Systems based forecasts of electron fluxes at GEO

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Abstract

Accurate forecasts of the electron environment in the radiation belts are vital in order to model the health and status of satellites whose orbits pass through this region. Currently, the best forecasts for GEO are obtained using systems science models e.g. NARMAX. This presentation discusses the application of the NARMAX methodology to the estimation and forecasts of radiation belt electron fluxes for energies in the range ~30keV to >2MeV, and provides a comparison of the forecasts with measurements GOES 13 and 15.

Radiation Belts

The high fluence of these energetic electrons can cause a number of problems on spacecraft depending on the electron energy.

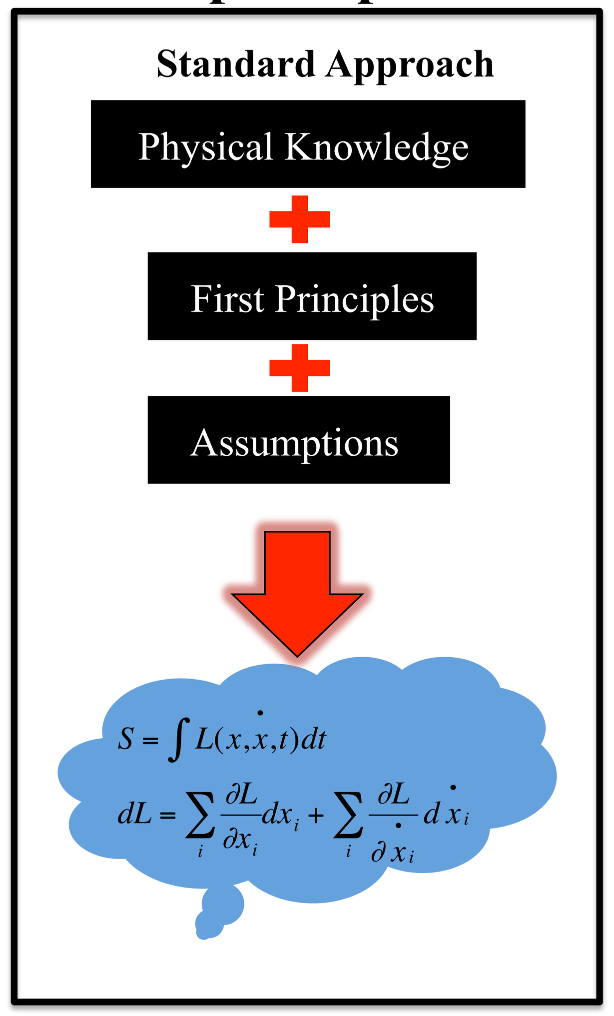
For example, low energy electrons (10 keV to a few hundred keV) can cause surface charging that interferes with the satellite electronic systems.

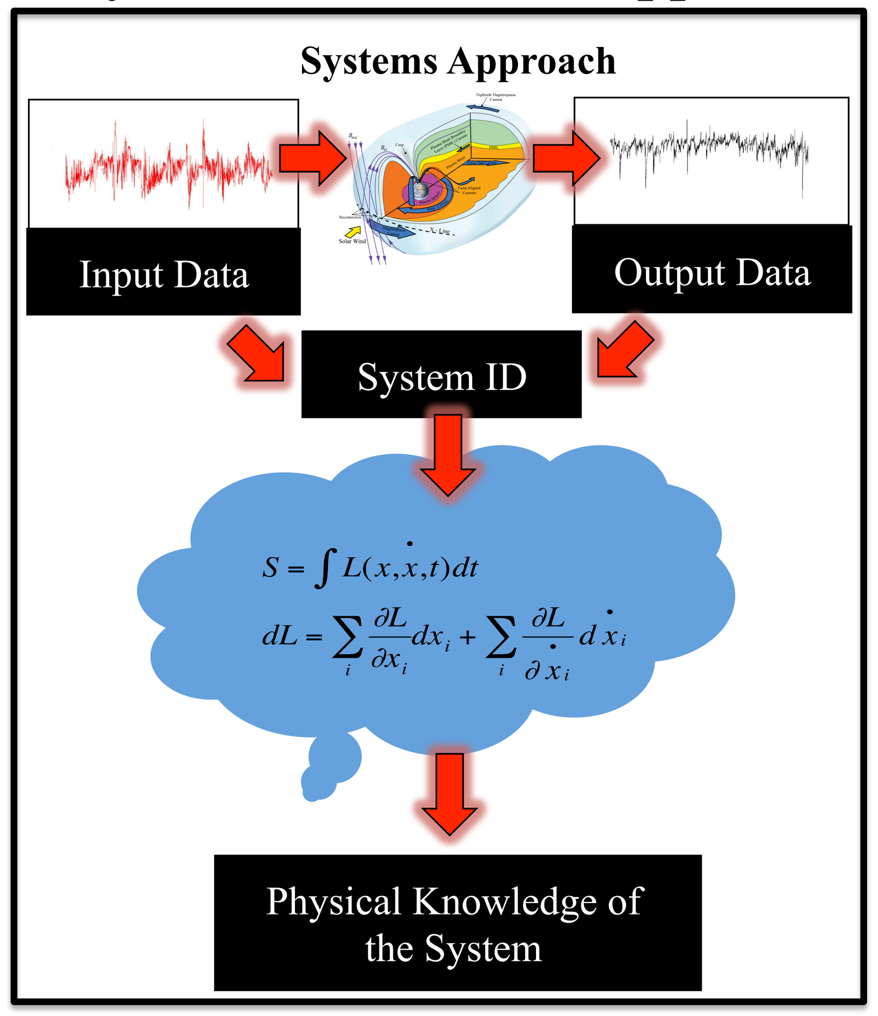
For higher energies (about 1 MeV and above) cause deep dielectric charging that may permanently damage the dielectric material onboard the satellite.

Some of the effects of the energetic particles can be mitigated. However, this requires prior knowledge of high energetic electron populations that are dangerous to satellites. Models are required for these forecasts.

Modelling

First principles vs. System identification approach





NARMAX

Nonlinear AutoRegressive Moving Average eXogenous inputs

$$y(t) = F[y(t-1),...y(t-n_y), u_1(t-1),...,u_1(t-n_{u_1}),..., u_m(t-1),...,u_m(t-n_{u_m}), e(t-1),...,e(t-n_e)] + e(t)$$

Involves three stages

1. Structure selection:
2. Coefficient estimation
3. Model validation

Data

The NARMAX algorithm requires both input and output data for the algorithm to deduce a model.

Inputs Data: Velocity, Density, pressure, the fraction of time that the solar wind remains southward within each day, and $B_T \sin^6(\theta/2)$

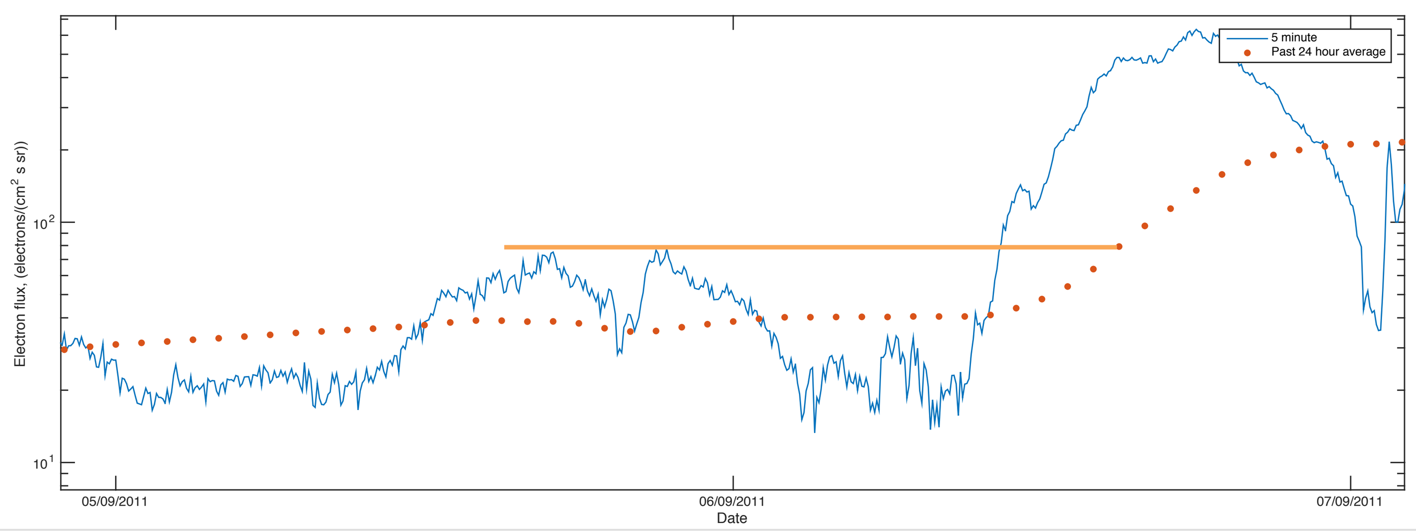
These data were from the Advanced Composition Explorer (ACE) spacecraft positioned at the L1 Lagrange and supplied by the OMNI website for training the model.

The models also included the Dst index as an input, which was supplied by the World Data Center for Geomagnetism, Kyoto.

Output Data: The output for each of the models are the daily averaged electron flux measurements taken from GOES at GEO and are supplied by NOAA NWS Space Weather Prediction Center.

Moving Average Data

After training the models on daily average data, the 5-minute electron flux values were time averaged resulting in a data set with 1-hour resolution, such that each 1-hour point was determined by averaging the 5-minute data over the past 24 hours, e.g., the point at 15:00:00 UTC on 6 September 2011 is average of the 288 5-minute points between 15:05:00 UTC on 5 September 2011 and 15:00:00 UTC on 6 September 2011. This data would then be compared to the model forecast.



Statistical Analysis of the Models Performance

Prediction Efficiency

$$PE = 1 - \frac{\sum_{t=1}^{N}\left[\left(y(t)-\hat{y}(t)\right)^2\right]}{\sum_{t=1}^{N}\left[\left(y(t)-\bar{y}(t)\right)^2\right]}$$

Correlation coefficient

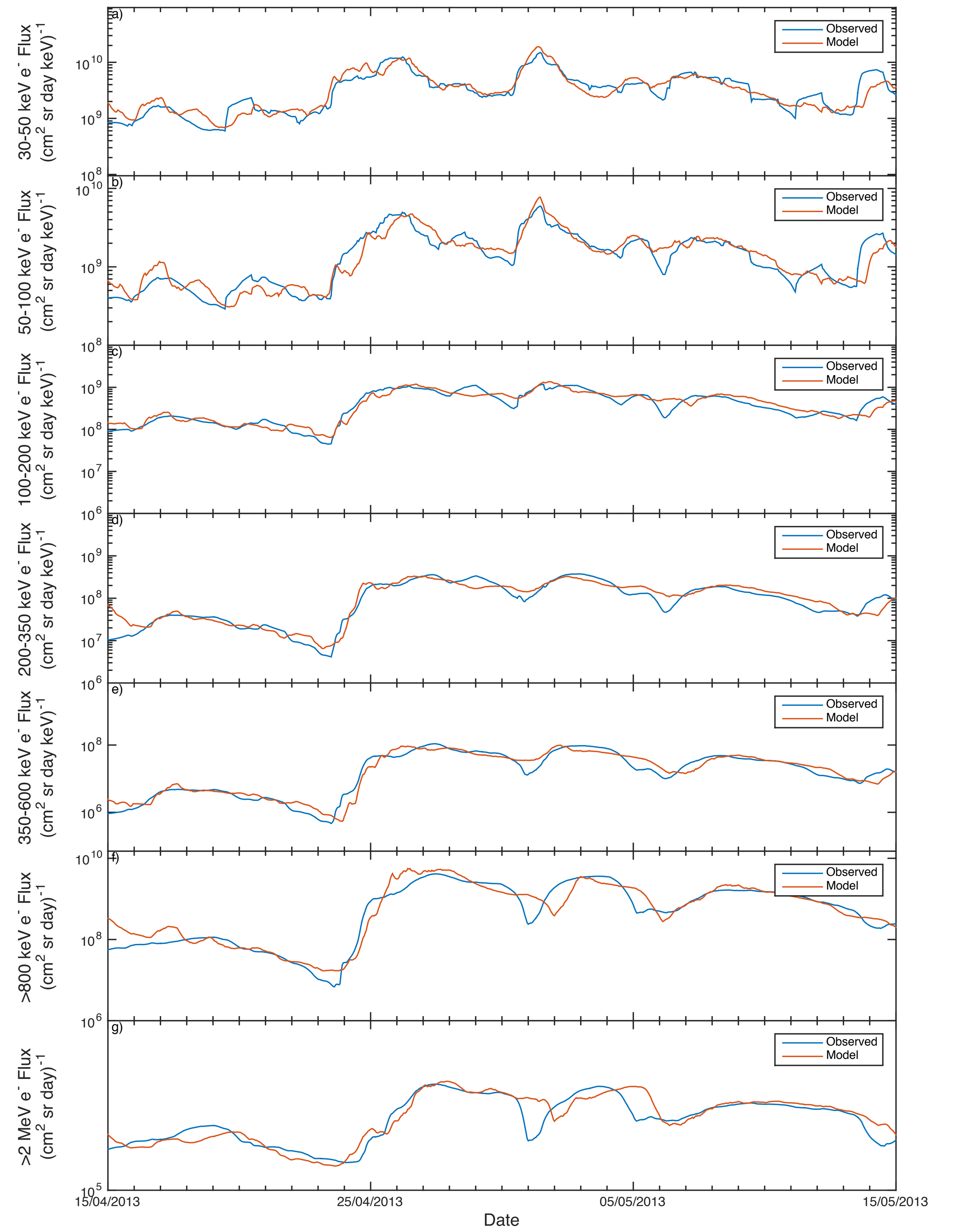
$$CC = \frac{\sum_{t=1}^{N}\left[\left(y(t)-\bar{y}(t)\right)\left(\hat{y}(t)-\bar{\hat{y}}(t)\right)\right]}{\sqrt{\sum_{t=1}^{N}\left[\left(y(t)-\bar{y}(t)\right)^2\right]\sum_{t=1}^{N}\left[\left(\hat{y}(t)-\bar{\hat{y}}(t)\right)^2\right]}}$$

Where $y(t)$ is the measured output at time t, $\hat{y}$ is the forecast output, N is the length of the data and the bar indicates the mean.

The PE and CC were calculated for each of the model forecasts over the time period shown in the Table below

Model	Forecast Time (hours)	PE (%)	CC (%)	Period
40-50 keV	10	66.9	82.0	01.03.2013-28.02.2015
50-100 keV	12	69.2	83.5	01.03.2013-28.02.2015
100-200 keV	16	73.2	85.6	01.03.2013-28.02.2015
200-350 keV	24	71.6	84.9	01.03.2013-28.02.2015
350-300 keV	24	73.6	85.9	01.03.2013-28.02.2015
> 800 keV	24	72.1	85.1	01.01.2011-28.02.2015
> 2MeV	24	82.3	90.9	01.0.12011-28.02.2015

Model Performance Figures



Conclusions

The aim of this study was to create forecast models for the electron flux energy ranges observed by the third generation GOES satellites.

NARMAX is the most robust method for probing nonlinear processes in data.

All of these models will be implemented in real time to forecast the electron fluxes on the University of Sheffield Space Weather website: www.ssg.group.shef.ac.uk/USSW/UOSSW.html

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