2012 – 2014	**Continuum climate variability: Atmosphere, ocean, land, and ice**
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1. Introduction

Continuum temperature variability represents the response of the Earth's climate to deterministic external forcing. Scaling regimes are observed which range from hours to millennia with low frequency fluctuations characterizing long-term memory in weather and climate: (i) In the tropical atmosphere 1/f scaling ranging *from hours to weeks* is found for several variables; it emerges as superposition of uncorrelated pulses with individual 1/f-spectra. (ii) The daily discharge of the Yangtze shows 1/f within *one week to one year*, although the precipitation spectrum is white. (iii) *Beyond one year* mid-latitude sea surface temperatures reveal 1/f-scaling in large parts of the global ocean. Long-term memory on time scales *up to millennia* reveal global sea surface temperature and Greenland ice core records (GISP2, GRIP) using $\delta^{18}O$ temperature proxy data during the Holocene. Complex atmosphere-ocean general circulation models reproduce this behavior quantitatively without solar variability, interacting land-ice and vegetation components and can be interpreted, to a first order, as a two-layer heat diffusion process forced by uncorrelated stochastic atmospheric surface fluxes. But more research is required.

2. Recent Highlights

Extremes: The link to long-term memory has been established by the recurrence time statistic, which follows a Weibull distribution with parameters determined by long term memory alone (first publication, combining shorter and longer time scales). Furthermore, updated non-linear trend-analysis of drought and wetness based on delay-coordinate singular spectrum analysis revealed the recently observed trend change (first publication). And the dynamics of the extreme Russian summer heatwave 2010 dynamics has been analyzed [1].

Predictability: Applicability of fluctuation theorem is demonstrated in the GCM environment indicating 'return of skill' in terms of largest local Lyapunov exponents being negative (first publication with spectrum of dynamical cores of A-GCMs); that is, a return of forecast-skill in identical twin predictability experiments is dynamically possible up to a relatively high model resolution [2].

Prediction in weather and climate: (i) Weather (Hurricane tracks) predictions being used in Weather Services (Bureau of Meteorology) are based on a non-linear dynamics approach. (ii) For climate prediction (Yangtze River Basin, Tibetan Plateau), a biased bootstrap Ansatz has been applied for Eastern Asian watersheds: Yangtze River and Tibetan Plateau [3].

Hysteresis: The suite of hysteresis model analyses, ranging from the conventional approaches of static to dynamic hysteresis with adiabatically and continuously changing external parameters has been amended by the novel memory hysteresis, by prescribing trendy greenhouse gas concentrations ([4] first publications on transient and abrupt changes including low-order model interpretation).

Theories: Empirical laws governing the Earth's climate have been derived for the rainfall-runoff chain (linking climate-vegetation-soil compartments on catchment scale (Schreiber formula) and the worldwide maximum rainfall depth-duration scaling (or Jennings law) ([5] first theoretical publication).

Climate and Vegetation: To complement geographical presentation of remote sensing vegetation information, a physical state space diagram is used to analyze functional climate relations. Interannual variability of dryness is lowest where the largest climate mean NDVI values of greenness (forests) occur. Thus, measures of interannual variability may be included in Budyko's classical framework of geobotanic analysis of the Earth's surface climates [6].

3. Outlook

Lakes in the tropics and mid-latitudes are indicators of regional paleoclimates, for which a novel Ansatz is being developed. It is based on the equilibrium water and energy balances and a previously derived equation of state to combine catchment and lake eco-hydrology. This Ansatz provides climate estimates using only the lake-catchment area ratio [7]. Likewise, the changing ocean-continent area ratio can be estimated employing the maximum entropy production principle to parameterize the underlying complex dynamics. Eco-hydrology and freshwater sources of islands and their role in global climates can be analysed analogously.

An eco-hydrological state space is introduced spanned by water and energy related physical flux ratios characterizing the unused (or excess) water- *and* energy supply. Direction and magnitude of trajectories in this state space provide the attribution of change to (i) external or climate induced impact versus (ii) internal or anthropogenic causes. This state space analysis can be extended to include remote sensing information (like vegetation-greenness) which, projected onto the state space, is applied to problem climates of the Earth (the Tibetan Plateau, the Amazon and the S-American Altiplano).

Arid regions in long-term climate equilibrium are affected by shorter term internal variability of drought and wetness. The underlying dynamics is related to an information flow associated with teleconnection patterns induced by wave-trains modulated by feedbacks through synoptic scale perturbations, wave-breaking etc. Their representation and predictability by Global Climate Models is subject of future analyses focusing on the role played by soil moisture.

[1] Schneidereit, A., S. Schubert, P. Vargin, F. Lunkeit, X. Zhu, D. Peters, and K. Fraedrich, 2012: Large scale flow and the long-lasting blocking high over Russia: Summer 2010. *Mon. Wea. Rev.* 140, 2967-2981

[2] Schalge, B., R. Blender, J. Wouters, K. Fraedrich, and F. Lunkeit 2013: Towards a fluctuation theorem in an atmospheric circulation model. Phys. Reviews E 87, 052113-1-4

[3] Zhu, X., W. Wang, and K. Fraedrich, 2013: Future climate in the Tibetan Plateau from a statistical regional climate model. *J. Climate* 24, 10125-10138

[4] Bordi, I., K. Fraedrich, A. Sutera, and X. Zhu 2013: On the effect of decreasing CO-2 concentrations in the atmosphere. *Climate Dynamics* 40, 651-662

[5] Zhang, H., K. Fraedrich, X. Zhu, and R. Blender 2013: World's greatest observed point rainfalls: Jennings (1950) scaling law. *J. Hydromet.* 14, 1952-1957

[6] Cai, D., K. Fraedrich, F. Sielmann, Y. Guan, S. Guo, L. Zhang, and X. Zhu 2014: Climate and vegetation: An ERA-1 Interim and GIMMS NDVI Analysis, *J. Climate 27*, online.

[7] Fraedrich, K. 2014: A minimalist model of terminal lakes: Qinghai Lake (China) and Lake Chad (N-Africa). *Hydrology Research 44*, doi:10.2166/nh.2013.015(6)

Publications 2012 – 2014

2014

Barbini, L., I. Bordi, and K. Fraedrich 2014: Stochastic resonance in the Benard system. Eur. Phys. J. Plus 129, 190, 2-11.

Blessing, S., T. Kaminski, F. Lunkeit, I. Matei, R. Giering, A. Köhl, M. Scholze, E. Kirk, P. Hermann, K. Fraedrich, and D. Stammer, 2014: Testing variational calibration and initialization of an Earth System Model. Tellus A 66, 1-15

Bordi, I., K. Fraedrich, A. Sutera, and X. Zhu, 2014: Ground-based GPS measurements: Time behavior from half-hour to years. Theor. Appl. Climatol. 115, 615-625

Cai, D., Y. Guan, S. Guo, C. Zhang, and K. Fraedrich 2014: Mapping plant functional types over broad mountainous regions: A hierarchical soft time-space classification applied to the Tibetan Plateau. Remote Sensing 6, 3511-3532

Cai, D., K. Fraedrich, F. Sielmann, Y. Guan, S. Guo, L. Zhang, and X. Zhu 2014: Climate and vegetation: An ERA-1 Interim and GIMMS NDVI Analysis, J. Climate, 27, 5111-5118.

Holden, P.B., N.R. Edwards, P.H. Garthwaite, K. Fraedrich, F. Lunkeit, E. Kirk, M. Labriet, A. Kanudia, and F. Babonneau, 2014: PLASIM-ENTSem: a spatio-temporal emulator of future climate change for impacts assessment. Geoscientific Model Development 7, 433-451

Hui, T., H. Borth, K. Fraedrich, B. Su, and X. Zhu, 2014: Drought and wetness variability in the Tarim River Basin and connection to large-scale summer atmospheric circulation. Intern. J. Climatology, 34, 2678-2684

Hui, T., K. Fraedrich, C. Menz, and J. Zhai 2014: Trends in extreme temperature indices in the Poyang Lake Basin, China. Stoch. Environmental Research and Risk Assessment (SERRA), 28, 1543-1553,

You, Q., J. Min, K. Fraedrich, L. Zhang, S. Kang, and X. Meng, 2014: Projected trends in mean maximum and minimum surface temperature in China from simulations. Global and Planetary Change 112, 53-63.

You, Q., K. Fraedrich, S. Kang, X. Zhu, 2014: Observed surface wind speed in the Tibetan Plateau since 1980. Intern. J. Climatol. 34, 1873-1882

You, Q., K. Fraedrich, F. Sielmann, J. Min, S. Kang, Z. Ji, X. Zhu, and G. Ren, 2014: Present and projected degree days in China from reanalysis and simulations, Climate Dynamics 43, 1449-1462

Zhang, L., X. Zhu, K. Fraedrich, F. Sielmann, and X. Zhi, 2014: Interdecadal variability of winter precipitation in Southeast China. Climate Dynamics 43, 2239-2248

2013

Bathiani, S., M. Claussen, and K. Fraedrich, 2013: Detecting hotspots of atmosphere-vegetation interaction via slowing down – Part I: A stochastic approach. Earth Systems Dynamics 4, 63-78

Bathiani, S., M. Claussen, and K. Fraedrich, 2013: Detecting hotspots of atmosphere-vegetation interaction via slowing down – Part II: Application to a global climate model. Earth Systems Dynamics 4, 79-93

Barbini, l., I. Bordi, K. Fraedrich, and A. Sutera, 2013: The stochastic resonance in a system of gradient type. European Physics Journal Plus 128, doi: 10.1140/epjp/i2013-13013-5, 1-12

Bordi, I., K. Fraedrich, A. Sutera, and X. Zhu, 2013: On the effect of decreasing CO-2 concentrations in the atmosphere. Climate Dynamics 40, 651-662

Bye, J.T., K. Fraedrich, S. Schubert, and X. Zhu, 2013: The changing length of the warming period of the annual temperature cycle in the high latitudes under global warming. Atmosphere-Ocean 51, 309-318

Fraedrich, K., F. Sielmann, L. Zhang, and X. Zhu, 2013: Applications of an ideal rainfall-runoff chain: validation and climate change. European Water Resources Association (EWRA), 845-852

Li, S., Y. Rong, Y. Liu, Z. Liu, and K. Fraedrich, 2013: Dynamic analogue initialization for ensemble forecast. Advances in Atmospheric Sciences 30, 1406-1420

Neu, U., M.G. Akperov, N. Bellenbaum, R. Benestad, R. Blender, R. Caballero, A. Cocinozza, H.F. Dacre, Y. Feng, K. Fraedrich, J. Grieger, S. Gulev, J. Hanley, T. Hewson, M. Inatsu, K. Keay, S.F. Kew, J. Kindem, G.C. Leckebusch, M.L.R. Liberato, P. Lionello, I. I. Mokhov, J.G. Pinto, C.C. Raible, M. Reale, I. Rudeva, M. Schuster, I. Simmonds, M. Sinclair, M. Sprenger, N.D. Tilinina, I.F. Trigo, S. Ulbrich, X.L. Wang, and H. Wernli, 2013: IMILAST - A Community Effort to Intercompare Extratropical Cyclone Detection and Tracking Algorithms. Bull. Amer. Meteor. Soc., 94, 529–547

Schalge, B., R. Blender, J. Wouters, K. Fraedrich and F. Lunkeit, 2013: Towards a fluctuation theorem in an atmospheric circulation model. Phys. Reviews E 87, 052113-1-4

Sun, R., X. Zhang, Y. Sun, D. Zheng, and K. Fraedrich, 2013: SWAT-based streamflow estimation and its responses to climate change in Kadongjia River Watershed, South Tibet, China. J. Hydromet. 14, 1571-1586

You, Q., A. Sanchez-Lorenzo, M. Wild, D. Folini, K. Fraedrich, G. Ren, and S. Kang, 2013: Decadal variation of surface solar radiation in the Tibetan Plateau from observations, reanalysis and model simulations. Climate Dynamics 40, 2073-2086

You, Q., K. Fraedrich, G. Ren, N. Pepin, and S. Kang, 2013: Variability of temperature in the Tibetan Plateau based on homogenized surface stations and reanalysis data. International Journal of Climatology, 1337-1347

You, Q., K. Fraedrich, G. Ren, N. Pepin, and S. Kang, 2013: Can temperature extremes in China be calculated from reanalysis? Global and Planetary Change 111, 268-279

You, Q., G. Ren, K. Fraedrich, Y. Ren, P. Wang, and S. Kang, 2013: Winter temperature extremes in China and their possible causes. International Journal of Climatology, 33, 1444-1445

Zhang, D., R. Blender, and K. Fraedrich, 2013: Volcanoes and ENSO in millennium simulations: global impacts and regional reconstructions in East Asia. Theoretical and Applied Climatology, 111, 437-454

Zhang, H., K. Fraedrich, R. Blender, and X. Zhu, 2013: Precipitation extremes in CMIP5 simulations on different time scales. J. Hydromet. 14, 923-928

Zhang, H., K. Fraedrich, X. Zhu, and R. Blender, 2013: World's greatest observed point rainfalls: Jennings (1950) scaling law. J. Hydromet. 14, 1952-1957

Zhu, X., K. Fraedrich, and W. Wang, 2013: Future climate in the Tibetan Plateau from a Statistical Regional Climate Model. J. Climate 24, 10125-10138

2012

Bathiany, S., M. Claussen, and K. Fraedrich, 2012: Implications of climate variability for the detection of multiple equilibria and for rapid transitions in the atmosphere-vegetation system. Climate Dynamics, 38, 1775-1790

Bordi, I., K. Fraedrich, A. Sutera, and X. Zhu, 2012, On the climate response to zero ozone. Theoretical and Applied Climatol. 108, 293-300

Bordi, I., K. Fraedrich, A. Sutera, and X. Zhu, 2012 Transient response to well-mixed greenhouse gas changes. Theor Appl Climatol 109, 245–252

Bothe, O., K. Fraedrich, and X. Zhu, 2012: Precipitation climate of Central Asia and the large-scale atmospheric circulation. Theoretical and Applied Climatol., 345-354

Bothe, O., K. Fraedrich, and X. Zhu, 2012: Tibetan Plateau summer precipitation: covariability with circulation indices. Theoretical and Applied Climatol., 108, 293-300

Espa, S., I. Bordi, T. Frisius, K. Fraedrich, and A. Sutera, 2012: Zonal jets and cyclone-anticyclone asymmetry in decaying rotating turbulence: Laboratory experiments and numerical simulations. Geophysical and Astrophysical Fluid Dynamics, doi:10.1080/03091929.2011.637301

Fraedrich, K., 2012: A suite of user-friendly global climate models: Hysteresis experiments. Eur. Phys. J. Plus, 127, doi: 10.1140/epjp/i2012-12053-7

Hannachi, A., T. Woolings, and K. Fraedrich, 2011: The North Atlantic jet stream: Preferred positions, paths and transitions. Q. J. R. Meterol. Soc., 138, 862-877

Langmack, H., K. Fraedrich, and F. Sielmann, 2012: Tropical cyclone track analog ensemble forecasting in the extended Australian basin: NWP combinations. Q. J. R. Meterol. Soc., 138, 1828-1838

Schneidereit, A., S. Schubert, P. Vargin, F. Lunkeit, X. Zhu, D. Peters, K. Fraedrich, 2012: Large scale flow and long-lasting blocking high over Russia: Summer 2010. Mon. Wea. Rev, 140, 2967–2981

Sienz, F., O. Bothe, and K. Fraedrich, 2012: Monitoring and quantifying future climate projections of dryness and wetness extremes: SPI bias. Hydrol. Earth Syst. Sci., 16, 2143–2157

You, Q., K. Fraedrich, G. Ren, B. Ye, X. Meng, and S. Kang, 2012: Inconsistencies of precipitation in the eastern and central Tibetan Plateau between surface adjusted data and reanalysis. Theoretical and Applied Climatology, 109, 485-496, doi:10.1007/s00704-012-0594-1