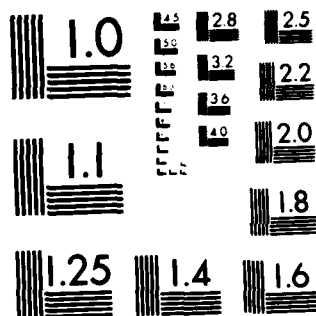AD-A127 122   A QUANTITATIVE STUDY OF MAGNETIC FLUX TRANSPORT ON THE   1/1
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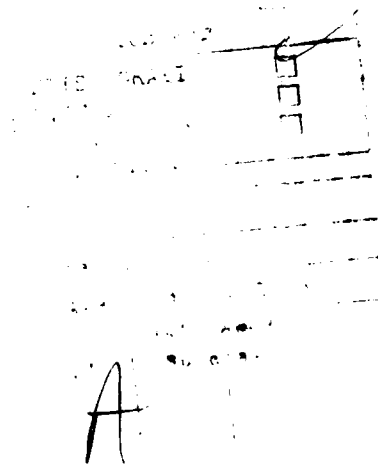
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A QUANTITATIVE STUDY OF
MAGNETIC FLUX TRANSPORT ON THE SUN

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Abstract: A computational model, based on diffusion, differential
rotation, and meridional flow, has been developed to simulate the
tranport of magnetic flux on the Sun. Using Kitt Peak magneto-
grams as input, we have determined a best-fit diffusion constant by
comparing the computed and observed fields at later times. Our value
of 730 + 250 km^2/s is consistent with Leighton's (1964) estimate
of 770-1540 km^2/s and is significantly larger than Mosher's (1977)
estimate of 200-400 km^2/s. This suggests that diffusion may be fast
enough to account for the observed polar magnetic field reversal
without requiring a significant assist from meridional currents.

This paper presents the initial results of a project to simulate
the transport of solar magnetic flux using diffusion, differential
rotation, and meridional flow. The study concerns the evolution of
large-scale fields on a time scale of weeks to years, and ignores
the rapid changes that accompany the emergence of new magnetic regions
and the day-to-day changes of the supergranular network itelf.

Our initial objective was to determine the value of an effective
diffusion constant that would provide the best fit between the
computed and observed fields. To our knowledge, no fully quantitative
determination has been attempted using modern computational techniques
and high-quality observations. A resolution of the discrepancy
between Leighton's (1964) model-dependent estimate of (770-1540
km^2/sec) and Mosher's (1977) semi-quantitative estimate of (200-400

km^2/sec) would help to determine the relative importance of diffusion and meridional flow in transporting flux to the Sun's poles. With a value as low as Mosher's, diffusion would require a substantial assist from meridional flow to produce a timely reversal of the polar magnetic field, whereas with a value as high as Leighton's, diffusion could accomplish the reversal alone.

We assume that the photospheric field's radial component satisfies a continuity equation containing the transport effects of Leighton diffusion, differential rotation, and meridional flow. In spherical coordinates this equation is:

$$\frac{\partial B}{\partial t} = \frac{1}{\tau_1} \left[\frac{1}{\sin\theta} \frac{\partial}{\partial\theta}(\sin\theta \frac{\partial B}{\partial\theta}) + \frac{1}{\sin^2\theta} \frac{\partial^2 B}{\partial\phi^2} \right] + \frac{1}{\tau_2}[\cos^2\theta \frac{\partial B}{\partial\phi}]$$

$$+ \frac{1}{\tau_3} \left[\frac{1}{\sin\theta} \frac{\partial}{\partial\theta} (B \sin\theta \sin2\theta) \right],$$

where the time constants are $\tau_1 = R^2/K$ (K is the diffusion constant), $\tau_2 = 1/\omega_0$ (ω_0 is the differential rotation rate), and $\tau_3 = R/V_0$ (V_0 is the amplitude of the meridional flow speed). Typical values are $\tau_1 = 20$ years (for K = 800 km^2/sec), $\tau_2 = 21$ days (for a Newton and Nunn rate of 2.77 deg/day), and $\tau_3 = 1$ year (for a meridional flow amplitude of 20 m/sec (Duvall, 1977)).

Our study has progressed through several increasingly difficult and realistic phases. First, to test our modeling procedures, we used photographic prints of Kitt Peak magnetograms to estimate the location, pole separation and strength of new bipolar magnetic regions during 1976-1981 as the present sunspot cycle evolved. Using these doublet sources, and an assumed initial global dipole field of 1 Gauss, we calculated the evolution of the large-scale fields and displayed the fields in Carrington synoptic charts which we updated at 27-day intervals to include the contributions of flux from newly emerging regions.

Second, to estimate the diffusion constant, we selected four relatively isolated magnetic regions which were observed on several consecutive solar rotations. For each of these regions, our objective was to deposit the Kitt Peak digital magnetic measurements into the simulator during the initial solar rotation, and to compute the evolving large-scale magnetic fields at elapsed times of 1, 2, and 3 rotation periods for a range of values of the diffusion time τ_1. In practice, we also considered other combinations such as depositing the flux during its second disk appearance and comparing the computed and observed fields on the third rotation. This procedure not only provided additional tests of our measurement consistency but also helped to avoid possible magnetic field calibration errors associated with the presence of sunspots during the initial rotation. In this second phase of our study, we deposited digital data for only a limited area including the source region. The surrounding area contained the typical, but unrealistic, background field computed from the doublet sources of phase one. To minimize the unknown errors

associated with this unrealistic background field we limited our
comparisons to the immediate area of the expanding bipolar region.

For each region, the best fit was obtained numerically by
minimizing the sum of the squared errors between the computed and
observed fields and by allowing for a possible bias in the zero level
of the Kitt Peak measurements. A relatively broad minimum was always
obtained probably due to the unknown influence of the weak background
fields. However, in half of these cases the minimum solution also
provided close agreement between the observed and computed values of
the centroids and the total surviving flux of the magnetic region.

The results for the case of $V_0=0$ are shown in the following table:

TABLE 1 - DIFFUSION CONSTANT MEASUREMENTS

Region	A	B	B	C	C	C	D	D
Deposition Rotation	1	0	2	0	0	1	0	2
Comparison Rotation	2	1	3	1	2	2	1	3
Diffusion Constant	470*	680*	700*	1160	1140	1220	1690	1070*

Summary: $K = 1050 \pm 400$ km^2/s (all 8 measurements)

$\quad\quad\quad$ $K = 730 \pm 250$ km^2/s (4 best measurements)

* most reliable determinations, based on considerations of the loca-
tion and total flux of the evolving region.

The eight determinations in Table 1 yield an average diffusion
constant of 1050 ± 400 km^2/sec, but the four most reliable measure-
ments give the smaller value of 730 ± 250 km^2/sec. Both are signi-
ficantly larger than Mosher's (1977) 200-400 km^2/sec, and are consis-
tent with Leighton's (1964) 770-1540 km^2/sec. In future phases, we
plan to study the effects of including the observed background field
as well as a non-zero value of meridional flow speed.

Figure 1 illustrates some of our procedures graphically. The
upper left frame shows a Kitt Peak magnetogram on December 30, 1976.
A large bipolar magnetic region (BMR) is visible in the southern hemis-
phere on this otherwise quiet day near sunspot minimum. The upper
middle frame shows these fields after suppressing the short wavelength
components of their Fourier representation. Obviously on this day
the Kitt Peak zero level was biased in the negative (blue) direction
and the positive-polarity north polar field is not visible. The upper
right frame, displaying the normal component rather than the line-of-
sight component of field, shows the same BMR deposited within the
artificial background field. Relatively few BMRs have contributed
to this background field at this early stage of the new sunspot cycle.

The lower frames in Figure 1 show the situation 28 days later
on January 27, 1977. The lower left and center frames show the raw
and smoothed Kitt Peak measurements, respectively. The lower right
frame shows the BMR and its surroundings as they would have evolved
with a diffusion constant of 680 km^2/sec. At this time, a newly
emerged BMR, visible in the magnetogram's northern hemisphere, has

not yet been deposited in the simulator. A recently deposited doublet
is visible west of the large BMR in the southern hemisphere. Our
measurements are based on a comparison of the flux distributions
only in the immediate vicinity of the evolving BMR and not in the
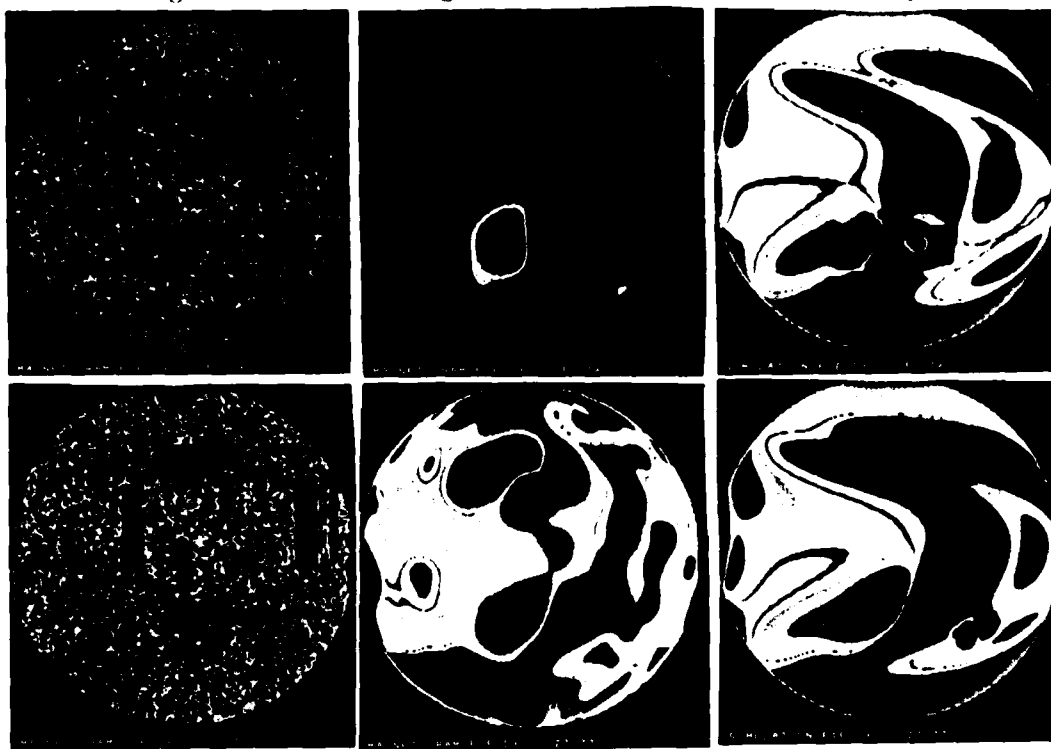surrounding areas where disagreement is both obvious and expected.

Fig. 1: Observed BMR (upper left and center) is deposited into simu-
lated field (upper right), evolved (lower right), and compared with
later observed field (lower left and center).

In conclusion, we should like to emphasize that our study is just
reaching the point where most of the technical problems have been
overcome. While our results to date are tentative, they are encour-
aging and in particular give a diffusion constant that is consis-
tent with Leighton's original estimate.

REFERENCES

Duvall, Jr., T.L.: 1979, Solar Phys. 63, 3.
Leighton, R.B.: 1964, Astrophys. J. 140, 1547.
Mosher, J.M.: 1977, The Magnetic History of Solar Active Regions, Ph.D.
    Thesis, Calif. Inst. of Tech.

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