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Interplanetary scintillation observation of the CMEs and its application for space weather forecasting using MHD simulation

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Interplanetary scintillation (IPS) is a radio scattering phenomenon caused by the turbulence contained in the solar wind plasma. The speed and density disturbances of the solar wind can be measured from the IPS signatures that are derived during the ground-based radio observation of the extra-galactic radio sources. Rapidly propagating Coronal mass ejections (CMEs) sweep the background solar wind, forming dense regions in front of the CMEs. These regions can significantly scatter radio emissions. Hence, IPS observations can be used to detect CMEs propagating in interplanetary space. The CMEs cause various disturbances of the space environment. Therefore, forecasting their arrival time is very important. However, forecasting accuracy is hindered by limited CME observations in interplanetary space. This study investigates the forecasting method of the CME arrival times at the Earth by three-dimensional (3D) magnetohydrodynamic (MHD) simulations based on IPS observations. We used the IPS data observed at 327 MHz by the Institute for Space-Earth Environmental Research (ISEE), Nagoya University. In the forecasting system, CMEs are approximated as spheromaks with various initial speeds. Then MHD simulations with different CME initial speed are tested. The simulated IPS is derived from the density distributions of each simulation run, and they are compared with the observed IPS data of ISEE. The CME arrival time of the simulation run that most closely agrees with the IPS data is selected as the forecasted time [1]. We then validated the accuracy of this forecast using 12 halo CME events. The average absolute arrival-time error of the IPS-based MHD forecast is approximately 5.0 h, which is one of the most accurate predictions that ever been validated, whereas that of MHD simulations without IPS data, in which the initial CME speed is derived from white-light coronagraph images, is approximately 6.7 h. This suggests that the assimilation of IPS data into MHD simulations can improve the accuracy of CME arrival-time forecasts [2]. The average predicted arrival times are earlier than the actual arrival times. These early predictions may be due to overestimation of the magnetic field included in the spheromak and/or underestimation of the drag force from the background solar wind, the latter of which could be related to underestimation of CME size or background solar wind density. A part of this IPS based forecasting system has been used in the space weather forecasting operation in the National Institute of Information and Communications Technology (NICT). During the daily operation, CME arrival times should be forecasted as soon as possible after a CME is observed and the initial forecast should be given automatically or semi-automatically by human forecasters with a large error range. IPS data can be made available approximately 1–2 days after the onset of CMEs exhibiting typical speeds, that can be used to limit the range of the initial forecast.

1. K. Iwai, D. Shiota, M. Tokumaru, K. Fujiki, M. Den, and Y. Kubo, Y., "Development of a coronal mass ejection arrival time forecasting system using interplanetary scintillation observations", *Earth, Planets and Space*, **71**, 1, April 2019, article id. 39, doi:10.1186/s40623-019-1019-5.

2. K. Iwai, D. Shiota, M. Tokumaru, K. Fujiki, M. Den, and Y. Kubo, "Validation of coronal mass ejection arrival-time forecasts by magnetohydrodynamic simulations based on interplanetary scintillation observations", *Earth, Planets and Space*, **73**, 1, December 2021, article id.9, doi:10.1186/s40623-020-01345-5.