PhD position

Statistical geometry for the spatiotemporal modeling of compound climate events

LJAD, Université Côte d'Azur, Nice; BioSP, INRAE, Avignon; LSCE, IPSL, Gif-sur-Yvette

Funding project. The "Collaborative Research Chairs" project (COCHAIR) is a cross-disciplinary project within *PEPR Risques IRiMa*[1], dedicated to the implementation of collaborative research chairs to develop and promote a range of cross-disciplinary scientific activities. COCHAIR is organized into Chairs with the goal to foster the integration and synthesis of the various results in interaction with the other focus projects of the Risk Program, and to the dissemination of results: Chair 1 – Data, models and decision-making in risk science, Chair 2 – Multirisks, Chair 3 – Science, expertise and policy in the era of global change, Chair 4 – Risk culture and mediation. This Phd thesis is a project included in the actions of the first Chair *Data, models and decision-making in risk science* directed by Elena Di Bernardino (Laboratoire J.A. Dieudonné) for the Université Côte d'Azur and it is cofunded by the PEPR Maths-Vives[2].

This PhD scholarship aims to investigate open problems in spatio-temporal extreme-value modeling by adapting stochastic geometry tools and by developing applications to environmental risk assessment.

Duration. 3 years starting from September/October 2025
(Monthly gross salary is around 2650€, with various other additional benefits)

Required qualification. Master 2, or equivalent level, in study programs with focus on Mathematical Statistics or Data Science.

Required training and skills. The following skills are required:

- Solid background in multivariate probability and multivariate statistical theory,
- Possible knowledge in extreme value theory and spatial statistics would be a plus,
- Knowledge in climate science and skills for processing large climate datasets would be a plus,
- Solid knowledge of programming languages (as R, Python, C++ or Matlab).

Goals

The methodological developments of this PhD project will focus on the following directions with the overarching goal to facilitate analysis, modeling and interpretation of complex extreme events and their dynamics using large datasets. Climate applications will be conducted using climate model output (reanalysis and simulations).

– Methodology

- Define geometric representations of extreme events in multivariate spatiotemporal data based on excursion sets (calculated from threshold exceedances, see Huser and Wadsworth [2022], Dombry et al. [2024]) or extremal partitions (based on the occurrence times of pointwise maxima, see Dombry and Kabluchko [2018]).

[1] https://www.pepr-risques.fr/fr
[2] https://www.cnrs.fr/fr/pepr/mathematiques-en-interaction-maths-vives

- Develop theory and statistical methods to characterize and estimate key geometric features (e.g., area, perimeter and Euler characteristic, known as Lipschitz–Killing Curvatures – LKCs, see Biermé et al. [2019], Di Bernardino and Duval [2022], Di Bernardino et al. [2024]) in such representations and study how they evolve dynamically [for example, Zhong et al., 2024]. Spatial theory and estimators are already quite well documented, but work on extensions to multivariate and spatiotemporal setting is scarce since traditional applications focus on a single spatial field.
- A specific goal is to adapt Topological Data Analysis (TDA, see Wasserman [2018]) to exploit geometric properties of multivariate space-time data observed on regular voxel grids. This could be achieved by including LKC features in the birth-and-death process of the persistence diagram used in the TDA to improve information content and predictions while remaining parsimonious.
- A statistical toolbox with reusable and documented generic implementations of newly developed algorithms should be produced.

– **Applications: analysis, attribution and early warning for climate risks**

  - The newly developed approaches will be applied to better understand the spatiotemporal structure and dynamics of compound extreme climate events [Zscheischler et al., 2020, AghaKouchak et al., 2020], defined as events producing important risk impacts on society, agriculture and ecosystems.
  - Specific case studies will include heatwaves, droughts and wildfire weather.
  - One goal is to better understand the physical drivers of such high-impact events – for example, what are typical geometric properties of the spatial fields of atmospheric pressure, soil moisture and surface temperature that lead to extreme heatwaves? Can such properties be used as early-warning indicators for risk management? How predictable are extreme climate risks?
  - Another goal is to assess anomalous events and temporal changes in geometric properties associated to drivers and impacts using observation- and simulation-based data of past, present and future climate. This concerns specifically detection of climate change signals.
  - The climate datasets to be used are publicly available and we will focus on daily data in datasets such as ERA5 (global reanalysis, past and present period), CMIP (global climate simulations, relatively coarse resolution, past, present and future) and EURO-CORDEX (downscaled simulations for Europe, past, present and future).

How to apply? Send an email with the required documents to the prospective PhD supervisors:

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Required documents for candidates.

- Detailed Curriculum vitae;
- Motivation letter;

- Academic transcripts of a master's degree(s) or equivalent;
- Two reference contacts willing to provide a letter of recommendation;
- Internship report.

References

Amir AghaKouchak, Felicia Chiang, Laurie S Huning, Charlotte A Love, Iman Mallakpour, Omid Mazdiyasni, Hamed Moftakhari, Simon Michael Papalexiou, Elisa Ragno, and Mojtaba Sadegh. Climate extremes and compound hazards in a warming world. *Annual Review of Earth and Planetary Sciences*, 48(1):519–548, 2020.

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Peng Zhong, Manuela Brunner, Thomas Opitz, and Raphael Huser. Spatial modeling and future projection of extreme precipitation extents. *Journal of the American Statistical Association*, 0 (ja):1–22, 2024. doi: 10.1080/01621459.2024.2408045. URL https://doi.org/10.1080/01621459.2024.2408045.

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