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Global water cycle and solar activity variations

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ABSTRACT

The water cycle is the most active and most important component in the circulation of global mass and energy in the Earth system. Furthermore, water cycle parameters such as evaporation, precipitation, and precipitable water vapour play a major role in global climate change. In this work, we attempt to determine the impact of solar activity on the global water cycle by analyzing the global monthly values of precipitable water vapour, precipitation, and the Solar Modulation Potential in 1983–2008. The first object of this study was to calculate global evaporation for the period 1983–2008. For this purpose, we determined the water cycle rate from satellite data, and precipitation/evaporation relationship from 10 years of Planet Simulator model data. The second object of our study was to investigate the relationship between the Solar Modulation Potential (solar activity index) and the evaporation for the period 1983–2008. The results showed that there is a relationship between the solar modulation potential and the evaporation values for the period of study. Therefore, we can assume that the solar activity has an impact on the global water cycle.

1. Introduction

The Sun is the star closest to our planet, and is the central source of energy for the Earth's climate system. The Earth receives, on average, 342 W/m^2 of solar power at the top of the atmosphere, where observations show that solar energy varies according to processes occurring on the Sun, which lead to different solar output variables received by the atmosphere, consequently leading to changes in Earth's climate system.

The study and investigation of the relationship between solar activity and terrestrial weather/climate, along with the different impacts of solar variability on Earth's climate, are of interest to various scientific fields. Many studies have dealt with the relationship between solar output (cosmic ray flux, sunspot numbers, irradiance, solar wind, solar flares, and brightness) and atmospheric parameters (temperature, precipitation, amount of clouds, precipitable water vapour) or atmospheric phenomena (North Atlantic Oscillation, El-Nino, atmospheric circulation, monsoons). Svensmark and Friis-Christensen (1997) suggested a modulation of the Earth's total cloud cover by variations in the galactic cosmic ray (GCR) flux. This hypothesis was subsequently modified by Marsh and Svensmark (2000), by linking the GCR flux to low clouds, which have a particular strong cooling effect on climate. Kristjánsson et al. (2004) asserted that the GCR flux has decreased throughout the 20th century, causing a decrease in low cloud cover by more than 8% and a significant fraction of the observed global warming (see review by Kristjánsson et al., 2004). The global atmospheric electric circuit is considered as a useful tool for studying the influence of solar activity on the weather and climate on Earth (Rycroft et al., 2000). Svensmark (2000) confirmed that solar activity is causing the annual temperature variations on Earth by demonstrating the correlation between the cosmic ray flux and the variations in Earth's cloud cover. Svensmark claimed if the influence of cosmic rays on clouds is real, then the ionisation produced by GCR affects the microphysics in cloud formation. Carslaw et al. (2002) provided further explanation on the influence of cosmic rays on cloud formation, and suggest further laboratory studies at the mechanistic level to understand these ion–aerosol–cloud interactions. Tsiropoula (2003) stated that the similarities of periodicities between several solar activity indices and different meteorological parameters are evidence of the relationship between solar activity and climate. In contrast, Kristjánsson et al. (2004) asserted that the correlation between low cloud cover and solar irradiance (positive feedback) is better than between low cloud cover and sunspot number. There is a significant solar signal in the troposphere, and it depends on latitude and longitude (De Jager, 2005). Courtillot et al. (2007) suggested that Earth's magnetic field may affect the climate. In addition, there is no clear relationship between cosmic rays and clouds since the low cloud–cosmic ray correlation is affected by higher clouds in some geographical regions where low clouds may

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also affect the relationship between higher clouds and cosmic rays in some regions (Usoskin et al., 2006). Pierce and Adams (2009) reached a similar conclusion about the ion–aerosol clear–air mechanism, suggesting that it is too weak to explain the putative correlations between the cloud cover and the solar cycle. Hiremath and Mandi (2004) and Hiremath (2006) discovered that Indian rainfall is correlated with the sunspot activity. Rainfall variability has a significant positive correlation with the sunspot activity during the corresponding period. Decreasing solar activity and/or increasing cosmic ray intensity are associated with higher rainfall, along with the lower temperature of Indian summer monsoon (Badruddin et al., 2009). Solar activity is one of the reasons for climate change (Gray et al., 2010; Lockwood, 2012; Solanki et al., 2013). Georgieva et al. (2012) established the different effects of two types of solar activity (sunspot number/geomagnetic activity indices) on atmospheric circulation, and their influence is opposite to the changes in North Atlantic Oscillation. Rampelotto et al. (2012) indicated that temperature and rainfall time series show similar frequencies; at low frequencies, the 22-year solar cycle is an important factor in climate modulation during the analysed period. The relationship between the Indian temperature anomalies and the solar activity (SSN) provides evidence in favor of the mechanism that depends not only on the level of sunspot activity, but also on the solar polarity (Aslam et al., 2014). Todorović and Vujović (2014) studied the relationship between solar activity (solar wind) and meteorological parameters (cold fronts, precipitation, and temperature drop on the surface and in higher layers of the atmosphere). These scholars confirmed that the time intervals between two occurrences of some meteorological parameters correlate with the solar wind and the A-index.

The aim of this work is, first, to estimate the global evaporation rate for the period 1983–2008 based on using satellite data of precipitable water vapour, and then, to investigate the relationship between the Solar Modulation Potential (as the solar activity index) and the evaporation for the period 1983–2008.

2. Solar activity

Solar activity is a set of processes and phenomena that occur in the photosphere and chromosphere, associated with changes in the solar magnetic fields, such as sunspots, prominences, and coronal disturbances. Sunspots cannot be considered as the only indicator of solar activity, as there are solar activity phenomena that do not coincide with sunspots, such as the appearance of magnetic flux tubes and the variations in the global solar magnetic field. Before the 1970s, solar activity was estimated using proxy variables, such as tree rings, ice cores, and sunspots. After the 1970s, solar activity has been measured via satellites through proxy variables such as the total spectral irradiance.

2.1. Wolf number or sunspots number

Sunspots are among the most visible manifestations of solar activity, thus their characteristics are the most common quantitative measure of the solar cycle. In the method of the Swiss astronomer R. Wolf, the total number of spots visible on the face of the sun and the number of groups into which they cluster are counted as

$$R = k(10g + s)$$

where g is the number of sunspot groups and s is the total number of distinct spots. The scale factor K (usually less than unity) depends on the observer, and is intended to normalise the conversion to the scale originated by Wolf. This index of relative number of spots, later called 'Wolf's numbers' series starts in 1749, and ranges from zero, an activity minimum to more than one hundred units, a maximum (Usoskin, 2008; Hathaway, 2010).

2.2. Solar flux at 10.7 cm

The solar radio flux at 10.7 cm (2800 MHz) is the most reliable indicator of solar activity. Since 1963, the F10.7 index has been measured in solar flux units (sfu), where the unit sfu is 10^{-22} W/(m^2 Hz). F10.7 ranges 50–300 sfu, and this index has a physical meaning greater than the index sunspot number, because the intensity of the ionising solar radiation is proportional to the change of the radio emission intensity in this range (http://www.swpc.noaa.gov). David Hathaway in 2010 (Hathaway, 2010) showed that F10.7 lags behind R by one month.

2.3. Solar Modulation Potential (SMP)

Galactic cosmic rays (GCR) that enter the heliosphere are affected by both the interplanetary magnetic field and the solar wind. Consequently, it causes the modulation of their total flux and the differential energy spectrum as measured in the vicinity of periods of high solar activity. This process does not allow a direct application of the force field method to investigate the heliospheric transport of cosmic rays (Usoskin et al., 2005). Finally, SMP values are estimated using a long-term data series of cosmic ray measurements, balloon-borne data of the ionising radiation in the stratosphere, obtained by the Lebedev Physical Institute (Usoskin et al., 2011).

3. Data and method

In this paper, we analyse the global monthly precipitable water vapour (PWV) (mm) in 1983–2008 as given by the International Satellite Cloud Climatology Project (ISCCP-D2) dataset (http://isccp.giss.nasa.gov) in a 2.5° × 2.5° geographical grid. Precipitable water vapour is the total atmospheric water vapour contained in a vertical column of a unit cross-sectional area extending between any two specified levels, expressed in terms of the height to which that liquid water would stand if completely condensed and collected in a vessel of the same unit cross section. PWV is a very important parameter for studying the influence of solar activity on the hydrological cycle. Additionally, the amount of water vapour in the atmosphere indicates the changes in weather and cloud formation. Here, we use the global monthly precipitation rate (P) (mm/day) in 1983–2008 as given by the Global Precipitation Climatology Project (GPCP-Version 2.2) dataset (http://www.esrl.noaa.gov) in the 2.5° × 2.5° geographical grid. Precipitation indicates climate change, and is considered as the most important component of the hydrological cycle. As precipitation and precipitable water vapour constitute the Water Cycle Rate (WCR), this paper uses monthly values of the Solar Modulation Potential (SMP) in 1983–2008 during the solar cycle 22–23 as given by Usoskin et al. (2011). SMP is the solar activity index of GCR. However, the SMP is considered as a more credible indicator of solar activity, because, like the GCR it originates outside of the Earth's sphere. Fig. 1a shows the Sun Spot Number (SSN) with the 10.7 cm solar flux in 1947–2010 with a correlation coefficient of 0.97, and Fig. 1b shows the SSN with the SMP in 1947–2010 with a correlation coefficient of 0.75. Although the correlation between SSN and SMP is weaker than SSN/F10.7, the SMP parameter is used here because it has a clear physical explanation and can be used by numerical models as an input parameter.

The monthly mean gridded climatic PWV and P data were averaged globally and yearly for period 1983–2008. The widely known package Climate Data Operator (CDO) was used for this