PRediction Of Geospace Radiation Environment and Solar wind parameterS

Forecast of the radiation belt environment

Modeling Methodologies

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

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

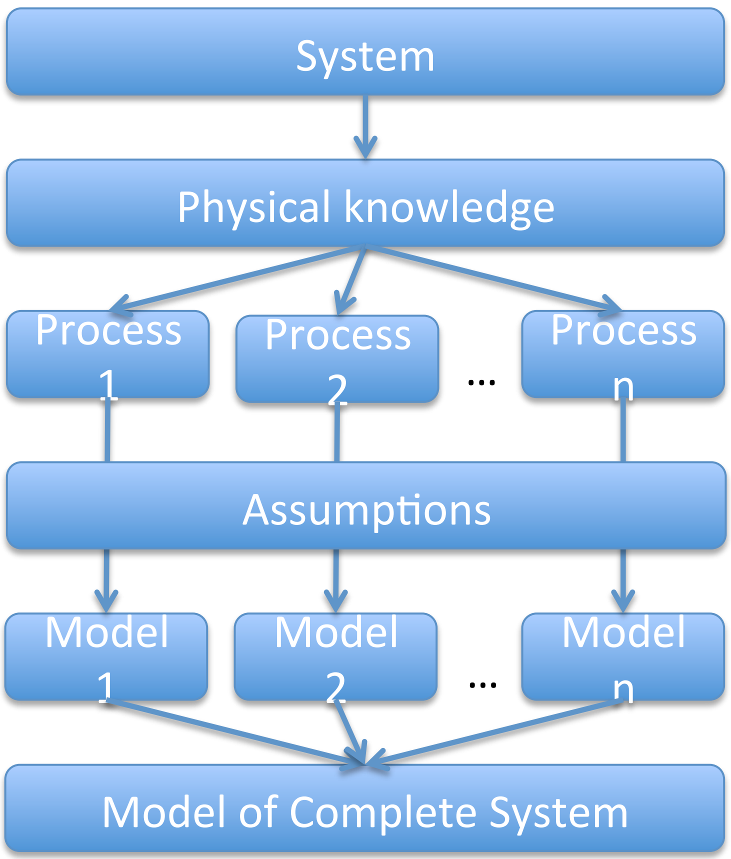
Empirical codes

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

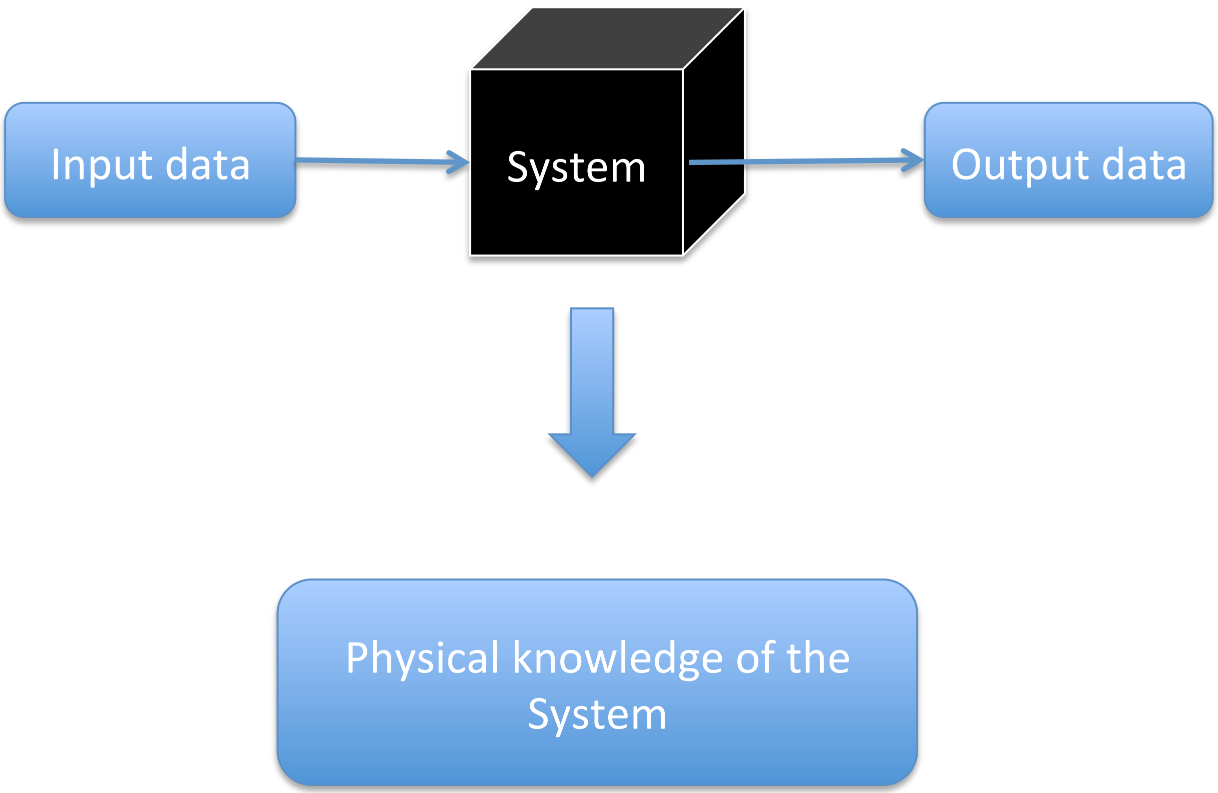
Both methods have their advantages and disadvantages.

Modeling Methodologies

First principles physical modeling



Systems Approach



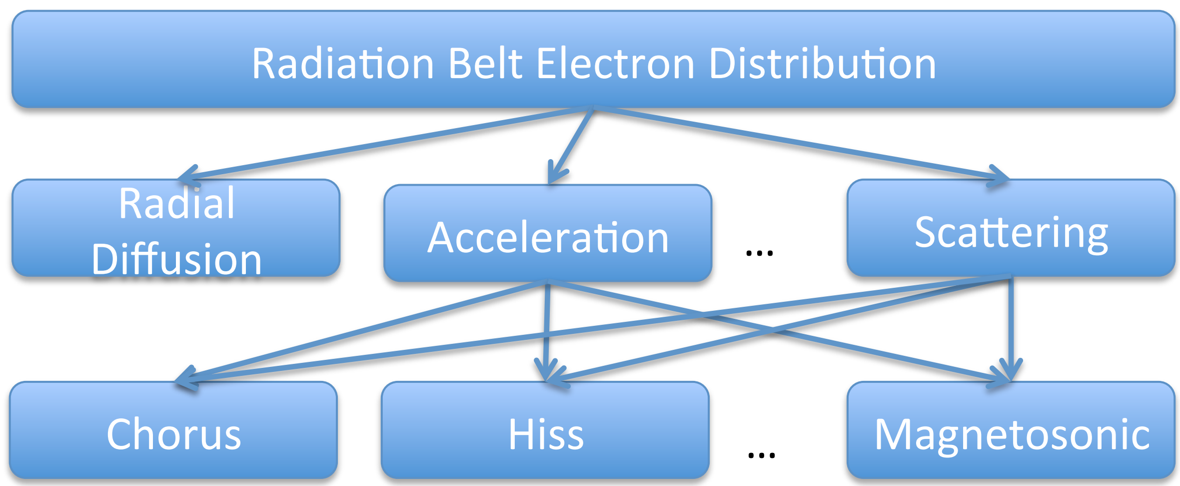
Advantages/ Disadvantages

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

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

- VERB, the Versatile Electron Radiation Belt
- bounce averaged Fokker-Planck equation
- radial, pitchangle, energy, and mixed diffusion

$$\frac{\partial f}{\partial t} = L^{*2} \frac{\partial}{\partial L^*}\bigg|_{\mu,J} \left(D_{L^*L^*} L^{*-2} \frac{\partial f}{\partial L^*}\bigg|_{\mu,J} \right)$$
$$+ \frac{1}{p^2} \frac{\partial}{\partial p}\bigg|_{y,L} \left(p^2 \langle D_{pp}(y,p) \rangle \frac{\partial f}{\partial p}\bigg|_{y,L} + p^2 \langle D_{py}(y,p) \rangle \frac{\partial f}{\partial y}\bigg|_{p,L} \right)$$
$$+ \frac{1}{T(y)y} \frac{\partial}{\partial y}\bigg|_{p,L} \left(T(y)y \langle D_{yy}(y,p) \rangle \frac{\partial f}{\partial y}\bigg|_{p,L} + T(y)y \langle D_{yp}(y,p) \rangle \frac{\partial f}{\partial p}\bigg|_{y,L} \right)$$
$$- \frac{f}{\tau}, \qquad (1)$$

Radial Diffusion

- Violation of third adiabatic invariant
- Transport particles into regions of increased or decreased magnetic field
- Associated with increase or decrease in particle energy respectively
- VERB uses time dependent radial diffusion based on Kp index (Brautigan and Albert 2000)

Energy/pitchangle diffusion

- Interaction with localised plasma waves results in diffusion in energy and pitchangle
- Diffusion coefficients estimated from observations of the variation in wave mode amplitude as a function of location, geomagnetic activity

Initial/Boundary conditions

Solve Fokker-Planck equation for

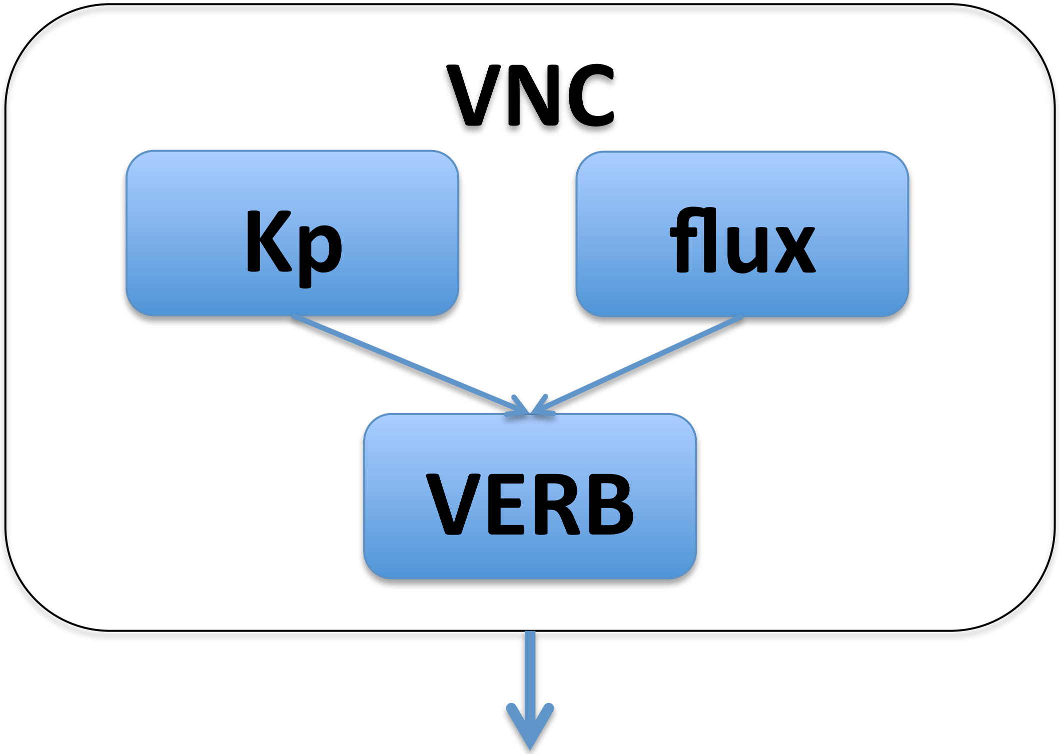
- Radial distance $1 < L^* < 7$
- Energy 0.01-10 MeV at $L^* = 7$
- Pitch angle 0-90 degrees

Boundary	Condition	Explanation
$E = E_{min}$	$f = const$	Balance of convective source and losses
$E = E_{max}$	$f = 0$	Absence of high-energy electrons at multi-MeV energies
$\alpha_0 = 0°$	$f = 0$	Empty loss cone in the week diffusion regime
$\alpha_0 = 90°$	$\partial F/\partial \alpha_0 = 0$	Flat pitch angle distribution at 90°
$L = 1$	$f = 0$	Losses to atmosphere
$L = 7$	$f = f(\text{time})$	measurements

SNB^{3}GEO

- SNB^{3}GEO is the Sheffield NARMAX model for forecasts of electron fluxes at GEO
- Models for >2MeV, >800keV, 475keV, 275keV, 150keV, 75keV, 40keV
- Overview plots - https://ssg.group.shef.ac.uk/progress/html/narmax_results.phtml
- Models provide the most accurate forecasts of these fluxes, better than NOAA REFM

VNC



Radiation Belt forecasts

VNC

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

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

Measurements (GOES 13, 15) and forecasts (SNB^{3}GEO) provide electron fluxes

- Energy range: >2MeV and >800 keV
- Radial distance: L ~ 6.6 (GEO)

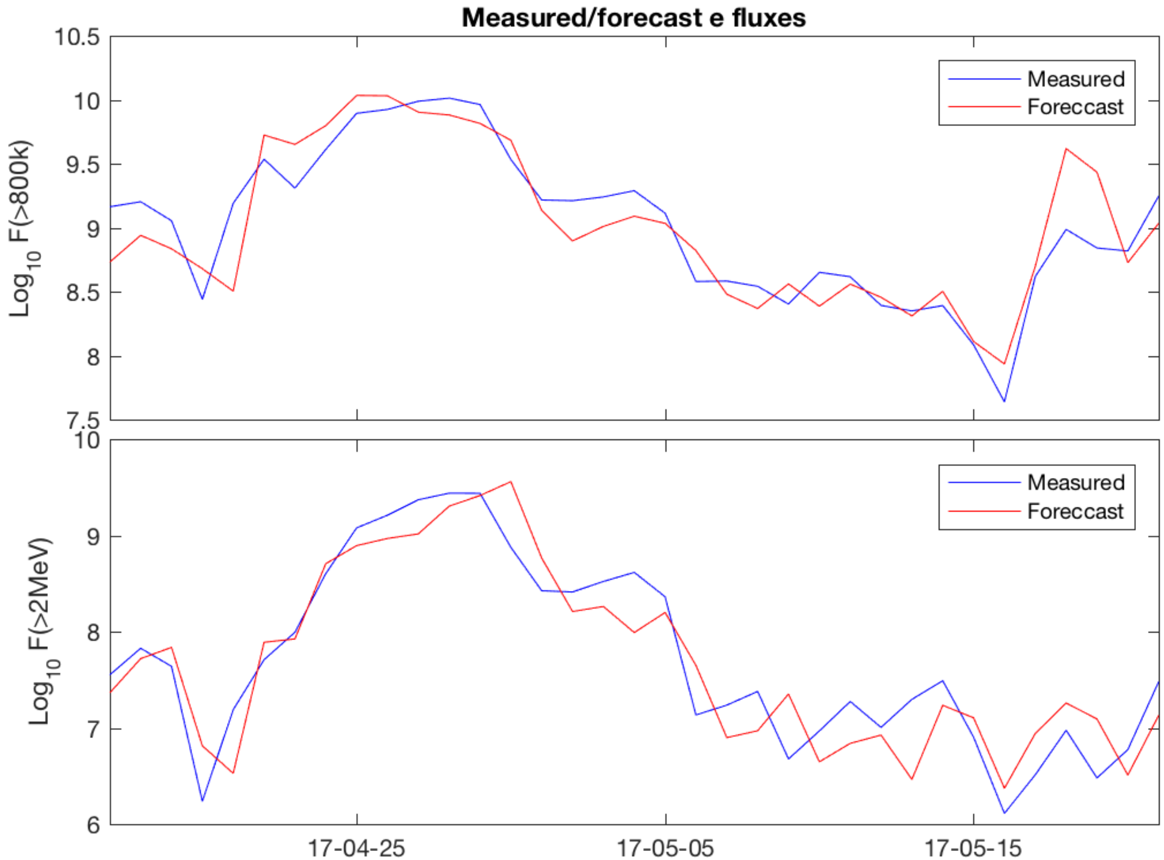
VERB initialised using electron flux

- Energy: 900 keV
- Radial distance: L* = 7

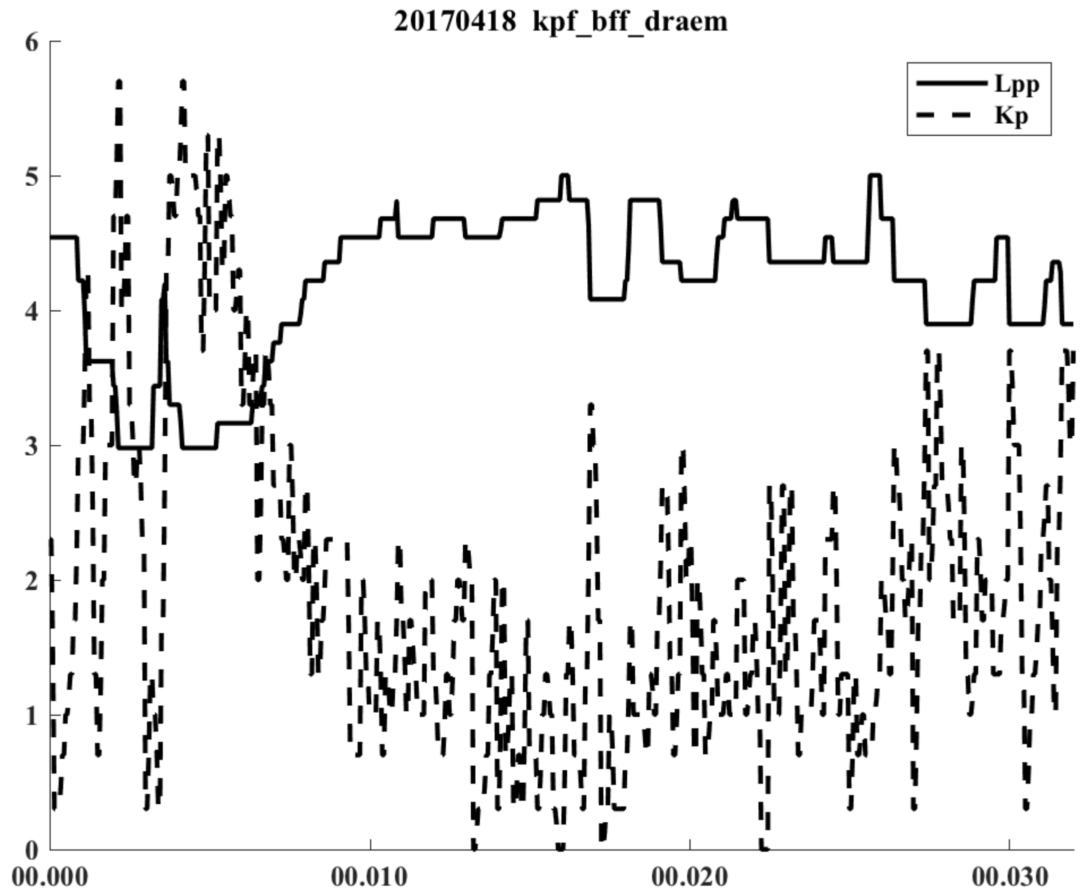
Assume

- Average L* for GEO is 6.2
- Phase Space Density of particles does not vary significantly between L*=6.2 and L*=7

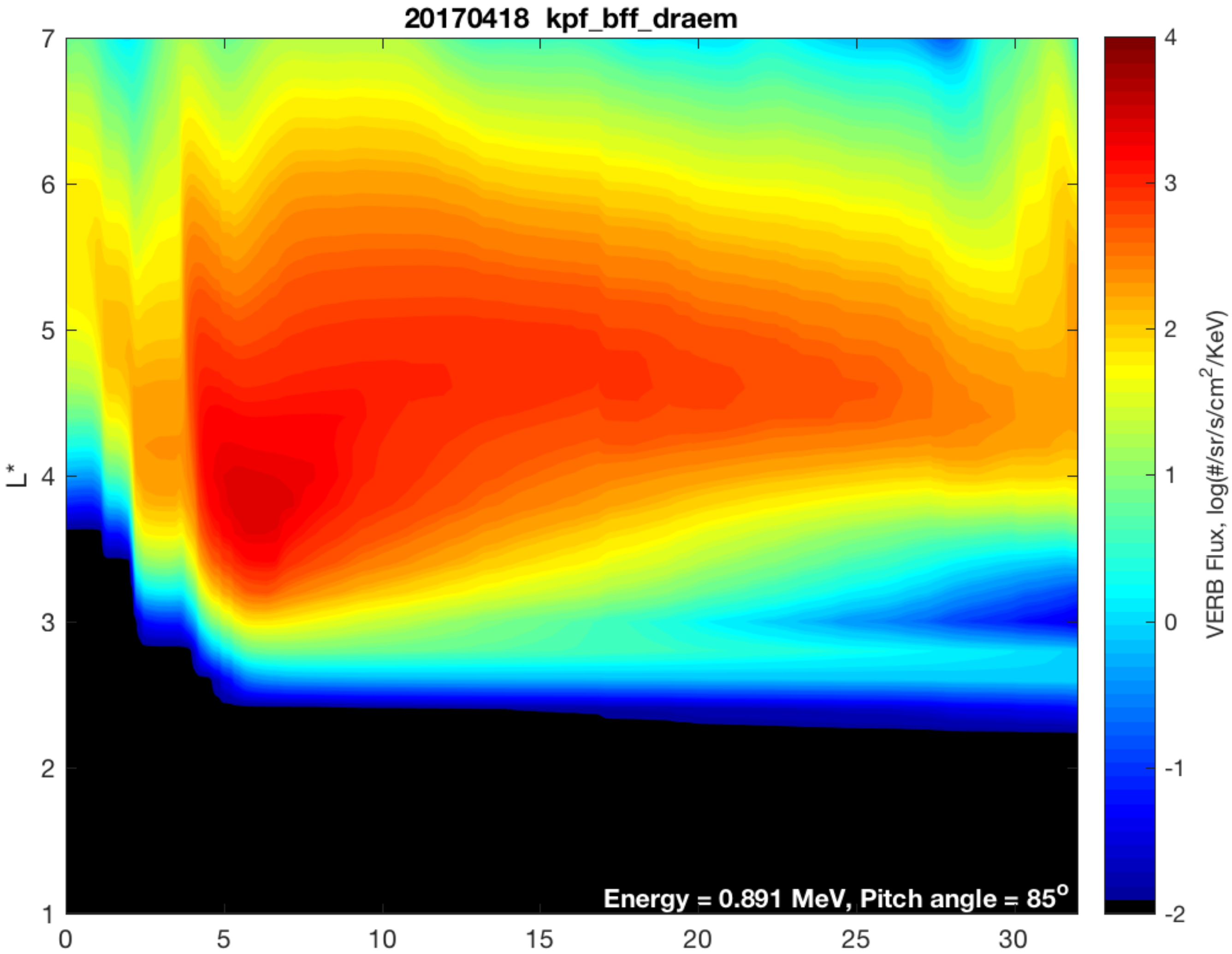
Input SNB^{3}GEO fluxes



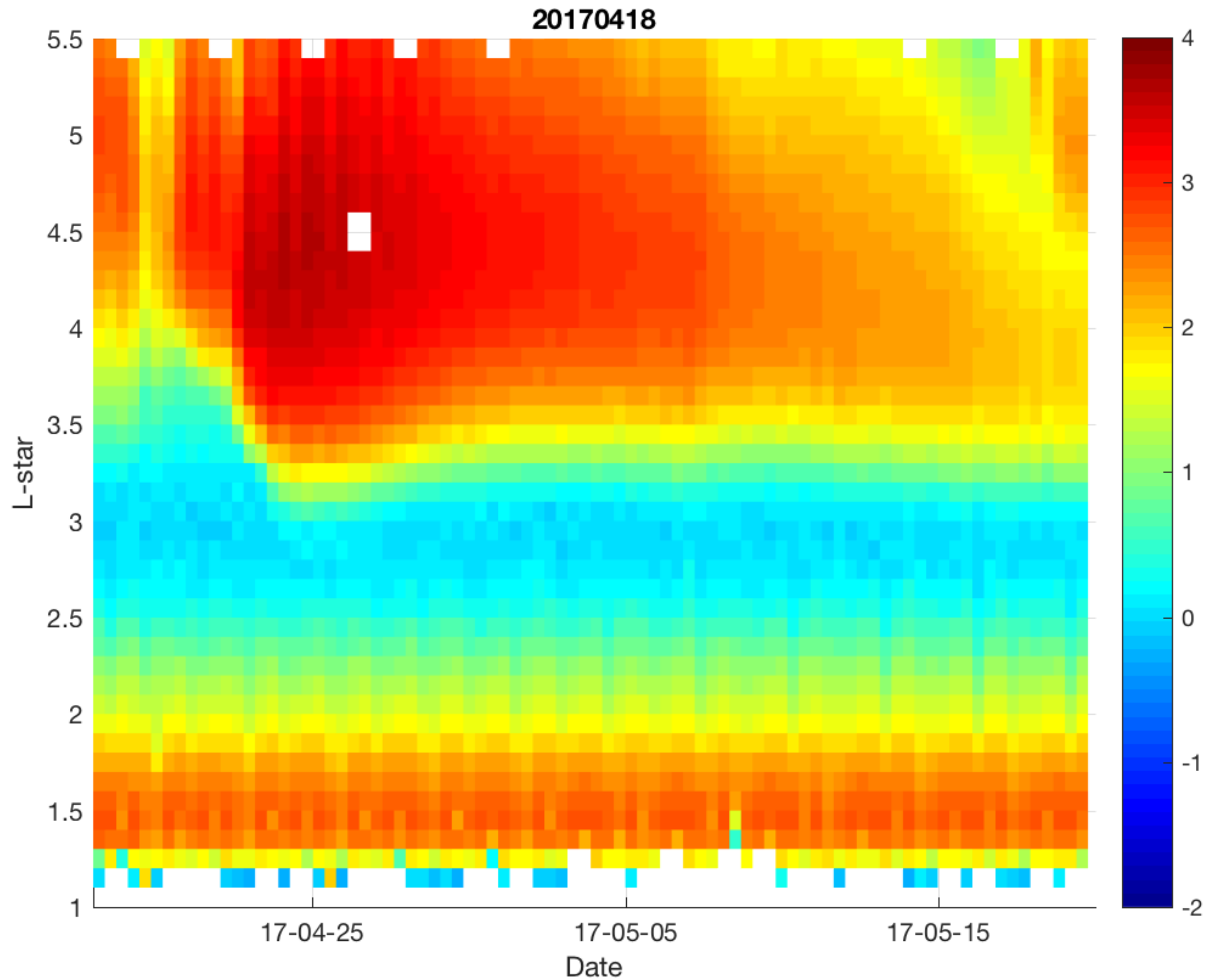
Input - Kp

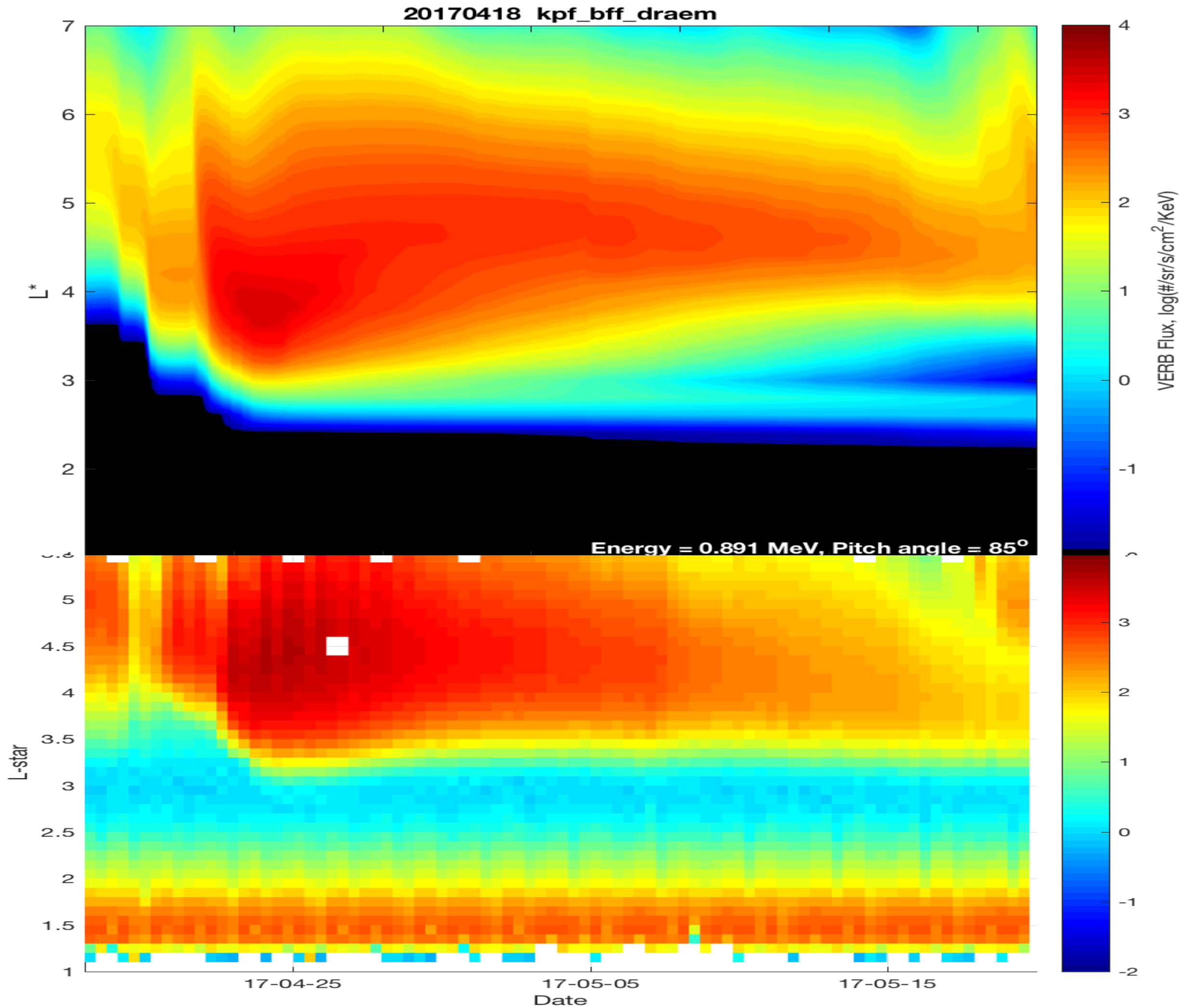

20170418 kpf_bff_draem
Lpp
Kp
0
1
2
3
4
5
6
00.000
00.010
00.020
00.030

VERB results



MagEIS measurements



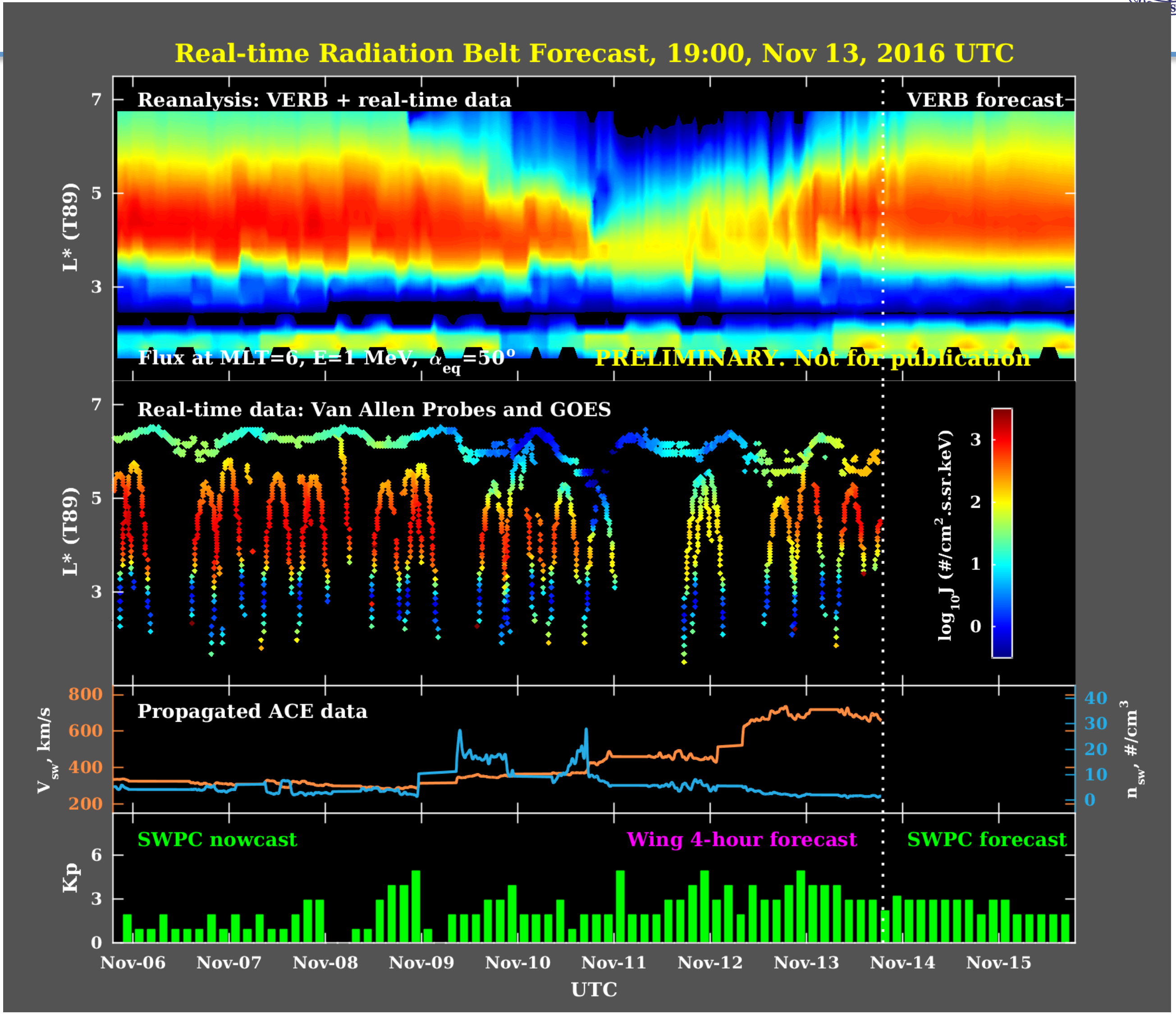


20170418 kpf_bff_draem
L*
Energy = 0.891 MeV, Pitch angle = 85°
VERB Flux, log(#/sr/s/cm2/KeV)
L-star
17-04-25
17-05-05
17-05-15
Date

VERB

MagEIS

VERB



Real-time Radiation Belt Forecast, 19:00, Nov 13, 2016 UTC
Reanalysis: VERB + real-time data
VERB forecast
L* (T89)
Flux at MLT=6, E=1 MeV, α_{eq}=50°
PRELIMINARY. Not for publication
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

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 for entire radiation belt region
- Qualitatively, the results reproduce measurements from the Van Allen Probes MagEIS instrument

PRediction Of Geospace Radiation Environment and Solar wind parameterS

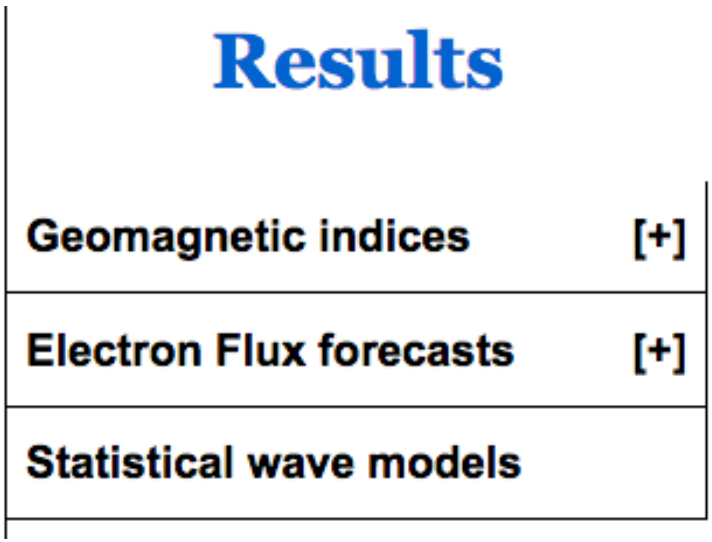
Fusion of tools

Objectives

- Collect and implement models for geomagnetic index forecast at Sheffield and provide access to their forecasts via project web page.
- To provide access to the forecasts of models developed in WP 4 via the project web page.
- To implement the VERB-NARMAX and VERB-IMPTAM models, developed in WP 5 and 6 at USFD, and provide access to their forecasts via the project web page.
- Develop a tool to calculate the integrated electron fluxes along a user defined part of satellite orbit
- Implement a traffic light system and create an email circular summarising current and evolution of space weather conditions.

Current status

Project website has a results menu



Geomagnetic indices

- Lund Kp (WP 3)
- Lund Dst (WP 3)

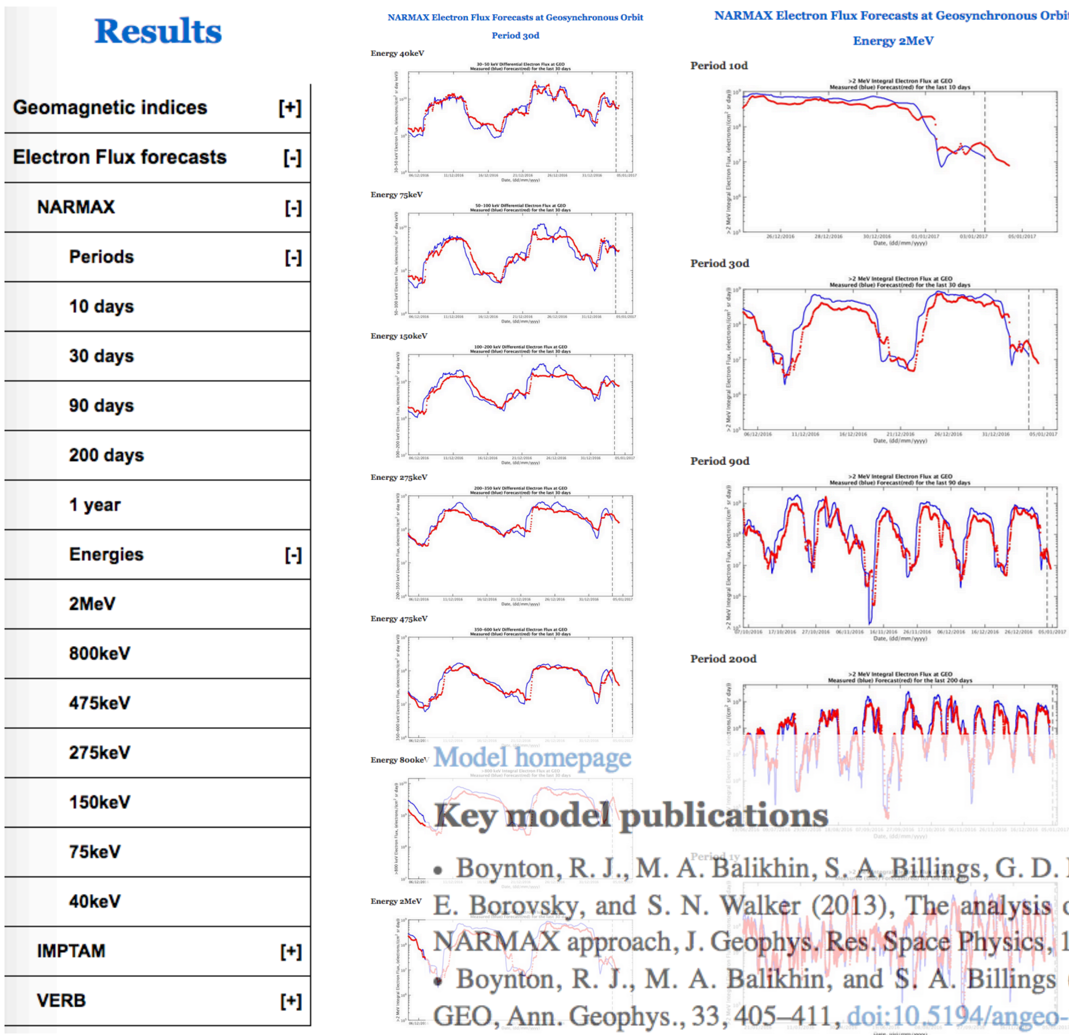
Electron fluxes

- NARMAX GEO fluxes (WP 6)
- IMPTAM low energy electrons (WP 5)
- VERB high energy electrons (WP 6)

Statistical wave models

- **Chorus**
- **Hiss**

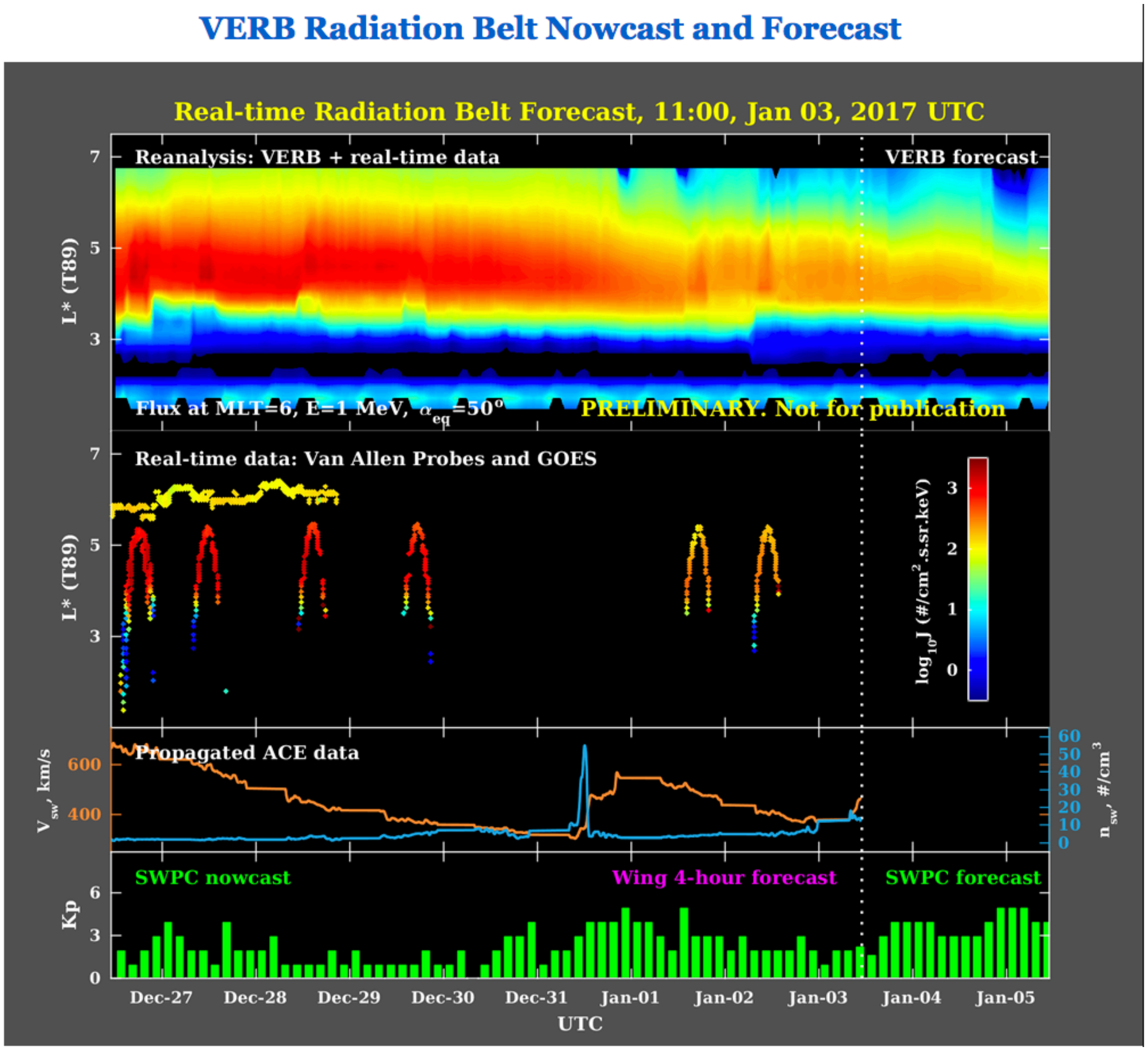
NARMAX GEO fluxes



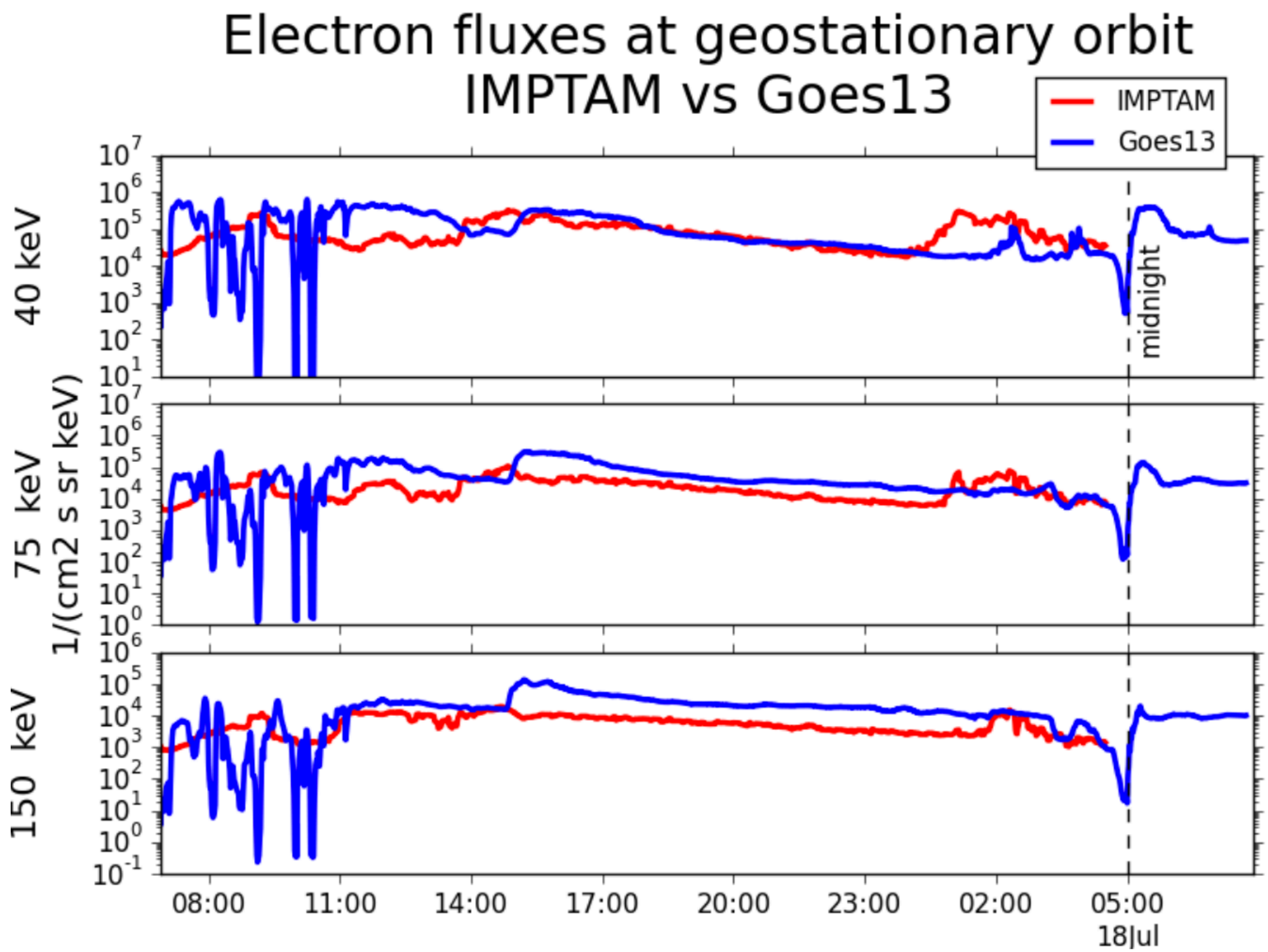
NARMAX GEO e- fluxes

- Menu
- Forecasts v measured fluxes for past #days, all energies
- Forecasts v measured fluxes for single energy over various time periods
- Model information

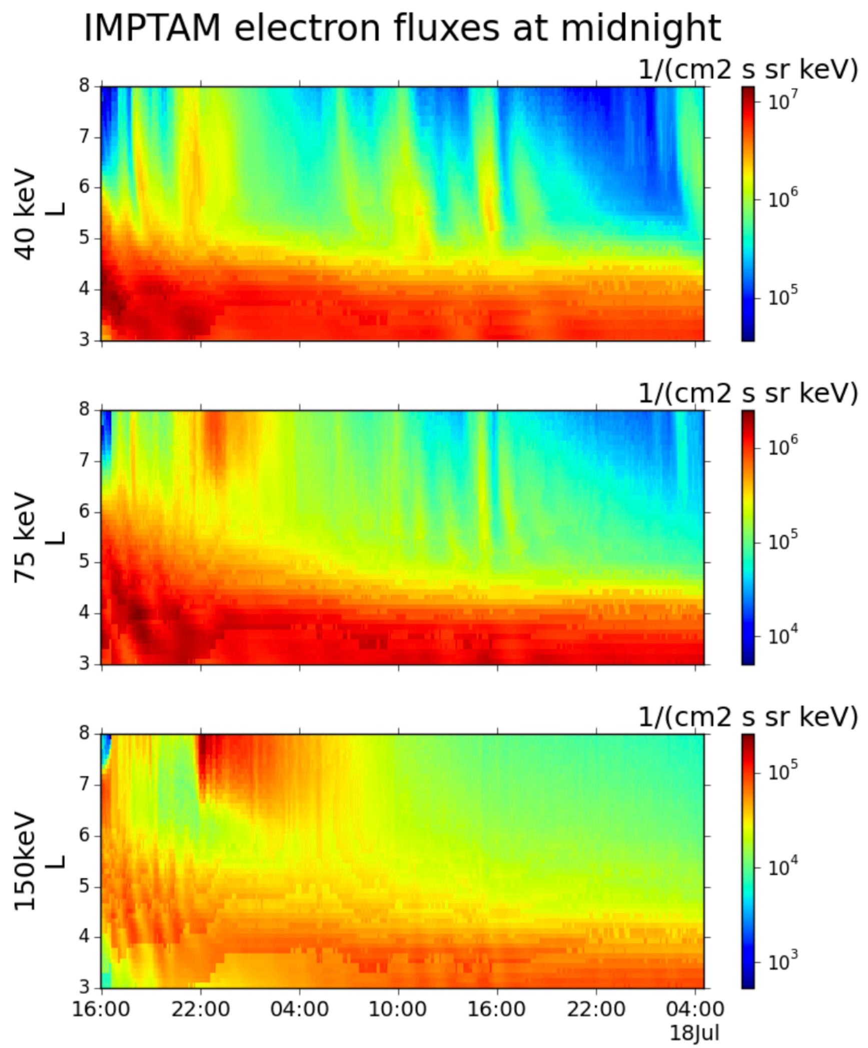
VERB electron Fluxes



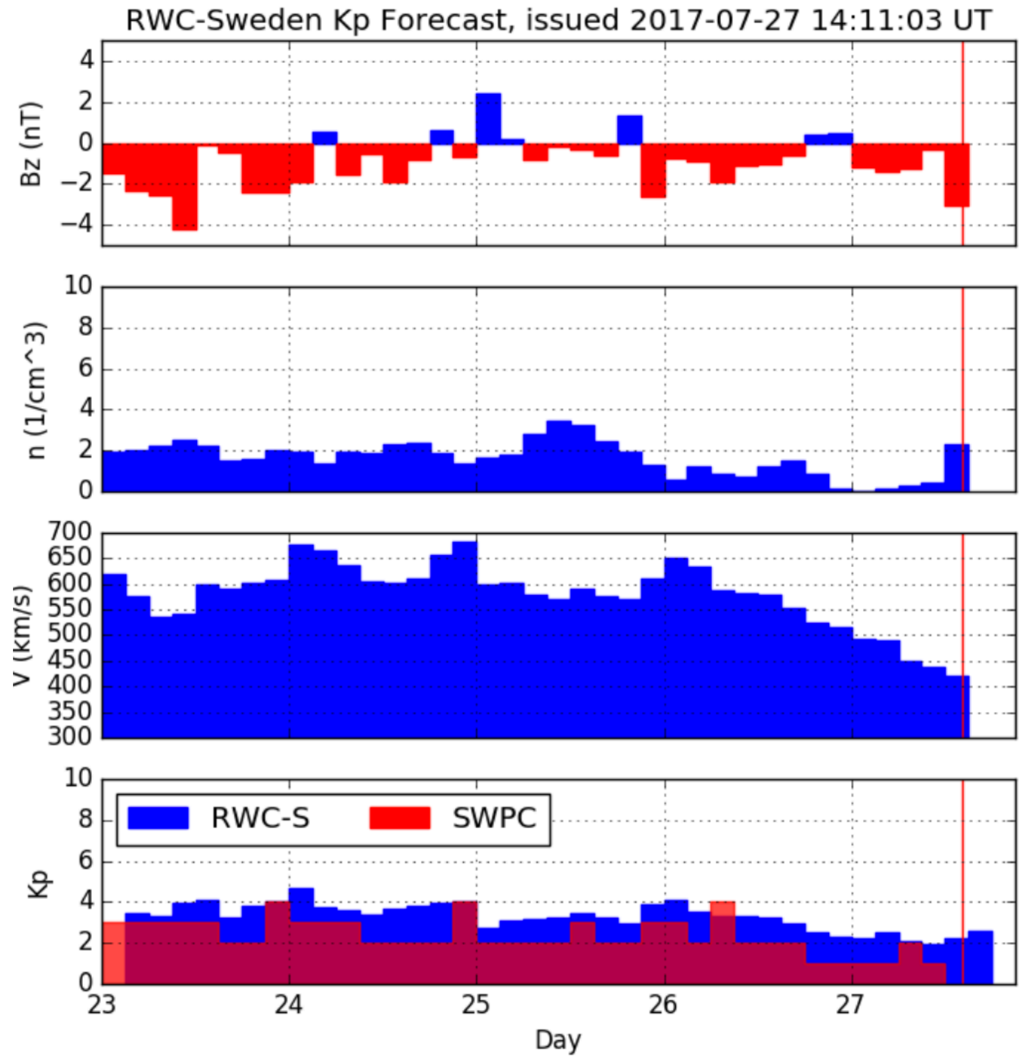
IMPTAM electron fluxes



IMPTAM electron fluxes

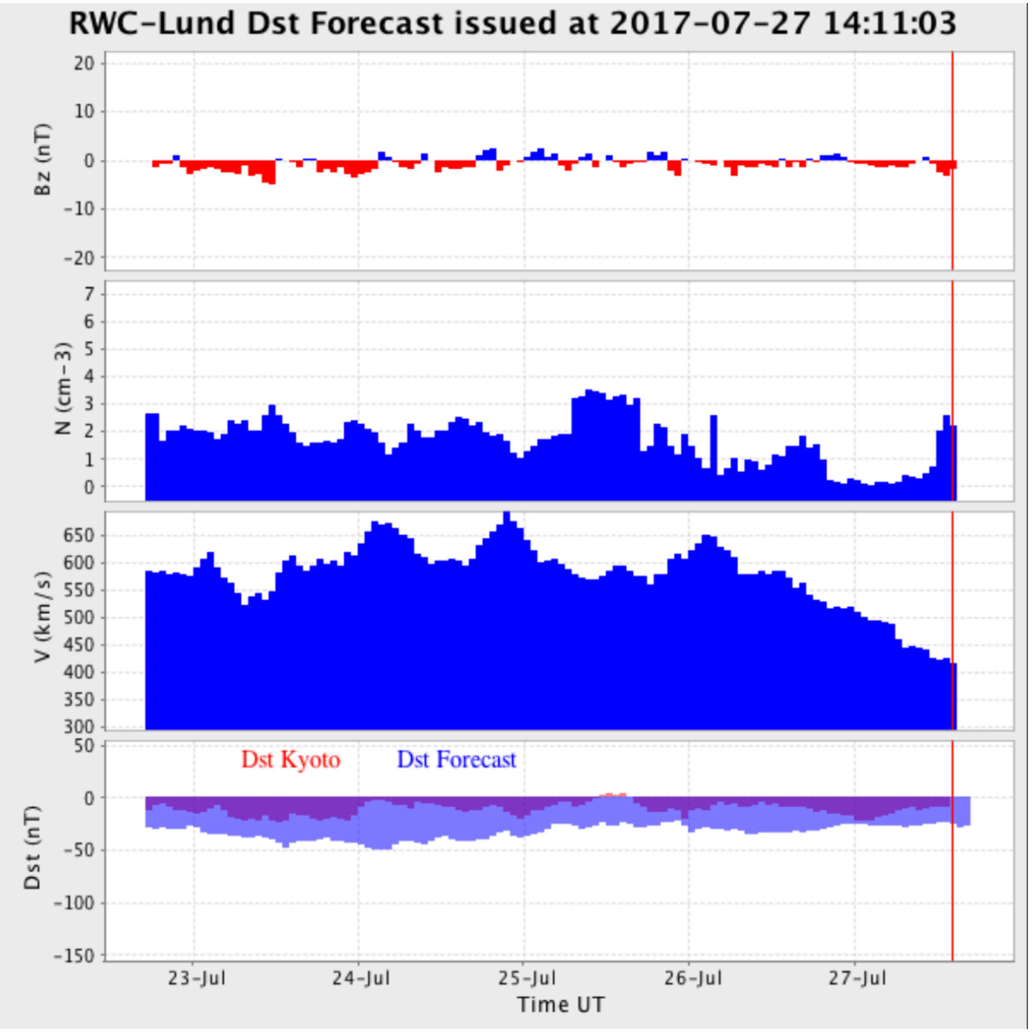


Lund Kp



RWC-Sweden Kp Forecast, issued 2017-07-27 14:11:03 UT
Bz (nT)
n (1/cm^3)
V (km/s)
Kp
RWC-S
SWPC
Day
23
24
25
26
27

Lund Dst



RWC-Lund Dst Forecast issued at 2017-07-27 14:11:03
Bz (nT)
N (cm-3)
V (km/s)
Dst (nT)
Dst Kyoto
Dst Forecast
23-Jul
24-Jul
25-Jul
26-Jul
27-Jul
Time UT

Statistical wave models

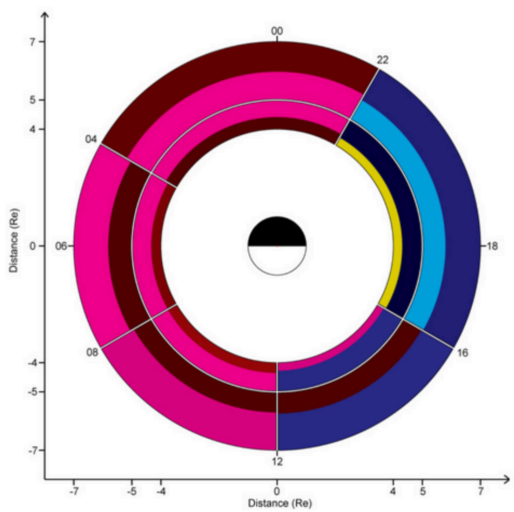
Statistical Wave Models

Magnetic field wave data from the Cluster and THEMIS missions has been used as the basis to compute new statistical wave models for the amplitudes of lower band chorus, hiss, and equatorial magnetosonic waves. The models are based on the results of an Error Reduction Ratio analysis of solar wind parameters, location, and geomagnetic indices in order to determine which of the input set of parameters are in most influential of the evolution of the magnetic field amplitudes of the wave modes under consideration.

- Description of the Error Reduction Analysis and it application
- Description of the calculation of the Statistical Wave Models
- Download the set of Statistical Wave Models

Lower band chorus

Download the set of LBC wave models



Time lag (hours) / Input	1	2	3	4	5	6	7	8	9	10
Velocity										
Density										
Pressure										
IMF Factor										
Dst Index										
AE Index										

Notes:

None

New developments

New developments, currently on the test web site

Current space weather conditions (WP 7)

Shows current (and forecast) values for

- geomagnetic indices
- various solar wind parameters
- GEO electron fluxes

Current conditions

Current Conditions

Magnetosphere	Current	Forecast
Dst (nT)	0	
Kp	7	
Solar wind	**Current**	**Forecast**
|B| (nT)	3.8	
Bz (nT gsm)	-1.5	
Density (cm^{-3})	4.7	
Velocity (kms^{-1})	334.2	
GEO e^- flux	**Current**	**Forecast**
F>2MeV	8.829	8.553
F>800keV	9.7006	9.3311

Geomagnetic indices

Dst – WDC Kyoto

Kp – GFZ Potsdam

Solar wind

All data from ACE real time

GEO electron flux

GOES observations

Sheffield NARMAX models