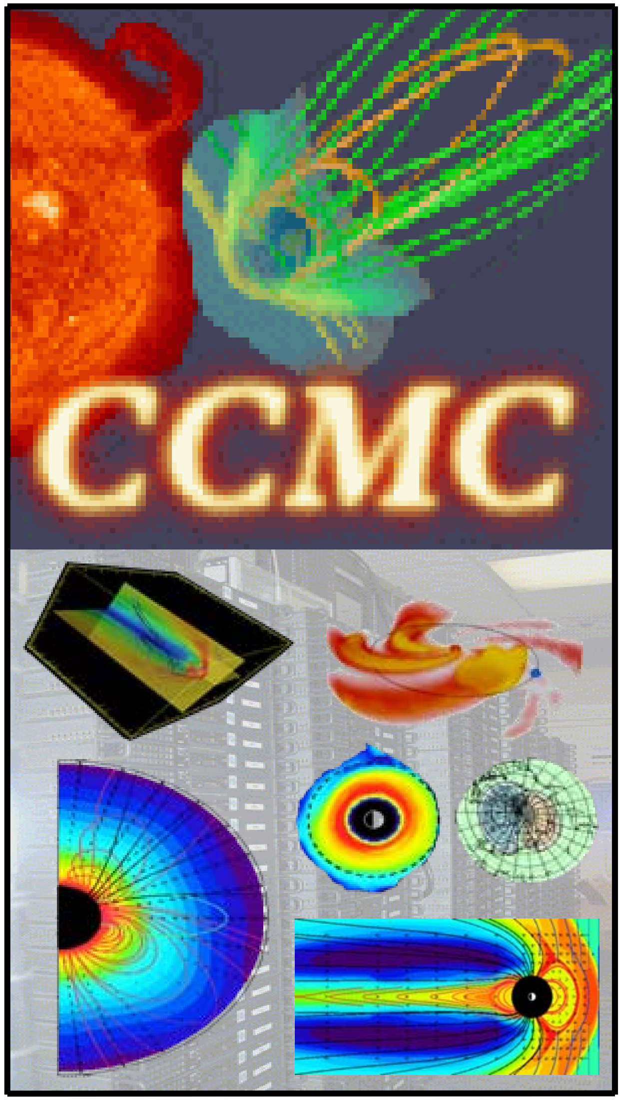


Metrics Studies, Verification & Validation

Masha Kuznetsova

CCMC Workshop, 2005

http://ccmc.gsfc.nasa.gov

CCMC Function

- Evaluate scientific research models to address National Space Weather needs.
- Perform independent and unbiased model testing and validation.

Model Testing and Validation Components

- **Science-based validation**
  - Test model validity
  - Address natural events or model capabilities
  - Detailed analysis for selected events
  - Broad feedback to code developers
  - Essential for further model improvement
- **Metrics studies**
  - Measure model usefulness for operations in comparison with some simple standard model.
  - Create simple measure of model capabilities (“one number”).
  - Allow objective comparison between models with comparable output.
  - Measure the improvement of model capabilities over time (usefulness of model upgrades).
  - Focus on parameters useful for operations
  - Based on repeatable comparison between model output and measurements.
  - Blind studies

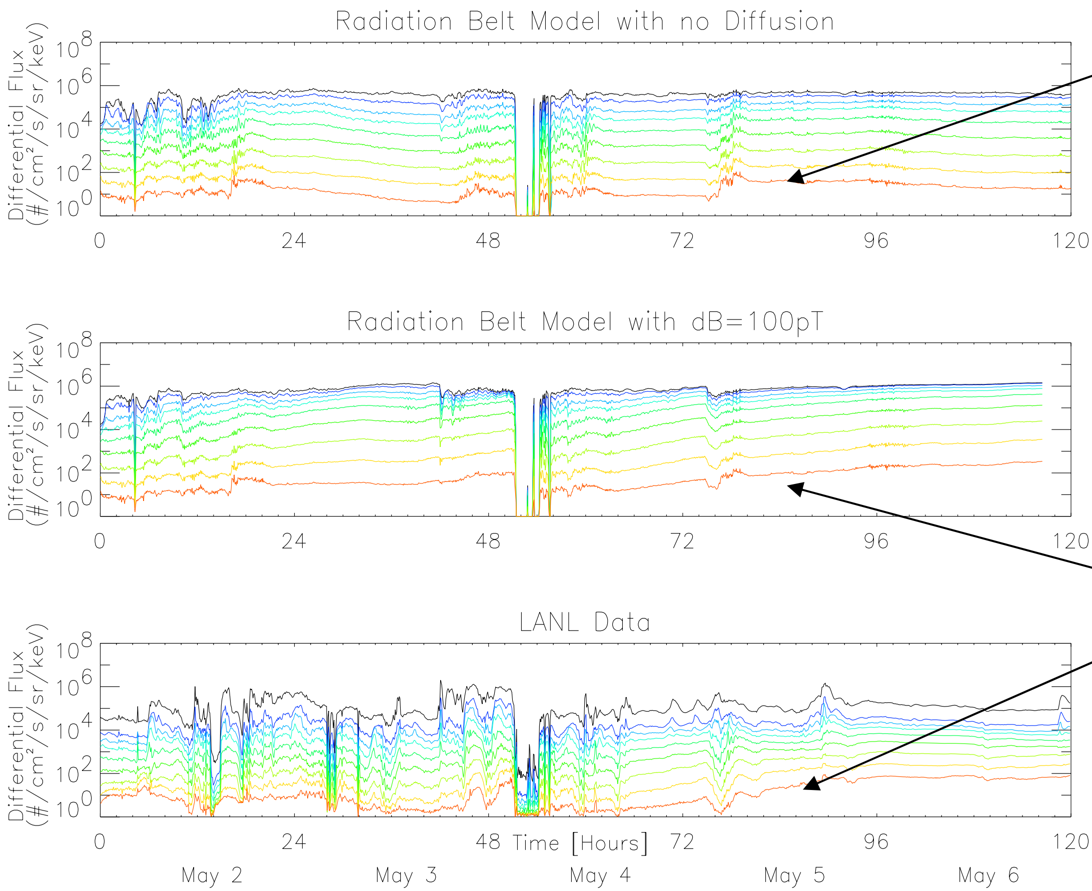
Outline

- Examples of Science-Based Validation Studies
- Role of Runs on Request System Users in V&V
- Examples of Current Metrics
- Other Metrics Opportunities
- Future Plans

Radiation Belt Model Improvement

Particle Fluxes at Geosynchronous Orbits

- 50 - 75 keV
- 75 - 105 keV
- 105 - 150 keV
- 150 - 225 keV
- 225 - 315 keV
- 315 - 500 keV
- 500 - 750 keV
- 0.75 - 1.1 MeV
- 1.1 - 1.3 MeV



flux decrease/flat

Original Model

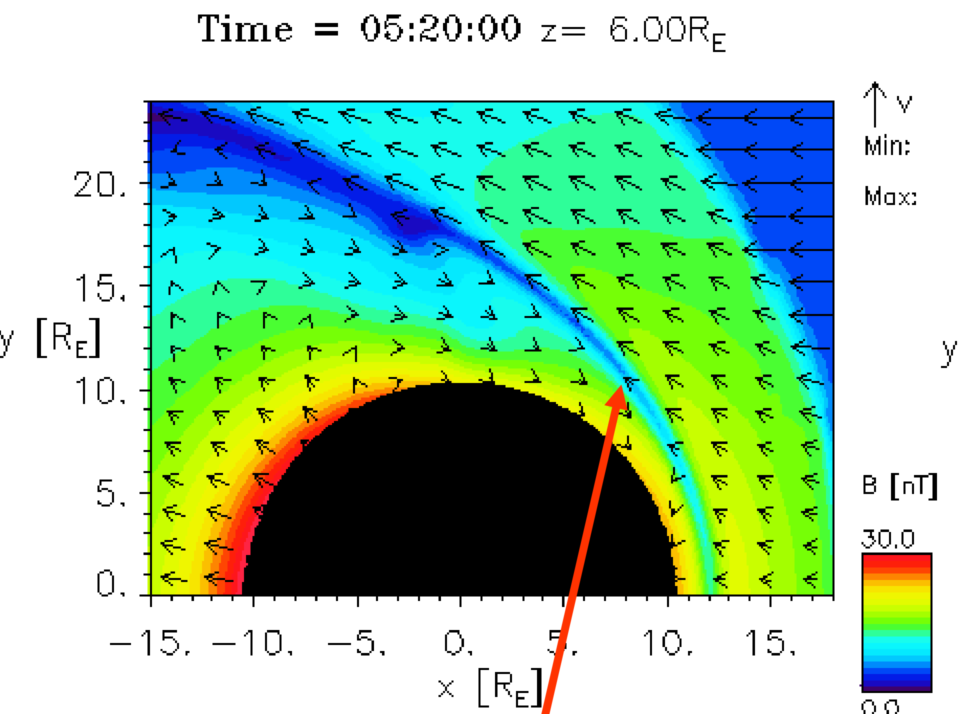
Improved Model

flux increase

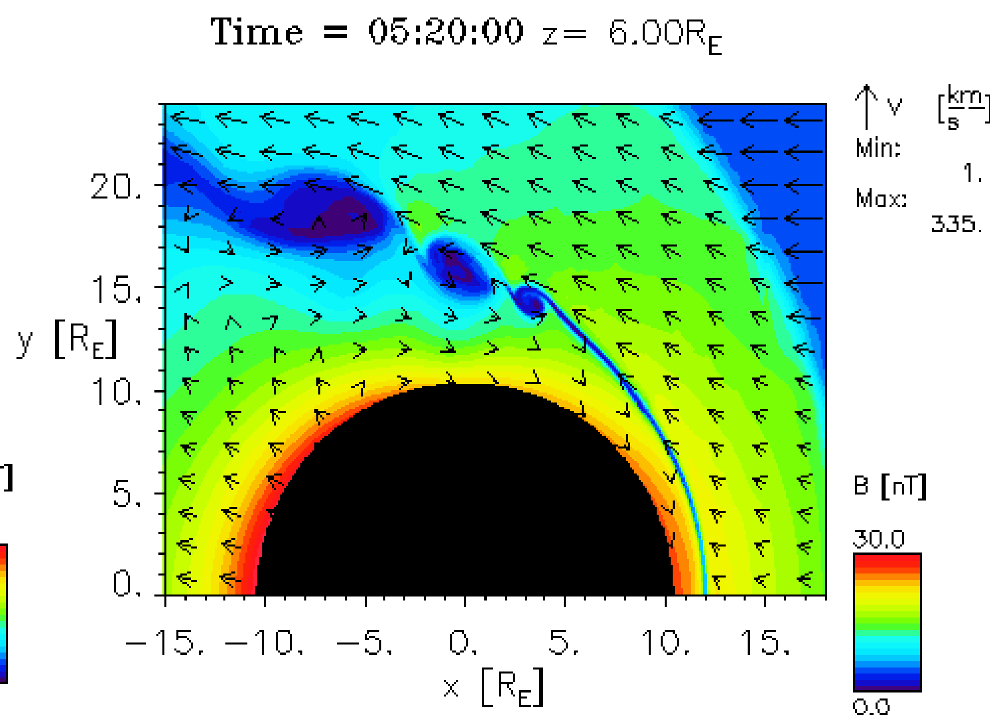
Los Alamos National Laboratory Satellite Data

Role of Spatial Resolution in Modeling Magnetopause Position and Structure

Spatial resolution 1/4 Re



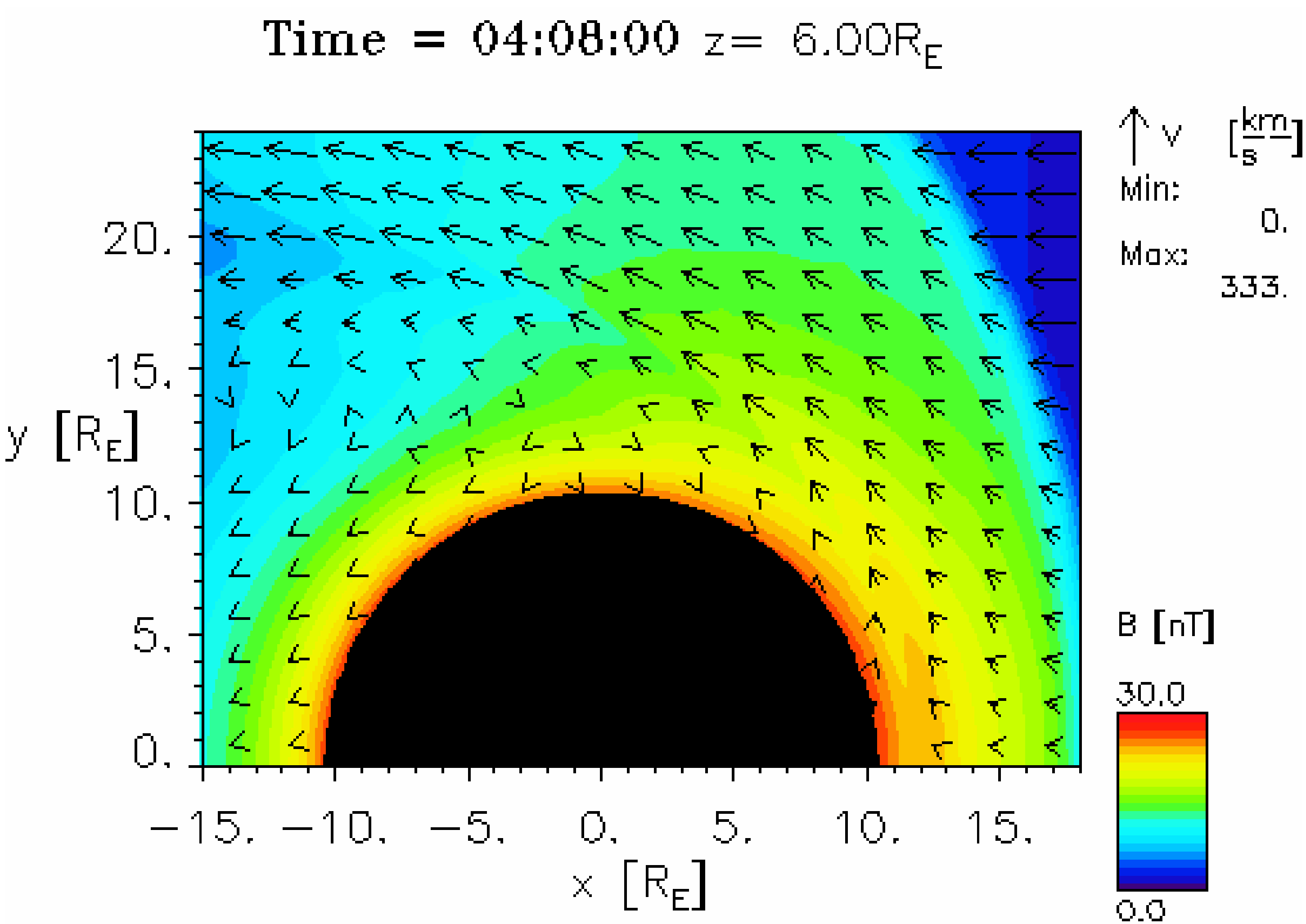
Spatial resolution 1/16 Re



Magnetopause

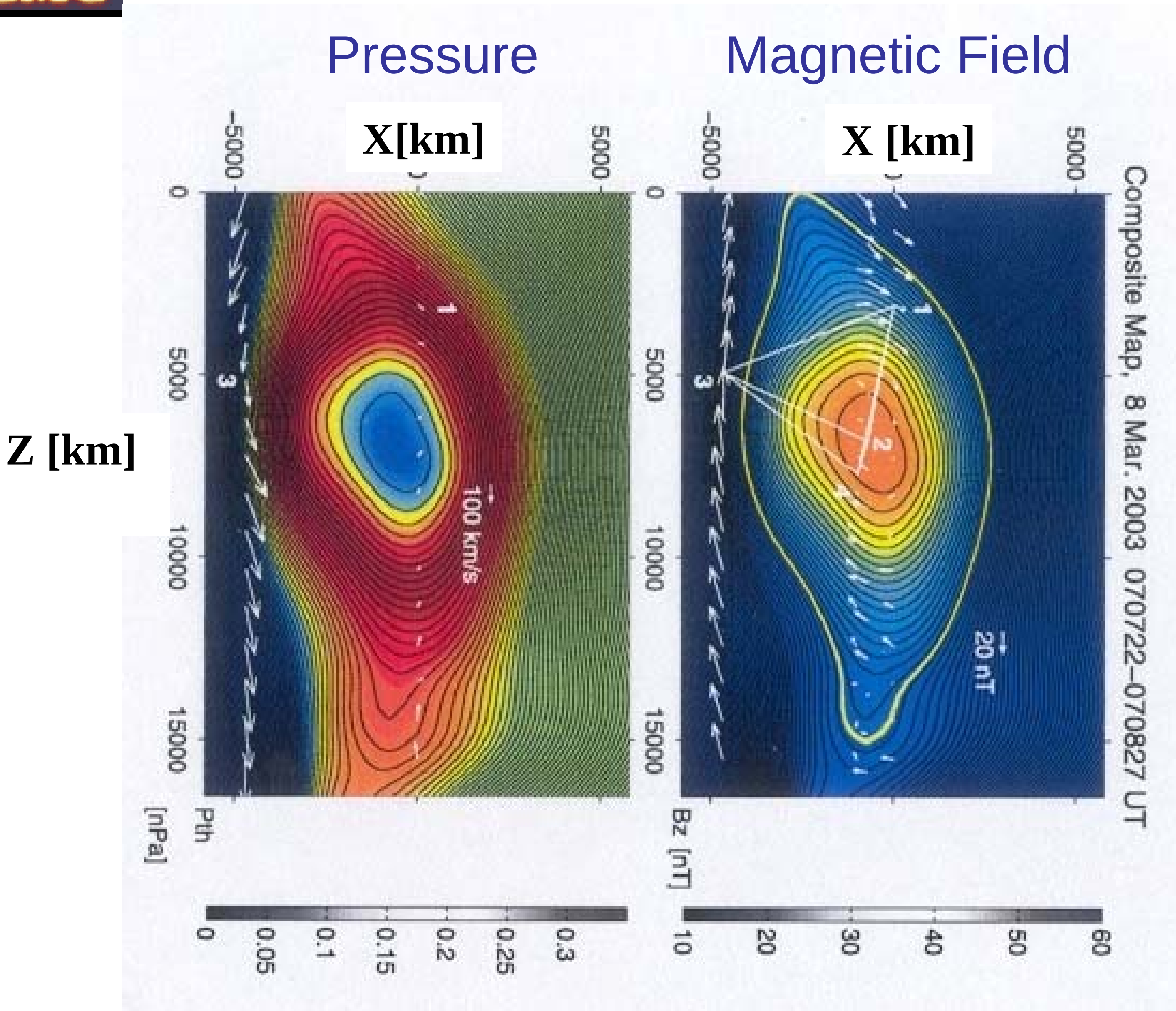
Kuznetsova et al., 2005

Magnetopause Structure Validation



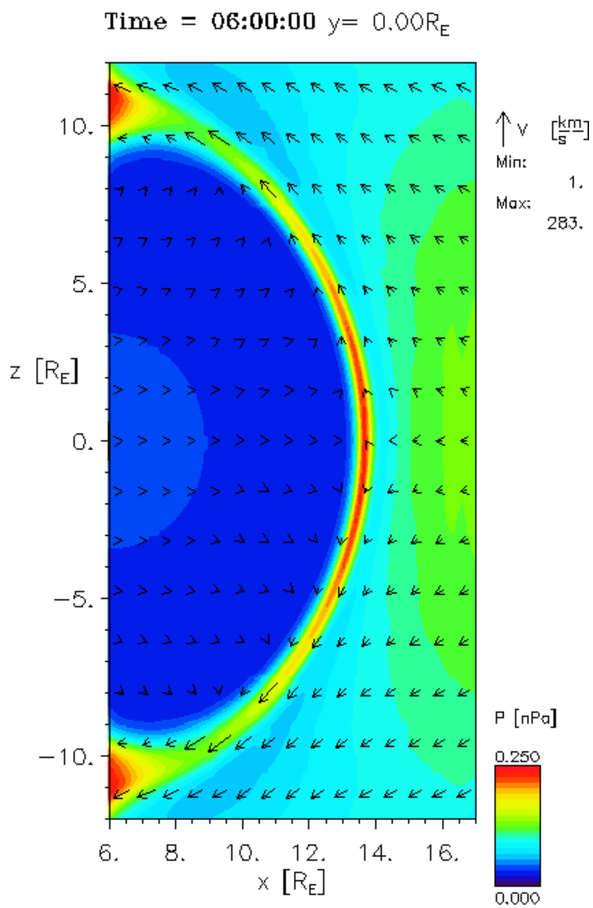
Flux Transfer Event seen by Cluster

Sonnerup et al, Geophys. Res. Letters, L11803, 2004

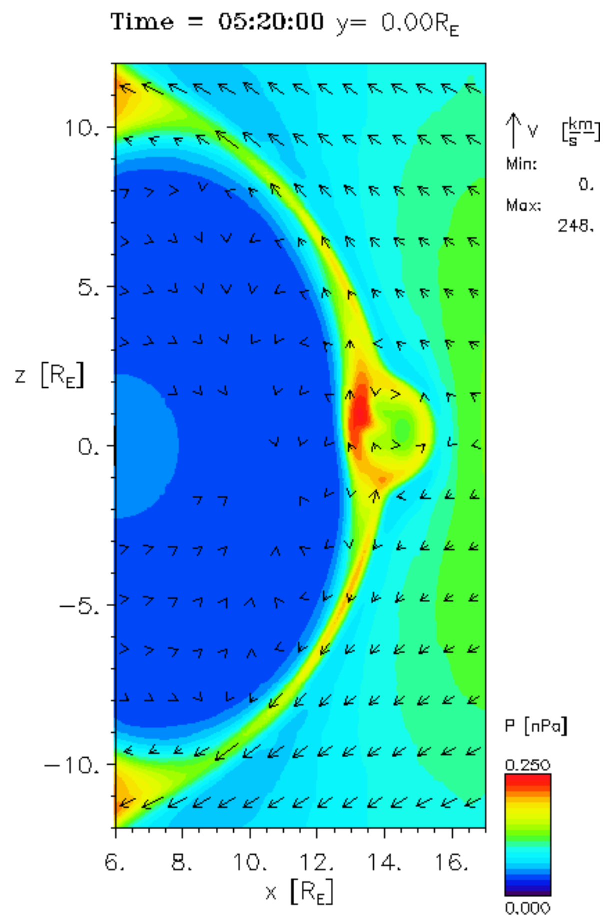


Testing the Ability of Global MHD Models to Simulate Flux Transfer Events

Spatial resolution 1/4 Re



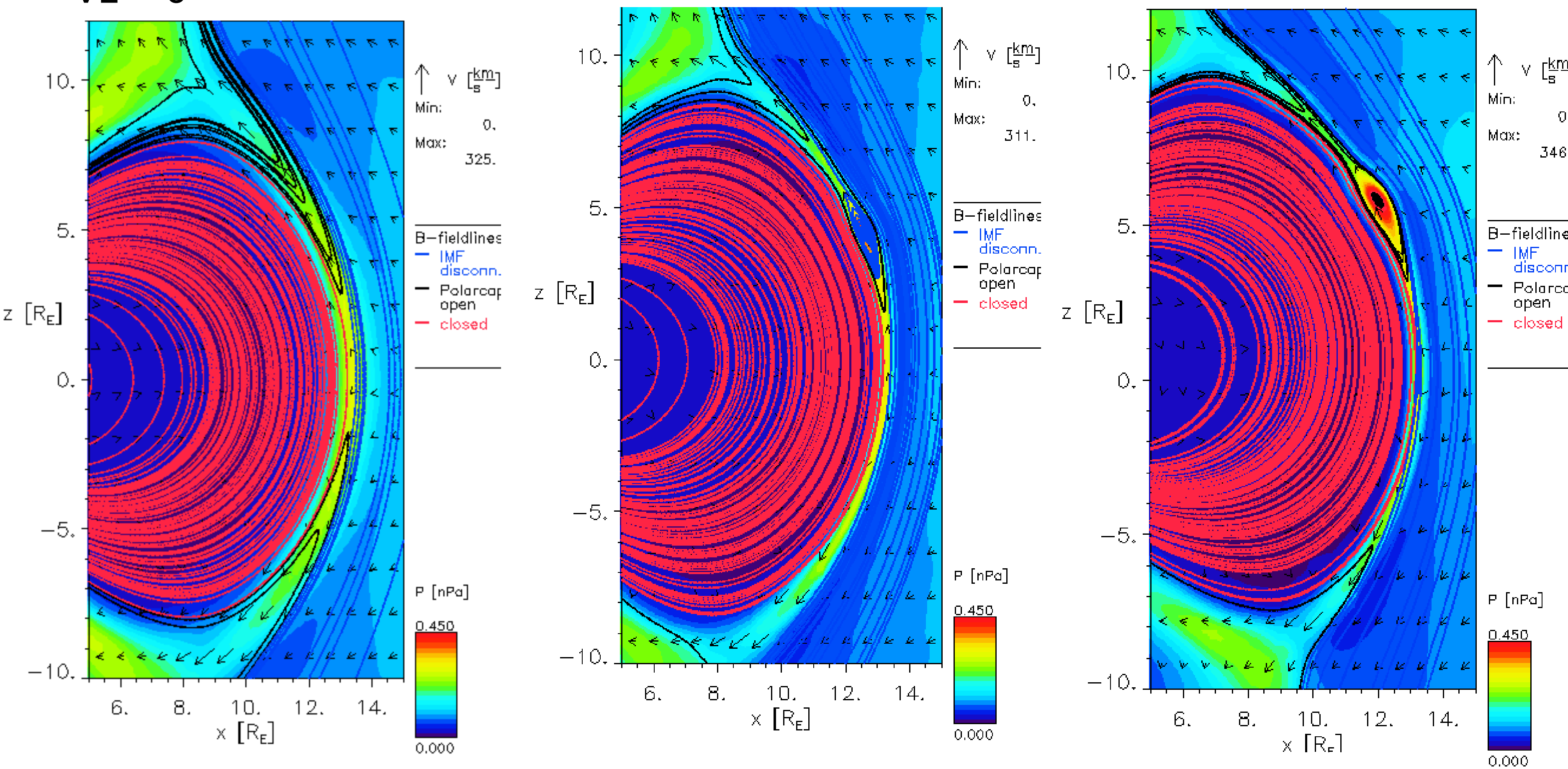
Spatial resolution 1/16 Re



Role of Spatial Resolution and Grid Orientation

55 minutes after southward ($\theta = 180^o$) IMF turning, y = 0

Dipole Tilt = 0^o Vx = V = - 300 km/s Vz = 0	Dipole Tilt = 0^o Vx = V = -300 km/s Vz = 0	Dipole Tilt = -10^o Vx = V cos (10^o) Vz = V sin (10^o)



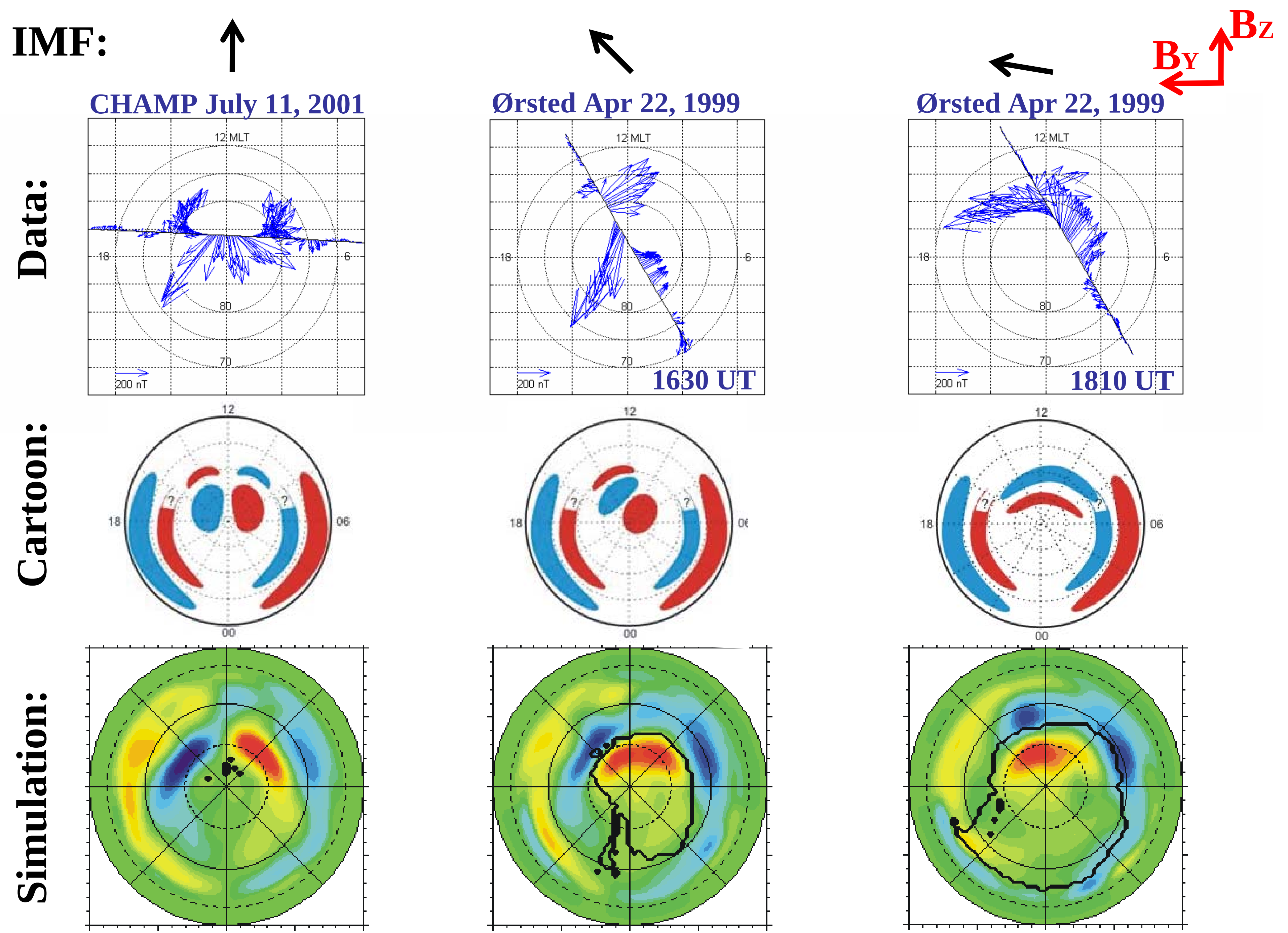
Resolution: 1 / 4 Re	Resolution: 1 / 16 Re	Resolution: 1 / 16 Re

Role of RoR Users in V&V

2001 – 2003: ~ 200 requests,
10 publications/presentations

2004 – 2005: ~ 400 requests,
> 30 publication/presentations

Informal feedback from users



Vennerstrøm et al. JGR 2002; 2005

Metrics Studies:
Elements of a Metric

- An output **parameter** from a model.
- A **measurement** that can be used for comparison (satellite or ground-based).
- **Model Score**: assesses the difference between the parameter from the model and the measurement.
- **Standard model** for comparison
  - mean (no perturbations)
  - persistence (use previous measurements as prediction)
- **Skill Score** (M): model score vs. standard model score.

$M < 0$	worse than standard
$M = 0$	as good as standard
$0 < M < 1$	better than standard
$M = 1$	perfect score

Heliosphere Metrics

- Data
  - ACE velocity and density.
- Models
  - Heliospheric Tomography (B. Jackson and P. Hick).
  - ENLIL (D. Odtrcil)
- Standard Models: mean, persistence
- Metrics
  - Model score: D_i= sqrt ($\Sigma|\Delta H_{model}$ - $\Delta H_{data}|^2$/npts).
  - Skill score: M_i= 1- D_i/ D_s

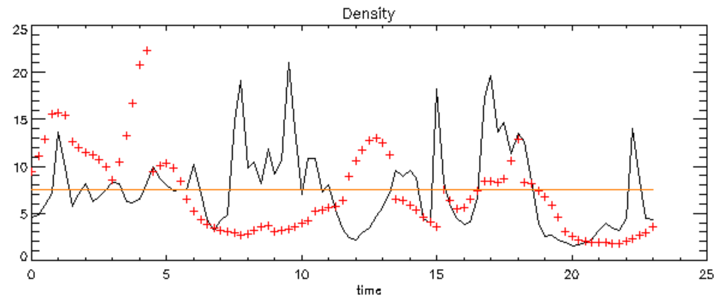
Heliospheric Tomography: Model and Data Comparison

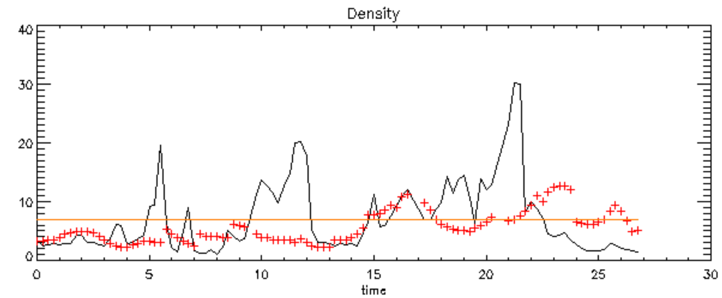
ACE Data (averaged every 6 hours)

HelTomo Model output every 6 hours

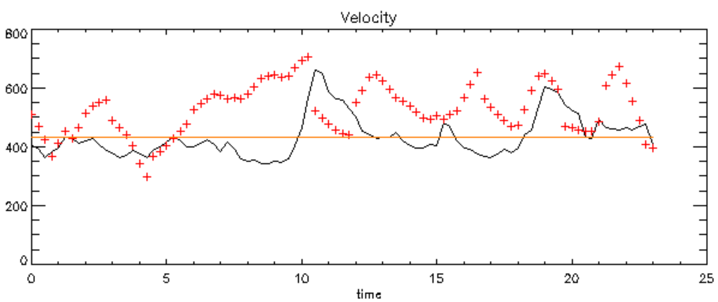
Mean

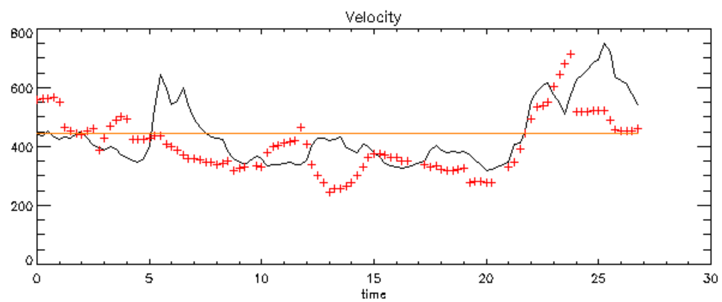
Density





Velocity





Time

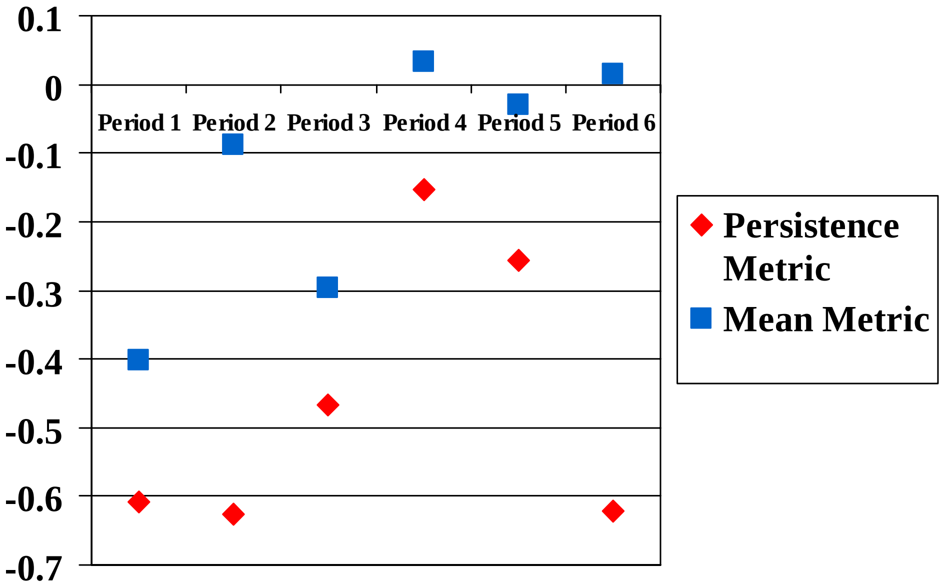
Time

Period 1 (27 days)

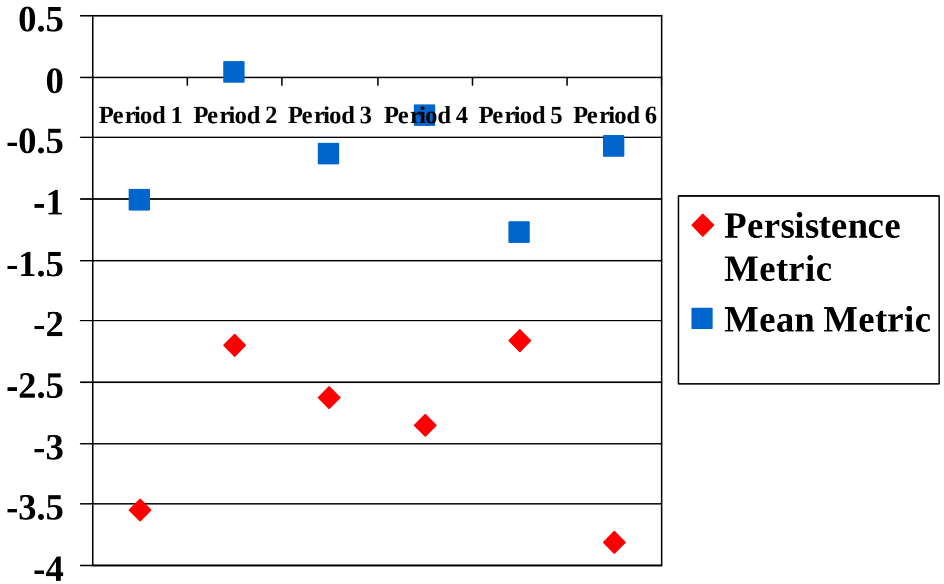
Period 2 (27 days)

Heliospheric Tomography Skill Score

Scores for Density



Scores for Velocity



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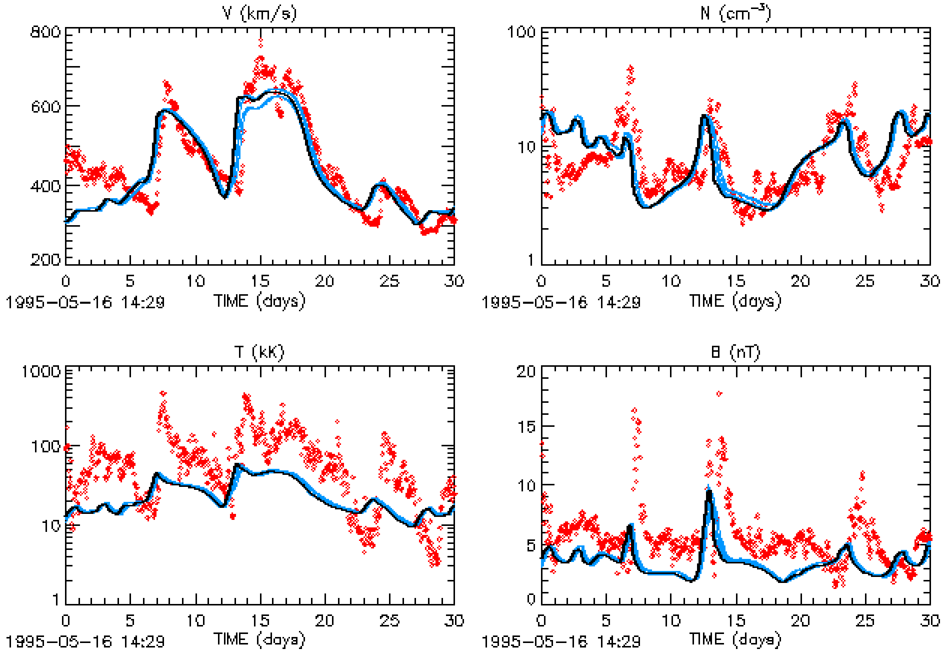

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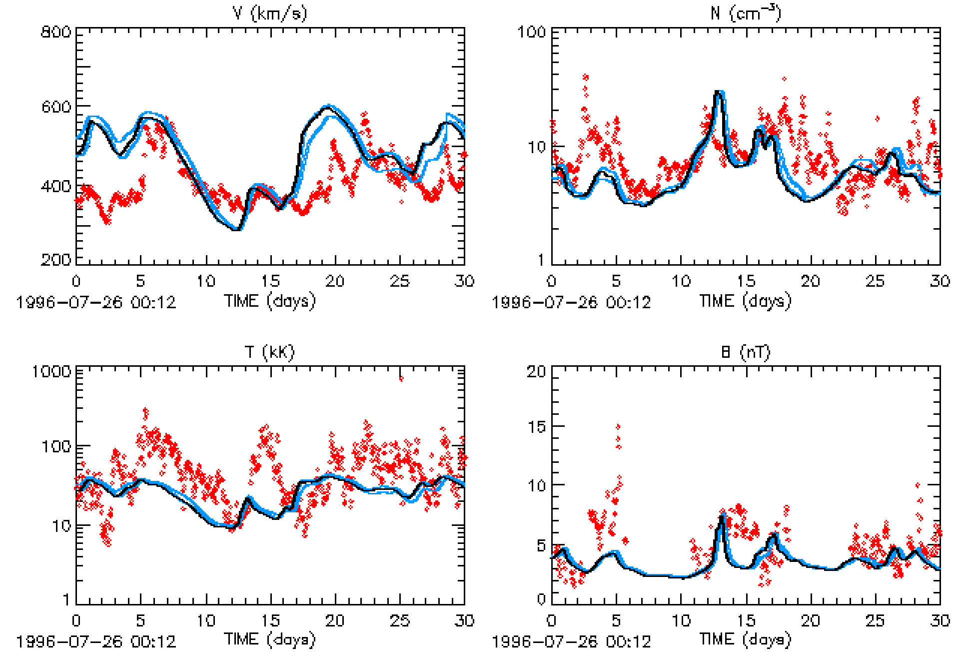
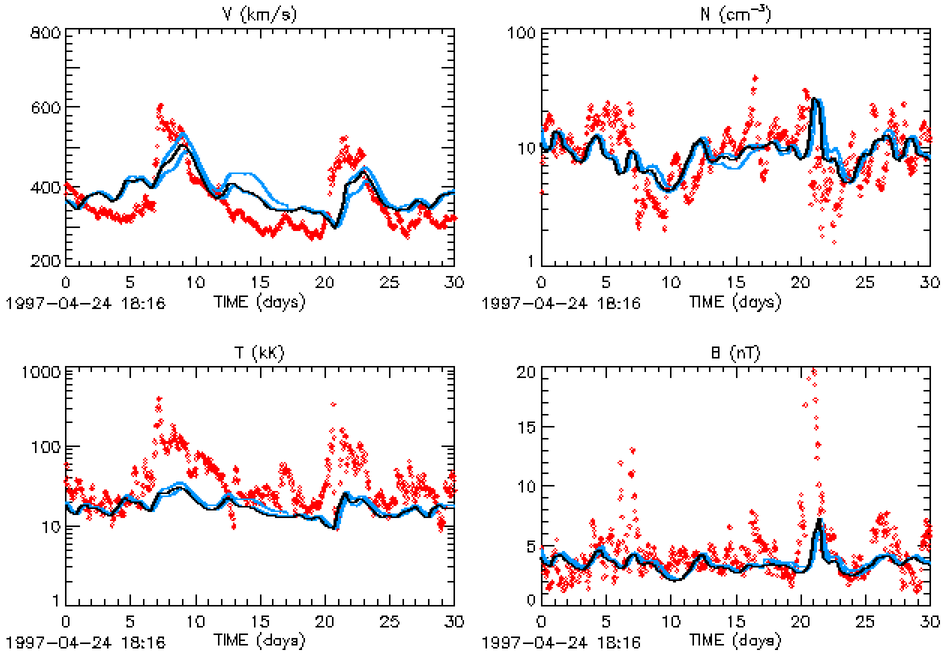


PROJECT = helsir RUN = 1922b7u0.256x40x180.1-mp3m-1.par1

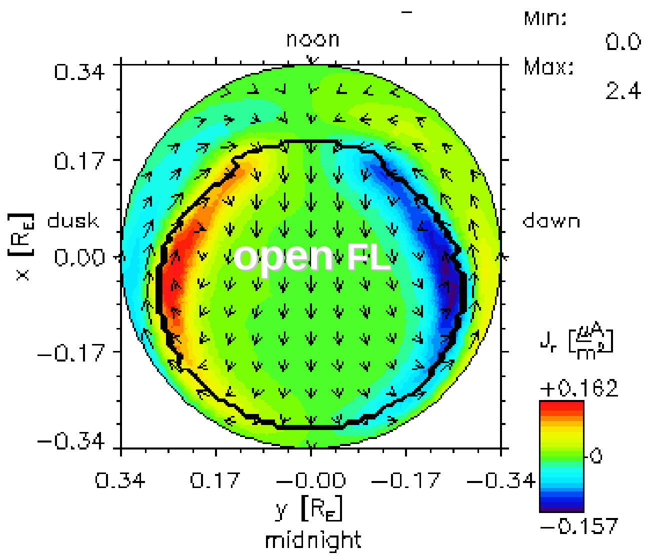


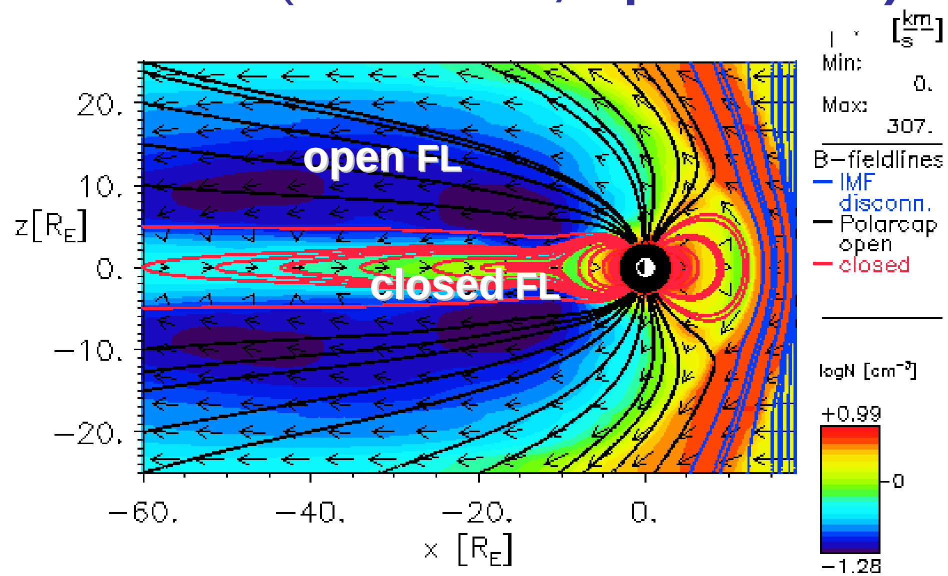
ENLIL: Model and Data Comparison

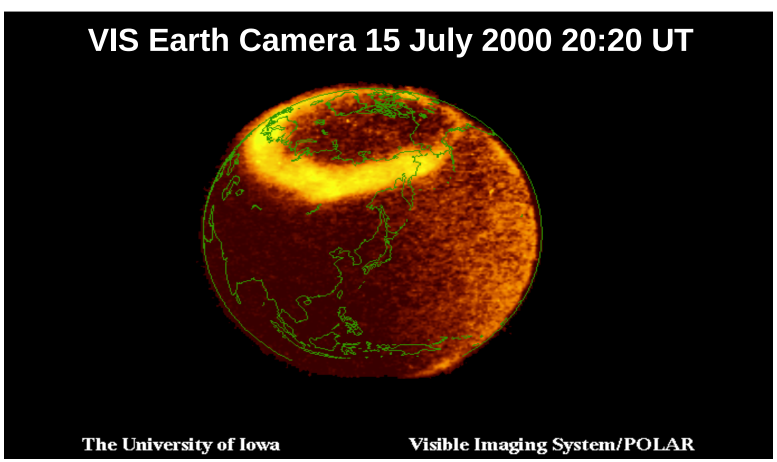
D. Odstrcil, P. Macneice

Polar Cap Size Metrics

Boundary between open and closed field lines (**BATSRUS, OpenGGCM)**





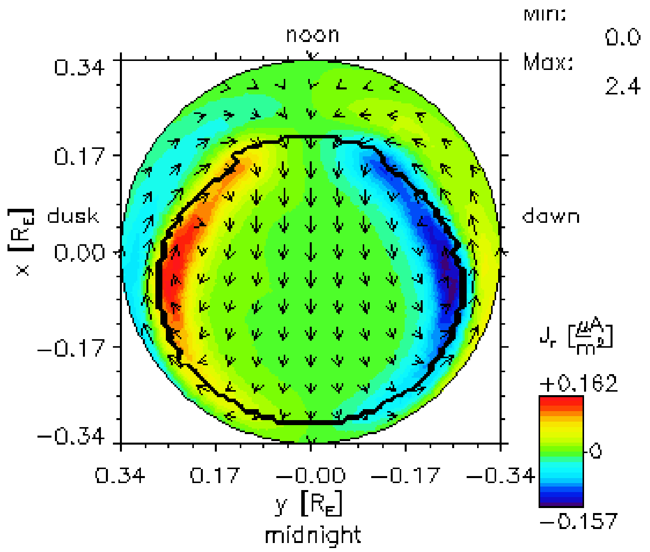


← **Polar cap boundary observed by POLAR**

Lutz Rastaetter, 2005

Polar Cap Size Metrics

Polar cap from field-aligned currents pattern

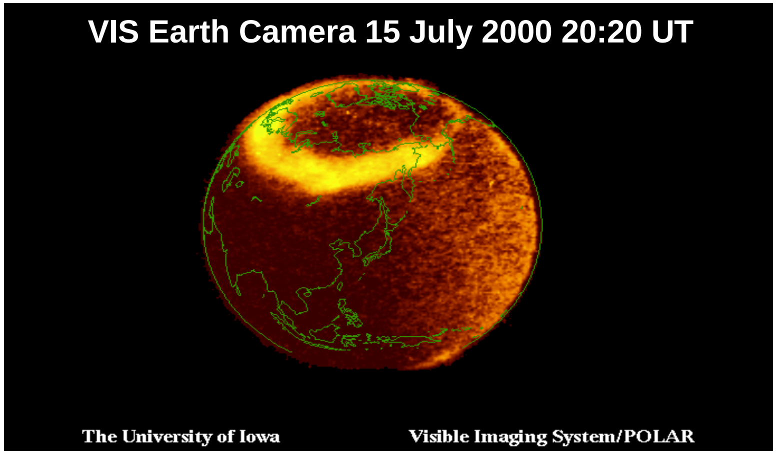


(Weimer 2K, BATSRUS, OpenGGCM)

Positions of the maximum or minimum of the field-aligned current in each of the 16 sectors of local time.

To reduce influence of currents near the pole use FAC*sin(co-latitude)

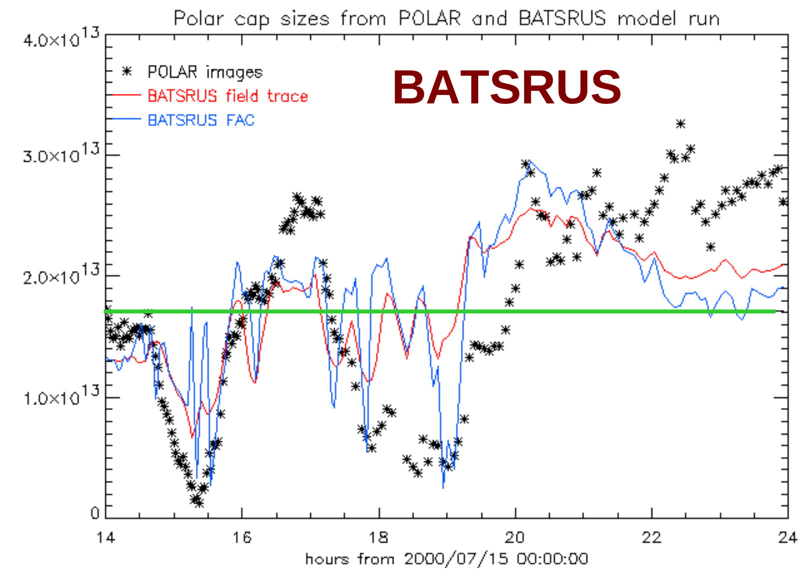
Disregard 7 degrees near low-latitude boundary of patterns (for Weimer-2K)

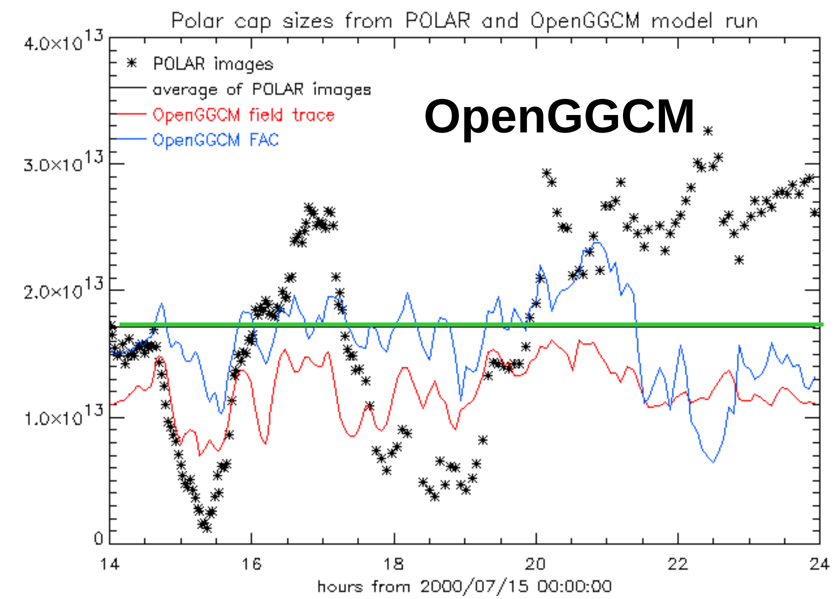


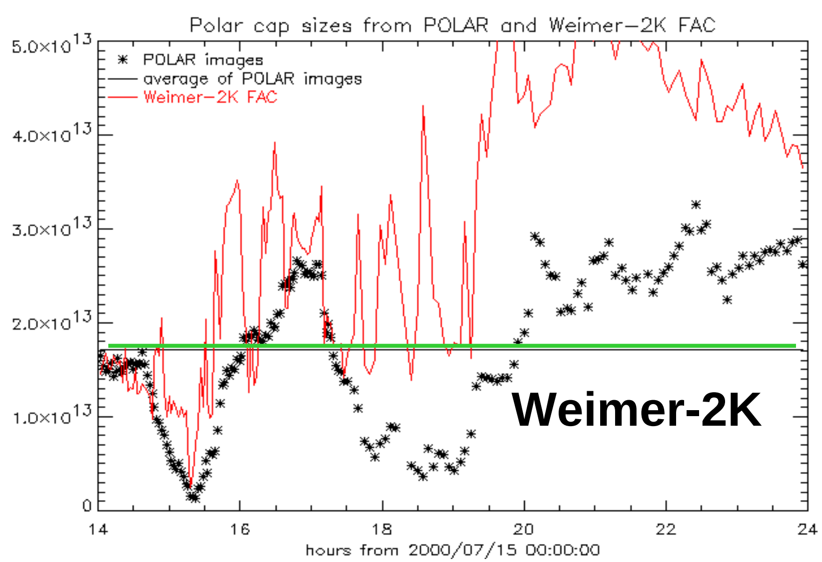
Polar cap boundary observed by POLAR

Lutz Rastaetter, 2005

July 15, 2000 – Bastille Day Storm:
Time period: 14:00 – 24:00







Mean — **Skill Score**

BATSRUS FL tracing: 0.226

BATSRUS FAC: 0.149

OpenGGCM FL tracing: - 0.137

OpenGGCM FAC: - 0.252

Weimer-2K FAC: - 0.473

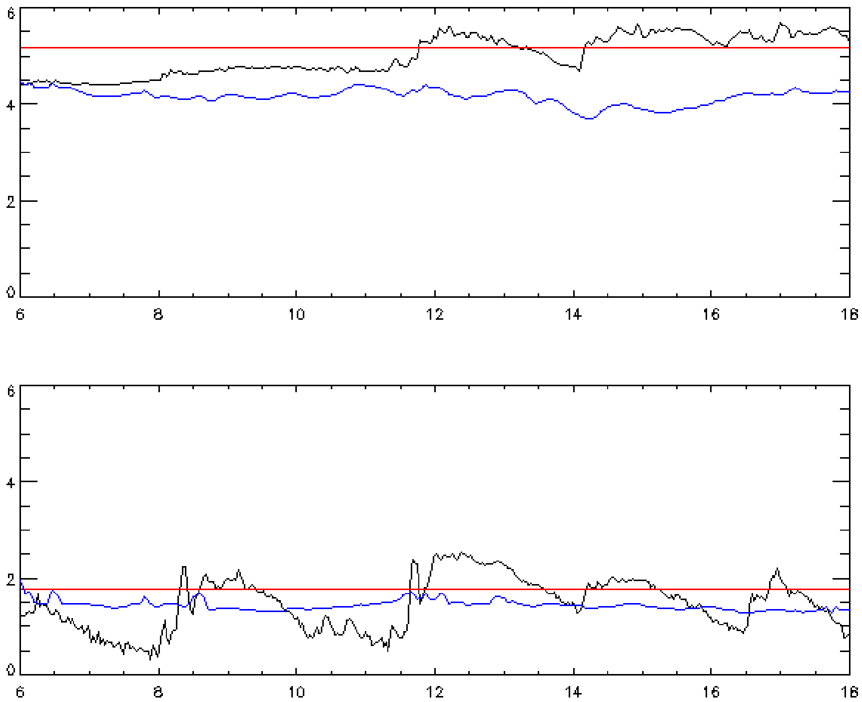
Lutz Rastaetter, 2005

Inner Magnetospheric Metric

- Data
  - Proton fluxes from LANL geosynchronous satellites
- Model
  - Fok Ring Current model driven by a MHD model
- Skill Score using the Root Mean Square Deviation

Ring Current Metrics

Log(Pitch Angle-Averaged Differential Flux (#/cm^2/s/sr/keV))



Time

Energy Band (keV)	Skill Score
50-75	-.995
250-400	0.232

Geosynchronous proton flux data was provided by the Energetic Particle team at Los Alamos National Laboratory, Richard Belian (PI).

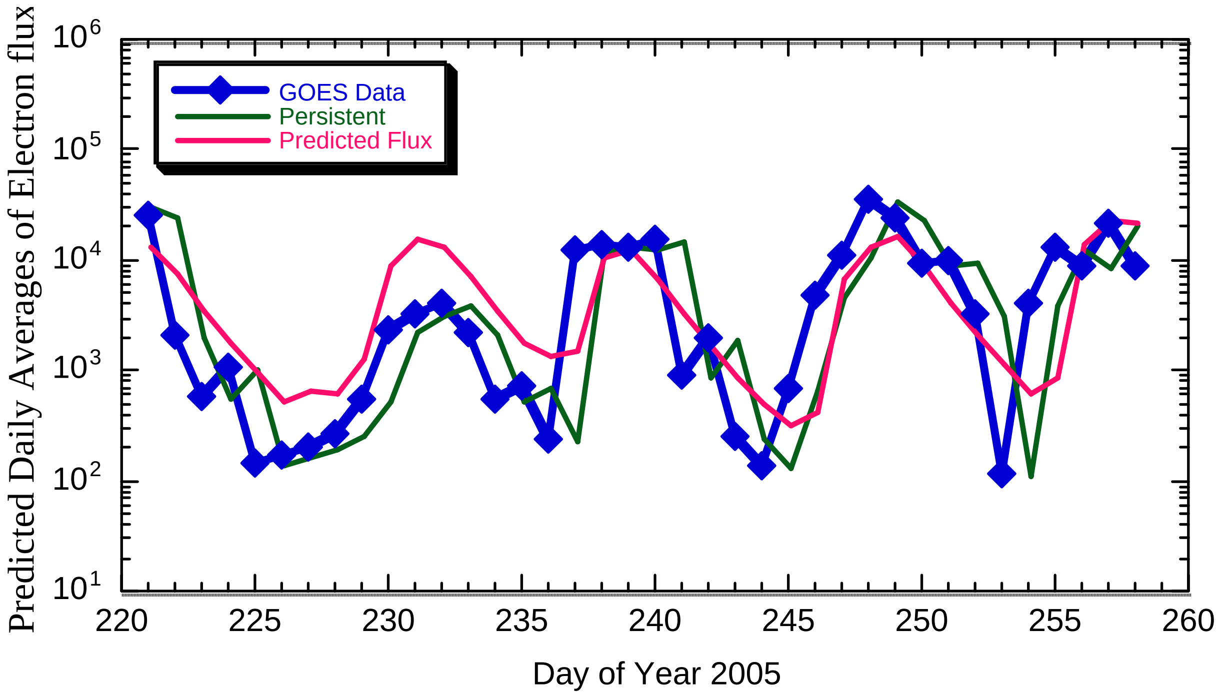
Black: LANL data.

Blue: Model results.

Red: Mean

K. Keller

Prediction of Daily-Averaged MeV Electron Intensity at Geostationary Orbit (UPOS, APL)

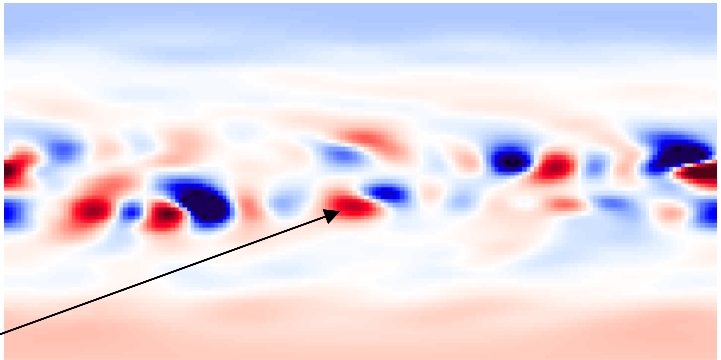


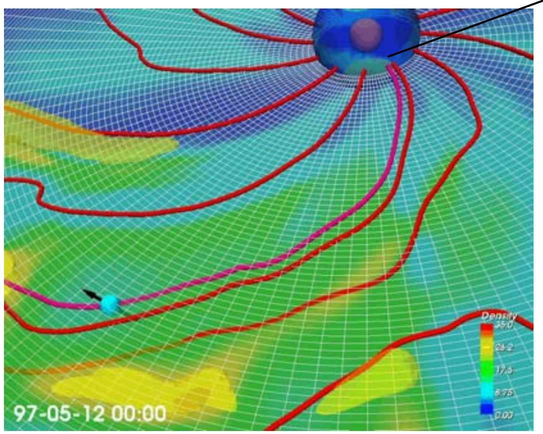
Skill score: 0.08

A. Chulaki

Other Metrics Opportunities.
Solar Wind, Energetic Particles Forecasting.

Connection to active region



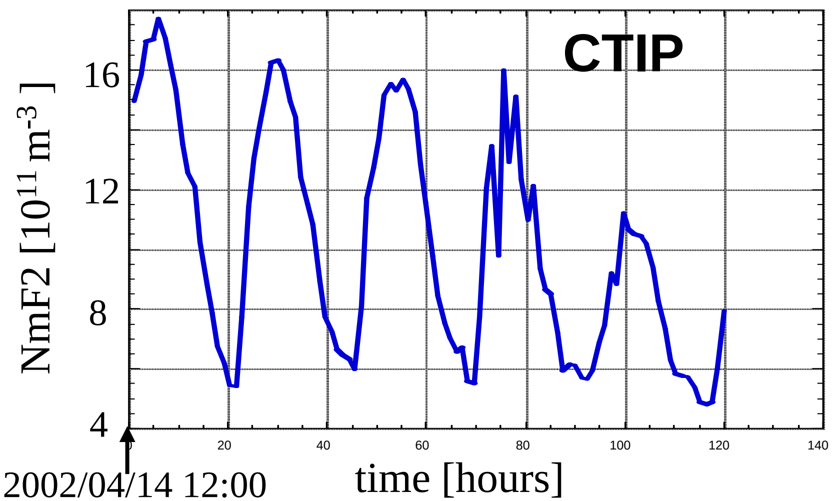


Model: ENLIL

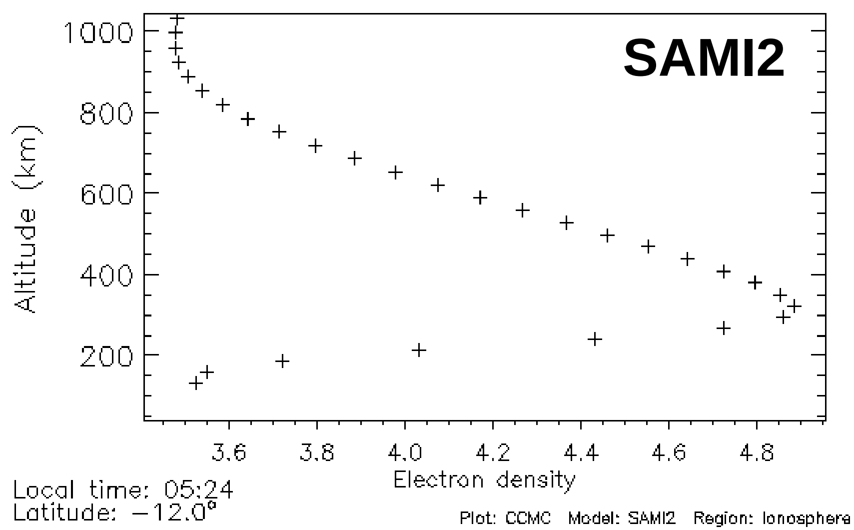
Other Metrics Opportunities. Ionospheric Forecasting.

Electron Density Parameters: Vertical Profiles, NmF2, TEC

Arecibo [18.3, 293.2]



Jicamarca [-11.96, 283.13]

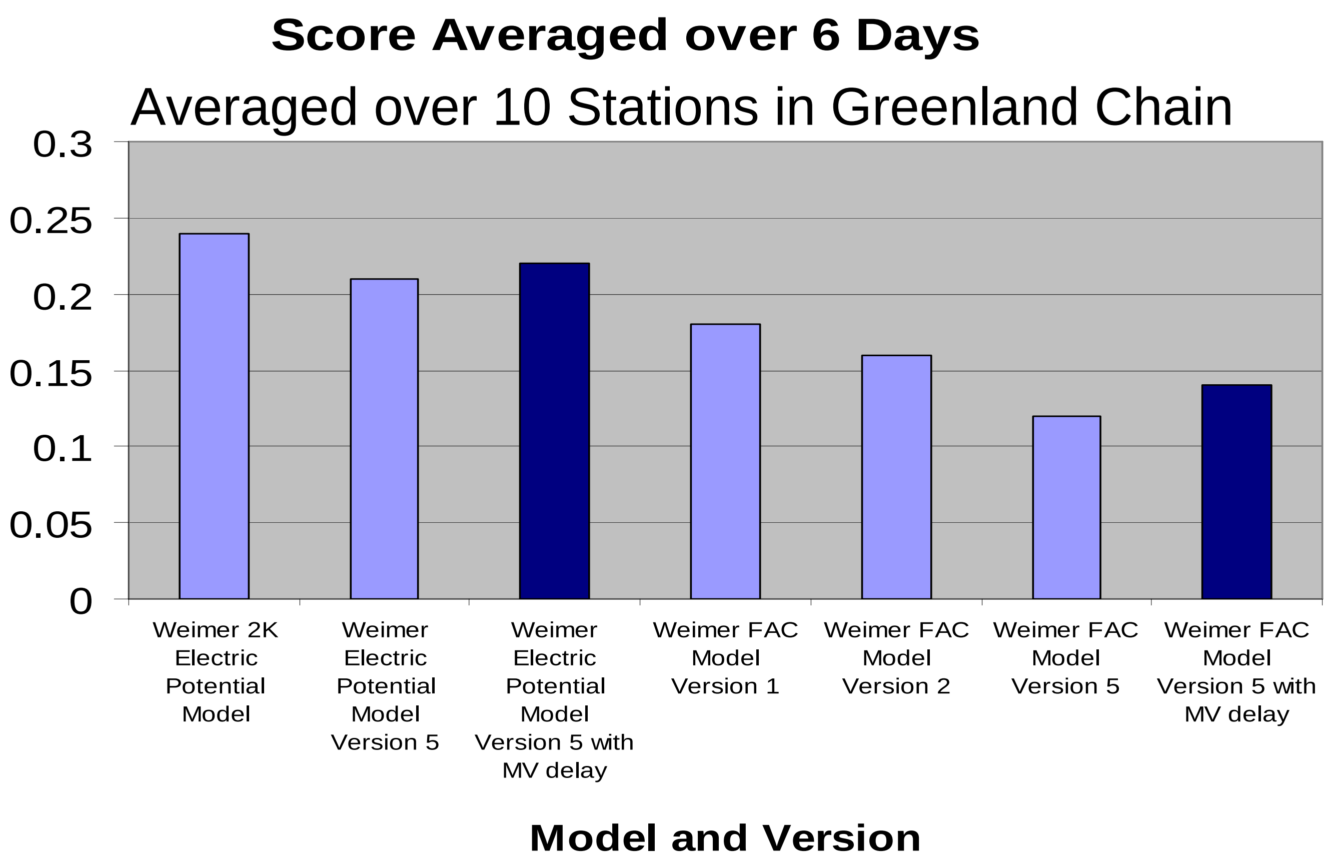


Models: CTIP, SAMI2, GITM2, GAIM

Observations: Incoherent Scatter Radars, GPS, Ionosonds

Ionosphere Electrodynamics Metrics: Ground Magnetic Perturbations (H component).

Skill Scores for Weimer Models



K. Keller, 2003

Future Plans

- Continue to follow National Space Weather Program Implementation Plan guidelines.
- More models (GAIM, AbbyNormal,…), model chains, frameworks. Focus on physics-based models with operation benefits.
- Focus on parameters most useful to operations that CCMC models can provide. Work with operators to identify suitable metrics.
- Priority evaluations for operations
- Development of reusable V &V and metrics software.
- Expand RoR System to benefit V&V studies
- Continue working with model developers to improve model performance.

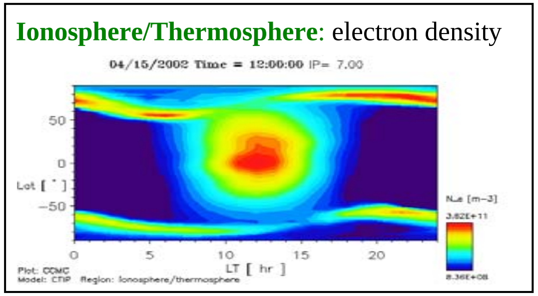
We are open to suggestions !

Other Metrics

- Ionospheric forecasting (CTIP, GAIM)

  Electron density parameters

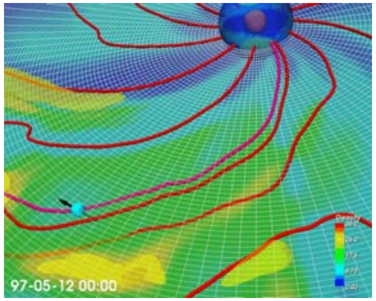
  (vertical profiles, TEC, NmF2)

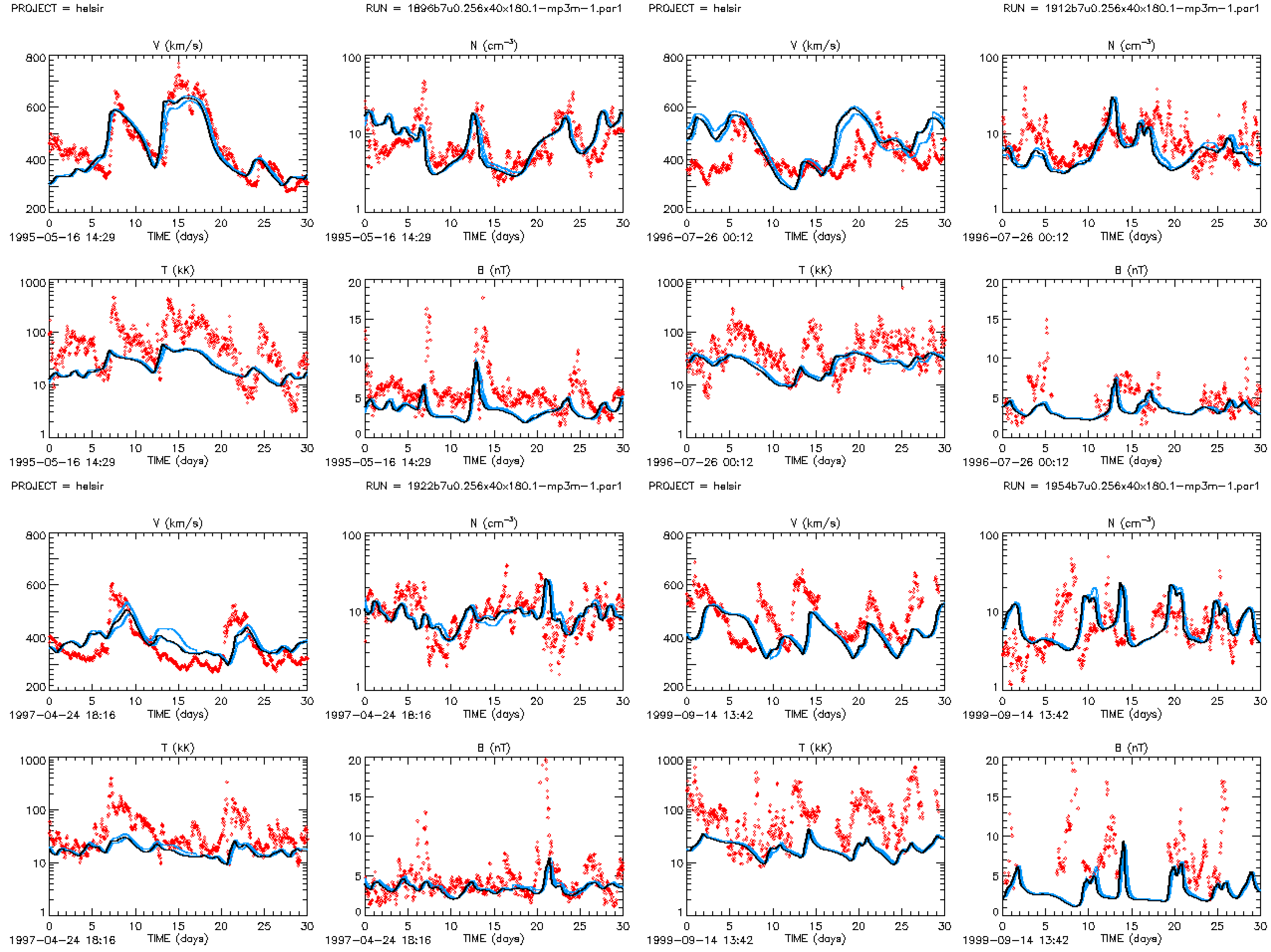


- Solar Wind Forecasting, Energetic Particles

  Plasma and magnetic field parameters

  Connection to active region




PROJECT = helsir
RUN = 1896b7u0.256x40x180.1-mp3m-1.par1
V (km/s)
N (cm⁻³)
T (kK)
B (nT)
TIME (days)
1995-05-16 14:29
PROJECT = helsir
RUN = 1912b7u0.256x40x180.1-mp3m-1.par1
V (km/s)
N (cm⁻³)
T (kK)
B (nT)
TIME (days)
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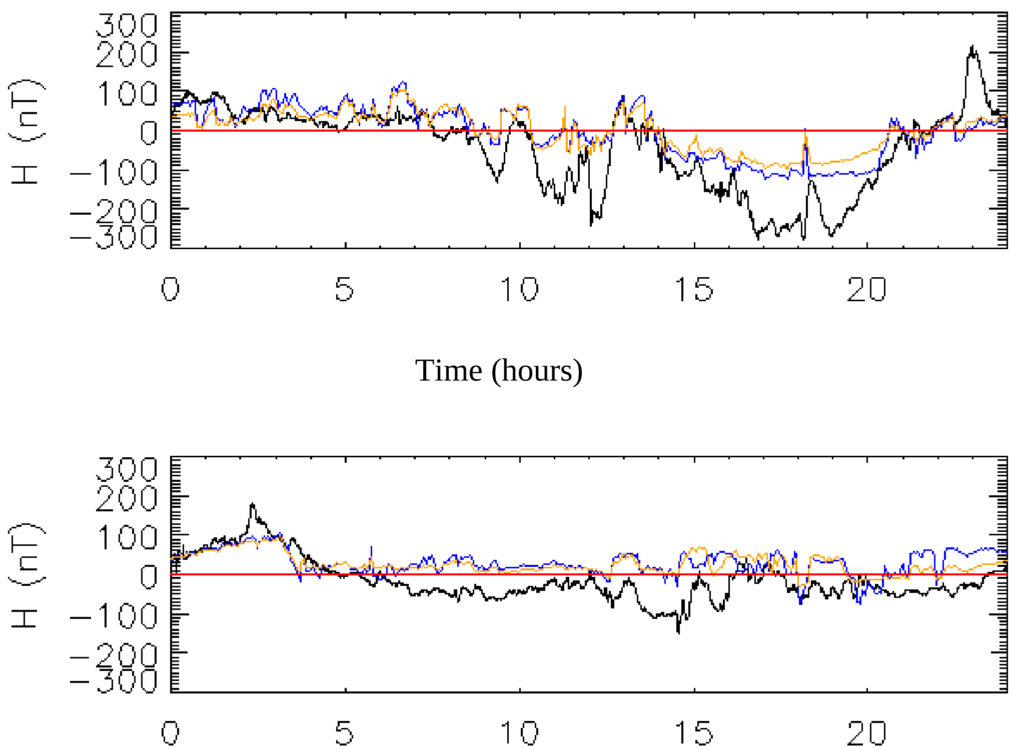
RUN = 1922b7u0.256x40x180.1-mp3m-1.par1
V (km/s)
N (cm⁻³)
T (kK)
B (nT)
TIME (days)
1997-04-24 18:16
PROJECT = helsir
RUN = 1954b7u0.256x40x180.1-mp3m-1.par1
V (km/s)
N (cm⁻³)
T (kK)
B (nT)
TIME (days)
1999-09-14 13:42

Ionospheric metrics

- Data
  - Ground magnetic perturbations measured at 10 stations in the Greenland chain using the H component of the data.
- Models
  - Weimer electric potential model (2 different versions).
  - Weimer field-aligned current model (3 different versions).
- Standard model: no perturbations
- Metrics
  - Model score: $D_i = \Sigma|\Delta H_{model} - \Delta H_{data}|/npts.$
  - Skill score: $M_i = 1 - D_i / D_s$

Comparison of Model Results to Data



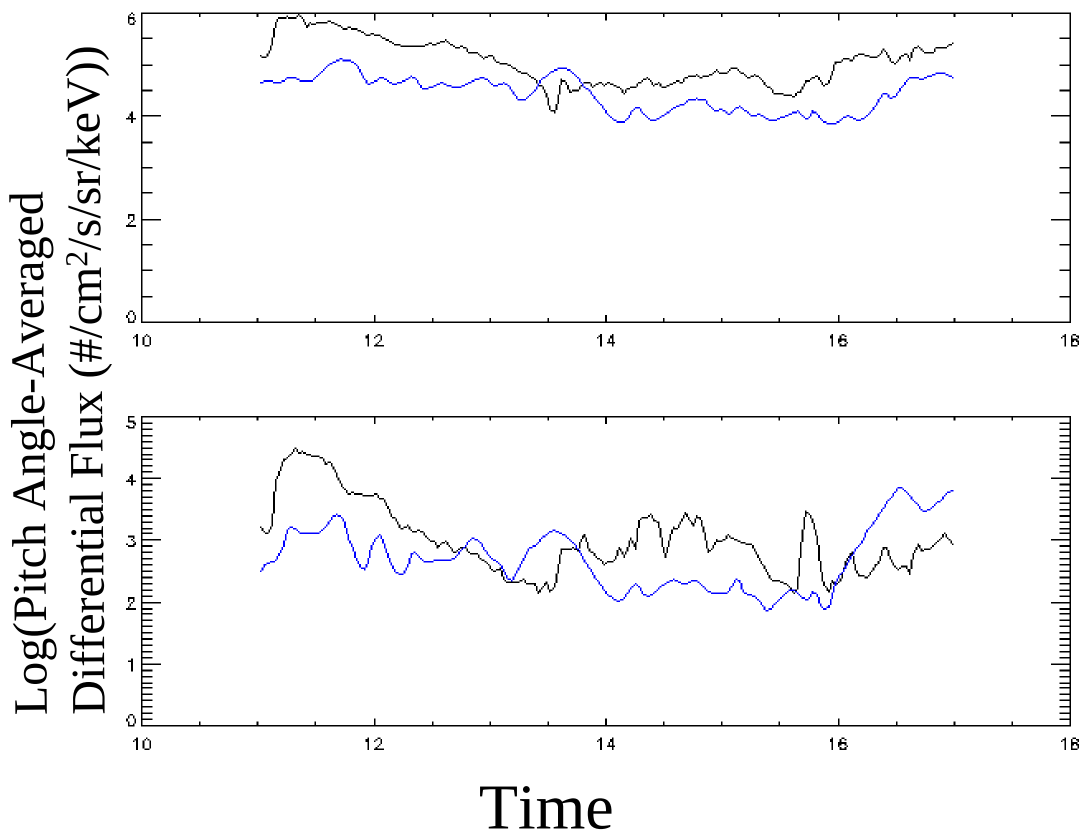
Black: Data from ground magnetometers

Orange: Model results from Weimer 2k Electric Potential Model

Blue: Model results from Weimer Electric Potential Model Version 5

Magnetometer data was provided by the Danish Meteorological Institute (Dr. Jurgen Watermann, Project Scientist)

Sample of Ring Current Metric



Energy Band (keV)	Skill Score	Cross Correlation
50-75	0.135	.59
113-170	-0.02	0.07

Black is LANL data. Blue is the model results.

Methods of polar cap determinations

- **Field line tracing:**

  Polar cap boundary is between open and closed field lines as traced through the magnetosphere. Field lines start in the high-latitude region at the near-Earth boundary.

  Models: **BATSRUS**, **OpenGGCM**

- **Polar cap from field-aligned current (FAC) pattern:**

  Positions of the maximum or minimum of the field-aligned current in each of the 16 sectors of local time form the cap:

  Models: **BATSRUS**, **OpenGGCM**, **Weimer-2K FAC**

  Use FAC*sin(co-latitude) to reduce influence of currents near the pole (e.g., NBZ currents).

- **Weimer-2K FAC:** disregard 7 degrees near low-latitude boundary of patterns.

Future Plans

- Global magnetosphere, Inner magnetosphere
  - Extend polar cap study
  - Comparison with GOES magnetic field data
  - Extend ring current study
  - Perform similar analysis for Fok Radiation Belt Model
  - Prediction of MeV Electron Intensities at geostationary orbit.
- Global magnetosphere models
  - Comparison with GOES magnetic field data
- Solar, Heliosphere
  - Extend metric to new models
- Ionosphere
  - GAIM, Absoption model
  - Total Electron Content, NmF2