Connections between the polar faculae and radio bright areas in the polar zones of the Sun

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Introduction

Our present investigation is devoted to the study of the connections between the ETRs (enhanced temperature regions) which we see in the mm radio observations at the Metsähovi radio telescope, the polar faculae observed at Kislovodsk solar station, and the radio bright areas in the polar zones of the Sun obtained at the Nobeyama radioheliograph at 17 GHz. In consideration were taken the observational data obtained in June (37 GHz) and August (87 GHz) 1997 (in Metsähovi and Kislovodsk) and the corresponding solar images from Nobeyama. The time difference between the Metsähovi and the Kislovodsk measurements is about 2.5 hours, and between Metsähovi and Nobeyama (17 GHz) about 8 hours. The results show a connection between the radio enhanced temperature regions in the polar zones of the Sun at all observing frequencies and between the polar faculae. In addition we consider the differential rotation rate obtained from the Nobeyama and Metsähovi (37 GHz) data.

Differential rotation at high solar latitudes

In our previous work (Riehokainen et al., 1996) we measured the differential rotation rate using the long lived ETRs in the polar zones (18 ETRs). The ETRs have typical lifetimes of some hours, but in some rare cases their lifetimes are a few days. These long lasting ETRs were used for the differential rotation estimation. Identification of an ETR from day to day and even during one day is very difficult. For this reason we did a new analysis. In this case we used 22 long lived ETRs. Some of these are the same as in the previous work. Because the identification for shorter time intervals is more secure, we have in some cases used shorter time spans as compared with the previous work. Four new long lived ETRs were added, identified in a new analysis of the solar maps. In Table 1 are shown the latitudes (in degrees), and the sideral rotation rates (in degree/day) of each analyzed long lived ETR.

Using data presented in Table 1, we constructed Figure 1 showing the sideral rotation rate as a function of latitude for the previous and the new analysis. In Figure 2 we show a comparison of our results with the results obtained by other authors using different methods for estimation of the solar differential rotation rate at high solar latitudes. The comparison shows that our results (lines 5 and 6) are in a good agreement with the spectroscopic observations of the photosphere obtained by Howard and Harvey (1970), with the polar faculae rotational rate obtained by Waldmeir and Muller (as presented in Hansen et al., 1969), and also with the sideral rotation rate obtained by A.G. Tlatov (unpublished) from Nobeyama data.

Table 1. The solar latitude and the sideral rotation rate

N	*latitude* previous work	*sid. rot. rate* previous work	*latitude* present	*sid. rot. rate* present
1			55.5 ± 0.6	12.7
2			47.8 ± 1.7	9.3
3			49.3 ± 0.5	11.6
4	53.9 ± 0.7	8.2	53.5 ± 0.9	14.1
5	50.1 ± 1.6	10.8	51.5 ± 1.2	15.9
6			55.3 ± 2.0	11.4
7	51.1 ± 0.6	9.6	51.7 ± 0.7	9.6
8	556.3 ± 0.4	10.4	56.4 ± 0.4	10.3
9	54.1 ± 0.4	12.0	54.1 ± 0.4	11.6
10	63.0 ± 0.9	11.2	63.5 ± 1.0	11.6
11	55.0 ± 0.8	9.6	55.1 ± 0.8	9.2
12	65.8 ± 1.1	7.9	65.8 ± 1.1	7.9
13	54.0 ± 2.0	12.5	54.0 ± 2.0	12.5
14	61.5 ± 0.9	7.5	61.5 ± 0.9	7.5
15	54.2 ± 0.7	9.2	54.2 ± 0.7	9.2
16	62.5 ± 1.1	11.1	62.6 ± 1.1	10.9
17	51.6 ± 0.6	11.3	51.6 ± 0.6	11.3
18	55.9 ± 1.4	11.3	$55,9 \pm 1.4$	11.3
19	62.7 ± 0.8	9.0	62.0 ± 0.3	11.0
20	63.8 ± 0.9	13.5	63.8 ± 0.9	14.0
21	54.8 ± 1.0	11.0	54.8 ± 1.0	10.6
22	60.9 ± 1.2	8.5	61.7 ± 1.2	8.8

ETRs, "Nobeyama" bright areas and polar faculae

The radio observations were made at the Metsähovi radio telescope at two different frequencies, during June 24, 25, and 27 at 37 GHz and in August 7, 8, 14, 24, 26, and 29 at 87 GHz. The optical observations were made at Kislovodsk mountain solar station in Russia. From optical observations were measured the coordinates of the polar faculae groups, the number of the polar faculae in each group and their relative brightness. From radio observations we have estimated the maximum and the average temperature of each ETR. The average was calculated as the mean of the pixels within the area boundary. The boundary of each ETR was defined as 50 percent of the maximum temperature enhancement present. The quiet Sun level was estimated as 7200 K at 87 GHz and 7800 K at 37 GHz. (A comparison with the Nobeyama radioheliograph images, obtained at 17 GHz during the same days is also ongoing.) Next we superposed the optical coordinates of the polar faculae groups on the radio maps and calculated the number of the polar faculae within each ETR. This allowed us to compare the number of the polar faculae with the maximum and the average temperature of each ETR. One example of the solar radio images with superposed polar faculae coordinates is presented in Figure 4. The results of the comparison are shown in Figure 4. As one can see, the temperature enhancement depends on the number of the polar faculae within the region. The four regression lines have different inclinations, but all show a positive correlation. The regression parameters are given in Table 2. As one can see, the quiet Sun level obtained for each frequency is in a good agreement with the previous estimated value. Each polar facula contributes about 20 K to the temperature enhancement at 87 GHz and about 5 K at 37 GHz.

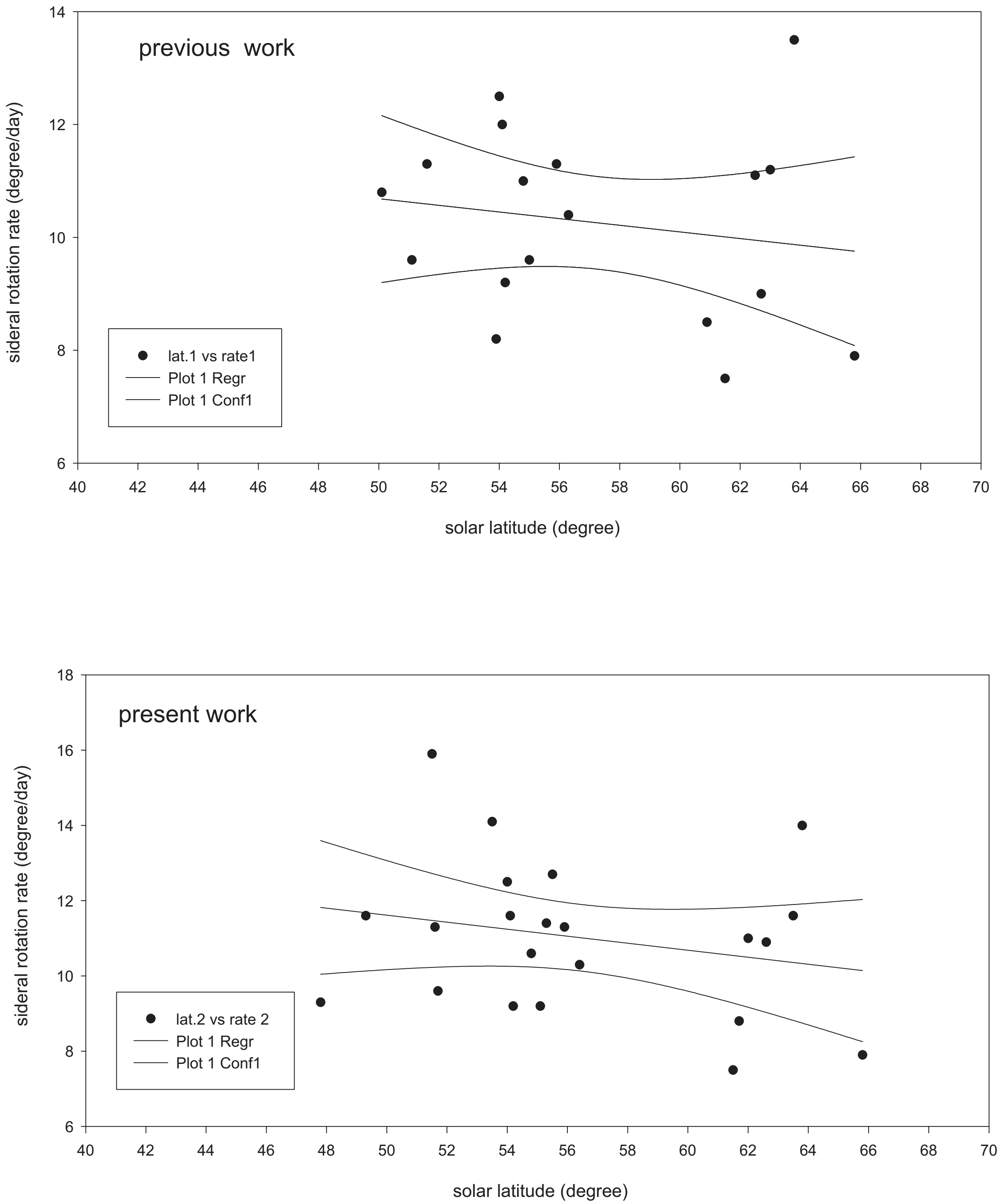

Figure 1: A: Sideral rotation rates for 18 high latitude ETR's (the previous case). B: Sideral rotation rate for 22 high latitude ETR's (present work)

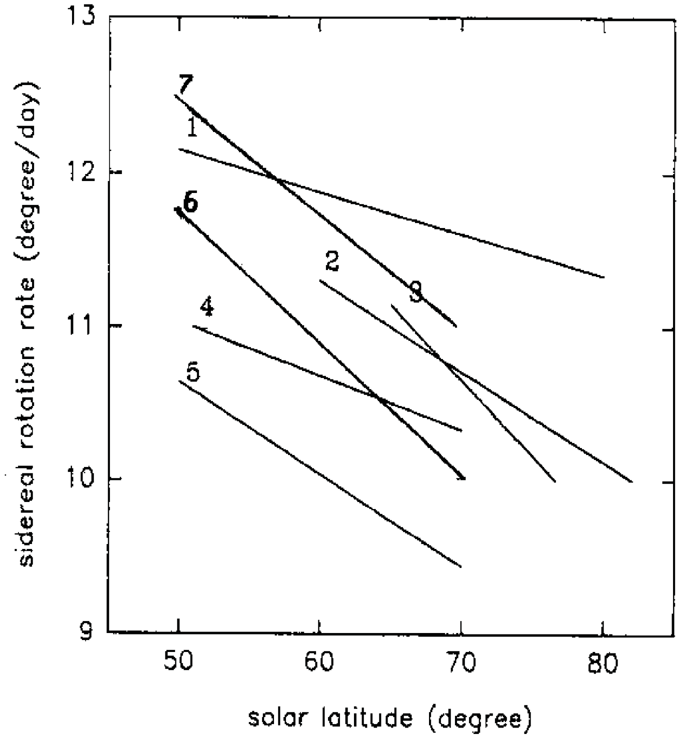

Figure 2: The sideral rotation rates at high solar latitudes. 1: Polar faculae (Makarova and Solonsky, 1987), 2: Spectroscopic observations of the photosphere (Howard and Harvey, 1970), 3: Polar 5faculae (Waldmeir, 1955 and Muller, 1954, as presented in Hansen et al., 1969, 4: ETR (Urpo et al., 1989), 5: ETR (Riehokainen et al., 1996 (previous case), 6: ETR (present work), 7: "Nobeyama"

As Figure 4 shows, the ETR areas coincide, in general, with the polar faculae areas. One notices that when we see an ETR, we tend to see polar faculae in the same area. The converse is not valid, because sometimes we see only polar faculae without ETRs above them. This may depend on the polar faculae characteristics such as the magnetic field strength and structure, or the facula temperature as compared to the undisturbed surface temperature.

Table 2.Regression parameters. Equation for the regression line defined as $y = y_0 + a * x$

line	$y_0 \pm stderr$ [K]	$a \pm stderr$
Tm87	7441 ± 87	21.2 ± 7.9
Tav87	7354 ± 66	15.9 ± 6.0
Tm37	7907 ± 47	5.5 ± 1.7
Tav37	7876 ± 32	3.8 ± 1.2

Conclusion

Taking into account all facts established in this work, such as the differential rotation of the ETRs, the "Nobeyama" brightness areas, and the polar faculae, the temporal and

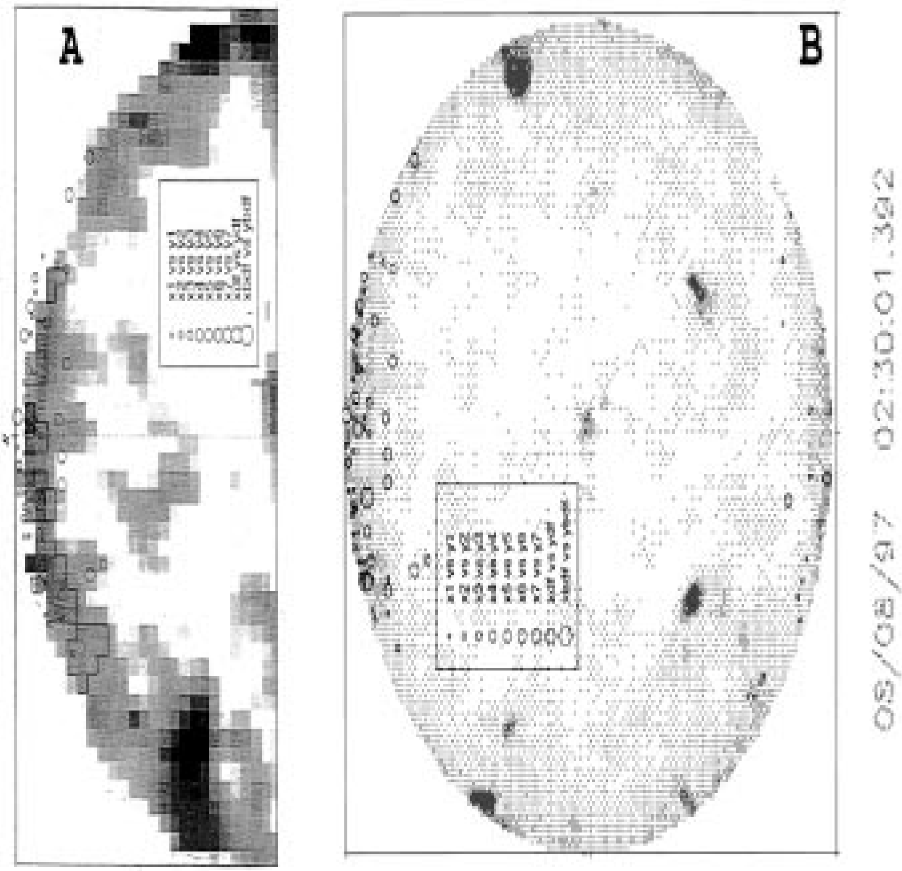

Figure 3: A:The Metsähovi solar radio map (87 GHz) on 8.8.97 (N-pole) with superposed polar faculae positions. The symbol sizes indicate the number of faculae in each group (1-7), and the diffuse (df) and big diffuse (bdf) areas. The grayscale of the solar radio temperature is arbitrary and varies from figure to figure with the white areas corresponding to temperatures below the quiet Sun level. The borders of the ETR areas are also shown. B: The Nobeyama solar image from the same day with superposed polar faculae group coordinates

the spatial distribution of the Metsähovi ETRs over a long period (Riehokainen et al., 1998), in intra-day time scales (also seen in the Nobeyama images), we can put forward the hypothesis that the polar faculae, the ETRs observed in the mm regime and the "Nobeyama" radio bright areas (17 GHz) are closely connected to each other and also to the polar faculae groups. We believe that all the structures which we can see in the solar atmosphere are also present at the solar photospheric level as sunspots, faculae, polar faculae or granulation. These structures govern all higher level chromospheric and coronal features through their magnetic field. In our future work we will consider the temporal and the spatial distribution of the ETRs separately for the south and the north polar zones. In addition, we will try to identify connections between the polar faculae, the ETRs at 87 GHz and the coronal features such as mini coronal holes, plumes, etc, which have been reported by Pohjolainen et al. (1998) using simultaneous data.

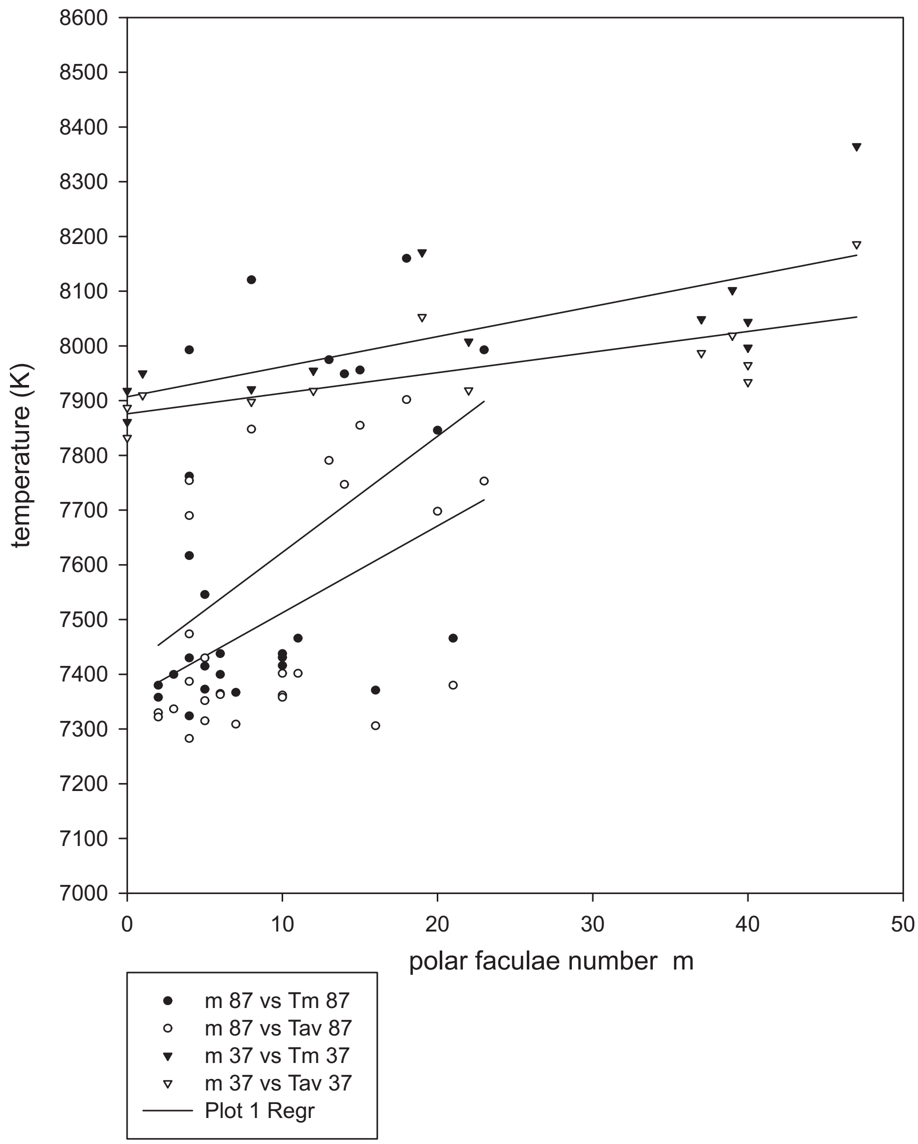

Figure 4: Correlation between the number of the polar faculae (m), the maximum temperature of the ETR (Tm) and the average temperature of the ETR (Tav)

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