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OPERATIONAL GEOMAGNETIC FORECAST SERVICE

An operational service for predicting the geomagnetic indices Dst and Kp in near real time is described. The lead times are 1-4 hours past Earth crossing for Dst and 3 hours past Earth crossing for Kp. The skill scores, defined as relative mean square error reduction with respect to persistence, are about 40% for Dst and 15% for Kp. The service is publicly available online via the STAFF viewer at http://www.staff.oma.be/.

Keywords: geomagnetic service.

Most space weather events affect the geomagnetic field by altering the pattern of magnetospheric currents. These changes are measured at the ground level by magnetic observatories around the globe. The changes of the geomagnetic field vary at different locations due to a complex geometry of magnetospheric currents. At this time, geomagnetic variations are analyzed through the use of geomagnetic indices. There are various indices with different definitions, each having its advantages and drawbacks. Some indices are used for general purpose, some are highly specialised. The most popular geomagnetic indices (Kp and Dst) are good indicators of the general state of space weather, and are used as inputs for many space weather models.

Under the EU-funded FP7 project Advanced Forecasting For Ensuring Communications Through Space (AFFECTS) (http://www.affects-fp7.eu/), our team has developed a near real-time (NRT) geomagnetic forecast service, capable of forecasting the geomagnetic index Dst 1 to 4 hours in advance and the geomagnetic index Kp 3 hours in advance. Geomagnetic indices were chosen for several reasons: 1) they serve as proxies of the general state of space weather; 2) they are often used as inputs to models describing other phenomena, e.g. magnetic field, atmospheric density, storm time Total Electron Content (TEC), etc.; 3) the physics behind geomagnetic indices is relatively simple (at least for Dst), as compared to other space weather parameters. NRT here means that the forecast is made within 5 minutes after the data become available. Both the construction of models and the forecasting are fully automated and do not require human intervention. The NRT forecast can be found at the Space Weather Application Centre ionosphere (SWACI) AFFECTS website http://swaciwebdevelop.dlr.de/geomagnetic-indices/dst-index/ developed and hosted by the German Aerospace Centre (DLR), as a part of the Solar Timelines Viewer for AFFECTS (STAFF) http://www.staff.oma.be/ developed and hosted by the Royal Observatory of Belgium (ROB), and as a part of the AFFECTS Mobile App (www.affectsmob.oma.be/files/affects.apk) developed by Space Research Institute (SRI) for the Android platform. It is used as an input for the DLR's perturbed TEC forecast model (http://swaciwebdevelop.dlr.de/gnss-based-tec/tec-europe/) as well as a standalone product. Live demonstrations of the geomagnetic forecast tool were held at the 9th and 10th European Space Weather Weeks and at the AFFECTS User Workshop hosted by the Royal Observatory of Belgium on 28 February 2013.

The scientific background of the prediction method was described in the articles [1; 2]. There are two main problems of the construction of the prediction model: 1) identification of the model structure, i.e. determining the drivers affecting the predictand, and 2) the identification of the model parameters, i.e. determining how exactly the predictand depends on these drivers. The second problem has a number of readily available solutions, among which we chose the most common one – the least squares method. The first problem, however, is much more difficult and complicated. First of all, even for stationary linear systems, this is an ill-posed problem, because it is both underdetermined (by the number of measured values) and overdetermined (by the number of data points) at the same time [3, Vol.1, p.670]. In our case the system (the magnetosphere) is dynamical, which means that its properties change with time, and strongly nonlinear. No formal solutions exist for this case and research activities in this area were very limited until recently.

To make this problem manageable, we constrain ourselves to polynomial models. This leads us to the classical partial linear regression analysis [4] Note that the word "linear" here applies to the fitted coefficients, and not to the measured values, so the regressors can be generally nonlinear. The statistical significances of the regressors are determined according to Fisher's F-test [5]. This test allows separating significant and insignificant regressors. The insignificant regressors are then rejected and the routine is repeated until the regression contains only significant regressors. We use the following routine for the selection of the regressors: first we construct an autoregression model, then we add all the other inputs with lags (linear model) and finally we construct nonlinear combinations of the most significant regressors (nonlinear model). Thus, from the information science's point of view, our models belong to the NARX class (Nonlinear AutoRegression models with eXogeneous inputs). To avoid overfitting, we then reject insignificant regressors over a different sample, which we call a tuning sample. The articles [1] and [6] give some physical analysis of the models' structure.

The predictive models were trained using the NASA NSSDC/SPDF OMNI2 database (http://omniweb.gsfc.nasa.gov/). We selected 3 samples from this database: years 1976 to 2000 for model training and years 2001 to 2008 for model tuning (these two have approximately equal number of data points). We used only those parameters, which are available in near real time. The spacecraft measured quantities enter the models with lags up to 24 hours. For operation the geomagnetic forecast service uses NRT Advanced Composition Explorer (ACE) data, provided by the NOAA Space Weather Prediction Center (SWPC), Boulder CO, USA (http://www.swpc.noaa.gov/ace/ace_rtsw_data.html), and NRT geomagnetic indices: Dst from the World Data Centre for Geomagnetism (WDC-C2), Kyoto, Japan (http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/presentmonth/index.html) and Kp from the German Geosciences Centre (GFZ), Potsdam, Germany (http://www.gfz-potsdam.de/en/research/organizational-units/departments-of-the-gfz/department-2/earths-magnetic-field/services/kp-index/).

The use of different datasets for model training and for operations yields a problem. The low-resolution OMNI2 data were produced from high-resolution data using a technique called time shifting. It means that high-cadence data were shifted in time with the current solar wind velocity to the point of Earth crossing. The reason for using this trick was that OMNI2 database contained data from multiple spacecraft with different orbits, and this technique allowed bringing their data to a common time frame. However, the NRT data from ACE are not time-shifted, which introduces a systematic error in time. To address this issue, we decided to apply the same time shifting routine to the NRT ACE data as described in the OMNI2 documentation. The use of time shifting brought two additional benefits: an effective increase of the lead time by the propagation time from L1 to the Earth (typically about 1 hour), and the ability to use data from other spacecraft, not limited to those in L1 halo orbit like the NASA/NOAA Deep Space Climate Observatory (DSCOVR) mission, which is the successor to ACE. One example of such possible spacecraft is the NASA SunJammer mission, which will use a solar sail to stay roughly at the Sun-Earth line about twice as far as the L1 point.

However, time-shifting in near real time is challenging due to the fact that solar wind velocity data are not always available. Our solution to this problem was to replace missing data with running average values – a strategy we followed for all spacecraft data, not just the solar wind velocity data. This ensures that predictions are made even in the situation when spacecraft data are only partially available, which is the usual case during strong space weather events.

The current version of the service operates since February 2014. Thus, not enough statistics was yet gathered to perform its validation. The validation results for previous versions of the service are given in the articles [7] – [9]. The article [7] contains early validation results; the article [8] describes the results of the first NRT run during a particularly complicated event; and the article [9] contains the results of an extended validation.

By the overall performance, the geomagnetic forecast service surpasses all existing analogues. The errors of our forecast are almost exclusively in timing, and not in magnitude. It offers longer lead time and higher accuracy for the Dst index, and is the only operational forecast of the official Kp index so far. Future development will be aimed at increasing the lead time, increasing the cadence, and introducing regional and local geomagnetic forecasts.

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СЛУЖБА ОПЕРАТИВНОГО ГЕОМАГНІТНОГО ПРОГНОЗУВАННЯ

Описано операційний сервіс для прогнозування в реальному часі геомагнітних індексів Dst та Kp. Час упередження по перетині Землі для Dst індексу складає 1-4 години, для Kp індексу – 3 години. Параметр skill score, що визначається як зниження відносної середньоквадратичного похибки по відношенню до тривіальної моделі, склав приблизно 40% для Dst та 15% для Kp. Сервіс працює в режимі он-лайн у вільному доступі через оглядач STAFF http://www.staff.oma.be/.

Ключові слова: геомагнітне прогнозування.

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СЛУЖБА ОПЕРАТИВНОГО ГЕОМАГНИТНОГО ПРОГНОЗИРОВАНИЯ

Описано операционный сервис для прогнозирования в реальном времени геомагнитных индексов Dst и Kp. Время предупреждения по пересечению Земли для Dst индекса составляет 1-4 часа, для Kp индекса – 3 часа. Параметр skill score, который определяется как понижение относительной среднеквадратичной погрешности по отношению к тривиальной модели, составил приблизительно 40% для Dst и 15% для Kp. Сервис работает в режиме он-лайн в свободном доступе через обозреватель STAFF http://www.staff.oma.be/.

Ключевые слова: геомагнитное прогнозирование.