Unraveling spatio-temporal climatic patterns via multi-scale complex networks

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Abstract

The climate is a complex dynamical system involving interactions and feedbacks among different processes at multiple temporal and spatial scales. Although numerous studies have attempted to understand the climate system, nonetheless, the studies investigating the multiscale characteristics of the climate are scarce. Further, the present set of techniques are limited in their ability to unravel the multi-scale variability of the climate system. It is completely plausible that extreme events and abrupt transitions, which are of great interest to climate community, are resultant of interactions among processes operating at multi-scale. For instance, storms, weather patterns, seasonal irregularities such as El Niño, floods and droughts, and decades-long climate variations can be better understood and even predicted by quantifying their multi-scale dynamics. This makes a strong argument to unravel the interaction and patterns of climatic processes at different scales. With this background, the thesis aims at developing measures to understand and quantify multi-scale interactions within the climate system.

In the first part of the thesis, I proposed two new methods, viz, multi-scale event synchronization (MSES) and wavelet multi-scale correlation (WMC) to capture the scale-specific features present in the climatic processes. The proposed methods were tested on various synthetic and real-world time series in order to check their applicability and replicability. The results indicate that both methods (WMC and MSES) are able to capture scale-specific associations that exist between processes at different time scales in a more detailed manner as compared to the traditional single scale counterparts.

In the second part of the thesis, the proposed multi-scale similarity measures were used in constructing climate networks to investigate the evolution of spatial connections within climatic processes at multiple timescales. The proposed methods WMC and MSES, together with complex network were applied to two different datasets. In the first application, climate networks based on WMC were constructed for the univariate global sea surface temperature (SST) data to identify and visualize the SSTs patterns that develop very similarly over time and distinguish them from those that have long-range teleconnections to other ocean regions. Further investigations of climate networks on different timescales revealed (i) various high variability and co-variability regions, and (ii) short and long-range teleconnection regions with varying spatial distance. The outcomes of the study not only re-confirmed the existing knowledge on the link between SST patterns like El Ni\~no/ Southern Oscillation and the Pacific Decadal Oscillation, but also suggested new insights into the characteristics and origins of long-range teleconnections.

In the second application, I used the developed non-linear MSES similarity measure to quantify the multivariate teleconnections between extreme Indian precipitation and climatic patterns with the highest relevance for Indian sub-continent. The results confirmed significant non-linear influences that were not well captured by

the traditional methods. Further, there was a substantial variation in the strength and nature of teleconnection across India, and across time scales.

Overall, the results from investigations conducted in the thesis strongly highlight the need for considering the multi-scale aspects in climatic processes, and the proposed methods provide robust framework for quantifying the multi-scale characteristics.