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LONG-TERM MIGRATION OF THE SOLAR SECTOR STRUCTURE

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INTRODUCTION

Periodicities are often seen in weather records and immediately dismissed as not due to solar variability because the period is not a simple multiple of 27 days or 11 years. This is wrong because solar observations of the last few centuries show numerous other periodicities ranging from many months to many years. A theory is now under development which can predict the values of these periods and which will put this subject on a sound physical basis if the theory continues to be successful. Weather records can then be analyzed in a more comprehensive and respectable manner because the variable solar input will be more rigorously modelled.

The magnetic sector boundaries on the sun and in the solar wind have a high correlation with winter low pressure systems on earth. Roberts and Olson (1973) and Wilcox, et al. (1974) found that the vorticity-area index typically declines by about 10% during several days centered on the time when a sector boundary sweeps past the earth. The physical connection between these two events is not established. A whole group of other correlations exists between weather and solar activity (Goldberg and Herman, 1978). Again, much of the detailed physics is in doubt. Progress in understanding these phenomena is slow, partly because there are a very large number of possible explanations--each with its free parameters--and a relatively modest number of truly independent observational results. This paper is part of a continuing attempt to reduce the degrees of freedom available to sun-weather theories and, perhaps, to discover some more fundamental inputs to those theories. In what follows, we present new evidence that BOTH the sector structure and solar activity levels can be understood as being under the influence of the same regular, internal solar mechanism. Because of this, long-term predictions of each phenomenon may ultimately be possible.

Observed Position of Sector Boundaries

There are now available 50 years of observations of the magnetic sector boundaries, both those detected by spacecraft and those inferred from high latitude geomagnetic records. Svalgaard and Wilcox (1975) published the data for the predominant 4-sector pattern. The whole pattern is defined by giving the solar longitude of one of the boundaries and their result appears at the top of Figure 1. Each short horizontal dash on the figure represents the longitude of the boundary, averaged over 37 solar rotations. However, a new average is made every 6 rotations, forcing the graph to be fairly smooth. Approximately then, their graph displays 3 year averages of boundary locations updated every one-half year. Svalgaard and Wilcox concentrated on trends lasting for many years and pointed out these two tendencies: Prior to each minimum of sunspot activity the boundary migrates toward larger longitudes (corresponding to a rotation period of about 27.15 days) and after the minimum it migrates toward smaller longitudes (period ≈26.85 days). For our purposes, more information can be obtained by considering the many shorter-term trends which could also have been defined by this data. We have identified with the broken curve all trends lasting more than half a year, in the raw data. For clarity, the broken curve is displaced downward by 4 days of longitude relative to the raw data on Figure 1. The slope of each segment of the broken curve gives the mean drift of the sector boundary in that time interval. We will now compare these 27 drift rates with theoretical expectations.

Comparison with Theory

First, we give a very brief summary of the theory which has been developed in a series of papers during the last four years. It is based on the normal modes of oscillation of a star, those whose amplitudes are large in the interior but small at the surface. Astronomers call these g-modes. Oscillation periods appropriate for these modes have already been seen in the sun by groups in Arizona and the Soviet Union (Hill, 1977). Once these modes are excited in a slowly rotating star like the sun, their rotation periods are one of the more reliably predictable properties. Each mode has a rotation period which is a simple function of its angular harmonic number if the lowest radial harmonics are ignored. Precise beat periods are also calculable as the antinodes of various modes rotate into temporary alignment with each other. The beat periods range from many years down to fractions of a year. The pattern containing many of these beat periods has already been detected to a high degree of certainty in records of sunspot activity for the last two and one-half centuries (Wolff, 1976). In summary, beats occurring deep inside the sun appear to be causing the main episodes (lasting many months) of solar activity. We now ask the question: Do these same beats have any demonstrable effect on the migration of sector boundaries?

The beat and its associated convective upwelling will be assumed to have a significant physical interaction with the sector structure at the surface. It follows that there must be a relative alignment between the longitude of the beat and the longitude of a sector boundary which minimizes their interaction energy. This is the stable configuration. (Probably, boundaries caused by upwelling fluid will prefer to be at the same longitude as the beat.) When a new beat develops at some other longitude, it should accelerate the appropriate sector boundary toward it. Figure 2 shows the torque which we expect the oscillation modes to exert in each one-half year interval into which Svalgaard and Wilcox subdivided their observations. A positive torque is one pulling the sector boundary toward higher Bartels longitude. The torque was modelled very simply by the function,

$$\sum_i A \sin \left[B(L_i - L_{sb})\right]$$

where L_i is the longitude of the i^{th} beat occurring in the time interval, L_{sb} is the observed longitude of the sector boundary, and A is an unknown proportionality constant taken as unity. For our unit of longitude which ranges from 0 to 27 days, B = (4 π radians)/(27 days) which is the proper value for a pattern of 2 sector boundaries of upwelling and 2 of subsidence. It is clear from Figure 2 that many rapid changes are to be expected in the direction of migration of the sector structure. Unfortunately, the observations were heavily smoothed and have lost much of this detail. But, by averaging the theory over intervals longer than one-half year increments of Figure 2, a valid comparison becomes possible. We computed the mean theoretical torque in each of the 27 time intervals corresponding to segments of the broken curve identifying trends in the observations. Then we plotted these against the mean observed drift in the same intervals, Figure 3 is the result and it shows a significant correlation which we have fitted with the straight line. This figure shows that, over its 50 year history, this sector boundary has tended to drift towards the longitudes where beats between oscillation modes were located.

Figure 3 is our first preliminary view of this correlation. The points have a rather large scatter which can be reduced in the future by several improvements. First, the observers can be encouraged to shorten or remove the 3 year smoothing of their observations to permit more of the expected detailed motions to appear. Secondly, the theory can be upgraded by taking into account the known lifetimes of each individual beat and the varying strengths of the oscillation modes. Up to now, the theory has been used in its most primitive form so as to eliminate virtually all free parameters except for an essential statement of how many oscillation modes are being considered. In this paper, we used all the modes from spherical harmonics ℓ = 4 to ℓ = 9 in equal strength. This is similar to the range found appropriate in earlier work for matching periodicities in solar activity.

References

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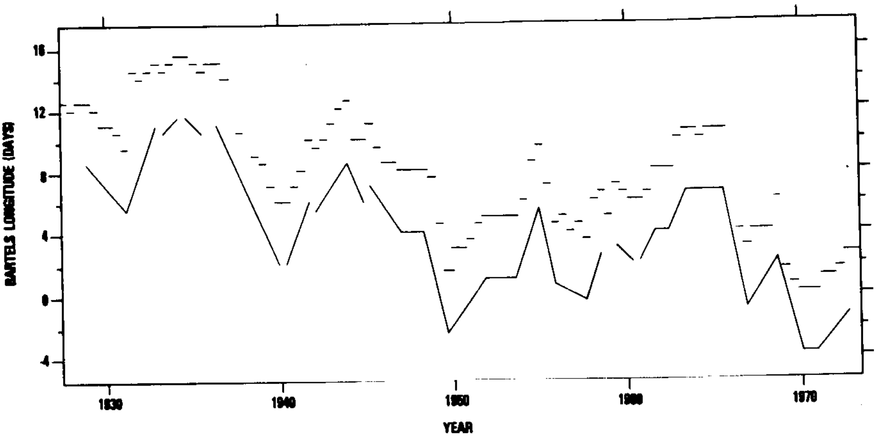

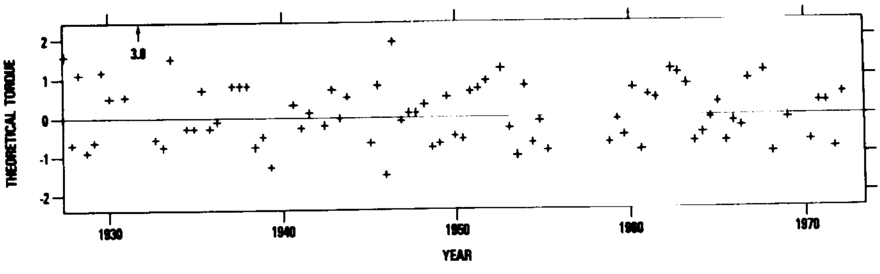

Fig. 1--(upper graph) History of the solar sector boundary migration since the year 1926. Short horizontal dashes locate the boundary longitudes determined by Svalgaard and Wilcox for each interval of 6 solar rotations ($\simeq \frac{1}{2}$ year). Pronounced trends in the observations, lasting from one to four years, are emphasized by the diagonal line segments just below.

Fig. 2--(lower graph) The torque expected to be exerted upon the sector structure by beats between the theoretical system of solar oscillation modes.

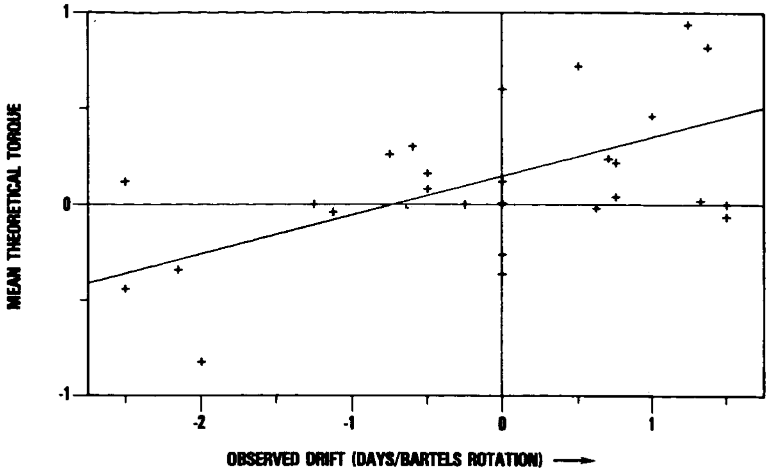

Fig. 3--The torque exerted by solar beat phenomena is compared to the observed drift in longitude of the magnetic sector structure. Each point corresponds to one of the 27 pronounced trends marked on Figure 1. The positive correlation shown on this graph indicates that the beats are influencing the location of the sector boundaries.