PRediction Of Geospace Radiation Environment and Solar wind parameterS

Work Package 7
Fusion of Forecast Methods

Deliverable 7.4
Environmental Summary

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Contents

Summary

The timely dissemination of accurate forecasts indicating the possible occurrence of hazardous conditions due to space weather is of vital importance in a number of industrial sectors such as satellite operations, communications, aviation, and power generation and transmission. Sufficient warning of potentially high-risk conditions enables operators to implement mitigating steps to minimise the effects such events may have on our technological infrastructure.

Within PROGRESS a number of tools have been developed to model and forecast the evolution of the terrestrial response to changes in the solar wind resulting from processes occurring on the Sun. The goal of Work Package 7 is to bring these tools together so that their results are publicly accessible and easy to interpret.

This report, Deliverable D7.4, describes the steps taken to disseminate the results from the PROGRESS project via the PROGRESS web site and an email circular.

1 Introduction

The aim of the PROGRESS project is to develop a set of tools to enable the accurate and reliable forecast of space weather hazards. These tools comprise

- an MHD based model for the forecast of the solar wind conditions at the L1 point, the location of the ACE and DSCOVR satellites that provide direct measurements, based on magnetograms of the solar surface,
- a set of models, based on different modelling methodologies, to forecast the evolution of the geomagnetic indices Kp, Dst, and AE,
- a new set of statistical wave models to characterise the interactions between the plasma wave modes observed in the inner magnetosphere,
- forecasts of the low energy electron populations using the physics based numerical code IMPTAM,
- development of data based models to forecast the fluxes of electrons at geostationary orbit
- extension of the VERB numerical code, using forecasts of geomagnetic indices and electron fluxes as drivers

Work Package 7 collects the results from the various models developed within PROGRESS and presents their results via the project web site. These PROGRESS results are complemented by data from other sources to build up a picture of the current space weather conditions in geospace and provide some indication as to how they are expected to evolve.

This report details work carried out in Task 7.4, the objective of which is to provide an summary of the results obtained within PROGRESS and their dissemination to a wider audience. This report is structured as follows. Section 3 provides details of the data sources used within this task, Section 4 describes the implementation of this task while Section 5 shows examples of the data that is accessible from the PROGRESS web site.

2 Overview of Task

The objectives of Task 7.4 involve the collection and display of data that may be used to assess the current state of the local geospace environment. The data are to be displayed such that a potential user can see at a glance if either the current conditions or the their forecasted evolution are deemed as potentially hazardous. Data should also be made available to enable the user to look more deeply if required, with the chance to analyse past events providing data are available.

3 Data sources

The data required for this task come from many sources. the overall objective of this task is to obtain and display the latest data to the user so that they may use it in their assessment of potential risks resulting from space weather effects.

3.1 Geomagnetic indices

Geomagnetic indices are used to quantify the current level of geomagnetic activity based on variations in the terrestrial magnetic field measured at the surface of the Earth at numerous locations. These values are regularly used as inputs to numerical models of the inner magnetosphere.

Data for geomagnetic indices may be divided into two general classes, namely measurements available in near real time and forecasts of their evolution.

The calculation of geomagnetic indices involves the measurement and validation of the terrestrial magnetic field data sets from different sets of observatories located around the globe. The methodology for collecting, cleaning, and processing the data may take years to provide definitive values. However, real time quick-look estimates of these parameters are available with the proviso that they are best estimates and may change in future once they have been properly processed and validated to form the final definitive data product. For the purposes of this task, quick-look (near real time) data sets for the indices Kp, Dst, and AE are downloaded.

All forecast models developed by PROGRESS have been previously described in the deliverables D3.4, D3.5, and D3.7.

3.1.1 Kp

The Kp index is used to summarise the global level of geomagnetic activity. It was introduced in 1939 (Bartels et al. 1939) as a weighted average of a set of K indices from geographically dispersed magnetic observatories.

Nowcast values of the Kp index are available from GFZ, Potsdam Germany as part of the International Service of Geomagnetic Indices. Data for the current and previous month are stored in files called qlyymm.wdc and pqlyymm.wdc that are formatted according to the standard WDC convention (other formats are available but this seems to be the easiest to use) and are downloaded from http://www-app3.gfz-potsdam.de/kp_index/*file_name*.

Since these data values have a 3 hour time resolution they are only downloaded every three hours.

Forecast values of *Kp* are available from a number of sources. Within PROGRESS, various models for the forecast of *Kp* have been developed using different methodologies at IRF, USFD, and SRI. The modeling methodologies have been described in deliverables D3.4 and D3.7.

3.1.2 *Dst*

The *Dst* index is calculated from variations measured in the terrestrial magnetic field by four near equatorial geomagnetic observatories. It represents the intensity of the westward equatorial electrojet or ring current and is used to assess the severity of magnetic storms and substorms (Sugiura et al. 1964, Sugiura 1991).

Quicklook values for the *Dst* index are obtained from World Data Centre for Geomagnetism in Kyoto, Japan and are downloaded using the URL http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/*yyyymm*/dst*yymm*.for.request where *yyyymm* and *yymm* represent the year (as 4 digit and two digit) and month of the data for the period of interest.

Forecast values for the *Dst* index have been developed by IRF, USFD, and SRI. These developments were described in deliverables D3.4 and D3.7.

3.1.3 *AE*

The *AE* and the related *AU* and *AL* indices were introduced by (Davis & Sugiura 1966) to measure the global activity of the auroral electrojet based on variation of high latitude magnetic field.

Due to the demand, quicklook values for the *AE* index have recently become available online from World Data Centre for Geomagnetism in Kyoto, Japan. It should be noted that these data are intended for monitoring, diagnostic, and forecasting purposes only.

In particular, quick-look *AE* products are released with the following provisos.

- Values are derived from raw unverified data and often contain spikes.
- Values may be revised as more data become available or base lines are corrected.
- Values will be replaced by provisional and then final values at a later date.

They are available for the period from January 2018 at http://wdc.kugi.kyoto-u.ac.jp/ae_realtime/index Provisional *AE* values are available for the period January 1996 to March 2018 at http://wdc.kugi.kyoto-u.ac.jp/ae_provisional/index.html.

PROGRESS has enabled the development of *AE* model forecasts using ANN (IRF) and GNM (SRI) methodologies. These models are fully described in deliverables D3.5 and D3.7.

3.2 Electron fluxes at GEO

Observations of electron energy distributions within the radiation belts have shown the existence of variations by orders of magnitude within periods of an hour or less. The production of large fluxes of energetic electrons can cause problems to satellites whose orbits lie or traverse the radiation belts due.

PROGRESS has developed a set of models to forecast the evolution of electron fluxes for energies >2MeV, >800keV. The results of these models can be compared directly to the fluxes measured by the GOES 13 MAGD instrument.

These data are downloaded from USFD using the URL http://www.ssg.group.shef.ac.uk/USSW/ where the forecasts and measures fluxes for the past year may be found in the text files 2M_Output.txt and 800k_Output.txt respectfully.

3.3 Local solar wind parameter at L1

Solar wind parameters such as particle density, bulk velocity, pressure, and magnetic field are among the parameters used as inputs to the PROGRESS data based models for geomagnetic indices as well as physics based models of the radiation belts. Large changes in these parameters are usually indicative of the occurrence of events on the Sun such as CMEs and flares. Events such as these are the main causes of space weather hazards and so there measurement and forecast is of primary importance.

For this task, current measurements of the solar wind are taken from ACE, a satellite that sits between the Sun and Earth at the Lagrange L1 point. Real-time data with a 1 minute resolution are retrieved from the NOAA ACE real-time data web site at ftp://ftp.swpc.noaa.gov/pub/lists/ace/.

Sets of forecast values for the solar wind parameters at L1 are produced using the AWSoM/SWIFT model developed in the framework of the PROGRESS project. These forecasts are based on the determination of plasma and field parameters from magnetograms of the solar surface and their subsequent propagation to L1. These data are available from https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/bennett/swift-data/results3/, and are contained in JSON formatted files.

4 Implementation

The implementation of the applications to display the current solar wind and geomagnetic environmental parameters is divided into two sub tasks, one to collect the data, format, plot, and transfer subsets of the data to the host on which the PROGRESS web site runs, and a second to read the data on the web server and display the most recent values and provide access to graphical representations of the data.

4.1 Data collection

As mentioned in Section 3 the data used in this task is extracted from a number of different sources, distributed from the United States of America to Japan. Section A summarises the data sets collected.

The code used to download the various data sets is written in MATLAB. It is run once per hour as a `crontab` process on a Linux host. Since the rate of update of the data sources is dependant upon the data set, not all data sets will be downloaded all of the

Table 1: The relationship between the level of risk (low, medium, or high) and the range of parameters.

Parameter	**Low risk**	**Medium risk**	**High risk**
Dst	$100 < Dst \leq -50$	$-50 < Dst \leq -150$	$-150 < Dst \leq -500$
Kp	$-1 < Kp \leq 3.5$	$3.5 < Kp \leq 6.5$	$6.5 < Kp \leq 10$
AE	$-1 < AE \leq 100$	$100 < AE \leq 300$	$300 < AE \leq 5000$
e^- flux (>2MeV)	$0 < flux \leq 9$	$9 < flux \leq 11$	$11 < flux \leq 13$
e^- flux (>800keV)	$0 < flux \leq 9$	$9 < flux \leq 11$	$11 < flux \leq 13$
IMF	$0 < \|B\|, B_z \leq 20$	$20 < \|B\|, B_z \leq 30$	$30 < \|B\|, B_z \leq 100$
Plasma density	$0 < n \leq 20$	$20 < n \leq 40$	$40 < n \leq 100$
Plasma velocity	$0 < \|V\| \leq 600$	$600 < \|V\| \leq 800$	$800 < \|V\| \leq 2000$

time. Currently, the code is configured to download the ACE solar wind parameters, Dst related data, and electron flux data each hour, Kp every 3 hours, and AWSoM/SWIFT solar wind forecasts daily.

4.2 Data processing

Data are downloaded using either the `webread` or `urlread` MATLAB commands in conjunction with the URL defined in Section A and written out as JSON formatted files, one file per data set. Plots of the data for the last 7 days are created and saved as PNG files.

4.3 Transfer to web server

The JSON and PNG files are then transferred to the web server where they can be read and displayed by the web page. Due to local constraints, this transfer is achieved using SFTP processes. They are placed into the web site `data` directory.

4.4 Visualisation of the data

The data are presented to the user as part of the home page. A panel has been created that displays the current and forecast values of the various parameters in tabular form. The background colour used for the table cells is set depending on whether the value of the parameter falls into low risk category (green), medium risk (orange), or high risk (red). The parameter value ranges for each risk category are defined in a configuration file to enable ease of modification. Currently, these ranges are set as shown in Table 1.

4.5 Dissemination to the wider community

The PROGRESS web site is able to display the current solar wind and geomagnetic conditions. However, this relies on the user accessing and refreshing the home page. In order to disseminate the results, and in particular provide timely information during periods for which the risk is perceived to be high, a different method of dissemination is required. If the basic classification of risk results in a level deemed to be high PROGRESS

```
prog_alert_20180706173216.txt

PROGRESS Geomagnetic activity summary
=====================================

Issued: 2018-07-06 17:32:16 UT

Geomagnetic Indices
-------------------

Dst
---
Quicklook (Kyoto)      9       at 2018-07-06T08:00:00 (LOW)

Kp
--
Quicklook (Potsdam)    1.0     at 2018-07-06 06:00:00 (LOW)

Electron fluxes at GEO
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>800keV
-------
Measured (GOES 13)     9.155   at 2018-07-06 00:00:00 (MEDIUM)
Forecast (SNB3GEO)     8.722   at 2018-07-08 00:00:00 (LOW)

>2MeV
-----
Measured (GOES 13)     7.258   at 2018-07-06 00:00:00 (LOW)
Forecast (SNB3GEO)     6.285   at 2018-07-08 00:00:00 (LOW)

Current solar wind conditions
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Figure 1: An example of the structure of a warning bulletin issued by PROGRESS

will issue a bulletin by email that will be sent to all registered users of the PROGRESS web site. This bulletin, an example of which is shown in Figure 1, will provide details of the current geospace conditions as well as the forecast conditions that are perceived to be of potential high risk.

This procedure is implemented as a `crontab` process running on the PROGRESS web server at hourly intervals. It checks the latest forecasts and measurements, comparing them with the scales shown in Table 1. If a potentially high risk situation is identified an email bulletin will be issued.

5 Results

Figure 2 shows the panel displaying the current and forecasted geomagnetic conditions that has been incorporated into the PROGRESS home page. The top half of the panel contains quick-look near real time measurements for the geomagnetic indices Kp, Dst, and AE together with forecasts from some of the models developed within the framework of PROGRESS. As the data from more of these models becomes available they will be added to the display. In the centre of the panel there are the daily electron fluxes of >800 keV and >2 MeV at Geostationary Orbit as measured be the GOES 13 spacecraft as well as the forecasts from the SNB^3GEO models for these energies. Finally, at the bottom

Current Conditions

Dst (nT)	
Measured	-7
IRF-Dst-2017_ANN	-4.2
Kp	
Measured	0.3
IRF-Kp-2017_ANN	1.7
USFD-Kp-2017_N	1.2
AE	
IRF-AE-2017_ANN	160.3
GSO >800keV e^- flux	
Measured	8.628
SNB^3GEO	8.9601
GSO >2MeV e^- flux	
Measured	6.3295
SNB^3GEO	6.6118
Solar Wind	
|B| (ACE)	5.2
Bz (ACE)	1.8
Density (ACE)	15.2
Velocity (ACE)	391.3

Plot

Figure 2: Display of current conditions

of the panel the latest solar wind measurements from the ACE spacecraft are displayed. Note that this display only shows the IMF total magnetic field $||B||$ and the B_z component in the GSM coordinate frame, the plasma density, and bulk solar wind velocity. Other parameters are available e.g. complete magnetic field vector of plasma temperature and could be easily added if required.

The background of the entries displaying data values has been coloured to allow the user to form an instant assessment of the level of activity of each parameter, and to draw attention to values that may be considered as potentially hazardous. The ranges of the parameters defining the levels of risk are shown in Table 1. Thus, if any of the table cells possess a red background it indicates that there is a potentially high risk situation.

Each of the values displayed relates to a specific time e.g. the time of measurement of forecast time. These time tags may be displayed by placing the cursor over the numerical value. This causes a pop-up information box to appear containing the time tag related to the particular measurement.

Beside each parameter name there is a selection box. These may be used, in conjunction with the plot button at the bottom of the panel, to generate plots of these parameters showing their variation over the past 7 days. Figure 3 shows part of the resulting web page that appears when the parameters Kp and solar wind are selected for plotting. The top panel shows the values of the Kp index taken from the quicklook near real time measurements obtained from GFZ, Potsdam (light blue) together with model outputs from the IRF-Kp-2017 (red) and USFD-Kp-2017 (blue).It can be seen that the forecast value of Kp do reproduce the quicklook data product for the period from July 10 to 13, 2018. However, after this period, both models forecast values that are higher that those measured by 1.5–2 levels. This may be due to gaps and data spikes occurring in the solar wind input data sets and may be related to a small dropout observed in the radiation belt electron fluxes.

The names of the parameters provide links to an information page, providing some background details about the parameters, their source, and the perceived levels of risk. An example page is shown in Figure 4.

6 Summary

In summary, the activities carried out as part of Task 7.4 have resulted in the generation of a panel to display the current measured and forecasted values of the geomagnetic indices Kp, Dst, and AE, the electron fluxes at geostationary orbit, and the latest conditions of the solar wind as measured by the ACE satellite.

These parameters are classified according to perceived risk level and are coloured accordingly so that the user can see at a glance if there are any potential space weather hazards.

When periods are assessed as high risk an email bulletin is automatically issued to registered users informing them of this situation.

7 Future tasks

Possible improvements to this application include

- Inclusion of more model forecasts for geomagnetic parameters.
- Addition of more detailed information regarding changes in the various parameters observed over time e.g. rates of change of parameters, estimates of the spread of measurements/forecasts.
- Better tuning of the parameter risk ranges.

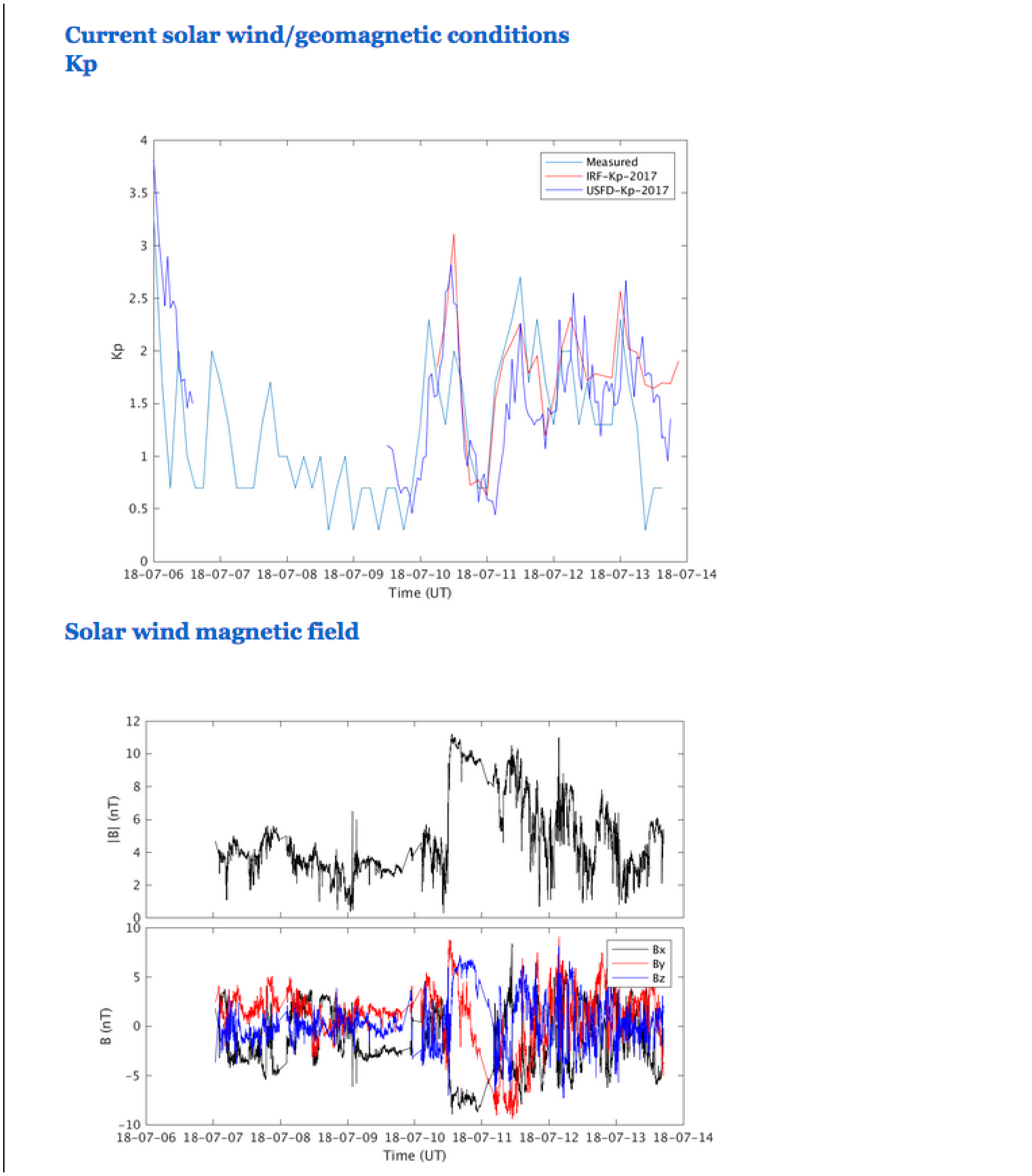

Figure 3: Example of plotted parameters

Current geospace environment background

This page provides some background information regarding the values displayed in the list of current conditions.

Dst

Source:	World Data Center for Geomagnetism, Kyoto
Data access:	Dst pages
Background information:	Calculation method
Colour levels:	Low 100 < Dst < -50
	Medium -50 < Dst < -150
	High -150 < Dst < -500

Kp

Source:	GFZ, Potsdam Germany
Data access:	Kp data
Background information:	Calculation method
Colour levels:	Low 0 < Kp < 3.5
	Medium -3.5 < Kp < 6.5
	High 6.5 < Kp < 10

Electron fluxes

Source:	SPace Systems Lab, University of Sheffield
Data access:	>800keV
	>2MeV
Background information:	Calculation method
Colour levels:	Low $0 < \text{Flux}_{>800\text{keV}} < 9$
>800keV	Medium $9 < \text{Flux}_{>800\text{keV}} < 11$
	High $11 < \text{Flux}_{>800\text{keV}} < 13$
Colour levels:	Low $0 < \text{Flux}_{>2\text{MeV}} < 9$
>2MeV	Medium $9 < \text{Flux}_{>2\text{MeV}} < 11$
	High $11 < \text{Flux}_{>2\text{MeV}} < 13$

Figure 4: Example of information about the parameters

References

Bartels, J., Heck, N. H. & Johnston, F. (1939), 'The three-hour-range index measuring geomagnetic activity', *J. Geophys. Res.* **44**, 411–454.

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Sugiura, M. (1991), Dst index, Technical report, Tokai University.
URL: *wdc.kugi.kyoto-u.ac.jp/dstdir/det2/onDstindex.html*

Sugiura, M., Kertz, W., Price, A. & Stone, D. (1964), *Hourly values of equatorial Dst for the IGY*, Annals of the international geophysical year, Pergamon Press.
URL: *https://books.google.co.uk/books?id=YtxwNAAACAAJ*

A Data source Information

Tables 2–6 provide information about the various sources for the geomagnetic indices *Kp*, *Dst*, and *AE*, electron flux forecasts, and solar wind data.

Note: Some filenames and directories are date dependent. In such cases URLs and file names contain the date format strings written in italic e.g. *yyyymm* represents the year as 4 digits and month as two digits including a leading zero if required.

Table 2: Summary of *Kp* data sources

Kp	**Quicklook**	
	Location	GFZ, Potsdam, Germany
	URL	http://www-app3.gfz-potsdam.de/kp_index/*file_name*
	Filename	qlyymm.wdc (current month)
		pqlyymm.wdc (previous month)
	Output format	Plain text file written in WDC format
	Forecast	
	Location	IRF Lund, Sweden
	URL	RESTful database query
	Query	http://lund.irf.se/progress/rest/datasets
		/irfkp2017/latest?limit=30&format=csv
	Output format	csv or json
	Forecast	
	Location	USFD, Sheffield, UK
	Storage format	Plain text files
	URL	http://www.ssg.group.shef.ac.uk/USSW2/Kp/*file_name*
	Filename	Kp_Output.txt (past year)

Table 3: Summary of *Dst* data sources

Dst	**Quicklook**	
	Location	WDC Kyoto, Japan
	URL	Query application
	Query	http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/ *yyyymm*/dst*yymm*.for.request
	Output format	Plain text in WDC format
	Forecast	
	Location	IRF Lund, Sweden
	Storage format	RESTful database
	URL	RESTful database query
	Query	http://lund.irf.se/progress/rest/datasets /irfdst2017/latest?limit=30&format=csv
	Output format	csv or json

Table 4: Summary of *AE* data sources

Dst	**Quicklook**	
	Location	WDC Kyoto, Japan
	URL	Query application
	Query	http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/ *yyyymm*/dst*yymm*.for.request CHECK ME
	Output format	Plain text in WDC format
	Forecast	
	Location	IRF Lund, Sweden
	Storage format	RESTful database
	URL	RESTful database query
	Query	http://lund.irf.se/progress/rest/datasets /irfae2017/latest?limit=30&format=csv
	Output format	csv or json

Table 5: Summary of GSO electron flux data sources

Forecast and Measurement	
Location	USFD, Sheffield, UK
Storage format	Plain text files
URL	http://www.ssg.group.shef.ac.uk/USSW/*file_name*
Filename	2M_Output.txt (past year)
	800k_Output.txt (past year)

Table 6: Summary of solar wind data sources

Measurement	
Location	NOAA
Storage format	Plain text files
URL	ftp://ftp.swpc.noaa.gov/pub/lists/ace/*file_name*
Filename	*yyyymmdd*_ace_mag_1m.txt (magnetic field)
	*yyyymmdd*_ace_swepam_1m.txt (plasma)