AREA OF POLAR CORONAL HOLES AND SUNSPOT ACTIVITY: YEARS 1939–1993

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(Received 23May, 1995; in final form 12 February, 1996)

Abstract. The correlation between the size of polar coronal holes and sunspot numbers has been investigated for the last five solar cycles. The area of polar coronal holes over the period from 1939 to 1993 was derived from ground-based observations of the green coronal line at 530.3 nm (Fe XIV). Correlation analysis revealed that there is no general shift in the maxima of the curves of these two solar indices. The analysis showed the same shift in months in cycles 21 and 22 when the best correlation between the indices is reached; the time shift found in cycle 20 is slightly different from that in cycle 18; in cycle 19, there is found a shift with a value between the values in cycles 18, 20 and 21, 22. The time between succesive peaks of smoothed polar hole size and smoothed sunspot number is different in each cycle.

1. Introduction

As is generally known, a strong correlation exists between the size of polar coronal holes that are larger during the solar minimum, and the sunspot number, larger during the maximum. Recently a relationship between these two indices of solar activity has been investigated by Bravo and Otaola (1989), Bravo (1992), Bravo and Stewart (1994). The authors compared polar hole size estimated from K-coronameter images with the sunspot number for cycles 20, 21, and 22. In this paper we investigate the correlation between the size of polar coronal holes and sunspot numbers over the period from 1939 to 1993 using the so-called homogeneous data set (HDS) of green coronal line intensity (Rybanský, 1975; Rybanský and Rušin, 1992; Rybanský *et al.*, 1994a), created on the basis of the measurements of the world-wide coronagraphic network.

The coronal hole is defined according to X-ray solar images as a region of low intensity (Kopp and Orrall, 1977). These authors assumed that the density and temperature in coronal holes is low compared to the quiet corona. The intensity of the green coronal line depends mainly on the density and less on the temperature. This led to the idea to compute polar coronal hole area by means of the coronal line intensity measurements. A similar method for determining the position and an area of equatoreal coronal holes was used earlier (Letfus, Kulčár, and Sýkora, 1980).

The course of the curve of the hole size shows an opposite tendency to that of the Wolf number curve. A gradual increase in the size to maximum is visible, followed by a steep decrease in size to minimum (see Figure 1). This refers to an inverse relationship between the size of the coronal holes and sunspots. A higher green-line intensity in the corona is measured above sunspots and active regions.

Solar Physics **167:** 419–426, 1996.

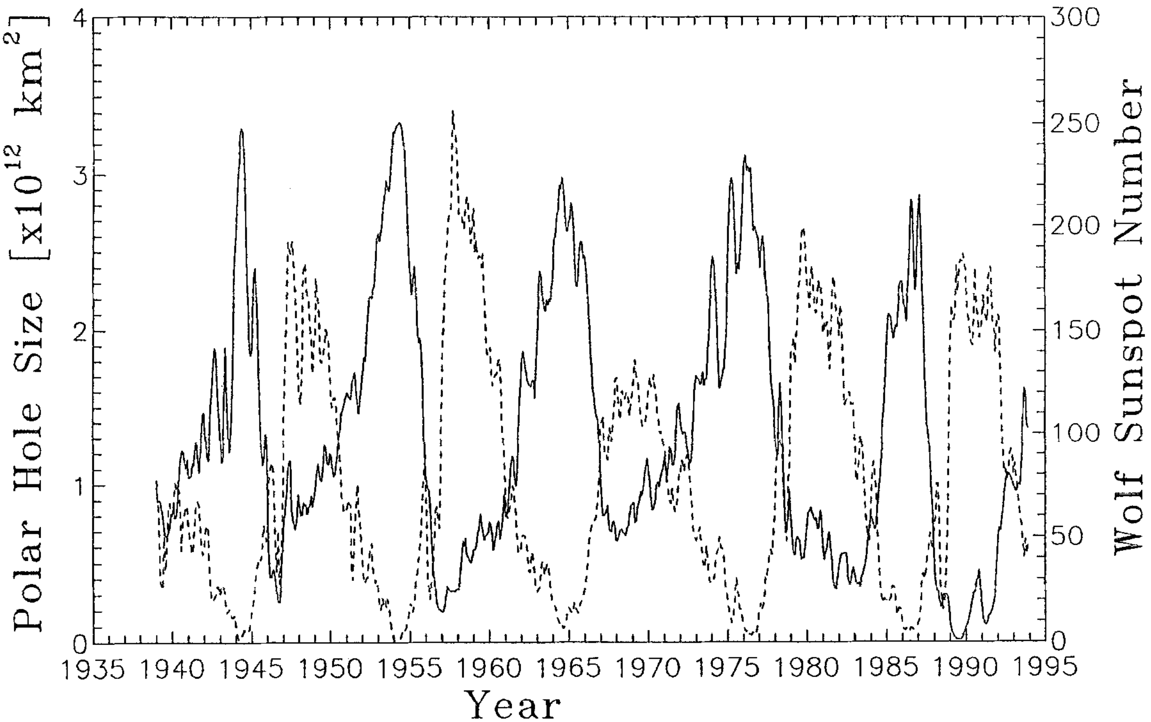

Figure 1. Monthly means of polar coronal hole size from HDS intensities of the green coronal line (solid line, scale at the left) and monthly mean of the Wolf sunspot number (dashed line, scale at the right) from 1939 to 1993.

When the number of sunspots decreases, the size of coronal holes increases. This fact should be used for estimating the peak times of the polar coronal holes defined according to the green line intensity for all sunspot cycles. We should obtain further information about the relationship between these two indices by investigating the correlation of daily data. This will be a topic of further research for us.

2. Method for Determining the Polar Coronal Hole Area

As has been said, HDS data can be used for computing the area of the polar coronal holes. Green coronal intensities (line of Fe XIV at 530.3 nm) at Lomnický Štít coronal station are measured at the height of 40″ above the solar limb (photosphere) around the whole Sun with a lag of 5°, beginning at the north solar pole. Since coronal holes evolve slowly, we suppose that an image of the solar corona in front of the disc can be modelled according to the data over 15 days (i.e., data of an arbitrary date and data of 7 days before the date and 7 days after the date) (Rybanský, 1995). The intensities of the particular date show the values around the limb. The image along meridians situated eastward of central meridian (CM)

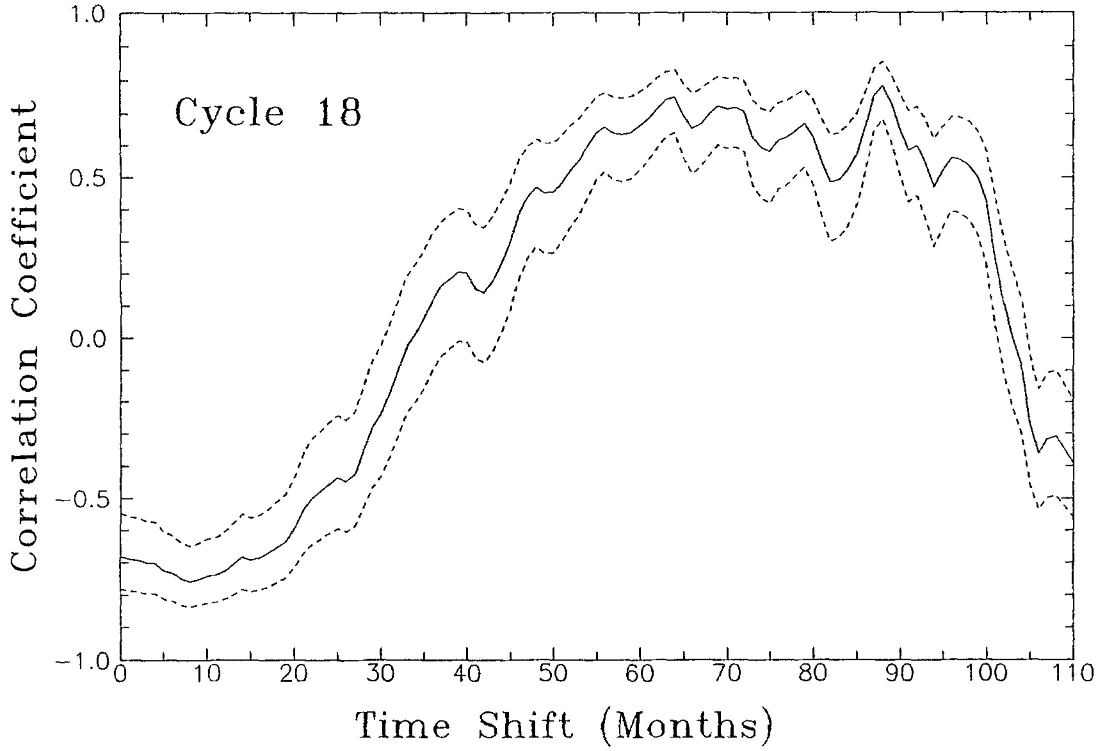

Figure 2a.

(each distant 13.2° from the previous one) is reconstructed using the data from six days before the date. The intensities along the CM are determined as an average of intensities of the two limit days. The image along meridians situated westward of the CM is reconstructed using the data from six days after the date. The image along the two neighbouring meridians near the CM is reconstructed at a distance 10.8°. We define that the coronal hole in the light of the green coronal line is present if the intensity of the line does not overlap 15 coronal units (CU). In this way we estimated the border of the coronal hole (with an accuracy of 5°) and computed its size as a sum of the areas of spherical triangles bordered by meridians and the border where the intensity already overlaps 15 CU. It should be mentioned that not every region of low brightness of the green corona is evident as an X-ray or EUV coronal hole. Therefore, the size of a hole estimated from the green line intensity and from X-ray or EUV images can be different. As a result, daily values of polar coronal hole size (as visible in front of the visible hemisphere) were obtained. Then monthly means of the size (expressed in square kilometers) were computed and compared with the monthly means of sunspot numbers as published in *Solar Geophysical Data*. Figure 1 shows the course of monthly polar coronal hole size together with the course of the monthly means of sunspot numbers.

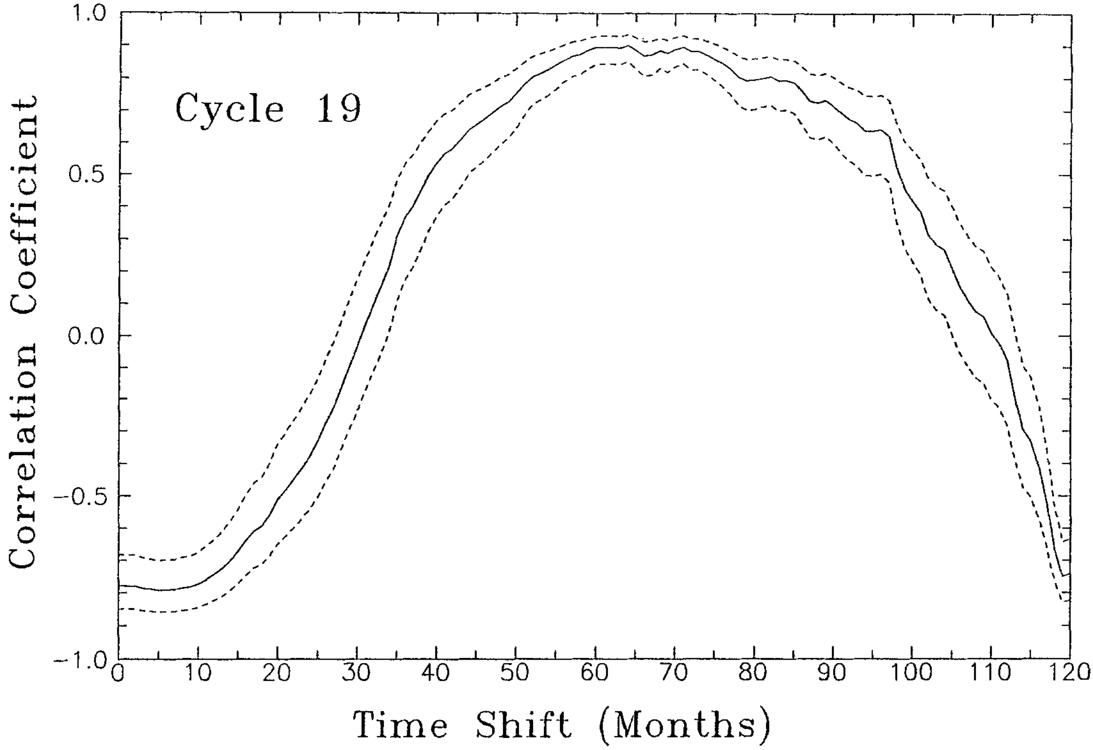

Figure 2b.

3. Correlation Analysis between Holes and Sunspots in Cycles 18–22

The monthly means of polar coronal hole areas and sunspot numbers were correlated for the last five cycles (individually in each cycle). Figures 2(a–e) show the correlation coefficient and 99% confidence limits for cycles 18–22 as a function of the shift of the coronal hole size curve. The 99% confidence limits were estimated by means of the standard Fisher r to z transformation. The shifts in months for the best correlation between sunspots and holes were found and corresponding correlation coefficients were obtained:

Cycle 18 – two peaks in the correlation function at a shift of the polar hole curve by 64 and 88 with correlation coefficients of 0.75 and 0.78, respectively. We estimated a mean shift of 76 months. The confidence interval for the month of the best correlation is 60–89 months.

Cycle 19 – two peaks at a shift of 62 and 71 months, with the correlation coefficient 0.895 (in both cases). The mean shift is 67 months, confidence interval 56–75 months.

Cycle 20 – peak at shift by 75 months, correlation coefficient 0.7, confidence interval 67–91 months.

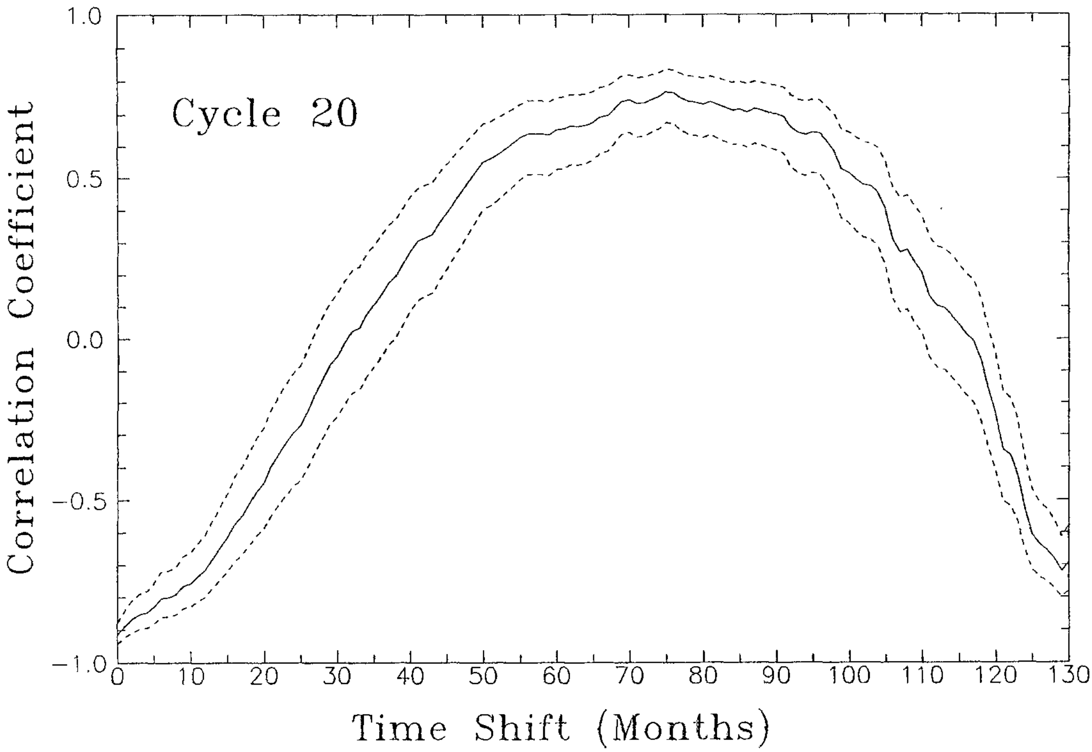

Figure 2c.

Cycle 21 – peak at shift by 59 months, correlation coefficient 0.81, confidence interval 48–60 months.

Cycle 22 – peak at shift by 59 months, correlation coefficient 0.895, confidence interval 52–60 months.

We found that the confidence intervals in cycles 20 and 21, and 20 and 22 as well does not overlap at all. In other cycles the intervals overlap.

Further, we compared the smoothed curves of the size of holes and sunspot numbers considering a five-month average in the value of each month. This analysis showed that the smoothed polar coronal hole size preceding cycle 18 culminated in June 1944 and that the smoothed maximum of sunspot number occured in August 1947; this gives a shift of 38 months. Similarly the following shifts in the maxima of both indices for the following cycles were obtained: cycle 19, a shift of 41 months, cycle 20, a shift of 55 months; cycle 21, a shift of 43 months; cycle 22, a shift of 33 months.

We determined the peak times of polar coronal holes size in the green line as follows: the maximum of the size preceding cycle 18 occurred in June 1944, the one preceding cycle 19 in May 1954, preceding cycle 20 in August 1964, preceding cycle 21 in March 1976 and finally, preceding cycle 22, in February 1987.

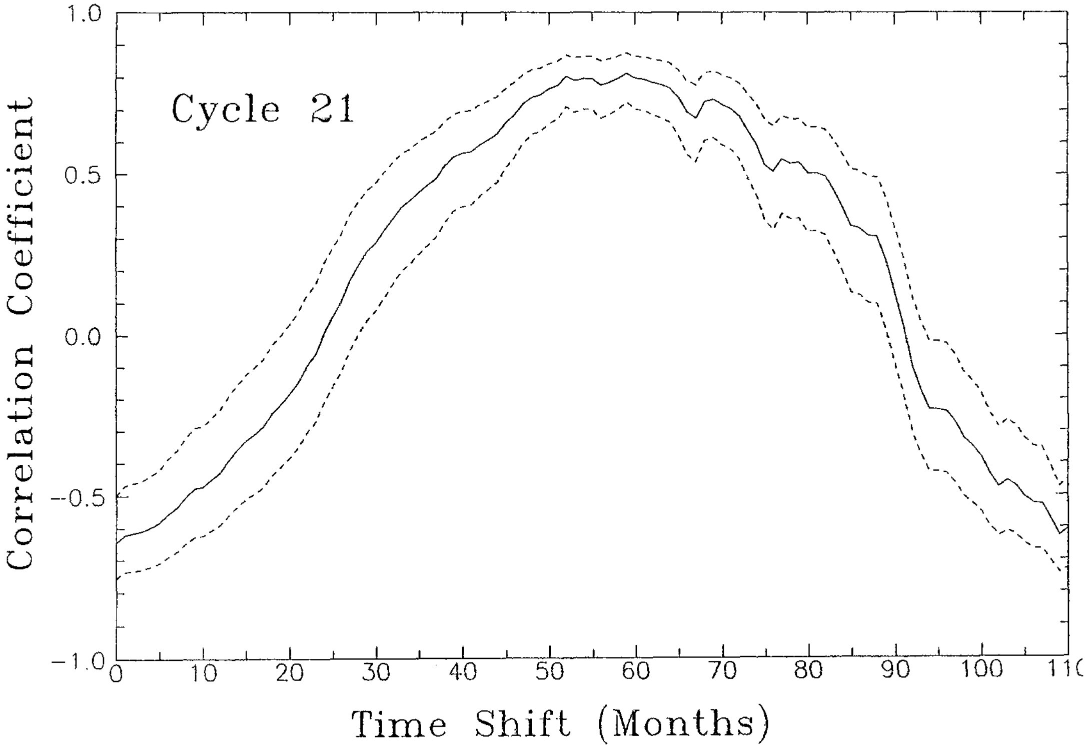

Figure 2d.

4. Discussion and Conclusions

We can conclude that there is a strong correlation between the size of polar coronal holes and sunspot numbers (as has been shown earlier by other authors as well). The high level of the maximum correlation coefficient confirms that the area of polar coronal holes can be derived from ground- based observations of the green coronal line at 530.3 nm (HDS) as well as that the choice of the threshold value of 15 CU of the green line intensity used for the definition of the area of the coronal hole was good.

However, the analysis did not show any general shift in the maxima of the curves of these two indices. The correlation analysis shows that in cycles 21 and 22 the same shift in months was found when the best correlation between the indices was reached. In cycles 18 and 20 a slightly different time shift was found. The time between succesive peaks of the smoothed polar hole size and smoothed sunspot number is different in each cycle and ranges from 33 to 55 months. This means that the modulation of polar coronal hole size cannot be unambiguously used as a tool for predicting the maximum of the next solar cycle.

We can compare our peak times with those estimated from K-corona images (Bravo and Stewart, 1994) for cycles 21 and 22. We found that the peak times from

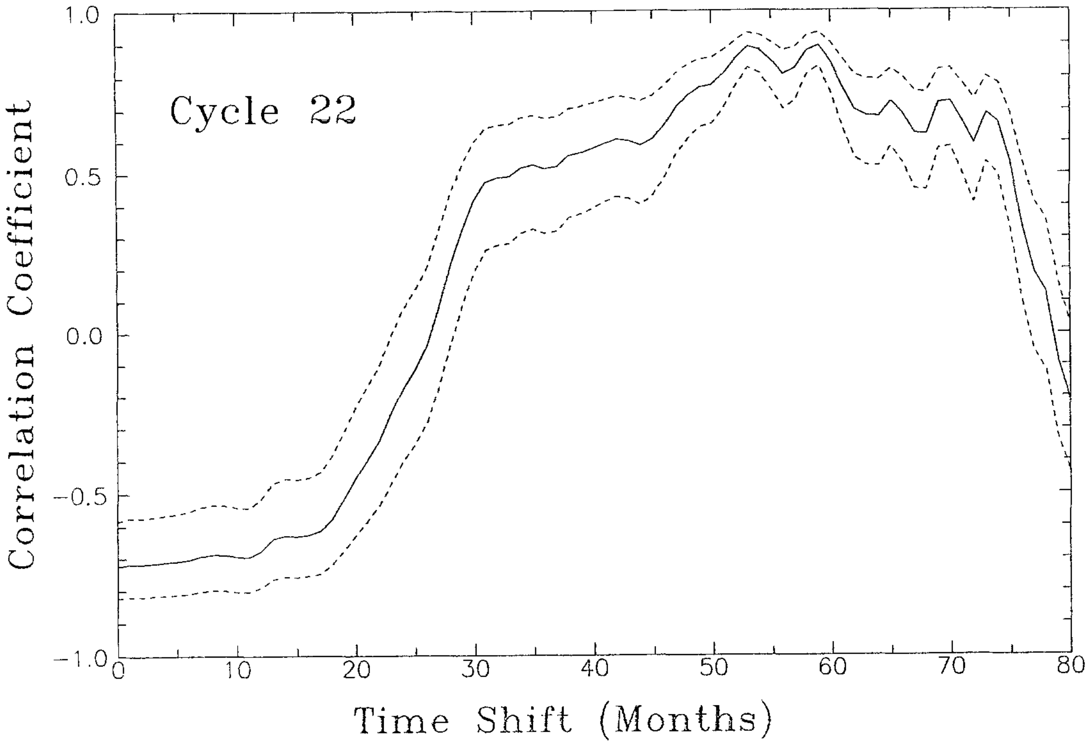

Fig. 2e.

Figure 2a–e. Correlation coefficient (solid line) and confidence limit (dashed lines) between polar coronal hole size and sunspot number in cycles 18–22, as a function of the time shift of polar hole size.

K-corona images occurred earlier in both cycles, and the shift is 10 months for cycle 21 and 21 months for cycle 22. These shifts should be caused by a different definition of the area of the coronal hole.

It is important to say that due to the low number of observational days in the coronal station network over the period of 1939–1946, a high level of data interpolation was needed in the process of the homogenisation of the coronal intensity data (Rybanský et al., 1994b). Therefore, both the HDS before 1947 and the correlation between the two mentioned indices in cycle 17 is not reliable enough, and we cannot draw any conclusions for this cycle.

Acknowledgements

I am very grateful to Dr Rybanský for supplying the HDS data (Rybanský and Rušin, 1992) and for valuable discussions and comments, as well as for encouraging me to write this article and for reading the manuscript. I thank Dr Lukáč and Dr Sýkora for helpful comments.

References

Bravo, S. and Otaola, J. A.: 1989, *Solar Phys.* **122**, 335.
Bravo, S.: 1992, *Ann. Geophys.* **10**, 449.
Bravo, S. and Stewart, G.: 1994, *Solar Phys.* **154**, 377.
Kopp, R. A. and Orrall, F. Q.: 1977, in J. B. Zirker (ed.), *Coronal Holes and High Speed Wind Streams*, University Press, Boulder, p. 179.
Letfus, V., Kulčár, L., and Sýkora, J.: 1980, in M. Dryer and Tandberg-Hanssen (eds.), *Solar and Interplanetary Dynamics*, D. Reidel Publ. Co., Dordrecht, Holland, p. 49.
Rybanský, M.: 1975, *Bull. Astron. Inst. Czech.* **26**, 367.
Rybanský, M.: 1995, private communication.
Rybanský, M. and Rušin, V.: 1992, *Contr. Astron. Obs. Skalnaté Pleso* **22**, 229.
Rybanský, M., Rušin, V., Gaspar, P., and Altrock, R.: 1994a, *Solar Phys.* **152**, 487.
Rybanský, M., Rušin V., Minarovjech, M., and Gaspar, P.: 1994b, *Solar Phys.* **152**, 153.