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The role of climatic forcings in variations of Portuguese temperature: A comparison of spectral and statistical methods

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ABSTRACT

Monthly series of temperature parameters measured by three Portuguese meteorological stations from 1888 to 2001 were used to study the effect of different climatic forcings. Three types of external forcings were considered: anthropogenic greenhouse gases and aerosols, volcanic aerosols, and solar and geomagnetic activity variations. Long-term variations of the temperature and other parameters with characteristic periods of decades were studied by various methods including the seasonal-trend decomposition based on LOESS (LOcally wEighted regreSSion), correlation and multiple regression analyses, and wavelet/wavelet coherence analyses. Obtained results confirm the statistical dependence of the temperature variations on the volcanic and the anthropogenic influence as well as variability that can be associated with the solar activity impact. In particular, surprisingly strong bi-decadal cycles were observed in temperature series whereas the observed decadal cycles are weaker and transient. Another interesting finding is the apparent non-stationarity of the relations between the solar and atmospheric parameters probably related to periods of strong/weak global circulation or frequent/occasional volcanic eruptions or interaction between the external forcing and internal atmospheric variability.

1. Introduction

Investigations of the external forcings effect on climate variability starts long ago. Various types of mathematical methods (statistical analyses, numerical simulations, time-frequency analyses etc.) were applied to a wide number of atmospheric parameters like temperature, pressure, precipitation, wind speed and wind direction etc. to understand the roles played in their variations by different external climatic forcings: anthropogenic gases and aerosols, volcanic aerosols, solar irradiance, and solar and geomagnetic activity as well as some internal variabilities like atmospheric circulation and oceanic impact. Some studies show non-stationarity of forcings control. For example, (Meehl et al., 2003, Hegerl et al., 2007, 2011, Lockwood and Fröhlich, 2007; Lean and Rind, 2008) showed that during the last centuries temperature variations until the beginning of the 20th c. can be explained using mostly volcanic and solar forcings, but the rapid increase of the temperature at the end of this century needs other source – anthropogenic greenhouse gases. Lockwood (2012) emphasizes the differences between the global and the regional climate sensitivity to forcings. The regional climate has stronger response and larger spatial variability in the sign and amplitude of such response. Differences in the reaction of the regional climatic series to the external forcings (in particular, solar activity and geomagnetic field variations) were found by (Usoskin et al., 2010). Their study highlights the difference (and its sources) in the response of climatic parameters form different latitudinal zones (polar, middle latitudinal and equatorial) to the solar forcing.

There is also a possibility that external factors can affect some atmospheric parameters twice: directly and indirectly. For example, the total solar irradiance variations affects lower atmosphere temperature both directly (changes of the radiation balance) and indirectly through (e.g.) changes of the global circulation patterns resulting in warm/cold air advection, changes of cloudiness and precipitation regimes. Same can be said for the volcanic and anthropogenic influences. The presence of a combined effect of the solar and volcanic activities on the 11-yr periodicity in the global Earth temperature was detected by (Barlyaeva et al., 2009). Further, the difference in a response of the regional air-surface temperatures to the solar, volcanic and geomagnetic forcings at the decadal (11-yr and 22-yr) timescale was shown in (Barlyaeva, 2013). In particular, it was found that the response of temperature to the solar forcing for distant climate zones differs from each other, changes with time and depends on the presence of other influencing factors. The widespread response was also observed to

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the 22-yr oscillations of the geomagnetic activity. The change of the phase in correlation between solar and atmospheric parameters is probably related to the interaction between the periodic external forcing and internal oscillations of the atmosphere or the atmosphere-ocean system was detected by, e.g., (Raspopov et al., 2004; Gusev and Martin, 2012) (see also references therein). Such phase changes can be generated in a non-linear climate system which has two quasi-stable states under the influence of a weak external signal (Tobias and Weiss, 2000 and references therein).

The climatic variations of the south-western Europe and Iberian Peninsula were studied previously using both observed or reconstructed data and simulations by the state-of-art atmospheric models (e.g., del Río et al., 2012; Gámiz-Fortis et al., 2011; Gómez-Navarro et al., 2010, 2012, 2013; Hegerl et al., 2011). In particular, Gómez-Navarro et al. (2012) modeled climate variability of this region over the last millennium in response to the externals forcings of anthropogenic gases (CO_2, methane, NO), volcanoes and total solar irradiance (TSI) variations due to solar activity cycles. del Río et al. (2012) analyzed measured temperature parameters over Spain in the second half of the 20th c. They found significant differences in the time trends of the daily minimum (Tmin) and maximum (Tmax) temperatures leading to specific trends in the daily temperature range (DTR). They indentified the main external forcings responsible for the observed trends such as greenhouse gases, solar radiation, and anthropogenic aerosols and paid attention to the internal atmospheric variability due to the changes in circulation patterns (mostly the North-Atlantic Oscillation, NAO).

In this study we used regional monthly temperature data measured by three meteorological stations located in a relatively small area of the Portuguese west region. The original temperature series are of a monthly resolution allowing us to study not only the mean annual climate response to the forcings but also its seasonal variations. These historical series (described in Section 2) were recently presented to the scientific community after the homogenization procedure done in the frame of the of the FP7 project ERA-CLIM. They cover a period from middle/end of the 19th c. to the beginning of the 21th c. As to the parameters used to characterize the external atmospheric forcings, we tried to use as much of direct measurements or reconstructions based on direct measurements as possible. Another advantage of our study is that the data were analyzed using two different mathematical approaches: statistical (based on the correlation and regression analysis) and spectral (using wavelet and wavelet phase/coherence analysis). The results obtained by one method (e.g., wavelet coherence/ phase analysis) can be cross-checked by others (e.g., running correlation with different time lags) to test or enhance the statistical significance of obtained results. Different mathematical methods applied to the data help to look at the problem from various points of view, to see different properties and different connections. The similarity of the results of a number of various mathematical approaches could be used as an additional way to ensure the reliability of the obtained results, since different methods can have different sensitivities to specific properties of the data. Certainly, any statistical relations do not guarantee real physical connections, even if we know that some of forcings taken into account do have physical ways to drive climatic variations, and others can be involved in mechanisms which are currently discussed.

The paper is organized as follows: Section 1 presents modern state of the art and briefly gives overview of the paper. Sections 2 and 3 contain the descriptions of the data sets in use and the applied mathematical methods, respectively. In Section 4 we analyze footprints of different climatic forcings in the regional temperature variations. We also compare results produced by the different mathematical methods and discuss sources of the multi-decadal variability of the temperature series. Section 5 gives summary on the obtained results. Appendices A and B present the detailed description of one of the mathematical methods we use in this study and which is not yet widely used: the seasonal-trend decomposition based on LOESS.

2. Data

A number of monthly and annually averaged data were used in this study to analyze variations of the climate in the studied region and their possible forcings. Brief descriptions and pre-processing procedures of these datasets are presented below. Please note, that we use here the term “normalization” for a linear transform of a series to have zero mean and unit variance (standard deviation).

2.1. Temperature

In this study we took advantage of a newly available homogenized data set which consist of sets of 12 monthly series for each of the following parameters: monthly means of the daily minimum (*Tmin*) and daily maximum (*Tmax*) temperatures measured by three Portuguese stations, and calculated from them monthly means of the mean daily temperature (*averT*) and daily temperature range (*DTR*).The stations are

1. Porto (φ=41°08′N, λ=8°36′W, from 1888 to 2001);
2. Coimbra (φ=40°12′N, λ=8°25′W, from 1865 to 2005);
3. Lisbon (φ=38°43′N, λ=9°09′W, from 1856 to 2008).

Non-climatic breaks that existed in the raw series were identified during the homogenization procedure and the series were corrected using available metadata and statistical homogeneity tests. For the full description of homogenization procedure see (Morozova and Valente, 2012). The data are available at http://doi.pangaea.de/10.1594/PANGAEA.785377. Recently, this data set was used in a study of the effect of the atmospheric aerosol variations on regional climate in the last quarter of the 20th c. (Morozova and Mironova, 2015). Here we use this data set in its full length (more than 100 years) to find the effect of different external forcings on the Portuguese climate. The monthly series were used to calculate the seasonally and annually averaged series (hereafter, “seasonal series” and “annual series” (An), respectively): December, January and February for winter (Wi), March, April and May for spring (Sp), June, July and August for summer (Su), and September, October and November for autumn (Au) series.

To remove individual features of climatic variations from the stations' data series (two coastal stations – Porto and Lisbon, and a station located in an elevated region at ~40 km from the coast – Coimbra) and obtain a series suitable for the analysis of the regional climate we averaged these three series using the Principal Component Analysis (PCA). PCA is a well known method to extract independent spatial-temporal modes of variability (principal components, PCs) when a number of series of the same parameter from different stations (grid points) are used. This method also estimates the explained variances for each of extracted modes. The first principal component (PC1) accounts for as much of the common variability in the original data as possible, the second PC accounts for as much of the remaining common variability and so forth. The PCs are orthogonal and conventionally non-dimensional, and all series are subjected to the PCA in the form of deviations from the each series time mean. The full descriptions of the method and its application to the analysis of different meteorological series can be found in (e.g.) (Bjornsson and Venegas, 1997, Hannachi et al., 2007; Shlens, 2009). In our study this technique was used as an averaging procedure extracting the