PROPERTIES OF THE LARGE- AND SMALL-SCALE FLOW PATTERNS IN AND AROUND AR 19824

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Abstract. We trace the photospheric motions of 170 concentrations of magnetic flux tubes in and around the decaying active region No. 19824 (CMP 23 October 1986), using a series of magnetograms obtained at the Big Bear Solar Observatory. The magnetograms span an interval of just over five days and cover an area of about 4 × 5 arc min centered on the active region. We find a persistent large-scale flow pattern that is superposed on the small-scale random motions of both polarities. Correction for differential rotation unveils the systematic, large-scale flow surrounding the core region of the magnetic plage. The flow (with a mean velocity of 30 m s\(^{-1}\)) is faster and more pronounced around the southern side of the core region than around the northern side, and it accelerates towards the western side of the active region. The northern and southern branches of the large-scale flow converge westward of the core region, dragging along the westernmost sunspot and some of the magnetic flux near it. The overall pattern of the large-scale flow resembles the flow of a river around a sand bar. The long-term evolution of the active region suggests that the flow persists for several months. We discuss the possible association of the large-scale flow with the torsional oscillation.

We correct the observed motions of concentrations of flux tubes for the large-scale flow in order to study their random motions. The small-scale random motions (with a mean speed of 150 m s\(^{-1}\)) can be characterized by a diffusion coefficient of \(\approx 250 \text{ km}^2 \text{ s}^{-1}\) for the area surrounding the core region of the magnetic plage. The diffusion coefficient characterizing the small-scale motions within the core region (mostly observed near its periphery and in areas of relatively low flux density) is only \(\approx 110 \text{ km}^2 \text{ s}^{-1}\). The lower diffusion coefficient in the core region appears to be caused mainly by a smaller step length rather than by a distinct difference in velocities.

1. Introduction

Once magnetic flux tubes surface in the solar photosphere, they are subject to motions on vastly different scales (e.g., Bogart 1987). The largest scale of these motions is the solar differential rotation. The very small scale of the granulation is expected to result in a wrapping of flux tubes, which has been proposed as a mechanism to transport energy into the high coronal regions (Parker, 1986). The apparently random displacements associated with the supergranulation (discovered by Hart, 1954, 1956, followed by statistical studies by Leighton, Noyes, and Simon, 1962; and by Simon and Leighton, 1964) occur on an intermediate scale.

If the flux-tube density is relatively small, i.e., in quiet regions, the magnetic field is transported to the cell boundaries where the flux tubes build up the network. Flux tubes that are trapped in the lanes between supergranules are subject to two distinct modes of displacement. The first of these modes, already recognized by Leighton, Noyes, and Simon (1962), is associated with evolutionary changes in the velocity cells as they grow.
or decrease in size, or divide into new cells (e.g., Wang, 1988). The second mode of
displacement is a flow along the network lanes, which was first indirectly found on
sequences of videomagnetograms by Smithson (1973) and has been studied recently in
detail by Simon et al. (1988) using observations made with the Solar Optical Universal
Polarimeter (SOUP) onboard Spacelab-2.

The continued random displacement of (bundles of) flux tubes results in a dispersion
of the magnetic flux that can be described as a diffusion process (Leighton, 1969).
Measuring the random motions yields a direct estimate of the diffusion coefficient which
measures the rate of flux dispersal. Mosher (1977), for instance, studies displacements
of flux-tube concentrations in Ca II K spectroheliograms of quiet regions and enhanced
network and finds typical diffusion constants in the range of 200 km² s⁻¹ up to
400 km² s⁻¹.

The properties of supergranulation, and by inference of the diffusion process, appear
to be distinctly different in the coherent region of high magnetic flux-density (the 'core
region') of active regions than in quiet regions or enhanced network. Observations with
the Transition-Region Camera (Foing and Bonnet, 1984), for example, illustrate that
some form of a chromospheric network is present in core regions of active regions, but
that its average dimension is ≈ 14 000 km, which is roughly a factor of 2 smaller than
the scale of the network in the quiet Sun (≈ 26 000 km, e.g., Singh and Bappu, 1981;
Brune and Wöhl, 1982; Küveler, 1983). Simon et al. (1988) infer the interaction of
magnetic flux and supergranulation flow from the fact that the horizontal flow velocities
for granules average around 400 m s⁻¹ in quiet regions and 100 m s⁻¹ in magnetic
regions. The (center-to-center) cell size in a core region that is measured in the SOUP
flow divergence maps, is typically 10 000 to 15 000 km.

Schrijver (1989) studies the effects of the interaction of the magnetic and velocity
fields in the random-walk decay of active regions. In order to study the interaction of
magnetic and velocity fields in more detail we traced the displacements of flux-tube
concentrations in an active region by using a sequence of videomagnetograms obtained
at Big Bear Solar Observatory. The most suitable data set, covering a period of just over
five days, was available for active region No. 19824 (CMP 23 October 1986, Mt. Wilson
Group 24341, NOAA/USAF 4750). The long-term evolution of that active region
(Figure 1) was discussed by Marquette and Martin (1988), who followed the evolution
of the region from its birth to its disappearance in the background network over a period
of 6 solar rotations. The observed paths of the features are presented in Section 2.

In addition to the small-scale random motions described above, evidence is some-
times found for flows on a scale between the supergranulation and the differential
rotation. A clear example of such a flow is seen in and around the active region that
we studied. Marquette and Martin (1988) already concluded that the region exhibited
a large-scale velocity field in addition to the expansion of the region by the random walk
of magnetic flux and differential rotation. Their conclusion was based on two anomalous
characteristics of the evolution of the magnetic flux of the region: (1) A large fraction
of the trailing polarity flux migrated south of the leading polarity flux, and continued to
do this for several months. The net effect of the migration was an apparent counter-