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SOLAR ACTIVITY INFLUENCE ON THE CLIMATE VIA MAGNETIC TURBULENCE

[*,**,***]Elbakidze Kh., [**,****]Kharshiadze O., [**]Ghurtchumelia A.

[*]Ilia Vekua Institute of Applied Mathematics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia
[**]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia
[***]Business and Technology University, Tbilisi, Georgia
[****]Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia
Khatuna.chargazia@gmail.com

Abstract. Earth's climate is determined by complex interactions among the Sun, oceans, atmosphere, cryosphere, land surface and biosphere. The Sun is the principal driving force for Earth's weather and climate. The influence of solar activity on the Earth's global surface is determined due to temperature variation, which in turn drives the instabilities and is expressed via turbulent effects. Standard approaches to identify such connections are often based on correlations between the appropriate time series. Here we present a novel method Granger causality, which can infer/detect relationships between any two fields. We compare Solar activity – climate connections via magnetic turbulence identified by correlation and Granger causality at different timescales.

Key words: time series; causality; information transfer; time reversal; solar wind-magnetosphere–ionosphere system; space weather.

1. Introduction

The climate is a complex system characterized by several subsystems and many bidirectional relations between them. At present, the standard strategy to catch the complex behavior of climate is the application of dynamical modeling for the description of this dynamical approach and the conceptual and practical relevance of these simulations. The problem of understanding and weighting the main causes of recent climate change is generally faced by numerical experiments within this modeling framework. The final aim of these studies is to evaluate if one is able to attribute this change to some specific causes out of a number of possibilities. The situation is quite complex but, at least as far as the attribution of global temperature changes is concerned (a case of climatic attribution), the results coming from dynamical models are quite clear and indicate that the fundamental causes of recent global warming are anthropogenic forcings.

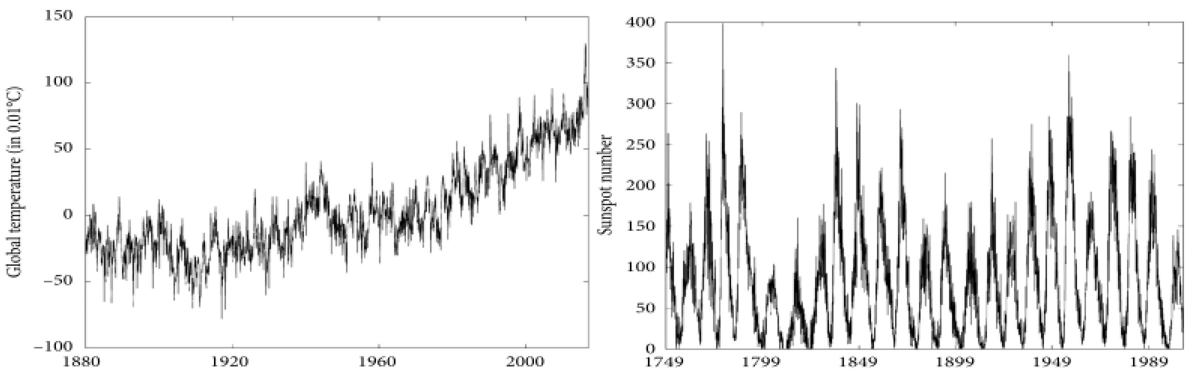


Fig. 1 (a) Monthly average of the sunspot number and (b) global surface temperature time-series profiles (Li et al 2018).

2. Data and Method

For sunspot numbers, we apply the data provided by the Solar Influences Data Analysis Center (http://www.-sidc.be/sunspot-data). The data, which are presented by monthly frequencies, cover the period from January 1749 to December 2016. The sunspot number series has been replaced by a new improved set (version 2.0) since 2015. The new time series contains some appreciable improvements, including (i) the adoption of a new reference observer A. Wolfer (a pilot observer from 1876 to 1928) instead of R. Wolf himself and (ii) corrections of several past inhomogeneities in the solar series (Locarno drift correction (1981–2015), Waldmeier jump (1947–1980), Schwabe–Wolf correction (1849–1863), etc.). The details of the new sunspot number series are given by Clette and Lefevre [2] and are not reported here. Meanwhile, the global temperature time-series profiles are obtained from the Goddard Institute for Space Studies surface temperature analysis (GISTEMP) (http://data.giss.nasa.gov/gistemp).

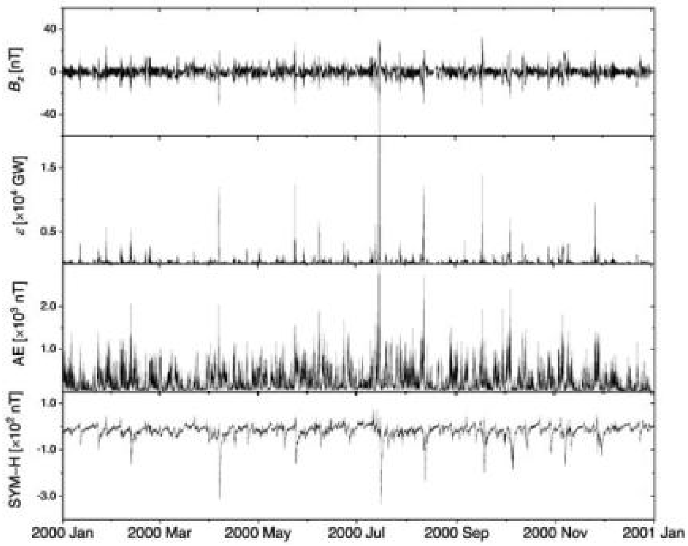


Fig. 2. One year period (2000) of (from top to bottom) the vertical component of the interplanetary magnetic field Bz and solar wind–magnetosphere coupling parameter ϵ along with the geomagnetic activity indices of auroral electrojet (AE) and the symmetric field in the H component (SYM-H), with clear, strong activities. Time points with missing values are excluded from the analysis (Pouya et al 2018).

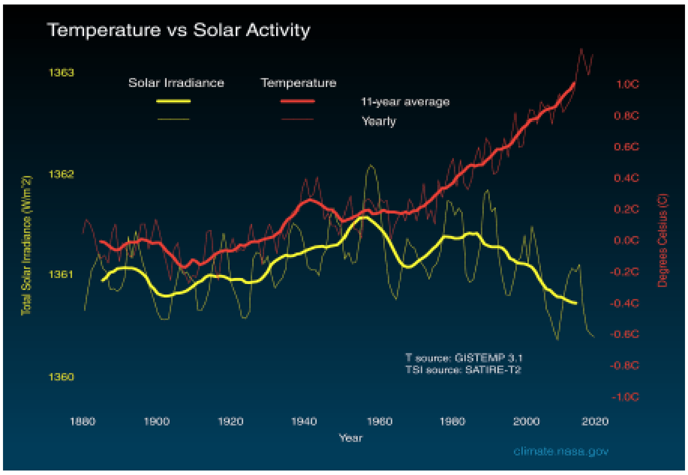
As shown in Figure 1(a), the sunspot numbers clearly have significant cyclical patterns with time-varying amplitudes, and they exhibit a dominant period every 128 months (approximately 11 years). Meanwhile, as shown in Figure 1(b), the global temperature variabilities are somewhat steady before 1960. However, from 1960 until the end of the analyzed period, a clear upward trend is observed.

During the last years, analyses using the concept of Granger causality [3] have been performed to investigate the possible causal relations between external forcings and temperature behavior. In this paper we review the studies of climatic atttribution via this inferential method.

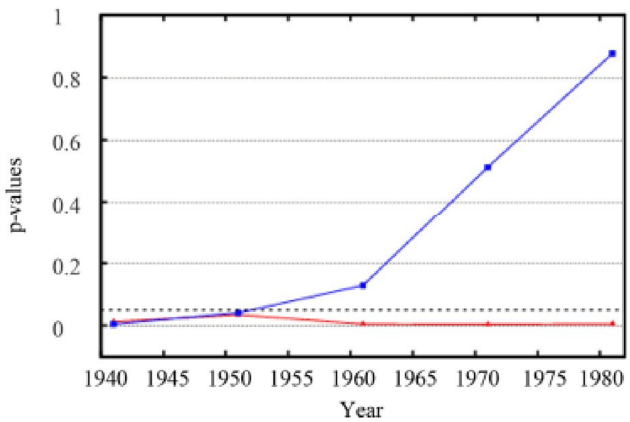
During the last decade the notion of Granger causality has been used quite frequently in addressing specific causality problems in the climate system. For instance, Diks and Mudelsee [4] analyzed the results of an ocean drilling program in order to estimate the causal relationships and directions among data about insolation.

Kaufmann et al. [5] used satellite data and a Granger causality analysis for estimating causal influences of snow cover and vegetation on temperatures in different seasons. In a further study, considered that the strength of Atlantic hurricanes is related to the sea surface temperatures (SST) of this ocean, Elsner [6,7] applied a Granger causality analysis to time series of global temperatures (GT) and SST and found a causal link from GT to SST, thus corroborating the hypothesis of changes induced by global warming. Mosedale et al. [8] investigated SST effects on North Atlantic Oscillation (NAO)—an index which substantially drives the European winter climate—using data from simulations made with a coupled Global Climate Model (GCM). They showed that the so-called SST tripole index provides additional predictive information for the NAO than that available by using only past values of NAO, i.e. the SST tripole is Granger causal for the NAO. Kaufmann et al. [9] studied the effect of urbanization and enlargement of towns on precipitation in a Chinese case study. They applied Granger causality and clearly found that, generally, urbanization causes a deficit in precipitation, even if differences for distinct seasons are detectable. Finally, Mohkov et al. [10] analyzed the relationship between El Niño Southern Oscillation (ENSO) and the strength of Indian monsoons. They found a bidirectional coupling which varies with time and this result shall be certainly useful for better understanding the dynamical mechanism behind this interaction.

The examples of application of Granger causality analyses just sketched show the potentiality of this technique in addressing causality problems in the climate system. Actually, however, in the realm of climate research there is a causality problem which overwhelms all other ones. It can be summarized in the question: what did cause the recent climate change or, at least, the recent global warming? Even considered the complexity of the climate system, which is the main external forcing that primarily induced the increase of temperature observed in the last century? Obviously, this is the main problem of attribution studies.



Given the potentialities of Granger analyses, it should not be a surprise that several studies have been performed by this technique in the framework of climatic attribution.



A number of attempts have been performed at applying the concept of Granger causality to climatic problems and, more specifically, to climatic attribution. After some pioneering works, where the choice of influencing variables is quite dubious or the dimensionality of the multivariate models probably exceeds the maximum number of parameters for obtaining reliable results, at present the application of Granger causality to the climate framework is quite well posed.

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