The University Of Sheffield.

Application of NARMAX methodology to the forecast of radiation environment in the Geospace.

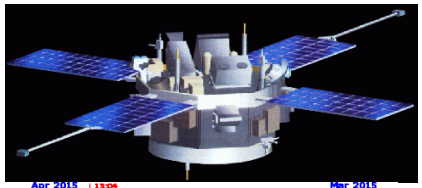
ssg.group.shef.ac.uk/progress/html

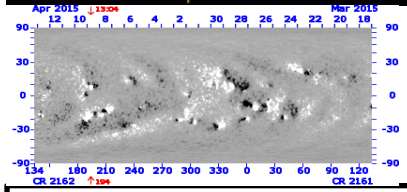
This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 637302.

Participants

 The University Of Sheffield.	R. Von Fay-Siebenburgen, M. Balikhin, S. Walker, R. Boynton
 ILMATIETEEN LAITOS METEOROLOGISKA INSTITUTET FINNISH METEOROLOGICAL INSTITUTE	N. Ganushkina, I. Sillanpaa, S. Dubyagin
 THE UNIVERSITY OF WARWICK	T. Arber, K. Bennett
 GFZ Helmholtz Centre POTSDAM	Y. Shprits
 UNIVERSITY OF MICHIGAN	M. Liemohn, B. van der Holst
 ІКД	V. Yatsenko
 LPC2E	V. Krasnoselskikh, V. Shastun
 IRF	P. Wintoft, M. Wik

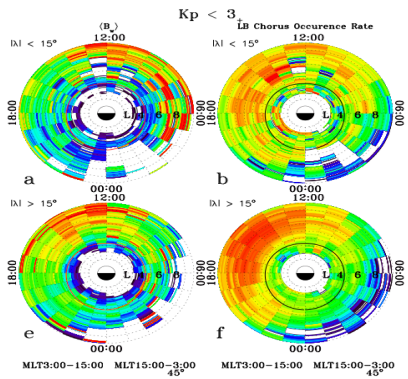
Overview





Solar wind propagation from Sun to L1 (AWSoM/SWIFT)

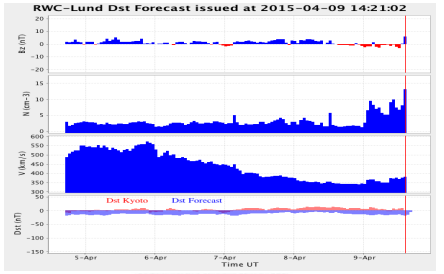
Development of new statistical models

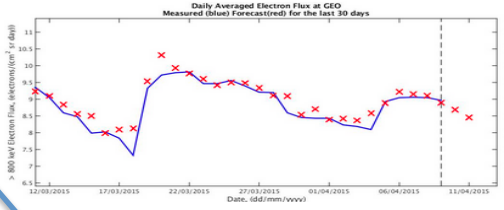


Low energy electron model (IMPTAM)

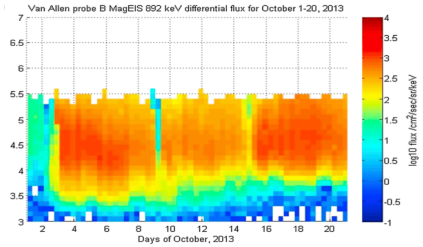
Forecast of the Evolution of Geomagnetic indices

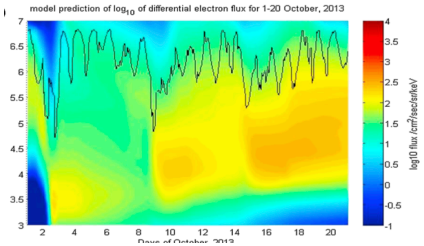
Forecast of the high energy electron environment





Fusion of forecast tools





Pakhotin, Shprits Drosdov, Balikhin VERB- NARMAX

System Identification Approach

Analytical Approach

$$S = \int L(x, \dot{x}, t)\,dt$$

$$dL = \sum_i \frac{\partial L}{\partial x_i} dx_i + \sum_i \frac{\partial L}{\partial \dot{x}_i} d\dot{x}_i$$

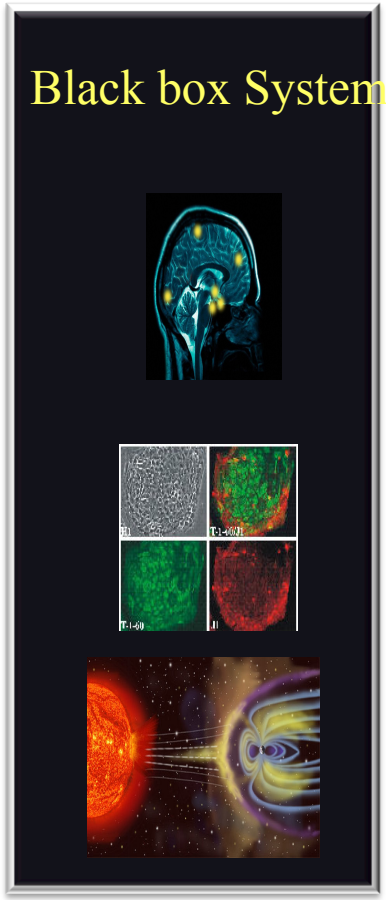
Assumptions

+

Physical Knowledge

+

First Principles

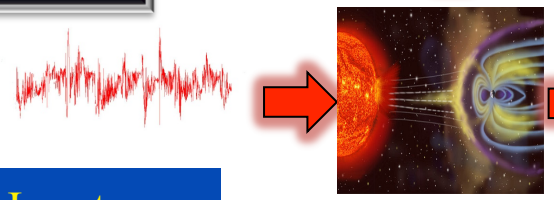


Systems Approach

Knowledge of the System

$$S = \int L(x, \dot{x}, t)\,dt$$

$$dL = \sum_i \frac{\partial L}{\partial x_i} dx_i + \sum_i \frac{\partial L}{\partial \dot{x}_i} d\dot{x}_i$$



Input Data

Output Data

The NARMAX approach

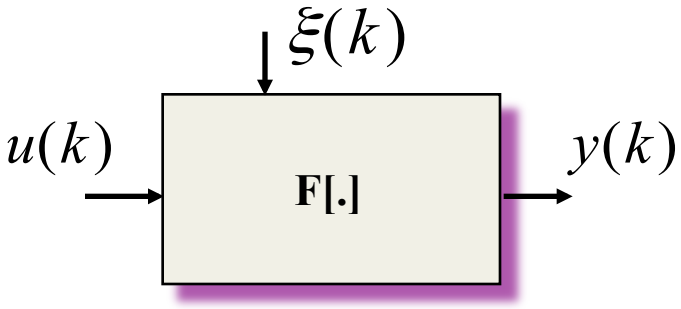
- the NARMAX model is given as:

$$y(k) = F[y(k-1),\ldots y(k-n_y),u(k),\ldots,u(k-n_u),\xi(k-1),\ldots,\xi(k-n_\xi)] + \xi(k)$$

$y(k)$: system output

$u(k)$: system input

$\xi(k)$: noise



$F[\cdot]$ nonlinear function (polynomial, rational, B-spline, RBF)

The NARMAX approach

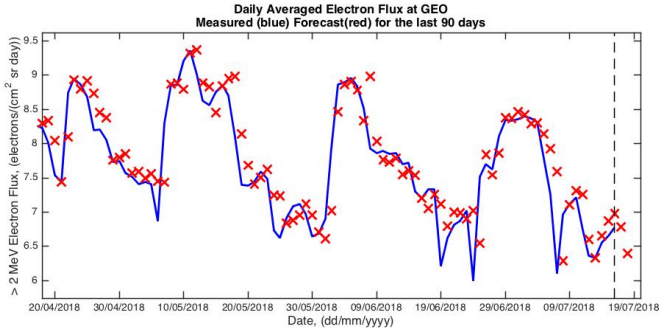
Identification methodology:

- Structure detection: Orthogonal Least-Squares estimator (ERR structure detection)
- Parameter estimation
- Model validation:
  - statistical validation
  - dynamical validation

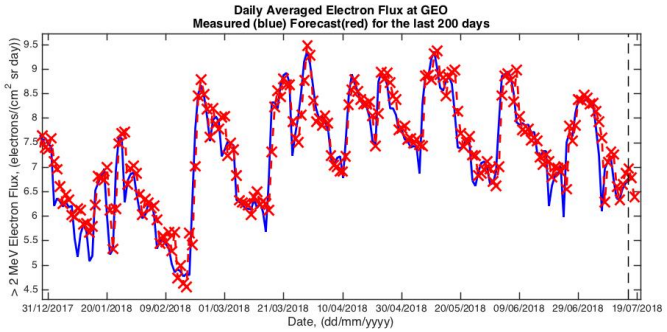
$$\frac{dy}{dt} = 3.1\frac{dx}{dt} + 4.2x - \frac{xdx}{dt} + 2x^3$$

Model Structure: $x; x^3; \frac{dx}{dt}; \frac{xdx}{dt}.$

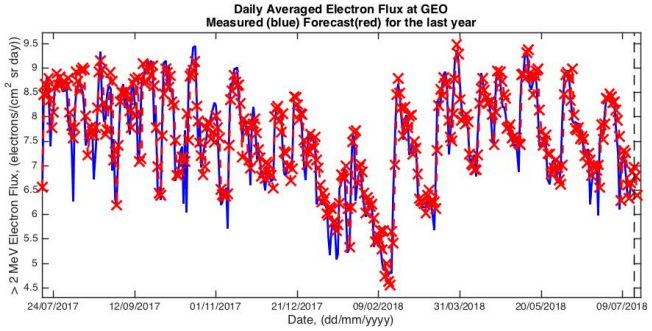
Online Forecasts – SNB^{3}GEO



Past 200 days



Past year



The one day ahead forecasts of the relativistic electron fluxes with energies greater than 2 MeV at GEO has been developed in Sheffield and is available in real time:

http://ssg.group.shef.ac.uk/ssg2013/UOSSW/2MeV_EF.html

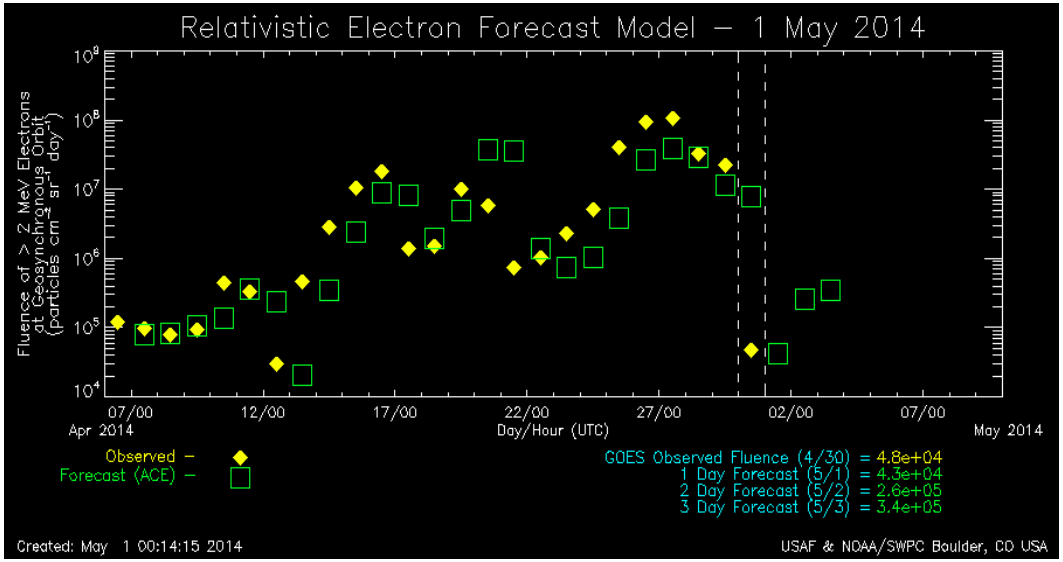
NOAA REFM Forecast

Space Weather Prediction Center 01/05/2014 21:09

NOAA / Space Weather Prediction Center

Relativistic Electron Forecast Model

Presented by the USAF and NOAA/ Space Weather Prediction Center



The impact of high-energy (relativistic) electrons on orbiting satellites can cause electric discharges across internal satellite components, which in turn leads to spacecraft upsets and/or complete satellite failures. The Relativistic Electron Forecast Model predicts the occurrence of these electrons in geosynchronous orbit.
Plots and data are updated daily at 0010 UT. Dashed vertical lines indicate the last vertical value.
When the input parameters are not available, the forecast is not shown.

REFM Verification Plot and Model Documentation

1 to 3 Day Predictions (text file) and corresponding Performance Statistics.
Predictions created using data from the ACE spacecraft.

Historical electron particle data is archived at the
National Geophysical Data Center for Solar-Terrestrial Physics.

Visually impaired users may contact SWPC for assistance.
Please credit SWPC when using these images.

Comparison of REFM and SNB^{3}GEO Forecasts

Balikhin, Rodriguez, Boynton, Walker, Aryan, Sibeck Billings, SW 2016

Model	Prediction Efficiency Flux	Correlation Flux	Prediction Efficiency Log Flux	Correlation Log Flux
REFM	-1.31	0.73	0.70	0.85
SNB^{3}GEO	0.63	0.82	0.77	0.89

$$PE = 1 - \frac{1}{N}\sum \frac{(Y(t) - Ym(t))^2}{\mathrm{var}(Y)} \; ; \; C_{cor} = \frac{1}{N}\sum \frac{(Y(t) - \langle Y(t)\rangle)(Ym(t) - \langle Ym(t)\rangle)}{\sqrt{\mathrm{var}(Ym)\mathrm{var}(Y)}}$$

Comparison of REFM and SNB^{3}GEO Forecasts

Balikhin, Rodriguez, Boynton, Walker, Aryan, Sibeck Billings, SW 2016

Table 2. Contingency tables and Heidke skill scores for the REFM predictions.

Fluence ($cm^{-2}sr^{-1}day^{-1}$)	$> 10^8$		$> 10^{8.5}$		$> 10^9$	
REFM HSS	0.666		0.482		0.437	
Observation:	Yes	No	Yes	No	Yes	No
Forecast						
Yes	86	22	23	22	4	7
No	43	510	21	595	3	647

Table 3. Contingency tables and Heidke skill scores for the SNB^{3}GEO predictions.

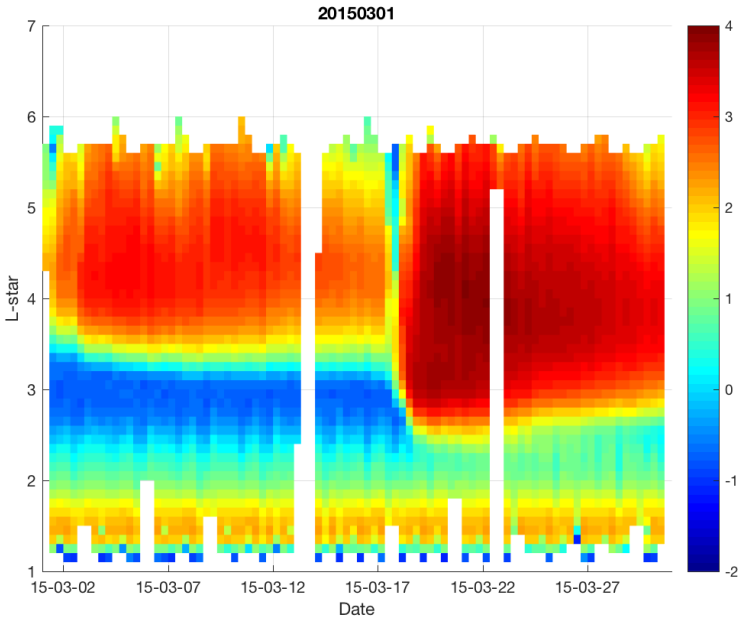
Fluence ($cm^{-2}sr^{-1}day^{-1}$)	$> 10^8$		$> 10^{8.5}$		$> 10^9$	
SNB^{3}GEO HSS	0.738		0.634		0.612	
Observation:	Yes	No	Yes	No	Yes	No
Forecast						
Yes	106	33	31	19	4	2
No	23	499	13	598	3	652

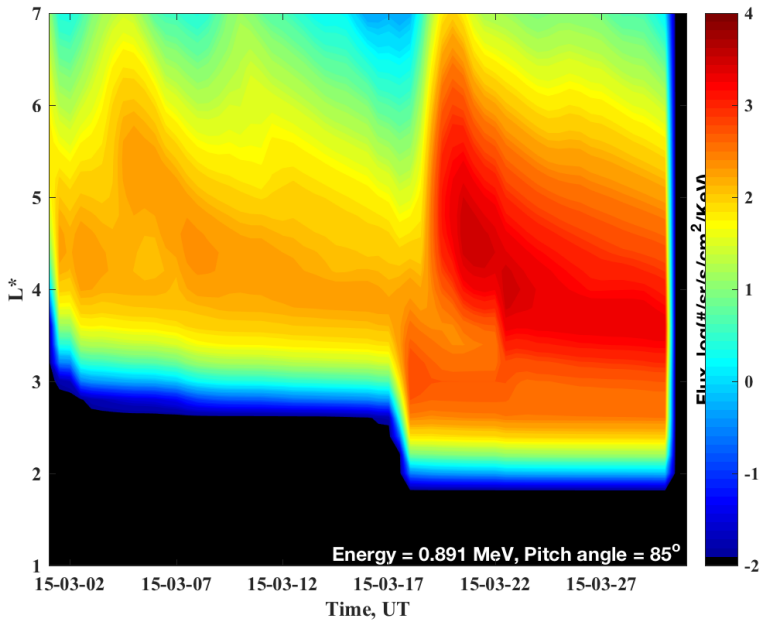
$$S = \frac{2(xw - yz)}{y^2 + z^2 + 2xw + (y + z)(x + w)}$$

Fusion of the "first principles" and data based forecasts

- Boundary conditions: VERB+SNB^{3}GEO

S. Walker, I. Pakhotin, A. Drozdov, Yu. Shprits, M. Balikhin



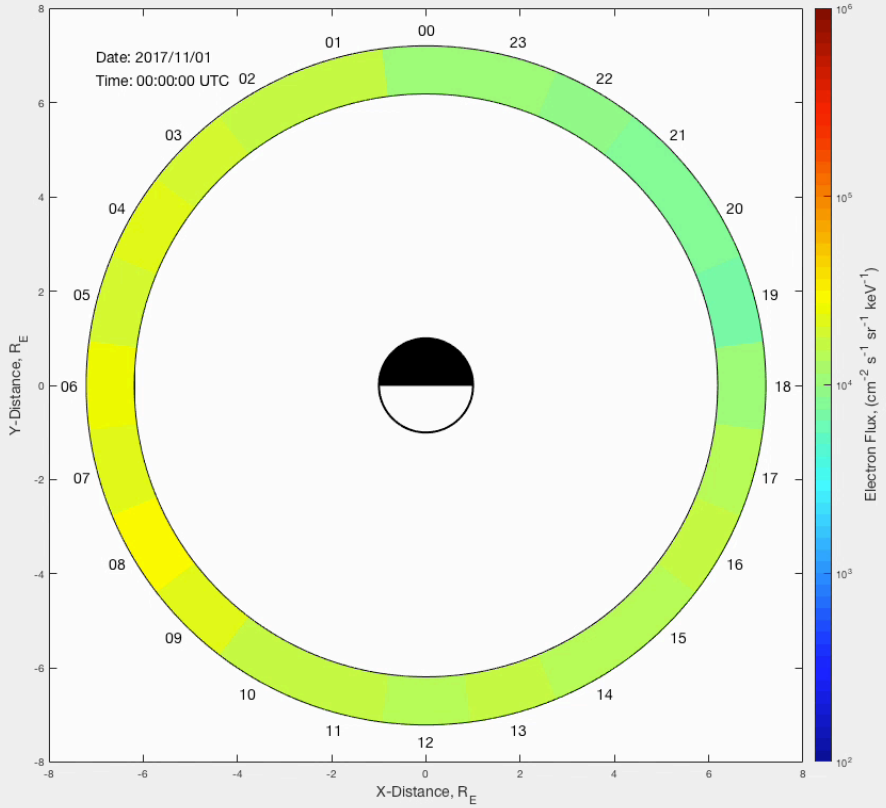


Simulation of high-energy radiation belt electron fluxes using NARMAX-VERB coupled codes

SNB3GEO provides forecast of a single integral value for the whole GEO orbit. NARMAX forecast of boundary conditions for each MLT is required to improve the performance of fusion model.

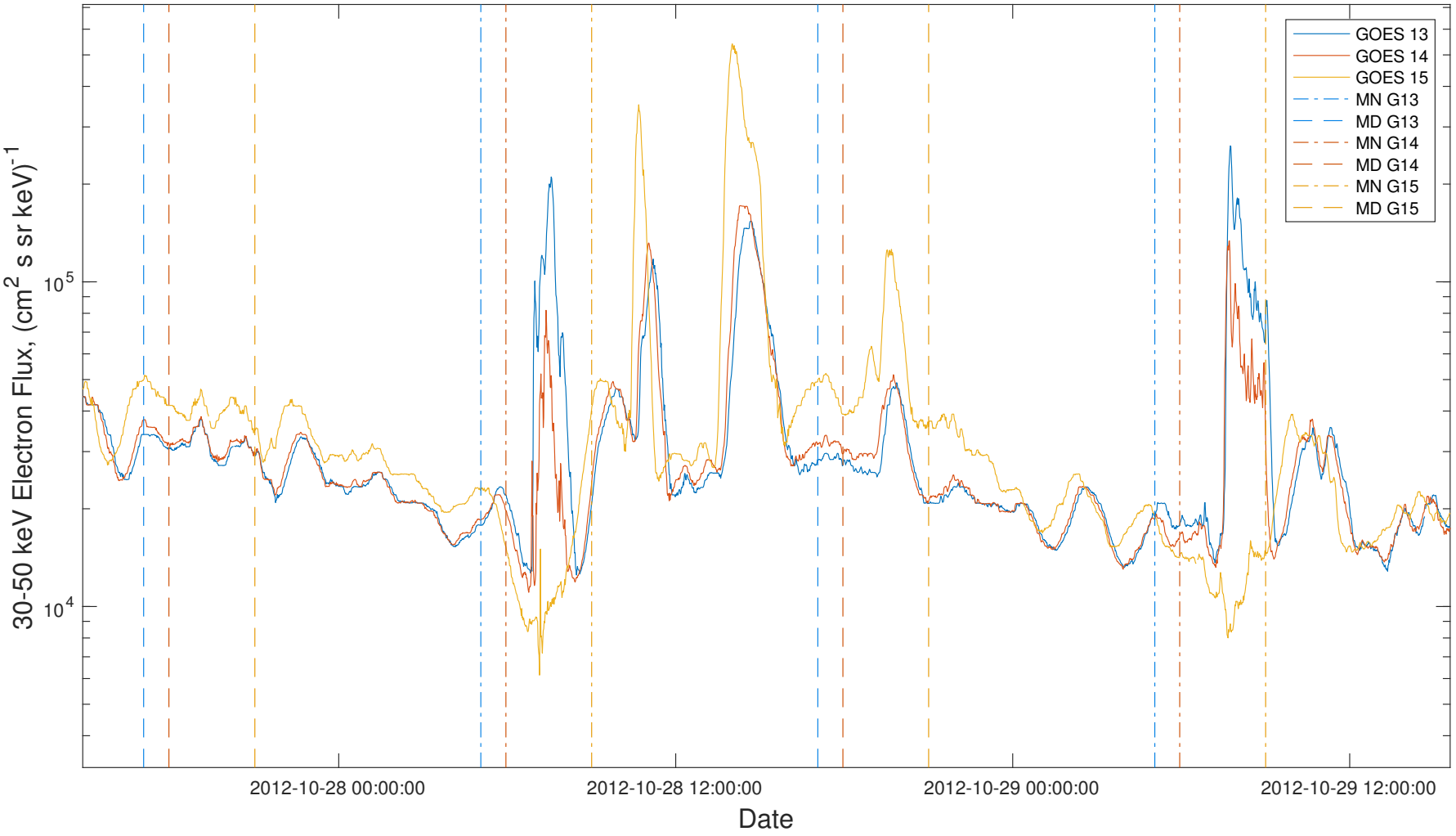
Local Time Dependant Electron Flux Models for GEO

R. Boynton, O. Amariutei, M. Balikhin



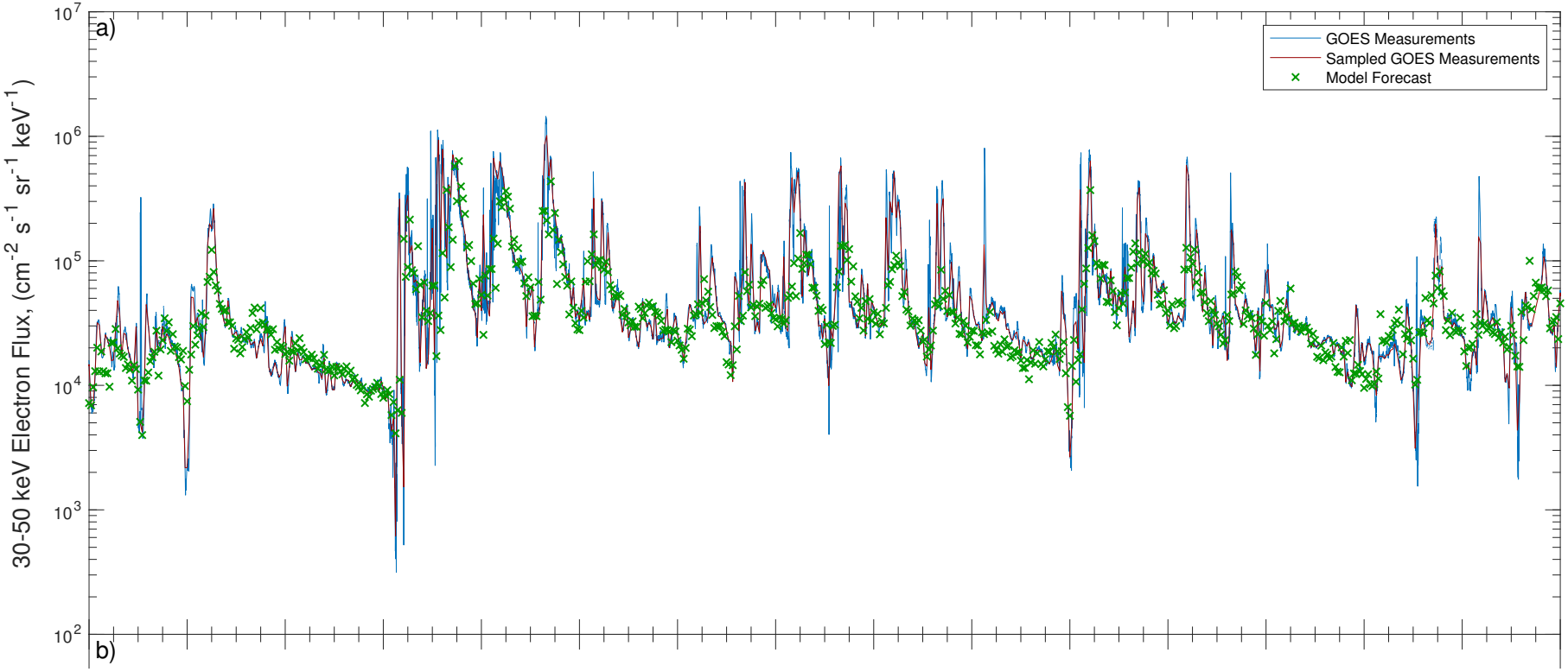
The University Of Sheffield.

Local Time Dependent Electron Flux Models for GEO (30-50 keV)



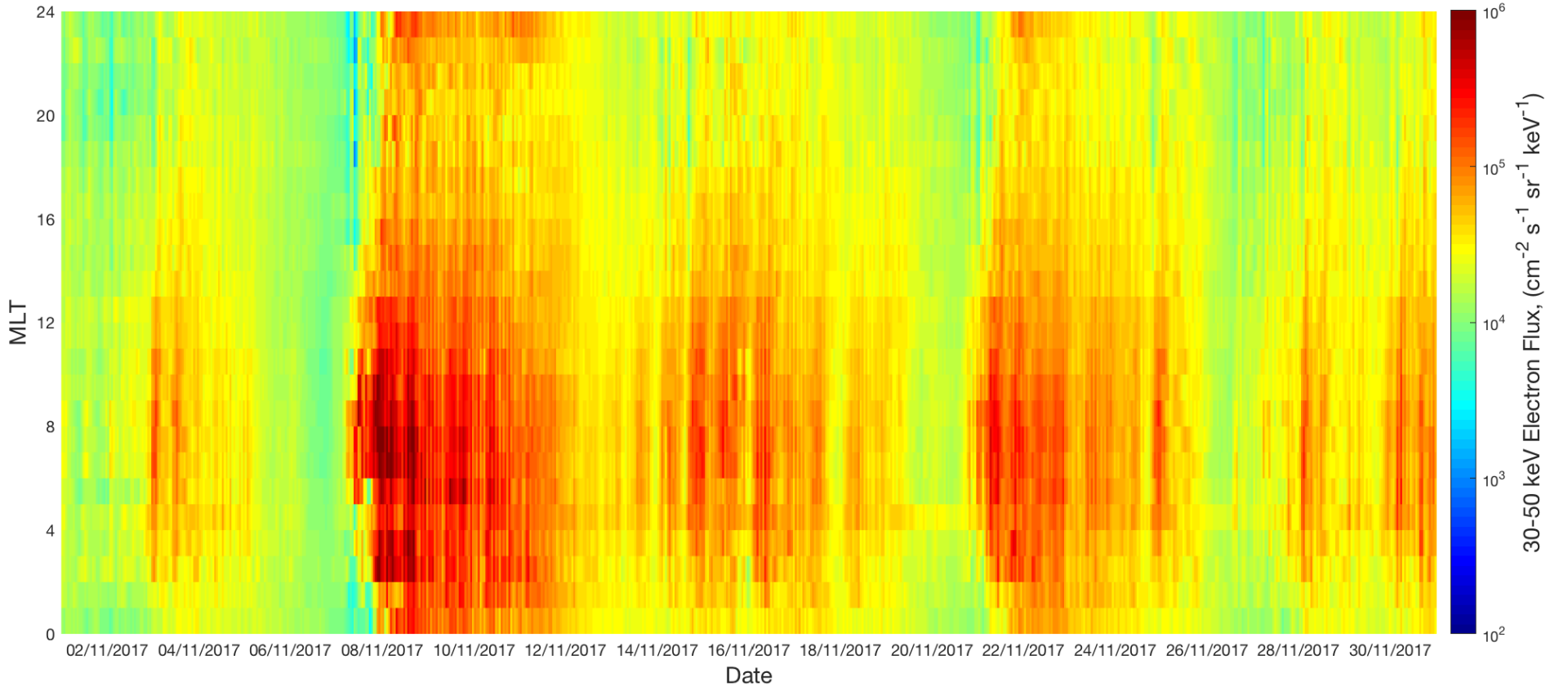
The University Of Sheffield.

Local Time Dependent Electron Flux NARX Models for GEO (30-50 keV)



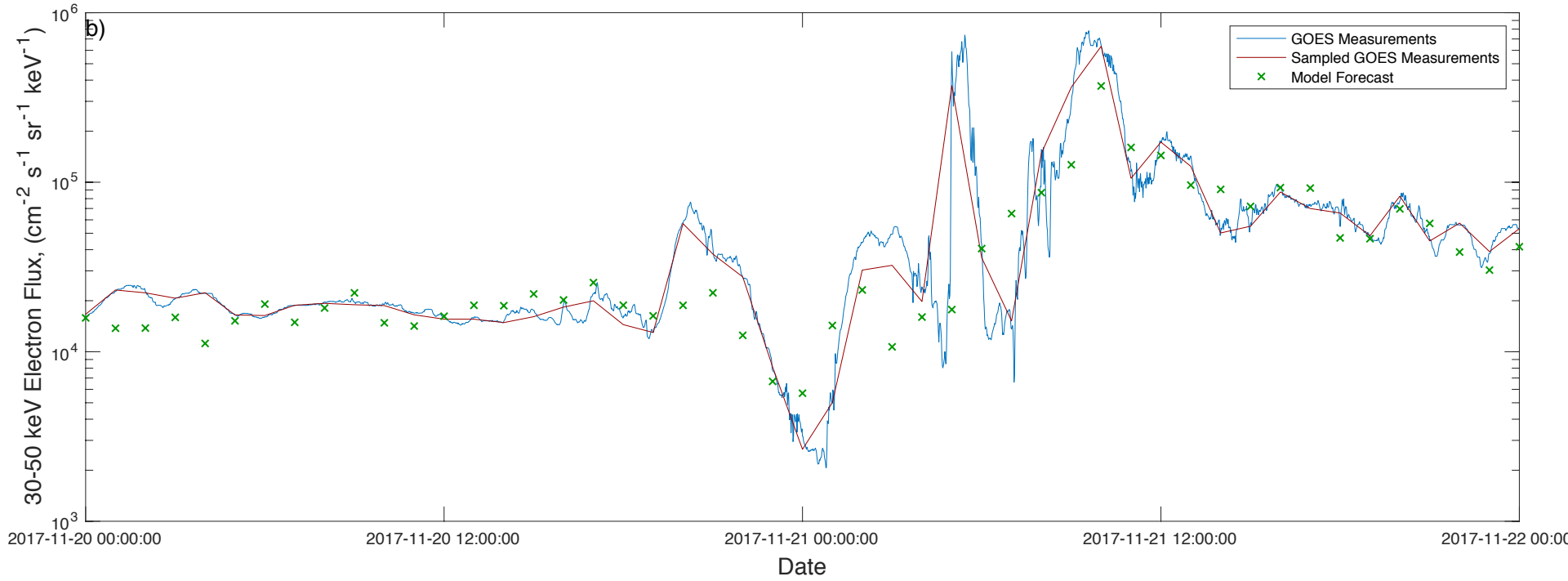
The University Of Sheffield.

Local Time Dependent Electron Flux NARX Models for GEO (30-50 keV)



The University Of Sheffield.

Local Time Dependent Electron Flux Models for GEO (30-50 keV)



Local Time Dependent Electron Flux Models for GEO (30-50 keV)

R. Boynton, O. Amariutei, M. Balikhin