

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

## **Utah State University**

R. W. Schunk, L. Scherliess, V. Eccles, L. C. Gardner, J. J. Sojka and L. Zhu

## **Jet Propulsion Laboratory**

X. Pi, A. J. Mannucci, B. D. Wilson, and A. Komjathy

## **University of Southern California**

C. Wang and G. Rosen

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# NASA/NSF Collaborative Space Weather Modeling Program

## 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**

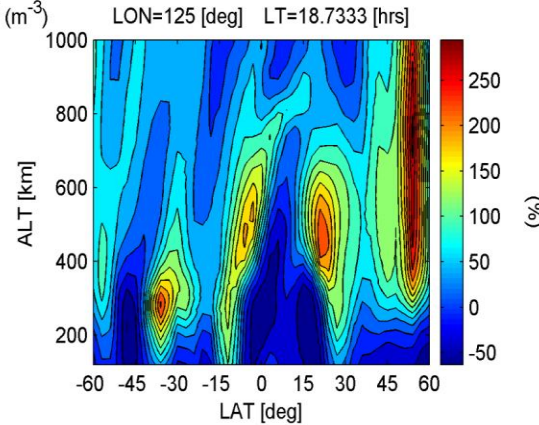
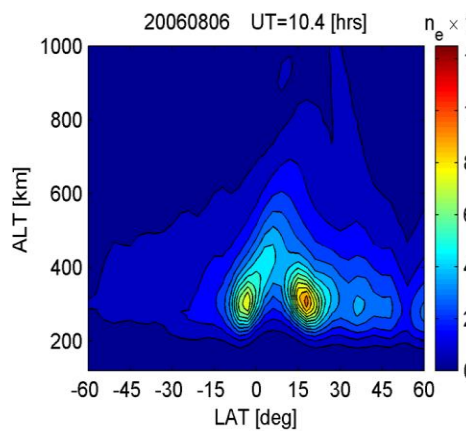
**Mid-Low Electro-DA → Ionosphere with Drivers**

**GTM-DA → Global Thermosphere**

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

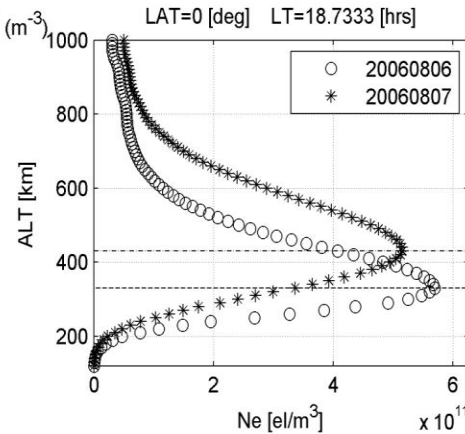
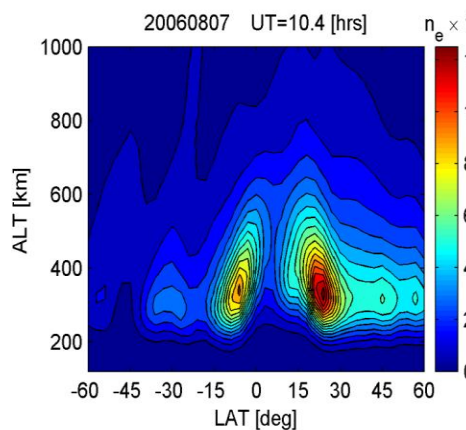
# GAIM-BL Ionosphere Reconstructions

Ne  
Quiet



$\Delta Ne$

Ne  
Storm

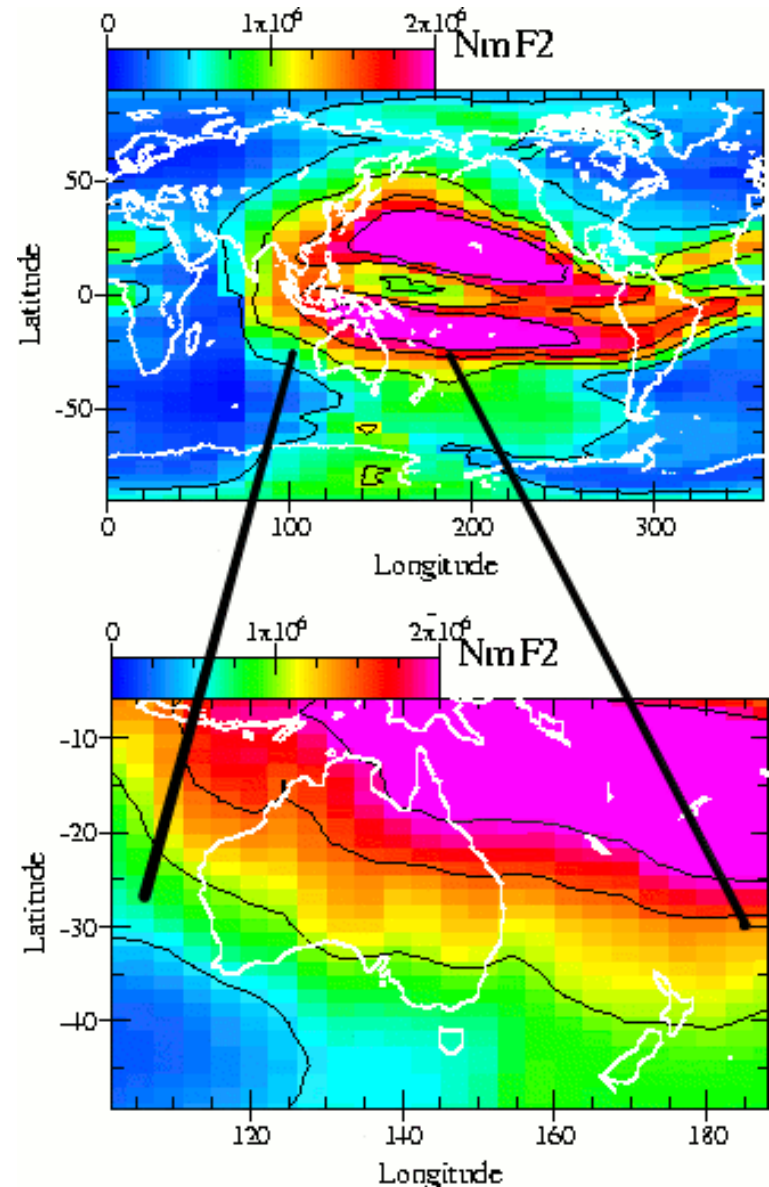


Ne Profiles

- 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.

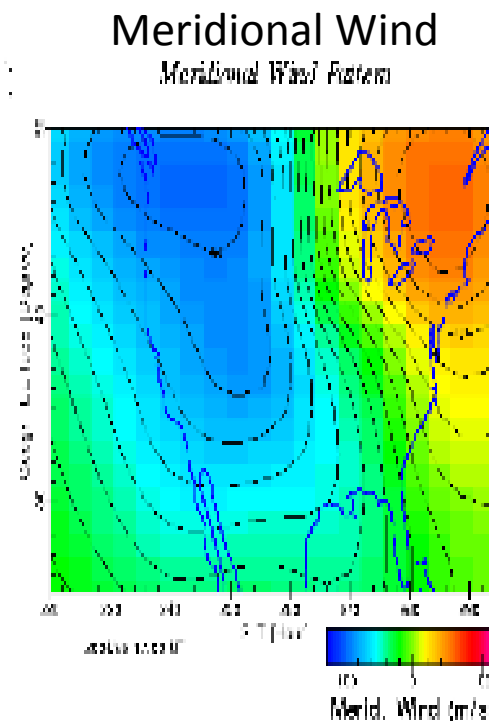
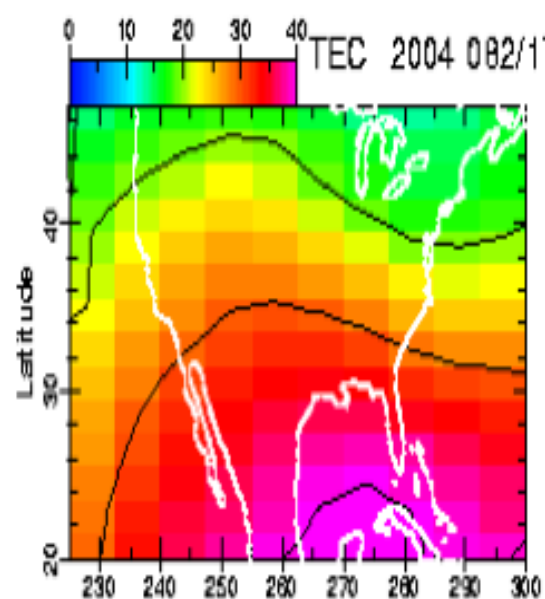
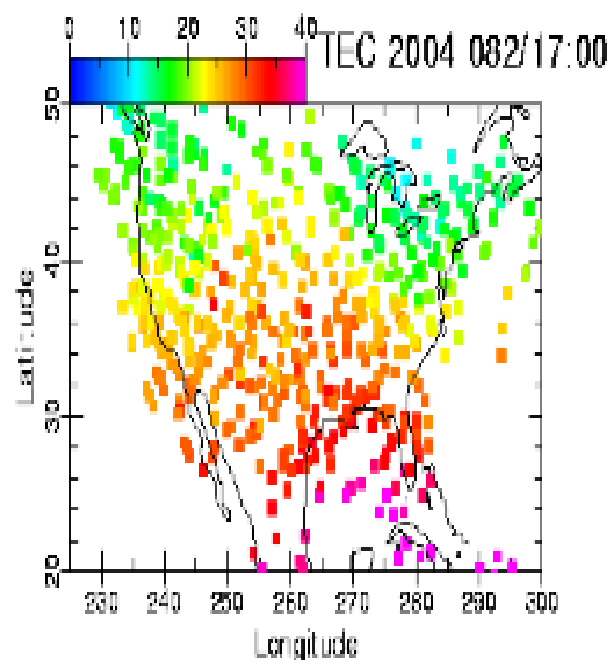
# GAIM-GM **Nested Grid** Capability

- 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

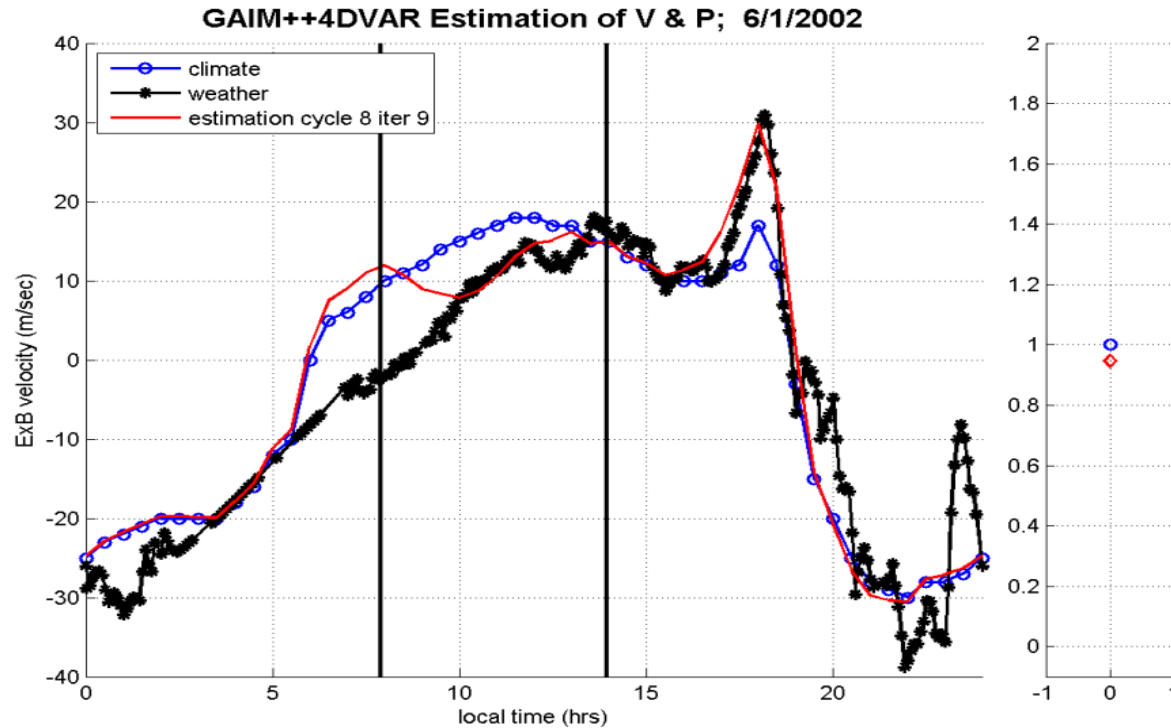
## GAIM-FP → Regional Run (Ensemble Kalman Filter)



- 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

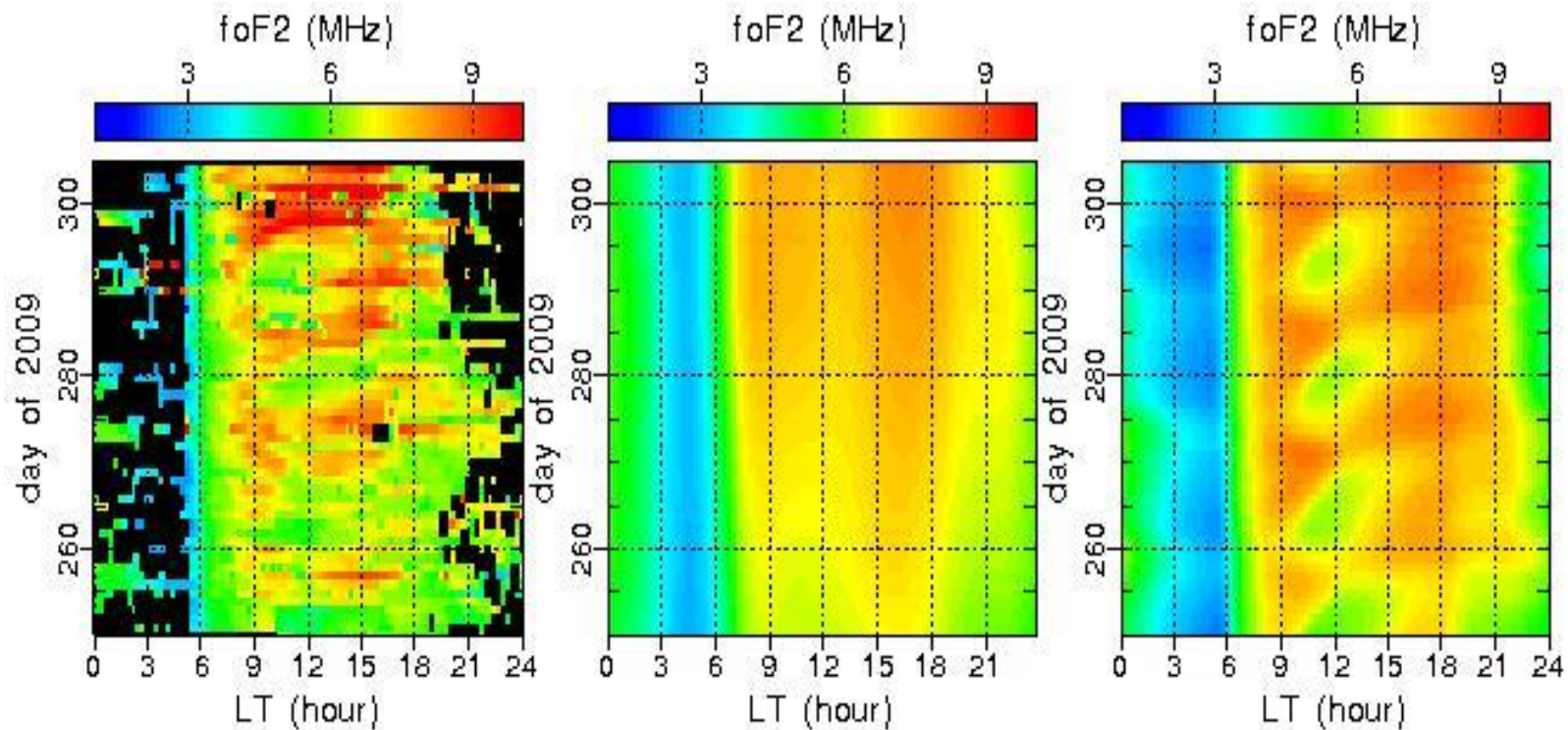


- Estimate equatorial electric field/plasma drift, ion production factor, and wind.
- Black circles indicate ISR measurements made at the Jicamarca Radio Observatory
- Blue curve is an empirical model result
- Red curve presents estimated vertical drift and a single-ion production factor
- Data assimilation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

[Pi et al., 2008].



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



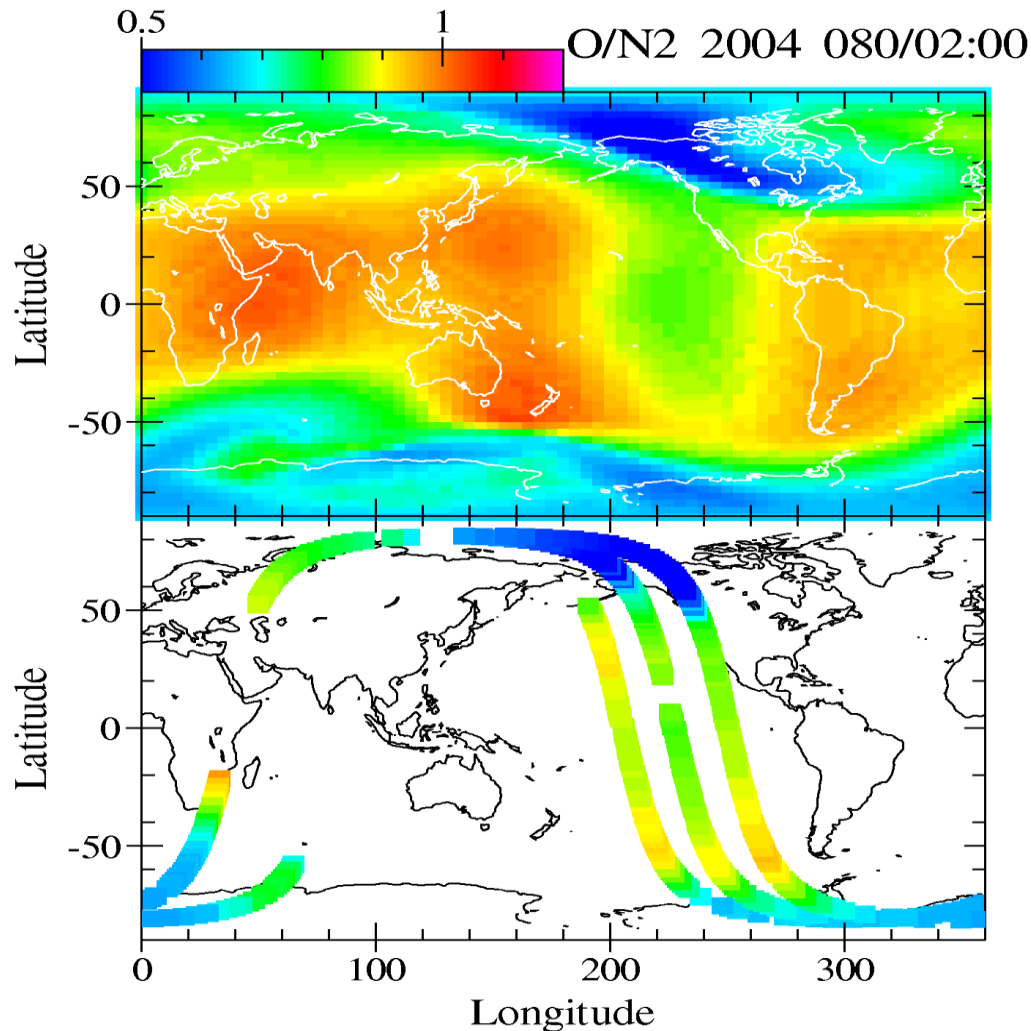
- Observed  $foF_2$  at Jicamarca (left)
- Modeled  $foF_2$  using Scherliess and Fejer plasma drifts (center)
- Derived  $foF_2$  using an **ensemble data assimilation model** (right)
- Captures lunar and solar tides

(Eccles et al., 2011)

# Global Thermosphere Reconstructions

## GTM-DA

### (Ensemble Kalman Filter)



**Global O/N<sub>2</sub> reconstruction  
from an ensemble Kalman  
Filter GTM-DA run**

**Synthetic SSUSI O/N<sub>2</sub> 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

- 0 3-D Density Distributions ( $\text{NO}^+$ ,  $\text{O}_2^+$ ,  $\text{N}_2^+$ ,  $\text{O}^+$ ,  $\text{H}^+$ ,  $\text{He}^+$ )
- 0 3-D  $T_e$  and  $T_i$  Distributions
- 0 Ion Drifts Parallel & Perpendicular to B
- 0 Hall & Pedersen Conductances

## M-I Electrodynamics Model

- 0 MHD Transport Equations & Ohm's Law
- 0 Alfvén Wave Propagation
- 0 Active Ionosphere
- 0 10 km & 5 sec Resolutions
- 0 Potential, E-field, Currents, Joule Heating

## Magnetic Induction Model

- 0 Calculates B Perturbations in Space & on Ground
- 0 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**

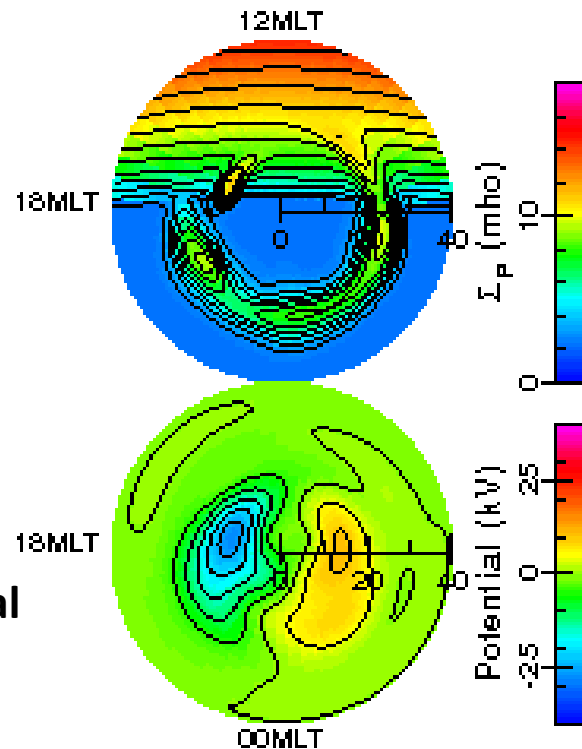
- **Electric Potential**
- **Convection Electric Field**
- **Energy Flux and Average Energy of Precipitation**
- **Field-Aligned and Horizontal Currents**
- **Hall and Pedersen Conductances**
- **Joule Heating Rates**
- **3-D Electron and Ion Densities**
- **3-D Electron and Ion Temperatures**
- **TEC**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

# Ionosphere-Electrodynamics Reconstructions

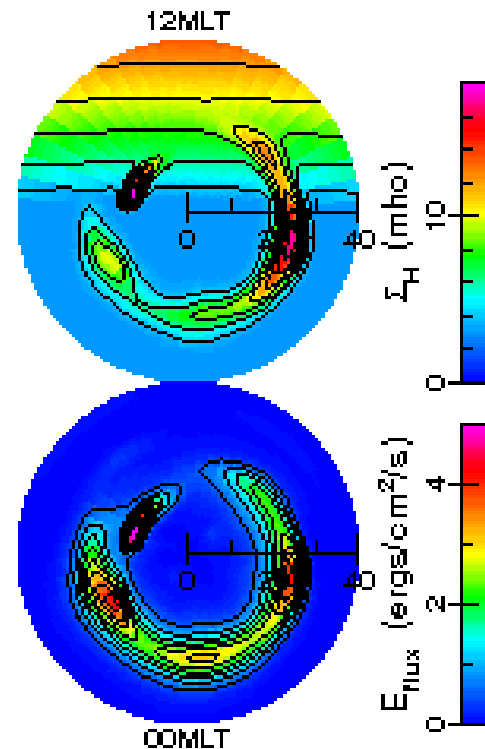
## IDED-DA

Storm Period 2000/043 16:00 UT

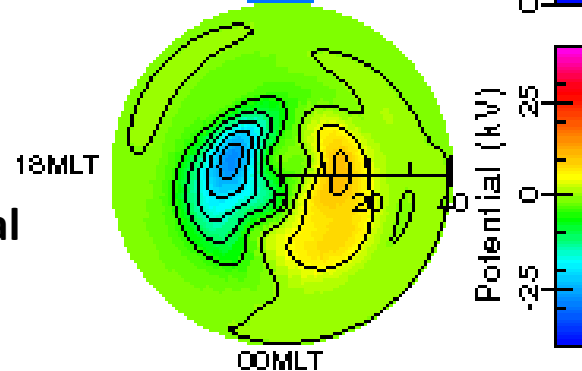
Height-integrated  
Pedersen  
conductance



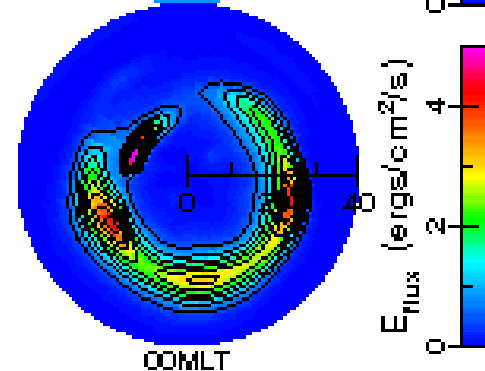
Height-integrated  
Hall conductance



Electric potential



Precipitating  
electron  
energy flux



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

Note Structure

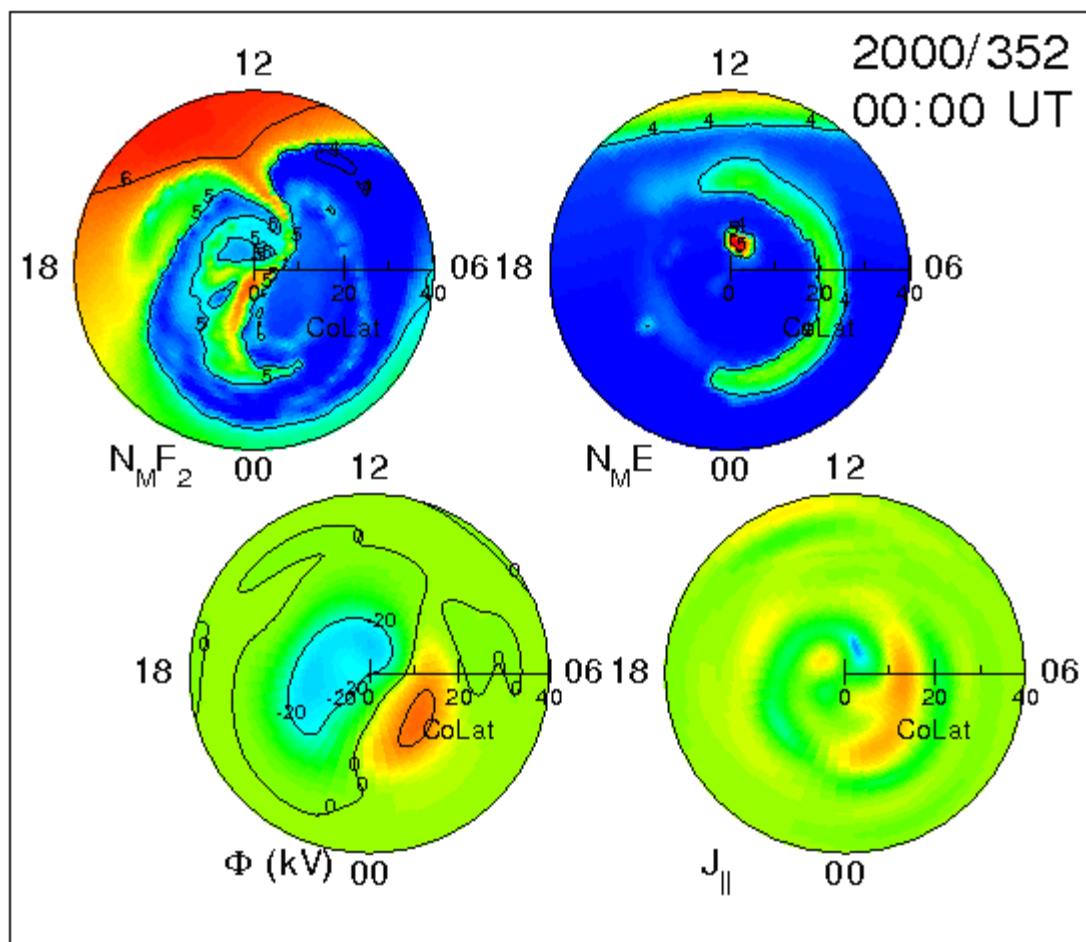
# Plasma Patch Dynamics

## 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  $B_z$  produced plasma patches**





# Data Sources for MEPS

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

<b>Ionosphere</b>	<b>Electrodynamics</b>	<b>Thermosphere</b>
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**