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# Initial results of coupling of IMPTAM and VERB

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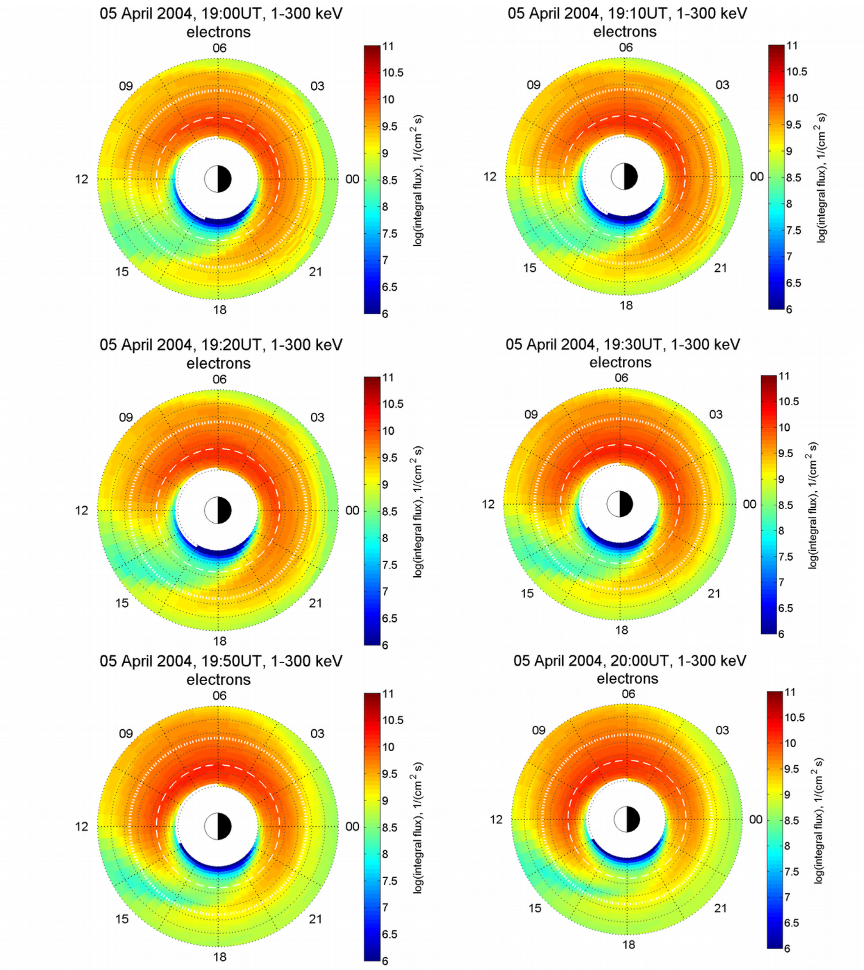
# Objectives

- Combination of advanced models of the ring current and radiation belts:
  - IMPTAM-model: tool for modeling and forecasting the dynamics and evolution of particles in the ring current
  - VERB-code: models and forecast the dynamics of high energy electrons in the radiation belts
- Use the coupled model to predict the dynamics of the near-Earth radiation environment.

# IMPTAM model

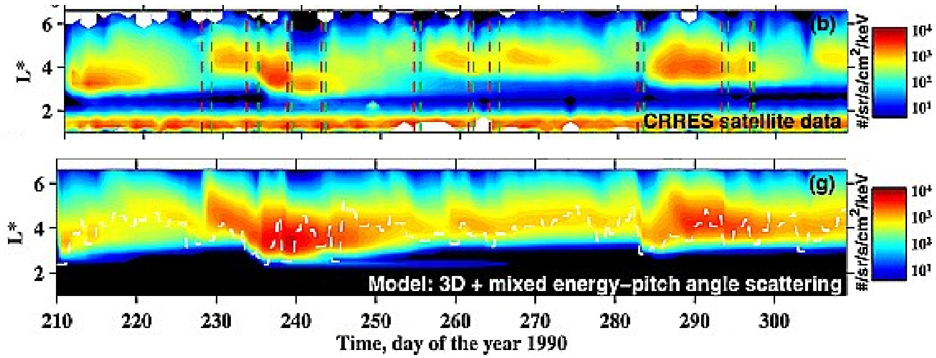
- IMPTAM: The Inner Magnetospheric Particle Transport and Acceleration Model
- The model uses the guiding center approximation to trace ions and electrons with energies up to 100s of keV from the plasma sheet to inner L-shell regions in time-dependent magnetic and electric fields
- Accounts for: radial and pitch angle diffusion, wave-particle interactions, losses to the atmosphere, coulomb collions, a.o.

**IMPTAM electron fluxes for 1-300 keV**

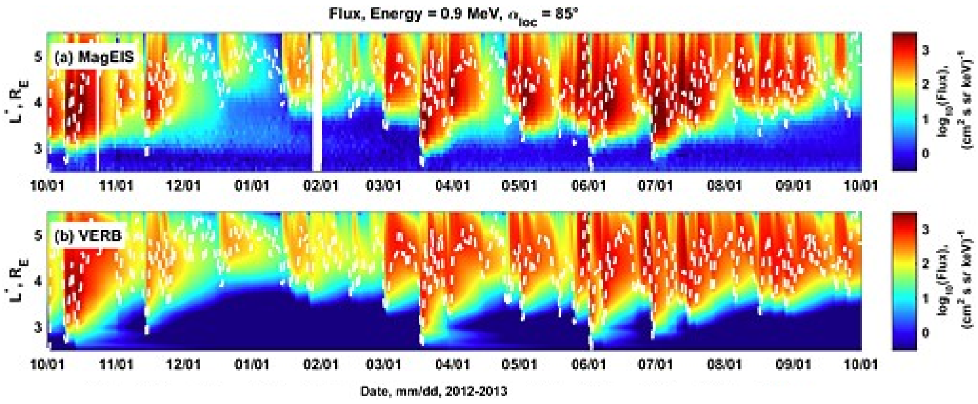


# VERB code

- VERB-code: Versatile Electron Radiation Belt code
- Describes the dynamics and evolution of the radiation belts calculating a numerical solution of the 3D Fokker-Planck equation (Energies: 10s of keV to MeV)
- Simulations account for: radial, pitch angle and mixed energy diffusion
- wave-particle interactions: chorus (dayside, nightside), hiss, VLF-transmitters, lightning, EMIC
- losses to the atmosphere
- magnetopause losses




*Subbotin et al. 2011b*




*Drozdov et al. 2015*

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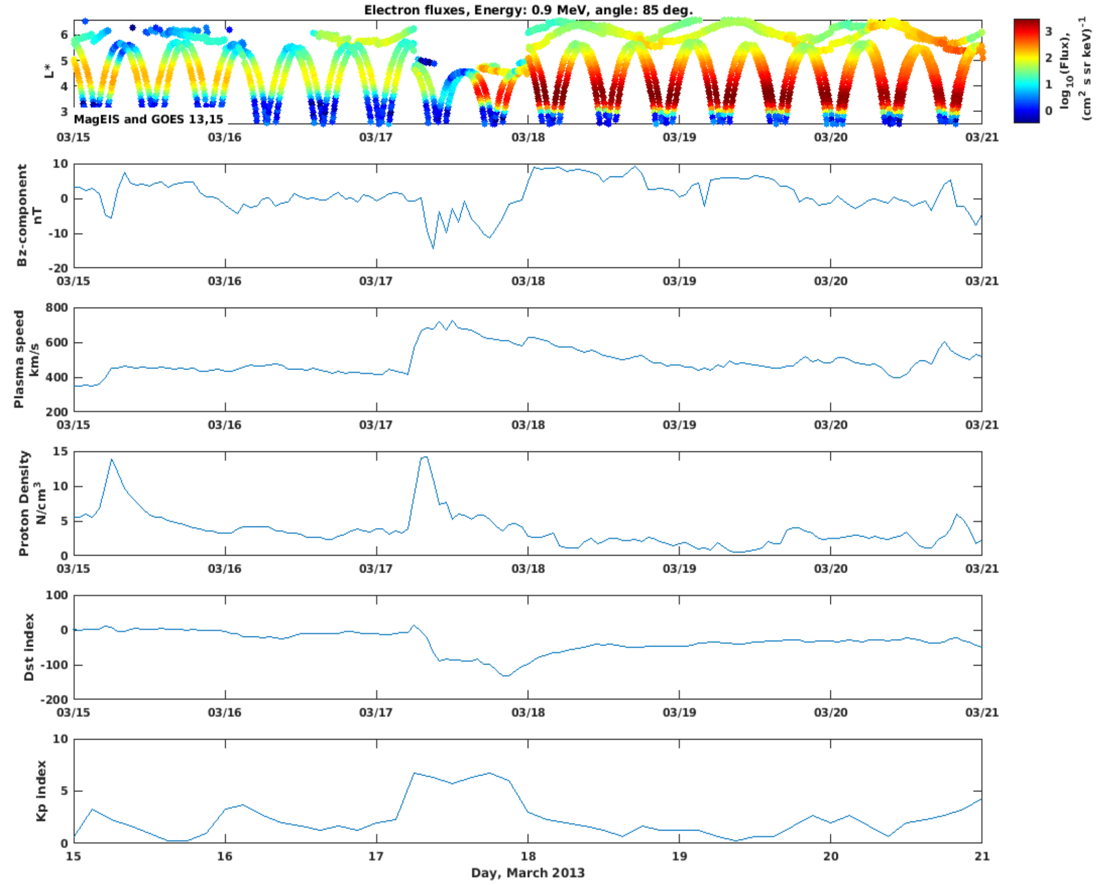
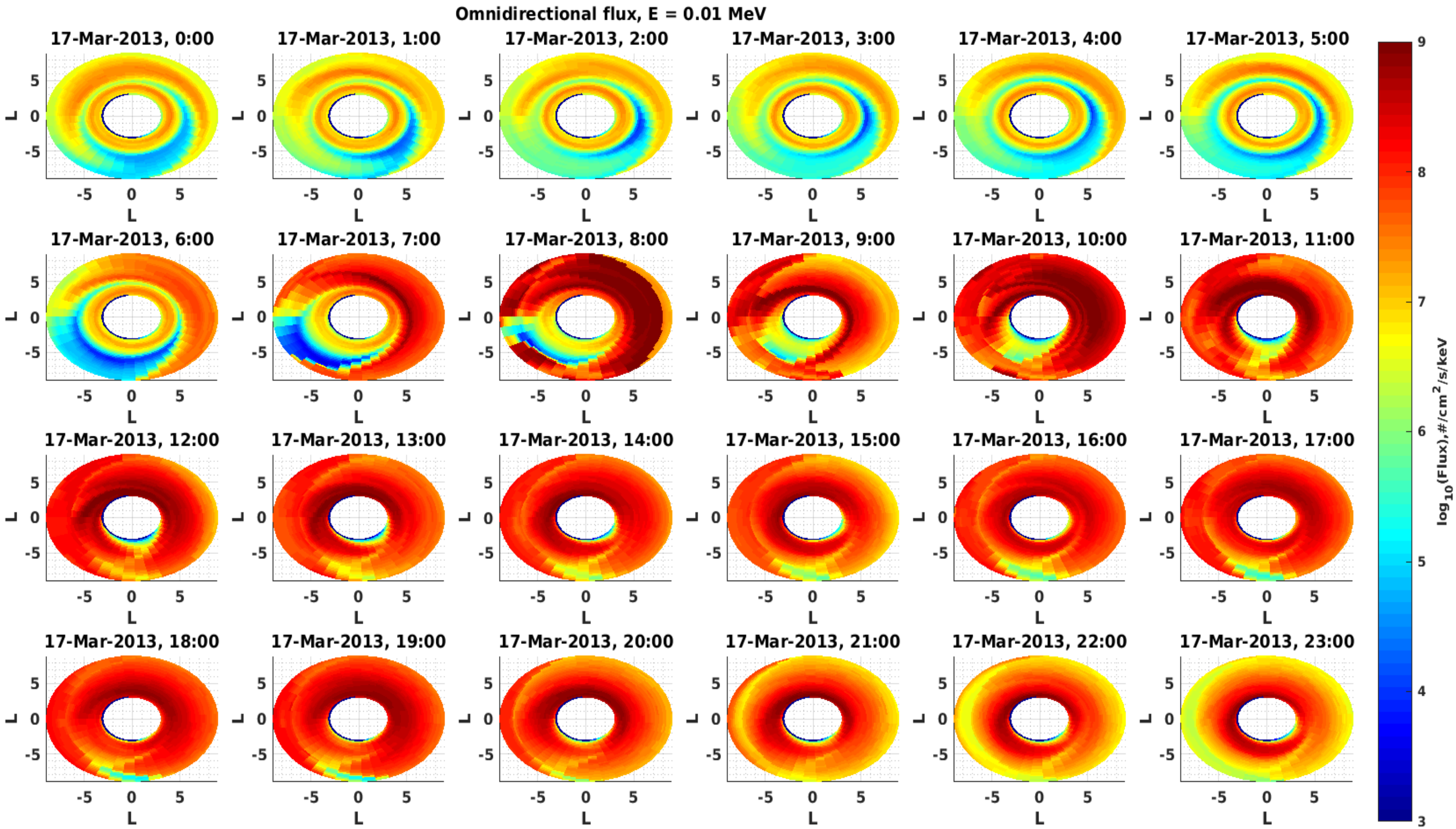
# Studied event

- March 17th, 2013 storm
- Satellite data observations: GOES and Van Allen Probes
- Strongest storm in the Van Allen probes era.
- GEM and CCMC challenge storm



# IMPTAM model

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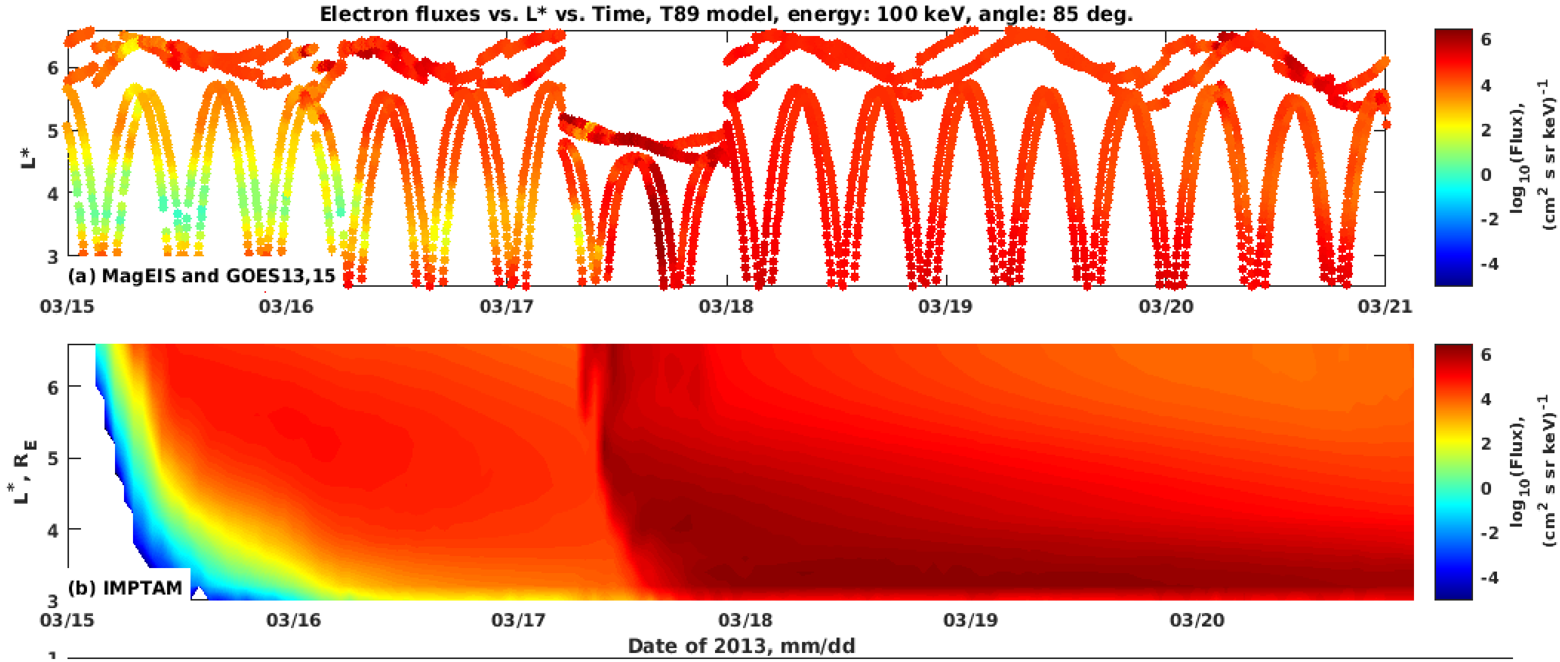
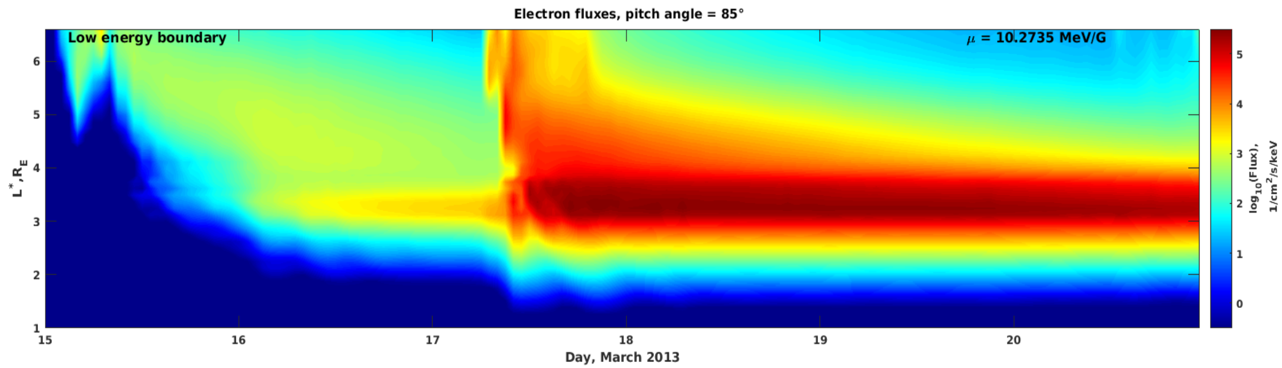
# Data processing

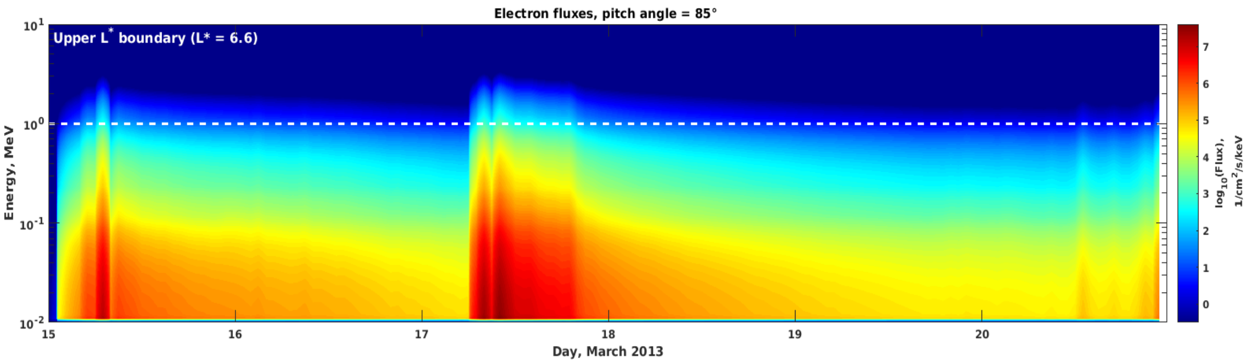


# Data processing

## Boundary conditions:

Extraction of low energy boundary fluxes




Estimation of the upper L* boundary

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# Set-up of simulations

**Table 1.** Wave Parameters Used for the Diffusion Coefficients Computation

| Type of Wave | $B_w$ (pT) | $\lambda_{max}$ | Density Model | Percent MLT | Wave Spectral Properties | Distribution in Wave Normal |
|---|---|---|---|---|---|---|
| Chorus day | $10^{0.75+0.04\lambda}(2 \times 10^{0.73+0.91Kp})^{0.5}/57.6$ for $Kp \leq 2+$; $10^{0.75+0.04\lambda}(2 \times 10^{2.5+0.18Kp})^{0.5}/57.6$ for $2+ < Kp \leq 6$; | 35 | *Sheeley et al.* [2001] | 25% | $\omega_m/\Omega_e = 0.2$, $\delta\omega/\Omega_e = 0.1$, $\omega_{uc}/\Omega_e = 0.3$, $\omega_{lc}/\Omega_e = 0.1$. | $\theta_m = 0°$, $\delta\theta = 30°$, $\theta_{uc} = 45°$, $\theta_{lc} = 0°$. |
| Chorus night | $50(2 \times 10^{0.73+0.91Kp})^{0.5}/57.6$ for $Kp \leq 2+$; $50(2 \times 10^{2.5+0.18Kp})^{0.5}/57.6$ for $2+ < Kp \leq 6$; | 15 | *Sheeley et al.* [2001] | 25% | $\omega_m/\Omega_e = 0.35$, $\delta\omega/\Omega_e = 0.15$, $\omega_{uc}/\Omega_e = 0.65$, $\omega_{lc}/\Omega_e = 0.05$. | $\theta_m = 0°$ $\delta\theta = 30°$ $\theta_{uc} = 45°$, $\theta_{lc} = 0°$. |
| Anthropogenic 1 | 0.8 | 45 | *Carpenter and Anderson* [1992] | 4 × 2.4% | $f_m = 17100$ Hz, $\delta f = 50$ Hz, $f_{uc} = 17000$ Hz, $f_{lc} = 17200$ Hz, | $\theta_m = 45°$, $\delta\theta = 22.5°$, $\theta_m = 22.5°$, $\theta_m = 67.5°$. |
| Anthropogenic 2 | 0.8 | 45 | *Carpenter and Anderson* [1992] | 4 × 2.4% | $f_m = 22300$ Hz, $\delta f = 50$ Hz, $f_{uc} = 22400$ Hz, $f_{lc} = 22200$ Hz, | $\theta_m = 45°$, $\delta\theta = 22.5°$, $\theta_m = 22.5°$, $\theta_m = 67.5°$. |

*Subbotin et al. 2011a,b*

- Hiss waves parametrization after Orlova et al. 2014
- Based on Drozdov et al. 2015
- Radial diffusion coefficients *Brautigam and Albert* [2000]: $D_{L^*L^*} = 10^{0.056Kp-9.325} L^{*10}$
- Plasmapause model *Carpenter and Anderson* [1992]: $L_{pp} = 5.6 - 0.46 * Kp_{\max 24}$,

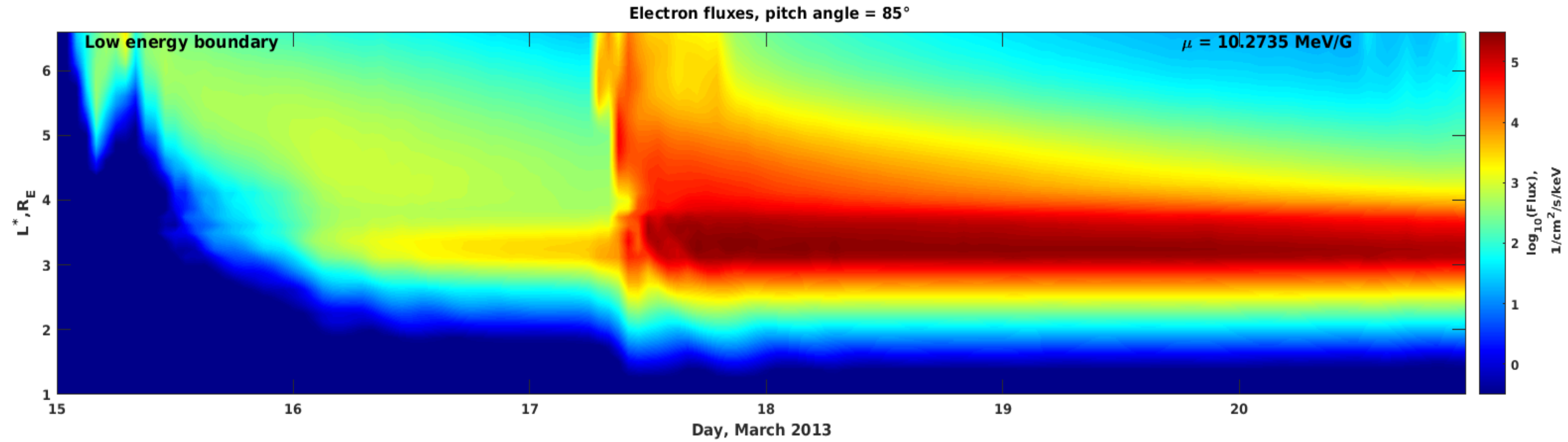
**Table 2.** Boundary Conditions Used for the VERB Code Simulations

| Boundary | Condition | Underlying Physical Processes |
|---|---|---|
| $\alpha_0 = 0°$ | $\partial (PSD)/\partial\alpha_0 = 0$ | strong and weak diffusion regimes |
| $\alpha_0 = 90°$ | $\partial (PSD)/\partial\alpha_0 = 0$ | flat pitch angle distribution |
| $L^* = 1$ | $PSD = 0$ | losses to the atmosphere |
| $L^* = 6.6$ | $PSD$ (*time*) | coupling with IMPTAM |
| $E = E_{\min}$ | $PSD$ (*time*) | coupling with IMPTAM |
| $E = E_{\max}$ | $PSD = 0$ | absence of multi-MeV energy electrons |

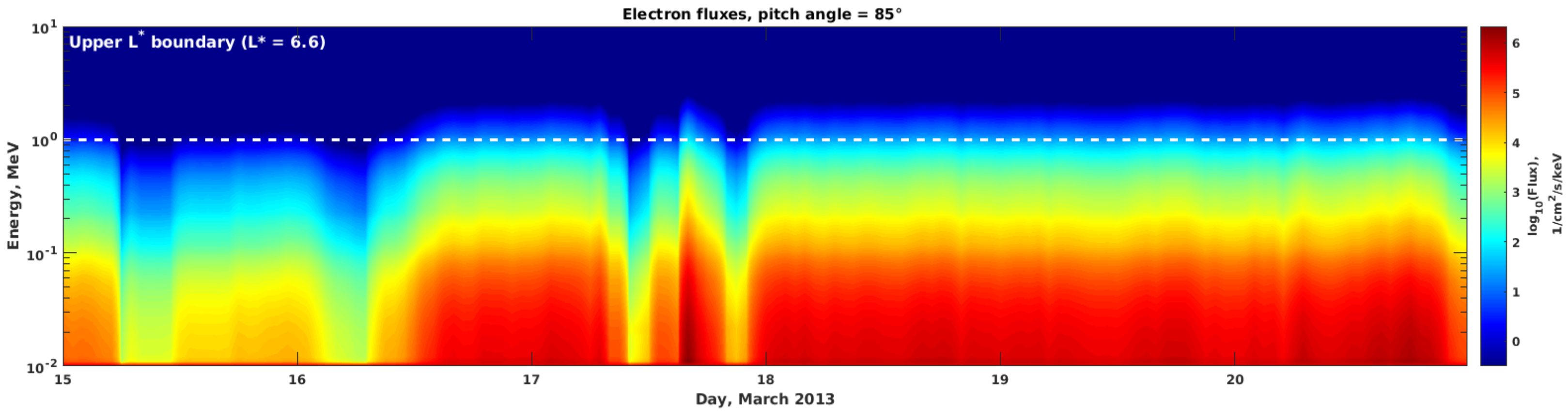
- Grid size: 49x101x91 (L*,Energy,alpha)
- Six boundary conditions
- Initial conditions are the solution of the steady state radial diffusion equation

# Coupled: Low-energy boundary from IMPTAM

## Low energy boundary

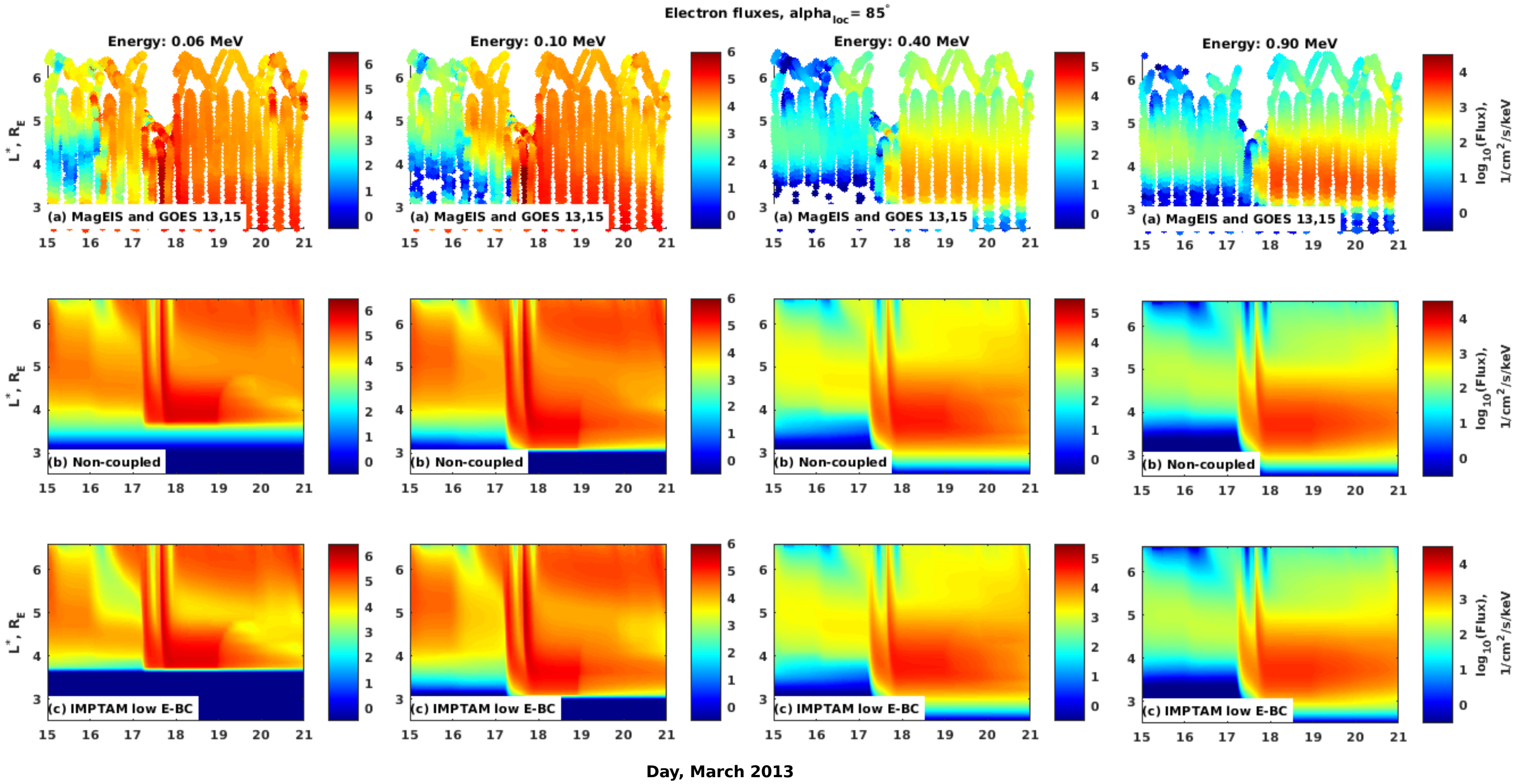



## Upper L* boundary



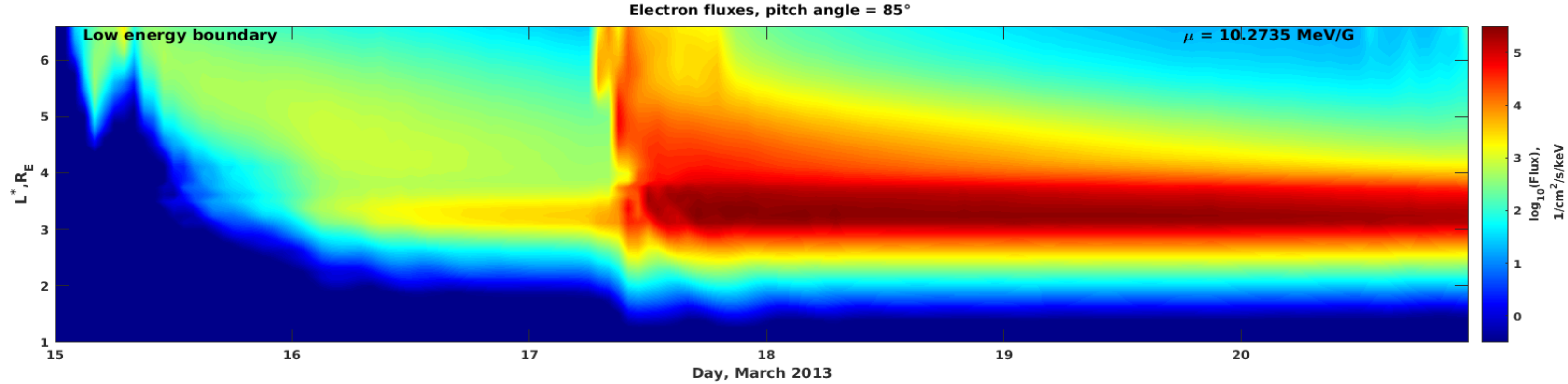
# Coupled: Low-energy boundary from IMPTAM

## Results

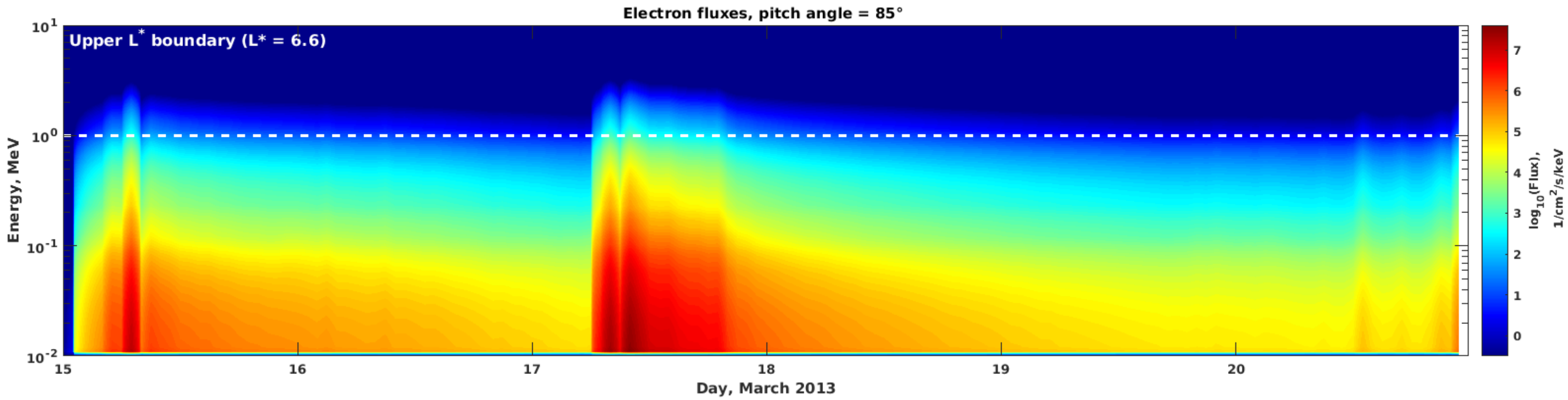


# Coupled: upper-L* boundary from IMPTAM

## Low energy boundary

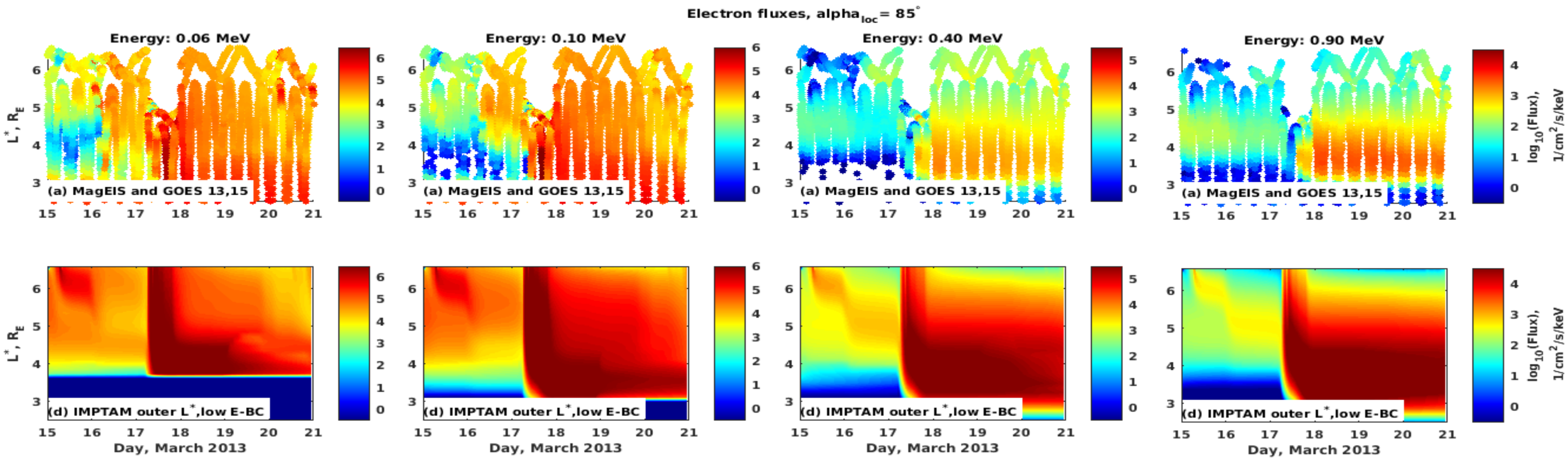



## Upper L* boundary



# Coupled: upper-L* boundary from IMPTAM

## Results




The coupled model reproduces increases and the general shape of electron fluxes.

Flux increases are overestimated, probably due to missing loss mechanisms in our simulations

# Conclusions

- Our initial simulation with the coupled model has prooved to be successful.
- General intensification of electron fluxes in the ring current and in the radiation belts is well reproduced by the model.
- Improvement could be achieved by including more accurate loss rates in the IMPTAM model and magnetopause losses in the VERB-code.
- This tool can be used for prediction of the evolution of electron fluxes in the near-Earth space environment.

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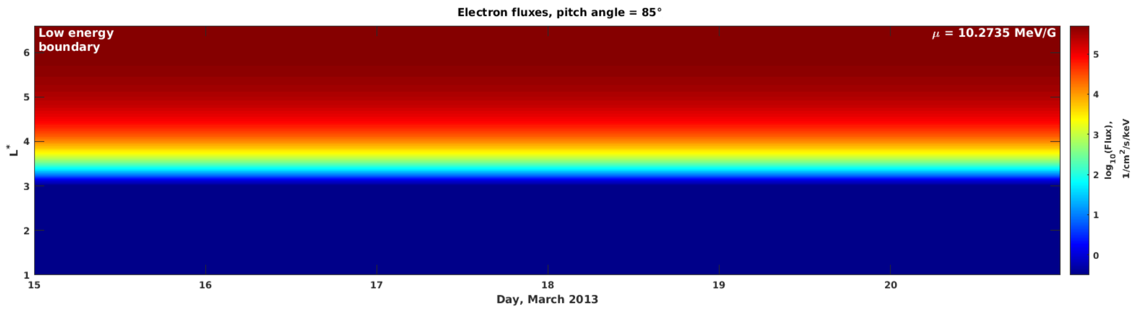
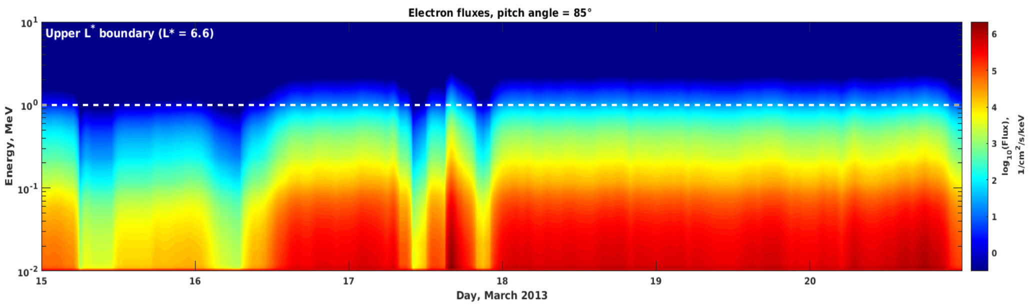
Thank you very much !!

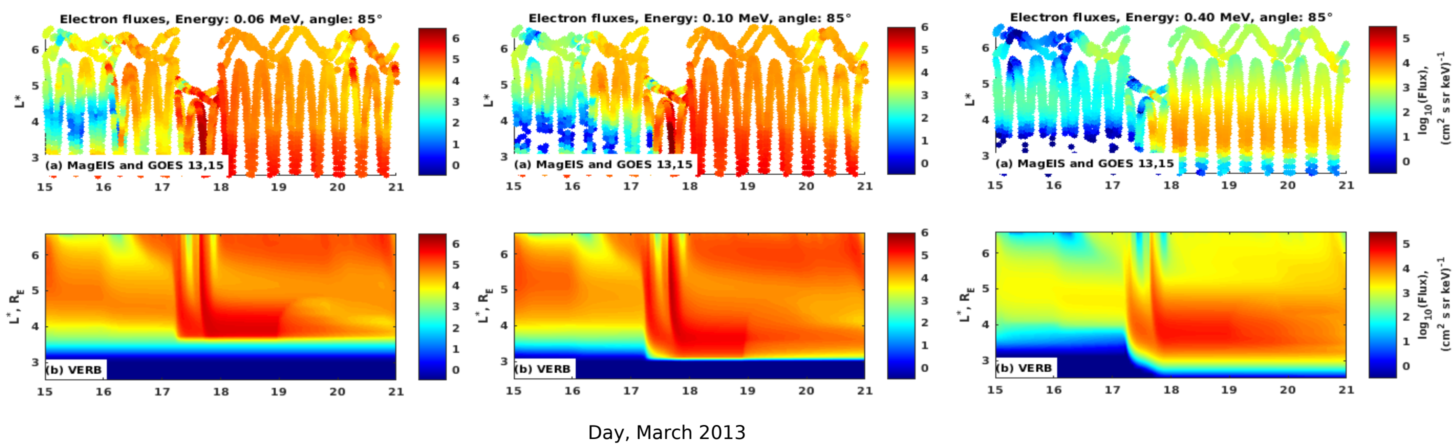
# Non-coupled VERB simulation

Low energy boundary: initial condition estimated at this boundary, representing balance between convective source and local losses.




Upper L* boundary: initial condition at L* = 6.6 scaled with energy-independent factor accounting for flux variations at L=6.6. Factor calculated as satellite data at L* = 6.6 divided by long-term PSD-spectrum.

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