Data Assimilation for the Ionosphere

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Data Assimilation

- Tomography
  - Ionospheric Reconstruction
- Physics-Based Assimilation
  - Ionospheric Inputs
  - Ionospheric Density

Data Assimilation for Ionospheric Inputs

- Inputs
  - Magnetospheric E-Field
  - Auroral Precipitation
  - Neutral Densities and Temperatures
  - Neutral Winds
  - Equatorial E-Field
- Approaches
  - AMIE
  - SuperDARN and Polar Images
  - DMSP and NOAA Satellite Precipitation
  - Digisonde Winds
  - Satellite UV Emissions for Neutral Composition (O/N_2 ratio)

AMIE Technique

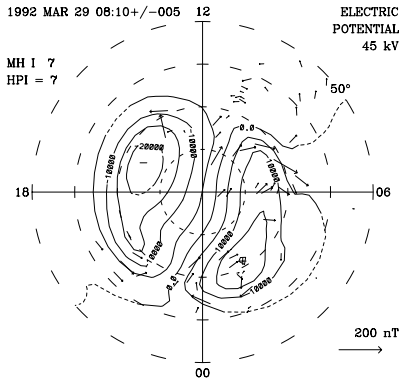
- Combines a Diverse Set of Real-Time Measurements and Statistical Models and Least-Square Fitting Algorithms

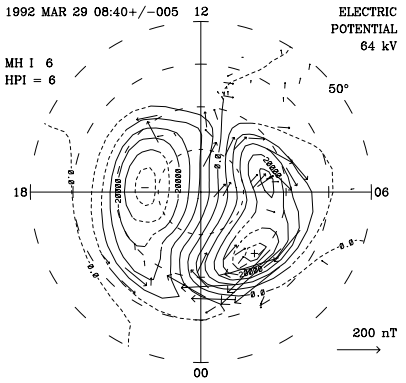
- Time-Dependent Patterns
  - Convection E-Field
  - $J_{\parallel}$ and $J_{\perp}$
  - Σ_P and Σ_H
  - Auroral Precipitation

- March 28-29, 1992
  - 93 Magnetometers
  - Sondrestrom ISR
  - Wick, Goose Bay and Halley Bay CSR

Electric Potential

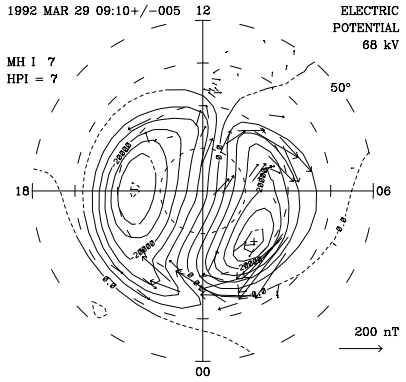
8:10 UT
42 kV

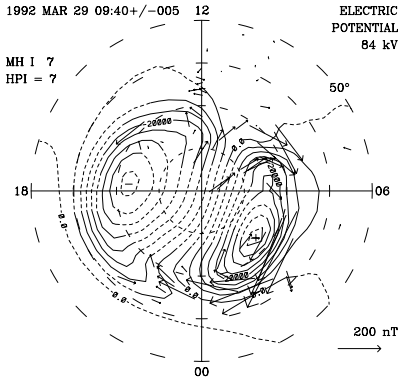




8:40 UT
65 kV

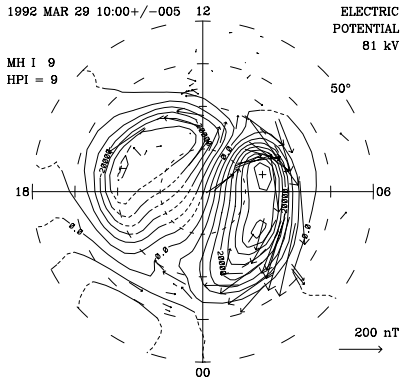
9:10 UT
61 kV

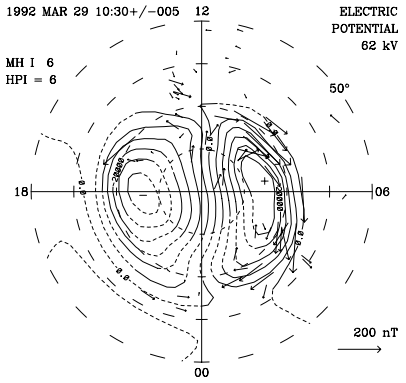




9:40 UT
78 kV

10:10 UT
78 kV





10:30 UT
62 kV

Lu et al. (1996)

MURI GAIM

Coordination Leaders: R. W. Schunk and C. Wang

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Global Assimilation of Ionospheric Measurements
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Universities of Colorado (Boulder), Texas (Dallas), and Washington

Organizations

Utah State University (USU)

University of Southern California (USC)

University of Colorado at Boulder (CU)

Jet Propulsion Laboratory (JPL)

University of Texas at Dallas (UTD)

University of Washington (UW)

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Basic Approach

We will use a physics-based ionosphere-plasmasphere model as a basis for assimilating a diverse set of real-time (or near real-time) measurements. GAIM will provide both specifications and forecasts on a global, regional, or local grid.

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GAIM Data Assimilation Model

- Produces Time-Dependent Global Ionospheric Density Distributions Regardless of the Amount of Data Available.
- Modular Construction so Improved Algorithms Can be Inserted Without Affecting the Rest of the System.
- System Can be Run on a 25-Node Beowulf Cluster (~$25,000).

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Global Ionosphere-Plasmasphere Model (IPM)

- 3-D Time-Dependent Parameters
  - NO^+, O_2^+, N_2+, O^+, H^+
  - T_e, T_i
- Auxiliary Parameters
  - N_mF_2
  - h_mF_2
  - N_mE
  - h_mE
  - TEC
- Grid System
  - Global
  - Regional
  - Localized
  - 90-30,000 km

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Model Drivers

- High-Latitude Convection and Precipitation
- Mid-Latitude Winds
- Low-Latitude Winds and Electric Fields
- Global Neutral Composition
- Global Neutral Winds

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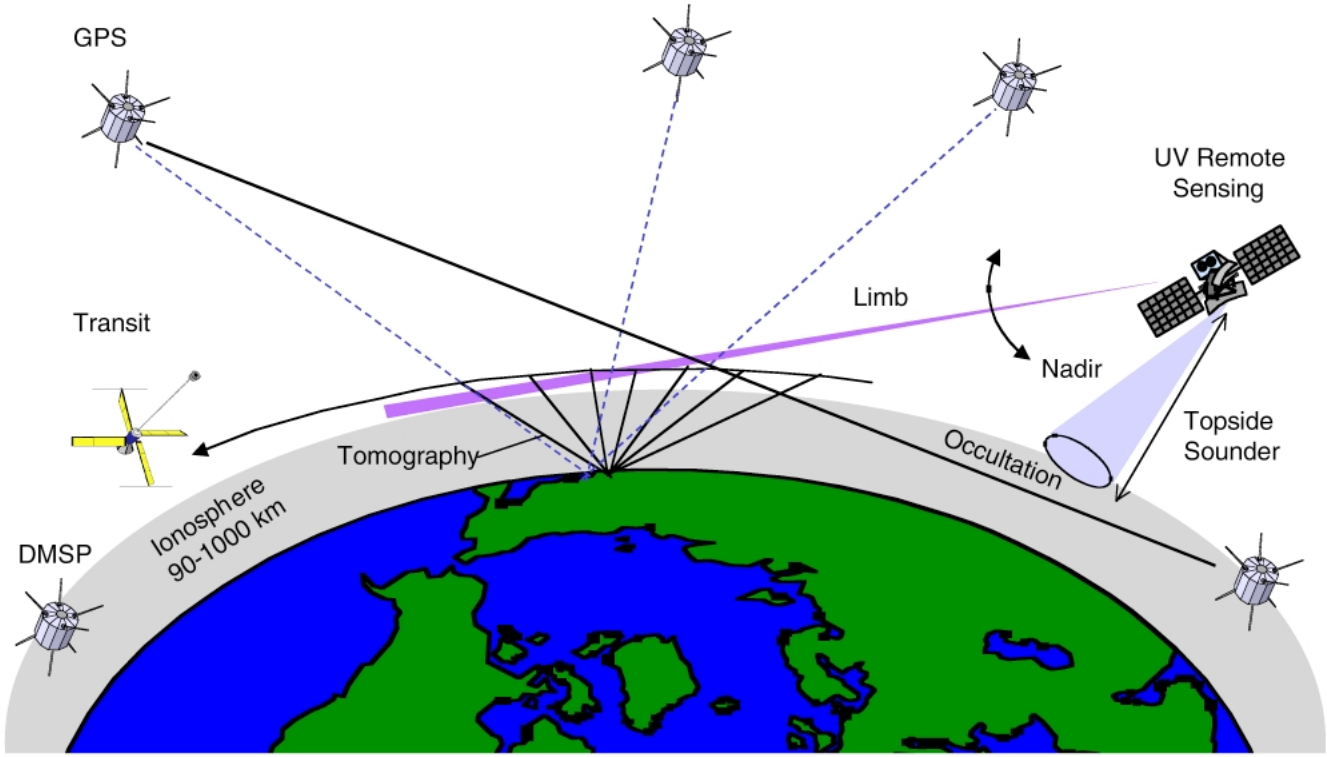
Multiple Data Sources



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Assimilation Techniques

- Full Kalman Filter
- Approximate Kalman Filter
- Adaptive Kalman Filter
- Ensemble Kalman Filter
- Adjoint Method
- Stochastic Data Assimilation

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Kalman Filter

- Powerful Way of Assimilating Data into a Time-Dependent, Physics-Based Model
- Performs a Recursive Least-Squares Inversion of All Data Types for N_e Using the Physics-Based Model as a Constraint
- It has the Least Expected Error Given the Measurements, Model, and Error Statistics

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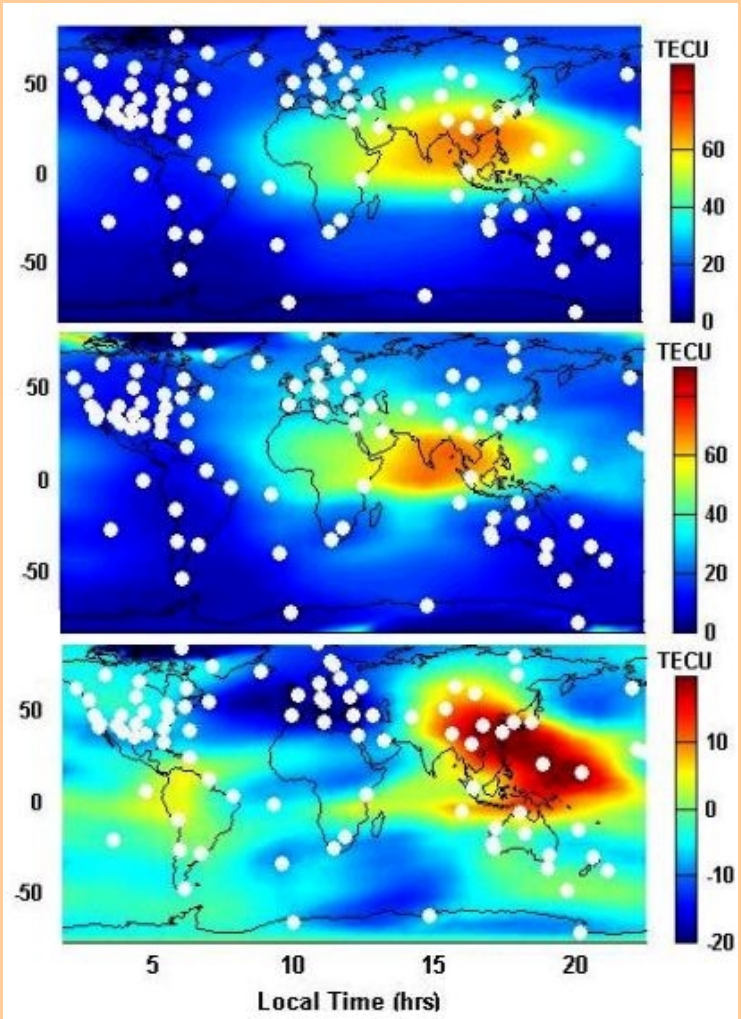
Kalman Filter Highlights

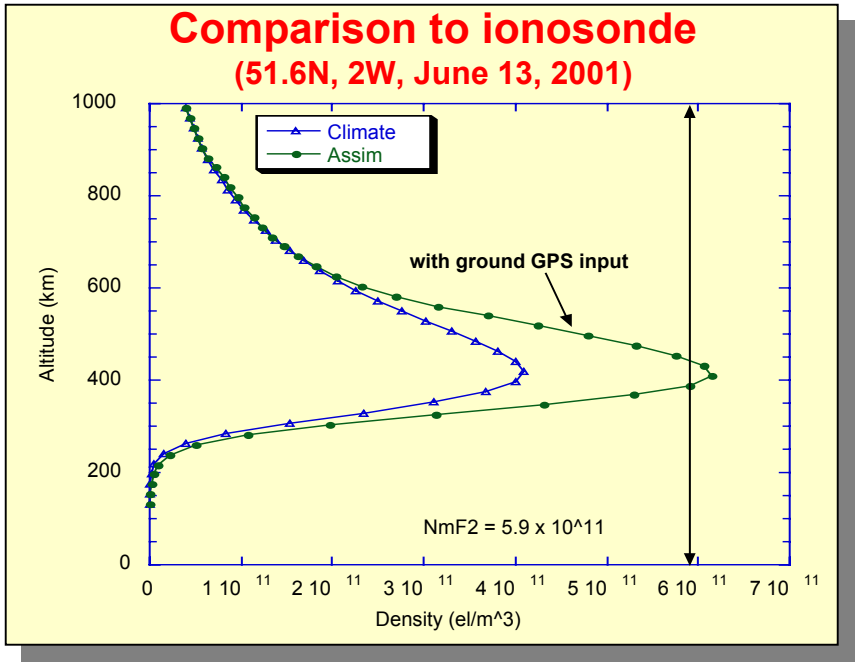
- Proper understanding of error sources
  - Data
  - Representiveness error
  - State apriori covariance
  - System Noise
- Observation System Simulation Experiments (OSSEs)
- Proper handling of covariance
  - Using model dynamics
- Consistency
  - χ^2 tests
  - Examination of pre- and post-fit residuals
- Computational efficiency and speed
- Examination of different approximations

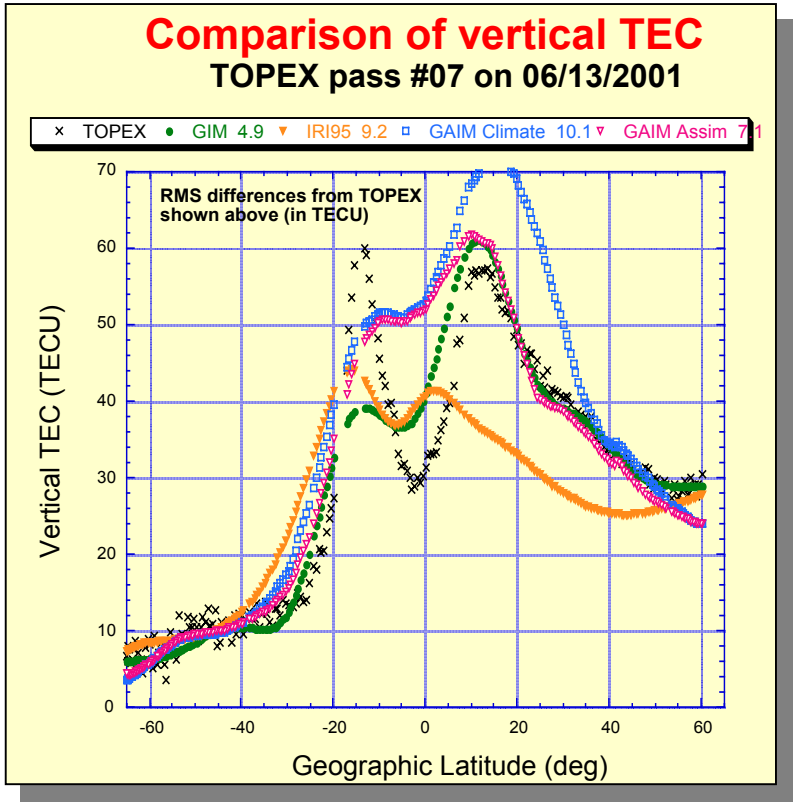
TEC global maps from GAIM climate (top), assimilation (middle) and their difference (bottom) on 990621, 10:00 UT



Validation of Kalman Filter

- Comparing GAIM derived TEC to vertical TOPEX TEC
- Comparing GAIM derived global TEC maps to purely data driven TEC maps such as GIM
- Comparing line-of-sight GPS TEC with GAIM predicted TEC
- Comparing GAIM profiles to ionosondes NmF2 measurements





Gauss-Markov Kalman Filter Reconstructions with Real Data

- **Physics-Based Background Model (IFM)**
- **Data Assimilation of Deviations from Background**
- **Gauss-Markov Process for ΔN_e [exp(-t/τ)]**
- **3-D Near Global Coverage**
  - All Longitudes
  - Spatially Varying Latitude Grid from -60ºS to 60ºN
  - Adaptive Altitude Grid from 90 to 3000km
- **Simultaneous Determination of N_e and GPS Ground Rx Biases**

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Ionospheric Data Assimilation

- Different Data Types are Assimilated in GAIM to Specify and Forecast the Global 3-D Plasma Densities
- Currently These Data Types Include:
  - Bottomside Profiles from 16 DISS Stations
  - Slant TEC from 42 GPS Stations
  - Topside Electron Densities from 2 DMSP Satellites
  - and Eventually Occultation Data from LEO and UV data from ARGOS and other Satellites

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Data Distribution

We Currently Assimilate Data from 16 Globally Distributed DISS Stations and 42 GPS Ground Stations that are also used by the Air Force. The GPS Stations are Linked to the Fleet of GPS Satellites. In Addition, We Assimilate Electron Density Data from Two DMSP Satellites in the Filter.

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

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Gauss-Markov Kalman Filter Reconstruction

In the Following Movie, a 3-Day Kalman Filter Reconstruction of the Global Distribution of Ionospheric Total Electron Content (TEC) is Shown from -60°S to 60°N.

Measurements from the 42 GPS Stations, 1 DISS Station (Wallops; Assimilation of the Additional DISS Stations is Currently in Process), and 2 DMSP Satellites were Continuously Assimilated in the Filter in 15-min Intervals Starting at 00UT on December 2, 1998. TEC was Then Calculated by Integrating Through the Reconstructed 3-D Electron Density Field.

Validation of These Results is Currently in Process.

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Kalman Filter Reconstruction

TEC

Background

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

Kalman Filter Reconstruction

% (Reconstruction-Background)

(50 : no change)

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Conclusions

- Preliminary Kalman Filter Reconstructions for Both the Ionospheric and Neutral Parameters are Very Encouraging.
- With Multiple Data Types Assimilated Over Time, the Kalman Filter Reconstructions Approach the Actual Time Varying Ionosphere and Thermosphere.
- When the GAIM Project is Completed, the Kalman Filter Reconstructions of the Ionosphere and Thermosphere will be Superior to Other Existing Specification and Forecast Models.

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