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Complexity and connectivity variability in the climate of the past

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Earth's climate is a complex dynamical system. Its underlying components interact with each other in linear or nonlinear ways on multiple several spatial and time scales creating possible positive and negative feedback loops. Understanding and studying such a system is a difficult challenge with crucial implications on our society but requires data mining through an extremely large and complex amount of data. In particular, the investigation of changes in dynamical and statistical properties in the climate of the past represents an invaluable opportunity to understand interactions between external forcing (e.g., orbital parameters) and the internal variability of the climate system. Given a simulated climate field embedded on a two dimensional grid, we propose a new methodology to (i) quantify nonlinear changes in variability in simulated climate fields by means of an information entropy quantifier, (ii) identify regions that undergo changes in entropy in a homogeneous way and (iii) investigate the time dependency of the connectivity patterns between these regions. To address these points, we analyze two global transient simulations ran with the IPSL Earth system model from mid- to late Holocene (6000 years BP to 1950). These simulations differ according to their horizontal resolution (3.75^ox 1.89^ovs. 2.5^ox 1.27^o), their hydrological component (2 vs. 11 layers) and the way vegetation interacts with climate (prescribed versus dynamic). Specifically, we focus on the variability and connectivity of two fields: sea surface temperature (SST) and precipitation. Time resolution is monthly. For a given field, the input of the algorithm is a two dimensional grid with detrended anomalies embedded in it. We consider time windows of 100 years of data every 20 years and for each time window we compute the entropy of every time series embedded in the grid. The entropy serves as a measure of complexity of time series and its computation depends on recurrence plots, an advanced nonlinear data analysis technique. The product of this first step is then a spatio-temporal entropy field. We then use δ-MAPS, a dimensionality reduction methodology recently proposed by the authors, to reduce the dimensionality of the entropy field by identifying semi-autonomous components, referred to as "domains". Domains are defined as spatially contiguous, possibly overlapping, structures that undergo changes in entropy in a homogeneous way. This allows to study both past climate regime shifts and their spatial heterogeneity. Finally, given two sets of domains (in the SST and precipitation fields), for each time window, we compute their signals and infer a functional network of networks (NoN) between them. The NoN is a weighted and potentially directed graph which, in a single framework, quantify the interactions between domains in the same field and the dependency among domains of different fields. A first analysis of the time dependency of domains' complexity and of their NoN topology is presented.