THE VERSATILE ELECTRON RADIATION BELT (VERB) CODE: LONG-TERM SIMULATIONS DURING THE VAN ALLEN PROBES MISSION

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Acknowledgments

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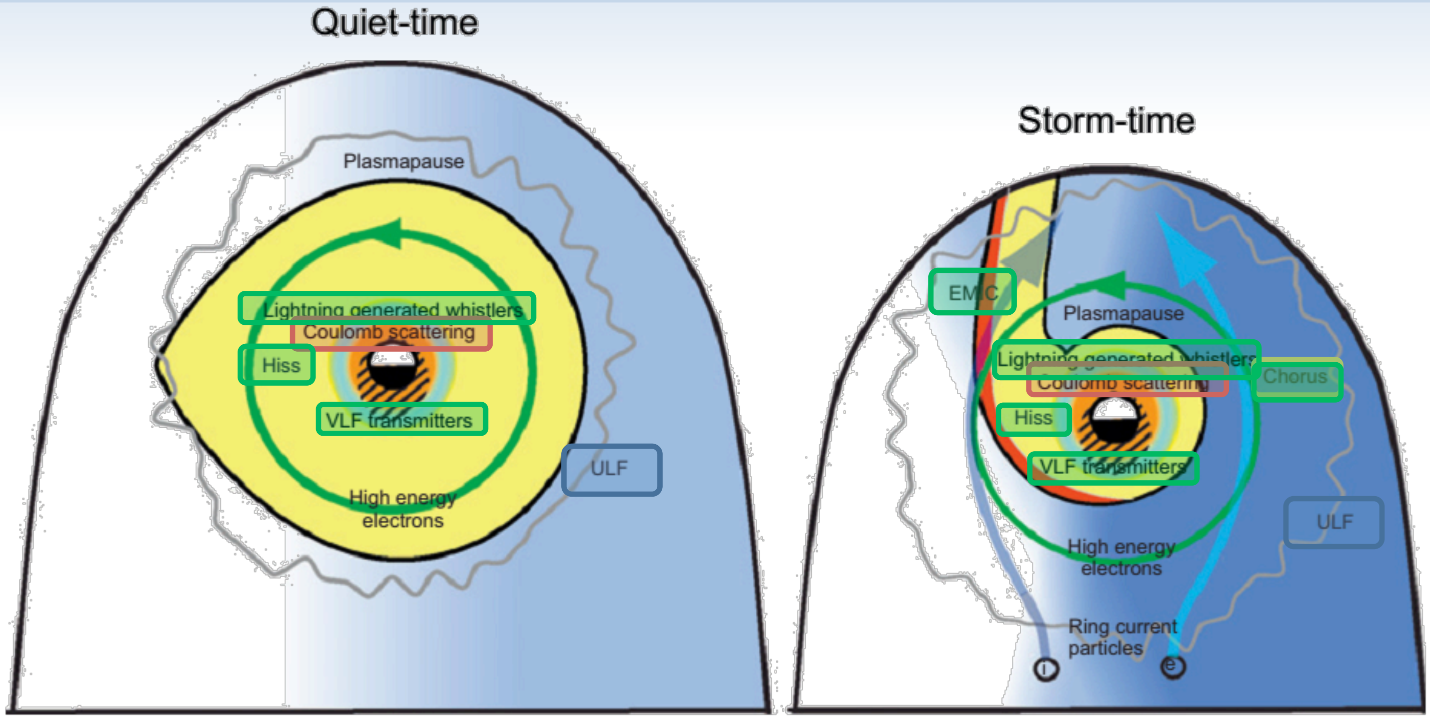
Outline

1. The VERB code
    - Long-term simulations
    - Contributions of the EMIC waves
2. VERB 4D
3. Nowcast and forecast
4. Conclusions

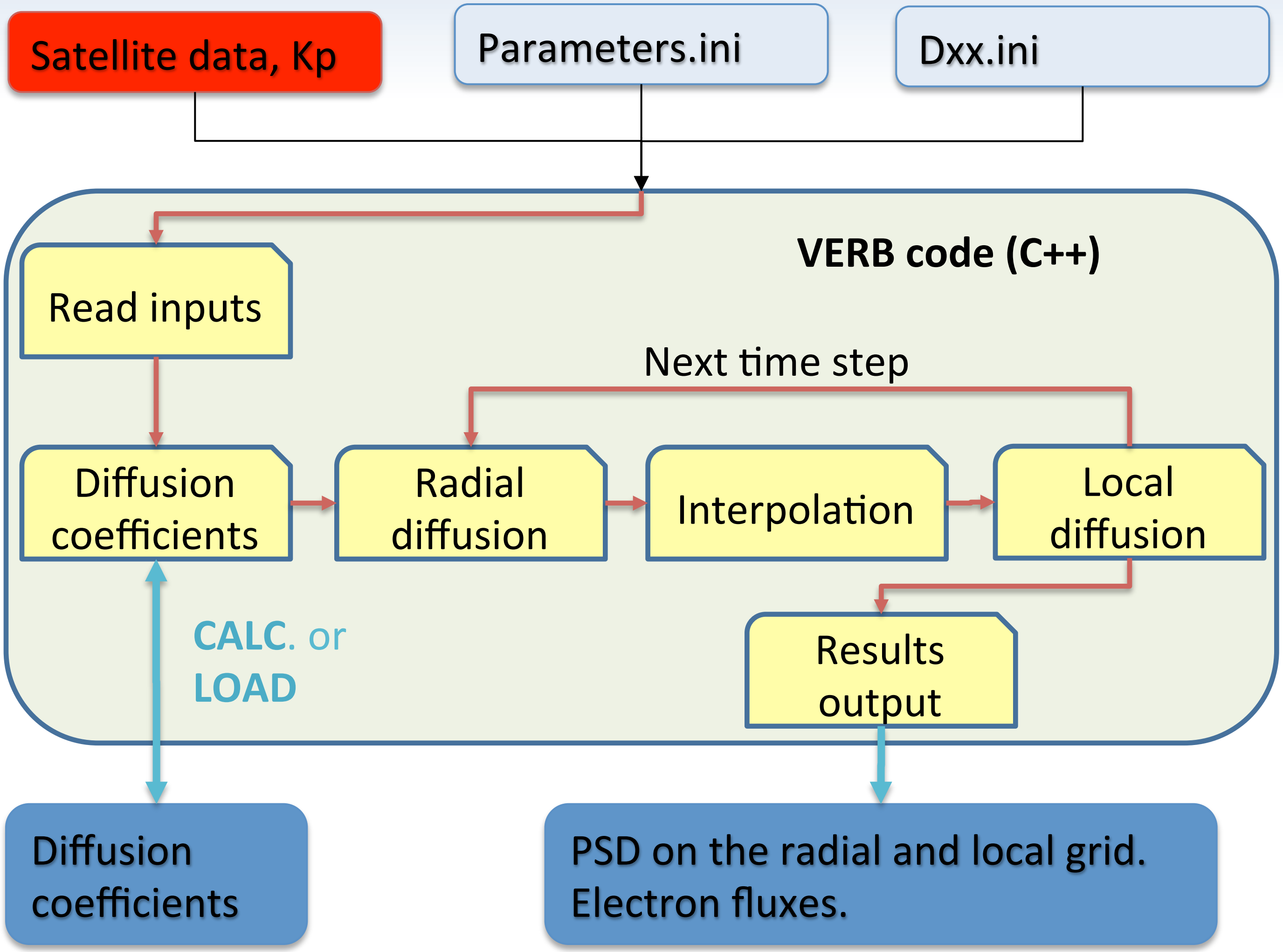
Fokker-Planck equation



Shprits et al., 2008

A number of different processes determine the evolution of the radiation belt electrons at different levels of geomagnetic activity

VERB code scheme



The VERB code uses an unconditionally stable, implicit scheme and the operator-splitting method to numerically solve the Fokker-Planck equation.

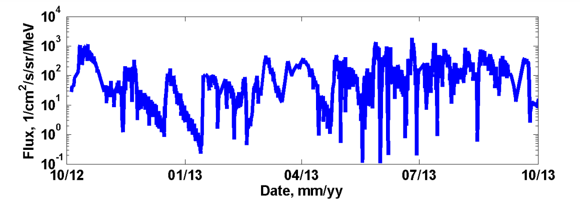
The VERB code

LONG-TERM SIMULATIONS

Long-term simulation with the VERB code and comparison with Van Allen Probes observations

Initial conditions	Steady state
Boundary conditions	PSD for the whole range of time and energy obtained with MagEIS 0.9 MeV flux variation and averaged spectrum
Grid	Energy, 0.01 – 10 MeV 101 points. Pitch-angle, 0.7-89.3 91 points. L*, 1 – 5.5 46 points. Time step, 1 hour.
Simulation period	• 365 days, Oct 1st, 2012 – Oct 1st, 2013
Losses	Coulomb scattering (loss into atmosphere), Magnetopause shadowing
Plasmapause	Carpenter and Anderson, 1992

Boundary conditions



Radial diffusion

[redacted]

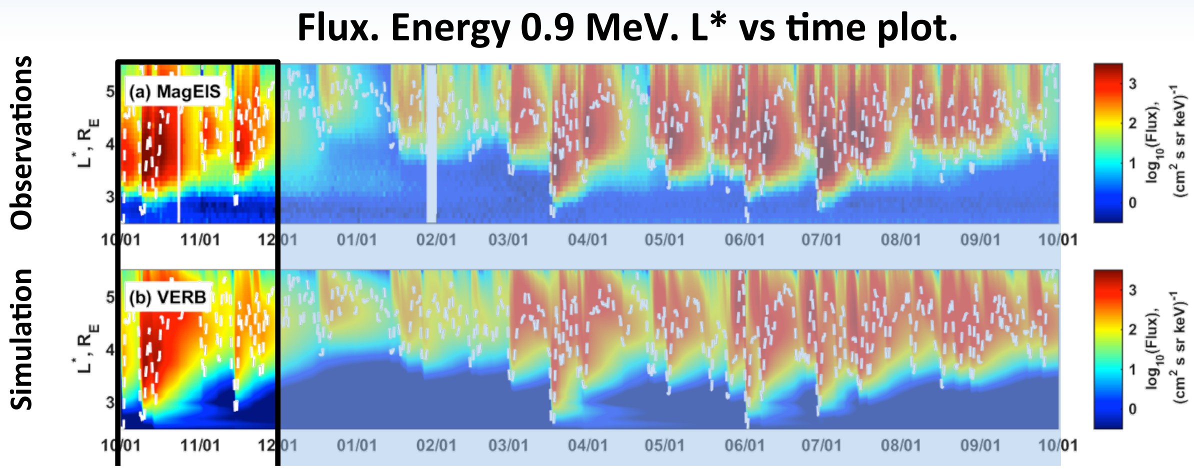
$-9.325\ L↑10$

Brautigam and Albert [2000]

Table of wave parameters

Wave	Amplitude <Kp=2>, [pT]	λ_{max}	Density model	MLT averaging	Spectral properties and wave normal angle
Chorus day	Kp scaled, <30>	35°	Sheeley et al. 2001	25%	See Subbotin at al. 2011
Chorus night	Kp scaled, <35>	15°		25%	
Plasmaspheric hiss	Kp scaled, <45>	45°	Denton et al. 2004, 2006	60%	Realistic, Orlova et al. 2014 (CRRES)
Lighting, 2xVLF	Kp scaled, <4>, 0.8	45°	Carpenter and Anderson 1992	100%, 4x2.4%	See Subbotin at al. 2011

Long-term VERB code simulation
Oct 2012 – Oct 2013



We reproduce the dynamics of relativistic electrons, but not for the ultra-relativistic energies

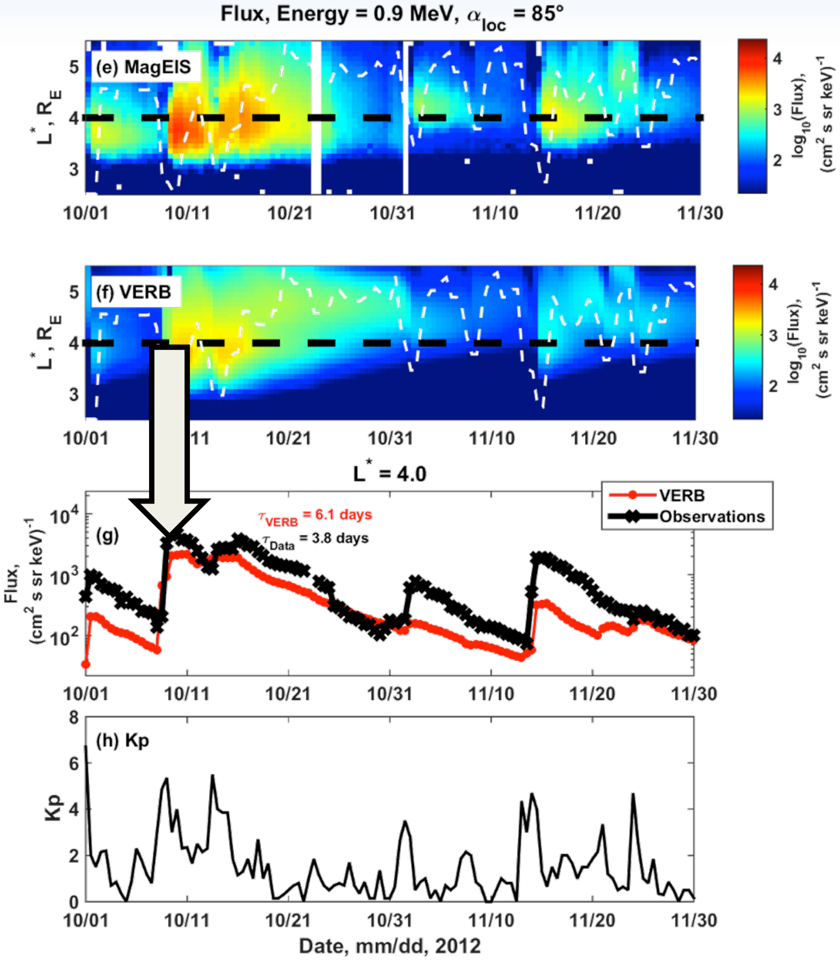
Decay rates comparison at $L^*=4$
Oct, 01 – Nov, 30, 2012

Observations

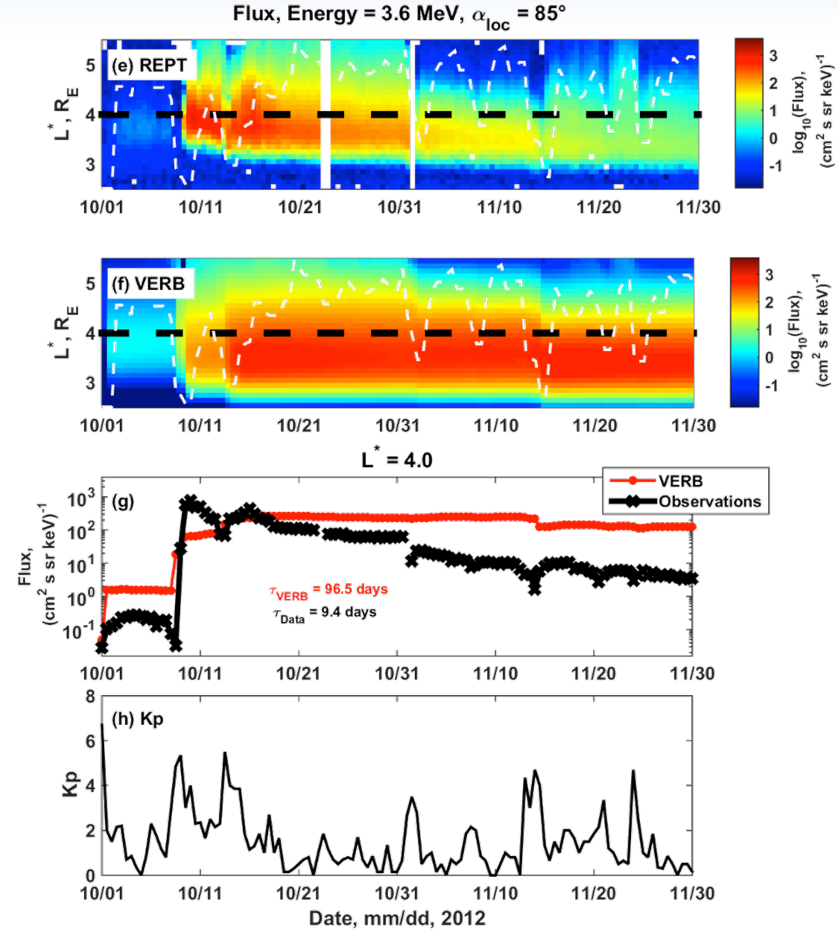
Simulation

$L^*=4$

Relativistic electrons. 900 keV



Ultra-Relativistic electrons. 3.6 MeV



$\tau_{VERB} = 6.1\ days,\ \tau_{Data} = 3.8\ days$

$\tau_{VERB} = 95.5\ days,\ \tau_{Data} = 9.4\ days$

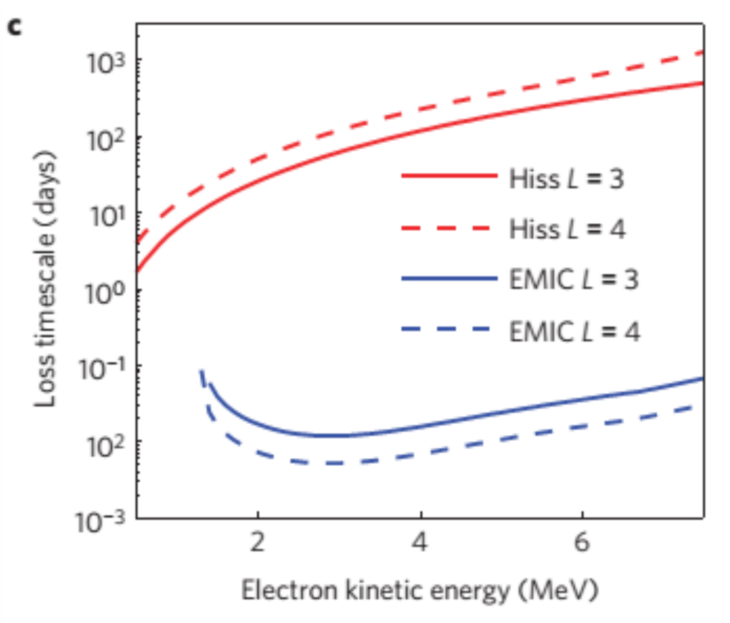
Observed and modeled decay rates are significantly different for ultra-relativistic electrons

Drozdov et al. 2015

EMIC waves are important!

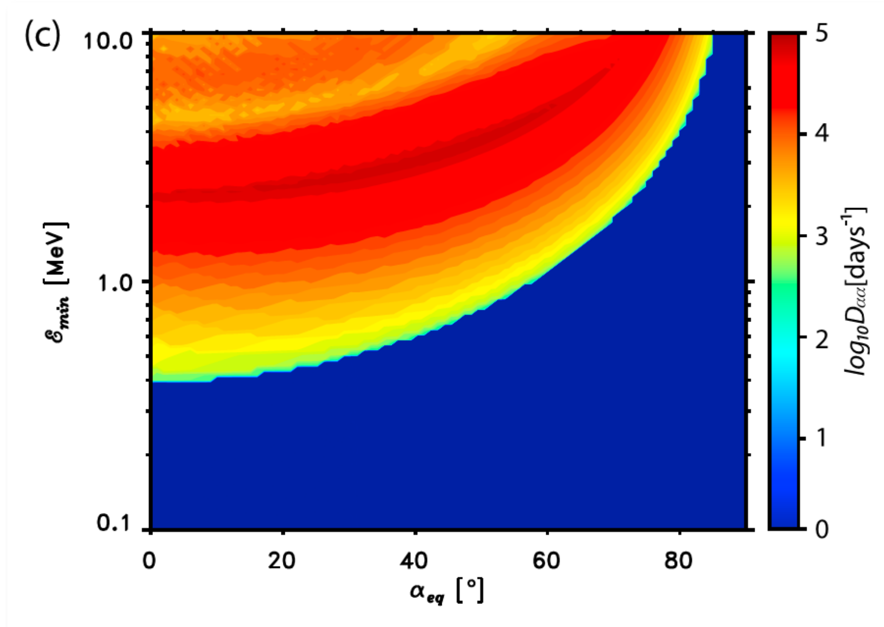
Thorne and Kennel [1971]; Summers and Thorne [2003]; Li et al. [2007] Ukhorskiy et al., [2010] suggested that **EMIC waves may provide efficient scattering mechanism for relativistic electrons**.

The loss time scale for EMIC and hiss waves



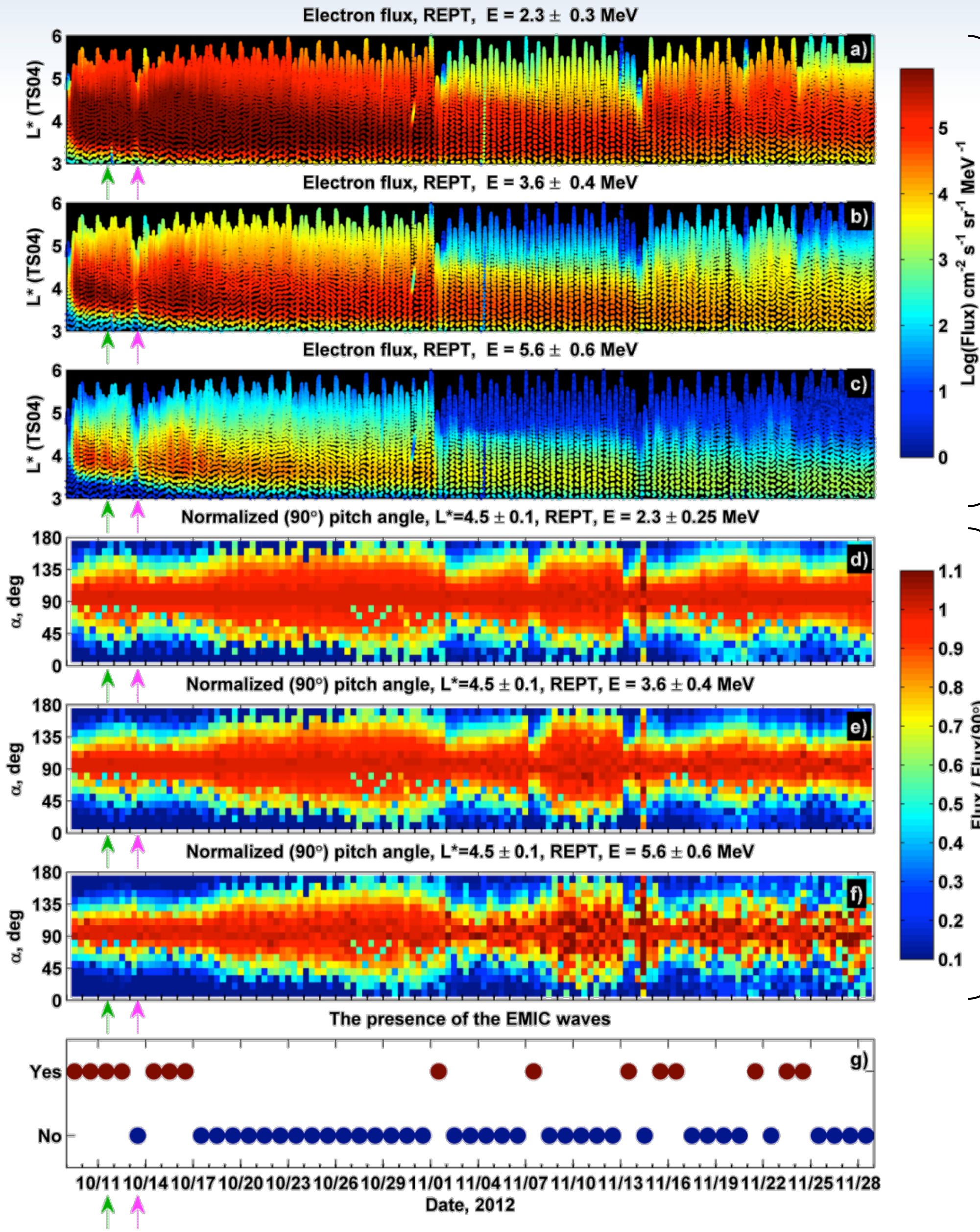
Shprits et al., 2014

Bounce-averaged pitch-angle diffusion coefficient for the EMIC waves



Ukhorskiy et al. 2010

EMIC waves
Oct, 01 – Nov, 30, 2012



Omnidirectional fluxes

Normalized pitch-angle distribution

We see the presence of the EMIC waves during this period.

Usanova et al. 2014

The parametrization of the

EMIC WAVES

EMIC waves parametrizations

$\mathbf{B_w^2 = 1\ nT^2}$ *[Ukhorski et al, 2010; Meredith et al. 2014]*

MLT = 25% , Occurrence = 2% [*Meredith et al. 2014*]

Kp ≥ 4 Sw ≥ 450 km/s P ≥ 5 nPa

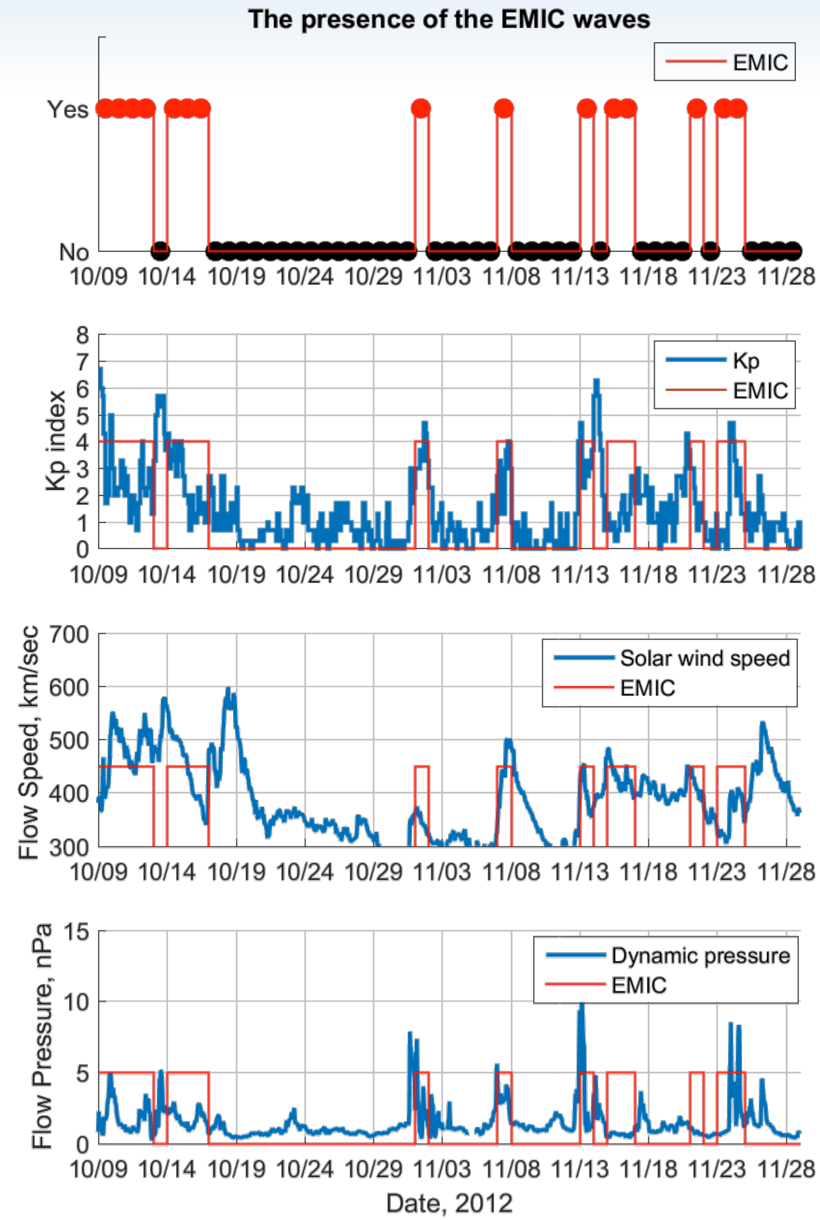
[Fraser and Nguyen, 2001]

$\Delta L = L_e - L_{pp}$

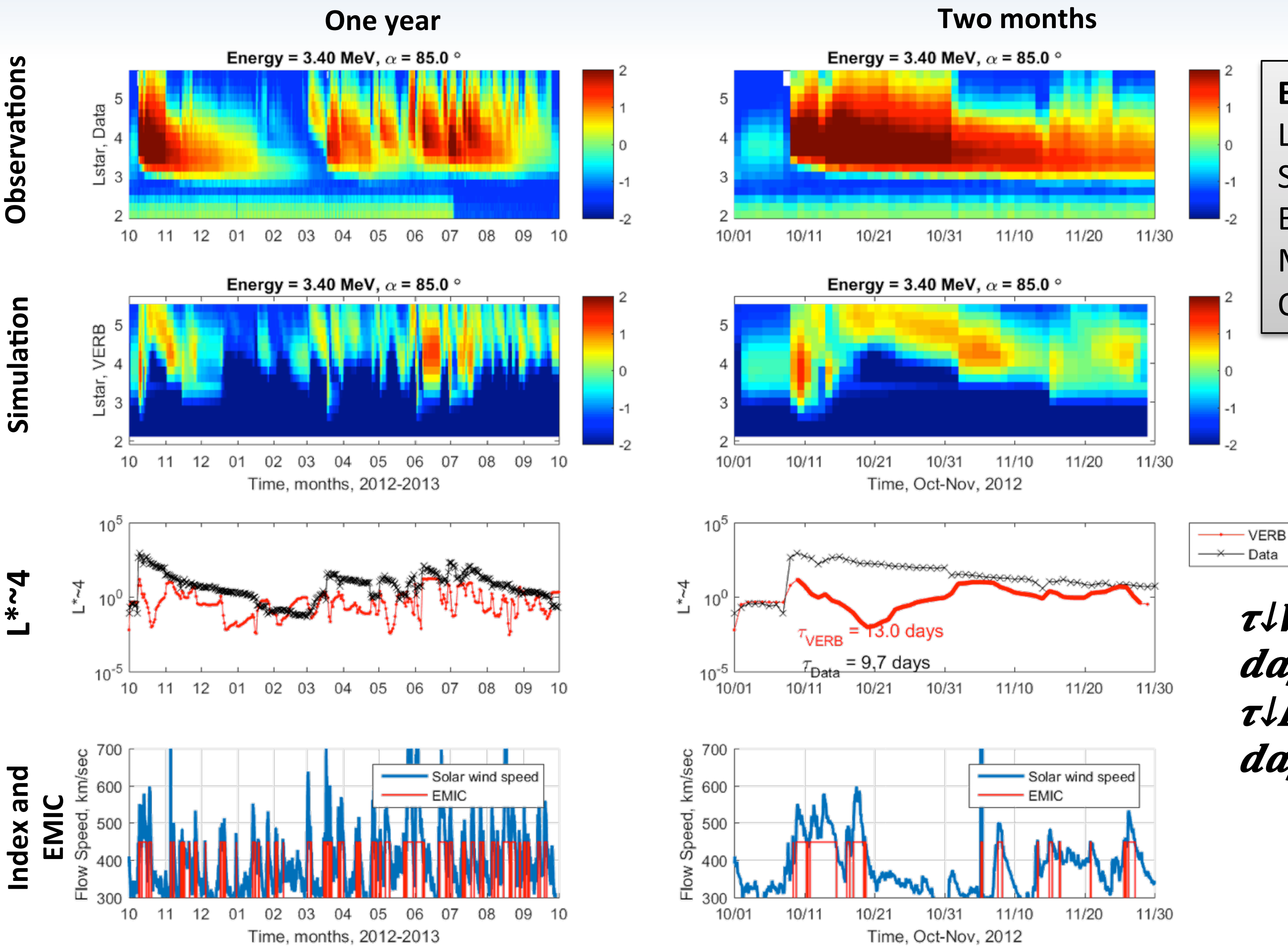
$\Delta L<0$: inside the plasmapause

$\Delta L>0$ outside of the plasmapause

L=−1<Δ*L*<4



Solar wind velocity ≥ 450 km/s parametrization



EMIC:

L= $-1<L_{EMIC}-L_{pp}<4$

Sw ≥ 450 km/s,

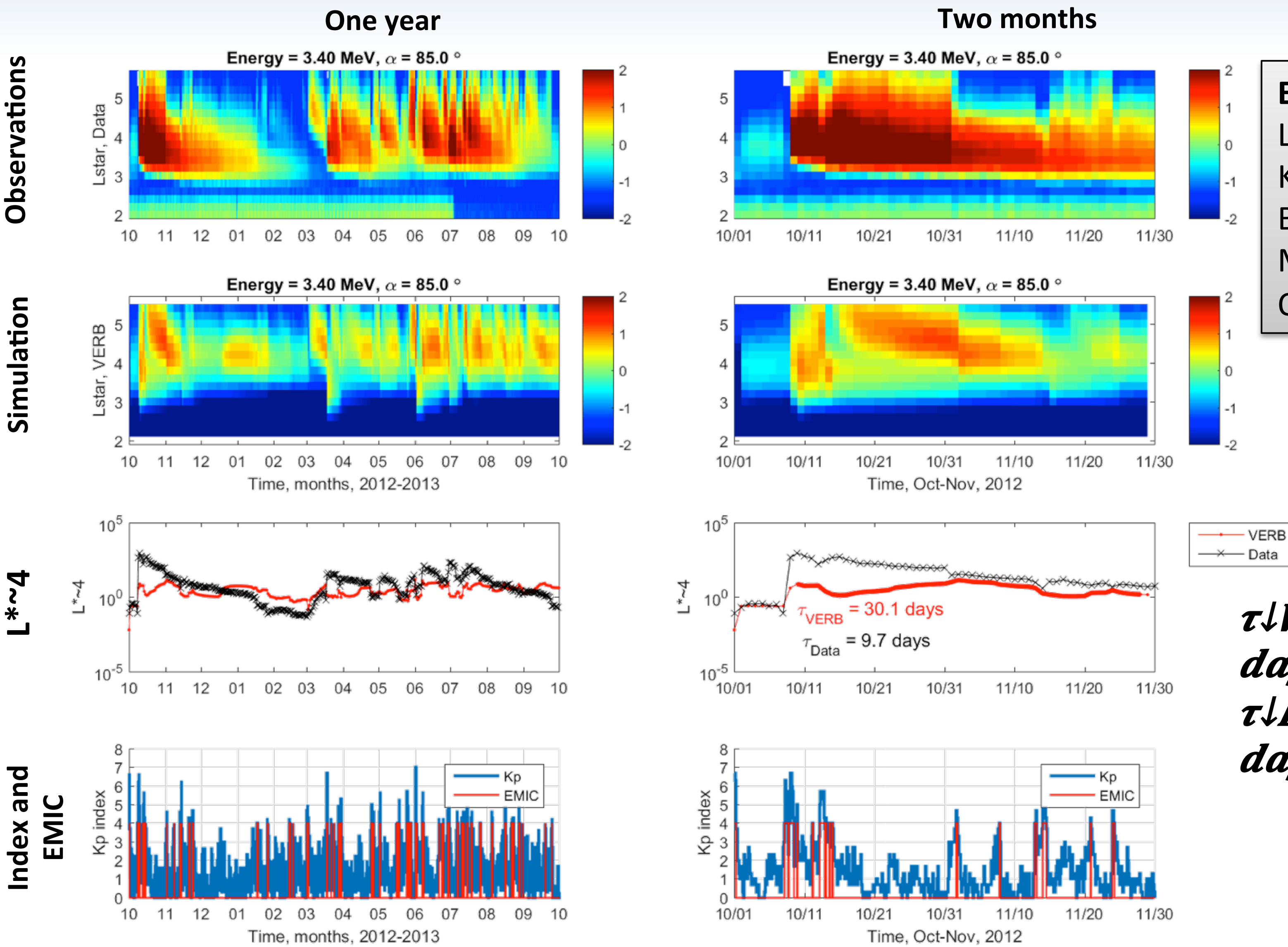
$B_w^2 = 1\ nT^2$

MLT = 25% ,

Occurrence = 2%

$\tau_{VERB}=13.0$ days, $\tau_{Data}=9.7$ days

Kp ≥ 4 parametrization



EMIC:

L= $-1<L_{EMIC}-L_{pp}<4$

Kp ≥ 4,

$B_w^2 = 1\ nT^2$

MLT = 25% ,

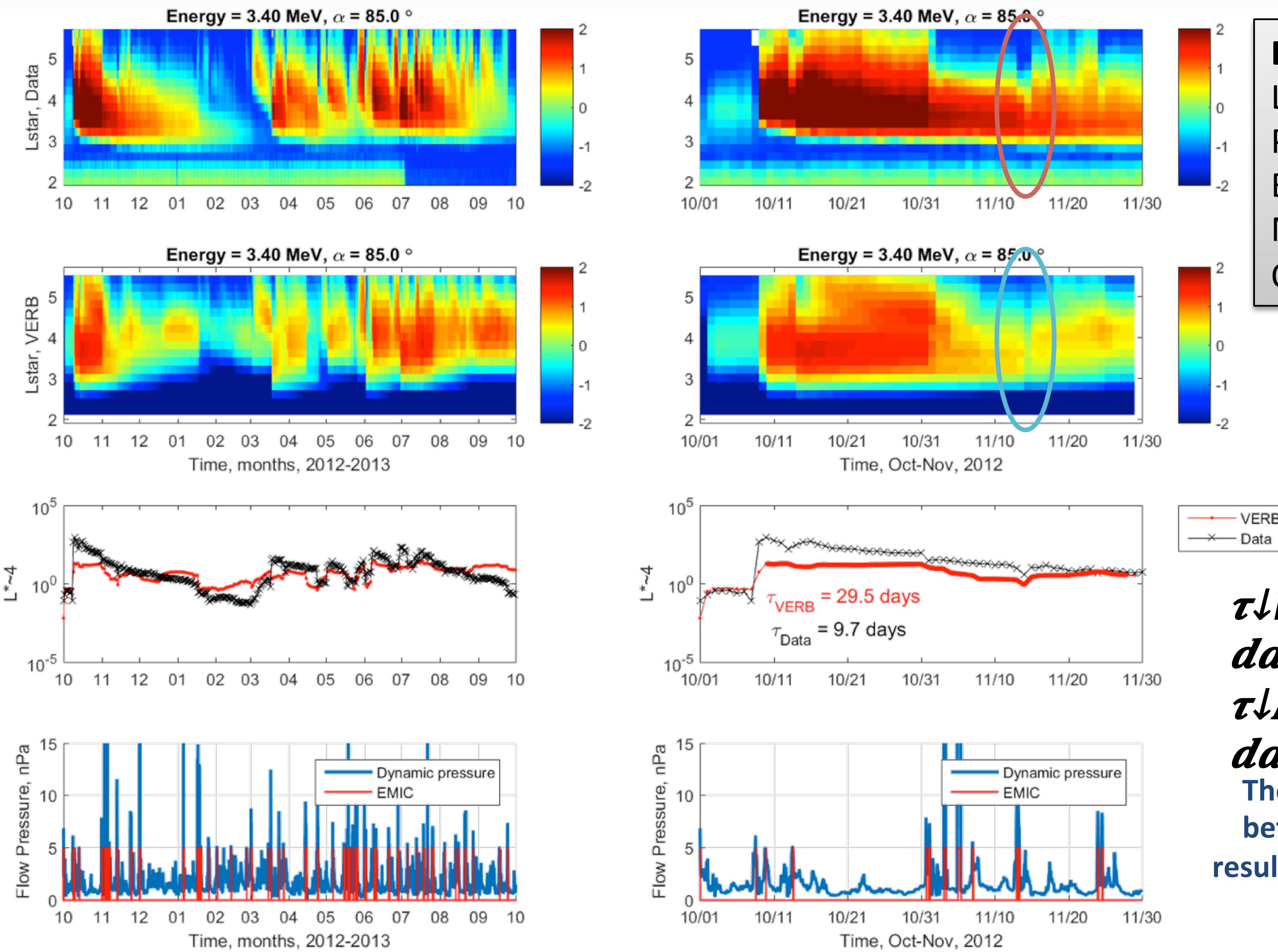
Occurrence = 2%

$\tau_{VERB} = 30.1$ ***days***, $\tau_{Data} = 9.7$ ***days***

Solar wind pressure ≥ 5nT parametrization

One year | **Two months**

Rows: **Observations**, **Simulation**, **L*~4**, **Index and EMIC**



EMIC:
L= $-1<L_{EMIC}-L_{pp}<4$
P ≥ 5 nT,
$B_w^2 = 1\ nT^2$
MLT = 25% ,
Occurrence = 2%

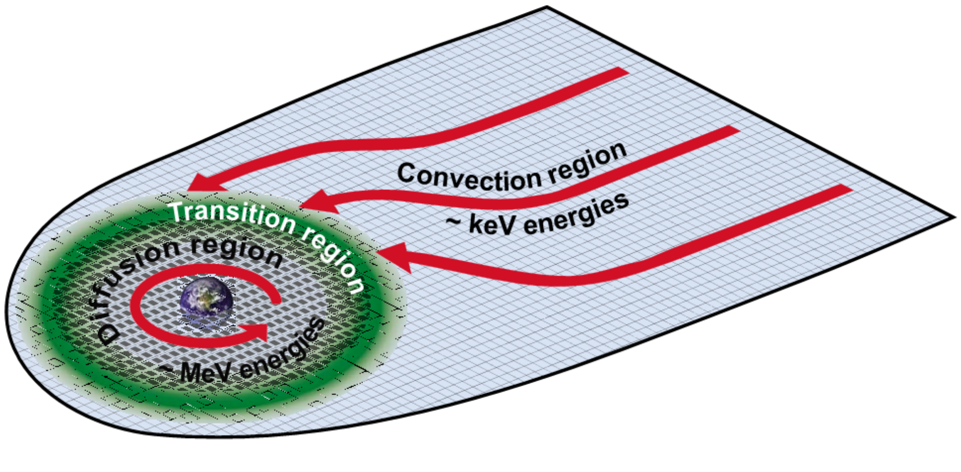
$\tau_{VERB} = 29.5$ *days*, $\tau_{Data} = 9.7$ *days*

The best agreement between simulation results and observations

The new version

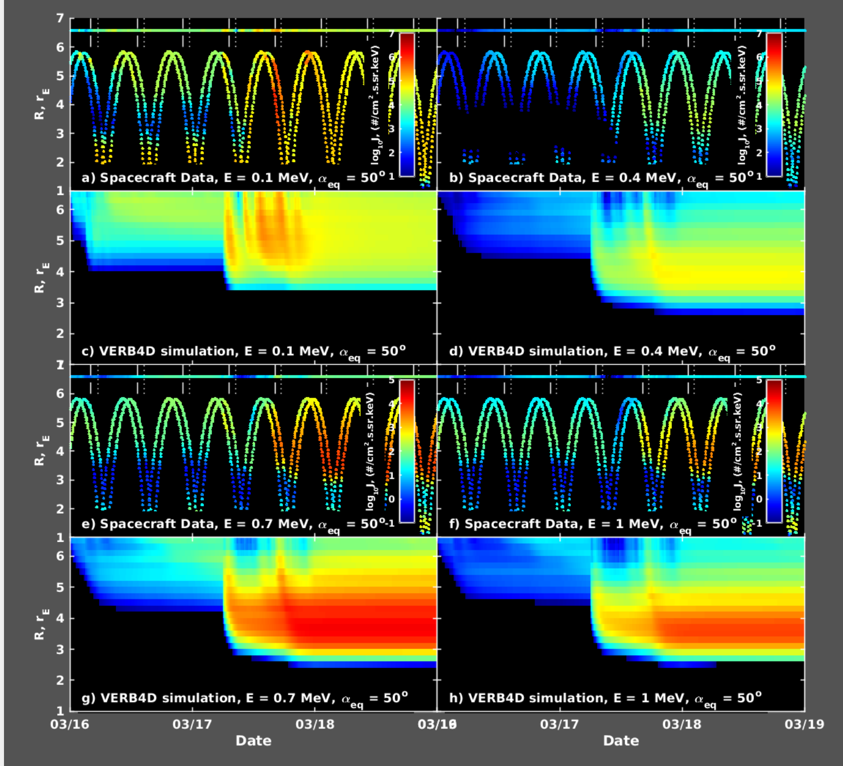
VERB 4D CODE

Convective and Diffusive simulations of March 17, 2013 storm



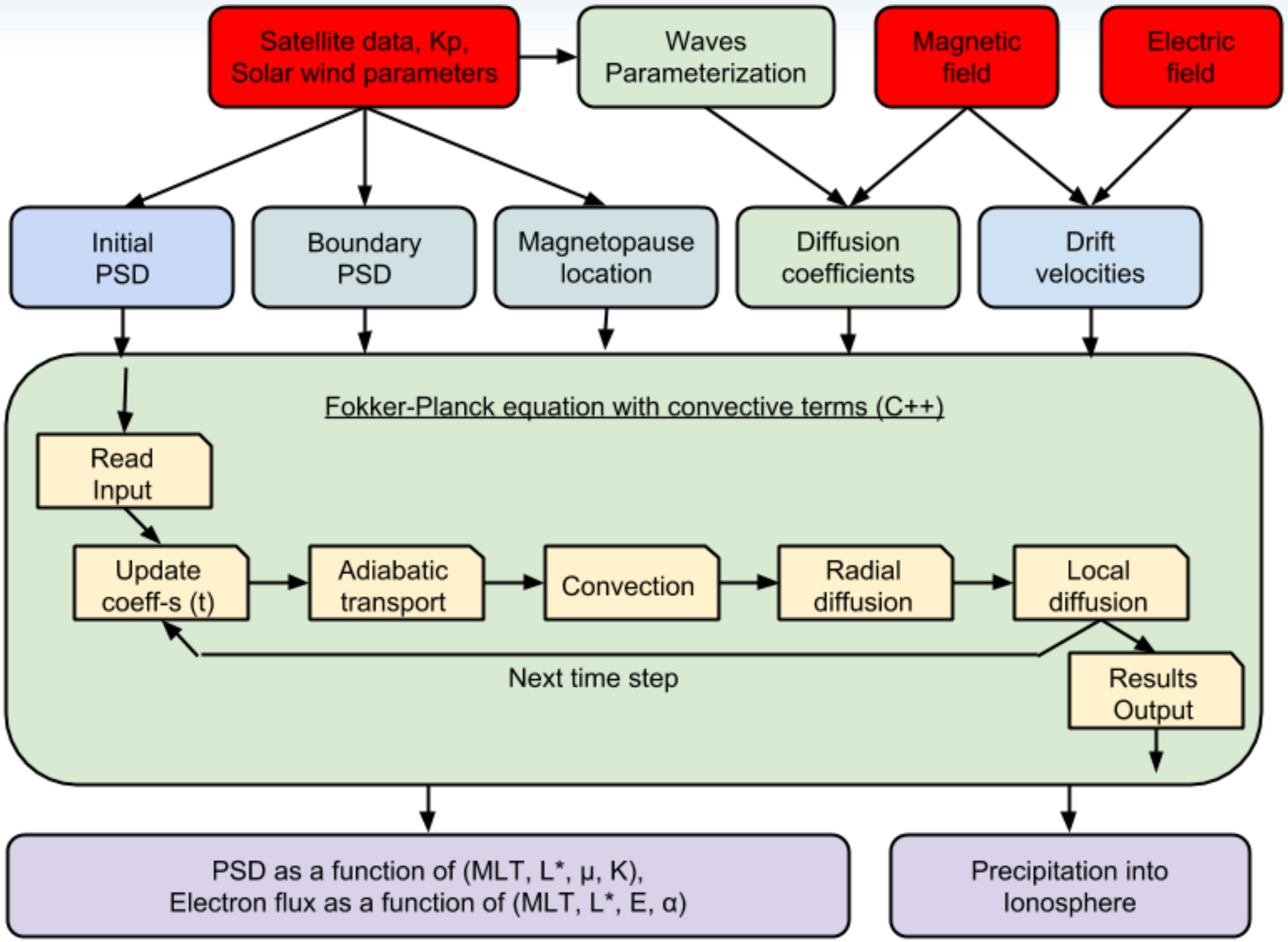
During the March 2013 storm energetic relativistic and ultra-relativistic electrons show very different dynamics. The comparison with observations at various energies can help validate the code and reveal if the dominant physical mechanisms operate at a wide range of energies. Simulations show similar dynamics as observations.

$\partial f/\partial V)-f/\tau$



Shprits et al, 2015

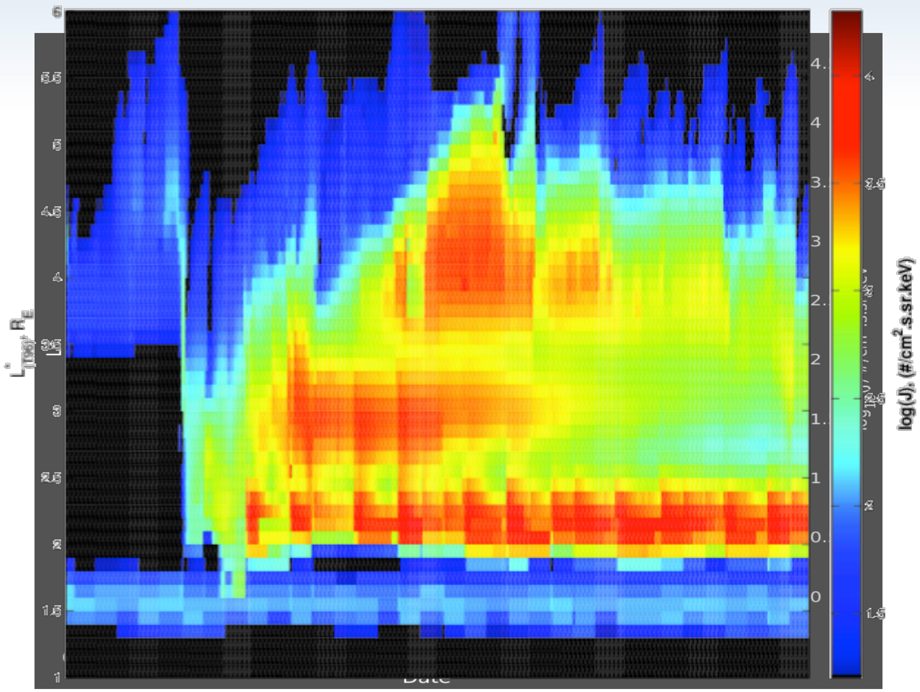
VERB 4D code scheme

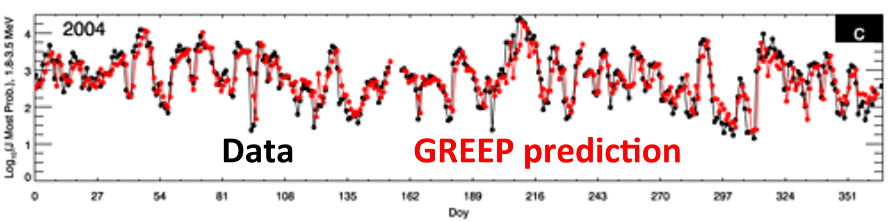


Radiation belts

NOWCAST AND FORECAST

Data assimilation and GREEP





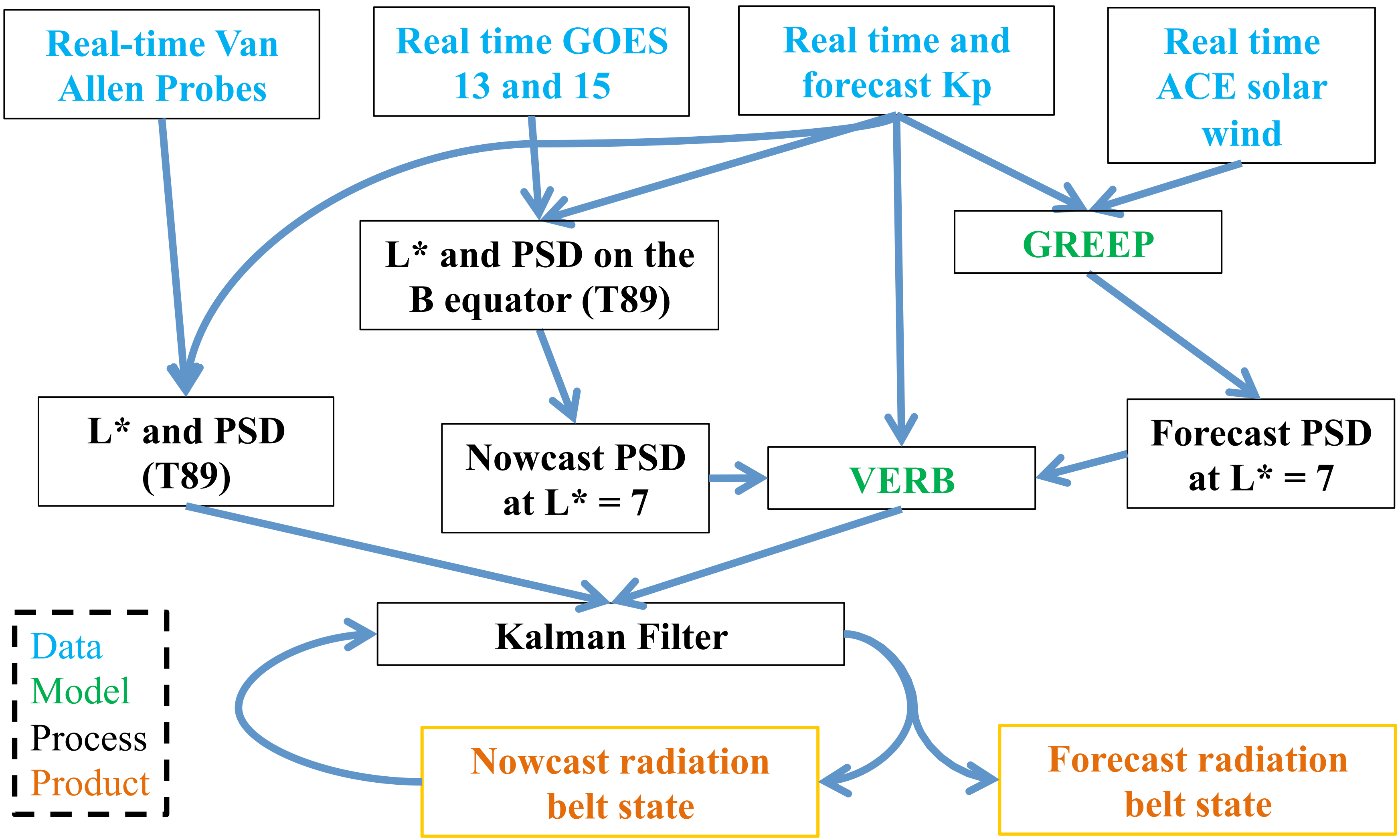
- We can reconstruct the PSD by combining the observations with the VERB code through a split-operator Kalman filter technique.

Kellerman et al. (2014), *Three-dimensional data assimilation and reanalysis of radiation belt electrons: Observations of a four-zone structure using five spacecraft and the VERB code*, JGR

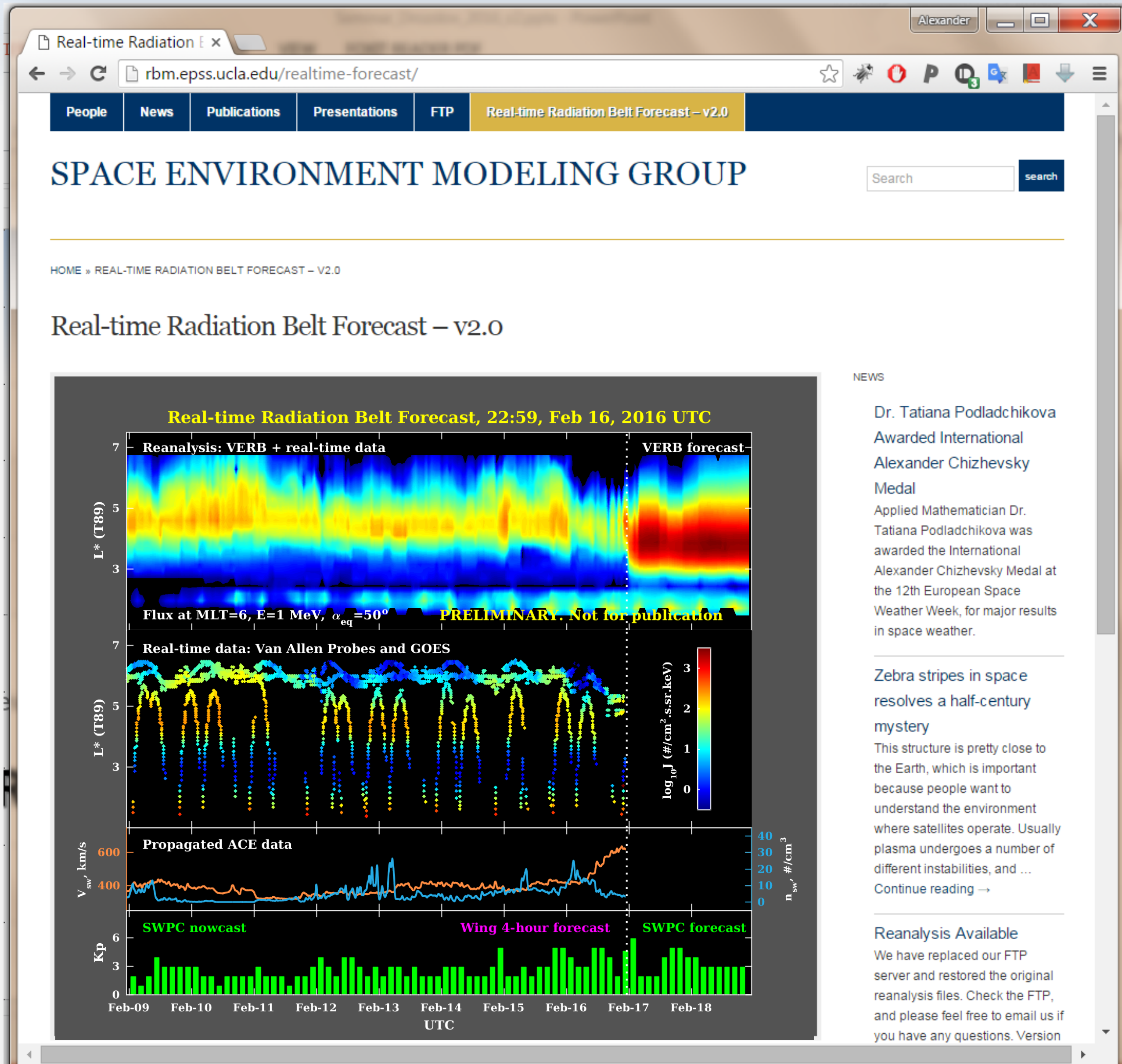
- **G**eosynchronous **R**adiation belt **E**lectron **E**mpirical **P**rediction model (GREEP) is based on the solar wind velocity and density conditions and can predict the daily averaged outer radiation belt electron fluxes .

Kellerman et al. (2013), *A Geosynchronous Radiation–belt Electron Empirical Prediction (GREEP) model*, Space Weather

Radiation Belt Forecast Framework

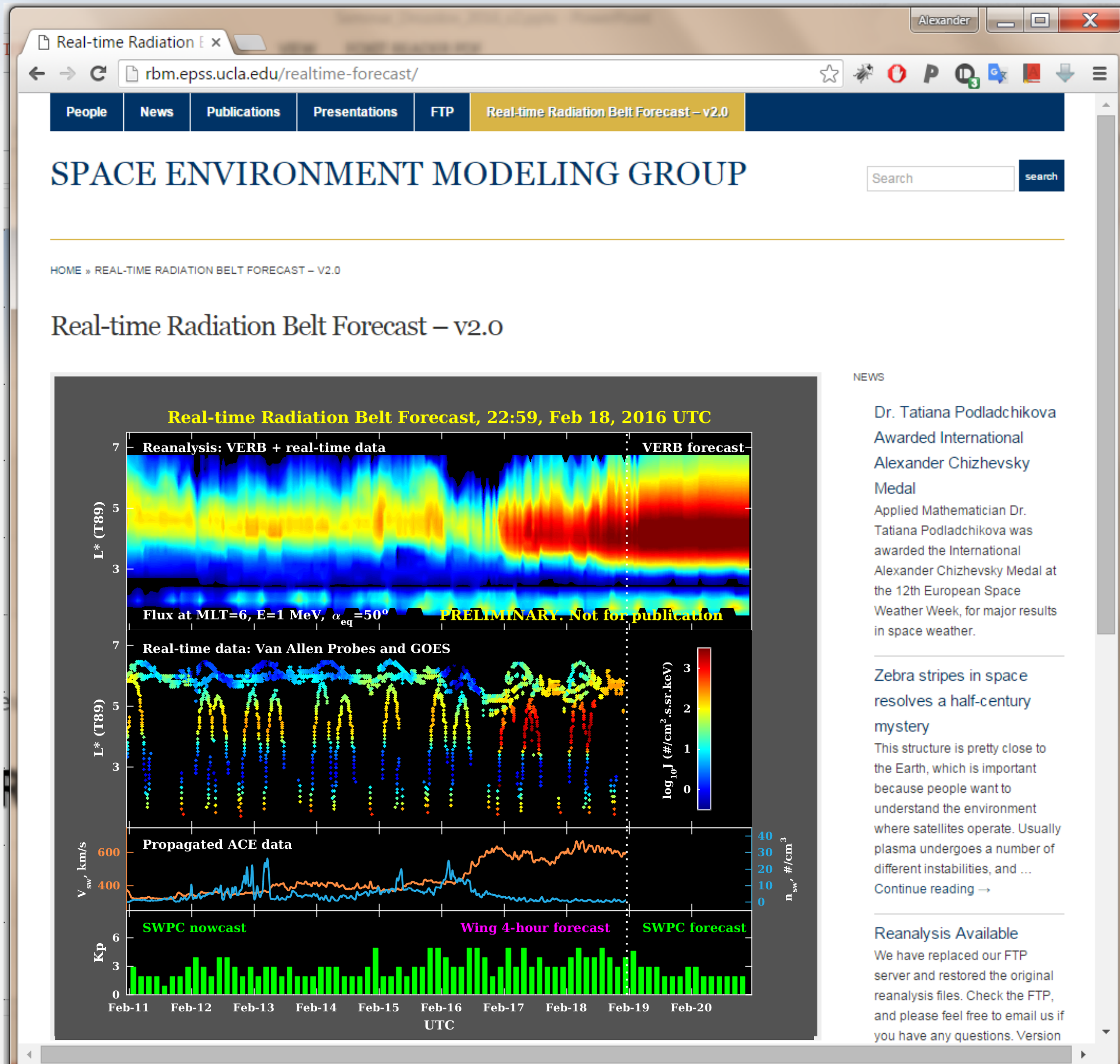


Forecast



Real-time forecast of the electron radiation belt dynamics is available on http://rbm.epss.ucla.edu

Forecast



Real-time forecast of the electron radiation belt dynamics is available on http://rbm.epss.ucla.edu

Conclusions

- The Versatile Electron Radiation Belt (VERB) code is capable of solving the Fokker-Planck equation, accounting for radial diffusion and local scattering.
- Comparison between long-term VERB code simulation and the observations shows good agreement for the relativistic (~1 MeV) electrons. However, the fluxes for the ultra-relativistic energies (>3 MeV) are overestimated.
- Most likely, EMIC waves are necessary additional losses. The simulation with parametrizes EMIC waves by solar pressure provides better results.
- The new VERB-4D code includes convection processes and uses new invariant grid to calculate radial and local diffusion. Simulations with the 4D code will allow to compare simulations at various MLT with multi point observations provided by Van Allen Probes, THEMIS, Cluster II, MMS, and other missions.
- The reanalysis provides a global reconstruction of the state and evolution of the radiation belts, as compared to sparse spacecraft observations.
- Data assimilation is currently applied to conduct operational forecasting of the electrons radiation belt for 1-2 days into the future.

THANK YOU