



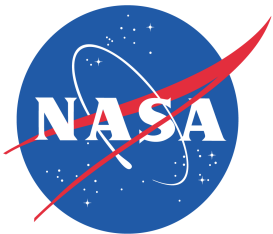
The Comprehensive Inner Magnetosphere-Ionosphere Model CIMI

Mei-Ching Fok

(and Natasha Buzulukova, Suk-Bin Kang, Alex Glocer, Colin Komar, ...)

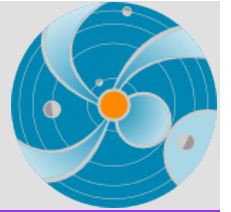
Geospace Physics Laboratory, Heliophysics Science Division
NASA Goddard Space Flight Center

CCMC 2016 Workshop
Annapolis, Maryland
April 11-15, 2016





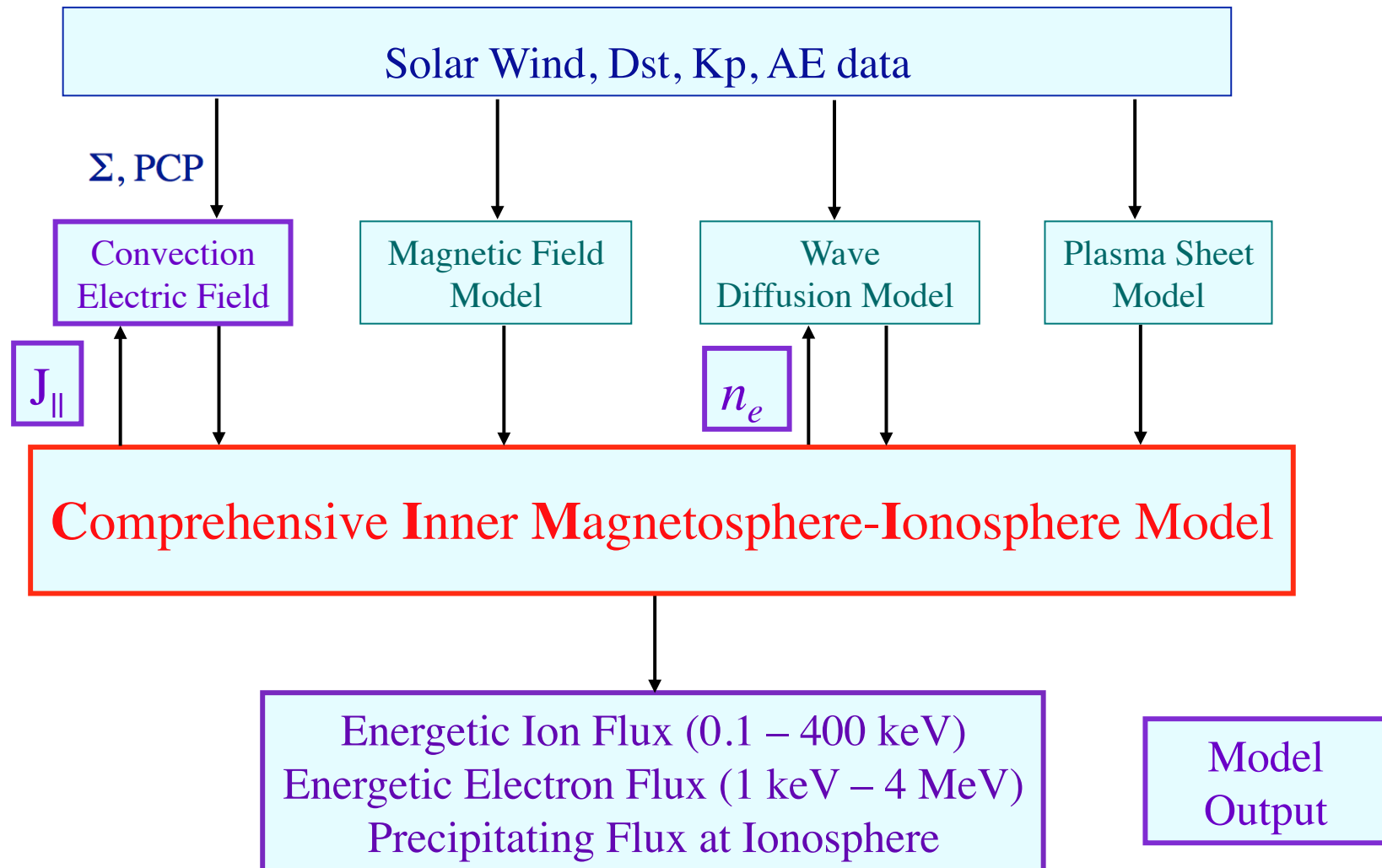
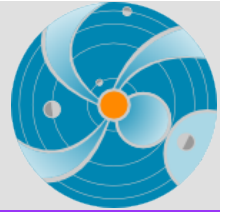
The CIMI Model



- Introduction to the CIMI Model
 - Model logic
 - Model equations
 - Model output
- CIMI Simulation of magnetic storms
- CIMI at CCMC

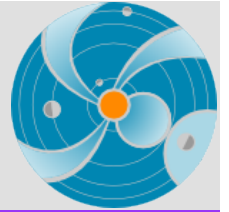


CIMI = CRCM + RBE





CIMI: Model Equations



f_s : radiation belt – ring current particle distribution function

$$\begin{aligned} \text{☀} \quad \frac{\partial f_s}{\partial t} + \langle \dot{\lambda}_i \rangle \frac{\partial f_s}{\partial \lambda_i} + \langle \dot{\phi}_i \rangle \frac{\partial f_s}{\partial \phi_i} = \frac{1}{G} \frac{\partial}{\partial \alpha_0} \left[G \left(D_{\alpha_0 \alpha_0} \frac{\partial f_s}{\partial \alpha_0} + D_{\alpha_0 E} \frac{\partial f_s}{\partial E} \right) \right] + \\ \frac{1}{G} \frac{\partial}{\partial E} \left[G \left(D_{EE} \frac{\partial f_s}{\partial E} + D_{E \alpha_0} \frac{\partial f_s}{\partial \alpha_0} \right) \right] - v \sigma_{sH} \langle n_H \rangle f_s - \left(\frac{f_s}{0.5 \tau_b} \right)_{\text{loss cone}} \end{aligned}$$

$$f_s = f_s(t, \lambda_i, \phi_i, M, K) \quad G = T(\alpha_0) \sin 2\alpha_0 (E + E_0) \sqrt{E(E + 2E_0)}$$

Φ : ionosphere potential; J_{\parallel} : field-aligned current

$$\text{☀} \quad \nabla \cdot (-\vec{\Sigma} \cdot \nabla \Phi) = J_{\parallel} \sin I \quad J_{\parallel} = \frac{B_i}{B} \hat{\mathbf{b}} \cdot \nabla V \times \nabla P_{RC}$$

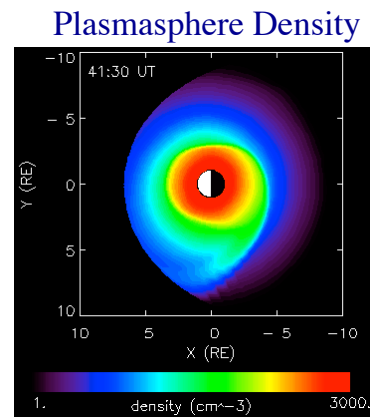
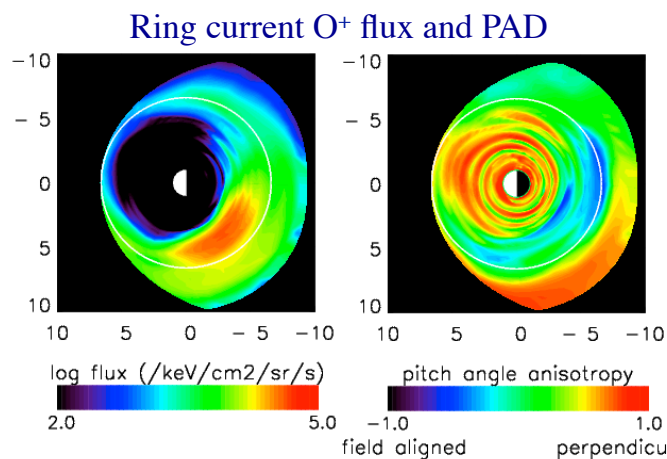
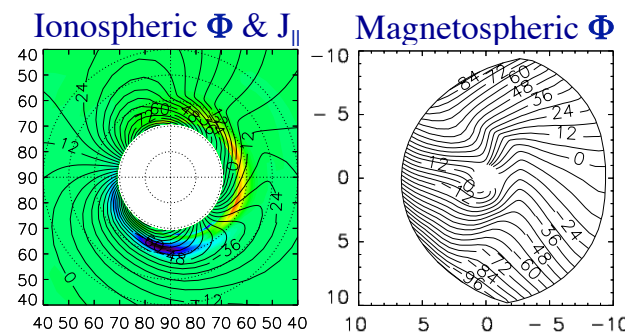
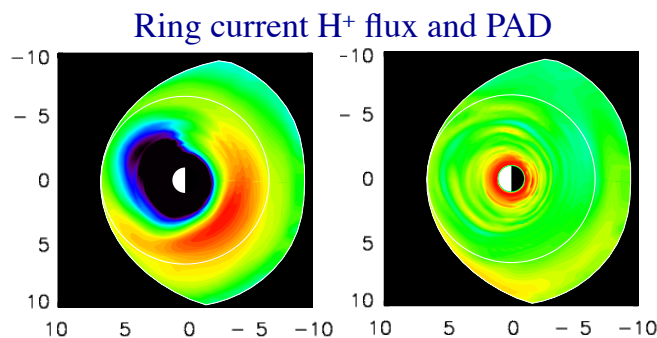
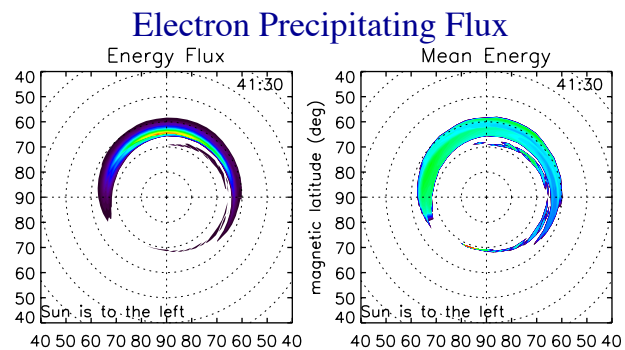
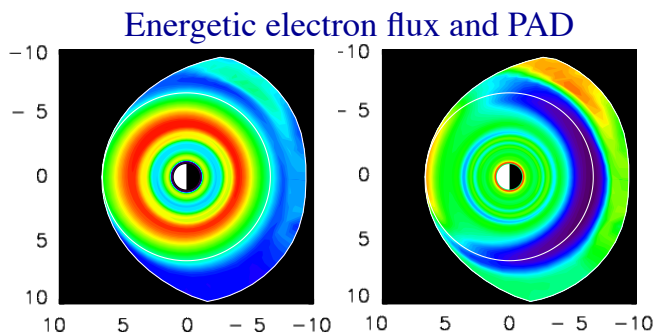
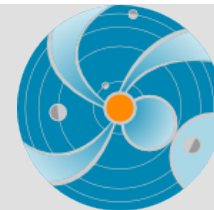
N : plasmaspheric electron content per unit magnetic flux

$$\text{☀} \quad \frac{\partial N}{\partial t} + \langle \dot{\lambda}_i \rangle \frac{\partial N}{\partial \lambda_i} + \langle \dot{\phi}_i \rangle \frac{\partial N}{\partial \phi_i} = \frac{F_N + F_S}{B_i}$$

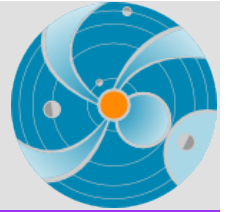
F_N, F_S : upward or downward flux from northern and southern ionosphere



Major Output from CIMI



Fok et al. [2014]



Identify Enhancement and Loss Processes by CIMI

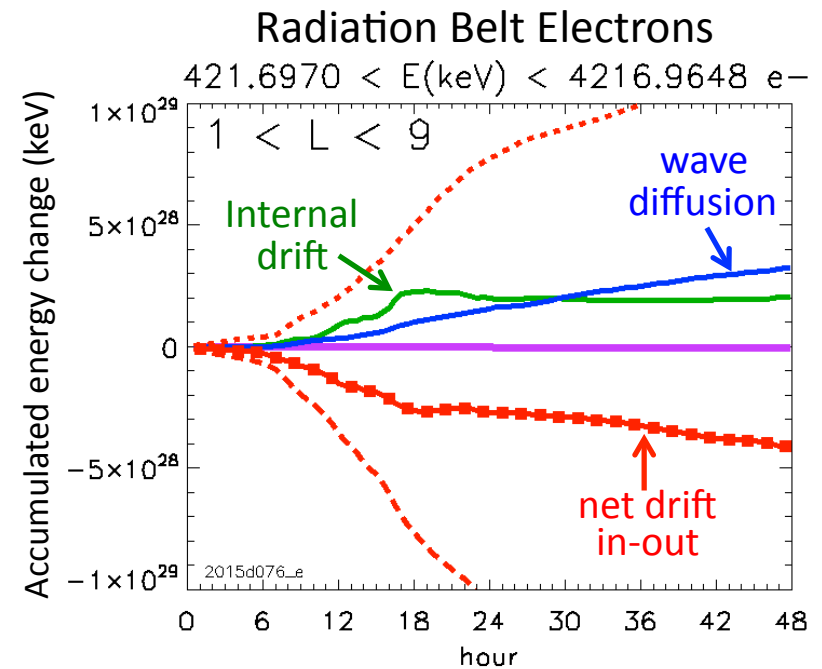
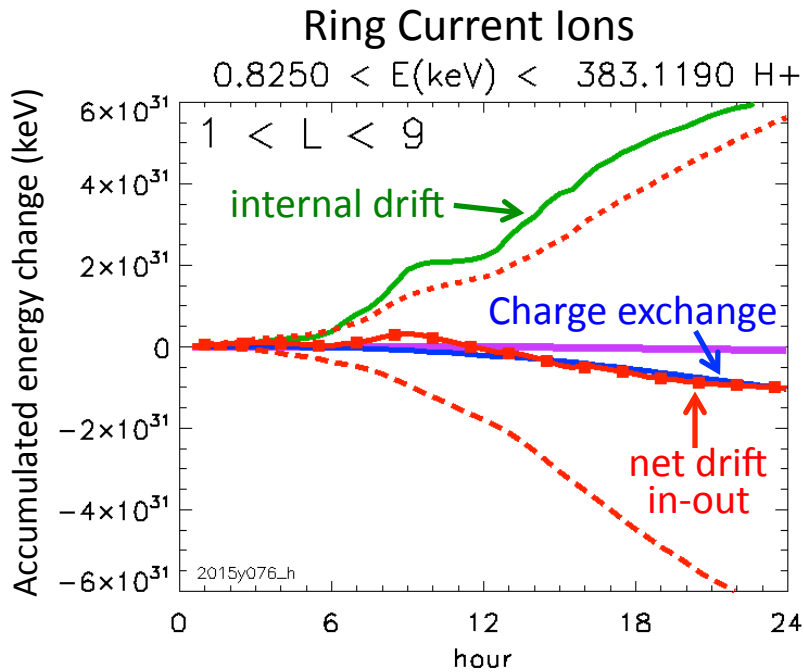
bounce-averaged drift

wave diffusion

$$\frac{\partial f_s}{\partial t} + \underbrace{\left\langle \dot{\lambda}_i \right\rangle \frac{\partial f_s}{\partial \lambda_i} + \left\langle \dot{\phi}_i \right\rangle \frac{\partial f_s}{\partial \phi_i}}_{\text{drift in/out}} = \underbrace{\frac{1}{G} \frac{\partial}{\partial \alpha_0} \left[G \left(D_{\alpha_0 \alpha_0} \frac{\partial f_s}{\partial \alpha_0} + D_{\alpha_0 E} \frac{\partial f_s}{\partial E} \right) \right]}_{\text{wave diffusion}} + \underbrace{\frac{1}{G} \frac{\partial}{\partial E} \left[G \left(D_{EE} \frac{\partial f_s}{\partial E} + D_{E \alpha_0} \frac{\partial f_s}{\partial \alpha_0} \right) \right]}_{\text{charge exchange}} - \underbrace{v \sigma_{sH} \langle n_H \rangle f_s}_{\text{loss cone}} - \underbrace{\left(\frac{f_s}{0.5 \tau_b} \right)_{\text{loss cone}}}_{\text{loss cone}}$$

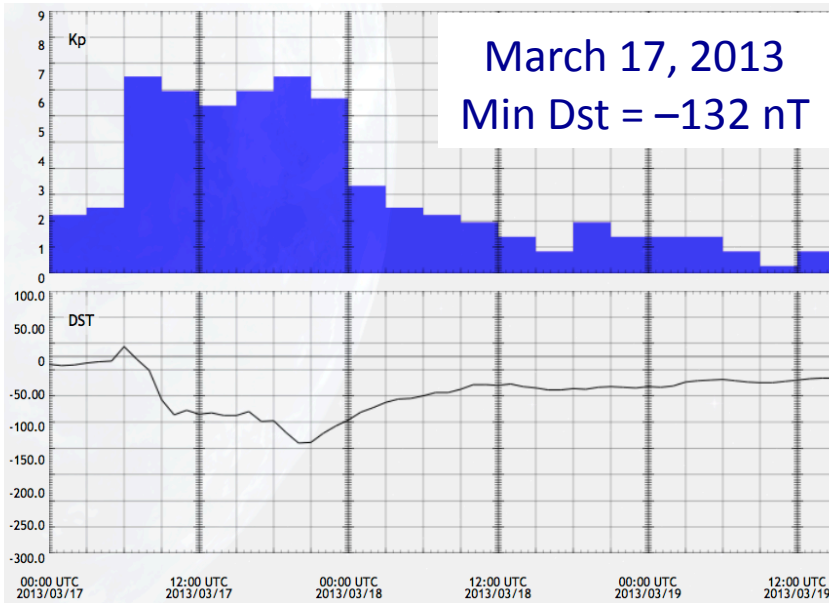
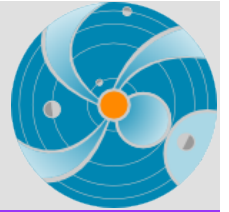
$f_s = f_s(t, \lambda_i, \phi_i, M, K)$, distribution function of RC and RB species

charge exchange





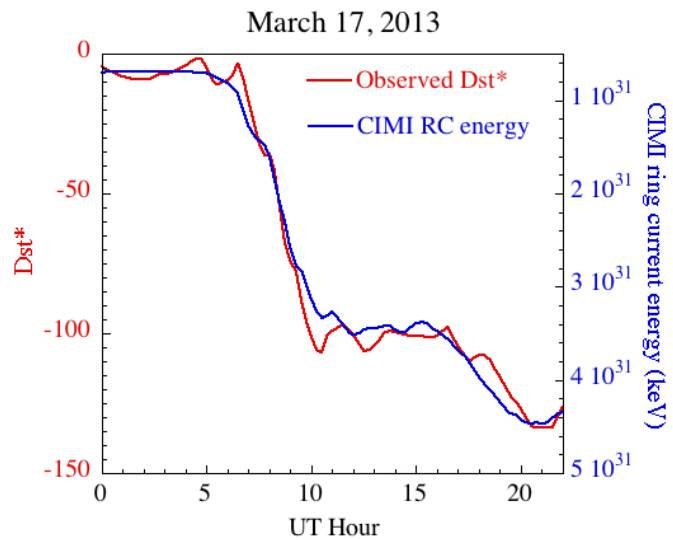
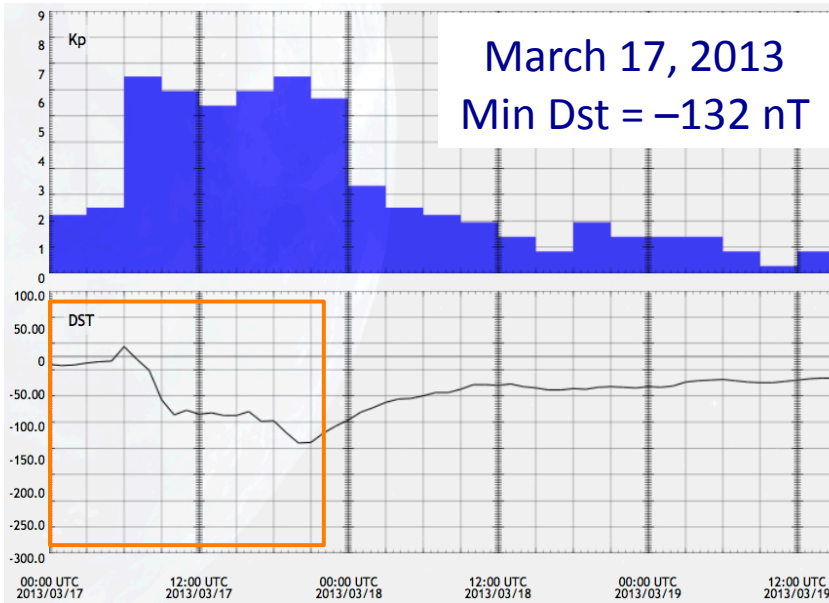
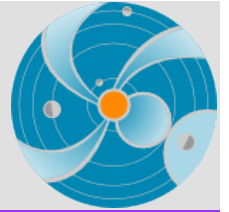
CIMI Simulation of Magnetic Storms



[Data from Van Allen Probes SCIENCE GATEWAY]

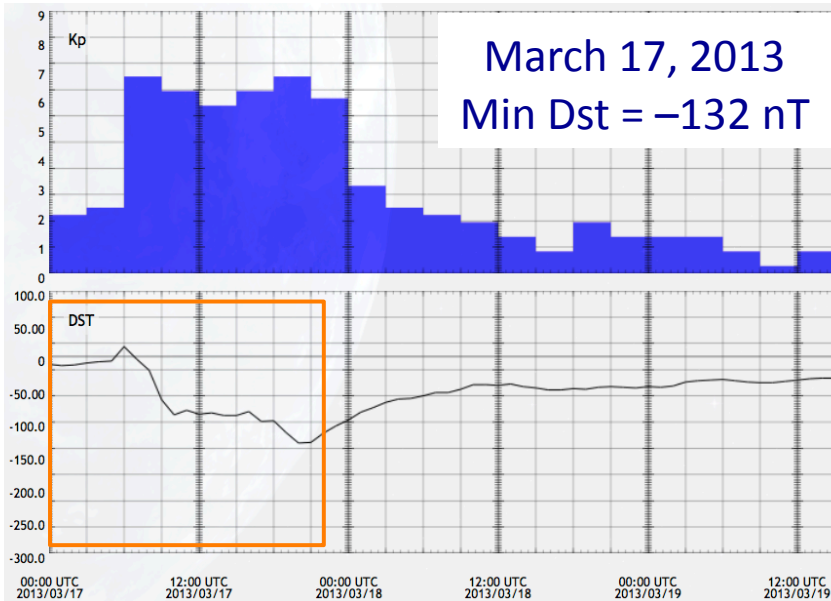


CIMI Simulation of Magnetic Storms

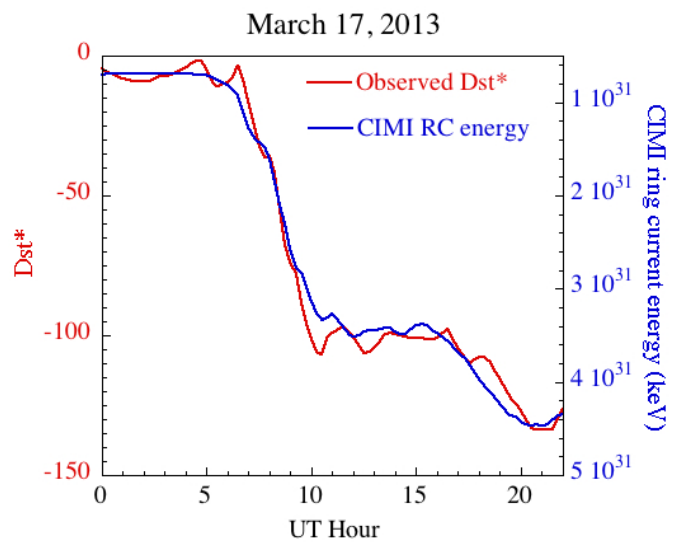
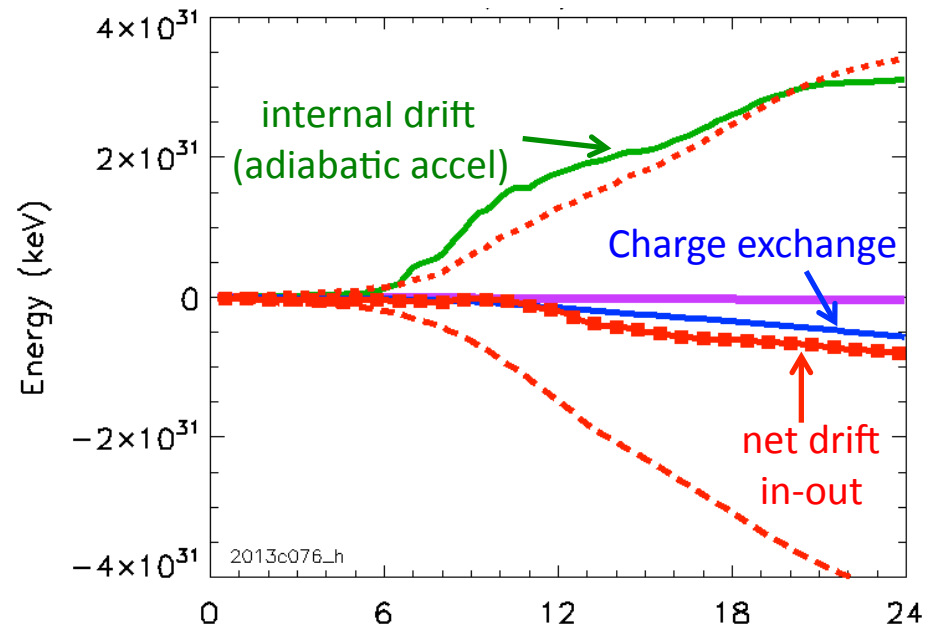




CIMI Simulation of Magnetic Storms



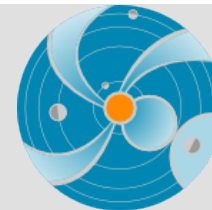
CIMI Accumulated Energy Changes



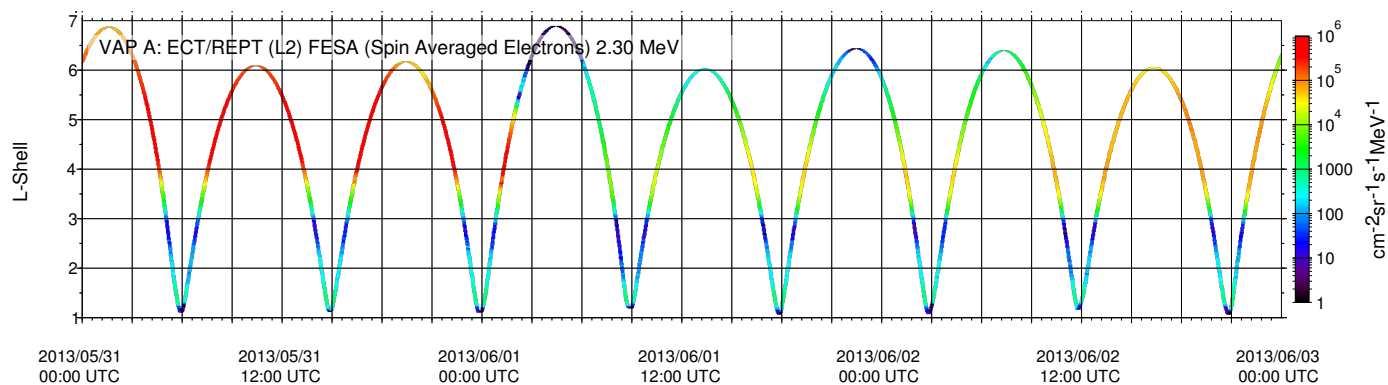
Adiabatic acceleration driven by convection dominates ring current buildup



CIMI Simulation of Magnetic Storms



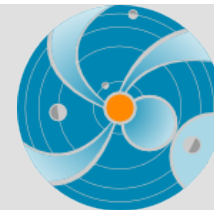
Electron flux dropout on May 31 – June 2, 2013



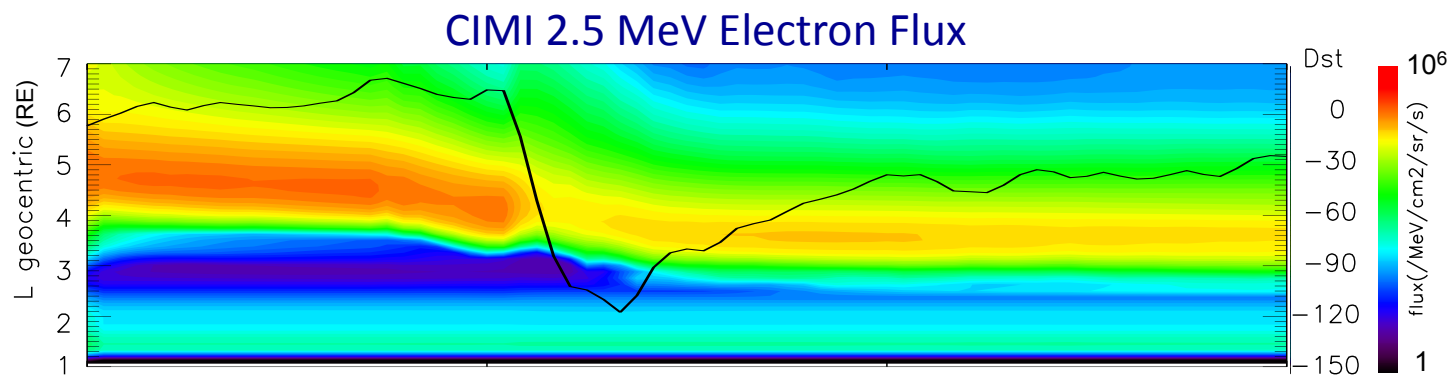
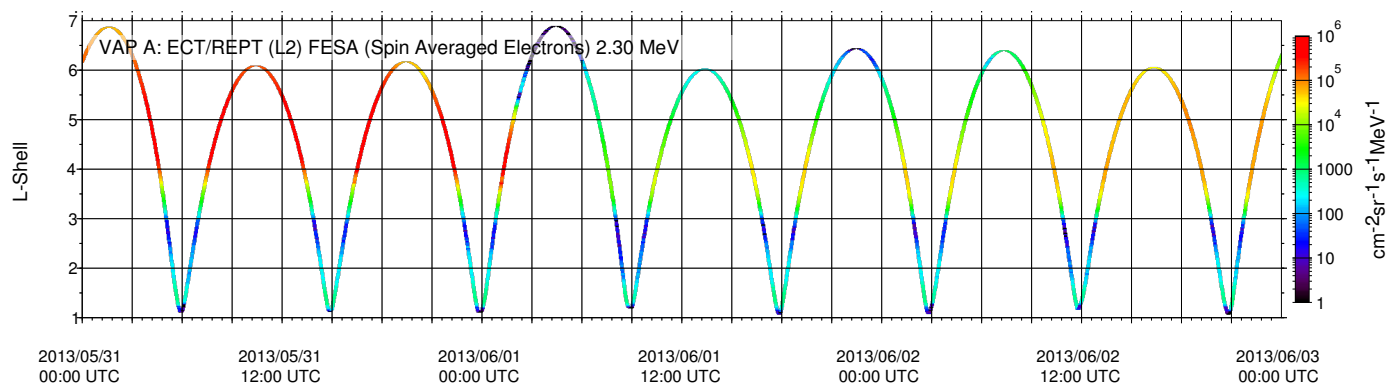
[Data from Van Allen Probes SCIENCE GATEWAY]



CIMI Simulation of Magnetic Storms



Electron flux dropout on May 31 – June 2, 2013



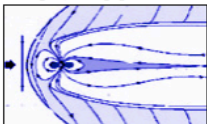
CIMI reproduces flux dropout



CIMI at CCMC

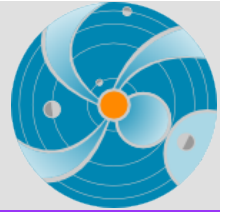


CCMC Hosted Models at a Glance

Domain	Model Name	Developer(s)	Institution	Model Class	Services Available				
					Runs on Request	Instant Run	Real Time Run	Widget	Source Code link
MAGNETOSPHERE 	Inner Magnetosphere:								
	SWMF/BATS-R-US with RCM	Tamas Gombosi et al., Richard Wolf et al., Stanislav Sazykin et al., Gabor Toth et al.	CSEM	Physics-based MHD	X				
	Plasmasphere	Viviane Pierrard	IASB-BIRA		X				
	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				
	Fok Radiation Belt Electron	Mei-Ching H. Fok	NASA, GSFC	Physics-based	X				
	CIMI	Mei-Ching H. Fok, Natalia Buzulukova	NASA, GSFC	Bounce-averaged drift-kinetic modeling of electrons, protons and oxygen ion particle distributions.	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 (wait for connection)
	AE-8/AP-8 RADBELT	Contact Person: D. Bilitza, NASA/GSFC	NSSDC, GSFC, NASA	Statistical		X			X (wait for connection)



CIMI is Available for “Runs on Request”



Runs on Request: Inner Magnetosphere Simulations Results

Total Number of Runs in the Database: 69
Total Number of Search Results in this Database: 28

Total Number of Runs in the Database: 69

Status	Run Number	Key Words	Model	Model Version	Grid	Validation Level	Run Type	Event Date	Start Time	End Time
Published	Abby_Azari_040116_IM_1	Magnetic field, storm time, pitch angle dependence	--	20150413	--	--	event	July 15, 2012	2012/07/15 01:00	2012/07/15 23:00
Published	Abby_Azari_040116_IM_2	Magnetic field storm time pitch angle dependence	--	20150413	--	--	event	July 15, 2012	2012/07/15 01:00	2012/07/15 23:00
Published	kris_borremans_021616_IM_1	test1	--	20150413	--	--	event	January 01, 2003	2003/01/01 00:00	2003/01/05 02:00
Published	Hugh_Evans_120915_IM_1	test, cimi, default parameters	--	20150413	--	--	event	January 01, 2000	2000/01/01 00:00	2000/01/01 02:00
Published	Yihua_Zheng_111715_IM_1	March 17, 2013 St Patrick storm, SSW16	--	20150413	--	--	event	March 15, 2003	2013/03/15 00:00	2013/03/20 02:00
Published	Ligia_DaSilva_101615_IM_1	relativistic electrons, outer belt	--	20150413	--	--	event	September 21, 2014	2014/09/21 00:00	2014/09/25 00:00
Published	Ligia_DaSilva_100515_IM_1	outer belt, electron flux	--	20150413	--	--	event	September 21, 2014	2014/09/21 00:00	2014/09/25 00:00
Published	JayantaKumar_Behera_092515_IM_2	event	--	20150413	--	--	event	April 02, 2011	2011/04/02 10:00	2011/04/02 16:00
Published	Miles_Bengtson_090415_IM_1	background magnetic field, RBSP, Van Allen Probes	--	20150413	--	--	event	March 21, 2014	2014/03/21 01:30	2014/03/21 04:00
Published	Miles_Bengtson_090315_IM_1	Magnetic Field, RBSP, Van Allen Probes	--	20150413	--	--	event	March 21, 2014	2014/03/21 00:00	2014/03/21 04:00
Published	Geeta_Vichare_030415_IM_1	magnetotail and Symetric, Partial ring curr contr	--	20130116	--	--	event	February 18, 2014	2014/02/18 00:00	2014/02/19 23:55
Published	Geeta_Vichare_030415_IM_2	magnetotail and Symetric, Partial ring curr contr	--	20130116	--	--	event	December 08, 2013	2013/12/08 00:00	2013/12/08 23:55
Published	Kun_Zhang_121714_IM_1	Field	--	20130116	--	--	event	January 01, 2000	2000/01/01 00:00	2000/01/01 02:00
Published	tao_huang_102714_IM_2	RCM_FAC_CIMI	--	20130116	--	--	event	September 21, 2004	2004/09/21 00:00	2004/09/22 00:00
Published	Homayon_Aryan_092914_IM_1	CME storm	--	20130116	--	--	event	July 31, 2007	2007/07/31 00:00	2007/08/01 02:00
Published	SNM_Hoque_091514_IM_1	OCB	--	20130116	--	--	event	November 04, 2001	2001/11/04 08:02	2001/11/04 08:02
Published	Suman_Chakraborty_082914_IM_1	Lightning-induced Electron Precipitation events	--	20130116	--	--	event	May 07, 2007	2007/05/07 18:00	2007/05/07 20:00
Published	Stuart_George_081514_IM_1	2013 Geomagnetic Activity	--	20130116	--	--	event	June 01, 2013	2013/06/01 00:00	2013/06/02 02:00
Published	Claudia_Martinez_071014_IM_1	stats, chorus	--	20130116	--	--	event	December 21, 2012	2012/12/21 00:00	2012/12/21 23:45
Published	Qingying_Shu_020714_IM_1	T01	--	20130116	--	--	event	February 13, 2004	2004/02/13 00:00	2004/02/14 00:00
Published	Lutz_Rastaetter_112613_IM_2	AGU Storm	--	20130116	--	--	event	December 14, 2006	2006/12/14 00:00	2006/12/16 00:00
Published	Lutz_Rastaetter_112613_IM_2	AGU Storm	--	20130116	--	--	event	December 14, 2006	2006/12/14 00:00	2006/12/16 00:00
Published	asif_ali_110213_IM_1	field	--	20130116	--	--	event	February 01, 2000	2000/02/01 01:00	2000/02/05 02:00
Published	anna_chulaki_091613_IM_1	test	--	20130116	--	--	event	January 01, 2000	2000/01/01 00:00	2000/01/01 02:00
Published	jeni_victor_091313_IM_1	high latitude potential	--	20130116	--	--	event	January 05, 2006	2006/01/05 00:00	2006/01/11 23:00
Published	jeni_victor_091313_IM_2	high latitude potential	--	20130116	--	--	event	January 23, 2006	2006/01/23 00:00	2006/01/28 23:00
Published	Anna_Chulaki_072413_IM_1	test run	--	20130116	--	--	event	February 03, 2001	2001/02/03 04:00	2001/02/03 05:00
Published	jeni_victor_043013_IM_1	high latitude potential	--	20130116	--	--	model	January 25, 2006	2006/01/25 17:00	2006/01/26 00:00
Published	jeni_victor_043013_IM_2	high latitude potential	--	20130116	--	--	model	January 26, 2006	2006/01/26 14:00	2006/01/26 19:00



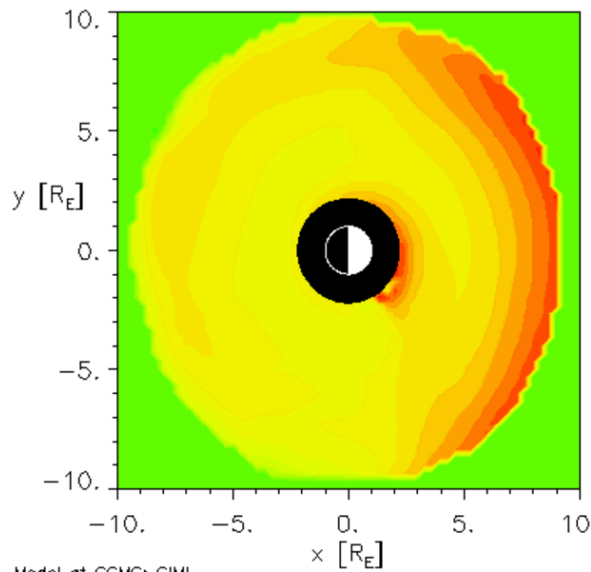
Questions from a CCMC-CIMI User



A question from Abby Azari (U of Michigan)
Why do the H⁺ pitch-angle anisotropies from the CCMC and the TWINS site vary?

CCMC-CIMI run with T96

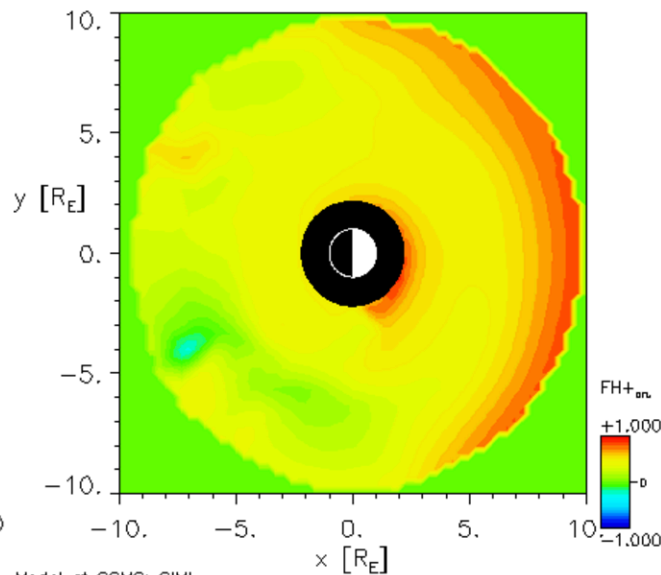
07/15/2012 Time = 10:00:00 UT En.= 17.8keV



Model at CCMC: CIMI

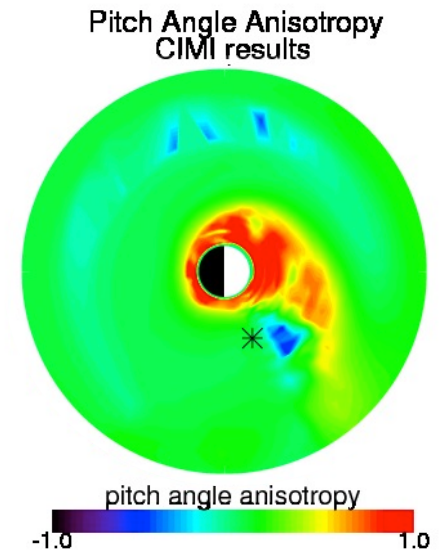
CCMC-CIMI run with T04

07/15/2012 Time = 10:00:00 UT En.= 17.8keV



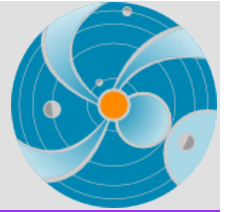
Model at CCMC: CIMI

CIMI PAD on TWIMS site





Summary



- CIMI: CRCM+RBE
- CIMI reproduced storm signatures of the ring current and radiation belts
- CIMI is able to identify energization and loss processes in ring current and radiation belts
- CIMI got a lot of “Runs on Request”