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
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.
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)
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 Forecast
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
Gauss-Markov Kalman Filter Reconstruction

Physics-Based Model Without Data

Kalman Filter

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

- 332 Sites
- Dual-frequency Receivers
- Slant TEC

CORS Sites on 2002 day 180
About 2000 Slant TEC Values are Assimilated every 15 min

Kalman Filter Reconstruction

IFM
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
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
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
Coupled Thermosphere-Ionosphere-Electrodynamics Data Assimilation Model
Waves are Generated at High Latitudes


- Bastille Day Storm
- July 14-15, 2000
- Snapshots During a 1-Hour Period
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
Qaanaaq, Greenland, October 29, 1989
All-Sky Images (630 nm)
2 - Minute Interval
Effect of Propagating Plasma Patches on High-Latitude Thermosphere
Shiokawa et al.: Traveling Ionospheric Disturbance: JAPAN

TEC
1000 GPS Sites
Mean Separation
25 km
1700 - 1740 UT
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
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
- $F_{10.7} = 150$

NCAR - Hanli Liu
$T_n$ Wave Structure

QuickTime™ and a BMP decompressor are needed to see this picture.
Ne Profiles with Upward Propagating Waves

Date: 25-Sep-2004

Ne Variation 20-25 %     Wavelength ~ 2-4 km
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