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C IV DOPPLER SHIFTS OBSERVED IN ACTIVE REGION FILAMENTS

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ABSTRACT

The Doppler shift properties of 21 active region filaments have been studied using C IV Dopplergram data. Most are associated with corridors of weak magnetic field that separate opposite polarity strong fields seen in photospheric magnetograms. A majority of the filaments are relatively blue shifted, although several lie very close to the dividing lines between relative blue and red shift. Only one filament in our sample is clearly red shifted. A new calibration procedure for Dopplergrams indicates that sizable zero point offsets are often required. The center-to-limb behavior of the resulting absolute Doppler shifts suggests that filament flows are usually quite small (< 3 km/s). It is possible that they vanish.

INTRODUCTION

In recent years there have been several studies of the dynamics of solar filaments observed in EUV emissions (e.g., Orrall et al. 1983, Schmieder et al. 1984, 1985, Engvold et al. 1985, Athay et al. 1986). The Kippenhahn-Schluter theory of prominence support suggests that upflows should be present, while the Kuperus-Raadu theory suggests downflows (Schmieder et al. 1984). A major goal, therefore, has been to test these theories and to otherwise guide the theoretical efforts.

An unambiguous description of filament dynamics is, unfortunately, still lacking. One difficulty is the considerable variety in the observational results. Both red and blue shifts have been reported, and it is not yet clear what, if any, Doppler shift properties are typical. A second, more fundamental difficulty is that all of the Doppler shifts measured to date have been relative to an assumed and somewhat arbitrary zero point. Without knowing the absolute Doppler shifts it is impossible to determine either the directions or the magnitudes of the flows.

In this contribution we add to the data base on relative Doppler shifts by presenting new results for 21 active region filaments. The relationship of these filaments to the photospheric magnetic field is discussed. We then describe a method of calibrating the Dopplergrams, and thereby obtain estimates of the absolute Doppler shifts. This allows us to infer some simple properties of the flows.

The reader is reminded that active region filaments may be substantially different from quiescent filaments and prominences discussed elsewhere in these proceedings. Active region filaments are well defined, low-lying features, whereas quiescent prominences are often diffuse and can extend to great heights above the solar surface. It is not obvious that the two should have similar flow properties.

OBSERVATIONS

The data used in this study consist of C IV (1548) Dopplergrams from the Ultraviolet Spectrometer and Polarimeter on SMM, photospheric magnetograms from Kitt Peak National Observatory, and H_α filtergrams from Big Bear Solar Observatory. Typical examples can be found in Figure 1. Frame (a) is a 4′ x 4′ Dopplergram with a pixel resolution of 3". As described by Simon et al. (1982), it is derived from intensities measured simultaneously in the red and blue halves of the line. Doppler shifts are inferred from these intensities by assuming a shape and a width for the profile. In this grey scale display light shades correspond to relative red shifts and dark shades correspond to relative blue shifts. The rms value is near 8 km/s, which is about average for Dopplergrams that contain active regions. Individual Doppler shifts are only accurate to a few kilometers-per-second, however, due to unknown variations in the profile.

The Dopplergram in frame (a) has been normalized in the traditional manner whereby the average Doppler shift vanishes across the raster. In frame (b) we present the same data, but with a much more realistic calibration. The Doppler shifts shown here are believed to be the true, absolute Doppler shifts of C IV. A discussion of the calibration procedure is postponed until later.

The middle row of Figure 1 contains two photospheric magnetograms having the same field-of-view as the Dopplergrams. On the left is a $\pm$ 100 Gauss filled in contour plot, and on the right is a continuous plot with a $\pm$ 100 Gauss dynamic range. Light and dark shades now correspond to positive and negative magnetic fields, respectively. The grey areas of the contour plot contain weak fields that are mostly less than 20 Gauss in magnitude. Recall that only the line-of-sight component of the field is measured by the magnetograph. In this case it corresponds approximately to the vertical component, since the active region is not far from disk center.

Completing the figure at the bottom is an on-band H_α filtergram to the left and an Fe I (8688) "wing spectroheliogram" to the right. The latter was obtained by summing, instead of differencing, the left and right circular polarization signals from Kitt Peak. It is useful for identifying sunspots, which show up as dark areas. All of the observations in this figure were made within a period of three hours.

The images of Figure 1 have been carefully coaligned to an accuracy of about 5". Doppler zero lines (DZLs), which separate areas of relative red and blue shift in uncalibrated Dopplergrams, have been marked in frame (a) and transferred to the other frames as a spatial reference. The transfer was made only after the DZLs were first corrected for distortions caused by solar rotation during the time lapse between observations. In this instance the distortions are minimal, but in other cases they can be important. A detailed description of the correction and alignment procedures can be found in Klimchuk (1985). We simply state here that the alignments do not depend solely on the SMM spacecraft pointing coordinates, which are uncertain by at least 12".

RELATIVE DOPPLER SHIFTS

Figure 1 reveals some rather striking spatial correlations between features seen in the different images. With the exception of sunspots, regions of strong magnetic field tend to be bright in H_α and red shifted in C IV. Areas of weak field, on the

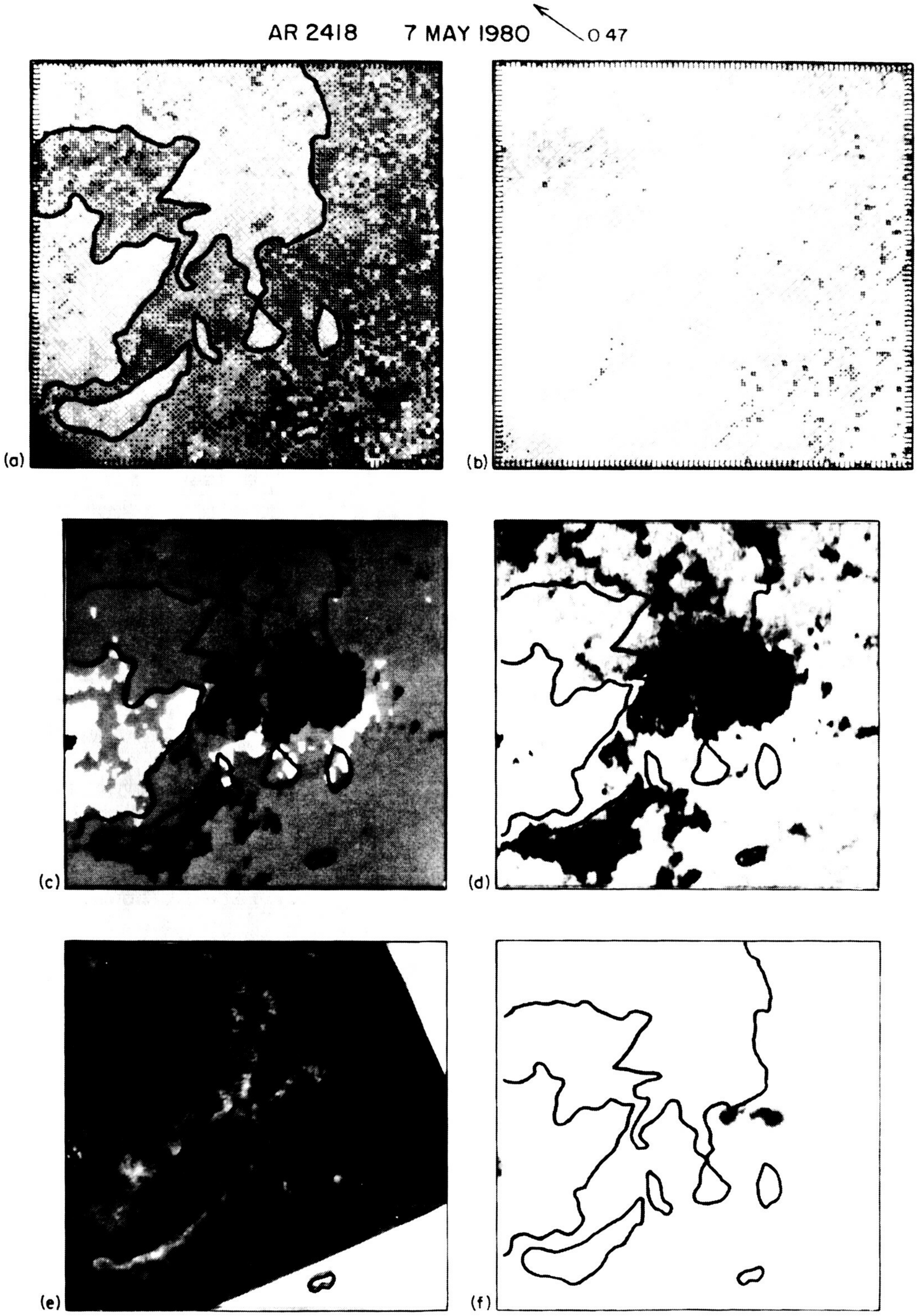

Figure 1. Six different images of Active Region #2418 observed on 7 May 1980: (a) C IV Dopplergram (uncalibrated), (b) calibrated C IV Dopplergram, (c) $\pm$ 100 Gauss contour plot, (d) continuous magnetogram plot, (e) H_α filtergram, (f) Fe I wing spectroheliogram. See text for details.

Table 1 Relative CIV Doppler Shifts of Active Region Filaments (number of occurences)				
	Blue	Red	DZL	Mixed
Disk*	11	0	3	1
Limb*	2	1	3	0
Total	13	1	6	1

* $\rho < 0.5$ for disk cases, $\rho > 0.7$ for limb cases.

other hand, are dark and mostly blue shifted. Notice the narrow yet distinct corridor of weak field that separates the opposite polarity strong fields of the active region. It corresponds closely with a band of blue shift, even down to some of the smaller details. Lying within this corridor, extending all the way from the lower left corner to near the center of the raster, is a long and thin active region filament.

These spatial relationships are not unique to this particular active region. In fact, they are common to a great majority of the 37 active regions we have examined. Most of the active region filaments we identified are associated with corridors of weak fields similar to the one shown here. Some occur in the middle of the corridor, and others lie near the boundary. Only rarely, however, is a filament seen to stray far into a region of strong field.

It is important to stress that corridors have a finite width. Because the measured fields are so weak, it is often not possible to precisely locate the neutral line. Furthermore, the position of the neutral line changes with the angle of observation in a manner that is consistent with horizontal fields in the upper photosphere (Klimchuk 1985). The commonly held notion that filaments are situated along neutral lines therefore has ambiguous meaning.

Since corridors are mostly blue shifted, so too are a majority of active region filaments. Many filaments are completely surrounded by blue shifts, while others, especially those that lie near a boundary, appear to coincide closely with DZLs - they have blue shifts on one side and red shifts on the other. Table 1 lists the relative Doppler shift properties of the 21 filaments comprising our study. Roughly two-thirds are clearly blue shifted, as indicated in the bottom row. A smaller number coincide with DZLs (to within about 5"), and only one is unambiguously red shifted. The filament listed as "mixed" passes through both a large area of blue shift and a large area of red shift. Although each of the filaments is assigned to a single category, local deviations in the Doppler shift may be present. Schmieder et al. (1985) have discussed a filament with a blue shifted body and red shifted "feet", for example.

The results of Table 1 are in good agreement with the blue shifts reported by Orrall et al. (1983) and Schmieder et al. (1984, 1985). They seem to differ, however, with the findings of Engvold et al. (1985), who identified just as many active region filaments with red shifts as with blue shifts (there are three of each kind, with two additional filaments that coincide with DZLs and one that is mixed). These results must be treated with some caution, however, as uncertain spacecraft pointing coordinates were used to coalign most of the Dopplergram/filtergram image pairs. A majority of the filaments examined by Athay et al. (1986) are reported to be associated with DZLs. Since those authors used relatively relaxed association criteria, it is likely that some cases would be classified as blue or red shifted in our analysis.

The first two rows of Table 1 give separate results for two subgroups of the 21 filaments - disk filaments, observed within 0.5 $R_\odot$ of sun center, and limb filaments, observed within 0.3 $R_\odot$ of the limb. Doppler shifts are most sensitive to vertical motions in the first group, but to horizontal motions in the second. Furthermore, limb observations are susceptible to projection effects when the C IV and H_α emissions do not originate at exactly the same height in the atmosphere. We see that the results are not obviously different for the two groups. The ratio of DZL to blue shift cases is higher near the limb, but the statistics are too small to know whether this is significant.

ABSOLUTE DOPPLER SHIFTS

To begin to really understand the flows in filaments it is necessary to first put the Doppler shift measurements on an absolute scale. This is a non-trivial task, since the UVSP instrument, like others of its kind, does not have an internal wavelength calibration. We have therefore attempted to calibrate the data after the fact using a procedure that is now described.

A limited number of "absolute" Doppler shift measurements have already been made in both active and quiet regions on the sun. From data collected by instruments such as the NRL slit spectrograph on Skylab, the CU spectrometer on OSO-8, the HRTS rocket experiment, and UVSP, a variety of authors have determined Doppler shifts of C IV (or similar lines) relative to nearby lines formed in the lower chromosphere (active regions: Feldman et al. 1982, Dere 1982, Brueckner 1981; quiet regions: Roussel-Dupre and Shine 1982, Dere et al. 1984, Doschek et al. 1976, Brueckner et al. 1978, Shine 1985). It is generally assumed that the lower chromosphere is a good zero point reference, since densities are very large there and velocities must be correspondingly small to maintain a reasonable mass flux.

On the basis of these results we conclude that low spatial resolution observations of the quiet sun should, on average, yield Doppler shifts that are represented by an 8 km/s vertical downflow. Low spatial resolution observations of active regions should yield average red shifts ranging from 15 km/s at disk center to 10 km/s near the limb (which is not consistent with vertical flow). We have therefore calibrated our Dopplergrams by artificially degrading their resolution and forcing them to agree with the expected values. Since the quiet sun values are believed to be more reliable, we place most of the emphasis on those areas.

For Dopplergram rasters that include part of the limb, an independent calibration can be used as a check. Under the assumption that horizontal motions average to zero, we force the average Doppler shift at the limb to vanish. Vertical motions are normal to the line-of-sight at the limb and therefore do not contribute to the

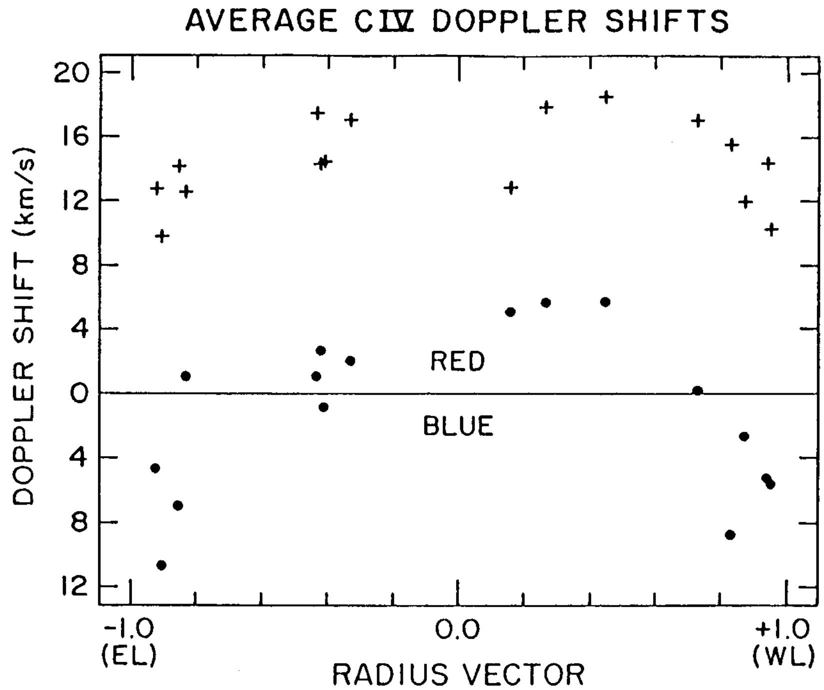

Figure 2. Absolute C IV Doppler shifts averaged over the weak field corridors (dots) and strong field plages (crosses) of 12 active regions. Four regions were observed twice. The points are plotted as a function of radius vector, or fractional distance to the limb from sun center. The east and west limbs are at -1.0 and +1.0, respectively. Corridor values are representative of the Doppler shifts in and around a majority of active region filaments. Their uncertainties are roughly $\pm$ 8 km/s.

Doppler shift there. The calibrations obtained in this way are able to confirm those obtained by the previous method.

Calibrated Dopplergrams are offset to the red by typically 4-11 km/s relative to their uncalibrated counterparts. This results in a large excess of absolute red shifts, as is clearly evident in frame (b) of Figure 1. The blue shifts that do remain are mostly very small in magnitude. Notice, in particular, how the Doppler shifts approximately vanish in the weak field corridor, where the filament is located.

Average Doppler shifts have been determined for the weak field corridors in several other active regions. They are plotted as dots in Figure 2 as a function of the radius vector of the observation. (Crosses indicate the average Doppler shifts in strong field regions and do not concern us here.) Not all of the corridors of Figure 2 contain filaments, but the observed Doppler shifts do not seem to depend on whether a filament is present. The values are thus representative of filament Doppler shifts.

An obvious trend in Figure 2 is for the Doppler shifts to be blue near both of the limbs and red near the center of the disk. This is difficult to understand in terms of simple, resolved flows. The symmetry about central meridian suggests that the motions are vertical, but vertical motions would produce Doppler shifts with a constant sign, contrary to the result. Perhaps a more involved interpretation is necessary. Before resorting to this, however, we note that the uncertainties in the plotted points are perhaps as large as $\pm$ 8 km/s. Given this, we see that the data is consistent with simple flows of very small magnitude ($\lesssim$ 3 km/s). No other interpretation is obvious, even allowing for the sizable error bars. We conclude, therefore, that high temperature mass motions are probably minimal in a majority of active region filaments. Their directions cannot be determined at this time.

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