Small-scale motions in the solar filaments as the precursors of eruptions

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Abstract

Filaments, the dense cooler plasmas floating in the solar corona supported by the magnetic fields, often show some activations before the eruptions. In our previous study (Seki et al. 2017), we found an increase of the standard deviation of small-scale motions in a filament prior to its eruption. However, since analyzed is only one event, it is unclear whether such increase of small-scale velocity is general in filament eruptions.

In this study, we examined 12 events of filament eruptions including 2 quiescent filaments, 4 active region filaments, and 6 intermediate filaments in the same way as our previous work. We confirmed that in all the 12 filament disappearance events, the standard deviation of small-scale motions increased before disappearance of filament. Moreover, we found that the time-scale of the increase is different in the types of filaments. We concluded that the standard deviation of small-scale motions in a filament could probably be used as the precursor of the filament eruptions, combining it with the H$_\alpha$ center image and the LOS velocity map.

Key words: Sun: coronal mass ejections (CMEs) — Sun: filaments, prominences — turbulence — methods: statistical — techniques: image processing
1 Introduction

A dark filament, or a prominence, is a dense and cool plasma supported by magnetic fields in the solar corona with its plasma density of $10^9$–$10^{10}$ cm$^{-3}$ and its temperature of $10^4$ K. In general a filament is globally stable, but at the end of its life it often becomes unstable and erupt (Parenti 2014). Filament eruption is often associated with various solar eruptive phenomena such as a flare, a coronal mass ejections (CME), and a giant arcade formation in the quiet sun. Although they are diverse in size, morphology, and emitting radiation spectrum, they are considered to be the different aspects of a common magnetohydrodynamical process that involves plasma ejection and magnetic reconnection (Shibata & Magara 2011).

Filament eruptions are often preceded by an activation such as slow rise (Sterling & Moore 2004; Sterling et al. 2011), twisting and rotational motions (Gosain et al. 2009), fragmentary brightnings (Ofman et al. 1998), weak heating (Chifor et al. 2006), oscillatory plasma motions (Isobe & Tripathi 2006), and increase of internal motions (Tandberg-Hanssen 1995; Seki et al. 2017) in the filaments.

In more general context of the solar eruptions, various kinds of "triggers" have been proposed, including emerging magnetic flux (Feynman & Martin 1995; Chen & Shibata 2000; Kusano et al. 2012), magnetic reconnection at various magnetic configuration (Antiochos et al. 1999; Moore et al. 2001), and helicity injection (Magara & Tsuneta 2008; Harra et al. 2009). Among others, increase in the non-thermal velocity before the onset of a flare is discussed in Harra et al. 2001. By spectroscopic observation in coronal lines, Harra et al. 2001 found a non-thermal line broadening before an increase in the X-ray flux and the electron temperature, suggesting an increase in the turbulent motion taking place before the onset of the flare.

In our previous study (Seki et al. 2017), we analyzed an intermediate filament near NOAA 12605 which erupted on 2016 November 5 and observed with 73 wavelengths around H$\alpha$ line. The data were taken by the Solar Dynamics Doppler Imager (SDDI) (Ichimoto et al. 2017) newly installed on the Solar Magnetic Activity Research Telescope (SMART) (UeNo et al. 2004) at Hida Observatory. The SDDI takes full disk solar images from H$\alpha$ - 9.0 Å to H$\alpha$ + 9.0 Å at every 0.25 Å. It allowed us to monitor the H$\alpha$ line profile and thus to determine the line-of-sight (LOS) velocity map before and during the eruption of the filament. From the velocity map, we made histograms of the LOS velocity at each pixel and calculated the standard deviation of the velocity distribution in order to quantify the small scale motions in the filament. As a result we found:

1. On the previous day of the eruption, the standard deviation was almost constant around 2–3 km s$^{-1}$, but at the beginning of the observation on the eruption day, it had already been 4–5 km s$^{-1}$.
The mean LOS velocity was constant at 0 km s\(^{-1}\).

2. Around 1 hour before eruption, the average of LOS velocity started decreasing from 0 km s\(^{-1}\) and got minus, whereas its standard deviation increased up to 10 km s\(^{-1}\).

The second finding is likely corresponds to the commonly observed slow-rise phase (Sterling & Moore 2004; Isobe & Tripathi 2006), while the first finding suggests an increase in the turbulent motion in the filament prior to the slow-rise phase and can be regarded as a sign that the filament is approaching to an unstable state or a loss of equilibrium that drives the eruption. Hereafter we call it “Phase 1” during which this period the standard deviation increases more than that well before the onset of the eruption and the mean LOS velocity is almost constant. And also we define “Phase 2” as the period during which not only the standard deviation but also the mean velocity changes compared to the temporal profile before this phase. Phase 1 can be regarded as the gradual increase in the turbulent motion well before the onset of the slow rise, and Phase 2 includes the slow-rise (with further increase of the turbulent motion).

The aim of this paper is to examine whether the findings of Seki et al. 2017 hold for other filament eruptions in general. For this purpose we examined 17 filament disappearance events observed by the SDDI from the beginning of its routine observation in 2016 May to 2017 May. After removing low-quality data sets we analyzed 12 filaments, including 2 quiescent filament, 4 active region filaments, and 6 intermediate filaments in the same way as Seki et al. 2017. We show the event list and the method in section 2 and the results in section 3. In section 4, we summarize and discuss our results to answer the question whether the increase of the standard deviation of LOS velocity, i.e. the increase of the small-scale motions of plasmas in solar filaments, is generally seen prior to filament eruptions.

2 Observations

2.1 Event List

The SDDI installed on SMART at Hida Observatory of Kyoto University has been operating routine observations since 2016 May 1. It takes the solar full disk images at 73 wavelengths with a step of 0.25 ˚A from H\(\alpha\) line center - 9.0 ˚A to H\(\alpha\) line center + 9.0 ˚A, i.e. at 36 positions in the blue wing, H\(\alpha\) line center, and 36 positions in the H\(\alpha\) red wing. A set of images with 73 wavelengths is obtained with a time cadence of 15 seconds and the pixel size is about 1.2 arcsec (Ichimoto et al. 2017). When the weather permits, it continuously monitor the sun during the day time in Hida. The detail of the instrument, the examples of images, and the line profiles can be found in Ichimoto et al. 2017.

By surveying the daily observation logs from 2016 May 1 to 2017 May 31 and checking fil-
Table 1. Filament disappearance events observed by the SDDI (2016 May–2017 May)

| Event | Date<sup>a</sup> | F.D. Time<sup>b</sup> [UT] | Type<sup>c</sup>       | Flare Time<sup>d</sup> & Class [UT] | CME<sup>e</sup> [UT] | Analyzed<sup>f</sup> |
|-------|------------------|-----------------------------|------------------------|-------------------------------------|----------------------|----------------------|
| 1     | 2016 May 4       | 01:20                       | AF (NOAA 12541)        | 1:20 (B 6.9)                        | –                    | yes                  |
| 2     | 2016 May 13      | 22:09                       | QF                     | –                                   | –                    | no                   |
| 3     | 2016 May 13      | 22:35                       | AF (NOAA 12544)        | 22:38 (B 5.5)                       | –                    | no                   |
| 4     | 2016 Jul 7       | 07:58                       | AF (NOAA 12561)        | 07:55 (C 5.0)                       | –                    | yes                  |
| 5     | 2016 Aug 10      | 03:13                       | IF (NOAA 12574, 12575) | –                                   | 04:00                | no                   |
| 6     | 2016 Sep 4       | 03:37                       | IF (NOAA 12586)        | –                                   | 12:48                | yes                  |
| 7     | 2016 Sep 9       | 05:44                       | IF (NOAA 12588)        | –                                   | –                    | yes                  |
| 8     | 2016 Sep 9       | 22:27                       | AF (NOAA 12588)        | 22:29 (B 4.0)                       | –                    | yes                  |
| 9     | 2016 Oct 1       | 03:06                       | QF                     | 02:23 (B 3.5)                       | 02:30                | no                   |
| 10    | 2016 Nov 4       | 04:47                       | QF                     | –                                   | 08:00                | yes                  |
| 11    | 2016 Nov 5       | 03:40                       | IF (NOAA 12605)        | 04:30 (B 1.1)                       | 04:36                | yes                  |
| 12    | 2017 Feb 19      | 05:40                       | IF (NOAA 12636)        | 05:47 (B 3.1)                       | –                    | yes                  |
| 13    | 2017 Apr 2       | 06:29                       | IF (NOAA 12644, 12647) | –                                   | –                    | no                   |
| 14    | 2017 Apr 23      | 04:52                       | AF (NOAA 12651)        | –                                   | –                    | yes                  |
| 15    | 2017 Apr 23      | 05:40                       | IF (NOAA 12652)        | 05:50 (B 1.7)                       | 06:00                | yes                  |
| 16    | 2017 Apr 24      | 02:06                       | QF                     | –                                   | 05:34                | yes                  |
| 17    | 2017 Apr 30      | 00:38                       | IF (NOAA 12653)        | 01:00 (B 3.0)                       | 02:36                | yes                  |

(a) Date the event started. (b) Time when the filament totally disappeared in Hα center observed by the SDDI. (c) Type of the filament. AF means active region filament, QF quiescent filament, and IF intermediate filament. (d) Peak time and class of the flare observed as the increase of soft X-ray flux between 1.0 and 8.0 Å by GOES around the F.D. time. (e) CME first observed time. (f) Analyzed or not analyzed due to the reasons mentioned in the section 2.

ament disappearance events by eyes, we obtained 17 events in total, shown in Table 1. Some of the data are not used because (1) clouds in the images prevent quantitative analyses, or (2) the filament was located above or very close to the solar limb. For these reasons 5 events were eventually omitted (Event 2, 3, 5, 9, 13 in Table 1). As for ”CME [UT]” column in Table 1 (the second column from the right), we determined the CME corresponding to each filament eruption by considering its first appearance time, central position angle, and the linear speed reported in SOHO/LASCO CME catalogue (Gopalswamy et al. 2009). At last, we identified 12 filament disappearance events including 2 quiescent filament, 4 active region filaments, and 6 intermediate filaments.

2.2 Analysis

We used the Beckers’ cloud model (Beckers 1964) to calculate the LOS velocity. By applying the model to the 73 images taken at multiple wavelengths around Hα, we determined the source function, the doppler width, the doppler shift, and the optical depth of a filament, assuming that the source functions is constant along the wavelengths and along the LOS direction, and that the line absorption
The coefficient is a gaussian (Morimoto & Kurokawa 2003a; Morimoto & Kurokawa 2003b; Morimoto et al. 2010; Cabezas et al. 2017; Sakaue et al. 2018; Seki et al. 2017). The LOS velocity at each pixel is then calculated from the doppler shift. The advantages of the SDDI are the wide wavelengths coverage around Hα and the high spectral and temporal resolution, which enable us to obtain the LOS velocity distribution with unprecedented detail. Figure 1 shows the images of Hα center, the red wing, the blue wings, and LOS velocity of the filament on 2016 November 5.

![Figure 1](image)

**Fig. 1.** From top to the bottom: Time series of Hα images at the line center, + 0.5 Å, - 0.5 Å, and - 1.0 Å and of the images of LOS velocity of the filament on 2017 February 19.

In the following we explain the procedure of our data analyses in more detail. It is composed of 3 steps: (1) Make a mask to extract the target filament, (2) Calculate the LOS velocity in the filament using the cloud model, and (3) Remove cloudy data.

In the step (1), we make a ”mask”, a binary image that covers the entire target filament. Since Becker’s cloud model can be applied only where there is a ”cloud” (= filament) above the top of the chromosphere, this process is necessary to determine the pixels where the LOS velocity is calculated. In this step, we first extract a time series of sub-images from the full-disk images that covers the entire filament prior and during disappearance. Then we select the pixels where the intensity $I(\lambda)$ is lower than $I_m(\lambda) - 2\sigma_f$ ($I_m(\lambda)$ is the mean intensities in a sub-image and $\sigma_f$ is the standard deviation) for each wavelength’s image. We then make one mask image for a set of 73 wavelengths images; each pixel in the mask image has a value of 1 if they satisfy $I(\lambda) < I_m(\lambda) - 2\sigma_f(\lambda)$ in at least one of the 73 wavelengths images, and zero if otherwise. The mask images thus made include spicules and other
small scale features outside the main body of the filament. In order to remove such noises, we apply a standard image processing called “erosion and dilation”. Dilation is a process that, if at least one of the surrounding pixels is 1 for a certain pixel, the pixel is set to 1, i.e. a pixel is set to 0 only if all the 8 pixels around it are 0. Erosion is the opposite process that a pixel is set to 1 only if all the surrounding 8 pixels are 1. By operating several times of dilation process after several times of erosion process (for example, erosion-erosion-erosion-dilation-dilation in order), we obtained a clean mask image covering most of the target filament. The number of the repetitions of both processes, which is determined by trial and error, is different in different events.

Once the mask images are made, we proceed to the step (2) Calculate the LOS velocity in the filament. Each image is multiplied with the mask image and the Becker’s cloud model is applied to the non-zero pixels. This yields the images of the source function, the doppler width, the doppler shift, and the optical depth in the filament at given time.

Finally we apply (1) and (2) for all the data to obtain the time series of the four physical parameters. Then we manually remove the images which fail the fitting due to clouds in the image. The Doppler shift is converted to the LOS velocity. In the following we use the LOS velocity only.

In order to quantify the small-scale plasma motions, we make histograms of each LOS velocity image. The standard deviation of the histograms can be regarded as a measure of the strength of the turbulent small-scale motion in the filament. Figure 2 shows 4 representative examples showing the standard deviation increasing with time due to the filament activation and eruption.

3 Result

3.1 Quiescent Filaments

3.1.1 Event 10

Figure 3 shows the images of the filament during Phase 2 on 2016 November 4 in Hα center and in SDO/AIA 304 (Lemen et al. 2012) and the time evolution of the average and the standard deviation of its LOS velocity. This filament is a typical large quiescent filament without any active regions around it and slowly erupted to the solar west, accompanied by a slow CME with its linear speed 147 km s$^{-1}$ in SOHO/LASCO C2/3. Around 2 days before the eruption, the standard deviation was around 2–3 km s$^{-1}$, and it slightly increased to 3–4 km s$^{-1}$ 1 day after. At the beginning of the observation on 2016 November 4, it has already been about 4 km s$^{-1}$ (Phase 1). From 01:24 UT to 02:51, the standard deviation started to increase to about 5 km s$^{-1}$ and the mean velocity became slightly minus, i.e. Phase 2 (the slow-rise phase) started (red shaded area). Finally, it disappeared around 04:47 UT (dash-dotted line). Even after the eruption, both the standard deviation and the
**Fig. 2.** Left: The histograms of the LOS velocity images. Each histogram corresponds to the right image. The mean and standard deviation of the LOS velocities are written on the upper left. Right: 4 LOS velocity images inside the black squares of Fig.1. Note that the LOS velocities on each right panel are shown with a scale of lower and upper limits of ± 50 km s$^{-1}$. 
average of the LOS velocity have some values, not zero. These values come not from plasma motions in the target filament but from the motions of other small clouds or spicules in the analyzed area. As stated in Section 2.2, our method cannot distinguish the target plasmas from other dark features in Hα center and its wings. In order to avoid the unwilling effects by high velocity components of other dark features, we checked all the LOS velocity map and removed such “noisy” data from plotting. In addition, the target filament consists of most of the analyzed pixels before its eruption. Therefore, we consider that such an unwilling effect is little to our result.

Fig. 3. Left: Hα center image and SDO/AIA 304 image showing the target filament of Event 10. The black dashed squares surrounding the filament are the area inside which we took the standard deviation of LOS velocity. Right: The standard deviation (black line, left axis) and the average (gray line, right axis) of the LOS velocity of the filament of Event 10. The bottom panel is the enlargement of the black squares in the top panel. The vertical dash-dotted line in the bottom panel is the time when the filament totally disappeared in Hα center line. Blue and red shaded areas correspond to Phase 1 and Phase 2 respectively. The horizontal dotted lines are shown at where the standard deviations are 2, 4, 6, 8, and 10 km s⁻¹ and the average is 0 km s⁻¹.

3.1.2 Event 16

This filament is also a typical large quiescent filament with no active region around it, and erupted on 2017 April 24 to the solar north-east, accompanied by a fast dynamic CME with its linear speed of 854 km s⁻¹. There was no notable geomagnetic storm within a few days after the eruption. Around 1
day before eruption, the standard deviation was 2–3 km s\(^{-1}\), and from 03:30 UT on April 23, it started to increase to about 4 km s\(^{-1}\), i.e. Phase 1 has started. Further increase of the standard deviation was observed from 23:00 UT, so was the average, and both values decreased about 30 minutes after. The increase and the decrease of both values before eruption was also observed in filament eruption event on 2016 November 5 (Seki et al. 2017). The standard deviation increased again from around 01:30 UT on April 24, and finally it totally disappeared at 02:06 UT. Phase 2 was hard to be confirmed in this event. That may be because this filament erupted in the almost perpendicular direction to the LOS direction.

![Fig. 4. Left: H\(_\alpha\) center and SDO/AIA 304 images showing the target filament of Event 16. The definitions of the black dashed squares are the same as those in Figure 3. Right: The standard deviation (black line, left axis) and the average (gray line, right axis) of the LOS velocity of the filament of Event 16. The bottom panel is the enlargement of the black squares in the top panel. The definitions of blue shaded area, the vertical black dash-dotted line, and the horizontal gray dotted lines are the same as those in Figure 3.](image-url)
3.2 Intermediate Filaments

3.2.1 Event 6

This filament was located near the active region NOAA 12586, not on it, so we classified it as an intermediate filament. This filament disappeared on 2016 September 4 both in Hα center and in SDO/AIA 304 without clear evidence of eruption, and the possible CME associated with this event was not observed in SOHO/LASCO C2/3. From around 21:00 UT on 2016 September 2, the standard deviation was about 4 km s\(^{-1}\) already. From around 00:00 UT on September 4, both the standard deviation and the average of LOS velocity started to change, and the standard deviation increased to above 4–5 km s\(^{-1}\) until the eruption, while the average velocity recovered to 0 km s\(^{-1}\). Except the difference of the sign, the profile was similar to Event 11 (Seki et al. 2017) and 16. Note that there was a data gap from 02:55 UT to 03:37 UT on 2016 September 4 because of the bad weather condition. In this event, Phase 1 was not observed.

Fig. 5. Left: Hα center and SDO/AIA 304 images of Event 6. The plage pointed by the white arrow is NOAA AR 12588. The definitions of the black dashed squares are the same as those in Figure 3. Right: The standard deviation (black line, left axis) and the average (gray line, right axis) of the LOS velocity of the filament of Event 6. The bottom panel is the enlargement of the black squares in the top panel. The definitions of red shaded area, the vertical black dash-dotted line, and the horizontal gray dotted lines are the same as those in Figure 3.
3.2.2 Event 7

This filament was located near the active region NOAA 12588, not on it. This filament also disappeared on 2016 September 9 both in H\(_\alpha\) center and in SDO/AIA 304 without a signature of eruption, and the possible CME was not observed. At the time of the disappearance, in fact no two ribbon flare was observed, but about 2.5 hours before eruption (around 03:14 UT), a B7.9 class flare was observed in NOAA AR 12588, and then the disappearance started. Therefore, this flare might affect this filament. From 03:00 UT to 03:45 UT the standard deviation of the velocity was almost constant (at 2 km s\(^{-1}\)) and so was the average. And then only the standard deviation started to increase to 3–4 km s\(^{-1}\) (Phase 1). Although the average velocity was not 0 km s\(^{-1}\) but around 2 km s\(^{-1}\), the value was almost constant from 03:45 UT to 05:10 UT, so we dared to decide this period as Phase 1. From 05:10 UT, the filament started to disappear and at 05:44 UT almost all of it disappeared.

3.2.3 Event 11

This filament was located near the active region NOAA 12605, not on it. It erupted dynamically to the solar north-east on 2016 November 5, accompanied by a moderate CME with its linear speed of 403 km s\(^{-1}\). This CME probably caused the moderate geomagnetic disturbance from 2016 November 9 to 2016 November 10. In this event, two ribbon brightening was observed in both H\(_\alpha\) center and SDO/AIA 304 on the near south of the filament location just after eruption. A B1.1 flare was observed with the peak time 04:30 UT (For more details, see Seki et al. 2017). The standard deviation was roughly 2–3 km s\(^{-1}\) until around 07:00 UT on 2016 November 4 (at the end of the previous day observation), but at 22:00 UT on 2016 November 5 it has already increased to 4–5 km s\(^{-1}\) with the average velocity of 0 km s\(^{-1}\). Therefore, we suppose that the Phase 1 started during the data gap period. It gradually increased until 02:30 UT (dashed line), and then both the standard deviation and the average velocity started to change more dramatically, i.e. Phase 2 started.

3.2.4 Event 12

This filament was located near the active region NOAA 12636. It erupted fast to the solar north on 2017 February 19, but the possible CME was not observed in SOHO/LASCO C2/3. In this event, two ribbon flare was observed near the filament location just after eruption, and a B 3.1 class flare was observed with the peak time 05:47 UT. From 04:40 UT to 05:08 UT (dashed line in Figure 8), the standard deviation gradually increased from 2–3 km s\(^{-1}\) to 4–5 km s\(^{-1}\). The mean LOS velocity was almost constant around 0 km s\(^{-1}\) during this period, and thus this increase represents Phase 1. Then, not only the standard deviation increased more sharply than before, but also the average of LOS velocity showed the gradual decrease in negative value. We believe this phase corresponds to Phase
2016-09-09 02:55UT

Fig. 6. Top: Hα center and SDO/AIA 304 images of Event 7. The plage pointed by the white arrow is NOAA AR 12588. The definition of the black dashed squares are the same as those in Figure 3. Bottom: The standard deviation (black line, left axis) and the average (gray line, right axis) of the LOS velocity of the filament of Event 7. The definitions of blue and red shaded areas, the vertical black dash-dotted line, and the horizontal gray dotted lines are the same as those in Figure 3.

2. From around 05:28 UT, both values began to change more dramatically, and finally it erupted.

3.2.5 Event 15

This filament was located near the active region NOAA 12652. It erupted fast to the solar south-east on 2017 April 23, accompanied by a fast dynamic CME with its linear speed of 955 km s⁻¹. In this event, two ribbon flare was observed near the filament location just after eruption, and a B 1.7 class
flare was observed with the peak time 05:50 UT. From 04:23 UT to 05:20 UT (red shaded area in Figure 9), the standard deviation gradually increased from 2–3 km s\(^{-1}\) to 5–6 km s\(^{-1}\). Since the mean LOS velocity was almost constant around 0 km s\(^{-1}\) during this period, this period represents Phase 1. Then, not only the standard deviation increased more sharply than before, but also the average of LOS velocity showed the gradual decrease in negative value (Phase 2). We believe the period from 05:20 UT to 05:30 UT corresponds to the slow-rise phase. From around 05:30 UT, both values began to change more dramatically, and finally it erupted.

### 3.2.6 Event 17

This filament was located near the active region NOAA 12653. It moved dynamically to the solar west and disappeared on 2017 April 30, accompanied by a slow CME with its linear speed of 282 km s\(^{-1}\). In this event, two ribbon flare was observed near the filament location just after eruption, and a B 3.0 class flare was observed with the peak time 01:00 UT. From 23:24 UT to 00:00 UT, the standard...
deviation gradually increased from 2 km s\(^{-1}\) to 4–5 km s\(^{-1}\). Since the mean LOS velocity was almost constant and not below 0 km s\(^{-1}\) during this period, it can be regarded as Phase 1. Then, not only the standard deviation increased more sharply than before, but also the average of LOS velocity showed its decrease to negative value.
3.3 Active Region Filaments

The last case is about active region filaments. We obtained 4 active region filament disappearance events. Note that generally speaking, the plasmas of active region filaments look moving very actively in Hα center. Therefore, the fluctuations of both statistical values are larger than in the previous 2 cases.

3.3.1 Event 1

This filament was located at the active region NOAA 12541. It erupted dynamically and fast to the solar west on 2016 May 4 without any CMEs. In this event, two ribbon flare was observed at the filament location just after eruption, a B 6.9 class flare was observed with the peak time 01:20 UT. The weather condition was not good before 23:45 UT. From 00:11 UT to 00:20 UT, the standard deviation started to increase from 4 km s\(^{-1}\) to 8 km s\(^{-1}\) with the average LOS velocity almost constant (Phase 1). It should be noted that unlike the temporal profile of any the previous events, both values
suddenly increased, i.e. the filament plasmas started to move toward the Sun globally. From around 01:00 UT, both values began to change again more dramatically, and finally it erupted on 01:20 UT.

3.3.2 Event 4

This filament was located at the active region NOAA 12561. This filament erupted very dynamically to the solar south-west on 2016 July 7 but no CME was accompanied. The LOS velocity of this eruption was over 130 km/s. In this event, two ribbon flare was observed on the filament location during the eruption, and a C 5.0 class flare was observed with the peak time 07:58 UT. It should be noted that this filament became invisible in H\alpha from about 02:00 UT to 07:40 (the data gap in upper right panel) and it appeared again at 07:40. There was no Phase 1 detected probably because the plasmas in active region filaments move more dynamically than ones in quiescent filaments, which
makes it hardly possible to recognize slight gradual change of the standard deviation of the velocity. From 07:47 UT to 07:52 UT the filament showed the slow-rise phase (the red shaded period) as the standard deviation started increasing from around 6 km s\(^{-1}\) to 8–10 km s\(^{-1}\) and the average became minus. From 07:52 UT, both values began to change more dramatically, and finally it erupted.

3.3.3 Event 8
This filament was located at the active region NOAA 12588. It erupted very dynamically to the solar north-east on 2016 September 9 without any CMEs. In this event, two ribbon flare was observed on the filament location just after eruption, and a B 4.0 class flare was observed with the peak time 22:29 UT. On the previous day of the eruption, the standard deviation was fluctuated dynamically from around 4 to 8 km s\(^{-1}\), and at the beginning of the next day observation it has already been high.
Fig. 12. **Left**: Hα center and SDO/AIA 304 images showing the filament on NOAA AR 12561 (Event 4). The white arrow points at the target active region filament, and the black square surrounding the filament is the area we analyzed. **Right**: The standard deviation (black line, left axis) and the average (gray line, right axis) of the LOS velocity of the filament of the Event 4. The bottom panel is the enlargement of the black squares in the top panel. The definitions of blue shaded area, the horizontal dotted lines, and the vertical dashed and dash-dotted lines are the same as those in Figure 3.

value (17 km s\(^{-1}\)). The average was almost 0 km s\(^{-1}\) until 22:06 UT, which means that Phase 1 lasted for less than 14 hours.

### 3.3.4 Event 14

This filament was located at the active region NOAA 12651 and disappeared on 2017 April 23, not accompanied by any CMEs. In this event, a B 3.8 class flare was observed at NOAA AR 12651 about 1.8 hours before disappearance with the peak time 03:06 UT. Soon after that the filament started disappearing, and the dynamic changes of both the standard deviation and the average velocity began. The filament disappearance itself was not accompanied by a two ribbon flare.
4 Summary & Discussion

In this study, we analyzed 12 filament disappearance events observed by the SDDI in Hida Observatory during 2016 May to 2017 May in the same way as Seki et al. 2017 with the purpose of clarifying whether the precursor of the filament eruption suggested in Seki et al. 2017 is a common feature prior to filament eruptions. We calculated the unprecedented detailed LOS velocities of the plasmas inside each filament by applying cloud model to the multi-wavelengths data around Hα line obtained by the SDDI and tracked the average and the standard deviation of the LOS velocity of each filament. In Table 2, the summary of our result is shown.

In all the 12 events, the increase of the standard deviation of the LOS velocity was observed prior to filament disappearance regardless of the types of filaments and their associations with CMEs. From Table 2, we can recognize that there are wide variations in the durations of Phase 1 and Phase 2. The duration of Phase 1 can be from 0.15 to 42 hours. If we focus only on the events for which
the duration of the Phase 1 was determined reliably, there may be a relation between surrounding magnetic field strengths (i.e., types of the filaments) and the durations. To make it clear, further investigation like Alfvén time normalization is necessary. As for Phase 2, the range of the duration is more limited between 0.17 to 3.5 hours, and the relation between the types of the filaments and the durations can hardly be seen.

During Phase 1 of intermediate and quiescent filament, the standard deviation increased from 2–3 km s$^{-1}$ to 4–5 km s$^{-1}$ regardless of types and durations in all the detected events (Event 7, 10, 11, 12, 15, 16, 17). Active region filaments took higher values than 4 km s$^{-1}$ even before Phase 1.

In addition, in some of the events (Event 6, 11, 16) there are the periods during which both the standard deviation and the average of the LOS velocity changed and returned to the previous
value with the time scale of about 1 hour (from 00:00 UT to 01:00 UT during Event 6, from 00:30 UT to 01:30 UT during Event 11, and from 23:00 UT to 00:00 UT during Event 16). These short events found in the mean doppler velocity and the standard deviation prior to the eruption may reflect the intermittent events such as emerging flux and magnetic reconnection that contribute the global evolution of the magnetic flux system.

From the space weather point of view, filament eruptions have a potential risk to disturb the space weather. McAllister et al. 1996 reported the event of a polar crown filament, which erupted on 1994 April 14. This eruption showed a giant coronal arcade in the soft X-ray image, and finally a huge geomagnetic storm (Dst = ~ -200 nT) occurred 3 days after the eruption. Considering the result, we conclude that it is possible to use the average and the standard deviation of LOS velocity map to know the precursor of filament eruptions for the operational prediction. It is obvious that even in the events not accompanied by CMEs both the statistical values changed, but we can distinguish the reason of the increase by checking the Hα image and LOS velocity map simultaneously. For the actual operation, it is necessary to build not only the Hα center observation network like the Global Oscillation Network Group (Harvey et al. 2011) and the Global Hα Network (Steindegger et al. 2000) but also the red and blue wings observation network like the Continuous Hα Imaging Network (Ueno et al. 2007; Seki et al. 2018). In addition, it should be emphasized that this method is currently based only on the data taken by ground-based telescopes. Although the space-borne data are indispensable for the space weather prediction, it is also true that the artificial satellites are vulnerable to the space weather effect.
(National Research Council 2008). Also in this reason, the prediction of the filament eruption based on our method can be highly valuable for supporting the current space weather prediction system.

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