SOLAR CYCLE EVOLUTION OF THE GENERAL MAGNETIC FIELD

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The data from magnetic field synoptic charts at Mt. Wilson for 16 years are separated into axisymmetric and nonaxisymmetric fields. The axisymmetric field derived simply by averaging over longitude corresponds to the general magnetic field and can be regarded as reflecting the poloidal (radial) field since bipolar magnetic fields which have been regarded as reflecting the toroidal field are cancelled out by the averaging. The evolution of pattern of the latitudinal distribution of this field shows a conspicuous appearance similar to the Butterfly Diagram of sunspots but having two branches of different polarity in each hemisphere. The two branches start from the middle latitudes, and one branch propagates towards the pole and the other toward the equator. This shows that the solar general magnetic field behaves like a quadrupole not a dipole as was previously believed. This feature is exactly what has been predicted by a numerical solar cycle model driven by the dynamo action of the global convection. Another axisymmetric field is also derived by averaging over longitude the absolute value of the magnetic field after subtracting the poloidal field. This field corresponds to the toroidal field since if this field is averaged over longitude it vanishes. The evolutionary pattern of the latitudinal distribution of this field shows a feature quite similar to the Butterfly Diagram of sunspots. These features of the two fields become conspicuous only after averaging over many rotations, e.g., over 27 rotations (2 yr): such a diagram averaged over a small number of rotations shows rather large noise.

The Butterfly Diagram of sunspots is drawn for the same period as the magnetic field data. There are slight differences between the Butterfly Diagram of sunspots and the Butterfly Diagram of the general toroidal magnetic field. That is, in the former case, the equatorial migration is quite clear but not so clear in the latter case. This can be interpreted as reflecting the state of the rotation in the upper and lower parts of the convection zone where the magnetic field observed at the surface and the sunspots originate respectively. These three kinds of information, i.e., the evolutions of the poloidal field, of the toroidal field, and of the sunspots should be considered as important indicative phenomena of the solar cycle to distinguish the validity of the various solar cycle models and to determine the basic mechanisms of the solar cycle.

References

Yoshimura, H.: 1975a, *Astrophys. J. Suppl. Series* **29**, 467.
Yoshimura, H.: 1975b, *Astrophys. J.* **201**, 740.
Yoshimura, H.: 1976, *Solar Phys.* (in press).

Bumba and Kleczek (eds.), Basic Mechanism of Solar Activity, 137–143.

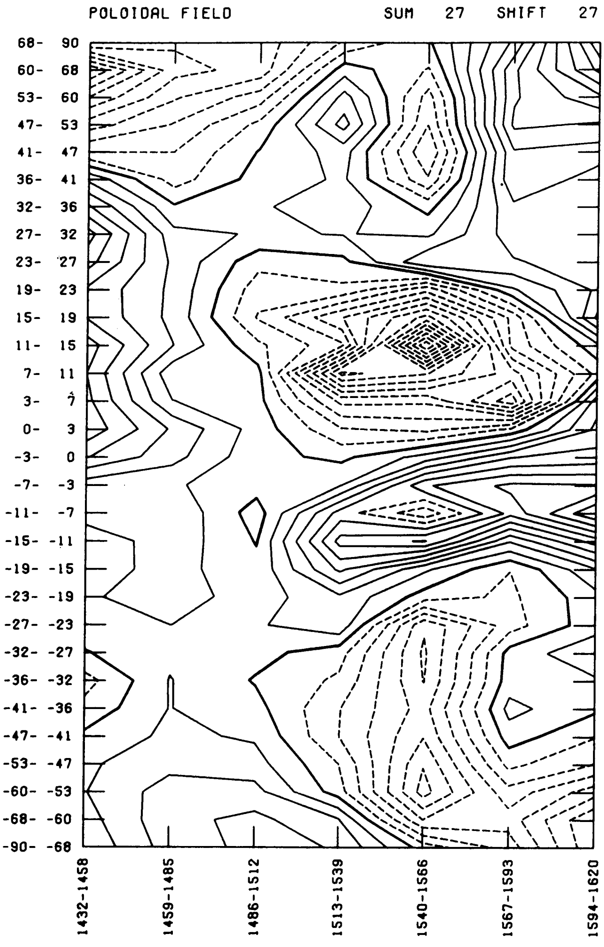

Fig. 1. The evolution of the latitudinal distribution of the *poloidal* general (axisymmetric) magnetic field which was derived by simply averaging the observed magnetic field over longitude, thus cancelling the magnetic field with bipolar structure. The abscissa is time from Carrington rotation number 1432 (1960 September) to 1620 (1974 October) and the coordinate is sin (latitude). The original data are stored in card form with 30 sections with equal interval in sin (latitude). The corresponding latitudes are shown in the figure. The broad lines designate zero lines; solid lines positive field, dotted lines negative except in the donut-like situations. Note that there are two branches with opposite polarities in each hemisphere so that the general magnetic field of the Sun behaves quadrupole-like not dipole-like. These features appear only if we average over many rotations (27 rotations) to cancel noises although there still are some fluctuations even in this figure. The maximum value in this field is 1.5 G.

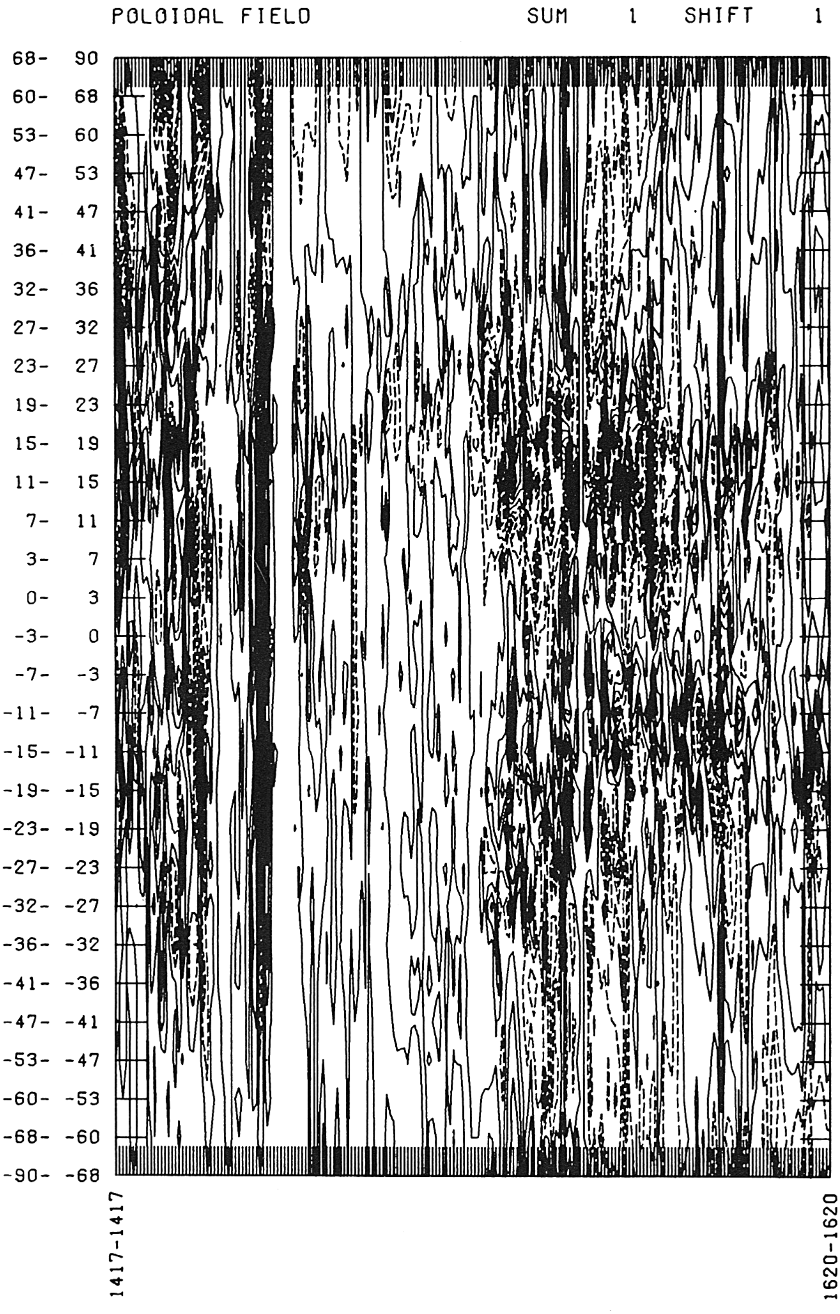

Fig. 2. The same as Figure 1 but the averaging over rotations is not done. Note that the noise is so large that clear features in Figure 1 cannot be seen.

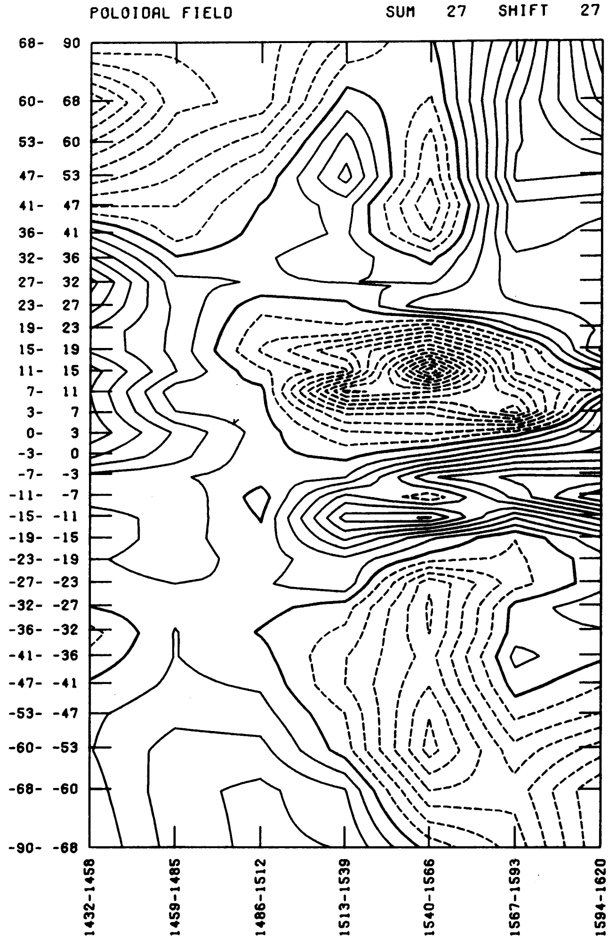

Fig. 3. The same as Figure 1 but the coordinate is drawn with equal interval in latitude. Note that the main branches are rather concentrated near the equator.

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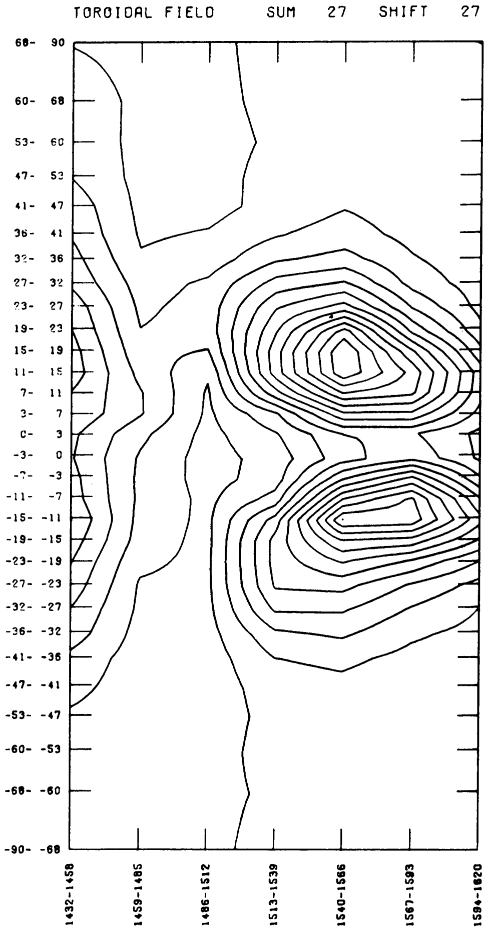

Fig. 4. The evolution of the latitudinal distribution of the *toroidal* general (axisymmetric) magnetic field which was derived by averaging the absolute value of the magnetic field after subtracting the poloidal field. Thus this diagram shows the solar magnetic field which has bipolar structure. Note that this is similar to the butterfly diagram of sunspots but there seems to be some slight differences in the equatorial propagation of the wings (branches). Note also that, in order to compare it with the Butterfly Diagram of sunspots of the same period shown in Figure 6, the ratio of the scales of the abscissa and the coordinate is adjusted to that of Figure 6 where only the latitude region between -50 to $+50$ is shown. The maximum value on this figure is 6.9 G.

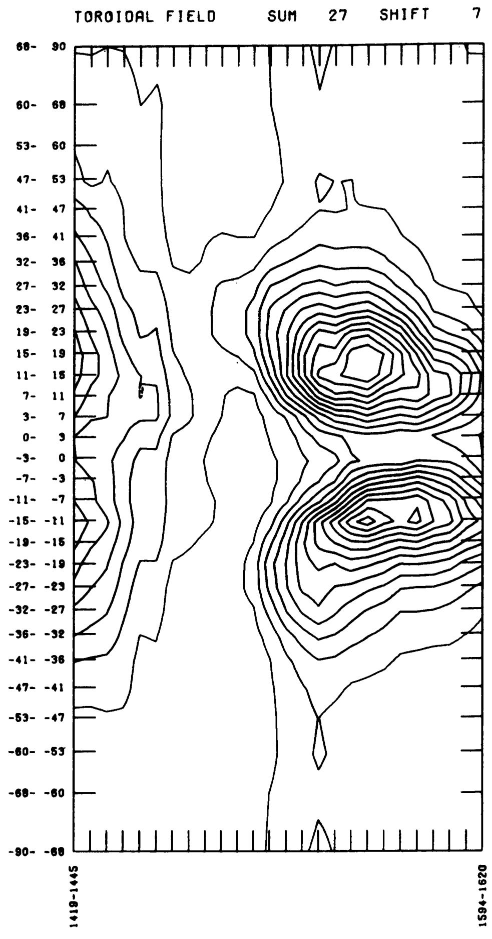

Fig. 5. The same as Figure 4, but the averaging over rotation is now running, the origin point of each averaging is shifted by 7 rotations not 27 rotations in order to show more details of the propagation of the wings. The propagation gives us important information about rotation law inside the Sun. The evolution of the distribution of the magnetic field shown above gives us information independent from that of the sunspot Butterfly Diagram since the zones from which the sunspots and surface magnetic field originate differ.

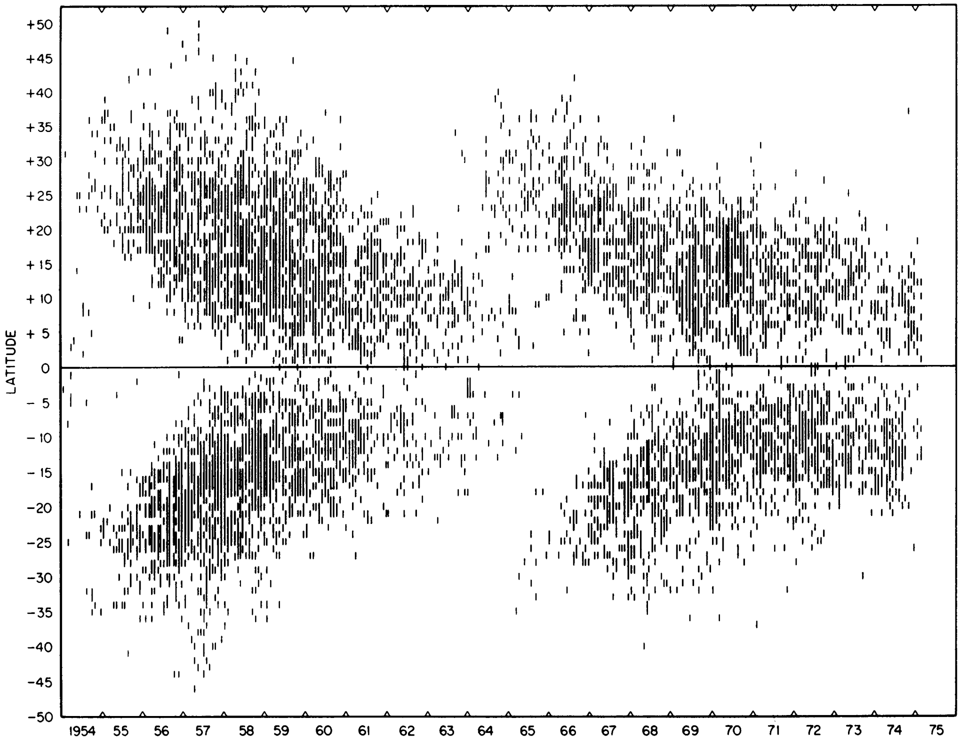

Fig. 6. The Butterfly Diagram of sunspots of the period from 1954 to 1975. Note that in the most recent cycle 20, the equatorial propagation occurs first and then the wings go on rather parallel to the equator. This implies, according to Yoshimura (1975a) model, that the dynamo processes are weak. This can also be verified by the rather lower activity shown by the sunspot relative number curve. According to Yoshimura (1975a, b) model, this predicts longer period of the cycle 20. This figure was drawn by Dr Howard using Mt. Wilson sunspot data.

DISCUSSION

Stix: Could you determine a phase-shift between the poloidal and toroidal mean fields?

Yoshimura: Yes, I could. However it depends on how we interpret the phase-shift observed at the surface. According to my numerical model of the solar cycle, the dynamo waves propagate mainly radially. So, if we accept this model, we should not regard the observed phase-shift as the phase-shift of the dynamo waves along the propagation path. However, the observed phase-shift at the surface could be an important index of the solar cycle.