

CIMI

The Comprehensive Inner Magnetosphere-Ionosphere Model

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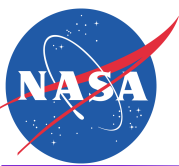
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College Park, MD



Outline



- **CIMI: Comprehensive Inner Magnetosphere-Ionosphere Model**
 - + Convection-Diffusion Model of Radiation Belts and Ring Current
 - + Convection Model of the Plasmasphere
 - + Ionospheric Potential Solver
- CIMI Capabilities: a great tool to study storm dynamics
- CIMI at CCMC and iSWA
- Future Developments



Modeling Approaches of Radiation Belts/Ring Current



$$\frac{\partial f}{\partial t} + \mathbf{\theta} \cdot \frac{\partial f}{\partial \mathbf{\theta}} + \mathbf{J} \cdot \frac{\partial f}{\partial \mathbf{J}} = (\delta f / \delta t)_{\text{coll}}$$

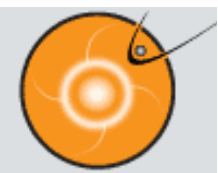
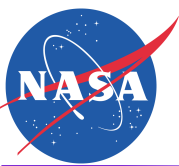
Models	Equations	Pros and Cons	Examples
Convection-Diffusion Model	$\frac{\partial f_b}{\partial t} + \langle \mathbf{\theta} \frac{\partial f_b}{\partial \mathbf{\theta}} \mathbf{\theta} \rangle + \langle \mathbf{J} \frac{\partial f_b}{\partial \mathbf{J}} \mathbf{J} \rangle = \sum_{ij=1}^2 \frac{\partial}{\partial J_i} D_{ij} \frac{\partial f_b}{\partial J_j} + (\delta f_b / \delta t)_{\text{coll}}$	<p>P: Drift-phase dependent, valid for wide range of energy (RC to RB)</p> <p>C: Solving advection for RB particles is challenging</p>	RAM-SCB, CIMI, VERB-4D
Diffusion Model	$\frac{\partial f_d}{\partial t} = \sum_{ij=1}^2 \frac{\partial}{\partial J_i} D_{ij} \frac{\partial f_d}{\partial J_j} + \frac{\partial}{\partial J_3} D_{33} \frac{\partial f_d}{\partial J_3} + (\delta f_d / \delta t)_{\text{coll}}$	<p>P: Efficient, good for long-term simulation</p> <p>C: No drift-phase dependence</p>	Salamambo, Dilbert, VERB-3D, BAS-RBM, DREAM
Convection Model	$\frac{\partial f_b}{\partial t} + \langle \mathbf{\theta} \frac{\partial f_b}{\partial \mathbf{\theta}} \mathbf{\theta} \rangle + \langle \mathbf{J} \frac{\partial f_b}{\partial \mathbf{J}} \mathbf{J} \rangle = (\delta f_b / \delta t)_{\text{coll}}$	<p>P: Drift-phase dependent</p> <p>C: Diffusion in velocity space is not included</p>	RCM, HEIDI

f_b : Bounce-averaged phase space density

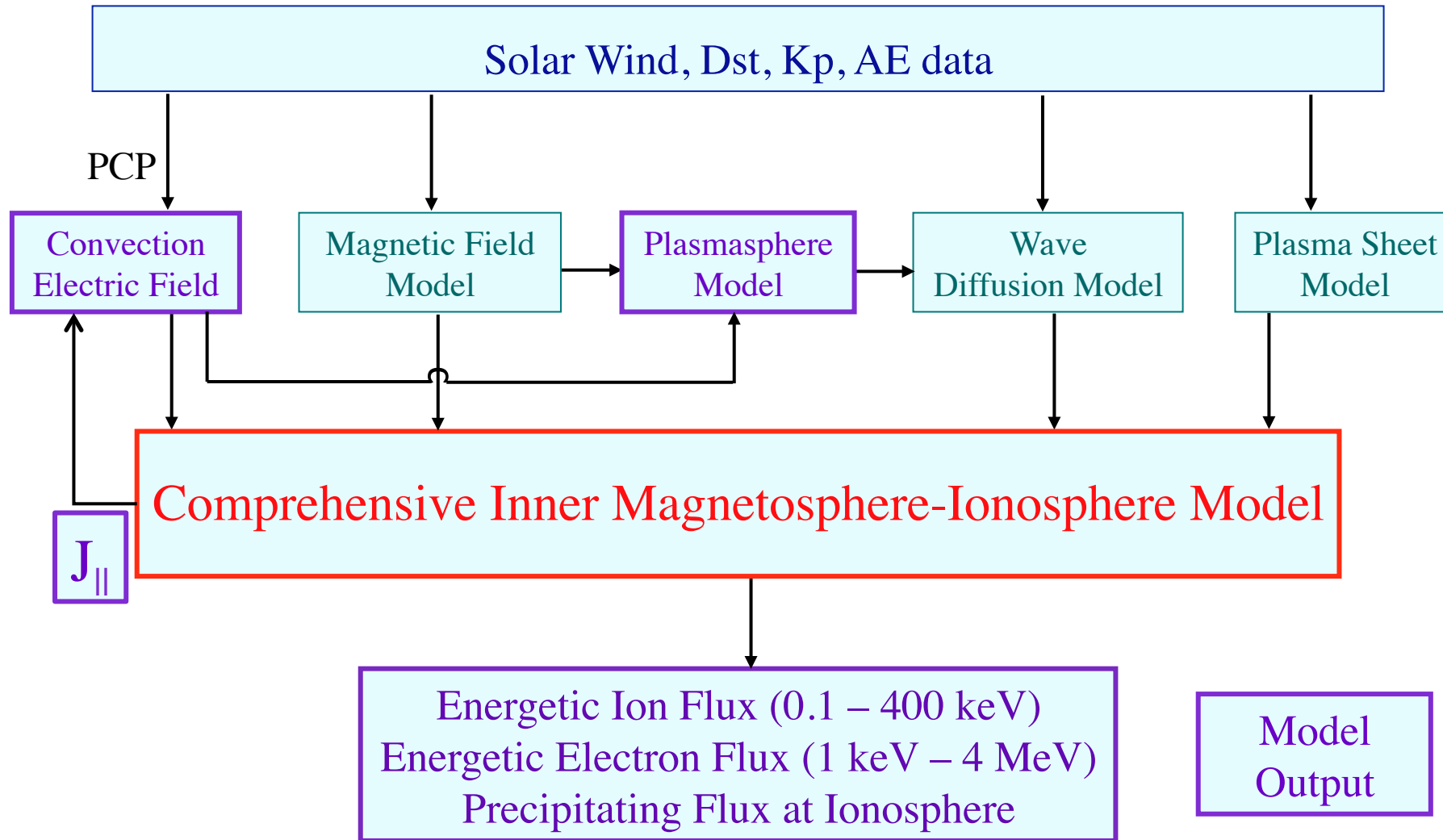
f_d : Drift-averaged phase space density

RB: Radiation Belts

RC: Ring Current

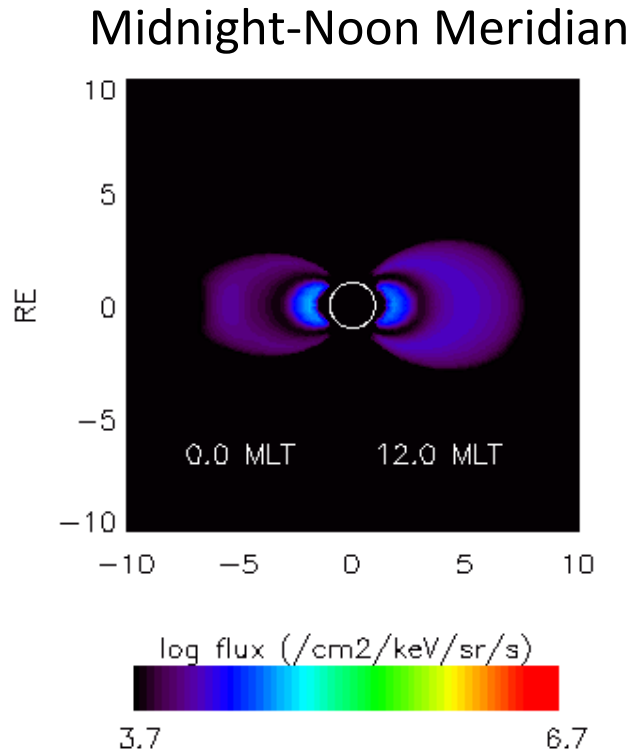
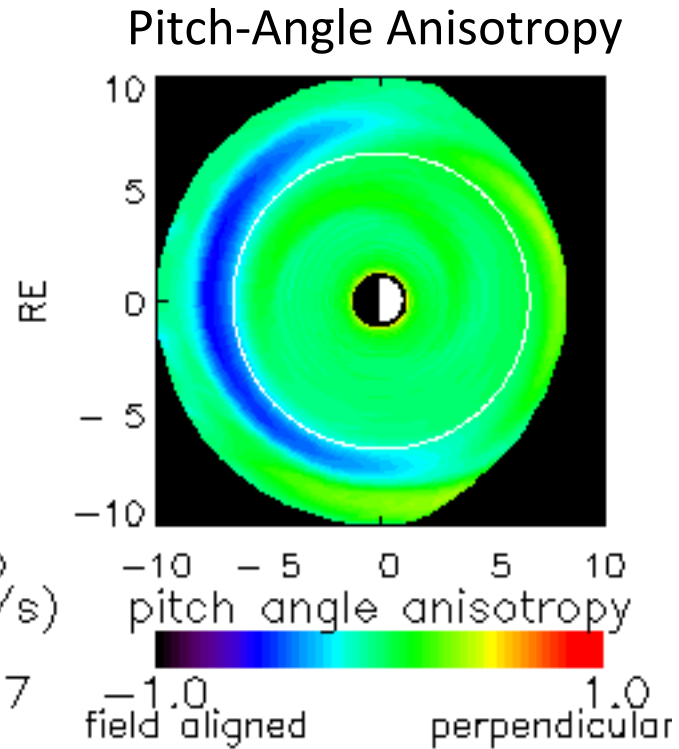
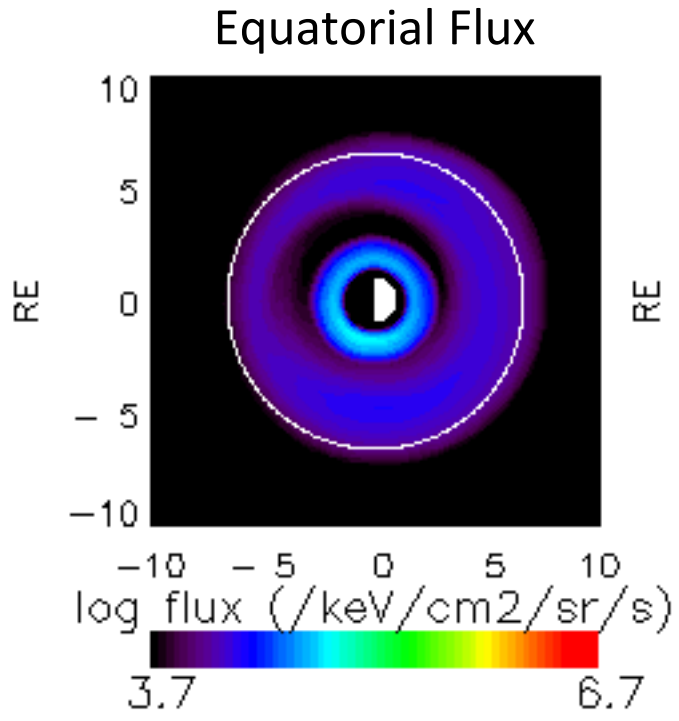
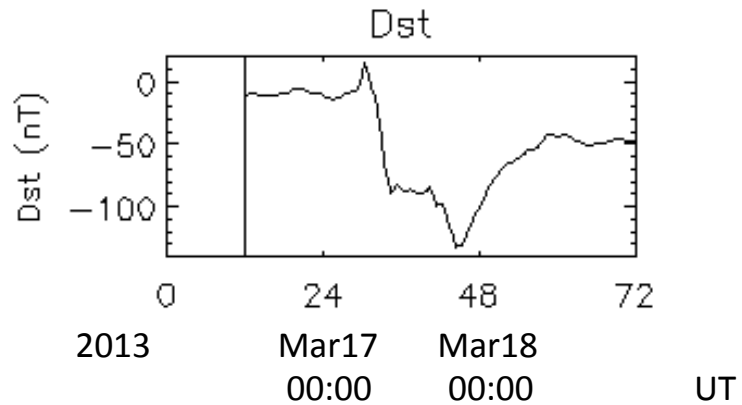


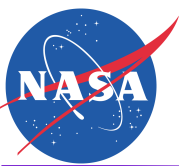
CIMI: Model Structure



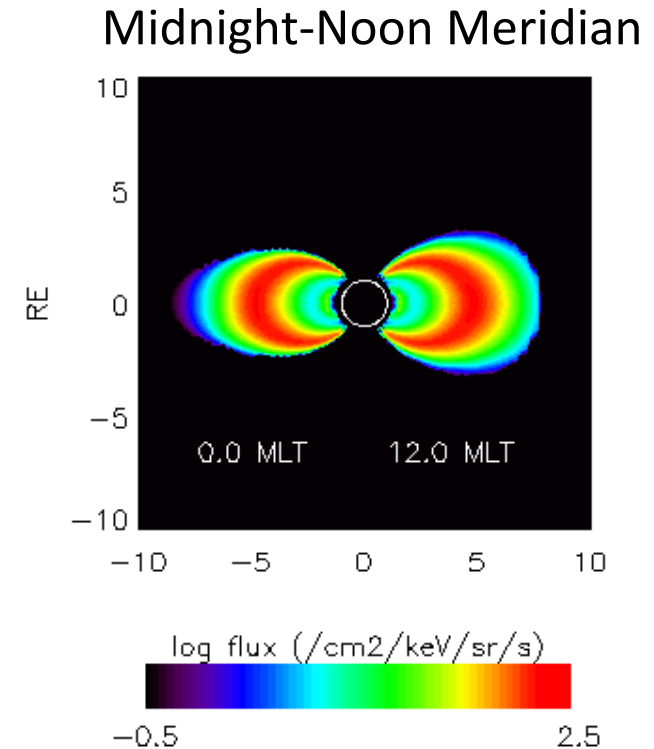
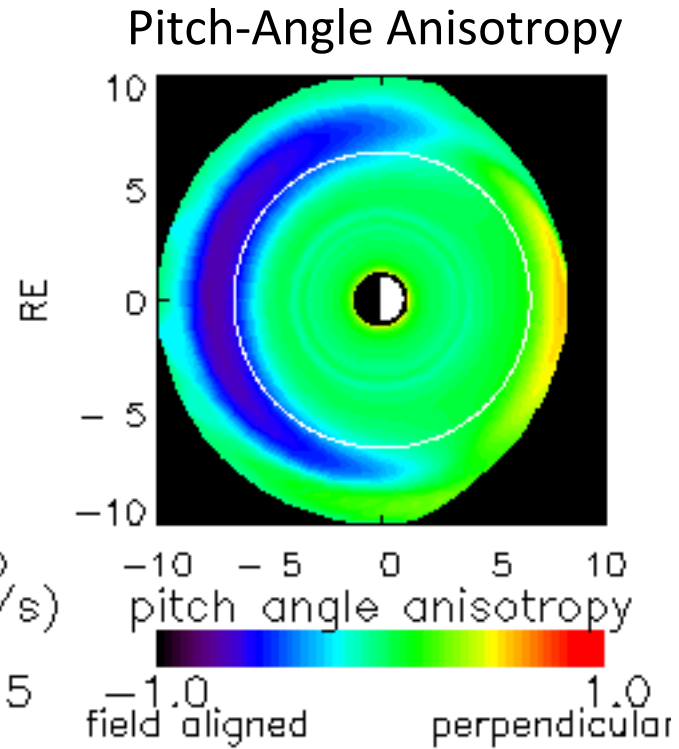
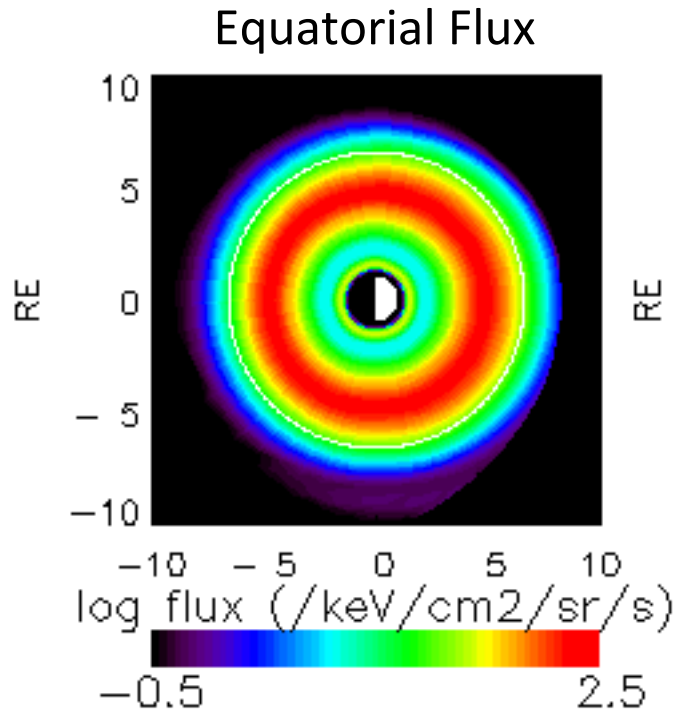
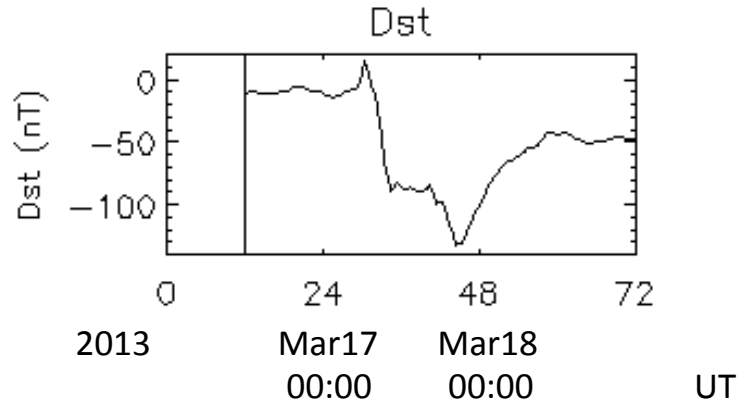
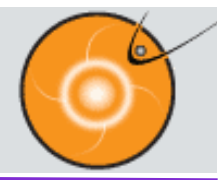


CIMI Storm Simulation (100 keV e-)





CIMI Storm Simulation (1 MeV e-)

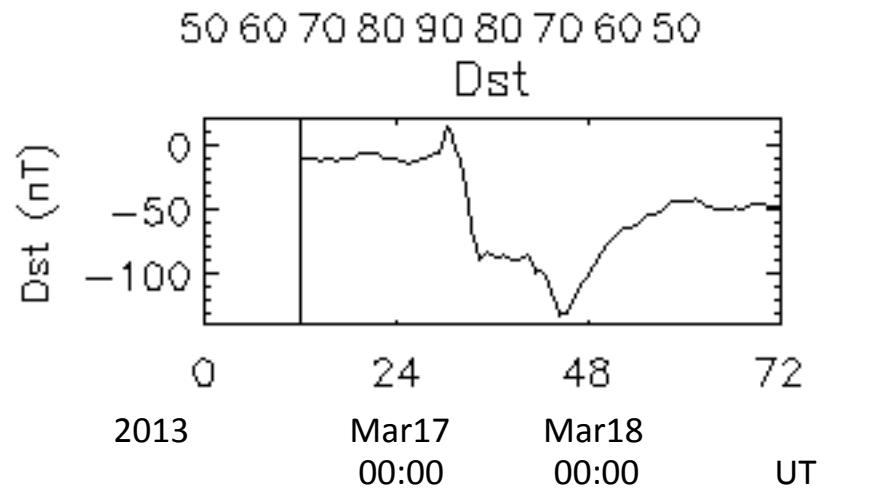
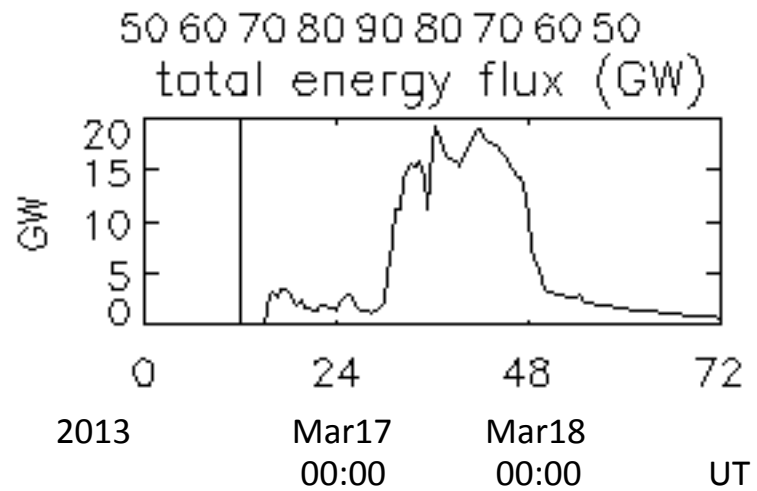
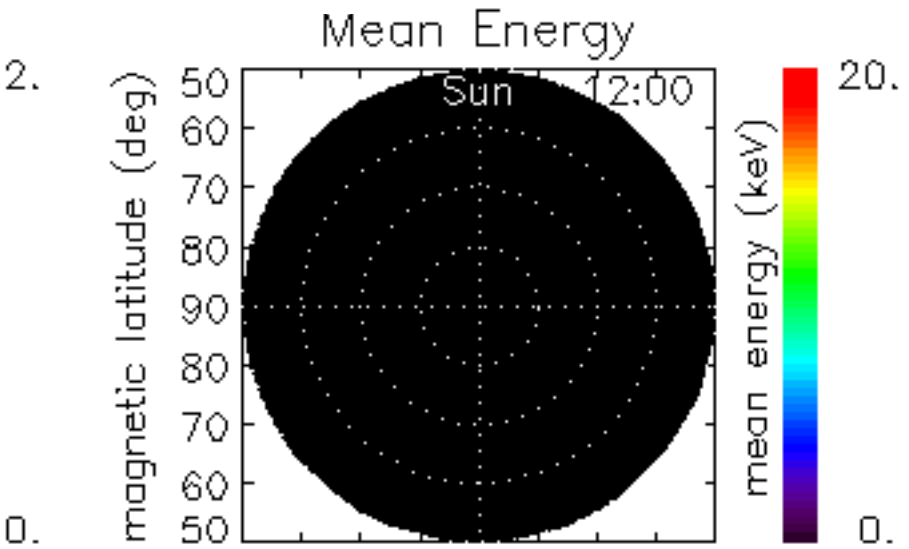
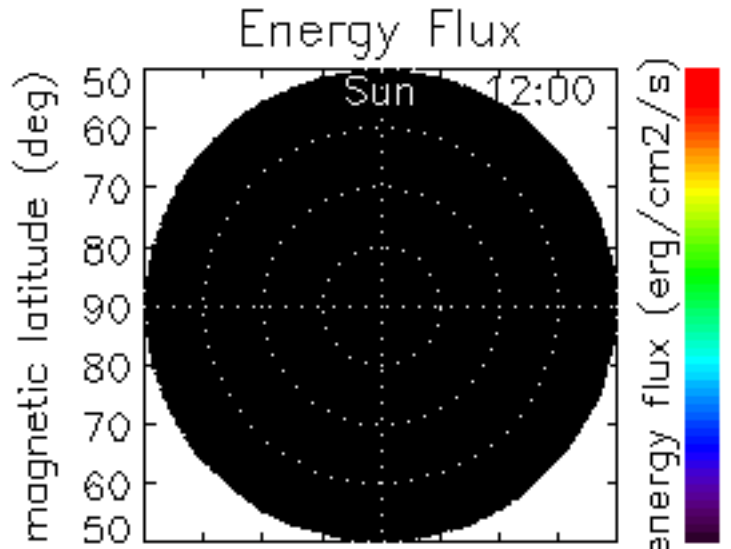


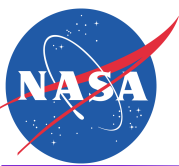


CIMI Prediction of Electron Precipitation

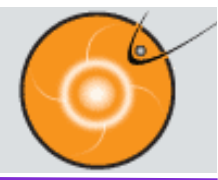


Electron Precipitation (< 40 keV)

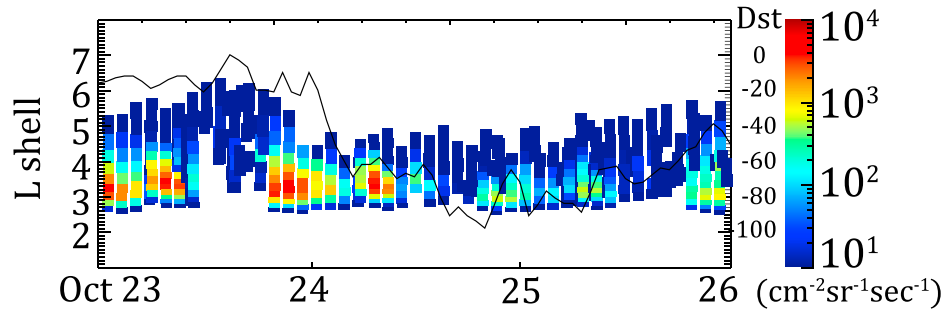




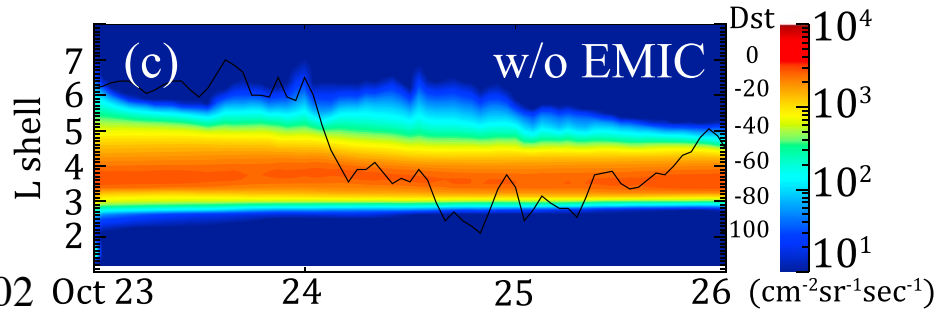
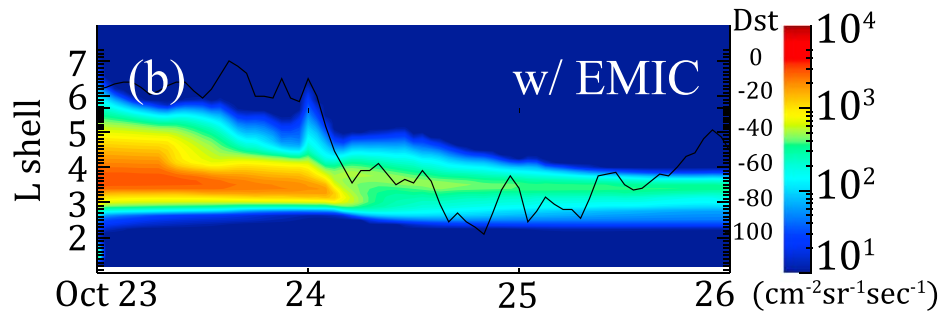
CIMI Predicts RB/RC Flux Along Satellite Paths



(a) SAMPEX > 2.5 MeV electron flux ($\text{cm}^{-2} \text{sr}^{-1} \text{sec}^{-1}$)



RBE > 2.5 MeV electron flux at 670 km



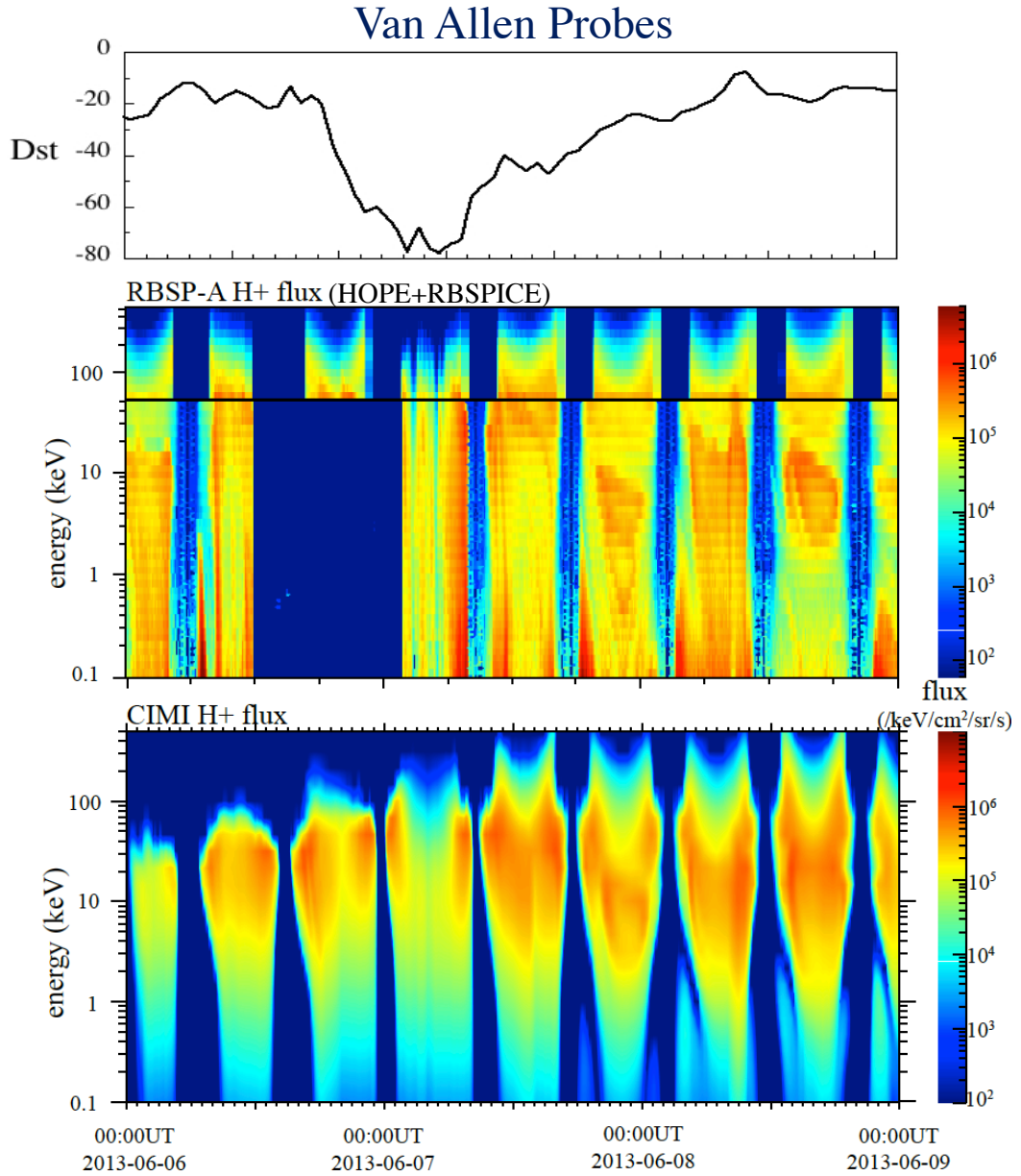
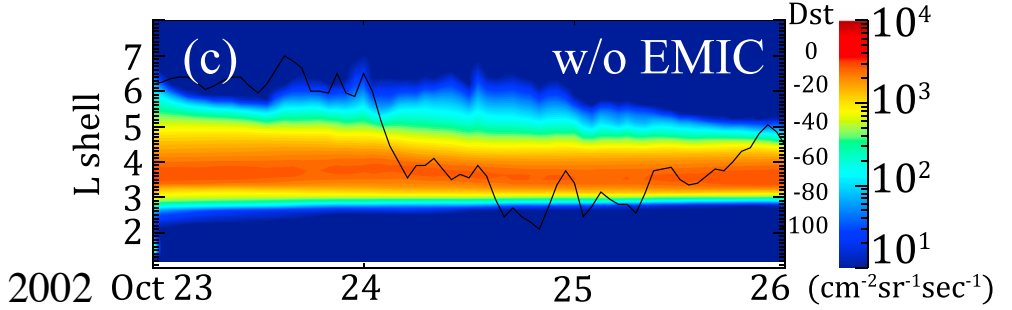
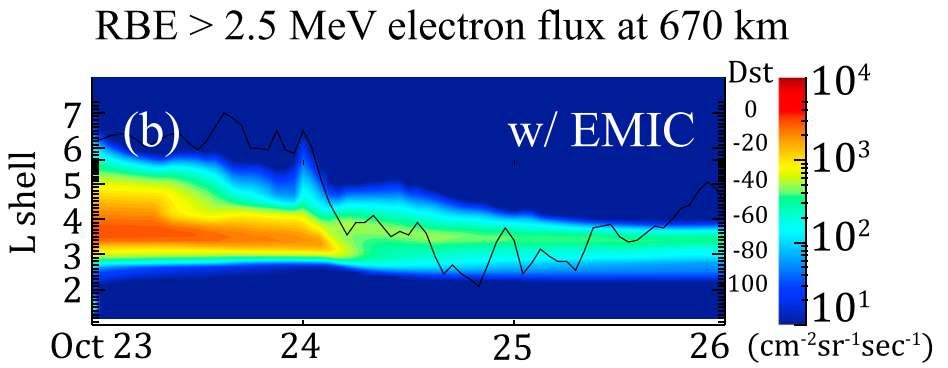
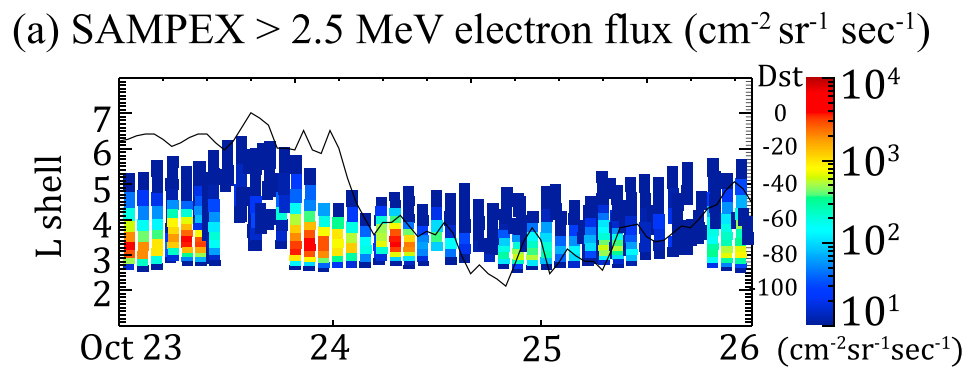
RBE: **R**adiation **B**elt **E**nvironment Model

CIMI = RBE + CRCM

[Kang et al., 2016]

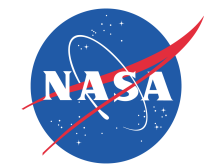


CIMI Predicts RB/RC Flux Along Satellite Paths



RBE: **R**adiation **B**elt **E**nvironment Model
 CIMI = RBE + CRCM

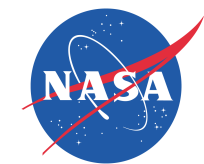
[Kang et al., 2016]



CIMI at CCMC



Model Name	Developer(s)	Institution	Model Class	Services Available				
				Runs on Request	Instant Run	Real Time Run	iSWA Cygnet	Source Code link
Inner Magnetosphere:								
RCM	Stanislav Sazykin, Richard A. Wolf	Department of Physics and Astronomy, Rice University		X				
Fok Ring Current	Mei-Ching H. Fok	NASA, GSFC	Physics-based	X			X	
Fok Radiation Belt Electron	Mei-Ching H. Fok	NASA, GSFC	Physics-based	X			X	
CIMI	Mei-Ching H. Fok, Natalia Buzulukova	NASA, GSFC	Bounce-averaged drift-kinetic modeling of electrons, protons and oxygen ion particle distributions.	X			X	
UPOS Radiation Belt	Tony Lui, Syau-Yun Hsieh	JHU/APL	Physics-based					
Tsyganenko Magnetic Field	Nikolai Tsyganenko	Univ. of St.- Petersburg, Russia	Statistical	X	X			X
AE-8/AP-8 RADBELT	Contact Person: D. Bilitza, NASA/GSFC	NSSDC, GSFC, NASA	Statistical		X			X
VERB	Y. Y. Shprits	MIT		X				



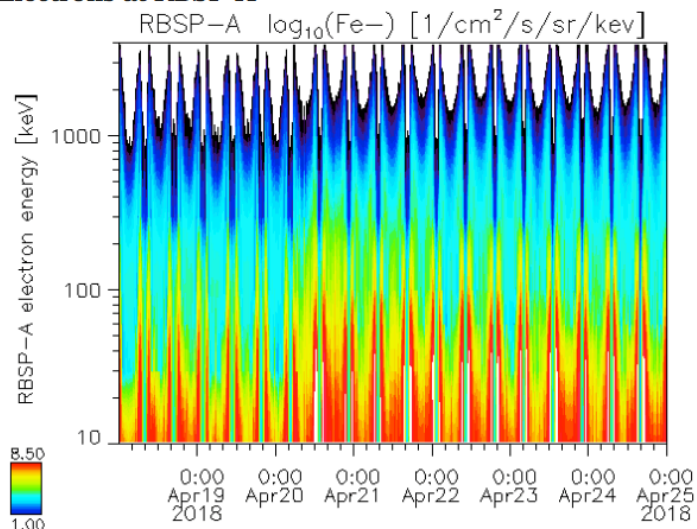
CIMI at iSWA Cygnet



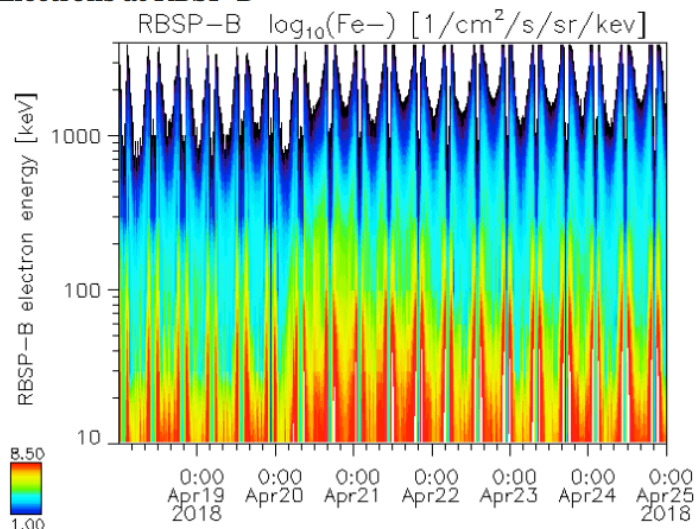
CIMI-RT (version as of 2013/12/16): latest real time plots

RBSP spectral plots (RBSP L-time, CIMI 2D electrons, CIMI 2D protons)

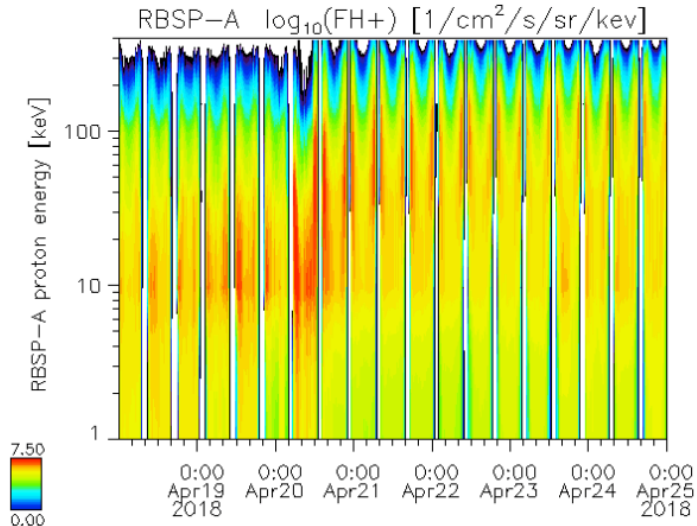
Electrons at RBSP-A



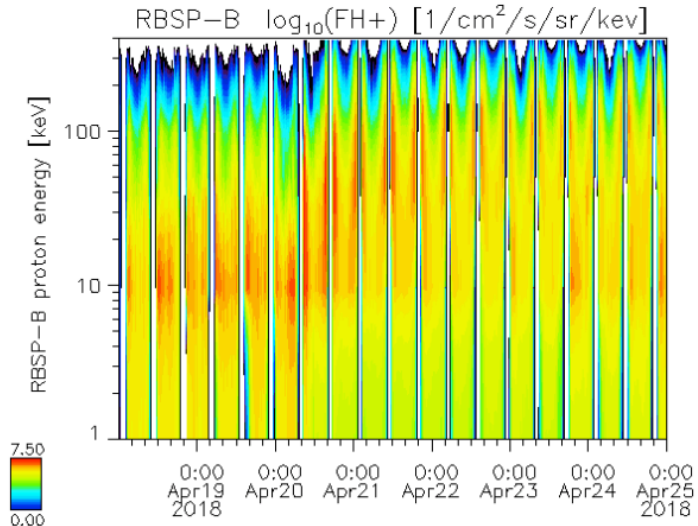
Electrons at RBSP-B



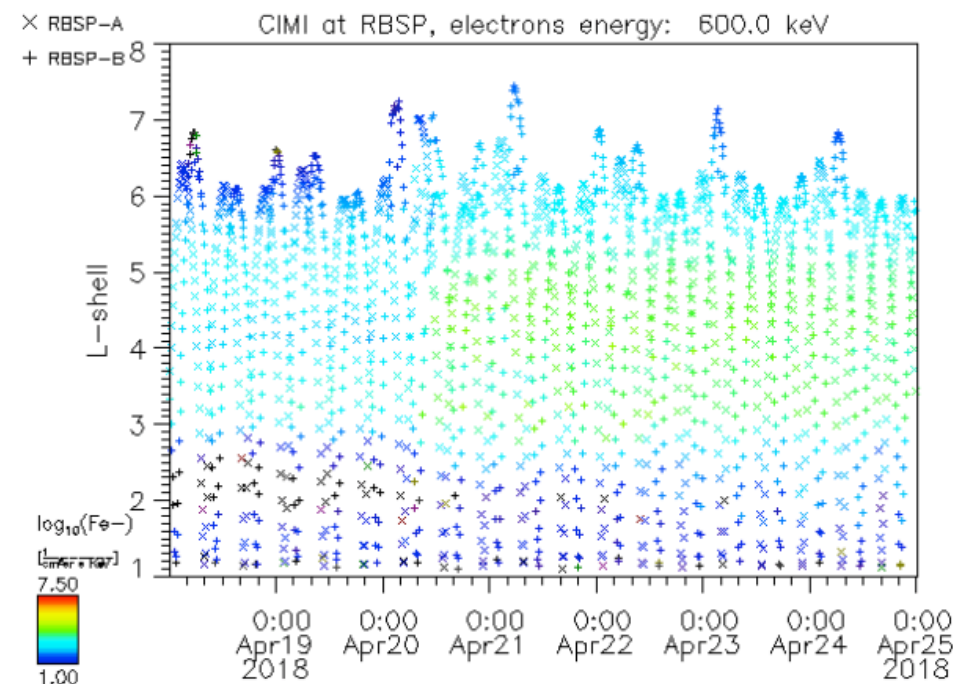
Protons at RBSP-A

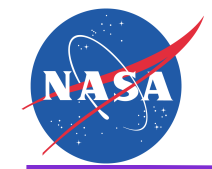


Protons at RBSP-B



L-time at RBSP: Electrons at 600 keV





Summary and Future Works



- * Summary: CIMI is great!

- * Future Works:
 - transform CIMI transport equation to new coordinates with uniform grid
i.e., $\ln E$ instead of E
 - transform to new coordinates in which cross diffusion vanishes (J. Albert)
 - need to understand the sources of warm (0.1 – 1 keV) plasma
 - get not only qualitative agreements with data but also quantitatively
 - make BATSRUS-CIMI available at CCMC