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Temporal derivative of Total Solar Irradiance and anomalous Indian summer monsoon: An empirical evidence for a Sun–climate connection

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Abstract

Identifying the pattern of natural climate variability is of immense importance to delineate the effects of anthropogenic climate changes. Global and regional climates are suspected to vary, in unison or with delays, with the Total Solar Irradiance (TSI) at decadal to centennial timescales. Here we show that the Indian summer monsoon rainfall correlates well with the temporal derivative of TSI on multi-decadal timescales. This linkage between the temporal derivative of TSI and the Indian summer monsoon is tested and corroborated both for the instrumental period (1871–2006) and for the last ~300 years using a speleothem $\delta^{18}O$ record representing rainfall in southwestern India. Our analyses indicate that anomalous dry periods of the Indian monsoon are mostly coincident with negative TSI derivative. This study thus demonstrates the potential of 'TSI derivative' as an important indicator of natural monsoon variability on an interdecadal timescale.

Highlights

► First study on the relationship of rate of change of total solar irradiance and terrestrial climate. ► Temporal derivative of Total Solar Irradiance (TSI) has been obtained for the past three centuries. ► Most severe droughts recorded in India were during the episodes of large negative TSI derivatives. ► Droughts during negative TSI derivative episodes supported by both instrumental and proxy data.

Introduction

Monsoonal precipitation in the densely populated countries of South Asia is a very important component of the global climate system, and has large socio-economic impacts (Khandekar, 2010 and references therein). In anticipated response to global warming caused by anthropogenic activity, several inconsistencies have been predicted to occur in precipitation patterns in both the All India Summer Monsoon Rainfall (AISMR), and globally (Goswami et al., 2006a, Ashfaq et al., 2009). Monsoon rainfall in south Asia is precariously balanced on several boundary conditions ranging from stratosphere to the depth of Indo-Pacific warm pools (e.g., Claud and Terray, 2007, Khandekar, 2009), so that even slight deviations from the normal climatology may result in a significant change in the distribution and amount of rainfall. Acknowledging the concern that anthropogenic activity may impact on global climate through changes in precipitation distribution, it is mandatory to understand the magnitude and pattern of natural variability in Indian monsoonal precipitation on interdecadal and longer timescales.

Numerous proxy based paleo-records from both the northern and the southern hemispheres reveal that intrinsic solar variability acts as a key player in governing decadal to millennial scale climate variation (Verschuren et al., 2000, Bond et al., 2001, Neff et al., 2001, Agnihotri et al., 2002, Burns et al., 2002, Agnihotri and Dutta, 2003, Fleitmann et al., 2003, Hu et al., 2003, Higginson et al., 2004, Gupta et al., 2005, Mangini et al., 2005, Mayewski et al., 2005, Wang et al., 2005, Sinha et al., 2007, Kurian et al., 2009). In addition, three recent studies that deal with changes in annually resolved precipitation or its direct manifestation (e.g., lake levels, stream flow of major rivers) reinforce the idea of solar-controlled or solar-modulated hydrologic changes (Bhattacharyya and Narasimha, 2005, Stager et al., 2007, Mauas et al., 2008, Mauas et al., 2010).

All these studies suggest that the relatively small changes in solar energy output represented by Total Solar Irradiance (TSI) control one or more drivers within the Earth's climate system (Shaviv, 2008) that result in the observed climate change (please see Section 3 below for discussion on other plausible solar drivers and physical mechanisms). The TSI, formerly known as the solar constant, amounts to ~1367 $W m^{-2}$ and is the wavelength-integrated energy of solar radiation received at the top of the Earth's atmosphere, within which perturbations occur in the amount and distribution of magnetic fluxes associated with sunspot variability and additional solar magnetic features (Fontenla et al., 1999, Trujillo Bueno et al., 2004). The Sun is brighter when sunspot numbers are high because brightening effect due to the faculae network outweighs the darkening effect of sunspots (Fontenla et al., 1999). *In-situ* TSI data measured by radiometers installed on satellites are available for the last ~40 years, and has been used by several researchers to reconstruct the annual variability in TSI over the last few centuries (Hoyt and Schatten, 1993, Lean et al., 2002, Krivova et al., 2007, Wang et al., 2005, Bard and Frank, 2006). Over one 11-year (Schwabe) cycle of sunspot activity, TSI varies by less than 1 $W m^{-2}$ from its mean value, which is a very small contribution to the net radiative forcing (Foukal et al., 2006, Gray et al., 2010). However, Harder et al. (2009), analyzing the 2004–2007 data from the Spectral Irradiance Monitor onboard the Solar Radiation and Climate Experiment satellite, pointed out recently that the observed solar irradiance variability is disproportionately larger in the UV wavelength (200–400 nm), up to almost 10 times larger than the extrapolation from the model of Lean (2000). This empirical result adds another layer of complexity in the physical processes involved in how the Earth's climate system responds to incoming changes in solar radiation. Nonetheless, evidences are now compelling that intrinsic solar variability plays a significant role in influencing Earth's climate, not only on the decadal (~11-year) sunspot cycle but also at longer (multi-decadal to centennial) timescales.

The TSI, though latitude independent, should properly be convolved with the strong annual and seasonal signals that arise from the progression of the Sun–Earth orbit. The outcome of such convolution should yield a modulated representation of the incoming seasonal solar radiation on decadal to centennial timescales (e.g., Soon, 2009). Soon (2009) has shown how TSI variability on multi-decadal to multi-centennial timescales may connect tropical to extra-tropical regions, and thereby systematically modulate the equator-to-Arctic transport of heat and moisture to influence the cryosphere and hydrology of the Arctic. The Arctic-North Atlantic-originated modulation of the freshwater budgets on multi-decadal to multi-centennial timescales, via the Atlantic thermohaline circulation with delays, ultimately in turn modulates tropical climate processes, including ENSO and both the South and East Asian monsoon (Delworth et al., 2007, Timmermann et al., 2007, Rajeevan and Sridhar, 2008, Wang et al., 2009). It is also clear that TSI-influenced modulations of sea surface temperature and land–sea contrast in the Indian and Western Pacific Oceans (van Loon et al., 2004) can reinforce or act against the effects of long-distance teleconnection between the North Atlantic and the Indian and East Asian monsoonal regions.

TSI changes are linked to sunspot number cycles, as part of which that several climate records have been found to vary in synchrony with sunspot number variability (Jagannathan and Bhalme, 1973, Hiremath and Mandi, 2004, Bhattacharyya and Narasimha, 2005, Stager et al., 2007, Claud et al., 2008, Mauas et al., 2008, Mauas et al., 2010). But the actual physical measure of energy change in the solar output is the TSI. Therefore, the fundamental question we are raising here: ‘can temporal variations in TSI on their own explain Earth's natural climate variability over the last few decades?’ (see e.g., the pioneering study by Mehta and Lau, 1997). If annual time series of AISMR data (Sontakke et al., 2008) are plotted against the corresponding TSI or sunspot number data (Fig. 1), a linkage between extra-terrestrial forcing and Indian monsoon variability is not conspicuously present. In order to understand exactly how TSI variability is linked to terrestrial climatic manifestation (e.g., AISMR), we use a new index of solar irradiance herein to show that the Sun–climate connection is deeply influenced by a steadily increasing or decreasing magnitude of TSI variations.

Using the annual reconstruction of TSI data of Krivova et al. (2007), we calculated the temporal derivative of the TSI series for the last ~300 years. Then we compared the annual time series data of AISMR (from 1871 to 2006) with the contemporaneous temporal derivative of TSI to test our hypothesis. This temporal derivative of TSI can be viewed as a measure of differential addition or subtraction of solar energy to the climate system at any given time, thus providing a useful measure for the study of climatic responses to changes in the incoming solar radiation.

Observed covariance and cross-spectral analyses appear to support our hypothesis, and thus prompted us to explore whether the observed linkage existed also in the pre-instrumental era. For this, we used the speleothem $\delta^{18}O$ record of regional monsoonal rainfall in Karnataka state published by Yadava et al. (2004) and compared it with our temporal derivative of TSI. Despite uncertainties of chronology, and the possibility of a smeared signal caused by the occasional mixing of inter-annual layers of carbonate, a significant covariance exists, demonstrating usefulness of the TSI derivative as an index for studying regional climate change at least over the last ~300 years. In addition, we also find several historically recorded droughts coinciding with negative TSI derivative periods. In aggregate, our analyses show that the temporal derivative of TSI provides a useful measure to assess the solar influence on monsoonal rainfall variability on the multi-decadal timescale over the last ~300 years.

Section snippets

Data analyses and results

To test our hypothesis, we adopted the recent TSI reconstruction by Krivova et al. (2007) for the last three centuries (AD 1700–2004). We focused on the instrumental period (AD 1871–2004). This reconstruction represents variations of the surface distribution of the solar magnetic field, calculated from the historical record of the sunspot number and using physical models that successfully reproduce three independent datasets, viz., TSI measurements available by satellites since 1978, total…

Discussion

There is an emerging consensus that intrinsic solar irradiance and magnetic forcing affect Earth's local and regional climate on decadal to centennial timescales, through one or more internal amplifiers (Gray et al., 2010). Meehl et al. (2009) recently modeled the amplification of the perturbations of 11-year solar cycles in the Pacific climate system. Meehl and colleagues mainly show that although globally averaged solar forcing at the top of the atmosphere of $0.2\,W\,m^{-2}$ is too small to affect…

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> …Many studies have been carried out attempting to find a possible association of solar activity with Indian rainfall. The direct and indirect effects were studied and the results were often localized and contradictory (Jagannathan and Bhalme, 1973; Jagannathan and Parthasarathy, 1973; Bhalme et al., 1981; Ananthakrishnan and Parthasarathy, 1984; Hiremath and Mandi, 2004; Bhattacharyya and Narasimha, 2005; Hiremath, 2006; Bhattacharyya and Narasimha, 2007; Lihua et al., 2007; Selvaraj et al., 2009; Agnihotri et al., 2011; Selvaraj and Aditya, 2011, 2012; Selvaraj et al., 2013; Hiremath et al., 2015; Badruddin and Aslam, 2015; Warrier et al., 2017; Malik and Brönnimann, 2018). In this paper, our objective is to explore the dominant periodicities present in annual values of sunspot number and rainfall over Kerala and to identify possible relationship between them.…

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