2014 – 2017 **Continuum Climate Variability: Atmosphere, ocean, land, and ice**

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1. Introduction

Climate variability comprises internal and external components related to constant and to changing forces affecting the system. Climate variability has been analyzed and interpreted in terms of stationary processes (2011-2014): that is, as 1/f-type scaling and long-term memory, which characterize the complex dynamics of tropical convection (hours to weeks), sea surface temperature fluctuations (up to millennia) and continental river discharges (one week to one year), to climate changes documented in the ice cores of Greenland during the Holocene. Now (2015-2017), the ongoing research is turning to the analysis of non-stationarity processes underlying climate variability, going beyond time-slice and trend diagnostics. The effect of non-stationary external forces, ranging from abrupt to slow changes in climate dynamics, is analyzed by direct and inverse methods. They range from direct *modeling*, via *attributing* observed changes to human and climate induced causes, to *identifying* causes of non-stationarity of climate index variations by novel time series analysis methods (second section). Dynamic processes generating intrinsic climate variability and regional extreme events are investigated on both global and regional scales in Eurasia, S-America, Africa (third section). These analyses are extended to eco-hydrologic processes (fourth section) describing climate and its relation to the Earth's topography (lakes and islands), vegetation (biomes) and animals (biodiversity), and to humans (city light).

2. Non-stationarity: model experiments, static attribution and dynamic analyses

Owing to external perturbations of the climate system, most observational time series are non-stationary and the underlying complex dynamics covers multiple time scales. Generally, the effective degrees of freedom, which are interrelated with the largest time scale, act as driving forces for those modes which change on shorter time scales. This non-stationarity is analysed by inverse and direct methods:

(1) Global Climate Model (GCM) experiments have been designed to analyze the responses to static, abrupt and transient forcings and the results are interpreted by global energy balance models (EBM). For example, the abrupt change from the present to a zero-greenhouse gas climate is first dominated by dynamic (water vapor-radiation) and then by thermal (sea-ice-albedo) feedback processes. They characterize a two-tier 'spin-up' trajectory from the initial via an intermediate (snapshot-attractor like) state before reaching snowball earth; the attractor regimes are approached by exponential convergence rates.
(2) Attribution: Observed changes of surface energy and water fluxes can be attributed to climate and human induced causes employing a novel *diagnostic* scheme to trajectories in eco-hydrological state space. This technique separates external or climate induced forcing (by water supply and demand) from internal human induced partitioning (of energy and water fluxes). Successful applications to Tibetan Plateau and S-America are related to measures of life.
(3) Identifying causalities: Novel analysis methods are developed and applied to climate indices to determine the driving forces of observed non-stationary time series: (i) Slow feature analysis (SFA) determines the forcing of regional precipitation variability (SW-USA). (ii) Cross-prediction error analysis is proposed to retrieve the forcing from non-stationary time series which also include stationary phases (applied to NH surface air temperature anomalies).
(4) PLASIM-GENIE: A new intermediate complexity AOGCM has been developed in collaboration with the Open University (England).

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3. Dynamics: intrinsic climate variability and extremes

Intrinsic climate variability characterizes the rarely analyzed dependence between the means and the variability. A new climate metric relating regional means and standard deviations of the annual surface temperatures is discussed: (i) non-overlapping 100-yr segments from equilibrium simulations (Max Planck Institute Earth System Model); (ii) elevation dependent hiatus.
Extreme events caused by dynamical processes have been analyzed focusing on the Eurasian-Pacific region: (i) Central Asian wave-breaking dynamics and rainfall extremes in deserts (Aksu-Tarim); (ii) E-Asia summer rainfall extreme and wave-trains from Europe; (iii) SE-Asian winter rain maxima and SST; (iv) N-Pacific hurricane intensity and ENSO.

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4. Outlook on eco-hydrology: Land, plants, animals and humans

Lakes (rivers and islands): Tropical and mid-latitude lakes are regional climate indicators, for which a novel diagnostic has been developed combining water and energy fluxes and the eco-hydrological states of the lake and basin. Next, the changing ocean-continent area ratio will be estimated employing the maximum entropy production principle.
Plants, animals, and humans: Components of life, which can be characterized by biomes, biodiversity and city light, are embedded in eco-hydrological spaces spanned by suitable water and energy flux ratios to estimate distribution of states and their trajectories to quantify causes of change.

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