Interacting Tipping Elements in the Natural and Social Components of the Earth System

728. WE-Heraeus-Seminar

15 – 18 August 2021
hybrid at the Paulinen Hof Bad Belzig, 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 728. WE-Heraeus-Seminar:

Tipping elements are natural and socio-economic components of the Earth system that could be pushed into qualitatively different states by small external perturbations, with profound environmental impacts possibly endangering the livelihoods of millions of people. Examples include climate tipping elements such as the ice sheets of Greenland and Antarctica, the Atlantic ocean's meridional overturning circulation or biomes as well as potential social tipping elements such as processes in public opinion formation, consumption patterns, conflict and migration, or climate policy changes, and their societal implications.

There are indications for significant interlinkages between climate tipping elements and even the potential for tipping cascades or domino effects from the climate to the social sphere. This WE Heraeus Seminar will discuss and synthesize physics-based efforts in modelling these natural and socio-economic tipping elements and their complex interaction dynamics using methods from relevant subfields such as statistical physics, nonlinear dynamics and complex network theory. A particular focus will be placed on educating early career researchers in physics to be able to work on the forefront of these problems and contribute to efforts in better understanding the options to induce rapid mitigation of anthropogenic climate change and pathways to sustainability transformations.

Scientific Organizers:

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Program

Sunday, 15 August 2021

15:00 – 18:00	Arrival and registration	
18:00 – 19:30	*DINNER*	
19:30 – 19:45	Scientific organizers	**Welcome words**
19:45 – 21:00	Tim Lenton	**Positive tipping points to avoid earth system tipping points**
21:00 – 23:00	Ice breaker reception with drinks	

Program

Monday, 16 August 2021

08:00	*BREAKFAST*	

Earth: tipping dynamics in natural components

09:00 – 09:15	Stefan Jorda	**About the WE-Heraeus-Foundation**
09:15 – 10:15	Ricarda Winkelmann	**Interacting tipping elements and the risk of domino effects in the Earth System**
10:15 – 10:45	Vasilis Dakos	**Understanding change: Stability and Early warnings**
10:45 – 11:00	*COFFEE BREAK*	
11:00 – 11:30	Clara Zemp	**Cascading effects in tropical (agro)forests**
11:30 – 12:00	Anna von der Heydt	**Cascading tipping in past climates: The Eocene-Oligocene transition**
12:00 – 12:30	Jonathan Donges	**Critical conditions for social tipping dynamics towards sustainability**
12:30 – 13:30	*LUNCH*	
14:00 – 15:30	**Ignite talks I**	
	Julius Garbe	**The hysteresis of the Antarctic ice sheet**
	Sacha Sinet	**Cascading in a coupled ice-ocean model**
	Boris Sakschewski	**Towards testing the uncertainties of the land carbon sink under climate change**
	Lucia Layritz	**Towards a multidimensional quantification of resilience change in ecological systems**

Program

Monday, 16 August 2021

Ignite talks I

	Nico Wunderling	**Network dynamics of drought-induced tipping cascades in the Amazon rainforest**
	Ann Kristin Klose	**Cascading tipping behavior of the interacting Greenland Ice Sheet and Atlantic Meridional Overturning Circulation in a model of low complexity**
	Victor Couplet	**Cascade of tipping points: investigating the 'cool Earth' / 'hothouse' narrative with dynamical systems**
	Emmy Wassénius	**Portfolio diversification of earth system risks**
	Eviatar Bach	**Combining multiple physical and data-driven models for data assimilation and forecasting**
	Ruth Chapman	**Stochastic data adapted AMOC box models**
	Toyo Vignal	**Resilience in dry rangelands: how to destock livestock in water-stressed environments?**
15:30 – 16:00	*COFFEE BREAK*	
16:00– 17:30	Breakout discussions and short plenary on **"Doing global systems science in a politicized environment & the role of models"**	
19:00 – 21:00	*DINNER*	

Program

Tuesday, 17 August 2021

08:00	*BREAKFAST*	

World: tipping dynamics in socio-economic components

09:00 – 10:00	Rachael Shwom	**Theorizing climate relevant social tipping points**
10:00 – 10:30	Jürgen Scheffran	**Modeling resource conflicts, climate security cascades and sustainability transitions**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:30	E. Keith Smith	**Concern and anticipation of sea-level rise provide grounds for social tipping towards climate action**
11:30 – 12:00	Veronika Stolbova	**Tipping in climate finance**
12:00 – 12:30	Franz Mauelshagen	**Social and earth system tipping in industrial transformations**
12:30 – 13:30	*LUNCH*	
14:00 – 15:30	**Ignite talks II**	
	Fabian Dablander	**Overlapping time scales obscure early warning indicators of COVID-19 in Europe**
	Sara Ansari	**The estimation of citizen commitment to climate change mitigation based on perceptual computing**
	Luana Schwarz	**Joint environmental action: multi-level dynamics of movement participation**
	Niklas Kitzmann	**Contagious transformations? Inter-city spreading of sustainability innovations**

Program

Tuesday, 17 August 2021

	Ignite talks II	
	Isabell von Falkenhausen	**Reproducing the Spreading of Urban Sustainability Innovations using generative models**
	Petter Bjerser	**Utilising social media data to identify social-ecological tipping points in public acceptability and framing of policy problems. The case of Net Zero Climate Targets.**
	Roger Cremades	**The role of cognitive dissonance on social tipping points: Applications to the circular economy**
	Marvin Lücke	**Analyzing tipping behavior of social dynamics on networks using hybrid models**
	Sina Loriani	**Towards systematic screening of tipping points in model intercomparison projects**
	Tuan Pham	**Predicting collapse of adaptive networked systems without knowing the network**
	Claus Sarnighausen	**Methods of risk estimation and propagation for studying cascading tipping dynamics**
	Juan Rocha	**Cascading regime shifts within and across scales**
15:30 – 16:00	*COFFEE BREAK*	
16:00– 16:45	**Poster session part 1**	

Tipping interactions and methods I

17:00 – 18:00	Matthew Ives	**Four interventions and a funeral for fossil fuels**
19:00 – 23:00	*HERAEUS DINNER and informal reception with drinks*	

Program

Wednesday, 18 August 2021

08:00	*BREAKFAST*	
09:00 – 09:45	**Poster session part 2**	

Tipping interactions and methods II

10:00 – 10:30	Michel Crucifix	**Earth dynamics, dynamical systems and tipping points : mainstream mathematical background and some speculations**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:30	Anne-Sophie Crépin	**Regime shifts in social-ecological systems in the Anthropocene**
11:30 – 12:00	Frank Hilker	**Mathematical models of lake pollution dynamics with both ecological and social tipping points**
12:00 – 12:30	Jobst Heitzig	**Best contributed award** **Closing words and farewell**
12:30	*LUNCH*	

End of the seminar and departure

Posters

Posters

Sara Ansari	**The estimation of citizen commitment to climate change mitigation based on perceptual computing**
Eviatar Bach	**Combining multiple models for data assimilation and forecasting using a multi-model ensemble Kalman filter**
Petter Bjerser	**Social tipping points in swedish political discourse on NETs**
Ruth Chapman	**Stochastic data adapted AMOC box models**
Victor Couplet	**Cascade of tipping points: investigating the 'cool Earth' / 'hothouse' narrative with dynamical systems**
Roger Cremades	**The role of cognitive dissonance on social tipping points: Applications to the circular economy**
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Tuan Pham	**Predicting collapse of adaptive networked systems without knowing the network**
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Toyo Vignal	**Resilience in dry rangelands: how to destock livestock in water-stressed environments?**
Isabell von Falkenhausen	**Reproducing the spreading of urban sustainability innovations using generative models**
Emmy Wassénius	**Portfolio diversification of earth system risks**
Nico Wunderling	**Network dynamics of drought-induced tipping cascades in the Amazon rainforest**

Abstracts of Talks

(in alphabetical order)

Regime shifts in social-ecological systems in the Anthropocene

Anne-Sophie Crépin[1]

[1]*The Beijer Institute of Ecological Economics at the Royal Swedish Academy of Sciences, Stockholm, Sweden.*

Human interventions, such as harvest or pollution in natural systems create a coupled social-ecological system which can exhibit tipping points. This could occur if the natural system was prone to tipping but also in situations when it was not. Typically the social-ecological system will tip under different conditions to those triggering a regime shift in the pristine system. Phenomena intrinsic to the Anthropocene, such as climate change and increased velocity and scale of change, influence these dynamics too. These phenomena transform the conditions for defining appropriate management rules for these systems. I will provide an overview of these issues based on my own research in the field. I will put particular focus on uncertainty, the interplay of fast and slow dynamics and spatial connectivity.

References

[1] C. Z. Li, A.S. Crépin, & C. Folke, International Review of Environmental and Resource Economics, *11*(4), 309-353 (2018)

[2] A. S. Crépin, E. Nævdal. The Scandinavian Journal of Economics 122(4), 1259-1285 (2020)

[3] A. S. Crépin, R. Biggs, S. Polasky, M. Troell & A. De Zeeuw. Ecological Economics, *84*, 15-22 (2012)

[4] A. S. Crépin and J. C. Rocha, Beijer Discussion Paper 275 (2021)

Earth dynamics, dynamical systems and tipping points : mainstream mathematical background and some speculations

M. Crucifix[2]

[1]Earth and Life Institute, UCLouvain, Belgium

It has been customary to model large geological or climatic transitions with dynamical systems: Using reasoning on physics or biogeochemistry, we write equations that equate rates of changes in variables of the system with functions of these variables. Once we have accepted this conceptual leap, we have access to a huge literature in mathematics that helps us to understand and predict the way the system behaves or might behave in the future. In this concept, “Events” (abrupt or qualitative) may correspond to bifurcations. Mathematicians define a bifurcation as a topological or a stability change of the invariant manifold of the dynamical system. This is a bit technical, but again with some conceptual good will we understand it as a change in the qualitative dynamics of the system that occurs when a small (or “gradual”) environmental change occurs. See how much we must trust our dynamical system approach to make this connection. Yet, it works. It is a rich and successful approach that has been generalised and extended to account for variable external forcings and the presence of noise (so-called non-autonomous dynamical systems).

The concepts and imagery that comes with dynamical systems theory are also largely used to evoke “social tipping”. A classical example is the famous “S-curve” that features two bifurcation points associated with the dynamical system dx/dt = - x^3 + x/3 + p. But is this actually a good concept to describe social tipping ?

While many might feel this is not quite right, no-one really knows how to do it better, at least if we want some mathematical background for describing social phenomena. So-called integrated assessment models are dynamical systems, and they are used for advising decision-making.

One of the difficulties we face with social phenomena, and, some would argue, with living phenomena at large, is that the ‘dynamical system’ is not fixed once for all. It can undergo structural changes. Complex systems such as societies partially adapt and redefine themselves based on what they perceive from their environment. There may be a fundamental reason, that has to do with a duality of form and function. Structures impose material constraints (physical limitations). This is what we encode in the dynamical system. However, what the system produces is also “observed” by the system and its components, in a way that is context dependent. A complex system perceives its environment and processes information through an internal model, in a way that generally results in (adaptive) anticipatory action that has been learned through time. Deciduous trees lose their leaves before frost (and damages) comes. In the near term, powerful countries or even individuals might respond to extreme heat waves and social unrest by unilaterally opting for aggressive geoengineering. Such radical action, perhaps perceived as an act of war, would suddenly change the rules in a way that would make the current models ‘maladaptive’.

We view this as a ‘second-order’ tipping point: a change in regime that actually breaks the model and its predictions. The objective of the presentation is to trigger discussion around this topic.

Understanding change: Stability and Early warnings

Vasilis Dakos

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Understanding stability of ecosystems and communities has always been major challenge for ecologists. Definitions and measures of stability abound and at times are confusing [1]. Nowadays, it is in general accepted that stability is multidimensional and it needs to be measured in different ways. Some of these measures have been developed to highlight the approach to tipping points, that is catastrophic transitions between different dynamical states [2,3]. As long-term data become increasingly available and experimental approaches are improving, the challenge is how to apply such theoretical metrics to quantify stability in order to understand change in ecological and not only systems.
In this talk, I will present different metrics for measuring stability in ecological communities (and by extension any multidimensional system) [4]. More in depth, I will also focus on how changes in dynamical properties of a system can be used as early warnings to abrupt changes using examples from ecology.

References

1. Kéfi S, Domínguez-García V, Donohue I, Fontaine C, Thébault E, Dakos V. Advancing our understanding of ecological stability. Ecol Lett. 2019;22: 1349–1356. doi:10.1111/ele.13340
2. Scheffer M, Bascompte J, Brock WA, Brovkin V, Carpenter SR, Dakos V, et al. Early-warning signals for critical transitions. Nature. 2009;461: 53–59. doi:10.1038/nature08227
3. Dakos V, Carpenter SR, Brock WA, Ellison AM, Guttal V, Ives AR, et al. Methods for detecting early warnings of critical transitions in time series illustrated using simulated ecological data. PLoS One. 2012;7: e41010. doi:10.1371/journal.pone.0041010
4. Domínguez-García V, Dakos V, Kéfi S. Unveiling dimensions of stability in complex ecological networks. Proc Natl Acad Sci. 2019;116: 25714–25720. doi:10.1073/pnas.1904470116

Critical conditions for social tipping dynamics towards sustainability

Jonathan F. Donges (1)*, E. Keith Smith (2)*, Anne-Sophie Crépin, Christina Eder, Niklas Harring, Jobst Heitzig, Alexia Katsanidou, Timothy M. Lenton, Franz Mauelshagen, Manjana Milkoreit, Kelton Minor, Ilona M. Otto, Armon Rezai, Jürgen Scheffran, Isabelle Stadelmann-Steffen, Rick van der Ploeg, Nico Wunderling, Ricarda Winkelmann

[1]*Potsdam Institute for Climate Impact Research, Potsdam, Germany*
[2] *ETH Zurich, Zurich, Switzerland*

Societal transformations are necessary to address critical global challenges, such as mitigation of anthropogenic climate change and reaching UN sustainable development goals. Recently, social tipping processes have received increased attention, as they present a form of social change whereby a small change can shift a sensitive social system into a qualitatively different state due to strongly self-amplifying (mathematically positive) feedback mechanisms. Social tipping processes with respect to technological and energy systems, political mobilization, financial markets and sociocultural norms and behaviors have been suggested as potential key drivers towards climate action.

We present a framework developed to characterize such social tipping processes. We find that social tipping processes are distinguishable from those of already more widely studied climate and ecological tipping dynamics. In particular, we identify human agency, social-institutional network structures, different spatial and temporal scales and increased complexity as key distinctive features. Considering these characteristics, we propose a formal definition for social tipping processes and filtering criteria for those processes that could be decisive for future trajectories towards climate action. Building on this framework and definition, we discuss why an emphasis on research to identify critical conditions under which social tipping dynamics is likely to emerge is promising and give examples of key factors that determine this criticality of complex social-economic system.

References

J.F. Donges*/R. Winkelmann*/E.K. Smith*/M. Milkoreit*, C. Eder, J. Heitzig, A. Katsanidou, M. Wiedermann, N. Wunderling, T.M. Lenton, **Social tipping processes for sustainability: an analytical framework**, in review (2021), preprint arXiv:2010.04488 [physics.soc-ph].

Mathematical models of lake pollution dynamics with both ecological and social tipping points

T. Anthony. Sun[1,2] and Frank M. Hilker[1]

[1] *Institute of Mathematics and Institute of Environmental Systems Research, Osnabrück University, Osnabrück, Germany*

[2] *Currently at Dept. Molecular Biology, Umeå University, Umeå, Sweden*

The eutrophication of shallow lakes is an iconic example of ecological regime shifts. When the water body becomes progressively enriched with nutrients and minerals, there may be a rapid transition to algal blooms. Human discharge of nutrients is a key driver of lake pollution. At the same time, human behavior is affected by the state of the environment as well as socio-economic factors. This talk introduces generic mathematical models that couple human behavioral and ecological dynamics as well as their interactions. The models consist of two nonlinear differential equations, one describing lake water pollution (based on ecological processes) and the other one describing human behavior of discharging pollutants (using evolutionary game theory to derive collective behavior from individual utilities). Analyzing the models with dynamical systems and numerical bifurcation tools reveals a complex interplay of ecological and social tipping points, involving cusp, Hopf, and Bogadanov-Takens bifurcations. Some very preliminary results will be shown to indicate potential effects of discontinuous policy instruments.

References

[1] T.A. Sun, F.M. Hilker, Ecological Complexity **43**, 100834 (2020)
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[3] Y. Suzuki, Y. Iwasa, Ecological Research **24**, 479-489 (200)

Four Interventions and a Funeral for Fossil Fuels

Matthew C. Ives[1]

[1]*Institute for New Economic Thinking, University of Oxford, UK*

There is a growing body of literature on tipping points in relation to the 'earth system' (Lenton et al. 2008). Historically, this literature has considered mostly undesirable tipping points (e.g. melting of the Greenland icesheet) but is now beginning to consider desirable tipping points or sensitive intervention points in socio-economic system that might enable rapid decarbonisation (Farmer et al. 2019, Otto et al. 2020). The features common to such tipping points include: (i) multiple stable states in a system; (ii) abruptness (i.e. non-linearity between cause and effect); (iii) feedback dynamics; and (iv) limited reversibility. We apply a framework for understanding sensitive intervention points to our largest source of global emissions, the energy system, to identify four key interventions that might enable decarbonisation to proceed at the pace required for our Paris targets, and might also herald the end of the fossil fuel age (Ives, et al. 2021).

References

[1] Lenton, T. M. et al. Tipping elements in the Earth's climate system. Proc. Natl. Acad. Sci. 105, 1786–1793 (2008)

[2] Farmer, J. D. et al. Sensitive intervention points in the post-carbon transition. Science (80-.). 364, 132–134 (2019).

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Positive Tipping Points to Avoid Earth System Tipping Points

T. Lenton[1]

[1]*Global Systems Institute, University of Exeter, UK*

Tipping points exist in social, ecological and climate systems and those systems are increasingly causally intertwined in the Anthropocene. Climate change and biosphere degradation have advanced to the point where we are already triggering damaging environmental tipping points, and to avoid worse ones ahead will require finding and triggering positive tipping points towards sustainability in coupled social, ecological and technological systems. To help with that I outline how tipping points can occur in continuous dynamical systems and in networks, the causal interactions that can occur between tipping events across different types and scales of system – including the conditions required to trigger tipping cascades, the potential for early warning signals of tipping points, and how they could inform deliberate tipping of positive change. In particular, the same methods that can provide early warning of damaging environmental tipping points can be used to detect when a socio-technical or socio-ecological system is most sensitive to being deliberately tipped in a desirable direction. I provide some example targets for such deliberate tipping of positive change.

Social and Earth System Tipping in Industrial Transformations

Franz Mauelshagen[1]

[1] *Department of History, University of Bielefeld, Germany*

Over the history of the last 200 to 250 years, industrial transformations have triggered multiple tipping processes in, both, social systems and the earth system. I will focus on specific examples of social tipping in demographics and labor history, which is just as connected to energy transformations as global warming. Assuming that this connection is well-known in the climate science community as it is among historians and social scientists, and therefore will make it intuitively easier to follow my presentation, I will draw conclusions on what we can learn about the parallelism and asynchrony of tipping in coupled complex systems.

Modeling resource conflicts, climate security cascades and sustainability transitions

Jürgen Scheffran[1]

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An integrative framework is used to analyse multiple pathways connecting climate change, natural resources, human security and societal instability. The presentation discusses how climate stressors such as weather extremes, water, food and health risks interact with forced migration and violent conflict, possibly multiplied through tipping points, compound effects and cascading events. Agent-based approaches are adequate to analyze multi-level decisionmaking under uncertainty, the formation and breakup of coalitions and the transition between conflict and cooperation. Vulnerable hot spots serve as examples to assess complex interactions and sustainability transitions.

Theorizing Climate Relevant Social Tipping Points

R. Shwom

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As “climatic tipping points” in the human-climate system, such as rapid sea-level rise driven by an ice sheet collapsing, have garnered much media and research attention for their potentially catastrophic impacts, researchers have started to turn their attention to social tipping points relevant to climate. With the interdisciplinary climate research community embarking on this topic, it is important to engage the rich body of social science theory and empirics on how social change occurs. Often when societal change is described, it is characterized as rapid, non-linear, exponential, or a “social tipping point”, but this implies that there must also be slow, gradual, or incremental change as well. In this presentation, I will advance a general social science of tipping points by theorizing the conditions and mechanisms that underlie punctuated and non-punctuated social changes. Using well studied social tipping points like technology adoption and neighborhood segregation, I provide hypothesized mechanisms and conditions for which the pattern of social change may be observed. I then identify four potential social tipping points in the human-climate system: 1) public opinion and policy change, 2) technology adoption for adaptation or mitigation, 3) migration, and 4) conflict. I argue that further theorizing and empirically studying these climate related phenomena from a social tipping points perspective can advance a science of social tipping points beyond metaphor and greatly improve our understanding of non-linear human-climate dynamics.

Concern and anticipation of sea-level rise provide grounds for social tipping towards climate action

E. Keith Smith[1], Marc Wiedermann[2], Jonathan Donges[2,3], Jobst Heitzig[2] and Ricarda Winkelmann[2,4]

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[2] Potsdam Institute for Climate Impact Research, Potsdam, Germany
[3] Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden
[4] Institute of Physics and Astronomy, University of Potsdam, Potsdam, Germany

Effective climate change mitigation necessitates swift societal transformations. Social tipping processes, where small triggers initiate qualitative systemic shifts, are potential key mechanisms instigating societal change. With large shares of the world's population coastally concentrated, sea-level rise is among the most severe impacts of climate change. Here we combine future sea-level rise estimates, social survey data and a social activation model to exemplify a transformative pathway where climate change concern increases the social tipping potential, and extended anticipation time horizons for future sea-level rise shift the system towards an alternative sustainable state of climate action. We find that in many countries, climate change concern is sufficient, such that opportunities for social activation towards this tipped state already exist. Accordingly increased anticipation time horizons lowers the required size for critical interventions, such as social movements or the sudden salience of political issues, which can kick the system into a more sustainable state.

Tipping in climate finance

Veronika Stolbova*[1]

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July 18, 2021

Abstract

Financial contagion costs resulting from the propagation and amplification of financial distress in the economy may result in significant financial burden for the public as shown by the financial crisis of 2008-2009. When these costs can not be absorbed by the capital cushion of economic actors, a tipping point can occur that may lead to financial instability and, in extreme cases, financial crisis. Climate change has been recognized as a major recent thread for financial stability, with policy inaction leading to increased long-term financial burden, while policy action potentially causing financial instability through re-evaluation of climate-sensitive investments – those affected by the policy (fossil-fuel, utility, energy-intensive, transport and housing). Here, I will address major challenges that exist in the climate finance nexus and discuss climate change-induced tipping in the financial system. In particular, I will show how to assess the proximity to the tipping point and estimate the financial contagion costs of climate-sensitive investments. The results show that the majority of financial contagion costs occur due to investments in finance and other sectors, rather than in climate-sensitive sectors by a factor of six. I also find that stringent climate policies lead to costs that currently can be withstand by the Euro Area.

[1] Reinders, H. J., Schoenmaker, D., Van Dijk, M. (2020). Is COVID-19 a Threat to Financial Stability in Europe? *SSRN Electronic Journal*.

[2] Stolbova, V., Monasterolo, I., and Battiston, S.. A Financial Macro-Network Approach to Climate Policy Evaluation. *Ecological Economics*, 149, 2018.

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Cascading tipping in past climates: The Eocene-Oligocene transition?

A. S. von der Heydt[1]

[1]*Institute for Marine and Atmospheric Research, Utrecht University, Utrecht, The Netherlands*

Over the last 65 million years, the Earth's climate has undergone a large transition from a warm and ice-free *greenhouse* climate to an *icehouse* climate with extensive ice sheets on both hemispheres. The gradual cooling may be seen as response to the overall slowly decreasing atmospheric CO_2-concentration due to weathering processes in the Earth System, however, continental geometry has changed considerably over this period and the long-term gradual trend was interrupted, by several rapid transitions and periods where temperature and greenhouse gas concentrations seem to be decoupled. The Eocene-Oligocene transition (~34 Ma) reflects a first major phase of Antarctic ice sheet build-up and global climate cooling. In detail, the transition consists of two distinct steps in the oxygen isotope record, where the first reflects mostly ocean cooling, while during the second a large ice sheet has built up.

Here we consider the possibility of two coupled critical transitions in explaining the two-step nature of the Eocene-Oligocene climate change. We introduce a framework of (directionally) coupled tipping elements exhibiting *cascading tipping*, i.e. a small sequence of abrupt transitions as tipping in one subsystem changes the background conditions for another subsystem [1]. For the Eocene-Oligocene transition, the *leading* system could be a bistable ocean meridional overturning circulation, while the second *following* system reflects the bistable land-ice system coupled by the atmospheric CO_2 concentration.

References

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Cascading effects in tropical (agro)forests

Delphine Clara Zemp[1,4], Henrique Barbosa[2], Dirk Hölscher[3], Nathaly Guerrero Ramirez[4], Holger Kreft[4], Vannesa Montoya[1,4], Anja Rammig[5], Carl Schleussner[6]

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Tropical (agro)forests are complex systems whose biotic and abiotic components interact at a range of spatial and temporal scales. Consequently, perturbations such as climate and land-use changes can trigger cascading effects in the ecosystem that are difficult to predict. Here, we present two study cases of such dynamics analyzed using a complex network approach. First, cascading recycling of rainfall by the Amazon forest [1] (Fig. 1a) leads to self-amplified Amazon forest loss with increasing drought [2] and deforestation [3]. Second, correlation networks of beta-diversity in experimental agroforests in Indonesia suggest that biotic interactions shape biodiversity at landscape scale (Fig. 1b). In summary, complex networks improve understanding of cascading effects in tropical (agro)forests, urgently needed to guide conservation and restoration strategies of tropical forests facing global changes.

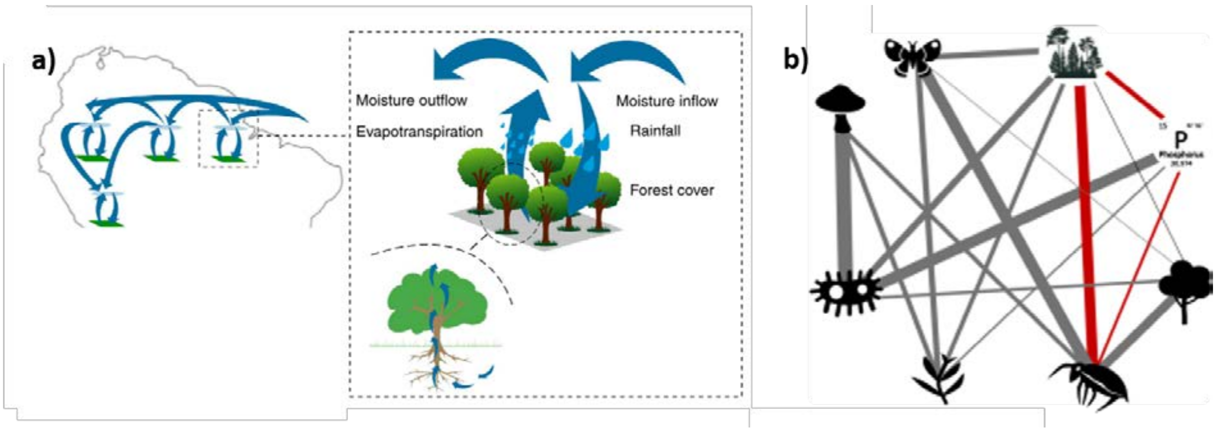

Figure 1: Two examples of cascading effects in tropical (agro)forests.

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Abstracts of Posters

(in alphabetical order)

The Estimation of Citizen Commitment to Climate Change Mitigation based on Perceptual Computing

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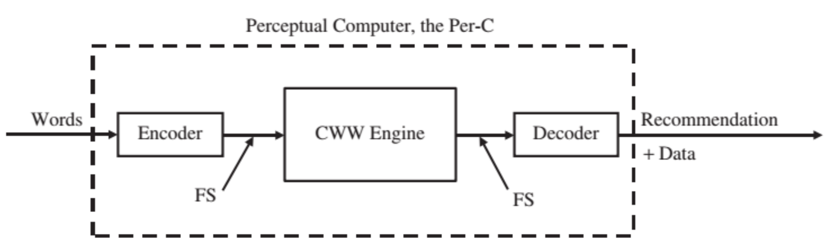
Abstract

Computing with words (CWW) has been extensively studied in the last years. It is applicable to any applications in which input data are not numerical rather words or in applications in which the input data are numerical but using words are simpler and cheaper. Perceptual computing (Per-C) is one of the leading applications of CWW. In this study, we use this methodology for developing a new tool for the estimation of citizen's commitment to climate change mitigation [and ranking of social tipping point elements at the micro-level]. Individual state their opinions for each climate change related question or criteria in words. The encoder then convert them into proper fuzzy set model, here IT2FS. The tool is called citizen judgment advisor (CJA). CJA has some important features, the first and the most important one is that the input data are collected from a group of citizens or subjects and they could describe their opinions and thoughts about climate change with use of arbitrary words. The second one is applying various linguistics weights for both citizens and questions to have more realistic results. Finally, the output could be represented in words rather than numbers.

Key words computing with words (CWW), tipping points, Per-C, IT2FS, Citizen Judgment Advisor



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Combining multiple models for data assimilation and forecasting using a multi-model ensemble Kalman filter

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Due to the recent success of machine learning (ML) in many prediction problems, there is a high degree of interest in applying ML to Earth system prediction. However, because of the high dimensionality of the system, it is critical to use hybrid methods which combine data-driven models, physical models, and observations. We propose to achieve this by using multi-model data assimilation. Multi-model data assimilation can be derived as a generalization of the variational or Bayesian formulation of the Kalman filter [1]. However, previous implementations of this framework have not estimated the model error, and have thus been unable to correctly weigh the models and observations. Furthermore, they have not been used for real-time forecasting. Here, we show how multiple models can be combined both for data assimilation and forecasting using an ensemble Kalman filter with adaptive model error estimation. We show results on forecasts of the Lorenz '96 model, with significant error reductions compared to a regular multi-model ensemble. We discuss applications to probabilistic forecasting of tipping points.

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Social Tipping Points in Swedish Political Discourse on NETs

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In my MSc Thesis, I will study linguistic traces of social tipping points in the discourse on Negative Emissions Technologies (NETs), and their role in shaping potential and desirable pathways of sustainability transformations (Otto et al, 2020; Milkoreit et al, 2018; Winkelman, 2020).

Reliance of large-scale NETs as an alternative to more comprehensive mitigation action is associated with great uncertainty and risks to realising safe and just futures for all (Fuss et al., 2014; Honegger & Reiner, 2018; Mix et al, 2018). Therefore, it is important to understand how contemporary NETs discourse shapes eligible future sustainability pathways (Lenzi, 2018).

Climate policy design and public acceptability for climate policies can be considered as Social Tipping Elements (STEs) “subdomains of the planetary social-economic systems” (Otto et al, 2020: 2355). Arguably, interventions targeting STEs can trigger social-ecological tipping points and ensue cross-scale sustainability transformations (Green, 2018; Nyborg et al., 2018; Otto et al., 2020). With some notable exceptions, there is little research into self-reinforcing feedbacks between STEs in general, and public acceptability for NETs, in particular (see, Hepburn et al., 2020; Otto et al., 2020).

I will use Natural Language Processing (NLP) to find linguistic traces of emergence, diversity, and heterogeneity in the discourse on NETs in Sweden (Swarnakar, 2021). This Complex Adaptive Systems perspective allows to study the emergence of lock-ins, and/or tipping points, variations of opinions between contexts and over time, and heterogenous views of actors (Schlüter et al., 2019; Presier et al., 2018). Representations of the political debate is based on Parliamentary Transcripts from the Swedish Riksdag since 1992, and the public debate is derived from social media such as Twitter and large daily news media.

NLP methods such as word-embeddings are used to convert the large amounts of raw text to data in the form of vectors. Thereafter, word-associations, sentiment analysis, and social-network analysis are used as numerical representations of opinion formation in public and political debate (Bodin, 2020; Gentzkow, 2019; Rocha & Daume, 2021; Wilkerson & Casas, 2017).

I will draw on non-linear time-series analysis, to describe and explain potential changes in the linguistic structure of NETs discourse over time (Zou et al., 2019). This invites inquiry into the interactions between public and political debate, and the role of external- and internal political, social, and economic shocks, have contributed to shape discourse on NETs.

I will contribute with novel methods for studying social tipping points, bring light to the formation of the contemporary public and political debate on NETs, and provide input on how NETs discourse can be altered to realise safe and just futures for all.

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Stochastic data adapted AMOC box models

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The Atlantic meridional overturning circulation is known to be responsible for the comparatively temperate climate in North West Europe. It is also generally accepted that it displays bistability, and paleo data suggests that previous tipping of the AMOC into an 'off' state could have contributed to past glacial periods. A modern day tipping to this 'off' state would have major consequences on the climate of much of Europe. The Stommel two box model [1] has been widely used as a helpful conceptual model of the AMOC to understand it's dynamics. Recent work detailed in Wood et al. [2] has developed a five box model (and a three box simplification) which allows a more accurate study of AMOC tipping points and can make computationally cheap predictions. Modern data suggests that the AMOC may be slowing down and we could be approaching a tipping point due to anthropogenic climate change. In this ongoing work we have studied the three and five box models under a number of different freshwater hosing scenarios, and begun to consider additive and correlated stochastic processes, the noise amplitude of which have been estimated from GCM data. We have begun to look at the possibility of noise-induced tipping of the AMOC using these box models, building on previous work by Alkhayuon et al. [3] on rate dependent and bifurcation tipping.

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Cascade of tipping points: investigating the 'cool Earth' / 'hothouse' narrative with dynamical systems

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Both in the scientific literature and in the media is evoked the possibility that Earth's climate may undergo, in the foreseeable future, a so-called cascade of tipping points that would precipitate our planetary environment into a highly challenging state for humanity[1]. The general objective of our present research is to investigate this scenario thoroughly, by adopting clear mathematical definitions and well-stated hypotheses combining realism and parsimony. Specifically, we are developing a dynamical system coupling different tipping elements and taking into account their response time scales and non-linear characteristics based on current knowledge. We use non-stationary forcings to emphasize the role of the different time scales involved. This allows us to study the impact of phenomena discussed in recent studies such as ‘rate induced tipping’[2] or ‘overshooting thresholds without tipping’[3] on the stability of our model. We then formulate the following questions. Given a family of emission scenarios, does the range of response presents itself under the form of discontinuous branches, as suggested by the 'cool earth' / 'hothouse' narrative? In mathematical terms, does the range of future trajectories present a non-autonomous bifurcation point? If yes, what causes the bifurcation, and does it occur for a large or a narrow range of parameter values? How realistic is this given knowledge provided by climate simulations and paleoclimate evidence?

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The role of cognitive dissonance on social tipping points: Applications to the circular economy.

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Cognitive dissonance is a form of psychological stress experienced by individuals exposed to contradictory beliefs and behaviours [1]. Cognitive dissonance is assumed to play a role in behaviour change towards sustainability, and also on social tipping points [2,3]. However, social tipping points have not been approached from the psychological perspective of the individual, despite positive results on parallel approaches form the communities working on Covid-19 and human behavior [4]. Plant-based protein consumption and recycling of the organic waste fraction are two of the necessary requirements for achieving a circular economy, however it is not well known how to trigger higher adoption levels. Based on the literature, we hypothesize and model cases in which their adoption depend on cognitive dissonance at the individual vs. media, and individual vs. society levels. We are developing a complex systems model combining social and psychological interactions that depict the role of cognitive dissonance, and that explore their upscaling in society with different networks properties. Our preliminary results reinforce existing knowledge about the role of cognitive dissonance on social tipping points, and especially on the game-changing effects of cognitive dissonance dynamics on social tipping dynamics.

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Overlapping Time Scales Obscure Early Warning Indicators of COVID-19 in Europe

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Early warning indicators based on critical slowing down have been suggested as a model-independent and low-cost tool to anticipate the (re)emergence of infectious diseases. We studied whether such indicators reliably anticipated the second COVID-19 wave in European countries. Contrary to theoretical predictions, we found that early warning indicators generally *decreased* rather than *increased* prior to the second wave. A model explains this unexpected finding as a result of transient dynamics and the multiple timescales of relaxation during a non-stationary epidemic. Particularly, if an epidemic that is initially contained after a first wave does not fully settle to its new quasi-equilibrium prior to changing circumstances or conditions that force a second wave, then indicators will show a decreasing rather than an increasing trend as a result of the persistent transient trajectory of the first wave. Our simulations show that this lack of time scale separation was to be expected during the second European epidemic of COVID-19. Overall, our results emphasize that the theory of critical slowing down applies only when the external forcing of the system across a critical transition is slow relative to the internal system dynamic.

The Hysteresis of the Antarctic Ice Sheet

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The Antarctic Ice Sheet stores enough freshwater to raise the mean elevation of the oceans by nearly 60 meters globally and is thus constituting by far the largest source of potential future sea-level rise[1]. Its long-term stability determines the fate of our coastal cities and cultural heritage on centennial and millennial time scales. Feedbacks with the atmosphere and ocean give rise to potential nonlinearities with respect to temperature changes.
In a comprehensive modelling analysis we show, using the ice-sheet model PISM[2], that the Antarctic Ice Sheet exhibits a multitude of temperature thresholds beyond which ice loss into the ocean is irreversible[3]. Each of these thresholds gives rise to hysteresis behaviour, i.e., the currently observed ice-sheet configuration is not regained even if temperatures are reversed to their present-day levels.
Our results imply that if the Paris Agreement is not met, one or more critical thresholds might be subsequently crossed in Antarctica, committing us to long-term, possibly irreversible, sea-level rise of several up to dozens of metres.

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Contagious Transformations? Inter-City Spreading of Sustainability Innovations

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To avoid a climate catastrophe, a rapid, global societal shift towards decarbonization and sustainability is imperative. Technological and political sustainability innovations, new or existing, may only solve this crisis if their rapid and world-wide implementation can be assured. Social Contagion and Tipping Processes related to sustainable behavior and innovations represent promising mechanisms by which the societal and economic transformation may be achieved in the remaining window of opportunity.

Such contagion processes are not limited to individual human beings; in their high political responsiveness and cultural radiance, cities may also be viewed as promising agents in the sustainability transformation. Responsible for a disproportionally large part of Planetary Boundary transgressions, and simultaneously one of the main drivers of sustainable policy innovation and implementation, cities may play a unique role in the global sustainability transformation. Learning from each other to reduce, prepare for and react to the coming environmental changes, they can be conceptualized as nodes in a globe-spanning network. Investigating and modeling such learning networks may yield insights into the social tipping dynamics that are so urgently needed to control the human impacts on the Earth System.

The work presented here aims to identify whether network-based contagion effects are dominant in sustainability policy adoption by cities. We propose a methodology for analyzing the spreading of sustainability-related municipal policies and innovations as contagion processes on global inter-city networks. Surrogate data methods and a dose-response-contagion approach are used to identify correlations between the network and the spreading processes. The nature of the spreading is then investigated using maximum likelihood methods. We demonstrate these methods by analyzing the spread of a specific public transport innovation (Bus Rapid Transit Systems, BRT), and approximating the inter-city innovation spreading network using the global air traffic network.
A closely related project, validating our methods using generative models, is presented at this seminar by Isabell von Falkenhausen.

Cascading tipping behavior of the interacting Greenland Ice Sheet and Atlantic Meridional Overturning Circulation in a model of low complexity

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The Greenland Ice Sheet (GIS) and the Atlantic Meridional Overturning Circulation (AMOC) have been identified as potential tipping elements of the climate system, transitioning into a qualitatively different state with the crossing of a critical driver threshold. They interact via freshwater fluxes into the North Atlantic originating from a melting GIS on the one hand, and via a relative cooling around Greenland with a slowdown of the AMOC on the other. The effect of this positive-negative feedback loop on the overall stability of the coupled system of climatic tipping elements is unknown. We qualitatively explore the dynamics and in particular the emergence of cascading tipping behavior of the interacting GIS and the AMOC by using process-based but still conceptual models of the individual tipping elements with a simple coupling under idealized forcing scenarios.

We identify patterns of multiple tipping such as (i) overshoot cascades, developing with a temporary threshold overshoot, and (ii) rate-induced cascades, arising under very rapid changes of tipping element drivers. Their occurrence within distinct corridors of dangerous tipping pathways is affected by the melting patterns of the GIS and thus eventually by the imposed external forcing and its time scales.

The conceptual nature of the proposed model does not allow for quantitative statements or projections on the emergence of tipping cascades in the climate system. Rather, our results stress that it is not only necessary to stay below a certain critical threshold to hinder tipping cascades but also to respect safe rates of environmental change to mitigate domino effects and in turn to maintain the resilience of the Earth system.

Towards a multidimensional quantification of resilience change in ecological systems

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Resilience – often defined as a system's "ability to absorb changes of state variables […] and parameters, and still exist" (Holling) - is an important concept for determining ecosystem stability [1]. Consequently, a wide range of indicators and metrics exists for measuring resilience of dynamical systems [2].
The future stability of terrestrial ecosystems is determined by its resilience to both gradual environmental change and disturbances or, in the language of dynamical systems theory, to parameter changes and stable variable perturbations [3]. Gradual changes in mean temperatures, precipitation and carbon dioxide concentrations influence global biogeography, favourably or unfavourably changing growing conditions [4, 5]. At the same time, ecosystem disturbances, often induced by extreme whether events, are expected to increase with climate change [6, 7].
To understand and quantify how global change affects ecosystem resilience, we are therefore in need of resilience indicators that can capture changes in both these resilience dimensions simultaneously. I will explore concepts and first results on how this can be achieved.

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Towards systematic screening of tipping points in model intercomparison projects

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In order to define targets for a safe and stable planet, it is essential to identify critical thresholds in the Earth system. Tipping elements take a prominent role - once a certain threshold is passed, their nonlinear character propels dynamics that drastically shift a system to a different state. However, their properties vary, and classification of a system as a tipping element may depend on the response to external forcing, internal dynamics, involved time scales and potential irreversibility.

In the frame of the Earth Commission[1] initiative, we explore various strategies to systematically detect and identify tipping elements in the Earth system. To this end, we develop tools to scan datasets from CMIP[2,3] and selected models, aiming to classify tipping points in a standardized way.

This guides the development of a metric that could be universally applied to model outputs and extended to take into account, for example, the results of commitment and hysteresis experiments. These investigations work towards an analysis protocol and design of a future dedicated tipping model intercomparison project (TIPMIP) and will allow to generate updated maps of tipping elements in the Earth system.

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Analyzing tipping behavior of social dynamics on networks using hybrid models

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We examine a continuous-time noisy voter dynamics on a network, i.e., each node on a graph represents an agent and has one of several discrete opinions, which may change over time. The time evolution of the opinion of an agent is modeled by a continuous-time Markov chain, where the transition rate from opinion a to opinion b is given by some predefined constant times the percentage of neighbors of the agent with opinion b. Additionally, we add some small constant to all transition rates to generate random transitions independent of the neighbors' states, i.e., noise.
Let us assume a homogenous and well-connected network (e.g., fully connected, or Erdős-Rényi graph, or uniformly random regular graph). We are especially interested in examining the dynamics of macroscopic variables, such as opinion counts, i.e., how many agents have each opinion, as these are often meaningful, e.g., for polls.
For a low number of agents we can observe a metastable behavior where almost all agents are of the same opinion but this consensus opinion changes regularly and suddenly (noise-induced tipping). Increasing the number of agents increases the disagreement in the system so that the opinion counts start to stabilize and the invariant measure becomes concentrated at some (central) point in phase space [1]. In the regime of a high number of agents, the time evolution of the opinion counts can be approximated by an ODE called the reaction rate equation (RRE) [2].
In real life social networks we often observe highly connected nodes, so called hubs. We artificially create a hub in our network by inserting an additional node called leader that is connected to every other node. Furthermore, the leader may be more persuasive than the other nodes. We can equivalently think about the leader as some external factor (e.g., propaganda, media, news) that slightly pulls all the agents towards some opinion [3]. Whenever the leader changes its opinion, the whole system tips towards its new opinion. Using a hybrid modeling approach [2], which uses the RRE approximation to model the follower nodes but employs a stochastic evolution for the leader node, we can approximate the frequency, severity, and length of tipping events without simulating the dynamics on the network.

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Predicting collapse of adaptive networked systems without knowing the network

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Predicting collapse in adaptive (dynamic) networked systems has received much less attention than finding precursors of collapse in static networks. In the most generic sense, collapse in co-evolutionary systems often may happen endogenously via a self-organisation of the network structure into a critical state where the states of nodes and links change irreversibly and drastically. Therefore, it seems hard or even impossible to answer the question of whether an adaptive networked system is about to collapse in the near future if the detailed structural information is unknown. In contrast to this intuition, based on classical results of algebraic graph theory, we introduce a new approach - so-called Eigenvector Quantisation which gives a positive answer to this question for linear (or linearized) dynamical systems. The presented approach offers a novel early-warning signals which uses only the state variables' (units) timeseries for the detection of a critical state of the underlying network of interactions between these units. It is shown that the critical state with a single directed cycle in the network can be detected by a "quantization effect" of node states, that exists as a direct consequence of a corollary of the Perron–Frobenius theorem. Within our framework, the likelihood of an impending collapse in the Jain-Krishna model of catalytic interactions can be estimated with high accuracy. We also show how the approach can be applied to other models of epidemic spreading and age-structured populations.

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Cascading regime shifts within and across scales

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Regime shifts are large, abrupt, and persistent critical transitions in the function and structure of ecosystems. Yet, it is unknown how these transitions will interact, whether the occurrence of one will increase the likelihood of another or simply correlate at distant places. We explored two types of cascading effects: Domino effects create one-way dependencies, whereas hidden feedbacks produce two-way interactions. We compare them with the control case of driver sharing, which can induce correlations. Using 30 regime shifts described as networks, we show that 45% of regime shift pairwise combinations present at least one plausible structural interdependence. The likelihood of cascading effects depends on cross-scale interactions but differs for each type. Management of regime shifts should account for potential connections.

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Towards testing the uncertainties of the land carbon sink under climate change

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Identifying potential tipping elements and tipping cascades in the Earth system strongly relies on results of Earth System Models (ESMs) in the CMIP. Here, tipping events caused by climate change are rather rare and tipping cascades are essentially not observed. Forcings often translate into smooth answers of the Earth system often explainable by strong negative feedbacks, for example regarding the carbon cycle. Generally those feedbacks are a prerequisite for the quasi equilibrium climate conditions in reality and models, but the question is whether Earth system models do reflect those feedbacks on the right timescales and magnitudes. As those feedbacks are caused by numerous mechanisms it is important to reality check the timescales and magnitudes of those mechanisms.

In my contribution to the seminar I want to list mechanisms which potentially bias the land carbon feedback in Earth system models in order to facilitate discussions on how to investigate the uncertainties of those mechanisms and their role for potential tipping events and tipping cascades. As an example I will show results of testing the uncertainty of CO_2-fertilization of global vegetation under climate change on different timescales using a dynamic global vegetation model and put those results into context of latest CMIP6 results.

Methods of risk estimation and propagation for studying cascading tipping dynamics

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Generally, inspired by the conceptual analysis of interactive tipping elements by Wunderling et al. 2021 [1], the poster and ignite talk will present relevant aspects and introduce methodical questions that await examination. Some of these questions might only require a brief literature review or a hint from a more experienced fellow, others might not be so easy to answer. **The model** assumes a set of linearly coupled differential equations to estimate the cascading risk of four interacting tipping elements. Uncertainties emerge from the global mean temperature, the individual tipping thresholds, and the interaction strengths. Additionally, there are uncertainties concerning the interaction structure. **Focus** lies upon the two following questions: (1) What methods are there for proper error propagation to the result except for the used Monte Carlo ensemble? (2) How to incorporate (qualitative) expert knowledge and other available system information into the model? [2], [3] can be starting points for addressing the latter.

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Joint environmental action: multi-level dynamics of movement participation

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Envisioning pathways for the socio-ecological transformation of our society, due to the mere scope of the endeavor, goes far beyond what single individuals can bring about – instead, collective action is required. This poster explores the process of joining a collective action group or movement. Individual circumstances, such as personality traits and values, but also personal experiences and background, as well as the fact that these characteristics do not emerge "in a void", are examined, paying tribute to the socio-cultural environment, as well as the biophysical surroundings [1].

Effects of movement participation on different levels of impact are layed out: in the individual sphere, social norms prevalent in the given group shape private values and behavior, perceived self-efficacy is amplified through joining forces to pursue a common goal. Hereby, on a meso level, group identity is formed and supports a shared interpretation of events, which can spread to shape mainstream social norms. This, in turn, puts pressure on institutions and organizational structures, such as governments, and can support reaching social tipping points [2].
The motivation for this approach stems from a system thinking viewpoint and hereby not only looks at the connections of the individual level (with all its heterogeneity) to broader, more institutionalized and organized structures, but puts a special emphasis on the interplay and feedback between these micro-, meso- and macro-sociological levels. It aims to not discard the importance of the individual and her decisions in such a social dynamical system, while placing the cognitive processes making these up in a context and highlighting their complex intertwinedness with the structures in her environment [3].

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Cascading in a coupled ice-ocean model

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In the climate system, many different large-scale components have been identified as tipping elements [1], i.e., components that may pass a tipping point, with a great and definitive impact on earth and societies. These climate components do not stand on their own but are dynamically coupled, which brings the question of cascading tipping, triggering much research in the recent years [2,3]. In our project, we aim at getting a better understanding of a possible cascading involving the formation and retreat of ice sheets in both poles and the Atlantic oceanic overturning circulation. To start with, we use an equatorially symmetric toy model, which has the specificity of including the marine ice sheet instability [4]. This dynamical peculiarity is of utmost importance for the Antarctic ice sheet, of which a considerable proportion of glaciers lies under sea level. In the future, this model will be improved with a more accurate representation of both ice sheets specificities, along with other physically relevant processes, such as sea level adjustments and noise [5].

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Resilience in dry rangelands: how to destock livestock in water-stressed environments?

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Half of the world's livestock is concentrated in arid regions, where an important proportion of the population relies fully or partially on animal husbandry for survival. However, overgrazing can lead to land degradation and subsequent socio-economical crises. Sustainable management of arid rangeland requires suitable stocking strategies and has been the subject of intense debate in the last decades.
Our goal is to understand how different destocking strategies interact with the environment and which ones provide both ecological and economic resilience. We describe the rangeland dynamics through a simple mathematical model consisting of a system of coupled ordinary differential equations: one for livestock density and one for vegetation density. We assume that the livestock density is limited by forage availability only, which is itself limited by water availability, hence rainfall. Given that the presence of plants increases water infiltration, we model plant-plant facilitation, which leads to the existence of an Allee threshold. We test different management strategies, namely non-adaptive and adaptive destocking rates, with varying sensitivity to the the available biomass. We find that
1) For all destocking strategies, there exists a threshold before a catastrophic collapse of the system: even gradual changes in the management can theoretically lead to abrupt and irreversible land degradation.
2) This threshold occurs at the maximal sustainable livestock density. Because the climax coincides with the tipping point, it is riskier to be at maximal productivity.
3) Higher reactivity of the destocking rate to available biomass i.e. increased opportunism in times of high vegetation and conservationism in times of low vegetation, makes the system both more resilient and potentially more profitable. In particular, with a highly adaptive destocking rate, the collapse is not more likely to occur than in the absence of livestock.
The first two results emphasize the need for adapted dry rangeland management strategies, in order to prevent an irreversible land degradation resulting from the conflict between profitability and sustainability. The third point offers a theoretical suggestion for such a strategy. However, the model is very simple and does not take into account spatial-temporal variability in rainfall nor market constraints.

Reproducing the Spreading of Urban Sustainability Innovations using generative models

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A global transition towards sustainability and decarbonization is necessary to mitigate and adapt to negative impacts of a changing planet. Cities as small and dynamic units can play an important role in this transformation. Their behavior towards sustainable innovations influences whether they contribute to or mitigate negative environmental and climate effects. The learning and adapting behavior between cities regarding sustainable innovations is hence an important earth system process that needs to be better understood. It can be conceptualized as a spreading event on a complex network through contagion. Current research is working to detect such contagious spreading processes. However, the methods applied to identify an innovation spreading process on a network of cities have only analyzed empirical data. Hence, no direct evaluation and validation of the methods is possible. This research project aims to fill this gap by investigating the performance of the deployed methods. A simulation data set will be generated that reflects critical aspects of the empirical data. Both simple and complex contagion models will be produced to introduce plausible simulation data sets that represent different underlying processes and that cover a wide range of the model parameters network size, network density, scope of the contagion, transmission velocity and noise. Consequently, applied methods will be validated on the simulated data with a focus on how well the methods perform at detecting different spreading processes. The methods to be validated include amongst others maximum likelihood parameter estimation and the surrogate data method. Lastly, a sensitivity analysis will be conducted.

Portfolio diversification of earth system risks

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In this project I investigate the intersection between financial risk assessments and the risks of crossing earth system tipping points. The process of financialization has increased the reach and influence of financial markets and financial actors in many systems today. The food system is being increasingly financialised and is a system completely reliant on well-functioning biophysical processes such as moisture recycling. Studies have recently highlighted the complex and often tele-connected interaction that influence the stable functioning of these vital processes. Financial investment into activities that promote or erode these processes can therefore have extensive impact on if we move towards or away from earth system tipping points. This work in progress addresses if financial risk assessments and risk mitigation strategies adequately cover the risks and uncertainties produced by complex interconnectivities and non-linearities in the earth system. In financial investments, risk assessments are based on variance and covariance of assets, where a diversified portfolio limits covariance and thus limits risk. Using a mixed-methods approach I first investigate different traditional financial risk measures of agricultural assets/portfolios, I then assess the covariance of biophysical processes such as evaporation and precipitation in regions causally connected through moisture recycling and simulate potential asset correlations. The difference between the standard risk metric and that based on added biophysical covariance will help address the adequacy of financial risk assessment metrics for addressing the risks of crossing earth system tipping points.

Network dynamics of drought-induced tipping cascades in the Amazon rainforest

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Tipping elements are nonlinear subsystems of the Earth system that can potentially abruptly and irreversibly shift if environmental change occurs. Among these tipping elements is the Amazon rainforest, which is threatened by anthropogenic activities and increasingly frequent droughts.
In this work, we assess how extreme deviations from climatological rainfall regimes may cause local forest-savanna transitions that cascade through the coupled forest-climate system. We develop a dynamical network model to uncover the role of atmospheric moisture recycling in such tipping cascades.
We account for the heterogeneity in critical thresholds of the forest caused by adaptation to local climatic conditions. Our results reveal that, despite this adaptation, increased dry-season intensity may trigger tipping events particularly in the southeastern Amazon. Moisture recycling is responsible for one-fourth of the tipping events. If the rate of climate change exceeds the adaptive capacity of some parts of the forest, secondary effects through moisture recycling may exceed this capacity in other regions, increasing the overall risk of tipping across the Amazon rainforest.