Journal of Advanced Research 8 (2017) 329–332

Contents lists available at ScienceDirect

Journal of Advanced Research

journal homepage: www.elsevier.com/locate/jare

Short Communication

# Long-term global temperature variations under total solar irradiance, cosmic rays, and volcanic activity

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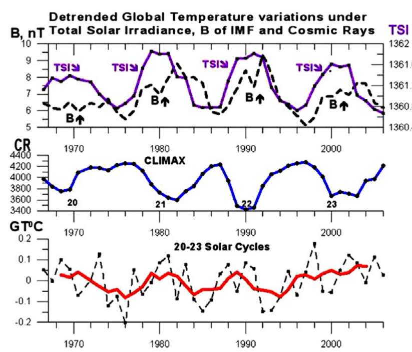
## GRAPHICAL ABSTRACT




ARTICLE INFO

*Article history:*
Received 30 October 2016
Revised 26 February 2017
Accepted 6 March 2017
Available online 14 March 2017

*Keywords:*
Global temperature
Total solar irradiance
Cosmic rays
Volcanic activity

ABSTRACT

The effects of total solar irradiance (TSI) and volcanic activity on long-term global temperature variations during solar cycles 19–23 were studied. It was shown that a large proportion of climate variations can be explained by the mechanism of action of TSI and cosmic rays (CRs) on the state of the lower atmosphere and other meteorological parameters. The role of volcanic signals in the 11-year variations of the Earth's climate can be expressed as several years of global temperature drop. Conversely, it was shown that the effects of solar, geophysical, and human activity on climate change interact. It was concluded that more detailed investigations of these very complicated relationships are required, in order to be able to understand issues that affect ecosystems on a global scale.


## Introduction

Numerous investigations carried out recently report apparent climate responses to the 11-year solar cycle, although the Sun's role for weather and climate remain a matter of controversy. Long-term global temperature variations can be exposed to different cosmophysical and geophysical factors. It has been suggested that the recent trend of global warming is mainly due to uncontrolled industrial activity. This trend is leading to irreversible changes in the atmosphere, hydrosphere and biosphere. The consequences of this process are also observed in seismic and volcanic activity. As hypothesized by Eddy [1], the climate variations might be due to the total solar irradiance. Total solar irradiance (TSI) is a measure of the solar energy flux. TSI describes the total radiant energy, in the form of electromagnetic radiation emitted by the Sun at all wavelengths, that falls for each second on 1 square meter outside the Earth's atmosphere, a value proportional to the "solar constant" introduced earlier in the previous century. Lean and Fröhlich [2] show that the radiative flux decreases when dark

Peer review under responsibility of Cairo University.
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http://dx.doi.org/10.1016/j.jare.2017.03.002
2090-1232/

sunspots are present on the disk, and increases due to bright faculae or plages. Fligge and Solanki [3], using a model of the total solar irradiance since 1700, found that long-term TSI variations exist due to the evolution of the solar network and other processes. However, these variations are not significant enough to explain climate change, especially on a scale as large as that of global warming. Since the discovery of galactic and solar cosmic rays, their influence on the Earth's climate has been subject to speculation, and now, cosmic ray activity as a possible mechanism affecting climate change is the subject of considerable debate. Cosmic rays (CRs) are high energy charged particles, originating in outer space, that travel at nearly the speed of light and strike the Earth from all directions. Cosmic rays can be divided into two types: galactic cosmic rays (GCRs) and solar energetic particles (SEPs). GCRs are high energy particles originating outside the solar system, whereas SEPs are high energy particles (predominantly protons) emitted by the Sun, primarily in solar particle events. However, the term "cosmic ray" is often used to refer only to the GCR flux. Recent studies by Pudovkin and Raspopov [4], Tinsley [5], and Swensmark [6], have shown that the Earth's cloud coverage is strongly influenced by cosmic ray intensity. Conditions in interplanetary space, which can influence GCRs and climate change, have been studied in numerous works. As has been demonstrated by Biktash [7], the long-term CR count rate and global temperature variations in 20–23 solar cycles are modulated by solar activity and by the IMF (interplanetary magnetic field). A possible geophysical factor which is able to affect the influence of solar activity on the Earth's climate is volcanism. The effects of volcanism can lead to serious consequences in the atmosphere and the climate, as shown by Robock [8]. A study of solar activity influence on global air–surface temperature with and without volcanic impact is presented by Barlyaeva et al. [9]. The main findings and mechanisms have implications for the question of where and how the Sun exerts influence on the climate system.

The purpose of this work is to find out whether there are decadal variations in the Earth's climate, try to establish their spatial and temporal distribution, and how this distribution comes about. The findings will then be used in the important task of finding a possible explanation for the contradictory results presented in literature studies of the impact of solar activity on the Earth's climate. Volcanic signals in the 11-year variations of the Earth's climate are discussed, with a final proposal suggesting that solar, human and volcanic activity extert a combined effect on the Earth's climate.

## Data and method

The sunspot numbers (SSN), global surface air temperatures (GSAT), TSI, interplanetary magnetic field (IMF), cosmic rays annual means data during solar cycles 19–23 are used for studying long-term air temperature variations. The IMF and SSN data were obtained from the OMNI database http://omniweb.gsfc.nasa.gov/. TSI data are used from https://www.ngdc.noaa.gov/. CR data were taken from the Climax (http://ulysses.sr.unh.edu) neutron monitor and annual means of air temperature were obtained from http://data.giss.nasa.gov/gistemp/. The air temperature trend is analyzed by the least square fit to the linear relation $y = bx + a$, where y is GSAT, x is years of trend study.

## Results and discussion

Camp and Tung [10] obtained a global warming signal attributable to the 11-year TSI cycle. It was found that there was a globally averaged warming of objectively almost 0.2 K during solar max as compared to solar min. More importantly, they established that the global-temperature response to the solar cycle is statistically significant at over 95% confidence level. The spatial pattern of the warming is of interest, as it shows the polar amplification also expected for the greenhouse effect. The statistical significance of such a globally coherent solar response at the surface was established first time by Camp and Tung [10]. The result of this paper is open to debate, as several interpretations can be suggested from the graphs and conclusions. It should also be noted that the current finding contradicts our previous results [7]. Camp and Tung [10] show the detrended temperature variations in K and show ±0.2 K during solar max and solar min, whereas our calculation of detrended GSAT demonstrates ±0.1 °C variations. It is important to carry out a secondary analysis to compare results presented before [7,10]. The detrended annual means of GSAT variations (denoted as GT) throughout of solar cycles was calculated by the expression $GT = 0.016X - 0.11$ [7] with the high correlation ($R = 0.86$) for the trend removal. It was shown that the GT variations are very small and their running average changes from +0.1 °C to −0.1 °C during solar cycle 20–23. For these solar cycles, our calculations of SSN, CRs and IMF B (B is module of interplanetary magnetic field) trends do not show a significant effect, whilst the GSAT trend is very large, and significant. Fig. 1 shows the annual variations of SSN (Panel a), GSAT (dashed line in Panel b) and its trend. It should be noted that GSAT does not have a trend during solar cycle 19, and varies according the solar cycle. Detrended GSAT (thick curve in Fig. 1) and its running average variations (solid curve) changes from +0.1 °C to −0.1 °C and is reduced by about 50% compared to Camp and Tung's results [10].

Thus, the relationship of SSN and GT supports the argument that climate variations might be due to the TSI. The change in the amount of solar energy entering the lower atmosphere should lead to a change in the temperature of the atmosphere. However, there is a large gap between the energy of atmospheric processes and the TSI changes. It is now generally accepted that centennial modulation of 11 year TSI driving alone is too small to explain global warming. TSI measurements differ widely in experiments, and show unusual behaviour of ultraviolet irradiance during solar cycles. For these reasons, the Sun's role in observed global warming has remained a matter of controversy. The disparity of the findings and the lack of established physical mechanisms that could amplify energetically weak TSI variations results in a confusing state of affairs.

Let us consider, one after another, the effects of TSI, CRs, and volcanic activity in the course of development of solar activity cycles for a clear explanation of the effect on detrended GSAT. Fig. 2 shows GT (Panel a, dashed curve), and its running average variations (Panel a, solid curve). Annual means of the IMF B and TSI are presented in Panel b; CR variations are presented in Panel c (CLIMAX measurements). It is clearly evident that GT varies accordingly to TSI and opposite to CRs. It is apparent that the rising of GT during solar maxima is a result of these processes. The physical mechanism of the influence of TSI on GT variations can be represented from Fig. 2 as follows. As has been pointed out and cited above, the Earth's atmosphere varies in transparency with the level of solar activity under modulated streams of CRs. In these conditions the cloud cover in the atmosphere is decreased during solar maxima and increased during solar minima. TSI energy entering to the Earth's atmosphere owing to CR variations has a different effect on GT, even though TSI is small variated or constant. Thus, having established the existence of a solar cycle effect on the main part of climate variations, unequal energy input of TSI to the lower atmosphere can be explained as a result of cloud cover variation during a solar cycle under the variation of the intensity of the cosmic ray fluxes. Therefore, enhanced cloud cover in solar min acts as gray filter which blocks part of TSI falling on the Earth's surface and GT is reduced.