Dynamics in the Transition Region beneath Active Region Upflows Viewed by IRIS

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Abstract

Coronal upflows at the edges of active regions (ARs), which are a possible source of slow solar wind, have been found to connect with dynamics in the transition region. To infer at what scale transition region dynamics connect to AR upflows, we investigate the statistical properties of the small-scale dynamics in the transition region underneath the upflows at the edge of NOAA Active Region 11934. With observations from the Interface Region Imaging Spectrograph (IRIS), we found that the Si IV 1403 Å Doppler map consists of numerous blueshifted and redshifted patches mostly with sizes less than 1 Mm². The blueshifted structures in the transition region tend to be brighter than the redshifted ones, but their nonthermal velocities have no significant difference. With the SWAMIS feature-tracking procedure, we found in IRIS slit-jaw 1400 Å images that dynamic bright dots with an average size of about 0.3 Mm² and lifetimes of mostly less than 200 s were spread all over the region. Most of the bright dots appear to be localized, without clear signature of plasma propagation to a long distance on the projection plane. Surge-like motions with speeds of about 15 km s⁻¹ could be seen in some events at the boundaries of the upflow region, where the magnetic field appeared to be inclined. We conclude that the transition region dynamics connecting to coronal upflows should occur in at a very fine scale, suggesting that the corresponding coronal upflows should also be highly structured. It is also plausible that the transition region dynamics might just act as a stimulator at the coronal base, which then drives the upflows in the corona.

Unified Astronomy Thesaurus concepts: Solar active regions (1974); Solar transition region (1532); Slow solar wind (1873); Doppler shift (401); Solar corona (1483); Solar atmosphere (1477); Solar active region velocity fields (1976); Solar coronal transients (312)

Supporting material: animation

1. Introduction

The edges of solar active regions, where the magnetic topology might be open (Wiegelmann et al. 2014), have been recognized as a source region candidate of the slow solar wind (e.g., Sakao et al. 2007; Brooks & Warren 2011; van Driel-Gesztelyi et al. 2012; Démoulin et al. 2013; Slitz et al. 2013; Culhane et al. 2014; Brooks et al. 2015; Fu et al. 2015; Zhang et al. 2015; Harra et al. 2017, etc.). These regions are usually identified as plasma upflows on Doppler velocity maps measured with coronal spectral lines (e.g., Marsch et al. 2004; Doschek et al. 2008; Harra et al. 2008; Brooks et al. 2015). The line-of-sight velocities of these plasma upflows in the corona are normally in the range of 10–50 km s⁻¹ (for summaries, see reviews by Abbo et al. 2016; Hinode Review Team et al. 2019; Tian et al. 2021).

Many studies (e.g., Brooks & Warren 2011, 2012; Culhane et al. 2014; Brooks et al. 2015) found that the relative abundance of low first ionization potential (FIP) elements of the active region upflows is enhanced significantly, indicating a source region different from the photosphere (Fu et al. 2017). Marsch et al. (2004) found a consistency between upflow features in C IV (with a formation temperature of 0.1 MK) and those in Ne VIII (with a formation temperature of 0.6 MK), which suggests the upflows might have started in a place where C IV is formed (i.e., the midtransition region) or lower. The existence of upflows in the transition regions of open-field regions have also been confirmed by observations of O IV lines (March et al. 2008). Using both imaging and spectral data, He et al. (2010) found a case where the plasma intermittently flows upward along a strand with chromospheric jets occurring at its root, suggesting a chromospheric origin of the upflows. Similarly, De Pontieu & McIntosh (2010) suggest that chromospheric jets that are rapidly heated to coronal temperatures at low heights are associated with quasiperiodic upflows along coronal loops (Guo et al. 2010; Tian et al. 2011, 2012; Ruan et al. 2016). A study by Nishizuka & Harra (2011) also shows a similarity between the spectral profiles of a jet and those of the upflow, and thus it suggests that the upflow might originate in the lower corona via explosive processes. A case study on the interaction between an Extreme Ultraviolet Imaging Telescope (EIT) wave and a region of active region upflows suggests that the upflows can be disturbed by activities in various layers of the solar atmosphere (Chen et al. 2011).

A further study involving Hα images suggests that chromospheric jets alone cannot supply enough materials to the active region upflows (Vanninathan et al. 2015). The phenomenon might result from both magnetic-reconnection-induced jets and pressure-induced flows in the lower solar atmosphere (Liu & Su 2014; Srivastava et al. 2014; Galsgaard et al. 2015) and it requires even more complicated processes to allow the plasma to escape to the slow solar wind (Démoulin et al. 2013; Mandrini et al. 2014; Baker et al. 2017). On the other hand, Warren et al. (2011) found that the upflow region can have complex velocity structures, including the outflow regions with
little or no emission in Si IV and those along fan loops with downflows in their cooler footpoints (see also Ugarté-Urra & Warren 2011; Young et al. 2012). Such complex velocity structures in active region upflows have also been confirmed from the aspects of images (Boutrou et al. 2012), density distributions (Kitagawa & Yokoyama 2015), and field extrapolations (Edwards et al. 2016).

Recently, by analyzing coordinated data from Hinode and the High-resolution Coronal Imager, Brooks et al. (2020) found that the emission of the active region upflow region contains two components, one from expanded plasma related to expelled close loops and the other from the dynamic activity in the plage region. More importantly, the abundance of the emission component from the dynamic activity in the plage region is similar to that of the photosphere (Brooks et al. 2020). The lower solar atmospheric origin has also been confirmed by a very recent study on the upflows in a newborn active region (Brooks et al. 2021).

Based on high-resolution spectral observations from the Interface Region Imaging Spectrograph (IRIS), Polito et al. (2020) analyzed in detail the spectral data of Mg II (low-chromosphere line), C II (midchromosphere line) and Si IV (low transition region line) underneath two upflow regions. Their statistics indicate that the probabilities of blueshifted pixels in the C II and Si IV observations of upflow regions are significantly higher than those from nearby moss regions. They also found the signature of chromospheric upflows in the asymmetries of Mg II lines emitted from the upflow regions. They concluded that the atmosphere (from the low chromosphere to the corona) of the upflow regions should be treated as an interconnected system.

Here, we analyze an IRIS data set of active region upflows, in which we observe clear velocity and intensity structures in the transition region. Thanks to the unprecedentedly high resolution of the data, we can measure the properties of the dynamic structures in the transition region. This will allow us to quantitatively infer at what scale the transition region dynamics are connecting to the coronal upflows, and thus help us to understand how the activities in the lower atmosphere link to the upflows in the corona.

2. Observations

The coordinated data analyzed here were taken on 2013 December 27 by IRIS (De Pontieu et al. 2014), the EUV Imaging Spectrometer (EIS; Culhane et al., 2007), and the Solar Optical Telescope (SOT; Tsuneta et al. 2008) on board Hinode (Kosugi et al. 2007) and the Atmospheric Imaging Assembly (AIA; Lemen et al. 2012) and Helioseismic and Magnetic Imager (HMI; Scherrer et al. 2012) on board the Solar Dynamics Observatory (SDO; Pesnell et al. 2012). The observational experiment coordinating IRIS and Hinode was targeted at the NOAA Active Region 11934. The fields of view (FOVs) of IRIS and EIS on the context image (AIA 171 Â) can be seen in Figure 1(a).

The IRIS data studied here were taken from 21:02 UT to 21:36 UT on 2013 December 27, while the instrument was running in a “very dense raster” mode. The IRIS spectrograph slit (with a width of 0.35) scanned the region for 400 steps with a step size of 0.35 and an exposure time of 4 s. The pixel size along the slit is 0.17. In this work, we mainly analyze the spectra in the windows of Si IV 1403 Å, 2832 Å, and Mg II h, all with a spectral sampling of ~25.4 mÅ pixel^{-1}. The slit-jaw (SJ) images taken at the 1400 Å passband with a spatial resolution of 0.33 and a cadence of 10 s are included. The latest version of level-2 data provided by the IRIS team are reanalyzed and the wavelength calibration is better than 0.5 km s^{-1} (Wüstler et al. 2018). To derive the rest wavelength of Si IV 1403 Å, the same procedures as described in Huang et al. (2015) are adopted. To derive nonthermal velocity, the instrumental broadening (FWHM) is given as 26 mÅ (De Pontieu et al. 2014).

EIS scanned the region repeatedly with 27 rasters with a 2º slit, a step size of 3º, and an exposure time of 3 s. It started taking observations from 21:13 UT and took about 4 minutes to complete one raster. The data are then calibrated with the standard procedures including the wavelength calibration. Here, we mainly analyzed the data of Fe XII 195 Å, which provides the general morphology of the active region upflows, including their location and size. The rest wavelength of the Fe XII line was obtained from a relatively quiet region at the top right of the EIS FOV and is given as 195.119 Å.

SOT provides three magnetograms taken at Na I 5896 Å and 11 snapshots taken at Ca II H. The spatial resolutions of the magnetograms and the Ca II H images are 0.3º32 and 0.3º22, respectively. Although these data do not allow for a study on the evolution of the region, they can show the magnetic and chromospheric structures in great detail. Both AIA images and HMI line-of-sight magnetograms are used to coalign the data from different instruments and also give a global overview of the connection of the region. Both data have a spatial resolution of 1º2. The AIA 171 Å images have a cadence of 12 s and the HMI magnetograms have a cadence of 45 s.

3. Data Analyses and Results

The region of coronal upflows shows a blueshift of 10–20 km s^{-1} in Fe XII (with a formation temperature of 1.6 × 10^6 K), located at the east side of the active region (see Figures 1(a)–(c)). Here we focus on the core of the upflows, which presents a dark region with the roots of fan loops surrounded, as seen in AIA 171 Å images (see Figure 1(a)). Such morphology is typical for active region upflows as shown in previous studies (e.g., Harra et al. 2008; Brooks et al. 2020; Polito et al. 2020). The blueshifted area of the selected region as seen in EIS Fe XII 195 Å line (see the contours shown in Figure 1(c)) is about 897 Mm^2. If we consider only the dark region surrounded by bright footpoints of the fan loops, it has an area of about 156 Mm^2 (see the region between the two dashed lines in Figure 1(a)).

3.1. Analyses of Si IV 1403 Å Spectral Data

In IRIS Si IV 1403 Å (with a formation temperature of 8 × 10^4 K) observations, the region is highly structured, where abundant dot-like brightenings are seen on the intensity map (Figures 1(e) and (h)) and very fine blue- and redshifted features on the Doppler velocity map (Figures 1(f) and (i)). Compared to a surrounding region with similar intensity structures (see the region around X = 310, 340, Y = [-270, -240] in Figure 1(f)), it is notable that the upflow region includes more blueshifted structures. This is in agreement with the results shown in Polito et al. (2020). The nonthermal velocity map of the region shows no significant difference from the surrounding area (see Figures 1(d) and (g)), which is similar to that of a normal plage region (e.g., Hou et al. 2016b).
We then manually identify the patches of fine structures in the Si IV 1403 Å Doppler map underneath the coronal upflows (i.e., blueshifts in the Fe XII line, see the contour in Figure 1). The edge of each blue- or redshifted patch is defined at the place where the absolute speeds are less than 5 km s\(^{-1}\). Most of the identified velocity patches have Doppler shifts from 10–20 km s\(^{-1}\). The identified small-scale velocity structures and their corresponding intensity and nonthermal velocity structures are shown in Figure 2. In total, 102 blueshifted patches and 96 redshifted patches are identified. The sizes of the blueshifted patches are in the range of 0.05–6.79 Mm\(^2\), and those of the redshifted patches range from 0.05–12.18 Mm\(^2\). With these samples, 99% of the blueshifted ones and 97% of the redshifted ones are smaller than 5 Mm\(^2\), and more than 70% are smaller than 1 Mm\(^2\) (see Figure 1(d)). The total areas of the blueshifted and redshifted patches are 74 Mm\(^2\) and 98 Mm\(^2\), respectively. Please note that
the average Doppler velocity in this region remains redshifted. We can see that the total area of the upflow region in the corona is larger than the size of any single patch of these velocity structures in the transition region for 2–3 mag. The histogram of SiIV intensity of blueshifted features shows a clear enhancement at higher intensity (see Figure 1(e)). The average intensity of the blueshifted pixels is 75 DN in comparison to 43 DN for the redshifted ones. This indicates that compared to the redshifted features, the blueshifted ones tend to be associated with brighter regions in the transition region. The nonthermal velocities, however, do not show any obvious difference in their histograms (Figure 2(f)), suggesting that heating in these velocity structures should be statistically similar to the ambient region.

3.2. Transition Region Dynamics Seen in IRIS 1400 Å Slit-jaw Images

From IRIS SJ 1400 Å observations (see Figure 3 and the associated animation), we can see that the upflow region is full of dynamic dot-like brightenings. Some of them correspond to the bright dots in the Si IV intensity image.

In order to study the dynamic properties of these bright dots, we adopt a feature-tracking method, the Southwest Automatic Magnetic Identification Suite (SWAMIS), to identify and trace them in the IRIS SJ 1400 Å observations. SWAMIS has been widely used in tracking magnetic features on the photosphere (e.g., Lamb 2008; Parnell et al. 2009; Huang et al. 2012; Lamb et al. 2014, etc.), and the detailed methodology of SWAMIS can be seen in a series of papers (DeForest et al. 2007; Lamb et al. 2008, 2010, 2013). To set up the program, the high threshold was set to be 2σ above the average of the intensities of all pixels of the upflow region in the entire observing period, which triggers identification of a feature; the low threshold was set to be the average value, which involves the definition of the starting and ending time and also the edges of a feature. The downhill method was chosen to detect the edges of a feature, it then defines the edges of a feature at the zero gradient toward zero intensity unless it reaches the low threshold. The thresholds were

![Figure 2. The identified velocity structures in the transition region underneath the active region upflows as seen in IRIS Si IV 1403 Å. (a) The map of Doppler velocity structures, (b) the corresponding intensity map in a logarithmic scale, (c) the corresponding nonthermal velocity map, (d) the histograms of the sizes of the identified structures, (e) histograms of the Si IV 1403 Å peak intensity for the pixels of the identified blueshifted features (blue curve), the redshifted features (red curve), and the whole region (black curve), and (f) histograms of the Si IV 1403 Å nonthermal velocity for the pixels of the identified blueshifted features (blue curve), the redshifted features (red curve), and the whole region (black curve). The histograms shown in panels (e) and (f) are enhanced by a factor of 2.](image-url)
selected such a way that they are given robustly and they can cover most of the bright dots as seen manually (see an example in Figure 4). In the observations from 21:02 UT to 21:25 UT, SWAMIS identified 20,667 bright dots in the transition region underneath the coronal upflows. With the above settings, the area, birth time, death time, and birth and death locations of the identified bright dots can be achieved. In Figure 5, we give the statistics of the areas (panel (a)), lifetimes (panel (b)), shifts between the birth location and death location (panel (c)), and effective speeds (i.e., shift divided by lifetime, panel (d)) and distributions of the bright dots in the spaces of shifts versus lifetimes (panel (e)) and areas versus effective speeds (panel (f)).

The areas of all these bright dots have an average of 0.3 Mm$^2$. The histogram of the areas peaks at about 0.1 Mm$^2$ and 99% of the bright dots are smaller than 1 Mm$^2$. This again confirms that the transition region dynamics underneath the upflow region occur at a very fine scale. While about 95% of the bright dots have lifetimes shorter than 200 s, we also notice that about 44% are identified in only one frame of the images, indicating their lifetimes are shorter than 10 s. Quantitatively, this confirms the highly dynamic nature of the transition region underneath the upflow region. We also confirm that many bright dots can be born in the same locations, suggesting that they are intermittent phenomena.

From the animation of SJ 1400 Å observations (Figure 3), we can see that most of the bright dots at the center of the upflow region are mostly localized without significant motions away from the initial locations. This is confirmed by the measurement of shifts of their brightest centers given by SWAMIS (Figure 5(c)), where we can see that more than 75% of the bright dots hardly have any movement and more than 98% shift over a distance less than 1 Mm. If we took their sizes into account, only about 6% can shift further than their initial boundaries. Accordingly, the effective speeds of about 65% of the bright dots are around zero and 98% are less than 15 km s$^{-1}$.

The scatter plot in Figure 5(e) shows that bright dots with larger shifts tend to have longer lifetimes, although with a weak trend and a rather dispersed distribution. The scatter distribution of the bright dots in the space of areas versus effective speeds (Figure 5(f)) indicates that high-speed (>20 km s$^{-1}$) bright dots are concentrated at areas around 0.3 Mm$^2$ and bright dots with larger areas tend to have a smaller upper limit of speeds.
Surge-like motions can be seen in the bright dots at the edge of the region, where elongated dark threads are also abundant (suggesting an inclined magnetic field). In Figure 6, we show two examples of surges. A distinguishing characteristic is that these surges normally show a bright front (see the top row of Figure 6), which is similar to light walls occurring above light bridges of sunspots (see, e.g., Yang et al. 2015; Hou et al. 2016a), and might indicate shocks (Hou et al. 2017, 2018; Zhang et al. 2017). The upward motions of these surges have speeds of $12 - 17 \text{ km s}^{-1}$, and the downward speeds are slightly smaller (see the bottom row of Figure 6). These values are consistent with the velocity structures measured in the spectral data. Therefore, it remains possible that some of the bright dots in the center region also have surge-like motions but they cannot be resolved due to the projection effect.

### 3.3. The Chromosphere and Photosphere underneath the Active Region Upflows

In Figure 7, we further investigate the counterpart of the upflow region in the lower chromosphere and photosphere. The high-resolution magnetogram shows that the region is dominant in negative polarity (Figure 7(g)). This suggests that a (quasi-open) magnetic field could exist in a part of this region, in agreement with previous studies (e.g., Baker et al. 2009). The radiation image near $2832 \text{ Å}$ shows that the upflow region has the typical morphology of faculae (Figure 7(b)). Consistent with the faculae in the photosphere, a chromospheric plage in the region is clearly seen in the SOT Ca II image (Figure 7(c)).

The upflow region seen in the Mg II line is shown in Figures 7(d)–(f). We can see that the intensity maps of the Mg II wings and line center are generally in agreement with each other, suggesting that this region in the middle and upper chromosphere is coherent (Leenaarts et al. 2013; Pereira et al. 2013). At the edge of the region, the elongated dark threads shown in SJ 1400 Å images are also seen in the chromosphere. While cross-checking these maps in detail, we can see that some blueshifted structures present as dark features in the blue-wing image but as bright ones in the red-wing image, or vice versa for some redshifted structures. This suggests that plasma flows in the chromosphere and transition region are coherent in these locations (see the relevant discussion in Testa et al. 2020). This is consistent with previous studies as summarized in the Introduction.

### 4. Summary and Discussion

To infer at what scale the transition region connects to the coronal upflows at the edge of active region, in the present study we investigate the statistical properties of small-scale dynamics in the transition region underneath the upflows of NOAA AR 11934. Consistent with previous studies, the
transition region underneath the coronal upflows is also highly structured. While the upflows in the corona are a continuous region with an area of about 897 Mm$^2$, the velocity structures in the transition region are finely scaled as shown on the Si IV 1403 Å Doppler map. In the Si IV 1403 Å Doppler velocity map, we identified 102 blueshifted patches and 96 redshifted patches. We found that 99% of the blueshifted patches and 97% of the redshifted patches are smaller than 5 Mm$^2$, and more than 70% are smaller than 1 Mm$^2$. The total area of the blueshifted features is about 74 Mm$^2$, a magnitude smaller than the coronal upflows. Statistically, the Si IV 1403 Å intensities of the blueshifted features are biased toward the large values, compared to those of the redshifted ones. The histograms of nonthermal velocities of both the blue- and redshifted features do not show any obvious differences from that of the entire region.

The IRIS SJ 1400 Å images show that dynamic bright dots spread all over the transition region underneath the coronal upflow region. Using SWAMIS, more than 20,000 bright dots in the SJ 1400 Å images were identified and tracked. We found that their average area is 0.3 Mm$^2$. The distribution of their areas peaks at 0.1 Mm$^2$ and 99% of them are smaller than 1 Mm$^2$. Their lifetimes are from 10 s to a few minutes, and more than 95% are present for fewer than 200 s. Statistically, about 94% of the bright dots do not show any distinguishable shifts in the plane of sky. Some bright dots might have high apparent speeds ($>20$ km s$^{-1}$), and the distribution of their areas concentrates at around 0.3 Mm$^2$. Surge-like motions with speeds of 10–20 km s$^{-1}$ are clearly seen at the edge of the region, and they normally have a bright front. We speculate that similar motions should also exist in the center part of the region, but they cannot be resolved due to the projection effect.

The high-resolution magnetogram reveals that the upflow region is of a single polarity, indicating a (quasi-)open magnetic geometry. The coronal upflows locate above faculae as seen in the IRIS 2832 Å image and the plage region in the SOT Ca II image, suggesting an active magnetic environment. In agreement with the previous studies (see a summary in the Introduction), we found that plasma flows in some velocity structures in Si IV 1403 Å are consistent with those revealed by Mg II h, suggesting a coherence of plasma flows in these places between the chromosphere and transition region.

In light of these observations, we might further discuss the formation of the active region upflows in the corona. As summarized in the Introduction, many previous studies found that active region upflows have a strong connection to dynamics of the transition region or even lower. This is also confirmed by our observations. In the present study, we further carry out a statistical analysis on small-scale dynamics in the transition region underneath the active region upflows. The size and dynamic properties of these structures indicate that the connection between the transition region and the coronal upflows most likely takes place in a small-scale ($\lesssim 1$ Mm$^2$), rapid, and intermittent process (evolving over a timescale of less than a few minutes). The question is how such small-scale dynamics in the transition region link to the upflows in the corona.

An interpretation is that the plasma in the transition region is directly heated and pumped into the corona. In this way, the coronal upflows should be structured over a smaller scale rather than as a continuous region, since the upflows in the transition

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**Figure 5.** Statistics of parameters of the dynamic bright dots in the transition region underneath the active region upflows as determined from SWAMIS. (a) The histogram of their areas, (b) the histogram of their lifetimes, (c) the histogram of their shifts from birth to death in the plane of sky, (d) the histogram of their effective speeds, (e) a scatter plot showing the distribution of the dynamic bright dots in the space of shifts vs. lifetimes, and (f) a scatter plot showing showing the distribution of the dynamic bright dots in the space of areas vs. effective speeds.
region are localized with sizes of about 1 Mm². Such smaller structures might not be able to be resolved with EIS data, and spectral data with higher resolutions, such as from the Spectral Imaging of the Coronal Environment instrument (SPICE Consortium et al. 2020) on board the Solar Orbiter (Müller et al. 2020) should be helpful. Comparing the total blueshifted area in the transition region and the coronal upflows, we can estimate a filling factor of about 0.08 for the EIS observations of this coronal upflow region. For EIS observations of typical fan loops, Young et al. (2012) found a filling factor of about 0.2, which is more than twice the value derived here. A possible reason for this inconsistency could be the expansion of the fan loops and their projection effects. For an isolated typical fan loop shown in the south of the studied FOV (see Figure 1(a)), we estimate from the AIA 171 Å image that a fan with a cross section of about 6″ near the footpoint can expand to about 20″ at a distance of 25″ on the projection plate. Supposing the fan has a circular disk for a footpoint (with a diameter of 6″), we found that the projection area can be more than 10 times the footpoint. Although this factor can be seriously influenced by inclined angles and overlapping effects, the expansion of fan loops can easily explain the relatively small filling factor estimated here. Another reason could be the underestimation of the area of upflows in the transition region, since only one raster of data was taken here and one cannot exclude the possible contribution from regions other than the blueshifted patches.

Alternatively, the small-scale dynamics in the transition region can just act as drivers that stimulate the coronal base of the open-field region and then force the plasmas there to move upward to form the coronal upflows. Similarly, evidence that dynamics from the lower solar atmosphere can drive coronal propagating disturbances has been reported by some studies (e.g., Jiao et al. 2015; Pant et al. 2015; Hou et al. 2018, etc.). With this scenario, the upflows in the transition region can fall back after stimulating the coronal base and transferring energy to the corona, thus this explains why the blueshifted features tend to be brighter than the redshifted ones. Also, the transition region dynamics can have any size and not be necessary be comparable to the coronal upflows. The abundance of the small-scale dynamics in the transition region at any given time should be able to provide enough drivers to the coronal base. We might assume a funnel geometry of the upflows, similar to those in coronal holes (see e.g., Dowdy et al. 1986; Tu et al. 2005), two possible processes might then be involved in driving the coronal upflows. One is interaction with shocks, in which the shock energy carried by surges hits the coronal base of the funnel and transfers energy to corona (Hou et al. 2018). The other is interchange reconnection between a funnel and small-scale loops (Fisk 2005). Actually, the interchange reconnection scenario for

**Figure 6.** Two examples of transition region surge events appearing at the edge the field of the upflow region. The top row (panels (a) and (c)) shows the regions of these surges in the IRIS 1400 Å passband, on which the dotted lines denote the trajectories of the surges. The bottom row (panels (b) and (d)) shows the corresponding time–distance maps obtained along the trajectories of the surges (i.e., the dotted lines shown in the top row). The dotted lines shown in the bottom row trace the motions of the blobs in the surge and the speeds (in kilometers per second) determined from them are indicated in red.
active region upflows has been proposed or suggested by many previous studies (e.g., Baker et al. 2009; Del Zanna et al. 2011; Barczynski et al. 2021, etc.). The small-scale loops here could be understood as small transition region loops that might be propelled by surges and then interact with coronal funnels, or small magnetic islands associated with energetic events in the transition region (Innes et al. 2015) that carry close fields moving and interacting with coronal funnels.

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