EGU2017-17250

PROGRESS: Fusion of forecasts from the Sun to the Earth

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PROGRESS has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 637302

ABSTRACT

The particle environment of the inner magnetosphere is strongly coupled to variations in the solar wind. The introduction of large fluxes of electrons into the radiation belts and their subsequent acceleration to high energies can result in the internal and surface charging of space assets, possibly leading to disruption and even cessation of essential services. Reliable forecast of the fluences of these electrons can assist in the mitigation of undesirable effects on spacecraft.

PROGRESS, an EU Horizon 2020 funded project, aims to provide forecasts of the evolution of the geospace environment beginning from the surface of the sun to the radiation belts. We review the current status of the projects and the challenges that still lie ahead.

For further details, visit the project web site
http://ssg.group.shef.ac.uk/progress/html/

Overview

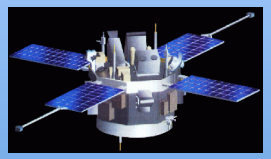
PROGRESS exploits space and ground based data as well as physical and systems based modeling techniques to develop accurate and reliable forecast of space weather.

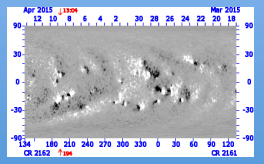
In particular, PROGRESS will:

- Develop a European model for solar wind forecasts at L1 (WP2).
- Develop new forecasting tools for geomagnetic indices (WP3).
- Construct new statistical wave models for plasma waves in the inner magnetosphere incorporating solar wind data sets (WP4).
- Expand now-cast capabilities of IMPTAM to provide forecasts of radiation belt (RB) low energy electron fluxes (WP3, 5).
- Develop a novel, reliable, and accurate RB forecast model exploiting the fusion of SNB^{3}GEO, IMPTAM, and VERB (WP6).
- Combine forecasts of geomagnetic indices, the RB, and solar wind at L1 to greatly increase prediction times (WP7).

Overview

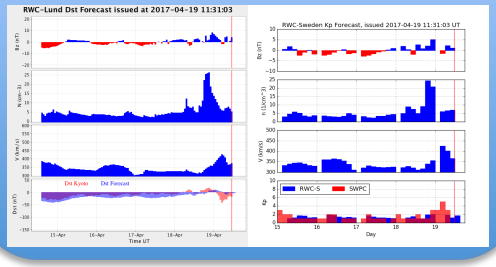
WP 2: Propagation of the Solar wind from the Sun to L1



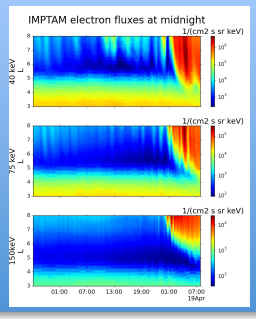


AWSoM/SWIFT

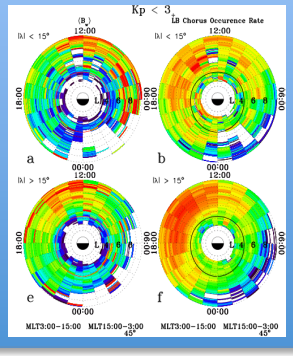
WP 3: Forecast of the Evolution of Geomagnetic indices



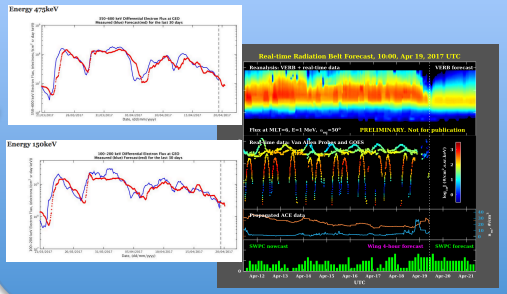
WP 5: Low energy electron model



WP 4: Development of new statistical models and the re-estimation of quasi-linear diffusion coefficients



WP 6: Radiation belt forecasts



WP 7: Fusion of forecast tools

Current Conditions

Time: 2017-04-19 12:15:12 UTC

Magnetosphere	Current	Forecast
Dst (nT)	-18	-40
Kp	1	1
Solar wind	Current	Forecast
|B| (nT)	10.1	9.2
Bz (nT gsm)	3.2	1
Density (cm^{-3})	5	6.5
Velocity (kms^{-1})	375.1	382.2
GEO e⁻ flux	Current	Forecast
F>2MeV	7.6409	6.1694
F>800keV	9.0563	8.1747

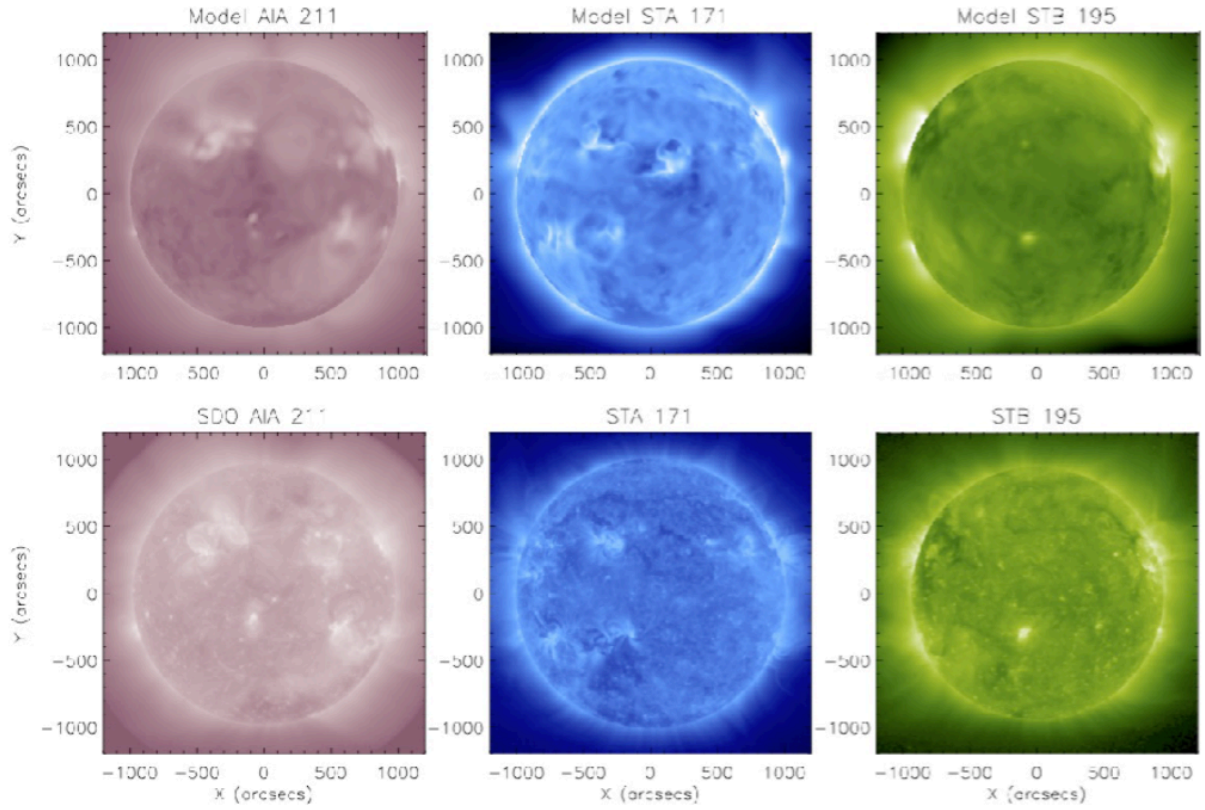
Solar wind propagation - Sun to L1

- Two models are used to estimate solar wind parameters at L1
  - AWESoM (U. Michigan) uses GONG magnetogram data to construct a potential field model out to $2.5R_S$. This provides input to full 3D AWESoM, propagating these fields out to ~$20R_S$.
  - SWIFT (U. Warwick) then propagates the solar wind conditions out to L1

Results

Current status

- AWESoM can qualitatively reproduce spectral features on the solar surface. Top line show model results, bottom line SDO observations

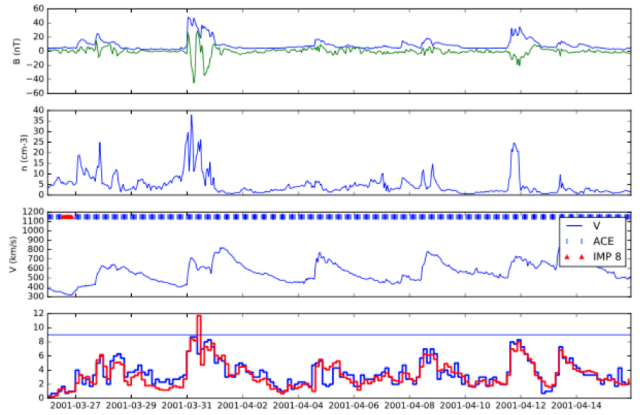


Forecast of Geomagnetic indices

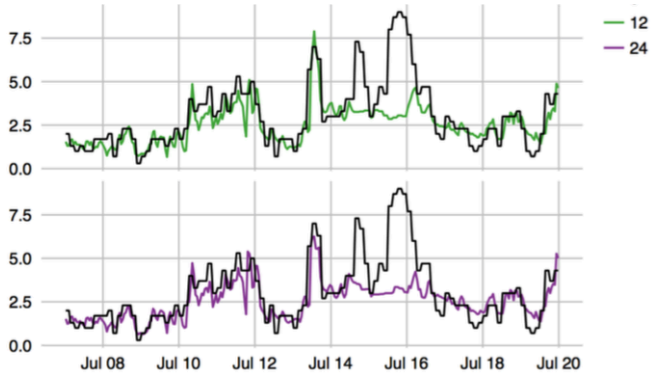
- Geomagnetic indices are used as inputs to many numerical models to encode different levels of geomagnetic activity
- Within PROGRESS new models for Dst, Kp, and AE are being developed
- The new models are based on different methodologies
  - Neural Networks (IRF-Lund)
  - NARMAX (U. Sheffield)
  - Robust bi-linear (SRI)

Examples of Kp forecasts

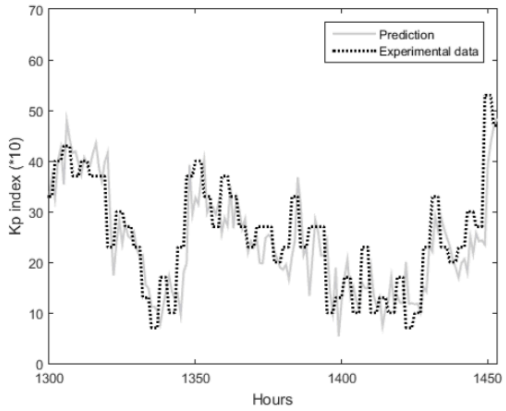
The top set of panels show soalr wind measurements of |B|, density, and velocity. The bottom panel shows the observed (blue) and forecast (red) from the new Lund Kp model.



The central two panels show the observed (black) and 12 (green) and 24 (purple) hour ahead forecast models from the new Sheffield NARMAX models



The lower panel shows the forecast outputs from the SRI robust bilinear model for a 7 day period.

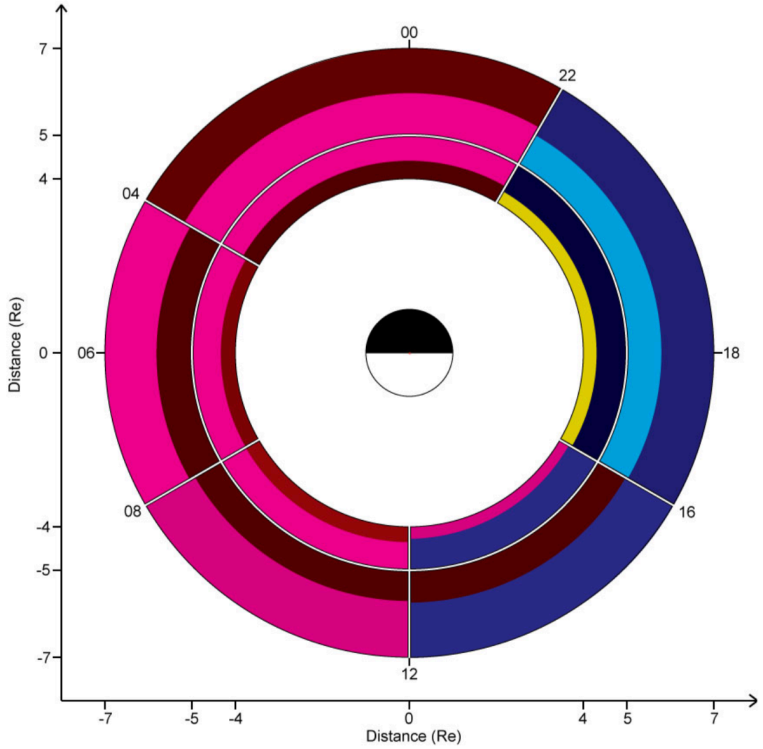


New statistical models

- Statistical wave models are used by numerical models to quantify effects of wave-particle interactions between the electron populations and various plasma wave modes.
- Prior to PROGRESS, such models were characterised by observation location and current level of geomagnetic activity.
- Within PROGRESS a new set of statistical wave models have been generated based on location and time histories of geomagnetic activity and solar wind parameters, using the NARMAX ERR methodology.

Example model

The figure shows the two parameters and their respective time lags that are determined to have the greatest influence on the amplitude of lower band chorus waves in various MLT and L-shell sectors.



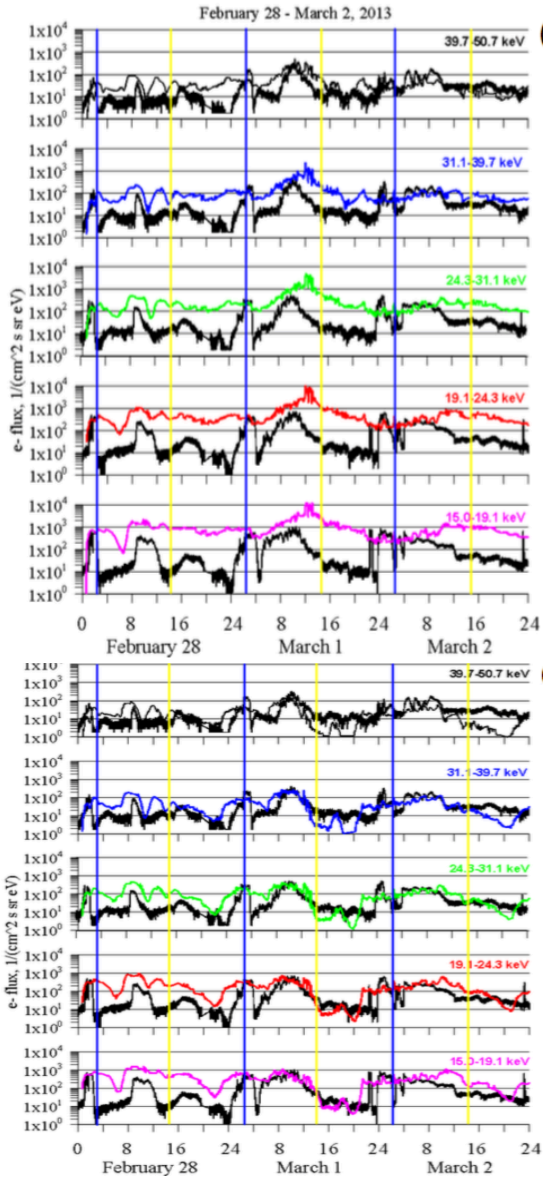
Input \ Time lag (hours)	1	2	3	4	5	6	7	8	9	10
Velocity										
Density										
Pressure										
IMF Factor										
Dst Index										
AE Index										

Low energy electron model

- Large fluxes of low (keV) electrons within the radiation belts are responsible for the surface charging effects experienced by satellites.
- Forecast of realistic flux levels enable satellite operators to estimate the likelihood of surface charging events.
- Mitigation steps may be put into action to reduce the level of impact of such events, enabling longer, more continuous operation of satellite infrastructure.

IMPTAM updates - results

- Within PROGRESS the IMPTAM low energy electron model has been substantially improved to yield realistic flux forecasts.
- New sets of diffusion coefficients have been included as well as new models for electron loss.
- The figures show results in which no loss mechanisms are considered (top) and the inclusion of losses due to hiss and chorus waves and the new set of electron lifetime figures.



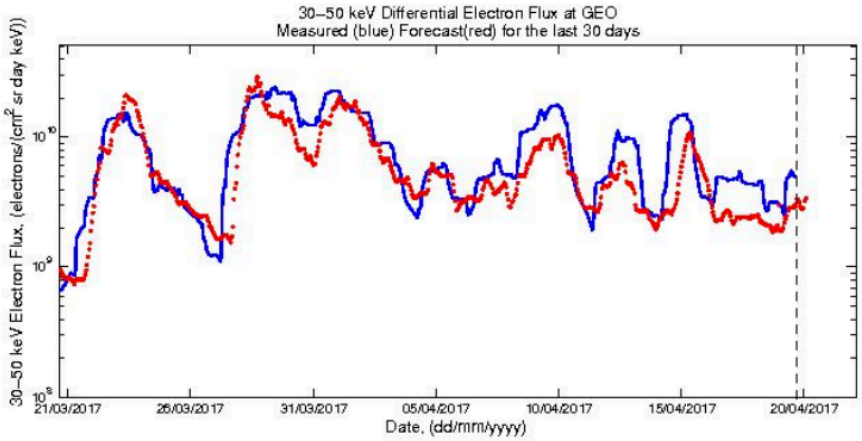
Radiation belt forecasts

- Large fluxes of high energy electrons lead to internal charging of satellites.
- Internal discharges can upset satellite subsystems, even cause permanent damage.
- PROGRESS provides models for:
  - Electron fluxes at GEO using NARMAX
  - Electron fluxes within the whole radiation region using VERB
  - VERB driven by NARMAX flux estimates

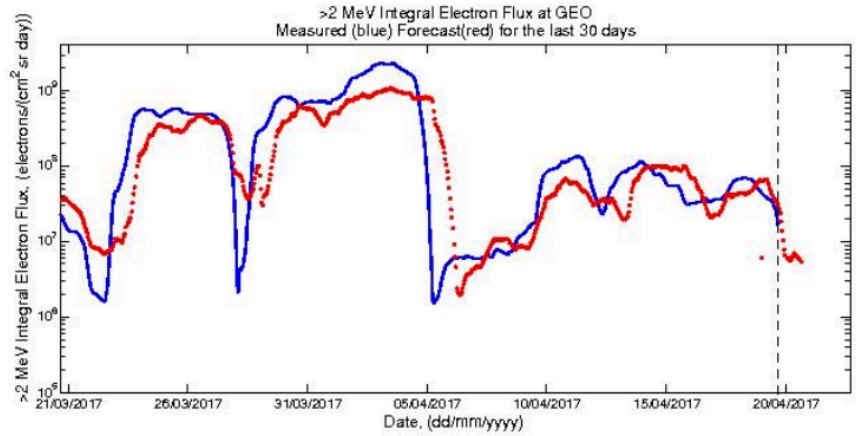
Electron Fluxes at GEO

- NARMAX models are used to forecast electron fluxes at energies of 40, 75, 150, 275, 475, >800, >2000 keV at GEO
- Models found to out perform NOAA REFM.
- Plots available for time scales 10d, 30d, 90d, 200d, 1y

Energy 40keV



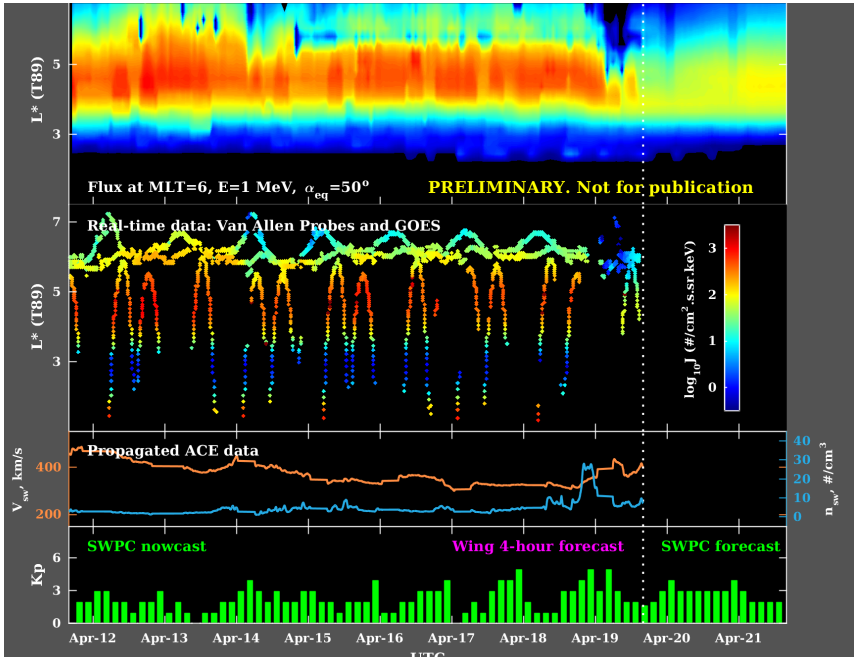
Energy 2MeV



VERB updates

PROGRESS updates to VERB include:

- Better diffusion coefficients
- Inclusion of wave modes such as hiss
- Data assimilation



VERB-NARMAX

- Combines advantages of the NARMAX flux models for GEO and VERB
- VERB is driven by values of Kp and electron boundary flux
- NARMAX electron flux forecasts are used to compute the electron boundary flux used as input to VERB
- Methodology currently being tested and validated

Fusion of forecast tools

- Tools and results generated by PROGRESS are being integrated into the project web site.

- Currently available plots:
  - Forecasts of Dst and Kp generated by the new models developed at Lund
  - Forecasts of electron fluxes at geostationary orbit
  - Forecasts of low energy electron fluxes in the RB
  - Forecasts of high energy electron fluxes in the RB

- Future developments
  - Panel summarising current and forecasted solar wind conditions
  - Access to the new statistical wave models
  - Tool for estimating electron environment along a satellite orbit
  - Access to numerical results