USU Data Assimilation Models

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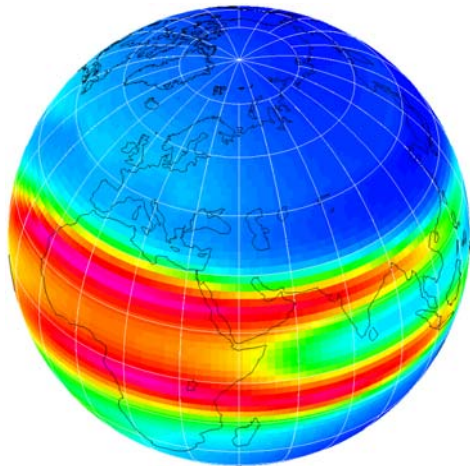Utah State University
Logan, Utah**

USU Physics-Based Data Assimilation Models

1. **Kalman Filter Models of the Ionosphere**
   o   **Gauss-Markov Model**
   o   **Full Physics Model**
2. **Ensemble Kalman Filter Model of High-Latitude Electrodynamics**
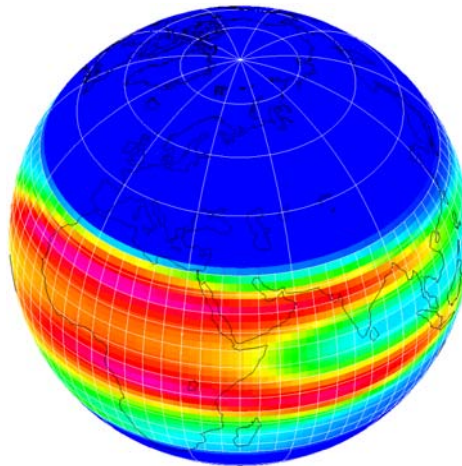3. **Ensemble Kalman Filter Model of the Thermosphere**

GAIM Basic Approach

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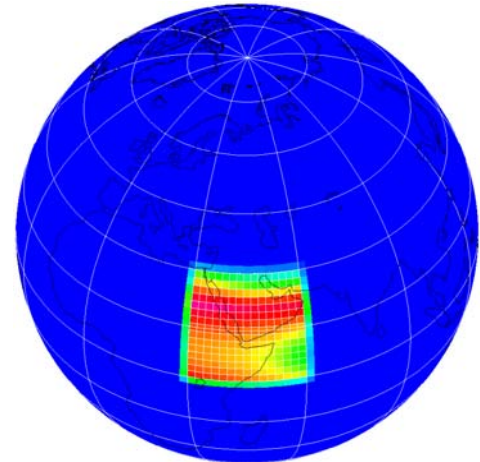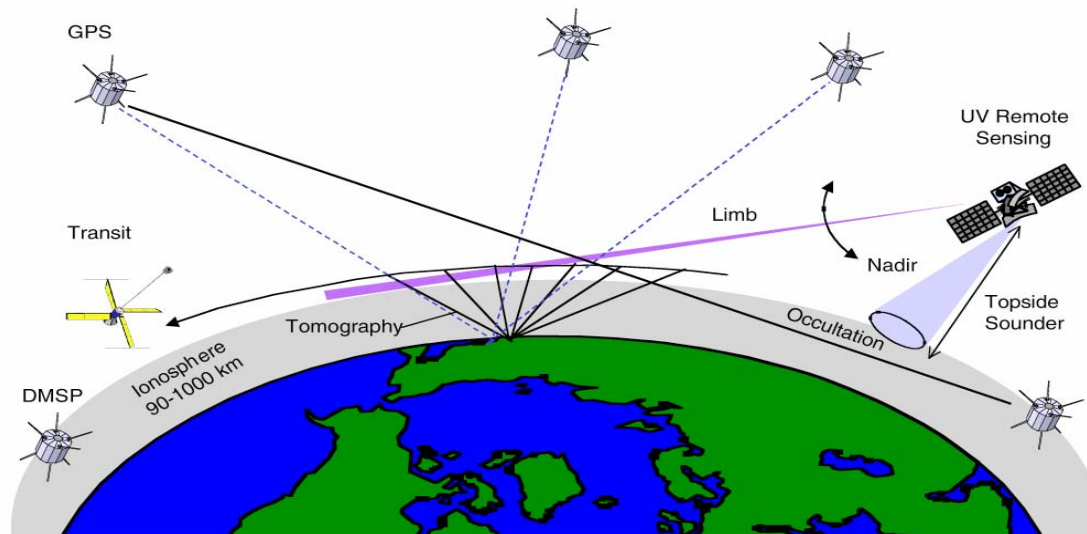
Global	Regional	Local

GAIM Assimilates Multiple Data Sources

- **Data Assimilated Exactly as They Are Measured**

  - Bottomside N_e Profiles from Digisondes (30)

  - Slant TEC from more than 1000 Ground GPS Receivers

  - N_e Along Satellite Tracks (4 DMSP satellites)

  - Integrated UV Emissions (LORAAS, SSULI, SSUSI, GUVI)

  - Occultation Data (CHAMP, IOX, SAC-C, COSMIC)

Gauss-Markov Kalman Filter Model

Runs at the CCMC

Runs on 2 CPUs

Gauss-Markov Kalman Filter Model

- **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 use N_e**

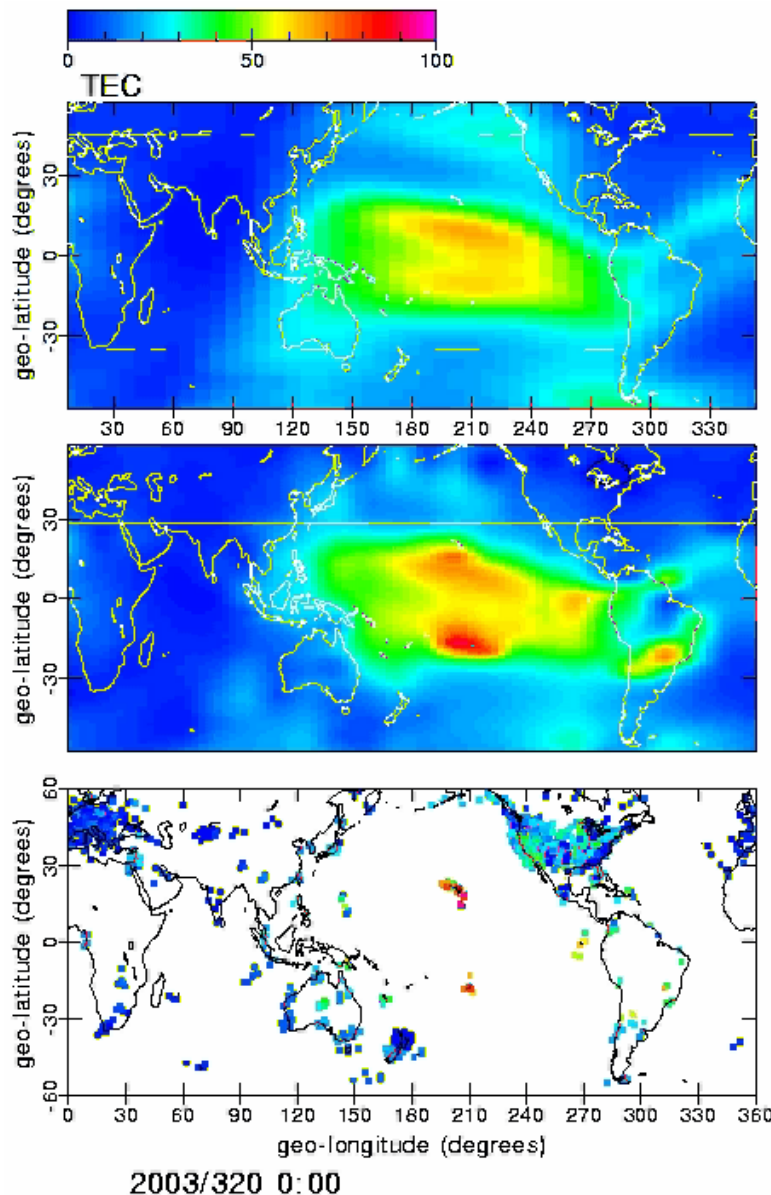- **Kalman solves for deviations from background**

"Bringing the pieces together"

G A I M

Gauss-Markov Kalman Filter Reconstruction

Physics-Based Model Without Data

Kalman Filter

More than 3000 Slant TEC Measurements are assimilated every 15 minutes.

What is it like to work with the CCMC?

- **Easy**

- **Efficient**

- **Rewarding**

What is next for the CCMC?

- **Run GAIM in Real Time**

- **Add COSMIC and UV Data**

- **Install Full Physics GAIM**

Full Physics Data Assimilation Model

Ensemble Kalman Filter

Runs on 30 CPUs

Global Ionosphere-Plasmasphere Model (IPM)

- **3-D Time-Dependent Parameters**
  - $NO^+, O_2^+, N_2^+, O^+, H^+, He^+$
  - T_e, T_i
  - $u_\parallel, u_\perp$
- **Auxiliary Parameters**
  - N_mF_2
  - h_mF_2
  - N_mE
  - h_mE
  - TEC

- **Grid System**
  - Global
  - Regional
  - Localized
  - 90-30,000 km
  - Realistic Magnetic Field (IGRF)
- **Spatial Resolution Along B**
  - 0.9 km in E-Region
  - 1.3 km in F-Region
  - 3.8 km in Topside
  - 240 km at 17,000 km

Longitudinal Resolution

Resolution is Externally Adjustable

● **Operational Mode:**

➡ **Global: ~ 7.5⁰**

➡ **Regional: ~ 1⁰**

30 Global Simulations are Launched at Each Assimilation Time Step

Full Physics GAIM 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**
    - **Neutral Winds**
    - **Neutral Composition**

Full Physics-Based GAIM Model

- **Ionospheric Drivers are determined via an Ensemble Kalman Filter**
- **Regional Run Over United States**
- **3-D Electron Density**
- **Meridional Neutral Wind**

Example of Full Physics-Based GAIM Model Reconstructions

GAIM

IPM

x GPS Rx
□ Ionosonde

Global Assimilation of Ionospheric Measurements
Utah State University, (435) 797-2962, schunk@cc.usu.edu;
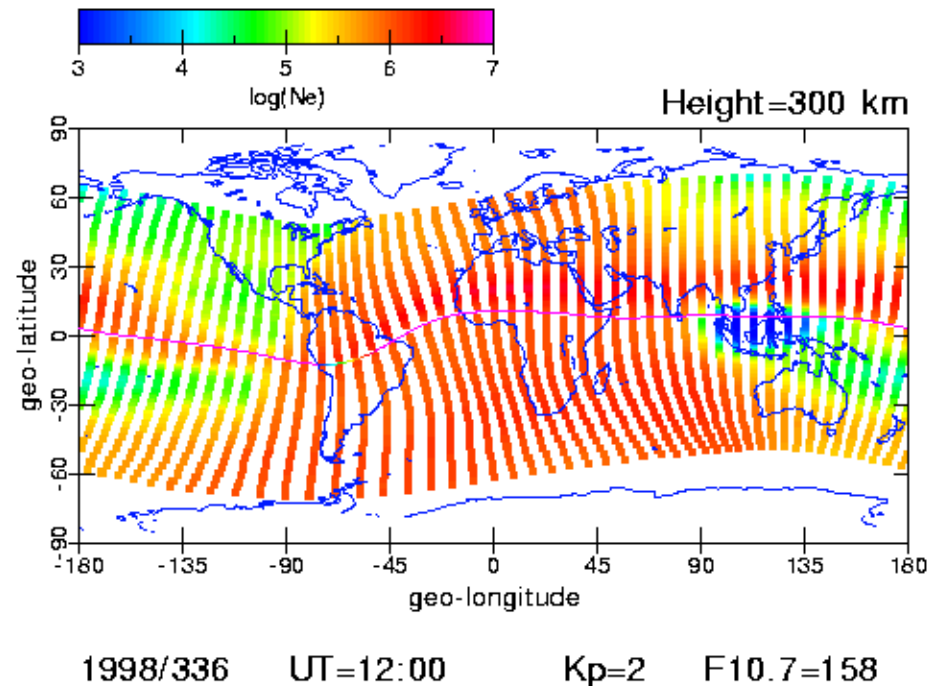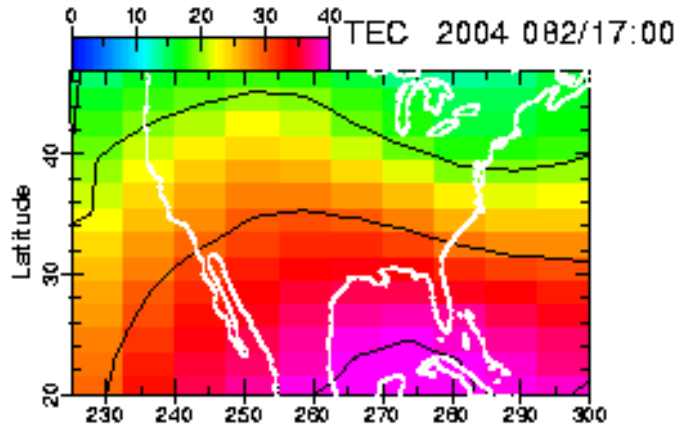Universities of Colorado (Boulder), Texas (Dallas), and Washington

GAIM

"Bringing the pieces together"

Example of Full Physics-Based GAIM Model Reconstructions

Meridional Wind

GAIM

TEC 2004 082/17:00

GAIM

IPM

HWM

GAIM

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Full Physics-Based GAIM Model

- **Ionospheric Drivers are determined via an Ensemble Kalman Filter**
- **Global Run at Mid and Low Latitudes**
- **3-D Electron Density**
- **Neutral Wind and Electric Field**

Full Physics-Based GAIM Model

- **Several Days in March/April of 2004**

- **Geomagnetically Quiet Period**

- **Data Assimilated**
  - **Slant TEC from 162 GPS Ground Receivers**

- **Use Ionosonde Data for Validation**

G A I M

"Bringing the pieces together"

Global Assimilation of Ionospheric Measurements
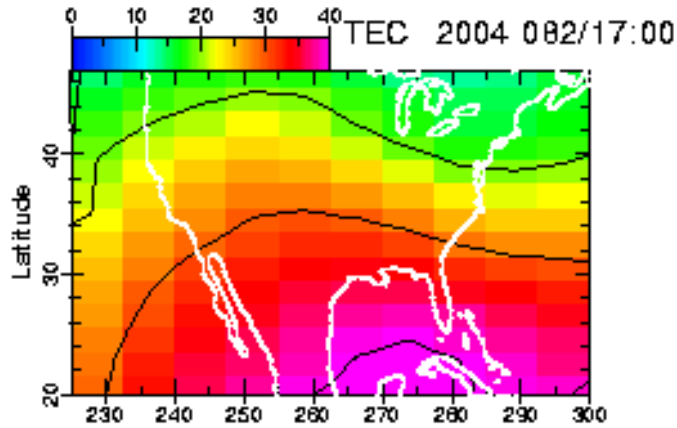Utah State University, (435)797-2962, schunk@cc.usu.edu;
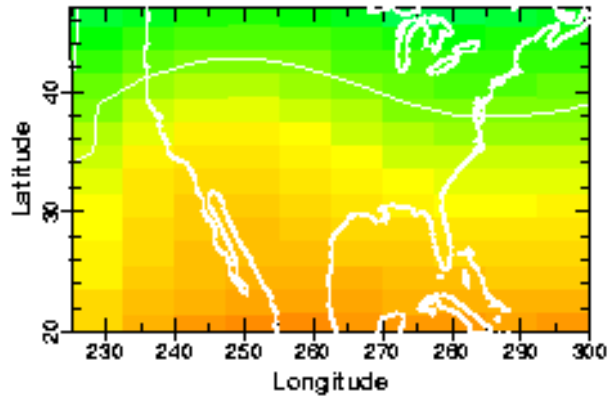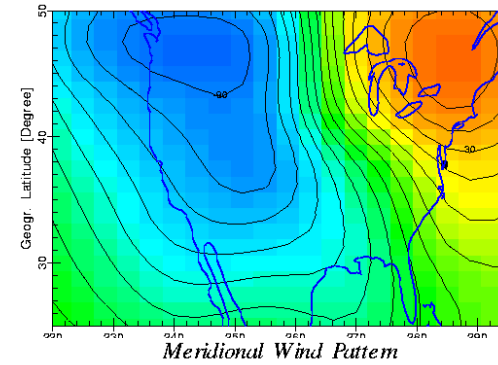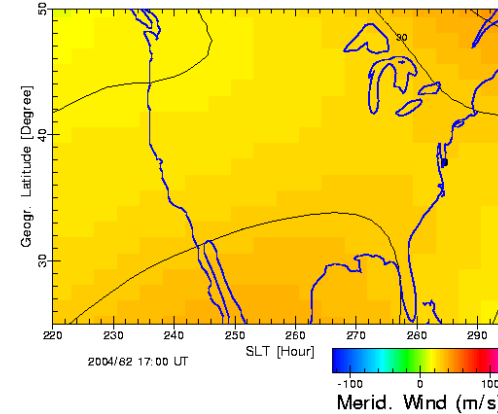Universities of Colorado (Boulder), Texas (Dallas), and Washington

Full-Physics-Based Kalman Filter Example

TEC 2004 080/11:00
USU Full-Physics-GAIM
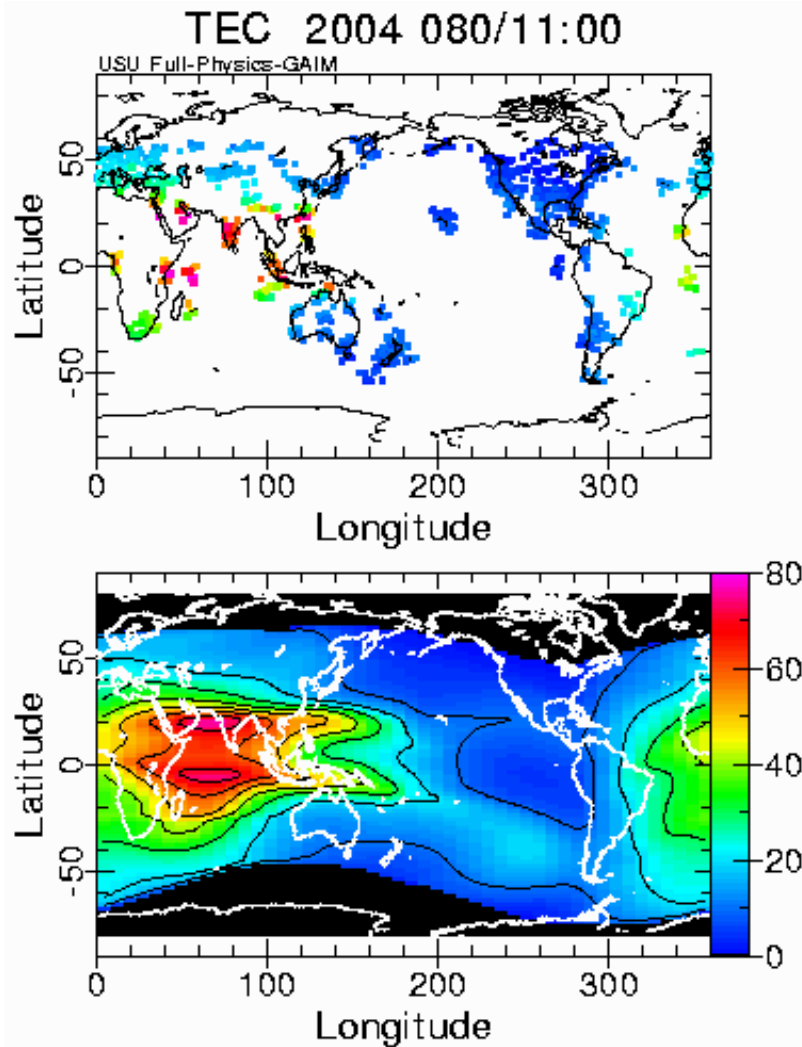
GPS/TEC Data: Slant TEC Values have been mapped to the Vertical Direction

GAIM Specification of Global TEC Distribution

Comparison with Ionosonde Data
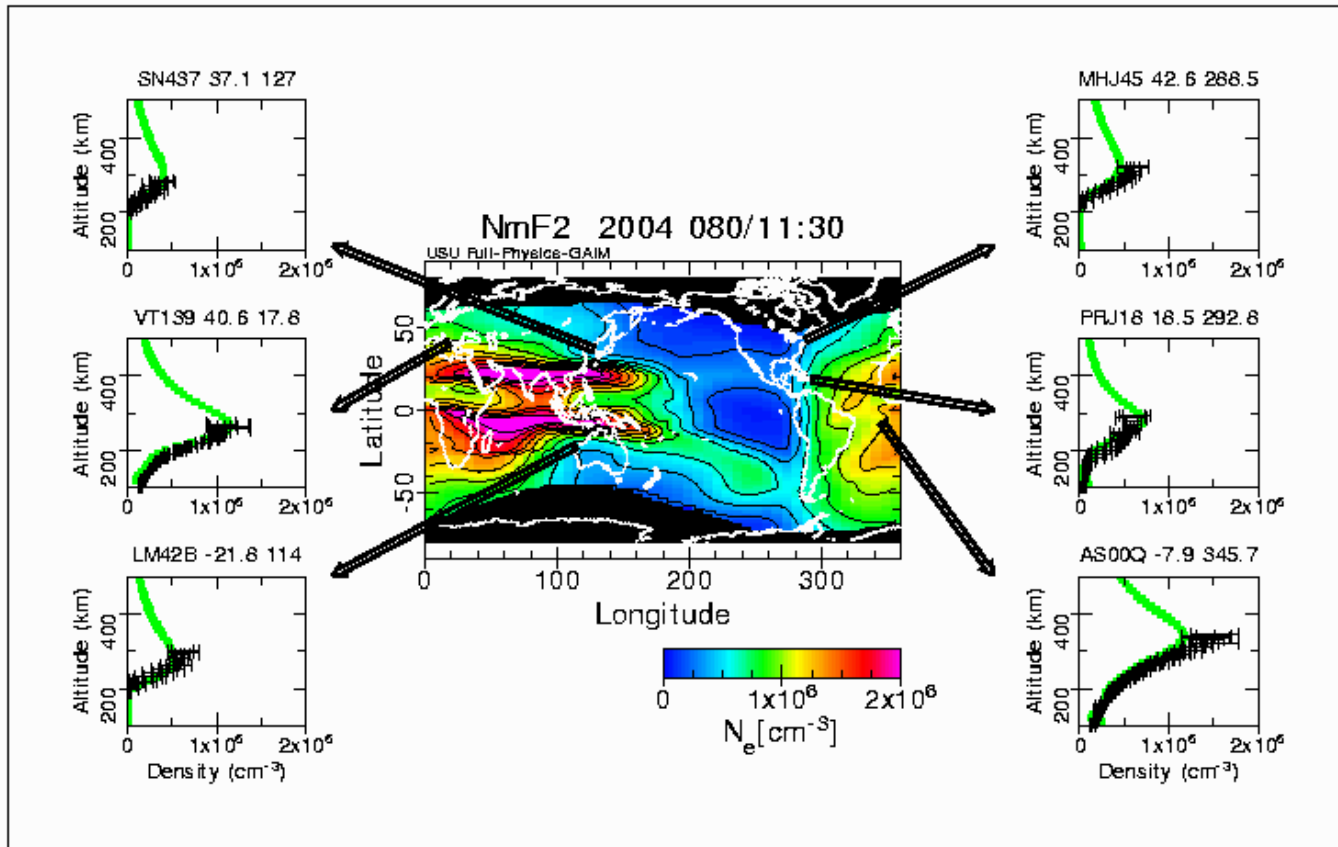
Ionosonde Data were NOT assimilated!

Global Meridional Wind Obtained from GAIM

Meridional Wind Pattern

Horizontal Wind Model (HWM)

Full Physics-Based Data Assimilation Model

2004/81 00:00 UT

Southward — Northward

Merid. Wind (m/s)
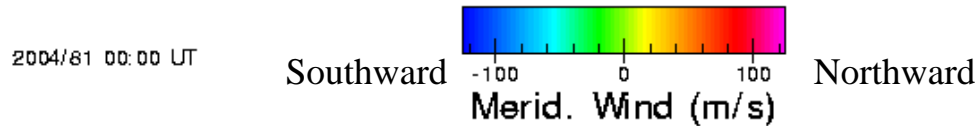
2. Ensemble Kalman Filter for High-Latitude Electrodynamics

High-Resolution Specification of Convection, Precipitation & Currents

Runs on 30 CPUs

Physics-Based Model of High-Latitude Electrodynamics

Time-Dependent Ionosphere Model

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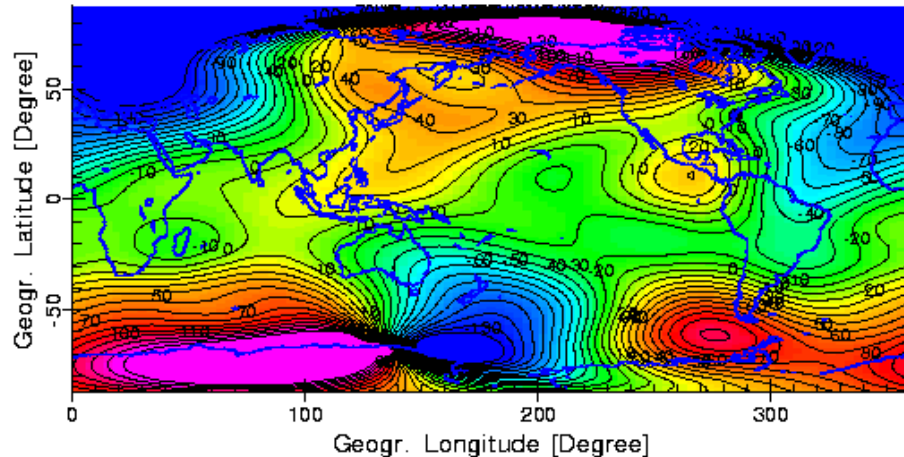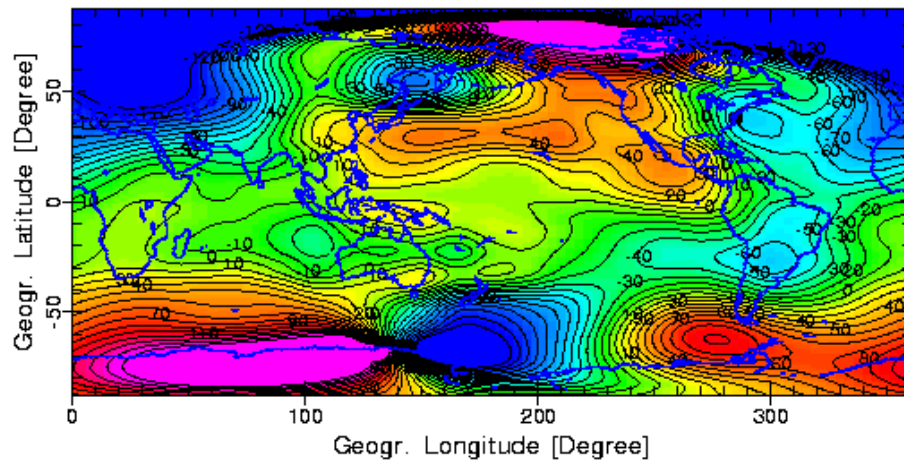- Ion Drifts Parallel & Perpendicular to B
- Hall & Pedersen Conductances

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

- **Ground Magnetic Data from 100 Sites**
- **Cross-Track Velocities from 4 DMSP Satellites**
- **Line-of-Sight Velocities from the 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
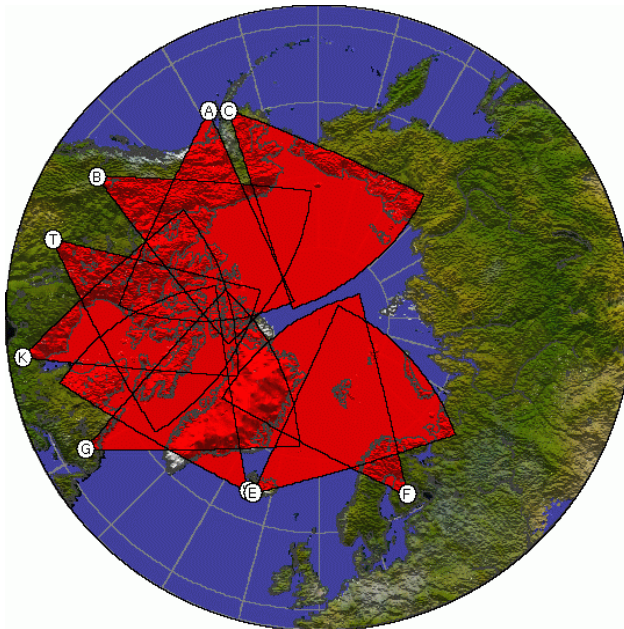
South

SuperDARN Data Coverage
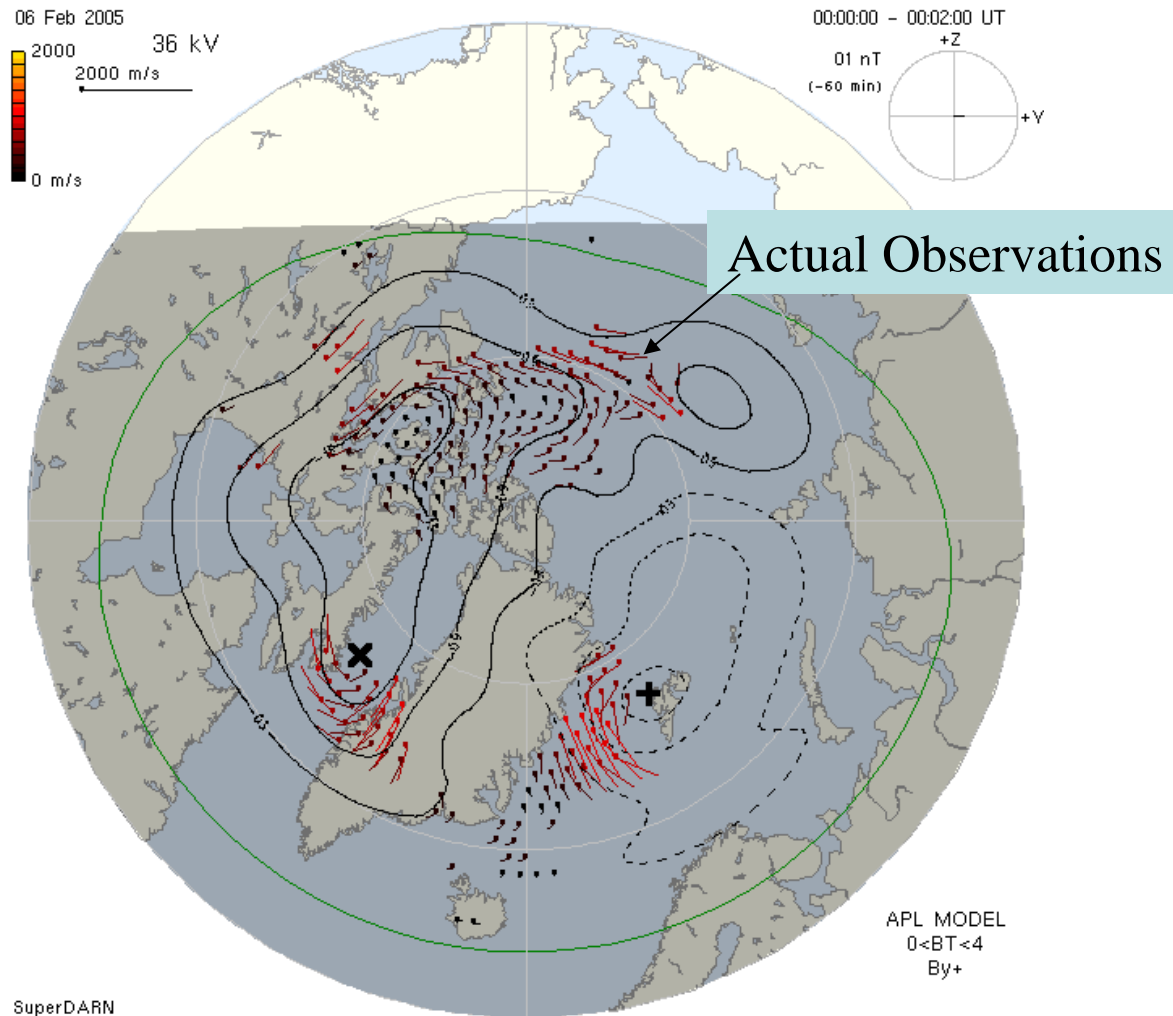
SuperDARN Data Coverage

The actual data coverage is constantly changing

QuickTime™ and a
Cinepak decompressor
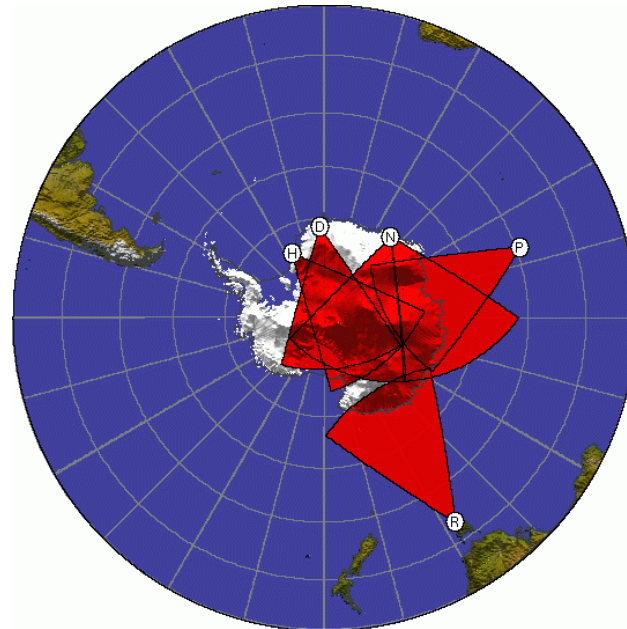are needed to see this picture.

Output of the Electrodynamics Model (High Resolution)

- **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**

High-Latitude Electrodynamic Environment
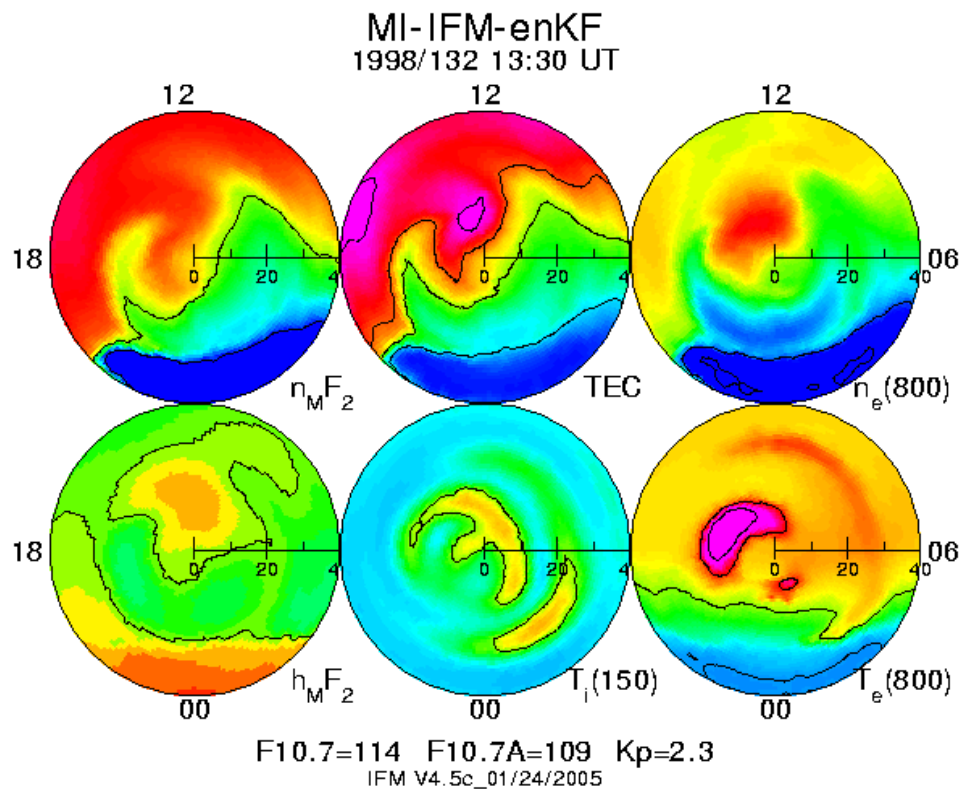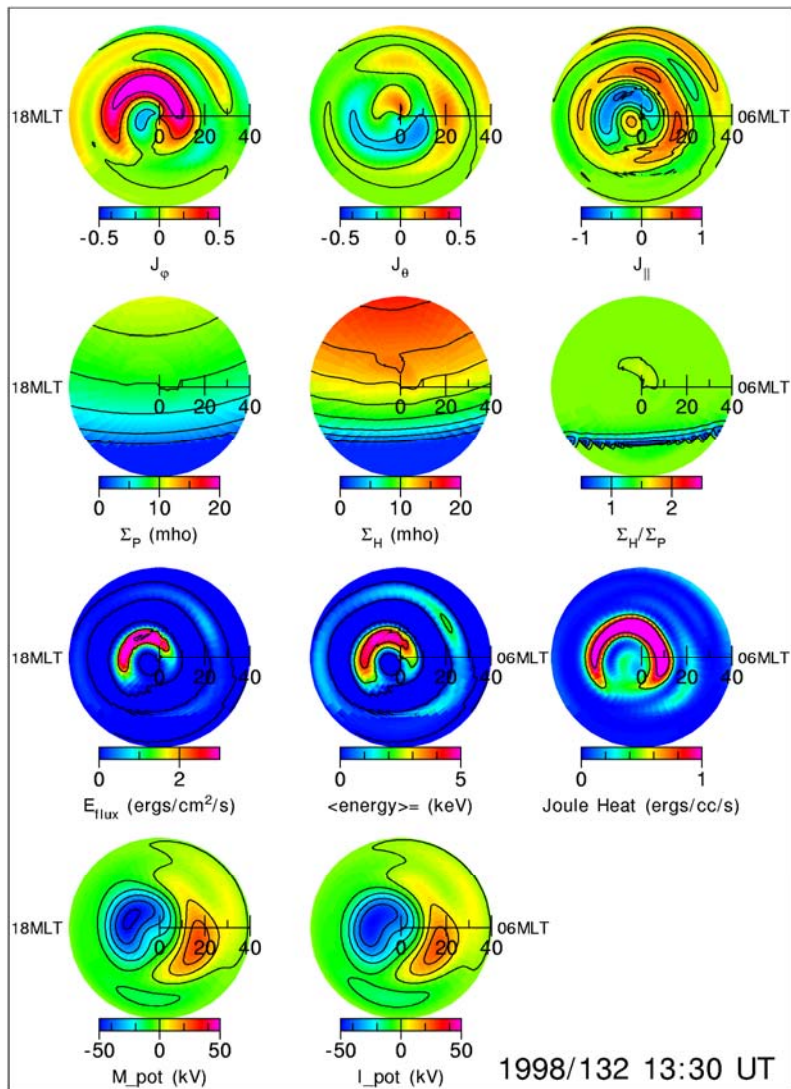
QuickTime™ and a
GIF decompressor
are needed to see this picture.

Ensemble Kalman Filter

QuickTime™ and a
GIF decompressor
are needed to see this picture.

Ensemble Kalman Filter

3. Ensemble Kalman Filter for the Global Thermosphere

High-Resolution Specification of Neutral Densities, Temperatures & Winds

Runs on 30 CPUs

Physics-Based Model of the Thermosphere

- **Numerical Solution of Neutral Gas Continuity, Momentum, and Energy Equations**
- **Time-Dependent, High-Resolution, Global Model**
- **49, 98 Non-Uniform Altitude Layers from 90-600 km**
- **0.5, 0.1 deg in latitude, 3 deg in longitude**
- **50 km resolution in polar region**
- **Flux-Corrected-Transport (FCT) Numerical Method**
- **Rotating Coordinate System fixed to Earth**
- **Tidal and Gravity Wave Forcing from Below**

Ma and Schunk (1995)

Data Assimilated

- **Will be able to Assimilate**

  - **In situ Densities & Winds**
  - **Satellite Drag Data**
  - **UV Emissions From Satellites**
  - **Deduced Neutral Parameters from ISR**

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3. **Ensemble Kalman Filter Model of the Thermosphere**