Extreme Events: Identification, Analysis and Prediction

808. WE-Heraeus-Seminar

22 – 26 April 2024 at the

Physikzentrum, Bad Honnef, Germany

WILHELM UND ELSE HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 808. WE-Heraeus-Seminar:

Extreme events are of great importance due to their devastating impact on nature, society, and even on single subjects. There is thus an urgent need for improving our understanding of generation and termination of such events as well as for identifying precursors to be able to predict them in advance such that mitigating measures can be taken. There is also a high demand for new insights into propagation and spreading of extreme events, either in space or into different parts of a system, since such couplings can lead to domino effects and to particularly dangerous compound extreme events.

The aim of this highly interdisciplinary seminar is to discuss possible causes and mechanisms leading to the formation of extreme events, contemporary methods of their statistical and theoretical analysis as well as novel methods for their prediction. As regards theoretical approaches, the focus will be on cutting-edge methods from nonlinear dynamics, network theory, data analysis, and large deviation theory. We will bring together scientists from a large variety of disciplines, in which extreme events become increasingly important: climate science, earth system science including ecology, as well as neuroscience and human health. Furthermore, we will discuss experiments from laser physics, combustion, and ecology which are designed to help understanding generation and termination of extreme events.

Potential participants range from excellent scientists leading in their fields to give comprehensive overviews via outstanding young scientists to PhD students who are interested in interdisciplinary approaches. We expect every participant to contribute to this Seminar by either giving a talk or by presenting a poster.

Introduction

Scientific Organizers:

Prof. Dr. Syamal Dana	Dept. of Mathematics Jadavpur University Kolkata, India
Prof. Dr. Ulrike Feudel	Theoretical Physics/Complex Systems Institute for Chemistry and Biology of the Marine Environment Carl von Ossietzky University, Oldenburg, Germany
Prof. Dr. Klaus Lehnertz	Neurophysics Department of Epileptology, Medical Center University Bonn, Germany

Administrative Organization:

Dr. Stefan Jorda Marion Reisinger	Wilhelm und Else Heraeus-Stiftung Kurt-Blaum-Platz 1 63450 Hanau, Germany Phone +49 6181 92325-18 Fax +49 6181 92325-15 E-mail reisinger@we-heraeus-stiftung.de Internet: www.we-heraeus-stiftung.de

Introduction

Venue:

Physikzentrum
Hauptstrasse 5
53604 Bad Honnef, Germany

Conference Phone +49 2224 9010-120

Phone +49 2224 9010-113 or -114 or -117
Fax +49 2224 9010-130
E-mail gomer@pbh.de
Internetwww.pbh.de

Taxi Phone +49 2224 2222

Registration:

Marion Reisinger (WE Heraeus Foundation)
at the Physikzentrum, reception office
Sunday (17:00 h – 21:00 h) and Monday morning

Program

Program

Sunday, 21 April 2024

17:00 – 21:00	Registration	
From 18:00	*BUFFET SUPPER*	

Monday, 22 April 2024

08:00 – 08:45	*BREAKFAST*	
08:50 – 09:00	*Ulrike Feudel; Syamal Dana, Klaus Lehnertz*	**Welcome and Introduction**
09:00 – 09:40	Jürgen Kurths	**Forecasting extreme events related to tipping elements in the climate system**
09:40 – 10:20	Melinda Galfi	**The typicality of weather and climate extreme events**
10:20 – 11:00	*COFFEE BREAK*	
11:00 – 11:40	Freddy Bouchet	**New ways for dynamical prediction of extreme heat waves, extreme of renewable electricity production, and abrupt climate change: rare event simulations and machine learning**
11:40 – 12:05	Dániel Jánosi	**An ensemble based approach for the effect of climate change on the dynamics of extremes**
12:05 – 12:30	Sebastian Buschow	**How extreme was the Christmas 2023 flood event?**
12:30 – 14:15	*LUNCH*	

Program

Monday, 22 April 2024

14:30 – 15:10	Joachim Peinke	**Non-equilibrium thermodynamics of extreme events in wind turbulence and water waves**
15:10 – 15:35	Hildegard Meyer-Ortmanns	**Methods of dimensional reduction to assess rare events of blackouts in power grids**
15:35 – 15:50	Stefan Jorda	**About the Wilhelm and Else Heraeus Foundation**
15:50 – 16:30	*COFFEE BREAK*	
16:30 – 17:10	Themistoklis Sapsis (online)	**Extreme event catalogues from coarse climate models and the value of data**
17:10 – 17:35	Ohad Shpielberg	**Thermal activation of interacting particles: a different kind of universality, and dynamical phase transitions**
17:35 – 18:00	Michael Möckel	**Hybrid physics-based and data-driven approaches for predictive maintenance in the case of rare events**
18:00	*DINNER*	

Program

Tuesday, 23 April 2024

08:00 – 09:00	*BREAKFAST*	
09:00 – 09:40	Holger Kantz	**Analysis and modeling of precipitation extremes**
09:40 – 10:20	Thordis Thorarinsdottir	**Evaluating forecasts of extreme events**
10:20 – 11:00	*COFFEE BREAK*	
11:00 – 11:40	Davide Faranda	**Understanding and attributing extreme weather events in a changing climate**
11:40 – 12:05	Vidar Frette	**Spontaneous transition from smoldering to flaming combustion**
12:05 – 12:30	Milan Palus	**Non-Shannonian information theory connects inference of causality and understanding of extreme events**
12:30 – 12:40	*Conference Photo*	
12:40 – 14:15	*LUNCH*	
14:30 – 15:10	Christian Meisel	**Towards predicting extreme events in neurology with theory-based and machine learning approaches**
15:10 – 15:35	Svenja Szemkus	**How ClimXtreme builds a knowledge base for decision support**
15:35 – 16:00	Alexander Hartmann	**First-passage area distribution and optimal fluctuations of fractional Brownian motion**
16:00 – 16:40	*COFFEE BREAK*	
16:40 – 17:30	**POSTER FLASH 1**	
18:00 – 19:00	*DINNER*	
19:00 – 22:00	**POSTER SESSION 1**	

Program

Wednesday, 24 April 2024

08:00 – 09:00	*BREAKFAST*	
09:00 – 09:40	Dibakar Ghosh	**Extreme events in dynamical networks**
09:40 – 10:20	Ying-Cheng Lai	**Machine-learning prediction of tipping and collapse of the Atlantic Meridional Overturning Circulation**
10:20 – 11:00	*COFFEE BREAK*	
11:00 – 11:40	Jörn Davidsen	**Earthquakes in the lab: From accelerated seismic release to magnitude clustering**
11:40 – 12:05	Jonas Wassmer	**Hidden Vulnerabilities in Emergency Response Post-Flood Disasters**
12:05 – 12:30	Gisela Charo	**Topological analysis of extreme events**
12:30 – 14:00	*LUNCH*	
14:00 – 18:30	Excursion	
18:30	*HERAEUS DINNER* *(social event with cold & warm buffet and complimentary drinks)*	

Program

Thursday, 25 April 2024

08:00 – 09:00	*BREAKFAST*	
09:00 – 09:40	Cristina Masoller	**New indicators for early detection of critical transitions**
09:40 – 10:20	Yujiang Wang	**Charting the pathway of extreme events in the brain**
10:20 – 11:00	*COFFEE BREAK*	
11:00 – 11:40	Thomas Guhr	**Multivariate distributions in highly correlated, nonstationary complex systems**
11:40 – 12:05	Leo Sahaya-Tharsis	**Routes to large-intensity pulses in laser models**
12:05 – 12:30	Sabin Roman	**Modelling the collapse of societies**
12:30 – 14:15	*LUNCH*	
14:30 – 14:55	Ryan Deeley	**The increased likelihood of plankton community changes following marine heatwaves**
14:55 – 15:20	Frank Kwasniok	**Data-driven quantification of weather and climate risk using large-deviation theory**
15:20 – 15:45	Timo Bröhl	**A subnetwork in the evolving functional epileptic brain carries predictive information about impending seizures**
15:45 – 16:15	COFFEE BREAK	

Program

Thursday, 25 April 2024

16:15 – 16:55	Marcel Clerc *(online)*	**Spatiotemporal Chaos Induces Extreme Events in an Extended Microcavity Laser and Kerr Resonators**
17:00 – 17:45	**POSTER FLASH 2**	
18:00	*DINNER*	
19:00 – 22:00	**POSTER SESSION 2**	

Program

Friday, 26 April 2024

08:00 – 09:00	*BREAKFAST*	
09:00 – 09:40	R. Sujith (online)	**Extreme Covid-19 Waves and Flame Blowout in Jet Engines: What is in common?**
09:40– 10:20	Tomasz Kapitaniak	**Transition to hyperchaos: Sudden expansion of attractor and intermittent large-amplitude events in dynamical systems**
10:20 – 11:00	*COFFEE BREAK*	
11:00 – 11:25	Reik Donner	**Quantifying statistical associations among persistent events: From event coincidence to interval coverage analysis**
11:25 – 11:50	Sara Vallejo-Bermal	**The role of atmospheric rivers in the spatio-temporal organization of heavy precipitation events in North America**
11:50 – 12:15	Samudrajit Thapa	**Leveraging large-deviation statistics to decipher the stochastic properties of measured trajectories**
12:15 – 13:00	*Ulrike Feudel; Syamal Dana, Klaus Lehnertz*	**Closing**
13:00 – 14:00	*LUNCH*	

End of the seminar and departure

NO DINNER for participants leaving on Saturday; however, a self-service breakfast will be provided on Saturday morning

Posters

Posters

Fatemeh Aghaei A.	**Return time of extreme events in climate systems and global warming**
Togueu Motcheyo Alain Bertrand	**Discrete rogue waves induced in a nonlinear pendulum chain**
Eloisa Bentivegna	**The role of equation residuals in the discovery of anomalous PDE solutions**
Enrique Chipicoski Gabrick	**Seasonal forcing induces unpredictability in diseases spread**
Prakash Duraisamy	**Investigation of vibration dynamics and extreme events during failure prediction of ball bearing in two rotor system: Qualitative and Quantitative approach**
Petra Friederichs	**ClimXtreme II: Climate change and weather extremes in Europe: building a knowledge base for decision support**
Anupam Ghosh	**Comprehending extreme events in dynamical systems amidst stochastic interaction**
Bruno Valdemar Guerrero Borges	**Some considerations on time dependency and ergodicity in epidemiological modeling**
Oisin Hamilton	**The impact of model resolution on variability in a coupled land atmosphere model**
Jayati Kaushik	**Using Topological Data Analysis to detect outliers: A Review**
Finn Köhne	**Short-time prediction of extreme events in atmospheric turbulence**
Viacheslav Kruglov	**Genealogical Particle Analysis in Oceanic Tracer Studies**

Posters

Michał Łepek	**Insight into deviations in aggregation processes: A new theory based on combinatorics applied to protoplanetary formation**
Jan Meibohm	**Finite-time dynamical phase transitions in non-equilibrium relaxation**
Priyanka Mondal	**Modelling plant-aphid interactions with Holling type-II functional response under the influence of adaptive mutualistic plant-ant interactions**
Daniela Moreno	**Extremely large periods of constant wind speed in the atmospheric turbulent wind**
Benjamin Musci	**Investigating extreme-event morphology and correlation with large-scale bifurcations using enstrohpy conditioned statistics**
Sayantan Nag Chowdhury	**Extreme events in globally coupled chaotic maps**
Pauleo Nimtz	**Introduction to Varieties of Democracy in Times of Global Change**
Paulo José Paulino de Souza	**Large deviation full counting statistics in adiabatic open quantum dynamics**
Paul Sanders	**Navigating Early Warning Systems: Bridging Gaps with Spatial Coherence**
Zhen Su	**On the global-scale interdependence patterns of extreme rainfall**
Yu Wang	**Dynamics of Systems with Time Delay: Coexistence and Stability of Periodic Solutions**

Peter Werner

Simulation of equilibrium and non-equilibrium unfolding and refolding processes for RNA secondary structures

Abstracts of Talks

(in alphabetical order)

New ways for dynamical prediction of extreme heat waves, extreme of renewable electricity production, and abrupt climate change: rare event simulations and machine learning

B. Cozian[2], G. Milosevich[2], C. Le-Priol[1], F. Ragone, C. Herbert[2] and F. Bouchet[1]

[1]CNRS, LMD/IPSL, ENS, Université PSL, Paris, France
[2] ENSL, CNRS, Laboratoire de Physique, Lyon, France

In the climate system, extreme events or transitions between climate attractors are of primarily importance for understanding the impact of climate change. Recent extreme heat waves with huge impact, or period very low production of renewable energy in the electricity system are striking examples. However, a key challenge is the lack of data, because these events are too rare and realistic models are too complex.

I will discuss new algorithms and theoretical approaches, based on rare event simulations, and machine learning for stochastic processes, which we have specifically designed for the prediction of the committor function (the probability of the extreme event to occur). To illustrate the performance of these tools, I will discuss results for the study of midlatitude extreme heat waves and the extremes of renewable energy production in relation with the resilience of the electricity system.

I will also briefly explain how the same rare event simulation and machine learning tools can be used to study rare transitions between different states of the climate system, leading to abrupt climate change. I will explain past works in this direction and current research projects.

References

[1] F. Ragone, J. Wouters, and F. Bouchet, Proceedings of the National Academy of Sciences, vol 115, no 1, pages 24-29, https://doi.org/10.1073/pnas.1712645115, and arXiv:1709.03757, [pdf] (2018)

[2] G. Miloshevich, B. Cozian, P. Abry, P. Borgnat, and F. Bouchet, Phys. Rev. Fluids 8, 040501, doi.org/10.1103/PhysRevFluids.8.040501 and *arXiv:2208.00971*, [pdf] (2023)

[3] D. Lucente, J. Rolland, C. Herbert and F. Bouchet, J. Stat. Mech. 083201, *arXiv:2110.05050*, [pdf] (2022)

[4] B. Cozian, C. Herbert, and F. Bouchet, *arXiv:2311.13526*, [pdf] (2024)

A subnetwork in the evolving functional epileptic brain carries predictive information about impending seizures.

T.Bröhl[1,2] **and K. Lehnertz**[1,2,3]

[1] *Department of Epileptology, University of Bonn Medical Centre, Bonn, Germany*
[2] *Helmholtz Institute for Radiation and Nuclear Physics, University of Bonn, Bonn, Germany*
[3] *Interdisciplinary Center for Complex Systems, University of Bonn, Bonn, Germany*

Epileptic seizures can be regarded extreme events in the complex dynamical system brain.
Considering epilepsy as a network disease that affects the brain across multiple spatial and temporal scales has helped considerably to further improve prediction, control, and understanding of the dynamics of such events.
Novel approaches based on the concept of a time-evolving functional epileptic network allow one to identify vital network constituents, which carry predictive information about impending seizures.
These constituents comprise various brain regions (vertices) and interactions between their dynamics (edges), yet, their role as well as their interplay in the larger network remain to be investigated.
Here, we retrospectively investigate time-evolving, large-scale, functional epileptic brain networks that we derived from multi-day, multi-electrode intracranial electroencephalographic recordings from subjects with pharmacoresistant epilepsies with different anatomical origins.
We combine multiple complementary vertex and edge centrality metrics to assess the structural and functional integration of constituents in the network as well as the change of this integration in time. Interestingly, we find that a vital and large subnetwork is predictive of impending seizures, which covers about half of the network.
Our findings provide novel insight in how seizures might be generated within the functional epileptic brain network and in future might aid in identifying targets that may be used for controlling seizures.

How extreme was the Christmas 2023 flood event?

S. Buschow[1] and the ClimXtreme consortium

[1]*Institute of Geosciences, Bonn, Germany*

In the weeks around Christmas 2023, Germany was affected by wide-spread, long lasting rainfall. The resulting floods along several Northern German rivers caused damages and disruptions and attracted considerable public interest at the time [1]. Key questions include (a) how unusual such an event is in the present climate and (b) whether its occurrence probability was or will be modified by man-made climate change.

Questions of this nature are at the core of the ClimXtreme research program. In its current second phase, ClimXtreme aims to quickly apply and disseminate state-of the art techniques and research outcomes in the context of a current extreme event of interest. The 2023 Christmas flood serves as a first example, which is analyzed with respect to local return times, spatial patterns of extremal dependence, weather regimes, regional precipitation trends from climate models, and possible attribution to climate change.

Preliminary results indicate that, while no local records were broken, the combination of large affected area and long duration is indeed very unusual in German winters. In some locations, the 7-day aggregate rainfall reaches return periods close to 100 years. A principal component analysis tailored to extreme events [2] reveals that the main spatial pattern related to the 2023 flood reached its second highest peak on record (1940-2023), exceeded only by the new year floods of 1987. An established methodology for climate change attribution is applied to quantify the human imprint on events of this type [3]. It is found that most available climate models do not adequately reflect the observed statistics of maximum winter precipitation; those that do, do not agree on the sign and magnitude of the climate change signal. In the synthesis, a weak increase of 5% compared to a 1.2°C cooler pre-industrial climate emerges.

References

[1] F. Kaspar, M. Rauthe, C. Brendel, T. Junghändel, …, R. Ullrich, Bericht des Deutschen Wetterdienstes (2024).

[2] Szemkus, S., & Friederichs, P., Advances in Statistical Climatology, Meteorology and Oceanography, **10(1)**, 29-49 (2024).

[3] Tivig, M., Schröter, J., Lorenz, P., Sauerbrei, R., Knauf, J. und Kreienkamp, F. Bericht des Deutschen Wetterdienstes (2024).

Topological analysis of extreme events

G. D. Charó[1,2] D. Faranda[1,3,4], M. Ghil[4,5,6] and D. Sciamarella[7,8]

[1]*Laboratoire des Sciences du Climat et de l'Environnement, CEA Saclay l'Orme des Merisiers, UMR 8212 CEA-CNRS-UVSQ, Université Paris-Saclay & IPSL, 91191, Gif-sur-Yvette, France.*
[2] *Universidad de Buenos Aires. Centro de Investigaciones del Mar y la Atmósfera (CIMA), C1428EGA CABA, Argentina.*
[3] London Mathematical Laboratory, 8 Margravine Gardens,London, W6 8RH, UK
[4]*Geosciences Department and Laboratoire de Météorologie Dynamique (CNRS and IPSL), École Normale Supérieure and PSL University, 75231 Paris CEDEX 05, France*
[5] *Department of Atmospheric & Oceanic Sciences, University of California , Los Angeles, CA 90095-1567, USA.*
[6]*Departments of Mathematics and of Finance, Imperial College London, London, SW7 2BX, UK.*
[7]*CNRS – IRD – CONICET – UBA. Institut Franco-Argentin d'\'Etudes sur le Climat et ses Impacts (IRL 3351 IFAECI), C1428EGA CABA, Argentina.*
[8]*Centre National de la Recherche Scientifique, 75794 Paris CEDEX 16, France*

Numerical and theoretical studies have shown that transient atmospheric motions leading to weather extremes can be classified through the stability of a state of a dynamical system and the instantaneous dimension [1]. While the asymptotic values of these quantities can be computed theoretically only for specific systems, their numerical counterpart for climate observables provides information on the rarity, predictability, and persistence of specific states. There is therefore both theoretical and practical interest in bridging such numerical metrics with their theoretical counterpart. In this work, we present a first attempt to relate the instantaneous dimension and other local metrics with the topological properties of the templex in the deterministic [2]. The templex provides the key characteristics of the topological structure underlying a dynamical system. This work will present results for the classical, deterministic and random Lorenz attractor [3;4].

References

[1] Faranda D., Messori G., & Yiou P., Scientific reports **7(1)** 41278 (2017).
[2] Charó G. D, Letellier C. & Sciamarella D., Chaos: An Interdisciplinary Journal of Nonlinear Science, **32.8** (2022).
[3] Lorenz, E. N.Journal of atmospheric sciences, ***20*(2)**, 130-141, (1963).
[4] Ghil M. & Sciamarella D., Nonlinear Processes in Geophysics, ***30*(4)**, 399-434. (2023)

Spatiotemporal Chaos Induces Extreme Events in an Extended Microcavity Laser and Kerr Resonators

Marcel G. Clerc

Departamento de Física and Millennium Institute for Research in Optics, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Casilla 487-3, Santiago, Chile

Extreme events such as rogue waves in optics and fluids are often associated with the merging dynamics of coherent structures. In this talk, we present experimental and numerical results on the physics of extreme event appearance in a spatially extended semiconductor microcavity laser with an intracavity saturable absorber [1] and Kerr Resonators [2]. These systems can display deterministic irregular dynamics. We have identified parameter regions where extreme events are encountered and established the origin of these dynamics in the emergence of deterministic spatiotemporal chaos (extended microcavity laser) and the transition between a transition to amplitude turbulence via spatiotemporal intermittency (Kerr Resonators), through the correspondence between the proportion of extreme events and the dimension of the strange attractor.

References

[1] A. Chowdhury, S Barbay, M.G. Clerc, I Robert-Philip, and R Braive, Phys. Rev. Lett. **119**, 234101 (2017).

[2] [2] S. Coulibaly, M Taki, A. Bendahmane, G. Millot,aand B. Kibler, and M. G. Clerc, Phys. Rev. X, 011054 (2019).

Earthquakes in the lab: From accelerated seismic release to magnitude clustering

J. Davidsen[1,2]

[1]Department of Physics & Astronomy, University of Calgary, Calgary, Canada
[2] Hotchkiss Brain Institute, University of Calgary, Calgary, Canada

The mechanical failure of natural or man-made structures due to the variations of the external loads or long exposure to extreme external conditions constitutes a common hazard of major concern in seismology and civil engineering. Yet, failure is difficult to forecast because of the sensitivity to the unknown internal details of the system. For example, failure of intact rock in the brittle domain has long been studied experimentally to better understand the mechanical properties of heterogeneous materials. When rock is sufficiently stressed, first small microfractures or mini-earthquakes occur before the rock ultimately breaks. These microfractures show many similarities with natural earthquakes at much larger scales suggesting that lab experiments can help us to understand at least some aspects of earthquake dynamics. One pronounced characteristic close to dynamic failure along faults and macroscopic fracturing of intact rock samples is the increase in the overall seismic energy rate released by microfractures, the so-called accelerated seismic release. This is accompanied by localization of the recorded microfractures along the future failure plane. The co-occurrence of temporal and spatial correlations is a manifestation of an underlying damage localization process from isolated flaws to interacting flaws and finally macroscopic fracture as described in a plethora of studies. The exact nature of these underlying interactions, however, remains an open question. Here, I discuss new insights provided by various recent lab experiments and theoretical model studies with a particular focus on (i) the determining factors of the characteristics of compressive failure leading to different types of accelerated seismic release, and (ii) our ability to forecast the size of seismic events.

References

[1] J. Davidsen, G. Kwiatek, T. Goebel, E.-M. Charalampidou, S. Stanchits, M. Rueck, G. Dresen, Physical Review Letters **119**, 068501 (2017)
[2] J. Baro, K. Dahmen, J. Davidsen, A. Planes, P. Castillo, G. Nataf, E. Salje, E. Vives, Physical Review Letters **120**, 245501 (2018)
[3] J. Baro, J. Davidsen, Physical Review E **97**, 033002 (2018)
[4] J. Davidsen, T. Goebel, G. Kwiatek, S. Stanchits, J. Baro, G. Dresen, Journal of Geophysical Research – Solid Earth **126**, e2021JB022539 (2021)
[5] A. Patton, T. Goebel, G. Kwiatek, J. Davidsen, Physical Review E **108**, 014131 (2023)
[6] O. Khajehdehi, T. Goebel, J. Davidsen, submitted (2024)

The increased likelihood of plankton community changes following marine heatwaves

R. Deeley[1], **T. Grafke**[2], **U. Feudel**[1]

[1]*Theoretische Physik/Komplexe Systeme, ICBM, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany*
[2] *Mathematics Institute, University of Warwick, Coventry, UK*

When modelling climatic systems, it is important to carefully assess the interaction between the many timescales, as certain changes in their interplay can affect the likelihood of observing extreme transitions to distinct environmental regimes. Marine heatwaves weaken state-based resilience in plankton communities. The communities become more susceptible to noise-induced shifts in species' concentration levels following prolonged periods of increased temperatures. This is shown in a Truscott-Brindley model [1], a stochastic fast-slow system that encapsulates the interaction of phytoplankton and zooplankton during *red tide* events. Deterministically, the system is bistable, with stable states of high/low phytoplankton biomass; environmental perturbations to the (temperature-driven) species' growth rates are modelled using Ornstein-Uhlenbeck processes with correlation time parameter τ. During marine heatwaves, the correlation time τ will temporarily increase. With ensemble simulations of phytoplankton collapses, we assess how mean first-exit times from the basin of attraction scale as the noise strength weakens, across different prescribed values for τ. These scalings reveal the systems' quasipotential barrier heights, a concept of Freidlin-Wentzell theory [2] quantifying resistance to noise-induced escape from a domain. We observe a convex-type relation between the vulnerability to critical transitions and correlation time τ of the perturbations. Indeed, system resilience falls substantially as the noise becomes more correlated, across a physical parameter range for τ. This trend is also seen in the action values of most probable transition paths for escaping the basin of attraction, found using an augmented Lagrangian method [3] to overcome the degenerate noise structure. To dynamically explain these findings and assess their generality, we examine results from other studies on how climate tipping points, or stochastic escapes, depend on the correlation time of perturbations.

References

[1] Truscott, J.E., Brindley, J. Ocean plankton populations as excitable media. *Bltn Mathcal Biology* **56**, 981–998 (1994).

[2] Freidlin, M. I. & Wentzell, A. D. *Random Perturbations of Dynamical Systems*. vol. **260** (Springer Berlin Heidelberg, Berlin, Heidelberg, 2012).

[3] Schorlepp, T., Grafke T., May S., Grauer R. Spontaneous symmetry breaking for extreme vorticity and strain in the three-dimensional Navier–Stokes equations *Phil. Trans. R. Soc. A.***380** (2022)

Quantifying statistical associations among persistent events: From event coincidence to interval coverage analysis

R.V. Donner[1,2], **G. Di Capua**[2] **and D. Diedrich**[1,3]

[1]*Magdeburg-Stendal University of Applied Sciences, Magdeburg, Germany*
[2]*Potsdam Institute for Climate Impact Research, Potsdam, Germany*
[3]*Otto von Guericke University, Magdeburg Germany*

In order to quantify statistical associations between the occurrences of events of different types in two or more time series, the concept of event coincidence analysis (ECA) [1,2] has recently found numerous applications in climatic and environmental contexts. While several studies have highlighted possible benefits of ECA in comparison with similar metrics like event synchronization strength, particularly in the case of temporally clustered or persistent events [3-5], especially the latter aspect has not been conclusively addressed in the existing methodological frameworks. Notably, ECA has been traditionally based on the idea of interdependent point processes, where persistent events are not considered by definition. To account for the particular importance of event persistence in case of societally, environmentally and/or economically climate extremes like droughts or heatwaves, we introduce here a straightforward extension of ECA to studying the mutual coverage between intervals of different types, referred to as interval coverage analysis (InCA). While being based on the same rationale as ECA, InCA is specifically tailored to studying statistical dependencies between persistent extremes or other types of events with non-negligible temporal extent. The application of InCA is demonstrated for the example of statistical interdependencies between specific atmospheric Jetstream configurations and heat extremes during Northern hemisphere summer.

References

[1] J.F. Donges et al., PNAS, 108, 20422 (2011)
[2] J.F. Donges et al., Eur. Phys. J. ST, 225, 471 (2016)
[3] F. Hassanibesheli and R.V. Donner, Chaos, 29, 083125 (2019)
[4] A. Odenweller and R.V. Donner, Phys. Rev. E, 101, 052213 (2020)
[5] F. Wolf et al., Chaos, 30, 033102 (2020)

Understanding and attributing extreme weather events in a changing climate

D. Faranda[1]

[1] French National Centre for Scientific Research, Versailles Saint-Quentin-en-Yvelines University, Institut Pierre-Simon Laplace, CEA Saclay, Laboratoire des Sciences du Climat et de l'Environnement, University of Paris-Saclay, Laboratoire de Météorologie Dynamique, London Mathematical Laboratory

In this presentation, I will delve into the ongoing efforts towards creating a framework for attributing extreme events to climate change. I will be discussing the relationship between climate change and the frequency, intensity, and spatial distribution of these cyclones, and how this information can be used to better understand the causes and consequences of these weather events. I will also touch upon the challenges and limitations that come with attributing cyclones to climate change and the significance of this research for improving predictions and informing adaptation strategies. In response to this pressing issue, I will also introduce ClimaMeter, a platform designed to assess and contextualise extreme weather events relative to climate change. The platform offers near real-time insights into the dynamics of extreme events, serving as a resource for researchers, policymakers, and being a science dissemination tool for the general public. ClimaMeter currently analyses heatwaves, cold spells, heavy precipitation and windstorms

References

[1] Faranda, D., Messori, G., Coppola, E., Alberti, T., Vrac, M., Pons, F., Yiou, P., Saint Lu, M., Hisi, A. N. S., Brockmann, P., Dafis, S., and Vautard, R.: ClimaMeter: Contextualising Extreme Weather in a Changing Climate, EGUsphere, https://doi.org/10.5194/egusphere-2023-2643, 2023.

Spontaneous transition from smoldering to flaming combustion

V. Frette

Western Norway University of Applied Sciences,
Bjoernsons gt 45, N-5528 Haugesund, Norway

Smoldering is a low-temperature, flameless, and incomplete type of combustion, where oxidation occurs directly at the surface of a solid fuel. Thus, it is fundamentally different from standard combustion, which is a gas-phase reaction with a flame.

Smoldering and smoldering fires are poorly understood from a fundamental point of view, and the number of scientific studies devoted to this topic is limited. Considering the role smoldering plays – directly or as a precursor – in wildfires, fire in buildings, and industrial fire, this is surprising. We have experienced that even fire-safety professionals (fire brigades, consultants) have a low awareness of risks connected to smoldering.

Furthermore, smoldering displays several fascinating types of behavior, and it has a lot to offer as a laboratory for statistical physics. As an example, we have previously reported spontaneous synchronization during smoldering [1].

After an introduction to smoldering as a phenomenon, as well as its occurrence in various contexts, laboratory experiments from our group on the spontaneous transition from smoldering to flaming combustion/fire will be reported (Refs. [2,3] as well as ongoing projects). Self-driven and accelerated processes culminating at the transition will be described.

The transition from smoldering to flaming fire emerges as an extreme event in several contexts: when a smoldering fire in the forest floor trigger a full forest fire, or when smoldering in material of organic origin stored in a silo leads to explosions.

References

[1] R. F. Mikalsen et al, EPL (Europhysics Letters) **121**, 50002 (2018)
[2] B. C. Hagen et al, Fire Safety Journal **71**, 69 (2015)
[3] B. C. Hagen et al, Fire Safety Journal **121**, 103292 (2021)

The typicality of weather and climate extreme events

Vera Melinda Galfi

Institute for Environmental Studies, Vrije Universiteit Amsterdam, Amsterdam, the Netherlands

In this talk I will present a large deviation theory-based perspective on extreme events, which led to the concept of typicality of certain weather and climate extremes. This denotes their property to exhibit similarities in spatial patterns, temporal evolution, and underlying physical processes, with this resemblance intensifying as events become more extreme. Recent findings highlight that highly intense heatwaves, defined as prolonged local temperature anomalies, are consistently associated with specific large-scale circulation patterns [1], [2], [3]. This suggests that there is a typical way the atmosphere realises a very extreme local temperature anomaly. Furthermore, I will explore typical properties of intense hemispheric anomalies, defined as large zonal variations in air temperature or geopotential height. This investigation aims to study preferred atmospheric configurations leading to the simultaneous occurrence of heatwaves on a hemispheric scale.

References

[1] V. M. Galfi and V. Lucarini, "Fingerprinting Heatwaves and Cold Spells and Assessing Their Response to Climate Change Using Large Deviation Theory," Phys Rev Lett, **vol. 127**, no. 5, p. 58701 (2021).

[2] V. Lucarini, V. Melinda Galfi, J. Riboldi, and G. Messori, "Typicality of the 2021 Western North America summer heatwave," Environmental Research Letters, **vol. 18**, no. 1 (2023).

[3] R. Noyelle, P. Yiou, and D. Faranda, "Investigating the typicality of the dynamics leading to extreme temperatures in the IPSL-CM6A-LR model," Clim Dyn, **62**, 1329–1357 (2024).

Extreme events in dynamical networks

Dibakar Ghosh

Indian Statistical Institute, Kolkata, India

The role of topological heterogeneity in a network in the origin of extreme events [1] for identical oscillators will be discussed here [2]. On the other hand, the role of parameter mismatch in the local dynamics of each nodes of a homogeneous networks are investigated [3]. Extreme events are observed in different networks including time varying connections among mobile nodes [4]. For a global network of identical chaotic maps, which splits into two different clusters, despite the interaction between all nodes are uniform and the distance between these two chaotic synchronized populations often deviates more than eight times of standard deviation from its long-term average [5]. We have also studied extreme precipitation from the collected data of daily precipitation as well as daily maximum temperatures from the meteorological station of Bjornoya located on the Bear island, operated by the Norwegian Centre for Climate Services for a period spanning from January 1, 1960 to December 31, 2021 [6]. Finally, we will discuss the extreme value theory for the different routes of extreme events in dynamical systems.

References

[1] S. Nag Chowdhury, A. Ray, S. K. Dana and D Ghosh, Physics Reports **966**, 1-52 (2022)

[2] A. Ray, A. Mishra, D. Ghosh, T. Kapitaniak, S. K. Dana and C. Hens, Phys. Rev. E **101**, 032209 (2020)

[3] A. Ray,T. Br¨ohl, A. Mishra, D. Ghosh, T. Kapitaniak, S. K. Dana, and C. Hens, Chaos **32**, 121103 (2022)

[4] S. N. Chowdhury, S. Majhi, M. Ozer, D. Ghosh, M. Perc, New Journal of Physics **21**, 073048 (2019)

[5] S. Nag Chowdhury, A. Ray, A. Mishra and D. Ghosh, Journal of Physics: Complexity **2**, 035021 (2021)

[6] A. Ray, T. Chakraborty, A. Radhakrishnan, C. Hens, S. K. Dana, D. Ghosh, and N. Murukesh, arXiv:2312.04502

Multivariate distributions in highly correlated, non-stationary complex systems

Thomas Guhr

Fakultät für Physik, Universität Duisburg-Essen, Germany

Risk assessment for large and rare events is important for understanding the stability of a system. Most complex systems are correlated which has to be taken into account for such an assessment. Furthermore, complex systems are often non-stationary which poses challenges for statistical model building.

We develop a new statistical approach to model such multivariate distributions for non-stationary complex systems by using random matrices. Our approach is generic and the model distributions only depend on few parameters.

We perform a thorough empirical analysis of the US stock markets as an example of such a correlated, non-stationary complex system. We apply aggregation to obtain the multivariate distributions of stock returns. We carry out a comparison of the empirical results with our model. We briefly discuss the impact on credit risk.

References

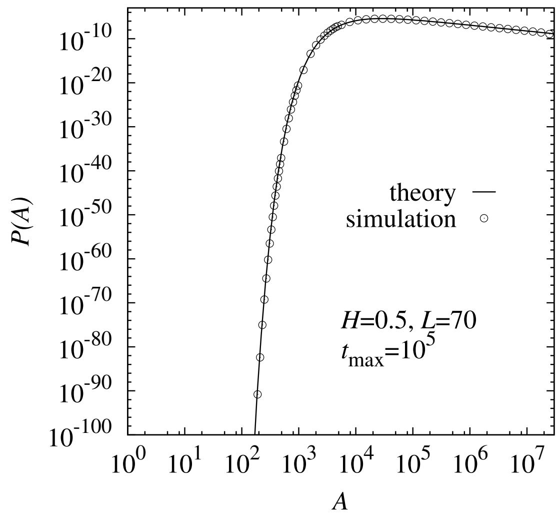
[1] T. Guhr and A. Schell, Journal of Physics A54 (2021) 125002
[2] E. Manolakis, A. Heckens and T. Guhr, in preparation
[3] T.A. Schmitt, R. Schäfer and T. Guhr, Journal of Credit Risk 11 (2015) 73

First-passage area distribution and optimal fluctuations of fractional Brownian motion

Alexander K. Hartmann[1] **and Baruch Meerson**[2]

[1]University of Oldenburg, Germany
[2]Hebrew University of Jerusalem, Israel
a.hartmann@uni-oldenburg.de

We study the probability distribution $P(A)$ of the area $A = \int_0^T x(t)dt$ swept under fractional Brownian motion (fBm) $x(t)$ until its first passage time T to the origin. The process starts at $t = 0$ from a specified point $x = L$. We show that $P(A)$ obeys the exact scaling relation $P(A) = \frac{D^{\frac{1}{2H}}}{L^{1+\frac{1}{H}}} \Phi_H \left(\frac{D^{\frac{1}{2H}} A}{L^{1+\frac{1}{H}}} \right)$, where $0 < H < 1$ is the Hurst exponent characterizing the fBm, D is the coefficient of fractional diffusion, and $\Phi_H(z)$ is a scaling function. The small-A tail of $P(A)$ has been recently predicted [1] as having an essential singularity at $A = 0$. Here [2] we determine the large-A tail of $P(A)$. It is a fat tail, with the average value A diverging for all H.
We also verify the predictions for both tails by performing simple-sampling as well as large-deviation Monte Carlo [3] simulations. The verification includes measurements of $P(A)$ up to probability densities as small as 10^{-100}. As example, the result for the standard case $H = 1/2$, including the comparison to the analytical result, looks as follows:



We also perform direct observations of paths conditioned on the area A. For the steep small-A tail of $P(A)$ the "optimal paths", *i.e.* the most probable trajectories of the fBm, dominate the statistics. Finally, we discuss extensions of theory to a more general first-passage functional of the fBm.

References

[1] B. Meerson and G. Oshanin, Phys. Rev. E **105**, 064137 (2022).

[2] A.K. Hartmann and B. Meerson, preprint arXiv:2310.14003, accepted at Phys. Rev. E (2024)

[3] A.K. Hartmann, Phys. Rev. E **89**, 052103 (2014).

An ensemble based approach for the effect of climate change on the dynamics of extremes

D. Jánosi[1,2], **M. Herein**[2,3] **and T. Tél**[1,3]

[1]*Department of Theoretical Physics, Eötvös Loránd University, Budapest, Hungary*
[2] *HUN-REN Institute of Earth Physics and Space Science, Sopron, Hungary*
[3]*HUN-REN-ELTE Theoretical Physics Research Group, Budapest, Hungary*

In view of the growing importance of climate ensemble simulations, we propose [1] an ensemble approach for following the dynamics of extremes in the presence of climate change. A strict analog of extreme events, a concept based on single time series and local observations, cannot be found. To study nevertheless typical properties over an ensemble, in particular if global variables are of interest, a novel, statistical approach is used, based on a ”zooming in” into the ensemble. To this end, additional sub-ensembles with initially very close members are generated around trajectories of the original ensemble. Plume diagrams initiated on the same day of a year are generated from these sub-ensembles. The trajectories within a plume diagram strongly deviate on the time scale of a few weeks. By defining the extreme deviation as the difference between the maximum and minimum values in a plume diagram, a growth rate for the extreme deviation can be extracted. An average of these taken over the original ensemble (i.e. over all sub-ensembles) characterizes the typical, exponential growth rate of extremes, and the reciprocal of this can be considered the characteristic time of the emergence of extremes. Using a climate model of intermediate complexity, these are found to be on the order of a few days, with some difference between the global mean surface temperature and pressure. Measuring the reciprocal of the growth rate in several years along the last century, results for the temperature turn out to be roughly constant, while a pronounced decaying trend is found in the last decades for the pressure.

References

[1] Herein M, Jánosi D and Tél T, Front. Earth Sci. **11**, 1267473 (2023)

Analysis and Modeling of Precipitation Extremes

K. Polotzek, Xinjia Hu, and H. Kantz

Max Planck Institute for the Physics of Complex Systems, Dresden, Germany
Email: kantz@pks.mpg.de

The distributions of daily precipitation amounts in mid-latitudes have heavy tails, with rare huge outliers. In addition, the time series of precipitation exhibits long range temporal correlations. We propose a non-Gaussian model for such data. We show that despite the heavy tails, the GEV distribution is a Gumbel distribution, and we discuss return levels. A critical issue is whether climate change has already become visible in statistical properties of the data, in particular, whether extremes are becoming more intense. We show results of such analysis for a large number of data sets.

Transition to hyperchaos: Sudden expansion of attractor and intermittent large-amplitude events in dynamical systems

Tomasz Kapitaniak

Division of Dynamics, Lodz University of Technology, Stefanowskiego 1/15 90-924 Lodz, Poland

Complex dynamical systems have received considerable attention during the past few decades due to surprising dynamical effects, such as sudden transitions, extreme events, and regime shifts. Specifically, extreme events (EE) occur unexpectedly, creating disastrous consequences in both nature and society. Understanding the dynamical origin of EE, distinct transitions, and their possible earlier prediction is a pressing problem in recent times to minimize the impact or forecast unanticipated disastrous events and global warming. Using the dynamical system theory in a wide range of complex systems will help to enhance the understanding of EE formations. In the first part of this talk, I would like to explain the discrete formation of large-intensity pulses and their transition in a Zeeman laser. In the second part, I will explore the intriguing connection between hyperchaos and large-intensity events in a few nonlinear dynamical systems.

References

[1] S. L. Kingston, A. Mishra, M. Balcerzak, T. Kapitaniak, and S. K. Dana, *Phys. Rev. E* **104**, 034215 (2021).

[2] S. L. Kingston, T. Kapitaniak, and S. K. Dana, *Chaos* **32**, 081106 (2022).

[3] S. L. Kingston, M. Balcerzak, S. K. Dana, and T. Kapitaniak, *Chaos* **33**, 023128 (2023).

[4] A. Mishra, S. L. Kingston, C. Hens, T. Kapitaniak, U. Feudel, and S. K Dana, *Chaos* **30**, 063114 (2020).

[5] S. N. Chowdhury, A. Ray, S. K. Dana, and D. Ghosh, *Phys. Rep.* **966**, 1-52 (2022).

Forecasting extreme events related to tipping elements in the climate system

Jürgen Kurths[1]

1 Potsdam Institute for Climate Impact Research, Potsdam, Germany
Email: kurths@pik-potsdam.de

Tipping elements are components of the Earth system that may shift abruptly and irreversibly from one state to another at specific thresholds. An important aspect is how different tipping points are interrelated and how do the corresponding teleconnections are changing due to forcing. Here, we propose a climate network approach to analyse the global impacts of a prominent tipping element, the Amazon Rainforest Area (ARA). We find that the ARA exhibits strong correlations with regions such as the Tibetan Plateau (TP) and West Antarctic ice sheet. Models show that the identified teleconnection propagation path between the ARA and the TP is rather robust under climate change. We further uncover that various climate extremes between the ARA and the TP are synchronized and it is discussed how they can be forecasted.

Data-driven quantification of weather and climate risk using large-deviation theory

F. Kwasniok[1]

[1]*Department of Mathematics and Statistics, University of Exeter, Exeter, UK*

The statistical analysis of short-duration extreme events like heavy precipitation or gust wind speeds is highly developed. Classical extreme value theory provides well-established techniques for estimating return levels of those events: the block maxima method based on the generalised extreme value distribution or the peak-over-threshold method based on the generalised Pareto distribution. In comparison, long-duration extreme events like heatwaves, cold snaps or droughts are underresearched in weather and climate science. Quantifying the likelihood of long-duration extremes as a function of duration and severity is a big challenge and obviously of high importance.

In this contribution, large-deviation theory is discussed, a tool from statistical physics to characterise rare persistent events. The key quantity in large-deviation theory is the so called large-deviation rate function. Once convergence has occurred it allows to estimate by extrapolation the probability of unobserved very long-duration and high-amplitude events from the statistics of observed less extreme events. We investigate methods for estimating the large-deviation rate function from data and checking for convergence; these include the Legendre transform method, estimating the probability density using exponential families as well as novel extensions thereof. A couple of examples are discussed: (i) high average wind speed over a long time period in an atmospheric model corresponding to particularly stormy seasons, (ii) unusual frequency and duration of certain weather regimes (zonal or blocked) in an atmospheric model, and (iii) UK heatwaves in observational data. We also estimate multivariate rate functions and investigate the effect of climate change on persistent extremes using time-dependent rate functions.

Machine-learning prediction of tipping and collapse of the Atlantic Meridional Overturning Circulation

Ying-Cheng Lai

Arizona State University, USA

A tipping point in complex and nonlinear dynamical systems is a transition from one stable steady state supporting the normal functioning of the system to another corresponding to system collapse as a system parameter passes through a critical point. An urgent problem with potentially dire consequences is the possible collapse of the Atlantic Meridional Overturning Circulation (AMOC) that supports mild and livable temperature conditions in Western Europe. The AMOC transports warmer, upper waters in the Atlantic northward and returns colder, deeper waters southward. Studies suggested that, since about 30 years ago, there has been a tendency for the AMOC to weaken. At the present, the AMOC is still in a “healthy” steady state that maintains a stable circulation of the pertinent ocean flows. A potential halt of the circulation would signify a collapse of the AMOC, corresponding to another stable steady state of the underlying dynamical system. Such a collapse meets the criterion of a tipping point. A recent study based on a simplified stochastic dynamical system model suggested that the AMOC may be approaching a potential collapse through a tipping point, which could occur as early as 2025. A more recent work analyzing physics-based early warning signals indicates that the AMOC is on a tipping course.

The nonlinear-dynamics group at ASU has developed a machine-learning approach to predicting tipping in noisy dynamical systems with a time-varying parameter and test it on a number of systems including the AMOC, ecological networks, an electrical power system, and a climate model. For the AMOC, our prediction based on simulated fingerprint data and real data of the sea surface temperature places the time window of a potential collapse between the years 2040 and 2065.

The speaker will present the machine-learning approach and the prediction results. This is joint work with Dr. Shirin Panahi (current postdoctoral fellow), Dr. Ling-Wei Kong (former PhD student), Mr. Mohammadamin Moradi (current PhD student), and Zheng-Meng Zhai (current PhD student), as well as two collaborators from the Army Research Laboratory: Dr. Mulugeta Haile and Dr. Bryan Glaz.

References

[1] S. Panahi, L.-W. Kong, M. Moradi, Z.-M. Zhai, B. Glaz, M. Haile, and Y.-C. Lai, “Machine-learning prediction of tipping and collapse of the Atlantic Meridional Overturning Circulation,” preprint (2024).

[2] S. Panahi, Y. Do, A. Hastings, and Y.-C. Lai, “Rate-induced tipping in complex high-dimensional ecological networks,” *PNAS* **120** (51), e2308820120, 1-9 (2023).

[3] L.-W. Kong, Y. Weng, B. Glaz, M. Haile, and Y.-C. Lai, “Reservoir computing as digital twins for nonlinear dynamical systems,” *Chaos* **33**, 033111, 1-21 (2023).

New indicators for early detection of critical transitions

G. Tirabassi and C. Masoller

Departament de Física, Universitat Politecnica de Catalunya, Terrassa, Spain

Complex systems can display abrupt and irreversible regime transitions. Anticipating these changes can be crucial for avoiding extreme fluctuations and for implementing adaptation measures. So far, many data-driven indicators of approaching critical bifurcations and regime shifts have been proposed. However, their performance depends on the characteristics of the system under analysis, and on the characteristics of the observed data. In this talk, I will discuss the performance of classical and new early warning indicators, using empirical, real-world data (vegetation images to identify desertification transitions), as well as experimental and simulated data, generated with controlled variation of the critical parameter.

References

[1] G. Tirabassi and C. Masoller, Chaos, Solitons & Fractals **155**, 111720 (2022)
[2] G. Tirabassi and C. Masoller, PNAS **120**, e2215667120 (2023)

Towards predicting extreme events in neurology with theory-based and machine learning approaches

C. Meisel

Charité – Universitätsmedizin Berlin, Berlin, Germany

The health-disease-continuum in neurology is often characterized by more or less rapid state shifts. A better understanding of these shift along with appropriate monitoring methods is desirable as it may afford more proactive interventions and better outcomes. The advent of novel sensor technologies, clinical data warehouses capturing multimodal longitudinal data, and advanced computational methods provides new opportunities and challenges in this field. In this talk I will first provide a survey on our and others recent efforts in creating a data warehouse neurology for monitoring patients in the in-hospital and in the ambulatory settings using neuromonitoring, wearables and more. I will briefly discuss some clinical applications in predicting rare events, including atrial fibrillation, stroke-associated pneumonia and seizures. For the main part of the talk I will then discuss new results on monitoring the stability and function of cortical neural networks over extended periods of time and under distinct perturbations, including seizures, antiseizure medications, interictal epileptiform discharges and sleep. I will argue that dynamics and effect of these perturbations can be understood best using the framework of criticality, i.e. that neural networks reside in the vicinity of a phase transition. This framework makes several testable predictions linking network structure to dynamics and function.

Methods of dimensional reduction to assess rare events of blackouts in power grids

Hildegard Meyer-Ortmanns

Constructor University, Bremen, Germany

hmeyerortm@constructor.university

We discuss the frequency of blackout or desynchronization events in power grids for realistic data input, in particular with time correlations in the fluctuating power production. Our desynchronization events are caused by overloads. We propose and discuss different methods of dimensional reduction to considerably reduce the high-dimensional phase space. The first method splits the system into two areas, connected by heavily loaded lines, and treats each area as a single node. This corresponds to the so-called synchronized subgraph approximation, here applied to the swing equations. The second one considers a separation of the timescales of power fluctuations and phase angle dynamics and completely disregards the phase angle dynamics. Rare events are captured by the WKB-method for classical stochastic systems. The obtained average desynchronization times obtained for the different versions of the dimensionally reduced system are compared with those obtained for the full system, simulated via the swing equations. As it turns out, the number of desynchronization events does not automatically increase with non-Gaussian fluctuations in the power production as one might have expected. We point out under which conditions the number of desynchronization events decreases.

References:

T. Ritmeester and H. Meyer-Ortmanns, Rare desynchronization events in power grids: On data implementation and dimensional reductions, J. Phys. Complex. 3, 045010~1-28 (2022).

Hybrid physics-based and data-driven approaches for predictive maintenance in the case of rare events

Michael J. Moeckel[1]

[1]TH Aschaffenburg, Würzburger Straße 45, 63743 Aschaffenburg

Using machine learning techniques to predict the remaining useful life (RUL) of a component or device, also known as predictive maintenance, has received a lot of attention in the context of Industry 4.0 recently [1]. The analysis of rare failure events remains, however, a challenging task [2].

Hybrid physics-based and data-driven approaches bridge the gap between physics-based modeling and data-driven machine learning. They promise to reduce the amount of training data required in ML-based anomaly detection and to improve explainability as well as generalizability in predictive maintenance applications.

We develop a physically inspired framework for predicting RUL for selected components by integrating physically motivated feature extraction, degradation modelling and machine learning. The discussed approach is promising for situations of limited data availability or large data heterogeneity, which occurs, for example, in fleets of customized vehicles optimized for particular tasks.

References

[1] Zonta, Tiago, et al. "Predictive maintenance in the Industry 4.0: A systematic literature review." Computers & Industrial Engineering 150 (2020): 106889

[2] Dangut, Maren David, et al. "A rare failure detection model for aircraft predictive maintenance using a deep hybrid learning approach." Neural Computing and Applications 35.4 (2023): 2991-3009.

Non-Shannonian information theory connects inference of causality and understanding of extreme events

M. Paluš[1]

[1] *Institute of Computer Science of the Czech Academy of Sciences, Pod Vodárenskou věží 2, 182 00 Prague 8, Czech Republic*

Inference of causality and understanding of extreme events are two intensively developing multidisciplinary scientific areas. Surprisingly, there is only a limited interaction of the two research areas.
One approach considers conditional distributions in data with heavy tails [1,2], basically asking the question: Do extremes in one variable cause extremes in another variable? In order to ask a more general question, in particular, which of potential cause variables is the likely cause of extremes in the effect variable, we employ the information-theoretic generalization of the Granger causality [3]. The information theory of Shannon, however, needs to be extended by the entropy concepts of Rényi and Tsallis which have been proposed to cope with variables with heavy-tailed probability distributions. We reformulate the conditional mutual information, a.k.a. transfer entropy in the framework of Rényi information and demonstrate its performance using simulated data with known causal structure. As a real data example from the Earth climate system, we apply the approach to assess the causal influence of the North Atlantic Oscillation, blocking events and the Siberian high on winter and spring cold waves in Europe. Using the non-Shannonian information-theoretic concepts we bridge the inference of causality and understanding of the occurrence of extreme events.

This study was supported by the Czech Academy of Sciences, Praemium Academiae awarded to M. Paluš.

References

[1] N. Gnecco, et al., Ann. Stat. **49(3)**, 1755–1778 (2021). https://doi.org/10.1214/20-AOS2021
[2] J. Bodik, M. Paluš, Z. Pawlas, Extremes (2023). https://doi.org/10.1007/s10687-023-00479-5
[3] K. Hlaváčková-Schindler, M. Paluš, M. Vejmelka, J. Bhattacharya, Physics Reports **441(1)**, 1-46 (2007). https://doi.org/10.1016/j.physrep.2006.12.004.

Non-equilibrium thermodynamics of extreme events in wind turbulence and water waves.

A. Fuchs[1], M. Wächter [1]and J. Peinke[1,2]

[1]Cral von Ossietzky University, Oldenburg, Germany
[2] Fraunhofer IWES, Oldenburg, Germany

Extreme events may be initiated by changing conditions (parameters), by sudden jumps, or as intrinsic feature of a complex system. The ladder case will be discussed here based on investigations of waves and turbulence. Well-known extreme events of these two systems are monster waves and wind gusts.

We approach the complexity of these systems by general joint multipoint statistics, which can be captured by special scale-dependent Fokker-Planck equations derived from empirical data. This stochastic description allows us to define entropy values for all wave and wind events. Negative entropy identifies extreme events. In addition, the statistics of the entropy values follow the fluctuation theorems, i.e. negative and positive entropy events balance each other out. Thus, in these cases, extreme events are an integral part of all (extreme and non-extreme) fluctuations.

Finally, the stochastic approach for these complex systems allows the definition of instantons and the search for the rarest events, even those that are not measured. For waves, we find the "three sisters" as a very rare event.

References

[1] J. Peinke, M. R. R. Tabar, and M. Wächter, Annual Review of Condensed Matter Physics 10, 107-132 (2019)
[2] A. Fuchs, C. Herbert, J. Rolland, M. Wächter, F. Bouchet, and J. Peinke, Phys. Rev. Lett. **129,** 034502 (2022)
[3] A. Fuchs, S. Kharche, M Wächter, and Joachim Peinke, Physics of Fluids **34** (10), 101801 (2022)

Modelling the collapse of societies

Sabin Roman[1]

[1]*Centre for the Study of Existential Risk, University of Cambridge, Cambridge, UK*

The presentation will provide an overview on modelling long-term societal evolution and the potential for collapse [1-3]. As a specific example we propose a simplified model of a socio-environmental system [4] that accounts for population, resources, and wealth, with a quadratic population contribution in the resource extraction term. Given its structure, an analytical treatment of attractors and bifurcations is possible. In particular, a Hopf bifurcation from a stable fixed point to a limit cycle emerges above a critical value of the extraction rate parameter. The stable fixed-point attractor can be interpreted as a sustainable regime, and a large-amplitude limit cycle as an unsustainable regime. The model is generalized to multiple interacting systems, with chaotic dynamics emerging for small non-uniformities in the interaction matrix. In contrast to systems where a specific parameter choice or a high number of dimensions is necessary for chaos to emerge, chaotic dynamics here appears as a generic feature of the system. In addition, we show that diffusion can stabilize networks of sustainable and unsustainable societies, and thus, interconnection could be a way of increasing resilience in global networked systems. Overall, the multi-systems model provides a timescale of predictability (300-1000 years) for societal dynamics comparable to results from other studies, while indicating that the emergent dynamics of networks of interacting societies over longer time spans is likely chaotic and hence unpredictable.

References

[1] Roman, Sabin, Seth Bullock, and Markus Brede. "Coupled societies are more robust against collapse: A hypothetical look at Easter Island." Ecological Economics 132: 264-278 (2017).

[2] Roman, Sabin, and Erika Palmer. "The growth and decline of the Western Roman Empire: quantifying the dynamics of army size, territory, and coinage." Cliodynamics 10.2 (2019).

[3] Roman, Sabin. "Theories and Models: Understanding and Predicting Societal Collapse." The Era of Global Risk: An Introduction to Existential Risk Studies. Open Book Publishers: 27-54 (2023).

[4] Roman, Sabin, and Francesco Bertolotti. "Global history, the emergence of chaos and inducing sustainability in networks of socio-ecological systems." Plos one 18.11 (2023): e0293391.

Routes to large-intensity pulses in laser models

S. Leo Kingston[1], Tomasz Kapitaniak[1], and Syamal Dana[1,2]

[1]*Division of Dynamics, Lodz University of Technology, Stefanowskiego 1/15 90-924 Lodz, Poland,*

[1,2] *Jadavpur University, Kolkata, India.*

Understanding the origins of instability in laser models and their diverse dynamical transitions is crucial for unraveling discrete complex dynamics. In 2007 Solli *et al*., [Nature 450(7172), 1054 (2007)] reported an unusual type of instability in optical systems: so-called rogue waves or extreme events that emanated due to local instabilities in the phase space of the system. This pioneering research paved the way for exploring discrete extreme large-intensity dynamics across various laser models. In this talk, we would like to present the different formations of large-intensity pulses in a Zeeman laser model. The instabilities in the system occur via three distinct dynamical processes, such as quasiperiodic intermittency, Pomeau-Manneville intermittency, and the breakdown of quasiperiodic motion to chaos followed by an interior crisis. Notably, the Zeeman laser model offers a robust platform for investigating a wide spectrum of instabilities across diverse parameter ranges. Furthermore, we explore the emergence of extreme pulses in a CO2 laser, where large-intensity pulses originate from grazing-sliding bifurcation phenomena. By elucidating these phenomena, we gain deeper insights into the intricate dynamics underlying extreme events in laser systems, advancing our understanding of nonlinear optical dynamics and their implications across various fields.

References

[1] S. L. Kingston, S. Kumarasamy, M. Balcerzak, and T. Kapitaniak *Opt. Express* **31**, 22817 (2023).

[2] S. L. Kingston, A. Mishra, M. Balcerzak, T. Kapitaniak, and S. K. Dana, *Phys. Rev. E* **104**, 034215 (2021).

[3] S. L. Kingston, M. Balcerzak, S. K. Dana, and T. Kapitaniak, *Chaos* **33**, 023128 (2023).

[4] A. Mishra, S. L. Kingston, C. Hens, T. Kapitaniak, U. Feudel, and S. K. Dana, *Chaos* **30**, 063114 (2020).

[5] S. N. Chowdhury, A. Ray, S. K. Dana, and D. Ghosh, *Phys. Rep.* **966**, 1-52 (2022).

Extreme event catalogues from coarse climate models and the value of data

Themistoklis Sapsis

Massachusetts Institute of Technology - MIT, Cambridge

Due to the rapidly changing climate, the frequency and severity of extreme weather is expected to increase over the coming decades. As fully-resolved climate simulations remain computationally intractable, policy makers must rely on coarse-models to quantify risk for extremes. However, coarse models suffer from inherent bias due to the ignored “sub-grid” scales. The aim of this work is the development of data-driven correction operators for coarse scale climate models. A related objective is to quantify which data is the most informative for the development of such operators.

Specifically, in the first part of the talk we introduce a framework to non-intrusively debias coarse- resolution climate predictions using neural-network (NN) correction operators. Previous efforts have attempted to train such operators using loss functions that match statistics. However, this approach falls short with events that have longer return period than that of the training data, since the reference statistics have not converged. We introduce a dynamical systems approach where the correction operator is trained using reference data and a coarse model simulation nudged toward that reference. The method is demonstrated on debiasing an under-resolved quasi-geostrophic model and the Energy Exascale Earth System Model (E3SM).

In the second part of the talk, we focus on the development of a quantification framework for the value of data. This is essential given the vast amount of information but also the need for targeted observations. We build on the active-learning framework and derive acquisition functions with proven optimality properties. These acquisition functions provide the most valuable data for the modeling of extreme events of any given quantity of interest. We showcase the developed framework by quantifying the weather events that provide the most important information in training debiasing operators with prescribed objectives, such as capturing the temperature statistics for specific modes or locations.

Thermal activation of interacting particles: a different kind of universality, and dynamical phase transitions

V. Kumar[1,2] and A. Pal[1,2] and O. Shpielberg[3]

[1]*The institute of mathematical sciences, Chennai, India*
[2] *Homi Bhabha National Institute, Mumbai, India*
[3] *University of Haifa, Haifa, Israel*

Protein folding, chemical reactions, and flashing of fireflies are all examples of thermal activation processes. In its most basic form, we will be interested in the escape rate of a particle in a potential trap, due to thermal fluctuations. The Arrhenius law famously captures the escape rate of this problem. For deep traps, Arrhenius law states that the escape rate is universal, independent of the details of the trap. Here, we revisit the escape problem for interacting systems. Unlike the single body case, known for over a century, we will show that the many-body escape problem leads to a different kind of universality, to dynamical phase transitions, and result in novel applications.

References

1. V. Kumar, arXiv:2306.068 79 (2023) [to appear in PRE]
2. V. Kumar, arXiv:2312.05839 (2023)

Extreme Covid-19 Waves and Flame Blowout in Jet Engines: What is in common?

Induja Pavithran, Ankan Banerjee and R. I. Sujith

Indian Institute of Technology Madras, Chennai 600036, India

Critical phenomena such as stock market crashes, earthquakes, Rayleigh-Taylor instabilities, or avalanches, that occur in disparate complex systems, show generic features on approaching a critical point, regardless of the specific physical processes that govern the dynamics. COVID-19 transmission and flame blowout in combustors are two unrelated phenomena; however, we unravel striking similarities between the two. We identified the presence of a hyperexponential growth decorated with log-periodic oscillations preceding flame blowout [1] and during the early phase of extreme COVID-19 waves [2]. In both cases, hyperexponential growth is accompanied by unbounded growth and finite-time singularity. The observation of oscillations decorating the power-law growth, which are periodic in logarithmic scale, known as log-periodic oscillations, unravel the existence of discrete scale invariance. Furthermore, flame blowout in real-world systems, as well as COVID-19 waves, are undesirable. The faster than exponential growth phase is more hazardous in comparison with the commonly believed exponential growth and would entail stricter regulations to minimize further spread. Characterizing these log-periodic oscillations enable better prediction of the finite-time singularity in both cases.

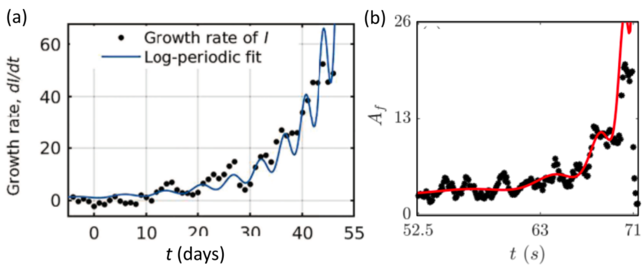


Figure 1: Extreme COVID-19 waves and flame blowout are preceded by hyperexponential power laws decorated with log-periodicity.

References

[1] A. Banerjee, I. Pavithran, and R. I. Sujith. Imprints of log-periodicity in thermoacoustic systems close to lean blowout. Physical Review E, 107(2):024219 (2023).

[2] I. Pavithran and R. I. Sujith. Extreme covid-19 waves reveal hyperexponential growth and finite-time singularity. Chaos: An Interdisciplinary Journal of Nonlinear Science, 32(4) (2022).

Understanding climate extremes: How ClimXtreme builds a knowledge base for decision support

P. Friederichs[1] and S. Buschow[1] and S. Szemkus[1]

[1] *Institute of Geosciences, University of Bonn, Germany*

The ClimXtreme program, funded by the German Federal Ministry of Education and Research, is dedicated to the study of historical extreme weather events in Central Europe, their frequency, intensity and associated impacts. Our focus is on understanding the underlying dynamical and thermodynamic processes that drive these events and predicting their potential changes under increased anthropogenic climate forcing. We combine a better understanding of climate extremes, novel methods to statistically assess their occurrence, and the role of characteristics and preconditions for the severity of impacts.
Through this comprehensive approach, we aim to provide stakeholders with tailored data, software, and information to support decision-making processes.

In the ClimXtreme Module B, "Statistics", we develop the probabilistic and statistical-dynamic framework that is essential for improving our understanding of the physical processes. This foundation serves as a basis for impact-related studies and decision-making processes, including the improved quantification of uncertainties.
Illustratively, we present recent findings from the CoDEx project, that gives a compact statistical-dynamical description of multidimensional spatio-temporal weather extremes. Recognizing the challenge posed by additional variability obscuring climate change signals, we emphasize the importance of reducing degrees of freedom to enhance signal-to-noise ratios and improve detection sensitivity. An appropriate reduction of the degrees of freedom can improve the signal-to-noise ratio and thus increase the potential to detect less strong signals.

This contribution will give an overview of the major achievements and challenges encountered within the ClimXtreme program, shedding light on our progress toward understanding and addressing extreme weather phenomena in Central Europe.

Leveraging large-deviation statistics to decipher the stochastic properties of measured trajectories

Samudrajit Thapa[1,*], Agnieszka Wyłomańska[2], Grzegorz Sikora[2], Caroline E. Wagner[3], Diego Krapf[4], Holger Kantz[1], Aleksei V. Chechkin[2,5,6], and Ralf Metzler[5]
[1] *Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany*
[2] *Faculty of Pure and Applied Mathematics, Hugo Steinhaus Center, Wrocław University of Science and Technology, Wyspianskiego 27, 50-370 Wrocław, Poland*
[3] *Department of Bioengineering, McGill University, Montreal, QC H3A 0E9, Canada*
[4] *Department of Electrical and Computer Engineering, Colorado State University, Fort Collins, Colorado 80523, USA*
[5] *Institute for Physics & Astronomy, University of Potsdam, 14476 Potsdam-Golm, Germany*
[6] *Akhiezer Institute for Theoretical Physics National Science Center "Kharkov Institute of Physics and Technology" 61108 Kharkov, Ukraine*
[*] *Email: samudrajit11@gmail.com*

Extensive time-series encoding the position of particles such as viruses, vesicles, or individual proteins are routinely garnered in single-particle tracking experiments or supercomputing studies. They contain vital clues on how viruses spread or drugs may be delivered in biological cells. Similar time-series are being recorded of stock values in financial markets and of climate data. Such time-series are most typically evaluated in terms of time-averaged mean-squared displacements (TAMSDs), which remain random variables for finite measurement times. Their statistical properties are different for different physical stochastic processes, thus allowing us to extract valuable information on the stochastic process itself. To exploit the full potential of the statistical information encoded in measured time-series we here propose an easy-to-implement and computationally inexpensive new methodology, based on deviations of the TAMSD from its ensemble average counterpart. Specifically, we use the upper bound of these deviations for Brownian motion (BM) to check the applicability of this approach to simulated and real data sets. By comparing the probability of deviations for different data sets, we demonstrate how the theoretical bound for BM reveals additional information about observed stochastic processes. We apply the large-deviation method to data sets of tracer beads tracked in aqueous solution, tracer beads measured in mucin hydrogels, and of geographic surface temperature anomalies. Our analysis shows how the large-deviation properties can be efficiently used as a simple yet effective routine test to reject the BM hypothesis and unveil relevant information on statistical properties such as ergodicity breaking and short-time correlations.

Evaluating forecasts of extreme events

T. L. Thorarinsdottir[2]

[1]*University of Oslo, Oslo, Norway*

Predictions for events with significant inherent uncertainty should be probabilistic in nature to convey information on the uncertainty associated with the outcome. This holds, in particular, for settings where the prediction is subsequently used by many different users to derive further predictions for both expected outcomes and associated risks. Examples of such predictions include weather and climate forecasts such as predictions of extreme precipitation and flooding. We thus take a probabilistic view and assume that forecasts are given as predictive distributions. Evaluation of extreme forecasts then falls in three distinct categories, depending on the question being asked:

a) A probabilistic forecast is issued for the extremes only and we want to know how good it is.
b) A probabilistic forecast is issued for every type of outcome, and we want to know how good it is at predicting extreme outcomes.
c) A probabilistic forecast is issued for every type of outcome, and we want to know how well certain tail properties or functionals of the predictive distribution match those of the true data distribution.

When predicting extreme events and assessing risk, the evaluation of the forecasts is additionally complicated by a lack of substantial observation set due to the rarity of the outcome of interest. We discuss how to perform the evaluation for all three categories above under these constraints within the frameworks of proper scoring rules and consistent scoring functions, and review the available literature on these topics.

The role of atmospheric rivers in the spatio-temporal organization of heavy precipitation events in North America

S. M. Vallejo-Bernal[1,2]**, F. Wolf**[1]**, N. Boers**[1,3,4]**, N. Marwan**[1,2]**, and J. Kurths**[1,2]

[1]*Research Department Complexity Science, Potsdam Institute for Climate Impact Research, Potsdam, Germany*
[2] *Institute of Geosciences, University of Potsdam, Potsdam, Germany*
[3] *Earth System Modelling, School of Engineering and Design, Technical University of Munich, Ottobrunn, Germany*
[4]*Global Systems Institute and Department of Mathematics, University of Exeter, Exeter, UK*

Atmospheric rivers (ARs) are transient corridors of extensive water vapor transport in the lower atmosphere that play a crucial role in the distribution of freshwater but can also cause natural and economic damage by facilitating heavy precipitation events (HPEs). Recent studies have demonstrated that ARs trigger HPEs along the western coast of North America (NA) when making landfall. However, the spatial and temporal extension of their lag-dependent impacts following landfall remains unresolved. Here, we investigate the large-scale spatiotemporal synchronization patterns of HPEs driven by ARs in NA from 1979 to 2018. We employ daily time series of HPEs and land-falling ARs, and we use event synchronization and a complex network approach incorporating varying temporal delays to examine the evolution of spatial patterns of HPEs in the aftermath of land-falling ARs. Our analysis reveals a cascade of synchronized HPEs, triggered by strong ARs. On the first 3 days after an AR makes landfall, HPEs mostly occur and synchronize along the western coast of NA. In the subsequent days, moisture can be transported to central and eastern Canada and cause synchronized but delayed HPEs there. Analyzing the anomalies of integrated water vapor transport, geopotential height, upper-level meridional wind, and precipitation, we find atmospheric circulation patterns that are consistent with the spatiotemporal evolution of the synchronized HPEs. Revealing the role of ARs in the precipitation patterns over NA will lead to a better understanding and forecasting of inland HPEs and the effects that changing climate dynamics will have on precipitation occurrence and consequent impacts in the context of a warming atmosphere.

Charting the pathway of extreme events in the brain

Yujiang Wang

[1]*School of Computing, Newcastle University, UK*
[2] *Institute of Neurology, University College London, UK*

Epileptic seizures are an extreme event in the brain's activity in many regards. Not only do we see unprecedented levels of neuronal activity, for example measured by the electrical signature of the brain. Seizures are also extreme events in terms of brain function. They interrupt normal brain function and often present with a range of symptoms such as loss of awareness, uncontrolled movements, and behaviour.

However, seizures are not random deviations from normal healthy brain activity. Instead, we were able to chart the pathway of seizures [1] in patients with epilepsy. These excursions into the extreme follow a map, which is modulated, constrainted, and determined by a complex interplay of factors [2,3,4] in each patient.

By charting the pathway through the extreme, we hope to not only understand epileptic seizures better, but also brain function and fundamentals of neuronal networks.

References

[1] Schroeder, G.M., Diehl, B., Chowdhury, F.A., Duncan, J.S., de Tisi, J., Trevelyan, A.J., Forsyth, R., Jackson, A. Taylor, P.N., Wang, Y., 2020, Seizure pathways change on circadian and slower timescales in individual patients with focal epilepsy. Proceedings of the National Academy of Sciences , 117(20)

[2] Panagiotopoulou, M., Papasavvas, C.A., Schroeder, G.M., Thomas, R.H., Taylor, P.N., Wang, Y., 2022. Fluctuations in EEG band power at subject-specific timescales over minutes to days explain changes in seizure evolutions. Human Brain Mapping

[3] Schroeder, G.M., Chowdhury, F.A., Cook, M.J., Diehl, B., Duncan, J.S., Karoly, P.J., Taylor, P.N., Wang, Y., 2022. Seizure pathways and seizure durations can vary independently within individual patients with focal epilepsy. Brain Communications

[4] Schroeder, G.M., Karoly, P.J., Maturana, M., Taylor, P.N., Cook, M.J., Wang, Y., 2023. Chronic intracranial EEG recordings and interictal spike rate reveal multiscale temporal modulations in seizure states. Brain Communications

Hidden Vulnerabilities in Emergency Response Post-Flood Disasters

Jonas Wassmer[1,2], Seth Bryant[1,3], Norbert Marwan[2,1], Maria Pregnolato[4], Bruno Merz[3,1]

[1] University of Potsdam, 14469 Potsdam, Germany
[2] Potsdam Institute for Climate Impact Research, 14473 Potsdam, Germany
[3] German Research Centre for Geosciences, 14473 Potsdam, Germany
[4] Delft University of Technology, 2628 Delft, Netherlands

In this study, we address the escalating risks to emergency response systems posed by flood disasters, exacerbated by anthropogenic climate change. We present a novel method for analysing the impact of natural hazards on transport networks, recognising the significant societal and environmental impacts these events can have, particularly in terms of disruption to transport infrastructure. The method, rooted in the gravity model of travel, provides a unique lens through which to examine the stability of transport networks following a disaster. Specifically, we apply this approach to understand the vulnerability of the emergency response system in Germany to flooding.

To simulate flood scenarios in Germany's major river basins, we use a comprehensive regional flood model. This model includes a weather generator for realistic rainfall prediction, a hydrological model for flow conversion and a hydrodynamic model to simulate channel dynamics and overtopping. This allows us to assess potential damage to road infrastructure, including the destruction of bridges and roads, which can lead to critical traffic congestion and hamper emergency response, even in areas far from the flood epicentre. Our findings reveal non-intuitive vulnerabilities for hospitals that are not in the immediate vicinity of the flood event.

Our research highlights the need for targeted road repair and reinforcement strategies that focus on maintaining traffic flow for emergency response. By providing new insights into the resilience of transport networks, this study contributes to the wider discourse on mitigating the economic and social costs of future extreme weather events.

Abstracts of Posters

(in alphabetical order)

Return time of extreme events in climate systems and global warming

F. Aghaei A.[1] **and H. Kantz**[1]

[1] Max Planck Institute for the Physics of Complex Systems, Nothnitzer Straße 38, 01187 Dresden, Germany
E-mail: aghaei@pks.mpg.de

Global warming caused more frequent weather and climate extreme events such as heatwaves, floods, drought, heavy downpours, and tornadoes. To quantify the influence of climate change on these extreme events, we study recurrence times or return intervals between extreme events before and after the warming phase. We first use a parsimonious dual-linear fit to climate variable time series including temperature, precipitation, and humidity to identify the transition point to the warming trend. Then by applying the Generalized Extreme Event distribution and calculating the return time for each segment, we investigate the influence of climate change on the frequency of extreme event occurrence.

References

[1] S. Albeverio, V. Jentsch, and H. Kantz, Extreme Events in Nature and Society, Frontiers Collection (Springer, Berlin, 2006)
[2] L. Haan and A. Ferreira, Extreme value theory: an introduction. (Springer, 2007)
[3] F. Aghaei A., E. T. Phillips, and Holger Kantz, Change point detection in ERA5 ground temperature time series (In preparation, 2024)

Discrete rogue waves induced in a nonlinear pendulum chain

Alain B. Togueu Motcheyo[1,*], M. Kimura[2], Y. Doi[3] and Juan F. R. Archilla[4]

[1] Laboratory of Mechanics, Department of Physics, Faculty of Science, University of Yaounde I, P.O. Box 812, Yaounde, Cameroon.

[2] *Department of Electrical and Electronic Engineering, Faculty of Science and Engineering, Setsunan University, Japan*

[3]*Department of Mechanical Engineering, Graduate School of Engineering, Osaka University 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*

[4] *Group of Nonlinear Physics, Universidad de Sevilla, ETSI Informática, Avda Reina Mercedes s/n, 41012-Sevilla, Spain*

[*]alain.togueu@univ-yaounde1.cm

We numerically generate a discrete rogue wave in the chain of a nonlinear pendulum using the nonlinear supratransmission way and the instability of the shaken pendulum[1]. This work may pave the way for the experimental generation of discrete rogue waves within simple devices.

Reference

[1] A. B. Togueu Motcheyo, M. Kimura, Y. Doi. J. F. R. Archilla, Physics Letters A **497,** 129334 (2024). https://doi.org/10.1016/j.physleta.2024.129334

The role of equation residuals in the discovery of anomalous PDE solutions

E. Bentivegna[1]

[1]IBM Research, Keckwick Lane, Daresbury WA4 4AD, United Kingdom

Nonlinearities are pervasive in Physics, but notoriously difficult to model; for continuum systems, nonlinear Partial Differential Equations (PDEs) are typically used to obtain the system's behaviour, corresponding to a given initial and boundary configuration. Exploring a nonlinear PDE's solution space is a complex undertaking, as interactions between a system's degrees of freedom lead to novel branches which have no counterpart in the linear regime. This may result in the emergence of anomalous or extreme solutions; identifying all of them via brute force is an intractable problem.

I will discuss an approach to extreme-solution discovery based on the study of the structure of the PDE residual and its relationship to solution variability. I will also describe how this information could be used in a Physics-Informed—AI setting to both drive a model's representation and enable the search of extreme configurations therein.

Seasonal forcing induces unpredictability in diseases spread

E. C. Gabrick[1,2], **A. M. Batista**[2] **and J. Kurths**[1]

[1] *IPotsdam Institute for Climate Impact Research, Potsdam, Germany*
[2] *Graduate Program in Science, Ponta Grossa, Brazil*

In this work, we study the unpredictability of seasonal infectious disease in a Susceptible-Exposed-Infected-Recovered-Susceptible (SEIRS) forced model. To investigate the dynamical behavior, we explore the bifurcation diagrams in the forward and backward direction of control parameter. Our results shows that for the analyzed parameters the system exhibit bi-stability where chaotic and periodic attractors coexists. Choosing the inverse of latent period as control parameter, our results shows that 70% of the analyzed range exhibit the coexistent between chaotic and periodic attractors. The bi-stable region is split in two big ranges in the control parameter. One of these regions is limited by periodic attractors, while the another has periodic and chaotic attractors as neighbors. As the boundary of the second bi-stable region is composed of periodic and chaotic attractors, it is possible connect the transition from periodic to chaos as a tipping phenomena. In other words, depending on the latent period, a periodic attractor (predictability) can evolve to a chaotic attractor (unpredictability). In addition, we show that this transition is due a crise. Therefore, we show that unpredictability is associated with bi-stable dynamics where the chaotic attractor has more probability to be reach. In addition, our work show that the unpredictability in infectious diseases can be associated with tipping phenomena. Furthermore, is important note that this phenomena can happen in various ways, for instance due to extreme events.

References

[1] E.C. Gabrick, E. Sayari, P.R. Protachevicz, J.D. Szezech Jr., K.C. Iarosz, S.L.T. de Souza, A.C.L. Almeida, R.L. Viana, I.L. Caldas, A.M. Batista Chaos, Solitons and Fractals **166,** 113001 (2023).

[2] E.L. Brugnano, E.C. Gabrick, K.C. Iarosz, J.D. Szezech Jr., R.L. Viana, A.M. Batista, I.L. Caldas Chaos **33**, 123123 (2023).

Investigation of vibration dynamics and extreme events during failure prediction of ball bearing in two rotor system: Qualitative and Quantitative approach

Prakash Duraisamy[1], Suresh Kumarasamy[2], Karthikeyan Rajagopal[3]

[1,2,3] *Centre for Nonlinear systems, Chennai Institute of technology, Chennai, India*

This research investigates the pivotal role of extreme events in predicting the failure of mechanical systems, focusing specifically on bearing failures attributed to rubbing conditions. The study stems from the recognition that extreme events, such as abrupt changes in vibration patterns and heightened energy dissipation, serve as precursors to critical failures in rotating machinery.

Through extensive experimentation and analysis, we have identified distinct extreme events in the vibrational signatures of bearings subjected to rubbing conditions. These events manifest as sudden spikes in vibration amplitudes, irregularities in frequency spectra, and variations in energy dissipation patterns. Leveraging advanced signal processing techniques and machine learning algorithms, we have developed a predictive model that harnesses the information embedded in these extreme events to forecast impending bearing failures. Our findings not only contribute to the understanding of the complex dynamics associated with rubbing-induced bearing failures but also offer a practical and effective means of failure prediction. By monitoring and analyzing the occurrence of extreme events, maintenance professionals can proactively address potential issues, thereby reducing downtime, minimizing repair costs, and enhancing the overall reliability of mechanical systems.

This research presents a significant advancement in the field of predictive maintenance, emphasizing the importance of considering extreme events as valuable indicators for failure prediction. The insights gained from this study have broader implications for the proactive management of mechanical systems, ensuring optimal performance and longevity.

References

[1] Dudkowski et al., Physics Reports,Volume 637 (1), 2016

[2] Escalante-González et al., The European Physical Journal Special Topics, volume 231(351), 2022.

[3] Varshney et al., International Journal of Bifurcation and Chaos, Volume (28) 1850013, 2018.

[4] Leonov et al., Physics Letters A, volume 375, 2230, 2011.

ClimXtreme II: Climate change and weather extremes in Europe: building a knowledge base for decision support

P. Friederichs[1], S. Buschow[1], S. Szemkus[1], U. Ulbrich[2], J. Grieger[2], J. Pinto[3], H. Feldmann[3], F. Kaspar [4], and D. Niermann[4]

[1] *Institute of Geoscience, University of Bonn, Germany*
[2] *Institut für Meteorologie, Freie Universität Berlin, Germany*
[3] *Karlsruhe Institute of Technology, Karlsruhe, Germany*
[4] *Deutscher Wetterdienst, Offenbach, Germany*

The ClimXtreme program, funded by the German Ministry of Education and Research[1], focusses on the assessment of the frequency and intensity of historical extreme events and their impacts in Central Europe, their association with dynamical and thermodynamical processes and how these extreme events might change according to enhanced anthropogenic climate forcing. We combine improved understanding of climate extremes, novel ways of statistical assessment of their occurrence, the role of characteristics and preconditions on the severity of impacts. The program aims at the development of a basis for stakeholder decision making that consists of data, software, and information tailored to their needs.

The ClimXtreme Module B "Statistics" considers the complex process of decision making and provides the probabilistic, statistical-dynamic foundation to underpin and utilize physical process understanding, and to guide impact-related studies and decision making, including improved quantification of uncertainty. ClimXtreme II continues to standardize the attribution framework for weather extremes, and assesses how weather extremes will change in the future. This will help to improve hazard risk management as part of the German adaptation strategy to climate change.

This contribution will give an overview of the major achievements and challenges in ClimXtreme.

1 https://www.fona.de/de/aktuelles/nachrichten/2023/231207_ClimXtreme_Phase_2_b.php

Comprehending extreme events in dynamical systems amidst stochastic interaction

Anupam Ghosh[1] and Milan Paluš[1]

[1]*Department of Complex Systems, Institute of Computer Science of the Czech Academy of Sciences, Prague 18200, Czech Republic*
E-mail: ghosh@cs.cas.cz

Investigating extreme events amidst time-varying interactions has garnered considerable attention in recent research [1-2]. This study focuses on the dynamics of extreme events under the influence of stochastic time-varying interactions [3] across parameter regimes. Our aim is to ascribe the transition point shifting between extreme events and regular oscillations in response to stochastic interactions between systems. By selecting an appropriate interaction time, we can effectively mitigate extreme events, offering significant advantages in controlling undesired fluctuations within engineering applications. Our analysis uses two distinct coupled systems: the FitzHugh–Nagumo neuron model and the forced Liénard system. We aim to contribute valuable insights into managing and regulating extreme events in dynamic systems influenced by stochastic time-varying interactions.

References

[1] S. Kumarasamy et al., Commun. Nonlinear Sci. Numer. Simul. **107**, 106170 (2022)
[2] S. L. Kingston et al., Chaos **33**, 123134 (2023)
[3] A. Ghosh & S. Chakraborty, Eur. Phys. J. B **93**, 113 (2020)

Some considerations on time dependency and ergodicity in epidemiological modeling

Bruno V. Guerrero[1]

[1]Basque Center for Applied Mathematics, Bilbao, Spain

Outbreaks of infectious diseases threaten public health and can have devastating social and economic consequences. In order to understand the underlying mechanisms influencing the spread of the disease and to characterize its dynamical behavior, epidemiological SIR-like compartmental models are widely used in basic research and as a tool for surveillance, forecasting and public health preparedness. In the case of some recurrent infectious diseases, an explicit time dependency in one or more parameters (e.g., in the transmission rate) is sometimes required to reproduce the observed seasonal pattern. But even in simplistic seasonal forced models, their chaotic dynamics (highly sensitive to initial conditions) reduce the model's predictive power and generate a complex interaction between the system's natural oscillations and the external forcing. The unpredictability of chaos and the onset of complex dynamics make the design of timely seasonal outbreak control measures (such as vaccination campaigns or lockdowns) a very challenging task.

A theoretical tool used to determine the stability of the model's solution and to define a sort of "prediction horizon" is the largest Lyapunov exponent, which is rooted in the notion of ergodicity. In simple terms, ergodicity refers to the equivalence between the expectation value and the time average of a given observable. Although ergodicity has profound implications from a theoretical point of view (e.g., it can give insight into the memory effects of the studied process), in practice, it is a feature often overlooked which may lead to misleading interpretations of the results.

Here, I will present a concrete physical example where, based solely on the observable's time series, the ergodicity breaking is quantified in statistical terms and rationalized through a sub-diffusive model [1]. Then, the applicability of this approach to the epidemiological context will be discussed, and the implications of using non-Poissonian distributions and introducing time dependencies will be briefly treated.

References

[1] Bruno. V Guerrero, Bulbul Chakraborty, Iker Zuriguel, Angel Garcimartín, Nonergodicity in silo unclogging: Broken and unbroken arches, Physical Review E, **100**, 032901 (2019).

The impact of model resolution on variability in a coupled land atmosphere model

<u>Oisín Hamilton</u>[1,2] and Jonathan Demaeyer[1]

Anupama Xavier[1,2], Stéphane Vannitsem[1]

[1]Royal Meteorological Institute of Belgium
[2] Université Catholique de Louvain, Belgium

Reduced order quasi-geostrophic land-atmosphere coupled models display qualitatively realistic mid-latitude atmosphere behaviour, meaning that such models can produce typical atmospheric dynamical features such as atmospheric blocking. At the same time, due to a low number of degrees of freedom, they are still simple enough to allow for analysis of the system dynamics. These features mean that these models are well suited to investigating bifurcations in atmospheric dynamics, and use a dynamical systems approach to better understand the corresponding atmospheric behaviour.

This project introduces a symbolic python workflow for using the flexible land-atmosphere (qgs [1]) spectral model with the continuation software AUTO. This work builds on the results of Xavier et al. [2] to understand how the model variability and predictability is impacted by the model resolution. We also use bifurcation diagrams to better understand how parameters such as atmosphere-land friction impact the atmospheric blocking, and in turn the model atmosphere predictability. This is done for a range of model resolutions to investigate how the number of degrees of freedom impacts both the realism of the model, but also the structures found in the dynamics.

References

[1] Demaeyer, Jonathan & De Cruz, Lesley & Vannitsem, S.: qgs: A flexible Python framework of reduced-order multiscale climate models. Journal of Open Source Software. 5. 2597. 10.21105/joss.02597, 2020.

[2] Xavier, A. K., Demaeyer, J., and Vannitsem, S.: Variability and Predictability of a reduced-order land atmosphere coupled model, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2023-2257, 2023.

Using Topological Data Analysis to detect outliers: A Review

Jayati Kaushik[1]

[1]Ludwig Maximillian University, Town, Country

Topological data analysis (TDA) is a data science technique that uses methods from algebraic topology to extract insights and information from the shape of data. Studying the shape of data gives new perspective to the data by uncovering previously unknown relationships amongst the variables. This method has many applications when working with high dimensional datasets, non linear data.
We look at the uses of Topological Data Analysis(TDA); Mapper; and use of TDA with machine learning to look at detecting outliers in different fields and classification problems in various fields. We look at climate data, healthcare data and some examples of time series belonging to neither climate nor health care to see how TDA is being used to detect outliers in the data. Some of the applications we look at are:

1. Stock market crashes
2. Quantifying Diurnal cycles in hurricanes
3. TDA for fraud detecting in various fields.
4. Outlier detection in cyber log analysis
5. Biomolecular Folding pathways using mapper
6. Arrhythmia Detection through modular neural networks

Among others.
Primary references are listed below.

References

[1] G. Carlsson, Bulletin of the American Mathematical Society, Topology and Data (2009)

[2] M.Dindin, Y. Umeda, F. Chazal , Advanced in Artificial Intelligence,**177**, (2020)(33rd Canadian Conference on Artificial Intelligence, Canadian AI 2020)

[3] Gunnar Carlsson , Mikael Vejdemo-Johansson, Topological Data Analysis with Applications

Short-time prediction of extreme events in atmospheric turbulence

F. Köhne[1], A. Fuchs[1], M. Wächter[1] and J. Peinke[1]

[1]*Carl von Ossietzky Universität Oldenburg, School of Mathematics and Science, Institute of Physics, ForWind - Center for Wind Energy Research, Küpkersweg 70, 26129 Oldenburg, Germany*
E-mail: finn.koehne@uol.de

We present a method to forecast extreme wind events, such as gusts, by forecasting short-term, one-dimensional wind speed fluctuations of non-stationary atmospheric turbulence.
Assuming the increment time series is Markovian, the evolution of the probability density functions at several points in time can be modeled by a set of Fokker–Planck equations estimated self-consistently from given historical data measured offshore at the FINO1 platform and onshore at the Hamburg weather mast. We will show that the description of the underlying stochastic process of the fluctuation retains the characteristics of short-term dynamics of atmospheric wind speed fluctuations.
By using this stochastic approach based on multipoint statistics, it is possible to estimate fluctuations in the wind speed data on time scales in the order of seconds to minutes.
Accordingly, this stochastic multipoint reconstruction of wind data is ideal for investigating the dynamical effects of the wind energy conversion process, given that wind turbines and their control systems generally respond within seconds to minutes. Additionally, this approach could potentially prolong the lifetime of wind turbines by allowing the control system to reduce loads during extreme events.

Genealogical Particle Analysis in Oceanic Tracer Studies

<u>Viacheslav Kruglov</u> and Ulrike Feudel

ICBM, Carl von Ossietzky University, Oldenburg, Germany

Recently, a benthic cyst bed of *Alexandrium catenella*, a dinoflagellate dangerous to e.g. human health, was discovered in the Chukchi Sea near the Alaska coast [1]. With the Arctic Ocean experiencing decreasing ice coverage, early ice breakage, and late freezings in recent years, these harmful cysts can be dispersed by ocean currents further north during the summer months. Increasing warming of ocean waters as a result of climate change could lead to germination of those cysts leading to large concentration boosts of this harmful algal species initiating harmful algal blooms in the Arctic.

In this report, we present preliminary results from simulations of tracer particle dispersal by Arctic Ocean waters. Tracers are massless, sizeless particles, providing a suitable approximation for single-cell organisms. The equations of motion for tracers are solved numerically, with eastward and northward velocities as the right-hand sides, interpolated from data available at hycom.org.

The objective is to check the possibility of the dinoflagellate to spread to the west coast of Greenland, a region where people rely heavily on fisheries.

The initial conditions for the simulations were set in the area with the highest cyst concentrations, located approximately at coordinates 194° longitude and 69° latitude with a daily tracer particle release from June 1, 2019, through the end of September. The equations were solved using an explicit Euler method with a time step of 3 hours, incorporating the Earth's curvature to enhance the accuracy of the results. The calculations were then extended over the subsequent years to track the long-term dispersal patterns.

The image shows that the tracers adhere to the Alaskan and northern Canadian coastlines. However, at this stage, it is impossible to definitively determine whether the particles can navigate through the Northwest Passage and ultimately reach Baffin Bay.

References

[1] Anderson DM et al. Proc Natl Acad Sci USA. **118**, e2107387118 (2021)

Insight into deviations in aggregation processes: A new theory based on combinatorics applied to protoplanetary formation

M. Łepek

Faculty of Physics, Warsaw University of Technology, Warsaw, Poland

Recently, a combinatorial approach to discrete, finite, and irreversibly aggregating systems has been progressively developed [1,2]. Here, we first present the basic assumptions and combinatorial foundations of the approach, which are based on direct counting of the system states, in contrast to the previous approaches of Smoluchowski and Marcus-Lushnikov. In this approach, theoretical predictions of the average number of clusters of a given size for any given aggregation kernel (reaction rate) may be obtained by using a recursive expression with no need to find an explicit solution [3]. We exploit this opportunity to present the use of combinatorial expressions to solve a kernel related to the planetesimal formation [4].

Planetesimals are solid objects thought to exist in protoplanetary disks. They can efficiently accrete left-over pebbles and directly form the cores of planets, i.e., protoplanets of sizes greater than 1000 km, which may later evolve into terrestrial planets or gas giants. It may be shown that planetesimal formation coincides with an extreme rise in the standard deviation of the cluster size distribution and that the combinatorial theory of aggregation may theoretically predict such a rise.

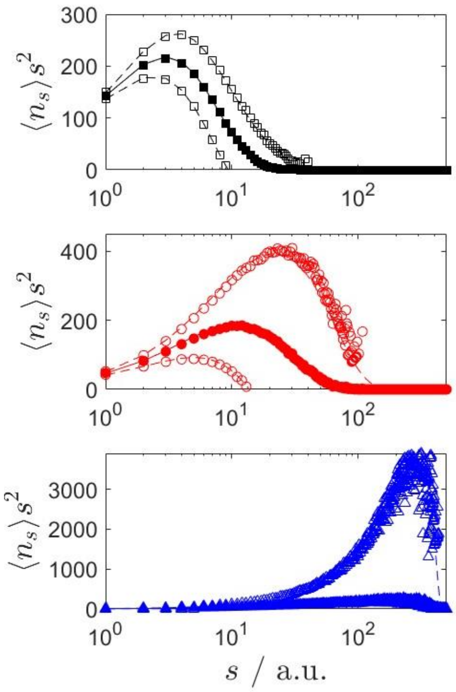


Figure caption: Average number of clusters of given size *s* multiplied by s^2 (lines) and its standard deviation (dashed lines) for the gravitational aggregation kernel [4], compared to the results of numerical simulations (symbols) for three stages of the evolution. Theoretical predictions follow the shape of the cluster size distribution and its standard deviation even for the latest stage of the process and include an extreme rise of the standard deviation – a phenomena that may be used for statistical prediction of planetary embryo formation events.

References

[1] A. Fronczak et al., Phys. Rev. E **97**, 022126 (2018)

[2] M. Łepek et al., Physica D **415**, 132756 (2021)

[3] M. Łepek et al., A review on combinatorial approach to aggregation (2024), under review

[4] Y. Ricard et al., Icarus **285**, 103-117 (2017)

Finite-time dynamical phase transitions in non-equilibrium relaxation

Jan Meibohm[1], Nalina Vadakkayil[2], and Massimiliano Esposito[2]

[1]*Technische Universität Berlin, Germany*
[2] *University of Luxembourg, Luxembourg*

Our poster gives an overview over a recently discovered class of phase transitions, so-called finite-time dynamical phase transitions[1-3]. Finite-time dynamical phase transitions occur in the extreme-event statistics of relaxing systems in non-equilibrium statistical mechanics.

These transitions appear in the transient relaxation of dissipative single and many-body systems after an instantaneous quench of the environment. During the transient relaxation, the rare-event statistics of certain thermodynamic observables exhibit singular points, i.e., kinks. These kinks are the consequence of sudden switches in the most likely rare-event dynamics[1,2], the optimal fluctuation, and they occur at sharp, finite times, so-called critical times.

We explain how the kinks and switches correspond to dynamical phase transitions, whose control parameter is time, as opposed to non-dynamical external parameters such as temperature or pressure, as in equilibrium phase transitions. The interpretation as phase transitions proves to be fruitful, as established concepts from equilibrium and non-equilibrium statistical mechanics can be used to identify and classify the transitions. In particular, a dynamical Landau theory enables one to classify finite-time dynamical phase transitions in the magnetisation[1] and the heat flow[2] of the Curie-Weiss model. Perhaps unsurprisingly for a mean-field model, these phase transitions turn out to be of mean-field type.

For lattice-based models, finite-time dynamical phase transitions exhibit critical fluctuations, with non mean-field critical exponents[4]. A finite-size scaling analysis enable us to extract the critical properties in this case.

References

1. Meibohm, J., Esposito, M., *Phys. Rev. Lett.* **128**, 110603 (2022)
2. Meibohm, J., Esposito, M., *New J. Phys.* **25**, 023034 (2023)
3. Blom, K., Godec, A., *arXiv:2209.14287* (2022)
4. Vadakkayil, N., Esposito, M., Meibohm, J., *to be submitted* (2024)

Modelling plant-aphid interactions with Holling type-II functional response under the influence of adaptive mutualistic plant-ant interactions

Priyanka Mondal[1] and S R V Prasad Bhuvanagiri[2]

[1]Vellore Institute of Technology, Vellore, India
[2] Vellore Institute of Technology, Vellore, India

Abstract

Plant-aphid interactions play a crucial role in determining the success of biological control programs of agricultural systems. Mathematically, these systems can be modelled using prey-predator systems, with pests assuming the role of plants and predators being the aphids. It is well known that plants exhibit various strategies to escape from predation pressure. One such technique is to bait a non-prey species by offering some resources and intervening with predators directly, benefiting both plant and non-prey species. This kind of mutualistic interaction can be seen in many plant-aphid-ant systems. It is proven in many studies that ants show adaptive foraging behaviour and decide which food (whether the plant-provided food or the supplementary food provided by humans or other plants) needs to be taken. This adaptive foraging behaviour can influence the protective services offered by ants to plants. In the present work, using a variation of the Rosenzweig-MacArthur prey-predator model representing the plant-aphid-ant interactions, we tried to investigate how the ant's mutualistic interactions with adaptive foraging behaviour influence the plant-aphid dynamics. The system analysis reveals very interesting and complex dynamics, such as the existence of alternating stable states, limit cycles, homoclinic orbits, etc. The present work finds its applications in agricultural systems wherein the plant can alter the predator's foraging efficiency with the help of changing ant's protective behaviour.

References

[1] Tomás A. Revilla, Vlastimil Křivan, Applied Mathematics and Computation 433, 127368 (2022)
[2] M.Rosenzweig and R.MacArthur, Graphical representation and stability conditions of predator-prey interaction, American Naturalist 97, 209-223 (1963)

Extremely large periods of constant wind speed in the atmospheric turbulent wind

Daniela Moreno[1], Jan Friedrich[1], Matthias Wächter[1], Jörg Schwarte[2], and Joachim Peinke[1]

[1]Carl von Ossietzky Universität Oldenburg, Institute of Physics. Oldenburg, Germany. [2]Nordex Energy SE & Co.KG, Erich-Schlesinger-Straße 50, 18059 Rostock, Germany.

The loads experienced by an operating wind turbine are estimated by numerical simulations of the turbine exposed to incoming wind fields. Therefore, accurate models describing the atmospheric wind structures are essential for the correct assessment of the loads. We investigate periods of constant wind speed in turbulent atmospheric wind. We hypothesize that extremely large events of such periods may lead to special and as yet unstudied responses of the turbine. Our results from the statistical characterisation of the lengths of wind speed periods reveal a challenging power-law behaviour of their extreme events. Depending on the threshold for considering the wind speed as constant, the characteristic exponent of the power-law decay can lead to non-convergence of the statistical moments of the distribution. In other words, events of infinite length are expected. The challenges of predicting such extremely large events from atmospheric wind may be undesirable for the operation of a wind turbine if critical loading scenarios (i.e. resonance) are induced.

Investigating extreme-event morphology and correlation with large-scale bifurcations using enstrohpy conditioned statistics

Benjamin Musci[a], Jean Le Bris[a], Adam Cheminet[a], Christophe Cuvier[b], Pierre Braganca[b], Cecile Wiertel-Gasquet[a], and Berengere Dubrulle[a].

Turbulence remains a fundamental puzzle in fluid dynamics, with the dissipative anomaly standing as a central enigma[1,3]. This anomaly, as suggested by previous studies, may find its origins, in the presence of quasi-singularities, capable of inertially dissipating energy near or below the Kolmogorov scale[1]. Such singularities, conjectured by mathematicians, are thought to be linked to the phenomenon of "spontaneous stochasticity. [1]" Despite these theoretical underpinnings, experimental validation of this concept has remained elusive.

Addressing this gap, our work leverages cutting-edge experimental data from the Giant-von-Karman (GvK) facility at CEA Paris-Saclay[2]. By exploring a broad range of Reynolds numbers (6,000-150,000) with unprecedented spatial resolution (down to ¼ Kolmogorov scale) through 4D Particle Tracking Velocimetry, we delve into the intricate dynamics of turbulence. This fine-grained resolution is instrumental in shedding light on the elusive description of the smallest scales within turbulent flows.

Our investigation extends beyond statistical analysis by delving into the amplification of vorticity gradients during intermittent extreme events. By correlating these statistics with enstrophy, we unveil the mechanisms underlying vortex stretching, particularly within regions of intermittency, while excluding quiescent areas[4]. Additionally, we revisit the potential universality of vorticity vector alignment with the intermediate strain-rate eigenvector[5].

Moreover, our research scrutinizes individual intermittent/extreme-event morphologies, with a specific focus on understanding the vorticity amplification processes preceding specific symmetry-breaking bifurcations in the large-scale flow. By tracking these events spatiotemporally and examining the evolving alignment of strain and vorticity vectors, we aim to unravel the intricate dynamics governing extreme-event generation, enstrophy production, and the possible link with flow bifurcations. This comprehensive approach offers new insights into the complex interplay between turbulence dynamics and large-scale flow structures to better reconcile turbulent theory and experiment.

References

[a] SPHYNX Lab, CEA-Saclay, 91191 Gif-sur-Yvette, France
[b] LMFL, Centrale Lille, 59655 Villeneuve d'Ascq, France

[1] B. Dubrulle, Beyond kolmogorov cascades, *Journal of Fluid Mechanics*, **867**, 2019.
[2] A. Cheminet, et. al, Eulerian vs Lagrangian Irreversibility in an experimental turbulent swirling flow, *Physical Review Letters*, **129.12**, 2022
[3] B. Pearson, P-A. Krogstad, W. Van De Water, Measurements of the turbulent energy dissipation rate, *Phys. Fluids*, **14**, 2002
[4] D. Buaria & A. Pumir, Nonlocal amplification of intense vorticity in turbulent flows, *Phys. Rev. Research*, **3**, 2021
[5] A. Pumir, H. Xu, & E. D. Siggia, Small-scale anisotropy in turbulent boundary layers, *J. Fluid Mech.*, **804**, 2016

Extreme events in globally coupled chaotic maps

Sayantan Nag Chowdhury1, Arnob Ray1, Arindam Mishra2 and Dibakar Ghosh1,

1 Physics and Applied Mathematics Unit, Indian Statistical Institute, 203 B. T. Road, Kolkata-700108, India

2 Division of Dynamics, Technical University of Lodz, Stefanowskiego 1/15, 90-924 Lodz, Poland

Understanding and predicting uncertain things are the central themes of scientific evolution. Human beings revolve around these fears of uncertainties concerning various aspects like a global pandemic, health, finances, to name but a few. Dealing with this unavoidable part of life is far tougher due to the chaotic nature of these unpredictable activities. In the present article, we consider a global network of identical chaotic maps, which splits into two different clusters, despite the interaction between all nodes are uniform. The stability analysis of the spatially homogeneous chaotic solutions provides a critical coupling strength, before which we anticipate such partial synchronization. The distance between these two chaotic synchronized populations often deviates more than eight times of standard deviation from its long-term average. The probability density function of these highly deviated values fits well with the generalized extreme value distribution. Meanwhile, the distribution of recurrence time intervals between extreme events resembles the Weibull distribution. The existing literature helps us to characterize such events as extreme events using the significant height. These extremely high fluctuations are less frequent in terms of their occurrence. We determine numerically a range of coupling strength for these extremely large but recurrent events. On-off intermittency is the responsible mechanism underlying the formation of such extreme events. Besides understanding the generation of such extreme events and their statistical signature, we furnish forecasting these events using the powerful deep learning algorithms of an artificial recurrent neural network. This long short-term memory (LSTM) can offer handy one-step forecasting of these chaotic intermittent bursts. We also ensure the robustness of this forecasting model with two hundred hidden cells in each LSTM layer.

References

[1] Sayantan Nag Chowdhury, Arnob Ray, Arindam Mishra, and Dibakar Ghosh. "Extreme events in globally coupled chaotic maps." *Journal of Physics: Complexity* 2, no. 3 (2021): 035021.

[2] Sayantan Nag Chowdhury, Arnob Ray, Syamal K. Dana, and Dibakar Ghosh. "Extreme events in dynamical systems and random walkers: A review." *Physics Reports* 966 (2022): 1-52.

[3] Sayantan Nag Chowdhury, Soumen Majhi, Mahmut Ozer, Dibakar Ghosh, and Matjaž Perc. "Synchronization to extreme events in moving agents." *New Journal of Physics* 21, no. 7 (2019): 073048.

Introduction to Varieties of Democracy in Times of Global Change

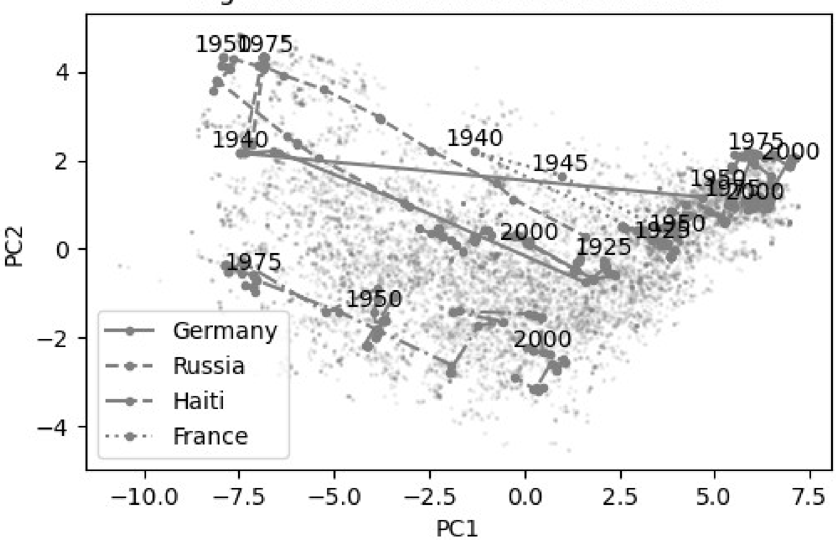
<u>Pauleo Nimtz</u>[1] *(nimtz@uni-potsdam.de)*

[1]*Potsdam University, Potsdam, Germany*

In my contribution, I want to focus on the empiric characterisation of political regime types, their dynamics, interactions, and correlations. This is work in progress: I aim to outline the cornerstones of my Bachelor's thesis rather than present my own results.

V-DEM is an international project headed by the V-DEM institute at Gothenburg, Sweden. Its goal is to gain sophisticated insights into commonalities and differences of various regime types. To this end, the project gathers regional experts and a plethora of opinions, classifying countries in time using sharply defined indicators[1].

Fig. 1: Evolution of selected countries



By principal component analysis, one can greatly reduce the dimensionality of this dataset, in particular the 24 indicators comprising the electoral democracy index (EDI). Indeed, the first component reproduces the EDI. PC2, however, seems to indicate the balance between the regularity of elections (positive) and freedom of expression/ association (negative)[2,3].

This yields a two-dimensional representation of a country's political state. In particular, we can trace specific countries and look for correlations with known events. Fig. 1 depicts some exemplary trajectories. Clearly, we can identify the impact of world war two on both Germany and France as well as the Soviet Union's transition towards a more democratic regime and back to a slightly more authoritarian state (Russia). Haiti, however, seems to be trapped in a rather disordered state.

This leads to a number of questions: Which countries interact and how to quantify this? How to quantify changes in trajectories, indicating extreme events? Are there general principles of motion or chaotic regions? In my thesis, I aim to apply methods of extreme value statistics and nonlinear dynamics to gain some further insights.

References:

[1] M. Coppedge et al, International Political Science Review **37.5** 580-593 (2016)
[2] K. Wiesner et al, V-Dem Working Paper, Series 2023:137 (2023)
[3] K. Wiesner et al, arXiv preprint arXiv:2402.11335 (2024)

Effects of toxicity and zooplankton selectivity under seasonal pattern of viruses with time delay on plankton dynamics

Samares Pal

Department of Mathematics, University of Kalyani, Kalyani, India

samaresp@yahoo.co.in

A mathematical model for the interacting dynamics of phytoplankton-zooplankton is proposed. The phytoplankton have ability to take refuge and release toxins to avoid over predation by zooplankton. The zooplankton are provided some additional food to persist in the system. The phytoplankton are assumed to be affected directly by an external toxic substance whereas zooplankton are affected indirectly by feeding on the affected phytoplankton. We incorporate seasonal variations in the model, assuming the level of nutrients, refuge and the rate of toxins released by phytoplankton as functions of time. Our results show that when high toxicity and refuge cause extinction of zooplankton, providing additional food supports the survival of zooplankton population and controls the phytoplankton population. Prey refuge and additional food have stabilizing effects on the system; higher values of the former results in extinction of zooplankton whereas phytoplankton disappear for larger values of the latter. We find that time delay accounts for recurrent stability switching event in the system. Seasonality in nutrients level and toxins released by phytoplankton generates higher periodic solutions while time-dependent refuge of phytoplankton causes the occurrence of a period-three solution. The possibility of finding additional food for zooplankton may push back the ecosystem to a simple stable state from a complex dynamics.

Large deviation full counting statistics in adiabatic open quantum dynamics

Paulo J. Paulino[1], **Igor Lesanovsky**[1,2], **and Federico Carollo**[1]

[1] *Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany*

[2] *School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom*

email: paulo.paulino.souza96@gmail.com

The state of an open quantum system undergoing an adiabatic process evolves by following the instantaneous stationary state of its time-dependent generator. This observation allows one to characterize, for a generic adiabatic evolution, the average dynamics of the open system. However, information about fluctuations of dynamical observables, such as the number of photons emitted or the time-integrated stochastic entropy production in single experimental runs, requires controlling the whole spectrum of the generator and not only the stationary state. Here, we show how such information can be obtained in adiabatic open quantum dynamics by exploiting tools from large deviation theory. We prove an adiabatic theorem for deformed generators, which allows us to encode, in a biased quantum state, the full counting statistics of generic time-integrated dynamical observables. We further compute the probability associated with an arbitrary "rare" time-history of the observable and derive a dynamics which realizes it in its typical behavior. Our results provide a way to characterize and engineer adiabatic open quantum dynamics and to control their fluctuations.

References

[1] P. J. Paulino, I. Lesanovsky, and F. Carollo. **arXiv:2401.11933** (2024).

Navigating Early Warning Systems: Bridging Gaps with Spatial Coherence

P.A. Sanders

Mathematical Institute (MI) and Institute for Marine and Atmospheric research (IMAU), Utrecht, Netherlands

In our uncertain and everchanging world, in the future many systems face the dangers of crossing tipping thresholds. Hence, there is an interest to develop swift and reliable early warning signs to signal for such crossings ahead of time. However, existing methods for detecting tipping points and understanding system dynamics are hindered by oversimplified models. These approaches frequently overlook critical dynamics, particularly in the vicinity of tipping points, or when models fail to account for a real systems multivariate and spatial response possibilities. In such spatially extended models, it has been shown that dynamics might evade tipping through spatial pattern formation.[1]

In this poster presentation, I present how existing early warning methods can be improved by integrating spatial heterogeneity into dynamical models. In particular, I will show how early warning methods can be developed that are able to distinguish between the imminent crossings of dangerous tipping points and of perhaps not so dangerous pattern forming Turing bifurcations.

References

[1] M. Rietkerk et al, Evasion of tipping in complex systems through spatial pattern formation, Science Vol 374, Issue 6564 (2021)

On the global-scale interdependence patterns of extreme rainfall

Z. Su[1,2], H. Meyerhenke[2], and J. Kurths[1,2]

[1]Potsdam Institute for Climate Impact Research, Potsdam, Germany
[2]Humboldt-Universität zu Berlin, Berlin, Germany

As pointed out in the Sixth Assessment of the Intergovernmental Panel on Climate Change (IPCC), precipitation extremes will be very likely to become more frequent in most locations. Understanding the global extreme-rainfall interdependence patterns is crucial for the improvement of the predictability of extreme events. For this, we focus on the identification of regions of similar extreme-rainfall patterns. We propose a complex-network-based clustering workflow which combines consensus clustering and mutual correspondences. More precisely, consensus clustering provides a reliable clustering structure under each dataset, while mutual correspondences build a matching relationship between different clustering structures obtained from different datasets. By applying this workflow to two satellite-derived precipitation datasets, we identify two main global synchronized structures of extreme rainfall, during boreal summer. These two structures are consistent and robust. From a climatological point view, they explicitly manifest the primary intraseasonal variability in the context of the global monsoon, including the “monsoon jump” over both East Asia and West Africa, and the mid-summer drought over Central America and southern Mexico. We highlight the advantage of network-based clustering in (i) decoding the spatio-temporal patterns of climate variability and in (ii) the intercomparison of these patterns, especially regarding their spatial distributions over different datasets.

References

[1] Z. Su, H. Meyerhenke, and J. Kurths, Chaos 32, 043126 (2022).
[2] “Sixth Assessment Report.” by https://www.ipcc.ch/assessment-report/ar6/
[3] N. Boers, B. Goswami, A. Rheinwalt, B. Bookhagen, B. Hoskins, and J. Kurths, Nature 566, 373 (2019).
[4] A. Lancichinetti and S. Fortunato, Sci. Rep. 2, 336 (2012).
[5] R. Glantz and H. Meyerhenke, in Proceedings of the 2018 SIAM International Conference on Data Mining (SIAM, 2018), pp. 1–9.
[6] Y. Y. Liu and Y. H. Ding, Acta Meteor. Sin. 66, 789 (2008).
[7] S. E. Nicholson, Int. Sch. Res. Not. 2013, 453521 (2013).
[8] V. Magaña, J. A. Amador, and S. Medina, J. Clim. 12, 1577 (1999).

Dynamics of Systems with Time Delay: Coexistence and Stability of Periodic Solutions

Y. Wang[1,2]

[1]*Potsdam Institute for Climate Impact Research, Potsdam, Germany*
[2]*Humboldt-Universität zu Berlin, Berlin, Germany*

Time-delay systems are characterized by the presence of delayed feedback or information transmission, and this can introduce complex dynamics. Research has shown that delay systems often have families of periodic solutions that repeat for an infinite number of delay times. As time delay increases, solution families overlap, leading to the increasing coexistence of multiple stable and unstable solutions. These solutions also may persist across a range of delay times, influencing each other's stability. Understanding the coexistence of multiple solutions is crucial because it provides insight into the system's flexibility and adaptability. In practical terms, it means that the system can respond differently to the same input or external conditions, showcasing a variety of behaviors. This phenomenon is particularly relevant in the study of dynamic systems, as it influences the stability and predictability of the system under different circumstances. In extreme events, which often entail unexpected and disruptive changes in the system's environment, the coexistence of multiple solutions becomes a crucial factor. Traditional models may struggle to accurately predict or adapt to such unforeseen circumstances. However, the presence of diverse periodic solutions allows the system to exhibit a range of responses, enhancing its ability to cope with and recover from extreme events.

References

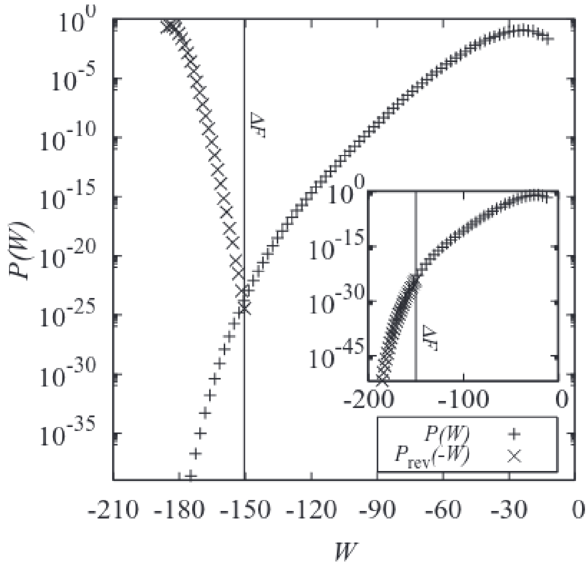
[1] S. Yanchuk, P. Perlikowski, PHYSICAL REVIEW E 79, 046221 (2009)
[2] M. Yang, Y. K. Liu, G. Q. Yang, Appl. Math. Model. 2, 89 (2021)
[3] M. Ghil, I. Zaliapin, I. *Extreme Events: Observations, Modeling, and Economics*, (2015), pp. 63-77.
[4] M. Ghil, I. Zaliapin, S. Thompson. *Nonlinear Processes in Geophysics*, *15*(3), 2008, pp. 417-433.
[5] B. W. Shen, R. Pielke Sr, X. Zeng, J. Cui, S. Faghih-Naini, W. Paxson, R. Atlas (2022). *Atmosphere*, *13*(11), 2022, pp. 1892.

Simulation of equilibrium and non-equilibrium unfolding and refolding processes for RNA secondary structures

Peter Werner and **Alexander K. Hartmann**

University of Oldenburg, Germany
peter.werner@uni-oldenburg.de

We study [1] numerically the behavior of RNA secondary structures under influence of a varying external force. An extension of the sampling algorithm of Higgs [2] to the case with external force, which allows us to perfectly sample secondary structures in true equilibrium, is presented. By using this approach, we are able to generate equilibrium unfolding and refolding trajectories.
Furthermore, by means of a Monte-Carlo sampling of secondary structures, we simulate, starting from equilibrium configurations, fast non-equilibrium unfolding and refolding processes, while measuring the performed work. Using a sophisticated large-deviation algorithm [3] to sample vectors of random numbers, utilized to sample the non-equilibrium trajectories, we can resolve the work distributions with high precision for a medium-size (length $L = 100$) RNA hairpin structure down to probabilities as small as 10^{-46}, which looks like:



By comparison with exact free-energy calculations, we are able to verify the theorems of Crooks and Jarzynski [4,5] . This can be seen in the figure above, by the intersection of the work distributions of the forward and reverse process at the ΔF line and the rescaled work distribution of the reverse process in the inset that matches the work distribution of the forward process. We also compare force-extension curves and the secondary structure configurations during unfolding and refolding, conditioned to selected values of the measured work W, with those of typical equilibrium processes.

References

[1] P. Werner and A. K. Hartmann Phys. Rev. E **104**, 034407 (2021).

[2] P. G. Higgs, Phys. Rev. Lett. **76**, 704 (1996).

[3] A. K. Hartmann, Phys. Rev. E **89**, 052103 (2014).

[4] C. Jarzynski, Phys. Rev. Lett. **78**, 2690 (1997).

[5] G. E. Crooks, J. Stat. Phys. **90**, 1481 (1998).