

USU GAIM Data Assimilation Models for Space Weather Specifications and Forecasts

**R. W. Schunk, L. Scherliess, V. Eccles, L. C. Gardner, J. J.
Sojka, and L. Zhu**

**Center for Atmospheric & Space Sciences
Utah State University
Logan, Utah 84322-4405**

**Space Weather Workshop
Westminster, Colorado
April, 2018**



USU Physics-Based Data Assimilation Models

Global Assimilation of Ionospheric Measurements

- Gauss-Markov Model (GAIM-GM)

Air Force Operational Model Since 2006

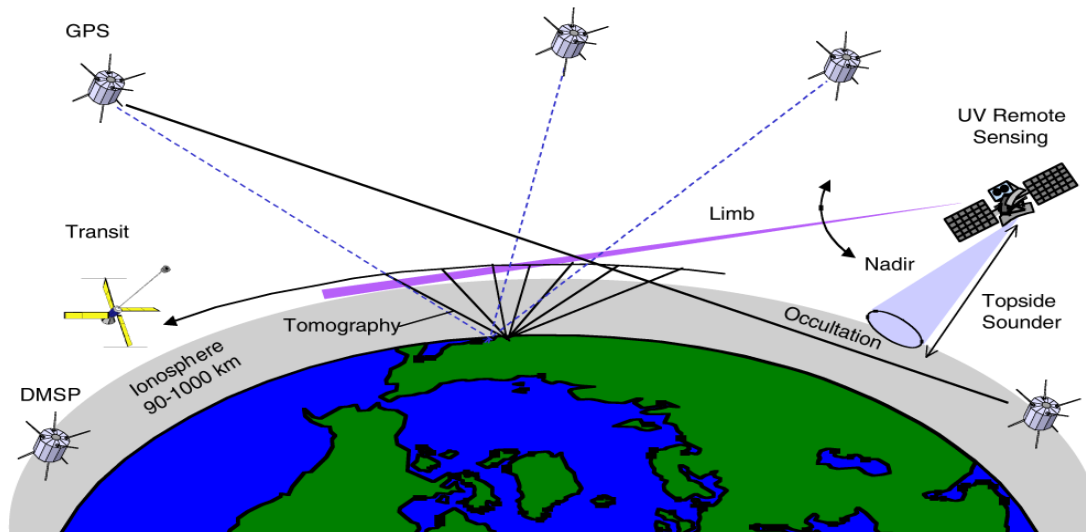
- Full Physics Model (GAIM-FP)

Final Testing Before Implementation as an Operational Model

Ensemble Kalman Filter Model for High-Latitude Ionosphere Dynamics & Electrodynamics (IDED-DA)

Next Major Improvement

GAIM-GM and GAIM-FP Assimilate Multiple Data Sources



- **Data Assimilated**

- Bottomside N_e Profiles from Digisondes (80)
- 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, C/NOFS)

GAIM-GM and GAIM-FP Models

- Air Force Operational Models
- Global, Regional, Nested Grid Modes
- Quality Control Algorithms
- Data Latency (up to 3 hours)
- Hot Start Capability
- 24-Hour Forecast Algorithm
- Independent Validation by AFRL, NRL, CCMC
- User's Manual and Training

GAIM-GM Model

- Ionosphere Forecast Model (IFM)
- Global physics-based model for background ionosphere
- 90 - 1400 km
- 15 - minute output cadence
- O^+ , H^+ , NO^+ , N_2^+ , O_2^+ , T_e , T_i
 - Only uses N_e
- Kalman Filter solves for deviations from background ionosphere
- GAIM-GM does not provide information about ionospheric drivers (electric fields, neutral winds, etc.)

GAIM-FP

- Ensemble Kalman Filter (24-48 CPU/Cores)
- Physics-based Ionosphere-Plasmasphere Model (IPM)
- Incorporates Ionospheric Physics in Data Assimilation
- 5 Data Sources as in Previous Slide
- Altitude, Latitude, Longitude Grids Set by User
- Ionospheric Specification and Forecasts and Drivers
 - Electric Field
 - Neutral Wind
 - Neutral Composition

Ionosphere – Plasmasphere Model (IPM)

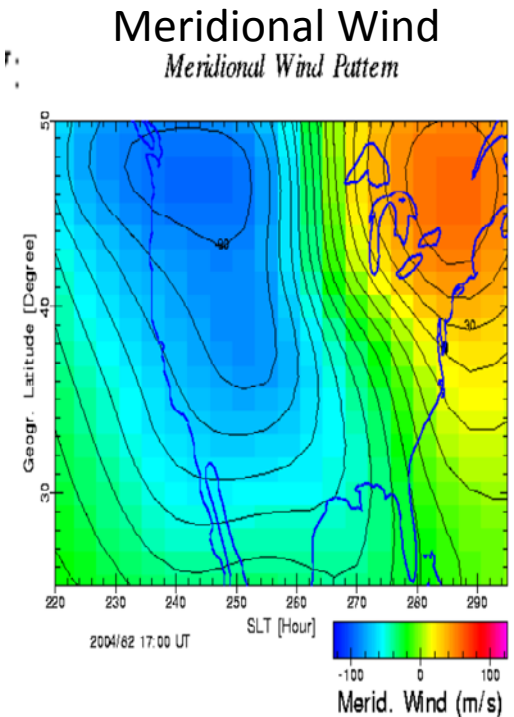
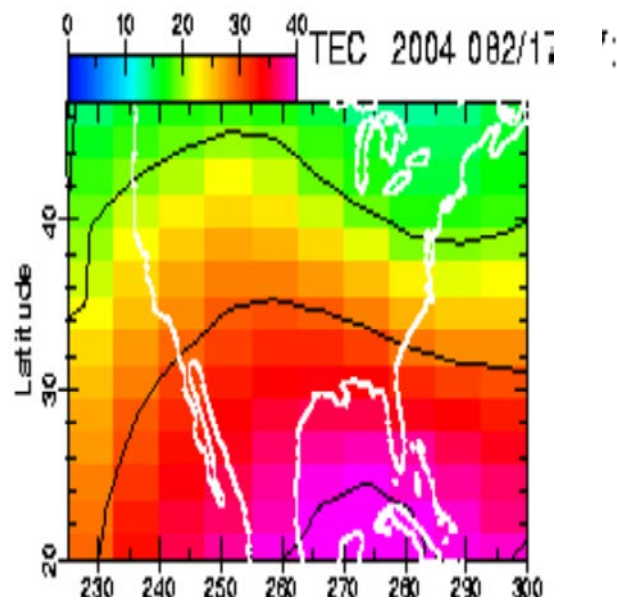
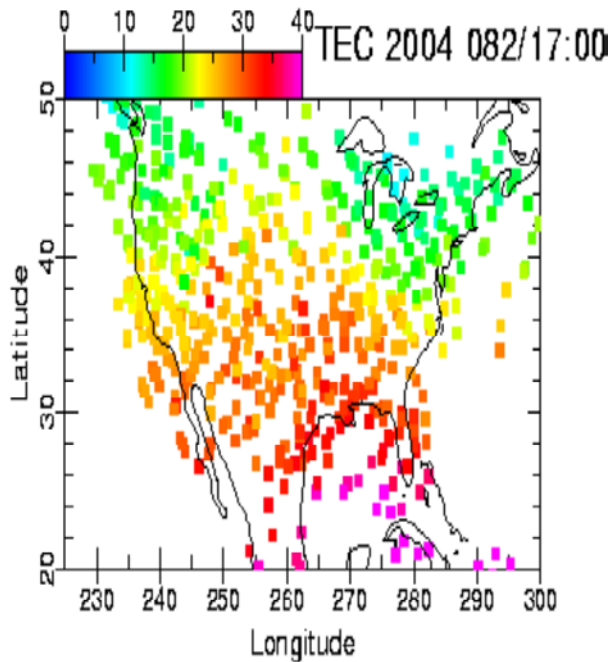
- 90-30,000 km
- Altitude, Latitude, Longitude Grids Set by User
- Six Ion Species (NO^+ , O_2^+ , N_2^+ , O^+ , H^+ , He^+)
- Realistic Magnetic Field (IGRF)
- Some of the Physical Processes included in IPM:
 - Field-Aligned Diffusion
 - Cross-Field Electrodynamic Drifts
 - Thermospheric Winds
 - Neutral 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-FP Output

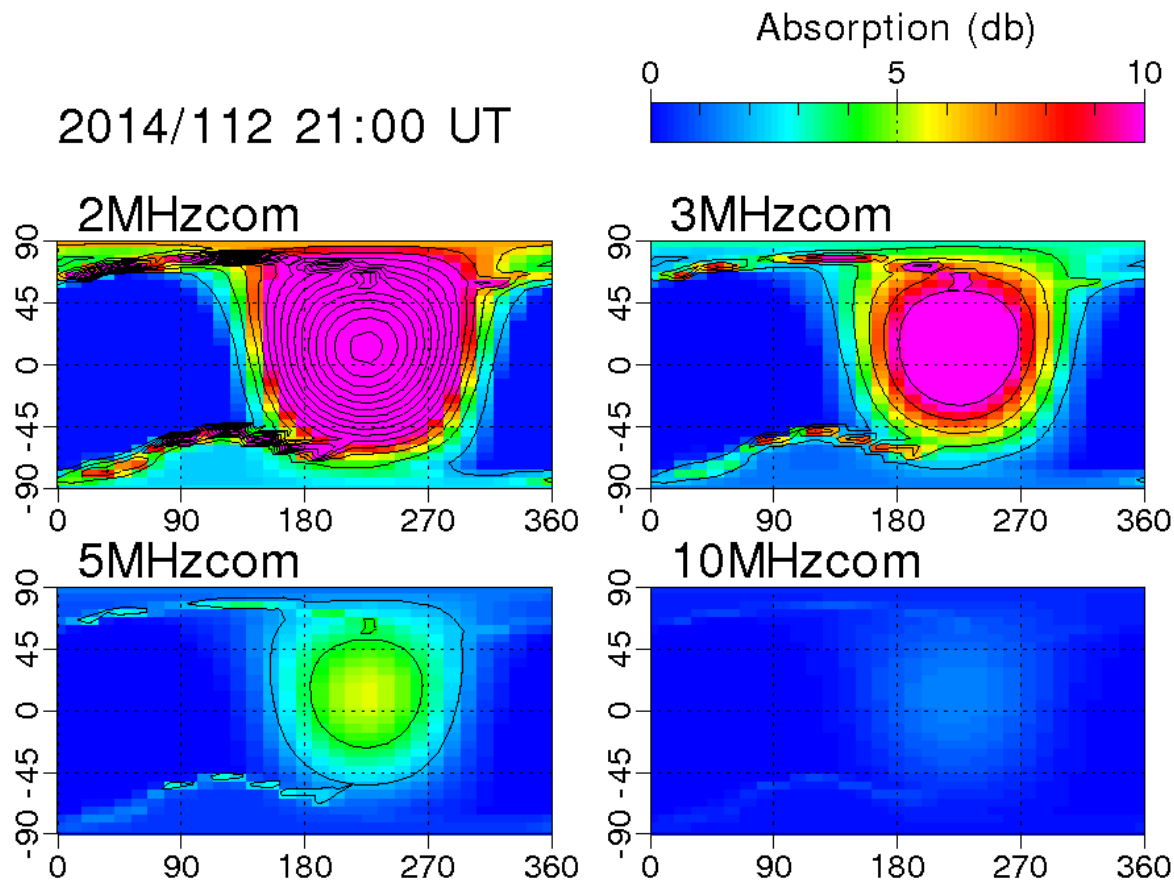
- Continuous Reconstruction of Global N_e Distribution
 - Ionosphere-Plasmasphere
 - 90-30,000 km
- Quantitative Estimates of the Accuracy of Reconstruction
- Auxiliary Parameters
 - $N_m F_2$, $h_m F_2$, $N_m E$, $h_m E$
 - Slant and vertical TEC
- Model Drivers
 - Electric Fields
 - Global Neutral Winds
 - Global Neutral Composition

Recent Developments - GAIM-FP

- Incorporation of D-Region
- Incorporation of Equatorial Bubble Information
- Assimilation of Generic Data Sets
- Improved Transition from Low-to Mid-Latitudes
- Internal Estimation of GPS Biases

GAIM Data-Driven D-Region Extension

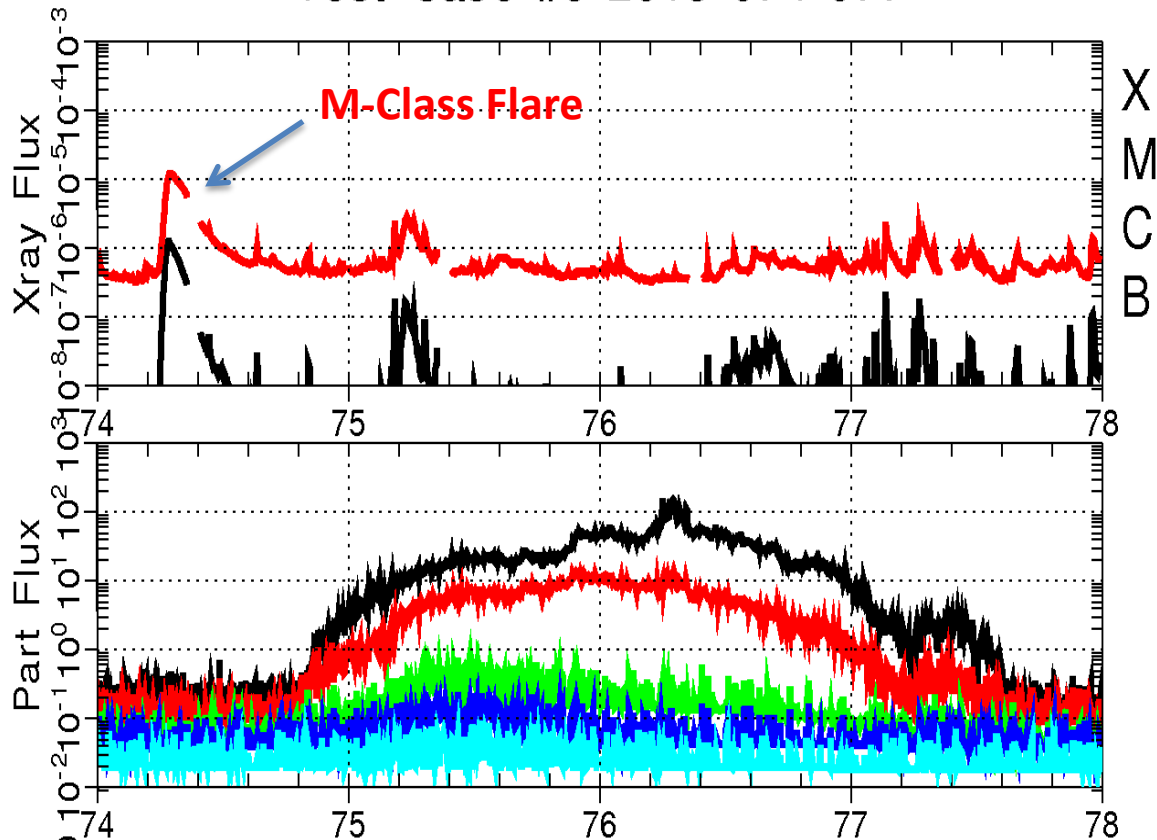
- Electron density extension down to 40 km altitude
- Uses GOES X-rays and Particles Observations
- Calculates HF Absorption



GAIM Data-Driven D-Region Extension

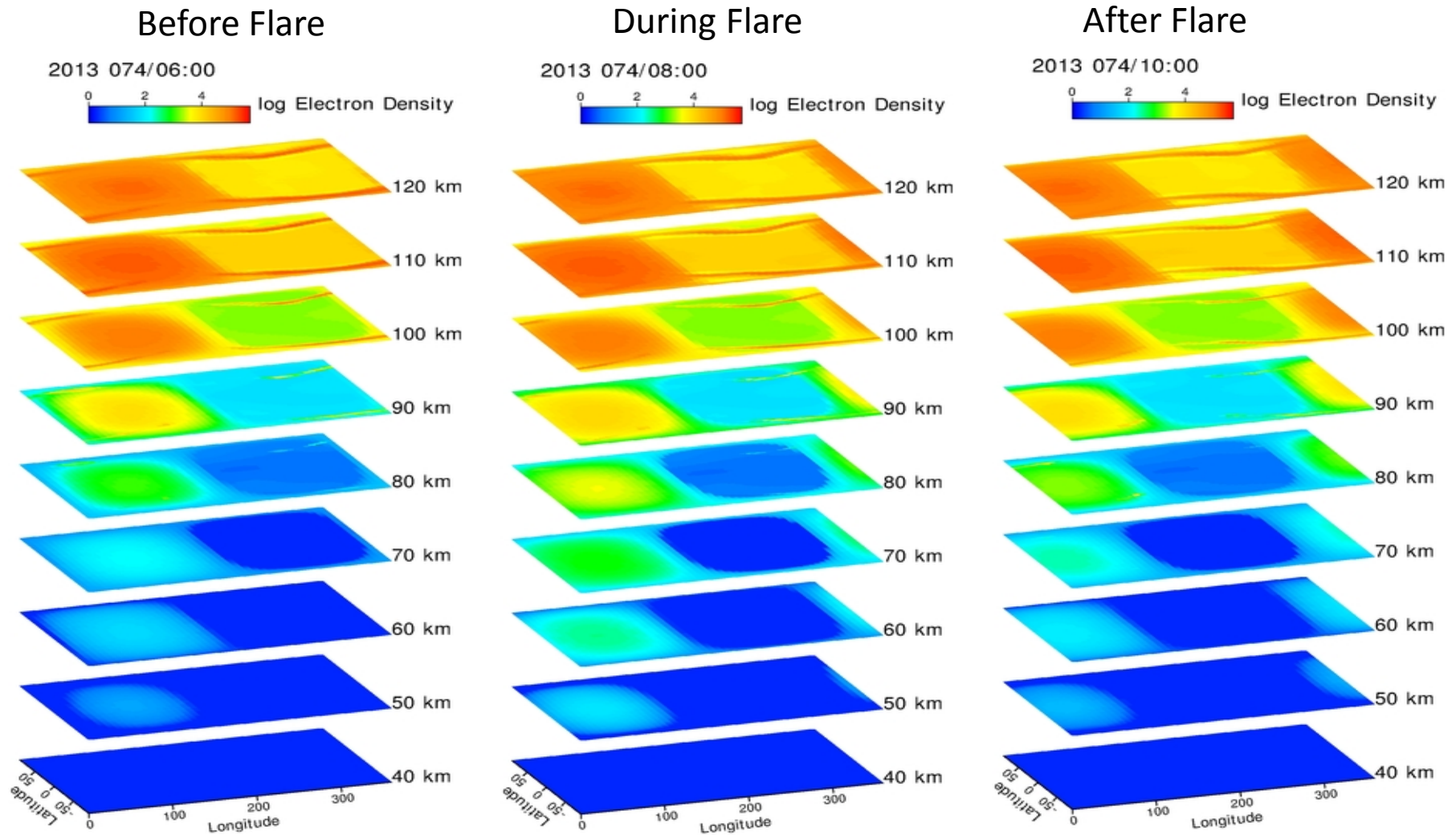
- Electron density extension down to 40 km altitude
- Uses GOES X-Ray and Particle Observations

Test Case #5 2013 074-077



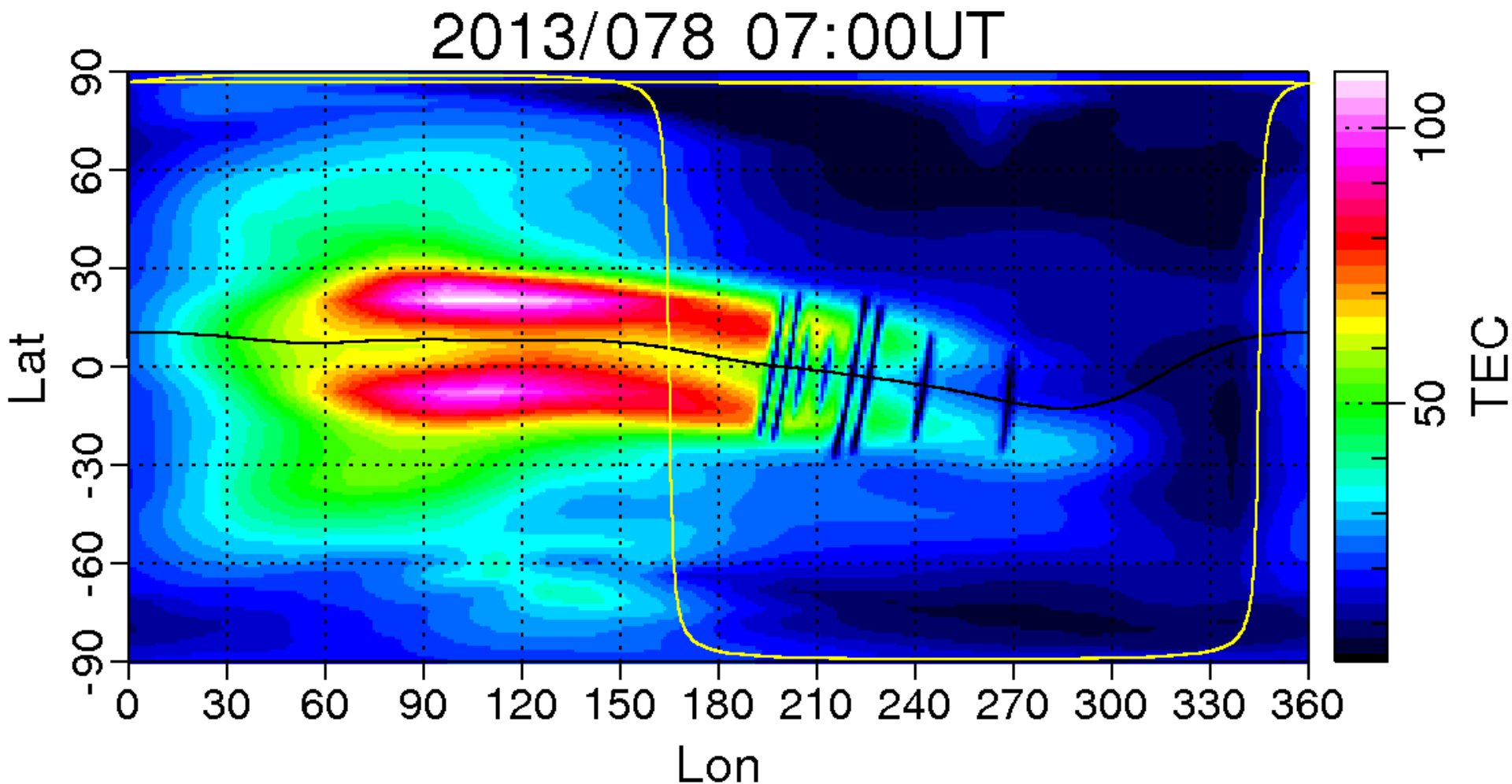
GAIM Data-Driven D-Region Extension

- Electron density extension down to 40 km altitude
- Uses GOES X-Ray and Particle Observations



Incorporation of Low-Latitude Bubbles into GAIM

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



Incorporation of New Data Sets into GAIM-FP

New capability to assimilate

- Generic orbit satellite to satellite slant TEC data
- Generic orbit satellite to ground slant TEC data
- Generic orbit satellite in-situ density measurements

This new capability adds the possibility to assimilate data from JASON-2, TEC from DORIS beacon data, and COSMIC-2 RO data

Ensemble Kalman Filter for High-Latitude Electrodynamics & Ionosphere (IDED-DA)

**High-Resolution Specification of Convection,
Precipitation, Currents & Ionosphere**

Runs on 30 CPUs

Currently a Science Model

IDED-DA Physics-Based Models

- Time-Dependent Ionosphere Model (IPM)
- M-I Electrodynamics Model
- Magnetic Induction Model

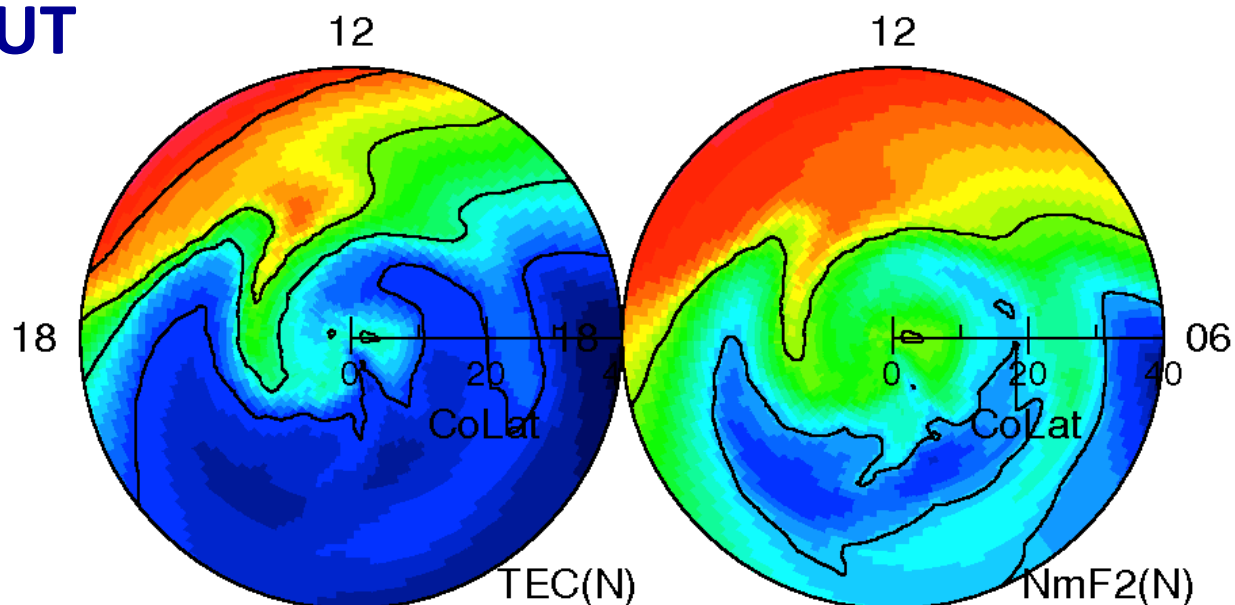
Data Assimilated in IDED-DA Model

- Ground Magnetic Data from 100 Sites
- Cross-Track Velocities from 4 DMSP Satellites
- Line-of-Sight Velocities from 9 SuperDARN Radars
- In-situ ΔB from the 66 IRIDIUM Satellites
- ACE IMF, solar wind velocity, Kp

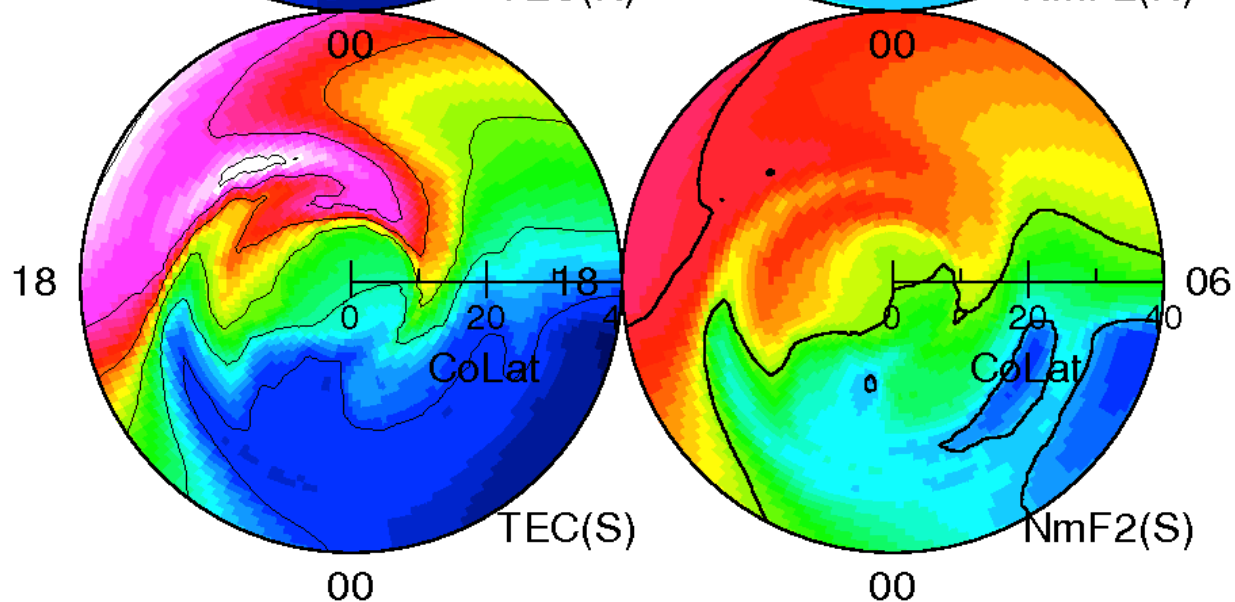
08:00 UT

Storm Day

North



South



2013/076 08:00 UT F10.7=125 F10.7A=113 Kp=6.0