Data Assimilation Models for Space Weather


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F-Region

O + hv → O⁺ + e*
O⁺ + N₂ → NO⁺ + N
O⁺ + O₂ → O₂⁺ + O

Topside

O⁺ + H ⇔ H⁺ + O
USU Physics-Based Data Assimilation Models

1. Kalman Filter Models of the Ionosphere
   - Gauss-Markov Model
   - 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
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.
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)

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

Specification & Forecast of the Global Ionosphere

Operational Model

2 CPU
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
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
Physics-Based Model
Without Data

Kalman Filter

More than 3000 Slant TEC Measurements are assimilated every 15 minutes.
Reconstruction of the 3-D Ne Distribution
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.
NOAA CORS Data

- 332 Sites
- Dual-frequency Receivers
- Slant TEC
Physics-Based Model (IFM)

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
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
Global Ionosphere-Plasmasphere Model (IPM)

- 3-D Time-Dependent Parameters
  - NO⁺, O₂⁺, N₂⁺, O⁺, H⁺, He⁺
  - T_e, T_i
  - u∥, u⊥

- Grid System
  - Global
  - Regional
  - Localized
  - 90-30,000 km
  - Realistic Magnetic Field (IGRF)
Longitudinal Resolution

Resolution is Externally Adjustable

- Operational Mode:
  - Global: ~ 7.5°
  - Regional: ~ 1°

30 Global Simulations are Launched at Each Assimilation Time Step
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
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

Ionosonde Data were NOT assimilated!
Global Meridional Wind Obtained from GAIM

Meridional Wind Pattern

Horizontal Wind Model (HWM)

Full Physics-Based Data Assimilation Model

2004/01 00:00 UT

Southward -100 0 100 Northward

Merid. Wind (m/s)
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