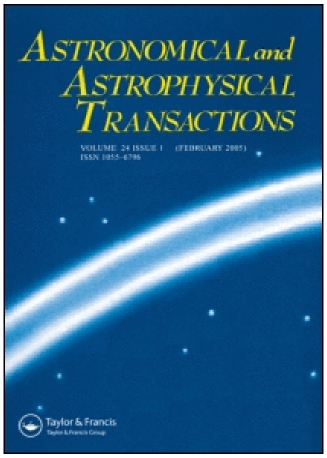

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SOLAR MAGNETIC CYCLES AS GIVEN BY THE WOLF NUMBERS AND RADIO FLUX SPECTRAL DENSITY

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The annual mean Wolf numbers and the radio flux spectral density in the wavelength ranges $\lambda \simeq 3$ cm and $\lambda \simeq 10$ cm have been analysed to show that the cyclic and quasi-biannual variations of both characteristics are practically identical and are likely to describe the same phenomenon – the dynamics of the integral magnetic field of active regions.

KEY WORDS Radio flux spectral density, Wolf numbers, cyclic and quasi-biannual variations, active regions

1 INTRODUCTION

Our earlier analysis of cyclic variations of the powerful local magnetic fields was based on the Wolf numbers (Rivin, 1993,1994,1995). The up-to-date methods of solar radiophysics allow one to use for the same purpose variations of the 10.7 cm solar radio flux F ($\sim$ 2800 MHz). The new data obtained by basically new measuring methods are useful to provide additional information about the characteristics of the solar magnetic cycle. In this paper, we investigate the correlation of the annual mean Wolf numbers W with the F values separately for cyclic and quasi-biannual variations, and discuss the probable origin of the F variations in the solar corona.

2 ORIGINAL DATA AND ANALYSIS

Figure 1(a) illustrates simultaneous variations of the annual mean Wolf numbers, W, and $F(10.7)$ values for the time interval about $\sim$ 50 years. The F values were taken from the latest Ottawa records, published by Vitinsky (1973) and *Solar-Geophysical Data prompt reports* (1995). Even in this form, the cyclic variations display a good agreement (linear correlation coefficient $r \simeq 0.99 \pm 0.11$), though both curves are

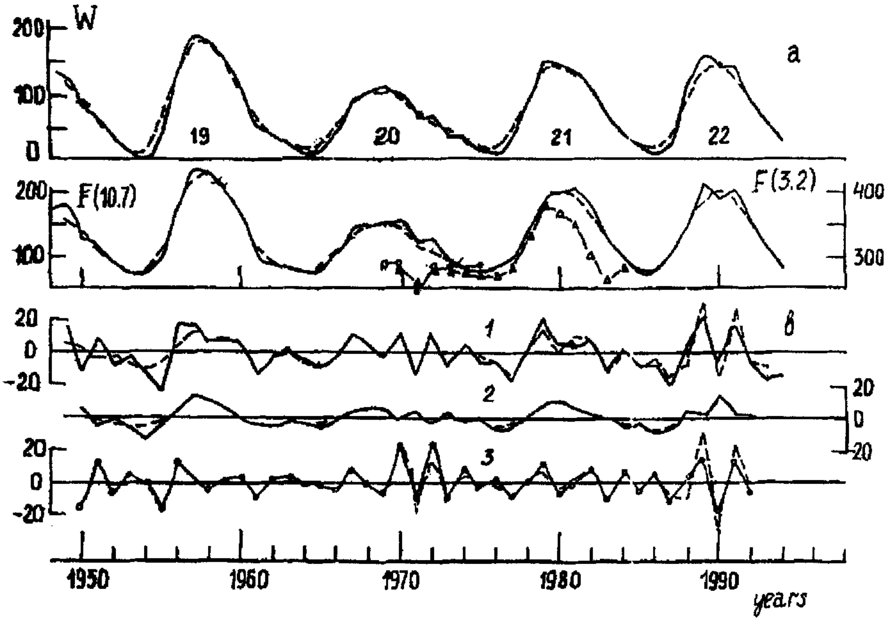

Figure 1 1948–1994: (*a*) the original (solid line) and smoothed (dashed line) W and F data; variations of the $F(3.2)$ values from Manila (circles) and Sagamore Hill (triangles) are additionally superimposed on the $F(10.7)$ curve. The figures under the W curves are the 11-year cycle numbers, (*b*) the quasi-biannual variations of the W (solid line) and $F(10.7)$ (dashed line); *1*, the difference after the first smoothing; *2*, the smoothed curve *1*; *3*, the high-frequency part of the variations of the curves *1*. The F values are given in the units 10^{-22} W/m^2 Hz.

complicated by short-period fluctuations. The latter were suppressed by smoothing the W and F time series over a running 3-year interval. For the smoothed curves $r = 1.00 \pm 0.05$. The high correlation coefficient corresponds to a similar behaviour of the two smoothed curves on the correlation plane (Figure 2(*a*)) approximated by a linear regression equation: $F(10.7) = 58.7 + 0.93W$. The equation coefficients are similar to those obtained by Kataja (1986). Comparison of the original and smoothed curves of W and $F(10.7)$ suggests that the phase shift observed at the maximum points between the two original curves (e.g., cycle 21) is due to a small variation of the superimposed high-frequency part. This produces the so-called "double-peak" maximum, which is absent on the smoothed curves.

The high-frequency part of smoothing difference curves *1*, (Figure 1(*b*)) is formed by fluctuations superimposed on the remainder of the 11-year cycle (the result of an insufficiently steep frequency/amplitude characteristic of the filter). The cycle was additionally suppressed by smoothing curves *1* in Figure 1(*b*) over the same interval to obtain the difference curves *3*. For the latter, $r \simeq 0.94 \pm 0.10$, i.e. the quasi-biannual variations of W and $F(10.7)$ (with $T \simeq$ 2–3 years) are practically synchronous, without any phase shift, but with a somewhat different amplitude modulation. The distribution of correlation points of these curves over the

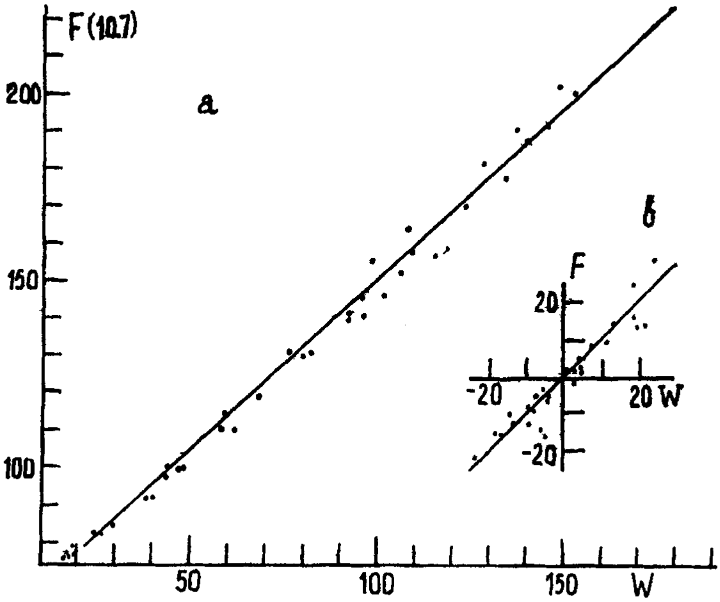

Figure 2 Relationship between the $F(10.7)$ and W data on the correlation plane for cyclic (a) and quasi-biannual (b) variations. The units along the ordinate axis are the same as in Figure 1.

correlation plane (Figure 2(b)) is approximated by the linear regression equation $F(10.7) \simeq 0.98W$.

Figure 1(a) illustrates separately the $F(\lambda = 3.2)$ data for the 10–15 year interval obtained at Manila and Sagamore Hill Observatories, adopted from (Danilchev, Morozova and Obridko, 1986). These curves differ significantly from the $F(10.7)$ curve. However not all the data agree with those given by Donnelly (1983) (see Figure 3). The latter display similar spectral density variation of the solar radio flux over the entire cm wave range.

3 DISCUSSION OF THE RESULTS

A good agreement between the annual mean W and $F(10.7)$ pattern curves has been earlier reported in the literature (Kataja, 1986; Vitinsky *et al.*, 1986; Xanthakis, 1985), but the corresponding coupling mechanism is still unknown. The long-term F variations over active regions are usually attributed to thermal radiation and identified with the slowly changing S-component of the solar radio emission (Zheleznyakov, 1964). The flux spectral density of the annual mean S-component is a maximum at $\lambda \sim 5$–10 cm.

The S-component increases over the sunspots and chromospheric faculae, where the electron density, magnetic field, and temperature are higher, than in the ambient medium. These regions extend from the bottom of the chromosphere to the lower

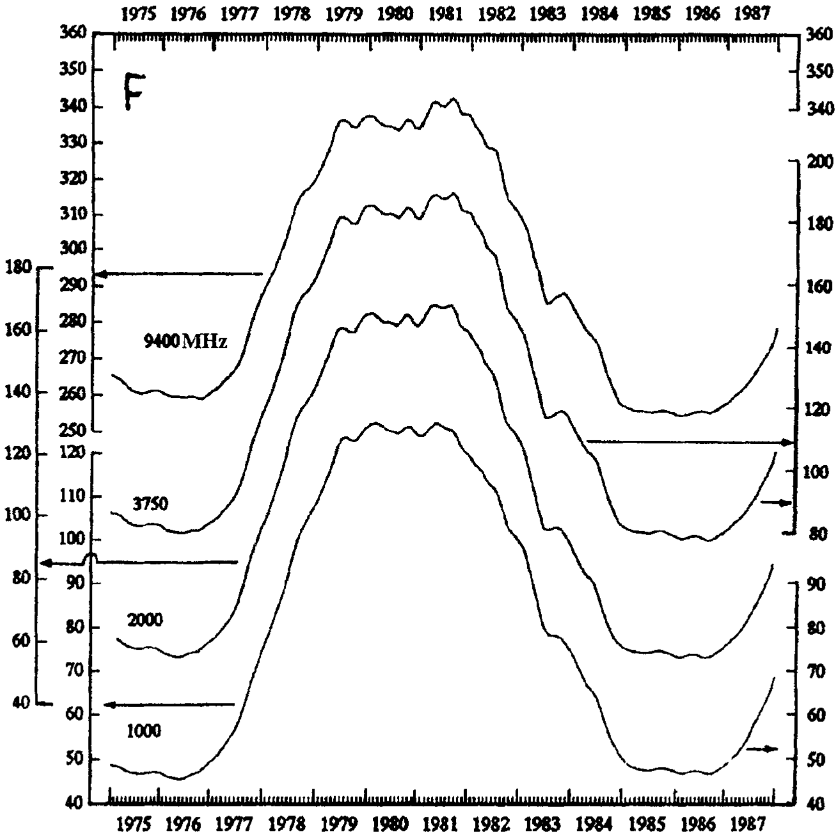

Figure 3 Monthly mean solar radio flux spectral density in the wavelength range $\lambda = 3.2$–30 cm as given by the Toyokawa measurements. Original data are smoothed over a running interval of 13 months (Figure 6, Donnelly, 1993). Figures on the curves are frequencies in MHz. The units along the ordinate axis are the same as in Figure 1.

corona and are due to coronal condensations. Their height differs for different cm wavelengths. For $F(10.7)$, $h \sim 0.006R_\odot$ above the photosphere. Density variations of the solar radio flux in this region are mainly due to electron bremsstrahlung in the magnetic field at $\omega \simeq 2\omega_H$ and $3\omega_H$, where ω_H is the gyrofrequency. The area of the emission region can only roughly coincide with the diameter of the corresponding sunspots. It is determined by facular fields as longer-lived features, rather than sunspots.

Krueger (1984) also indicates that the S-component of the F values is mainly due to thermal radiation. It should be noted that cyclotron radiation at the second and third gyrofrequency harmonics is predominant over strong umbral magnetic fields, and is mostly generated in the regions where the corresponding gyroresonance levels exist under coronal temperature conditions. However, active regions (AR) are not completely filled with bright points. The bright elements are usually surrounded by a quasi-quiet background with predominant bremsstrahlung emission.

A somewhat different approach was suggested by Tapping (1987). He believes that the full disk radiation of the S-component combines radiation from the quiet Sun, the background (extra-floccular) and the AR emission, the latter making a much smaller contribution than the other two types of radiation. In turn, the background emission is about twice as large as that from the quiet Sun. So, density variations of the solar radio flux at $\lambda \simeq 10$ cm are mostly determined by the free-free thermal emission of the chromosphere and the lower corona, where the main contribution is from beyond the active regions. Weak sources are usually situated in the chromosphere, and strong ones in the corona. At the same time, the $F(10.7)$ variations are a good indicator of the respective changes of the solar magnetic fields. They correlate perfectly with UV-radiation and the calcium plage area since all these radiations are due to a common factor – the matter supplied magnetic fields.

An alternative interpretation of the F sources in the cm range was suggested by Gelfreikh (1995). He claimed that the radio flux variation might be associated with radiation belts in AR magnetospheres. It manifests itself as a halo of the local source at $\lambda = 3$–4 cm with a maximum at $\lambda \simeq 10$ cm. It can be suggested that radio waves are mostly generated by synchrotron/cyclotron radiation of fast particles in magnetic traps (bottles) of radiation belts in analogy with radiation belts in the Earth is magnetosphere. Particle acceleration is due to narrow current streams, threading the entire diffusive region.

In terms of this approach, the similarity of variations of the annual mean Wolf numbers and $F(10.7)$ suggests that cyclic variations in radiation belts may occur under complete control of cyclic variations in the AR magnetic fields. However, one should not forget about some fundamental differences between the Earth and AR magnetospheres, pointed out by Krueger.

A better correspondence of radiation regions to the particular sunspots is observed at $\lambda = 3$–5 cm (Kataja, 1986; Xanthakis, 1985; Krueger, 1984). At these wavelengths, the radiation region has the same as the sunspot and is located at a somewhat lower hight, than for $\lambda = 1.7$ cm. However a comparison of the curves in Figure 3 shows that cyclic variations are practically the same all over the cm wavelength range. This phenomenon has no explanation in the literature. It probably shows that variations of the annual mean Wolf numbers display the total annual variation of magnetic fields in active regions, rather than in individual sunspots. Besides sunspots, which produce most of the magnetic flux, an active region may also comprise the fields of plages.

As shown above, the two basically different measuring methods – the optical (observation of sunspots) and radiophysical ones – reveal practically the same pattern of the annual mean local magnetic fields and the associated coronal processes. On the one hand, it shows that both processes are real; on the other it requires a thorough description of the probable coupling mechanism and the role of AR magnetic fields.

The close relationship between the W and $F(10.7)$ values is surprising. When R. Wolf suggested his relative numbers $W = k(10g + f)$ more than a hundred years ago, he complicated the algorithm by including not only the daily sunspot number, but also the number of groups, g, on the visible disk. It is difficult to say now what made him use a complicated algorithm, but it became the standard form to describe cyclic variations over active regions, that are either due to magnetic bremsstrahlung radiation of electrons in the AR corona, or to processes in the AR radiation belts.

For a complete description of the coupling between the two processes, it should be noted that the correlation between the monthly mean values of $F(10.7)$ and W is much lower (Danilchev *et al.*, 1986; Vitinsky and Petrova, 1981; Şastri, 1968). In some months, the correlation is practically absent (Sastri, 1968). This effect may be due to the fact that the composition of cm radio sources is the more complicated, the more discrete the original data. When the data are averaged over a year, part of the sources are filtered out, and the source, that is the function of the integral AR magnetic field, becomes dominant.

With reference to the problem of the description of the solar magnetic cycle, it is important to note that the variation pattern of the cycle amplitude and other parameters, obtained from cyclic variations of the $F(10.7)$ values, is practically the same as that given by the Wolf or Wolf–Anderson series. Such agreement is additional evidence of the reliability of these variations, but it does not provide any new information about the properties of the solar magnetic cycle. The close correlation between W and $F(10.7)$, especially their smoothed values, allows us to extrapolate the annual mean $F(10.7)$ values back to 1700, as well as to perform magnetic flux monitoring in active regions by two independent methods.

According to Krueger (1984) and Gelfreikh (1995), radio methods allow the monitoring of slow variations of the magnetic field intensity over a particular region in the solar corona. This is a step towards a better interpretation of variations of the annual mean Wolf numbers and towards establishing the relationship between the Wolf numbers and variations of the annual mean AR magnetic fields over a magnetic cycle.

4 CONCLUSIONS

(1) Cyclic variations of the Volt numbers and the radio flux density at $\lambda = 10.7$ cm for 1948–1994 are practically identical. They are likely to describe cyclic variations of the integral magnetic fields of active regions and the coronal processes, generated by these fields.

(2) The correlation between quasi-biannual variations of W and $F(10.7)$ is somewhat worse, but they seem to have the same origin.

Acknowledgments

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References

Danilchev, B. V., Morozova, L. P., and Obridko, V. N. (1986) *Soln. Danniye*, No. 4, 69.

Donnelly, R. F. (1993) In: J. Hruscka, M. A. Shea, D. F. Smart, G. Heckman (eds.), *Solar - Terrestr. Predict. - IV*, Boulder, 131.

Gelfreikh, G. B. (1995) *Izv. RAN, Phys. Series* **59**, 90.

Kataja, E. (1986) In: P. A. Simon, G. Hecknaan, M. A. Shea (eds.), *Solar-Terrestrial Predictions, Meudon 1984*, Boulder, 35.

Krueger, A. (1984) *Solar Radioastronomy and Radiophysics*, Mir, Moscow.

Rivin, Yu. R. (1993) *Astron. Zn.* **70**, 1257.

Rivin, Yu. R. (1994) In: V. A. Dergachev (ed.), *Solar Magnetic Fields and Helioseismology*, St.-Petersburg, FIT im. A. F. Ioffe, 52.

Rivin, Y. R. (1995) *Izv. RAN. Physical Series* **59**, 43.

Sastri, N. S. (1968) *Indian J. Meteorol. and Geophys.* **19**, 443.

Solar-Geophysical Data Prompt Reports (1995) NOAA, No. 615, Part 1.

Tapping, K. F. (1987) *J. Geophys. Res.* **D92**, 829.

Vitinsky, Yu. I. (1973) *Solar Activity Periodicity and Forecast*, Nauka, Leningrad.

Vitinsky, Yu. I. and Petrova, N. N. (1981) *Soln. Dannye*, No. 9, 102.

Vitinsky, Yu. I., Kopecky, M., and Kuklin, G. V. (1986) *Statistics of Sunspot Production in the Sun*, Nauka, Moscow.

Xanthakis, J. P. (1985) *Astrophys. and Space Sci.* **111**, 179.

Zheleznyakov, V. V. (1964) *Radio Emission from the Sun and Planets*, Glav. red. fiz.-mat. lit-ry, Moscow.