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PRediction Of Geospace Radiation Environment and Solar wind parameterS

Work Package 7
Fusion of Forecast Tools

Deliverable 7.1
Results of forecasts of geomagnetic indices

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Document Change Record

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0.1	2017-10-25	SNW	Initial draft
1.0	2017-10-31	SNW	Submitted version
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Contents

Summary

Access to a source of timely and accurate forecasts for the evolution of the geomagnetic activity in the terrestrial magnetosphere is essential to the successful and continuous operation of satellite and ground-based resources that provide the technical infrastructure that permeates our daily lives. These services include maritime and land based navigation, communications such as radio, TV, and telephone, distribution and transport of power such as electricity, oil, and gas, and so on. All of these essential services may be compromised as the result of the effects of Space Weather hazards caused by changes in the properties/composition of the solar wind and how it impinges upon the terrestrial magnetic field. While it is not possible to prevent changes in the solar wind and the subsequent response of the terrestrial magnetosphere, an accurate and reliable forecast of the occurrence of such events allows the service operators to take action to mitigate their effects on the services provided, protecting them against damage, and minimising downtime.

The aim of Work Package 7, "Fusion of forecasting tools", is to provide centralised access to the various forecasting tools generated within PROGRESS. As a first step, Task 7.1 will provide a single access point by which a user may access the results of models related to the forecasting of geomagnetic indices such as Kp, Dst, and AE. Periods of high activity, when technological assets are most vulnerable may be assessed, may be highlighted to interested parties who can then make a decision as to whether mitigation steps should be implemented. This report outlines the freely accessible forecasts of the geomagnetic indices Kp, Dst, and AE within the PROGRESS web pages.

1 Introduction

Todays modern technological infrastructure that provides the services that we use on a daily basis is vulnerable to the effect of space weather. Events on the Sun can have a strong effect on the terrestrial system as a whole, either by increasing levels of geomag-

netic activity or affecting the particle environment within the terrestrial magnetosphere. Giant explosions on the Sun give rise to bursts of electromagnetic radiation (EM) from flares, and resulting in the emission of clouds of particles, known as coronal mass ejections (CMEs), moving at very high speeds into the heliosphere. Occasionally, these emissions are directed Earthward, and the terrestrial system responds to their impact. EM radiation passes straight through the magnetosphere, dumping energy directly into the ionosphere, significantly altering its structure and severely interfering with radio communications by degrading propagation paths and even causing total blackouts. CMEs strike the terrestrial magnetosphere, causing it to change its configuration, an effect that can cause large geomagnetically induced currents within large power transmission systems with the potential to destroy transmission lines and transformers. CMEs may also introduces changes to the particle environment of the inner magnetosphere capable of increasing the numbers of particles and setting in progress processes to energise particles that may then seriously interfere with the operation of satellites.

The level of geomagnetic activity experienced by the Earth may be quantified using a set of geomagnetic indices. The main indices used are Kp, Dst, and AE. Each has its advantages and disadvantages in relation to quantifying the global level of geomagnetic activity.

Dst is a measure of the disturbance in the horizontal component of the terrestrial magnetic field, calculated using data from a set of ground-based magnetometers located at low geomagnetic latitudes. As a result it is used primarily describe changes in the terrestrial ring current although it may be affected by other current systems e.g. cross-tail and/or magnetopause currents. Other storm related effects, such as the particle population dynamics in the radiation belts, or ionospheric Joule heating are not captured by the Dst index.

The Kp index is a global standardised mean of variations of the geomagnetic field with respect to a "quiet day" measured at mid latitudes. It has been shown that many

Table 1: Work Package 3 tasks and deliverables

#	**Title**	**Deliverable**	**Completion**
T3.1	Survey of existing models	D3.1	M3
T3.2	Identification of relevant data	D3.2	M6
T3.3	Evaluate and verify existing models	D3.3	M9
T3.4	Development and update of existing Kp and Dst models	D3.4	M24
T3.5	Development of new AE models	D3.5	M30
T3.6	Implementation for real-time operation	D3.6	M36

magnetospheric phenomena may be parameterised using this index. Examples include ionospheric outflow, thermospheric density and satellite drag, and the evolution of hot plasma in the magnetosphere. As a result, many models of the magnetosphere/ionosphere are driven by the Kp index.

The AE index provides a global, quantitative measure of geomagnetic activity in the auroral zone and is calculated from the horizontal component of the magnetic field in the vicinity of the auroral oval.

As mentioned above, the use of one index alone cannot be used to successfully to indicate the level of geomagnetic activity. Recognising this fact, one of the aims of PROGRESS was to produce models for the three indices Kp, Dst, and AE. This modelling activity was carried out within Work Package 3. Table 1 lists the tasks within this work package and the current state of the deliverables. The activities of the Work Package have proceeded to the proposed project schedule and the deliverables submitted on time.

2 Implementation

The models that have currently been implemented on the PROGRESS web site are

- UoS-Kp-NARX-2016
- IRF-Kp-2017
- IRF-Dst-2017

Figure 1: PROGRESS home page.

Deliverables D3.4 and D3.5 provide details of the models for Kp, Dst, and AE developed within PROGRESS. Since these reports were initially submitted, development has continued on all models to further test and improve them, and also to provide various products such as plots of the forecasts and eventually real-time numerical values (this is task T3.6 of WP3, currently ongoing and due for completion at the end of the year).

Figure 1 shows the home page of the PROGRESS project `https://ssg.group.shef.ac.uk/progress/html/`. There are two ways to access/view the current results of the models, either from the left hand results menu by clicking on the (+) sign to expand the menu of geophysical index models and selecting the model of interest, or from the "Current conditions" information box on the right hand side of the page.

2.1 Graphical representations

Graphical representations of the results of these models are available from the PROGRESS web site, accessed from the results menu on the left side of the project home page. Each separate model is shown on a separate page and contains a figure, downloaded from the web site set up by and maintained by the model developers. This methodology allows the model developers to continue to improve their models putting them online when validated. Thus, the latest results are always available from the PROGRESS web site. Together with the plot, there are links (at the bottom of the plot) to key papers that describe the implementation of the models.

Examples of the web pages showing these results are shown in Figures 2 (Lund IRF-Dst-2017), 3 (Lund IRF-Kp-2017), and 4 (Sheffield UoS-Kp-NARX-2016).

2.2 Current solar wind conditions

As mentioned in Section 2 above, the PROGRESS web site presents the user with a panel that displays the latest measurements of

- Dst, downloaded from `http://wdc.kugi.kyoto-u.ac.jp/`
- Kp, from `http://www-app3.gfz-potsdam.de/`
- ACE solar wind measurements from `ftp://ftp.swpc.noaa.gov/`
- Electron fluxes from `http://www.ssg.group.shef.ac.uk/`

A process has been set up to obtain these data. This process runs each hour, ensuring that the latest data are always available for display. An example of their display is shown in Figure 5. The last time the download process ran is displayed on the first line of this table.

The display incorporates a "traffic light" mechanism to indicate whether the values are considered low, medium, or high risk and is indicated by changing the colour of the

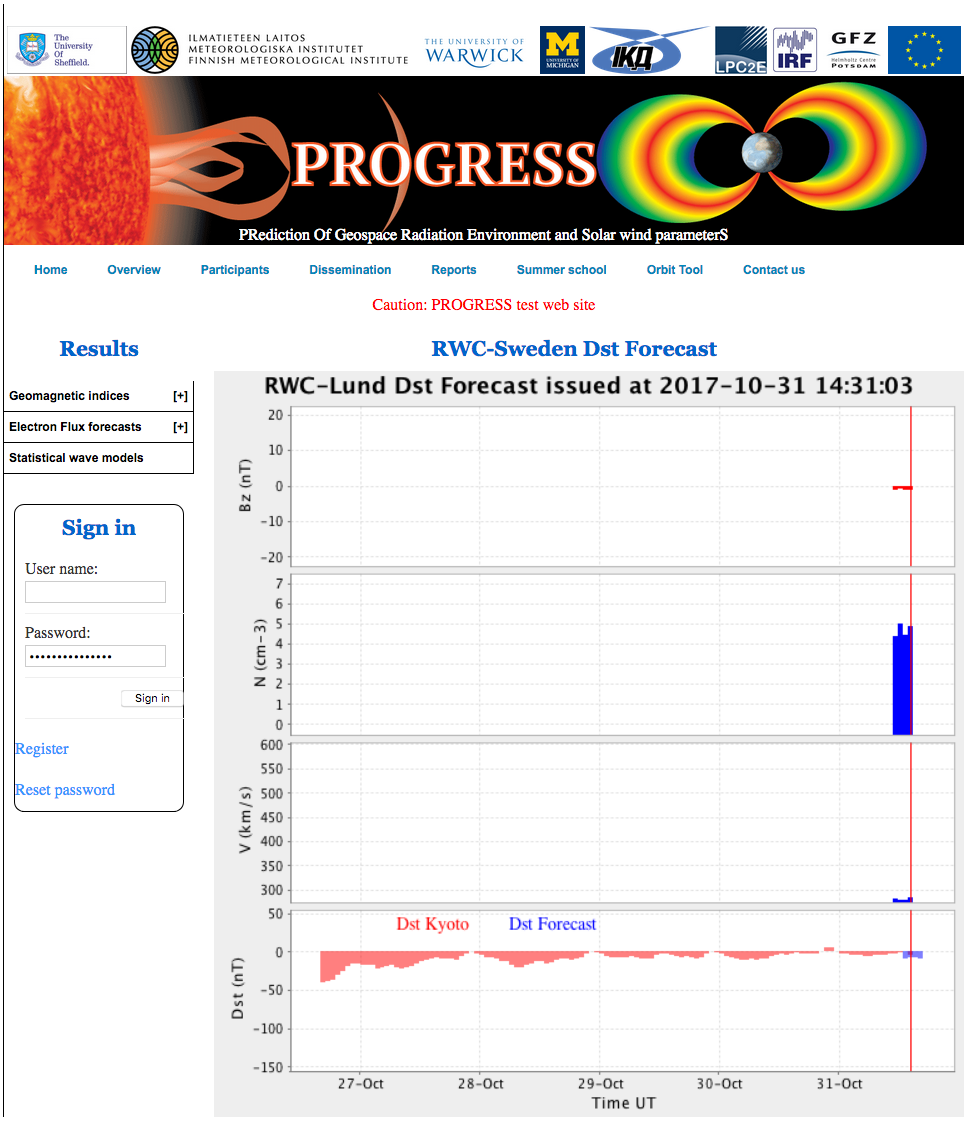

Figure 2: Forecast of the current Lund Dst model.

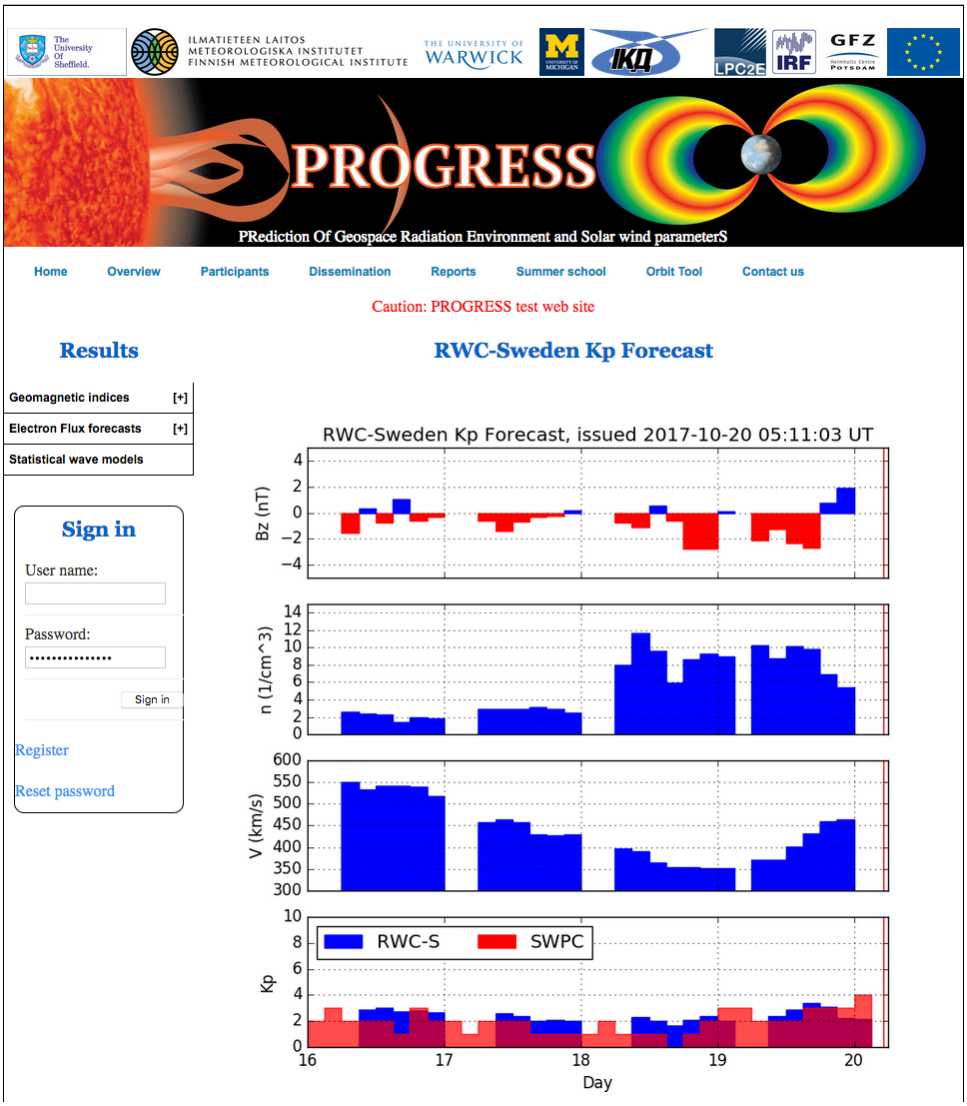

Figure 3: Forecast of the current Lund Kp model.

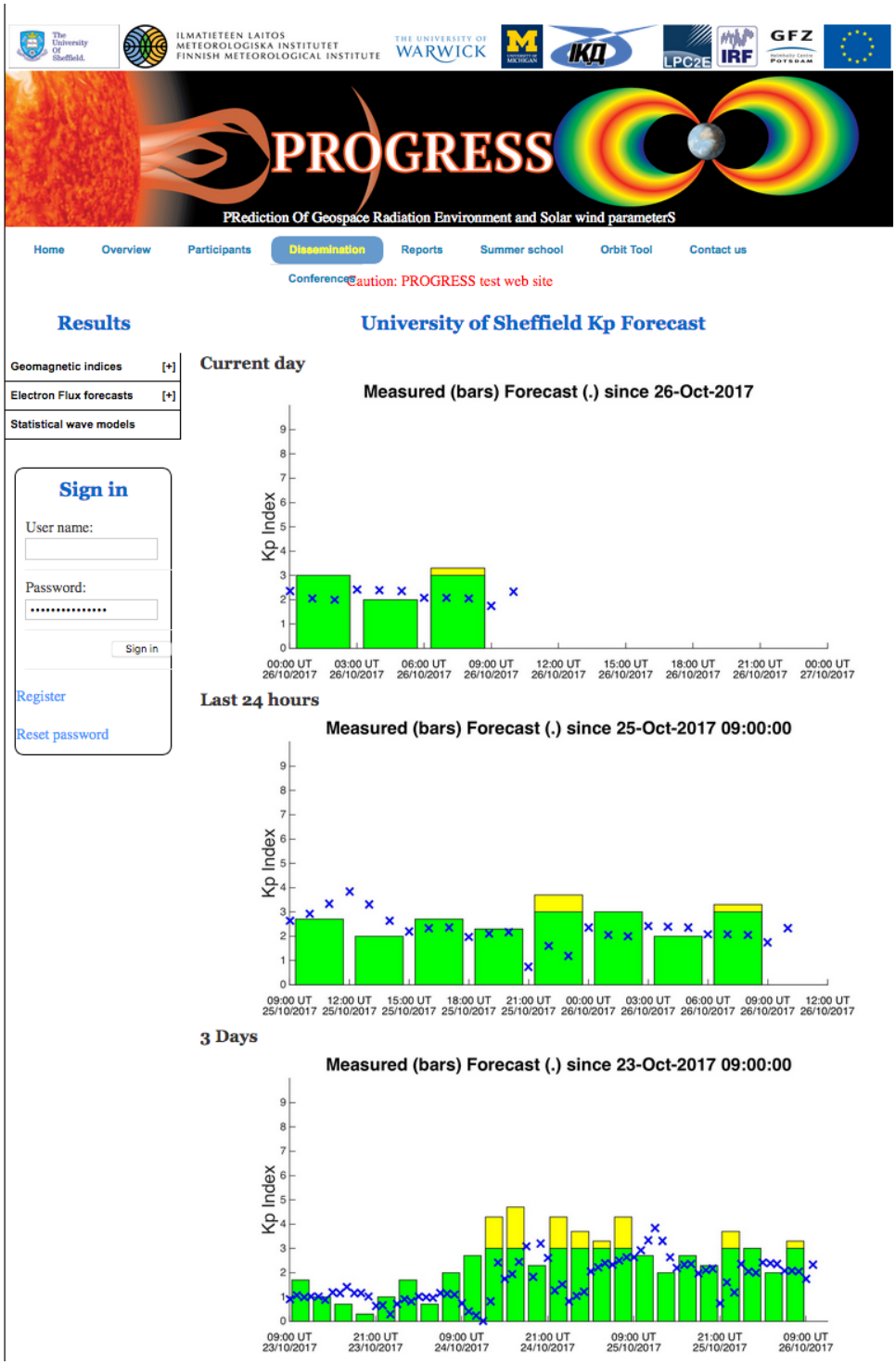

Figure 4: Forecast of the current Sheffield Kp model.

Table 2: Colour limit used for displaying the current solar wind parameters.

Parameter	**Colour**		
	Green	Orange	Red
Dst	$100 - > -50$	-50 $- >$ -100	< -100
Kp	$< 3^+$	$4^- - 6^+$	$\geq 7^-$
$\|B\|$	< 20	$20 - 30$	> 30
B_z	> 0	$0 - -20$	< -20
n	< 20	$20 - 40$	> 40
$\|V\|$	< 600	$600 - 800$	> 800
$E_{>800keV}$	$< 10^9$	$< 10^9 - 10^{11}$	$> 10^{11}$
$E_{>2MeV}$	$< 10^9$	$< 10^9 - 10^{11}$	$> 10^{11}$

background on which the numbers are displayed - green being low, orange medium, and red high so the user can see at a glance the level of activity. The current ranges of values shown by the background colour are listed in Table 2. More realistic values will be set later in the project, in consultation with the PROGRESS Stakeholder Advisory Board.

The table of current space weather conditions also contains the currently available forecast values generated by the Sheffield Kp model and the Sheffield electron flux models. These values will give the user some idea of how we expect the particular parameter to evolve based upon our models, using the same background colour scheme. If the user places the cursor over one of the values in this table then the time stamp to which that particular measurement of forecast pertains will be displayed as a tool tip.

The names of the parameters in the "Current conditions" table are all links. Clicking on this link will open up a new web page that contains a plot of the recent evolution of that particular parameter. An example of the recent evolution of the flux of > 800 keV electrons at geostationary orbit is shown in Figure 6.

3 Conclusions

The results from the first of the models of geomagnetic indices, developed within PROGRESS, have been added to the project web site to increase their availability and widen their dissemination. Work will continue to improve their presentation, increase the number of

Current Conditions

Time: 2017-10-26 09:15:11 UTC		
Magnetosphere	Current	Forecast
Dst (nT)	-10	
Kp	2.7	2.5
Solar wind	Current	Forecast
|B| (nT)	5.8	
Bz (nT gsm)	-3	
Density (cm^{-3})	2.9	
Velocity (kms^{-1})	559.3	
GEO e^- flux	Current	Forecast
F>2MeV	7.5369	7.8734
F>800keV	9.3826	9.85

Figure 5: Information box to show current solar wind conditions.

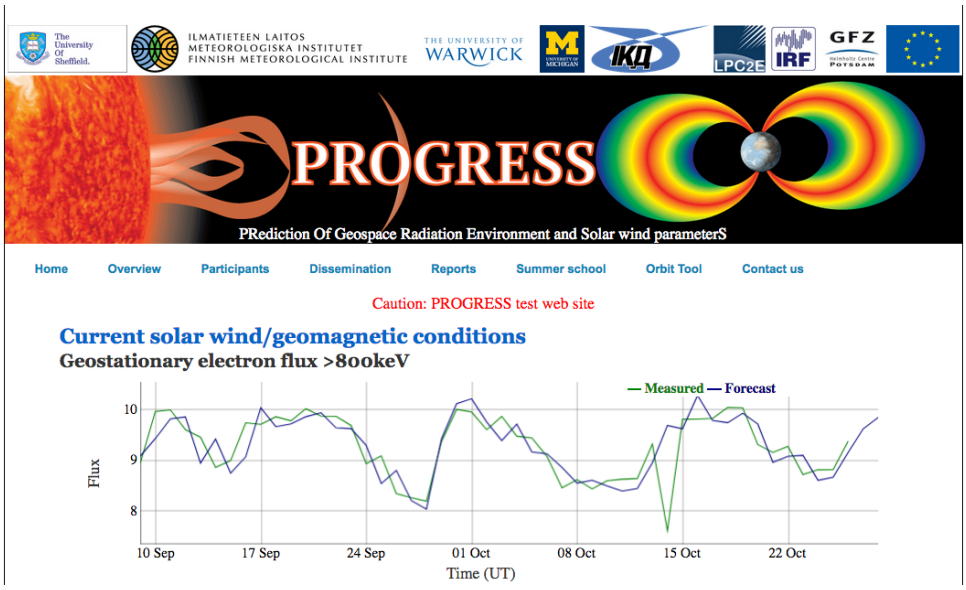

Figure 6: Example of plots of the current conditions. This plot shows the measured (GOES 13) and forecast values of the flux of > 800 keV electrons at geostationary orbit.

models available, and, in conjunction with members of the Stakeholder Advisory Board, to take these basic tools and their outputs and turn them into a useful, operational tool.

4 Future tasks

The web pages displaying the project results will continue to be developed during the remainder of the project. Future updates/developments will include:

- Inclusion of other models as their results come online. Examples include the Dst and Kp models developed by the partner SRI.
- Access to numerical results of the forecasts.
- Addition of some quality/accuracy indicators such as the prediction efficiency and correlation.