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Solar Activity Cycles, Their Long-Term Variations, and the Earth's Environment

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The Sun affects the environment of the Earth in several ways, through electromagnetic radiation of diverse wavelengths, high energy particles, the solar wind and its variations including CMEs (coronal mass ejections), and so on. How short timescale events like solar flares and CMEs disturb the Earth environment is the topic of space weather research. Although detailed processes are complex and yet to be studied further, our understanding has advanced significantly in these decades, particularly by in situ observations with satellite-borne instruments. On the other hand, longer timescale variations in the Sun and their influence on the Earth environment are less well understood, partly because of longer timescales involved and smaller amplitudes in such variations. This paper considers such space climate research.

The idea of possible variations in total solar irradiance (TSI) and their relationship with climate change dates back to the 19th century. The Smithsonian Institution conducted an extensive program of measuring TSI from the ground (from high mountains) for more than 60 years starting at the beginning of the 20th century. They claimed solar cycle related change in TSI, but nowadays it is considered as due to incomplete compensation of atmospheric changes. The first conclusive evidence of solar cycle changes in TSI came from satellite-borne radiometers in the 1980s. The TSI changes in phase with the sunspot number, which was not a naive outcome from the darkness of sunspots. Now the enhancement in TSI during the sunspot cycle maximum is understood as due to numerous bright points (faculae), whose positive contributions to TSI overwhelm the negative contributions from sunspots.

Shorter wavelength radiations (UV and X-rays) change in larger amplitudes with the solar cycle; a few tens of percent in the UV and more than ten times in X-rays. Changes in UV are important in the photo-chemistry of the upper atmosphere of the Earth. Spectral irradiance in the UV was measured with satellite-borne radiometers since 1990s, but the measurements are difficult in maintaining the accuracy due to instrumental degradation.

Before 1980s there were no direct records of total or spectral irradiance variations. Therefore one makes use of proxies to investigate such changes. Optical imaging observations of the solar chromosphere in the H-alpha and Ca K lines might be utilized for this purpose. The longest data samples are those of Greenwich and Kodaikanal (India) since 1904. NAOJ has data from 1917 and they are all digitized. Radio emissions (F10.7 of Ottawa since 1947, four frequency radiometers of Toyokawa since 1951) and airglow data (since IGY) can also be utilized.

The solar cycle is believed to be maintained by the so-called MHD dynamo process. Solar internal rotation derived from helioseismology, and numerical simulation of fluid motions in the Sun's convection zone have greatly advanced our understanding of the dynamo process. Observationally the data available were limited to sunspots (since 1610) and magnetic flux distributions measured with magnetographs (since 1950s). Starting 1980s the magnetic field vectors in active regions have been measured and led to the hemispheric sign rule of magnetic helicity; negative helicity in the northern hemisphere and positive helicity in the southern hemisphere (although with large dispersion). This property gives a crucial constraint on the so-called alpha-mechanism in the dynamo. Recently we claimed (Hagino and Sakurai, 2005) that the hemispheric sign rule of helicity tends to be violated near sunspot activity minimum, and its implication on the dynamo process and on the amplitude of the forthcoming activity cycles will be discussed.

Keywords: Sun, sunspots, solar cycle, total solar irradiance, dynamo mechanism, magnetic field observation