AXIAL TILT ANGLES OF ACTIVE REGIONS AND THEIR POLARITY SEPARATIONS

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Abstract. Sunspot group and magnetic (plage) data are examined to search for a relationship between the tilt angles of active regions and the separations of their leading and following portions. A relationship is found in the sense that larger positive tilt angles are associated with larger polarity separations. This is the direction predicted by recent theoretical work (D'Silva and Choudhuri, 1992). The explanation for this appears to be that smaller surface polarity separations lead to larger magnetic tension forces, which diminish the effect of the Coriolis force that acts to twist rising flux tubes.

1. Introduction

The tilt angles of the magnetic axes of regions have been the object of observational studies by many authors over many years (Hale *et al.*, 1919; Brunner, 1930; Wang and Sheeley, 1989; Howard, 1991a, b). It is well established from these studies that there is a latitude dependence of this quantity for sunspots and for plages. Recently it has been suggested that this tilt angle is due to the Coriolis force acting on the rising magnetic flux tubes that form the region at the surface (Choudhuri and Gilman, 1987; Choudhuri, 1989; Wang and Sheeley, 1991; D'Silva and Choudhuri, 1992). In one of these, a recent theoretical analysis, D'Silva and Choudhuri (1992) have looked at the effect on the tilt angle of the polarity separation of the region. They find that because of the increased magnetic tension forces corresponding to smaller polarity separations, the tilt angles for these regions should be smaller than for those regions with larger separations.

In this observational study, the tilt angles of both sunspot groups and plages are analyzed as a function of polarity separation. It is found that an effect exists in the direction predicted by D'Silva and Choudhuri (1992).

2. Data and Analysis

The Mount Wilson daily white-light photographs, which started in 1917, and their measurement were described in an earlier paper (Howard, Gilman, and Gilman, 1984). The current data set runs through 1985. These data are combined into sunspot groups, as described in this paper, and these groups are studied here. In the present analysis, only multi-spot groups are considered (in order to be able to define a tilt angle). The

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centroid of each group is determined by an area-weighted average of all the spots. Then leading and following spots are defined to be those spots west or east of the longitudinal centroid, respectively. The average positions of the leading and following spots are then calculated, again by area weighting, and the tilt angle is determined as the angle between the line joining those two points and the local parallel of latitude. The 'polarity separations' are obtained also from these area-weighted positions. These are the full separations, not just the longitudinal components, so there should be no influence of the tilt angle on the derived separation.

The 'plage' data are from the Mount Wilson magnetograph archive. Plages are determined from the magnetic data in a process defined in an earlier study (Howard, 1989). These data start in 1967 and extend into 1990. In this case the tilt angles and the polarity separations are determined from the magnetic flux-weighted centroids of the leading and following polarity pixels of the regions.

3. Results

3.1. Sunspot Groups

Figure 1 shows spot group tilt angles averaged over intervals of polarity separation of 5 Mm. A positive tilt angle indicates that the leading spots are equatorward of the following spots. A clear slope to this relationship is seen. A least-squares linear regression gives a slope of 0.058 deg Mm^{-1} with a standard deviation of 0.0047. There are 24548 groups in this data set. Both from the plot and the regression analysis it is seen that this is a significant result. The relationship seen in Figure 1 may not be linear. At the smallest polarity separations the curve may bend toward zero a bit more rapidly, although the error bar at 5 Mm is rather large. The slope for groups with separations less than 30 Mm is 0.088 ± 0.021 deg Mm^{-1}.

In this analysis and in Figure 1, polarity separations greater than 140 Mm were omitted. These larger separations may be influenced somewhat by the chance close proximity of two or more separate spot groups that are combined by the program to form one large group (Howard, Gilman, and Gilman, 1984).

3.2. Plages

Figure 2 shows the same plot but for magnetic regions (plages). Here, because of the fact that the locations of leading and following polarities are determined just by an area-weighted average of these pixel coordinates, the polarity separations of magnetically complex regions are likely to be underestimates (Howard, 1992). Thus the points on the left of the diagram do not fit the rather well-defined straight line determined from the rest of the diagram. There are, however, very few points here, so their influence on the result is quite small, as has been determined by running the regression analysis without these points. This slope is 0.016 ± 0.0073 deg Mm^{-1}. Here the data for separations greater than 230 Mm have been omitted for the same reason that large spot group separations were omitted, as discussed above.

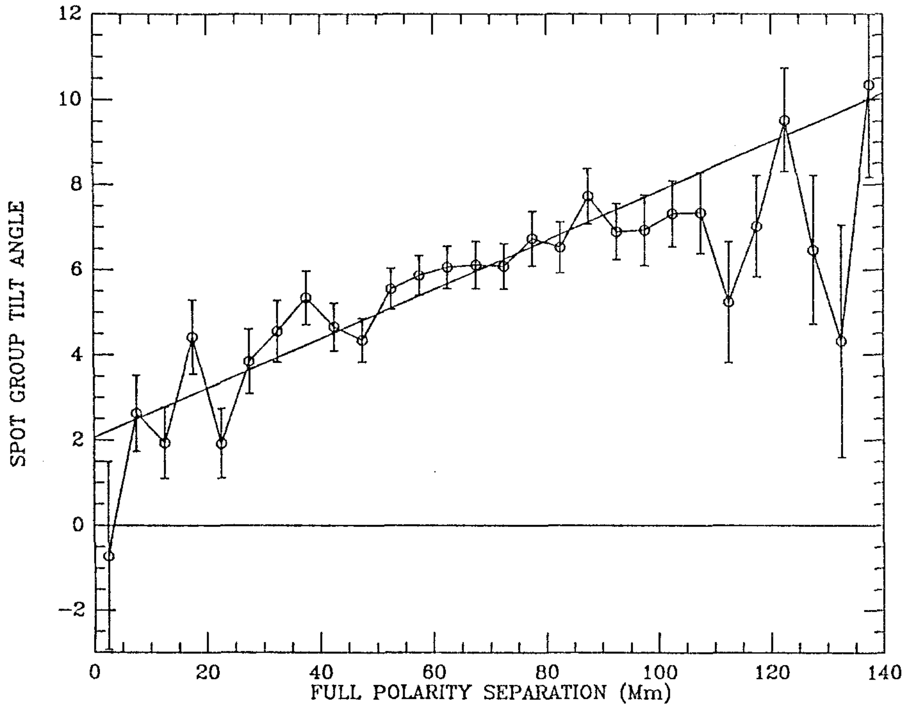

Fig. 1. Average sunspot group tilt angles over 5-Mm intervals of polarity separation. Positive tilt angles represent the configuration where leading spots are equatorward of following spots. Full error bars represent two standard deviations. There are 24548 multi-spot sunspot groups represented here in the interval 1917–1985

For the plages in Figure 2, as for the spot groups in Figure 1, there is a clear relationship that is well within the errors. Plages with smaller polarity separations have smaller positive tilt angles.

4. Conclusion and Discussion

We may draw the following conclusion from this study:

(1) Both for spot groups and for plages, larger polarity separations are observed to correspond to larger (positive) tilt angles of the magnetic axes of the regions.

If, as D'Silva and Choudhuri (1992) and earlier authors suggest, the magnetic tension force in the rising flux tube affects the resultant tilt angle of the region when it reaches the surface, then the final effect will be in the direction of smaller polarity separations corresponding to greater magnetic tension, and thus smaller tilt angles. This is the result of the theoretical analysis of D'Silva and Choudhuri (1992), and this is what is seen in Figures 1 and 2 both for sunspot groups and for plages.

Note that the slope of the relationship for spot groups (≈ 0.06) is several times that for plages (≈ 0.02). The reason for this discrepancy is not clear, but it suggests that there

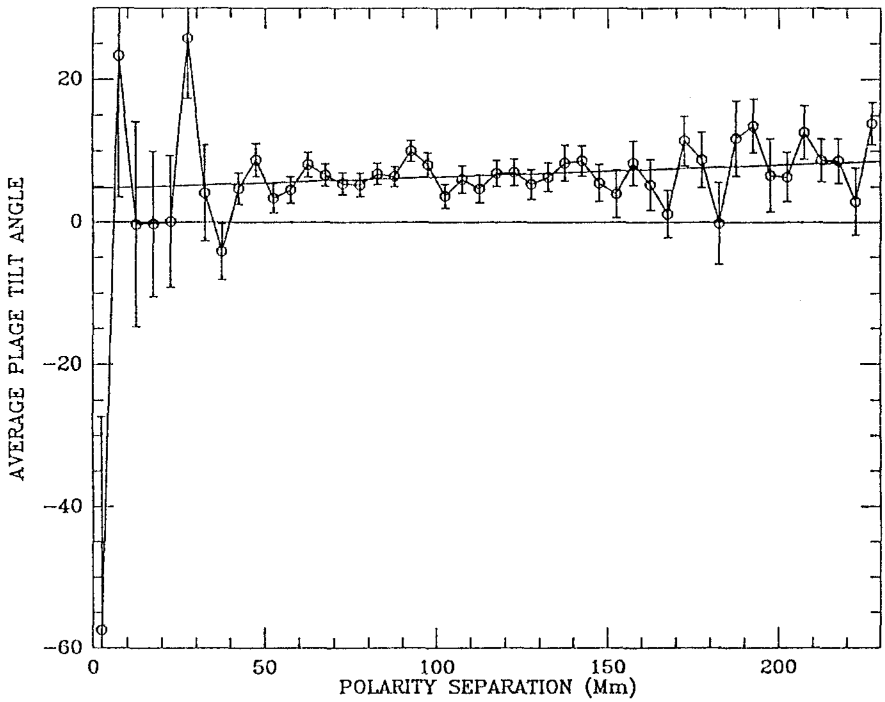

Fig. 2. Similar to Figure 1 but for plages in the interval 1967–1990. There are 17213 plages represented here.

are subsurface differences in the flux tubes of these two types of features, as has been suggested in the past (e.g., Howard, 1992). One might expect that because the subsurface field strengths for the spots may be greater than those for the plages, as is true at the solar surface, the changes in magnetic tension that result from variations in polarity separation for spots would be a smaller fraction than for plages of the magnetic tension already existing as a result of the flux in the loop. But this would lead to a smaller slope for spots than for plages, and exactly the opposite is observed, so this discrepancy remains unresolved.

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