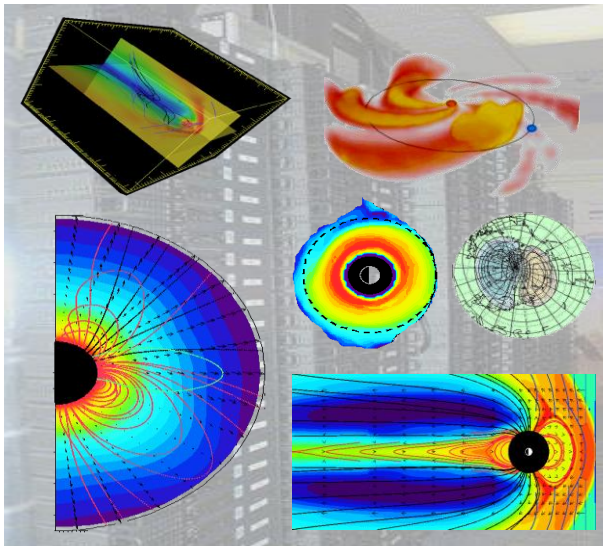
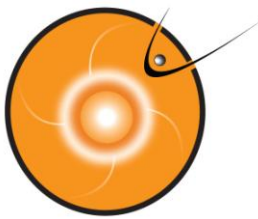


COMMUNITY  
COORDINATED  
MODELING  
CENTER

# GEM-CEDAR Community-Wide Model Validation Project

M. Kuznetova, J-S Shim  
and GEM-CEDAR  
Modeling Challenge Team





# Model Validation for Science and Space Weather Forecasting: Motivation

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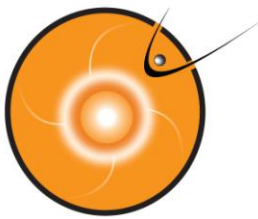
Space science research is increasingly relying on results from complex simulation codes. Scientists need to know:

- ✓ Can we trust scientific conclusions derived from model outputs?
- ✓ Could model coupling introduce unphysical numerical effects leading to false “discoveries” and misleading conclusions?
- ✓ How sensitive are the results to uncertainties in model settings and input parameters?

Space weather forecasters need to know:

- ✓ How good are model predictions? What is the level of confidence?
- ✓ What is current state-of-the-art? What model to install next?
- ✓ How to trace model performance over time? Is it time for upgrade?

**Model-data comparisons is a MUST!**

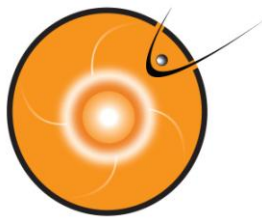


# Three Elements of Model-Data Comparison (Metrics Studies)

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- ✓ Physical parameter most useful for specific applications, e.g.,
  - dB/dt (key for GICs)
  - NmF2, hmF2, and TEC
  - orbit averaged neutral density (key for satellite drag)
  - orbit averaged Joule heating
  - timing of onset of dramatic changes caused by storms
- ✓ Good quality observational data.
- ✓ Algorithm for model-data comparison to produce one number (skill score) characterizing model performance, e.g.,
  - prediction efficiency based on RMS
  - averaged timing error
  - max-min difference during the event
  - threshold-based hit-or-miss metrics for selected time window

**Selection of appropriate parameters and metrics format for specific (science or operational) applications is important.**

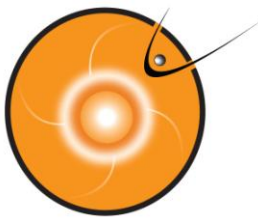


# Challenges in Model-Data Comparison

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- ✓ What metrics to use to evaluate model ability to reproduce a physical phenomena? How to quantify a physical phenomena (e.g. , ionosphere response to storm impact)? (*T. Fuller-Rowell*).
- ✓ How to address uncertainties in model settings (simulation grid resolution, etc.)?
- ✓ How to address uncertainties in model inputs?
- ✓ How to prepare observational data for model validation?
- ✓ Physical quantities important for certain applications require model output post-processing that introduce additional uncertainties (dependence on the post-processing method).

**Model validation is a challenging science problem.**

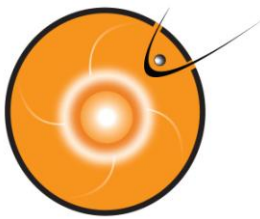


# Community-Wide Modeling Challenges

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**To address challenges of model-data comparison there is a need to bring together modelers, data providers, and science and operational model users.**

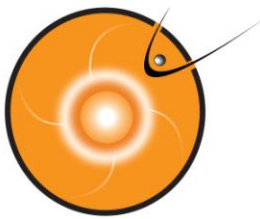
- Facilitate collaboration between modelers/data providers, between communities (e.g., GEM-CEDAR).
- Facilitate dialog between research and ops communities.
- Address challenges:
  - Measurement and model output uncertainties.
  - Define parameters and metrics formats relevant to specific applications.
  - Help evaluate the current state of geospace models.
  - Quantify effects of model coupling on model performance.
- Archive metrics results and track model improvements over time.
- Facilitate further model improvement.



# GEM-CEDAR Challenge

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- Community-wide modeling Challenges supported by CCMC:
  - ✓ GEM GGCM (2008), CEDAR ETI (2009), SHINE (2011)
- The CEDAR-GEM Challenge is built upon GEM GGCM and CEDAR ETI projects. Initiated during the 2011 Joint GEM-CEDAR Workshop.
- Continue regular meetings
  - Fall GEM-CEDAR pre-AGU Workshops (2011, 2012 and beyond)
  - Spring pre-SWW Workshop (2013 and beyond)
  - 2013 Summer CEDAR Workshop
- Address physical parameters and projects of common interest. Overlapping list of events.
- On-going projects:
  - Poynting flux (Joule heating) into ionosphere along DMSP tracks
  - Auroral oval position
  - Role of drivers on ionosphere/thermosphere.

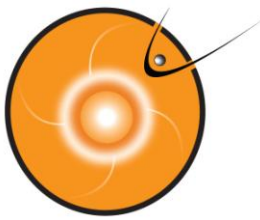


## CCMC Support

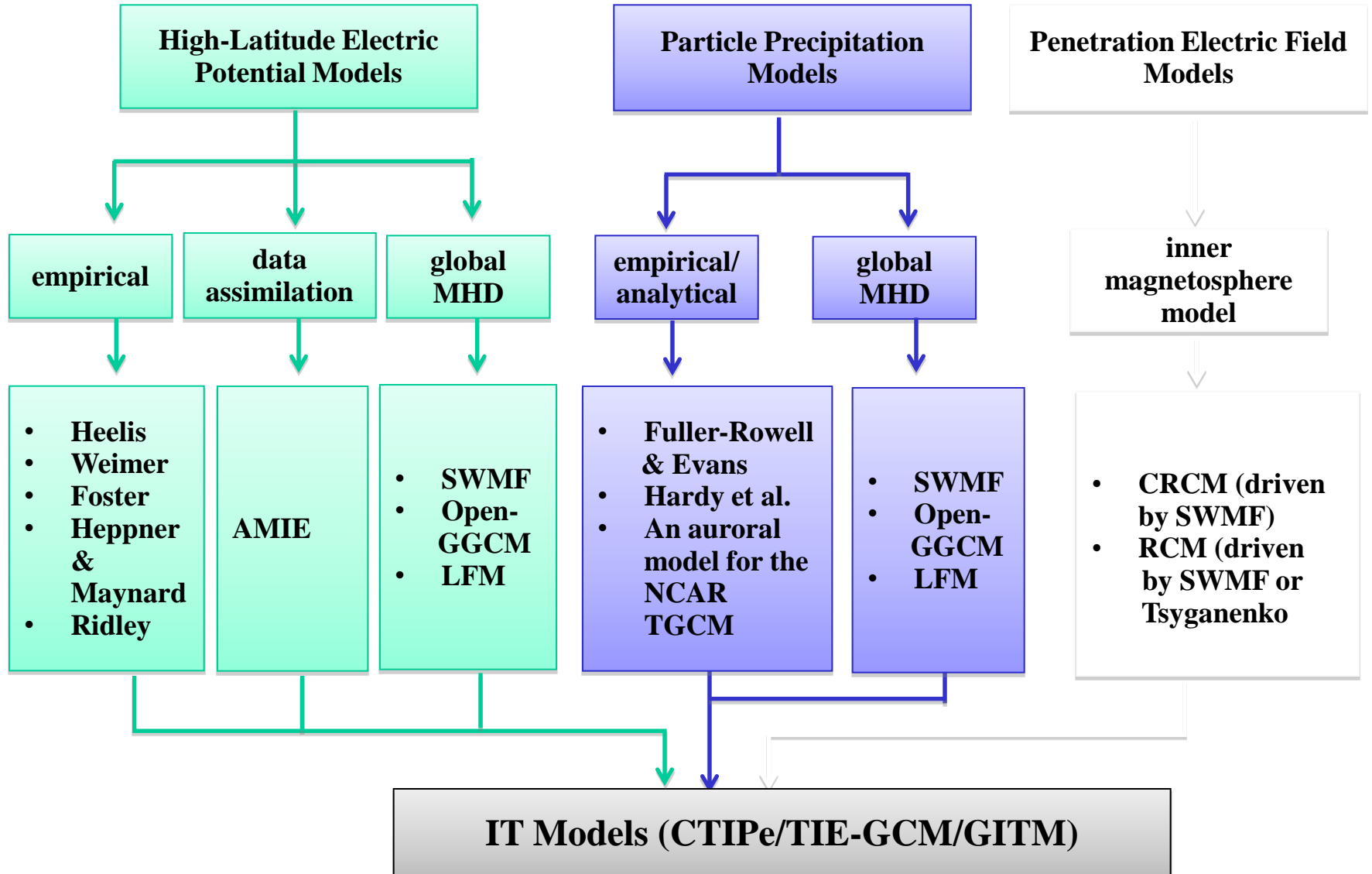
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<http://ccmc.gsfc.nasa.gov/challenges>

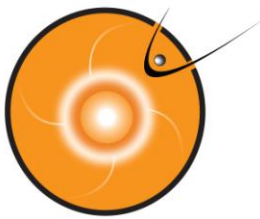
- Automated web-based metrics suite
  - Simulation results submission interface
  - Database of model settings
  - Metrics results archive
  - On-line time series plotting tool.
  - Interactive model score calculation and metrics selection.
- Coordinate development of driver-swapping-tool based on CCMC in-house kameleon converter and interpolator. All modelers are involved.



# MI Coupling: Driver-Swapping Community Tool

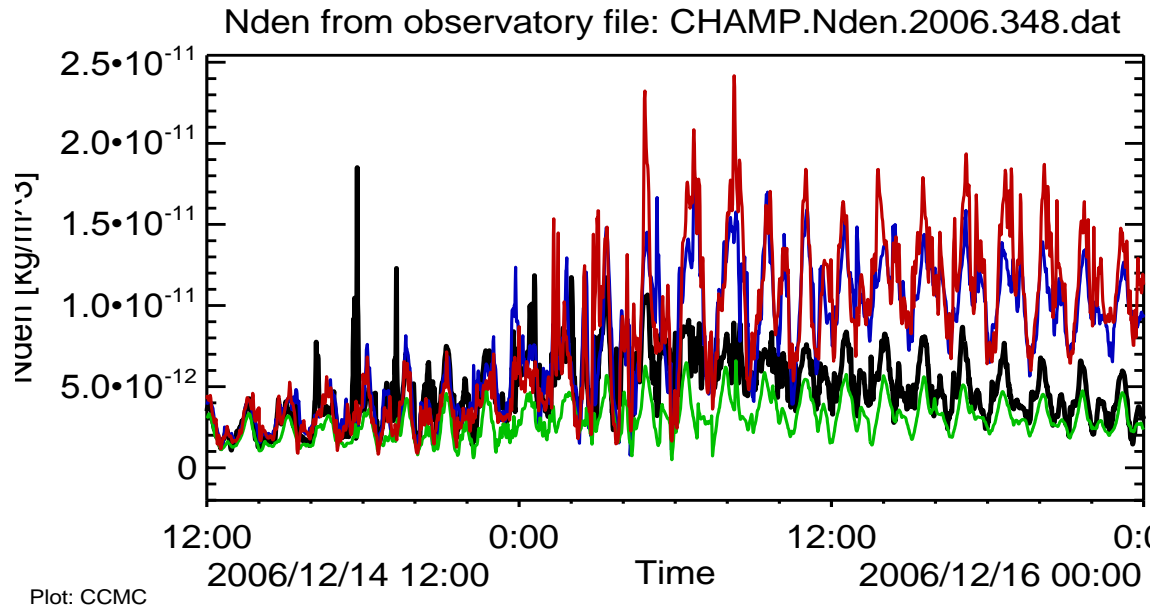




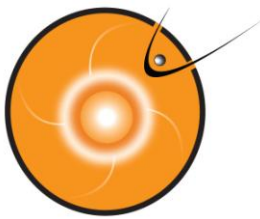


# Sensitivity to Drivers: CTIPe driven by SWMF/AMIE/Weimer

## Neutral density at the CHAMP location

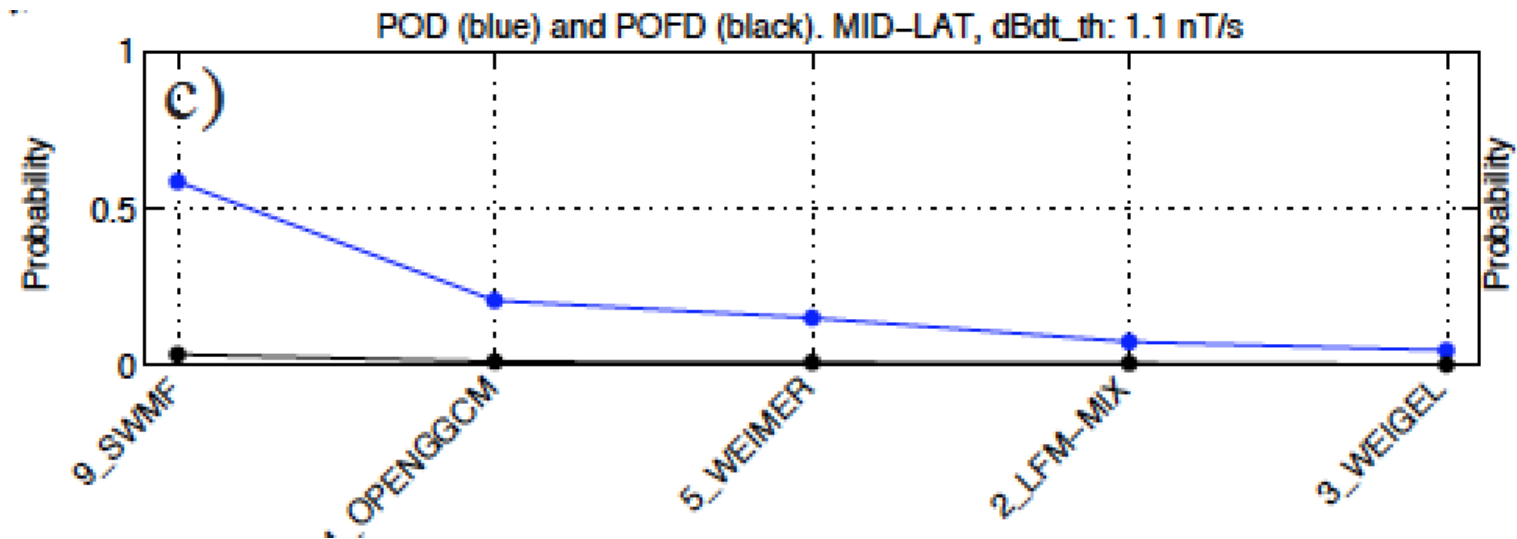


- Observation
- CTIPe with Weimer
- CTIPe with SWMF
- CTIPe with AMIE



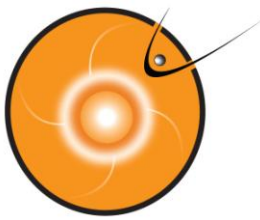
# From Community-wide Challenge to Operational Geospace Model Evaluation

- ✓ dB/dt at ground stations. Key parameter for GICs.
- ✓ Threshold-based metrics (0.3, 0.7, 1.1, 1.5 nT/s)
- ✓ Skill score depends on combination of probability of detection (POD) and probability of false detection (POFD)



**It takes several years (5 publications) to come up with metrics format relevant to SWPC users and to develop model output post-processing method.**

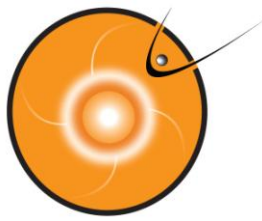
**Final report submitted in Apr 2013.**



# Summary

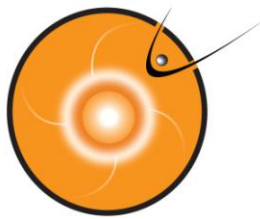
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- ✓ Metrics & Validation is a MUST for both science and operational model use.
- ✓ M&V is a challenging science project.
- ✓ Custom approach for each application is required.
- ✓ GEM-CEDAR community-wide model validation project is in full swing since 2011.
- ✓ CCMC is here to help.
- ✓ Broader GEM-CEDAR communities are invited to participate.



# Supplementary Slides

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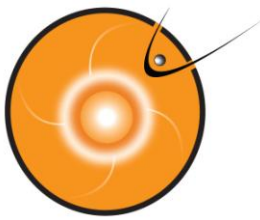


# Challenges in Model-Data Comparison

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- ✓ Model ranking strongly depends on physical parameter and metrics format. Selection of appropriate metrics for specific applications is a key for a meaningful model validation study.
- ✓ What metrics to use to evaluate model ability to reproduce a physical phenomena? How to quantify a physical phenomena (e.g. , ionosphere response to storm impact)? (*T. Fuller-Rowell*).
- ✓ How to address uncertainties in model settings (free parameters, simulation grid resolution, etc.)?
- ✓ How to address uncertainties in model inputs?
- ✓ Physical quantities important for certain applications require model output post-processing that introduce additional uncertainties (dependence on the post-processing method).
- ✓ How to prepare observational data for model validation?

**Model validation is a challenging science problem.**



# GEM Challenge: Initiated in 2008

## Events and Physical Parameters

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Event 1: Oct 29, 2003 06:00 UT - Oct 30, 06:00 UT

Event 2: Dec 14, 2006 12:00 UT - Dec 16, 00:00 UT

Event 3: Aug 31, 2001 00:00 UT - Sep 01, 00:00 UT

Event 4: Aug 31, 2005 10:00 UT - Sep 01, 12:00 UT

Metric Study 1: Magnetic field at geosynchronous orbit (GOES)

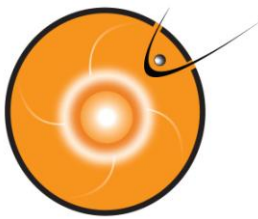
Metric Study 2: Magnetopause crossings by geosynch. satellite (GOES & LANL)

Metric Study 3: Plasma density/temperature at geosynch. orbit (LANL)

Metric Study 4: Ground magnetic perturbations (ground based magnetometers)

Metric Study 5: Dst Index (Sept 2009)

Metric Study 6: Poynting Flux into Ionosphere (Sept 2010)



# CEDAR Challenge: Initiated in 2009

## Events and Physical Parameters

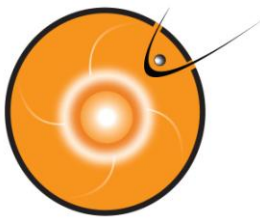
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### **GEM Events**

**Climatology Study:** 2007/03/01 – 2008/03/31

Year of incoherent scatter radar (ISR) observations

1. Vertical and horizontal drifts at Jicamarca
2. Neutral density at CHAMP orbit
3. Electron density at CHAMP orbit
4. NmF2 from LEO satellites (CHAMP and COSMIC) and ISRs
5. HmF2 from LEO satellites (CHAMP and COSMIC) and ISRs
6. Global Total Electron Content (TEC)



# Metrics Examples

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- Metrics based on RMS

**Model Skill Score :**

$$1 - \frac{\text{Model Score}}{\text{Reference Model Score}}$$

**Model Score against the observation :**

$$\sqrt{\frac{\sum (x_{obs} - x_{mod})^2}{N}}$$

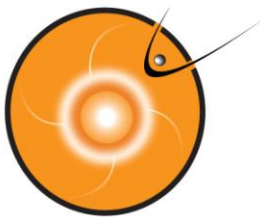
- > 0 : better than reference model,
- < 0 : worse than reference model

- Metrics based on ratio of the difference between maximum and minimum values during an event:

$$\frac{(x_{mod})_{\max} - (x_{mod})_{\min}}{(x_{obs})_{\max} - (x_{obs})_{\min}}$$

- > 1 : over estimate,
- < 1 : under estimate

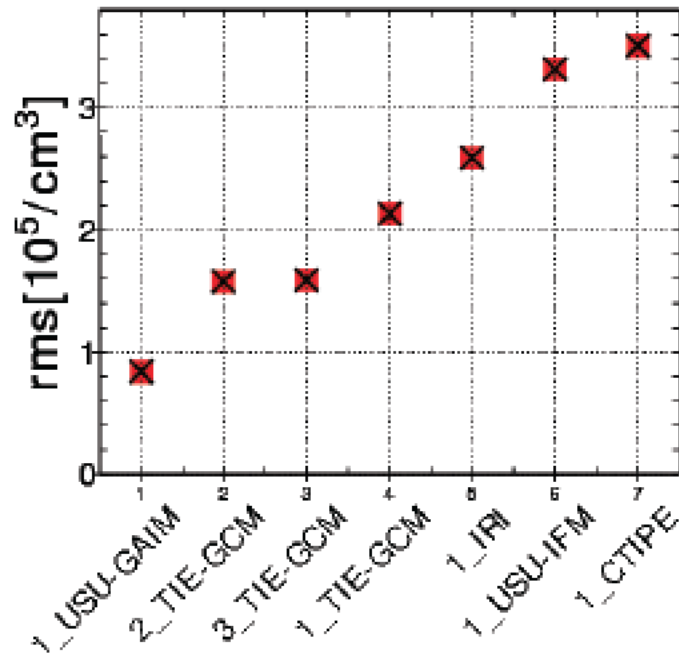




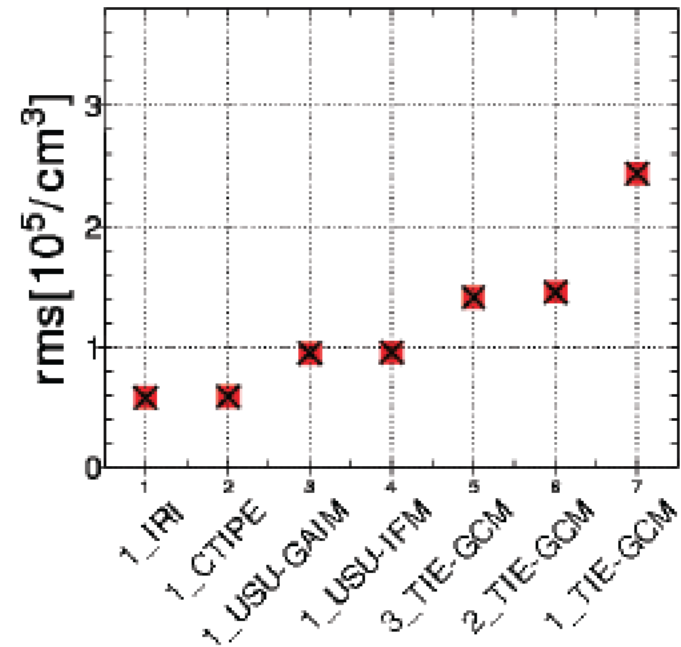
# Sensitivity to Metrics Format Example. Ne at 300 km from ISRs

Millstone Hill (42.62 N, 288.51 E)  
EISCAT Svalbard (78.09 N, 16.02 E)  
EISCAT (69.58 N, 19.23 E)  
Sondrestrom (66.99 N, 309.05 E)

Millstone Hill



high ( $|\text{lat}| > 50^\circ$ )



**Model ranking depends on latitude**