

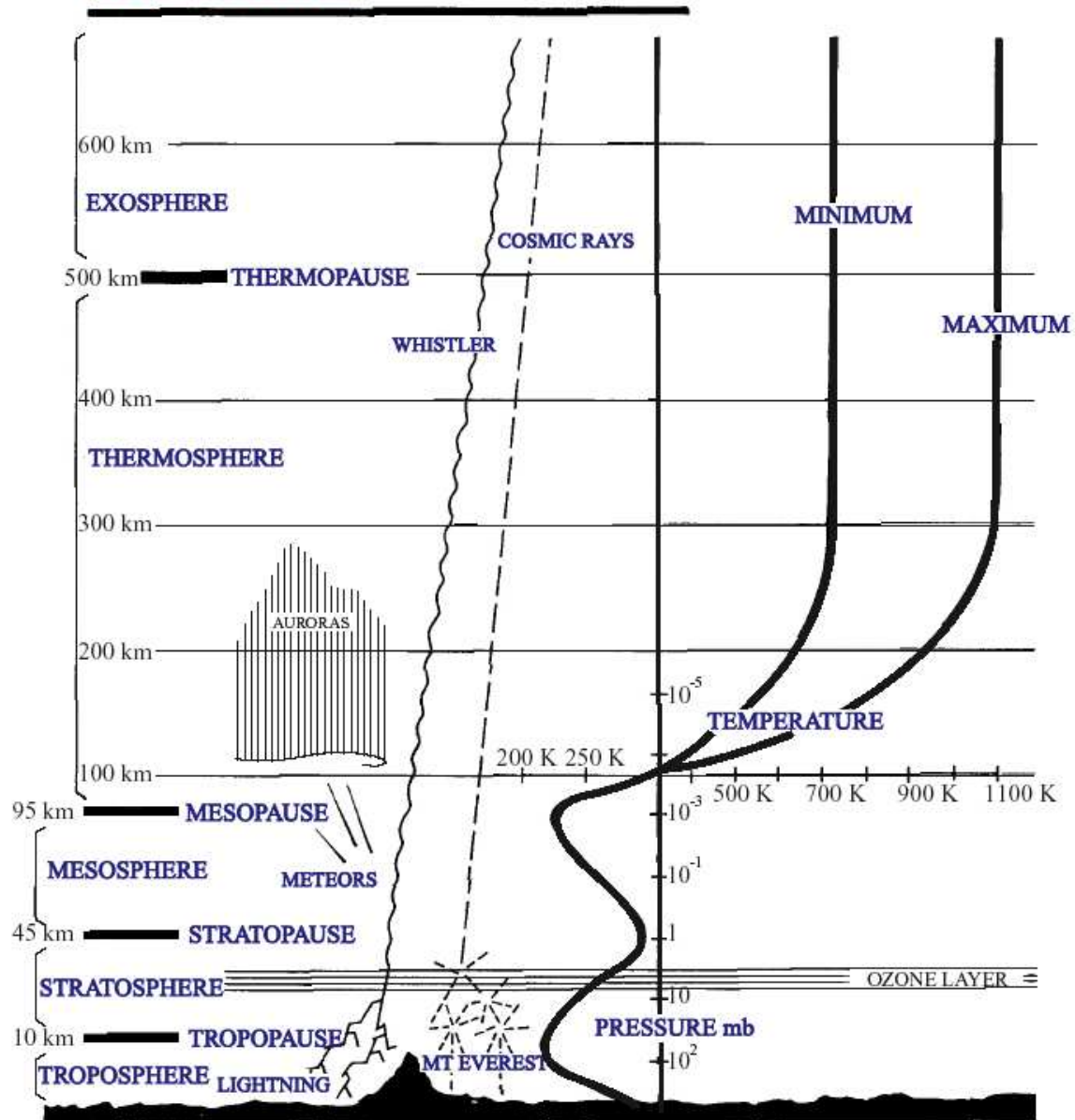
# **Data Assimilation Models for Space Weather**

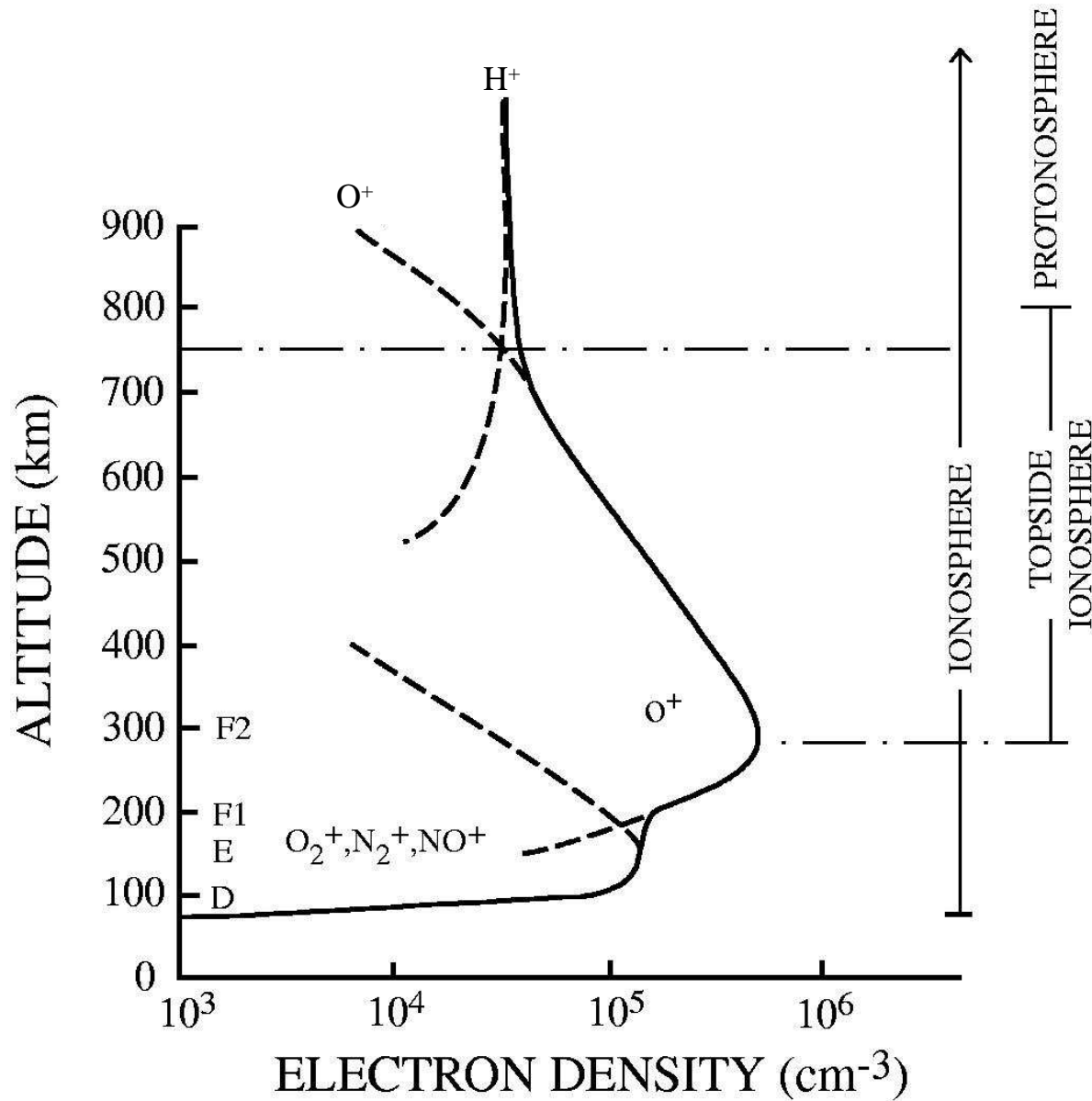
**R.W. Schunk, L. Scherliess,  
D.C. Thompson, J. J. Sojka, & L. Zhu**

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

**Presented at:  
SVECSE 2008 Workshop  
Bozeman Montana  
June 1 - 6, 2008**

# ATMOSPHERE





## F-Region



## Topside



# **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**

# Data Assimilation Models

- **Physics-based Ionosphere Model**
- **Data Sources**
- **Kalman Filter Data Assimilation Technique**



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Global Assimilation of Ionospheric Measurements

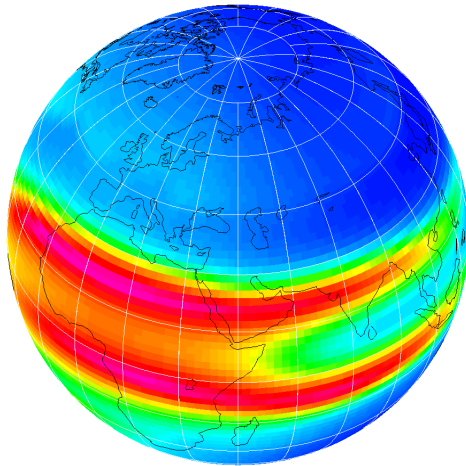
Utah State University, (435)797-2962, [schunk@cc.usu.edu](mailto:schunk@cc.usu.edu);

Universities of Colorado (Boulder), Texas (Dallas), and Washington

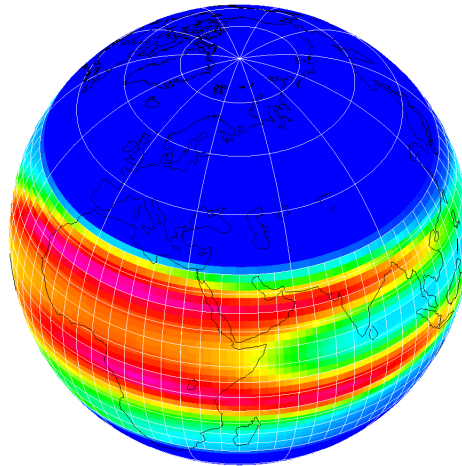
# GAIM Basic Approach

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.

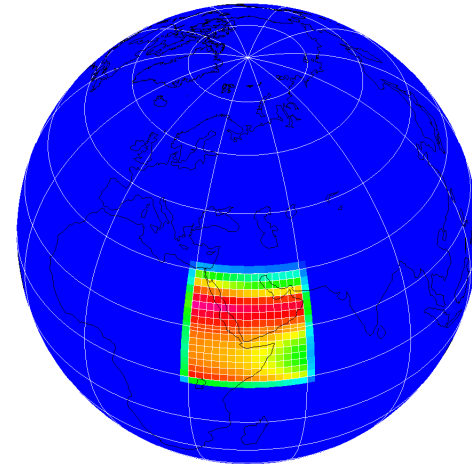
**Global**



**Regional**



**Local**

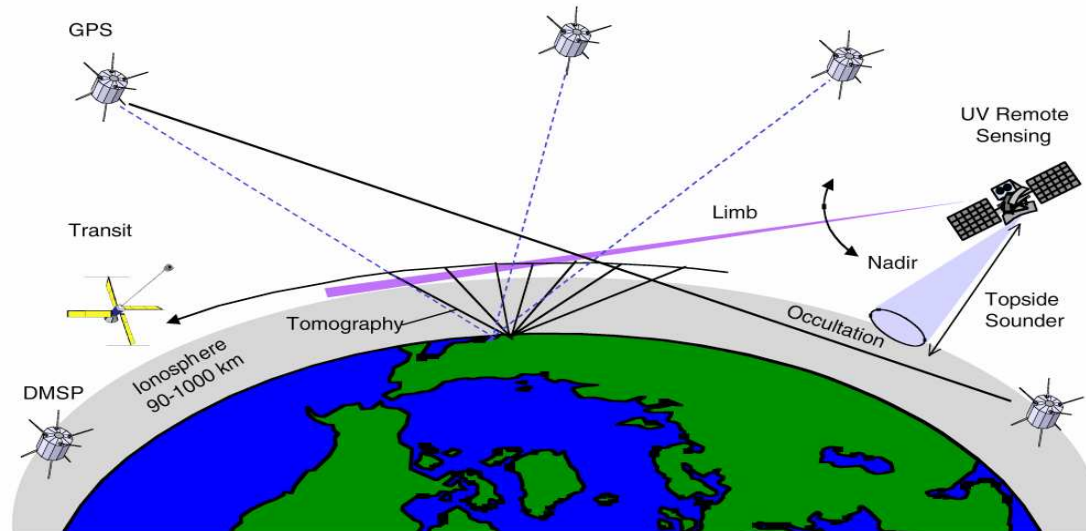


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# GAIM Assimilates Multiple Data Sources



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



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# Gauss-Markov Kalman Filter Model

**Specification & Forecast of the Global  
Ionosphere**

**Operational Model**

**2 CPU**



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# 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**



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# Gauss-Markov Kalman Filter Example

## Global Mode

- **November 16, 2003**
- **GPS Ground TEC measurements from more than 900 GPS Receivers ( SOPAC Data Archive)**
- **Includes Receivers from:**
  - ➔ **IGS**
  - ➔ **CORS**
  - ➔ **EUREF**
  - ➔ **and others**



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# Gauss-Markov Kalman Filter Reconstruction

**Physics-Based Model  
Without Data**

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

**Kalman Filter**

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

# Reconstruction of the 3-D $N_e$ Distribution

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

# Gauss-Markov Kalman Filter Example

## Regional Mode

- **3-D Ionospheric  $N_e$  Reconstruction over North America**
  - **Large Geomagnetic Storm on November 20-21, 2003**
  - **GPS Ground TEC Measurements from more than 300 GPS Receivers over the continental US and Canada**
  - **2 Ionosondes at Dyess and Eglin**
- **Observe large TEC Enhancements over the Great Lakes during November 20, 2003 @ 2000 UT.**

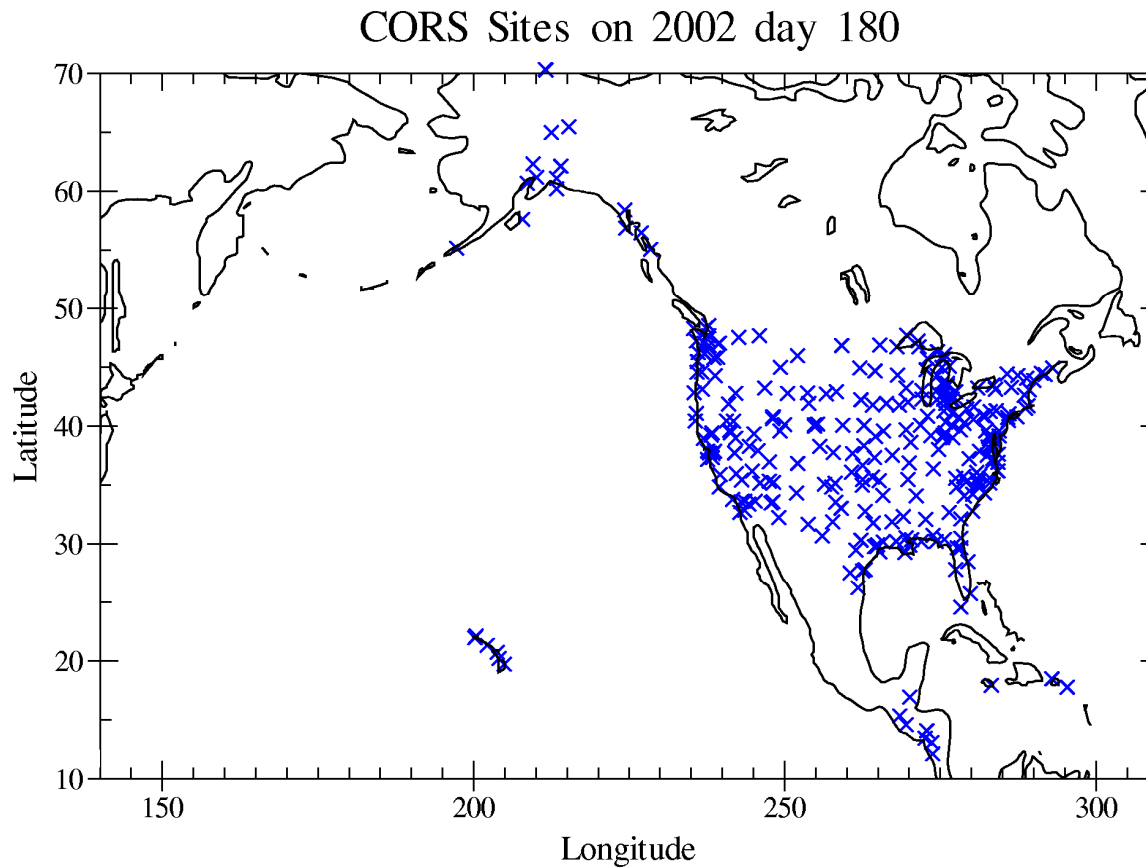


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# NOAA CORS Data

- **332 Sites**
- **Dual-frequency Receivers**
- **Slant TEC**



## **Physics-Based Model (IFM)**

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

## **Kalman Filter Reconstruction**

**About 2000 Slant TEC  
Values are Assimilated  
every 15 min**

# Full Physics Kalman Filter Model

## Specification & Forecast of the Global Ionosphere 30 CPU



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# Full Physics Kalman Filter Model

- **Ensemble Kalman Filter**
- **Physics-based Ionosphere-Plasmasphere Model**
- **Same 5 Data Sources as Gauss-Markov Model**
- **Altitude, Latitude, Longitude Grids Set by User**



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# Global Ionosphere-Plasmasphere Model (IPM)

- **3-D Time-Dependent Parameters**
  - $\text{NO}^+, \text{O}_2^+, \text{N}_2^+, \text{O}^+, \text{H}^+, \text{He}^+$
  - $T_e, T_i$
  - $u_{\parallel}, u_{\perp}$
- **Grid System**
  - **Global**
  - **Regional**
  - **Localized**
  - **90-30,000 km**
  - **Realistic Magnetic Field (IGRF)**



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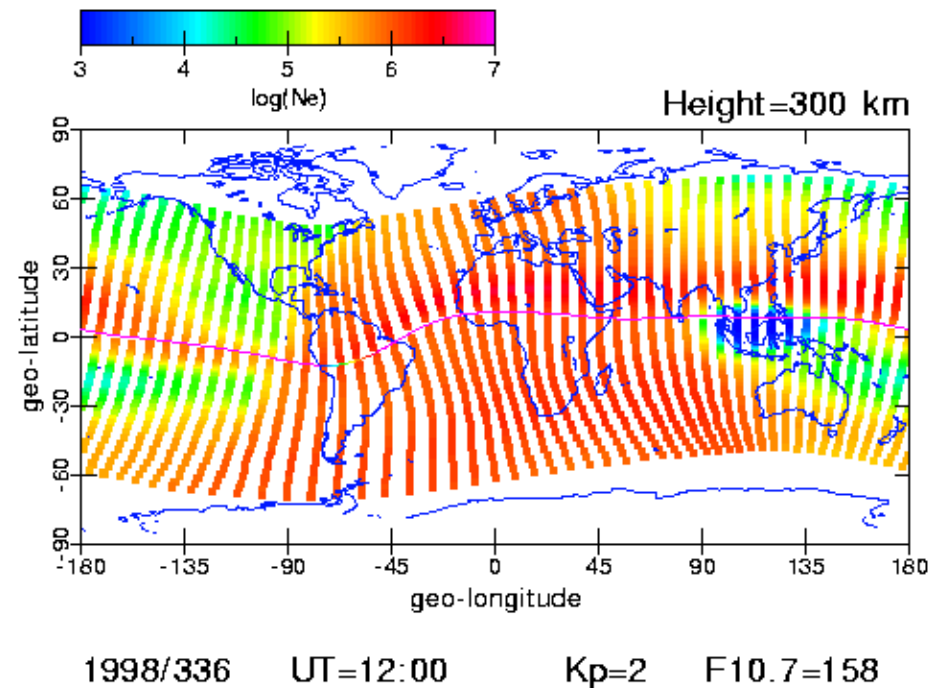
# Longitudinal Resolution

Resolution is Externally Adjustable

- **Operational Mode:**

- ➔ **Global: ~ 7.5°**
- ➔ **Regional: ~ 1°**

**30 Global Simulations  
are Launched at Each  
Assimilation Time Step**



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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 Reconstruction**
- **Neutral Wind and Electric Field**



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# 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**



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# Full-Physics-Based Kalman Filter Example

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

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

**GAIM Specification of  
Global TEC Distribution**

# Comparison with Ionosonde Data

K

MH

I

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

PR

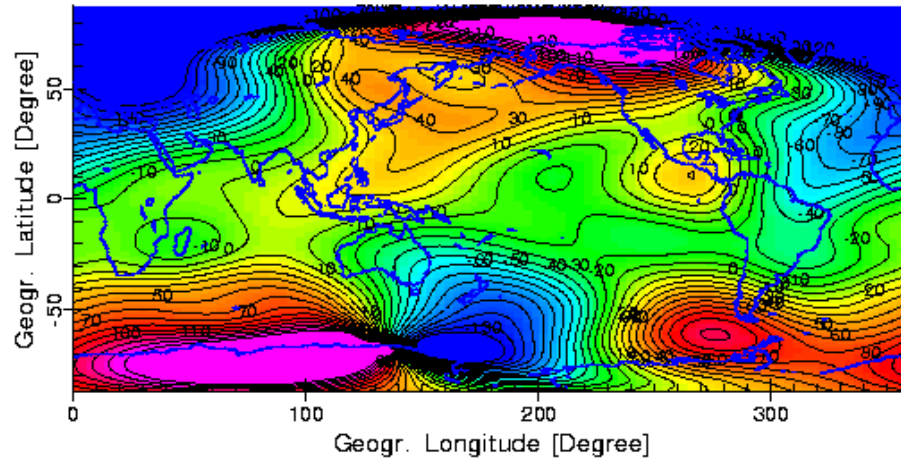
A

AI

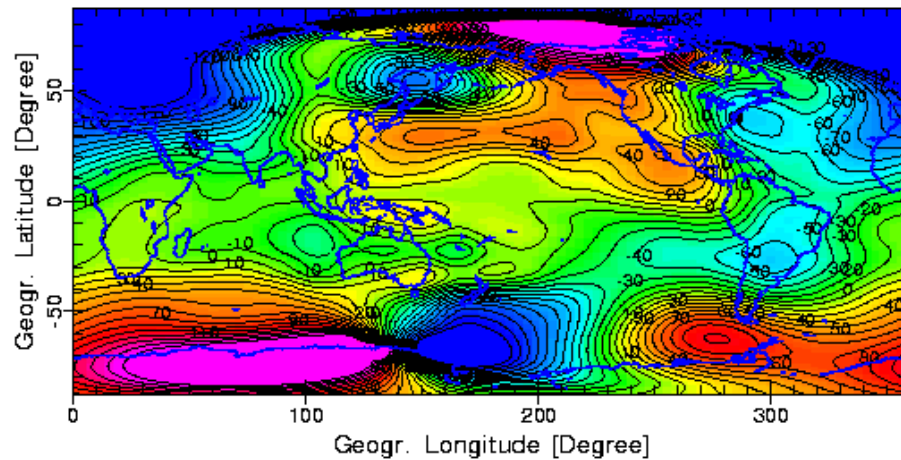
**Ionosonde Data were NOT assimilated!**

# Global Meridional Wind Obtained from GAIM

*Meridional Wind Pattern*



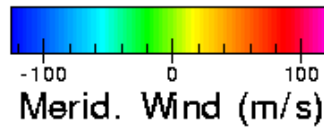
**Horizontal Wind Model  
(HWM)**



**Full Physics-Based  
Data Assimilation Model**

2004/81 00:00 UT

Southward



Northward

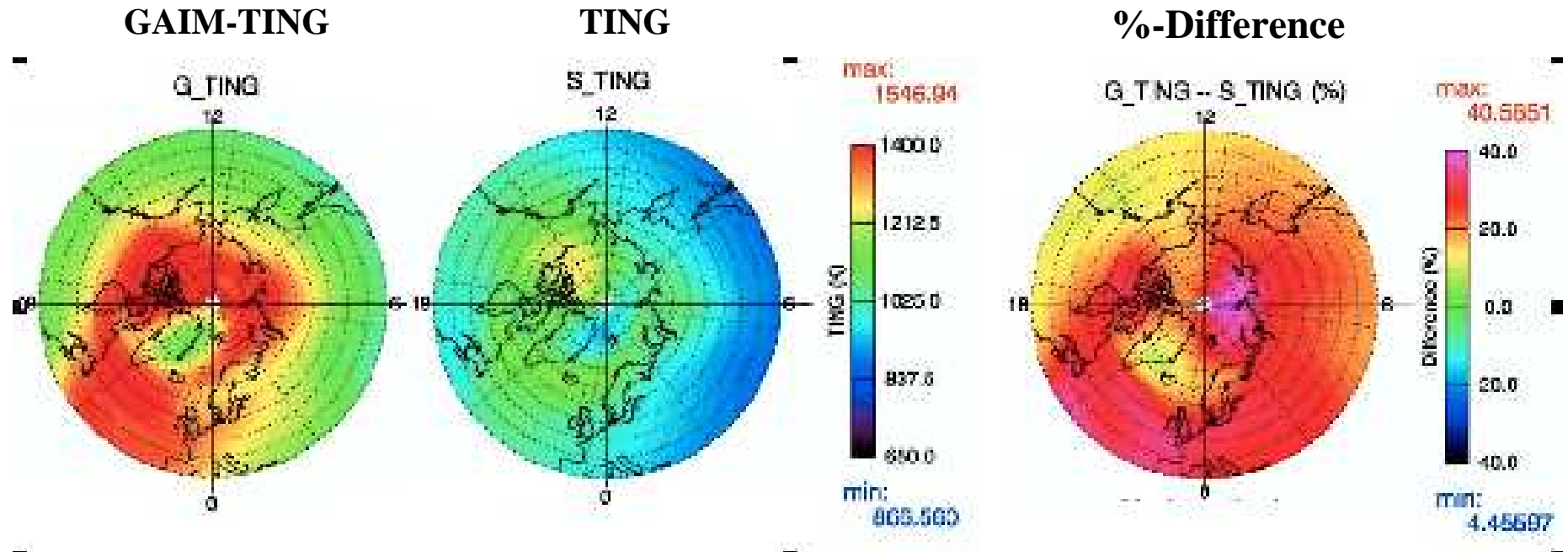


# **Ionosphere-Thermosphere Forecasting - Specification**

- **GAIM Ionosphere used to Drive NCAR TING  
Thermosphere-Ionosphere Model**
- **Results Compared to a Standard TING Run for 1-4  
April 2004**
- **Global Wind Differences During Quiet Period**
- **Global Wind,  $T_n$ , and  $O/N_2$  Differences During Active  
Conditions**
- **Critical to get the Ionosphere Correct for  
Thermosphere Calculations**

**USU-NCAR Collaboration**

## $T_n$ Distributions for Different Ionospheres



- Day 94 in 2004 at 23:30 UT
- Quiet and Disturbed Periods
- TING = Coupled Ionosphere-Thermosphere
- GAIM = Ionosphere Data Assimilation  
(GPS-TEC, Ne DMSP, Ne Ionosondes)

# **Ionosphere-Thermosphere Forecasting**

- **Specification Requires Data Assimilation**
- **Forecasting Requires Coupled Models**
- **Existing Coupled Models are not Adequate**
- **Continuous Ongoing Validation of Forecast Result is Needed**