Advection-diffusion-networks
On the relationship of flow dynamics and climate network topology

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Abstract

The earth's climate is an extraordinarily complex, highly non-linear system with a multitude of influences and interactions between a very large number of variables and parameters. Complementary to the description of the system using global climate models, in recent years, a description based on the system's interaction structure has been developed. Rather than modelling the system in as much detail as possible, here time series data is used to identify underlying large scale structures. The challenge then lies in the interpretation of these structures.

In this thesis I approach the question of the interpretation of network measures from a general perspective, in order to derive a correspondence between properties of the network topology and properties of the underlying physical system. To this end I develop two methods of network construction from a velocity field, using the advection-diffusion-equation (ADE) for temperature-dissipation in the system.

For the first method, the ADE is solved for δ-peak-shaped initial and open boundary conditions. The resulting local temperature profiles are used to define a correlation function and thereby a network. Those networks are analysed and compared to climate networks from data. Despite the simplicity of the model, it captures some of the most salient features of climate networks. As the method allows the free choice of node locations, this model is used to study the influence of the node locations on the topology of the network.

The second network construction method relies on a discretisation of the ADE with a stochastic term. The resulting linear stochastic recursive equation can be used to define a correlation matrix, based only on the transition matrix and the variance of the uniformly random noise term. This allows the construction of larger networks, due to its relative computational simplicity. It is straightforward to generalize this method to systems, with more general transition matrices and time-dependent velocity fields. I construct weighted and unweighted networks for four different cases and suggest network measures, that can be used to distinguish between the different systems, based on the topology of the network and the node locations.

For better applicability, another related model is described, that represents aspects of the monsoon system of the past 1000 years, demonstrating that it is possible to capture climate changes in a simple model, that generates correlation structures. All these methods provide networks of well-understood physical systems with parameters, that can be varied freely. To track and quantify the topological changes, resulting from parameter changes in the underlying system, a method is developed to quantify topological changes in linearly ordered sets of networks. This method is used to study changes in various types of networks.

The reconstruction methods presented in this thesis successfully model many features, found in climate networks from well-understood physical mechanisms. This can be regarded as a justification of the use of climate networks, as well as a tool for their interpretation.