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Impact of Solar Plasma on Earth's Magnetosphere and Earth Space Environment

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Abstract. The Earth's magnetosphere and upper atmosphere can be greatly perturbed by variations in the solar plasma and magnetic field caused by disturbances on the Sun. The state of near-Earth space environment is governed by the Sun and is very dynamic on all spatial and temporal scale. The geomagnetic field which protects the Earth from solar wind and cosmic rays is also essential to the evolution of life; its variations can have either direct or indirect effect on human physiology and health state even if the magnitude of the disturbance is small. Geomagnetic storms are seen at the surface of the Earth as perturbations in the components of the geomagnetic field, caused by electric currents flowing in the magnetosphere and upper atmosphere. Ionosphere and thermosphere storms also result from the redistribution of particles and fields. Global thermosphere storm winds and composition changes are driven by energy injection at high latitudes. Storm effects may penetrate downwards to the lower thermosphere and may even perturb the mesosphere. Many of the ionosphere changes at mid-latitude can be understood as a response to thermosphere perturbations. The transient bursts of solar energetic particles, often associated with very large solar flares, have been observed to have effects on the Earth's middle and lower atmosphere, including the large-scale destruction of polar stratospheric and troposphere ozone. In the present, we have discussed effect of solar influences on earth's magnetosphere and upper atmosphere that are useful to space weather and global warming.

1. Introduction

Climate change perceived as the biggest global threat of the 21st century. Climate change holds the significant changes in physical and biological systems in all the continents and oceans. It also threatens to destabilize natural phenomena on a regional as well as global scale; some warning signs are already visible. Unprecedented occurrence of severe droughts, heat waves, storms, heavy precipitation, floods, cyclones, shifts in climate zones and seasonality, and increase in sea level and temperature have been reported from various regions of the globe. As these ill effects intensify, they will increasingly cause stress to our ecosystems and tribulations to the livelihood and resources of islands, beaches and coasts. The deterioration of the earth's ecosystems will jeopardize human health; precipitation patterns; water and food supplies; energy supplies; and the integrity of natural systems.

2. Geomagnetosphere and upper atmosphere

The geomagnetosphere and upper atmosphere can be greatly perturbed by variations in the solar luminosity caused by disturbances on the Sun. The state of near-Earth space environment is governed by the Sun and is very dynamic on all spatial and temporal scales (Bothmer&Daglis 2006). The geomagnetic field which protects the Earth from solar wind and cosmic rays is also essential to the evolution of life; its variations can have either direct or indirect effect on human physiology and health state even if the magnitude of the disturbance is small. Geomagnetic storms are seen at the surface of the Earth as perturbations in the components of the geomagnetic field, caused by electric currents flowing in the magnetosphere and upper atmosphere. Ionosphere and thermosphere storms also result from the redistribution of particles and fields. Global thermosphere storm winds and composition changes are driven by energy injection at high latitudes. Storm effects may penetrate downwards to the lower thermosphere and may even perturb the mesosphere. Many of the ionosphere changes at mid-latitude can be understood as a response to thermosphere perturbations. The transient bursts of solar energetic particles, often associated with very large solar flares, have been observed to have effects on the Earth's middle and lower atmosphere, including the large-scale destruction of polar stratospheric and troposphere ozone.

3. Solar impacts

The solar activities vary with 11-year sunspot cycles. The measurements made with a solar telescope from 1976 to 1980 showed that during this period, as the number and size of sunspots increased, the Sun's surface cooled by about 6° Celsius. Apparently, the sunspots prevented some of the Sun's energy from leaving its surface. However, these findings tend to contradict observations made on longer time's scales. Observations of the Sun during the middle of the Little Ice Age (1650-1750) indicated that very little sunspot activity was occurring on the Sun's surface. The Little Ice Age was a time of a much cooler global climate and some scientists correlate this occurrence with a reduction in solar activity over a period of 88 or 176 years. Measurements have shown that these 88 and 176 year cycles influence the amplitude of the 11 year sunspot cycle. It is hypothesized that during times of low amplitude, like the Maunder Minimum, the Sun's output of radiation is reduced. Observations by astronomers during this period (1645-1715) noticed very little sunspot activity occurring on the Sun. During periods of maximum sunspot activity, the Sun's magnetic field is strong. When sunspot activity is low, the Sun's magnetic field weakens. The magnetic field of the Sun also reverses every 22 years, during a sunspot minimum. The Milankovitch theory suggests that normal cyclical variations in three of the Earth's orbital characteristics are probably responsible for some past climatic change. Periods of a larger tilt result in greater seasonal climatic variation in the middle and high latitudes. At these times, winters tend to be colder and summers warmer. Colder winters produce less snow because of lower atmospheric temperatures. As a result, less snow and ice accumulates on the ground surface. Moreover, the warmer summers produced by the larger tilt provide additional energy to melt and evaporate the snow that fell and accumulated during the winter months. In conclusion, glaciers in the polar regions should be generally receding, with other contributing factors constant, during this part of the obliquity cycle.

3.1 Long-term variability of total solar irradiance (TSI)

The total solar irradiance (TSI) is integrated solar energy flux over the entire spectrum which arrives at the top of the atmosphere at the mean Sun-Earth distance. The TSI observations show variations ranging from a few days up to the 11-year sunspot cycle and longer timescales (Lockwood and Fröhlich, 2008). TSI has been monitored from 1978 by several satellites, e.g. Nimbus 7, Solar Maximum Mission (SMM), the NASA, Earth Radiation Budget Satellite (ERBS), NOAA9, NOAA 10, Eureca and the UARS (Upper Atmospheric Research Satellite) etc. The Solar Radiation and Climate Experiment (SORCE), a NASA-sponsored satellite mission was launched to measurements of TSI. SORCE carries four instruments including the Spectral Irradiance Monitor (SIM), Solar Stellar Irradiance Comparison Experiment (SOLSTICE), Total Irradiance Monitor (TIM), and the XUV Photometer System (XPS). The TIM is TSI measurements monitor the incident sunlight to the Earth's atmosphere using an ambient temperature active cavity radiometer. The historical reconstruction of more recently accepted TSI absolute value is described by Kopp and Lean (2011) based on new calibration and diagnostic measurements by using TIM V.12 data on 19th January 2012, and find that decadal TSI variation trend follows with sunspot number within a limit, except Maunder Minimum period. The centurial variation trends of TSI have not shown clear association. Surface temperatures and solar activity both increased during the past 400 years, with close associations apparent in pre- and post-industrial epochs (Hoyt and Schatten, 1993; Lean et al., 1995; Reid, 1997). However, the inference from correlation studies that Sun-climate relationships can account for a substantial fraction of global warming in the past 150 years is controversial.

TSI are known to be linked to Earth climate and temperature. Accurate TSI measurements from the last 25 years are correlated with sunspots and faculae. These correlations can then be used to extrapolate the TSI to time periods prior to accurate space-borne measurements, since the solar records extend back 100 years for faculae and 400 years for sunspots. Proxies of the TSI based on sunspot observations, tree ring records, ice cores, and cosmogenic isotopes have given estimates of the solar influence on the Earth that extend back thousands of years, and correlate with major climatic events on the Earth. This extrapolation is important for understanding the relationship between TSI and the Earth's climate. The variation of TSI measured by several satellites (composite) from 1976 onwards and their association with yearly mean SSN is shown in **Figure 1**. The data of TSI were taken from SOURCE website (http://lasp.colorado.edu/sorce/index.htm) computed by Kopp and Lean (2011). From this plot, it is find that variation trend of TSI follows with 11-year sunspot cycle during the period 1976 onwards.

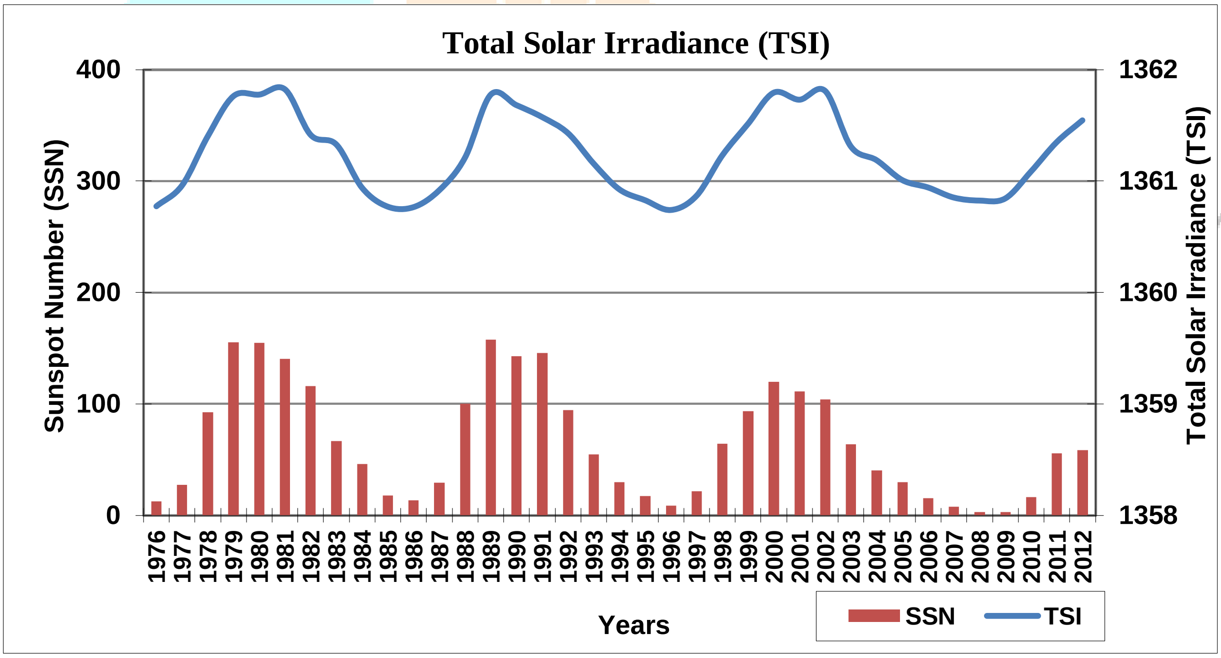

Figure 1 Showsthe variation of TSI measured by several satellites (composite) from 1976 onwards and their association with yearly mean sunspot number.

3.2 Long-term variability of solar energetic particle events (SPEs)

The solar energetic particle (SPEs) events are the energetic outbursts as a result of acceleration and heating of solar plasma during SFs and CMEs. SPEs events associated with SFs are called impulsive where as those associated with CMEs are gradual. SPEs events occur when high-energy protons are ejected from the Sun's surface during fast solar eruptions and causes geomagnetic and ionosphere disturbances on large scale. These effects are similar to auroral events, the difference being that electrons and not protons are involved. These events typically occur at the north pole, south pole, and South Atlantic magnetic anomaly, where the Earth's magnetic field is lowest. The more severe SPEs events can cause widespread disruption to electrical grids and the propagation of electromagnetic signals. Occurrence of SPEs events are varies with 11-year sunspot cycle. In the present section, we investigate the association of SPEs events on long-term basis. An association of occurrence of SPEs events (E ≥10 MeV) with 11-year sunspot cycle is plotted in **Figure 2**. We haven't shows very significant associations between the yearly occurrences of SPEs events with 11-year sunspot cycle except solar cycle 22. SPEs events are an important cause to produce geomagnetic and ionosphere disturbances on large scale. The more severe SPEs events can cause widespread disruption to electrical grids

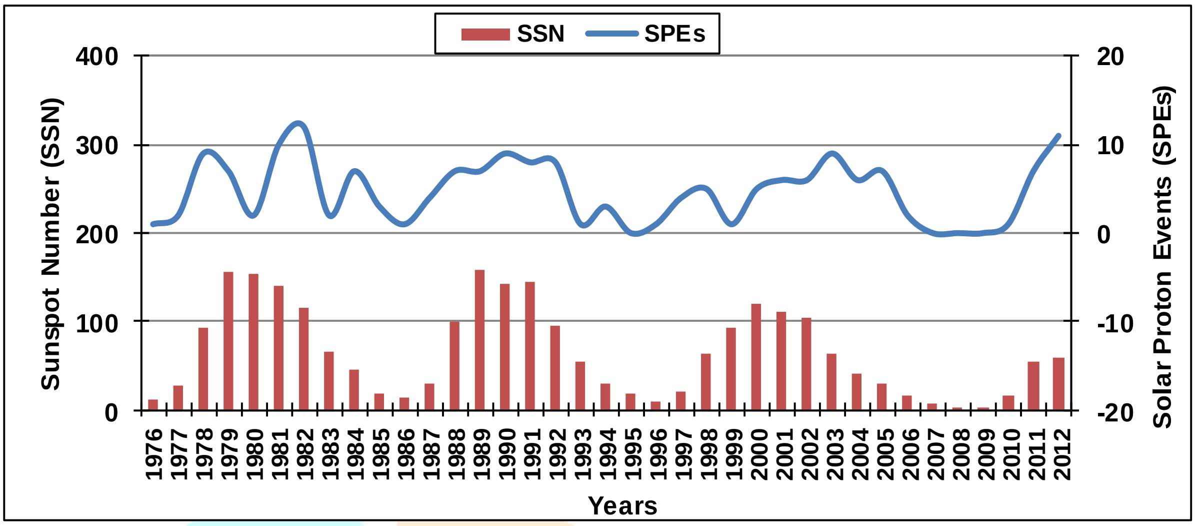

Figure 2 Shows the association of SPEs Events (E ≥10 MeV) and their association with 11-year sunspot cycle, observed during the period 1976 onwards.

3.3 Long-term variability of solar radio flux (SRF)

The Sun emits radio energy with slowly varying intensity. This solar radio flux (SRF), which originates from atmospheric layers high in the Sun's chromospheres and low in its corona, changes gradually from day to day in response to the number of sunspot groups on the solar disk. SRF from the entire solar disk at a frequency of 2800 MH_z has been recorded routinely by radio telescope near Ottawa since February 1947. Associations of SRF with annual mean SSN for the period 1976 onwards are plotted in **Figure 3**. We find that the yearly occurred value of SRF varies with 11-year sunspot cycle as similar as variation of solar transients. A difference between the first and second maxima for solar cycle on the one hand and SRF on the other is intriguing. If the radio emission is associated with sunspots, the relative values of the first and second maximum should be similar, at least qualitatively, for both. However, decimetric frequencies would-be from bremsstrahlung and may not follow sunspots. Between the radio emissions themselves, there is no consistency.

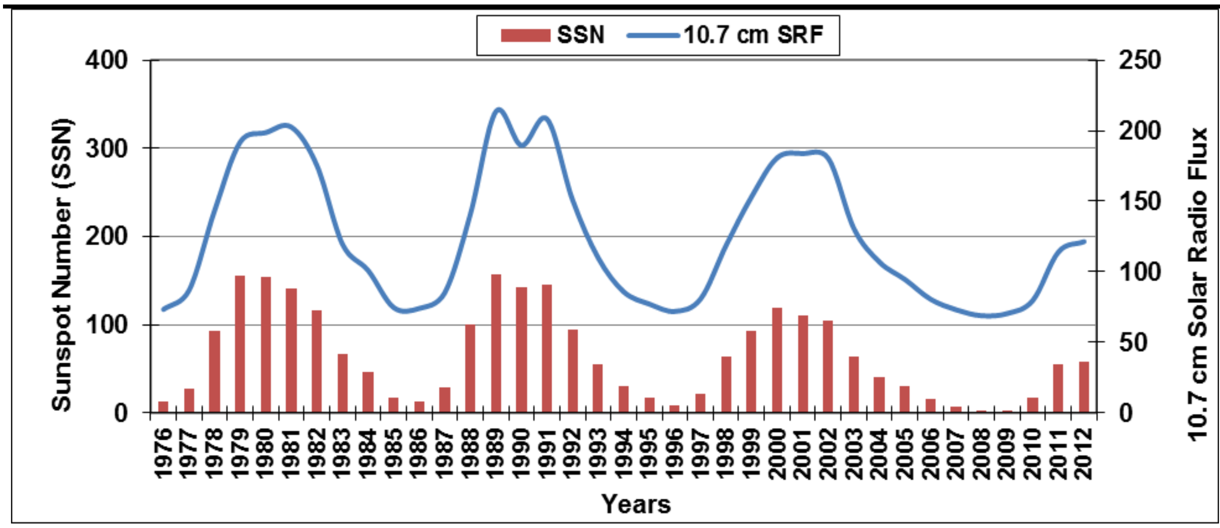

Figure 3 Shows the association of solar radio flux 10.7 cm/2800 MHz and their association with 11-year SSN, observed during the period 1976 onwards.

4.Galactic cosmic rays

The galactic cosmic rays increase the amount of C-14 in the atmospheric Co_2 and, consequently, also in vegetation. During the increased solar activity close to solar cycle maximum years, Earth is better shielded from the cosmic rays than during the minimum years, and the amount of C-14 decreases. Thus the C-14 content of, for example, annual rings of old trees may reveal something about the Sun's performance during the last few millennia. Some studies have indicated that there is a connection between long term climate change and Sun's activity (Friis-Christensen and Lassen, 1991; Lassen and Friis-Christensen, 1995). One possible mechanism operating is that during high activity levels the decreased amount of galactic cosmic rays could lead to reduced cloud formation in the atmosphere, and hence to increased temperatures. The basis of the hypothesis of Svensmark and Friis-Christensen (1997) is that weak solar activity causes a weak solar wind, which in turn increases the number of galactic cosmic rays penetrating the Earth's atmosphere. This increases low level cloud formation and the Earth's albedo. The Earth cools as a consequence.

5.Variations of atmospheric carbon dioxide

Atmospheric carbon dioxide is an important kind of greenhouse gas which influences global temperature. Its concentration variation could indicate the distribution of human and natural activities in various regions. The amount of Co_2 that can be held in oceans is a function of temperature. Co_2 is released from the oceans when global temperatures become warmer and diffuses into the ocean when temperatures are cooler. Initial changes in global temperature were triggered by changes in received solar radiation by the Earth through the Milankovitch cycles. The increase in Co_2 then amplified the global warming by enhancing the greenhouse effect. The long term climate change represents a connection between the concentrations of Co_2 in the atmosphere and means global temperature. Certain atmospheric gases, like carbon dioxide, water vapor and methane, are able to alter the energy balance of the Earth by being able to absorb long wave radiation emitted from the Earth's surface. Without the greenhouse effect, the average global temperature of the Earth would be a cold -18° Celsius rather than the present 15° Celsius. Co_2 concentrations in the atmosphere have increased from about 280 ppm in pre-industrial times to 387 ppm at present. These increases are projected to reach more than 560 ppm before the end of the 21st century.

6.Rising of sea level

Climate change will increase the ocean temperature, cause sea level rise, and will have impact on ocean circulation patterns, ice cover, fresh water run-off, salinity, oxygen levels and water acidity. Sea level is rising around the world. In the last century, sea level rose 5 to 6 inches more than the global average along the Mid-Atlantic and Gulf Coasts, because coastal lands there are subsiding. Due to global warming, higher temperatures are expected to further raise sea level by expanding ocean water, melting mountain glaciers and small ice caps, and causing portions of Greenland and the Antarctic ice sheets to melt. The International Panel on Climate Change (IPCC) estimates that the global average sea level will rise between 0.6 and 2 feet in the next century (IPCC, 2007). As the sea rises, the outer boundary of these wetlands will erode, and new wetlands will form inland as previously dry areas are flooded by the higher water levels. The amount of newly created wetlands, however, could be much smaller than the lost area of wetlands - especially in developed areas protected with bulkheads, dikes, and other structures that keep new wetlands from forming inland. The IPCC suggests that if sea level rise could convert as much as 33 percent of the world's coastal wetlands to open water by 2080. Tidal wetlands are generally found between sea level and the highest tide over the monthly lunar cycle. As a result, areas with small tide ranges are the most vulnerable.

Due to global warming many changes are taking place in India today. According to many studies by ISRO, GSI and other organizations indicate that the Northern Himalayan Glaciers are receding by about 16 meter per year. The Gangotri glacier is retreating about 28 meters per year. The receding glaciers have major implications for water availability in the glacier fed rivers such as the Ganga and the Yamuna. Glaciers in the Garhwal region of the Himalayas are retreating so fast that researchers believe they will disappear by 2035. Arctic ice has thinned significantly over the past half century. Between 1979 and 2007, it has shrunk by 44%, and it is predicted that a complete meltdown is possible by 2030 or sooner (Richard 2003). Adverse impacts of global warming and resulting climate change will be superimposed on these changes and will exacerbate water shortages in many water-scarce areas of the country. During different times in the past, different rivers changed their course a number of times.

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