Electric-Current Neutralization and Eruptive Activity

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Abstract

The physical conditions that determine the eruptive activity of solar active regions (ARs) are still not well understood. Various proxies for predicting eruptive activity have been suggested, with relatively limited success. Moreover, it is presently unclear under which conditions an eruption will remain confined to the low corona or produce a coronal mass ejection (CME).

Using vector magnetogram data from SDO/HMI, we investigate the association between the degree of electric-current neutralization and eruptive activity for a sample of ARs. We find that the majority of CME-producing ARs are characterized by a strong net current, while the total current in ARs that do not produce CMEs is well neutralized, even if those ARs produce strong (X-class) confined flares. This suggests that the degree of current neutralization can serve as a good proxy for assessing the ability of ARs to produce CMEs.
In (well-isolated) active regions (ARs), the currents are always balanced, i.e., all currents that flow into an AR \( (j_z>0) \) flow also out of it \( (j_z<0) \). However, there has been a long-lasting debate on whether or not AR-currents are neutralized \( (\text{Parker } 1996; \text{Melrose } 1996) \), which requires that the sum of all in and out-flowing currents is zero also within each AR polarity. Recent numerical studies \( (\text{e.g., Török & Kliem } 2003; \text{Török et al. } 2014; \text{Dalmasse et al. } 2015) \) suggest that current-neutralization breaks down if significant shear has developed at the neutral line of an AR.

In an isolated magnetic flux rope (as in the convection zone), electric currents are neutralized: the central \textbf{direct current (DC)} is surrounded by an oppositely directed \textbf{return current (RC)} of same strength \( (|\text{DC}/\text{RC}|=1; \text{top left image}) \). Non-isolated flux ropes (as in the corona), however, can, under certain conditions, carry a substantial \textbf{net current} \( (|\text{DC}/\text{RC}|>1; \text{top right image}) \).

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Our hypothesis: Since strong net currents indicate the presence of flux ropes, they may serve as a proxy for the capability of an AR to produce a CME.

Our approach: Measure |DC/RC| for a sample of ARs and compare with eruptive activity of AR. |DC/RC| is evaluated in closed-flux-area above eruptive neutral line.
Pilot study with four cases (Liu Y. et al. 2017)

| AR       | $\langle |DC/RC| \rangle$ | $\langle \Phi \rangle$ | $J$-pattern | Flares | CMEs |
|----------|-----------------|-----------------|-------------|--------|------|
| AR 11072 | 0.98 ± 0.01     | 25°1 ± 6°4      | No          | No     | No   |
| AR 12192 | 1.06 ± 0.01     | 41°2 ± 11°3     | No          | Yes    | No   |
| AR 11429 | 2.17 ± 0.01     | 67°4 ± 8°5      | Yes         | Yes    | Yes  |
| AR 11158 | 2.54 ± 0.02     | 63°6 ± 6°9      | Yes         | Yes    | Yes  |

<\Phi>: average shear angle along PIL; $J$-pattern: elongated current around neutral line
(1) CME-producing ARs exhibit a strong, double-J-shaped net current along their neutral line, whereas ARs that are quiet or produce only confined flares do not have such a feature and are almost perfectly current-neutralized.

(2) The differences in neutral-line shear are less pronounced, suggesting that $|DC/RC|$ may serve as a better proxy for an ARs capability to produce CMEs (i.e., eruptive flares) than the shear along the neutral line.

(3) In ARs with a strong net current, we found no indications for a localized return current surrounding the direct current, as it is the case in isolated magnetic flux ropes. Rather, return currents appear only as small, fibril-like patches, which cancel out with similar patches of direct current.
We are currently investigating a larger sample of flare-producing ARs (see table above). The preliminary results support main conclusions by Liu et al. 2017:

(1) ARs that produce CMEs have strong net currents (|DC/RC| ≥ 1.6), regardless of the strength of the associated flare. (ARs 11562 and 11944 have to be re-evaluated: the wrong neutral line was used for the current-integration in these cases).

(2) ARs that produce X-class flares but no CMEs are well neutralized (|DC/RC| ≤ 1.3)
References


