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

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Abstract

The unpredictable solar activity cycle is ancient problem in solar physics. It affects the entire space weather activity, which in turn can have trivial public impact. Solar activities are stoutly interrelated with the solar rotation. Spatial and temporal variation in inner and outer solar coronal rotation may be a remarkable issue to investigate which is one of the bases of most of solar activities. Present work investigates radial differential rotation of solar corona by using radio emission at different frequencies emitted from various layers of the solar corona during the time period 1980-1986 (Half Schwabe Cycle). Tracking of tracers on the surface of the sun, spectroscopic measurement and Flux modulation; are the different techniques to study solar rotation. The flux modulation method is used here in present work. Solar radio flux emerging at different heights in the solar atmosphere is recorded at different Radio Astronomical Observatories; as solar flux emission 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. . Annual time series is formed from daily recorded solar flux data. Periodic component present in such time series are estimated by statistical tool Lomb Scargle Periodogram (LSP). The estimated rotation period for different layers of solar corona are correlated with the annually averaged sun spot numbers (SSN) and solar flare index (SFI) for study period. The interrelation of variation in solar coronal rotation with solar activity through which possible space weather prediction will be covered as a full paper for publication in proceedings of (URSI-RCRS2024). Detail outcome of work would also be presented in the conference.

1. Introduction

The 11-year sunspot cycle and 22-year magnetic field reversal cycle is a prominent and essential characteristic of the Sun. For each solar cycle, there are differences in the intensity of magnetic field and reversal timings (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 impact to satellites, GPS navigation system, astronauts, electric power grids and many space-based devices.

Rotation of the Sun and its variation is a very important characteristic that grabs attention of several researchers. Over the last few decades, there has been extensive research on the solar rotation; in the solar interior and in as well as in its atmosphere. There are three different ways to determine the solar rotation, from the photosphere to the corona. Tracer Tracking of tracers (Newton & Nun 1951), spectroscopic method (Howard 1984), and flux modulation (Snodgrass 1984; Stenflo 1989; Snodgrass et al. 1990; Vats et al. 1998, 2001).

Howard and Harvey (1970) uses full solar disk magnetogram and reported that the average equatorial rotation period 28.2 days. Brajša et al. (1999, 2009) estimated altitudinal differential rotation by using daily observed solar full-disk maps, where microwave low-brightness temperature regions were identified in different phases of the solar cycle. They used low and high brightness-temperature regions, in the chromosphere at 37 GHz as tracer to determine solar rotation period using full-disc solar radio maps. Hara (2009) uses X-ray bright points (XBPs) as tracers and estimated the differential rotation rate and reported that the rotation rate of short lived XBPs vary from 14.2 deg day-1 to 14.4 deg day-1. Wöhl et al. (2010) uses small bright coronal structures as tracers from SOHO/EIT images for almost one solar cycle and found variation sidereal rotation period with latitude. Sudar et al. (2016) estimated rotation period by using six months SDO/AIA data for Fe XIV 5303 Å coronal emission line by tracer method.

Parker (1955a), suggested that plasma forms a convective motion inside sun, generates toroidal field derived from poloidal effect plays key role in differential rotation. Differential solar rotation is a basic characteristic that strongly affect the creation and irregularity of the solar magnetic properties (Howe 2009; Cameron et al. 2017; Jha et al.2021).

Vats et al (1998), uses daily observation of the integrated solar radio flux at 11 different frequencies emanating from different heights of solar corona to estimate sidereal rotation period and reported that coronal rotation varies between 24.07 to 26.44 days. Kariyappa (2008), reported about coronal differential rotation, as he used SFD image data from Yohkoh and Hinode. Chandra et al. (2010), reported the differential rotation of soft X-ray corona from

Yohkoh SFD image data. Bhatt et al. (2017) discovered a declining rotation rate with increasing altitude by using radio measurements. Similarly Sharma et al. (2021) found that the solar transition region rotates less differently than all the different solar corona layers.

2. Data Analysis

In the present work five different frequencies (430, 810, 1415, 2695 and 2800 MHz) emanating from different altitudes in solar coronal region are used for the time period of 1980 to 1986. (Figure 1). Frequencies 430 and 810 MHz are originating from outer corona while 1415, 2695 and 2800 MHz originating from inner corona (Kane R.P. 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 Penticton, Canada.

The daily recorded disk integrated solar radio flux data are available through NOAA-NGDC (https://www.ngdc.noaa.gov.). Annual time series are generated from daily recorded solar flux 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.

Rotation period thus obtained from 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.

In order to find variation in solar rotation with solar activities, annually averaged solar flare index is plotted with rotation profile at each frequency for period (1980-1986) in figure no. 4.

3. Result & Discussion

Rotation profile shows following points:

- 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 frequency.

- 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)

4 Figures

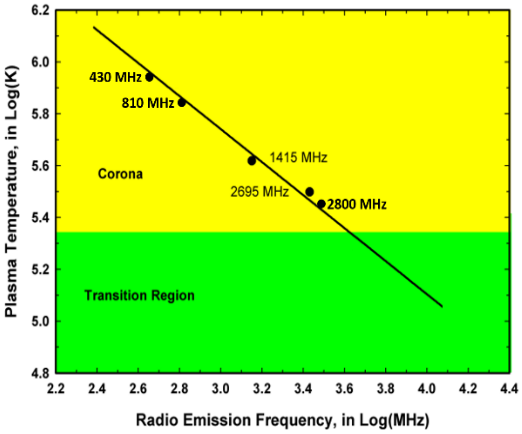

Figure 1. Different radio frequencies originating at different altitudes in the solar atmosphere (R.P. Kane 2009).

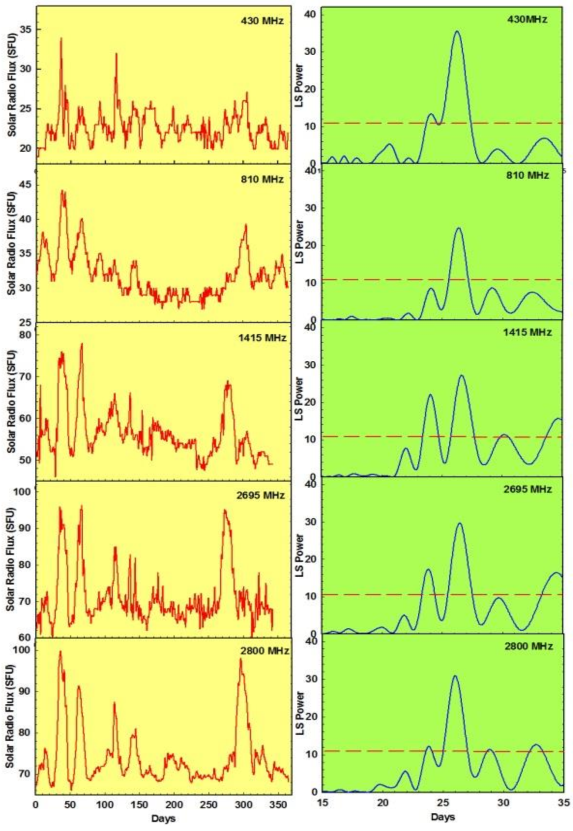

Figure 2. Left Panel: Typical example of annual time series of radio flux at frequencies (430, 810, 1415, 2695 and 2800 MHz) for year 1986. **Right Panel:** Corresponding Lomb Scargle Periodogram of each time series.

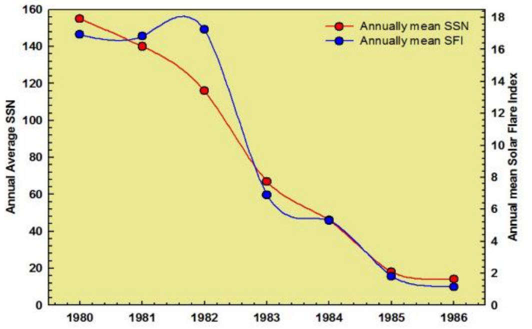

Figure 3. Variation of annually averaged sunspot numbers with annually average Solar flare index.

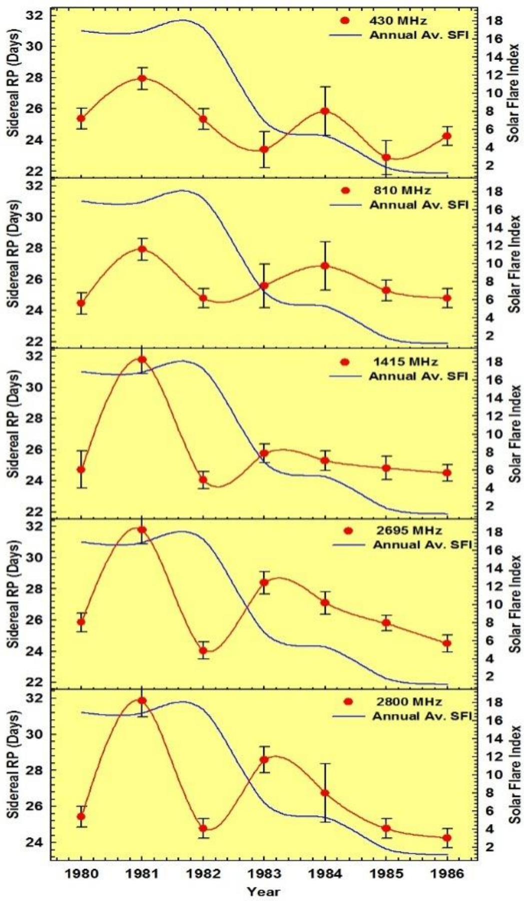

Figure 4. Rotation profile at five different frequencies (430, 810, 1415, 2695 and 2800 MHz respectively) with the error bar and compared with solar flare Index in descending phase of solar cycle 21.

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6. References

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