Observational Studies on Magnetic Helicity Injected by Self and Mutual Sunspot Rotations

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Solar flares and coronal mass ejections (CMEs) are explosive phenomena in the solar corona and responsible for geo-magnetic events on the earth. Excessive energy (called free energy) is stored in complex magnetic field and released through a flare. When, where and how free energy is stored and released is one of the most important issues for the research of space weather. Moreover, the trigger process of solar flares is also a relevant open question.

In the present, it is argued that magnetic helicity, which quantifies the complexity of the coronal magnetic field and can be estimated from observations, is useful to evaluate the energy state of the solar corona. Over-accumulation of magnetic helicity is thought to be a factor leading to CMEs. Furthermore, recent studies suggest that the annihilation of positive and negative magnetic helicity can trigger large flares. Therefore, observations of accumulation and spatial distribution of photospheric magnetic helicity injection are important for the space weather prediction.

In this work, we study the evolution of the magnetic field and magnetic helicity in a flare-productive active region named NOAA 12297. It is confirmed that 10 M-class flares and 1 X-class flare are produced in this region from 12UT on 2015 March 10th to 12UT on 13th. NOAA 12297 had 2 regions which showed different patterns of flare occurrences. In the eastern region (named Region 1 in this work) produced 2 M-class flares and 1 X-class flare. Whereas, the western region (named Region 2) produced 7 M-class flares.

We estimate the magnetic helicity injection and its spatial distribution in the active region with data obtained by the Helioseismic Magnetic Imager on board the Solar Dynamics Observatory. We also evaluate contributions of self-rotation of a sunspot and mutual rotation between a sunspot and emerging fluxes with spinning and braiding helicity injection. Furthermore, we perform NLFFF extrapolation using the magnetic field data obtained by Solar Optical Telescope/Spectro-Polarimeter on board Hinode, and discuss the topology of the 3-dimensional magnetic field.

Region 1 and 2 had a similar configuration; emerging fluxes moving counter-clockwise to a sunspot. We find that, although positive magnetic helicity was mainly accumulated monotonically in NOAA 12297 on the whole, the increase stopped before the X-class flare occurred. This was due to negative helicity injection in a sunspot which started soon after flux emergence in Region 1. Moreover, negative spinning helicity injection in the sunspot was larger than braiding helicity injection. Meanwhile, generally positive magnetic helicity was injected in Region 2. The most significant feature in Region 2 was fluctuating time profile of braiding helicity injection.

We consider that the negative spinning helicity injection was due to the reversal of the sunspot's rotation in Region 1, and this reversed rotation was forced by flux emergence. This argument is consistent with the flare model of helicity annihilation that the X-class flare occurred after opposite helicity injection. On the other hand, oscillating braiding helicity injection in Region 2 implies a recurrent energy input. This is also consistent with the fact that Region 2 produced M-class flares successively. Our results show that behaviors of magnetic helicity injection can determine behaviors of flare occurrences, and magnetic helicity injection is one of useful probes for the space weather forecasting.

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