Operational Data Assimilation Models for Ionospheric Applications

R. W. Schunk, L. Scherliess,
D. C. Thompson, J. J. Sojka and L. Zhu

Center for Atmospheric & Space Sciences
Utah State University
Logan, Utah

Presented at:
Space Weather Workshop
April, 2010

USU Physics-Based Data Assimilation Models

1. **Kalman Filter Models of the Ionosphere**
   - **Gauss-Markov Model (GAIM-GM) – AFWA**
   - **Full Physics Model (GAIM-FP) – AFWA (2012)**
   - **Solar Wind – GAIM (GAIM-HAF) – AFWA**
2. **Ensemble Kalman Filter Model of High-Latitude Electrodynamics – USU SWC**
3. **Ensemble Kalman Filter Model of the Thermosphere – USU SWC**

GAIM
"Bringing The Pieces Together"

UtahStateUniversity

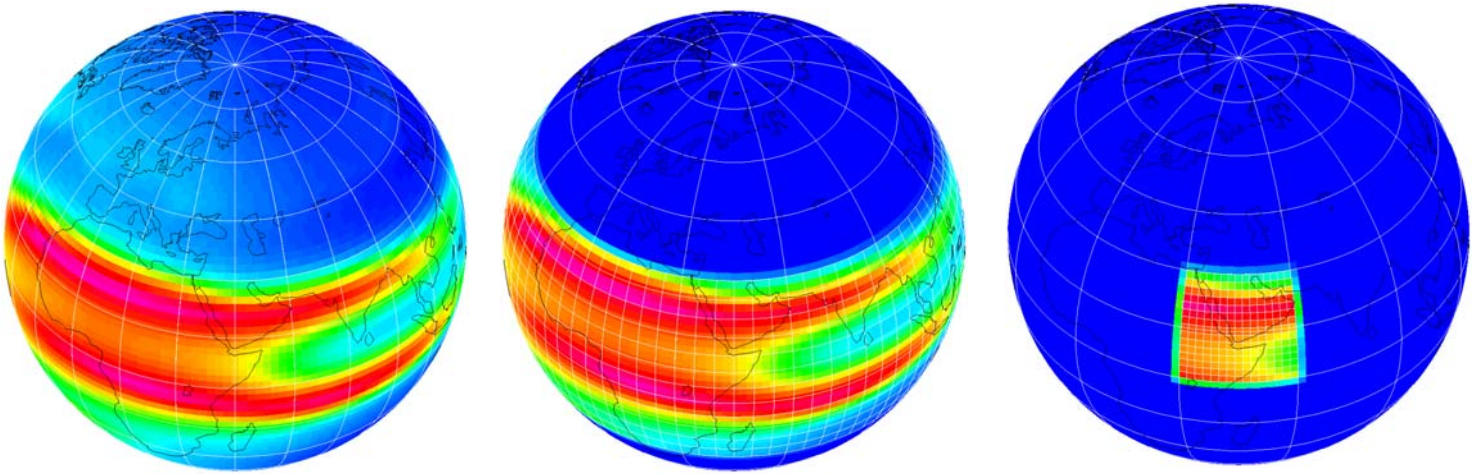
Other Operational Models

- **Ionosphere Forecast Model (IFM) – AFWA**
- **Kp Forecast Model – AFWA**
- **Real-time Dst Model – AFWA**
- **D- Region Model – CCMC**

GAIM Basic Approach

We use a physics-based ionosphere or ionosphere-plasmasphere model as a basis for assimilating a diverse set of real-time measurements. GAIM provides both specifications and forecasts on a global, regional, or local grid.

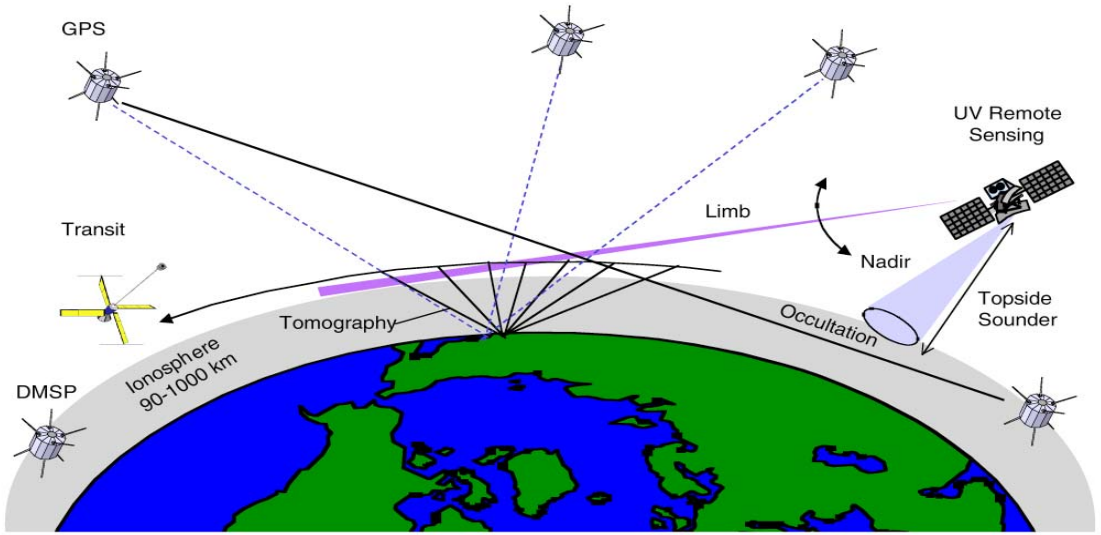
Global **Regional** **Local**



GAIM "Bringing The Pieces Together"

UtahStateUniversity

GAIM Assimilates Multiple Data Sources



- **Data Assimilated Exactly as They Are Measured**
  - **Bottomside N_e Profiles from Digisondes (80)**
  - **Slant TEC from more than 1000 Ground GPS Receivers**
  - **N_e Along Satellite Tracks (4 DMSP satellites)**
  - **Integrated UV Emissions (LORAAS, SSULI, SSUSI, TIP)**
  - **Occultation Data (CHAMP, IOX, SAC-C, COSMIC, C/NOFS)**

GAIM "Bringing The Pieces Together"

UtahStateUniversity

Gauss-Markov Kalman Filter Model (GAIM-GM)

- **Specification & Forecast of the Global Ionosphere**
- **Operational Model at AFWA**
- **Global Mode**
- **Regional Mode**
- **Nested Grid Combines Global and Regional Modes**
- **3-hour Latent Data Acceptance Window**
- **24-hour Forecast**
- **Independent Validation by AFRL**

GAIM
"Bringing The Pieces Together"

UtahStateUniversity

Ionosphere Forecast Model (IFM)

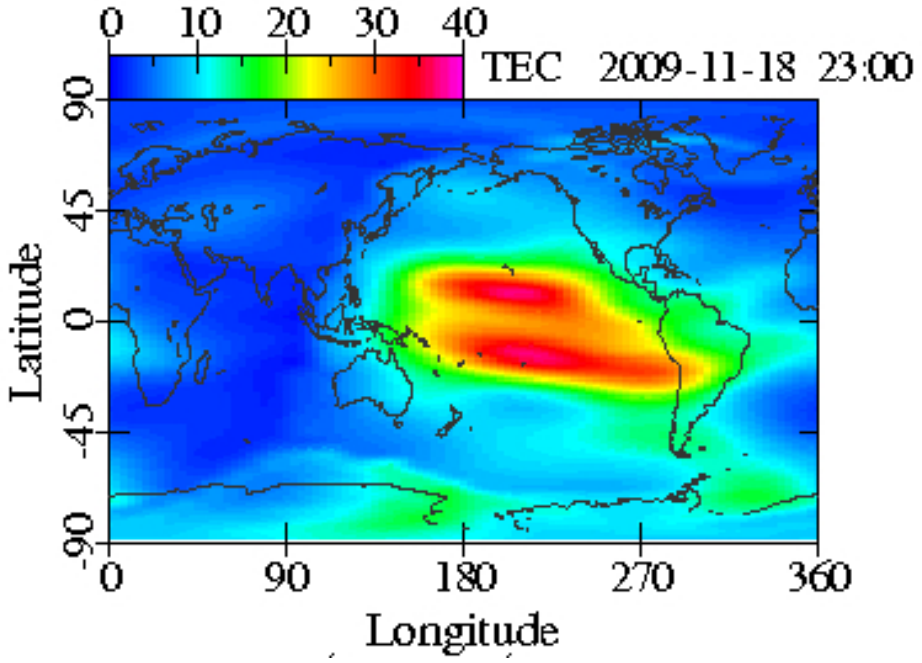
- **Global physics-based model**
- **Provides background ionosphere**
- **90 - 1400 km**
- **15 - minute output cadence**
- **O^+, H^+, NO^+, N_2^+, O_2^+, T_e, T_i**
  - **Only uses N_e**
- **Kalman solves for deviations from background**

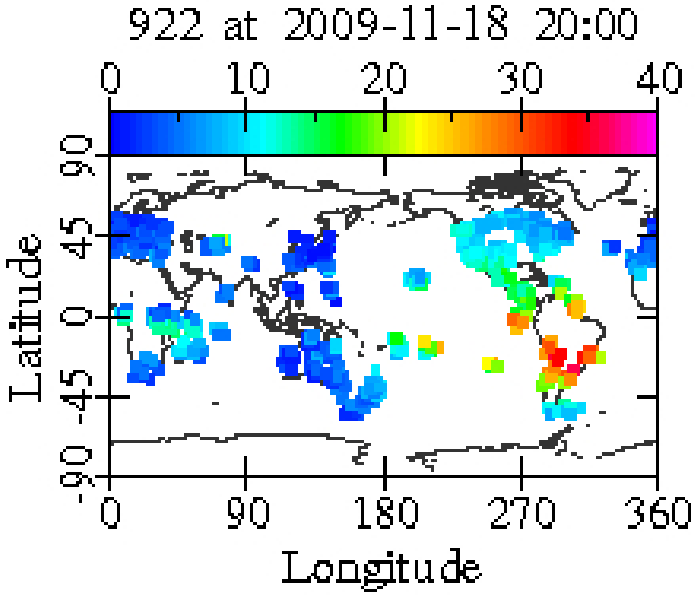
GAIM "Bringing The Pieces Together"

UtahStateUniversity

GAIM-GM global Run:

- 357 global TEC stations (IGS network) used in real-time at USU Space Weather Center
- Up to 10,000 measurements assimilated every 15- min



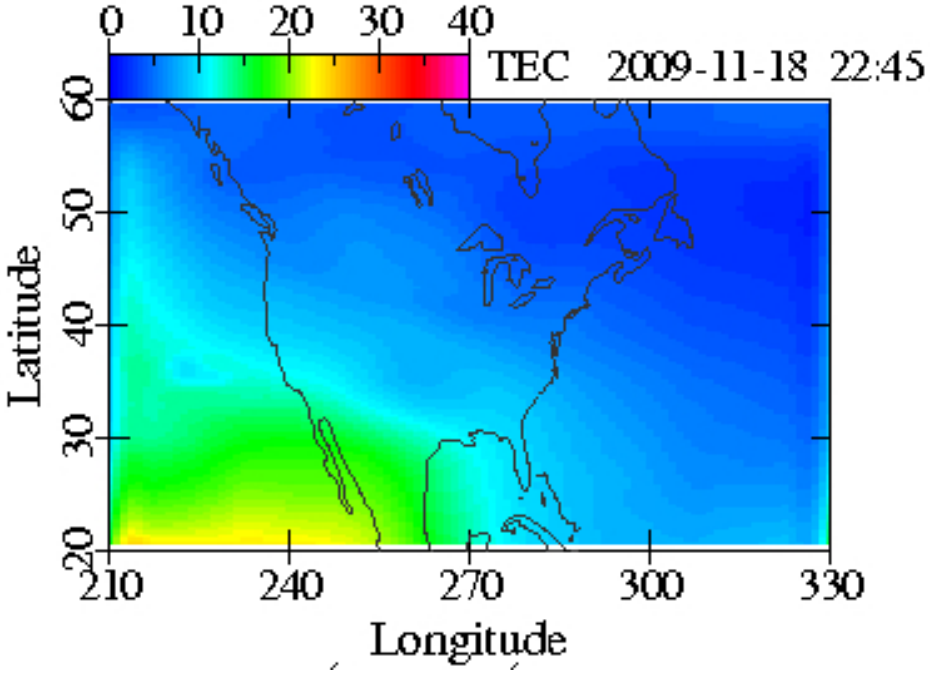


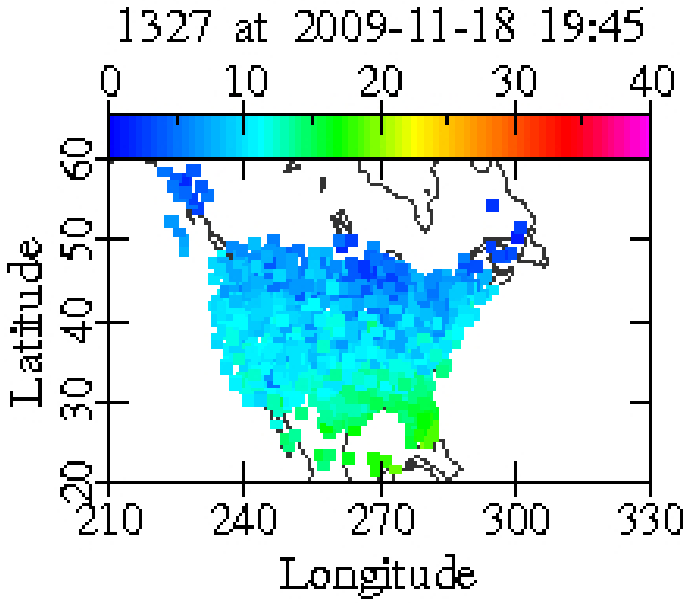
GAIM
"Bringing The Pieces Together"

UtahStateUniversity

GAIM-GM regional (High Resolution) Run:

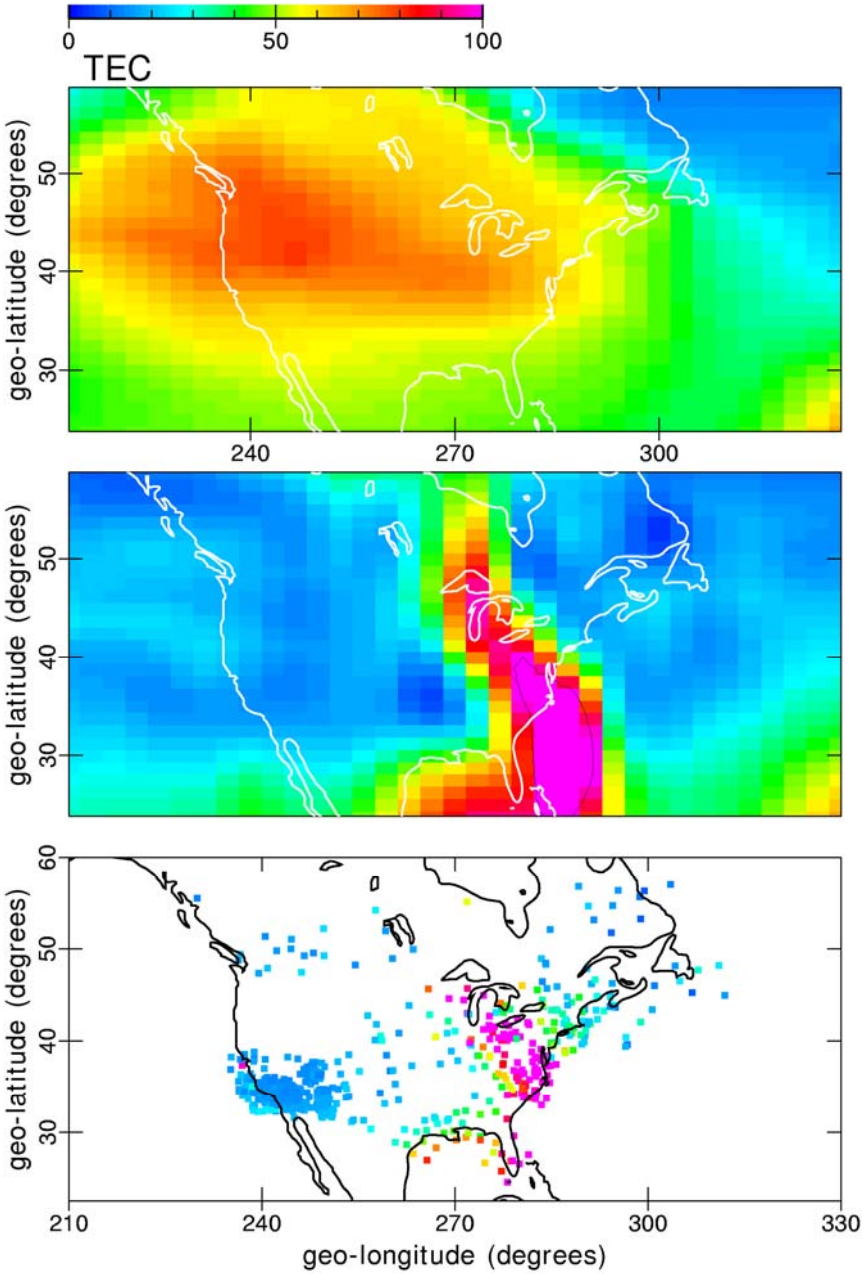
- 424 USTEC stations (CORS network) used in real-time at USU Space Weather Center
- Up to 10,000 measurements assimilated every 15-min





GAIM
"Bringing The Pieces Together"

UtahStateUniversity



IFM

Kalman Filter Reconstruction

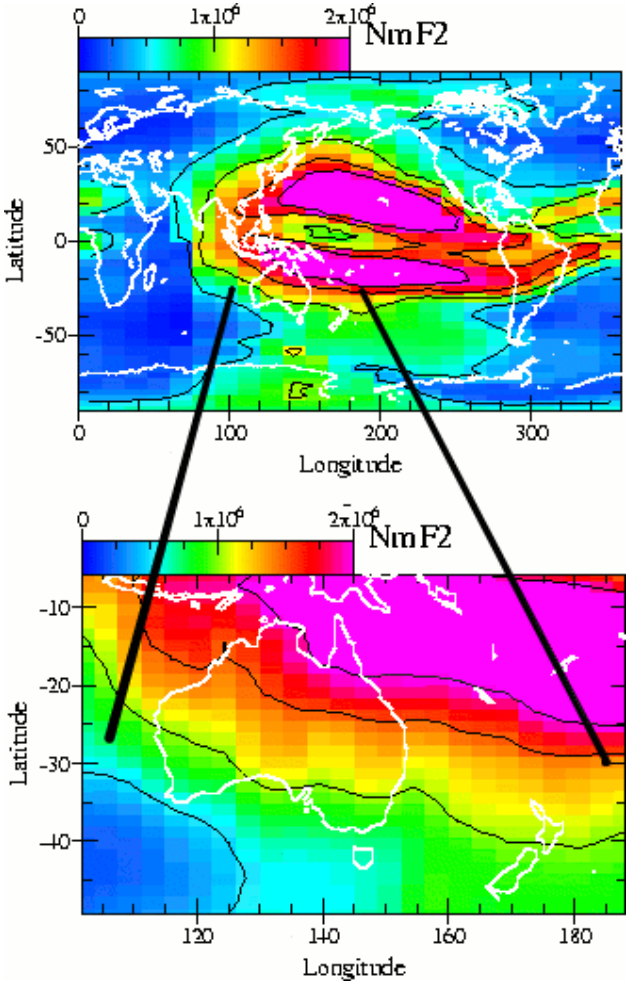
About 2000 Slant TEC Values were Assimilated every 15 min

GAIM
"Bringing The Pieces Together"

UtahStateUniversity

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



"Bringing The Pieces Together"

UtahStateUniversity

Full Physics Kalman Filter Model (GAIM-FP)

Specification & Forecast of the Global Ionosphere

Motivation is to Provide for the Future Needs of Operational Users

GAIM
"Bringing The Pieces Together"

UtahStateUniversity

GAIM-FP Basic Approach

- Focus on ionosphere-plasmasphere data assimilation (90-30,000 km)
- Uses a physics-based ionosphere-plasmasphere model.
- Can assimilating a diverse set of measurements.
  - Currently we can assimilate:
    - Slant TEC from ground-based GPS receivers
    - Slant TEC from Occultation Satellites (COSMIC)
    - Bottomside Ne Profiles from Ionosondes
- Uses an Ensemble Kalman Filter Technique
- Provides both specifications for the ionospheric plasma densities and drivers.

Global Ionosphere-Plasmasphere Model (IPM)

- **3-D Time-Dependent Parameters**
  - **NO^+, O_2^+, N_2^+, O^+, H^+, He^+**
  - **T_e, T_i**
  - **$u_{||}$, $u_\perp$**
- **Grid System**
  - **Global**
  - **Regional**
  - **Localized**
  - **90-30,000 km**
  - **Realistic Magnetic Field (IGRF)**

GAIM "Bringing The Pieces Together"

UtahStateUniversity

GAIM-FP Output

- **Continuous Reconstruction of Global N_e Distribution**
  - **Ionosphere-Plasmasphere**
  - **90-30,000 km**
- **Quantitative Estimates of the Accuracy of Reconstruction**
- **Auxiliary Parameters**
  - N_mF_2, h_mF_2, N_mE, h_mE
  - **Slant and vertical TEC**
- **Model Drivers**
  - **Electric Fields**
  - **Global Neutral Winds**
  - **Global Neutral Composition**

GAIM
"Bringing The Pieces Together"

UtahStateUniversity

Anticipated Advantages of the GAIM-FP Model

- **Improved Profile Shapes**
- **Improved F Region Layer Heights**
- **Improved Specification of Horizontal and Vertical Gradients**
- **Improved Forecast Capability**
- **Cover Ionosphere-Plasmasphere up to 30,000 km Altitude**
- **Provides Information about Thermosphere and Electric Fields**

Anticipated Advantages of the GAIM-FP Model

Goal - build a system that can provide what is needed

- **1º x 1º resolution**
- **1 TEC accuracy possible if the data have that accuracy and there is a very large amount of data**

GAIM "Bringing The Pieces Together"

UtahStateUniversity

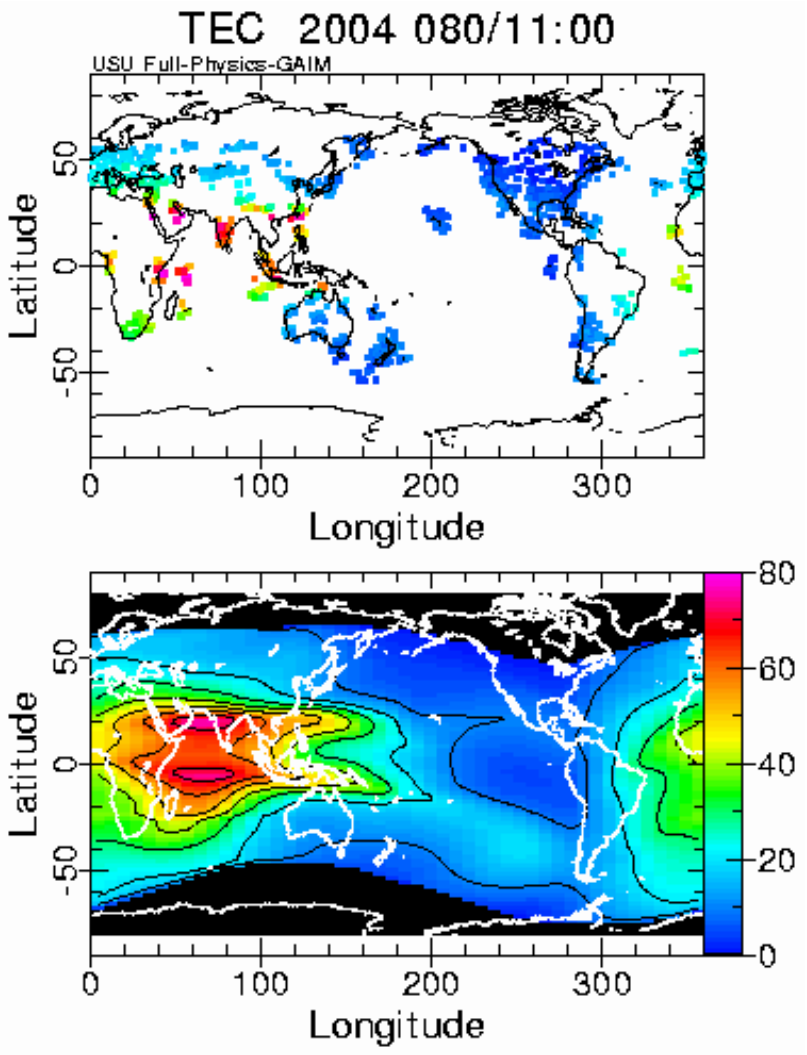
GAIM-FP Model

- Several Days in March/April of 2004
- Magnetically Quiet Period
- Data Assimilated
  - Slant TEC from 162 GPS Ground Receivers
- Use Ionosonde Data for Validation
- 3-D Electron Density Reconstruction
  - Neutral Wind and Electric Field

GAIM
"Bringing The Pieces Together"

UtahStateUniversity

GAIM-FP Example



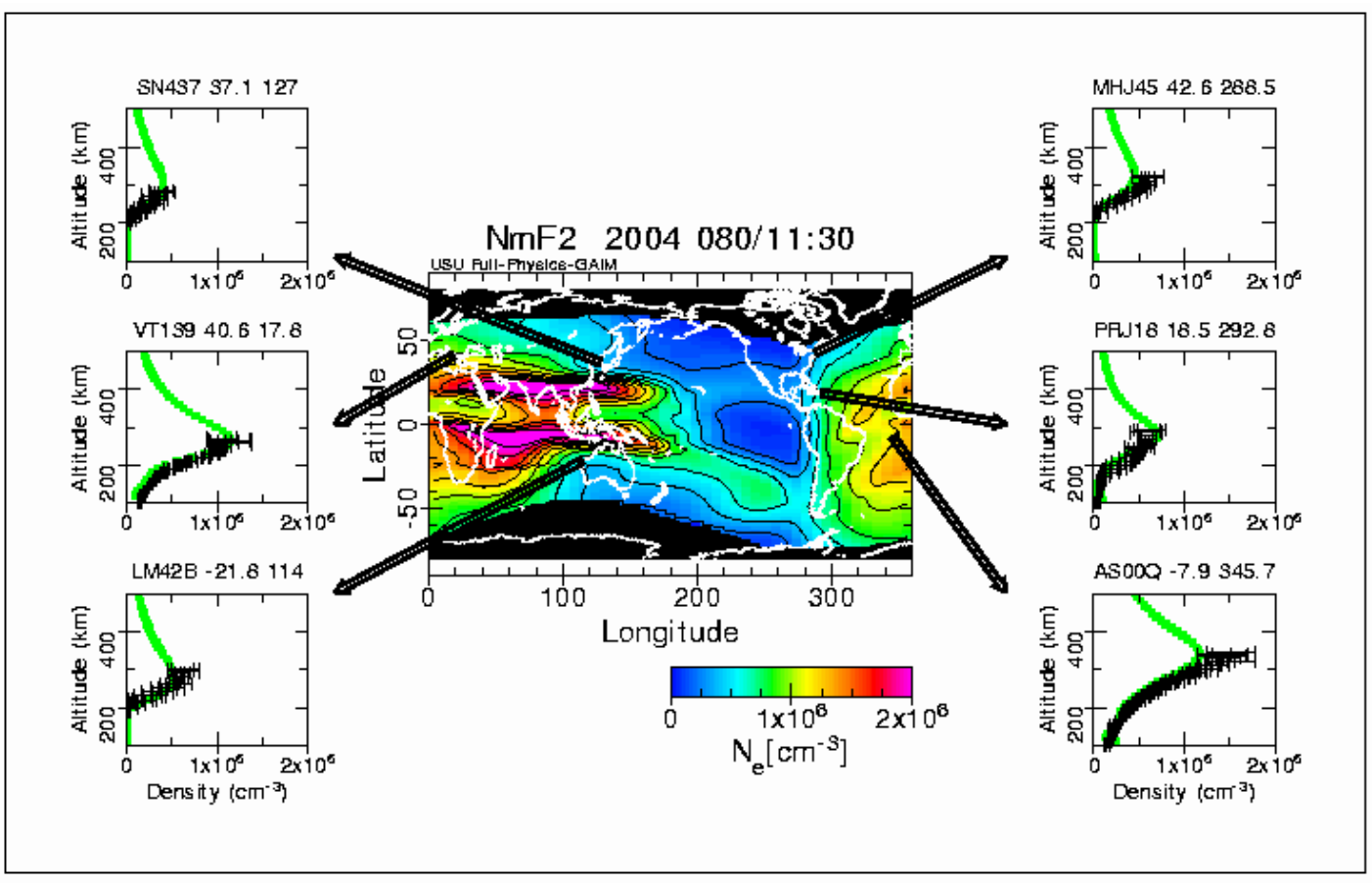
GPS/TEC Data: Slant TEC Values have been mapped to the Vertical Direction

GAIM Specification of Global TEC Distribution

GAIM
"Bringing The Pieces Together"

UtahStateUniversity

Comparison with Ionosonde Data



Ionosonde Data were NOT assimilated!

GAIM "Bringing The Pieces Together"

UtahStateUniversity

2. Ensemble Kalman Filter for High-Latitude Electrodynamics & Ionosphere (GAIM-HL)

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

Runs on Multiple CPUs

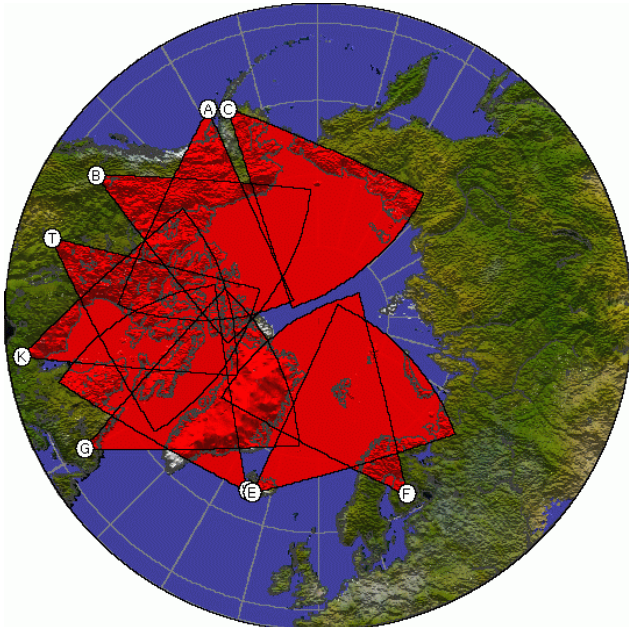
Data Assimilated by GAIM-HL

- **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**

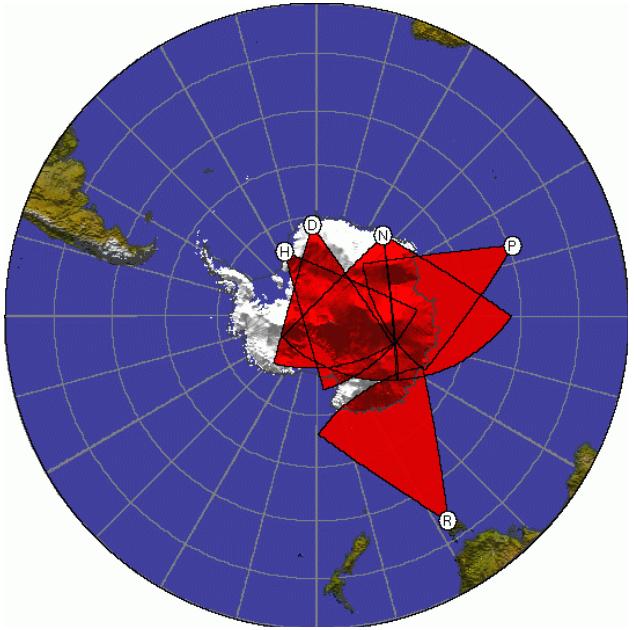
Assimilation of SuperDARN Data

- 9 Coherent Scatter Radars in the Northern High Latitudes
- 70% Coverage of Area
- Measures Line-of-Sight Velocities of Plasma Irregularities
- Line-of-Sight Velocities are Assimilated

North



South

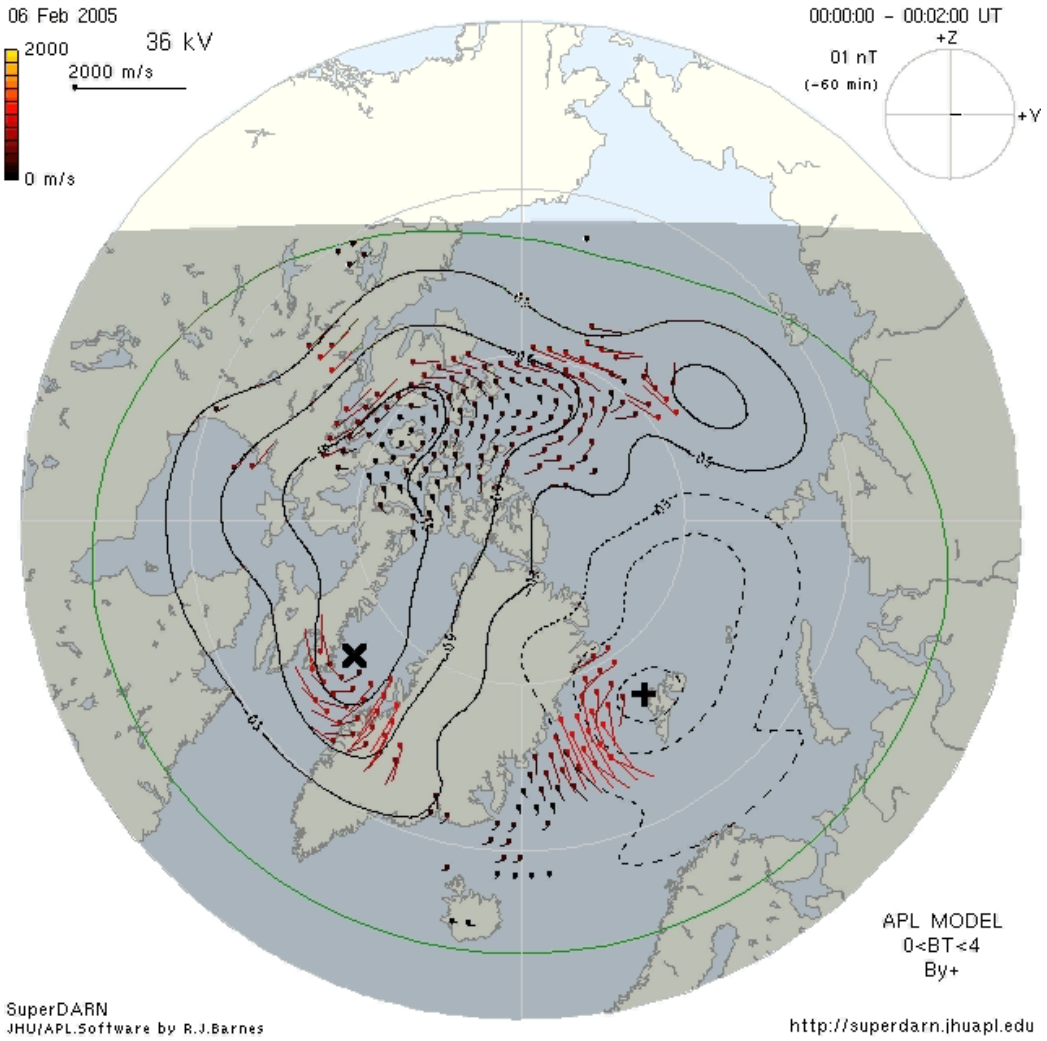


GAIM
"Bringing The Pieces Together"

UtahStateUniversity

SuperDARN Data Coverage

The actual data coverage is constantly changing

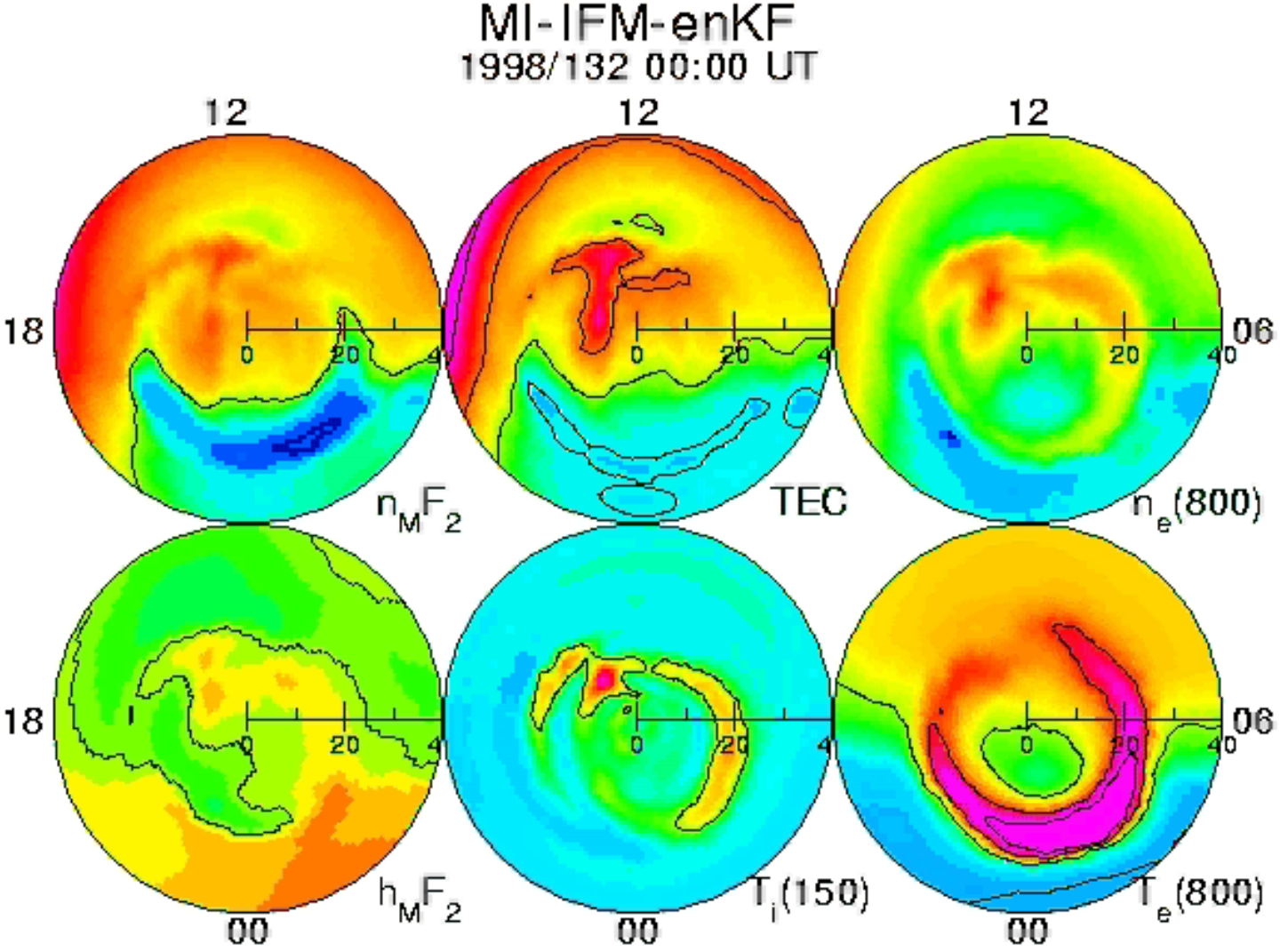


GAIM
"Bringing The Pieces Together"

UtahStateUniversity

Output of GAIM-HL

- 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



GAIM
"Bringing The Pieces Together"

UtahStateUniversity