Ensemble Modeling with Data Assimilation Models: A New Strategy for Space Weather Specifications and Forecasts

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Science Focus

- **Elucidate the fundamental physical, chemical, and coupling processes that operate in the I-T-E system for a range of *actual, global-scale, space weather events*, including storms & substorms.**

- **Identify the spatial and temporal scales over which mass, momentum, and energy flow in the system.**

- **Determine the effect that *plasma and neutral gas structures (100-1000 km) have on global-scale flows.***

Model Construction

Construct a *Multimodel Ensemble Prediction System (MEPS)* for the Ionosphere-Thermosphere-Electrodynamics (I-T-E) system that will incorporate existing, first-principles-based, data assimilation models with different physics, numerics and initial conditions.

MEPS will allow ensemble modeling with different data assimilation models.

Data Assimilation Models

GAIM-BL ➔ Mid & Low Latitudes

GAIM-GM ➔ Mid & Low Latitudes

GAIM-4DVAR ➔ Mid & Low Latitudes, with Drivers

GAIM-FP ➔ Mid & Low Latitudes, with Drivers

IDED-DA ➔ High Latitudes, with Drivers

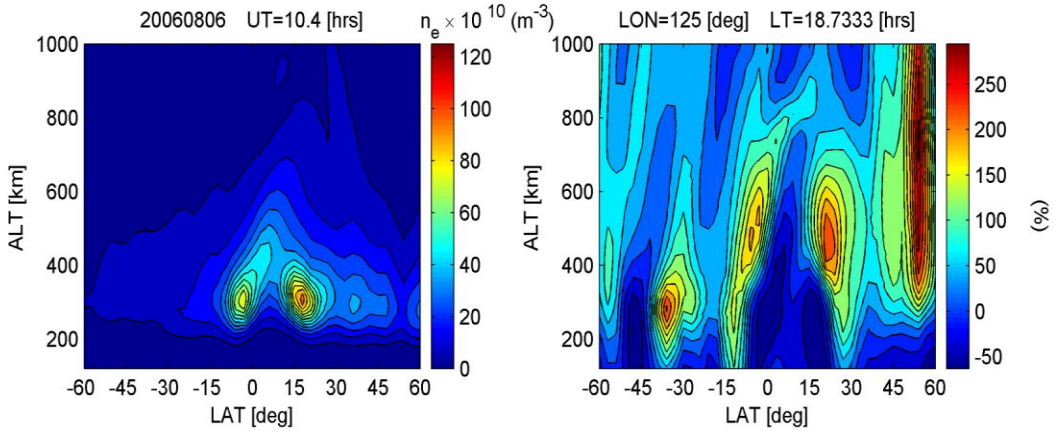
Mid-Low Electro-DA ➔ Ionosphere with Drivers

GTM-DA ➔ Global Thermosphere

- **Global, Regional & Nested GRID Capabilities**
- **GAIM-GM & GAIM-BL are Operational Models**
- **Specifications & Forecasts**

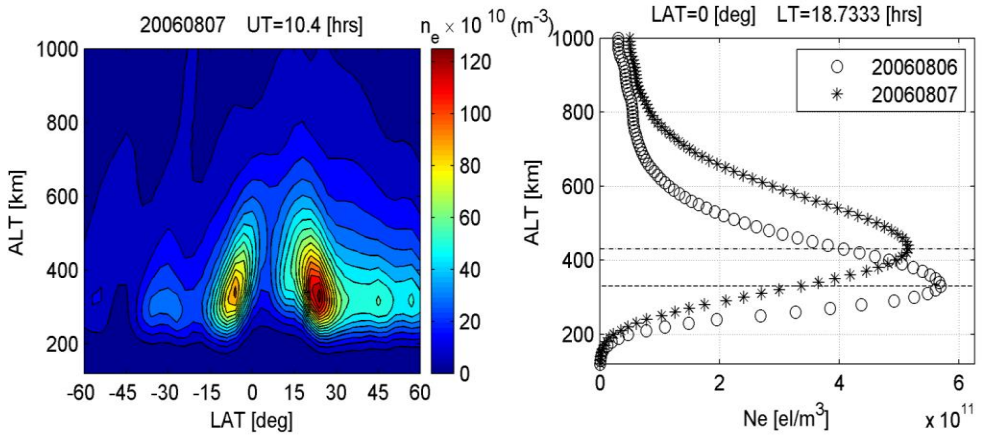
GAIM-BL Ionosphere Reconstructions

Ne Quiet



ΔNe

Ne Storm



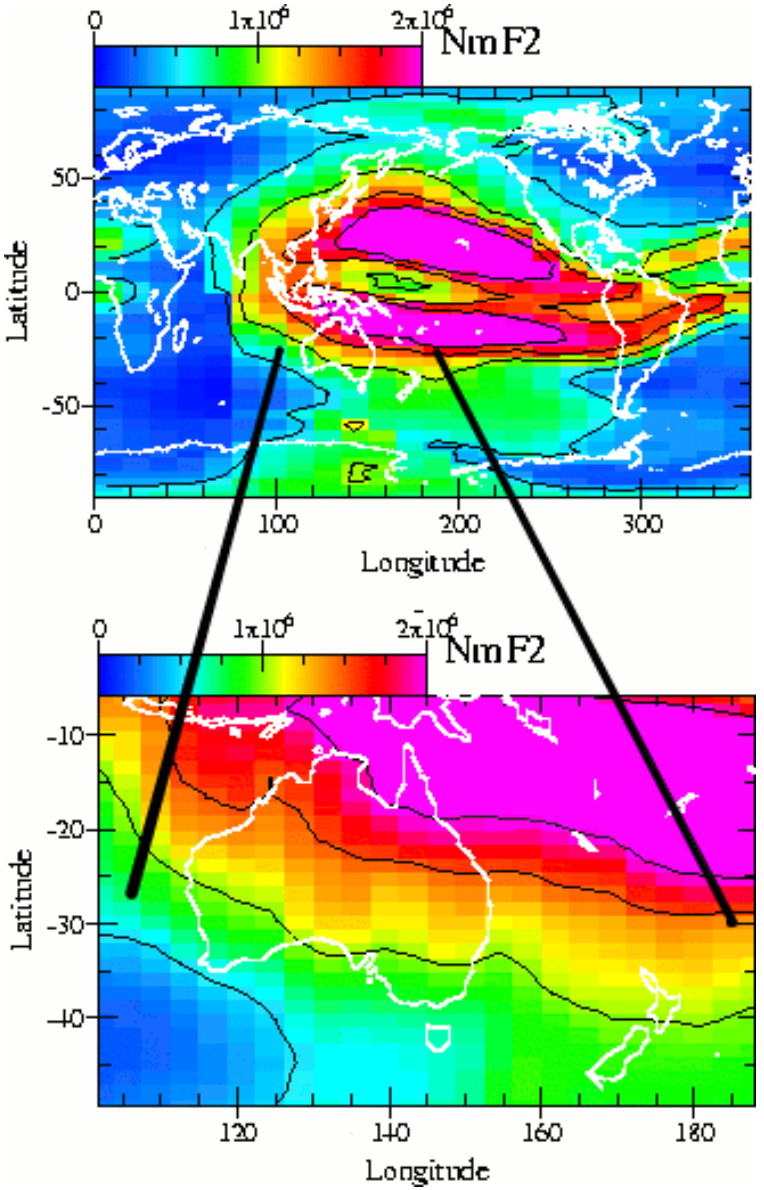
Ne Profiles

- **GAIM-BL assimilated ground-based and spaceborne (COSMIC) GPS data.**
- **August 7, 2006 storm**
- **Data assimilation reveals storm-time enhanced zonal E-field and equatorial anomaly.**

[Pi et al., 2009]

GAIM-GM Nested Grid Capability

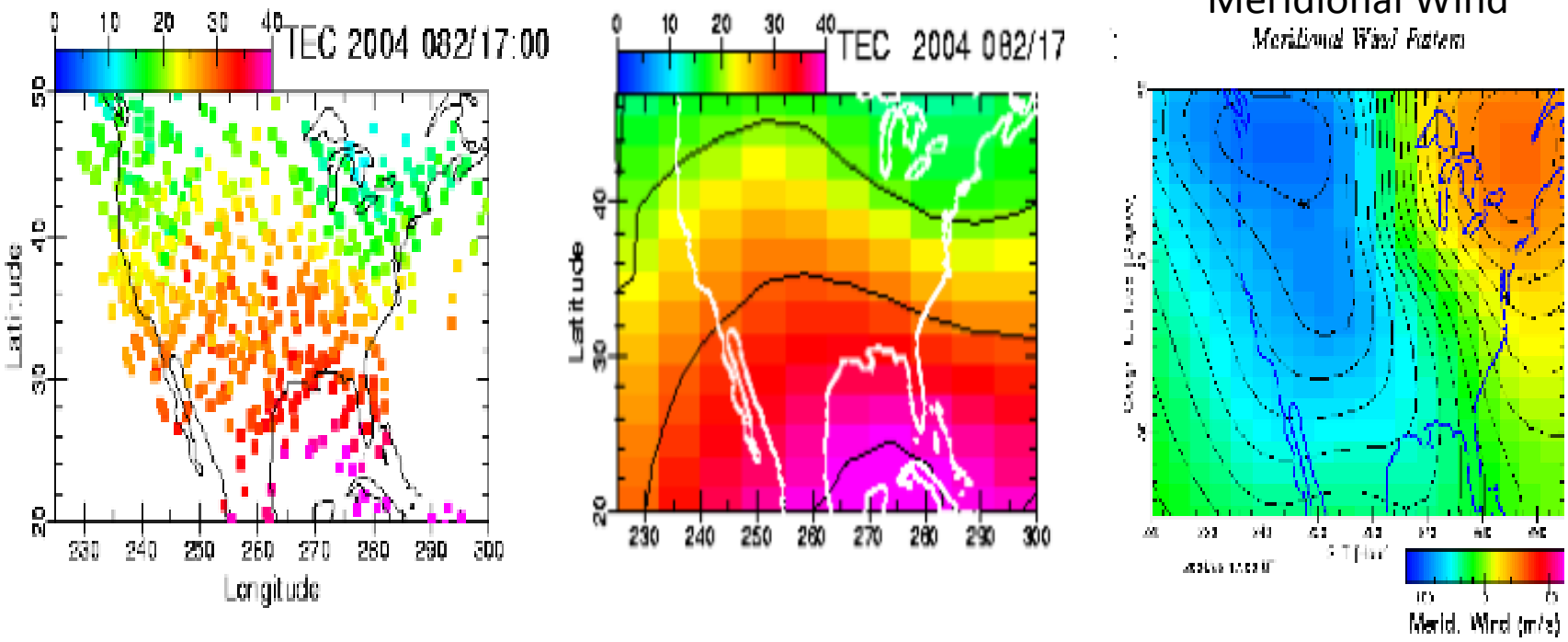
- Improved Spatial Resolution
  - 1˚ Latitude (variable)
  - 3.75˚ Longitude (variable)
- Usefulness Depends on Data
- Capability Since 2004 in GAIM-GM Operational Model
- In 2004 Run - 11 ionosondes & 15 GPS in Nested Grid Region
- Captures Edge of Anomaly



Ionosphere Reconstructions With Self-Consistent Drivers

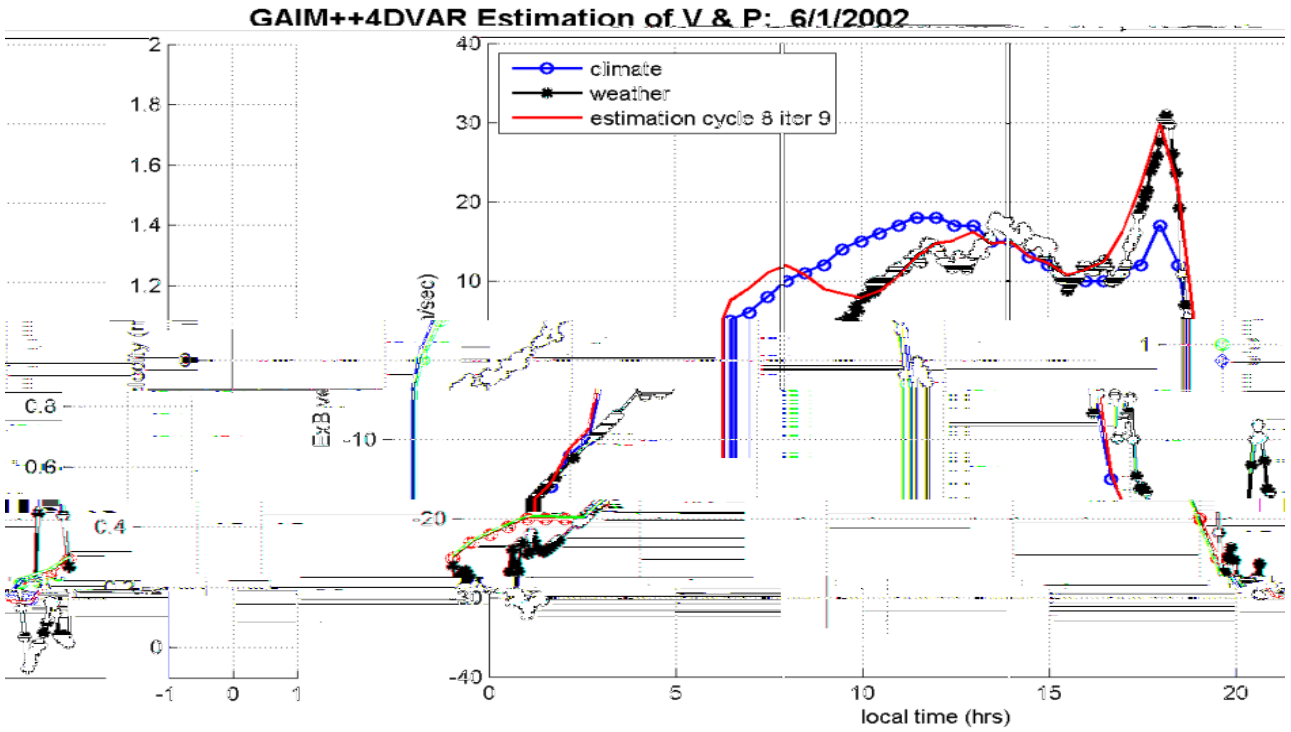
GAIM-FP ➔Regional Run

(Ensemble Kalman Filter)



- Snapshots of TEC measurements (left)
- GAIM-FP reconstruction (middle)
- GAIM-FP neutral wind at 300 km (right)
- 17:00 UT, day 82, 2004

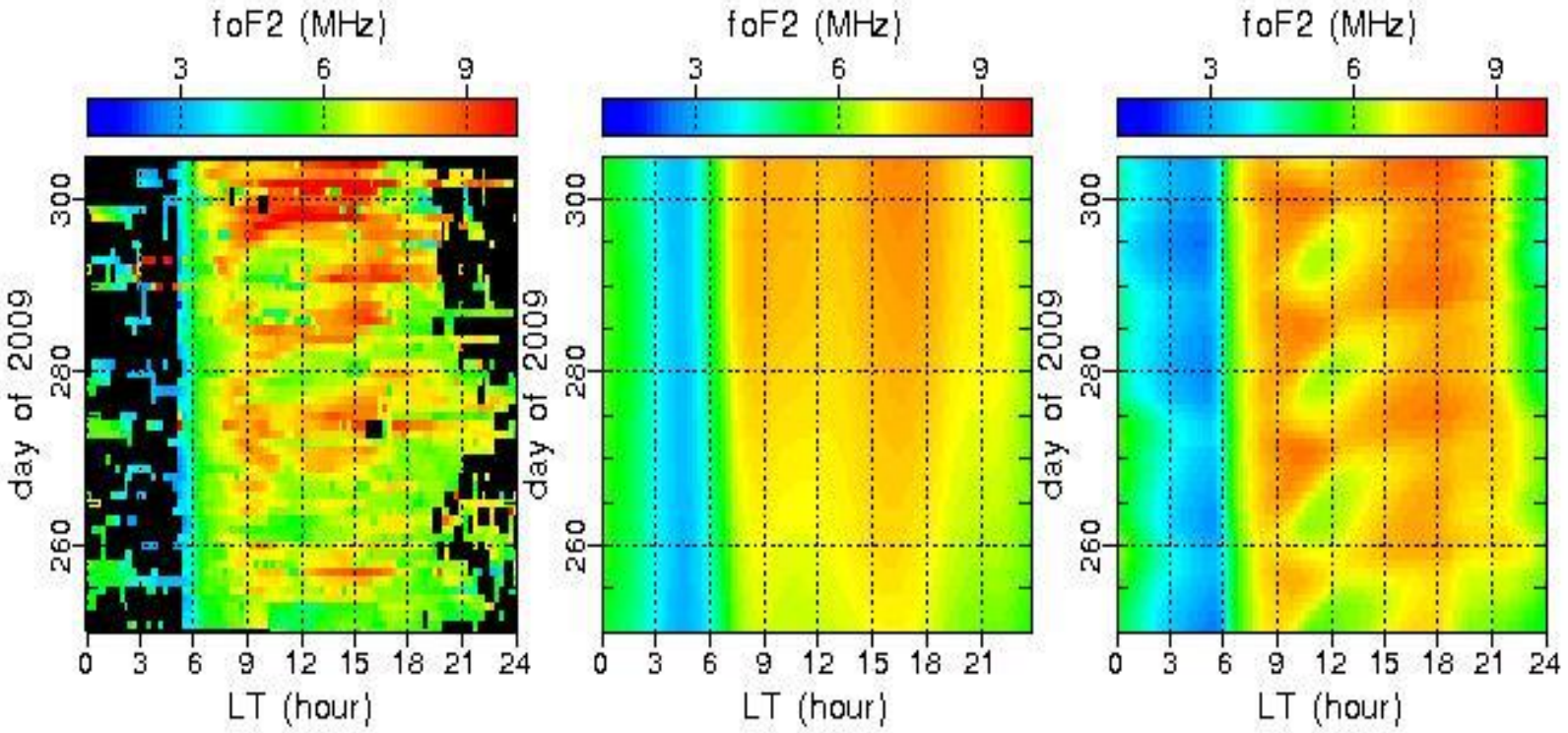
Ionosphere Reconstructions With Self-Consistent Drivers
GAIM - 4DVAR



- **Estimate equatorial electric field/plasma drift, ion production factor, and wind.**
- **Black circles indicate ISR measurements made at the Jicamarca Radio Observatory**
- **Blue curve is an empirical model result**
- **Red curve presents estimated vertical drift and a single-ion production factor**
- **Data assimilation helps GAIM catch the pre-reversal enhancement**

  [Pi et al., 2008].

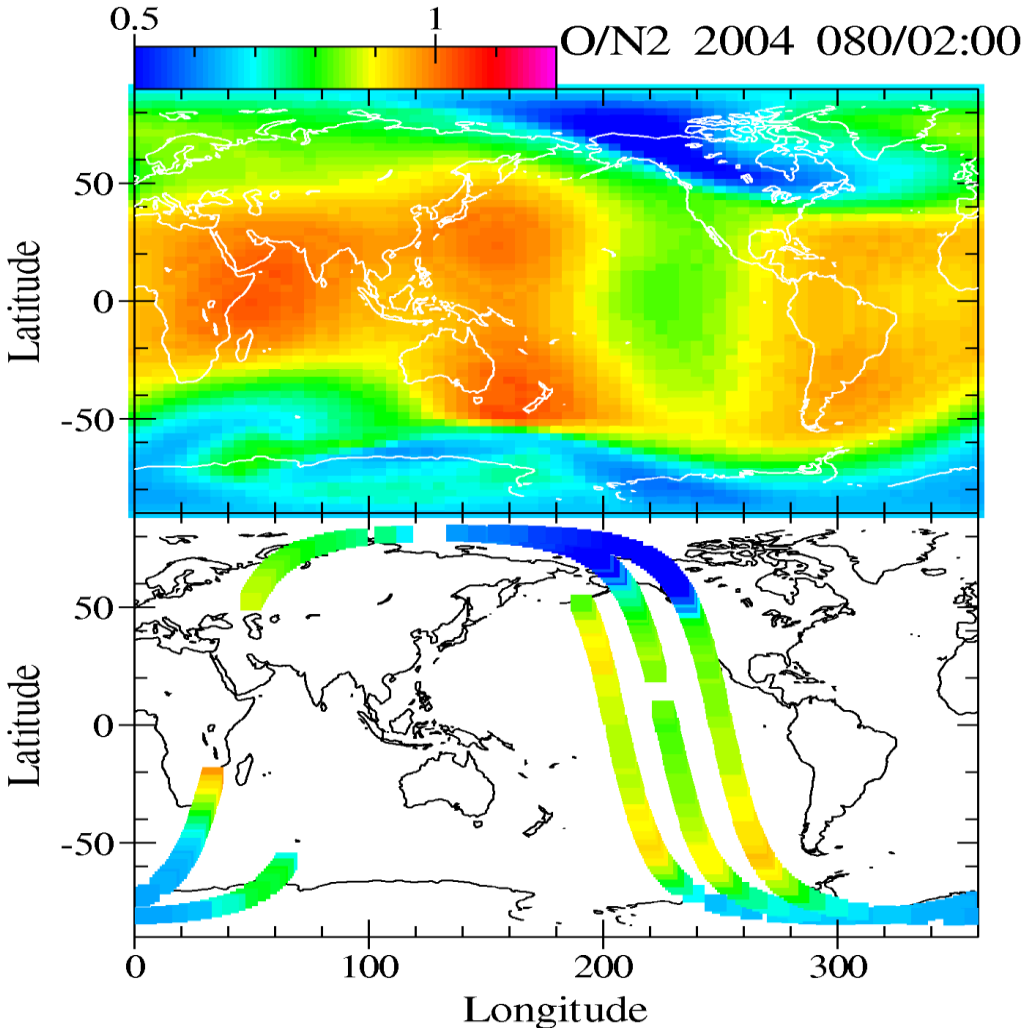
Ionosphere-Electrodynamics Reconstructions (Mid & Low Lat. Electrodynamics – DA)



- **Observed *foF$_2$* at Jicamarca (left)**
- **Modeled *foF$_2$* using Scherliess and Fejer plasma drifts (center)**
- **Derived *foF$_2$* using an ensemble data assimilation model (right)**
- **Captures lunar and solar tides**

(*Eccles et al., 2011*)

Global Thermosphere Reconstructions
GTM-DA
(Ensemble Kalman Filter)



Global O/N_2 reconstruction from an ensemble Kalman Filter GTM-DA run

Synthetic SSUSI O/N_2 observations from 3 DMSP satellites were assimilated

Ensemble Kalman Filter for High-Latitude Electrodynamics & Ionosphere (IDED-DA)

High-Resolution Specification of Convection, Precipitation, Currents & Ionosphere

Runs on 30 CPUs

Physics-Based Model

Time-Dependent Ionosphere Model

- 3-D Density Distributions (NO^+,O_2^+,N_2^+,O^+,H^+,He^+)
- 3-D T_e and T_i Distributions
- Ion Drifts Parallel & Perpendicular to B
- Hall & Pedersen Conductances

M-I Electrodynamics Model

- MHD Transport Equations & Ohm's Law
- Alfven Wave Propagation
- Active Ionosphere
- 10 km & 5 sec Resolutions
- Potential, E-field, Currents, Joule Heating

Magnetic Induction Model

- Calculates B Perturbations in Space & on Ground
- Includes Earth's Induction Effect

Data Assimilated in Model Runs

- Ground Magnetic Data from 100 Sites
- Cross-Track Velocities from 4 DMSP Satellites
- Line-of-Sight Velocities from 9 SuperDARN Radars
- In-situ Magnetic Perturbations from the 66 IRIDIUM Satellites

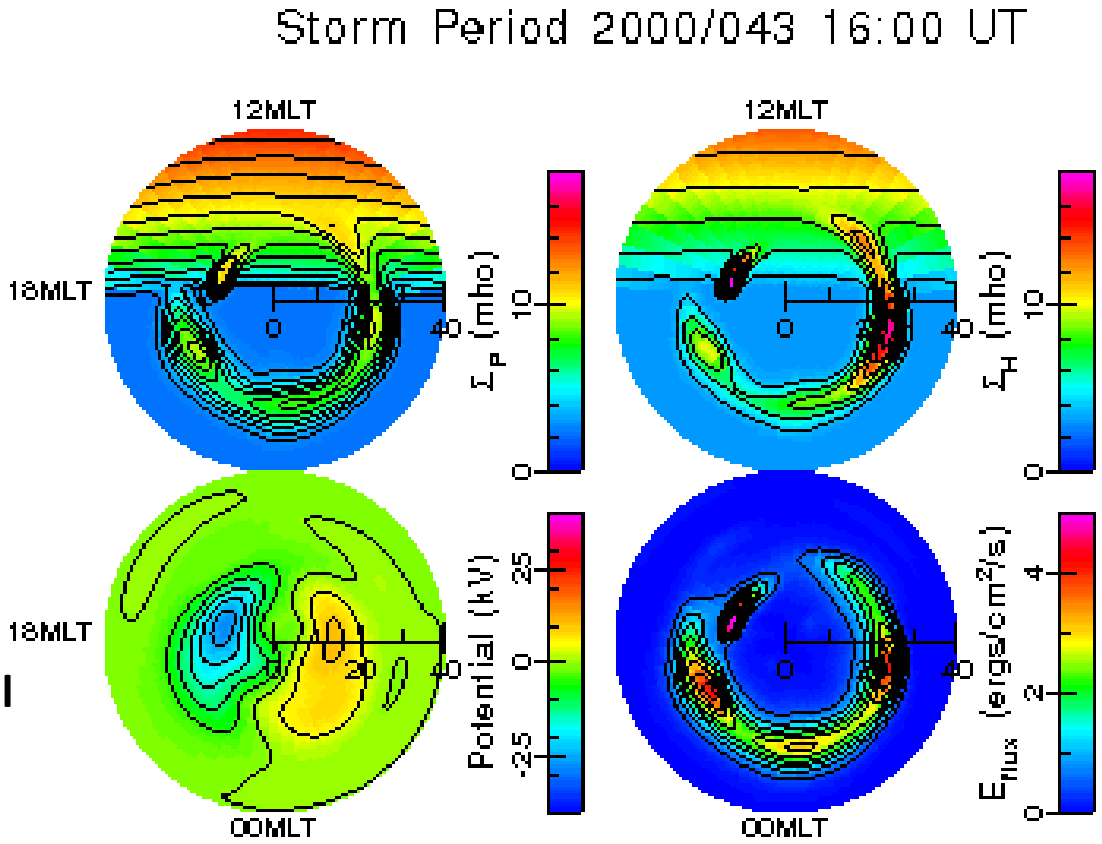
Output of the Ionosphere Dynamics & Electrodynamics Data Assimilation Model

- Electric Potential
- Convection Electric Field
- Energy Flux and Average Energy of Precipitation
- Field-Aligned and Horizontal Currents
- Hall and Pedersen Conductances
- Joule Heating Rates
- 3-D Electron and Ion Densities
- 3-D Electron and Ion Temperatures
- TEC
- Ground and Space Magnetic Disturbances

Ionosphere-Electrodynamics Reconstructions
IDED-DA

Height-integrated Pedersen conductance

Electric potential



Height-integrated Hall conductance

Precipitating electron energy flux

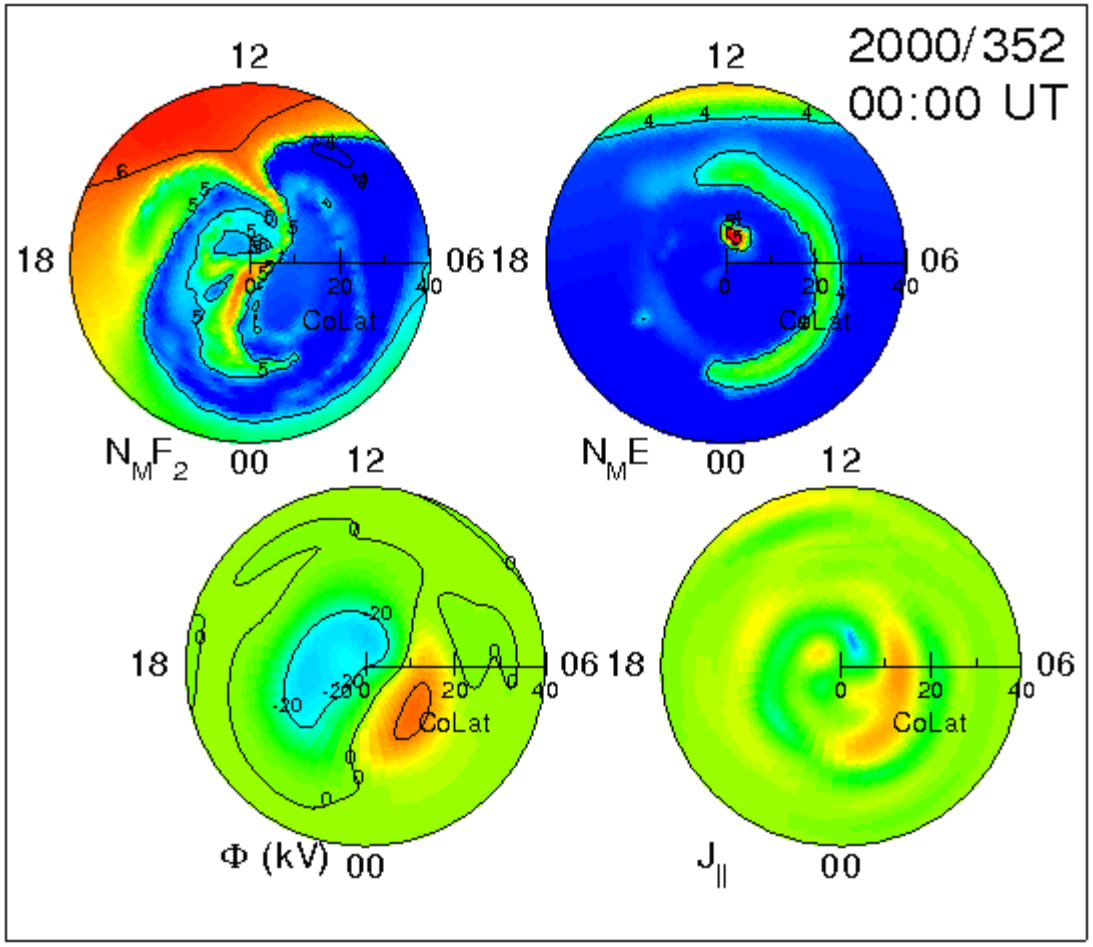
- Northern polar region
- Storm period 2000/43 12:00 UT

Note Structure

Plasma Patch Dynamics
IDED-DA

- Quiet to moderately disturbed geomagnetic conditions.
- Iono-Electro Model assimilated magnetometer data.
- Ionosphere Forecast Model (IFM) was run in 1 deg by 1 deg resolution (it can be run at higher resolutions)
- IFM used Electro results (5 minute cadence)
  - convection potential
  - precipitation fluxes
  - precipitation characteristic energy

  IMF change from southward to northward Bz produced plasma patches


2000/352
00:00 UT
12
18
06
00
CoLat
$N_M F_2$
$N_M E$
Φ (kV)
$J_{||}$

Data Sources for MEPS

Table 1. Data Sources that our new Data Assimilation System will assimilate

Ionosphere	Electrodynamics	Thermosphere
Ground-Based GPS-TEC	Ground magnetometers	Satellite UV emissions
Satellite-Based GPS Occultation	DMSP cross-track velocities	In situ neutral densities and winds
Ionosonde and Digisonde	SuperDARN line-of-sight velocities	Satellite accelerometer and drag
In situ N_e	Iridium magnetometers	FPI winds
911Å, 1356Å, limb, disk (UV)	ACE IMF, Dst	ISR Neutral parameters
Solar UV, EUV	Solar UV, EUV	Solar UV, EUV

Black: Data sources already being assimilated; Red: New data sources to be assimilated

Summary

- MEPS → ensemble modeling with different data assimilation models
- Data assimilation on multiple spatial & temporal scales
- Wide range of ground and space data
- An important tool for studying basic physics
- Can combine different data sets into a coherent picture
- Fills in regions where there are no data
- Can be used to study unresolved problems
- New approach to specifications and forecasts