LFM/CMIT at CCMC

Progress and Challenges

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Slava Merkin: APL
Erik Wilson: BU
Frank Toffoletto, Asher Pembroke: Rice

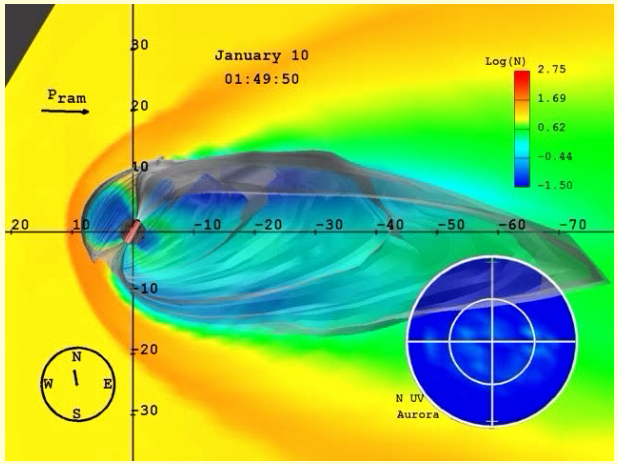
CCMC staff, particularly Lutz Rastaetter

CISM Coupling Framework

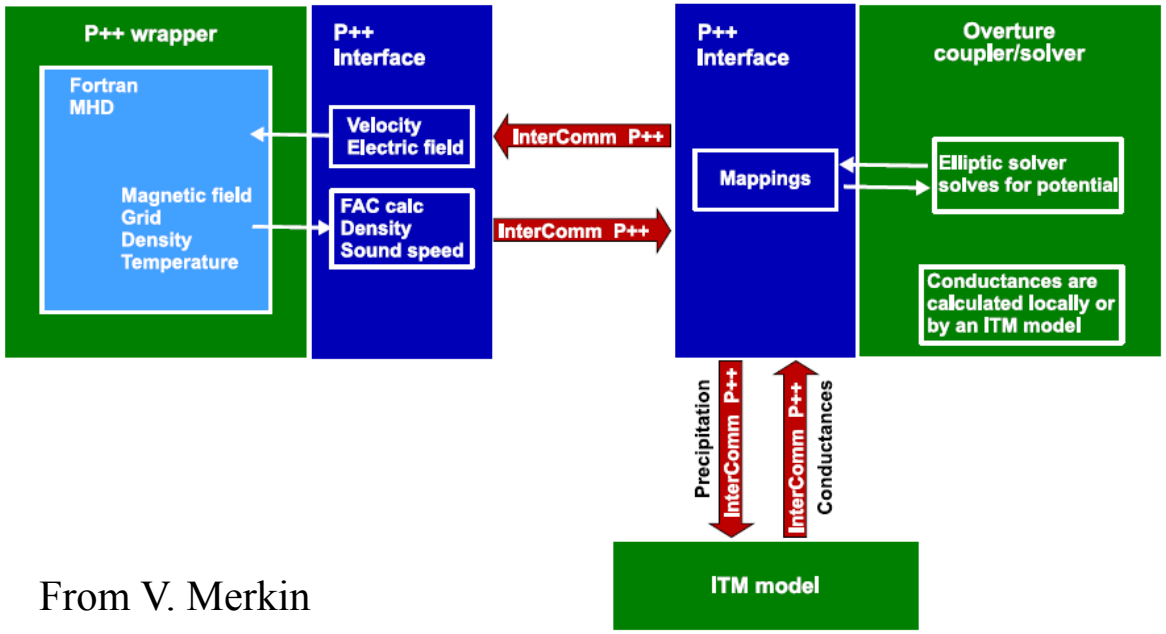
- Needed to develop programming paradigm which allows for efficient coupling of models and is flexible enough to allow adding new physics and models
  - efficient transmission of information among codes
  - interpolation of data between grids
  - translation of physical variables between codes
  - control mechanisms to synchronize execution and interaction between codes
  - minimal modifications to existing code base
- Intercomm – University of Maryland – A. Sussman
  - Solution to the MxN problem in coupling parallel codes
  - Addresses the control issues
- Overture - LLNL – B. Henshaw & D. Quinlan
  - C++ framework for solving differential equations on overset grids
  - Used to handle interpolation between model grids

LFM Magnetospheric Model

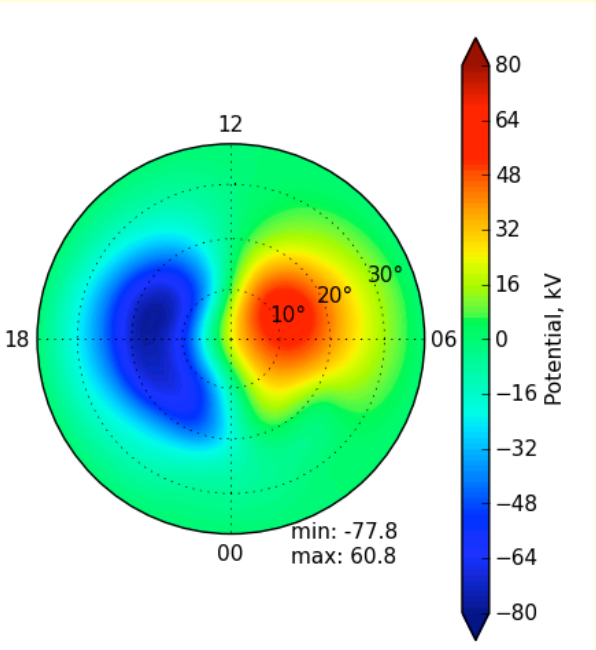
- Uses the ideal MHD equations to model the interaction between the solar wind, magnetosphere, and ionosphere
  - Computational domain
    - 30 R_E < x < -300 R_E & ±100R_E for YZ
    - Inner radius at 2 R_E
  - Calculates
    - full MHD state vector everywhere within computational domain
  - Requires
    - Solar wind MHD state vector along outer boundary
    - Empirical model for determining energy flux of precipitating electrons
    - Cross polar cap potential pattern in high latitude region which is used to determine boundary condition on flow



MIX – Ionospheric Coupler

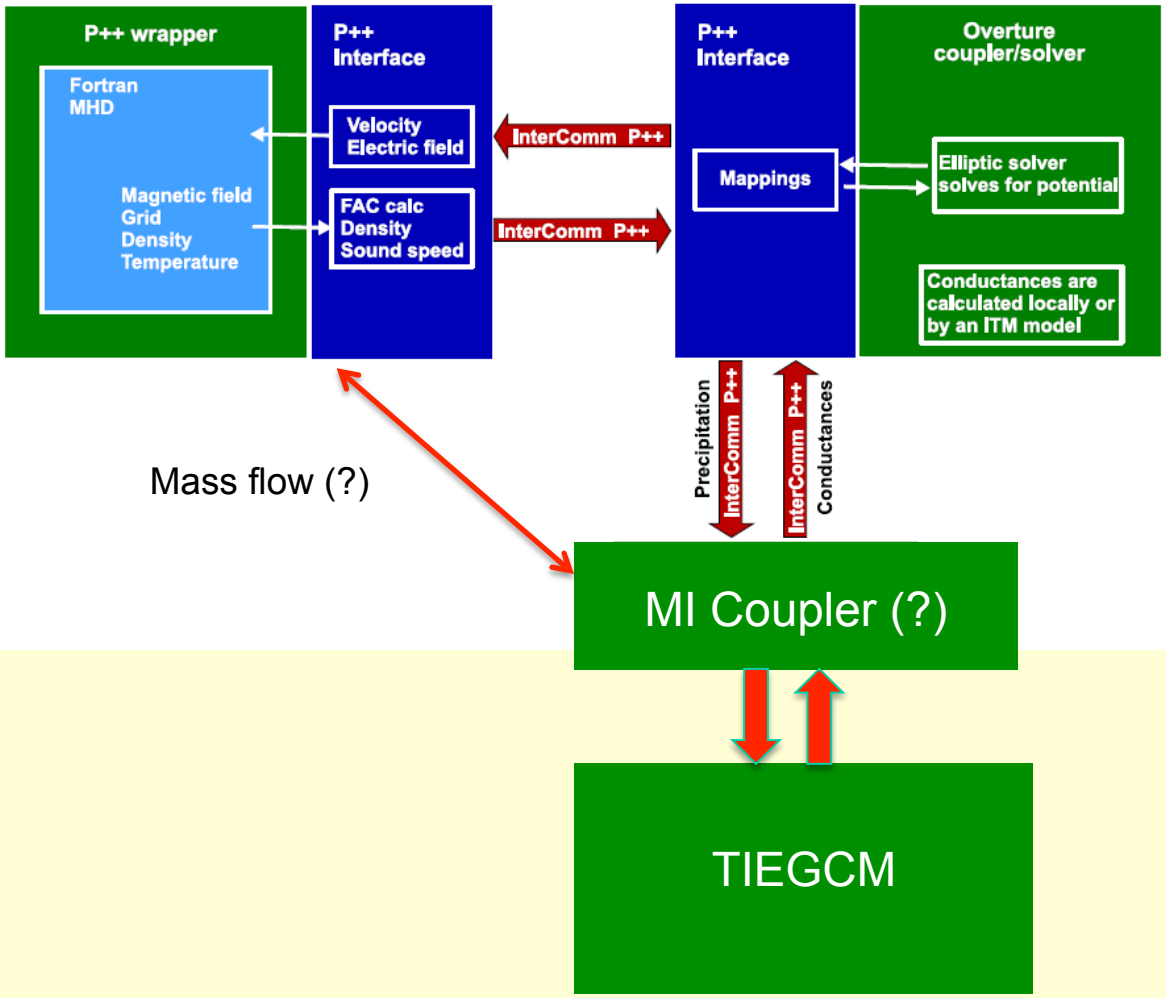


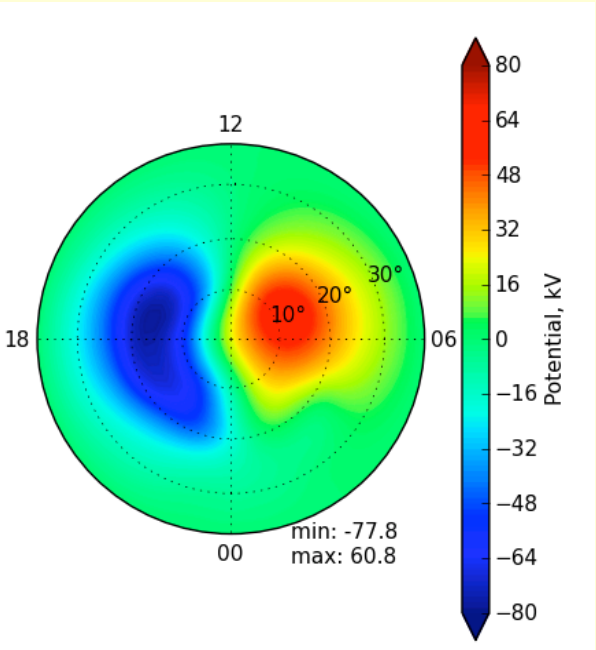
From V. Merkin



- Uses polar grid in ionosphere
- Flexible boundary conditions
- Can take field-aligned currents from multiple sources
- Completely separates MHD magnetosphere from ionospheric calculation

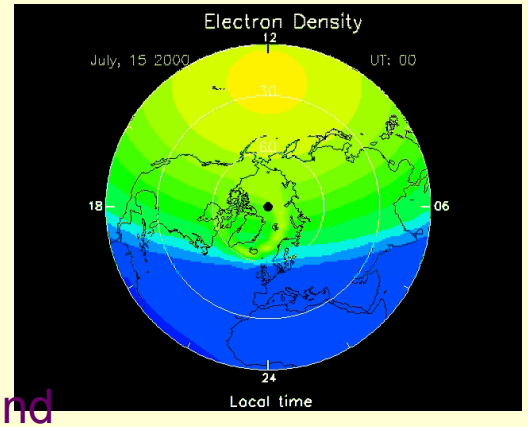
CMIT


P++ wrapper
Fortran MHD
Magnetic field
Grid
Density
Temperature
P++ Interface
Velocity
Electric field
FAC calc
Density
Sound speed
InterComm P++
InterComm P++
P++ Interface
Mappings
Overture coupler/solver
Elliptic solver solves for potential
Conductances are calculated locally or by an ITM model
Precipitation
InterComm P++
InterComm P++
Conductances
Mass flow (?)
MI Coupler (?)
TIEGCM

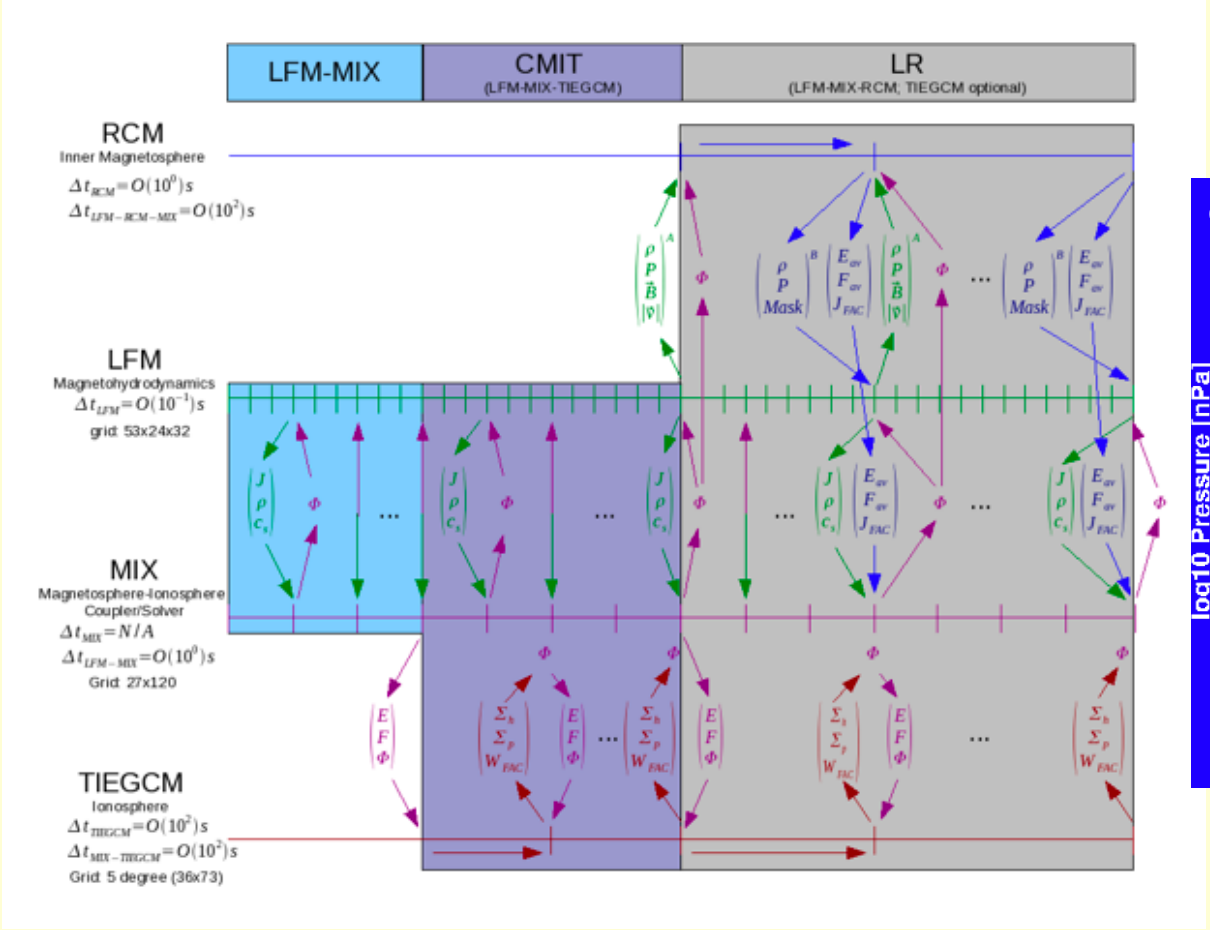

12
18
06
00
10°
20°
30°
min: -77.8
max: 60.8
80
64
48
32
16
0
−16
−32
−48
−64
−80
Potential, kV

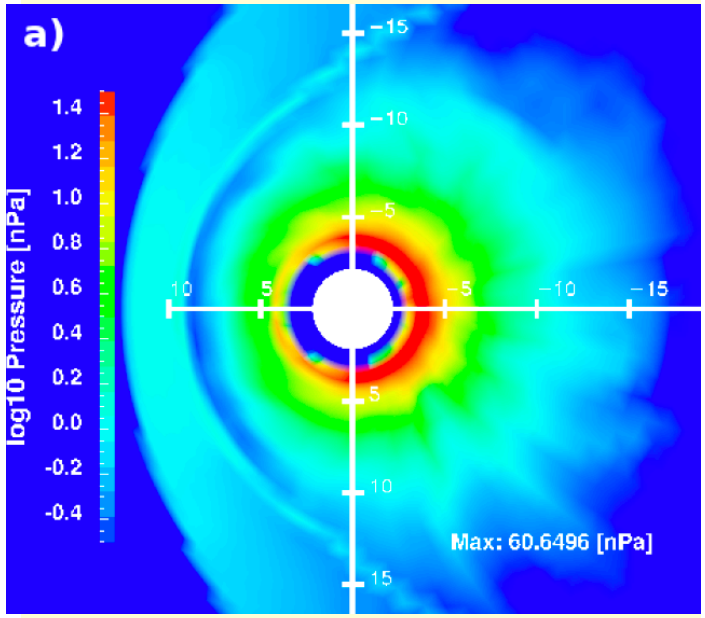
TIEGCM

- Uses coupled set of conservation and chemistry equations to study mesoscale process in the thermosphere-ionosphere
  - Computational domain
    - Entire globe from approximately 97km to 500km in altitude
  - Calculates
    - Solves coupled equations of momentum, energy, and mass continuity for the neutrals and O^+
    - Uses chemical equilibrium to determine densities, temperatures other electrons and other ions (NO^+, O_2^+,N_2^+,N^+)
  - Requires
    - Solar radiation flux as parameterized by F10.7
    - Auroral particle energy flux
    - High latitude ion drifts
    - Tidal forcing at lower boundary



LTR – Tightly Coupled System

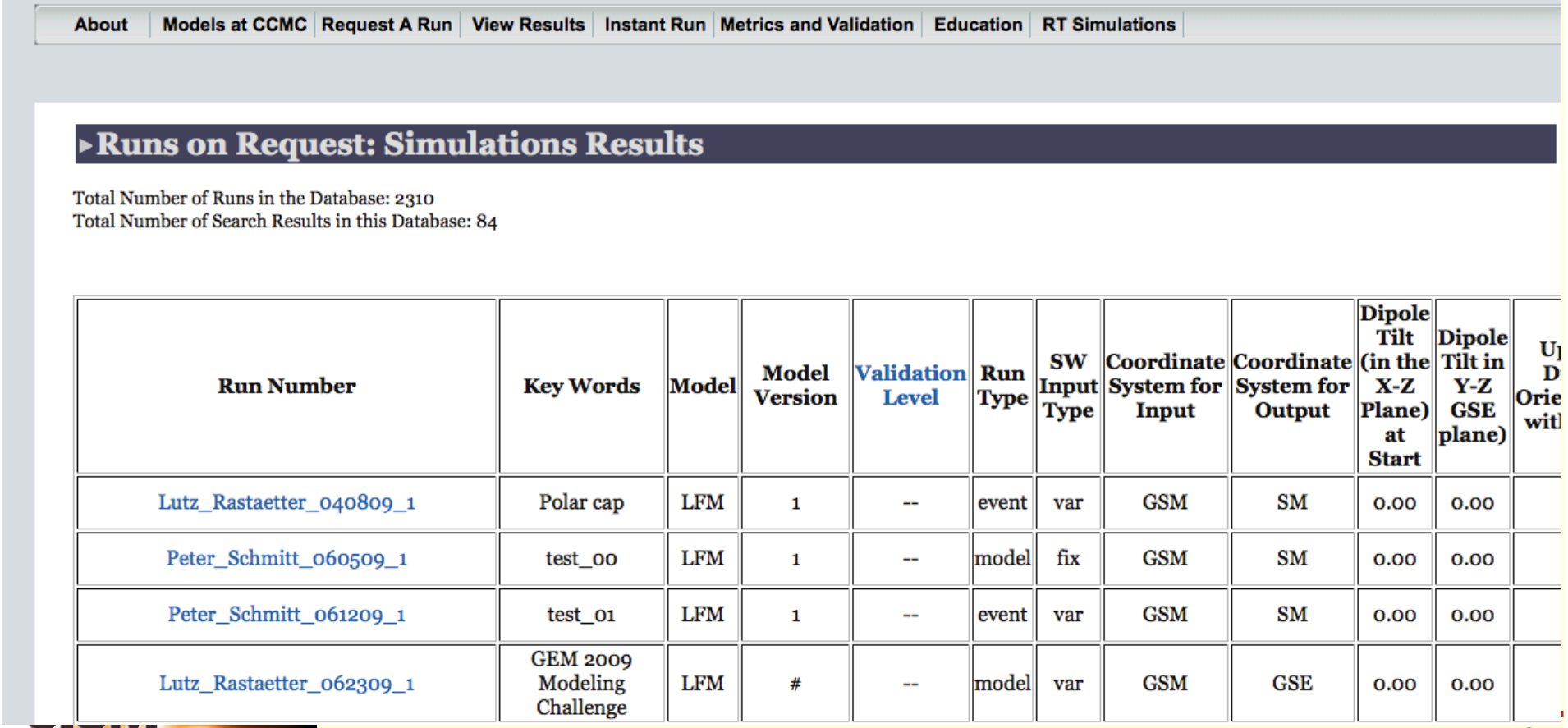




- Coupling thrust has worked closely with to implement coupling between CMIT and RCM
  - Now producing its first science results

LFM/CMIT at CCMC

- Initial work started about 5 years ago
  - OpenMP version (not very useful)
- Parallel version on line about 6/2009
  - 84 runs since, mostly this year



About | Models at CCMC | Request A Run | View Results | Instant Run | Metrics and Validation | Education | RT Simulations

Runs on Request: Simulations Results

Total Number of Runs in the Database: 2310
Total Number of Search Results in this Database: 84

Run Number	Key Words	Model	Model Version	Validation Level	Run Type	SW Input Type	Coordinate System for Input	Coordinate System for Output	Dipole Tilt (in the X-Z Plane) at Start	Dipole Tilt in Y-Z GSE plane)	U D Orie wit
Lutz_Rastaetter_040809_1	Polar cap	LFM	1	--	event	var	GSM	SM	0.00	0.00	
Peter_Schmitt_060509_1	test_00	LFM	1	--	model	fix	GSM	SM	0.00	0.00	
Peter_Schmitt_061209_1	test_01	LFM	1	--	event	var	GSM	SM	0.00	0.00	
Lutz_Rastaetter_062309_1	GEM 2009 Modeling Challenge	LFM	#	--	model	var	GSM	GSE	0.00	0.00	

SWPC_CMIT-LFM-MIX_031711_1	SWPC GEM Challenge	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00
SWPC_CMIT-LFM-MIX_031711_3	SWPC 2011 Challenge	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00
SWPC_CMIT-LFM-MIX_031711_4	SWPC 2011 Challenge	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00
HSS2011_LFMhr_060311_4	HSS2011, equinox, quiet, increased resolution	LFM	LTR-2_1_1	--	model	fix	GSM	SM	0.00
SWPC_CMIT-LFM-MIX-TIEGCM_031711_3	SWPC 2011 Challenge	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00
SWPC_CMIT-LFM-MIX-TIEGCM_031711_4	SWPC 2011 Challenge	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00
monte_andres_072211_1	magnetosphere response	LFM	LTR-2_1_1	--	model	var	GSM	SM	0.00
Bruce_Tepke_081011_1	storms	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00
michelle_mendoza_091311_1	test	LFM	LTR-2_1_1	--	model	fix	GSM	SM	-27.00
Xi_Shao_092011_1	ULF Wave Excitation	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00
rushat_shatur_093011_3	high resolution run	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00
Xi_Shao_111611_1	ULD wave, Storm	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00
Bruce_Tepke_121511_1	storm substorms	LFM	LTR-2_1_1	--	event	--	GSM	SM	0.00
Kris_Kersten_111511_1	22 oct 2001	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00
Kris_Kersten_121211_1	22 oct 2001	LFM	LTR-2_1_1	--	event	var	GSM	SM	0.00

Development Plans-2012

- Primarily Maintenance release
- New version LFM
  - Improved parallel performance
  - Multi-fluid capability
    - Can be used for outflow studies, plasmasphere, etc.
    - Creates challenges for CCMC interface
- MIX improvements
  - Better ionospheric conductance model based on work by Binzheng Zhang
- Current released version of TIEGCM
- RCM hooks added, but physics still being tested

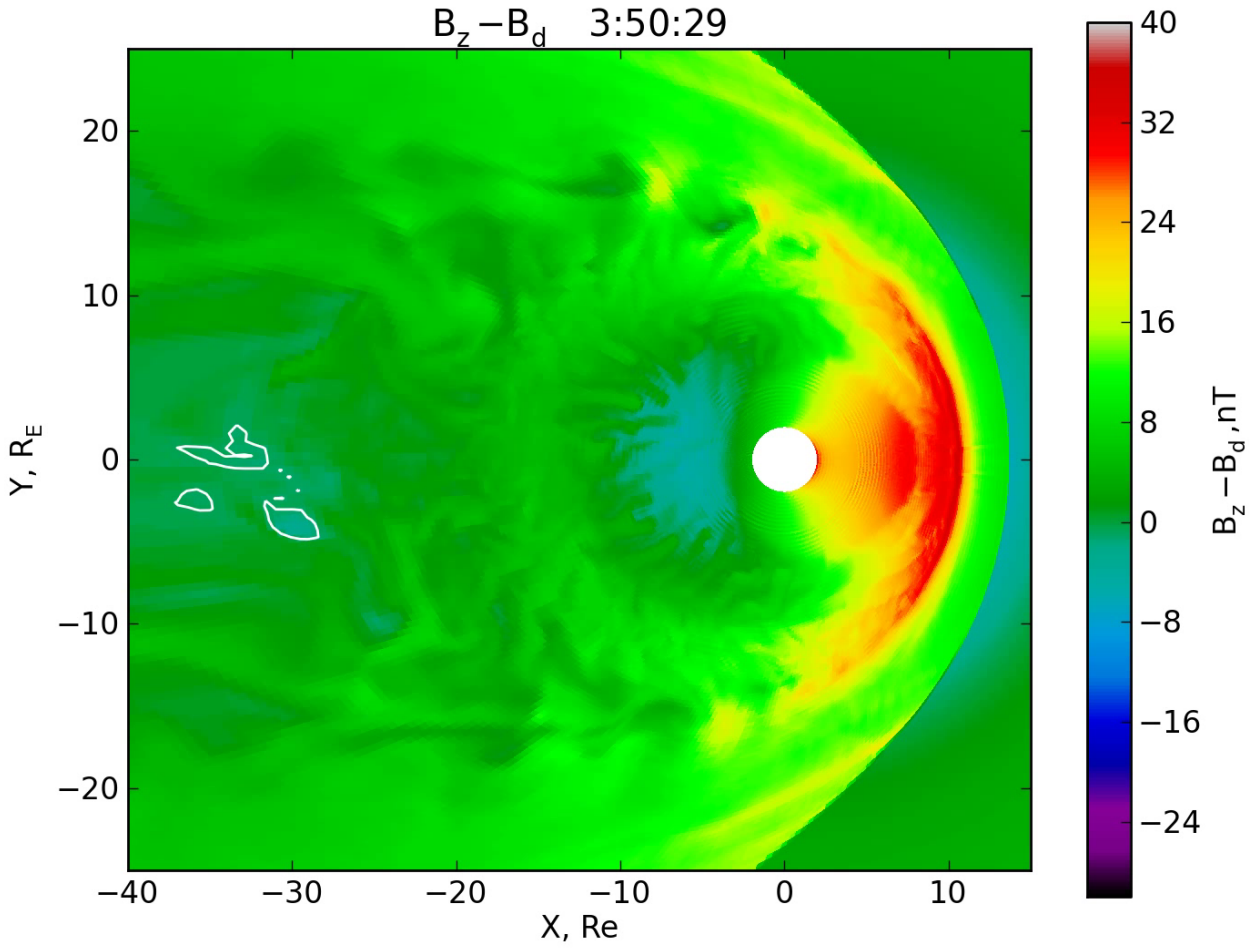
Challenges

- Resolution/Grid Convergence
  - In high Reynolds number flow no reason to expect absolute grid convergence
  - Good enough convergence
- Data Management
  - Higher resolution requires ways of handling large amounts of data
  - Data products
- Additional Physics
  - Can it be made available to the community

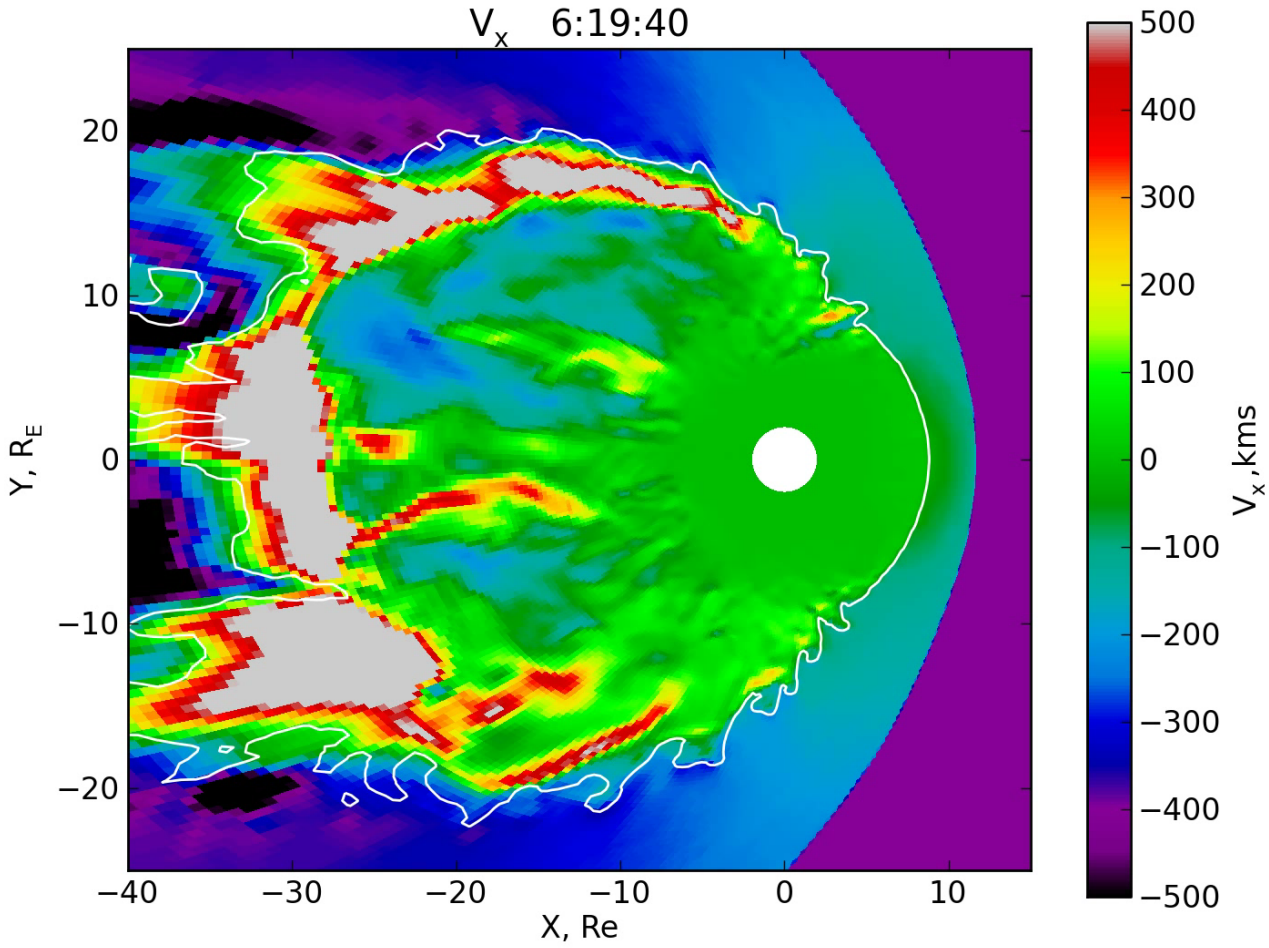
Grid convergence

- Some movies for a simple IMF case
  - 400 km/s
  - N = 5 /cm^3
  - 2 hrs B_z = -5 nT
  - 2 hrs B_z = 5 nT
  - then B_z = -5 nT
- Resolution:
  - 100 km in ionosphere
  - 1000 km (at 10 R_E) in magnetosphere
  - Approx. 8 million cells (run on 1000 processors)

B_Z-$B_{Z,dipole}$


$B_z - B_d$ 3:50:29
20
10
0
−10
−20
Y, R_E
−40
−30
−20
−10
0
10
X, Re
40
32
24
16
8
0
−8
−16
−24
$B_z - B_d$,nT

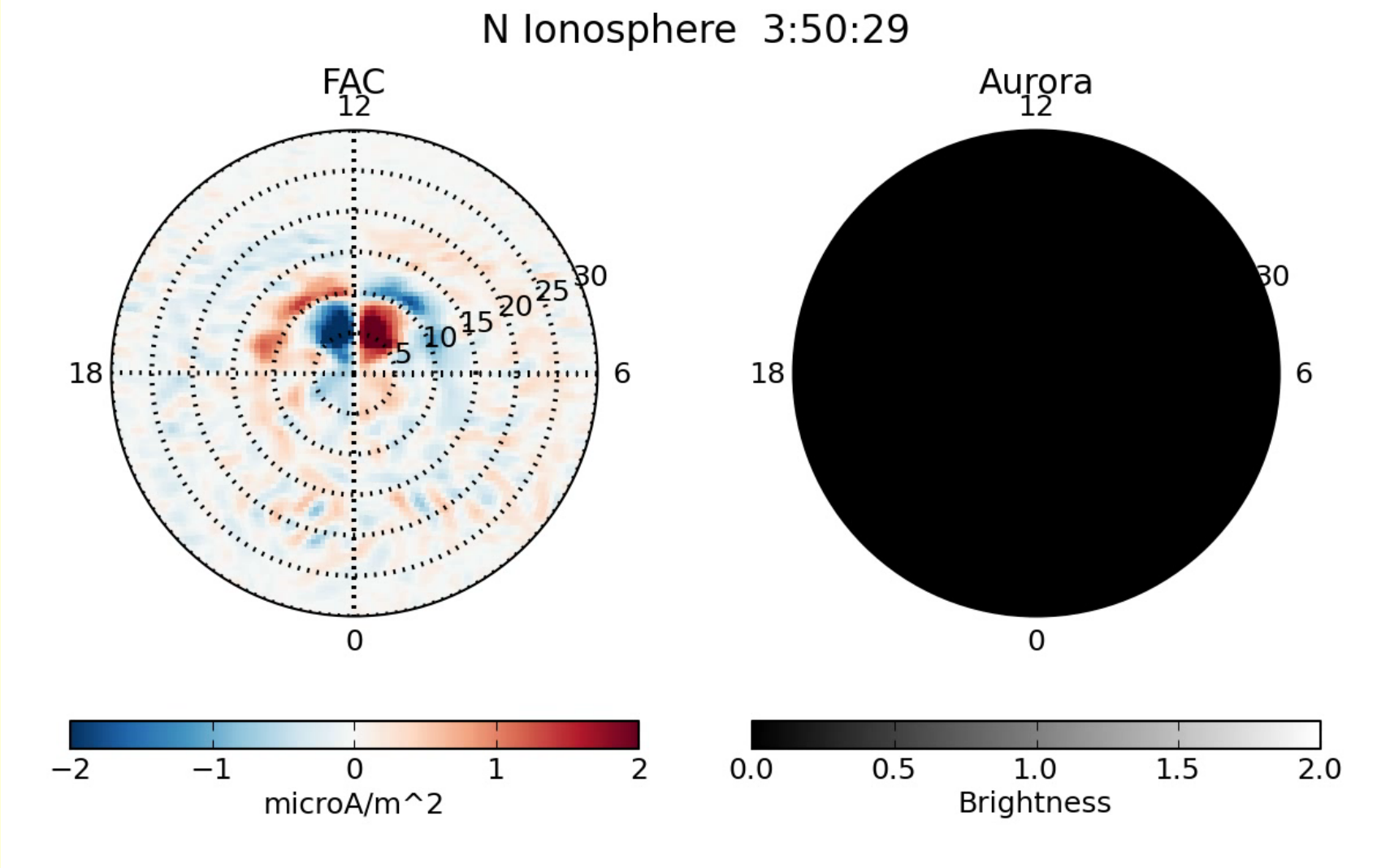
V_x


V_x 6:19:40
20
10
0
−10
−20
Y, R_E
−40
−30
−20
−10
0
10
X, Re
500
400
300
200
100
0
−100
−200
−300
−400
−500
V_x,kms

Features

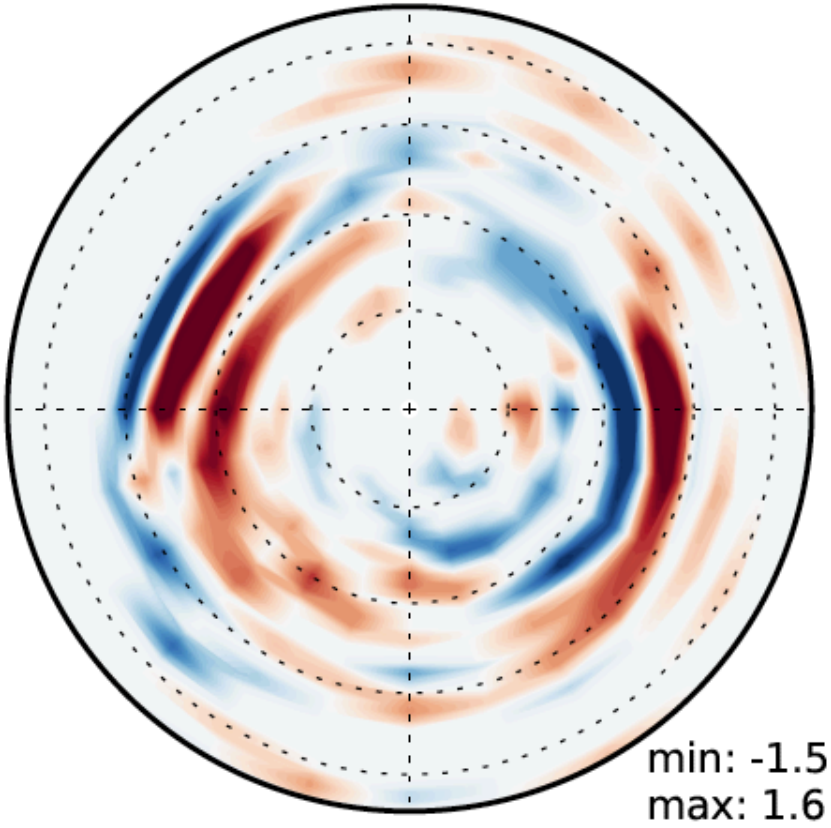
- Dipolarization fronts are regions of depleted flux tube entropy: Bubbles
- Scale size in mid tail seems resolved, but approaches grid scale in inner magnetosphere
- Is it real?
  - Flux tube entropy seems to be pretty well conserved

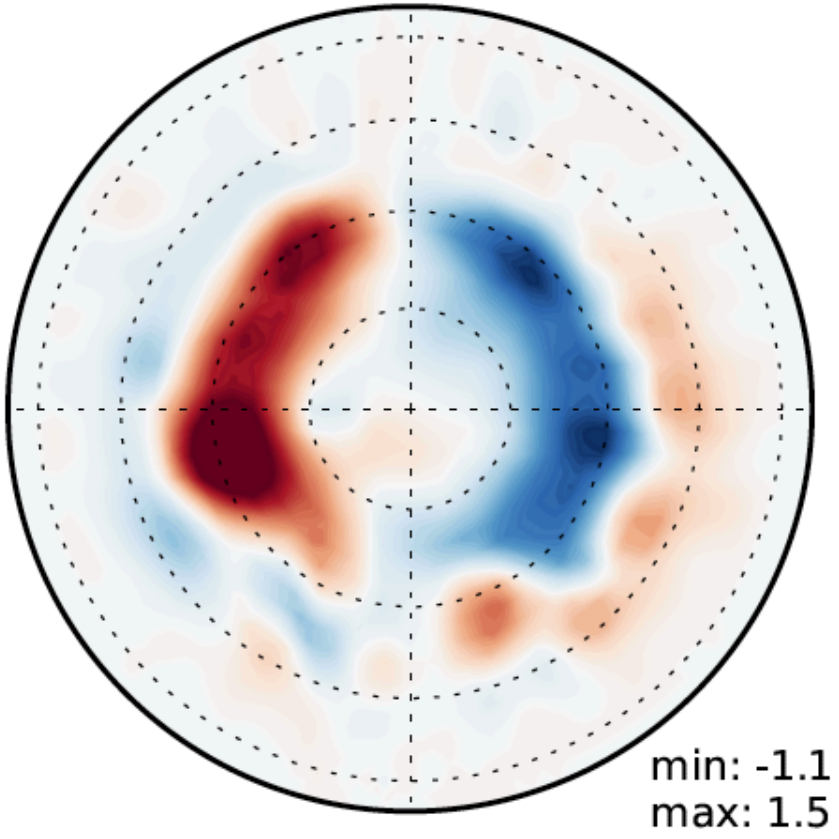
Ionosphere (FAC & Aurora)



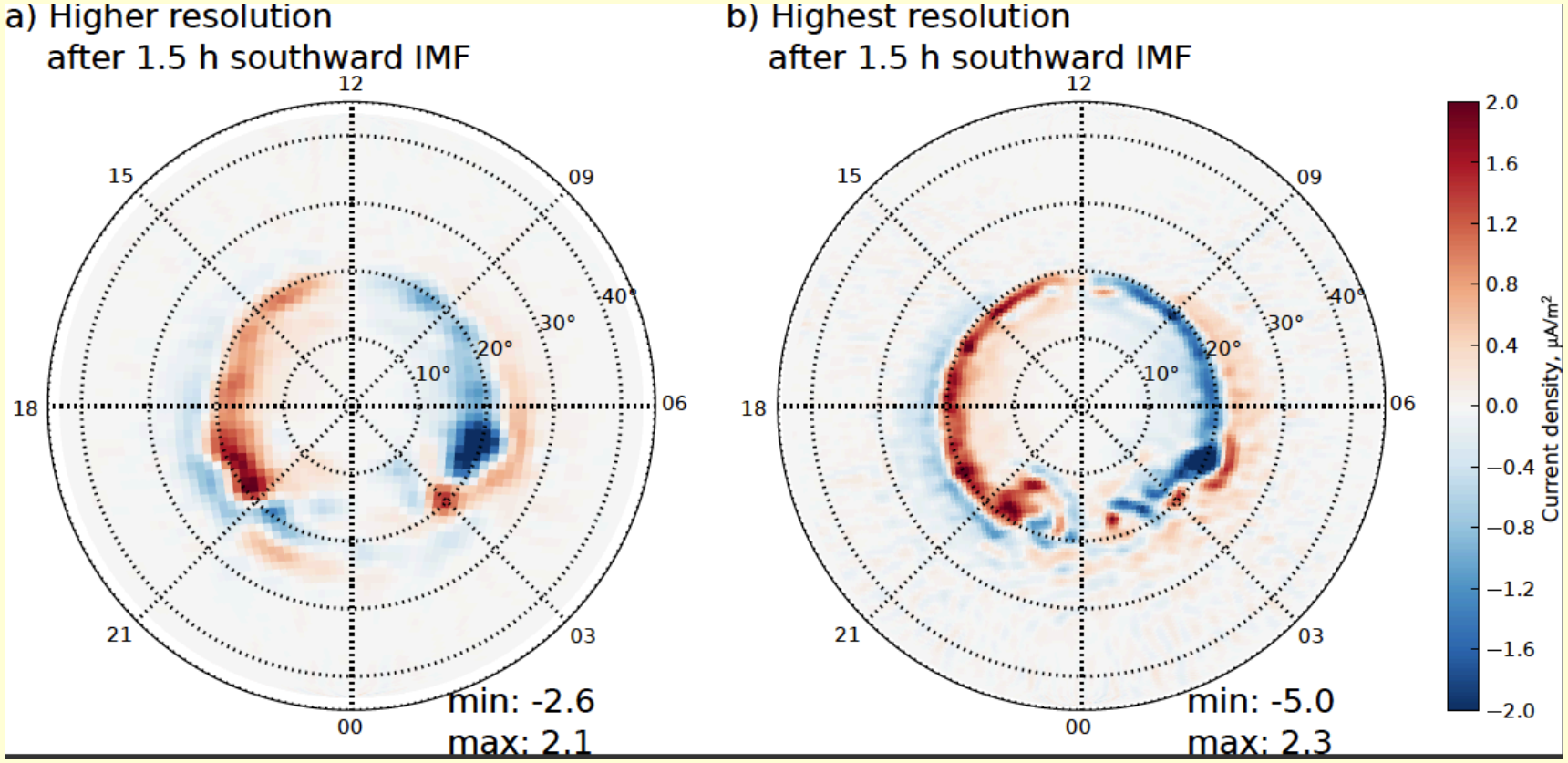
Good Enough Resolution?

- Comparison of AMPERE with LFM (CCMC resolution)





Better, Good Enough?



Good Enough!

- CCMC needs more computational resources
  - Could wait for Moore's Law
    - Then you should never start any computational project

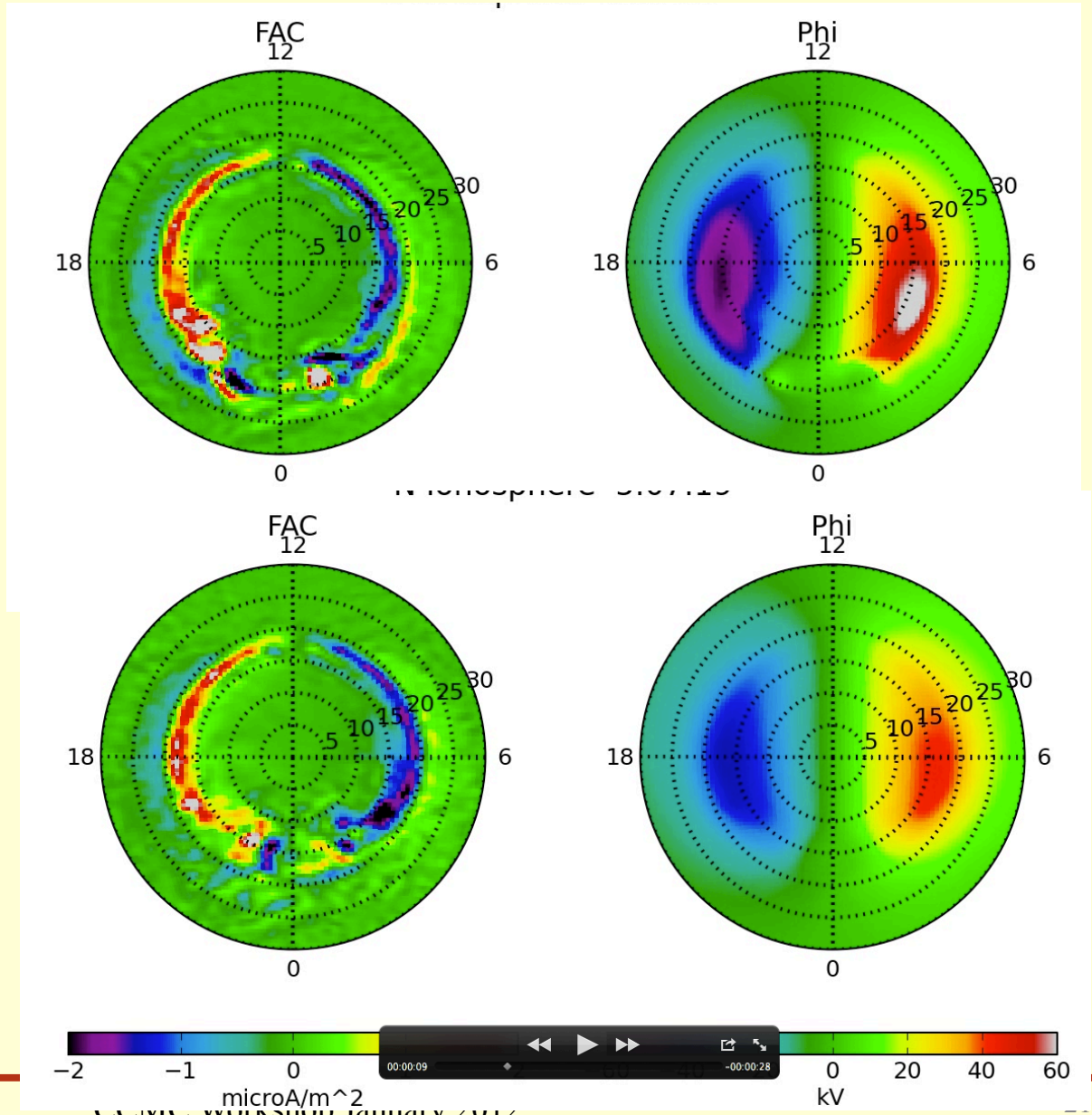
Data Management

- Previous run:
  - Individual step 0.8 Gbytes
  - Whole run ~ 1Tbyte
- CCMC idea of having runs archived at their facility right way to go
  - Need more facilities
  - User analysis needs a lot of resources
    - Computational
    - People!!!

New Physics

- MHD – Hall, anisotropic P, etc.
- Ionospheric Conductance
  - Note substorm current wedge
- Ionospheric outflow
- Challenge:

Return of the GEM Patch Panel



Conclusion

- CCMC is doing a great job, so much so that former LFM grad students are using it
- CCMC needs more resources to allow the community to have
  - Good enough resolution
  - Ability to tweak their own knobs

Backup