



ATMOSPHERIC & SPACE TECHNOLOGY RESEARCH ASSOCIATES

SCIENCE + TECHNOLOGY + APPLICATIONS // *Bringing it all together*

Private Sector Contributions to Ionospheric Modeling

Geoff Crowley, ASTRA

**ASTRA expertise: from fundamental scientific research,
to technology development, and transition to operational status**

ASTRA: Space Weather Analysis & Forecasting

❖ Science
❖ Technology
❖ Applications

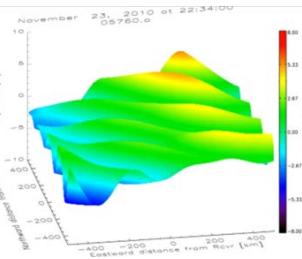
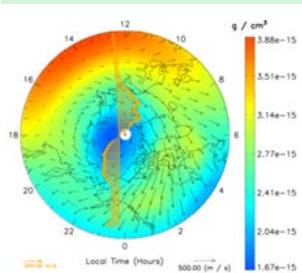
Bringing It All Together



Modeling

Physics-Based Modeling (TIMEGCM)

Real-Time Specification of Ionosphere/Thermosphere



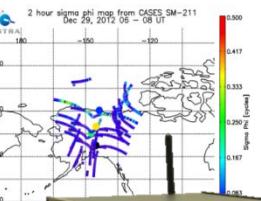
Data Assimilation

High-latitude Electrodynamics

Global Ionosphere

Thermospheric Neutral Density

Satellite Drag & Ballistic Coefficients



Data & Eng. Services

Space Based Data

Ground Based Data

Forensic Space Weather Analysis

Spacecraft Modeling

Systems Engineering

Celebrating our 13th Anniversary

Ground-based Instrument Development

GPS-based Space Weather Monitor

E-fields and Magnetometers

Low Power Ionospheric Sounder

HF TID Mapper

HF Systems

Lidar Systems

COLORADO COMPANIES TO WATCH

2016 WINNER

Space Systems

CubeSat Missions

NSF: DICE & LAICE

AF: DIME, SIPS & TSS

NASA: SORTIE & MiRaTa

Plug-N-Play Avionics

CubeSat Instruments

Scanning UV Photometer

E-field Double Probe

RF Waves & Sounder

Wind Profiler

GPS-based Space Weather Monitor

Magnetometer & Langmuir Probe

Hosted Payloads

- 1) TRL provides a metric locating where we sit in the R2O chain of action
- 2) Organize the R2O discussion around “TRL level”
- 3) Need to provide more funds for R2O
- 4) We need much more data for assimilation
- 5) Focus on low-hanging fruit:
(relatively inexpensive small systems)
e.g. deploy ground-based systems in place of a satellite mission

Technology Readiness Levels



TRL1 Basic Principles Observed	TRL2 Concept Formulation	TRL3 Proof of Concept	TRL4 Breadboard in Lab	TRL5 Breadboard in Rep Environment	TRL6 Prototype in Rep Environment	TRL7 Prototype in Ops Environment	TRL8 System Qual	TRL9 Mission Proven
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GRL, JGR papers

**Software engineering , test & documentation
(Different customers, different environments)**

Air Force SBIR Program

❖ Science

❖ Technology

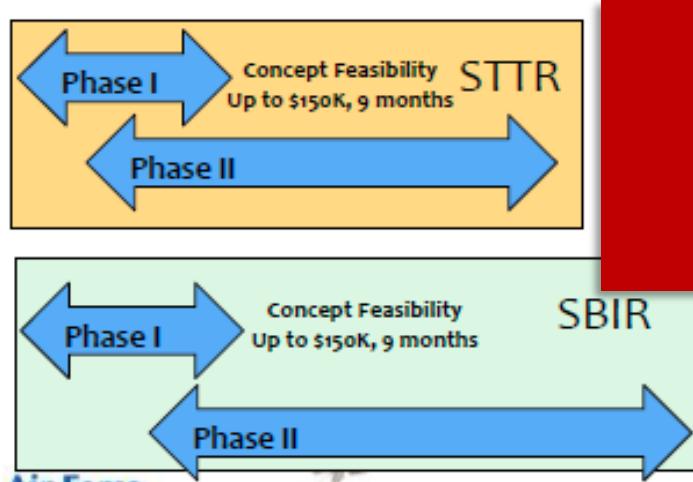
❖ Applications



Bringing It All Together



TRL 1 Basic Principles Observed	TRL 2 Concept Formulation	TRL 3 Proof of Concept	TRL 4 Breadboard in Lab	TRL 5 Breadboard in Rep Environment	TRL 6 Prototype in Rep Environment	TRL 7 Prototype in Ops Environment	TRL 8 System Qual	TRL 9 Mission Proven
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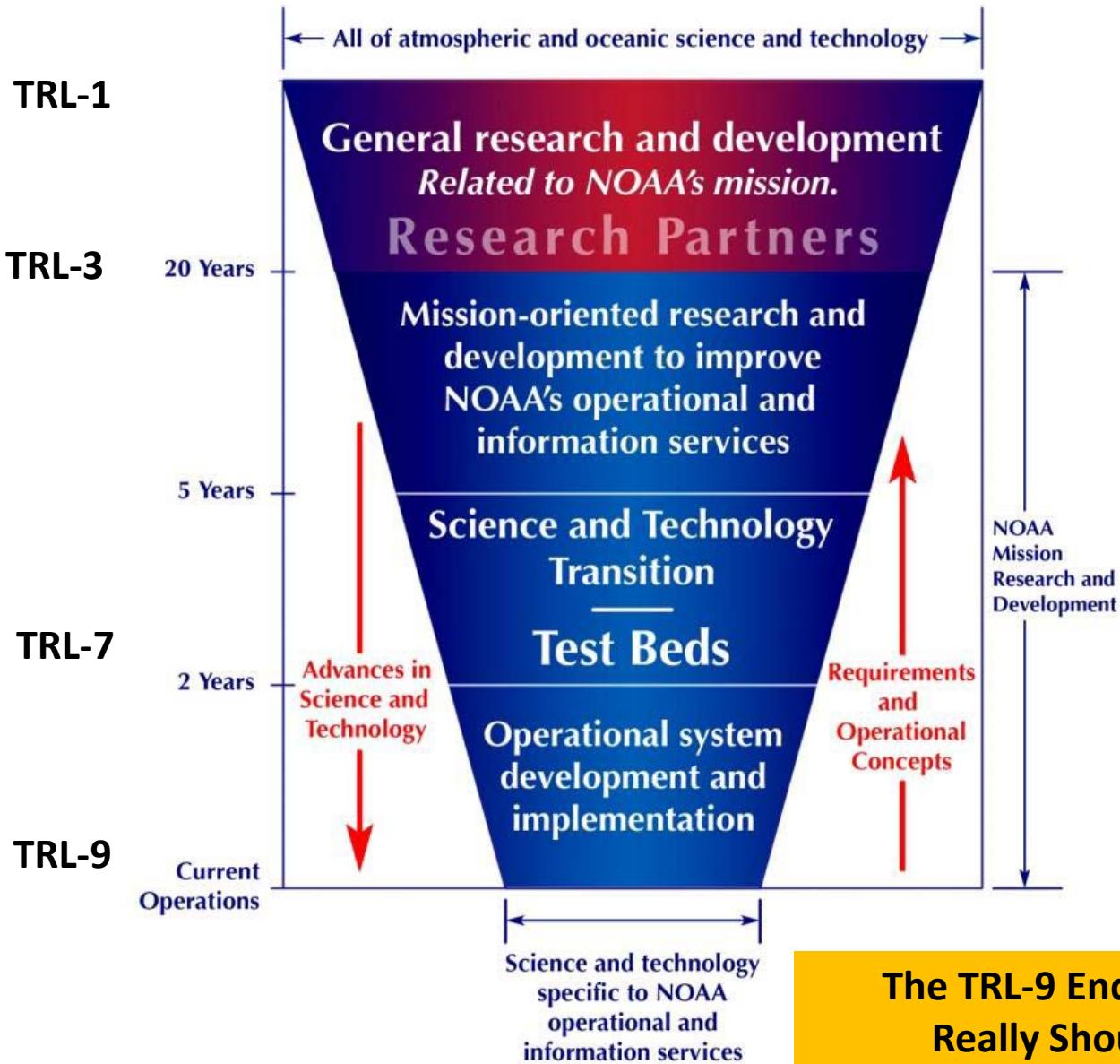
Valley of Death

Phase III Production Insertion (Non SBIR Funds)

Air Force
SBIR/STTR

DISTRIBUTION STATEMENT A. Approved for Public Release; Case Number: 88ABW-2012-5772

Powered by Air Force SBIR/STTR



The TRL-9 End of the Funnel
Really Should be Wide



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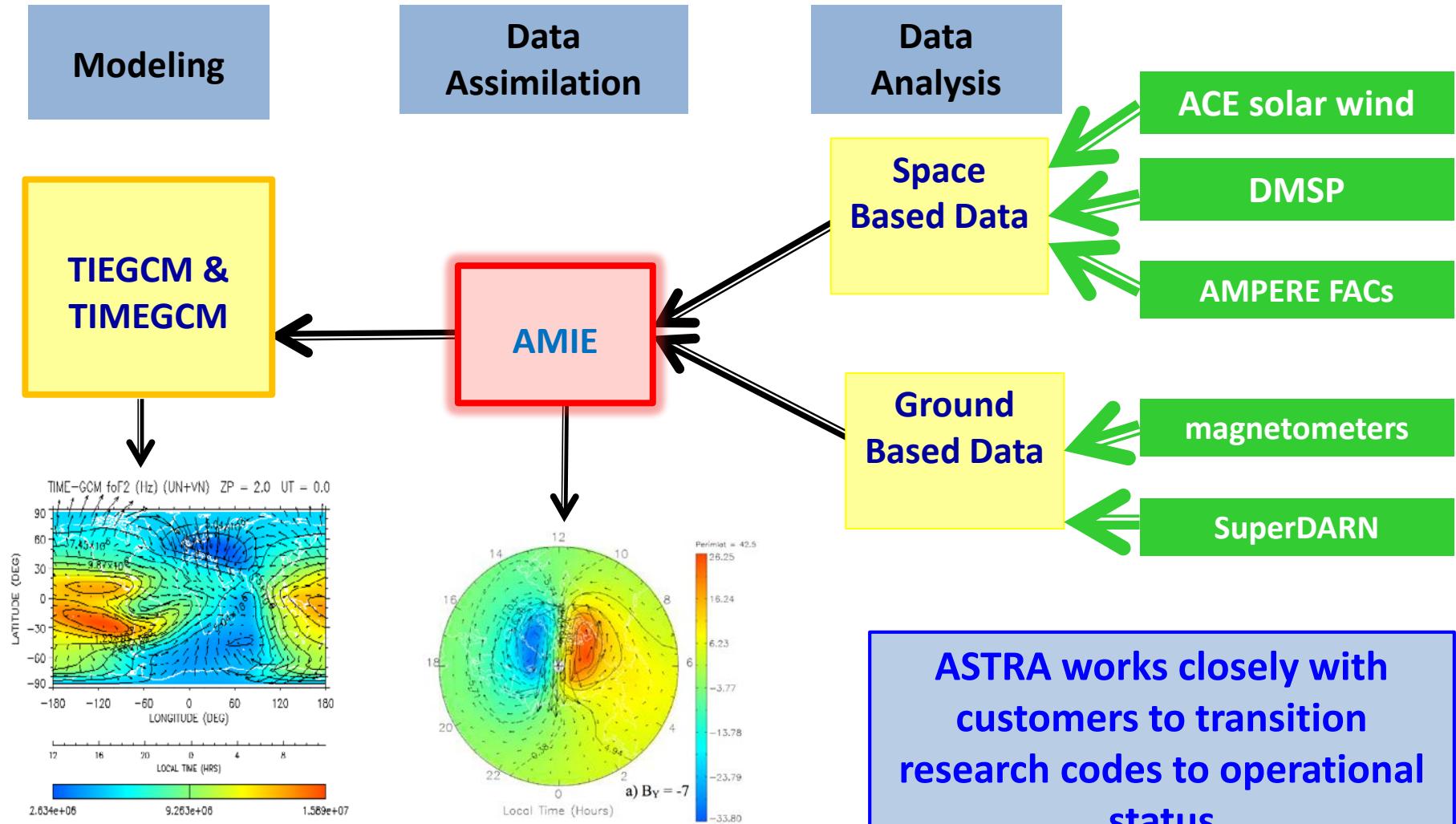
SCIENCE + TECHNOLOGY + APPLICATIONS // *Bringing it all together*

Physics-Based Modeling (TIEGCM, TIMEGCM)

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Model Transition to Operations



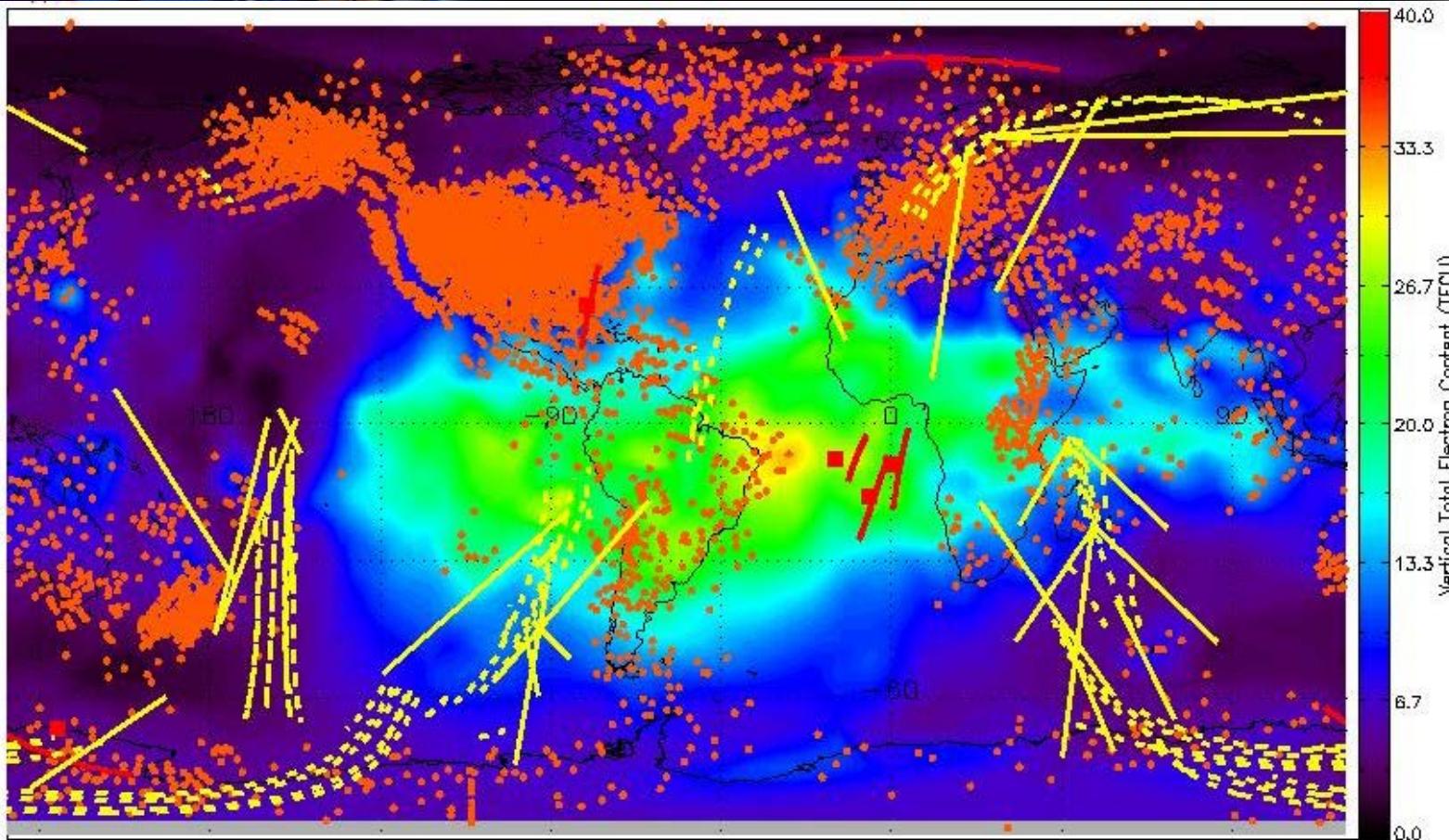
Ionospheric Data Assimilation

Science

Technology

Applications

Bringing It All Together



Ionosondes | Ground-based TEC | In situ Ne | UV

HF oblique sounders | Over-satellite TEC | GPS Radio Occultation

HF backscatter sounders | Radio Beacon | HF Vertical sounders

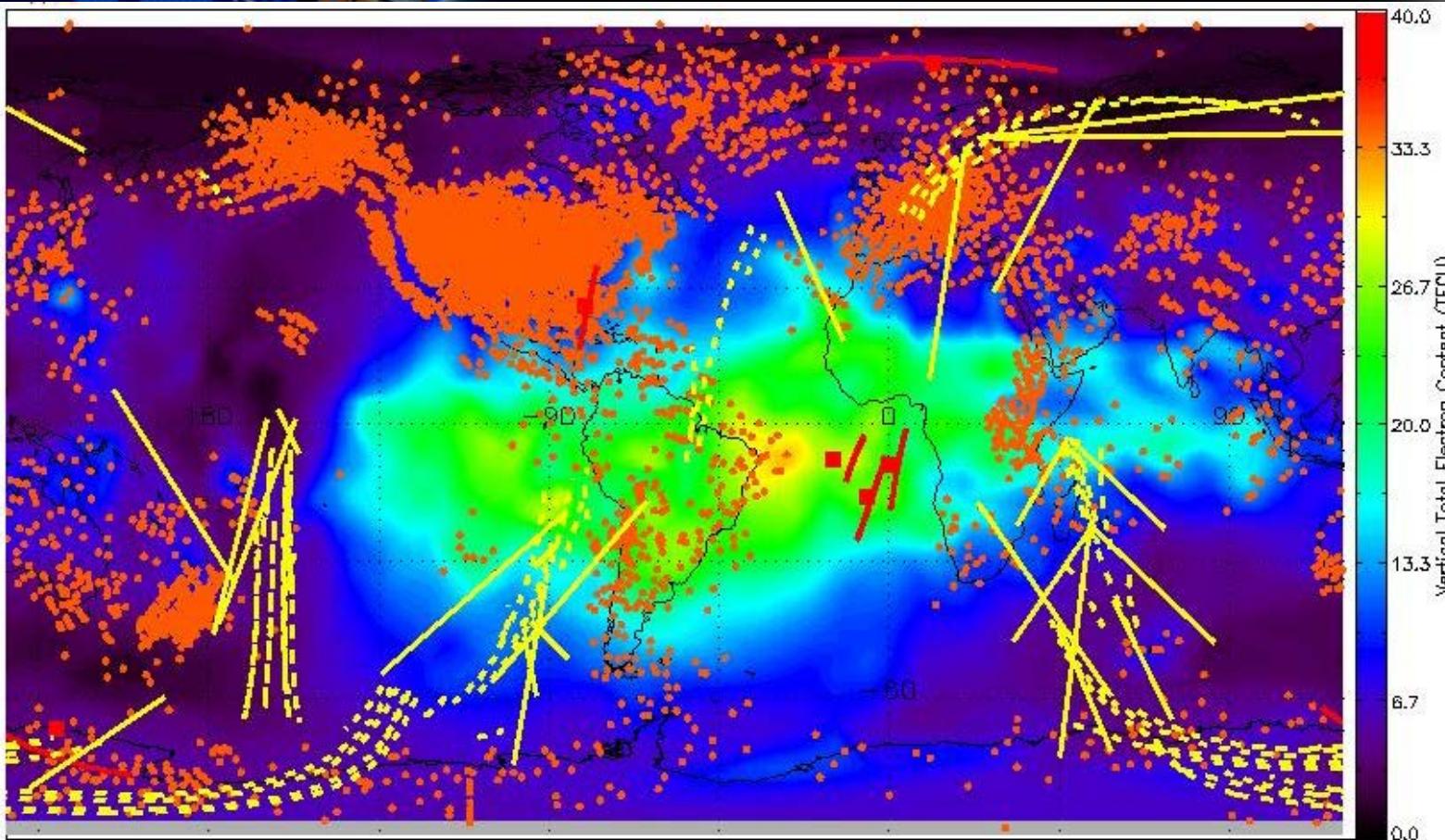
Ionospheric Data Assimilation

❖ Science

❖ Technology

❖ Applications

Bringing It All Together



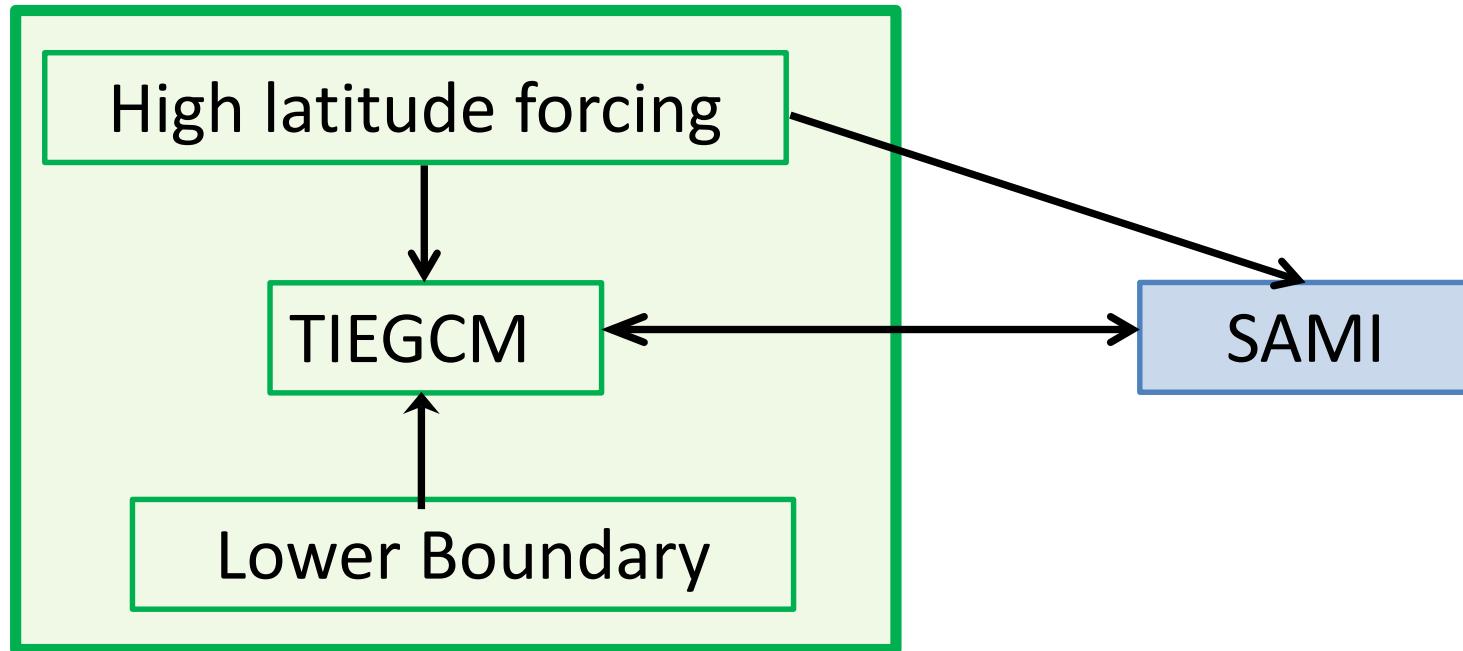
Do we have the right data types? Ground-based or space-based?

Do we have enough data? Do we have more than we need?

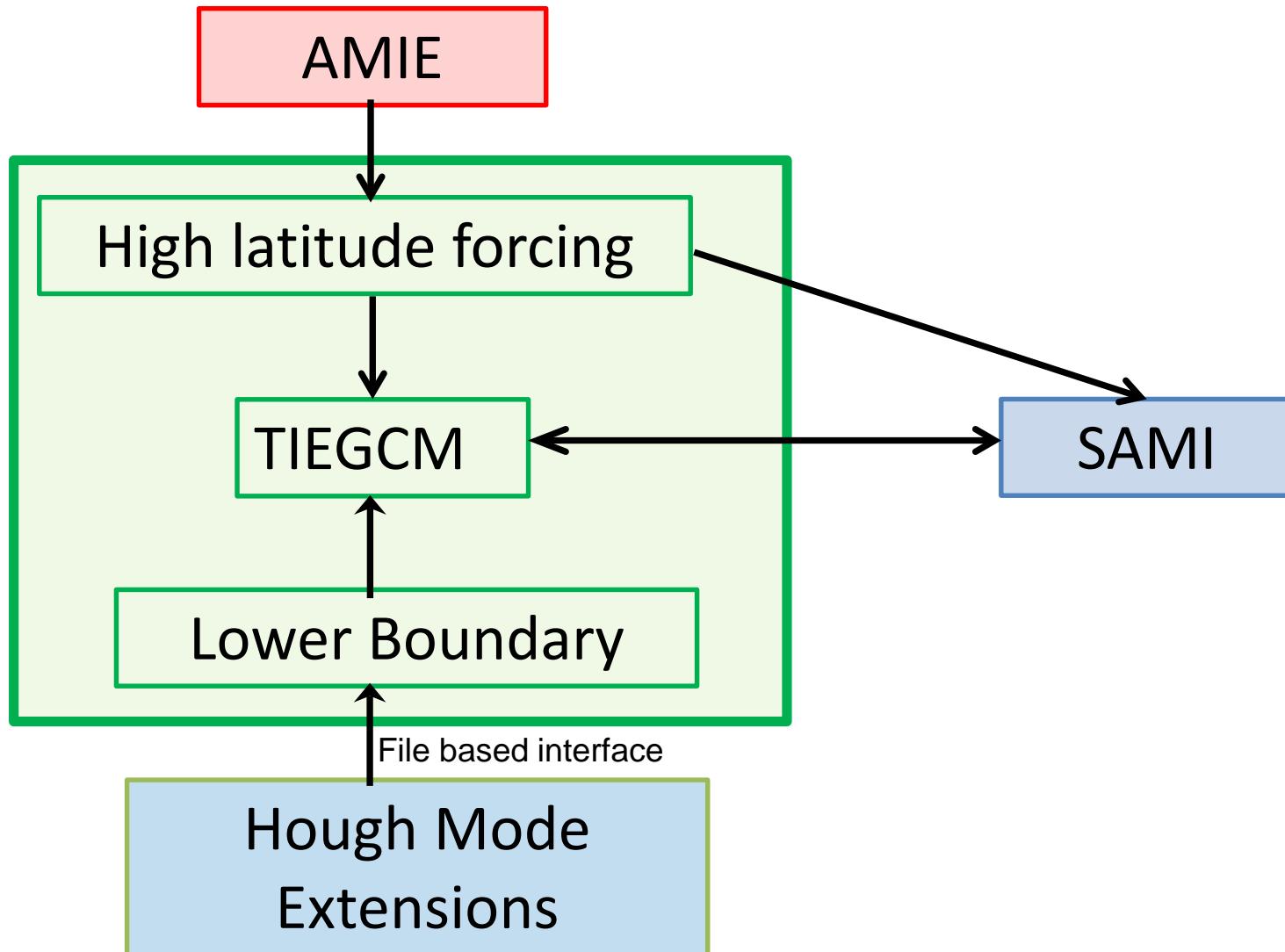
Do we have data in the right locations? Would more data be helpful?

Is the data quality adequate? Should we invest in new measurements or new systems?

NASA's ICON Mission: Model Support



NASA's ICON Mission: Model Support



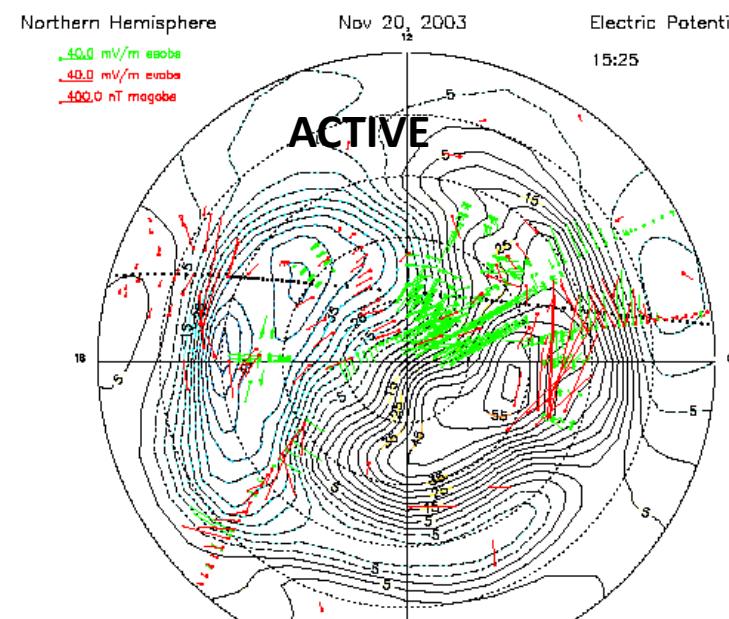
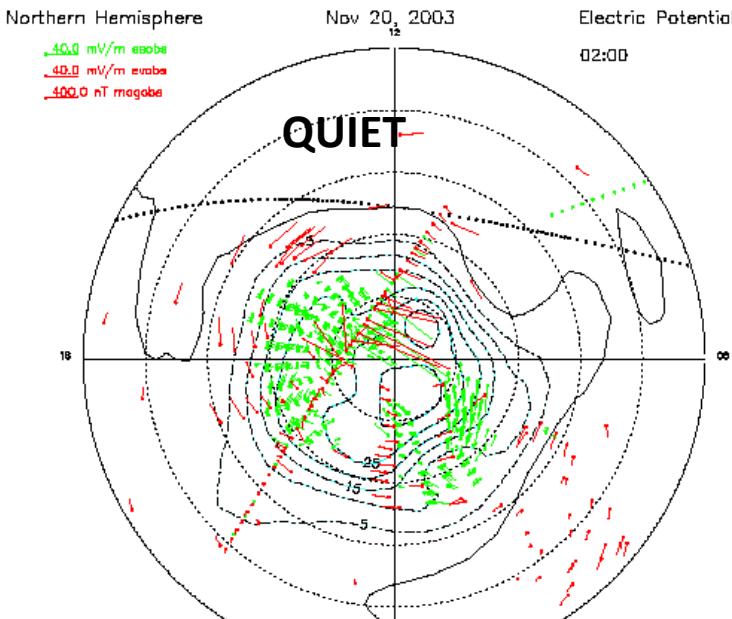
High Latitude Electrodynamics for ICON Mission

Science

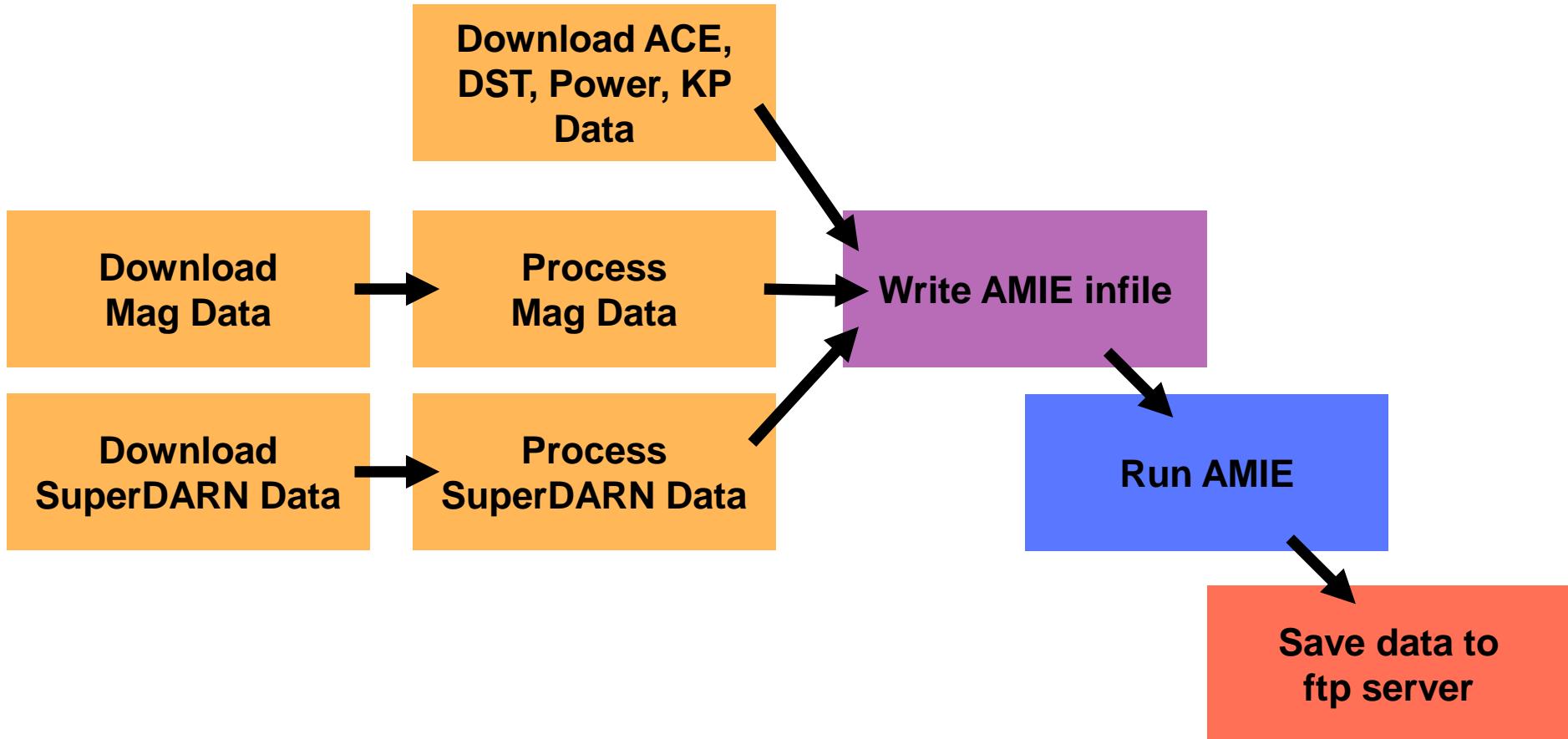
Technology

Applications

Bringing It All Together



Model	Inputs	Outputs
AMIE Assimilative Mapping of Ionospheric Electrodynamics <i>-Output typically saved every 5 min</i> <i>-Latitude resolution is 1.6°</i>	<ul style="list-style-type: none"> Magnetometer Data (Ground and Space) SuperDARN Radar Drifts In-Situ DMSP Drift Data AMPERE magnetic perturbations due to Field Aligned Currents Incoherent Scatter Radar Electric Field Data Energetic particles (e.g. DMSP J4/5) 	<ul style="list-style-type: none"> Electric Potential distribution (>40° Mag. lat.) Electric Fields (>40° Mag. Lat.) Field Aligned Currents (>40° Mag. Lat.) Ionospheric Conductance, $\Sigma_p \Sigma_H$ (>40° Mag. Lat.) Joule Heating (>40° Mag. Lat.) Auroral Boundaries (>40° Mag. Lat.)
	180-250 Mags 12-20 SuperDARNs 3-4 DMSP Satellites	



a) Magnetometers

❖ Science
❖ Technology
❖ Applications

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Magnetometer availability

❖ Science

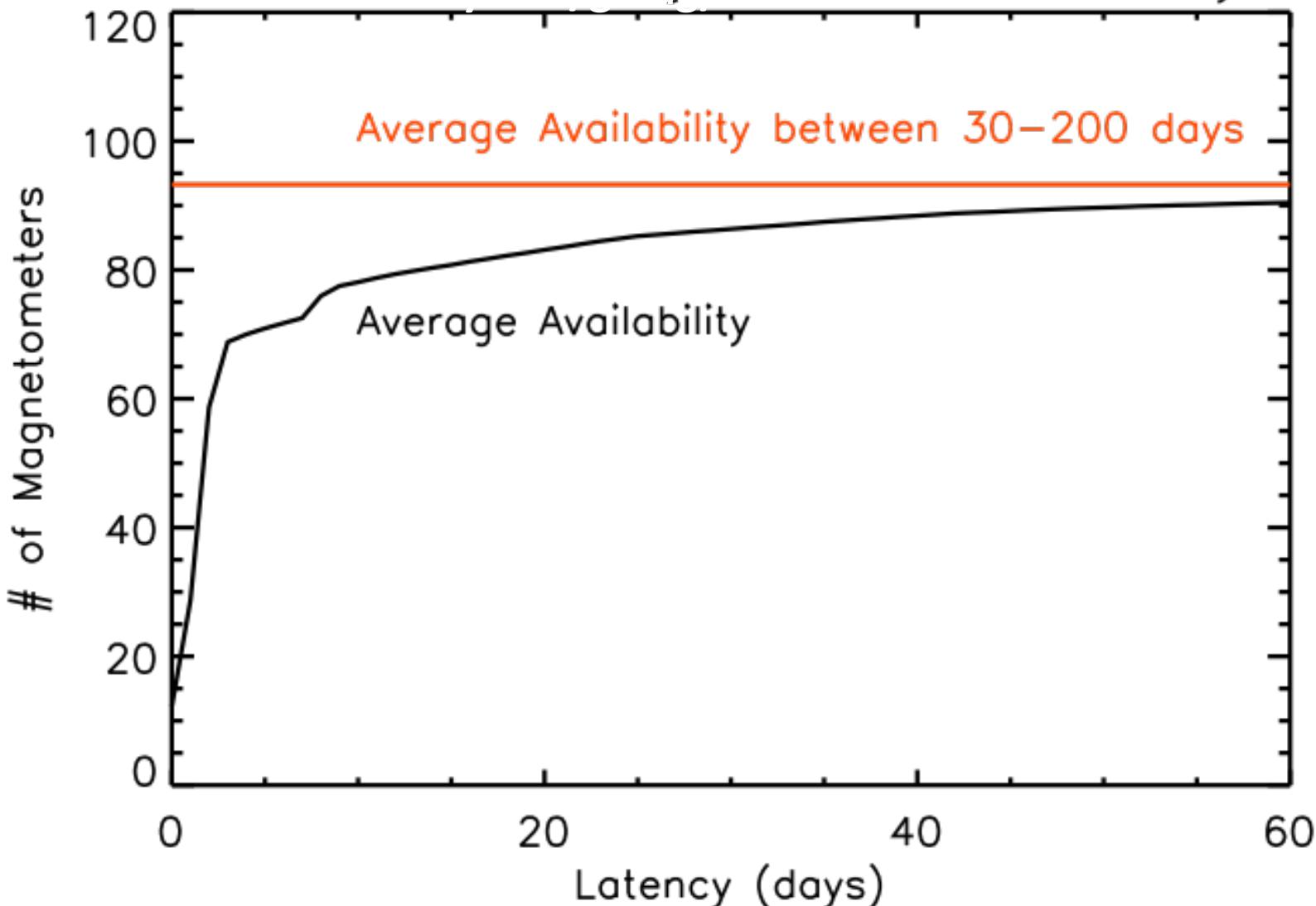
❖ Technology

❖ Applications

Bringing It All Together

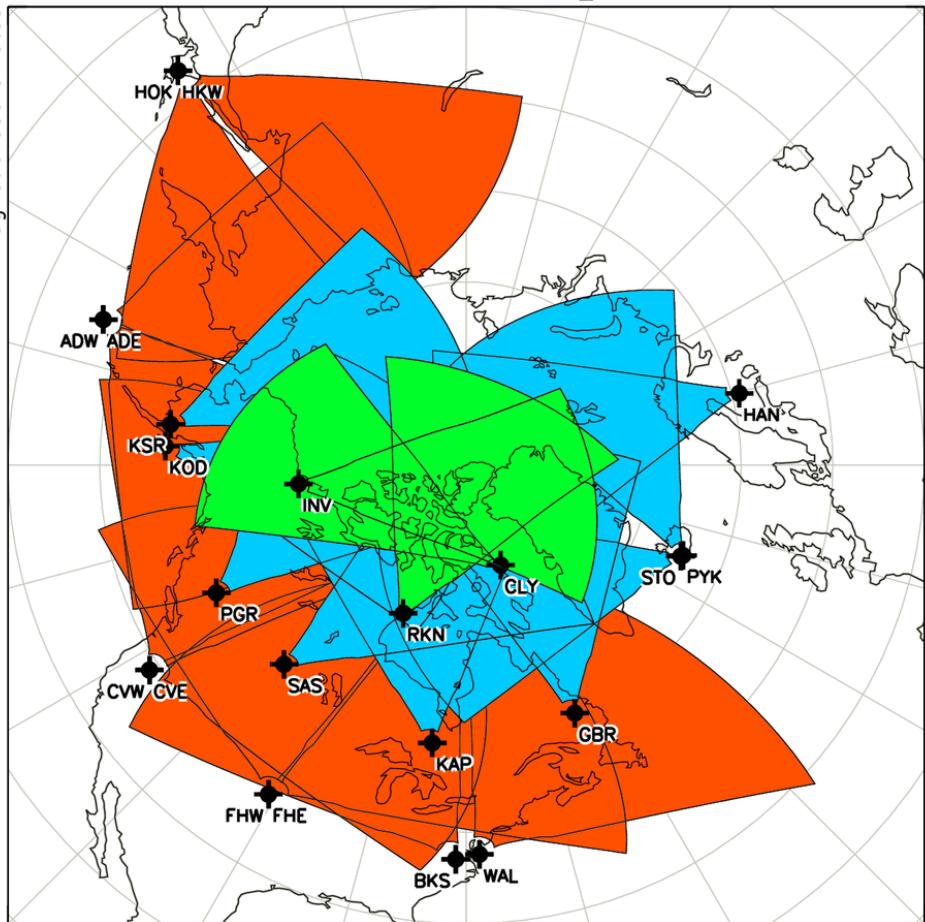


2016 THEMIS Magnetometer Availability

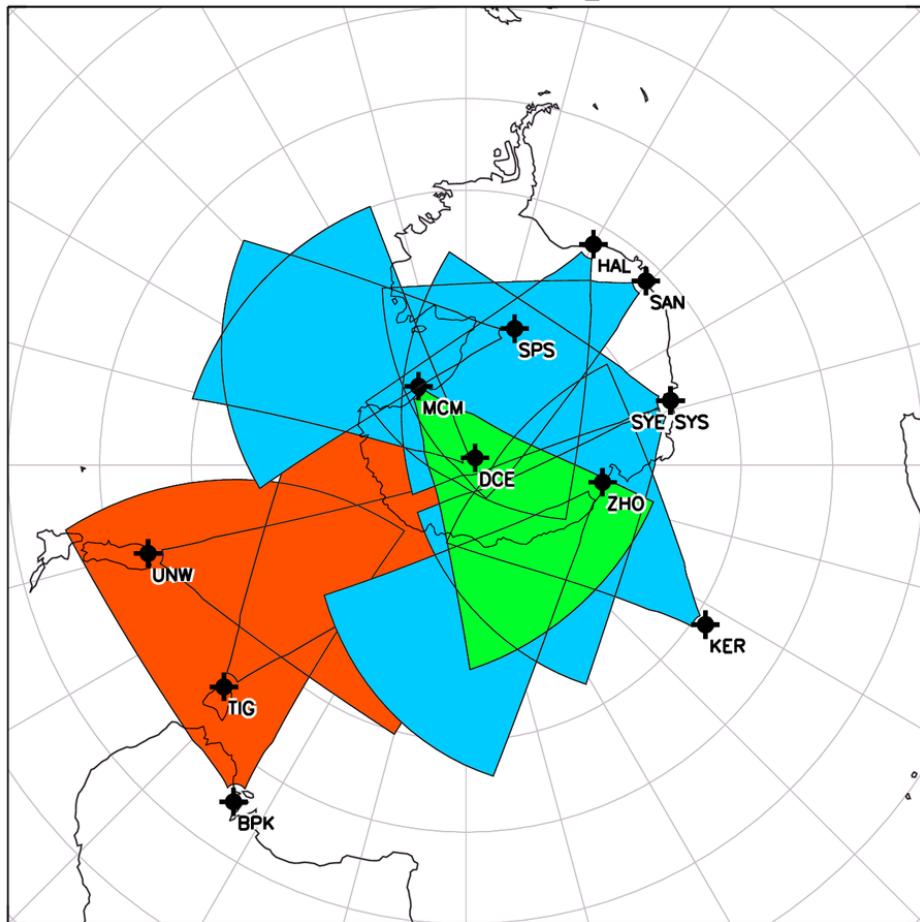


b) SuperDARN

Northern Hemisphere



Southern Hemisphere



Polar Cap

High-Latitude

Mid-Latitude

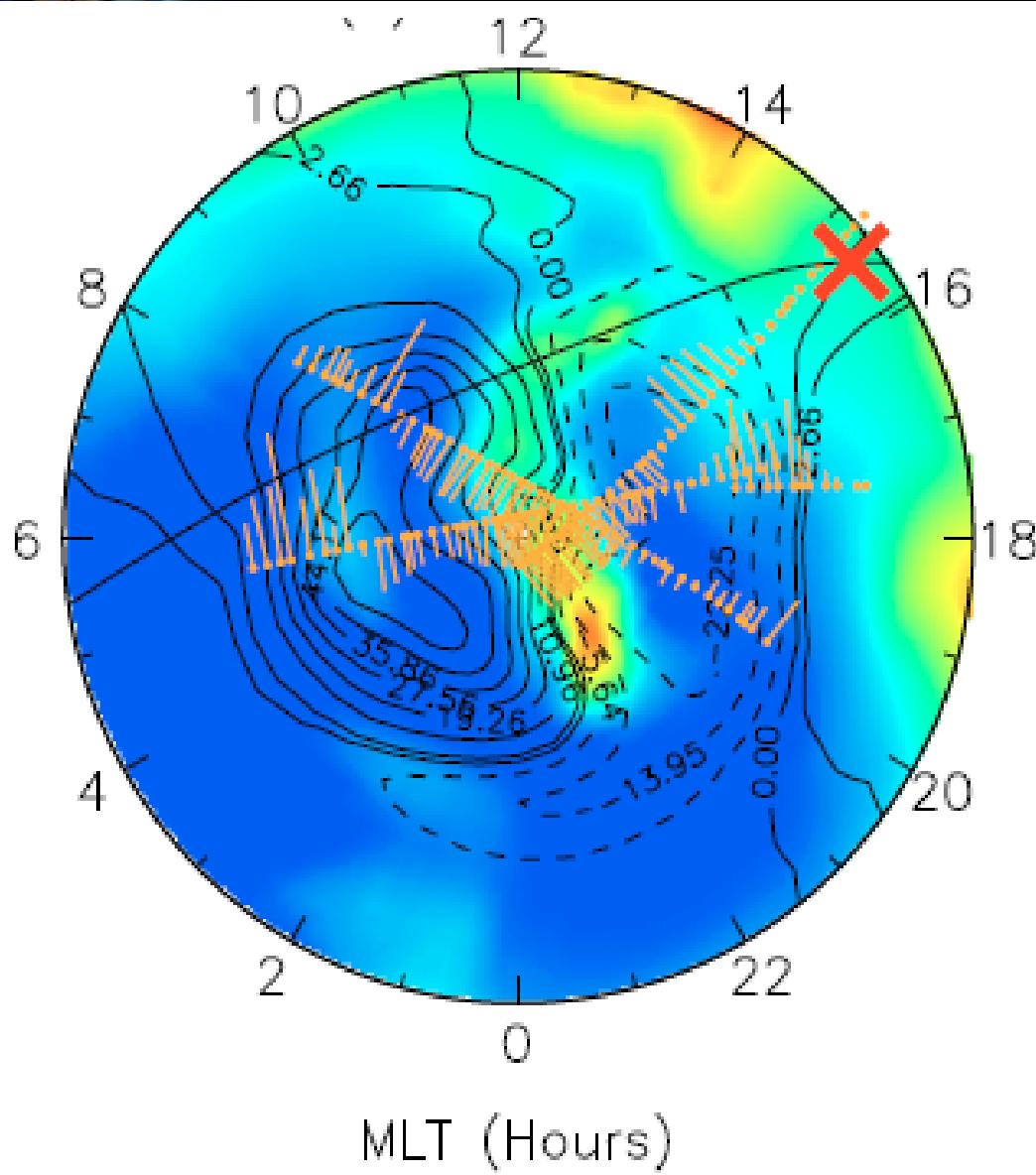
c) DMSP

❖ Science

❖ Technology

❖ Applications

Bringing It All Together



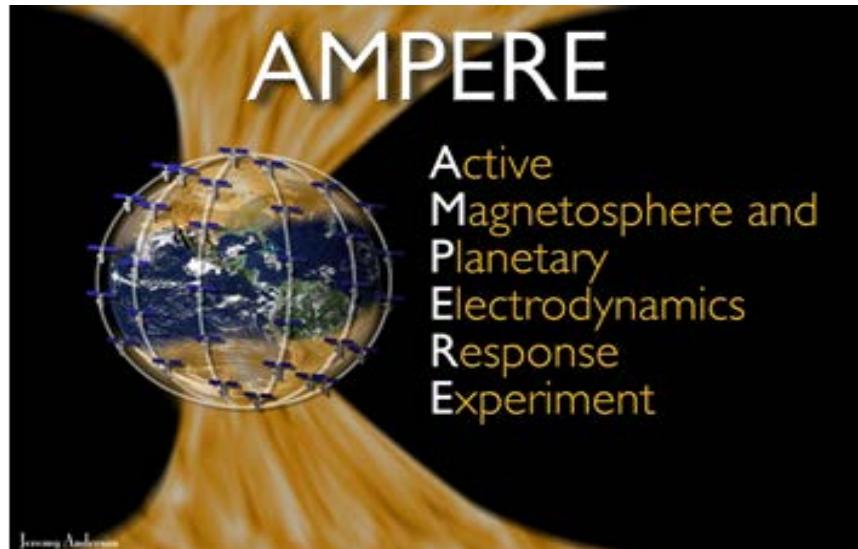
d) AMPERE/Iridium Constellation

❖ Science

❖ Technology

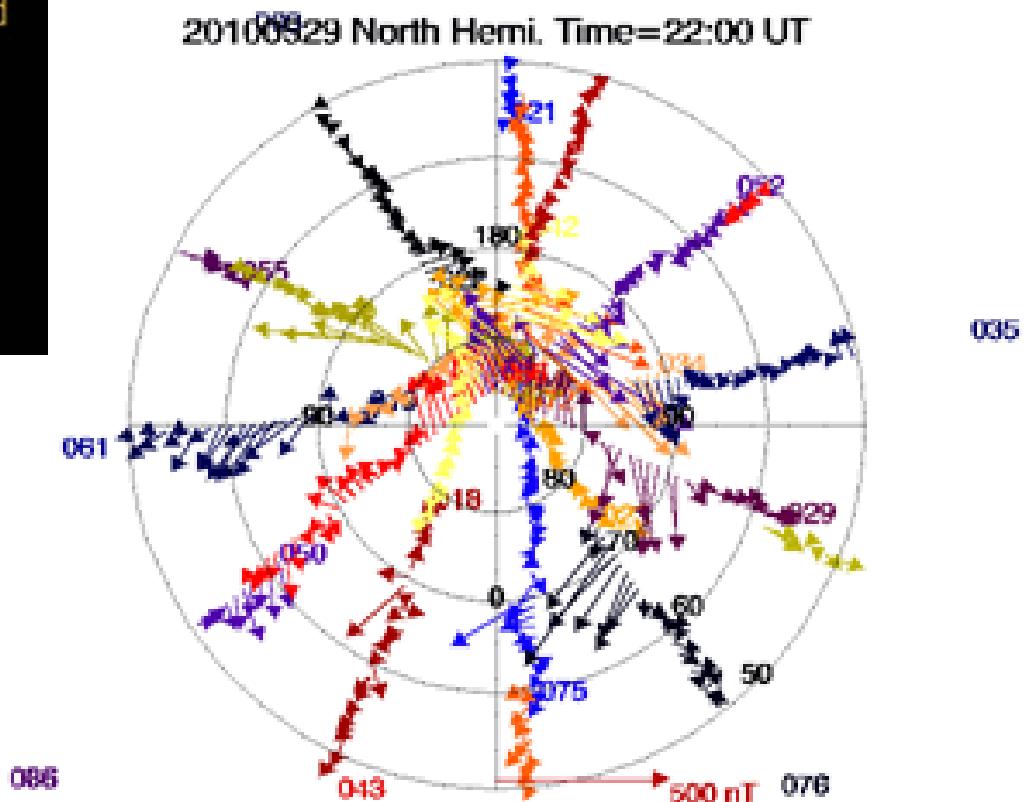
❖ Applications

Bringing It All Together



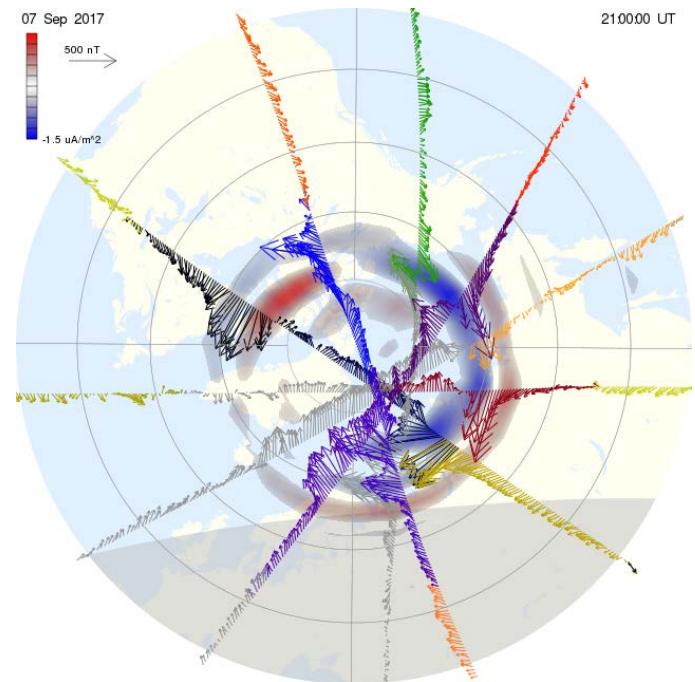
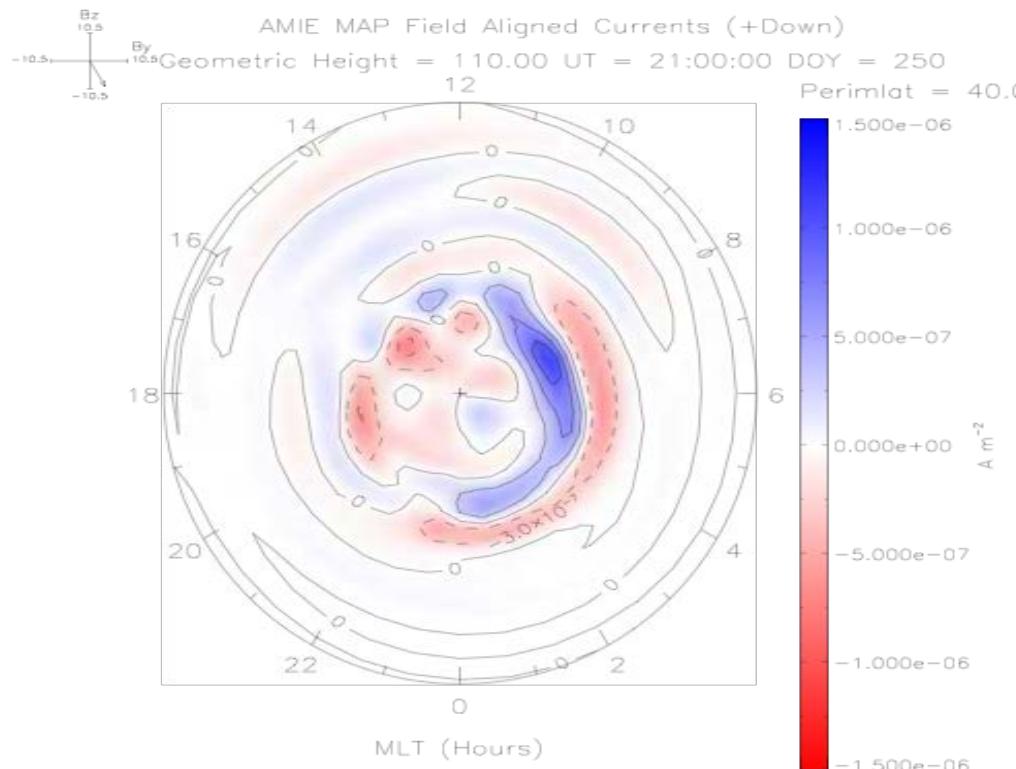
Active
Magnetosphere and
Planetary
Electrodynamics
Response
Experiment

Jonny Anderson



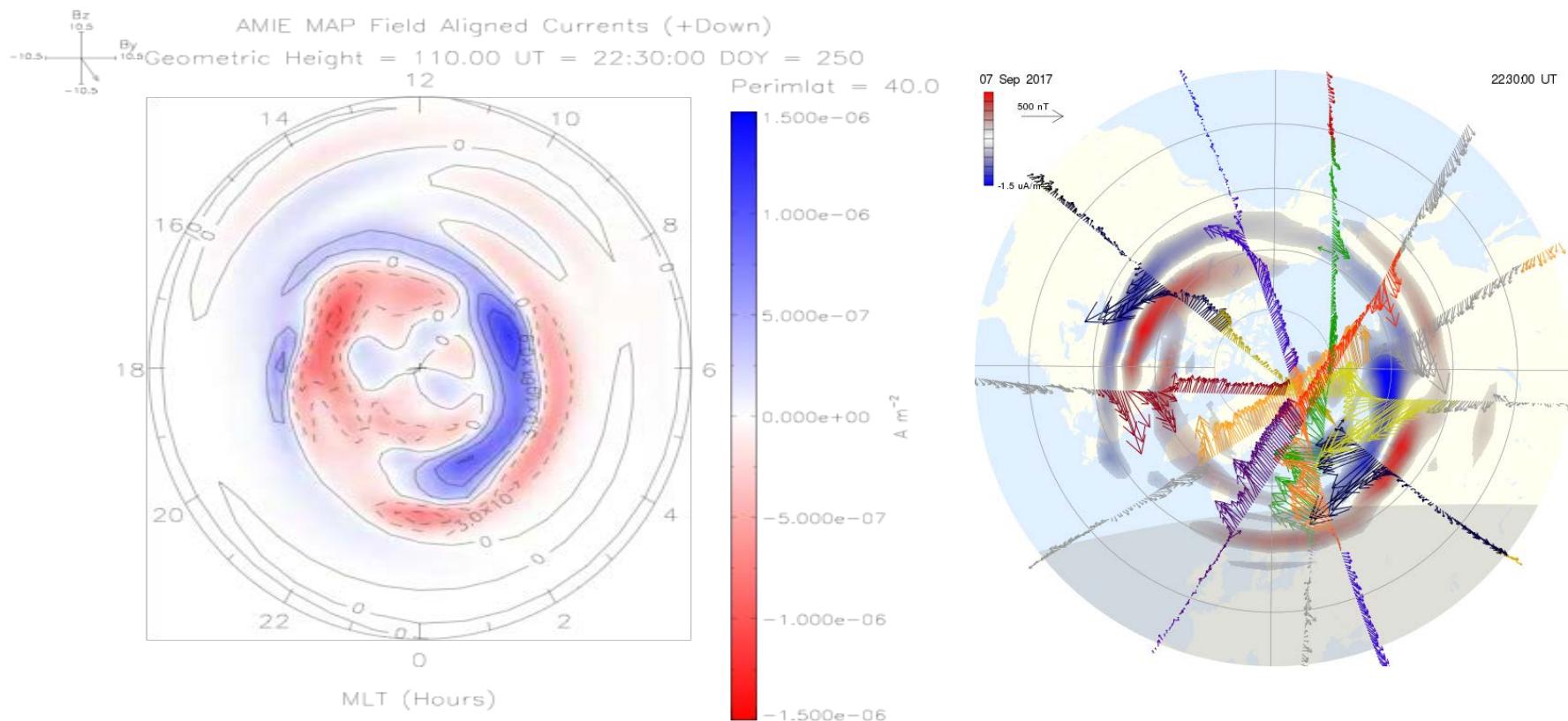
AMIE-AMPERE comparison

9/7/2017 21:00 UT



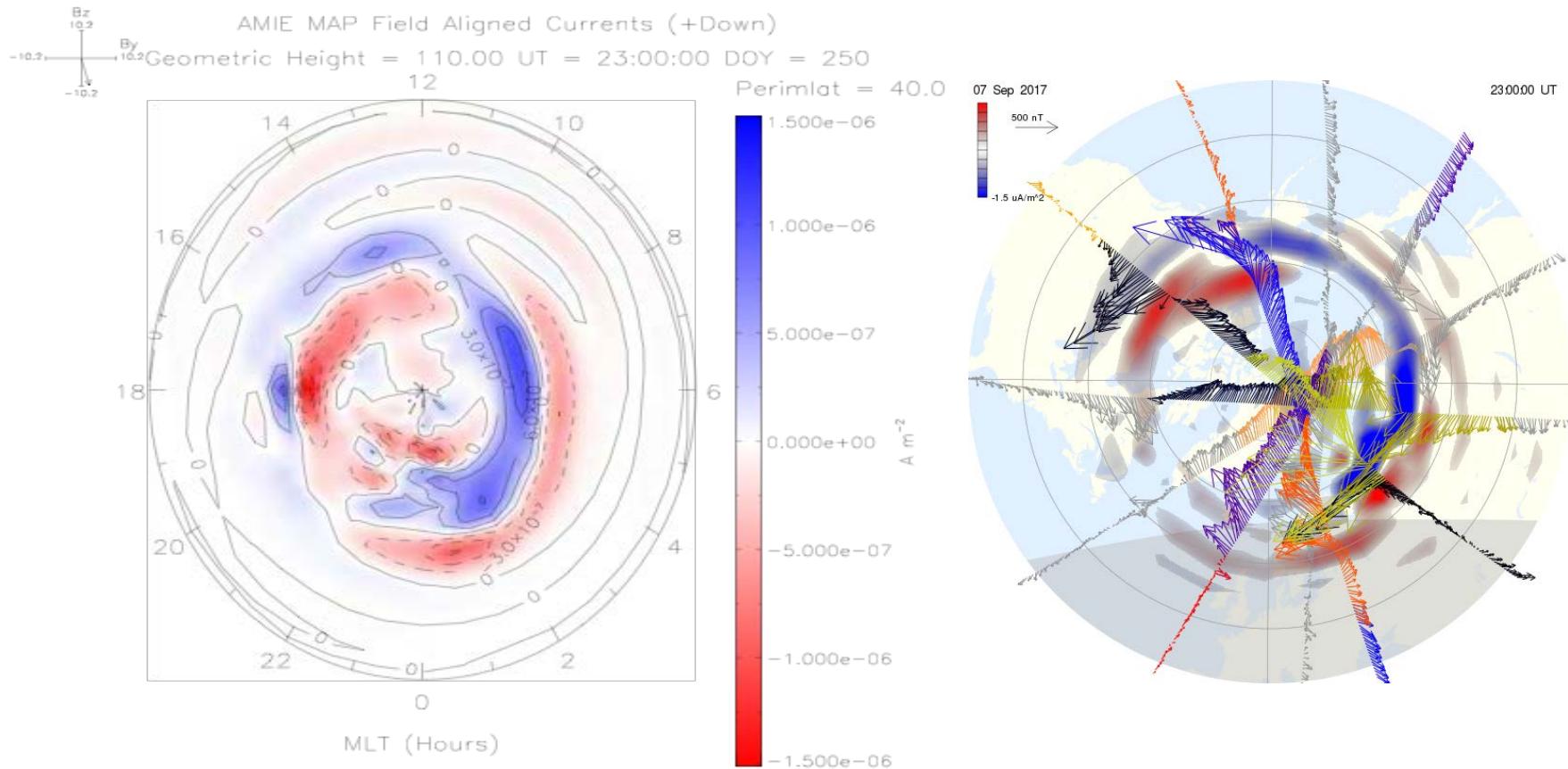
AMIE-AMPERE comparison

9/7/2017 22:30 UT



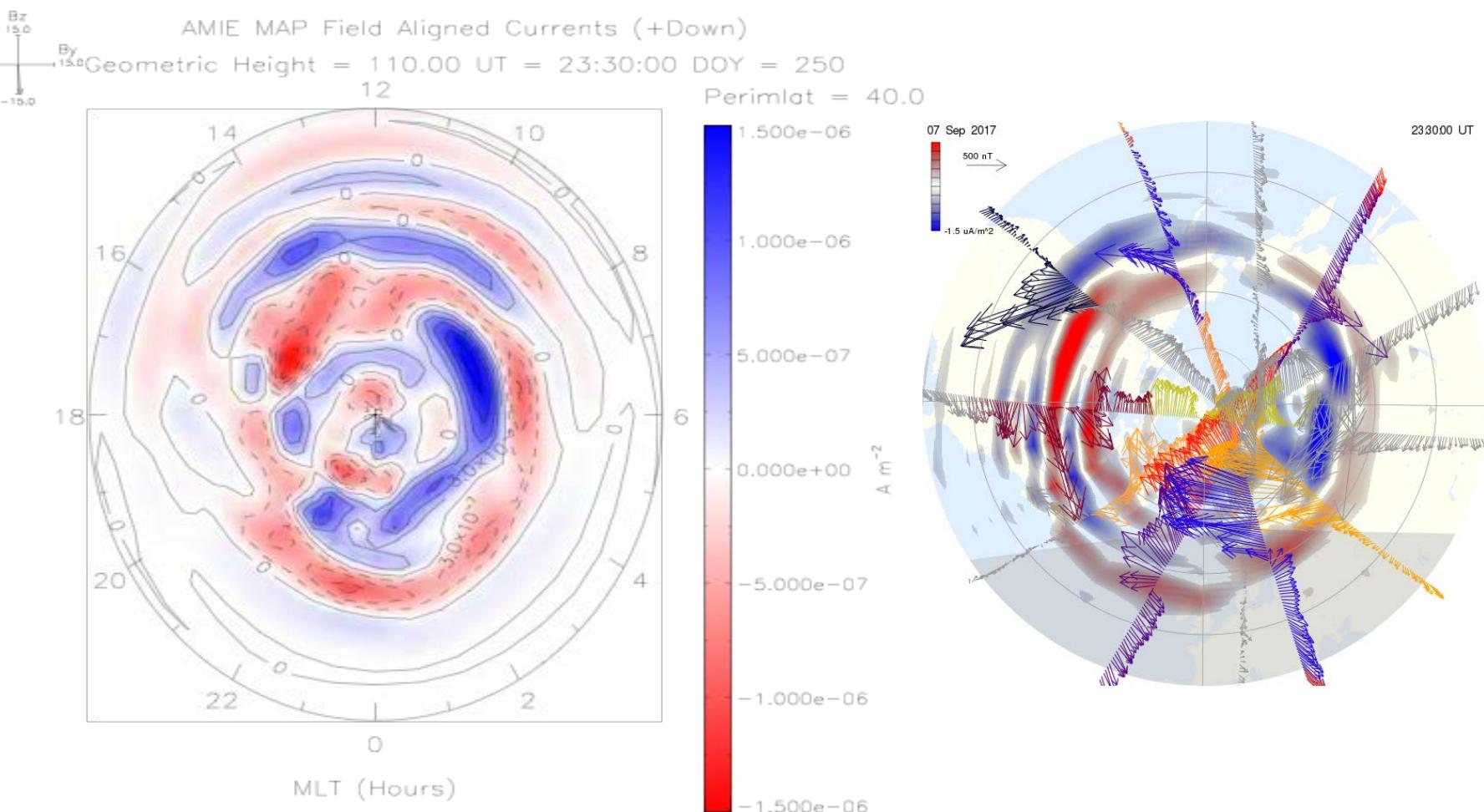
AMIE-AMPERE comparison

9/7/2017 23:00 UT



AMIE-AMPERE comparison

9/7/2017 23:30 UT





DRAGSTER

REDUCING CONJUNCTION ANALYSIS ERRORS WITH AN ASSIMILATIVE TOOL FOR SATELLITE DRAG SPECIFICATION

or

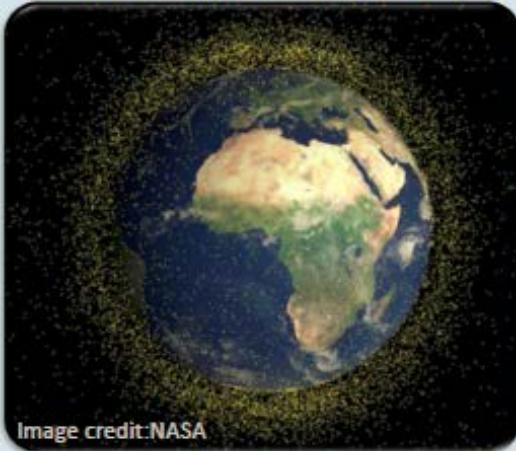
Improved Orbit Determination and Forecasts
with an Assimilative Tool for Atmospheric Density and Satellite Drag

Dr. Geoff Crowley

M. Pilinski, Eric Sutton, M. Codrescu

T. Fuller-Rowell, Mariangel Fedrizzi, S. Solomon, L. Qian, J. Thayer, T. Matsuo

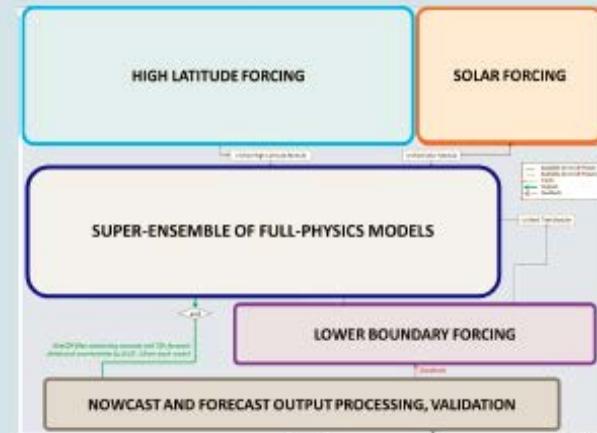
Resident Space Objects (LEO)



satellite drag and density observations

- **Orbit observations**
- GPS
- Accelerometers
- O/N₂
- Mass Spectrometer

Dragster Architecture



conjunction analysis

Results

- Improved satellite orbit nowcast and 72h forecast
 - Improvements over HASDM and JB08
 - Up to three-fold improvement during storms and solar minimum
- Densities, winds, and composition outputs
- Covers altitudes from 30 km to 1500 km
- Improved performance during geomagnetic storms

Dragster

orbital analysis

Super-Ensemble Approach



Image credit: TerraMetrics, Google

Output information feeds into existing orbit prediction and determination tools



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New Data Needed for Assimilative Models of Space Environment

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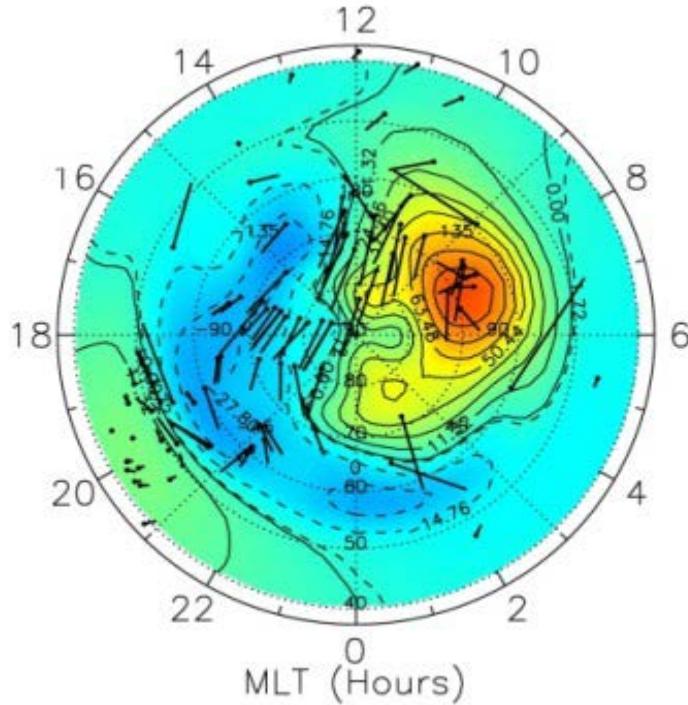
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Are IORD requirements being satisfied?

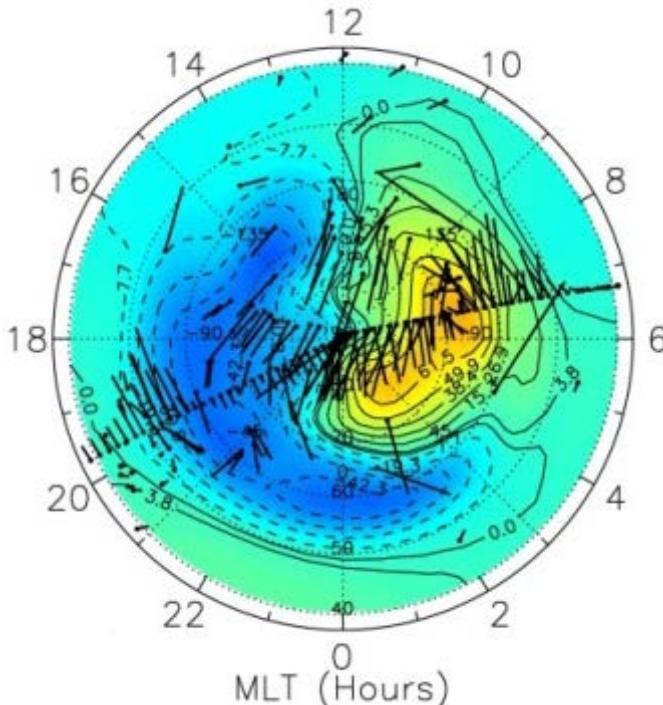
Quantity	Requirement	Goal
Range	0-150 mV/m	0-250 mV/m
Precision	± 2 mV/m	± 0.1 mV/m
Accuracy	± 3 mV/m	± 0.1 mV/m
In-track Res.	1.0 km	0.1 km

IORD requirements are not being met globally and temporally

Ground-based data only



DMSP Satellites Added



Monitoring the Global Ionosphere

❖ Science

❖ Technology

❖ Applications

Bringing It All Together

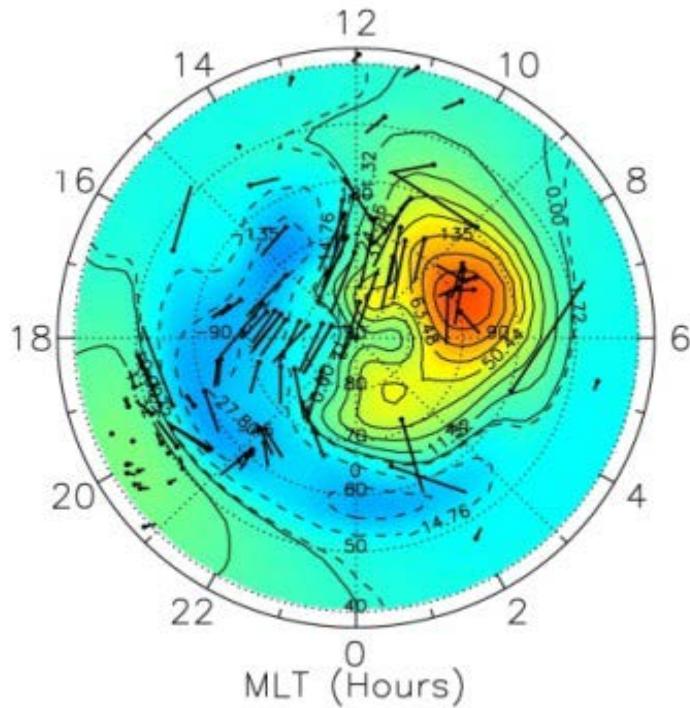


Are IORD requirements being satisfied?

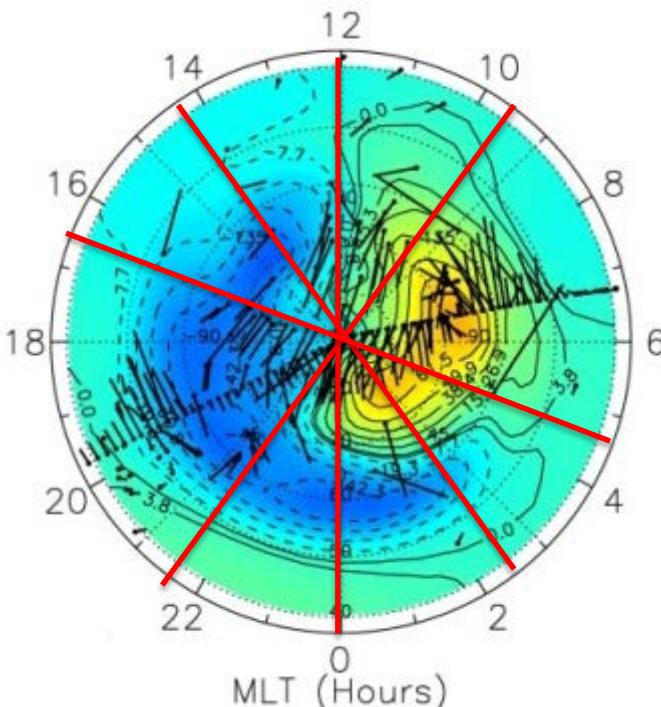
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Ground-based data only



Realistic constellation



Monitoring the Global Ionosphere

❖ Science

❖ Technology

❖ Applications

Bringing It All Together



Are IORD requirements being satisfied?

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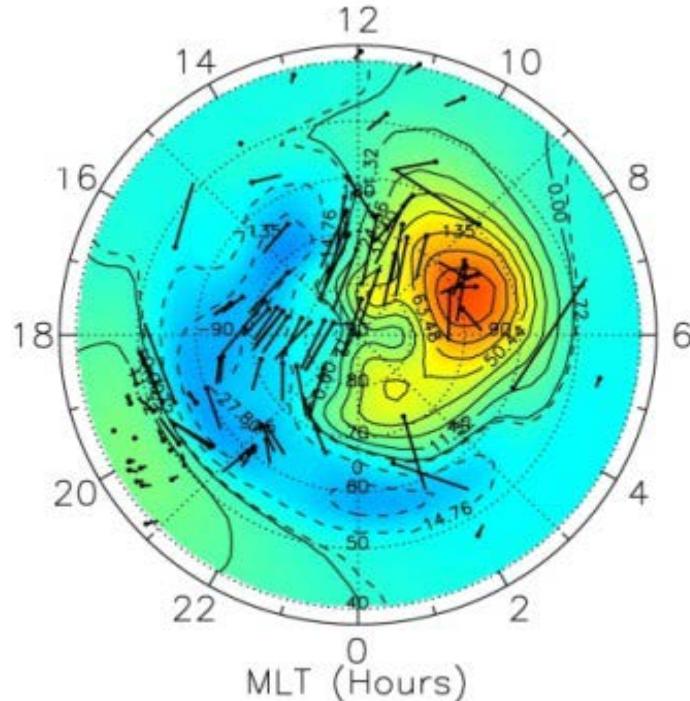
Modern Satellite Approach:

Constellation of 100 SmallSats for \$40-50M

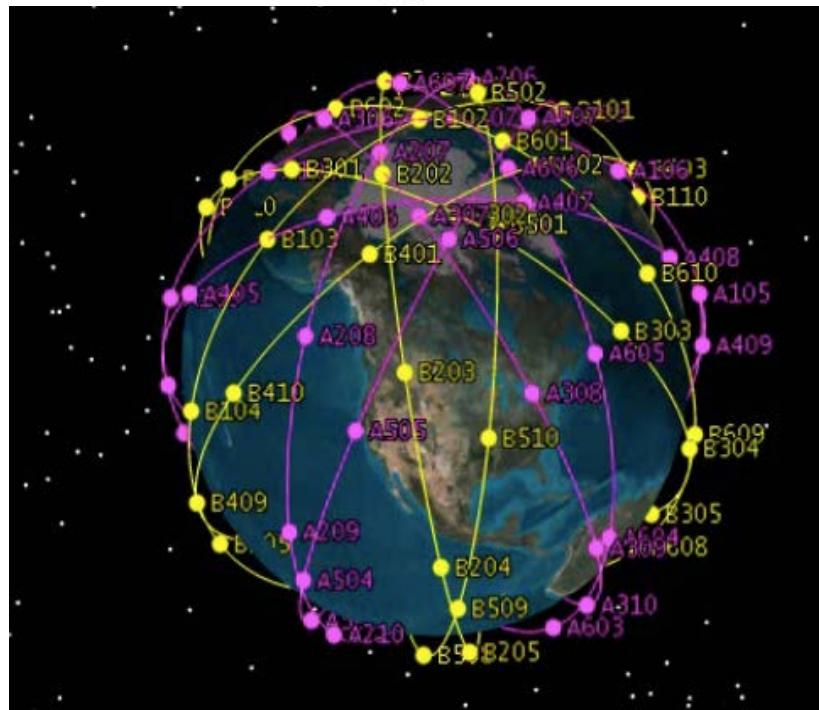
High spatial and temporal resolution E-field measurements

Will revolutionize nowcasting and forecasting of the ionosphere & thermosphere

Ground-based data only



Realistic constellation





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Real-time Data from Moving Platforms

ASTRA Receiver on Buoys / Ships / Aircraft

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New Capability: Ionospheric Monitoring from an Ocean Platform

❖ Science
❖ Technology
❖ Applications

Bringing It All Together



"No one else in the World has done this..."

– recent quote from Technical Director of a multi-Billion dollar International Commercial Services company that provides marine data services



- Near real-time ionospheric data from moving platform
- Data Products: TEC, scintillation data products, and system status
- Ground link via Iridium or cell towers
- Programmable data latency (Nominal 5 minutes)

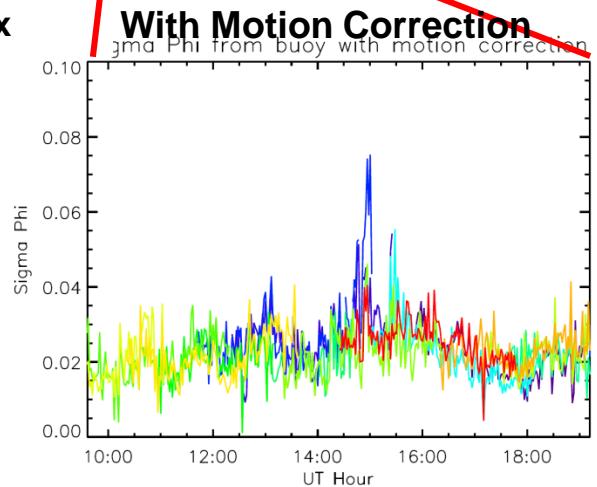
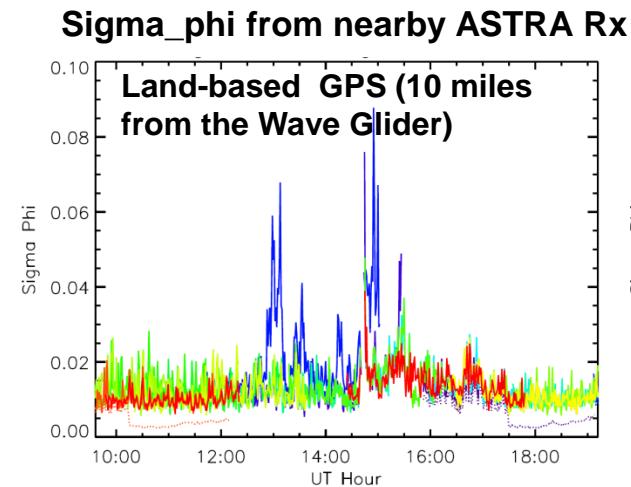
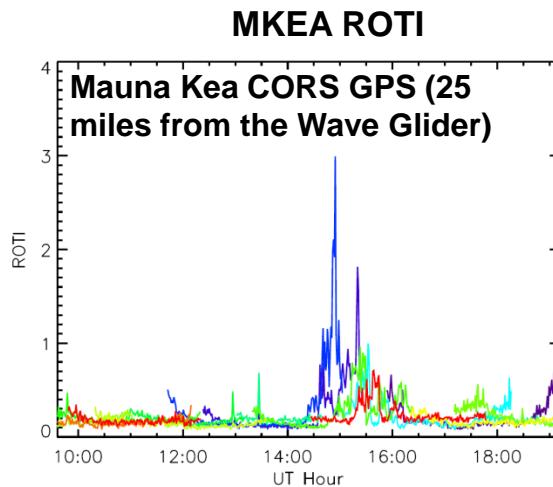
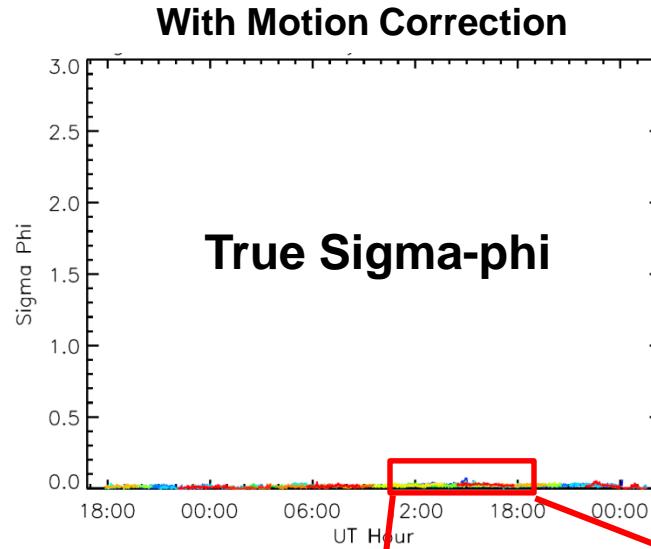
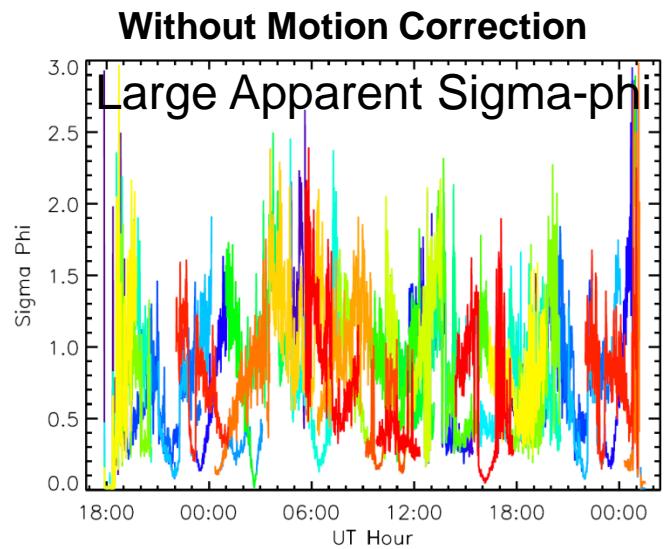
Validation of Motion Removal Against Land-based Receivers

Science

Technology

Applications

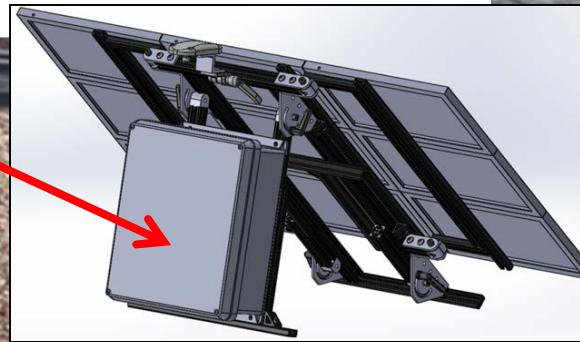
Bringing It All Together



Standalone System Support Module

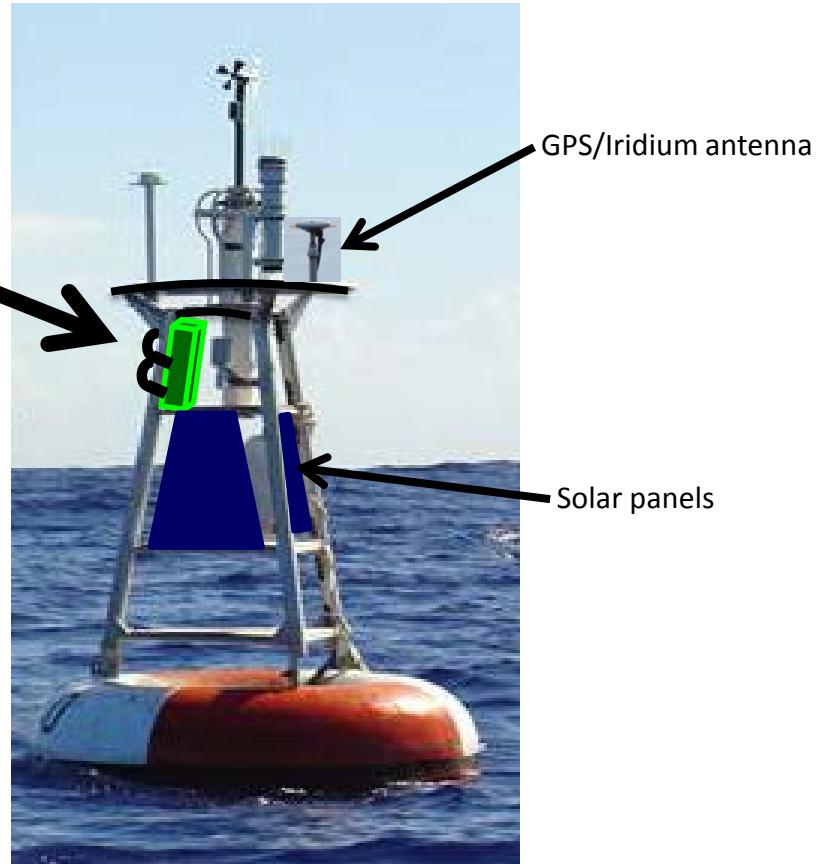
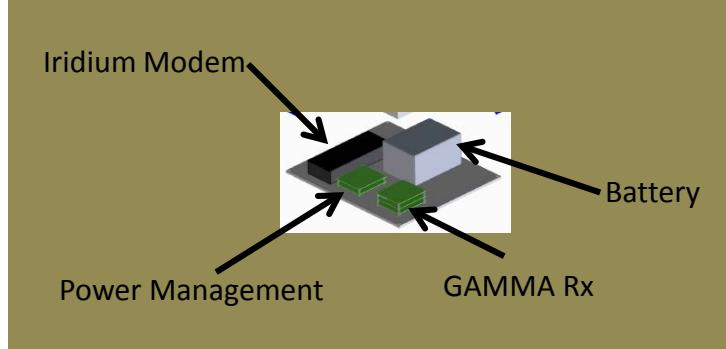
- Provides robust, power, thermal management and data communications capability for GAMMA (or other instrumentation) deployed in extreme, harsh, power deprived environments

Electronics enclosure



- Scalable
- ASTRA can support integration, customization and operation

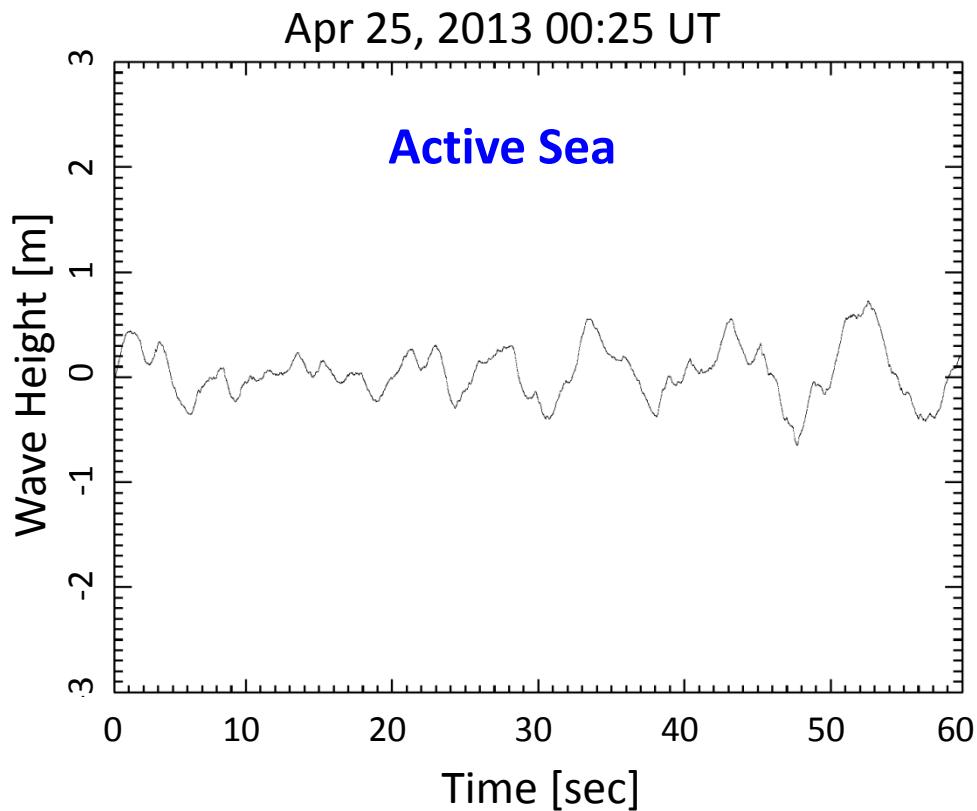
**Pressurized payload box
attaches to the buoy frame**



Wave Height Algorithms

❖ Science
❖ Technology
❖ Applications

Bringing It All Together

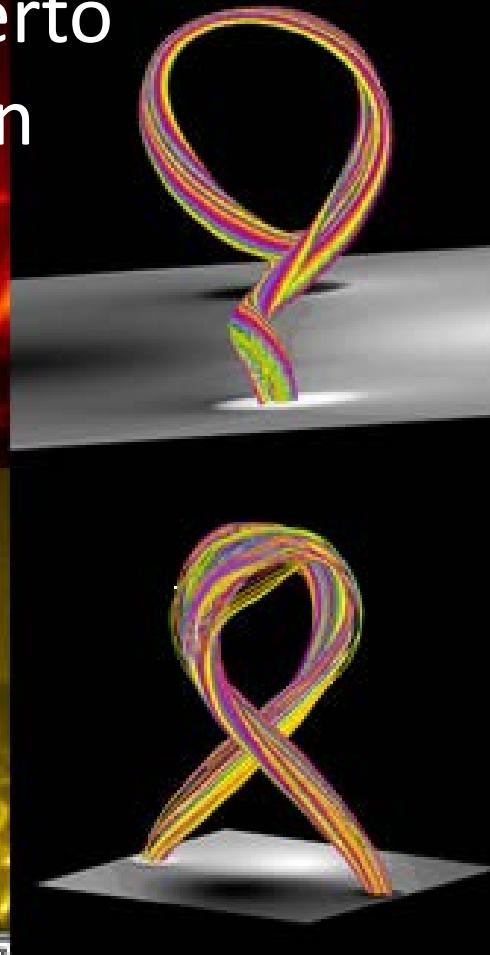
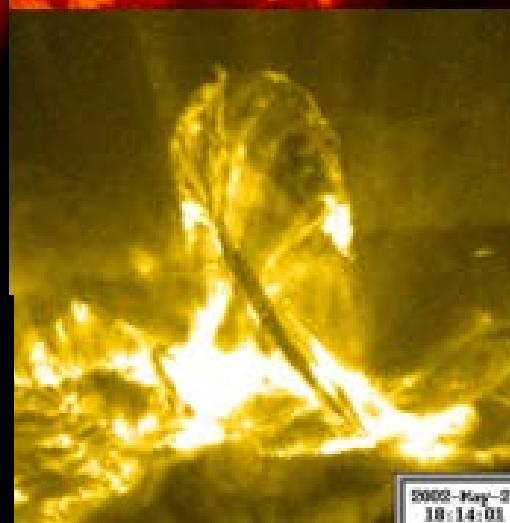
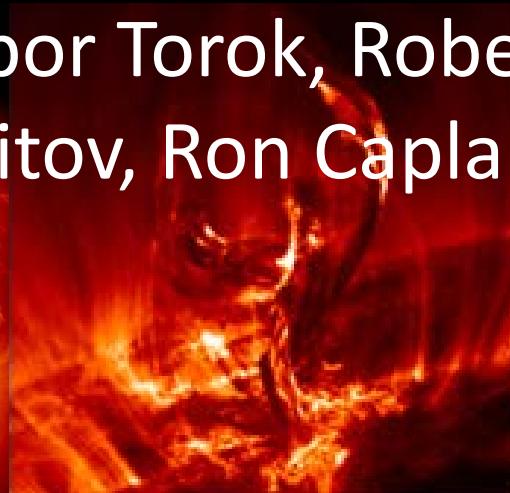
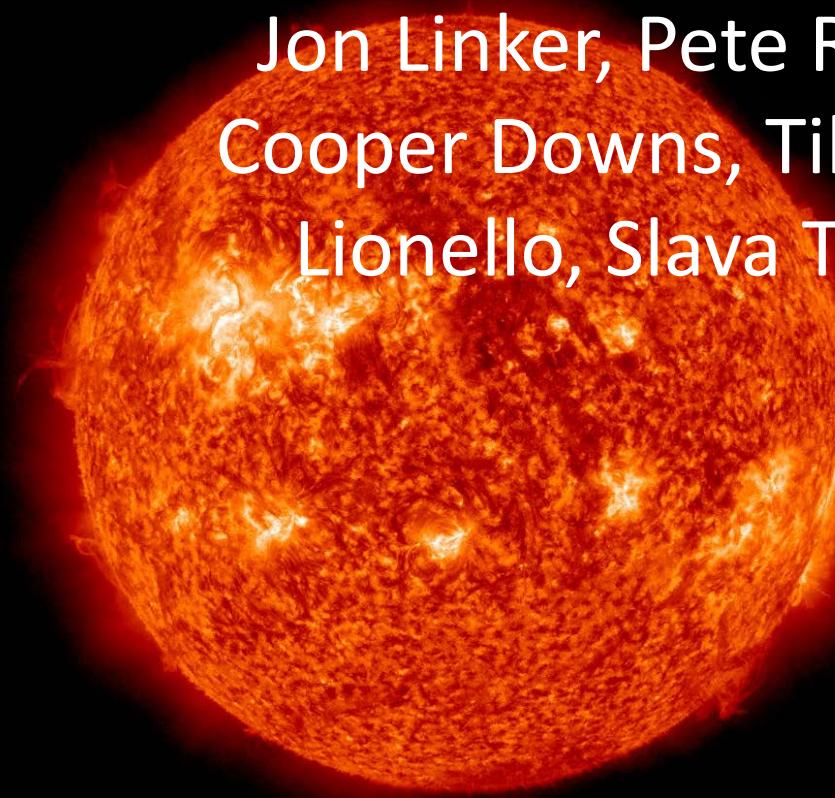


- 1) Organize the R2O discussion around “TRL level” metric locating where we sit in the R2O chain of action
- 2) Need to provide more funds for R2O
- 3) We need much more data for assimilation
- 4) Focus on low-hanging fruit:
(relatively inexpensive small systems)
e.g. deploy ground-based systems in place of a satellite mission



Predictive Science, Inc.

Jon Linker, Pete Riley, Zoran Mikic,
Cooper Downs, Tibor Tórok, Roberto
Lionello, Slava Titov, Ron Caplan



SDO/AIA 304 2012-06-04 11:15:45 UT

www.predsci.com

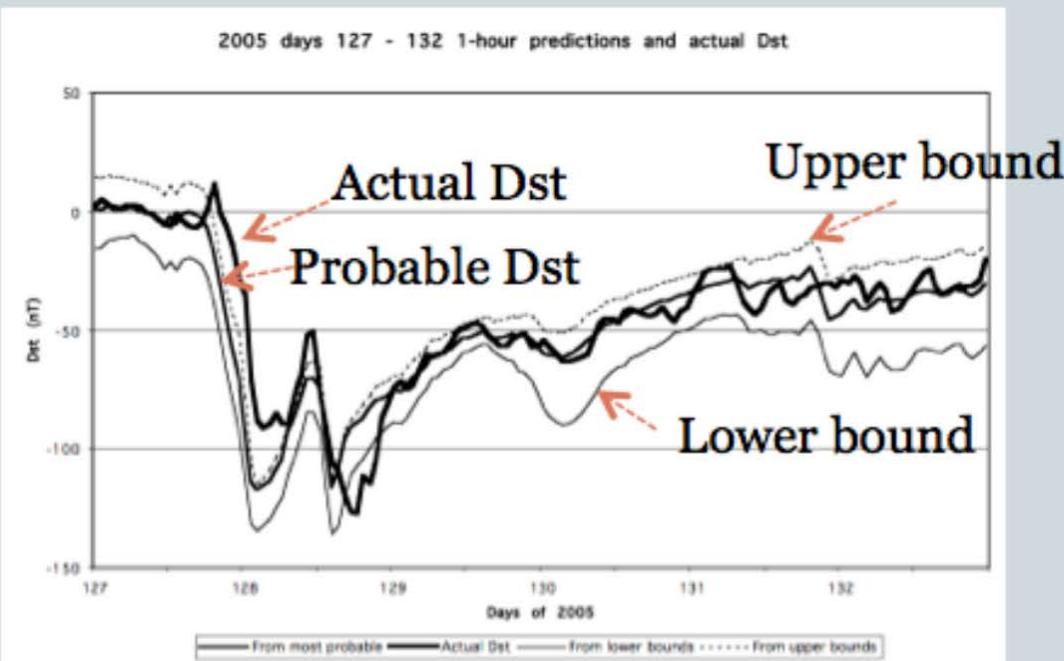


CARMEL RESEARCH CENTER (CRC)

CRC SPACE WEATHER FORECASTS



o 1–5 hour forecast of Dst



Courtesy of Devrie Intriligator

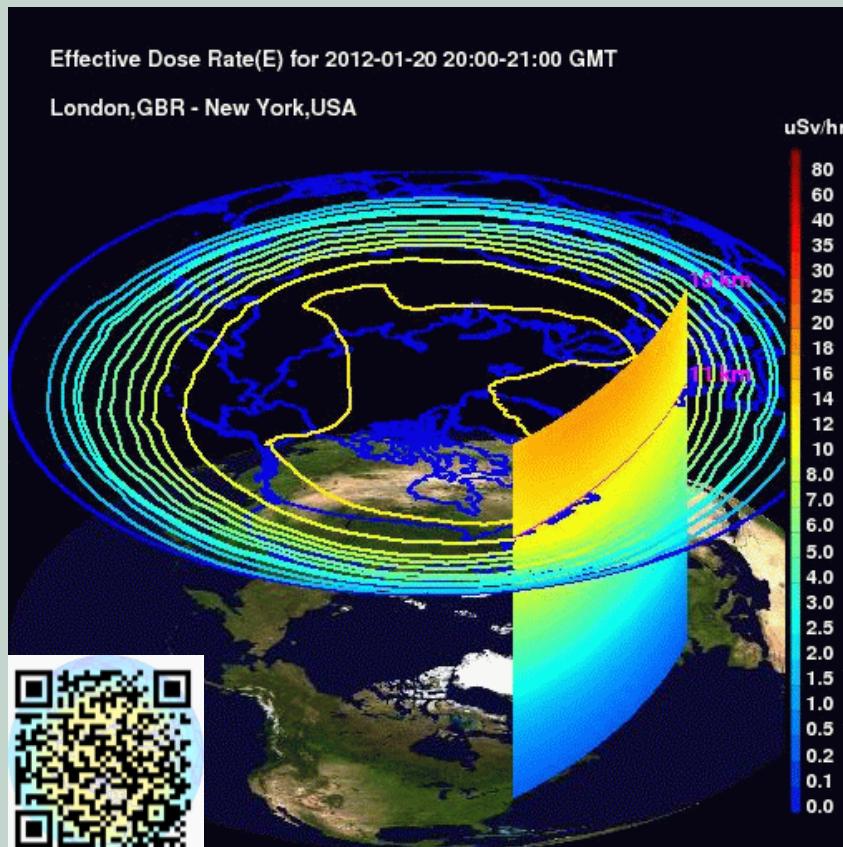
SET's real-time aviation radiation monitoring system for business jets – ARMAS FM5

- FM5 contains a micro dosimeter, data logger, GPS receiver, Iridium transceiver, battery, and Bluetooth in the size of a large smart phone
- Measures ALL radiation in all altitude ranges with NASA technology
- Reports personal dose exposure from anywhere in the world providing REAL-TIME situational awareness onboard or on ground
- Provides radiation region avoidance during events (like volcanic ash clouds)
- FM5 is FAA compliant with its own power and no attachment to plane

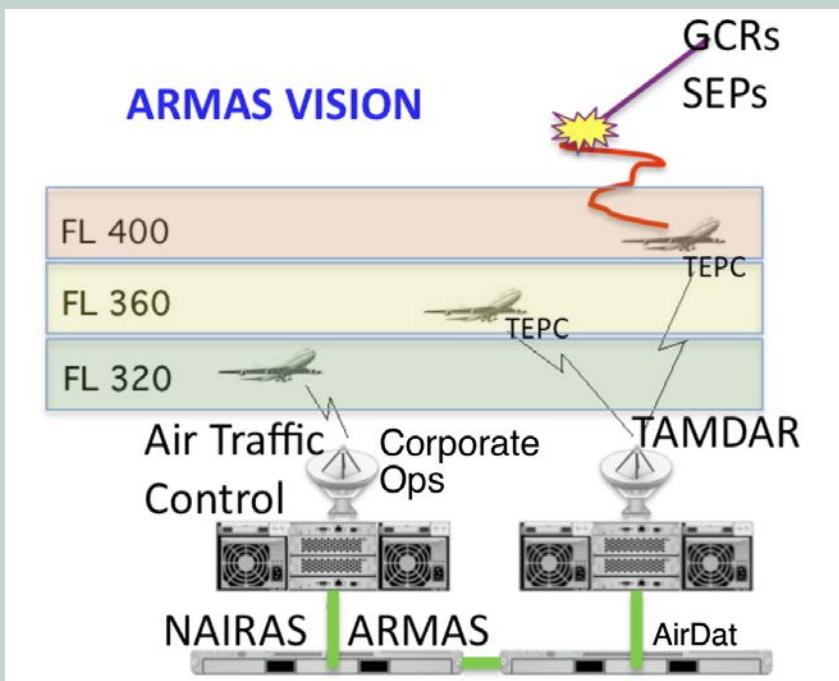


Characterizing Radiation for Aviation Customers

NAIRAS

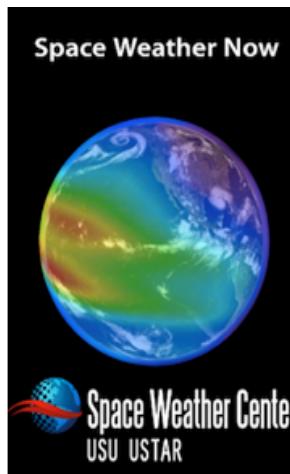
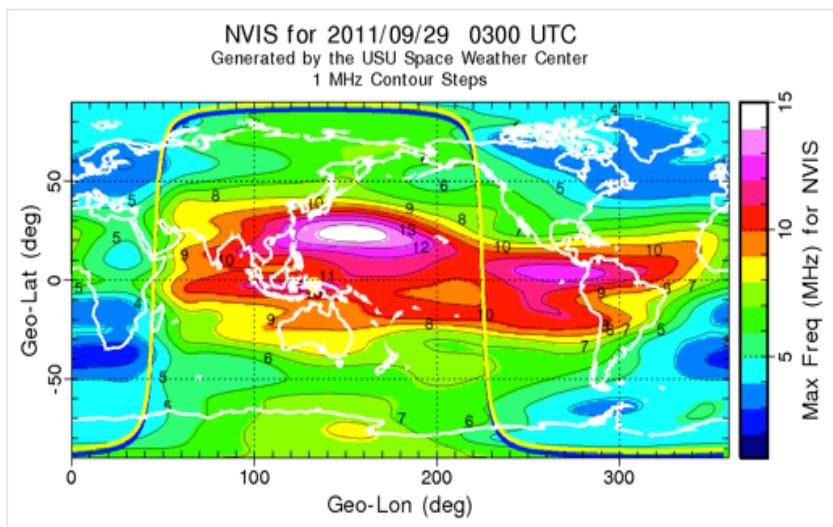


ARMAS



Courtesy of Kent Tobiska

Corporate and Hams HF propagation



At Q-Up Now we are dedicated to providing the best, most accurate real-time and forecast High Frequency (HF) radio frequencies for propagation.

What is Propagation?

Radio propagation is the transmission, including reflection, of a radio wave in a specific direction through a medium. Radio waves are a form of electromagnetic radiation (EM) and pass through free space, the ionosphere, air, and even solid materials. The reflections of the EM waves are affected by charged particles, such as electrons, in the ionosphere. As such, having a knowledge of how the ionosphere varies can help us understand how radio waves will propagate.



Courtesy of Kent Tobiska

- 1) TRL provides a metric locating where we sit in the R2O chain of action
- 2) Organize the R2O discussion around “TRL level”
- 3) Need to provide more funds for R2O
- 4) We need much more data for assimilation
- 5) Focus on low-hanging fruit:
(relatively inexpensive small systems)
e.g. deploy ground-based systems in place of a satellite mission

BACKUP SLIDES

❖ Science

❖ Technology

❖ Applications

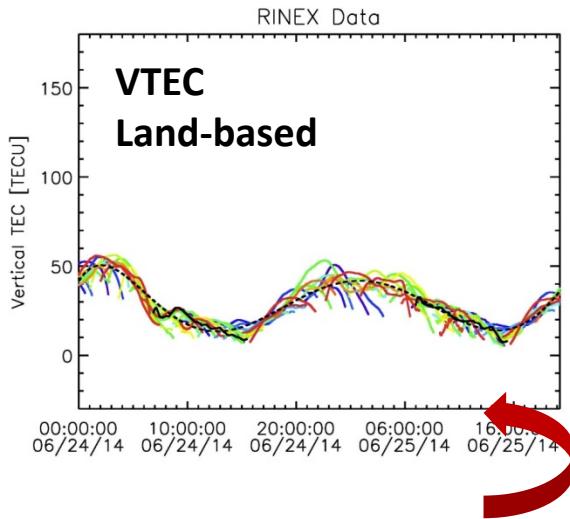
Bringing It All Together



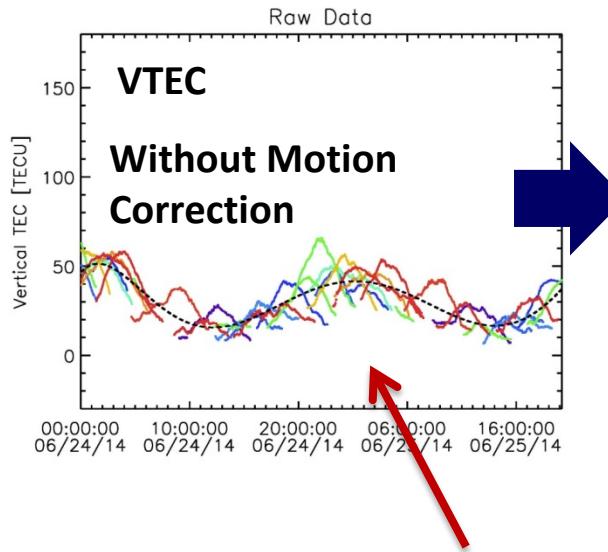
VTEC from a Buoy (Hawaii)

Land Based Measurement:

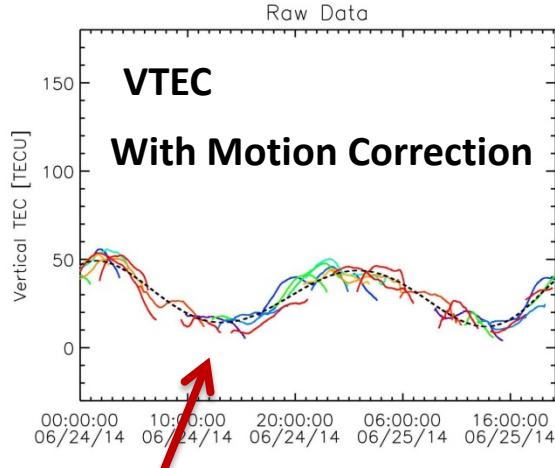
Mauna Kea CORS GPS (25 miles from the Wave Glider)



Vertical TEC from the CORS receiver at Mauna Kea.



Vertical TEC from GAMMA on the Wave Glider.



- Accurate TEC measurements are critical for extraction of TID signals.
- GAMMA GPS receiver provides accurate TEC measurements enabling TID characterization from moving platforms

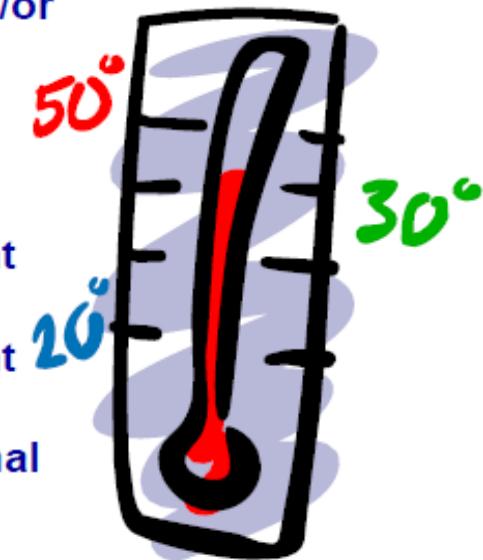


Department of Defense Software TRLs



Increasing maturity

1. Basic principles observed and reported.
2. Technology concept and/or application formulated.
3. Analytical and experimental critical function and/or characteristic proof of concept
4. Module and/or subsystem validation in a laboratory environment, i.e. software prototype development environment
5. Module and/or subsystem validation in a relevant environment
6. Module and/or subsystem validation in a relevant end-to-end environment
7. System prototype demonstration in an operational high fidelity environment
8. Actual system completed and mission qualified through test and demonstration in an operational environment
9. Actual system proven through successful mission proven operational capabilities





Outline

Private Sector Contributions to Ionospheric Monitoring

Geoff Crowley, ASTRA

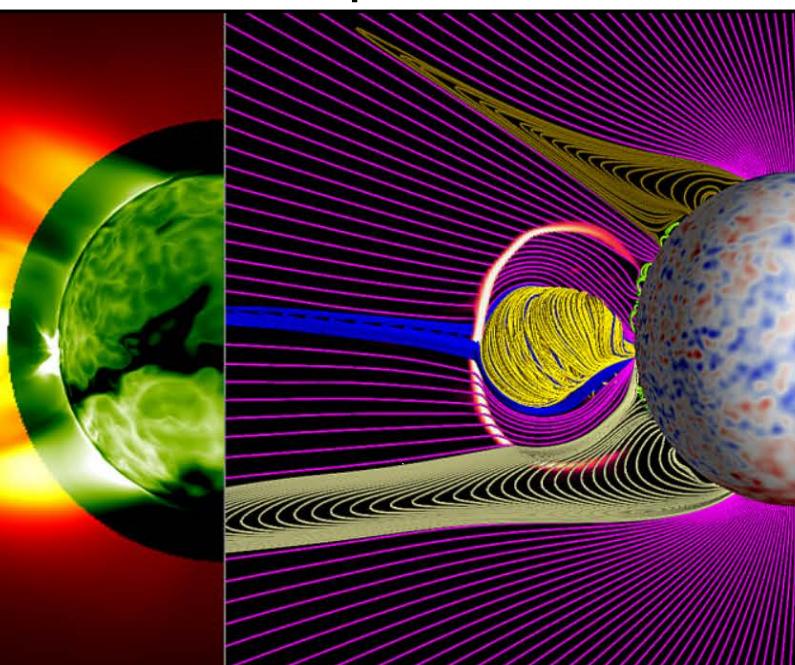
A number of models of the ionosphere and thermosphere have been transitioned to operations at ASTRA, including the TIEGCM, TIMEGCM, and AMIE. We describe ongoing work to improve these models and to provide model outputs at various latencies for different applications.



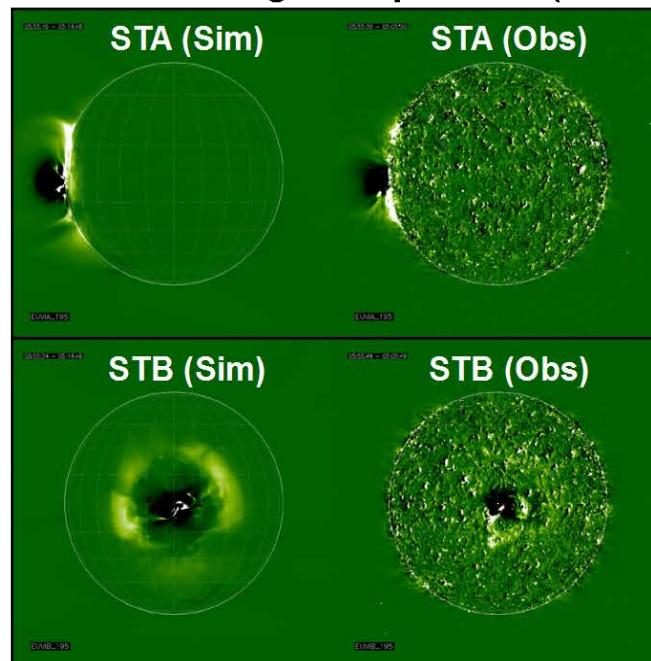
Predictive Science, Inc.

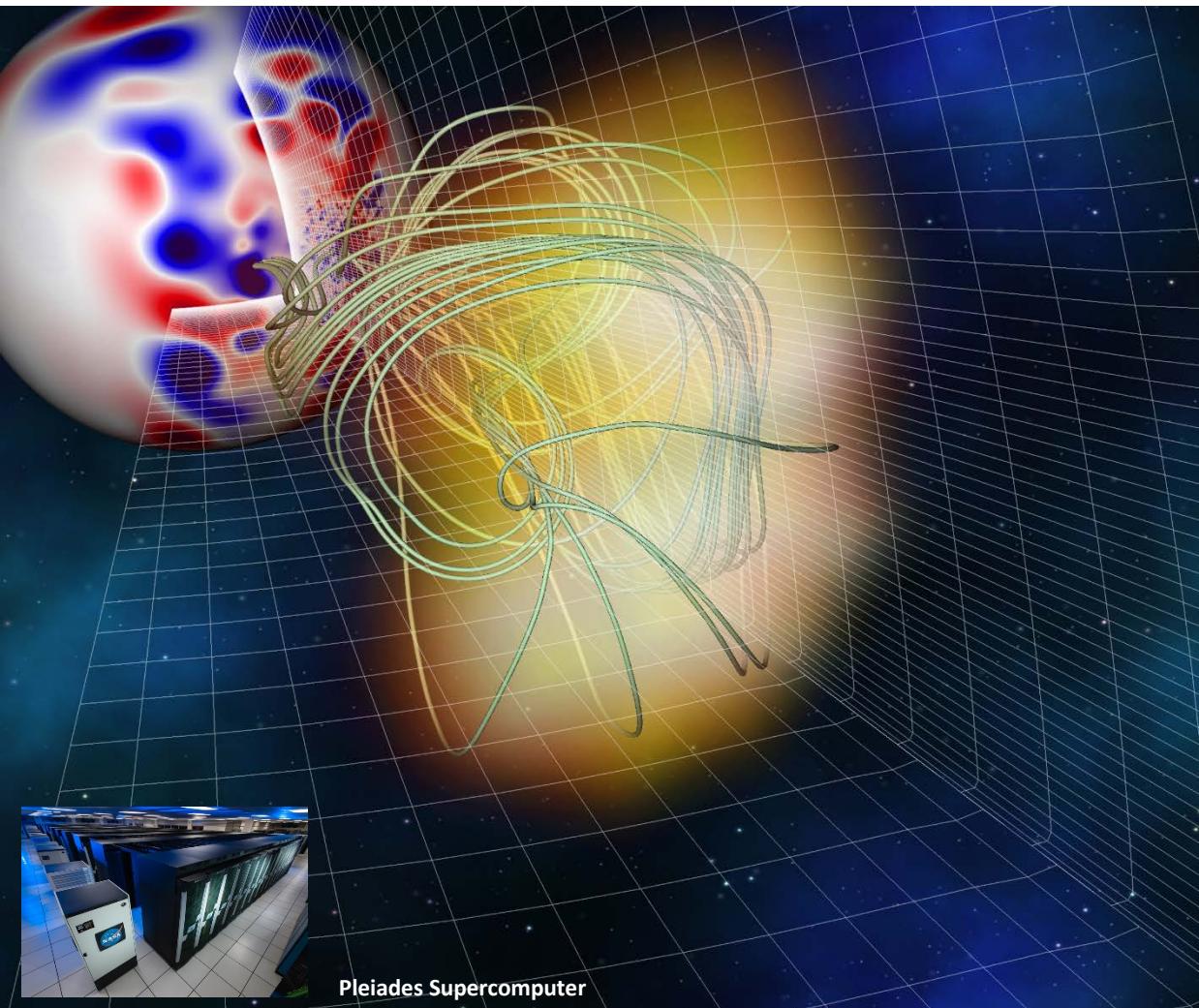
CME initiation and Evolution

CME Observables / Flux Rope Connection



CME Dimming Comparison (EUV)



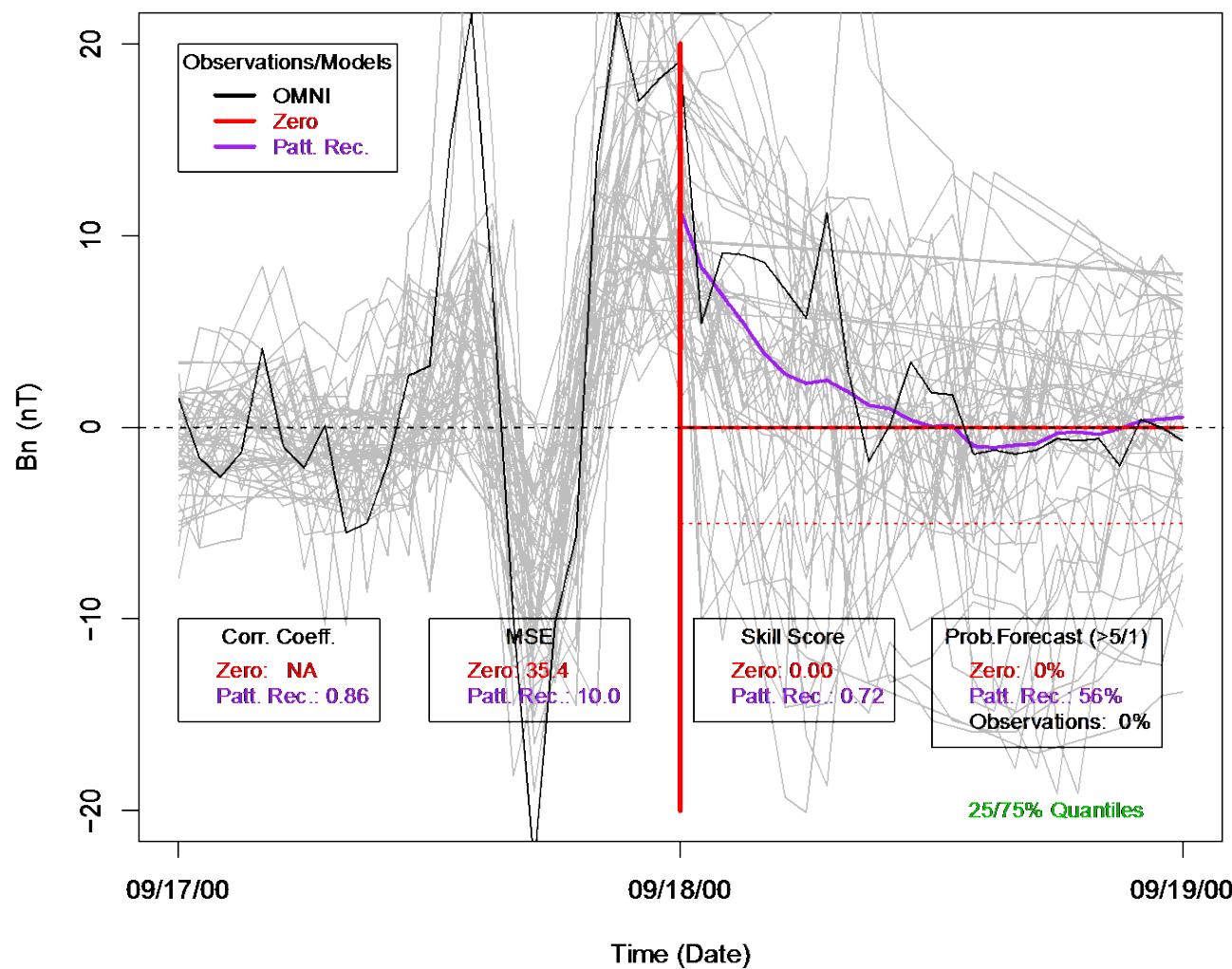


The MAS code

- Thermodynamic resistive magnetohydrodynamic model.
- Written in Fortran 90 with MPI parallelism.
- Non-uniform mesh.
- Semi-implicit predictor-corrector time-stepping.
- Actively developed over 10 years.
- Available for use at NASA's Community Coordinated Modeling Center (CCMC).
- Simulations of over 50 million cells scaled to thousands of processors are run on NASA's Pleiades supercomputer.



Predicting Bz at 1 AU using Pattern Recognition





Predicting Solar Wind Speed

