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Solar forcing on the ice winter severity index in the western Baltic region

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Abstract

The Sun is the fundamental energy source of the Earth's climate and therefore its variations can contribute to natural climate variations. In the present work we study the variability of ice winter severity index in the Baltic Sea since the 15th century and its possible connection with solar activity. Based on a new method for finding and measuring amplitude–phase cross-frequency coupling in time series with a low signal/noise ratio, we suggest that the ice winter severity index in the Baltic Sea is modulated by solar activity and solar motion in several frequency bands during the last 500 years. According to our model a strong coupling between the decadal periodicity in the ice winter severity index time series and the secular periodicity of solar activity is present. We found that the ice winter severity index is strongly modulated by solar activity at the decadal periodicity. We also found that the 180 year periodicity of the Barycentre motion modulates the amplitudes of the decadal periodicity of solar activity and the ice winter severity index. This method represents a useful tool to study the solar–terrestrial relationship.

Highlights

► We present a new method for assessing amplitude–phase cross-frequency coupling. ► We applied the cross-frequency coupling method to different time series. ► The ice winter severity index is strongly modulated by solar activity.

Introduction

The Baltic Sea is a semi-enclosed sea of about 415,000 km^2 connected to the North Sea and to the Atlantic Ocean (located from 10°E to 30°E and from 53°N to 66°N), see Fig. 1. The climate of the Baltic Sea basin is characterized by large seasonal contrasts, due to its geographical location, variable topography, and land–sea contrasts. The climate is influenced by major air pressure systems, particularly the North Atlantic

Oscillation during wintertime, which affects the atmospheric circulation and precipitation in the Baltic Sea basin (Helcom, 2007).

Ice is a very important element in the climate system of the Baltic region since it can affect directly or indirectly many of the oceanographic, climatic, ecological, economical and cultural patterns (Mikelsone et al., 2008). The extent and the thickness of the winter ice cover and the duration of the season can characterize the ice climate in the Baltic Sea.

The study of ice winter condition in the Baltic Sea is of great importance since it is expected that even the smallest climatic change will be due to the impact of ice (Eriksson et al., 2007). Sea ice conditions are an indicator of the severity of the winter season (Haapala and Lepparanta, 1997). The Baltic Sea experiences a seasonal ice cover. The maximum ice area and the day of its occurrence vary from year to year depending on the strength of the winter (Helcom, 2007). Unusual ice conditions have been documented since AD 690 but periodic recordings of ice observations started in the 16th century (Speerschneider, 1915).

The analyses of the 20th century time series have shown a tendency towards milder ice conditions. Jevrejeva et al. (2004) have shown a decrease of the probability of ice occurrence. Haapala and Lepparanta, 1997 have observed a diminution of the duration of the ice season in the Baltic Sea during 1889–1994 (1997).

In previous works it has been suggested that the increasing greenhouse gas (GHG) forcing may play a major role in diminishing the sea ice cover (Johannessen, 2008, Serreze et al., 2007, Stroeve et al., 2007) and has induced global warming. The ice conditions and the air surface temperature variations are not only caused by GHG, but are also caused by natural climate variations (Omstedt and Chen, 2001, Polyakov et al., 2002, Soon et al., 2011).

Lepy (2005) studied the influence of temperature on ice conditions; she found that temperature is an essential parameter for the formation of ice but it is not the only one. Jaani et al. (1999) studied the ice cover fluctuations in relationship with solar activity from 1720 to 1992 confirming the 22-year oscillation, corresponding to the whole cycle of solar activity. Loewe and Koslowski (1998) analyzed the relation between ice winter severity and solar activity since 1879; they showed that the accumulated areal ice volume ($Va\Sigma$) is modulated for the 8 year periodicity and the most severe winters occurred when the solar activity was low.

The study of climate and climate change is important because it will affect people around the world in diverse ways (The BACC Author Team, 2008, Adams et al., 1990, Frumkin and McMichael, 2008). During the last years, the majority of Baltic Sea analysis focuses on increasing greenhouse gas (Wesslander et al., 2010, Vehviläinen and Huttunen, 1997).

Many efforts have been made in order to explain the Baltic region climate. The causes of the climate changes are usually complex and require research and modeling in order to attempt to understand them (The BACC Author Team, 2008). Hansson and Omstedt (2008) provide a reconstruction of sea temperatures and they found that the late 20th century warming in the Baltic Sea region cannot be determined to be unprecedented over the past 500 years. Leijonhufvud et al. (2010) produced two new 500 year series taking advantage of the documentary records that reflect the sea ice conditions in the Stockholm Harbor. Shabalova and van Engelen (2003) presented a reconstruction of winter and summer temperatures in the Low Countries (the present-day Netherlands and Belgian Flanders), based upon documentary evidence. Jevrejeva (2001) presents the reconstructed severity of winter seasons in the northern Baltic Sea on the basis of historical time series of ice break-up at the port of Riga (1529–1990); he found a decreasing trend for the time series of ice break-up dates for severe winters. Tarand and Nordli (2001) also estimated the winter severity for the Tallin port using historical evidence (the first day of ice break-up in Tallin port, the first day of ice break-up on the river in Northern Estonia and the first day of rye harvest).

In this paper, we proposed to consider not only the fluctuations in ice winter in the western Baltic region due to greenhouse gases but also the secular solar variability and the Barycentre motion.

The Sun has an obvious effect on climate since its radiation is the main energy source for the outer envelopes of our planet. The Sun is a variable but the most obvious evidence for its variable activity is the appearance and disappearance of sunspots. Until now we still lack a fundamental understanding of all causal relationships between solar activity and climate (Bard and Frank, 2006).

The longest recorded aspects of solar variations are changes in sunspots. In the 17th century astronomers used the telescope to make observations of sunspots (Eddy, 1976). Direct irradiance measurements have only been available during the last three cycles and are based on a composite of many different observing satellites.

Some studies have suggested a long-term relationship between solar activity and Global climate (Eddy, 1976). The long-term behavior of solar activity can be reconstructed from the measured cosmogenic isotope content in terrestrial archives (Stuiver, 1961). Cosmogenic isotopes are produced in the Earth's atmosphere by energetic cosmic rays (CR) whose flux is modulated in the heliosphere by the turbulent heliospheric magnetic field and variable solar wind, both being ultimately defined by solar magnetic activity (Usoskin et al., 2006).

Since there are no direct observational data to study the solar variability over long period of time scales, we have to rely on proxy data, for instance, cosmogenic isotopes such as Beryllium-10. The analysis of the cosmogenic isotopes record is more difficult than the analysis of the number of sunspots. This is due to the fact that the ^{14}C and ^{10}Be concentration reflects the production rate, which is modulated not only by the solar activity, but also by atmospheric transport and deposition processes (Beer et al., 1994).

Some authors have proposed that geophysical oscillations of different frequencies can interact with one another (Rennert and Wallace, 2009). The solar motion around the barycentre of the solar system has been claimed as one of the possible origins of solar variability (Jose, 1965, Charvátová, 1988). Many authors tried to explain the influence of the planets on sunspot numbers (Brown, 1900, Jose, 1965, Charvátová, 1988); they assume that the cause for periodicities in solar activity is the motion of the Sun around the mass center of the solar system; however, a clear physical mechanism has not been identified yet. It has been suggested that a 179-year periodicity (barycentre periodicity) modulates the amplitudes of the 11-year sunspot cycle (Cohen and Lintz, 1974). Charvátová and Střeštík (2004) have established the possible relationship between the solar motion and the climate phenomena.

There has been several manifestation of cross-frequency coupling between the geophysical time series. Many efforts have been made in order to identify and measure this type of coupling, but no method has been chosen as the gold standard for detecting the phenomena. In the amplitude–phase cross-frequency coupling the amplitude of a high-frequency oscillation is modulated by the phase of low-frequency rhythms (Tort et al., 2010, Canolty et al., 2006, Demiralp et al., 2007). This type of coupling has been observed in studies on brain oscillations, climate systems, electronic devices, etc. (Knyazev, 2011, Wei et al., 2007, Mokhov et al., 2011, Blasius and Stone, 2000).

Several methods are applied to find the coupling between different frequencies, but nevertheless each of them exhibits their own limitations. There are two main limitations in the actual methods: they are sensitive to variations in cross-frequency over time and on the other hand a frequency band must be specified before the method is applied (Cohen, 2008). Here we present a new method to study the cross-frequency coupling based on coherent demodulation and wavelet filtering transform. This method is able to detect and quantify the intensity of coupling even in signals with low signal/noise ratio and over-modulation. We present an example of its application, applying the method to analyze how the ice winter severity index is affected by the solar activity.

We firstly examine the link between the Ice Winter Severity Index (IWSIB) and ^{10}Be, using the coherent wavelet transform (CWT), to verify if any coherent relationship between these time series is present. Secondly we test the mechanism of how the secular periodicity of solar activity modulates the ice winter severity index and also how the Barycentre motion influences the 180 year periodicity.

Section snippets

Method and data

We used the annual time series of IWSIB data since 1501–1995 for the western Baltic region.

The data from the study of Koslowski and Glaser, 1995, Koslowski and Glaser, 1999 was obtained from the Historical Climatic Data Bank [http://www.hisklid.de/downloads] and the 1400–1500 data obtained from an ice winter severity index extension made by Koslowski and Schmelzer (2007) and by Schmelzer and Holfort (2011).

We also used the annual ^{10}Be record for the 1424–1985 period, measured in an ice core…

Results

First we applied the wavelet transform to the normalized time series in order to find the main periodicities. The time series were transformed in order to have a normal probability density function; otherwise unreliable results can be obtained (Grinsted et al., 2004). Fig. 6(a) shows the IWSIB and Fig. 6(d) the ^{10}Be time series; the wavelet spectrum is presented in Fig. 6(b and e). The global wavelet spectrum (Fig. 6c and f) shows the main periodicities. Both time series present 8 and 12 year…

Discussion and conclusions

We use the coherence wavelet transform between the IWSIB and ^{10}Be in order to find a possible solar influence on ice winter severity index in the Western Baltic region in the last 500 years. From this analysis we found no clear evidence of any significant coherence because of the presence of noise, nonlinearities and/or time delays in the system. But using the coherence phase analysis we found that there is a phase lag of 30 years between the time series. We lagged the IWSIB time series and…

Acknowledgments

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I. Charvátová
The solar motion and the variability of solar activity
Advances in Space Research (1988)

I. Charvátová *et al.*
Periodicities between 6 and 16 years in surface air temperature in possible relation to solar inertial motion
Journal of Atmospheric and Solar–Terrestrial Physics (2004)

T. Demiralp
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2019, Journal of Atmospheric and Solar-Terrestrial Physics

> *Citation Excerpt :*
> …This movement mainly reflects the orbits of the two largest giant planets: Jupiter and Saturn, whose orbital periods are ~11.9 years and ~29.5 years respectively, and which constitute the 93% of the total planetary mass. Several authors have associated the SBM with climatic and solar activity series (Jose, 1965; Charvatova, 2000; Leal-Silva and Velasco Herrera, 2012 Scafetta, 2010; Cionco and Compagnucci, 2012; McCracken et al., 2014; Cionco and Abuin, 2016; Okhlopkov, 2016; Sun et al., 2017; McCrann et al., 2018). However, other authors criticize the statistical methods adopted and the significance of some of the results (Cameron and Schussler, 2013; Holm, 2014, 2015)….

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2016, Planetary and Space Science

> *Citation Excerpt :*
> …The possible relationship between solar motion and climate phenomena is established in Charvátová and Střeštík (2004). The relationship between climatic phenomena and the sun's movement around the barycentre they have quantified in Leal-Silva et al. (2012). In this work we study the relationship between the fall of meteoroids (or their associated meteors or bolides,1 and solar barycentric parameters (barycentric ecliptic longitude, solar barycentric distance, solar barycentric angular momentum and solar barycentric torque) using multiple cross wavelet analysis to identify any coherent relationship between these time series.…

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Precipitation over two Southern Hemisphere locations: Long-term variation linked to natural and anthropogenic forcings

2016, Advances in Space Research

> *Citation Excerpt :*
> …The hypothesis of a gravitational influence of the planets on the solar magnetic cycle is an old idea based on correlations between Sun's movement around the barycenter and sunspots that was recently revisited by Cionco and Compagnucci (2012). Climate on Earth may be also influenced by planetary movement (Leal-Silva and Velasco Herrera, 2012; Scafetta, 2010, 2014; Cionco and Abuin, 2016, and references therein) showing associations at several cycles, like quasi-decadal, 20, 30, and 60-year variations. This hypothesis is a new insight to the solar-climate topic.…

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On planetary torque signals and sub-decadal frequencies in the discharges of large rivers

2016, Advances in Space Research

> *Citation Excerpt :*
> …Abreu et al., 2012), have suggested that the planets can be torquing the solar tachocline with periodicities similar to those observed in long-term solar activity proxy series, but Cameron and Schüssler (2013) and Poluianov and Usoskin

(2014) recently criticised their methodology and conclusions. Several authors have also shown plausible dynamical planetary signals in climatic patterns on Earth, mainly in zonal-global temperature records and auroral activity cycles (Charvátová and Střeštík, 2004; Landscheidt, 1987; Leal-Silva and Velasco, 2012; Scafetta, 2014, 2012b, 2010; Scafetta and Willson, 2013b). If the conclusions of these works are widely "confirmed" (and they were not exempt from criticism, see e.g., Benesty et al., 2006; Holm, 2014a,b), a new perspective about the physical studies of solar action on climate should be considered....

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Reconstruction and prediction of the total solar irradiance: From the Medieval Warm Period to the 21st century

2015, New Astronomy

Citation Excerpt :

...Although the first candidate proposed for causing this periodicity is magnetic field changes in the solar surface, other sources of TSI variability have been proposed, such as changes in the photospheric temperature (Kuhn and Libbrecht, 1991) and long-term changes in the solar diameter (Sofia and Unruh, 1994) or in its convective strength (Hoyt and Schatten, 1998). This periodicity could also be associated with solar barycentric motion (Leal-Silva and Velasco, 2012). The 120-year and 240-year (de Vries or Suess cycle) periodicities have been reported using the cosmogenic isotopes 14C and 10Be (Velasco and Mendoza, 2008; Stuiver and Braziunas, 1993)....

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