Effects of the Magnetosphere and Lower Atmosphere on the Ionosphere-Thermosphere System

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USU Physics-Based Data Assimilation Models

1. **Kalman Filter Models of the Ionosphere**
   - **Gauss-Markov Model (GAIM-GM)**
   - **Full Physics Model (GAIM-FP)**
2. **Ensemble Kalman Filter Model of High-Latitude Electrodynamics**
3. **Ensemble Kalman Filter Model of the Thermosphere**

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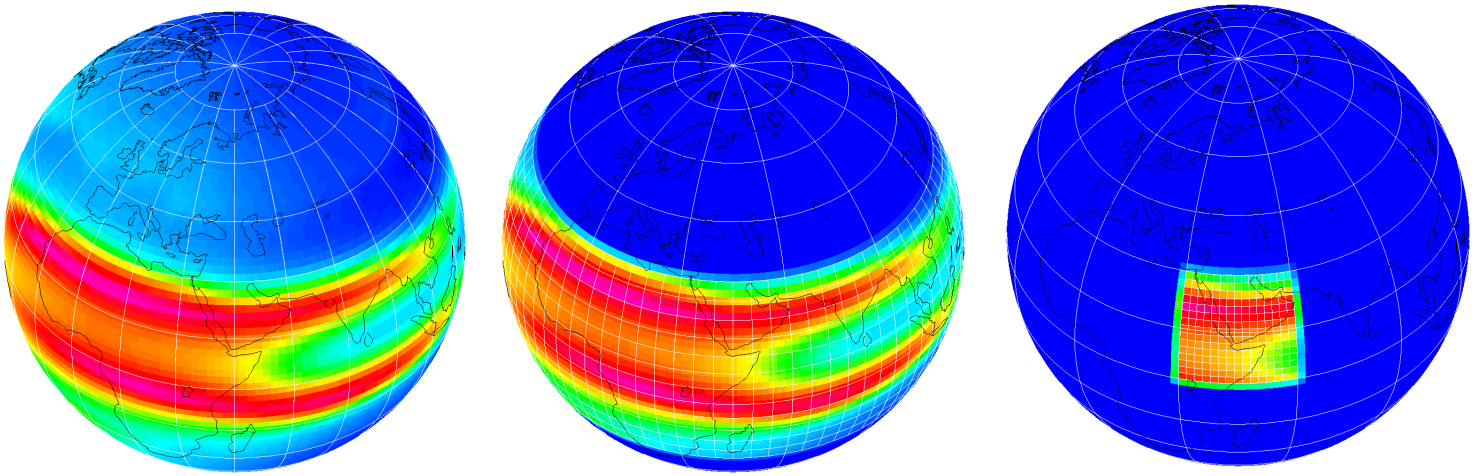
1. GAIM Basic Approach for Ionosphere

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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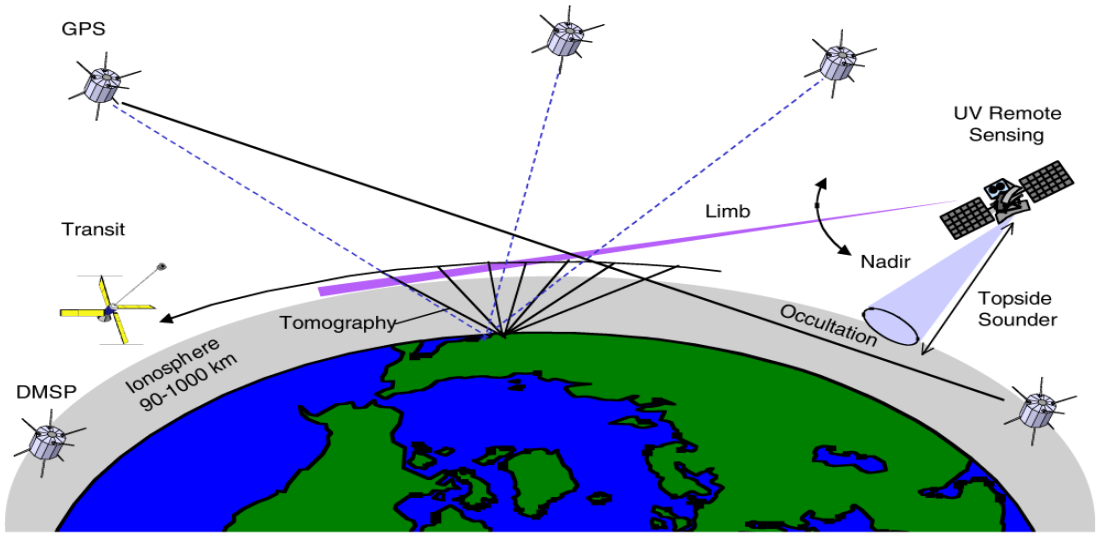
GAIM Assimilates Multiple Data Sources



- **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 (GAIM-GM)

- Specification & Forecast of the Global Ionosphere
- Operational Model
- Global Mode
- Regional Mode
- Nested Grid Combines Global and Regional Modes
- 3-hour Latent Data Acceptance Window
- 24-hour Forcast

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Gauss-Markov Kalman Filter
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

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

Physics-Based Model Without Data

Kalman Filter

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

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Gauss-Markov Kalman Filter
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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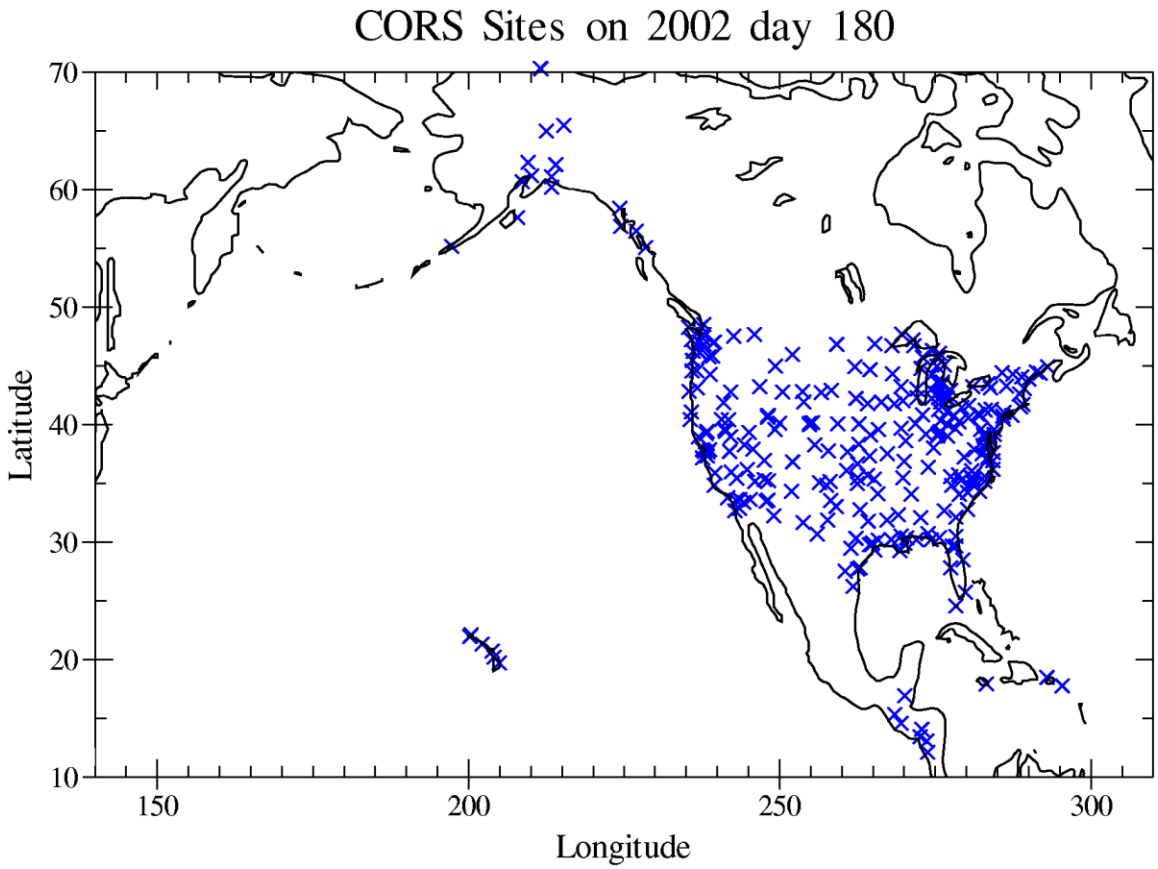
NOAA CORS Data

- 332 Sites
- Dual-frequency Receivers
- Slant TEC



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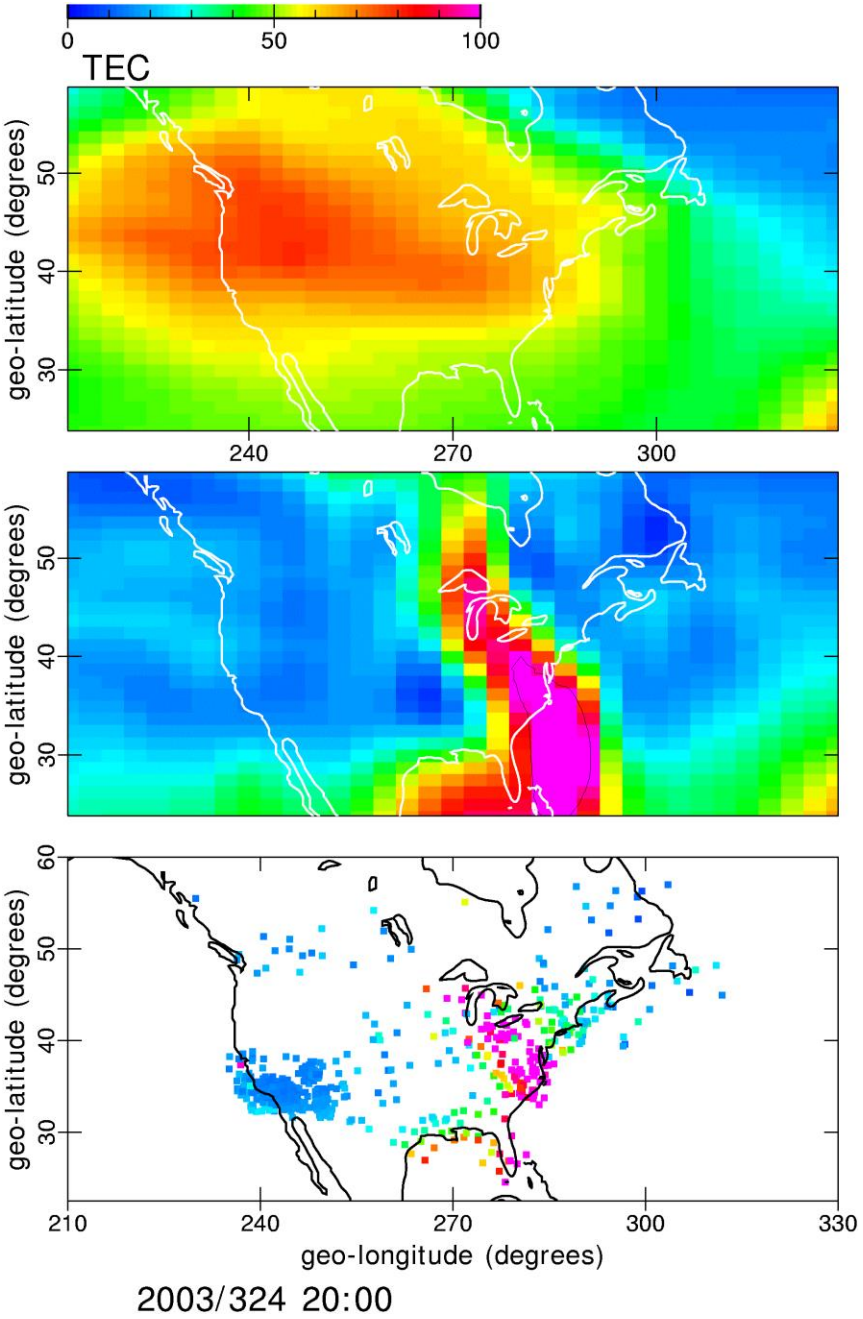

IFM

Kalman Filter Reconstruction

About 2000 Slant TEC Values are Assimilated every 15 min

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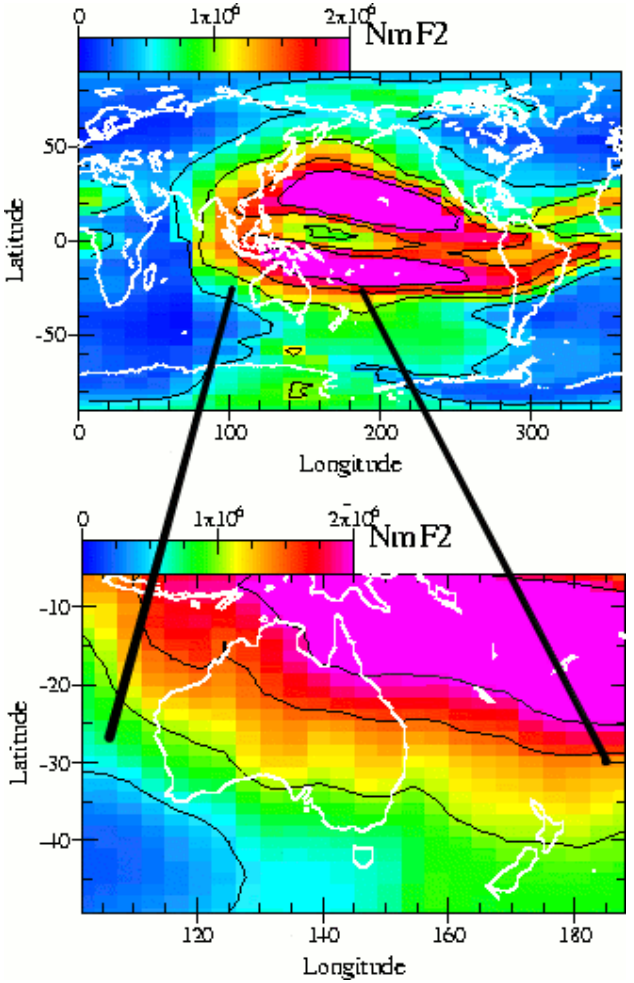
GAIM-GM Nested Grid Capability

- **Improved Spatial Resolution**
  - **1˚ Latitude (variable)**
  - **3.75˚ Longitude (variable)**
- **Usefulness Depends on Data**
- **Capability Already Exists in the GAIM-GM Operational Model**
- **In 2004 Run - 11 ionosondes & 15 GPS in Nested Grid Region**

- **Captures Edge of Anomaly**



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2. Ensemble Kalman Filter for High-Latitude Electrodynamics

High-Resolution Specification of Convection, Precipitation, Currents, Magnetic Perturbations & Ionosphere Parameters

- **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**

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3. Ensemble Kalman Filter for the Global Thermosphere

High-Resolution Specification of Neutral Densities, Temperatures & Winds

Will be able to Assimilate:

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

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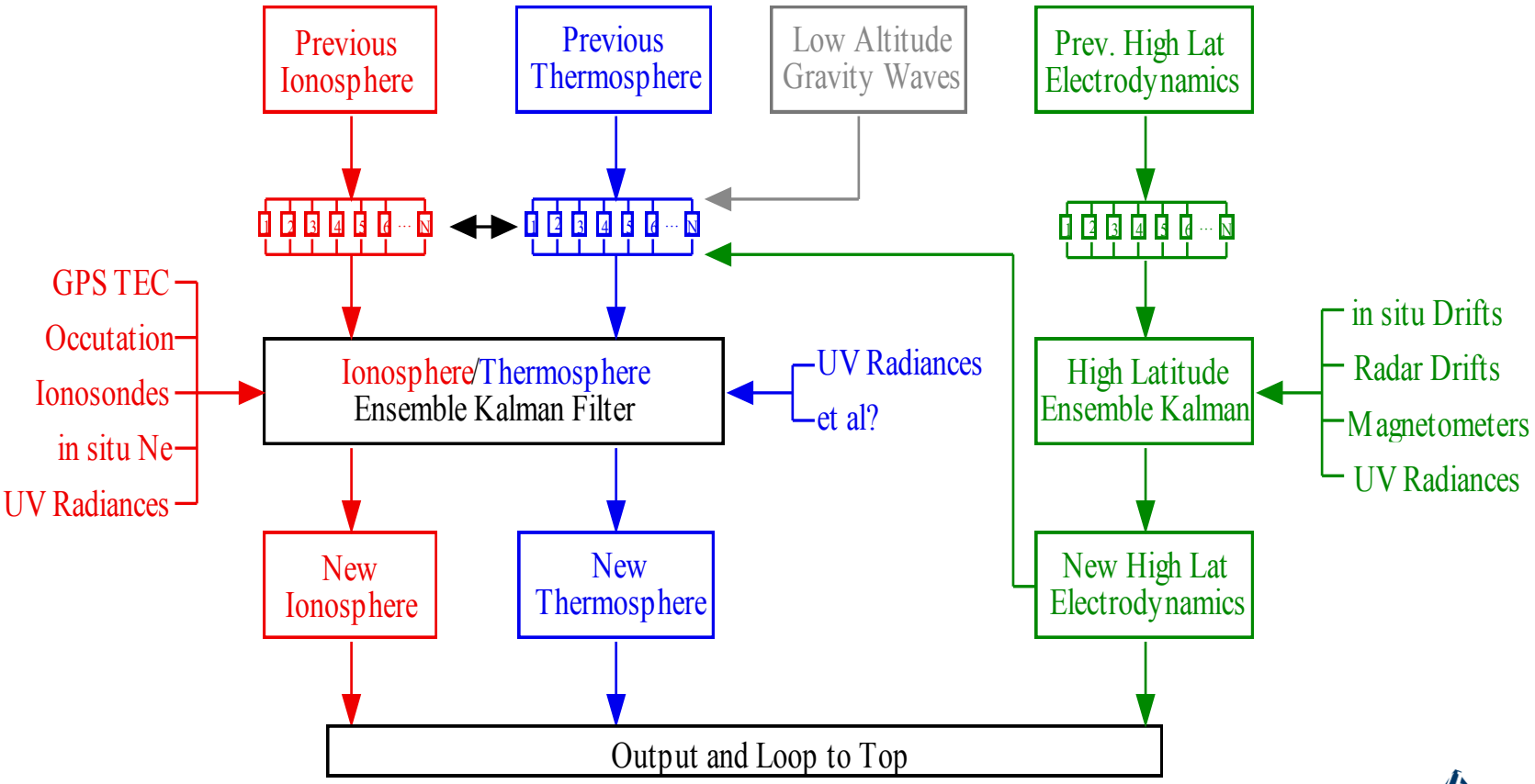
Coupled Thermosphere-Ionosphere-Electrodynamics Data Assimilation Model



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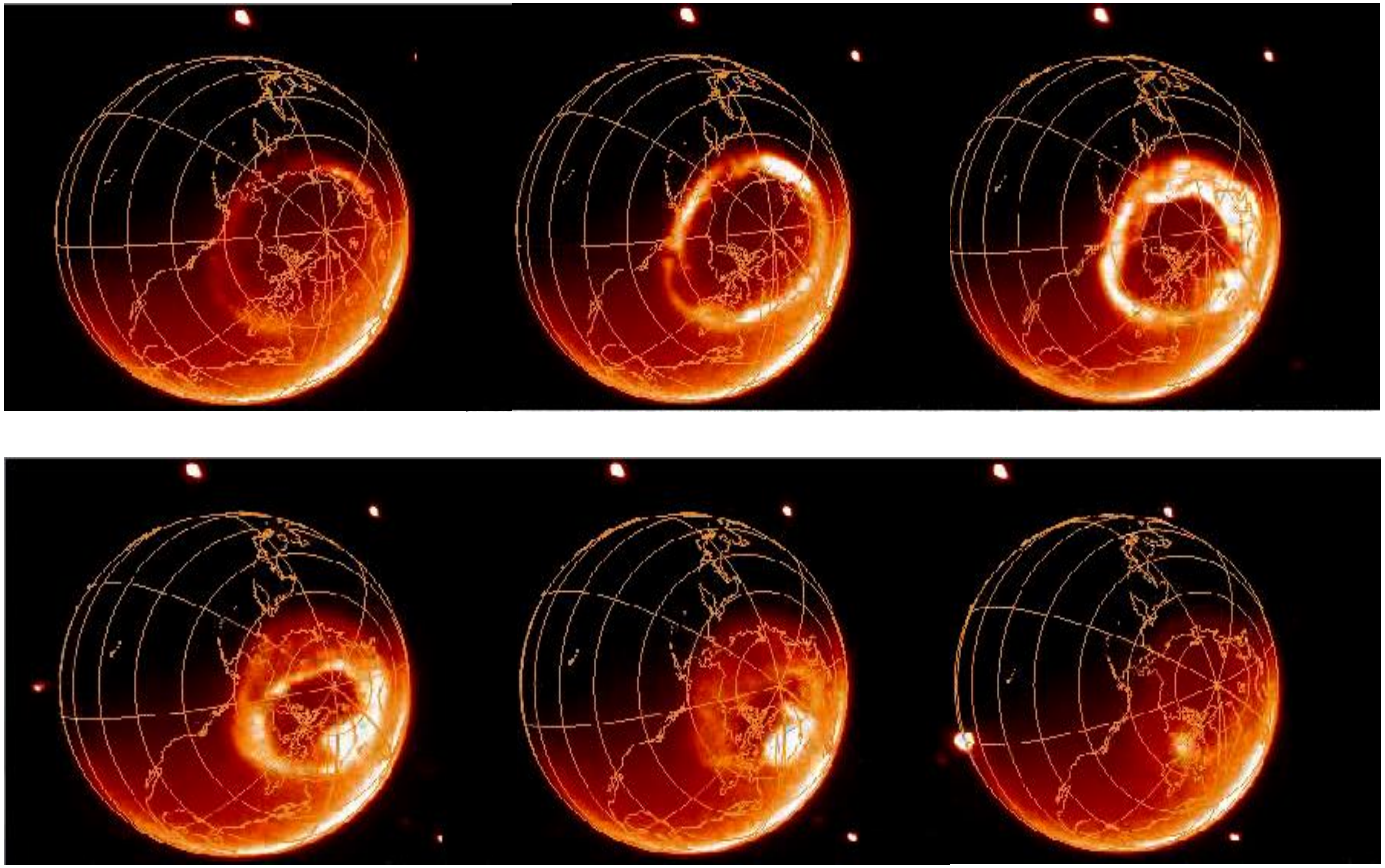
Waves are Generated at High Latitudes



Burch, J. L., *Scientific American, 284*, 72-80, 2001

- Bastille Day Storm
- July 14-15, 2000
- Snapshots During a 1-Hour Period

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Mesoscale High-Latitude Structures

- **Propagating Plasma Patches**
- **Propagating Atmospheric Hole**
- **Sun-Aligned Polar Cap Arcs**
- **Theta Aurora**
- **Boundary and Auroral Blobs**
- **Sub-Auroral Ion Drift Events (SAID)**
- **Storm Enhanced Densities (SED) Ridges**

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Qaanaaq, Greenland, October 29, 1989

All-Sky Images (630 nm)

2 - Minute Interval

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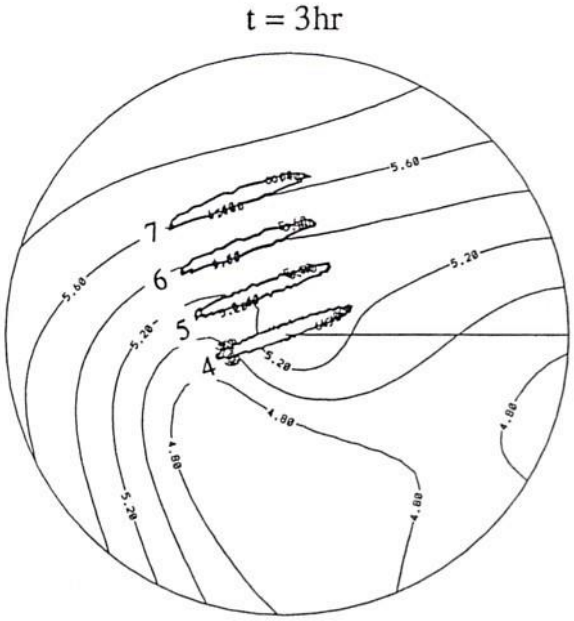
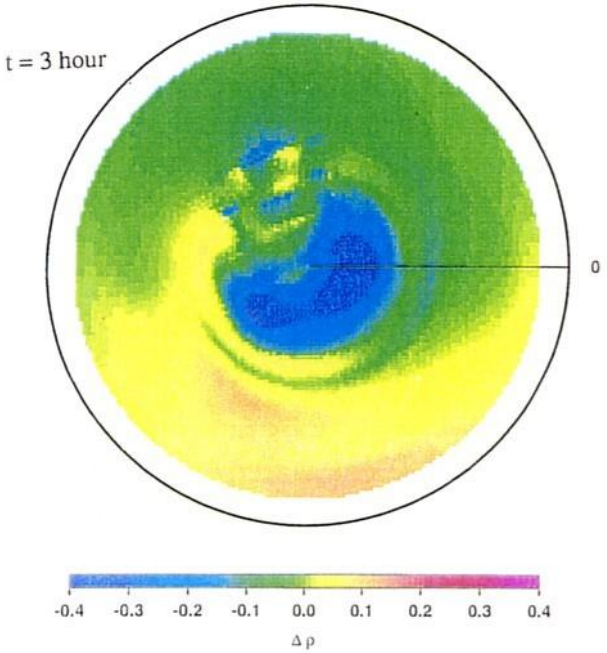
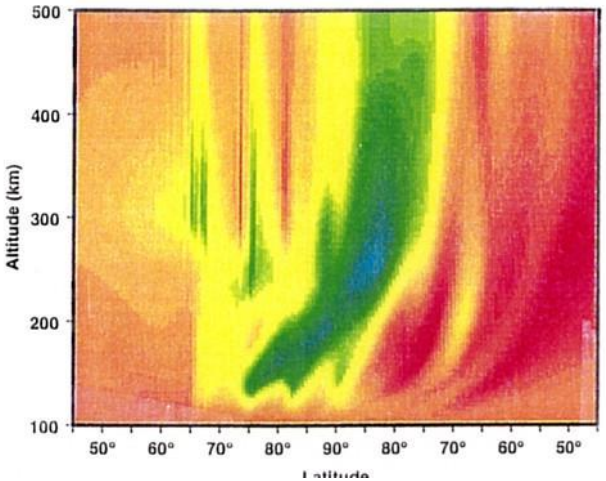
Global Thermosphere Simulation





Effect of Propagating Plasma Patches on High-Latitude Thermosphere



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QuickTime™ and a
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Neutral Density Perturbations Due to Plasma Patches

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Shiokawa et al.: Traveling Ionospheric Disturbance: JAPAN

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TEC

1000 GPS Sites

Mean Separation
25 km

1700 - 1740 UT

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Upward Propagating Waves

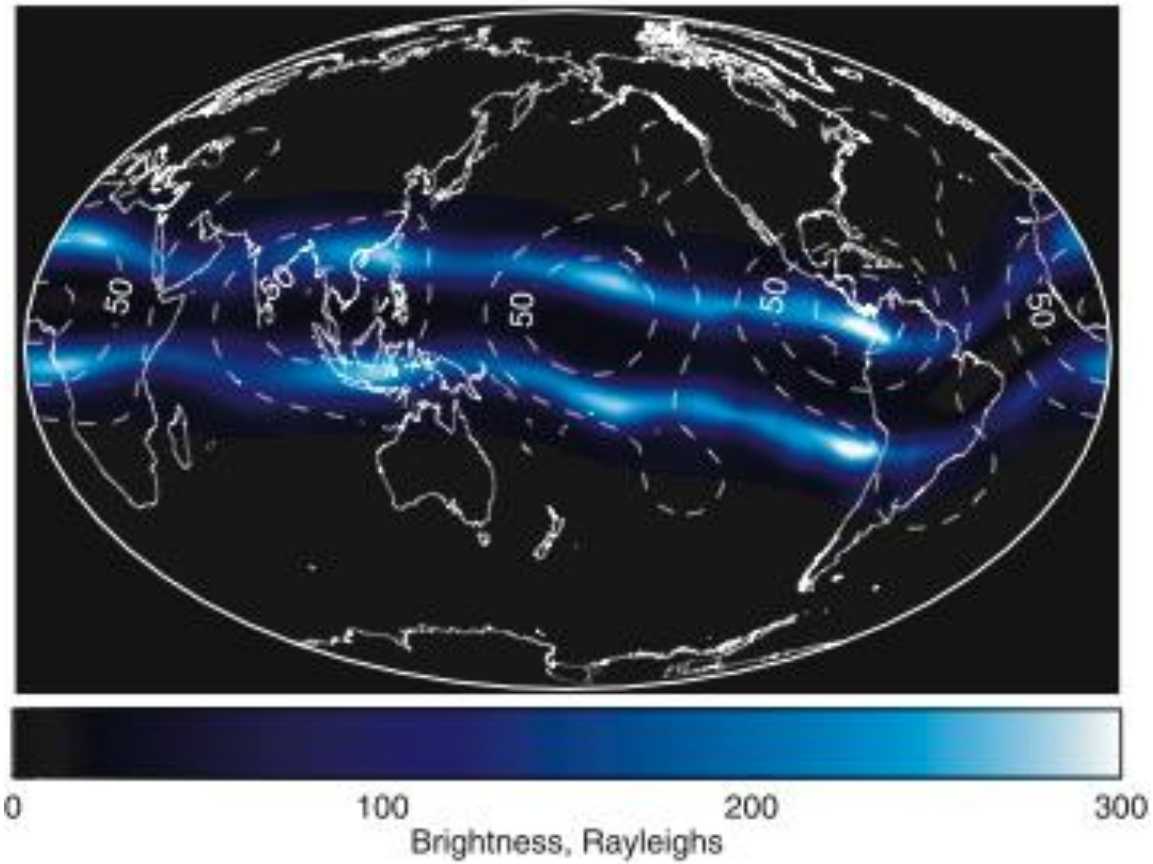
- **Planetary Waves**
  - **Large scale Global Oscillations**
  - **Generated in Troposphere by Mountains**
  - **Stationary or Zonal Propagation (2, 5, 10, 16 day periods)**
- **Tides**
  - **Wavelengths of Several Thousand km**
  - **Migrating and Non-migrating**
  - **Periods of 24-hr and Harmonics**
- **Gravity Waves**
  - **Generated by Disturbances in the Troposphere**
  - **Wavelengths of 5-1000 km**
  - **Periods of 5 min to Several Hours**

Effect of Lower Atmospheric Tides On the Ionosphere

IMAGE-FUV

4-Wave Structure

Immel et al. (2006)



30 Day Average
Solar Maximum
Equinox
20 Local Time
20 % Ne Change

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Lower Atmosphere Models

- **MSIS**
  - **Empirical Climate Model**
  - **Ground to 600 km**
  - **Provides Wave Fields at 90 km**
- **WACCM**
  - **NCAR Climate Model**
  - **Ground to 600 km**
  - **Provides Wave Fields at 90 km**
- **NOGAPS-ALPHA**
  - **Navy's Troposphere Weather Model**
  - **Extended to 120 km by NRL**
  - **Provides Weather Disturbances**

Global Thermosphere-Ionosphere Simulation
Upward Propagating Waves

- **Time-Dependent Global Run**
- **49 Non-Uniform Altitude Layers from 97-600 km**
- **3 deg in latitude, 5 deg in longitude**

- **WACCM Density Specified at 97 km**
- **2 January 1997 - 24 Hour Run**
- **F10.7 = 150**

NCAR - Hanli Liu

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T_n Wave Structure

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BMP decompressor
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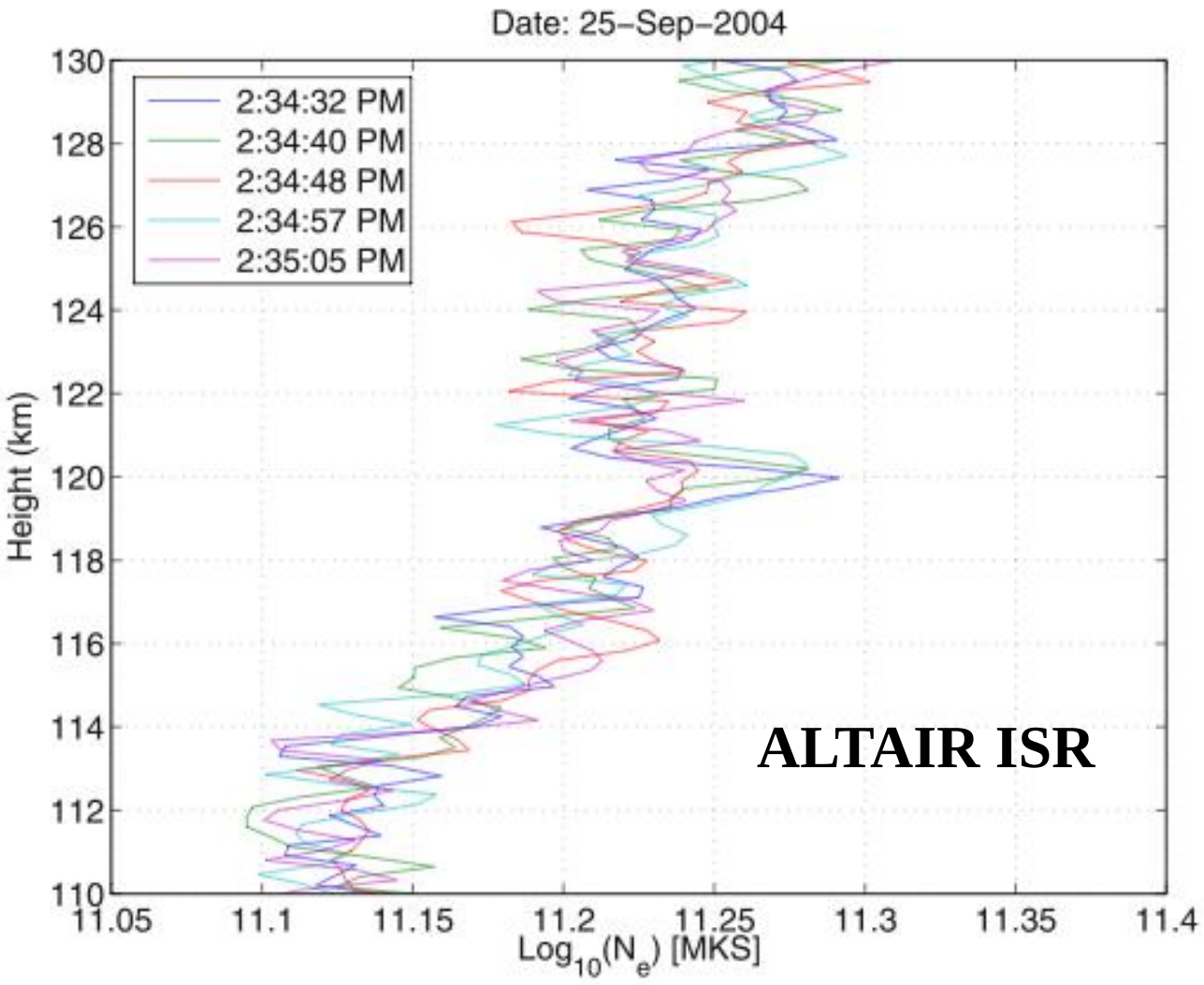
N_e Profiles with Upward Propagating Waves



N_e Variation 20-25 % **Wavelength ~ 2-4 km**

Thermosphere - Ionosphere Modeling

1. **Data Assimilation Models are Needed for Specifications**
2. **Coupled Physics-Based Models are Needed for Forecasts**
3. **Ensemble Model Forecasting is Needed**
4. **Planetary Waves & Tides are Relatively Easy to Incorporate**
5. **Gravity & Sound Waves are a Challenge**
   - **1 km Vertical Resolution**
   - **2 - 10 km Horizontal Resolution**
   - **Time Step less than a Minute**

Physics-Based Model of the Thermosphere

- Numerical Solution of Neutral Gas Continuity, Momentum, and Energy Equations
- Time-Dependent, High-Resolution, Global Model
- Non-Hydrostatic Equilibrium
- Solved versus Altitude not Pressure
- 49, 60, 98 Non-Uniform Altitude Layers from 90-600 km
- 0.5, 0.1 deg in latitude, 3 deg in longitude
- Flux-Corrected-Transport (FCT) Numerical Method
- Rotating Coordinate System fixed to Earth
- Tidal and Gravity Wave Forcing from Below
- Driven by Time-Dependent and Self-Consistent Thermosphere-Ionosphere