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Modeling the Radiation Belt Electron Environment: Fusion of Physics and System Science Approaches

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

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

[2] UCLA, and MIT, U.S.A.

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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 the processes occurring directly from measurements.

E.g. NARMAX

Both methods have their advantages and disadvantages.

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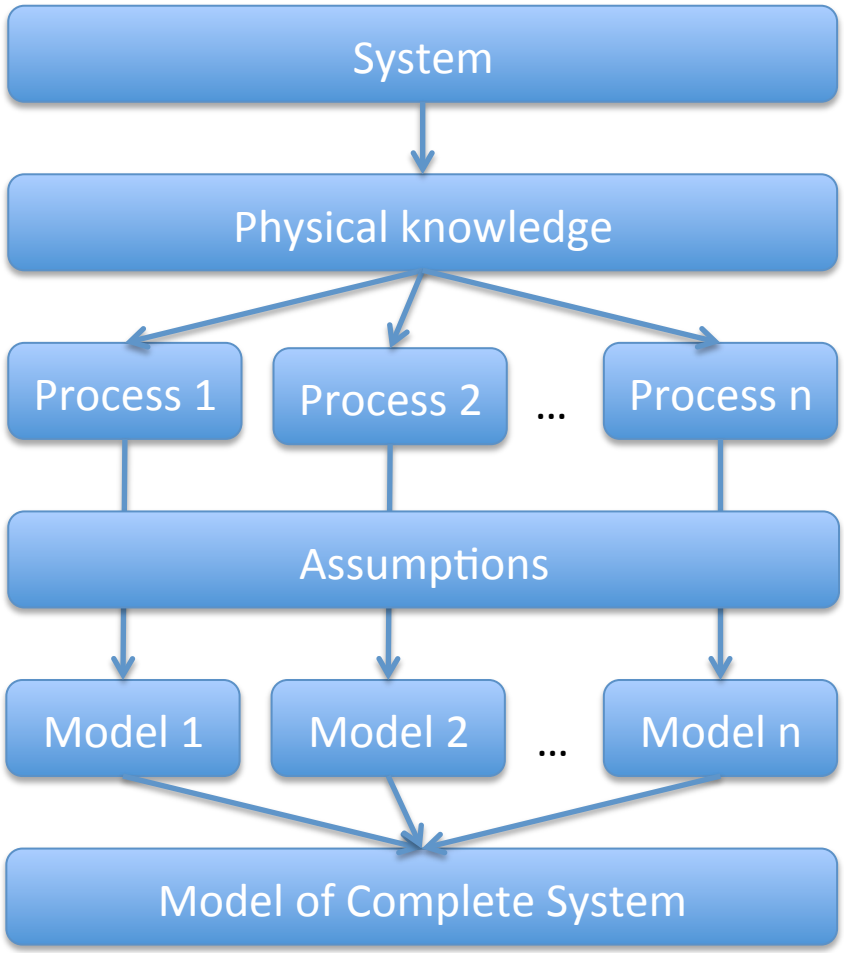
Modeling Methodologies

First Principles Model



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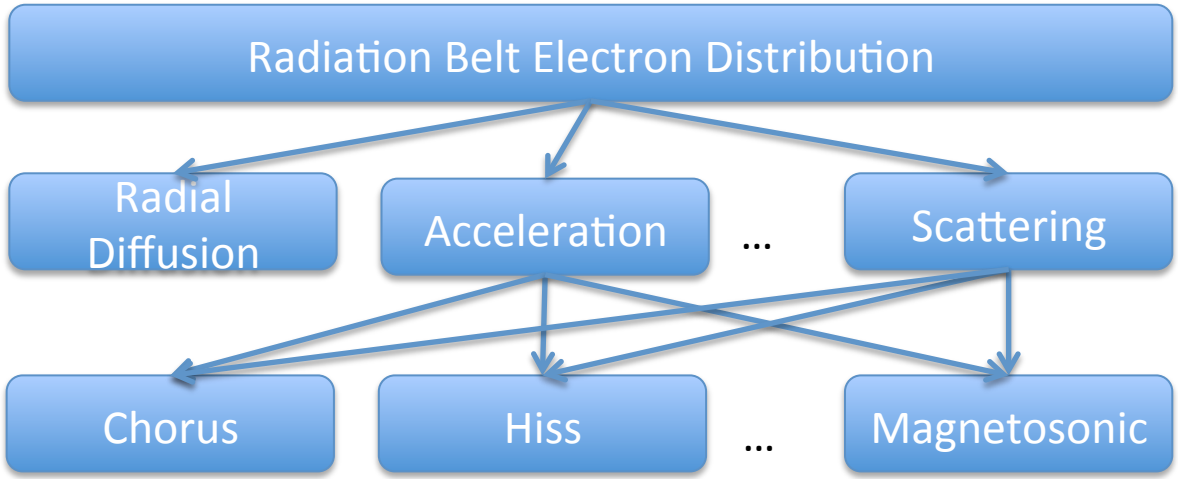
VERB

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.

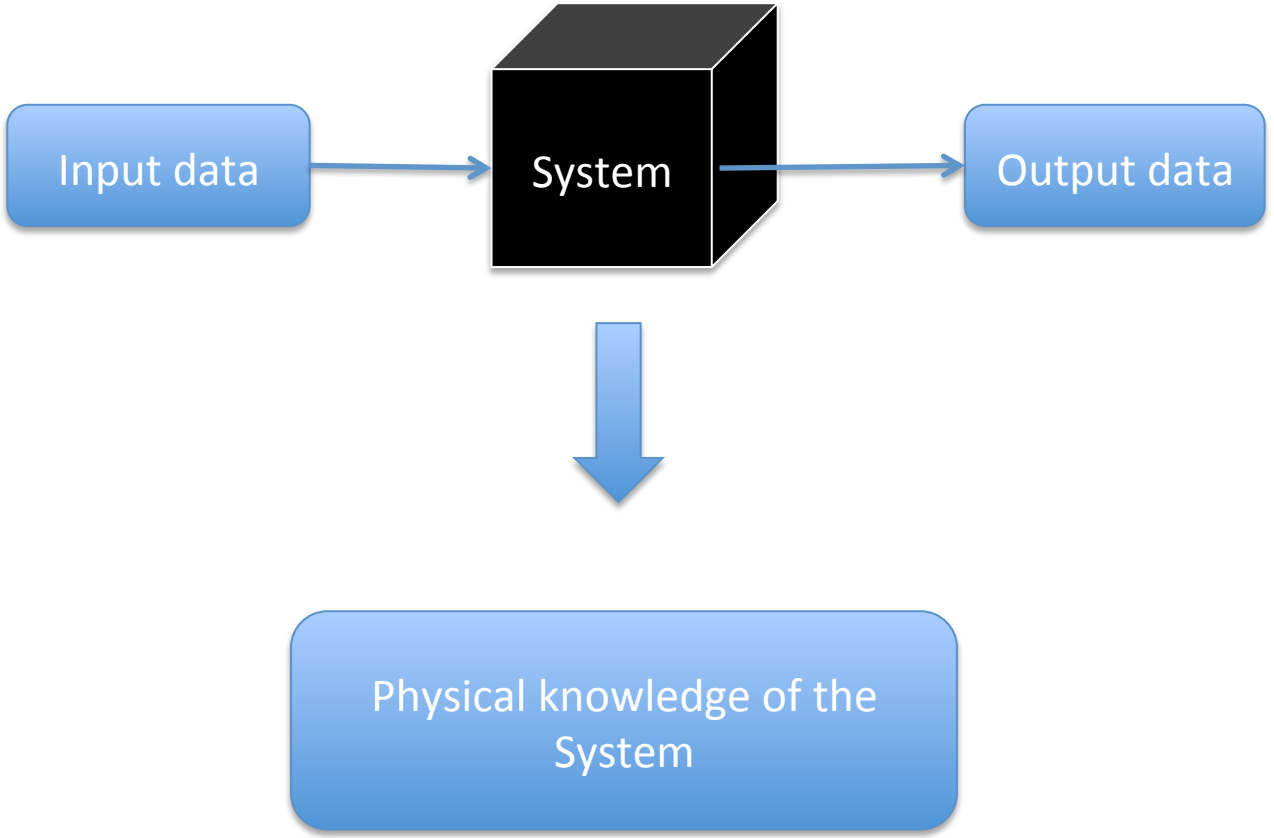


Required inputs

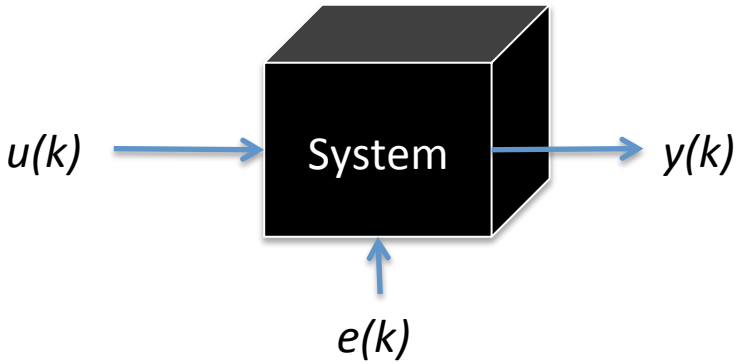
- Kp – measure of geomagnetic activity
- Boundary flux – characterise inflow of particles from magnetotail

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

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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

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Modeling Methodologies

Superposed epoch analysis + Linear prediction filters

- Find flux minima, max Kp, min Dst [Nagai et al., 1988]

Linear Prediction Filters

- Forecast high energy electrons using AE + solar wind velocity [Baker et al., 1990]

Neural Network

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

Empirical models

- 1 day ahead forecasts based on solar wind and magnetospheric inputs [Ukhorskiy et al., 2004]
- Continuity equations [Lyatsky and Khazanov, 2008]
- Time delays between different energy channels [Turner and Li, 2008]

VNC

The VERB-NARMAX-Coupled model attempts to integrate these two different yet complementary approaches for **forecasting** 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

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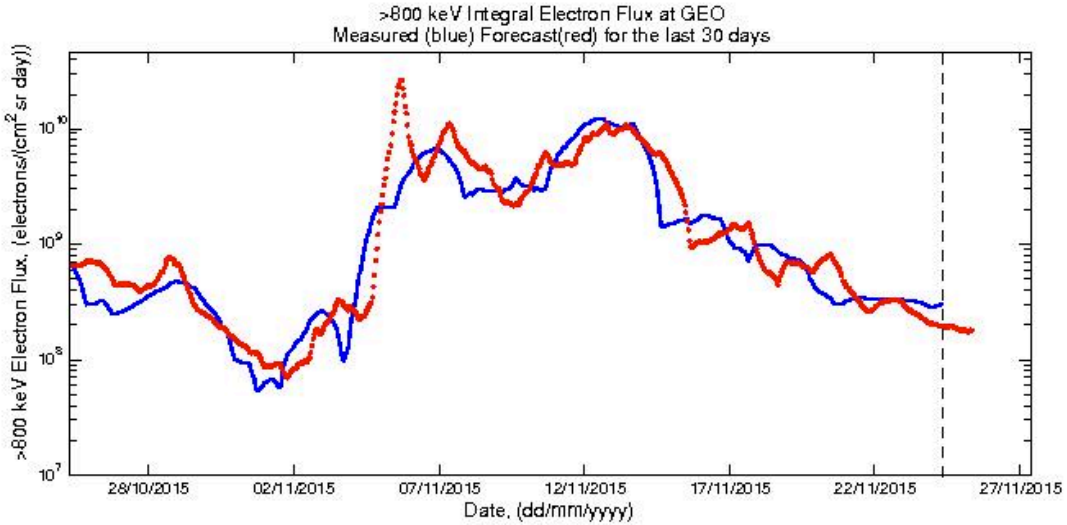
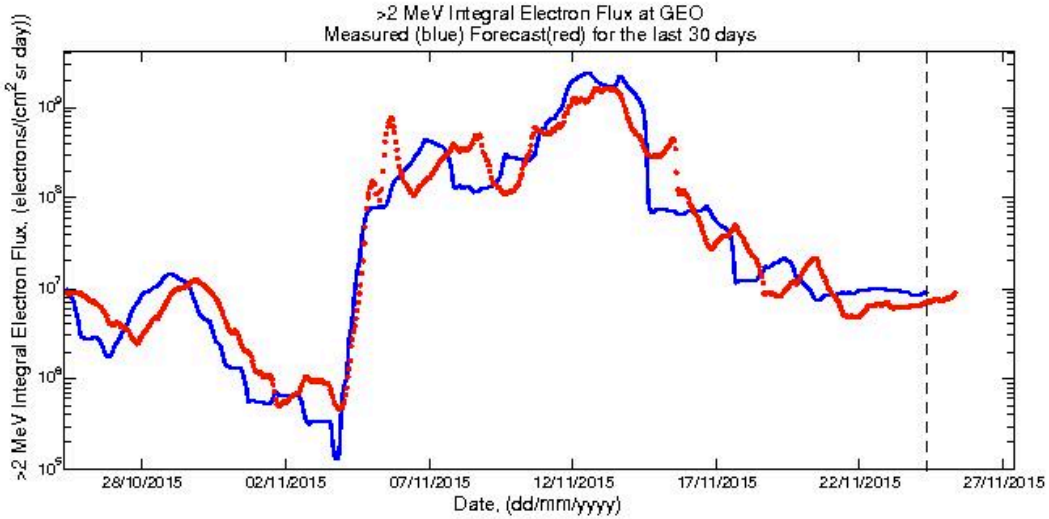
NARMAX



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

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



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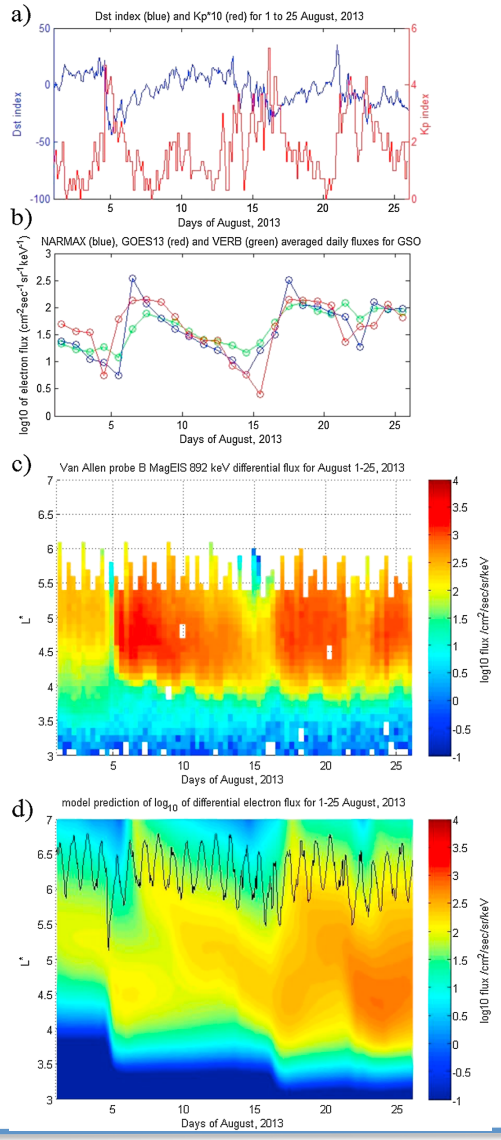
Example



Dst/Kp
Three disturbed periods

Differential flux
GOES 13 (red), NARMAX (blue), VNC (green)

MagEIS 892 keV

VERB simulation

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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 compute boundary fluxes required by VERB
- VERB was then used to simulate the electron fluxes
- The results reproduced measurements from the Van Allen Probes MagEIS instrument

Future work

- NARMAX models of lower energy fluxes are now available.
- Rescaling of NARMAX fluxes

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Thank you for listening

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