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Effect of solar activity on the repetitiveness of some meteorological phenomena

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Abstract

In this paper we research the relationship between solar activity and the weather on Earth. This research is based on the assumption that every ejection of magnetic field energy and particles from the Sun (also known as Solar wind) has direct effects on the Earth's weather. The impact of coronal holes and active regions on cold air advection (cold fronts, precipitation, and temperature decrease on the surface and higher layers) in the Belgrade region (Serbia) was analyzed. Some active regions and coronal holes appear to be in a geo-effective position nearly every 27 days, which is the duration of a solar rotation. A similar period of repetitiveness (27–29 days) of the passage of the cold front, and maximum and minimum temperatures measured at surface and at levels of 850 and 500 hPa were detected. We found that 10–12 days after Solar wind velocity starts significantly increasing, we could expect the passage of a cold front. After eight days, the maximum temperatures in the Belgrade region are measured, and it was found that their minimum values appear after 12–16 days. The maximum amount of precipitation occurs 14 days after Solar wind is observed. A recurring period of nearly 27 days of different phases of development for hurricanes Katrina, Rita and Wilma was found. This analysis confirmed that the intervals of time between two occurrences of some particular meteorological parameter correlate well with Solar wind and A index.

Keywords: Solar activity; Solar wind; Sun–weather relationship; Cold air advection; Repetitiveness; Tropical cyclones

1. Introduction

Active regions and coronal holes can persist on the Sun for a number of rotations. Coronal holes dominate on the corona around and during the minimum of solar activity, while active regions dominate during the maximum of solar activity. The Sun has its rotation period of 27 days, meaning the effects on the Earth caused by a persistent coronal hole will exhibit a 27-day cycle. Coronal holes tend to be geo-effective (i.e. to have effect on the Earth) only when they are located near the solar equator, at a longitude of around 30° west of the Sun's central meridian, and when they are on the earthward hemisphere of the Sun (http://www.ips.gov.au/Solar/6/1). The effect on Earth depends on the heliographic position of the eruptions, as well as the conditions in interplanetary space (Landscheieidt, 2000). The effect depends also on solar activity intensity. Tlatov (2014) proposed that in several subsequent double cycles the odd cycles should be weaker than their preceding even cycles.

The main large-scale solar phenomena that affect planetary bodies the most are solar flares, coronal mass ejections (CMEs) and fast Solar winds originating in coronal holes (Mendoza, 2011). They affect our planet at different time intervals, from short time intervals of a solar storm (from a few hours to a few days) to solar cycles taking place over

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the course of several years (11 or 22 years). The relationship between meteorological phenomena and space weather has been a popular topic of research (Heredia and Elias, 2013; Aslam and Badruddin, in press). Among meteorological phenomena, tropical cyclones have attracted much attention due to their destructive effects. Nyberg et al. (2007) suggested that peaks and trends of major north Atlantic hurricane activity correlate with lower total solar irradiance (i.e. lower solar activity), and vice versa, notably during several periods between 1730 and 2005. Some papers include not only sunspot number but also other solar activity-associated phenomena. Mendoza and Pazos (2009) showed that the highest significant correlations occur between the Atlantic and Pacific hurricanes, and Dst index. The Dst index is a geomagnetic index that measures worldwide magnetic storm levels, and is constructed by averaging the horizontal component of the geomagnetic field from mid-latitude and equatorial magnetograms from four stations. Most importantly, oceans present the highest hurricane-Dst relations during the ascending part of odd solar cycles, and the descending phase of even solar cycles. Conversely, for the ascending part of even cycles and descending part of odd cycles, the relationship is low. Comparing cyclonic activity at middle and subpolar latitudes, the North Atlantic cyclones also show a correlation with solar activity: long-period variations in the cyclonic activity along 1874–1995 indicate oscillations of the surface pressure with periods close to the main periods of solar activity (∼80 and ∼11 years, Veretenenko et al., 2007).

At present, there are two primary proposed solar-related mechanisms to account for the relation between space weather and climate: solar and ultraviolet radiation, and solar-modulated energetic particles (Mendoza, 2011). An active Sun warms the lower stratosphere and upper troposphere through ozone absorption of ultraviolet radiation. A warming response to it in the upper troposphere leads to a decrease in convective available potential energy in the atmosphere, leading to a weaker cyclone (Elsner and Jagger, 2008). Shindell et al. (2001) suggested that general circulation models show that changes in the stratosphere, induced by interactions between UV rays and the ozone, may penetrate down to the troposphere, affecting winds and sea level pressure. Increased solar radiation during solar maximum increases sea level pressure, which results in weaker easterly winds and therefore weaker vertical wind shear, in turn promoting more hurricanes (Nyberg et al., 2007). Regarding the role of solar-modulated energetic particles, there is a possible triggering mechanism for condensation and freezing within convective clouds of the cyclone (see review by Tinsley (2000)). The ionization of the upper part of a storm leads to additional latent heat release and additional warming of the cyclone core. The warming of the cyclone core is associated with the lowering of the surface pressure and therefore with the intensification of cyclones (Kavlakov et al., 2008).

There are no important large active regions with strong magnetic structures at the end of the 11-year solar cycle (so called the quiet Sun). Coronal holes dominating at the end of a cycle are much easier to perceive the influence of. When a coronal hole or an active region is approaching a geo-effective position, slow permanent Solar wind (SW) becomes stronger, and its effects on the Earth can be expected in 2–3 days (Lilensten and Bornarel, 2006). Elsner and Kavlakov (2001) confirmed a statistically significant relation between initial baroclinity in cyclones (hurricanes) and 11-day average values of Kp index.

The aim of the research was an establishment of guidelines that could aid in creating a method of long-range weather forecasts based on solar parameters. Attempts were made to find time correlations between particular solar parameters and meteorological parameters. In Section 2 we give a description of the data used. Section 3 gives an analysis of the influence of different coronal holes on the weather in Belgrade. Section 3.1 gives an analysis of the impact of one coronal hole in three successive Sun's rotation. Section 3.2 provides an analysis of the influence of five coronal holes in consecutive Sun's rotations and some particularly strong active regions. The obtained results suggest the existence of a relationship between SW and penetration of cold air in the Belgrade region. If one such principle could apply to a particular area, then it could apply to any region in the world. The time gap of correlations should have different values for the different regions and would be specific to the particular region. As an example, lawfulness of repetitiveness of tropical cyclones at Atlantic in 2005 is given (tropical cyclones Katrina, Rita and Wilma) in the third part of the article.

2. Material and methods

Geomagnetic storms are a natural hazard often causing electrical utility blackouts over a wide geographic area. The question is how these storms influence weather conditions on Earth. The idea was to find a time correlation between energy ejections from Sun, from CH, and active regions in geo-effective position (SW) and the passage of the cold fronts over the Belgrade region. In trying to find the trend, we began by taking the SW data from satellite ACE, and analyzed the time between a strong increase of SW appearance and the passage of a cold front over the Belgrade region. The solar data, i.e. CH, SW, planetary A index and active regions data were taken from www.xlc.com/solar/coronal_holes.html, http://umtof.umd.edu/pm/flare/, and http://www.solen.info/solar. Surface meteorological data was taken from the Meteorological Observatory in Belgrade ($\varphi = 44°48'$N, $\lambda = 20°28'$E, h = 132 m) and sounding data was taken from the meteorological station Belgrade-Košutnjak station ($\varphi = 44°46'$N, $\lambda = 20°25'$E, h = 203 m). In that way, we acquired surface temperature, pressure, and wind, as well as temperature, pressure, and wind at different heights.