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Solar-geomagnetic activity influence on Earth's climate

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Abstract

A long uninterrupted homogeneous data set on the annual mean Sea Surface Temperature (SST) anomaly records as a representative of the Earth's climatic parameter has been analyzed in conjunction with 158 year long time series on the annual sunspot indices, R_z and geomagnetic activity indices, a_a for the period 1850–2007. The 11-year and 23-year overlapping means of global (δt_g) as well as northern (δt_n) and southern (δt_s) hemispheric SST anomalies reveal significant positive correlation with both R_z and a_a indices. R_z, a_a and δt_g depict a similar trend in their long-term variation and both seem to be on increase after attaining a minimum in the early 20th century (~ 1905). Whereas the results on the power spectrum analysis by the Multi-Taper Method (MTM) on δt_g, R_z and a_a reveal periodicities of $\sim$ **79–80** years (Gleissberg's cycle) and $\sim$ **9–11** years (Schwabe solar cycle) consistent with earlier findings, MTM spectrum analysis also reveals fast cycles of 3–5 years. A period of ~ 4.2 years in a_a at 99% confidence level appears recorded in δt_g at ~ 4.3 years at 90% confidence level. A period of $\sim$ **3.6–3.7** years at 99% confidence level found in δt_g is correlating with a similar periodic variation in sector structure of Interplanetary Magnetic Field (IMF). This fast cycle parallelism is new and is supportive of a possible link between the solar-modulated geomagnetic activity and Earth's climatic parameter i.e. SST.

Research highlights

► Instrumental records of temperature anomalies analyzed in conjunction with sunspot, R_z and geomagnetic, a_a indices. ► Significant positive correlation exists between R_z and a_a when they are referred to long-term trends. ► Besides the 79 year and 11 year cycle the present investigation has also revealed fast cycle periods of 3–5 years in SST and a_a. ► Geomagnetic activity could be a possible link through which solar activity may influence the Earth's climate. ► The Sun has a significant role to play in the long-term and short-term climate change.

Introduction

The importance of the solar influence on the Earth's climate change is an important topic of current scientific debate. The beginning of the solar–climate relationship can be traced back to the work of Sir William Herschel who opened the window to this field in 1801 AD (Herschel, 1801). Although climate records were not readily available then, Herschel linked the frequency of sunspots for a number of periods with the price of wheat, under the assumption that the variability of the solar radiative energy output is reflected in the abundance and hence price of wheat. A modern study on this idea was initiated by astronomer Eddy. Eddy's (1976) seminal work drew attention to the near coincidence in time of the Maunder minimum, a period of cold temperature in Europe between 1645 and 1715 to a lull in solar activity known as the “Little ice age” and to the near coincidence in time of Grand solar maximum a period between 1100 and 1250 with increased solar activity known as the “Medival climatic optimum” or ”Middle ages warm epoch”. Eddy's (1977) work provided further evidence of the fact that solar activity changes were mirrored by changes in the global climate.

The investigations of the solar influence on the changes of the global or hemispheric temperatures gained considerable success in the last couple of decades. There is ample evidence in scientific literature emphasizing influence of the Sun's variable energy output on the Earth's climate change (see, for example Hoyt and Schatten, 1997, Douglass and Clader, 2002, Shaviv, 2008, Svensmark and Friis-Christensen, 2007 and references therein). Some of the studies point to this long-term aspect of the solar-climate relationship (Reid, 1987, Reid, 1991, Reid, 2000, White et al., 1997). Various possible mechanisms proposed to explain the influence of the Sun on the Earth's climate are: (1) long-term changes in solar irradiance resulting in the variation of the total energy input into the Earth's atmosphere (Solanki and Krivova, 2003, Friis-Christensen and Lassen, 1991, Wilson, 1998, Solanki and Krivova, 1999); (2) the solar ultravoilet variability and its effect on the stratospheric ozone and thermal structure (Haigh, 2003, Lean and Rind, 2001, Pudovkin and Raspopov, 1992); (3) the effect of galactic cosmic rays on the Earth's cloud cover (Svensmark and Friis-Christensen, 1997, Tinsley, 1996, Pulkkinen et al., 2001); (4) modulation of the atmospheric properties induced by galactic cosmic rays (Gerhard et al., 2001) and modifications of the global electric circuit and cloud microphysics (Tinsley, 1996). Friss-Christensen and Lassen obtained a correlation of high statistical significance between the global land air temperature anomalies and the length of the solar activity cycle (Friis-Christensen and Lassen, 1991).

There is also some evidence, pointing to the geomagnetic activity forcing of the Earth's climate. Statistically significant correlation at 99% confidence level among geomagnetic activity and some climatic parameters, such as the sea level atmospheric pressure (Bucha and Bucha, 1998) and surface air temperature (Cliver et al., 1998) have been found. Significant positive correlation between geomagnetic activity and global surface air temperature has also been found thereby suggesting that the sensitivity of global temperature to geomagnetic activity indices may be real (El-Borie and Al-Thoyaib, 2006, Valev, 2006).

Although there is yet no conclusive physical mechanism by which the solar activity controls the Earth's climate, there is empirical evidence favouring the hypothesis of a long-term (decadal, multi-decadal and centennial) solar influence on Earth's climate change. On the time scales exceeding one year the change in Total Solar Irradiance (TSI) has been shown to be $\sim 0.1\%$ between the minimum and maximum of the solar cycle (Wilson, 1998) and there is a contention that larger TSI changes over longer time scales are possible (de Jager and Usoskin, 2006). However, there are not sufficient measurements on TSI yet to conclusively support the hypothesis. Nevertheless, it is suggested that the solar activity contribution can substantiate from a slight cooling to as large as 65% of the observed global warming (Scafetta, 2009).

Since climate change on Earth is of a great concern, it is pertinent to further augment this area of research featuring solar-geomagnetic activity influence on the Earth's climate. In the present work global and hemispheric SST anomalies have been analyzed in conjunction with 158 year long time series on the sunspot indices, R_z and geomagnetic activity indices, a_a for the period 1850–2007. An aspect that is worth mentioning here is the restriction to instrumental data that mostly exhibits red noise contrary to both red and white noise in a data set employing proxy data. This implies that the inferences made about the spectral features obtained by the analysis of this data is possibly subject to less uncertainty (Burroughs, 2001). Furthermore, the inclusion of reconstructed data on a_a for solar cycle 9 and 10 gives an extended coverage for two additional solar cycles. The use of this lengthy interval of data ensures good spectral resolution. Apart from significant positive correlations among these solar-geomagnetic indices and SST anomaly, MTM spectrum analysis besides confirming the classical periodicities of $\sim$ 79–80 years (Gleissberg's cycle) and $\sim$ 9–11 years (Schwabe solar cycle) in R_z, a_a and δt_g, also reveal fast cycle periods of $\sim$ (3–5) years in a_a and δt_g. MTM results were also cross checked with Maximum Entropy Method (MEM) of power spectrum analysis. Given the fact that MTM and MEM power spectrum analysis techniques have some limitations in recovering low frequency cycles precisely (Rigozo et al., 2005) and the 60 year period oscillations reported by some authors in recent studies of the ocean temperature (Klyashtorin et al., 2009, Scafetta, 2010) and surface air temperature (Souza Echer et al., 2009) data, the period of ~ 79 years reported here, in δt_g, possibly cannot be claimed to be accurate and decisive. We believe an error of about 20% or more can not be ruled out in the ~ 79 years low frequency (large period) cycle of global SST anomaly, δt_g, revealed by the present analysis.

Section snippets

Data used in the analysis

Examining the solar-geomagnetic influence on climate variations requires reliable and homogeneous data sets on sunspot numbers, (R_z), geomagnetic activity indices, a_a, global SST (δt_g) and hemispheric SST $(\delta t_n$ and $\delta t_s)$ records, respectively. The data used in the present analysis is covered in the following subsections:…

Methodology

The present study investigates the data by the method of correlation and MTM power spectrum analysis in order to evolve and support a well balanced formation of opinion concerning the possible link between solar–climate relationship. MTM power spectrum analysis has been chosen for the present investigation to recover the periodicities in the data, because it succeeds in isolating noise from signals eminently and has been in favor of many geophysical applications (Ghil et al., 2002). MTM is a…

Results and discussion

The data on the annual averages of sunspot indices, R_z and geomagnetic activity indices, a_a for the period 1844–2007 covering solar cycle 9–23 are shown in Fig. 1. From this figure the well known 11-year cyclic variation is evident in both R_z and a_a. However, a_a indices exhibit an upward trend that is not mirrored in R_z. This trend in a_a has been attributed to doubling of the solar coronal magnetic field related to Sun's luminosity (Lockwood et al., 1999). Furthermore, the geomagnetic activity a…

Conclusion

Analysis of 158 years (covering about 15 solar cycles) of the data available on instrumental records of global and hemispheric temperature anomalies $(\delta t_g, \delta t_n, \delta t_s)$ in conjunction with sunspots indices, R_z and geomagnetic activity indices, a_a has been carried out. Significant positive correlation exists between R_z and a_a when they are referred to long-term trends. On the long-term scale, the correlation between climatic parameters and the geomagnetic activity is much higher than the correlation…

Acknowledgment

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> *Citation Excerpt :*
> …Besides, since the end of 19th century sunspot numbers decrease while geomagnetic aa index continues increasing (Georgieva and Kirov, 2006). Whereas sunspots are responsible for closed magnetic field regions, aa index reflects the manifestations of solar activity associated with both closed and open magnetic field regions, or polar coronal holes – sources of high speed solar wind (Richardson and Cane, 2002; Mufti and Shah, 2011). Therefore, aa index reflects the changes in the solar wind and the heliospheric magnetic field responsible for the modulation of GCR.…

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