FLOWS AND NONTHERMAL VELOCITIES IN SOLAR ACTIVE REGIONS OBSERVED WITH THE EUV IMAGING SPECTROMETER ON HINODE: A TRACER OF ACTIVE REGION SOURCES OF HELIOSPHERIC MAGNETIC FIELDS?

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ABSTRACT

From Doppler velocity maps of active regions constructed from spectra obtained by the EUV Imaging Spectrometer (EIS) on the Hinode spacecraft we observe large areas of outflow (20–50 km s$^{-1}$) that can persist for at least a day. These outflows occur in areas of active regions that are faint in coronal spectral lines formed at typical quiet-Sun and active region temperatures. The outflows are positively correlated with nonthermal velocities in coronal plasmas. The bulk mass motions and nonthermal velocities are derived from spectral line centroids and line widths, mostly from a strong line of Fe xii at 195.12 Å. The electron temperature of the outflow regions estimated from an Fe xii to Fe xii line intensity ratio is about (1.2–1.4) $\times$ 10$^5$ K. The electron density of the outflow regions derived from a density-sensitive intensity ratio of Fe xii lines is rather low for an active region. Most regions average around $7 \times 10^8$ cm$^{-3}$, but there are variations on pixel spatial scales of about a factor of 4. We discuss results in detail for two active regions observed by EIS. Images of active regions in line intensity, line width, and line centroid are obtained by rastering the regions. We also discuss data from the active regions obtained from other orbiting spacecraft that support the conclusions obtained from analysis of the EIS spectra. The locations of the flows in the active regions with respect to the longitudinal photospheric magnetic field suggest that these regions might be tracers of long loops and/or open magnetic fields that extend into the heliosphere, and thus the flows could possibly contribute significantly to the solar wind.

Subject headings: Sun: activity — Sun: corona — Sun: UV radiation

1. INTRODUCTION

The launch of the EUV Imaging Spectrometer (EIS) on the Hinode spacecraft on 2006 September 23 has given us the opportunity to investigate the dynamics of coronal plasma, i.e., bulk plasma flows and nonthermal motions, in more detail and with higher spatial resolution than previously possible. In addition, the dynamics can be associated with plasma diagnostic measurements of electron temperature and density. EIS can therefore help address fundamental unsolved problems in active region physics, such as heating in active region loops (e.g., Klimchuk 2006; Warren & Winebarger 2007), and the associations of active regions with the solar wind and heliospheric magnetic flux (e.g., Liewer et al. 2004; Schrijver & DeRosa 2003).

Plasma motions might be particularly useful as tracers of either active region heating or sources of solar wind and heliospheric flux. For example, motions that are highly transient, spatially well localized, and composed of both upflows and downflows might signify active region loop heating and wave activity. In contrast, motions that are unidirectional (either upflows or downflows), lasting over several days, and that cover an extensive spatial region might be expected to be associated with primarily long loops or open field regions and are possible indicators of sufficiently open magnetic flux to extend into the heliosphere; thus the flows could contribute to the solar wind. The association of flows with closed or open fields can be facilitated by the creation of flow maps of active regions constructed by rastering the EIS spectrometer slit over an active region and then correlating the maps with the underlying photospheric magnetic field.

Obtaining rasters of active regions and the creation of Doppler velocity flow maps was an early science goal of the EIS data analysis program. Doschek et al. (2007; and more recently Harra et al. 2008) showed that in active regions there are extensive areas of low intensity that are characterized by net bulk plasma outflows and enhanced nonthermal motions. The appearance of these outflow regions in areas of very low intensity is striking when compared with maps of spectral line intensity, also constructed from the EIS rasters. In this paper we expand the results of Doschek et al. (2007) and discuss in detail EIS rasters of Doppler shifts and nonthermal motions for two active regions. We estimate electron temperatures and densities of the outflowing regions, discuss data from other Hinode instruments and other satellites, and speculate on the types of magnetic structures that contain the flows and turbulent motions. We also estimate the mass flux of the flows into the corona. We show that the locations of the flows in the active regions and the underlying morphology of
the photospheric longitudinal magnetic flux suggest a link with
heliospheric open fields that originate in active regions. The flows
seem more associated with the solar wind and heliospheric mag-
netic fields than with heating of active region loops.

Experimentally, flows are determined from measurements of
a spectral line centroid, coupled with information on the rest wave-
length of the line. There are numerous observations of Doppler
shifts in the literature, the most recent being obtained from the
Solar Ultraviolet Measurements of Emitted Radiation (SUMER)
spectrometer on the Solar and Heliospheric Observatory (e.g.,
Teriaca et al. 1999b; Warren et al. 1997). Mass motions can be re-
lated to heating in coronal flux tubes and the acceleration of the
solar wind (e.g., Hassler et al. 1999; Tu et al. 2005; McIntosh et al.
2006). The solar wind work has centered mostly on Doppler-shift
measurements in coronal holes. There are also numerous coronal
flux tube dynamical numerical simulation models in the literature
(e.g., Hansteen 1993; Warren & Winebarger 2007; Petsourakos
& Klimchuk 2006). These models attempt to explain observed densi-
ty and temperature measurements in coronal loops and relate the
results to coronal heating mechanisms.

The origin of excess optically thin spectral line widths beyond
their thermal Doppler widths is unclear. Since a rocket flight
analyzed by Boland et al. (1975), it has been known that spectral
lines from ions present in the solar transition region and corona
have wider profiles than those expected from pure thermal Doppler
broadening alone, based on the ionization equilibrium temperatures
at which they are formed. The profiles of the majority of the lines
are Gaussian or close to Gaussian, and the excess broadening does
not appear to be a strong function of position on the solar disk.
The bulk of our current knowledge of these motions in nonflaring
plasma has been obtained from the SO82-B slit spectrograph on
Skylab (e.g., Mariska 1992), the High Resolution Telescope Spec-
trograph (HRTS) rocket stigmatic spectrograph (e.g., Bartoe 1982),
and SUMER (e.g., Chae et al. 1999a).

The excess spectral line broadening is usually expressed as a
nonthermal random mass motion component of unknown origin.
Although there are numerous published observations of Doppler
shifts and nonthermal motions, there is little information, particu-
larly for the corona, on the detailed relationship of the motions to
actual structures, for example, coronal loops. There is far less in-
formation on the relationship of these dynamical parameters to
other physical parameters such as electron temperature and den-
sity. The apparent close relationship between large line widths
and bulk plasma flows seen in the EIS spectra is one of the most
interesting aspects of the new observations.

In § 2 we present pertinent details of the EIS on Hinode. In § 3
we discuss the observations and data reduction. Results are given
in § 4, and the implications of the results are discussed in § 5.

2. THE EIS ON HINODE

The EIS is described in detail by Culhane et al. (2007) and
Korendyke et al. (2006). The instrument consists of a multilayer
telescope and spectrometer. The telescope mirror and spectrom-
eter grating are divided into two halves, each of which is coated
with different Mo/Si multilayers. This results in two observed
extreme-ultraviolet narrow wave bands: 170–210 and 250–290 Å.
Light from the telescope is focused onto the entrance aperture of the
spectrometer. The grating then diffracts and focuses the light onto
two CCD detectors.

The telescope mirror is articulated, and different regions of the
Sun can be focused onto the spectrometer aperture by fine mirror
motions. The entrance aperture of the spectrometer can be one of
four options: a 1" slit, a 2" slit, a 40" slot, or a 266" slot. The slits/
slots are oriented in the solar north/south direction. Their heights
can be variable, with a maximum height for most observations of
512".

There are several modes in which EIS can be operated. Images
of solar regions can be constructed by rastering a slit or slot west
to east across a given solar area with a set exposure time at each
step. At each raster position it is possible to read out the entire
CCD and obtain a complete spectrum for each wavelength band.
It is also possible to select a small set of lines, falling in narrower
spectral windows, the choices of which depend on the objectives
of the observation.

The spatial resolution of EIS along the slit is approxi-
mately 2" (1" pixel−1) and the spectral dispersion is quite high,
0.0223 Å pixel−1. The instrumental full width at half-maximum
(FWHM) measured in the laboratory prior to launch is 1.956 pixels.

However, we adopt an in-orbit instrumental width of 2.5 pixels, or
0.056 Å. This width was obtained by comparing the width of the
EIS Fe xii 193.51 Å line observed above the limb with Fe xi for-
bidden line observations made from the Skylab SO82-B spec-
trograph (Cheng et al. 1979) and SUMER (Doschek & Feldman
2000). The in-orbit instrument width is still being investigated
and may undergo small revisions in the future.

3. OBSERVATIONS AND DATA REDUCTION

Data from two active regions were examined for this work.
These regions are listed in Table 1, along with the start times of
the EIS observations, the solar locations, and the EIS exposure
times. The locations are given in arcseconds relative to Sun
center. Positive locations are west/north; negative ones are east/
south. The observations consist of rasters using the 1" slit stepped
from west to east in 1" increments for a total of 255 pointings. The
slit height is 256 pixels. Each spectrum at each location in the
raster contains 20 spectral lines, in 16 pixel wide spectral win-
dows. The locations in Table 1 refer to the centers of the rasters.
Data from other active regions have been qualitatively examined
and support the general conclusions from the two regions dis-
cussed herein.

Most of the line width and position results discussed in this
paper were obtained from the Fe xii 195.12 Å line. This is the
most intense line in the EIS spectrum in part because its wave-
length is near the maximum of the multilayer efficiency. It is
therefore ideal for line profile measurements because good count
rates are available for statistically meaningful results. In addi-
tion, the ratio of Fe xii lines (186.89+186.85/195.12) is used to
obtain electron densities, and the ratio of an Fe xii 202.04 Å line
to the Fe xii 195.12 Å line is used to detect changes in electron

| Date       | Time (UT) | Location (arcsec) | EIS Exposure Time (s) |
|------------|-----------|-------------------|-----------------------|
| Aug 23     | 01:55:43  | ~518, ~211        | 60                    |
| Dec 11     | 00:24:16  | ~178, ~144        | 60                    |
TABLE 2
SPECTRAL LINES AND TEMPERATURES OF FORMATION

| Ion   | Wavelength (Å) | Temperature (K) |
|-------|----------------|-----------------|
| Fe viii | 185.21         | 6.3 × 10^5      |
| Fe vi   | 184.54         | 1.0 × 10^6      |
| Fe xii  | 186.89 + 186.85 | 1.6 × 10^6      |
| Fe xii  | 195.12         | 1.6 × 10^6      |
| Fe xiii | 202.04         | 1.6 × 10^6      |
| Fe xiv  | 274.20         | 1.8 × 10^6      |
| Fe xv   | 284.16         | 2.0 × 10^6      |

EIS does not have an absolute wavelength calibration source. The wavelength scale for EIS was calibrated as described in Brown et al. (2007). However, in order to make active region Doppler maps, a choice must be made for each active region of a spectral line wavelength that we decide represents zero Doppler velocity. For each active region discussed herein, we have determined this wavelength by averaging low-intensity regions over large areas that are outside of the active region. These defined rest wavelengths are within ~0.002 Å or 3 km s^{-1} of each other.

Previous work with SUMER (e.g., Brekke et al. 1997; Chae et al. 1998b; Teriaca et al. 1999a) indicates that the average quiet-Sun Doppler velocity at the temperature of Fe xii is close to zero, or at most a few kilometers per second. There is some indication that a small velocity for Fe xii would be a blueshift (Teriaca et al. 1999a), which would make the flows we observe slightly larger than we report here. But this needs confirmation.

The nonthermal speed is obtained from the FWHM (in mÅ) of the line profile from the expression

\[
\text{FWHM} = 1.665 \times 10^3 \frac{\lambda}{c} \sqrt{\frac{2kT}{M}} + V^2, \tag{1}
\]

where \(\lambda\) is the wavelength (in Å in this paper), \(c\) is the speed of light, \(k\) is the Boltzmann constant, \(T\) is the electron temperature, and \(M\) is the ion mass. Equation (1) assumes that the instrumental width (56 mÅ) has been removed from the line profile and that all broadening mechanisms are Gaussian. Furthermore, if ionization equilibrium is assumed, there is the tacit assumption that the electron and ion temperatures are equal. These assumptions are highly likely valid in the low corona where the EIS observations are made, because electron densities at these altitudes in the corona are on the order of 10^9 to several times 10^10 cm^{-3}. At these densities equilibration times between electrons and ions are very short, and ionization and recombination processes are very rapid for ions such as Fe xii.

4. RESULTS

4.1. The 2007 August 23 Active Region

Figure 1 shows a summary of the results for the 2007 August 23 active region. The top left panel is an intensity plot for the Fe xii 195.12 Å line. The middle and bottom left panels show the line centroid shift (color-bar units in mÅ) and FWHM of the line (color-bar units in km s^{-1}), respectively. The top right panel shows a co-aligned Hinode SOT magnetogram of the area within the boxed region. The middle and bottom right-hand panels show the centroid and FWHM, respectively, within the boxed region shown in the left-hand panels.

The striking aspect of Figure 1 is that the Doppler shifts and nonthermal line widths are not only well correlated, but that the largest values for these quantities occur in regions where the Fe xii line intensity is very low. The Fe x (see Table 2) image does show activity in the area of the flows and nonthermal motions, but it is not spatially correlated well with the Fe xii features. For the region in Figure 1, the largest Doppler shift speeds (outflows) are on the order of 15–20 km s^{-1} and the nonthermal speeds become as large as 55–60 km s^{-1}. The SOT magnetogram in Figure 1 indicates that the outflow regions occur over fields of one dominant magnetic polarity, which may indicate either open field lines or long closed loops.

The temperature and density distributions in the flow regions are shown in Figure 2. The top two panels show the electron temperature and density as a function of the FWHM of the Fe xii line for the region within the box in the top right panel of Figure 1.
The temperature was determined from the Fe\textsuperscript{xxi} to Fe\textsuperscript{xxii} line ratio assuming ionization equilibrium and an isothermal plasma. The density was determined from the ratio of the Fe\textsuperscript{xxii} lines in Table 2. Figure 1 shows that the FWHM and Doppler shifts are well correlated, so the data in the top panels of Figure 2 that correspond to the largest FWHMs also correspond to the largest outflow speeds. There is a clump of data near a FWHM of 70 mÅ and a scattering of points toward larger FWHM that does not either increase or decrease with temperature. These data arise from the outflow regions. The large outflow regions have a characteristic temperature of \(\sim 1.2 \times 10^8\) K and a density of \(\sim 7 \times 10^8\) cm\(^{-3}\), just above quiet-Sun values. Thus, the large outflow regions are more representative of quiet-Sun regions than active regions.

The bottom two panels of Figure 2 show histograms of the Doppler shift and the FWHM. Both exhibit tails that show the correlation of FWHM with Doppler speed. The data in Figure 2 that clump near 70 mÅ and near zero Doppler speed are from the pixels surrounding the outflow regions. The clear correlation of Doppler speed and nonthermal velocity is shown in Figure 3. These results were obtained by removing the instrumental width from the line profiles and assuming an electron temperature as defined for Figure 2.

![Figure 1](image1.png)

*Fig. 1.* Top left: Images of Fe\textsuperscript{xxi} 195.12 Å intensity for the August 23 active region. Middle left: Centroid shift (blue is toward the observer). Bottom left: Line width. Top right: SOT magnetogram within the boxed region. Middle right: Centroid shift of region in the boxed area in the left panels. Bottom right: Line width within the boxed region. The ordinates are in the north-south direction; the abscissae are in the east-west direction.
The August 23 active region was not bright enough to compare with good statistics the Fe xii outflow speeds and FWHMs with other lines. The strength of the activity was weak enough such that there is no visible sunspot at the location of the active region. However, there is a general positive correlation with similar data from the Fe xiii line in Table 2, and some, but reduced, correlation with the Fe xi line. Transition Region and Coronal Explorer (TRACE) images show considerable activity in the 171 Å band near the EIS Fe xii outflows, but the spatial correlation of TRACE and EIS features is not particularly good.

The spectral line profiles in the wide-line outflow regions look fairly symmetric, with no obvious blueshifted separate component to an otherwise stationary component, as seen in X-ray line profiles at the onset of many flares. This result is similar to that found by Doschek et al. (2007) for an active region observed in 2006 December.

We note that there was considerable activity in the bright part of the August 23 region throughout the time of the EIS raster. Observations with TRACE and the Extreme Ultraviolet Imagers (EUVIs) on the two Solar Terrestrial Relations Observatory (STEREO) spacecraft show that the obvious large loop system in the shape of a u in the Fe xii intensity image near the center of the image did not exist at the start time of the EIS raster. It is the result of a filament eruption that occurred with the ends of the filament apparently anchored east and west of the outflow regions. The outflow regions do not appear to be involved in any of the activity to the east in the bright part of the active region.

The August 23 region was also observed on August 22, twice during August 23, and once on August 24. The August 22/23 observations cover a 24 hr period, and the August 24 observation extends the coverage by ~12 more hours. Outflows in the same general area are seen as in the observation under discussion. Thus, the outflows appear to be persistent with lifetimes on the order of at least 1.5 days. This result was also found by Del Zanna (2008), who in addition confirmed the conclusions of Doschek et al. (2007).

### 4.2. The 2007 December 11 Active Region

Figure 4 shows results for the December 11 active region presented in the same format as in Figure 1. Again, there is a clear separation of the largest outflow regions from the most intense regions in the Fe xii line, and there is a clear correlation between outflows and spectral line widths. And again, the large outflow regions are located in an area of primarily a single polarity. However, the December 11 active region is stronger than the August 23 region and contains a prominent sunspot group.
The SOT G band, Ca H, and magnetogram images of the active region are shown in Figure 5, co-aligned with the EIS FWHM image. It is clear that the large sunspot in the G-band image lies south of the large FWHM region. The circular region surrounded by large FWHM regions in the top left panel of Figure 5 is not delineating the sunspot, but rather is close to a region of weak magnetic field, as seen by comparing the magnetogram with the FWHM image. This circular region is also a region of weak Ca H emission. The alignment of the region in the SOT data with the EIS data is not precise, but is within $\pm 2''$.

Similar results as shown for the August 23 region in Figure 2 are shown for the December 11 region in Figure 6. These results correspond to the data within the boxed area shown in the top right panel of Figure 4. As found for the August 23 region, pixels for which large FWHM values are derived are characterized by quiet-Sun temperatures and relatively low densities. In contrast, the regions immediately surrounding the large width areas have densities in places that are on the order of $10^{10}$ cm$^{-3}$ and somewhat higher electron temperatures.

The bottom two panels of Figure 6 show histograms of the Doppler shift and FWHM for the Fe xii line. In this case there is clearly a strong outflow component in the Doppler-shift histogram, much stronger than for the August 23 region. Although the color scheme in Figure 4 shows where the strongest outflows are coming from, this can be seen more clearly in Figure 7. The top left panel of Figure 7 shows the Doppler shift, and the black and white images show where Doppler shifts of different magnitudes come from. The white pixels in each image represent those pixels for which the Doppler shift shown in Figure 6 is equal to or less than the value of $D_s$ mA specified for each image. Thus, the data in the top right panel of Figure 7 illustrate that all the outflows pixels with Doppler shifts less than $-8$ mA occupy the white area shown. The position of this value of $D_s$ can be seen in the Doppler-shift histogram of Figure 6, and it represents essentially all of the outflow regions. The part of the Doppler-shift histogram near zero shift in Figure 6 arises from all the regions surrounding the dark region in the top left panel of Figure 7. As $D_s$ is progressively decreased, the white area is reduced and reveals clearly the regions of strongest Doppler shift. The shift $D_s$ can be converted to a speed $V$ in km s$^{-1}$ by $V = 3 \times 10^5 \times Ds/195.120$.

The correlation between nonthermal speed and Doppler shift is given in Figure 8. The nonthermal speeds reach values of
~90 km s$^{-1}$ and the maximum Doppler outflow speeds are on the order of 45 km s$^{-1}$. Note that Doppler shifts as large as 140 km s$^{-1}$, as reported by Sakao et al. (2007) for a different active region, are not observed (see, however, Harra et al. 2008).

The December 11 active region is bright enough to examine the outflow images in a number of different spectral lines (see Table 2), formed at different electron temperatures. Results for the December 11 outflow region are shown in Figure 9. In Figure 9 there is a general resemblance of all the outflow images, implying a correlation. However, a close inspection shows that the easternmost (leftmost) outflowing region has approximately the same location in all the images, but the westernmost outflowing region shifts gradually more westward as the temperature of line formation increases. This is clearly seen by comparing the rightmost top and bottom panels in the figure, showing the Fe $x$ii and Fe $xv$ images, respectively. Note also that the fine structure varies among all the images, implying small-scale multitemperature outflowing regions.

Fig. 5.—Top left and bottom right: Fe $x$ii FWHM and SOT magnetogram shown in Fig. 4, respectively. Top right: SOT G-band image. Bottom left: SOT Ca $H$ image.

Fig. 6.—Top panels: Electron density and temperature distributions within the boxed area of Fig. 4 as a function of FWHM of the Fe $x$ii 195 Å line. The temperature is derived from the Fe $x$ii/Fe $x$ii ratio. Bottom panels: Histograms of centroid shift (left) and FWHM (right) within the boxed area of Fig. 4. The centroid shift in $m$A is converted to Doppler speed (upper axis). In the bottom right panel, 65 $m$A FWHM corresponds to 16 km s$^{-1}$ nonthermal velocity, and 110 $m$A corresponds to 82 km s$^{-1}$.
Fe xii line profiles in the outflow regions are symmetric in some areas, particularly the westernmost regions, but in the easternmost regions an asymmetric blue wing appears frequently on profiles. This further supports the concept of multiple flow sites with flows at different Doppler speeds.

Inspection of EIS images for spectral lines other than the Fe xii line formed at lower and higher temperatures, as well as STEREO EUVI movies, shows many long and not too bright loops in the vicinity of the outflows. These loops generally have a westerly component; some are even mostly parallel to the east/west direction. Other loops have substantial southern and northern components.

5. DISCUSSION

From the above analysis of active region dynamics with EIS we can conclude the following:

1. Extensive areas of active regions where the Fe xii emission line intensity is weak exhibit higher Doppler-shift outflows and higher nonthermal velocities than those found in other areas of
the active regions where the line intensity is much stronger. This does not rule out large flows and line widths in high-intensity areas of active regions; we are simply suggesting that there will be regions of low intensity in active regions that have significant Doppler-shift and line width signals. The outflows range from a few km s\(^{-1}\) to as much as 50 km s\(^{-1}\). The nonthermal motions range from \(\sim 20\) to 90 km s\(^{-1}\).

2. The temperatures of the outflow regions obtained from the intensity ratio of an Fe \(x_{\text{iii}}\) line to an Fe \(x_{\text{ii}}\) line are \(\sim 1.4 \times 10^6\) K, and electron densities vary from \(\sim 5 \times 10^5\) to \(\sim 10^{10}\) cm\(^{-3}\), depending on the particular region.

3. The outflow regions are concentrated primarily over or near magnetic regions of a single polarity and can last for at least periods of a day and a half, although there are variations within the flow region.

4. There is some evidence for variations of temperature within flow structures and multiplicity of flows; i.e., the excess widths of the lines need not be due to turbulence even in cases in which the line profiles appear well fit by single Gaussian profiles. It is possible that a wide profile is composed of the line profiles of many outflowing regions, each slightly Doppler-shifted with respect to each other due to slightly different Doppler shifts. This scenario might produce a summed wide profile that could be fit with a single Gaussian. A multicomponent scenario definitely holds for the December 11 event. Some of the outflow profiles show an obvious secondary outflowing component such that the overall profile departs significantly from a Gaussian.

5. The Fe \(x_{\text{ii}}\) intensity in the outflow regions is much less than that in the bright active region loops. However, it is brighter than that of a disk coronal hole that was observed by EIS on 2007 September 28 near 01:45 UT. In this coronal hole the Fe \(x_{\text{ii}}\) line is significantly fainter than in the active region outflow regions.

The faintness of the structures could be due to intermittency in the outflows. That is, if the outflows are events with timescales significantly less than the exposure times, they will appear faint simply because they are bright for only part of the exposure time. For example, two hypothetical regions, equally bright per second, would appear different by a factor of, say, 5 in brightness if one region only lasted 5 s while the other lasted for a longer exposure time of 25 s. Intermittent events of this nature would have to persist over time intervals of at least a day to explain the persistence of the outflows.

From inspection of context data from a number of spacecraft it appears that the outflow regions are associated with long magnetic flux tubes and/or open field lines that extend into the heliosphere. It is interesting to calculate the mass flux in the outflowing regions. For the December 11 event the outflow mass flux for all outflows greater than about 12 km s\(^{-1}\) in the boxed region of Figure 4 is about \(1 \times 10^{-5}\) g cm\(^{-2}\) s\(^{-1}\) and is about \(1.6 \times 10^{-6}\) g cm\(^{-2}\) s\(^{-1}\) for speeds exceeding 31 km s\(^{-1}\). For the August 23 event the mass outflow flux in the boxed region of Figure 1 is about \(5.7 \times 10^{-7}\) g cm\(^{-2}\) s\(^{-1}\) for speeds exceeding 12 km s\(^{-1}\). These quantities are obtained by multiplying the flow speed by
the mass density for each pixel in the boxed regions with an outflow speed greater than the specified speed and then summing the result over all pixels.

More investigation is needed to determine whether this mass flux, or a fraction of it, contributes to the solar wind. Alternatively, some of the mass flux might be confined within long closed flux tubes. Liewer et al. (2004), Schrijver & DeRosa (2003), Luhmann et al. (2002), Neugebauer et al. (2002), and Wang & Sheeley (2002) have found from data and modeling that active regions can contribute substantially to the heliospheric magnetic field and solar wind. Liewer et al. (2004) find that the open field lines are from the edges of active regions (see Figs. 11 and 12 in their paper), in locations similar to where we find the flows discussed in this paper. Schrijver & DeRosa (2003) assert that connections with the heliospheric field to active regions are common and long-lived, and that during solar maximum the contributions of active regions to the interplanetary magnetic field can be as much as 50%. As seen in Liewer et al. (2004), Figure 14 of the Schrijver & DeRosa paper shows open field lines connected to the edge of a plage region. Also, a comparison of their simulation results with the TRACE image in their figure shows that the open field regions emanate from a region that is largely dark in the TRACE image, qualitatively similar to the locations of the EIS flows in the active regions we have discussed. It is therefore quite tempting to associate at least some of the EIS flows as sources of the solar wind confined to open field lines that extend into the heliosphere.

Some of the Doppler results of this paper are similar to those found by Harra et al. (2008), who also analyzed flows in an active region discussed previously by Sakao et al. (2007), and these authors suggest that the flows might contribute to the solar wind. These authors found the same types of flows as reported earlier by Doschek et al. (2007), but Doschek et al. (2007) did not make a connection with the solar wind.

In addition to the two active regions analyzed in detail in this paper, we have qualitatively examined five other active regions that exhibit similar behavior to the two regions we discussed in detail. However, more studies with EIS will be needed along with simulations of the solar magnetic field in order to test quantitatively the solar wind connection. We are continuing to obtain high-resolution rasters of active regions and are refining our knowledge of the zero-velocity centroid wavelengths of lines in the EIS spectrum. In particular, deeper exposures that reveal the flows in spectral lines formed over a broad temperature range should be useful in connecting the flows back to their loop footpoint origins. More work also needs to be done on the line profiles in some of the flow regions, which exhibit obvious indications of multiple loop flows.

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