

Study of Radial Differential Coronal Rotation using Solar Radio flux for period (1980-1986)

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Abstract

Spatial and temporal variation of inner and outer corona of solar rotation are interesting topics to explore which is one of the root causes of most of its activities and impacts on space weather of the earth. The research presented here investigates radio emission released from various layers of the solar corona during the years 1980-1986 (Half Schwabe Cycle). The rotation of the sun can be studied through various methods such as tracking of tracers, spectroscopic and flux modulation. The flux modulation is used in our study to explore dynamics in solar rotation. Annual time series of radio emission data at frequencies 430 and 810 MHz recorded at Jagiellonian University Radio Astronomical observatory, Cracow, Poland; at 1415 and 2695 MHz recorded at Sagamore Hill Radio Observatory Massachusetts, USA and 2800 MHz recorded at Dominion Radio Astrophysical Observatory, Pentincton, Canada are used in our study. Any periodic component, if embedded in such time series, could not be found directly, hence Lomb Scargle Periodogram (LSP), a suitable statical method which can deal with such time series, having permissible data gaps, is used here to find periodic components from available time series. The rotation period so obtained is studied against emission frequency emanating from different heights in the solar coronal atmosphere.

Introduction

The 11-year solar activity cycle is prominent and fundamental characteristic of the Sun. For each cycle, there are differences in the reversal timings and the magnetic field's intensity (Hathaway 2015). This 11-year solar cycle can be predicted by various techniques explained by (Petrovay 2020). This prediction can help us in better understanding of solar magnetic field, which drives the space weather, may cause damage to satellites, GPS navigation system, astronauts, electric power grids and many space-based devices (Temmer 2021).

Solar rotation, a significant phenomenon grabs attention of several scientific researchers. Over the past 50 years, there has been a lot of research on the solar rotation, both inside the Sun and in its atmosphere (Bhatt et al. (2017).

Plasma forms a convective motion inside sun, generates toroidal field derived from poloidal effect also known as alpha and omega effect plays key role in differential rotation (Parker 1955a). Differential Solar rotation, a key phenomenon that strongly impacts the fluctuating and formation of the solar magnetic properties. (Howe 2009; Cameron et al.2017; Jha et al.2021). There are three different ways to determine the solar rotation, from the photosphere to the corona. Tracer tracking (Newton & Nun 1951), spectroscopic (Howard 1984), and flux modulation ((Snodgrass 1984; Stenflo 1989; Snodgrass et al. 1990; Vats et al. 1998, 2001). Studying solar activities and its variation with time

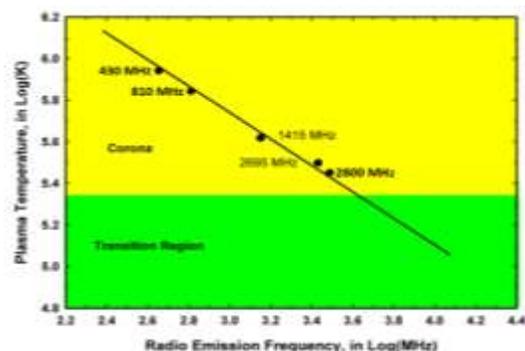
has become an interesting task for researchers and scientist. Research on solar rotation started from full disk magnetograms and observed that the average equatorial velocity rotates over a 28.2 day period by Howard and Harvey (1970). Sidereal rotation period of corona varies between 24.07 to 26.44 by Vats et al (1998). Kariyappa (2008) observed that corona exhibit differential rotation, obtained from solar full disk using data of observatories Yohkoh and Hinode. Chandra et al. (2011) did not found any systematic temporal variation of rotation period related to 22-yr magnetic reversal cycle or Hale's cycle. Solar burst activity and sunspot activity show a long-term cyclic behavior observed by Burleson (2010), and they introduced the theory behind the formation of sunspot from solar radio burst data, this involves Cyclotron and Synchrotron Radiation and Magnetic reconnection. Sun exhibits differential rotation but as compared to different layers, corona rotates less differentially than photosphere and chromosphere. Chandra et al. (2010), have examined the differential rotation of soft X-ray corona, verified similar findings. Hiep et al. (2013) analyzed by using two data sets of frequency 1415 MHz from April to September, they found that both sets of data show the same general features, including flares, of which three in early July were particularly strong. The rotation of the solar corona has also been studied using coronal bright point data (Karachik et al. 2006; Sudar et al. 2015). Bhatt et al. (2017) discovered a declining rotation rate with increasing altitude using radio measurements, similarly Sharma et al. (2021) found that the solar transition region rotates less differently than all the different solar corona layers.

Singh et al (2021 a) reported that there is no systematic variation in the solar coronal rotation with increasing altitude.

Data Analysis

In this paper we are using five different frequencies emanating from solar coronal region for the period 1980 to 1986. These frequencies are emanating from different heights of inner corona and outer corona (Figure 1).

Fig. 1 Different radio frequencies originating at different altitudes in the solar atmosphere (R.P. Kane 2009).



The radio frequencies 430 and 810 MHz are recorded at Jagiellonian University Radio Astronomical Observatory Cracow, Poland; 1415 and 2695 MHz are recorded at Sagamore Radio Hill Observatory, Massachusetts, USA and 2800 MHz are recorded at Dominion Radio Astrophysical Observatory Pentinction, Canada.

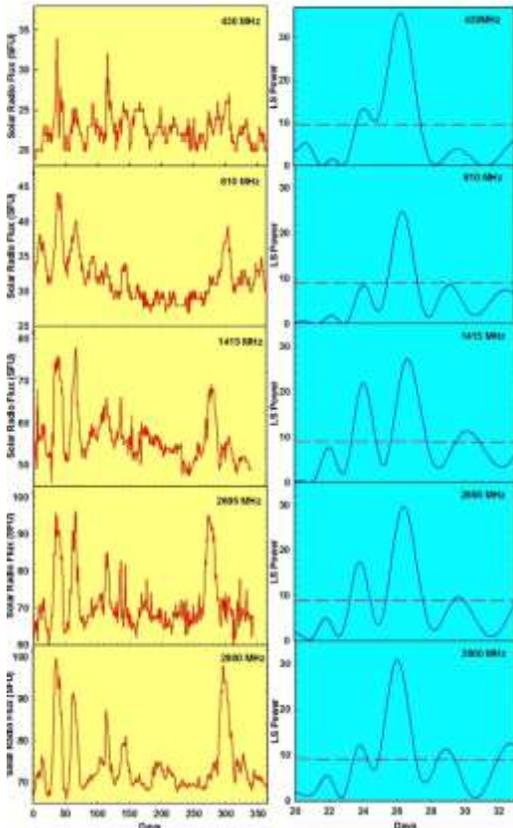


Fig. 2. Left Panel: Typical example of annual time series of radio flux at frequencies (430, 810, 1415, 2695 and 2800 MHz) for year 1986. **Right Panel:** Corresponding Lomb Scargle Periodogram of each time series.

The daily recorded solar radio flux data are available through NOAA-NGDC (<https://www.ngdc.noaa.gov>). Annual time series are generated from daily recorded solar flux data at each frequency. Periodic oscillations present in a time series could be estimated by statistical tools such as Auto Correlation used by (Chandra et al. 2009, 2010; Sharma et al. 2020a, 2020b, 2021), Wavelet Analysis, (Torrence and Compo 1998; Deng et al., 2013; Wang et al., 2022) and Lomb Scargle Periodogram (Singh et al., 2021 a, 2021 b). Here in the present work we are using LSP because it is widely used in astronomy and astrophysics community and able to deal with time series having permissible data gaps.

A typical example of an annual time series generated at each frequency and corresponding Lomb Scargle Periodogram for year 1986 is given in figure 2.

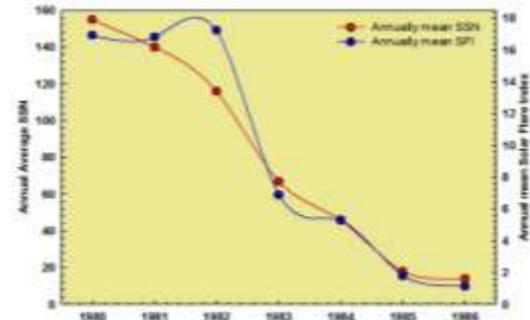


Fig. 3 Variation of annually averaged sunspot numbers with annually average Solar flare index.

Annually averaged sunspot number data for study period is available through NOAA-NGDC and solar flare index for same period is also prepared by the Kandilli Observatory and Earthquake Research Institute at the Bogazici University. Variation in annually averaged sunspot number and solar flare index for period (1980-1986) is given in the figure no. 3.

Result & Discussion

Rotation period obtained from the annual time series at each frequency is plotted with annually averaged solar flare index number for period (1980-1986) in figure no. 4. Depends on various factor depending upon either it is maxima or minima. By investigating temporal and spatial variations from the radio frequencies (430, 810, 1415, 2695 and 2800 MHz respectively).

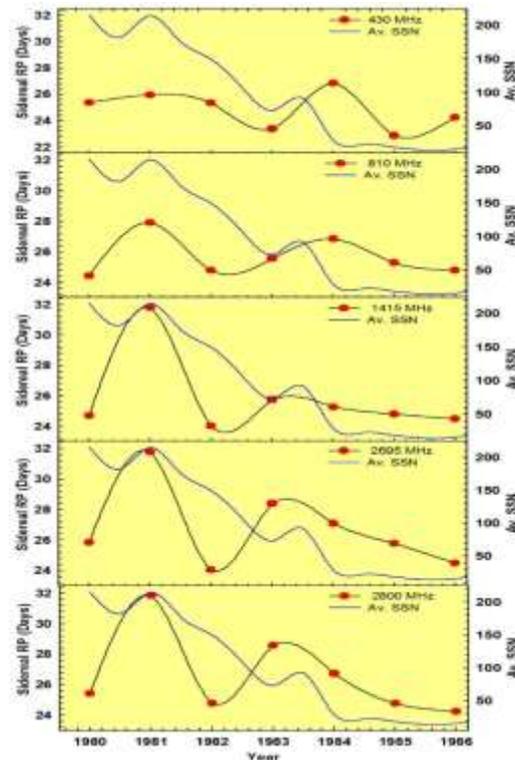


Fig. 4. Rotation profile at five different frequencies (430, 810, 1415, 2695 and 2800 MHz respectively) with the error bar and compared with solar flare Index in descending phase of solar cycle 21.

Rotation profile shows following outcomes:

- In the declining phase of solar cycle 21 (1980-1986) SFI decreasing continuously from 1981 to 1986.
- Solar rotation profile shows that rotation period is maximum in year 1981 for all frequencies; it becomes minimum in year 1982 except for frequency 430 MHz and also it approaches to minimum as cycle reaches to end.
- The variation in the maximum to minimum values of rotation period in the years (1980-1982) seems to be about 4 days; in the years (1983-1986), rotation period increases in 1983 and then decreases up to year 1986. Such trend followed by each investigated frequencies.
- Comparison of solar rotation profile with annually averaged solar flare index shows agreement with variation in rotation period i.e. for maxima year of declining phase of cycle 21 flare index seems to be maximum; in descending phase of cycle the flare index also decline and becomes minimum with minimal value of rotation period in year 1986.
- Any systematic variation in rotation period with altitude was not observed as reported by Vats et al. (1998) and Bhatt et al. (2001).

Solar rotation profile for each frequency follows the sunspot cycle in the declining phase of solar cycle 21. Similar result also reported by Vats et al. 2001, Mehta et al. 2005 and Chandra et al. 2011).

Such variation in solar rotation may be linked with the periodicity in solar mean magnetic field, which depends upon the modulation of amplitude of magnetic field eruption and in turn is responsible for the variation in rotation period (Mordvinov et al. 2000)

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