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Phase difference between the two components of the solar cycle

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Abstract. It is confirmed that near each solar minimum the latitude zone over which the *small* sunspot groups are distributed expands a few years before the expansion of the latitude zone of the *large* spot groups takes place. It is found that this expansion of the latitude zone of the small spot groups also preceeds the increase in the mean latitude of the small spot groups. These observations indicate that the thinner flux tubes of each fresh solar cycle start emerging earlier than the thicker flux tubes of the same cycle.

Key words : sunspots—solar activity—solar cycle—solar magnetic fields

1. Introduction

In a recent analysis of the distribution of the sunspot groups with respect to their maximum areas A_* Gokhale & Sivaraman (1981) have shown that each solar cycle has contributions from two categories of sunspot groups. The category I contributes predominently to spot groups of maximum areas $A_* \lesssim 30$ units (1 unit $= 10^{-6}$ $\times$ the solar hemisphere) and the category II contributes to sunspot groups with all values of A_*, ranging from very small to very large ones (Gokhale & Sivaraman 1981). We have also shown that enhancement in the sum of the total widths of the latitude zones in the two hemispheres, over which the small ($A_* \lesssim 30$ units) spotgroups are distributed, takes place one or two years before a similar increase in the case of large spot groups ($A_* \gtrsim 100$ units) commences. It was noted that the total width of the latitude zone over which the spot groups of any one category appear may or may not represent the latitude zone over which the corresponding magnetic flux tubes are distributed below the photosphere. For example the latitude zone of the spot groups may appear substantially wider than that of the subphotospheric flux tubes if a few *stray* flux tubes move to abnormal latitudes before they emerge. Therefore, it was deemed necessary to verify the earlier observation using a statististical parameter for the width of the latitude zones of spot groups. Here we define the width of the latitude zones as the root-mean-square deviation of the latitude in either hemisphere. We show that even with this definition, the expansion of the latitude zone of *small* spot groups can be seen to occur substantially earlier than the expansion of the latitude zone of the *large* spot groups. We also find that during the early parts of such expansions the mean latitude continues to decrease for a year or so. These observations lend additional support to the concept of the two components of the solar cycle as envisaged by the shock transition model of the solar cycle (Gokhale 1977, 1979).

2. Data analysis

In the earlier work (Gokhale & Sivaraman 1981) we listed the spot groups observed during the last eight solar cycles (1889–1976) in different class intervals according to their maximum areas and noted the mean latitude of each of them on the day its area reached the maximum value A_*. In the present analysis we choose intervals (0–25) and (200–500) of A_* as representing the *small* and the *large* varieties of spot groups and the interval (26–100) as representing the mixture of the two categories. For each of these A_* intervals and for each year we determined from the lists the mean latitude $\bar{\theta}$ and the root-mean-square deviation $W_{\rm rms}$ of θ for all the spot groups which appeared in either hemisphere during that year and had maximum areas in that interval. Here θ is the latitude of the spotgroup reckoned positive in either hemisphere.

In figures 1 and 2 we show the year-to-year variation of $\bar{\theta}$ and $W_{\rm rms}$ for spot-groups in the three aforementioned A_* intervals during the last eight solar cycles. We see in figure 1 that the value of $W_{\rm rms}$ for the A_* interval 0–25 increased, often dramatically, during the periods 1899–1901, 1911–13, 1921–22, 1930–33, 1941–43, 1953–54, 1963–64 and 1973–75. During all these time intervals except 1963–64, the $W_{\rm rms}$ for the A_* interval 200–500 continued to decrease. On the other hand the $W_{\rm rms}$ for the intermediate A_* interval 26–100 increased during some of the time intervals and decreased during others. It is also interesting to note from figure 2 that during the early parts or whole of these time intervals, there is no appreciable difference in the time-dependence of $\bar{\theta}$ corresponding to the three A_* intervals. Thus the beginning of the enhancement of $W_{\rm rms}$ for $A_* \lesssim 25$ units is not associated with, but preceeds the beginning of the enhancement of the corresponding $\bar{\theta}$.

3. Conclusions and discussion

The behaviour of $W_{\rm rms}$ during the above mentioned time periods confirms that near the solar minima, the latitude zone of the small spot groups expands a few years earlier than the latitude zone of the large spot groups. For each A_* interval, there is an overall increase of $\bar{\theta}$ and $W_{\rm rms}$ during the ascending phase of the solar cycle and an overall decrease of both these parameters during the descending phase. This suggests that the expansion of the latitude zone of each A_* interval must be caused by an increased supply of flux tubes of the corresponding thickness and the contraction must be caused by a depletion of such flux tubes. Therefore the initial increase of $W_{\rm rms}$ during the continued decrease of $\bar{\theta}$ for $A_* \leqslant 25$ units can only be interpreted as caused by the appearance of a few spot groups of that A_* interval, but

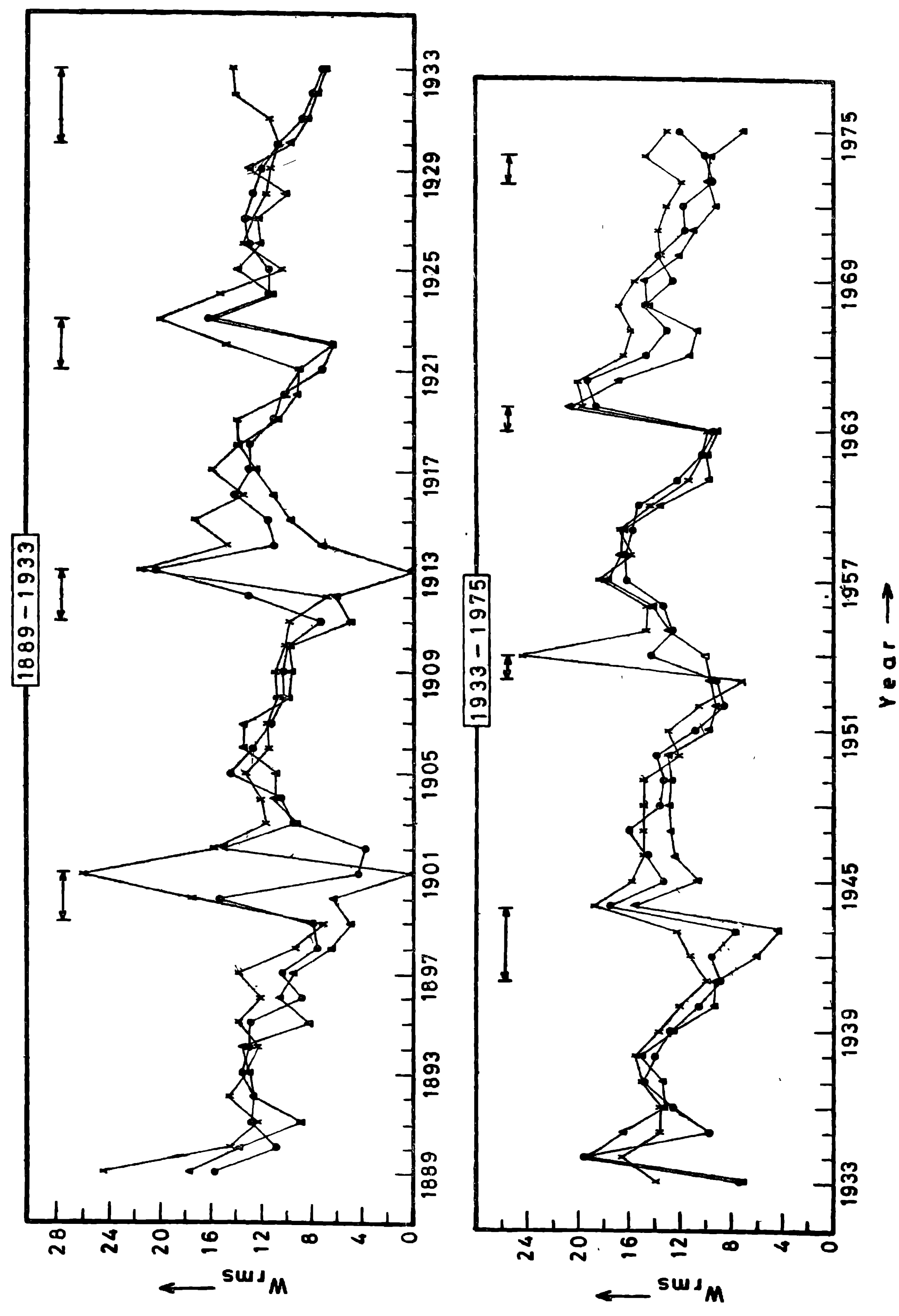

Figure 1. Year-to-year variation of W_{rms} for $0 < A_* \leqslant 25$ units (—×—), $25 < A_* \leqslant 100$ units (—●—), and $200 < A_* \leqslant 500$ units (—▲—). Periods of the expansion of W_{rms} for $A_* \leqslant 25$ units are indicated by horizontal bars.

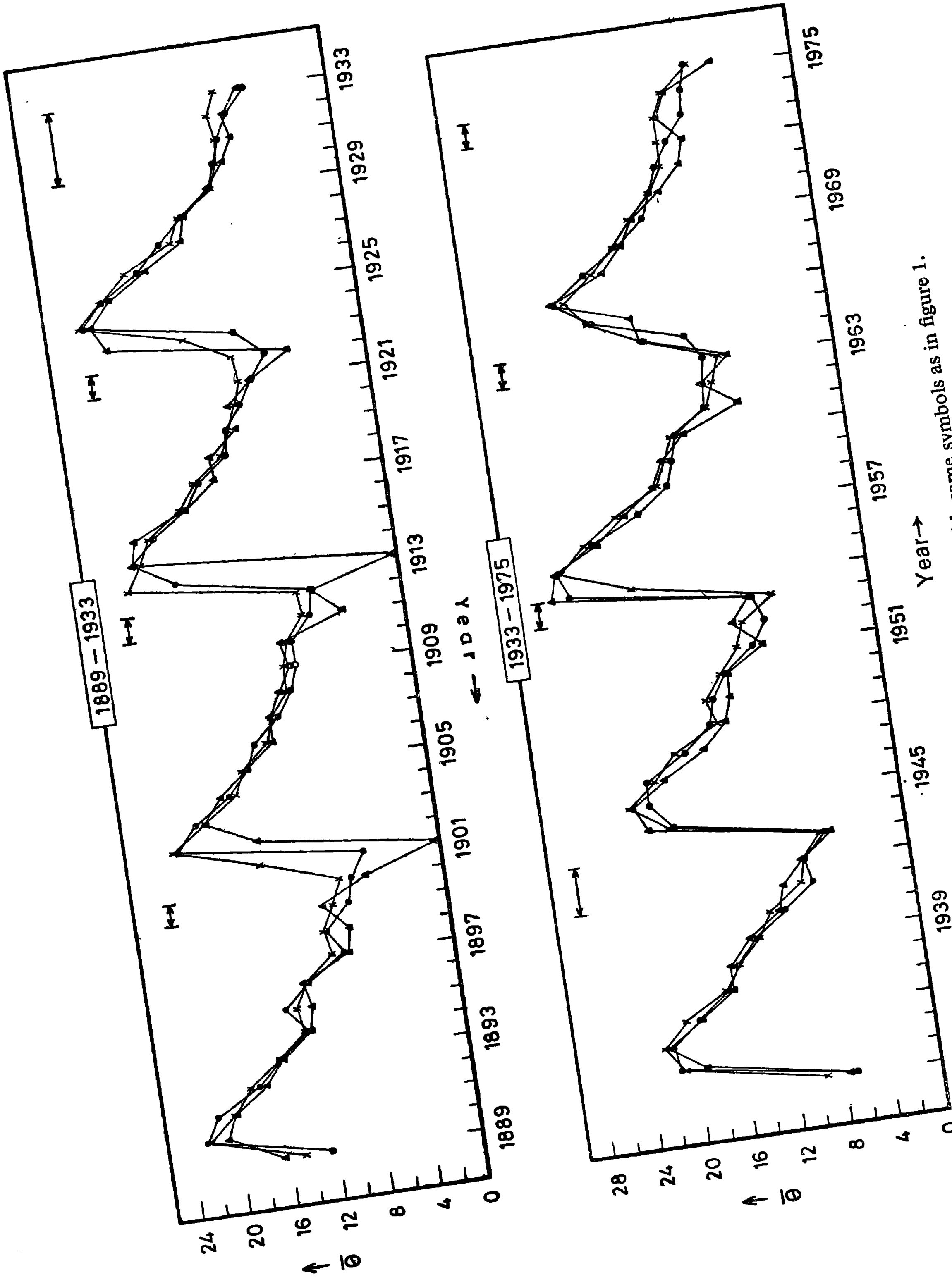

Figure 2. Year-to-year variation of $\bar{\theta}$ for the same A_*-intervals and with same symbols as in figure 1.

belonging to the *new* cycle, at relatively high latitudes. Therefore, the fact that the latitude zone of this A_* interval expands a year or two earlier than that of the interval 200–500 implies that the thin flux tubes of the new cycle start emerging a year or two earlier than the thicker flux tubes.

Probably it would have been more appropriate to determine $\bar{\theta}$ and $W_{\rm rms}$ separately in the two hemispheres in order to take into account the possible asymmetry in the distribution of spot groups in the two hemispheres. However, we note that such an asymmetry would tend to wash out the phase difference between the $W_{\rm rms}$ for small and large spot groups and that between $W_{\rm rms}$ and θ for $A_* \leqslant 25$ units. Thus the differences seen here are inspite of, and not because of, the asymmetries about the equator. It is also clear from figure 1 that the $W_{\rm rms}$ of thin flux tubes is larger than that of the thicker flux tubes.

Extrapolating these differences of phase and width one may conclude that the still thinner flux tubes of the new cycle, whose emergence may not produce sunspots or even pores, must be appearing even earlier during the old cycle and probably over a much wider latitude zone. If so, this could account for the phase difference between the solar cycles for the x-ray-bright points and the conventional active regions.

The anticorrelation between the x-ray-bright point activity and the sunspot-related activity has been explained in terms of the converse hypothesis that the thicker flux tubes emerge earlier than the thinner flux tubes belonging to the same cycle (Schlüssler 1980). However, the present analysis rules out such a converse hypothesis. The observed phase difference between the two components of the solar activity is more like that expected from the shock transition model.

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