Granular-scale Magnetic Flux Emergence and its Associated Features in an Emerging Active Region

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Abstract

Using the high-resolution photosphere and chromosphere observations made by the 1 m New Vacuum Solar Telescope, we studied the granular-scale magnetic flux emergence occurring in emerging active region NOAA 12579. Supplementary observations are also provided by the spacecraft Solar Dynamics Observatory. The studied granular-scale flux emergence took place at two different locations. One is completely embedded in the unipolar region of the following sunspots (Case 1), while another is located at the central part in the active region (Case 2). We find that both cases initially emerge from a dark patch like a wide intergranular lane, but showing the different subsequent features. In Case 1, the emerging granule grows in an elongated feature and reaches its maximum size of almost of 5″ × 3″, with an elongated speed of about 2–3 km s⁻¹. An eruption (i.e., surge) with bright footpoints is observed after the emerging granule reaches its maximum scale. There is a time delay of more than 10 minutes between the appearance of the abnormal granule and the Hα surge. Furthermore, its footpoints are clearly rooted at the intergranular lane. We propose that the eruptive surge could be triggered by the reconnection between the emerging magnetic flux and the preexisting ambient field, leading to the localized heating and bidirectional flows. In Case 2, the granular cell emerging is simultaneously associated with bright points with opposite magnetic polarity, showing the separating motion between them and a bunch of newly formed arch filament systems. We infer that the bright points are due to the strong-field magnetic concentration in the dark intergranular lanes rather than the instantaneous Ellerman bombs.

Unified Astronomy Thesaurus concepts: Solar photosphere (1518); Solar magnetic reconnection (1504); Solar granules (1875); Solar activity (1475)

Supporting material: animation

1. Introduction

Magnetic reconnection is believed to play a key role in powering various solar activities from the photosphere to the corona, such as large-scale solar flares, coronal mass ejections and small-scale jets/surges, Ellerman bombs (EBs) and UV bursts (Ellerman 1917; Priest & Forbes 2000; Hudson 2011; Peter et al. 2014; Sterling et al. 2015; Ni et al. 2017; Tian et al. 2018). In the past decades, numerous imaging and spectral observations have reported the small-scale magnetic reconnection in the lower atmosphere (Nishizuka et al. 2008; Morita et al. 2010; Tian et al. 2018), including EBs (Ellerman 1917; Georgoulis et al. 2002), hot explosions in the cool solar atmosphere (UV bursts) (Peter et al. 2014), and jets with an inverted Y-shaped configuration in a penumbral field (Cirtain et al. 2007; Tiwari et al. 2016; Zeng et al. 2016; Bharti et al. 2017). The small-scale magnetic reconnection even frequently appears in sunspot light bridges (Tian et al. 2018). Recently, many high-resolution observational studies have focused on magnetic flux emergence and its related phenomena in different solar atmospheric layers (Zeng et al. 2013; Vargas Domínguez et al. 2014; Yang et al. 2016; Wang et al. 2020). These small-scale activities are believed to be due to the magnetic reconnection between emerging magnetic flux from the subphotosphere and the preexisting ambient magnetic arcade (Sterling et al. 2015; Centeno 2012; Guglielmino 2012; Cheung & Isobe 2014; Schmieder et al. 2014), leading to enhanced thermal and kinetic energy of local plasma (Priest & Forbes 2000). Furthermore, EBs and photospheric brightenings are often accompanied by cool/hot surges or microflares (Yokoyama & Shibata 1995; Solanki et al. 2018). However, the relationship between magnetic flux emergence from subphotosphere and small-scale activities is still not fully understood.

Observations of emerging active regions are crucial for understanding the magnetic structure of sunspots and the origin of fine magnetic activities related with moving magnetic features, such as EBs (Yang et al. 2016). With the advent of the unprecedented high-resolution observations taken by the Interface Region Imaging Spectrograph (spatial resolution 0″07, IRIS; De Pontieu et al. 2014), imaging spectroscopy with the Swedish 1 m Solar Telescope (SST; Scharmer et al. 2003), Goode Solar Telescope (spatial resolution 0″034, GST; Cao et al. 2010), and New Vacuum Solar Telescope (spatial resolution 0″052, NVST; Liu et al. 2014), these high quality instruments provide us with an unprecedented opportunity to observe the temporal and spatial evolution of small-scale activities. EBs are short-lived brightenings of the far wings in the Hα line at 6563 Å, first discovered by Ellerman (1917). For some earlier observations, the brightening points on photosphere are regarded as EBs (Nelson et al. 2013, 2015). Actually, the bright points located in intergranular darker lanes...
are due to strong-field magnetic concentrations rather than true EBs (Hagenaar & Shine 2005; Rutten et al. 2013). For an emerging region, magnetic flux emergence episodes are often accompanied by Hα surges (Schmieder et al. 2014; Solanki et al. 2018; Reid et al. 2015; Nóbrega-Siverio et al. 2016, 2017; Kim et al. 2015; de la Cruz Rodríguez et al. 2015). Madjarska et al. (2009) pointed out that granular-scale magnetic flux emergence may trigger chromospheric jets/or surges.

Recently, observations with high temporal and spatial resolution have reported granular-scale emerging fluxes in emerging regions (Guglielmino et al. 2010; Yang et al. 2013, 2016; Zeng et al. 2013; Ortiz et al. 2016; Guglielmino 2012; Vargas Domínguez et al. 2014; Lim et al. 2011; Wang et al. 2020), which are believed to be the common signature of magnetic flux emergence on the photosphere. Vargas Domínguez et al. (2012) reported that granular-scale emergence in active and quiet regions shows the same dynamic processes, but chromospheric radiation in active regions is stronger than in quiet regions. Ortiz et al. (2016) reported that there was a 10 minute time delay for granule-scale emerging between the photosphere and transition region, which is believed to be an important mechanism of transporting energy from subsurface layers to the upper atmosphere, even the corona. Taking advance of high-resolution observations, Centeno et al. (2017). Fischer et al. (2019), and Wang et al. (2020) further reported that a horizontal magnetic field enhancement is simultaneously following the newly formed granules. It is different from the magnetic loop emerging that is within granular and drifting intergranular lanes (Smith et al. 2017; Moreno-Insertis et al. 2018). Yang et al. (2016) found that photospheric EBs are accompanied by elongated granule-like features displaying transversal motion driven by emerging flux in intergranular lanes, which are identified as moving magnetic features converging and merging the dipole fields. Guglielmino et al. (2010) reported that the localized heating and chromospheric surge are associated with granular-scale flux emergence. Most of these studies mainly focus on magnetic flux emergence and its relation with EBs and surges. Therefore, in order to better understand the energy transfer in the lower atmosphere, it is necessary to have a deep study of the relationship between these phenomena using high-resolution observations.

In this paper, we present the analysis of the evolution of granular-scale magnetic flux emergence and its relation to dynamic features in an emerging active region. Using high-resolution observations taken by the New Vacuum Solar Telescope (NVST) and Solar Dynamics Observatory (SDO), we studied two different regions of magnetic flux emergence; one is completely embedded in the unipolar region of the following sunspots (Case 1), while the other is located at the central part between the leading and following sunspots of the active region (Case 2). The granule-scale magnetic flux emergence in Case 1 displays an elongated granular features, and it is related with a small eruption (i.e., surge). The granular cell emerging in Case 2 is associated with simultaneous bright points with opposite magnetic polarities, showing the separating motion between them and a bunch of newly formed arch filament system. Section 2 describes the observation instruments and data processing. In Section 3, we present our observational results. We summarize and discuss our findings in Section 4.

2. Observations

On 2016 September 23, there occurred an emerging active region on the solar surface, NOAA 12579. The active region was located at S13, W12 on the disk, it was a \( \beta \)-type magnetic configuration. We carried out high-resolution observations using the NVST located at Fuxian Solar Observatories (Liu et al. 2014). Both the photospheric image in the TiO band (centered at 7058 Å) and the chromospheric observation in the Hα band (centered at line center and off-band \( \pm 0.8 \) Å) are taken, spanning from 01:12 UT to 05:06 UT. The temporal cadence of the photospheric images is about 30 s, with a pixel sampling of 0\( \prime \)052 per pixel. For images at the line center and the wings of Hα, the cadence is about 47 s for three wavelength changes. The pixel sampling is about 0\( \prime \)165. We also used space observations acquired by the Atmospheric Imaging Assembly (AIA; Lemen et al. 2012) and Helioseismic and Magnetic Imager (HMI; Scherrer et al. 2012) on board the SDO (Pesnell et al. 2012). We applied line-of-sight (LOS) and vector magnetograms taken by the HMI in the Fe I 6173 Å line. It is worth noting that the spatial resolution of HMI/LOS is 1.2\( \prime \), so its spatial resolution is almost 10 times larger than the NVST photosphere observations in the TiO band. The supplementary observations in the 1600 Å (Fe XVIII; log\( T = 3.5 \)) as well as 1700 Å (Fe XX; log\( T = 4.0 \)) bands of AIA are also available to trace the response of the temperature-minimum region. We aligned the NVST data to the SDO observations using the sunspots in continue images as reference.

In this paper, we focus on this emerging active region with a field of view of about 80\( \prime \)× 45\( \prime \), spanning from 02:45 to 05:00 UT. Figure 1 gives the multiband information of the active region observed with NVST and HMI. A series of arch filament systems are clearly seen in the Hα line center, connecting the positive leading sunspot and the negative following sunspots. Note that bright points are easier to be recognized under these filamentary structures, instead of being around the penumbra region of the sunspot. However, the most remarkable thing is the fact that we clearly observe the granular-scale flux emergence not only appearing in the region between two opposite polarities but also inside the unipolar negative one, taking advantage of the high-resolution photosphere observations. In Figure 1, we outline these emerging regions by using three rectangles and label them as ROI 1, 2, and 3. An animation is available in the online version of this journal (see online animation of the Figure 1).

3. Results

The emerging active region harbors a number of granular-scale flux emergence events, whose evolutions result in abnormal granulation expansion and fragmentation. In the following, we will perform a detailed analysis for two typical granular-scale emerging cases, i.e., Case 1 and Case 2, which take place in different regions.

3.1. Case 1: Emergence in the Unipolar Region

Case 1 represents the emergence embedded in the unipolar region as outlined by a black box ROI 1 in Figure 1(d). Figure 2 shows the temporal evolution of this area at different wavelengths (from left to right). The first column gives the evolution of the photospheric granule shown in the TiO band. At \( \sim 03:41 \) UT, we can see that the initial granule started to grow from a minipore or the wide intergranular lanes.
At \( \sim 03:52 \) UT, the granular structure became larger and more elongated than the normal granule, reaching a maximum size of about \( 5'' \times 3'' \), almost 5 times as large as its surrounding granular cells. The emergence lasted about 11 minutes (03:41-03:52 UT); then it became broken, and brightness enhancements are evidenced at their endpoints. After that, the major granule has completely broken into several new granules. Meanwhile, the pores close to the lower left endpoints also change their morphologies. The second and third columns show the response in the off-band 0.8 Å and in the line center of \( \text{H} \alpha \). It is interesting to find that a surge occurs and is initiated around 03:53 UT, when the emerging granulation has already fragmented. This eruptive surge can be significantly recognized in the \( \text{H} \alpha \) line wing as a dark front and two bright footpoints (see the snapshots from 04:04-04:21 UT or online animation for Case 1). Through comparison to the first column, it is found that the surge with bright footpoints are almost rooted at the boundaries of the emerging granule. The surge was observed in the \( \text{H} \alpha \) line center a few minutes later than in the \( \text{H} \alpha \) line wing. Meanwhile, we also illustrated the evolution in 1600 Å, which is thought to be the responses of the temperature-minimum region. The structure and temporal evolution of the magnetic flux emergence and relation with surge in ROI 1 are clearly visible in the online movie for Figure 1.

In order to show the spatial relation and the cause–consequence between the granular emergence and the following surge, we give the time–space diagrams of four slices in Figure 3 along with the elongation direction of the emerging granule and the eruption direction of the surge, as indicated by S1 (in the TiO-band images), S2 and S3 (in the line wing and core of \( \text{H} \alpha \) images) and S4 (in the 1600 Å images) of Figure 2.

It is clearly seen in Figure 3 that (1) the abnormal granulation emergence lasts about 12 minutes with an expansion speed of about 2 km s\(^{-1}\) during its emergence. We also use the local correlation tracking (LCT) method (November & Simon 1988) to confirm the similar elongated speed, as shown in the Figure 4. Then the supergranular structure was broken into a few new granules, in which localized brightness enhancements are shown. (2) It can be seen that the surge does not simultaneously appear at the beginning time of the granular emergence. Instead, it occurs at the time when the emerging granule reaches its maximum size. There is a temporal delay of more than 10 minutes. The occurrence of the surge shows a good coherence with the granule breaking, while its bright footpoints are rooted at the emerging granular lanes. (3) The surge related brightness enhancements observed in the \( \text{H} \alpha \) line center is about 12 minutes later than those observed in the \( \text{H} \alpha \) line wing and TiO band; however, they occur almost simultaneously with the intensity increase in 1600 Å. These observations may indicate that the surge is produced by magnetic reconnection occurring in the lower chromosphere.

Figure 4 shows a flow-field map computed over ROI 1 for 30 s by using the LCT method. Here the tracking window for the abnormal granulation emergence is the size of \( 5'' \times 5''\) (\( \text{xrange} = [-241'', -236''], \text{yrange} = [-350'', -345''] \)). During this time period, the granular cell expands and grows up to 5 times the size of a normal granule. Blue arrows in this map indicate the moving direction and speed of maximum granular emerging; the transversal speed of the emerging granular is about 2 km s\(^{-1}\), similar with the result derived from the time–space diagrams of S1.
3.2. Case 2: Emergence in the Bipolar Regions

In this section we concentrate on the central part of the emerging active region. In contrast to ROI 1, there exist many small fragmented bipolar structures located between the proceeding and following sunspots, which are believed to be the serpentine magnetic field structure (Strous & Zwaan 1999; Valori et al. 2012). Two similar cases of abnormal granulation expansions are observed in the regions marked by ROI 2 and ROI 3 (Figure 1). Figures 5 and 6 separately show their evolution in the multiwavelengths observations.

Figure 2. Evolution of the subregion ROI 1 at multiwavelengths from 03:41 to 04:22 UT. Displayed from left to right are the TiO-band images, the wing of Hα +0.8Å, the Hα line center filtergrams, and the AIA 1600 Å images. The grid dotted lines are plotted as a reference. The abnormal granulation expansion at its maximum size is delineated by a green contour in the TiO-band image at 03:51 UT. Slits (S1-S4) in this figure give the position used to make the spacetime diagrams in Figure 3.
Figure 5 shows the observations in the small emerging region, which is located in the rectangular box of ROI 2 of Figure 1(d). At $\sim$03:27 UT, a wide intergranular dark lane has formed, before granular emerging. At $\sim$03:30 UT, a mini granular cell emerges from a wide intergranular dark lane of the small emerging region, where is the origin of the emerging magnetic flux, similar to Case 1 studied above. The green arrows in each image correspond to the two endpoints of the expanding granule with time. After $\sim$03:30 UT, the granular cell is stretched and becomes an elongated granular-like feature with a growing speed of about 3 km s$^{-1}$. Combined with the observations in the H$\alpha$ line wing and TiO band, it is shown that

Figure 3. The spacetime diagrams obtained along the slices marked by S1–S4 in Figure 2. Images displayed from top to bottom are in the AIA 1600 Å, the H$\alpha$ line center, the line wing of H$\alpha$, and the TiO band. The two dashed vertical lines indicate the beginning of the surge in the wing of H$\alpha$ and response of the temperature-minimum region ($\sim$03:52 and $\sim$04:06 UT, respectively). Two inclined dashed lines in panel (d) are over-plotted on the dark granular lanes, indicating the expansion of the abnormal granule; their average speed is about 2 km s$^{-1}$. 

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the two bright points seen in the Hα line wing are almost located at the endpoints of the emerging granule. Contrarily to the erupting surge in Case 1, the emission of these bright points is much weaker. It is noted that the two bright points are always associated with the granular cell emerging process, showing a separating motion seen in the photosphere and the low chromosphere (indicated by the green arrows in the first and second columns). The observed phenomena are similar to the observations of Guglielmino et al. (2010), who reported the granular-scale emergence was nearly simultaneously with Ca II H enhancement. As a contrast, Yang et al. (2016) also reported Hα bright points/enhancement in the intergranular lanes during granular emergence, but they found that the emergence is obviously preceding these bright points.

From the LOS magnetogram of HMI, we find that the two bright points correspond to a pair of separating opposite polarities (indicated by the green arrows in the forth column). The bright points with opposite polarities show a separating motion that may be due to the abnormal granulation emergence occurring in the serpentine field. These results further indicate that brightenings often occur in the place of magnetic convergence. Our observations support the predicted result by Rutten et al. (2013) and Hagenaar & Shine (2005); the brightenings are due to the strong-field magnetic concentration in dark intergranular lanes. From the Hα line center images, a bunch of new arch filaments are formed over the granular emergence at ∼03:30 UT. A high-resolution movie in Hα reveals that the new formed arch filaments are stretched over this time and finally erupted. All the observations are favorable to a picture of an emergence of the magnetic field in an Ω-shaped configuration.

Figure 6 displays another group of abnormal granulation emergences within the subregion of ROI 3. From the TiO images (first column), we can recognize the expansion of an abnormal granule following a few recurring granulation formations (also seen in the online movie of Figure 1). The granular lanes in the expansion orientation are marked by green arrows. It is worth noting that we can clearly observe a pore formation associated with the abnormal granular emergence. Furthermore, bright points with emission enhanced in the Hα line wing (second column) occur in the granular lanes and show opposite polarities (forth column), similar with the result of ROI 2. Both the bright points and opposite polarities are diverging from each other, indicating magnetic convergence of the same polarity. Meanwhile, a bunch of newly formed arch filaments are clearly rooted from the pore (third column).

To study the magnetic field evolution associated with the abnormal granulation emergence, we also investigate the magnetic field integrating over three regions of interest separately (i.e., ROI 1, 2, and 3). The results are all shown in Figure 7. First, it is found that, in Case 1 (first column), the negative and total net magnetic fluxes keep increasing, particularly after ∼03:40 UT, which is nearly consistent with the granular expansion judged from the TiO images. However, the increasing magnetic flux occurs within 15 minutes before the surge eruption. At ∼04:00 UT, both of them begin to decrease and follow the continuous surge eruption. The most interesting find is a short-period positive flux just around the eruption, which is almost 4 orders of magnitude less than the positive magnetic flux, showing the obvious impulse during the surge. The impulsive appearance is just accompanied by rapid motion of adjoining negative magnetic features (see online movie in Figure 1).

Since the two events in Case 2 are located in the central part of the active region, in which the serpentine-field structure exists, the magnetic fluxes for the two emerging regions show continuous magnetic emergence and cancellation in Figure 7 (a2–c3). Nevertheless, the positive, negative, and total magnetic fluxes in ROI 2 suddenly decrease after the granular emergence. At ∼04:30 UT, the negative and total magnetic fluxes show a slow increase (see Figure 7(a2–c2)) because of another group of granular emergence in this region. For ROI 3, the magnetic fluxes display an evolution from decline to increase in the emerging region. After ∼04:00 UT, it is noted that these abnormal granulation emergences are more obvious than magnetic cancellation, showing a series of recurring emergences from 04:00 to 05:00 UT. In Figure 7, we also find that the evolution of all magnetic fluxes shows many small impulses for Case 1 and Case 2. On the other hand, the mean intensity of the horizontal magnetic field in Figure 7 (d1–d3) always increases in the three emerging regions, especially in ROI 3. Figure 8 gives snapshots of vector magnetograms and the velocity field as observed by HMI and deduced from the LCT analysis. The lower panel shows the separating motion of photospheric flow horizontal velocities between positive and negative polarities.

4. Summary and Discussion

In this paper, we give a detailed analysis of two type of granular emergence cases in active region NOAA 12579. One case is located between opposite polarities, and the other is completely embedded in the vicinity of the satellite of the unipolar region, at least, at the present resolution of the HMI LOS magnetogram. The observed granular-scale magnetic flux emergences are accompanied by the appearance of various
features and activities. The main results can be summarized in the following.

(1) In both cases, it is identified from high-resolution photospheric images that the abnormal granulation expansion originates from a dark region or a wide granular lane, where is believed to be the stronger magnetic convergence. Guglielmino et al. (2008) also reported that these dark lanes are associated with horizontal magnetic field and upflows. With time, the abnormal granules on the photospheric surface expand as an extending morphology with a speed of about 2–3 km s\(^{-1}\), which is similar to the speed of transverse motion driven by the abnormal granulation emergence, reported by Guglielmino et al. (2008) and Yang et al. (2016). All of these observations are consistent with the picture of an \(\Omega\)-shaped magnetic field loop emerging from the subphotosphere (Zwaan 1985; Bernasconi et al. 2002). As the loop emerges, it will be reconnected with the preexisting ambient field. Bidirectional flows and local heating are consequently generated during the reconnection process and result in photospheric brightening as well as chromospheric eruption.

(2) In Case 1, we find a clear cause–consequence relationship between the granule emergence and the following eruption (i.e., a surge). While the granule grew to its maximum size, it was broken into several new enhanced granules. The eruption first seen in the H\(_\alpha\) line wing showed double footpoints that lasted for 40 minutes. It is also worth noting that there is an obvious temporal lag of about 10 minutes between the emergence of the initial abnormal granulation and the occurrence of the eruption. Supposing the eruption is due to the reconnection between the emergence of an \(\Omega\) flux loop and the preexisting overlaying magnetic field, we infer that it takes the \(\Omega\) loop about 10 minutes to rise to the reconnection point. If the up-emerging speed is as fast as the separating speed seen in the horizontal direction, i.e., 2 km s\(^{-1}\), we can estimate that the reconnection point is about 1.2 Mm high above the photosphere. We also find that the intensity enhancement in the 1600 Å associated with the eruption occurs about 14 minutes later than that in the H\(_\alpha\) line wing. This is different from the results of Guglielmino et al. (2018), who reported that a granular-scale emergence embedded in the preexisting field leads to the heated upper chromospheric and coronal atmosphere (i.e., brightening in 1400 Å and even in 131 Å). However, there was no obvious time delay in the brightening between the different atmosphere layers due to the high reconnection location. For our observations, the reconnection may have taken place in the lower chromosphere, resulting in the longer delay time from photospheric granular emerging to surge in the chromosphere.

(3) Emergence events in Case 2 are a relatively common signature of magnetic flux emergence in the photosphere. We find that the emerging process is accompanied by the separating motion of the two bright points. This pair of bright
points can also be identified cospatially with a pair of opposite polarities from the LOS magnetogram. On the one hand, the continuous existing of the bright points suggests that they are different from the transient bright points/EBs reported by Yang et al. (2016). In our opinion, according to the predications in the work by Rutten (2013) and Hagenaar (2005), those brightenings are due to the magnetic field concentration, i.e., the granular lane. One of the important results is that moving dipolar polarities are just located at the place of the bright points, showing a separating motion between them during the granular cell emerging. On the other hand, a bunch of new arch filaments are formed and connected with two bright points during the granular cell emerging. This arch filament system displays a quite short-period dynamic process and seems like the eruption surge reported by Guglielmino et al. (2010). However, in our present observation, this arch filament and separating bright points (and the opposite magnetic polarities) are only the observation features from the emergence of the granular-scale magnetic flux, rather than the result of the reconnection. In addition, we find that, magnetic flux coalescence and cancellation can be observed for the same and dipolar polarity, respectively, which are largely determined by the collapsed granule in the process of emergence. However, in this paper, that is not the focus of our research.

From HMI observations, a pair of a negative and positive magnetic elements emerged and moved cospatially with the abnormal granulation emergence, and the bright points are easier to occur in the place of magnetic convergence, especially in the ROI 2 and ROI 3 regions. There occur many small bipolar flux emergences in-between the diverging dipolar polarities according to LOS observations, which is believed to be a serpentine-field topology (see online movie of Figure 1 (b) and Figure 8). Strous & Zwaan (1999), Valori et al. (2012), and Vargas Domínguez et al. (2010) have reported a serpentine structure during a growing emergence region in previous works; they thought that the configuration of flux emergence undergoes an evolution from a stack of undulatory flux tubes below the photosphere to a series of emerging top of Ω-shaped magnetic loops and finally develops a large-scale magnetic loop in the upper solar atmosphere. For the emerging region of Case 2, however, these small-scale abnormal granulation emergences are regarded as successive rising flux arch emergences and sheared Ω-loops, showing the separating motion of the opposite polarities with a speed of about 2–3 km s$^{-1}$. Therefore in our opinion, the continuous emergence of the serpentine-field lines into the upper atmosphere result in the dynamic filaments seen in Hα and the abnormal granulation expansion as well.

(4) The reconnection is also indicated by the investigation for the magnetic flux over ROI 1. In Case 1, there occurs an impulsive positive flux and follows the surge eruption process, though the positive flux is far less than the dominant negative one. The impulsive appearance is also accompanied by rapid motion of the adjoining negative magnetic features. All these suggest that the eruptive surge can be due to the magnetic reconnection between the emerging opposite field and

![Figure 6. Snapshot for the small-scaled flux emergence in the rectangular box of ROI 3 of Figure 1 (d), similar to Figure 5.](image-url)
preexisting ambient field. The evolution of the magnetic fluxes shows a decrease-to-increase trend in Case 2, which indicates that the magnetic flux in the two small emerging regions is closely related to the magnetic emergence and cancellation. In addition, similar to the reports by Fischer et al. (2019), the abnormal granulation emergence follows the averaged transverse field enhancement during the three emerging regions, as shown in Figure 7(d1–d3).

It is worth noting that the granular-scale magnetic emergence in Case 1 and Case 2 have similar sizes, but there is a negligible positive magnetic flux identified around the emerging granular lane in Case 1, by using the present HMI magnetogram. That could be due to a projection effect, but it has to be admitted that the spatial resolution of the magnetogram we used was much lower than that of the photosphere images observed by the NVST, which means it is still necessary to have higher-resolution (subarcsecond) magnetic field information in order to diagnose the small-scale reconnection processes and energy transfer mechanisms in the lower atmosphere.

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