Physica A 495 (2018) 436–453

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Dynamics and causalities of atmospheric and oceanic data identified by complex networks and Granger causality analysis

A.K. Charakopoulos, G.A. Katsouli, T.E. Karakasidis *

Laboratory of Hydromechanics and Environmental Engineering, Department of Civil Engineering, University of Thessaly, 38334 Volos, Greece

HIGHLIGHTS

- We understand spatiotemporal characteristics of the environmental time series.
- Cross correlations and causalities are significant among variables.
- We confirm the presence of patterns among atmospheric and oceanic variables.
- Visibility graphs reveal the different physical characteristics of the variables.
- Methodologies may be useful in supporting real time environmental data monitoring.

ARTICLE INFO

Article history:
Received 28 June 2017
Received in revised form 3 November 2017
Available online 14 December 2017

Keywords:
Complex network
Granger causality
Cross correlation
Seawatch buoys

ABSTRACT

Understanding the underlying processes and extracting detailed characteristics of spatiotemporal dynamics of ocean and atmosphere as well as their interaction is of significant interest and has not been well thoroughly established. The purpose of this study was to examine the performance of two main additional methodologies for the identification of spatiotemporal underlying dynamic characteristics and patterns among atmospheric and oceanic variables from Seawatch buoys from Aegean and Ionian Sea, provided by the Hellenic Center for Marine Research (HCMR). The first approach involves the estimation of cross correlation analysis in an attempt to investigate time-lagged relationships, and further in order to identify the direction of interactions between the variables we performed the Granger causality method. According to the second approach the time series are converted into complex networks and then the main topological network properties such as degree distribution, average path length, diameter, modularity and clustering coefficient are evaluated. Our results show that the proposed analysis of complex network analysis of time series can lead to the extraction of hidden spatiotemporal characteristics. Also our findings indicate high level of positive and negative correlations and causalities among variables, both from the same buoy and also between buoys from different stations, which cannot be determined from the use of simple statistical measures.

1. Introduction

For coastal engineering and marine scientists the ability to understand the underlying processes and extract detailed characteristics of how the oceans and atmosphere interact both individually and also together is an open issue which has not yet been fully answered [1–8].

* Corresponding author.
E-mail address: thkarak@uth.gr (T.E. Karakasidis).

https://doi.org/10.1016/j.physa.2017.12.027
0378-4371/

In order to investigate the essential rules of interaction between atmospheric and oceanographic variables, most research works have focused on observing the effects of the circulation of the corresponding basin and water mass formation processes using conventional methods [9–11].

Motivated by these issues, and also due to the fact that the knowledge of the atmospheric and oceanic variables can help to better understand the complex mechanisms of climate science, this study has two main purposes. The first primary concern of this research is to examine the effects of two different approaches for the investigation of relationships among atmospheric and oceanic variables. In particular we estimated the cross correlation coefficient as well as we performed the Granger causality analysis focusing especially on the interactions and possible causalities between variables by analyzing time series from Seawatch buoys provided by the Hellenic Center for Marine Research (HCMR) [12]. Besides that, complex network analysis of time series was employed for understanding the underlying complex spatiotemporal characteristics of climate dynamic. The second principal objective is to examine patterns in the dynamics of physical variables both locally at each station, but also correlation and causality relations between variables at different locations.

In particular, we first employed the cross correlation analysis in an attempt to identify time-lagged relationships as a function of the time lag. Since it is well known that the existence of correlation between two variables does not necessarily imply a relationship of causality between these two variables we applied the Granger Causality method [13]. Granger causality analysis has already been successfully applied to a wide range of phenomena in various fields of social science, economics, engineering and neurosciences, for the identification of directional interactions among variables from their time series, based on prediction theory [14–22]. The present results demonstrate the existence correlations and causalities between variables, both from the same buoy and also between buoys from different location. In addition, the proposed analysis suggests that is capable of extracting hidden qualitative differences between variables which cannot be determined from the performance of simple statistical measures.

In a second place, we employed the methodology of transforming time series to complex network [23–27]. The main idea is to analyze the dynamics of environmental variables through the analysis of the resulting complex networks. The transformation of time series to complex networks was performed through the visibility graph method that was introduced by Lacasa et al. 2008 [27]. Then, for each network we evaluated the main topological network properties and demonstrated how these properties can be used to identify spatiotemporal patterns among variables. The complex network methodology, has shown that the visibility graph analysis inherit several properties from their associated series. Specifically, we show that the network analysis provides a way to extract information on interactions among climate data associated with the temporal and spatial variation.

A preliminary study has been performed using data from only two locations which showed that one can identify the dynamics and causalities between several observations [28]. In the present work we extend this research taking into account more locations and more variables. Specifically, data from buoys presented in this work were provided from the Poseidon system [12] measured from buoys installed at Aegean and Ionian Sea. These locations are part of the Eastern Mediterranean, which is a marginal sea and plays an important role in general climate conditions. In this area, water masses of different basins interact and are transformed at various temporal and spatial scales [29,30].

The structure of the paper is as follows. In Section 2 we portray the site and data description. In Section 3 we present the methodology employed. The results and discussion are presented in Section 4. Finally, our conclusions are drawn in the final section.

2. Study area and data description

2.1. Morphological settings

The Mediterranean Sea is a marginal sea, which has been suggested to play an important role in general climate conditions. The East Mediterranean Sea consists of the Aegean Sea, Ionian Sea, Adriatic Sea and Levantine Sea. The Aegean Sea can be divided to the North-Central Aegean basin and to the South Aegean basin (Cretan Sea). One of the major characteristics of the North Aegean area is the intrusion of a low salinity water mass from the Black Sea through the Dardanelles Straits [29–32].

Also the water mass of the Aegean basin is influenced by water mass of Levantine origin, which enters to the South Aegean through the East Cretan Straits and from the Ionian Sea thought the strait lies between the Peloponnese peninsula of Greece [33,34]. In the South Aegean water mass of Atlantic origin enters mainly through the West Cretan Straits. Generally, water masses of different basins, having different characteristics, interact with each other.

The Ionian Sea is an area with a complex hydrology where water masses from Levantine Sea, Aegean Sea and Adriatic Sea interact with water masses of the Western Mediterranean Sea that enter through the Sicily Strait [35,36]. These water masses have different characteristics, conditions and circulation patterns.

We have to bear in mind that Kalamata station is positioned in the Messinian bay and more specifically is close to the coastline of Kalamata city. Messinian bay communicates with the basins of the SE Ionian, and also interacts with Pelops anticyclonic Gyre (PG) and Levantine Surface Water (LSW). The city of Kalamata is surrounded in the easterly region by Taygetos mountain, westward by Kyparrisia mountains and in the north extends the fertile Messinian plain. This morphology may affect the values of the variables being recorded.