NETWORKS IN CLIMATE

Over the last two decades the complex network paradigm has proven to be a fruitful tool for the investigation of complex systems in many areas of science, for example, the internet, neural networks and social networks. This book provides an overview of applications of network theory to climate variability phenomena, such as the El Niño–Southern Oscillation and the Indian Monsoon, presenting recent important results obtained with these techniques and showing their potential for further development and research. The book is aimed at researchers and graduate students in climate science. A basic background in physics and mathematics is required. Several of the methodologies presented here will also be valuable to a broader audience of those interested in network science, for example, from biomedicine, ecology and economics.

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Preface

Over the last two decades, the complex network paradigm has proven to be a fruitful tool for the investigation of complex systems in various areas of science, e.g., the internet, neural networks, and social networks. The application of complex network theory to climate science was the main focus of the LINC project (Learning about Interacting Networks in Climate)[1] funded by the European Commission under the FP7 program (FP7-289447). The LINC project was a *Marie-Curie Initial Training Network* (ITN) aimed at improving our understanding of the Earth's complex climate phenomena, such as the El Niño–Southern Oscillation (ENSO), by approaching the problem from a complex systems interdisciplinary perspective, bringing together experts from different fields such as physics, dynamical systems theory, computer science, and earth sciences.

In the network approach to the Earth's climate, the vertices of the network are identified with the spatial grid points of an underlying global climate data set. Edges are added between pairs of vertices depending on the degree of statistical interdependence between the corresponding pairs of time series taken from the climate data sets (pressure, temperatures, precipitations, etc.).

A crucial step for understanding the characteristic behavior of such systems consists in inferring the connection topology. When studying the connectivity structure, a main challenge is due to multiple spatial scales and temporal scales in the climate system. A basic tool for identifying connectivity is causality. There are various techniques to quantify causality, ranging from classic cross-correlation, to information theory measures, such as coarse-grained entropy or transfer entropy, to Granger causality, to recurrence-based measures. However, there is a need to develop appropriate statistical tests for several of these measures. For climate network identification, the Lagrangian description of air and water transport among

[1] https://cordis.europa.eu/result/rcn/187859_en.html and https://cordis.europa.eu/result/rcn/156590_en.html

Earth locations from observations or from the output of general circulation models (GCMs) can also be used.

This book summarizes the main results of the LINC project, which addressed these challenges from an interdisciplinary perspective. It begins with an introduction to the most relevant climate phenomena and models (Chapters 1 and 2), followed by a review of methods of data analysis (Chapter 3) and network construction (Chapter 4). Then, applications of climate networks to various climatological fields (pressure, temperatures, wind velocities, etc.) are presented. As the analysis requires the management of large data sets, high-performance computer algorithms need to be used for storing, processing, and visualizing the data. An overview of such tools is presented in Chapter 5. Then, Chapters 6 and 7 present new insights on atmospheric variability and ocean dynamics, which were gained through the use of the network approach.

As is well known, one of the most striking characteristics of the climate system, and probably the one with the greatest potential impact on humanity, is that it can operate in a variety of distinct regimes, with the possibility of sharp transitions among them. Methodologies to detect signatures of abrupt change in past climate and, most importantly, to identify warning signals of the closeness of future tipping points, are discussed in Chapter 8. Climate predictability is another challenge that has a huge economic and social impact for present and future generations, and can underpin advances in areas as diverse as energy, environment, agriculture, and marine sciences. The final chapter 9 is devoted to an overview of the progress made on this topic by using the complex network approach.

While this book is aimed at the general reader interested in climate science with a basic background in physics and math, several of the methodologies presented here will be of interest to a broader audience. For example, in the economy, banks, insurance companies, and firms interact and can be represented by interdependent networks. As another example, the network diagnostic tools developed to detect signatures of "climate shifts" can find applications for the analysis of complex biomedical signals, or in ecology.

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