ON THE CORRELATION OF LONGITUDINAL
AND LATITUDINAL MOTIONS OF SUNSPOTS

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Abstract. Using new measurements of positions of individual sunspots and sunspot groups obtained from 62 years of the Mt. Wilson white-light plate collection, we have recomputed the correlation between longitude and latitude motion. Our results for groups are similar to those of Ward (1965a) computed from the Greenwich record, but for individual spots the covariance is reduced by a factor of about 3 from the Ward values, though still of the same sign and still statistically significant. We conclude that there is a real correlation between longitude and latitude movement of individual spots, implying angular momentum transport toward the equator as inferred by Ward. The two thirds reduction in the covariance for individual spots as opposed to groups is probably due to certain properties of spot groups, as first pointed out in an unpublished manuscript by Leighton.

1. Introduction

Ward (1965a) first reported evidence of a systematic correlation between longitudinal and latitudinal motions of sunspot groups, of a sense that faster rotating groups tended to be also moving toward the equator. Ward interpreted this result as evidence for the existence of global eddies or waves in the solar photosphere. The sense of the correlation implied these eddies were transporting angular momentum toward the equator from higher latitudes in each hemisphere, and therefore could be responsible for the maintenance of the Sun's equatorial acceleration. The covariance of the longitude and latitude motions is directly proportional to this angular momentum transport. The magnitude of the effect found by Ward is large enough that it could generate the observed low latitude equatorial acceleration in just a few solar rotations (Ward, 1965a; Starr and Gilman, 1965). Since the equatorial acceleration is in dynamical balance over long time periods, this implies that a correspondingly strong braking mechanism (most likely small scale turbulent diffusion) is also at work.

The correlation found by Ward has subsequently been confirmed for other sunspot group data by, e.g., Coffey and Gilman (1969), and an even larger apparent angular momentum transfer toward the equator has been inferred from facular motions by Belvedere et al. (1976). Numerous theoretical models to explain the equatorial acceleration have been developed that contain such equatorward angular momentum transport. For a review of these models, see, e.g., Gilman (1980, 1984).

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At the time of Ward’s original analysis, his interpretation was questioned by Robert Leighton (1965) on the grounds that the correlation could arise instead from systematic properties of sunspot groups, and not reflect a true property of the flow of plasma in the solar photosphere at all. In brief, Leighton’s argument was that the ‘center of gravity’ of spot groups (which were determined either by eye or as a spot-area weighted average position of the group in the Greenwich Photo-Heliographic Results data that Ward used) will move about as a result of systematic changes in spot area, such as the growth and decay of spots in such a way as to give the correlation Ward found. The reason is that spot groups exhibit a characteristic tilt with respect to latitude circles, such that the leading edge (in the sense of solar rotation) is usually closer to the equator than the following edge. With such a tilt, even uncorrelated fluctuations along the major and minor axes of the group would produce a correlation between longitude and latitude motions. Leighton estimated the magnitude of the effect from simple statistical arguments and found good agreement with several details of Ward’s results. Ward (1965b) responded that a very similar correlation could be found from the single spots called out in the Greenwich record. Leighton’s counter argument was that large single spots probably still are part of a group, in the sense that they are associated with a more extended complex of magnetic field lines that still return to the photosphere from above somewhere in the neighborhood, but are apparently not concentrated in flux tubes large enough to produce visible spots. A presumed ‘group’ of this sort would still have its axis tilted with respect to the E–W direction in such a way as to give an apparent correlation from the spot motions, were there a preferred direction of motion along the major axis.

As described in detail elsewhere (Howard et al., 1984; Gilman and Howard, 1984), the authors have recently completed measuring sunspot positions on the Mt. Wilson white-light plate collection, from 1921 through 1982. We have found evidence of changes in solar rotation with phase of the sunspot cycle. In these measurements, the positions of all individual spots and spot groups have been determined and a pattern recognition technique used to identify the same spots on successive days in order to compute longitudinal and latitudinal motions. We are therefore also able to calculate the covariance between these two components of motion for both individual spots and for groups. Thus, we can perhaps shed new light on the nature of this covariance and its interpretation.

2. Results

Our covariances for both individual spots and spot groups are shown in Figure 1. These represent covariances of longitude and latitude motions of individual spots over the entire 62 year record, with northern and southern hemispheres folded. (Error bars are one standard deviation for the mean for each latitude bin.) Also plotted are the covariances determined by Ward (1965a) for groups from the 1925–1954 Greenwich data.

One can see that our covariances for groups are similar in magnitude and overall trend, i.e., increasing with latitude, to those of Ward. His weighted average for all
latitudes is $-0.073$, while ours is $-0.097 \pm 0.005$ (degrees/day)$^2$. Our single spot covariances are much smaller, but apparently real. Their weighted average over all bins is $-0.030 \pm 0.002$.

3. Discussion and Conclusions

We conclude from our analysis that Ward's interpretation of a reported correlation in motions of sunspot groups is supported by individual sunspot motion though the effect is considerably smaller (60%) than Ward originally estimated. That is, comparing our own covariance for groups and individual spots, about 70% of the covariance between longitude and latitude motions is due to systematic properties of spot groups, and does not represent a true angular momentum transport in the plasma, but the remaining 30% could represent such transport.

It might be argued that small spots, which dominate our correlation, are not good indicators of global motions and correlations. However, as Gilman and Howard (1984) have shown, small spot positions do register small, long term changes in solar rotation;

![Covariance of Longitude and Latitude Motion, Years 1921-1982]

Fig. 1. Covariances in (degrees/day)$^2$, of longitude and latitude motion of spots and spot groups computed from spot positions measured on Mt. Wilson white light plates (hollow and solid circles), and compared with results of Ward (1965a) (crosses) for spot groups. North and south latitudes are folded. Negative values imply that higher than average longitudinal motion in the direction of rotation is coupled with equatorward motion.
thus, if the eddy motions that were thought to transport angular momentum toward the equator were actually present at the depths where sunspots sample fluid motions, we should expect to detect a correlation. Much larger eddy motions are implied by the Belvedere et al. (1976) analyses of plage data — an angular momentum flux at least 50 times that of our estimate from covariance of individual spots. We suspect that Leighton’s interpretation of the role of spot groups in producing the correlation is also applicable to plages, perhaps even explaining a larger fraction of the covariance. That is, preferential movement of the centroid of a plage along an axis tilted with respect to a latitude circle, due to growth and decay of plages, combined with errors in area measurements, could be the cause of this covariance, rather than systematic, correlated motions of the plasma.

What implications do these results have for theories of solar differential rotation? The individual spot motion correlations we have found imply that it would take 6 months to 1 year to build up the observed equatorial acceleration; hence, whatever is braking differential rotation can be no more vigorous than that. One year is of the order of 10 convective turnover times for the deep parts of the convection zone (Simon and Weiss, 1968). In such a turbulent system it seems likely to us that this angular momentum transport, though 60% smaller than Ward estimated, could still remain the principal mechanism responsible for maintaining equatorial acceleration. It is also possible that the latitudinal transport is still stronger at depths where sunspots are not present. It could be that spots are a relatively shallow phenomenon, perhaps having concentrated structure no deeper than the supergranule layer on the Sun, and that the horizontal Reynolds stress that transports angular momentum toward the equator is larger in deeper layers. Recent (unpublished) calculations of compressible convection in a rotating spherical shell by Gilman and separately by Glatzmeier indicate the strongest horizontal Reynolds stresses occur near the top of the giant cell layer, at some intermediate depth in the convection zone.

From all the above, as well as previous efforts by others, one point seems clear — sunspots are imperfect tracers of angular momentum transport; we need alternative better methods to measure angular momentum flux in convective motions in the solar convection zone.

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References

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