A STUDY OF LONG-TERM SOLAR ACTIVITY AT 37 GHZ

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Abstract. In this paper we investigate the solar activity at the radio frequency (37 GHz) using an extensive data series (solar radio maps) from the Metsähovi Radio Observatory. This paper aims to present this unique solar radio map collection to the public knowledge. The data set covers the years from 1978 to 2011 (solar cycles 21–24). We investigate the long-term solar activity on the ground of the distribution of solar radio brightenings and the differential rotation of the Sun.

Key words: Sun: activity, radio radiation, differential rotation

1. INTRODUCTION

The solar cyclicity is one of the most widely studied field in solar physics. However, the continuous and accurate solar observations usually have a relatively short history. The main accents in the cyclicity studies are the differential rotation of the Sun and the distribution of sunspots or active regions (ARs). The differential rotation speed of the Sun varies during the solar cycle at different latitudes, being faster during solar maxima (Gelfreikh & Tlatov 2006; Gelfreikh et al. 2002). The Maunder butterfly diagram is a commonly-known model of the statistical distribution of sunspots (or ARs) during a solar cycle.

The total emission of solar radiation at the radio wavelength of 10.7 cm has a relatively long observational history starting from 1947 (see Mouradian et al. 2002; Chandra & Vats 2011). However, the history of observations of the full disk maps is relatively short at all wavelengths. One of the most extensive analysis of solar activity has been done by Gelfreich & Tlatov (2006) using the observations collected with the Nobeyama Radioheliograph (NoRH). This solar radio telescope started to operate in the early 90’s and is one of the most widely used instruments for studying solar activity at the wavelength 1.76 cm. Gelfreikh & Tlatov (2006) investigated the positions, intensity and polarization of sunspots and the solar differential rotation during one 11-year activity cycle.

frequency 37 GHz, even though our data sets are not fully continuous. In this study we investigate the differential rotation of the Sun and the distribution of the radio brightenings during the solar cycle. This work has been originally started by Riehokainen et al. (1998) and Riehokainen et al. (2001). The solar radio emission at 37 GHz comes from the chromosphere and the lower corona.

2. INSTRUMENTATION

The RT-14 telescope by the Metsähovi Radio Observatory (MRO), Aalto University (Helsinki Region, Finland, GPS: N 60:13.04, E 24:23.35) is a Cassegrain-type antenna with a diameter of 13.7 m. The working range of the telescope is 2–150 GHz (13.0 cm – 2.0 mm). The antenna provides solar mapping, partial solar mapping and tracking of any selected point on the solar disk. Only the 37 GHz band has been used for the radio observations presented here. The beam size of the telescope is 2.4′. The receiver is a Dicke type radiometer. For the temperature stabilization of the receiver, a Peltier element is used. The noise temperature of the 37 GHz receiver is around 280 K, and the temporal resolution during the observations is 0.1 s or less. The observational data are recorded in intensities. Because the measurements are always scaled relative to the Quiet Sun Level (QSL), the observations are comparable in between over the years. The maps can be observed both in the linear and logarithmic scales and measured both in right ascension and declination directions. The logarithmic scale is used only for strong solar radio brightenings. In this study, we have used maps at the linear scale only. The time span between the two consecutive solar radio maps is around 10 min. The QSL at 37 GHz is defined theoretically at a level of 7800 K. Meanwhile, the sky temperature at this frequency is approximately 3 K (Kallunki 2009).

3. OBSERVATIONS AND DATA ANALYSIS METHODS

Our data statistics is based on the selection of one representing solar radio map for each day and observed preferably at about 12:00 am. Thus, the maps (days) with poor weather conditions and technical failures were excluded from the final statistics. The catalog includes observations between 1978 September 6 and 2011 July 1. Therefore, our catalog covers 33 years and includes almost four solar cycles (solar cycle numbers 21–24).

We sorted the brightenings in such a way that the solar disk was divided into 14 different positions in the latitude direction, thus we had seven latitude belts on the southern and northern hemispheres. The width of the belt is roughly the resolution of the used beam size. To our final statistics only the radio brightenings exceeding 104% (8100 K) of the QSL were counted. The solar brightenings are detected automatically from solar radio maps using our special software. A typical solar radio map (2010-11-30) with one clear radio brightening is presented in Figure 1. The brightening is the red spot in the northern hemisphere, its intensity was 105% to QSL, ~8200 K. It coincides with the NOAA Active Region No. 11130. It was visible at several wavelenghts, including ultraviolet.
4. RESULTS

4.1. Statistical distribution of radio brightenings

In Figure 2 all solar radio brightenings, which were observed at MRO are plotted. The upper panel shows the number of the radio brightenings and the monthly numbers of sunspots. The lower panel shows the maximum values of the solar brightenings (relative to QSL). Both graphs indicate a well-known periodic solar cyclicity. For example, we notice a hole (double-peak structure) in the middle of the solar cycles 22 and 23, which also has been observed at 10.7 cm. Such double-peak structures can be caused by a modulation of the 11-year flux variations (Bruevich & Yakunina 2011). Furthermore, radio emission was weaker during the cycle 23 compared to previous cycles. Unfortunately, we have only a limited amount of data from the cycle 21, thus our results are not reliable. We also notice a long minimum before the cycle 24 and a low activity at its beginning.

The positions and strengths of the radio brightenings are shown in Figures 3 (3D-diagram), 4, 5 and 6. The radio brightenings at high solar latitudes might be related to polar faculae, which have their own cycles (Riehokainen et al. 1998, 2001). This can explain the difference with the standard Maunder butterfly diagram. Most of the solar radio brightenings are between 106–115 % (relative to QSL). The behavior of the sunspot occurrence is a partly unsolved problem (see for example Consolini 2009). So far no comprehensive explanation has been found for the changes in the sunspot distribution. Most probably, different mechanisms are involved.

4.2. Differential rotation

We also tried to determine the differential rotation speed (Ω, deg/day, sidereal rotation rate) based on the radio brightening sources. Unfortunately, as previously mentioned, the resolution of the observations is limited, and we need strong radio
Fig. 2. The upper panel shows the smoothed numbers of the radio brightenings (blue plot) and monthly sunspot numbers (green plot) from 1978 to 2011 (solar cycles 21–24). The lower panel shows the maximum value of the solar brightening (relative to QSL) from each day of observation.

Fig. 3. The distribution of locations of the solar radio brightenings from 1978 to 2011 (solar cycles 21–24). A color bar on the right indicates the temperature (relatively to QSL, 7800 K). The strongest solar radio brightenings are 145% to QSL (11300 K).

sources to track the movement. We selected about 40 representing sources, which have moved over the solar disk (Figure 7), and each source was tracked from five to seven days. We used a simple well-known rotation model by Newton & Nunn (1951) as it was presented in Zirin (1988), fitting observational results to the model by the method of least squares:

\[ \Omega = A - B \sin^2 \alpha - C \sin^4 \alpha, \]

where \( \alpha \) is the latitude, \( A \), \( B \) and \( C \) are the solar rotation parameters. According
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Fig. 4. The distribution of locations of the solar radio brightenings from 1978 to 2011.

Fig. 5. The strengths of the solar radio brightenings from 1978 to 2011.

Fig. 6. The strengths of the solar radio brightenings at different latitudes.

to our dataset, $A = 13.03$, $B = 0.93$ and $C = 0.22$. The Earth’s orbital velocity (0.9865 deg/day) was taken into account.

Gelfreikh et al. (2002), using the data from the NoRH, have found the following values for the differential rotation: $A = 13.38$, $B = 1.66$ and $C = 2.19$. We also
compared our values to those by Komm et al. (1993) \(A = 13.38, B = 1.95\) and \(C = 2.17\) and by Song et al. (2011) \(A = 13.45, B = 2.06\) and \(C = 1.37\). The differences are explained by the limited amount of sample, the low resolution and the relative small amount of samples on high \((\alpha > 35^\circ)\) and on low latitudes \((\alpha < -35^\circ)\). Furthermore, we have only a few tracking samples close to equator. A graphical comparison of different solar rotation parameters is presented in Figure 8.

The limited amount of the observational samples did not allow to study the variation of the differential rotation during the solar cycles (from maximum to minimum).

5. CONCLUSIONS

To our knowledge, this is the first study which covers such a long period (years
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1978–2011, solar cycles 21–24) of solar radio observations (radio maps), except the observations of the total solar microwave flux at 10.7 cm. Even though our data collection is not fully continuous, it enables us to receive the important results. The solar radio radiation, especially the frequency and intensity of radio brightenings, are shown to be good indicators of the solar cyclicity. Our goal was to investigate a long-term collection of solar radio maps and qualify the results by comparing them to those presented by other authors.

The results give more reason to speculate the connection and correlation between the radio brightenings and the sunspots. The mechanisms of sunspot emission are the gyro-resonance emission and the free-free radiation (Shibasaki et al. 2011). The solar radio brightenings at the polar regions probably have a different origin.

In the future we are planning to record more observations – at least one solar radio map every day. We also would like to study the change of sizes of the radio brightenings during the time. It would be important to know the average sizes of radio brightenings during the minima and maxima of solar activity, as well as their possible positional variations. We would like to conduct simultaneous observations at another radio frequency, which could give new aspects which could help to solve the mechanism of radio brightenings. In general, the solar cyclicity is still a partly unsolved process. The long data series, such as that presented above, will give new aspects and ideas for this open problem.

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