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# Solar wind control of the electron fluxes at geostationary orbit

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## ABSTRACT

The interaction of CMEs and other solar wind irregularities with the terrestrial magnetosphere may result in the production of large fluxes of high energy electrons within the radiation belts, posing a severe threat to the operations of spacecraft at geostationary orbit. It is observed that the time delay between cause and effect depends upon the particle energy. In the framework of the Horizon 2020 funded project PROGRESS, models for the forecast of daily electron fluxes at various energies driven by solar wind parameters have been developed. This presentation will discuss the development and performance of these models, comparing the results to other models. The methodology for the inclusion of an MLT dependence within these models is discussed and initial results presented.

## INTRODUCTION

The fluence of high energy electrons within the radiation belts may vary by orders of magnitude in less than a few hours, posing potential risk to satellites whose orbits cross this region. While we currently have a general understanding of the mechanisms involved in the processes of electron loss and acceleration within the radiation belts, the quantification of these processes is far from complete. As a result, numerically based can struggle to replicate the observed dynamics and evolution.

In this poster, we discuss the use of a complementary modelling scheme developed in the field of systems science. This class of models are data based and employ algorithms to automatically characterise a system based on measurements of the input and output to the system. Various systems methodologies have been used in space physics. These include linear prediction filters, dynamic linear models, neural networks (NN), as well as the method described in this poster NARMAX (Nonlinear Autoregressive Moving Average with Exogenous inputs). Of these methods, only NN and NARMAX are capable of dealing with nonlinear systems, but only NARMAX yields an interpretable model that can be related to the physical process occurring.

## NARMAX METHODOLOGY

The main advantage of NARMAX is its ability to generate physically interpretable models. This feature has meant that NARMAX has been successfully used in a large number of fields in science, engineering, and medicine including space physics.

A multi input single output NARMAX model (Leontaritis and Billings, 1985a,b) is expressed as

$$
\begin{aligned}
y(t) = F\,\big[&y(t-1), \dots, y\left(t-n_y\right), \\
&u_1(t-1), \dots, u_1\left(t-n_{u_1}\right), \dots, \\
&u_m(t-1), \dots, u_m\left(t-n_{u_m}\right), \dots, \\
&e(t-1), \dots, e\left(t-n_e\right)\big] + e(t)
\end{aligned}
$$

where y represents in the system output, $u_1$-$u_m$ the inputs, e the error terms, whose values are measured at various lag times t-1, to t-n where n is the number of lag terms considered and F[.] is a nonlinear function.

The first step on the NARMAX methodology is structure determination using the Error Reduction Ratio to find the combinations of the input parameters (at various time lags) that have the most significance on the variance of the output signal. Once the model structure terms have been extracted the coefficient for each term is calculated. The final stage is the validation of the resulting model.

NARMAX models have been produced for the energy ranges >2 MeV and >800 keV, corresponding to the energy channels used by the GOES Energetic Proton Electron and Alpha Detector (EPEAD) instrument (Hanser 2011). For the highest energy channels they provide 24 hour ahead forecasts of the electron fluxes. Examples of the available online plots (at https://ssg.group.shef.ac.uk/progress/html/narmax_results.phtml)

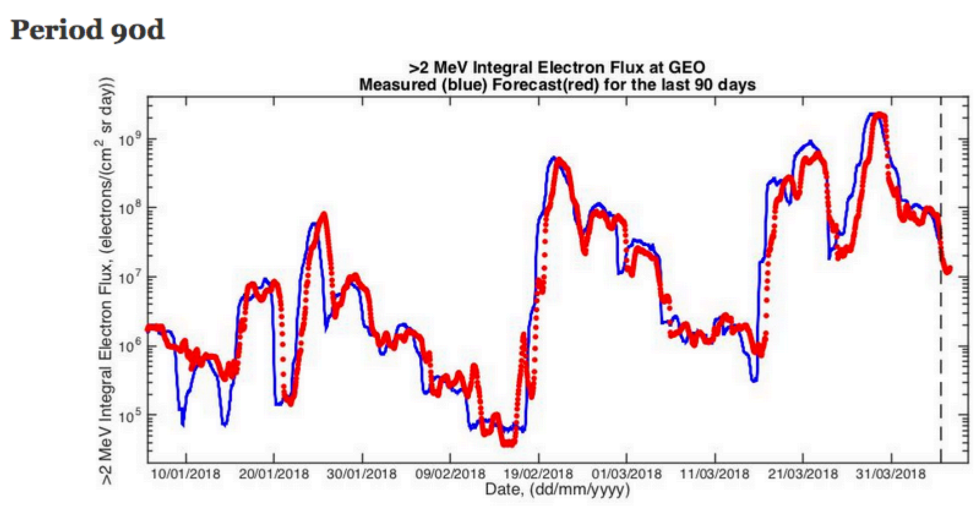


Figure 1: Comparison of model forecasts and observations.

## ELECTRON FLUX MODELS

The NARMAX models for electron fluxes in the energy ranges >2 MeV and >800 keV have been re-developed to use 24 hour running averages with a time resolution of 1 hour and their performance measured by calculating the Prediction Efficiency (PE) and correlation coefficient (ρ). The values, based on data in the period 1 Jan 2011 to 28 Feb 2015 are shown in Table 1. Figure 2 shows a comparison of the model output with observations and the error.

Table 1: Performance of the models

| Energy | PE | ρ |
|---|---|---|
| >800 keV | 72.1% | 85.1% |
| >2 MeV | 82.3% | 90.9% |

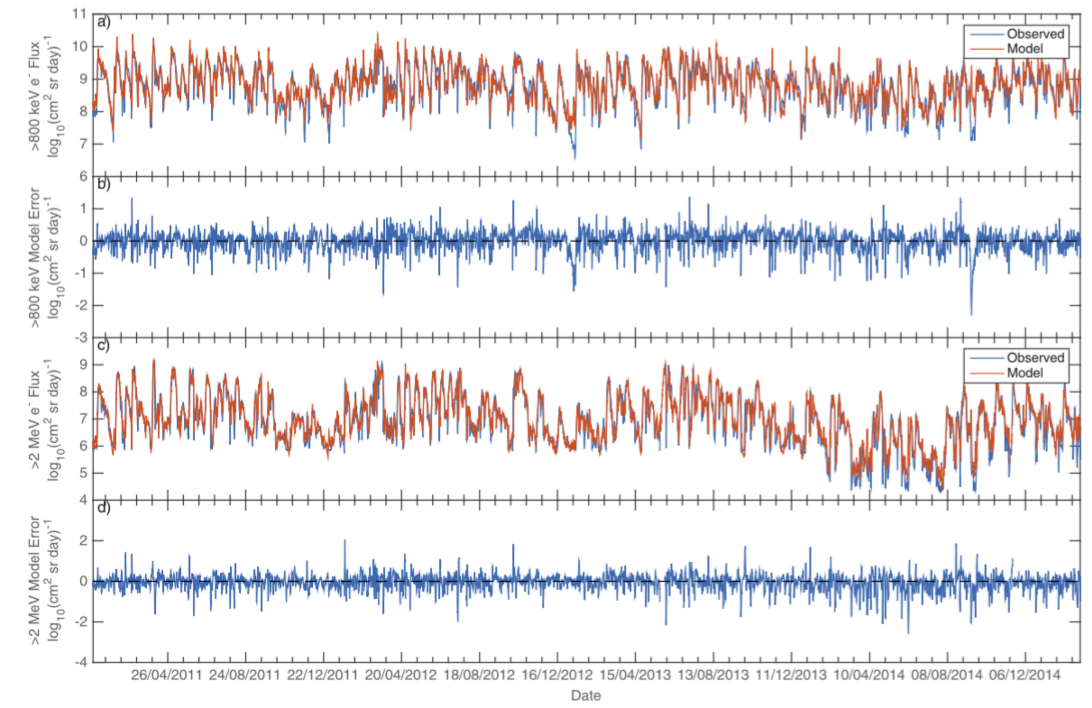

Figure 2: Comparison of model forecasts and observations.

A 24 hour ahead forecast can be generated for the >2MeV and >800 keV energy channels since the minimum time delay between changes in the solar wind and electron fluxes at these energies is greater than a day (Boynton 2013). However, for lower energies, the magnetospheric response time is less that one day and so 24 hour ahead forecasts are not really useful. The use of running 24 hour averages of the input parameters were used to investigate the forecast horizon of the lower energy channels. Figure 3 shows how the PE changes with minimum lag time for 30-50 keV electrons. It shows that the model may only forecast up to 10 hours ahead with decent accuracy.

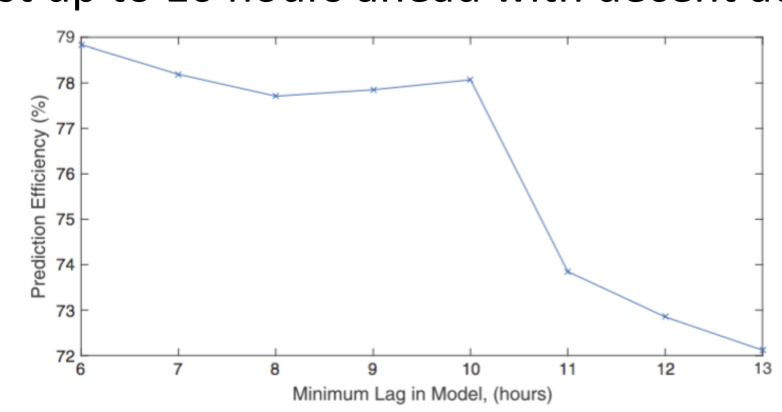

Figure 3: Change in PE with minimum lag time.

## MLT DEPENDENCE

The current set of models are built using 24 hour averages. As a result, any structure in MLT is lost. To address this point a set of MLT models are currently under development. The main problem encountered is the lack of continuous measurements in different MLT sectors. The two GOES spacecraft that measure the electron fluxes have orbited the Earth with a separation that has varied between 1 – 4 MLT since 2010, which means they are only at specific MLTs for a short time. To obtain a dataset that could be modelled by the NARMAX algorithm, the data was sampled at 1 hour MLT from 0 MLT to 23 MLT, resulting in 24 time series datasets for each MLT. A NARMAX model was developed for each one of the 24 datasets, trained on a period from 01 January 2011 to 01 March 2013 and then tested on data from 02 March 2013 to 31 December 2017. The models are able to forecast the electron fluxes with prediction efficiencies between 47% -75% and correlation coefficients between 51% - 79%.

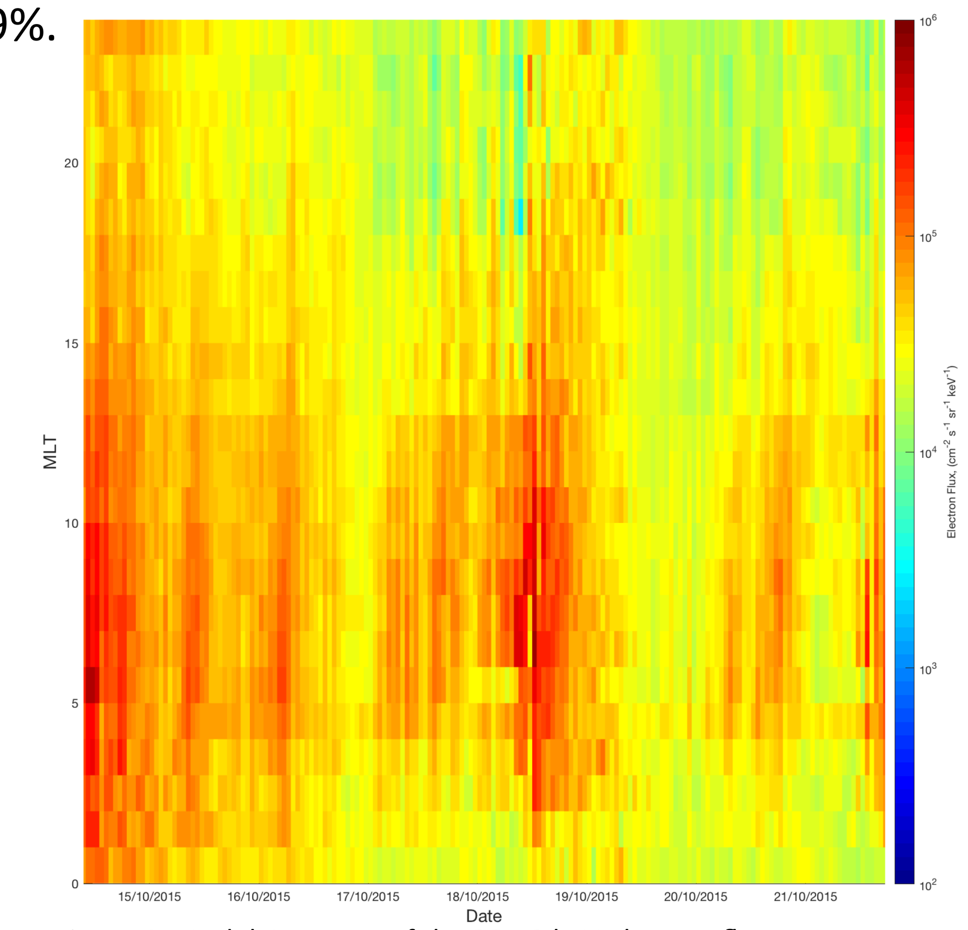

Figure 4: Model Pastcasts of the 30-50 keV electron fluxes at different MLT for GEO.

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