The USU-GAIM Data Assimilation Models for Ionospheric Specifications and Forecasts


Center for Atmospheric and Space Sciences
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Brief Overview of USU Data Assimilation Models

- **GAIM-GM** → Mid & Low Latitudes
- **GAIM-FP** → Mid & Low Latitudes, with Drivers
- **Mid-Low Electro-DA** → Ionosphere with Drivers
- **GAIM-High Lat** → High Latitudes with Drivers
- **GTM-DA** → Global Thermosphere
- **TWAM-DA** → Thermosphere Wind

- All Data Assimilation Models are Physics-Based
- Spatial and Temporal Resolutions are arbitrary
## GAIM Data Sources

![Diagram of GAIM data sources](image)

<table>
<thead>
<tr>
<th>Ionosphere</th>
<th>Electrodynamics</th>
<th>Thermosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground-Based GPS-TEC</td>
<td>Ground magnetometers</td>
<td>Satellite UV emissions</td>
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<tr>
<td>Satellite-Based GPS Occultation</td>
<td>DMSP cross-track velocities</td>
<td>In situ neutral winds</td>
</tr>
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<td>Ionosonde and Digisonde</td>
<td>SuperDARN line-of-sight</td>
<td>Satellite accelerometer and</td>
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<td>velocities</td>
<td>drag</td>
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<tr>
<td>In situ $N_e$</td>
<td>Iridium magnetometers</td>
<td>FPI winds</td>
</tr>
<tr>
<td>911Å, 1356Å, limb, disk (UV)</td>
<td>ACE IMF, Dst</td>
<td>ISR Neutral parameters</td>
</tr>
<tr>
<td>Solar UV, EUV</td>
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</tbody>
</table>

**Black:** Data sources already being assimilated; **Red:** New data sources to be assimilated
GAIM-Full Physics

• Ensemble Kalman Filter (24-30 members)
• Physics-based Ionosphere-Plasmasphere Model (IPM)
• 5 Data Sources as shown on previous slide

Additional Data Types that could be assimilated in GAIM-FP:

→ Electric Field
→ Neutral Wind
→ Thermospheric Temperature and Composition
→ Etc.
GAIM-FP uses the full physics that is included in the physics-based model (IPM) in the data assimilation scheme

- 90-30,000 km
- Altitude, Latitude, Longitude Grids Set by User
- Six Ion Species (NO⁺, O₂⁺, N₂⁺, O⁺, H⁺, He⁺)
- Realistic Magnetic Field (IGRF)
- Some of the Physical Processes included in IPM:
  - Field-Aligned Diffusion
  - Cross-Field Electrodynamic Drifts
  - Thermospheric Winds
  - Neutral Composition Changes
  - Energy-Dependent Chemical Reactions
  - Ion Production due to:
    - Solar UV/EUV Radiation
    - Auroral Precipitation
    - Star Light
GAIM-FP Global Run

- 400 global TEC stations (IGS network) used in real-time at USU Space Weather Center
- Up to 10,000 measurements assimilated every 15-min
- 40-50 Ionosondes/Digisondes
Reconstructions With Self-Consistent Drivers
GAIM-FP ➔ Regional Run

- Snapshots of TEC measurements (left)
- GAIM-FP reconstruction (middle)
- GAIM-FP neutral wind at 300 km (right)
- 17:00 UT, day 82, 2004
GAIM Data-Driven D-Region Extension

- Electron density extension down to 40 km altitude
- Uses GOES X-rays and Particles Observations
- Calculates HF Absorption

2014/112 21:00 UT

Absorption (db)
Incorporation of Low-Latitude Bubbles into GAIM

SSUSI bubble observations are incorporated into high-resolution GAIM specifications.
GAIM-FP Output

- Continuous Reconstruction of Global $N_e$ Distribution
  - Ionosphere-Plasmasphere
  - D, E, F Regions, Topside and Plasmasphere
  - 40-30,000 km

- Quantitative Estimates of the Accuracy of Reconstruction

- Model Drivers
  - Electric Fields
  - Global Neutral Winds
  - Global Neutral Composition
GAIM-High Latitude

Ensemble Kalman Filter for High-Latitude Ionosphere Dynamics and ElectroDynamics

High-Resolution Specification of Convection, Precipitation, Currents & Ionosphere
Physics-Based Model Behind GAIM-High Latitude Model

**Time-Dependent Ionosphere Model**
- 3-D Density Distributions ($\text{NO}^+, \text{O}_2^+, \text{N}_2^+, \text{O}^+, \text{H}^+, \text{He}^+$)
- 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 by GAIM-High Latitude Model

At High Latitudes it is critical to assimilate observations connected with the drivers

- Ground Magnetic Data from 100 Sites
- Cross-Track Velocities from 4 DMSP Satellites
- Line-of-Sight Velocities from 9 SuperDARN Radars
- In-situ $\Delta B$ from the 66 IRIDIUM Satellites
- ACE IMF, solar wind velocity, Kp
Output of GAIM-High Latitude 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
Operational Models

GAIM-Models are running at

• AFWA
• Northrup Grumman
• AFRL
• NRL
• USU SWC
• CCMC