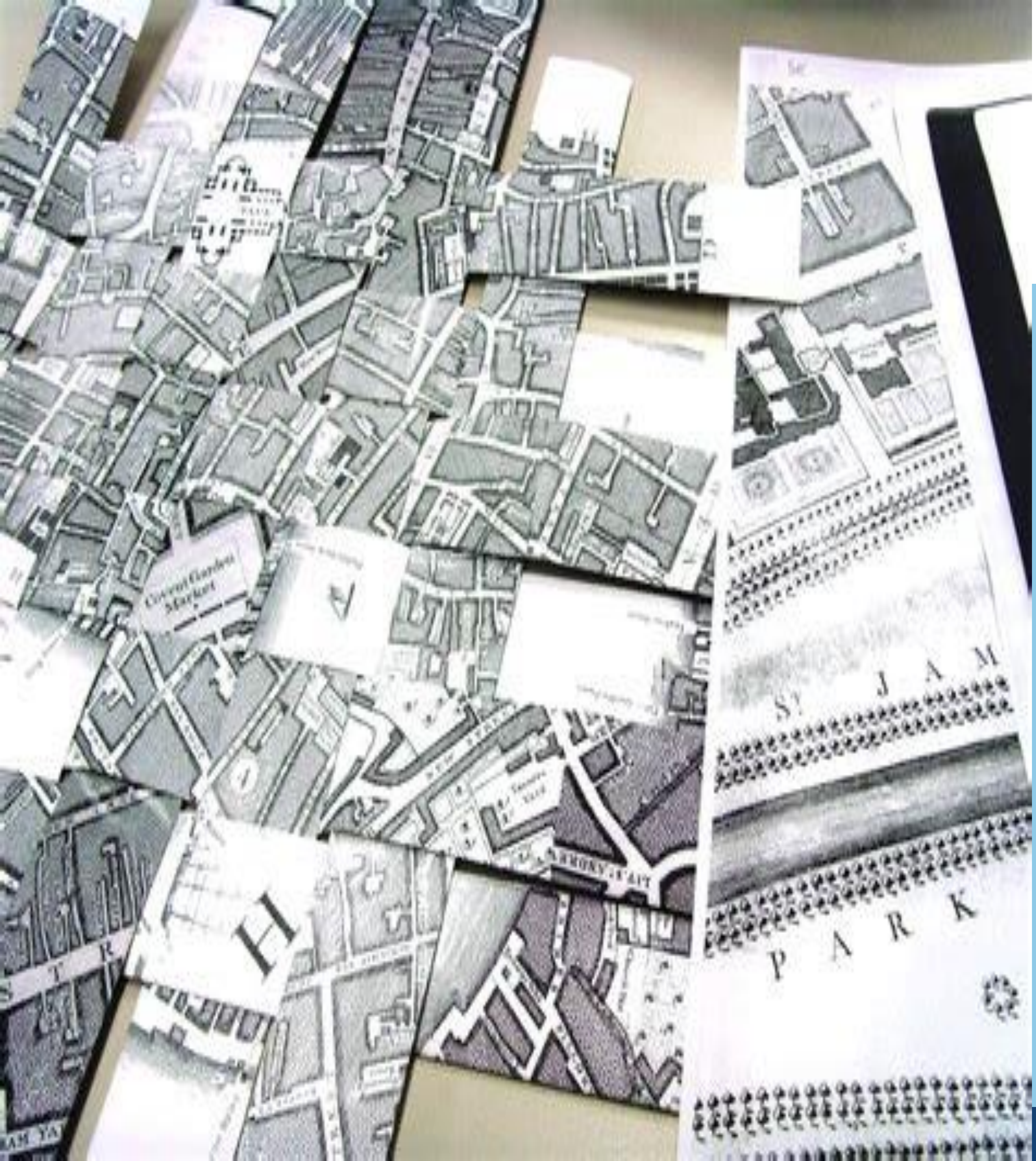
- Climate drivers of the 2016 yield failure in France
- Drivers behind disasters
- Drivers of the 2010 Russian heatwave
- Coastal flood impacts (see next lecture)

Thank you



Bart.vandenHurk@deltares.nl

Lecture 2b



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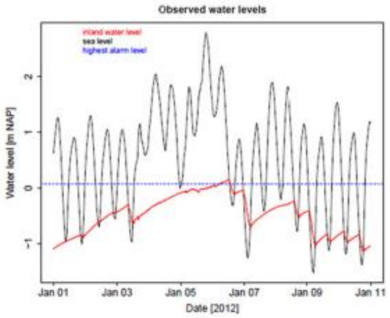
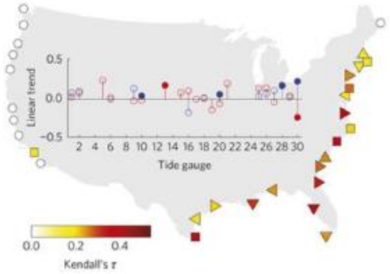
Compound weather and climate events:

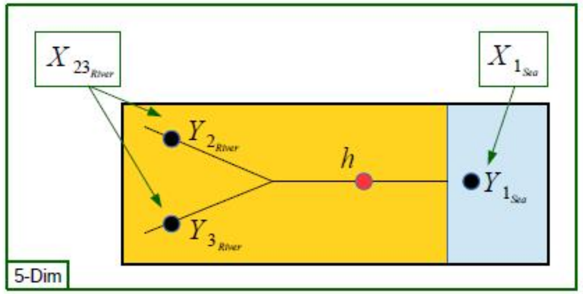
Coastal areas

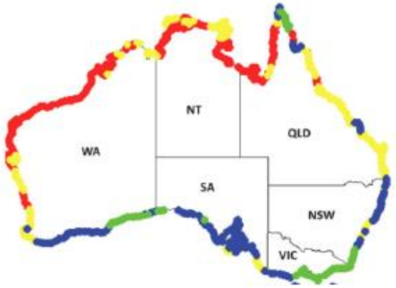
Bart van den Hurk (Deltares)

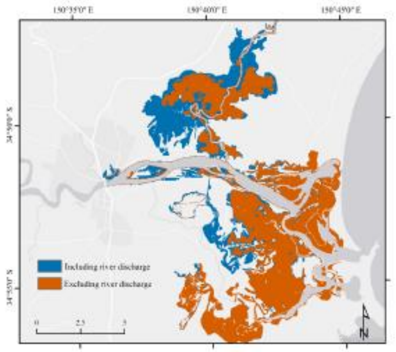
The scientific attention on CF has increased recently...

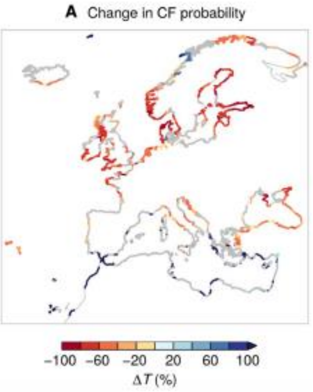


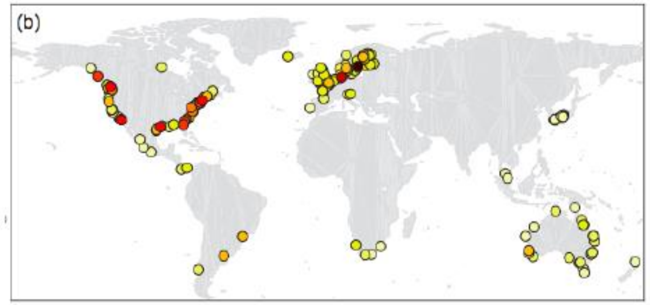


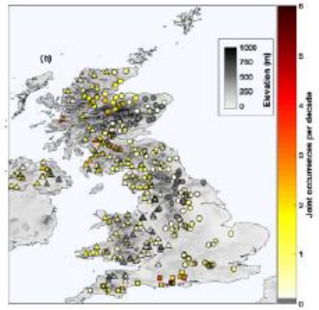












slide from EB

Hydrological mechanisms causing CF

River confluences

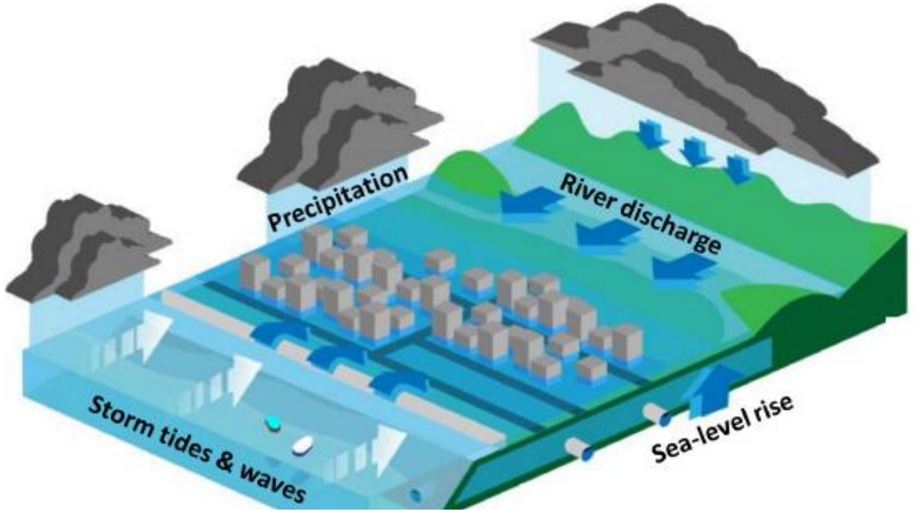
- Germany, 2013. In Passau, from high discharges into the confluence of the rivers Danube, Inn and Ilz. [Wahl, 2018; Blschl, 2013]
- Italy, 2014. Between the river Parma and the Po: "the rain over the Parma basin was only justifying a moderate river level but..."

slide from EB

Hydrological mechanisms causing CF

Coastal Compound Flooding: Different weather/climate and topography can lead to different flooding mechanisms: [Wahl et al., 2015; Bevacqua et al., 2019]:

- In estuaries where river runoff and sea level may combine initiating or exacerbating flooding (e.g., due to a moderate storm surge)



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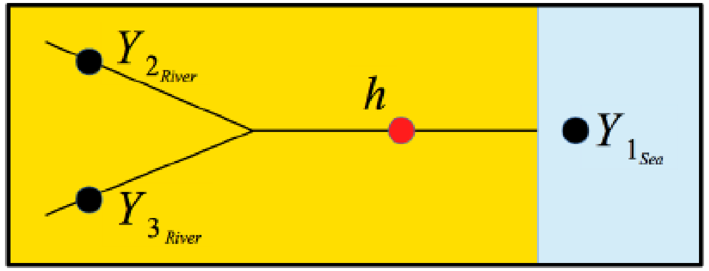
Hydrological mechanisms causing CF

River confluences near to the coast



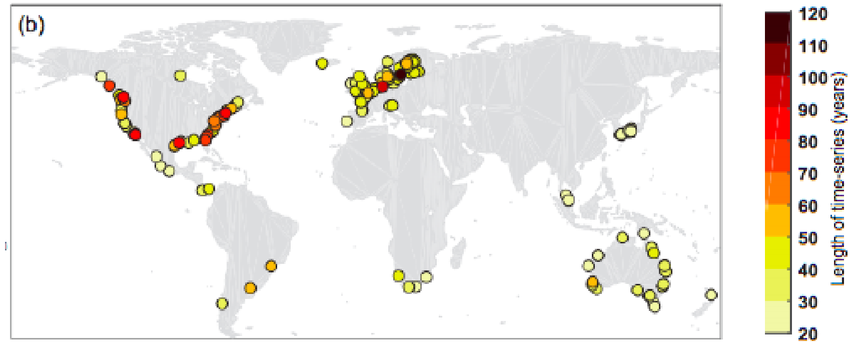
Combination of the previous two main mechanisms [Bevacqua et al., 2017].

Hydrologically non-interacting concurring extremes (Spatially compounding events)
The impacts resulting from concurrent flooding may combine non-linearly (e.g., if rescue teams are overloaded [Barton et al., 2016] [Martius et al., 2016]).

slide from EB

Data of the *contributing variables* to the CF

- Observations, often limited.



[CF in river estuaries: Ward et al., 2018]

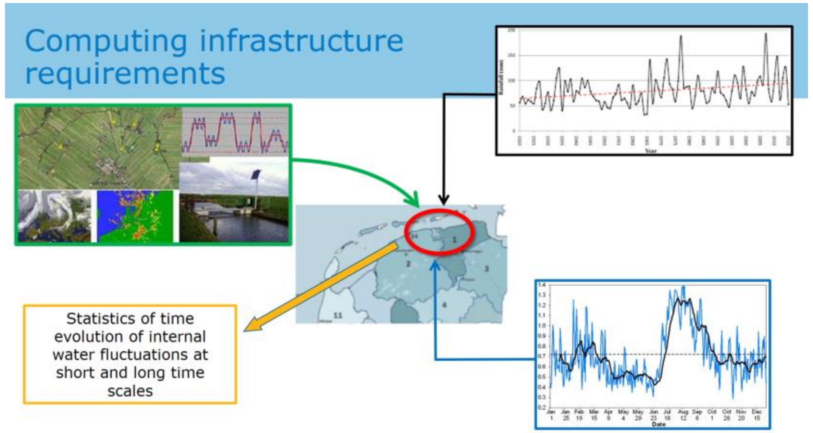
slide from EB

How to quantify the actual CF water level?

(Sea level, Pluvial/fluvial flooding) $\rightarrow$ CF water level

- Explicit modelling of the CF water level: Combining sea and pluvial/fluvial levels via: hydrodynamical or statistical models.

- Considering the probability of potential CF.



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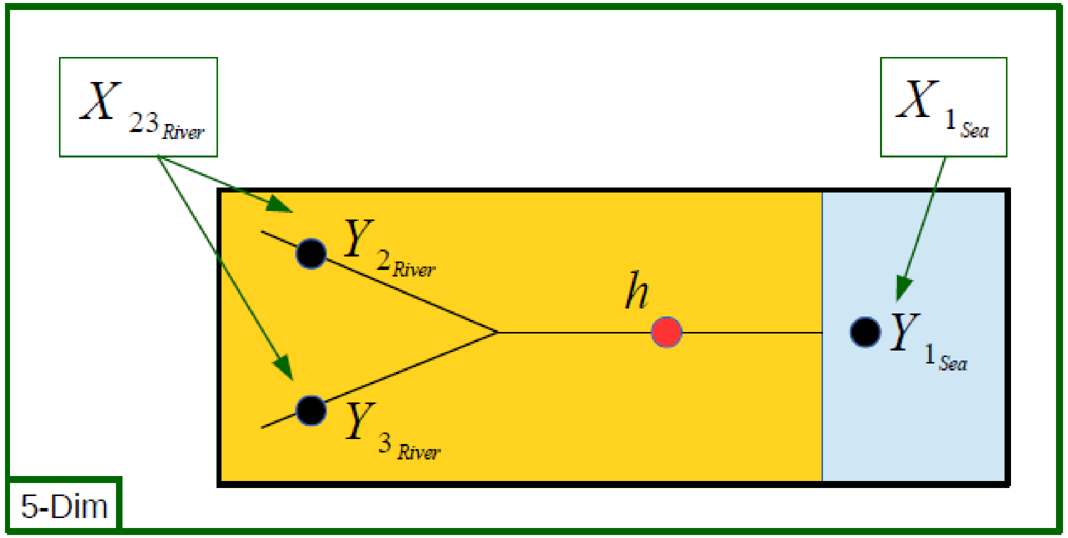
Statistical modelling of the CF - Ravenna (Italy)

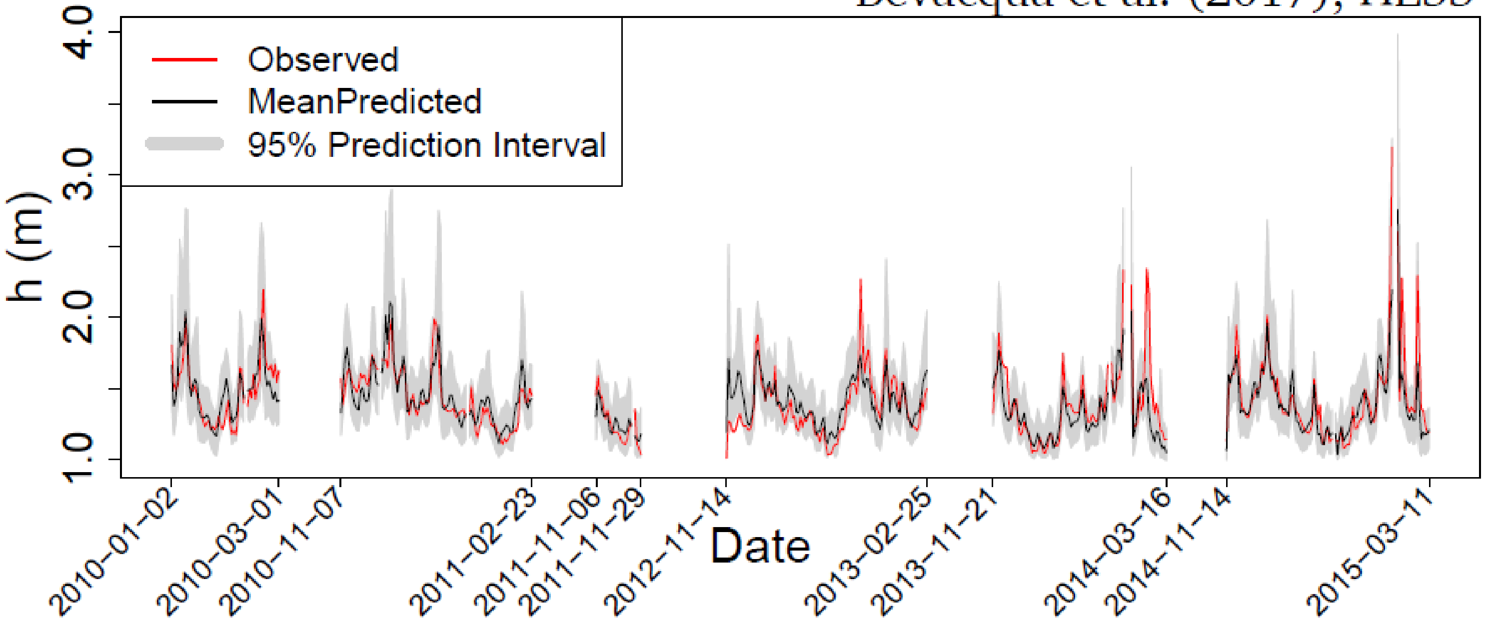


Multivariate stat. downscaling via $f_{\vec{Y}|\vec{X}}$ (PCCs):

$$(X_{23}, X_1)^{ERA} \to (Y_1, Y_2, Y_3)^{sim}$$

$$\to h^{sim} = h(Y_1, Y_2, Y_3)^{sim}$$

Bevacqua et al. (2017), HESS



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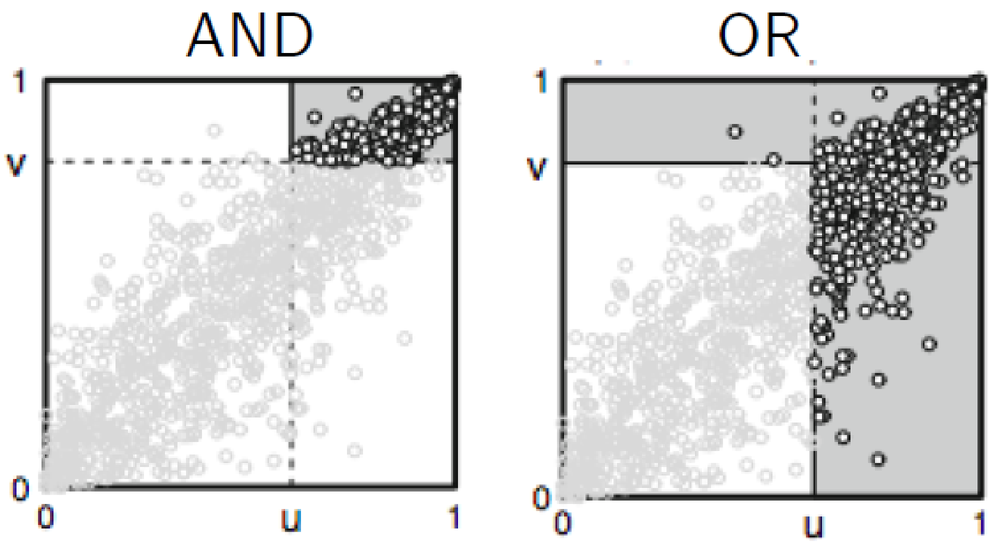
How to quantify the actual CF water level?

Potential compound flooding: if data from models or observations are not available, bivariate return periods:

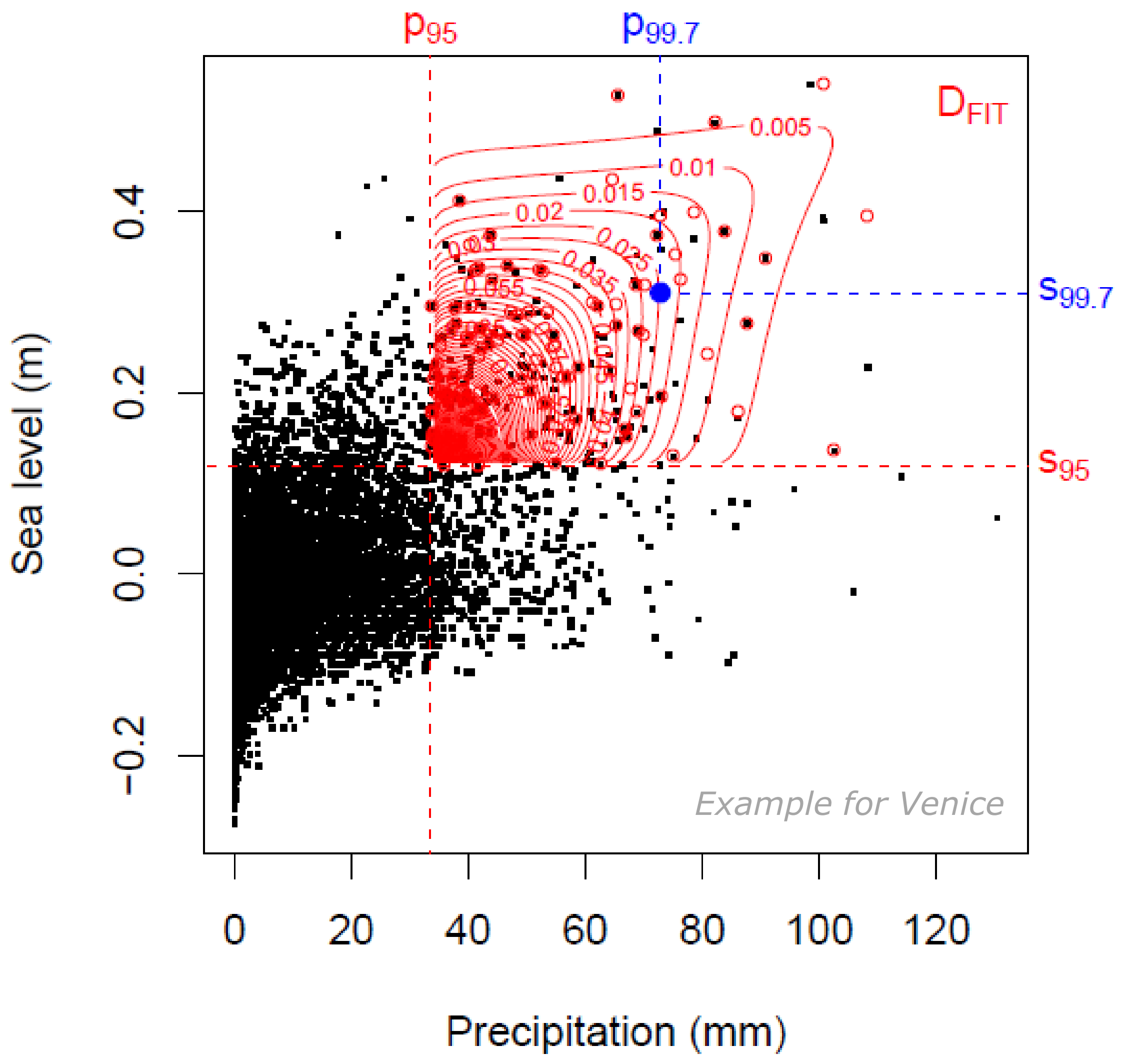


Serinaldi, 2015

- OR considers both CF and univariate flooding.
- AND allows for disentangling better CF.

slide from EB

Analysing compound return periods



1/yr level

5% highest values used for copula definition

Bevacqua et al. (2019) *Sci. Adv.*

Copula

A copula is the joint distribution of random variables, $U_1, U_2, \ldots, U_p$, each of which is marginally uniformly distributed as $U(0,1)$

$$C(u_1, u_2, \ldots, u_p) = P(U_1 \leq u_1, U_2 \leq u_2, \ldots, U_p \leq u_p)$$

If the variables are independent

$$C(u_1, u_2, \ldots, u_p) = u_1 \times u_2 \times \ldots \times u_p$$

slide from MCiP

Joint cumulative density function

Copulas are useful because of Sklar's Theorem:

For any *p* random variables with joint cumulative density function (c.d.f.)

$$F(x_1, x_2, \ldots x_p) = P(X_1 \leq x_1, X_2 \leq x_2, \ldots X_p \leq x_p)$$

and marginal c.d.f.s

$$F_j(x) = P(X_j \leq x) j = 1,2, \ldots, p$$

there exists a copula such that

$$F(x_1, x_2, \ldots, x_p) = C\{F_1(x_1), F_2(x_2), \ldots, F_p(x_p)\}$$

This allows us to separate the modeling of the **marginal distributions** from the **dependence structure**, which is expressed by the **copula**.

slide from MCiP

Joint probability density function

For any *p* random variables with joint cumulative density function (c.d.f.)

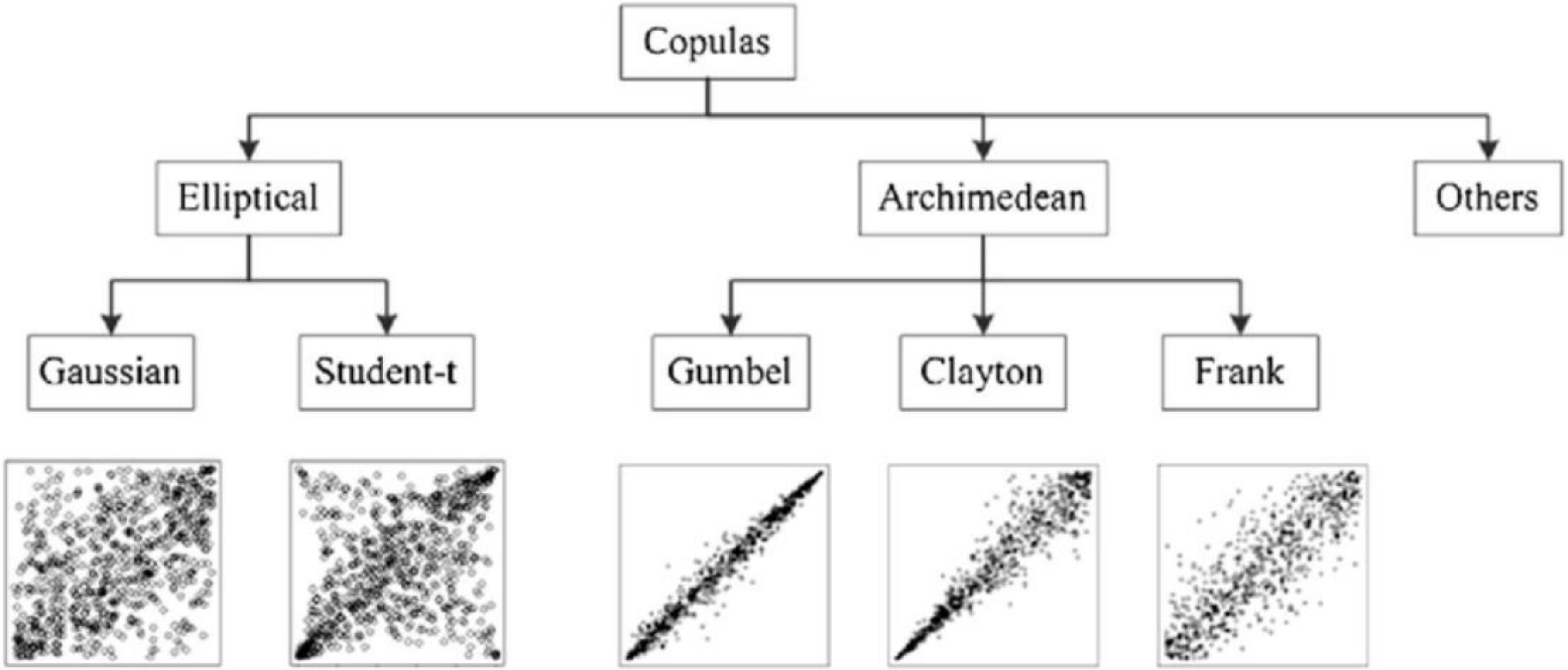
$$f(x_1, x_2, \ldots, x_p) = f_1(x_1) f_2(x_2) \cdots f(_p(x_p) \cdot c\{F_1(x_1), F_2(x_2), \ldots, F_p(x_p)\}$$

The pdf of the copula distribution can be seen as the **adjustment needed to convert the independence pdf into the joint pdf**

slide from MCiP

Intermezzo: some info on copulas

Classes of copulas



(J. Li, 2015)

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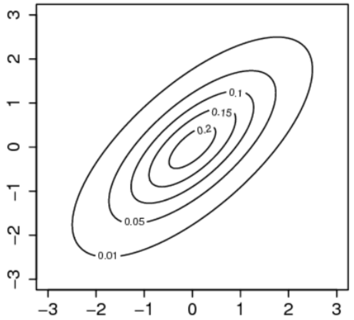
Intermezzo: some info on copulas

Elliptical copulas

Gaussian copula

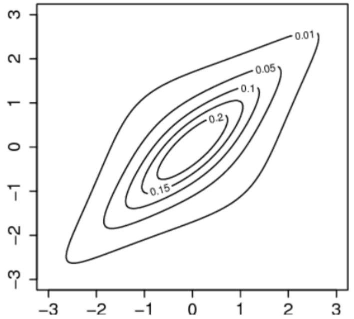
If the joint c.d.f is a **multivariate normal distribution**, then the copula is Gaussian



Zero tail dependence

Student-t copula

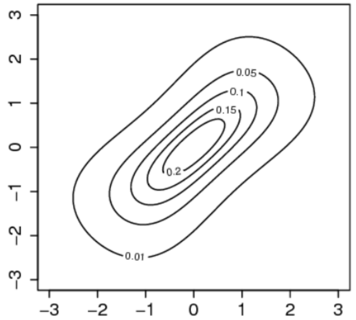
If the joint c.d.f is a **multivariate t-distribution**, then the copula is Student-t



Upper and lower tail dependence

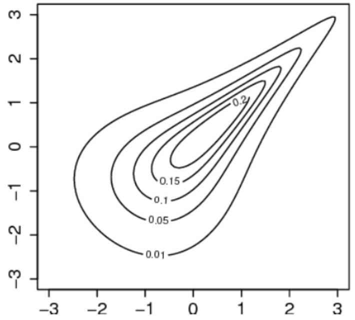
Classes of copulas

Frank $-\infty < \theta < \infty$



Symmetric copula with a wide range of dependence parameter, can include negative correlation

Joe $\theta \geq 1$

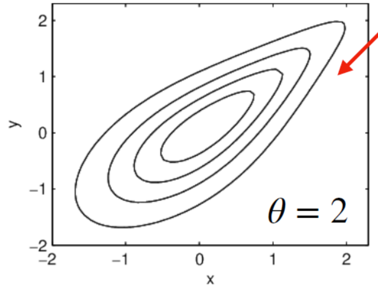


Stronger right tail dependence

Archimedean copula

Gumbel

$$C(u_1, u_2) = \exp(-[(-\ln u_1)^\theta + (-\ln u_2)^\theta]^{1/\theta}) \qquad \theta \geq 1$$



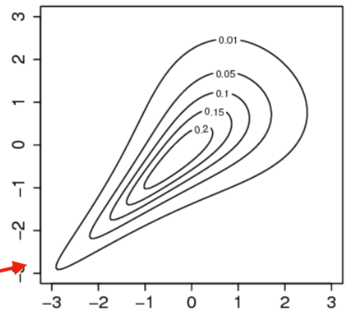
Right tail dependence

$$\tau = \frac{\theta - 1}{\theta}$$

Clayton

$$C(u_1, u_2) = ((u_1)^\theta + (u_2)^{-\theta} - 1)^{-1/\theta} \qquad \theta > 1$$

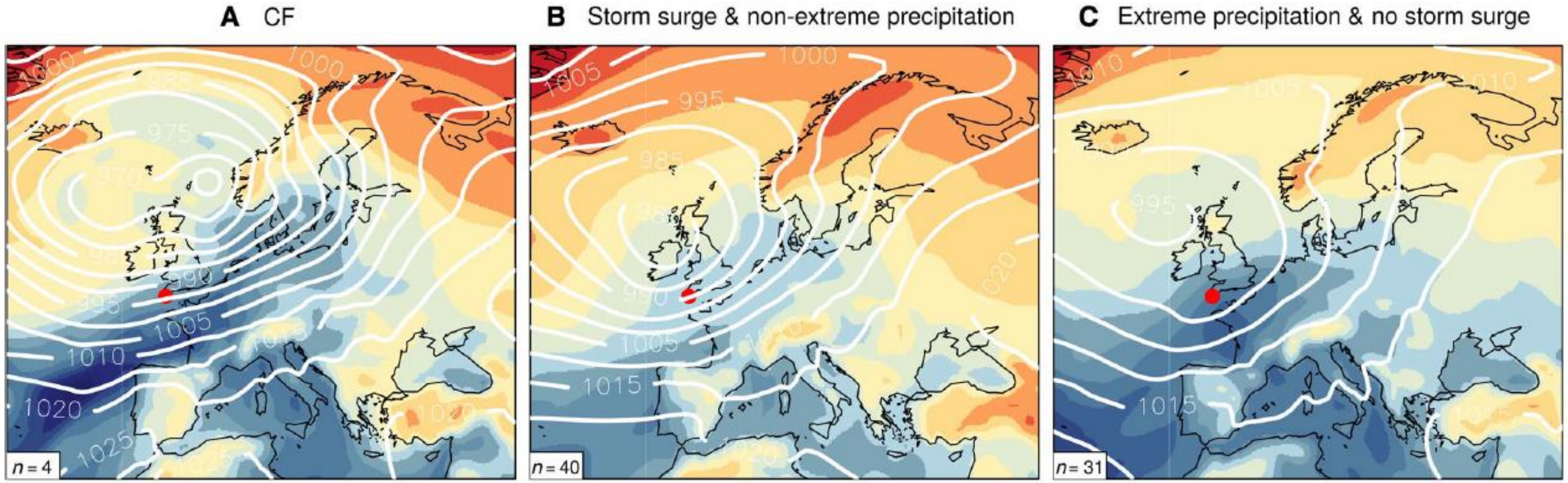
$$\tau = \frac{\theta}{\theta + 2}$$



Lower tail dependence

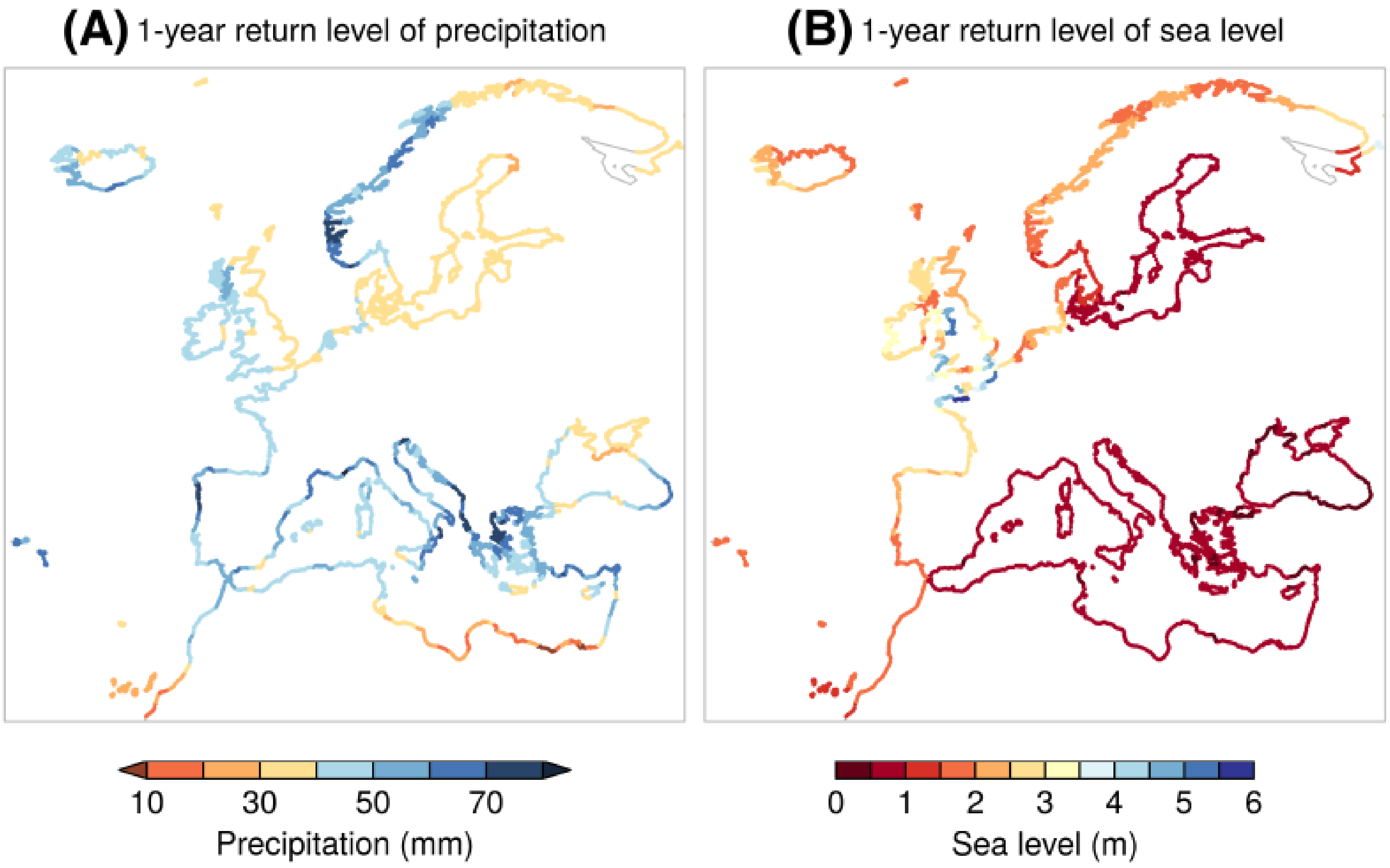
slide from MCiP

Configuration of compound coastal flood events



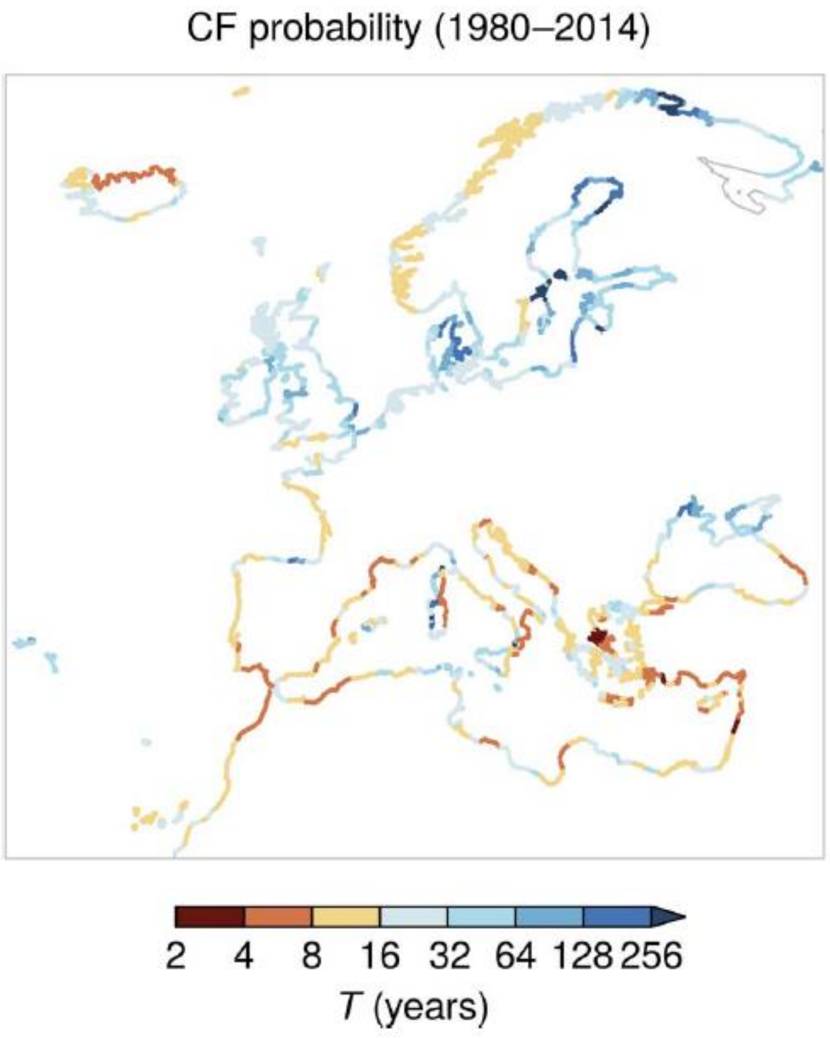
Bevacqua et al. (2019) *Sci. Adv.*

1/yr 1d precipitation and storm surge (ERA-int)



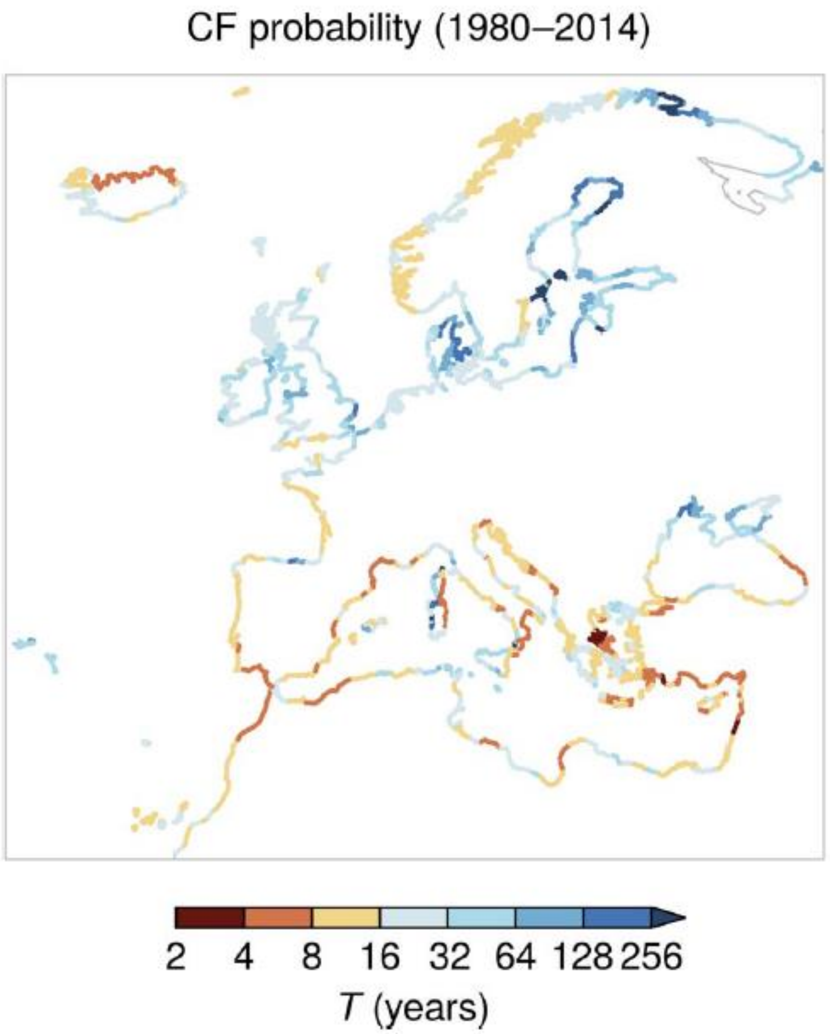
Bevacqua et al. (2019) *Sci. Adv.*

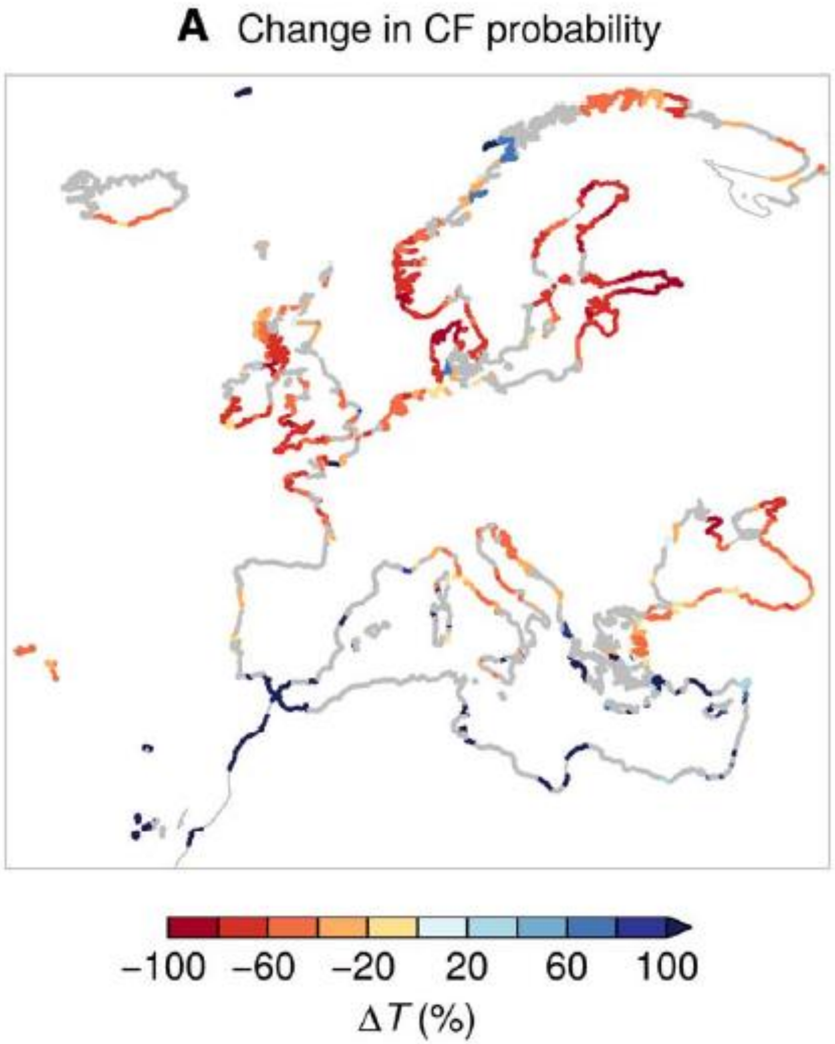
Return time of 1/yr combined precipitation and storm surge

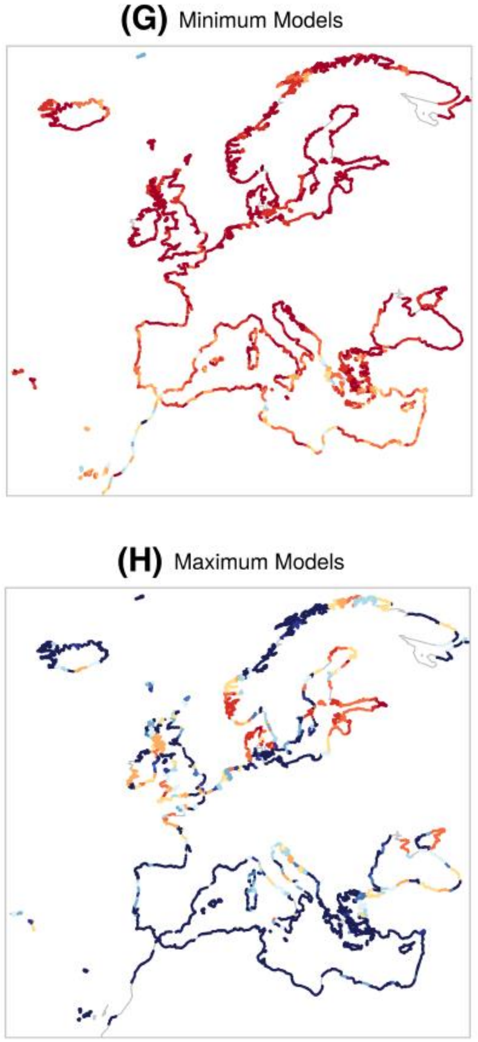


Bevacqua et al. (2019) *Sci. Adv.*

Return time of 1/yr combined precipitation and storm surge – climate change

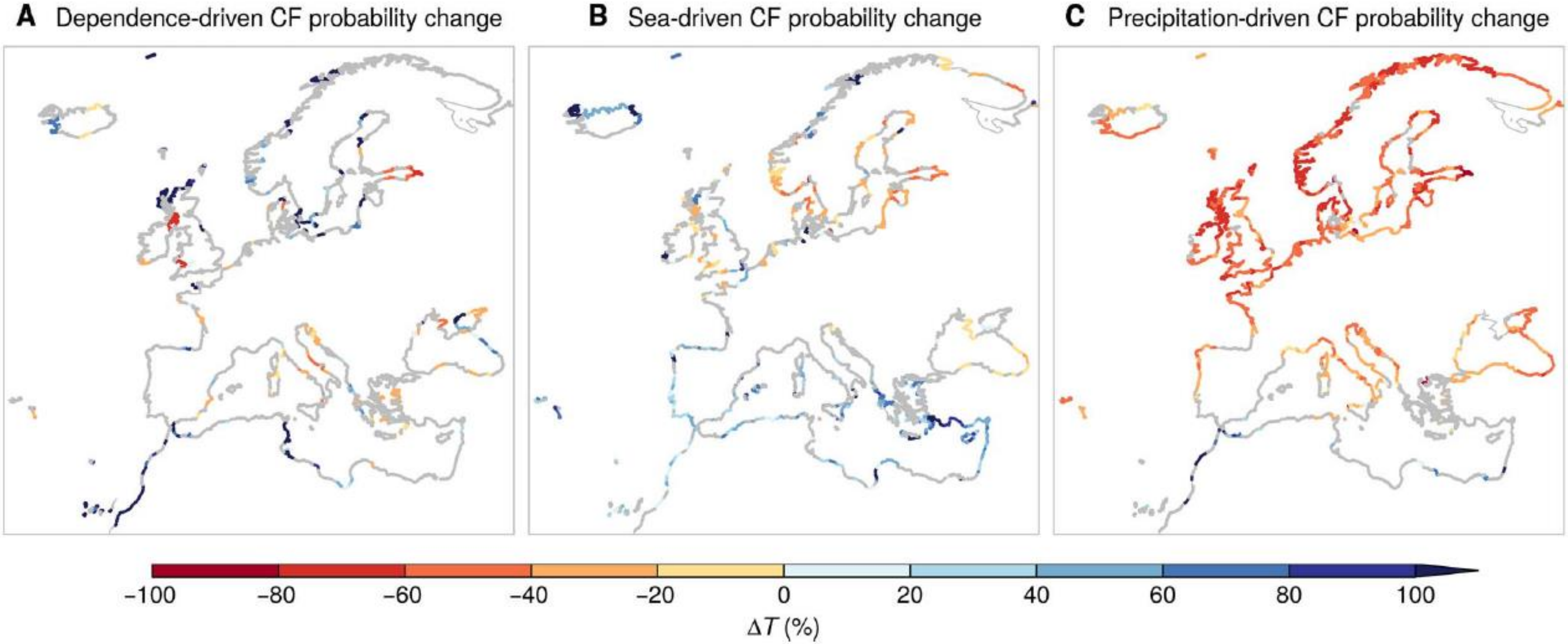






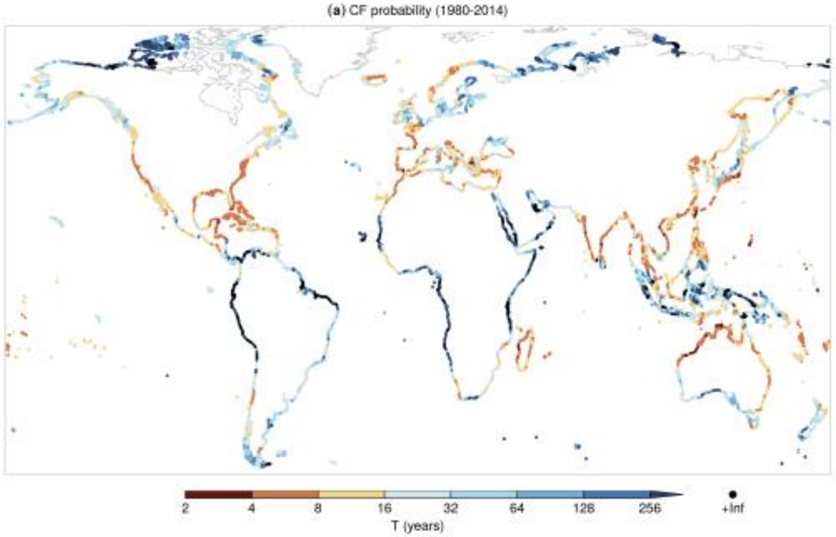
Bevacqua et al. (2019) *Sci. Adv.*

Effect of change in compound structure

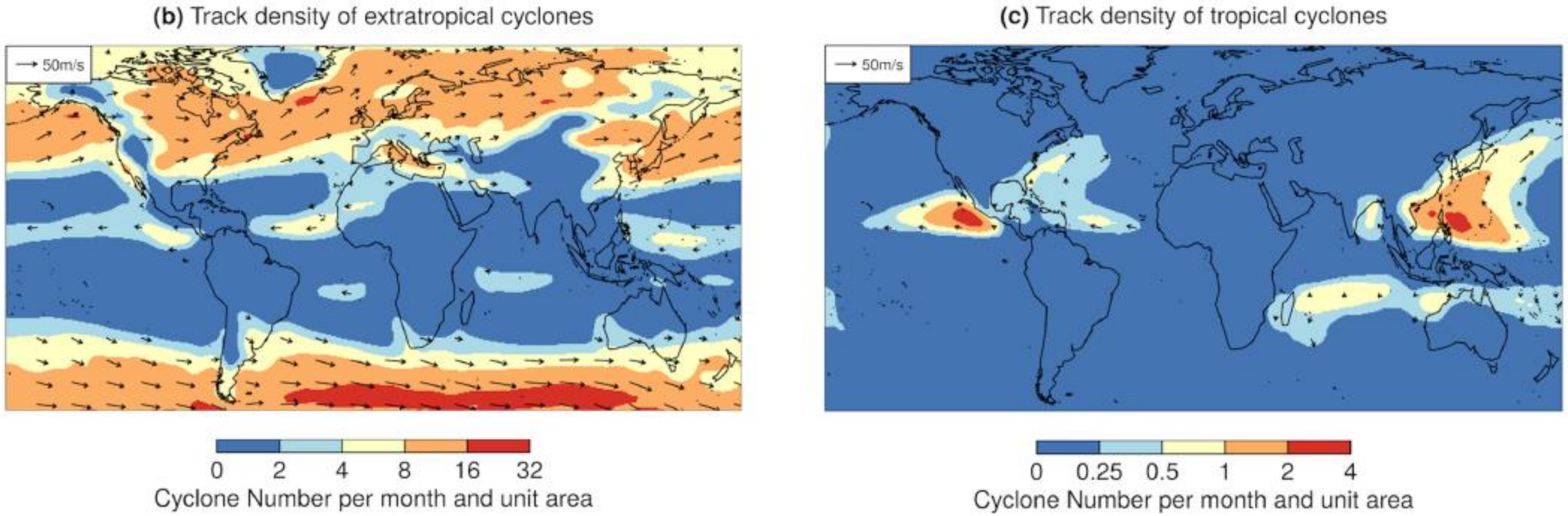


Bevacqua et al. (2019) *Sci. Adv.*

Present-day CF and storm tracks

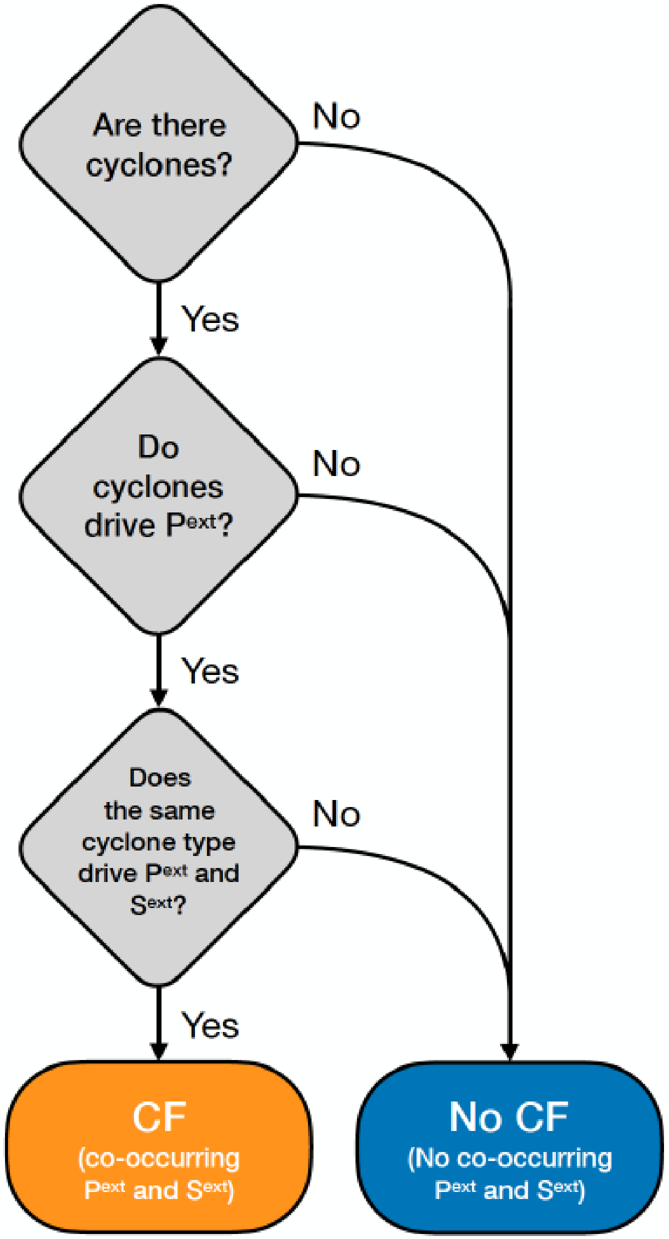


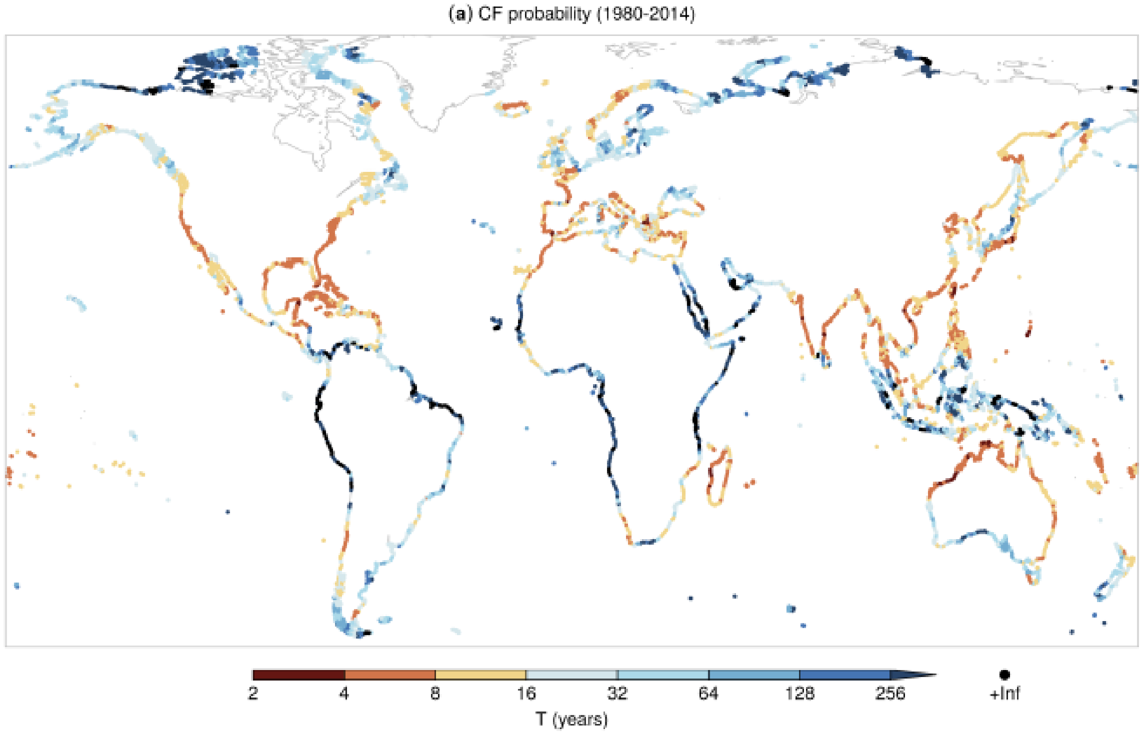
- No CF around the equator



slide from EB

Summary of the processes causing concurring P_{ext} and S_{ext}



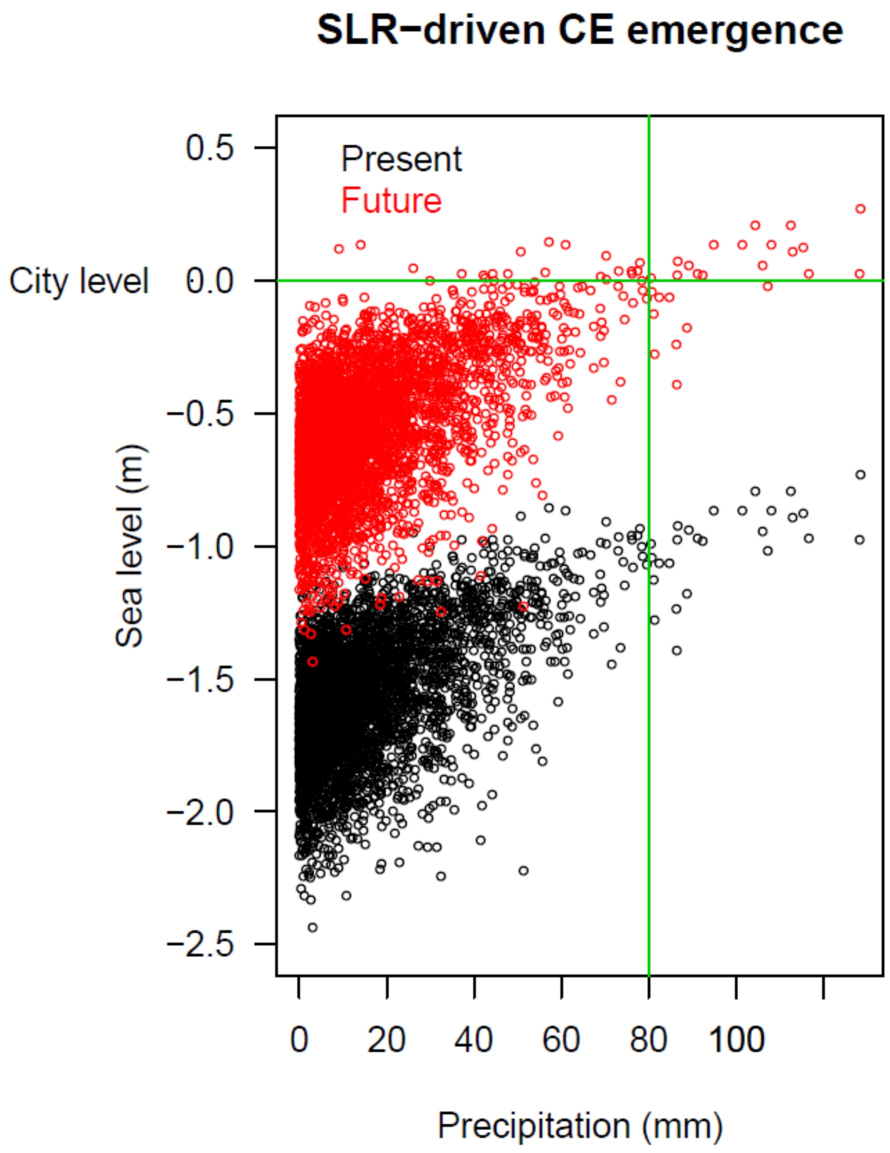


(In addition, astronomical tides.)

slide from EB

CE research: compound events may "emerge" in the future

- **The compound nature of an hazard might "emerge" in the future due to climate change**, which can modify the multivariate distribution of the actual drivers of an hazard (Bevacqua, 2018).



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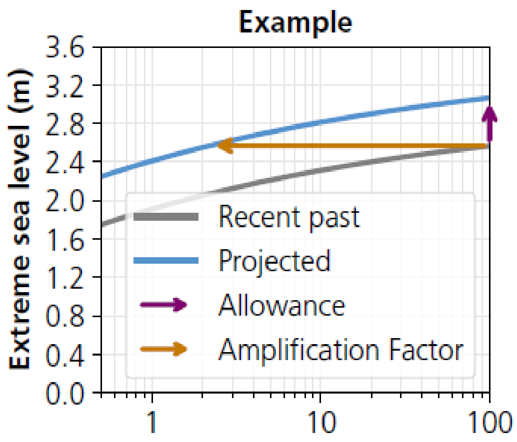
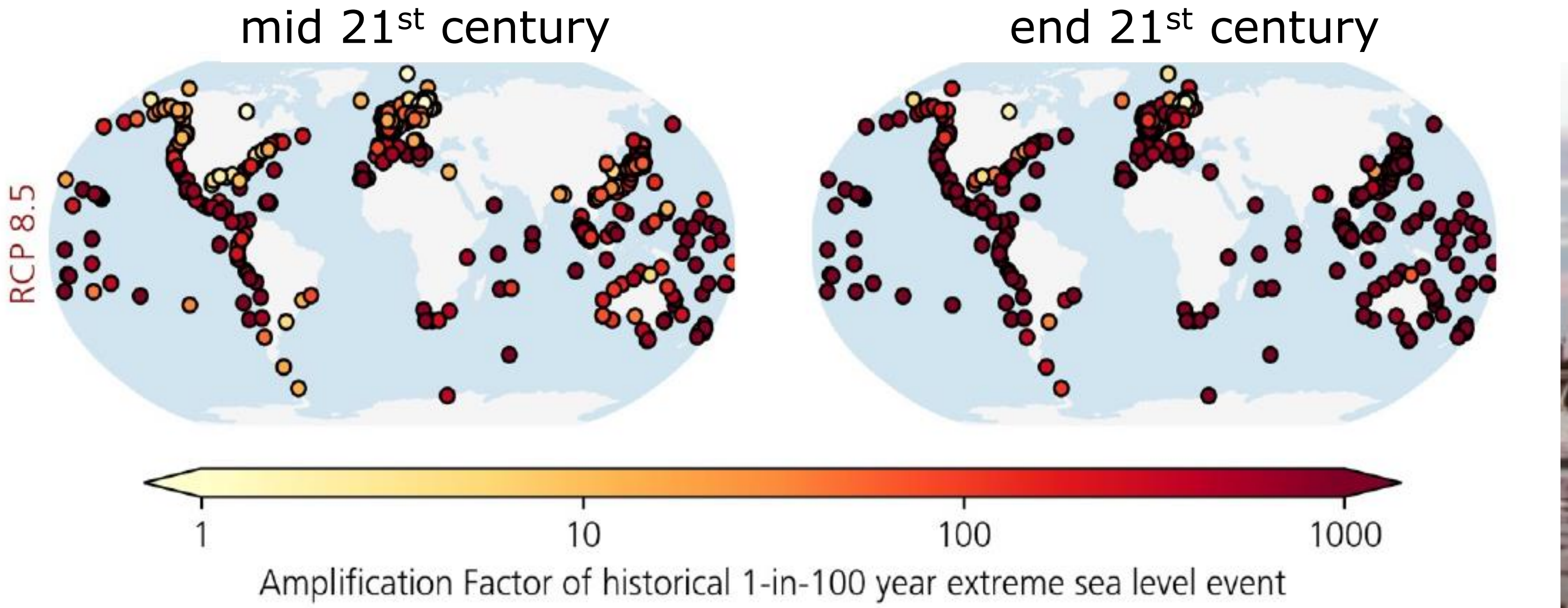
Extreme sea level rise

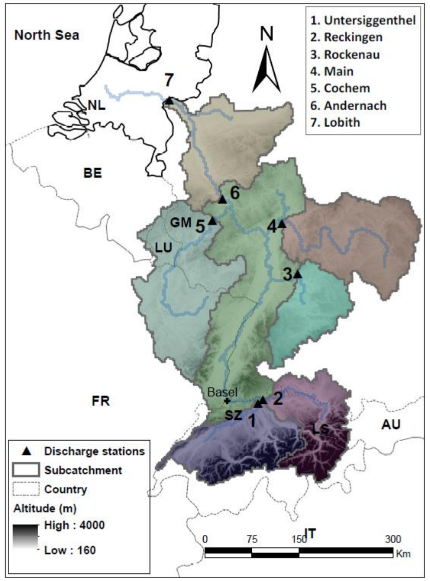
- Sea level rise may reduce return time of extremes considerably



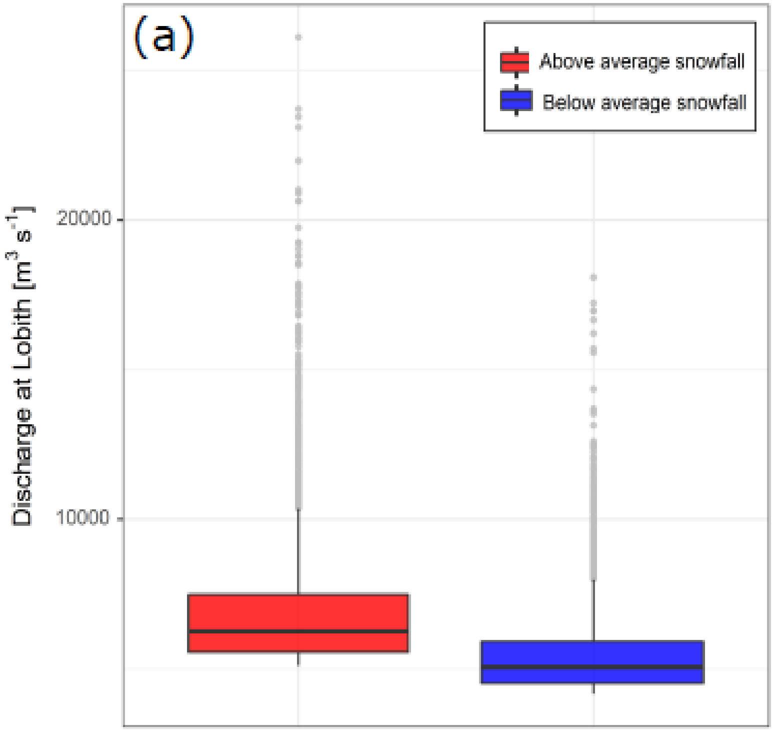


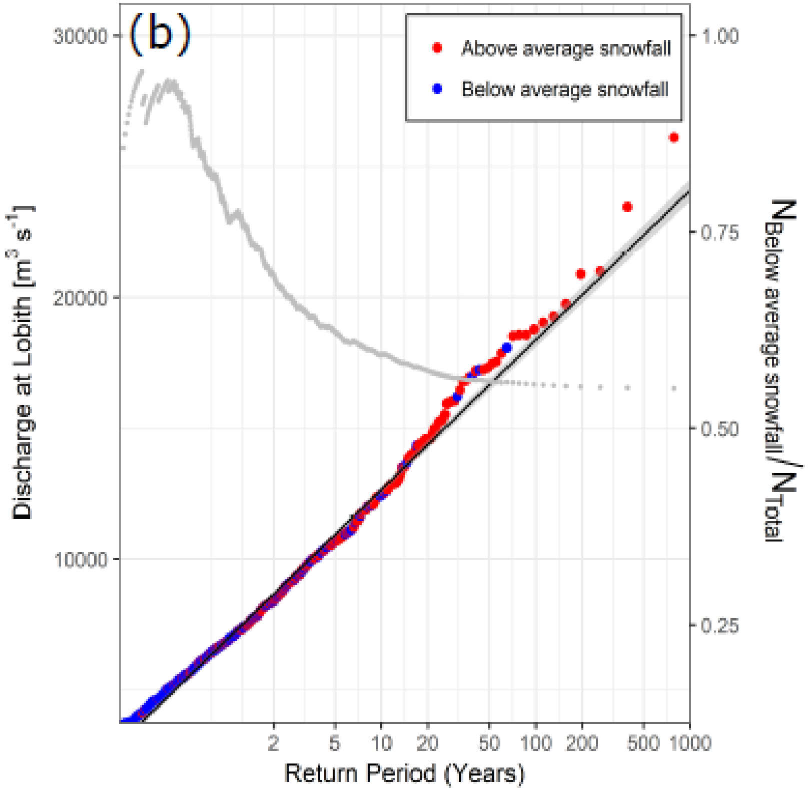
SROCC (Fig 4.12)

Memory effects for combined river/surge



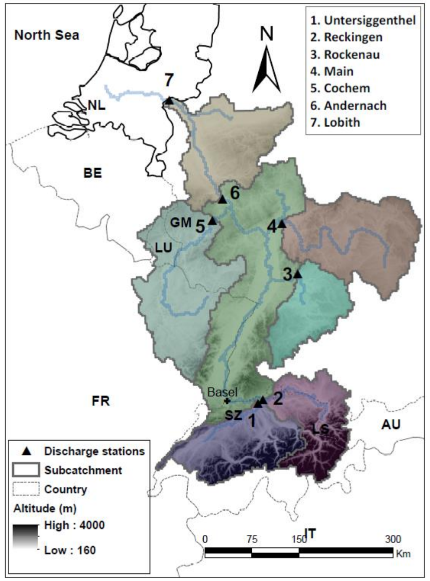
Snowfall



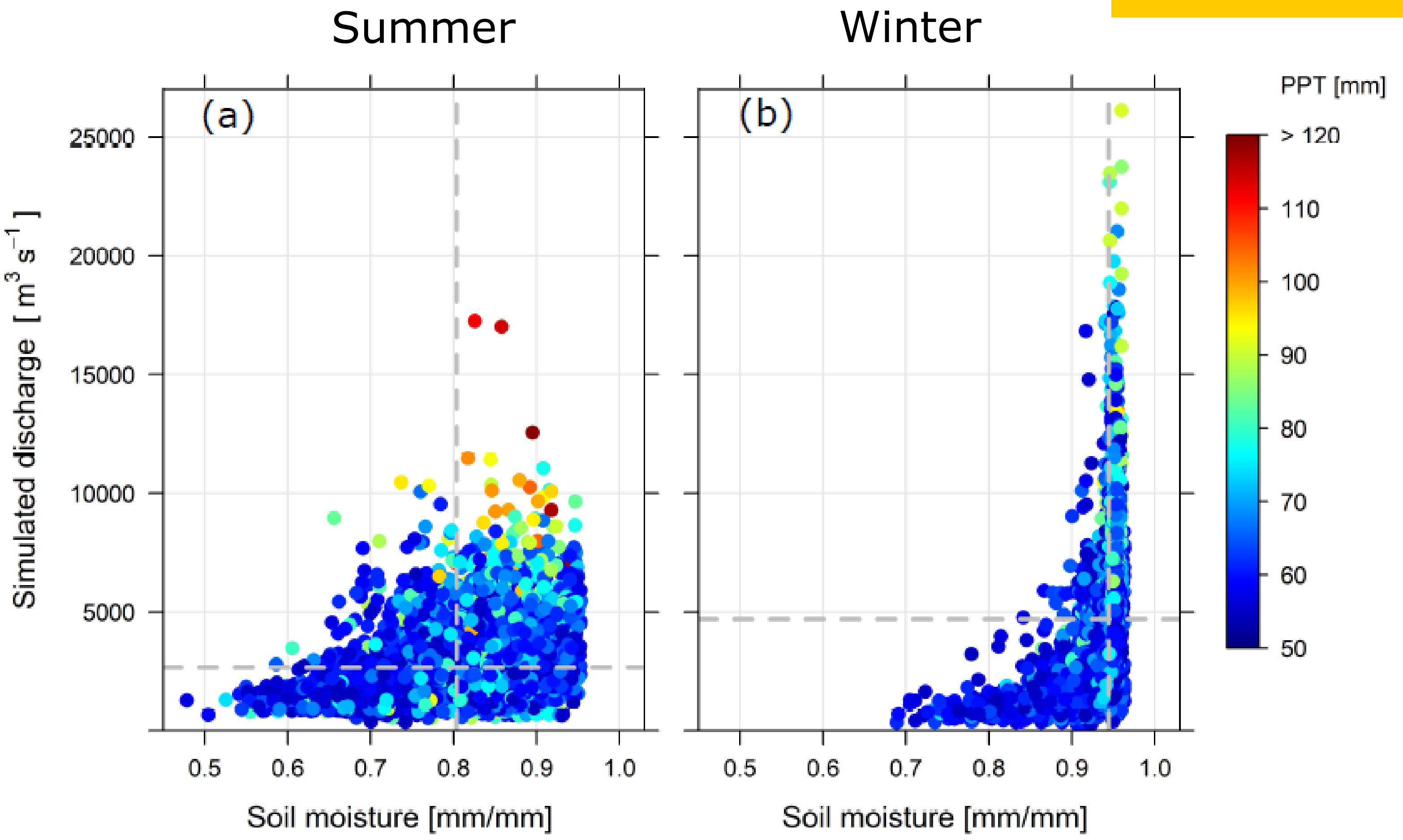


Khanal et al. (2019) *Atmosphere*

Memory effects for combined river/surge

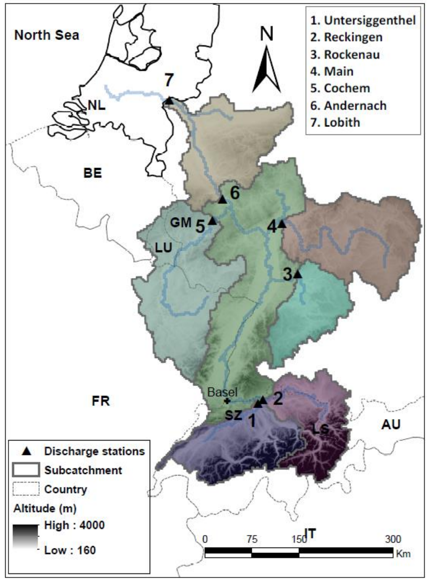


Soil moisture

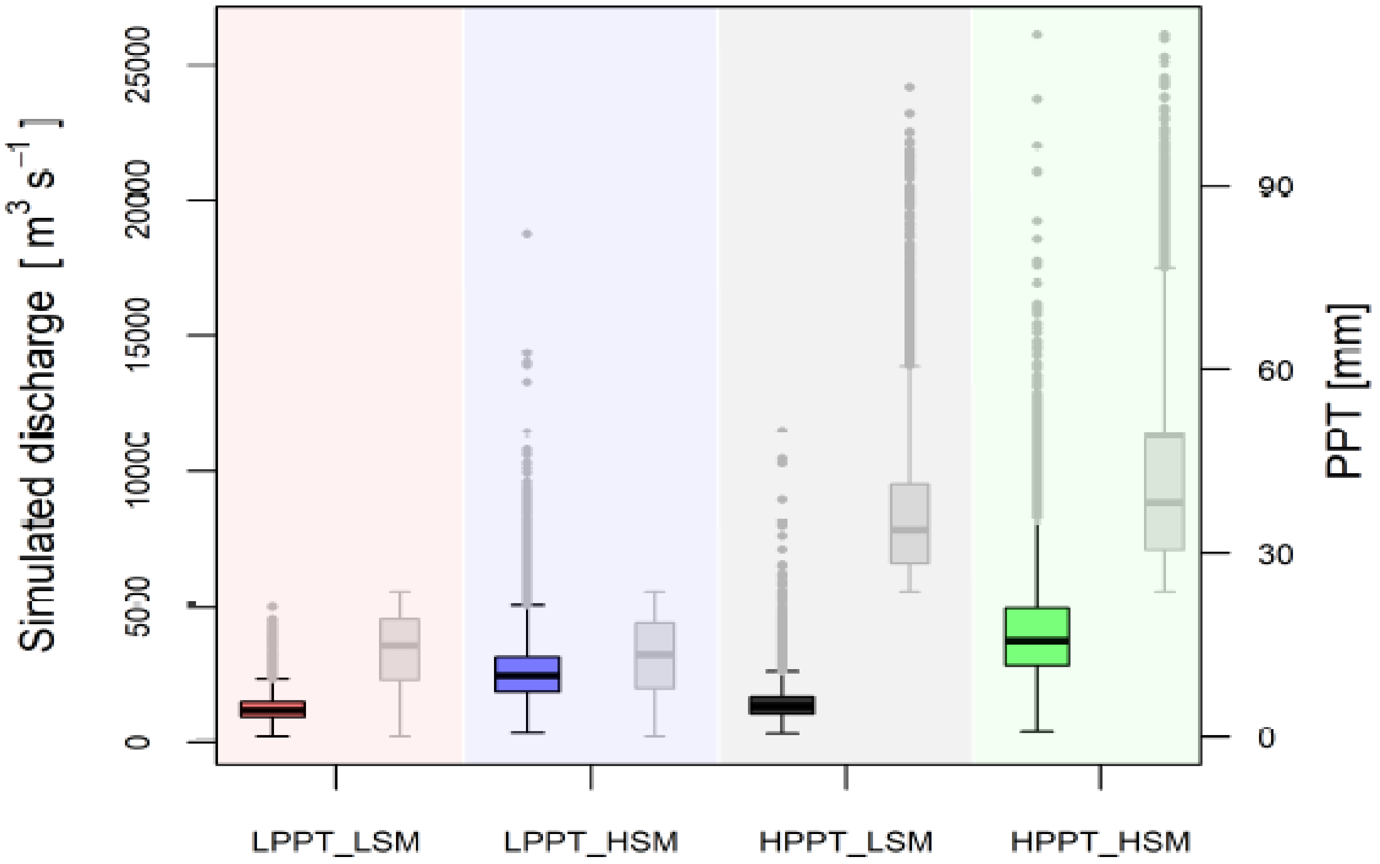


Khanal et al. (2019) *Atmosphere*

Memory effects for combined river/surge

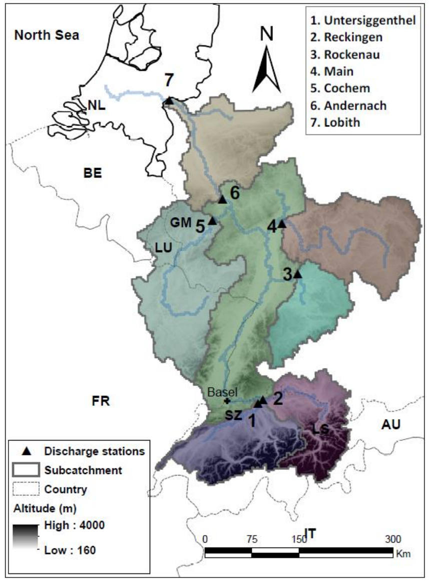


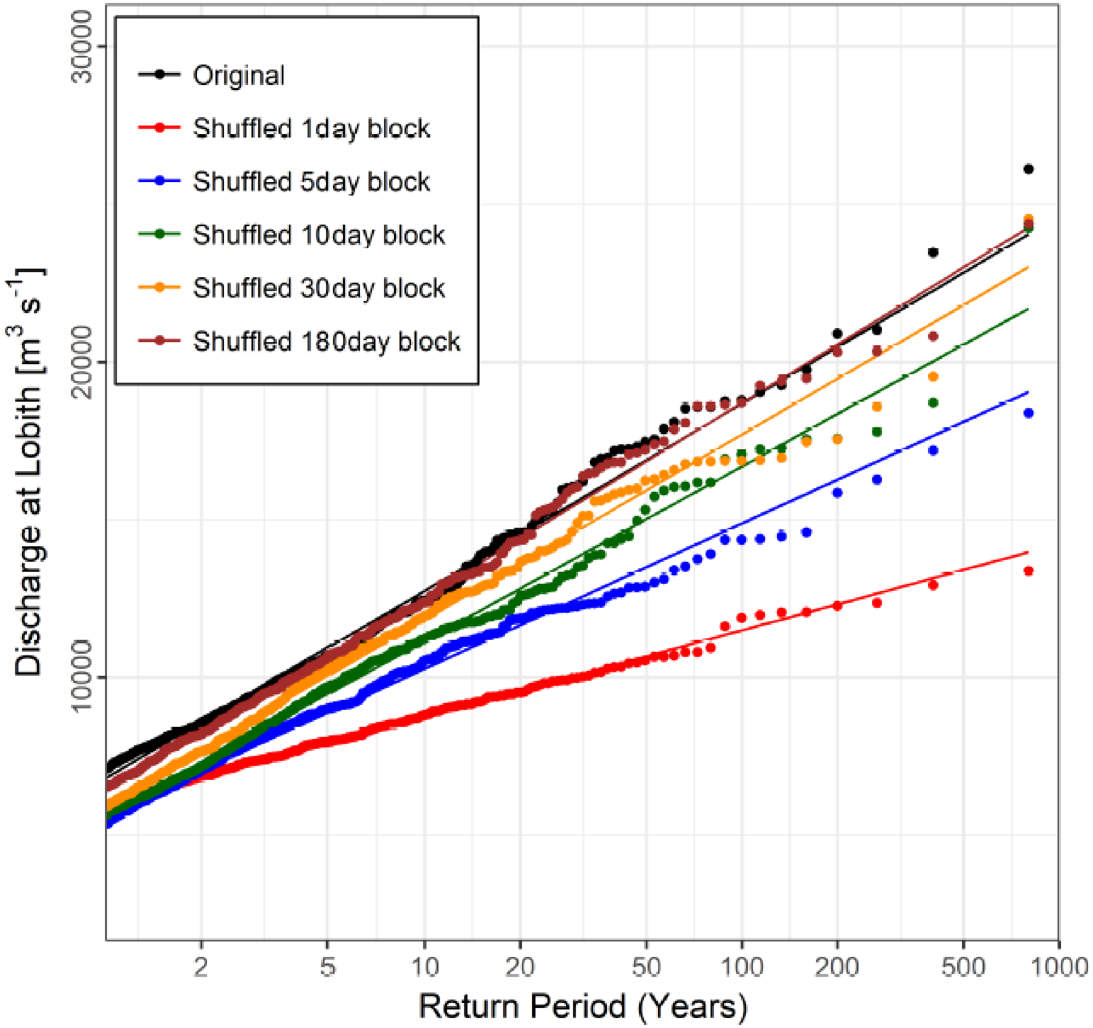
Soil moisture



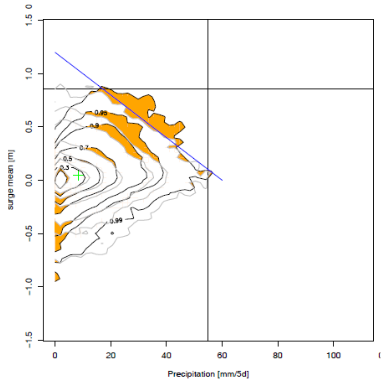
Khanal et al. (2019) *Atmosphere*

Memory effects for combined river/surge



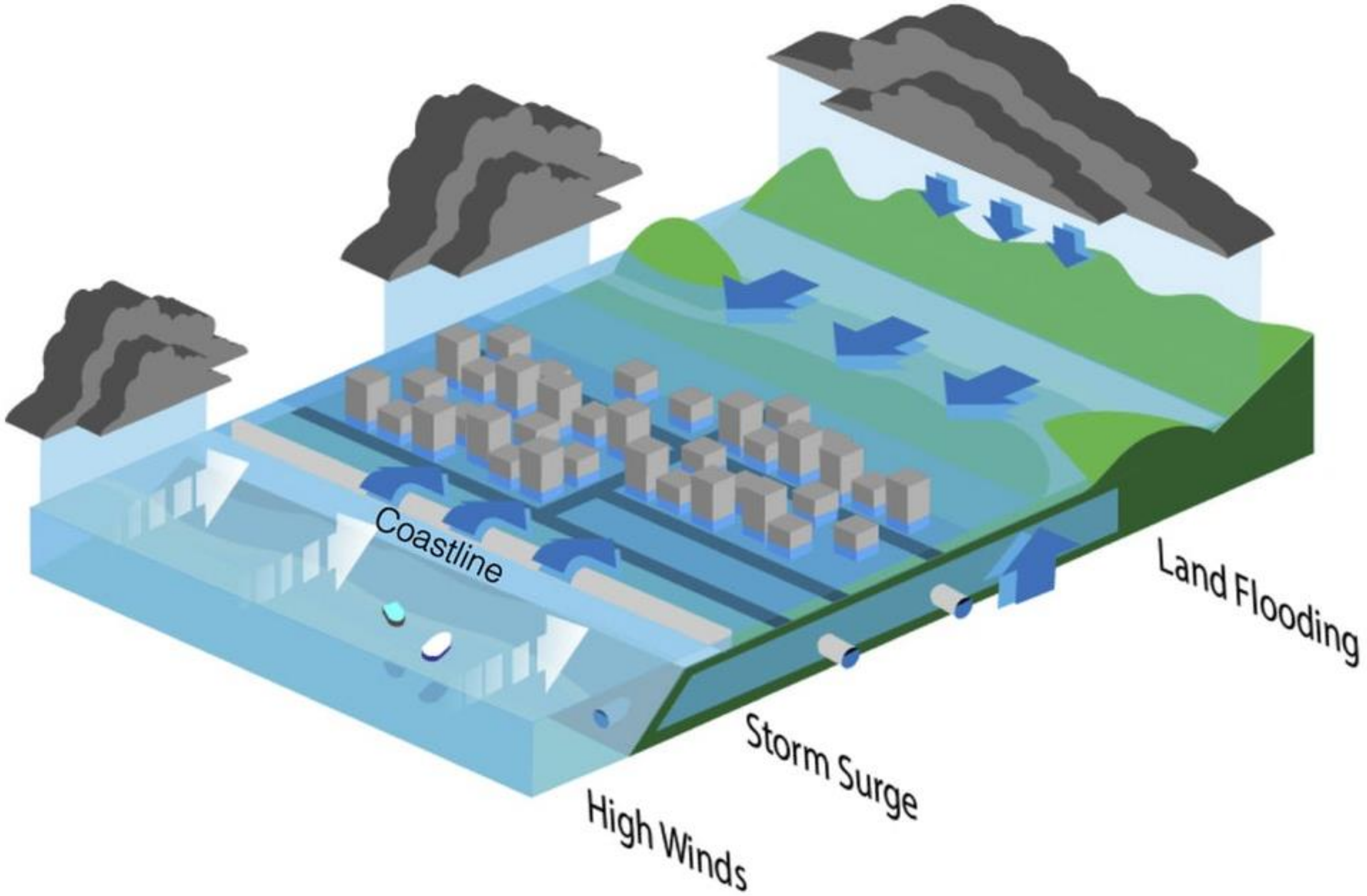


Atmosphere



Khanal et al. (2019) *Atmosphere*

Thank you



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