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Homologous prominence non-radial eruptions: A case study

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HIGHLIGHTS

- A sequence of four homologous prominence eruptions of confined type is analysed.
- Homologous behaviour during the pre-eruptive phase is found in 17 GHz radio data.
- A new (fourth) criterion for homology is defined.
- Maximum height increase of each consecutive eruption-an important homology feature.

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ABSTRACT

The present study provides important details on homologous eruptions of a solar prominence that occurred in active region NOAA 10904 on 2006 August 22. We report on the pre-eruptive phase of the homologous feature as well as the kinematics and the morphology of a forth from a series of prominence eruptions that is critical in defining the nature of the previous consecutive eruptions. The evolution of the overlying coronal field during homologous eruptions is discussed and a new observational criterion for homologous eruptions is provided. We find a distinctive sequence of three activation periods each of them containing pre-eruptive precursors such as a brightening and enlarging of the prominence body followed by small surge-like ejections from its southern end observed in the radio 17 GHz. We analyse a fourth eruption that clearly indicates a full reformation of the prominence after the third eruption. The fourth eruption although occurring 11 h later has an identical morphology, the same angle of propagation with respect to the radial direction, as well as similar kinematic evolution as the previous three eruptions. We find an important feature of the homologous eruptive prominence sequence that is the maximum height increase of each consecutive eruption. The present analysis establishes that all four eruptions observed in Hα are of confined type with the third eruption undergoing a thermal disappearance during its eruptive phase. We suggest that the observation of the same direction of the magnetic flux rope (MFR) ejections can be consider as an additional observational criterion for MFR homology. This observational indication for homologous eruptions is important, especially in the case of events of typical or poorly distinguishable morphology of eruptive solar phenomena.

1. Introduction

The relationship between eruptive prominences (EPs) and other eruptive solar phenomena such as CMEs and flares (e.g. St. Cyr and Webb, 1991; Subramanian and Dere, 2001; Schrijver et al., 2008; Chandra et al., 2010) suggests that the three eruptive events often occur in the same large-scale coronal magnetic field configuration (e.g. Forbes, 2000) in which the EP occupies a limited volume at its base. It is commonly accepted that solar prominence (filament) eruptions frequently accompany coronal mass ejections (CMEs). Thus, studying the pre-eruption phase, origin and evolution of EPs gives additional information relevant to CMEs' launch and propagation.

The observations and studies of early stages of prominence eruptions, i.e. prominence pre-eruptive activation, are crucial for the understanding of the signatures and pre-cursors of forthcoming solar eruptions. The observations of prominence motions before and near the eruption onset can provide information for the coronal magnetic field evolution during the pre-eruptive stages (e.g. Sterling et al., 2012). Multi-wavelength studies of the precursor signatures for eruptions, such as pre-eruptive brightenings in microwave, extreme ultraviolet (EUV), and X-ray emission changes are necessary to reveal the processes involved in the prominence destabilisation. In particular, microwave observations can show the full temporal and spatial prominence (filament)

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evolution, from early pre-eruptive stages to the end of eruption (e.g. Grechnev et al., 2006). Moreover, brightness temperature enhancements in microwave observations at 17 GHz and 34 GHz are a clear signature of heating in prominences (e.g. Hanaoka and Shinkawa, 1999; Hori et al., 2000; Chifor et al., 2006; Gopalswamy and Yashiro, 2013).

Among the wide variety of solar eruptions there is a specific type of so-called “sympathetic” eruptions. Sympathetic solar eruptions are defined as consecutive eruptions that occur within a relatively short time interval either in one complex active region (AR) (e.g. Liu et al., 2009a) or in different active regions located at large distances from each other (e.g. Zhukov and Veselovsky, 2007).

In addition to sympathetic eruptive events, there also exist the so-called “homologous” eruptions. This term was first introduced by Waldmeier (1938) and Woodgate et al. (1984) for solar flares, and by Zhang and Wang (2002) for coronal mass ejections. The authors define flare-CME events as “homologous” when they have the same surface source, an identical shape and location (in the coronagraph field of view), and are associated with homologous X-ray or EUV activities. Recently, in terms of magnetic flux ropes, the homologous definition was also applied to all three eruptive events, CMEs, flares, and EPs (Li and Zhang, 2013). It includes three criteria: the homologous flux ropes must originate from the same region within the same AR, the endpoints of the homologous flux ropes have to be anchored in the same location and the morphologies of the homologous flux ropes have to resemble each other.

Solar surges are other eruptive phenomena that exhibit homologous behaviour (e.g. Wang and Liu, 2012). They represent collimated plasma ejections along straight or slightly curved trajectories (Roy, 1973). They have typical peak velocities of 100–300 km s^{-1} and maximum heights of 10–200 Mm (Sterling, 2000). Their lifetime is in the range of 10–20 min (Roy, 1973; Jiang et al., 2007) and they can reoccur during an hour or more (Schmieder et al., 1984; 1995). Their origin and evolution are mostly associated with magnetic flux emergence and cancellation, as well as with flaring active regions. Surges often appear twisted and spiralled (e.g. Shibata et al., 1992; Schmieder et al., 1994; Chae et al., 1999; Liu and Kurokawa, 2004; Jiang et al., 2007; Uddin et al., 2012, for reviews).

There are different approaches to modelling solar eruptions, ranging from 2D analytical models to 3D numerical simulations (Forbes, 2000; MacTaggart and Hood, 2009, for reviews). Some of them use a breakout model (e.g. Antiochos et al., 1999; DeVore and Antiochos, 2008) to produce homologous eruptions.

In a recent study by Duchlev et al. (2014, hereafter Paper I) three homologous prominence eruptions that occurred on 2006 August 22 in AR NOAA 10904 were examined. The consecutive eruptions were observed at the solar limb between 04:48 UT and 07:32 UT with the Hα coronagraph at the National Astronomical Observatory Rozhen (NAO-Rozhen) taken with a 1.8 Å Hα filter. The successive eruptions were associated with the same fragment from the AR filament. The kinematic patterns and evolutions of the first two eruptions classified them as confined. The third eruption, linked to a narrow CME and a type III radio burst at 164 MHz, was not fully understood because of the early prominence disappearance in Hα. The similar coronagraphic appearance of the eruptions and their non-radial propagations at approximately the same angle of $\approx 50^{\circ}$ to the radial direction strongly suggests that the filament fragment underwent a triple homologous eruption.

The present research provides important findings on the pre-eruptive activity of homologous events by studying in great detail the pre-eruptive prominence activation in radio images taken at frequency of 17 GHz (10″ resolution and 10 min cadence) of the Nobeyama Radioheliograph (NoRH). We report a detailed study on a fourth consecutive homologous eruption that occurs 11 h later using Hα images (2.9″ resolution and 3 min cadence) obtained by the Polarimeter for Inner Coronal Studies (PICS) instrument at the Mauna Loa Solar Observatory (MLSO), Hawaii. The rest of the data related to this event are given in Paper I. The new additional analysis given here is crucial for the full understanding of the evolution of the homologous sequence of four prominence eruptions and the formulation of an observational evidence for the definition of a solar eruption as homologous. We also provide important information on the evolution of the overlying coronal field during the homologous eruptions. The results are given in Section 2, the pre-eruptive phase is reported in Section 2.1 and the forth prominence eruption is described in Section 2.2. The discussion and conclusions are presented in Section 3.

2. Results

2.1. Pre-activation phase

EPs, flares or CMEs often show pre-eruptive thermal or non-thermal signatures. Thermal signatures typically appear as a weak increase in the soft X-ray (SXR) light curve, while non-thermal are usually observed at radio wavelengths (Gopalswamy et al., 2006).

The sequence of prominence eruptions reported here was preceded by a distinctive pre-eruptive prominence activation that was observed in the NoRH radio data taken at a frequency of 17 GHz. These observations cover the quiet and pre-eruptive phases of the EP, the first, and part of the second eruptions (Fig. 1). We established a sequence of three activation periods each of them containing pre-eruptive precursors such as a brightening and enlarging of the prominence body followed by small surge-like ejections.

Until 00:00 UT on August 22, the prominence was in a relatively quiet phase. After this time the prominence body started changing its size, shape, and morphology, i.e. the first activation period began. The prominence body initially enlarged by stretching along the limb, which is most probably due to a heating of the prominence plasma (e.g. Hanaoka and Shinkawa, 1999). This led subsequently to the increase of the brightness temperature Tb shown in Fig. 2. The increased Tb can be explained by a combination of optically thick emission from the cool prominence core and an optically thin emission from the heated prominence-corona transition region above $\sim 10^4$ K (Gopalswamy and Yashiro, 2013). The dynamic evolution of the body shape and morphology can be followed in the online material (Fig. A.7). These changes suggest a heating and a turbulence increase, which have led to the prominence fragmentation. Between approximately 00:00 UT and 01:40 UT, in addition to the aforementioned pre-eruptive events, at the southern end of the prominence body a small surge-like ejection appeared at 00:50 UT (Fig. 1) that lasted until 01:10 UT (see the online material).

The described sequence of pre-eruptive events is repeated again between 01:40 UT and 03:00 UT (second activation period) and later between 03:00 UT and 04:20 UT (third activation period). Each period is characterised by small surge-like ejections that occurred in the same place of the prominence body (Fig. 1), where later all four prominence eruptions were observed (Fig. 3). Moreover, they are associated with peaks in the radio flux at 17 GHz marked with dotted lines in Fig. 2.

Each of these three pre-eruptive events was linked to weak narrow CMEs according to the LASCO CME catalogue (Fig. 4a). Weak three B-class SXR flares with a source AR 10904 (Fig. 4b) and three consecutive type III bursts (WIND/WAVES, Fig. 4c) were also recorded. The association of a prominence/filament pre-eruptive activity with slow and narrow CMEs, and weak SXR flares is typical for ARs with β magnetic field configuration (Yan et al., 2011) which is also the case for AR 10904 (see Paper I).