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Geomagnetic storms forecasting from solar coronal holes

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Coronal holes (CHs) are the source of high-speed solar wind streams (HSSs), which interact with the slow solar wind and form corotating interaction regions (CIRs) in the heliosphere. These high-speed streams and their associated structures influence the geomagnetic activity, causing recurrent geomagnetic storms. The propagation time of solar wind from Sun to Earth is about 1–5 days, creating a natural lead-time for early warning. However, the magnetic structure of an interplanetary perturbation, in particular the southward component Bz of the interplanetary magnetic field (IMF), driving the storm, cannot be determined from solar observations yet, which strongly limits the possibility of storm forecast several days in advance. Current approaches to quantitative storm predictions are often limited to a short-term forecast based on measurements of IMF and solar wind at the Lagrange point L1, which is possible due to the 1-hour difference in the propagation time from L1 to Earth between the radio signal and solar wind.

In this study, we focus on predictions of CIR-driven geomagnetic storms from solar observations with the aim of increasing the warning lead-time from hours to days. We develop a prediction technique of geomagnetic storms using coronal holes at the Sun as well as corresponding solar magnetic field data (cf. Vrsnak et al. 2007). The method is based on establishing empirical relations between the time-series of coronal hole areas on the Sun derived from SDO/AIA images and the solar wind speed at L1; between remote-sensing magnetic field maps of the solar photosphere and that measured in-situ at L1, and finally between coronal hole areas, corresponding magnetic field at Sun and geomagnetic Dst and Kp indices. We demonstrate that the inward/outward direction of the magnetic field originating from the base of a coronal hole is preserved in more than 80% of cases when compared to the related magnetic field measured at Earth. This opens the possibility to use the magnetic field derived from solar observations instead of that at L1. Additionally, to improve the predictions for which we need to derive the Bz component, we analyze the Russel-McPherron effect, which reflects the change of the Bz component and the associated geomagnetic activity through the seasons. The approach proposed in this study for forecasting the Dst/Kp indices makes use of the Gaussian Process Regression, a non-parametric Bayesian model, suitable in case of limited available data, flexible non-linear problems and known prior information about the output (e.g. periodicity). Testing the developed forecasting technique for the whole SDO period 2010-2020, we obtained that the correlation coefficient between the predicted and observed Dst (Kp) index reaches r = 0.68/0.73 (0.67/0.76), for coronal holes having the positive/negative polarity on the Sun. These results demonstrate that the proposed technique opens a possibility to predict CIR-driven geomagnetic storms from solar observations resulting in the extension of the lead time from hours up to several days, which is highly important for warnings of the space weather conditions in the near-Earth environment and other space weather applications.