MichaelStifelCenterJena
for Data-Driven and Simulation Science

Dynamics of natural (eco)systems: theory and applications

Autumn School, Sept. 26-30, 2016

Venue

- Max Planck Institute for Biogeochemistry
  Hans–Knöll–Str. 10 Jena, Germany
  www.bgc-jena.mpg.de

With kind support of

- Friedrich Schiller University Jena
- Max Planck Institute for Biogeochemistry
- CRITICS: EU Innovative Training Network “Critical Transitions in Complex Systems”
- yDiv: Young Biodiversity Research Training Group – yDiv
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- Gesellschaft der Freunde und Förderer der Friedrich-Schiller-Universität Jena e.V.

Contents

1 Introduction & Information

Understanding the dynamics of natural systems is often a complicated endeavor and requires dealing with responses to a changing environment, unobservable system states, or abrupt transitions. Many natural systems (e.g. biological or ecological) might additionally experience modifications of their intrinsic dynamics over their lifetime e.g. through long-range evolution or short-term adaptation. This remark holds true at various levels of organization from single organs, over organisms, organismic interactions, ecosystem dynamics, to the entire coupled biosphere-climate system.
Typically, dynamic phenomena are investigated either from a theoretical point of view or by following a rather empirical path via observations. Today model-data integration opportunities also allow integrating theory and observations to gain a deeper insight into the behavior of natural systems. However, young scientists generally receive little training and insight into dealing with both empirical and theoretical approaches for achieving a better understanding of dynamical systems of interest.
This autumn school aims at bringing together (prospective) PhD students and experts in multiple related fields ranging from autonomous and non-autonomous dynamical systems empirical analysis of nonlinear processes and model-data integration. Scientists experienced in applying novel concepts to study natural phenomena are bridging the gap between theory and application, hence offering novel perspectives to the students. This one-week autumn school aims at providing an overview of relevant developments in this very broad field to stimulate interdisciplinary dialogue and advance in the respective PhD (or potentially MSc. or PostDoc) projects. Hands-on tutorials will demonstrate to the students how recent methods can be effectively implemented and will give ample space to discuss applications to novel problems. We anticipate this autumn school to significantly broaden the horizon of all participants and to become a catalyzer for a variety of interdisciplinary activities at the intersection of theory and empirical data exploration.

1.1 Format and structure

The school is ranging from theoretical foundations of autonomous and non-autonomous dynamical systems for describing natural systems to novel insights on empirical methods to explore (spatio)tempoeral data in natural systems. Different experts share their views and ideas - but crucially depend on the students to discuss concepts and develop new ideas.
The format of this 5 full day school we will be a mixture of talks by different instructors with different backgrounds. This has the advantage, that one can always get a new chance to dive into a topic. But please be aware that that it also requires a lot of (mental) flexibility, concentration, and willingness to learn about new and alternative concepts and ideas.
We also need to emphasize that the participants have a very diverse background from biology, ecology, cli-

mate physics, informatics, to mathematics. This is intended to stimulate truly interdisciplinary exchange and mutual learning.
Every day will be dedicated with to a specific core topic, and not all topics are expected to be in the core interest of all participants. But we really hope that the contributions are sufficiently general and generic to be of interest to the diversity of people that will work together for this week.

1.2 Orientation & Preparations

Dear all, some important information to get ready:

- Very general: In case of emergency call: 112
- For non-emergency inconveniences, feel free to call the local organizers:
  - +49 3641 9 46428 (Alexander Freytag; Office; Friedrich Schiller University)
  - +49 3641 576265 (Miguel Mahecha; Office; Max Planck Inst. for Biochemistry)
  - +49 3641 576102 (Veruschka Jähnert; Office; Max Planck Inst. for Biochemistry)
- Try to bring a laptop - some lecturers may want to do exercises with you and make sure you installed R (if you which together with R Studio). If you have no laptop, please write us we may find one for you.
- Please make sure you don't arrive too late to Jena. We are a bit isolated from this world and this is well reflected in the train schedules. For checking trains visit https://www.bahn.de/p_en/view/ - but they have also an app which is very useful to get real-time information on delays (which is not very rare...). Check out "DB Navigator". We also have some bus services, e.g. https://www.flixbus.com/.
- The program is attached to this text, and if you have time we recommend browsing the papers that were recommended along with the speakers profiles.
- The cuisine in our region is not spectacular - we will do our very best, but please consider to get some emergency snacks in case you have specific dietary requirements.
- If you don't want to be alone on Sunday night before we start, we recommend you all go to the same pub and have a chat. We propose the "Grünowski" next to the theater, or in the unlikely case they are closed, you may want to go to the Theatercafe (just next door). Both are student pubs, and some of the Jena people have written a few papers there. The map is shown in Figure 1.1.

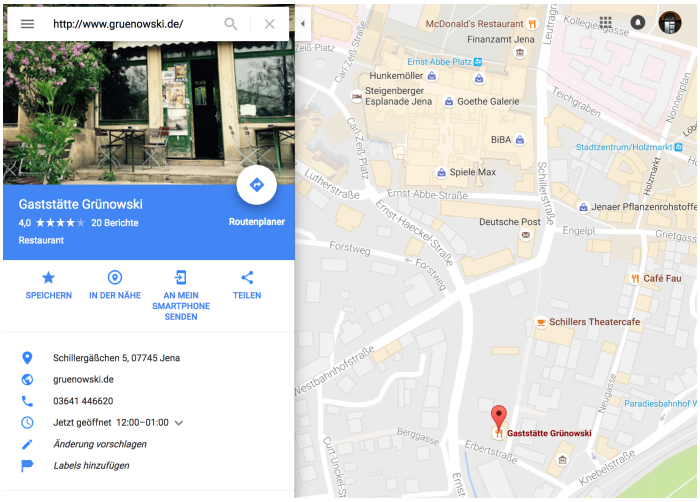


FIGURE 1.1: Icebreaker will be in the "Grünowski" on Sunday evening.

- The exact description to find the institute is here:
  www.bgc-jena.mpg.de/index.php/Institute/Directions?userlang=en .
  If you are in Jena, local buses start in the city center at a street called "Teichgraben". Bus lines with the numbers 10, 11, 12, and 13 (with the respective directions "Damaschkeweg", "Beutenberg Campus" or "Göschwitz") all will stop at the "Beutenberg Campus". Get off there, turn slightly right (there are some stairs, after which you cross a parking space) to the Hans-Knöll-Straße and walk straight uphill. At the very top take a left turn towards the Max Planck Inst. for Biogeochemistry. There is also a time-table online:
  http://www.nahverkehr-jena.de/index.php?id=169 ,
  but it is not needed as buses run very frequently. You pay like 2 Euros in the bus (make sure you pay tough, as the fine for not paying is absurd). To be sure you are on track, please check the map in Figure 1.2 displying the route from the center to the institute as it is taken by the buses.

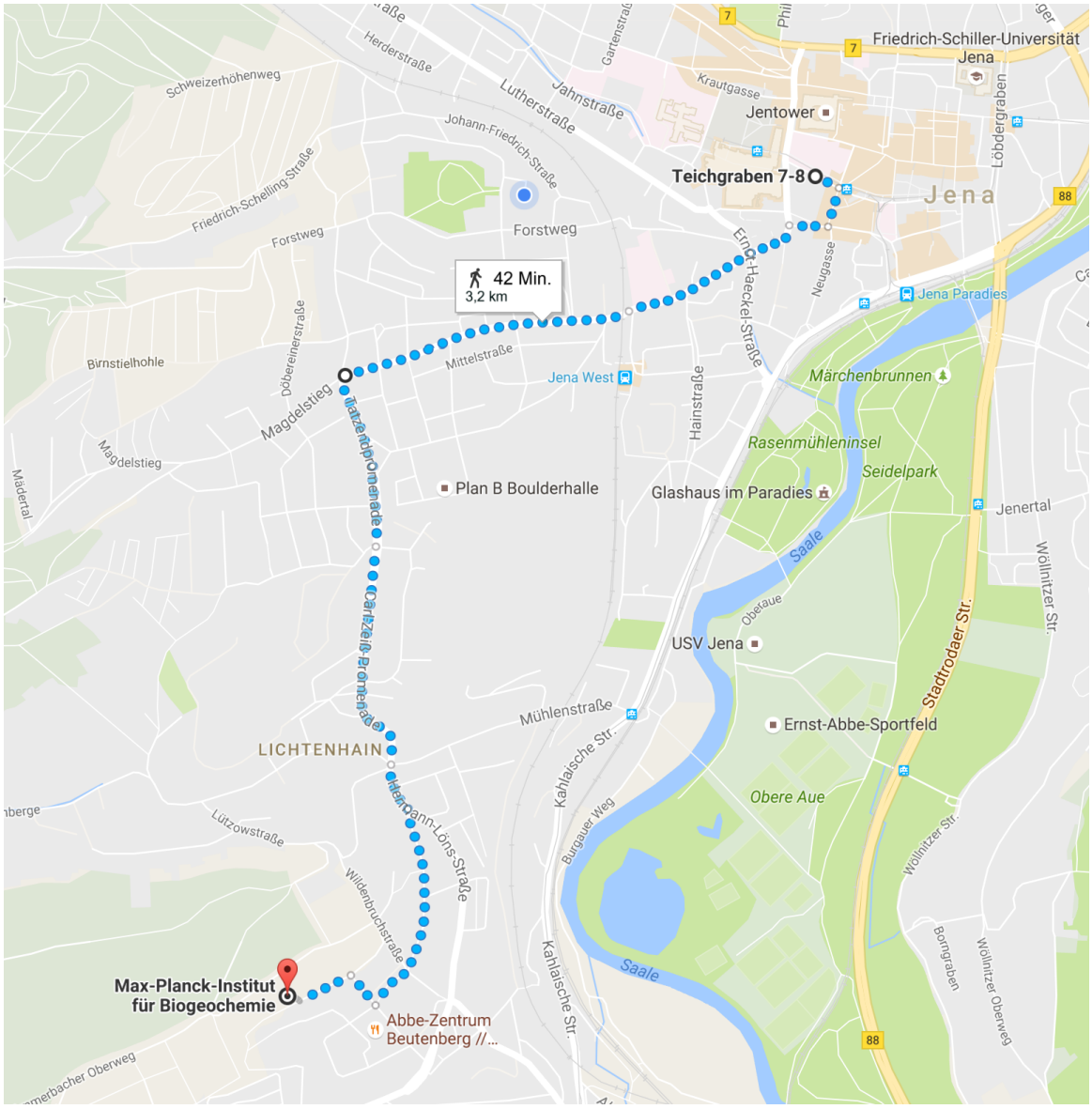


FIGURE 1.2: Route of the bus lines from Jena's center to the MPI campus.

2 Key-note speakers

We are very happy that the following key-note speakers have kindly agreed to support the School:

Michel Crucifix addresses mathematical and statistical aspects of climate and palaeoclimate dynamics. He uses dynamical system theory, experiments with general circulation models, methods of inference (emulation, dynamical system calibration) and time series analysis methods to characterise the dynamics of the climate system, estimate its predictability and identify physical mechanisms of variability.
For more information see: http://www.climate.be/users/crucifix/
Selected reference(s):

- M. Crucifix, T. Mitsui, and G. Lenoir. Challenges for ice age dynamics: a dynamical systems perspective. *Nonlinear and Stochastic Climate Dynamics*, 2016

Holger Kantz focuses on theoretical aspects of complex dynamics, nonlinear stochastic processes, the relationship between dynamics and statistical physics, non-equilibrium statistical physics and fluctuation theorems, extreme events, novel concepts for time series analysis, essentially based on the idea of reconstruction of a state space from observations. Data analysis, modeling, and prediction in atmospheric physics, ensemble forecasts, skill scores, systematic errors effects of long range correlations, identification of trends.
For more information see: http://www.pks.mpg.de/~kantz/
Selected reference(s):

- H. Kantz and T. Schreiber. *Nonlinear time series analysis*. Cambridge University Press, 1997
- E. Bradley and H. Kantz. Nonlinear time-series analysis revisited. *Chaos*, 25(9), 2015

Ben C. Nolting's research broadly involves studying how stochasticity (i.e., randomness) influences ecological processes. He uses quasi-potential functions to make predictions about the stability and resilience of ecological systems in the face of stochastic perturbations. Additionally, his research includes the use of stochastic search strategies to model how organisms forage for food.
For more information see: http://www.bennolting.org/
Selected references:

- B. C. Nolting and K. C. Abbott. Balls, cups, and quasi-potentials: quantifying stability in stochastic ecosystems. *Ecology*, 97(4):850–864, 2016
- B. C. Nolting, T. H. Hinkelman, C. E. Brassil, and B. Tenhumberg. Composite random search strategies based on non-directional sensory cues. *Ecological Complexity*, 22:126 – 138, 2015

Martin Rasmussen's research concentrates on nonautonomous and random dynamical systems, with emphasis on bifurcation theory. He has also made contributions to stability and attractor theory, Morse decomposition theory and invariant manifold theory, and is author of two books on the qualitative theory of nonautonomous dynamical systems (published by Springer and the AMS). For more information see:
For more information see: http://wwwf.imperial.ac.uk/~mrasmuss/
Selected reference(s):

- P. E. Kloeden and M. Rasmussen. *Nonautonomous dynamical systems,*. Mathematical Surveys and Monographs. American Mathematical Society, Providence, 176 edition, 2011
- Martin Rasmussen, Alan Hastings, Matthew J. Smith, Folashade B. Agusto, Benito M. Chen-Charpentier, Forrest M. Hoffman, Jiang Jiang, Katherine E. O. Todd-Brown, Ying Wang, Ying-Ping Wang, and Yiqi Luo. Transit times and mean ages for nonautonomous and autonomous compartmental systems. *Journal of Mathematical Biology*, pages 1–20, 2016

Christopher Stieha is an ecologist whose research interests revolve around understanding how individual-level interactions, such as competition or herbivory, scale up to affect dynamics at the population, metapopulation, and landscape levels. He uses mathematical models, computer simulations, laboratory experiments, and field biology to develop, test, and refine predictions. In particular, he is one of the developers of QPot, an R package for the implementation of quasi-potentials for the analysis of stochastic dynamical systems.
For more information see: stieha.com and
https://github.com/bmarkslash7/QPot

Selected reference(s):

- C. R. Stieha, K Abbott, and K. Poveda. The effects of plant compensatory regrowth and induced resistance on herbivore population dynamics. *American Naturalist*, 187:167–18, 2016
- C. M. Moore, C. R. Stieha, B. C.C. Nolting, M. K. Cameron, and K. C.C. Abbott. Qpot: An r package for stochastic differential equation quasi-potential analysis. *The R Journal*, 2016

3 Local speakers

Alexander Brenning is a quantitative geographer focusing on spatial statistical and computational tools and their application in a variety of contexts, in particular mountain geomorphology and environmental remote sensing. Amongst various topics, his research on mountain permafrost involves field studies on the dynamics of rock glaciers in the dry Andes. He works on the critical problem of developing reliable empirical models of environmental variables as a basis for decision-making in spatial planning and land management. The assessment of model uncertainties is of particular importance and needs to account for the spatial nature of spatial analysis problems.
For more information see: http://www.geographie.uni-jena.de/Brenning.html
Selected reference(s):

- A. Brenning. Spatial prediction models for landslide hazards: review, comparison and evaluation. *Natural Hazards and Earth System Sciences*, 5:853–862, 2005
- A. Brenning. Spatial cross-validation and bootstrap for the assessment of prediction rules in remote sensing: the r package 'sperrorest'. In *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pages 5372–5375, 2012

Peter Dittrich aims to apply and to develop new computational methods in order to understand complex dynamical phenomena found in living systems and to use this knowledge for the design of novel organic systems.
For more information see: http://users.minet.uni-jena.de/~dittrich/
Selected reference(s):

- C. Lasarczyk, P. Dittrich, and W. Banzhaf. Topology based training set selection. *Evolutionary Computation*, 12:223–242, 2004

Axel Kleidon's research aims to understand how the whole Earth functions as one complex system that is strongly shaped by interactions, what the role of life is within this system, and how humans alter it. In this broad context he investigates for instance atmosphere-biosphere interactions, geographic patterns of plant biodiversity, global vegetation modelling, non-equilibrium thermodynamics of Earth system processes, Gaia hypothesis, Earth system evolution, and natural limits to renewable energy.
For more information see: http://gaia.mpg.de
Selected reference(s):

- A. Kleidon. How does the earth system generate and maintain thermodynamic disequilibrium and

what does it imply for the future of the planet? *Philosophical Transactions of the Royal Society of London - Series A: Mathematical Physical and Engineering Sciences*, 370:1012–1040, 2012

- A. Kleidon. *Thermodynamic Foundations of the Earth System*. Cambridge University Press, 2016

Miguel Mahecha works on exploring new methods to decode the precious information in ecological observations for a better understanding of global land ecosystems. He is specifically interested on detecting and describing the effects of climate extremes, and the role of vegetation dynamics in this context.
For more information see:
https://www.bgc-jena.mpg.de/bgi/index.php/People/MiguelMahecha
Selected reference(s):

- M. D. Mahecha, L. M. Fürst, N. Gobron, and H. Lange. Identifying multiple spatiotemporal patterns: a refined view on terrestrial photosynthetic activity. *Pattern Recognition Letters*, 31:2309–2317, 2010
- M. D. Mahecha, M. Reichstein, N. Carvalhais, G. Lasslop, H. Lange, S. I. Seneviratne, R. Vargas, C. Ammann, M. A. Arain, A. Cescatti, I. A. Janssens, M. Migliavacca, L. Montagnani, and A. D. Richardson. Global convergence in the temperature sensitivity of respiration at ecosystem level. *Science*, 329:838–840, 2010

Britta Pester works on empirical causality analyses of very high-dimensional time series with application to Computational Neuroscience.
For more information see:
http://www.imsid.uniklinikum-jena.de/en/IMSID+_+Home.html
Selected reference(s):

- B. Pester, C. Ligges, L. Leistritz, H. Witte, and K. Schiecke. Advanced insights into functional brain connectivity by combining tensor decomposition and partial directed coherence. *PLoS ONE*, 10:e0129293, 2015
- B. Pester, L. Leistritz, H. Witte, and A. WIsmueller. Exploring effective connectivity by a granger causality approach with embedded dimension reduction. *Biomed Tech*, 58, 2014

Markus Reichstein is interested in various aspects of Earth System Science, in particular in climatic and non-climatic effects on biosphere dynamics and major global biogeochemical cycles (carbon, water, nitrogen, phosphorus). He is bringing together data-driven, simulation-driven and theoretical approaches to improve our understanding of the Earth System.
For more information see:
https://www.bgc-jena.mpg.de/bgi/index.php/People/MarkusReichstein
Selected reference(s):

- M. Reichstein, M. Bahn, P. Ciais, D. Frank, M. D. Mahecha, S. I. Seneviratne, J. Zscheischler, C. Beer, N. Buchmann, D. C. Frank, D. Papale, A. Rammig, P. Smith, K. Thonicke, M. van der Velde, S. Vicca, A. Walz, and M. Wattenbach. Climate extremes and the carbon cycle. *Nature*, 500:287–295, 2013

- M. Heimann and M. Reichstein. Terrestrial ecosystem carbon dynamics and climate feedbacks. *Nature*, 451:289–292, January 2008

Carlos Sierra focuses on understanding interactions between the environment and multiple biogeochemical cycles. He use mathematical tools, ecosystem models, and measurements to improve our predictions about the responses and feedbacks between climate and terrestrial ecosystems. He is particularly interested in tropical forests and their interactions with the climate system and leads an independent research group on Theoretical Ecosystem Ecology focusing on producing synthesis of ecosystem models and studying nonlinearities in biogeochemical cycling.
For more information see: http://www.bgc-jena.mpg.de/TEE/people/sierra/
Selected reference(s):

- C. A. Sierra, S. E. Trumbore, E. A. Davidson, S. Vicca, and I. Janssens. Sensitivity of decomposition rates of soil organic matter with respect to simultaneous changes in temperature and moisture. *Journal of Advances in Modeling Earth Systems*, 7:335–356, 2015
- C. A. Sierra. Temperature sensitivity of organic matter decomposition in the arrhenius equation: some theoretical considerations. *Biogeochemistry*, 108:1–15, 2012

Organizing team: The Autumn School was initiated and is jointly organized by various members of the MSCJ: Alexander Brenning, Ulrich Brose, Joachim Denzler, Alexander Freytag, Miguel D. Mahecha, Tobias Oertel-Jäger, Markus Reichstein, and Carlos Sierra. Other speakers from the MPI or FSU help as well. Kind technical assistance was provided by Cornelia Müsse, Birgitta Wiehl and Veruschka-Meike Jaehnert. The following members of the center will give insights to their research in during the Autumn School:

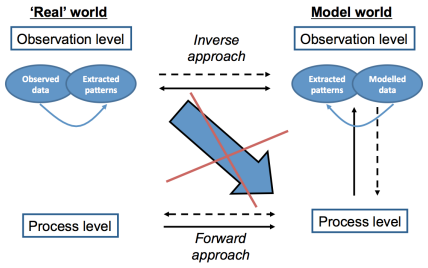
4 Programme

Exact timing is at the discretion of the individual speaker may deviate from the schedule.

4.1 Sunday, 25.09.2016

18:30 Informal student get-together in the student pub Grünovski.

4.2 Monday, 26.09.2016

Time	Speaker	Title	Type
08:30	All	Registration	Hang-out
09:00	Organizers	Welcome and background of the Autumn school	Talk
09:20	All	Getting to know each other (please prepare up to three slide per person and send it beforehand to rperez@bgc-jena.mpg.de)	Talks
			strong coffee and tea
10:30	M. Reichstein	Potentials and pitfalls in interpreting observations of global environmental dynamics 	Talk
			Lunch break

13:00	M. Mahecha	The emerging Earth system data cube: playground and challenge for understanding Earth system dynamics. • In-situ data expansion: patterns and processes • Spatiotemporal data expansion: patterns and processes • The ESDC as new analytics framework for high-dimensional analyses of the Earth system	Talk
14:00	C. Sierra	The global carbon cycle as a non-autonomous dynamical system.	Talk
			coffee, tea
15:00	H. Metzler	Carbon cycle models as continuous-time Markov chains: Transit time, age and entropy.	Talk
17:00	All	Team building.	Activity

4.3 Tuesday, 27.09.2016

Time	Speaker	Title	Type
09:00	H. Kantz	Time series analysis and short term forecasts by the method of analogues	Key-note
			strong coffee and tea
11:00	M. Crucifix	The complex climate system: a range of time scales. • The climate system as a complex dissipative system. Basic notions: open system, dissipation, dissipative structures. • A dual look at climate variability : background spectrum, or modes • Models for modes: dynamical systems • Models for background: stochastic models • Why we don't always see the modes (spectrum analysis) • Why we don't always see the background (modelling)	Key-note
			Lunch break
13:30	H. Kantz	Long range dependence/correlations, its detection and its implications to statistics.	Key-note
			coffee, tea
15:30	M. Crucifix	The Ice ages: an example of slow-fast time scale separation. • Conceptual models of ice ages • The problem of interpretation: different models giving sensible results • Robustness, predictability, stability: all the same thing?	Key-note

4.4 Wednesday, 28.09.2016

Time	Speaker	Title	Type
09:00	M. Crucifix	The modelling hierarchy: the right tool at the right scale. • The GCM as a ‘’(macro-)weather’ simulator • Do we need all this complexity ? • Model reduction strategies: (EMICS, empirical model reduction) • Keeping up with the noise level	Key-note
			coffee, tea
11:00	All	Poster session: All participants have the chance to show their research to other students but also to the members of the Michael Stifel Center for Data Driven and Simulation Science who will be present this day. **Note: takes places at the Abbe Center of Photonics, Albert-Einstein-Str. 6, Jena**	Discussion
			Parallel to poster session: lunch break
13:00	M. Rasmussen	Non-autonomous systems.	Key-note
			coffee, tea
15:30	M. Rasmussen	Non-autonomous systems.	Exercise

4.5 Thursday, 29.09.2016

Time	Speaker	Title	Type
09:00	M. Rasmussen	Non-autonomous systems.	Wrap-up
			strong coffee and tea
11:00	A. Kleidon	Thermodynamic perspective of the Earth system. • Thermodynamics sets direction and limits to the Earth system • Limits make complex systems behave in a simple way • Applications to surface energy balance and climate sensitivity	Talk
			Lunch break
13:30	B.C. Nolting	Quasipotentials.	Remote keynote
			coffee, tea
15:00	C. Stieha	Quasipotentials.	Exercise
17:00	All	Networking and brainstorming for future research collaboration.	Activity

4.6 Friday, 30.09.2016

Time	Speaker	Title	Type
09:00	P. Dittrich	Model reverse-engineering using genetic programing	Talk
			strong coffee and tea
11:00	B. Pester	Novel approaches for exploring highly resolved connectivity • High-dimensional quantification of directed connectivity • Solution of the problems due to a large number of input data: large scale Granger causality • Solution of the problems due to a large number of output data: combination of partial directed coherence and tensor decomposition	Talk
			Lunch break
13:30	A. Brenning	Modeling and Mapping Earth Surface Processes using Statistical and Machine Learning Techniques. • Introducing data-driven statistical and machine learning approaches for geospatial problems • Issues related to spatial autocorrelation • Case studies related to landslide susceptibility modeling and environmental remote sensing	Talk
			coffee, tea
15:30	All	Feedback Discussion.	Activity