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An application of the weighted horizontal magnetic gradient to solar compact and eruptive events

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Abstract

We propose to apply the weighted horizontal magnetic gradient (WG_M), introduced in Korsós *et al.* (2015), for analysing the pre-flare and pre-CME behaviour and evolution of Active Regions (ARs) using the SDO/HMI-Debrecen Data catalogue. To demonstrate the power of investigative capabilities of the WG_M method, in terms of flare and CME eruptions, we studied two typical ARs, namely, AR 12158 and AR 12192. The choice of ARs represent canonical cases. AR 12158 produced an X1.6 flare with fast "halo" CME (v_{linear}=1267 kms^{-1}) while in AR 12192 there occurred a range of powerful X-class eruptions, i.e. X1.1, X1.6, X3.1, X1.0, X2.0 and X2.0-class energetic flares, interestingly, none with an accompanying CME. The value itself and temporal variation of WG_M is found to possess potentially important diagnostic information about the intensity of the expected flare class. Furthermore, we have also estimated the flare onset time from the relationship of duration of converging and diverging motions of the area-weighted barycenters of two subgroups of opposite magnetic polarities. This test turns out not only to provide information about the intensity of the expected flare-class and the flare onset time but may also indicate whether a flare will occur with/without fast CME. We have also found that, in the case when the negative polarity barycenter has moved around and the positive one "remained" at the same coordinates preceding eruption, the flare occurred with fast "halo" CME. Otherwise, when both the negative and the positive polarity barycenters have moved around, the AR produced flares without CME. If these properties found for the movement of the barycenters are generic pre-cursors of CME eruption (or lack of it), identifying them may serve as an excellent pre-condition for refining the forecast of the lift-off of CMEs.

1. Introduction

There are many kinds of eruptions on the Sun and from these the solar flares and coronal mass ejections (CMEs) are the most gigantic energy explosions. These two major eruptions are powered by the free energy stored in the stressed magnetic fields in active regions (ARs). Sunspots appear as dark spots compared to surrounding regions on the photosphere and are considered as good markers of ARs. The concentration of magnetic field fluxes of AR, often modelled as flux tubes, reduce the temperature in the photosphere by inhibiting convection. Strongly twisted magnetic flux tubes and strongly sheared magnetic structures are candidates for facilitating the high intensity flares and flux rope eruption from AR. A number of specific mechanisms are proposed to lead to flare and CME occurrences, e.g. sunspot rotation (Yan & Qu, 2007; Zhang *et al.*, 2007; Yan *et al.*, 2009; Chandra *et al.*, 2011; Hardersen *et al.*, 2011; Vemareddy *et al.*, 2016) and shearing motion of the sunspots at photosphere (Vemareddy *et al.*, 2012) which contribute to helicity and accumulation of magnetic energy of an AR (Török & Kliem, 2003; Démoulin, 2007; Démoulin & Pariat, 2009). The magnetically complicated and highly dynamic delta-type sunspot groups are more likely for flare and CME genesis than bipolar ARs, see e.g. Künzel (1960), Sammis & Zirin (2000). It is now also well known that solar flares and CMEs occur close to the polarity inversion line (PIL) (Louis *et al.*, 2015). The PIL can be defined as the boundary separating positive and negative magnetic polarities (Babcock & Babcock, 1955).

Flare and CME often accompany each other, but not always. Yashiro (2006) found that the probability of a low energetic flare with CME occurrence is much smaller than an intensive flare being associated with a large CME. If these two phenomena do occur together then the pre-, rise- or decay-phase of a flare is temporally associate with the initial-, impulsive acceleration- or propagation-phase of a CME (Zhang *et al.*, 2001).

A main difference between solar flare and CME is the scale on which they occur. A flare is small and more local compared to a CME. Flares occur mainly in the low solar atmosphere where magnetic field lines of an AR are concentrated. CME is, however, an absolutely massive eruption that may occur on very large scales. A CME, in terms of its developed size, can even be bigger than