# RELATING 27-DAY AVERAGES OF SOLAR, INTERPLANETARY MEDIUM PARAMETERS, AND GEOMAGNETIC ACTIVITY PROXIES IN SOLAR CYCLE 24

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## Abstract

We analyzed correlations between solar, interplanetary-medium parameters, and geomagnetic-activity proxies in 27-day averages (a Bartels rotation) for the 2009–2016 time interval. We considered two new proxies:
i) $B_{zs}$ GSM (Geocentric Solar Magnetic), calculated as the daily percentage of the IMF southward component along the GSM z-axis and then averaged every 27 days;
ii) four magnetospheric indices (T-indices), calculated from the local north–south (X) contributions of the magnetosphere's cross-tail (TAIL), the symmetric ring current (SRC), the partial ring current (PRC), and the Birkeland current (FAC), derived from the Tsyganenko and Sitnov (*J. Geophys. Res.* **110**, A03208, 2005: TS05) semi-empirical magnetospheric model.
Our results suggest, among the parameters tested here, solar facular areas, interplanetary-magnetic field intensity and new proxies derived here could be taken into account in an empirical model, with a 27-day resolution, to explain geomagnetic activity felt on the Earth's surface in terms of solar surface features and the IMF condition.
We further retrieve a clear annual oscillation in series of 27-day-mean values of toward/away asymmetries of geomagnetic-activity indices, which can be interpreted in the light of the Russell–McPherron hypothesis for the semiannual variation of geomagnetic activity (Russell, C. T., and R. L. McPherron (1973), *J. Geophys. Res.*, **78**, 92–108).

## Overview

Our main goal is to identify those solar, interplanetary medium, and geomagnetic-activity parameters that show the strongest statistical relations, and to sort out the best candidates to relate meaningfully solar activity to geomagnetic disturbances felt on Earth's surface.

We use the Sun's northern and southern facular areas (FA-N and FA-S), total and southward components of the interplanetary magnetic field ([B] and $B_z$, respectively), and Newell's coupling function (NLL), and we test two new types of parameters.

The first new parameter is the daily percentage of the southward component of the interplanetary magnetic field (IMF) in the Geocentric Solar Magnetospheric (GSM) coordinate system, which we call $B_{zs}$, computed from hourly values of IMF $B_z$ in the GSM system. For day j:

$$B^j_{zs} = \frac{100\, n^j}{24} \qquad (1)$$

where $n^j$ is the number of IMF $B_z$ GSM negative (southward) hourly means on day j. Then we averaged the daily $B_{zs}$ over a 27-days period.

Another group of new proposed parameters consists in indices derived from simulations, using the TS05 magnetospheric semi-empirical model of the geomagnetic-field variations near the ground at middle latitudes, which we call T-indices. They were calculated using the X component of separate contributions from magnetospheric currents on the Earth's surface, from TS05 model simulations. Namely, the X component of the tail current sheet (T-TAIL), the symmetric ring current (T-SRC), the partial ring current (T-PRC), and the field aligned currents (T-FAC).

All parameters analyzed here were averaged over the Bartels period of solar rotation (27-days), in order to filter out the recurrence tendency of geomagnetic activity associated with the distinct influence of different solar sectors. Temporal averaging over the Bartels rotation period allows us to estimate the mean influence that the Sun may have on the Earth, taking into account the effect of all solar longitudes.

We consider the effect of solar hemispherical asymmetries of sunspot numbers using data from SILSO (Royal Observatory of Belgium, Brussels) and of the facular areas computed from spectroheliograms of the Geophysical and Astronomical Observatory of the University of Coimbra (OGAUC). The "toward–away" asymmetries (with respect to IMF polarity) of the 33 parameters were computed as follows. For each parameter, we split values into two groups and calculate separate averages for days when the IMF is directed toward the Sun (T), and days when the IMF is directed away from the Sun (W), and computed the two values:

$$\overline{T} = \frac{1}{n}\sum_{i=1}^{n} T^i \qquad \overline{W} = \frac{1}{m}\sum_{i=1}^{m} W^i \qquad (2)$$

where $\overline{T}$ and $\overline{W}$ are mean values of a certain parameter over a Bartels rotation period, counting only "toward" days in the former case (in a total of $n$) and only "away" days in the later (in a total of $m$). Then, for each parameter, we obtained the asymmetry $A$ over each Bartels period as the difference between the corresponding "toward" and "away" means:

$$A = \overline{T} - \overline{W} \qquad (3)$$

**THE SOLAR FACULAR AREAS, THE INTERPLANETARY-MAGNETIC FIELD INTENSITY AND THE NEW PROXIES DERIVED HERE, IN A 27-DAY RESOLUTION, CAN BE USED TO EXPLAIN GEOMAGNETIC ACTIVITY FELT ON THE EARTH'S SURFACE**

**WE RETRIEVE A CLEAR ANNUAL OSCILLATION IN THE SERIES OF 27-DAY-MEAN VALUES OF TOWARD/AWAY ASYMMETRIES OF THE GEOMAGNETIC-ACTIVITY INDICES AND THE TWO NEW PROXIES**

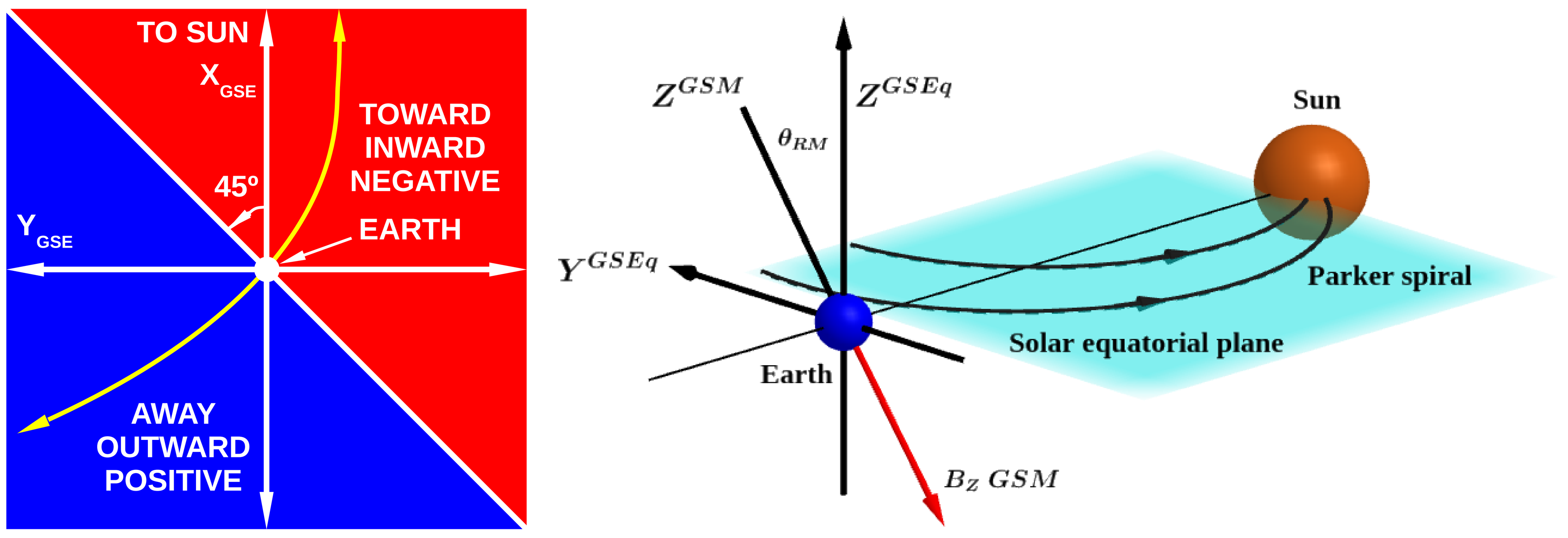


Figure 1: Left: Definition of the way and toward polarities seen from the Earth. Angles in [45º, 225º] mean the away (outward) or positive polarity. Other angles mean the toward (inward) or negative polarity. Yellow arrows represent the IMF's trajectory and direction in the azimuthal Geocentric Solar Equatorial (GSEq) reference frame (Sabbah, 1995, *Earth Moon and Planets*, **70**,173–178). Right: The angle $\theta_{RM}$ between the Z GSM and Z GSEq coordinate systems during the March equinox, with IMF toward the Sun. The $B_z$ GSM southward (red vector) increases due to the contribution of the negative $B_y$ GSEq (Figure adapted from Poblet, Facundo L., Azpilicueta, Francisco, Lam, Hing-Lan, 2020, *Annales Geophysicae*, **5**, 38, 953–968.

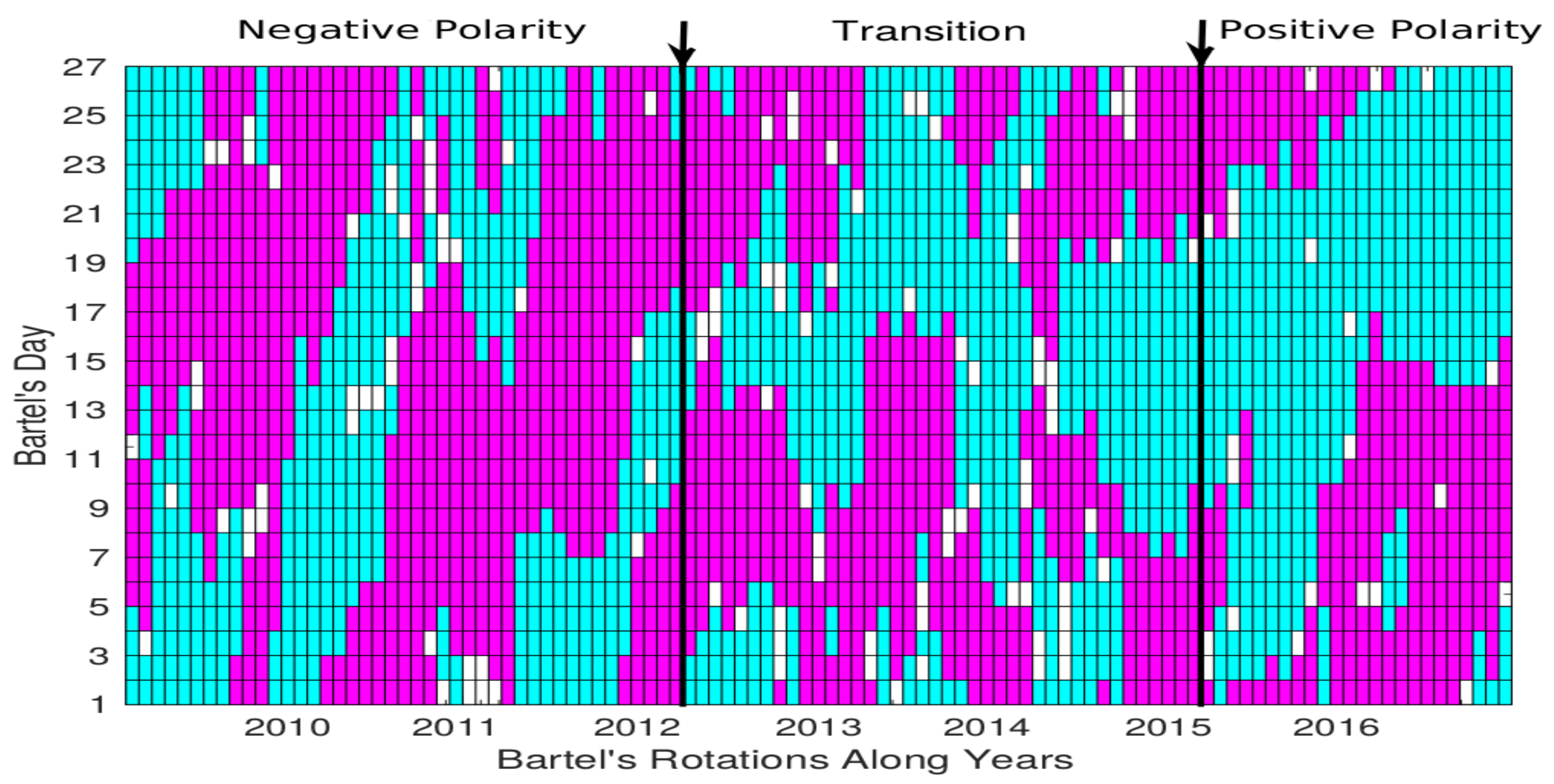


Figure 2: Days with the toward/negative polarity (magenta) and away/positive polarity (cyan) IMF. White days means missing data or polarity that could not be determined. Each column is a solar rotation (27 days) in the period 2009–2016. The solar magnetic field has negative polarity in 2009–2012 and has positive polarity in 2015–2016. The interval 2012–2015 is a transition period.

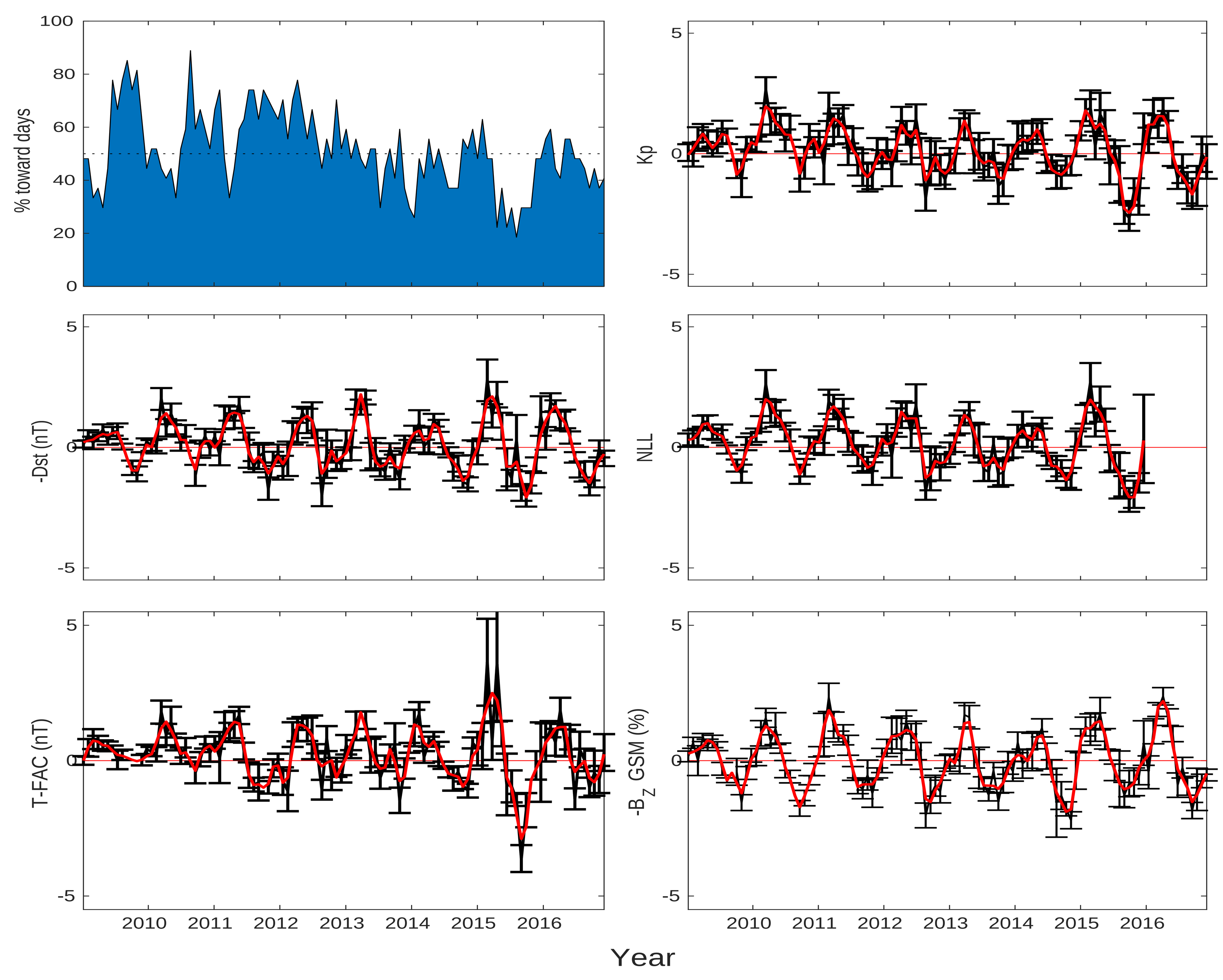


Figure 3: Top-left: Percentage of days with toward IMF during each Bartels rotation for the whole 2009–2016 period. Top-right: Time series of the asymmetry $A$ for the Kp-index. From top to bottom, left to right: time series of $A$ for $-$Dst, the coupling function NLL, T-FAC, and $-B_z$ GSM, with corresponding error bars.

## Conclusion

- Hemispheric facular areas computed as averages over 27-day periods show better correlations with solar-wind parameters (in particular with total IMF field [B]) and with geomagnetic-activity indices (in particular with Kp) than with other solar parameters such as the hemispheric sunspot numbers or the solar radio flux $F_{10.7}$ cm. Furthermore, they evolve in a more continuous way along the solar cycle than sunspots, never getting to zero.
- T-SRC and T-PRC indices are new parameters defined here to represent the dynamics of the ring current. Newell's coupling function computed from solar-wind and IMF parameters, and the planetary index Kp, both show significant correlations with a large number of other proxies. Nonetheless, their correlation with solar-surface parameters is lower than for the newly defined magnetospheric-activity proxies T-SRC and T-PRC.
- The $B_{zs}$ GSM index defined in this study, seems to be a better choice than $B_z$ GSM to characterize magnetospheric activity at the 27-day temporal resolution, since it shows higher correlations with all geomagnetic activity indices (GAI).
- The total field [B] averaged over 27 days is the solar-wind parameter that correlates the best with solar-surface parameters, in particular with facular areas.
- The annual oscillation found in series of toward/away asymmetry for the GAI parameters, NLL, and both $B_z$ GSM and $B_{zs}$ GSM parameters seems to support the assumption that the Russell–McPherron mechanism is the main mechanism explaining semi-annual variation of the geomagnetic activity.
- Further support for the hypothesis of the R–M mechanism is the variation of the amplitude of the toward/away asymmetry with the solar-magnetic field polarity, which can be also retrieved from our results. Our results suggest that, for the analyzed 2009–2016 period that covers the two different solar polarities, the solar positive polarity leads to more intense geomagnetic activity during the September equinox and the negative polarity leads to more intense geomagnetic activity during the March equinox.

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## Paper

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