

Peut-on quantifier les événements climatiques extrêmes ?

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Biostatistics and Spatial Processes

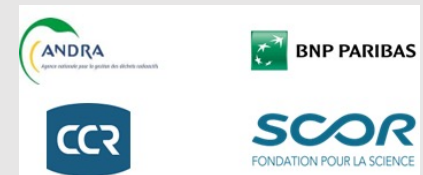
INRAE Avignon

Chaire Geolearning

Séminaire du 8 avril 2026



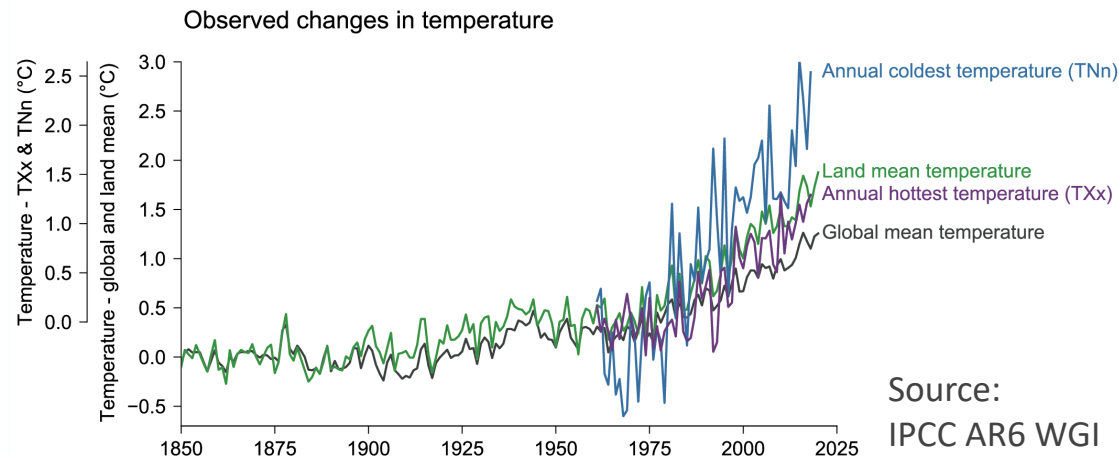
GEOLEARNING
CHAIRE /// Data Science for the Environment



Extreme events in climate and the environment



- Drivers and causes of extreme impacts (risks) on humans and ecosystems
- Even the best physical models cannot precisely predict the future! (see weather forecasts)
- Global changes increase frequency and intensity of high-impact events



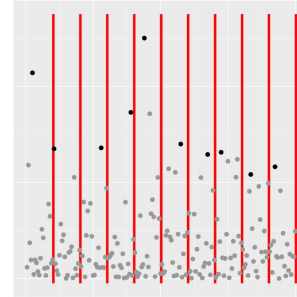
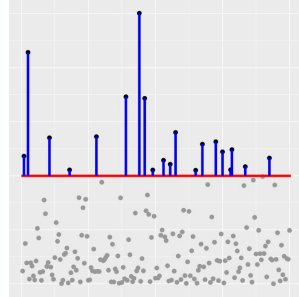
How do we model and predict climate extremes?

Rare events resulting from incompletely known or chaotic processes

→ Probabilities and Stochastic processes

→ Extreme-Value Theory

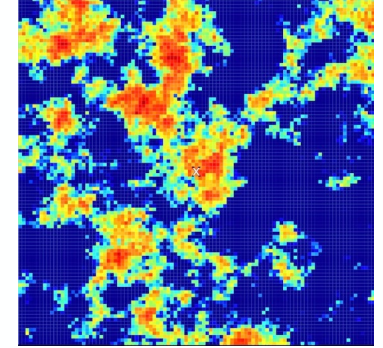
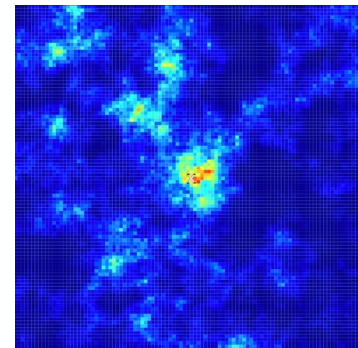
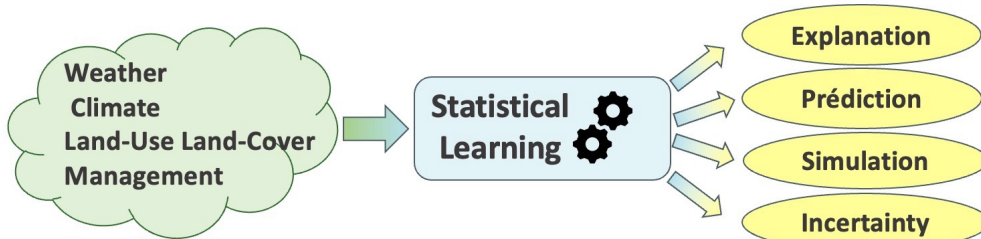
Threshold exceedances



Maxima

➤ From weather/climate to impacts
→ Predictive models for extremes

➤ Duration and spatial extent matter!
→ Spatiotemporal co-occurrences



Key tool: Extreme-Value Theory

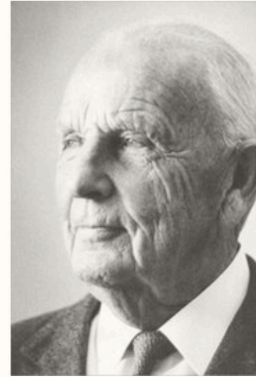
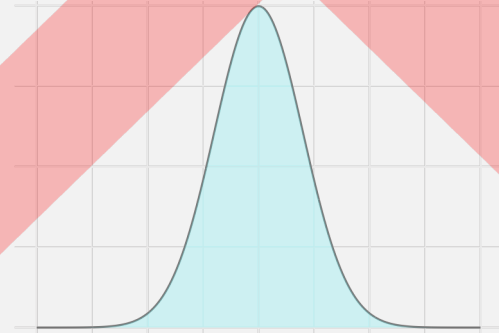
A theory for occurrence probabilities of the most extreme possible events:

- **Maxima** and **exceedances above high thresholds** instead of averages
- Tools for **statistical estimation** and **extrapolation** to new extremes



C. F. Gauss

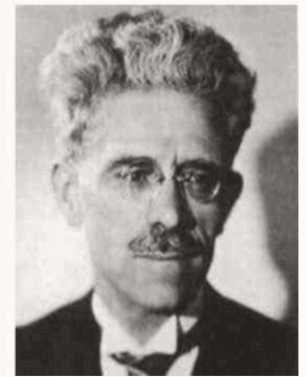
$$\frac{\text{Average}(X_1, \dots, X_n) - \mu_n}{\sigma_n} \rightarrow N \sim \mathcal{N}(0, 1)$$



W. Weibull

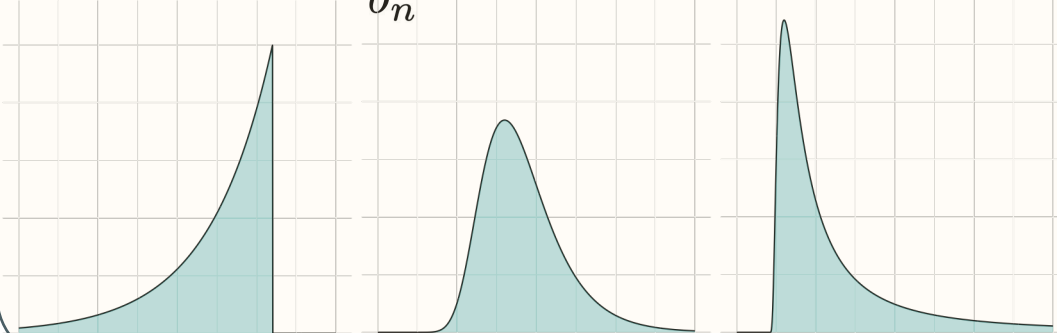


E. J. Gumbel



M. Fréchet

$$\frac{\max(X_1, \dots, X_n) - a_n}{b_n} \rightarrow Z \sim \text{GEV}(\xi)$$



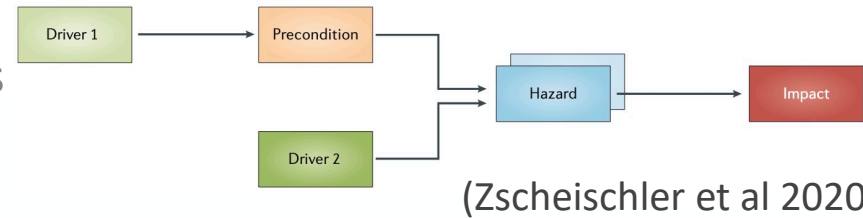
Focus topic 1: Compound events

Context:

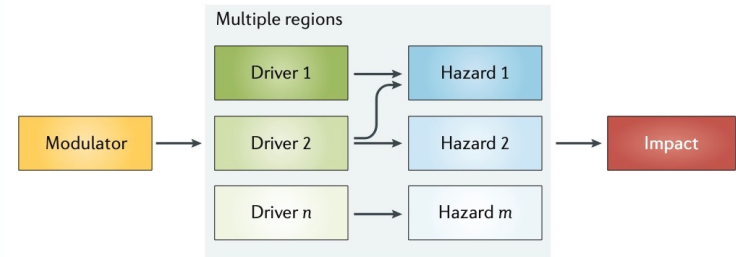
➤ **Combinations of several events** can be particularly devastating

❖ Examples of Flood-related compounds:

- Preconditioned :
Heavy precipitation on wet soils



- Spatial:
Multi-catchment events



Challenges:

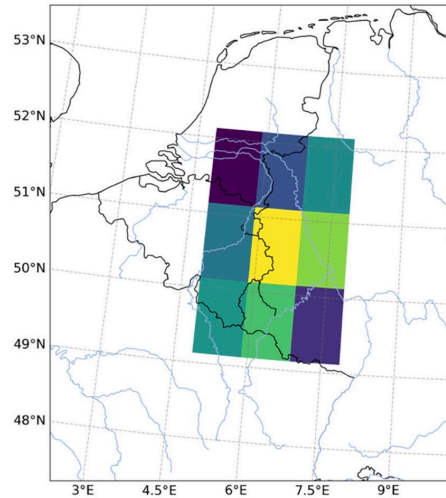
- Establish event timelines and relevant temporal and spatial scales
- Model joint probabilities several events

Methods:

- Multivariate and Spatial Extreme-Value Theory; Spatiotemporal statistics; Graphical models; Multirisk framework

Example: 2021 European floods

Assessment of compounds of heavy precipitation and very wet soils:



Precipitation [mm/day]

> 200 victims

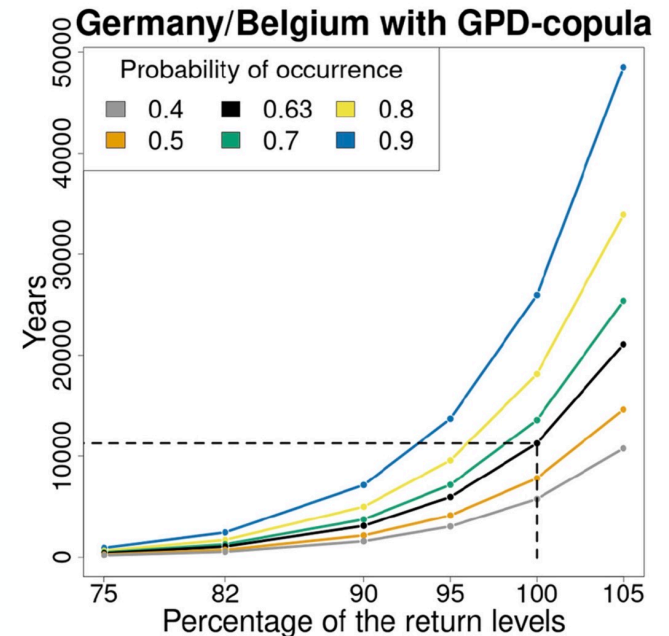
> 40 billion Euros damage

Modeling approach:

(INRAE, Mines-Paris, IPSL)

- Extract historical event catalogue
- Model bivariate threshold exceedances
- Calculate return periods for joint events

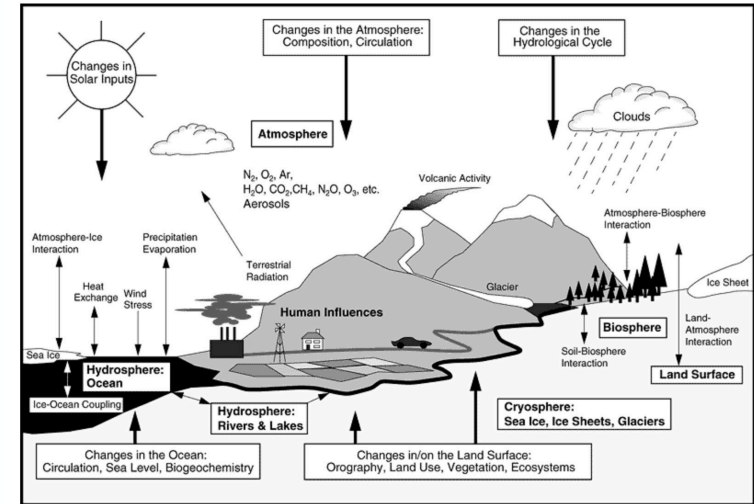
Jacquemin et al (2026). Return Period of Nonconcurrent Climate Compound Events: A Nonparametric Bivariate Generalized Pareto Approach. *Environmetrics*.



Focus topic 2: Hybridize statistics and climate physics

Context:

- Large-scale atmospheric processes are drivers and precursors of extreme events on the Earth surface
 - ❖ Pressure fields, “blocks”, Sea surface temperatures
 - ❖ Climate dynamics



Source: IPCC

Challenges:

- Extend statistical models to include large-scale properties
- Represent interactions across multiple scales in space and time

Methods:

- Spatial Extreme-Value Theory; Regression models; Downscaling; SPDEs; Graphical models ; Multi-resolution

Example : Maximum reachable temperatures

- Statistical upper temperature bounds often exceeded by new data
- Physical equation relates maximum surface temperature to „smoother“ atmospheric variables (Zhang, Boos 2023):

$$T_{s,max} = T_{500} + \frac{L_v}{c_p} (Q_{sat}(T_{500}) - Q) + \frac{g}{c_p} (Z_{500} - Z_s)$$

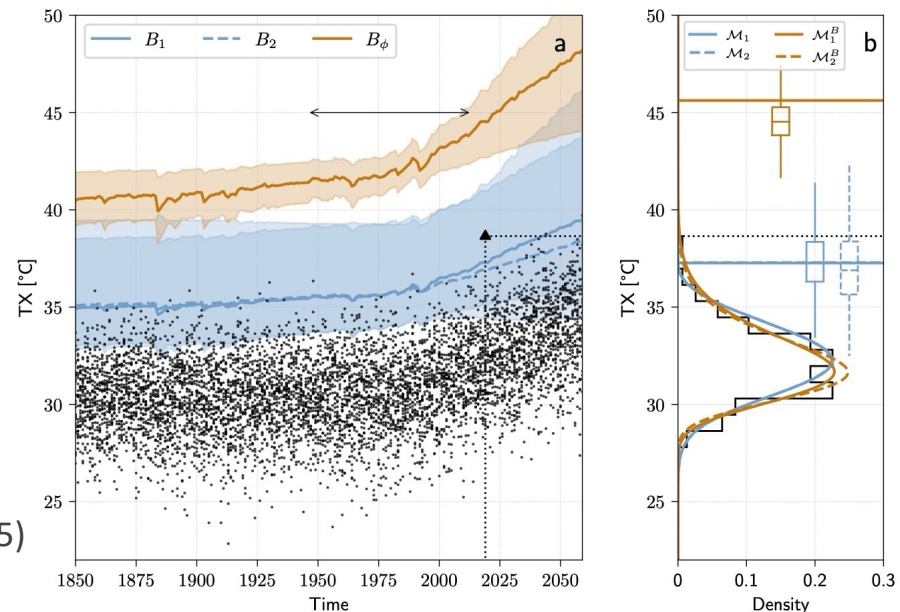
Modeling approach:

(INRAE, IPSL, Montpellier University, ETH Zurich)

- Improve estimation by constraining with climate model simulations
- Use physical information used to define Bayesian prior structure

- ✓ Higher physics-informed bound
- ✓ Statistical fit remains good

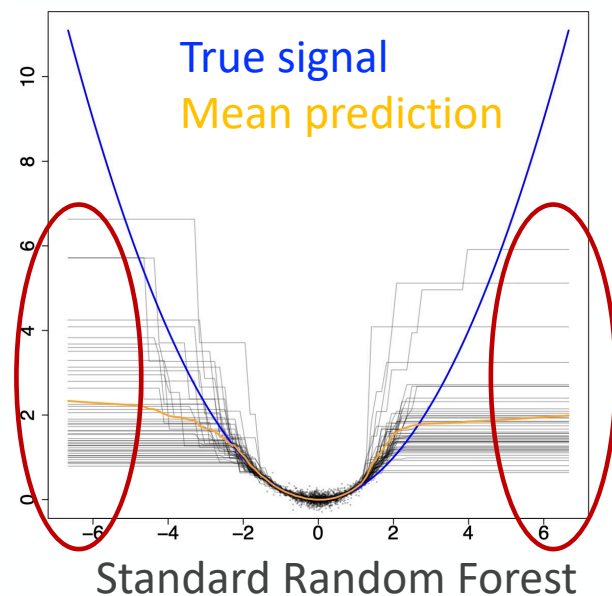
Source: Noyelle et al (2025)



Focus topic 3: Machine Learning and AI for extremes

Context:

- ML and AI excel at complex prediction and simulation
- **But standard methods often break down:**
 - ❖ **Heavy-tail data**
(Rare but devastating events)
 - ❖ **Unreliable prediction** with extreme predictors
(Constant extrapolation)



Source : Buritica & Engelke (2026+)

Challenges:

- Adapt standard architectures to extreme events
- Validation of predicted or simulated extreme events

Methods:

- Multivariate Extreme-Value Theory; Machine Learning; Likelihood/Score-based generative models

Example : Prediction under climate change

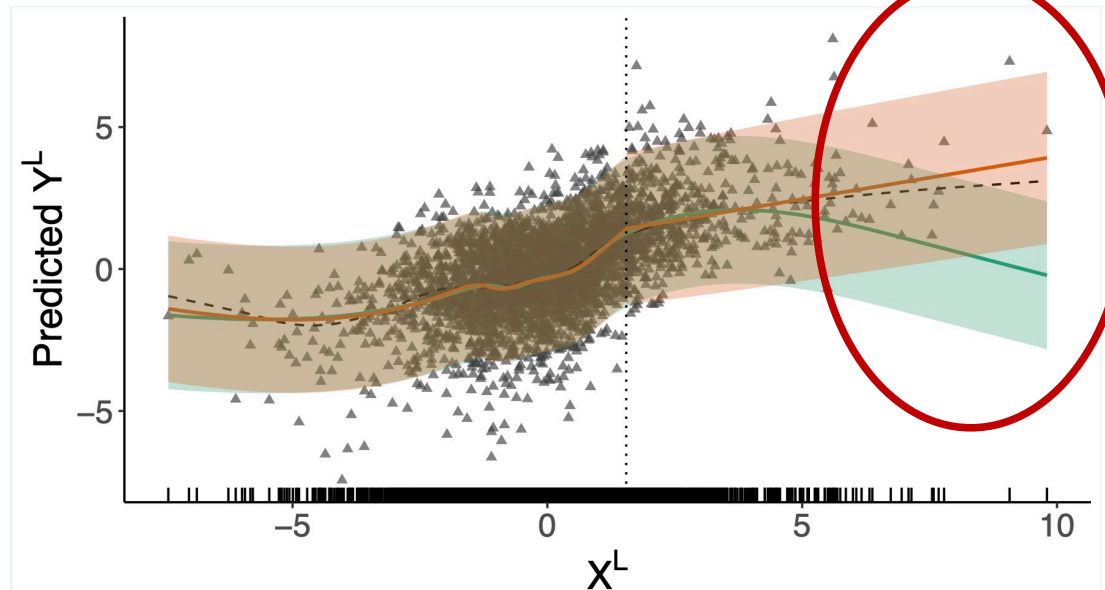
- Motivation: Prediction of extreme wildfire sizes in future climate
- Standard tools: Generalized Additive Models, Random Forests, ANNs
but not reliable for predicting with future new weather extremes

Modeling approach:

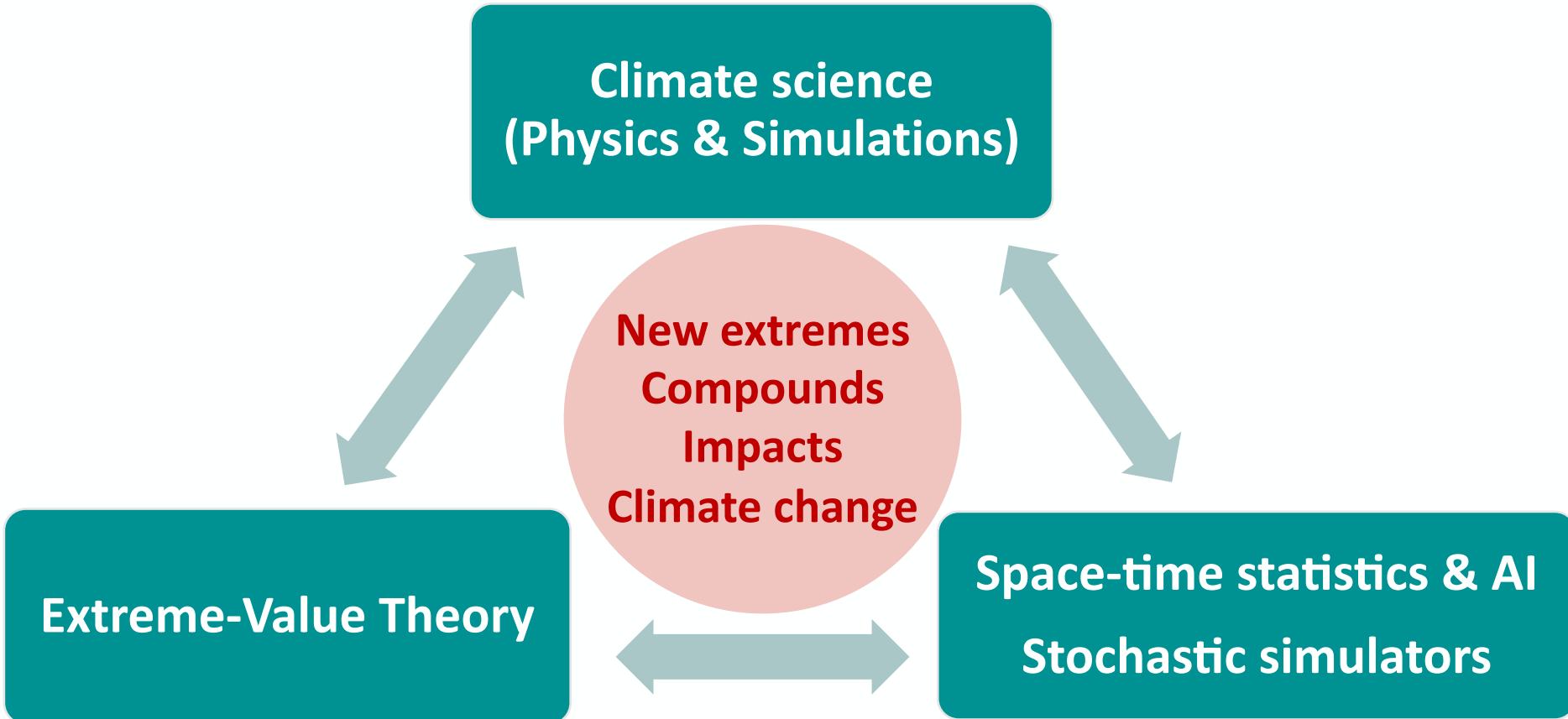
(INRAE, Universities of Brest and Geneva)

- Conditional extremes framework
 - Choose appropriate Link function, Predictor & Response distributions

- ✓ Plausible statistical extrapolation
- ✓ Reduced uncertainty



Geolearning of Extremes: Towards hybrid solutions



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- Knowledge & Resources
- Research frontiers
- Climate partnerships:
 - Academic (IPSL, France 2030...)
 - Private (Reinsurances, Banks...)