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Do trend extraction approaches affect causality detection in climate change studies?

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HIGHLIGHTS

- Causal relationship between GT and SS analyzed using historical data.
- Role of trend extraction studies in causal relationship of GT and SS.
- An advanced non-parametric test Convergent Cross Mapping (CCM) is adopted.
- CCM is used to find most reliable trend extraction technique.
- CCM indicate increasing significance of causal effect from SS to GT in recent years.

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ABSTRACT

Various scientific studies have investigated the causal link between solar activity (SS) and the earth's temperature (GT). Results from literature indicate that both the detected structural breaks and existing trend have significant effects on the causality detection outcomes. In this paper, we make a contribution to this literature by evaluating and comparing seven trend extraction methods covering various aspects of trend extraction studies to date. In addition, we extend previous work by using Convergent Cross Mapping (CCM) - an advanced non-parametric causality detection technique to provide evidence on the effect of existing trend in global temperature on the causality detection outcome. This paper illustrates the use of a method to find the most reliable trend extraction approach for data preprocessing, as well as provides detailed analyses of the causality detection of each component by this approach to achieve a better understanding of the causal link between SS and GT. Furthermore, the corresponding CCM results indicate increasing significance of causal effect from SS to GT since 1880 to recent years, which provide solid evidences that may contribute on explaining the escalating global tendency of warming up recent decades.

1. Introduction

Rising global temperature has both short and long term environmental and economic implications. As a result, there is growing interest among scientists worldwide to identify the factors that affect the rate of change in global temperature. The

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Nomenclature

ADF	Augmented Dickey–Fuller.
CCM	Convergent Cross Mapping.
DF − GLS	Dickey–Fuller test with Generalized Least Squares detrended residuals.
DGT	Detrended global temperature.
EDM	Empirical Dynamic Modeling.
EMD	Empirical Mode Decomposition.
GT	Global temperature.
HEN	Henderson Filter.
HP	Hodrick–Prescott Filter.
KPSS	Kwiatkowski–Phillips–Schmidt–Shin test.
LOESS	Local Regression Filter.
MBA	Model Based Approach.
NP	Ng and Perron test.
PP	Phillips and Perron test.
SIC	Schwarz Information Criterion.
SS	Sunspot number.
SSA	Singular Spectrum Analysis.
WAV	Wavelets Filter.

connection between solar activity and global warming has been well established in the scientific literature. For example, see Refs. [1,2,6,5,7,3,4,8–10]. An indication of solar activity is given by the sunspot number (SS). Sunspots appear as dark spots on the surface of the Sun. Temperatures in the dark centers of sunspots drop to about 3700 K (compared to 5700 K for the surrounding photosphere). They are magnetic regions on the Sun, with the strength of a magnetic field which is thousands of times stronger than the Earth's magnetic field. Sunspots usually come in groups with two sets of spots, namely positive (or north) magnetic field and negative (or south) magnetic field. Sunspots typically last for several days, although very large ones may live for several weeks.[1] The causality between sunspot number (SS) and global temperature has been explored in many scientific work using different causality detection techniques. The data on SS and GT contain many complex dynamic fluctuations. Also, there is a high possibility of the existence of non-stationary features in the data. This poses difficulty in deriving convincing results on causality using parametric techniques. Hence, our motivation for this paper is to provide evidence on the causality between SS and GT using various advanced causality methods [11,12].

Given the long time series in climate change studies, the detected structural breaks show significant effects on the causality detection outcomes. Also, in [11], we showed that the existing trend of GT can affect causality detection, which may lead to misleading or spurious results for both generally accepted and advanced causality detection methods. This motivates us to investigate the possible effects of the trend on causality detection. We evaluate the differences among various trend extraction techniques and the corresponding effects on the results derived.

In this paper, we adopt a non-parametric causality detection method Convergent Cross Mapping [13]. We use the same dataset of SS and GT, and the corresponding subsamples used in [11,12]. The analysis uses different representative trend extraction methods covering almost all aspects of trend extraction studies to date and evaluates their corresponding effects on these advanced non-parametric causality tests. The emphasis of this paper is not reviewing all available trend extraction methods. Instead, we focus on the crucial question of whether trend extraction has effects on the advanced causality detection methods and providing comparisons of those effects by a few representative trend extraction methods. To the best of our knowledge, this paper is the first to adopt Convergent Cross Mapping to provide evidence on the causality between sunspot numbers and the global temperature. We contribute to the scientific literature on climate change that focuses on determining the causes of global warming.

The paper is structured as follows: Section 2 briefly introduces both the empirical and advanced causality detection techniques adopted in recent climate change studies; Section 3 provides the descriptive summary of the original and various detrended data considering seven different trend extraction methods; Section 4 summarizes and compares the causality detection results by employing different causality detection techniques on the original and various extracted series respectively; Furthermore, Section 5 decomposes both SS and GT into representative components and conducts various causality tests respectively for the comprehensive understanding of the causal link between SS and GT; Finally, Section 6 concludes.

[1] Further details can be found at: http://solarscience.msfc.nasa.gov/feature1.shtml.