VNC: Application of Physics and Systems Science methodologies to Forecasting of the Radiation Belt Electron Environment

S. N. Walker[1], M. A. Balikhin[1], I. Pakhotin[1,2], and Y. Shprits[2]

[1] ACSE, University of Sheffield, U.K.,

[2]Now at University of Alberta, Canada

[3] GFZ, Potsdam, Germany

Introduction

Two categories of codes forecasting the radiation environment

First principles codes

Individual processes modeled from first principles ,
Combine these sets of models to describe the dynamic evolution of the environment. E.g. Versatile Electron Radiation Belt model

Empirical codes

Based on systems science approaches,
Extracts information about processes occurring directly from measurements.
E.g. NARMAX

Both methods have their advantages and disadvantages.

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Modeling Methodologies

space systems laboratory

Moving average linear filters

- Find flux >2Mev electrons based on Kp [Nagai et al., 1988]

Linear Prediction Filters

- Forecast high energy electrons using Kp, AE, and solar wind velocity [Baker et al., 1990, Vassiliadis et al., 2002]

Neural Network

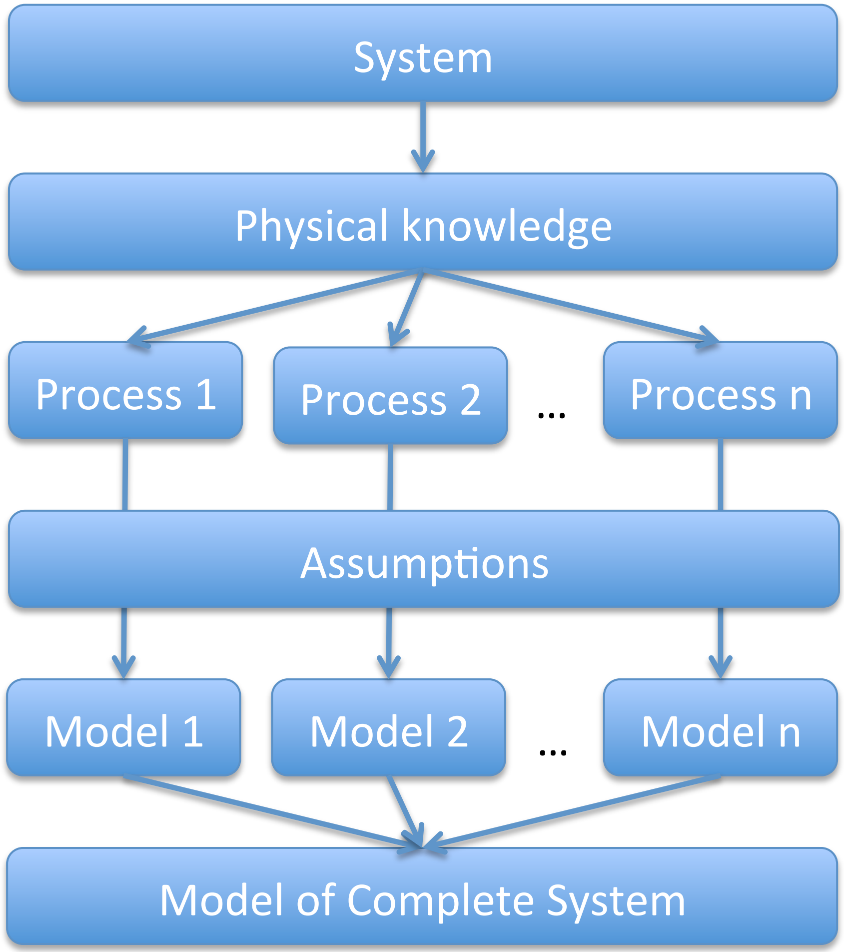
- Fluxes of >3MeV electrons at GSO using ΣKp for 10 consecutive days [Koons and Gorney, 1991]

Empirical models

- Li et al., 2001 - Radial diffusion -> diffusion multiplier
- Ukhorskiy et al., 2004 - Dynamical nonlinear time series analysis + conditional probability of solar wind + magnetospheric inputs
- Turner and Li, 2008 - Time delays between energy channels
- Denton et al., 2015 - Flux probability distributions

Modeling Methodologies

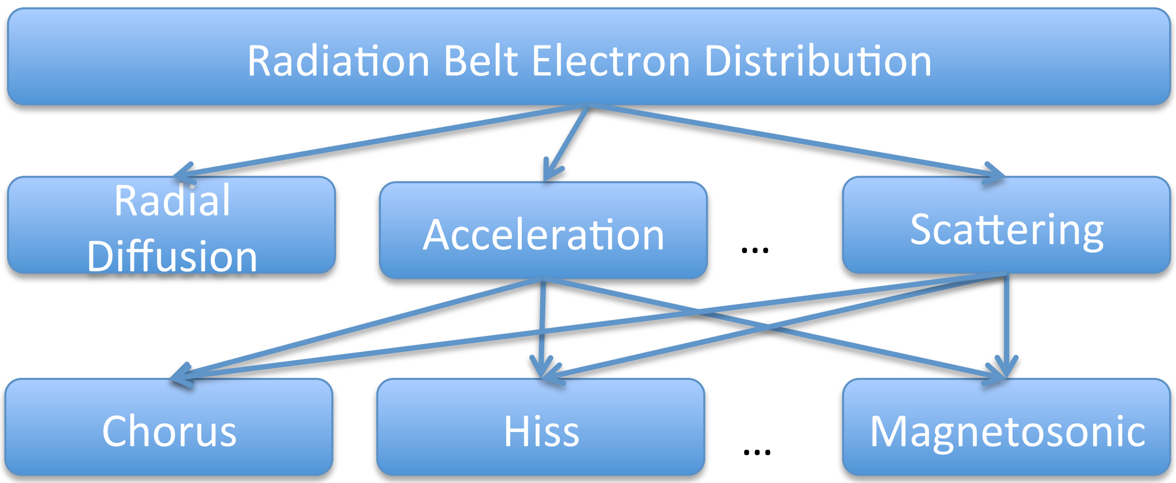
First Principles Model



VERB

VERB is a diffusion code that models radiation belt particle dynamics using the bounce averaged Fokker-Planck equation with radial, pitch angle and energy diffusion terms

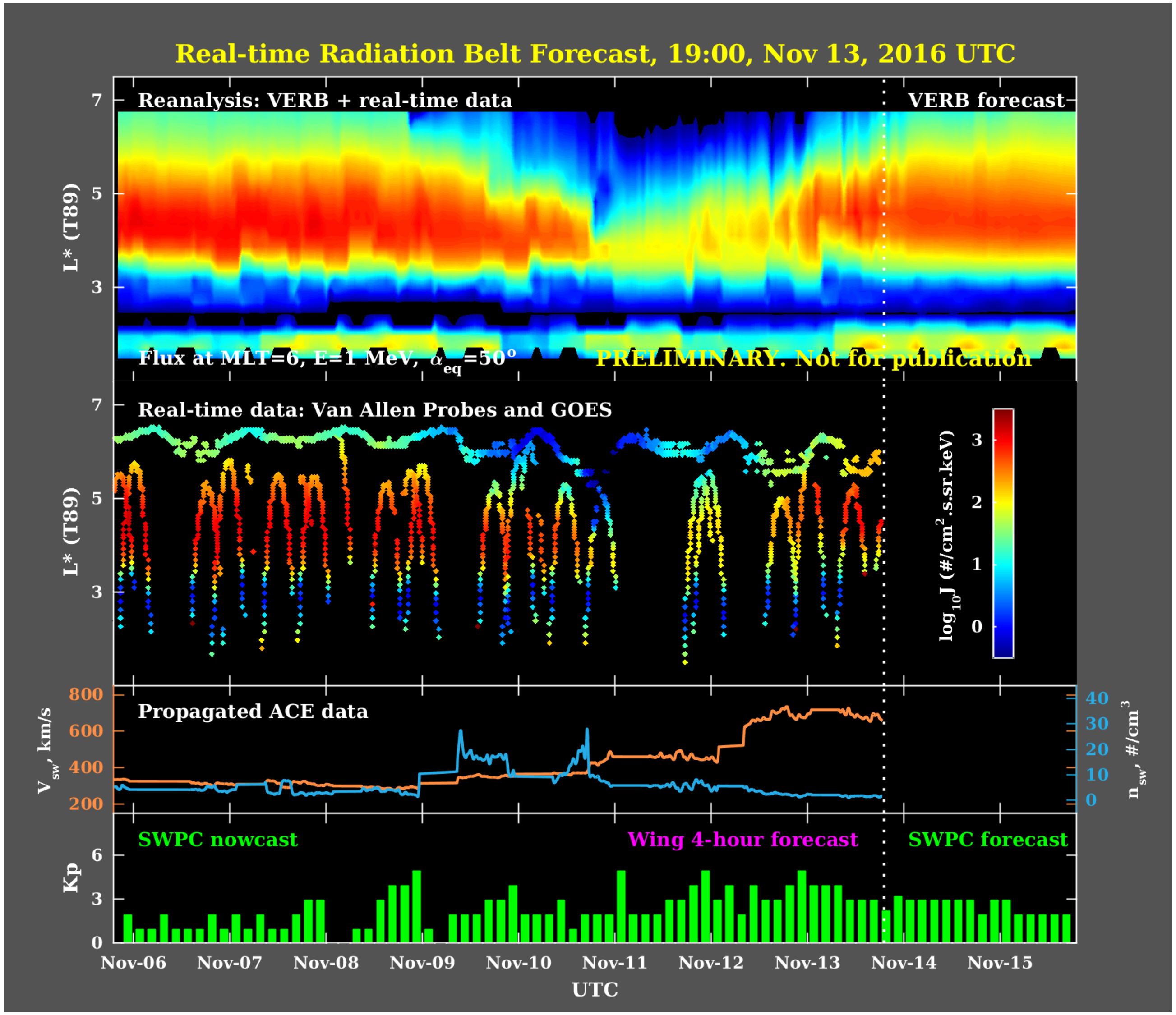
Acceleration and scattering processes are incorporated in terms of diffusion coefficients resulting from the interaction of the particles with plasma waves such as Chorus, hiss, and magnetosonic.



Required inputs

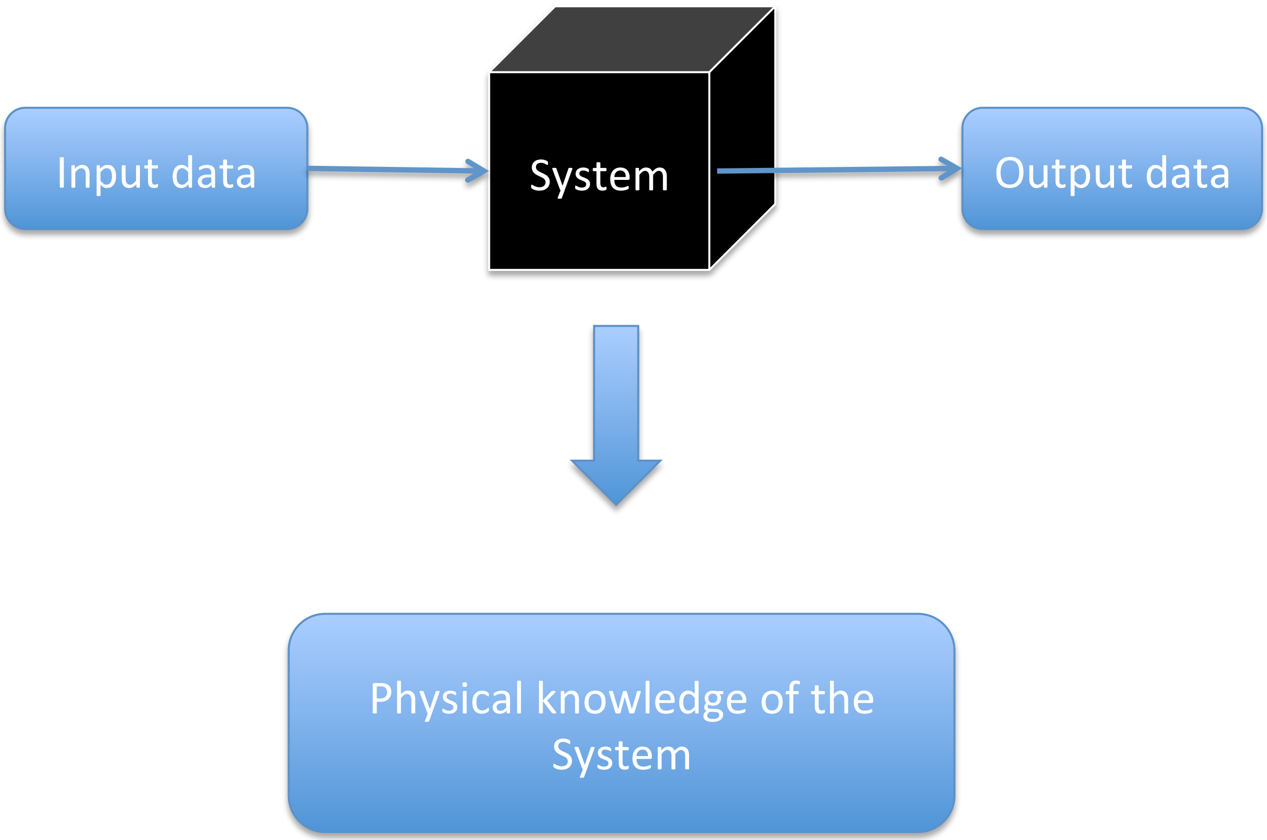
- Kp – measure of geomagnetic activity
- Boundary flux – characterise inflow of particles from magnetotail

VERB

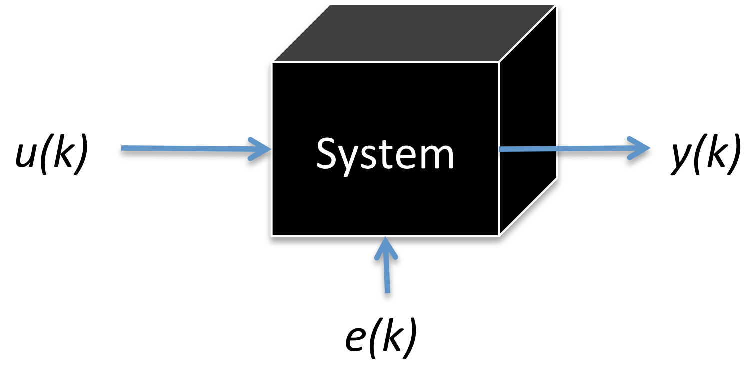

Real-time Radiation Belt Forecast, 19:00, Nov 13, 2016 UTC
Reanalysis: VERB + real-time data
VERB forecast
Flux at MLT=6, E=1 MeV, α_{eq}=50°
PRELIMINARY. Not for publication
L* (T89)
Real-time data: Van Allen Probes and GOES
$\log_{10}$J (#/cm^2.s.sr.keV)
Propagated ACE data
V_{sw}, km/s
n_{sw}, #/cm^3
SWPC nowcast
Wing 4-hour forecast
SWPC forecast
Kp
Nov-06
Nov-07
Nov-08
Nov-09
Nov-10
Nov-11
Nov-12
Nov-13
Nov-14
Nov-15
UTC

Modeling Methodologies

Systems Approach



NARMAX



$$y(k) = F[y(k-1),\ldots,y(k-ny),$$ System outputs

$$u(k),\ldots u(k-nu),$$ System inputs

$$e(k-1),\ldots e(k-ne)]$$ Noise/errors

F[] is a nonlinear function (polynomial, B-spline, radial basis function)

NARMAX

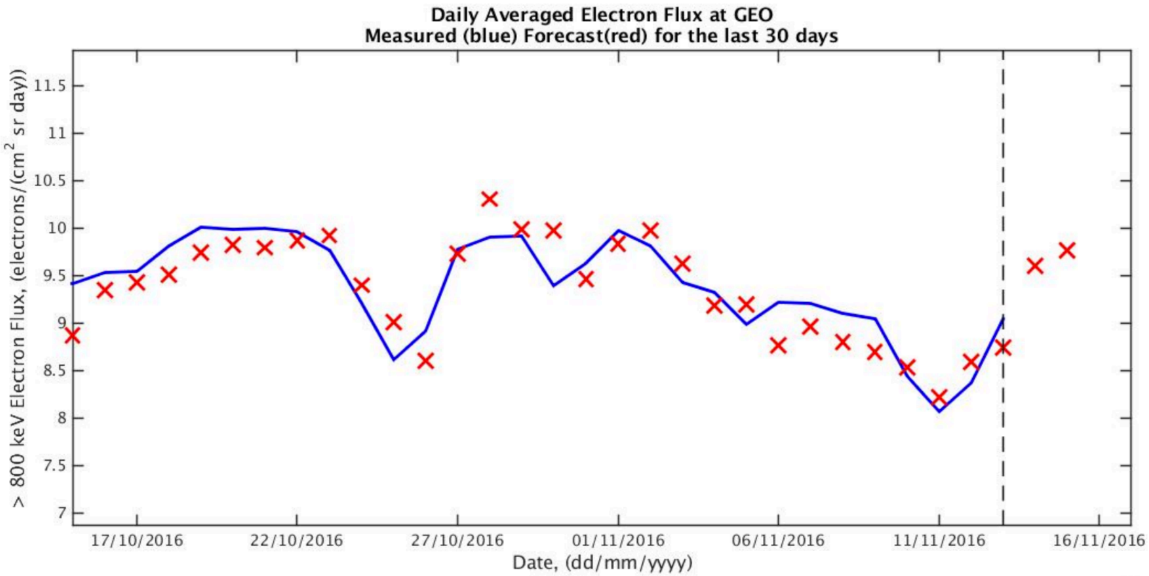
Three steps in NARMAX methodology

1. Structure selection

2. Coefficient estimation

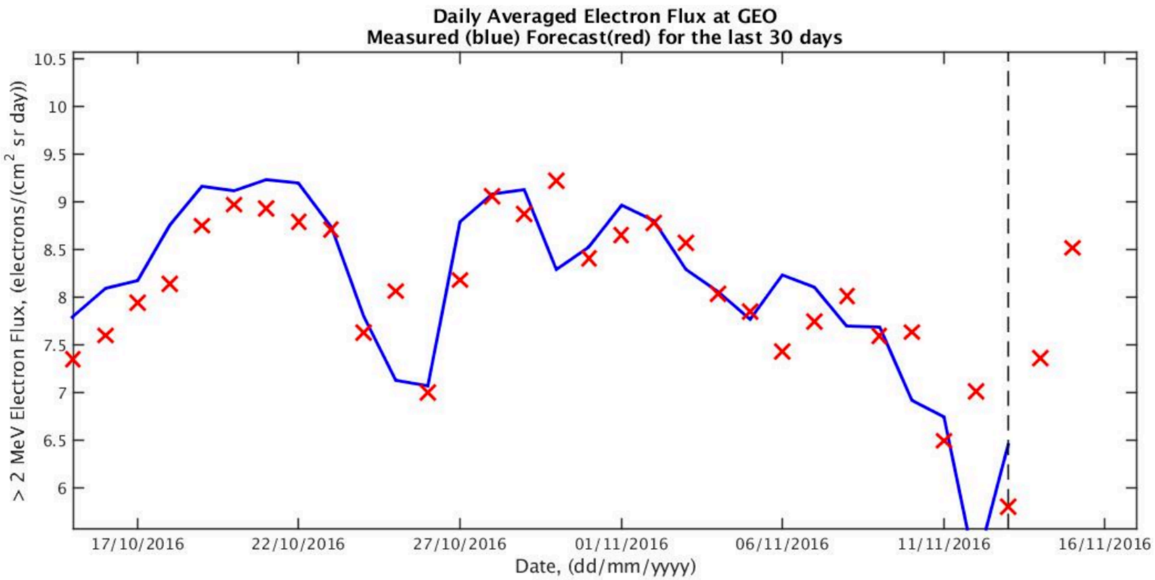
3. Model validation

NARMAX



http://www.ssg.group.shef.ac.uk/USSW2/EF800k/800keV_EF.html

http://www.ssg.group.shef.ac.uk/USSW2/EF2M/2MeV_EF.html



Advantages/Disadvantages

First Principles	Systems Analysis
Require knowledge of all processes occurring within a system	Often there is minimal knowledge of the system
Known/modeled processes may be included/excluded to determine their relative effects	All processes modeled as one system Role of input parameters
Require drivers Eg boundary electron fluxes, Geomagnetic activity eg Kp or Dst	Require constant stream of input data Only usable at geostationary orbit
Calculate electron fluxes in wide range of L-shell	Limited to region of high data density eg GSO
Lower accuracy	Resulting models are currently the most accurate

VNC

The VERB-NARMAX-Coupled model attempts to integrate these two different yet complementary approaches **for past/fore-casting** purposes.

NARMAX

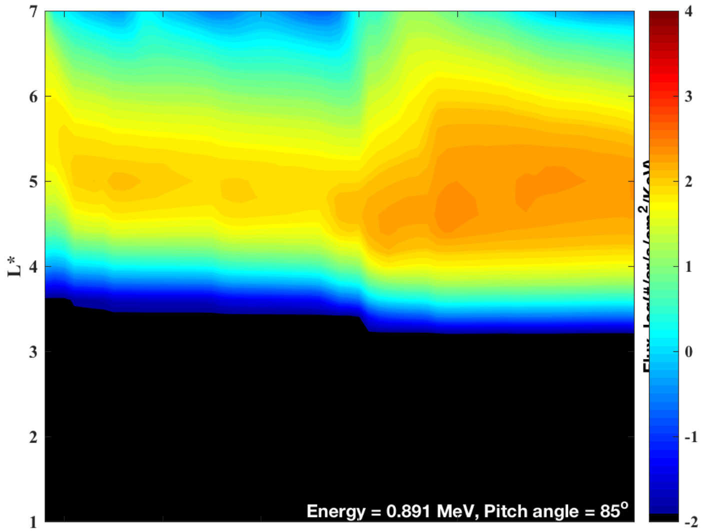
- Used to model measurements of electron fluxes at GEO based on data from GOES 13
- Provide a 24hr ahead forecast of electron fluxes at GEO

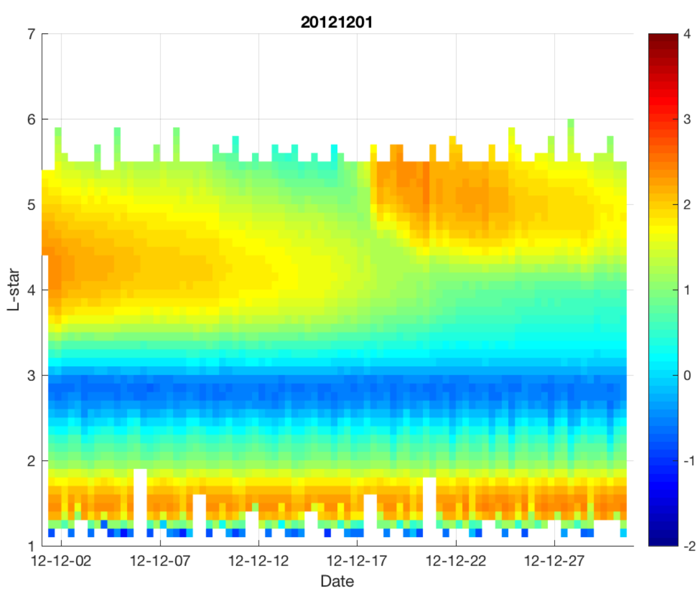
Model forecasts at GEO (L*~6.2) are used to estimate the outer boundary fluxes at L*=7 that are used by VERB

VERB

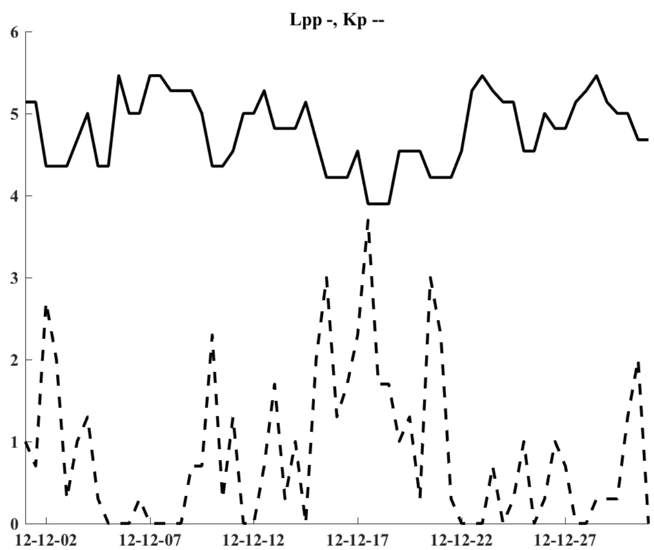
- Used to model the dynamics of the radiation belts based on estimated fluxes and Kp

VNC Example 1

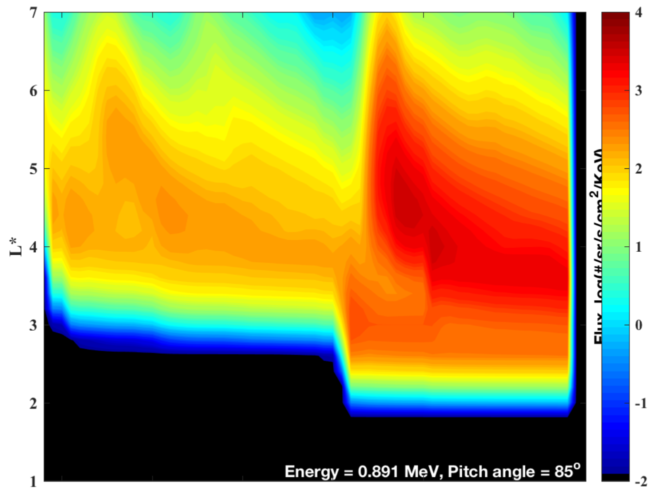


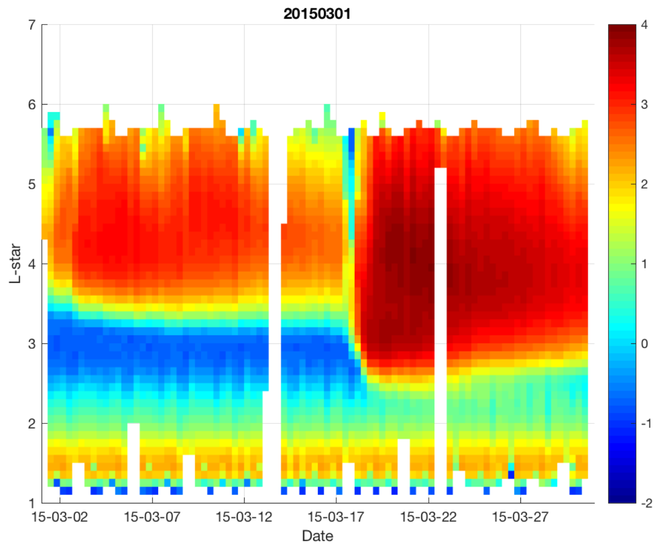


Quiet period

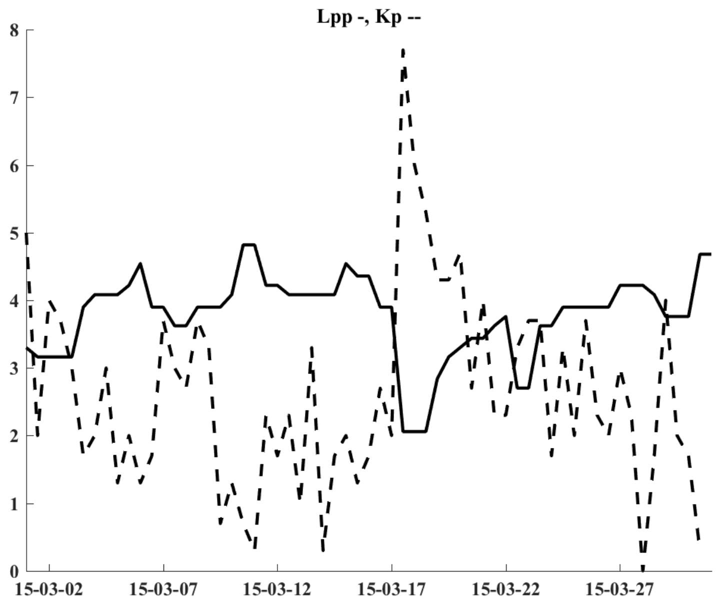


VNC Example 2





Disturbed period



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Summary

Coupling of the VERB first principles and NARMAX systems models

- NARMAX was used to forecast daily fluxes of >800keV and >2Mev electrons at GEO
- These fluxes were used to estimate the input boundary fluxes required by VERB
- VERB was then used to simulate the electron fluxes
- Qualitatively, the results reproduce measurements from the Van Allen Probes MagEIS instrument

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Future developments

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Under development

- Current (preliminary) Kp values from GFZ, Potsdam
- Forecasts of Kp
  - Wing model
  - Sheffield, Lund (EU funded project PROGRESS)
- Quantitative comparison with experimental data

Future plans

- Transfer system to web server
- Access https://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