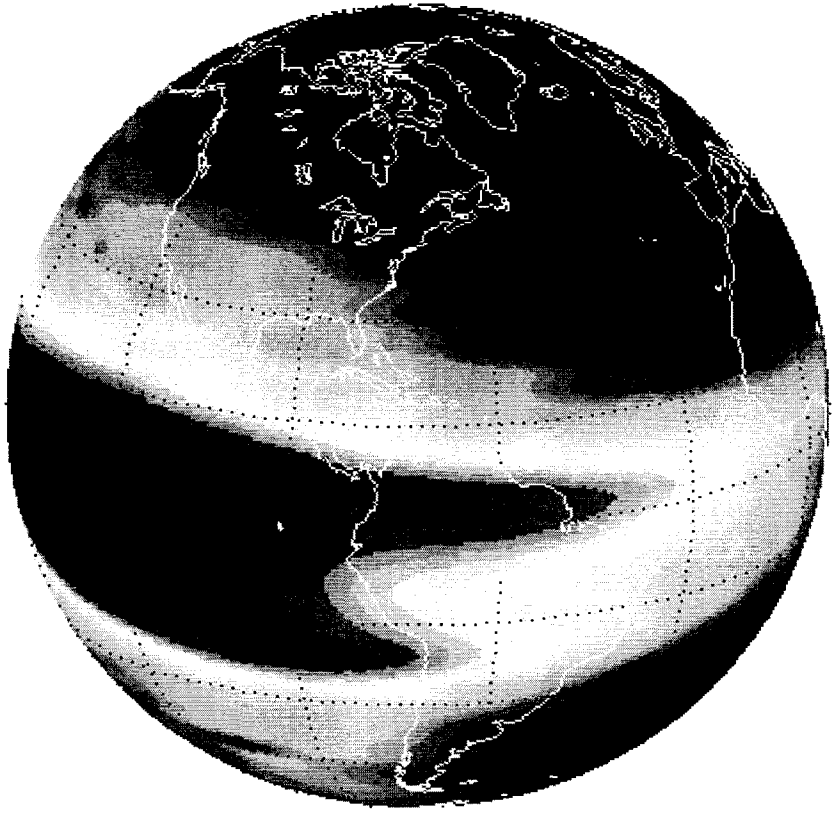
Assimilative Modeling of Low-Latitude Ionosphere



Xiaoqing Pi, JPL, USC

Chunming Wang, USC

George Hajj, JPL, USC

Gary Rosen, USC

Brian Wilson, JPL

Anthony J. Mannucci, JPL

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Outline

- Exploring and Validating 4DVAR approach
- 4DVAR Validation Experiment Settings
  - Assimilation of ground-based GPS data for low latitudes
  - Estimation of E×B drift and wind simultaneously
  - Ionospheric weather conditions
- Results
  - TEC comparisons with TOPEX, GIM, and IRI
  - Density comparisons with ionosonde
- Discussions of Optimization Issues

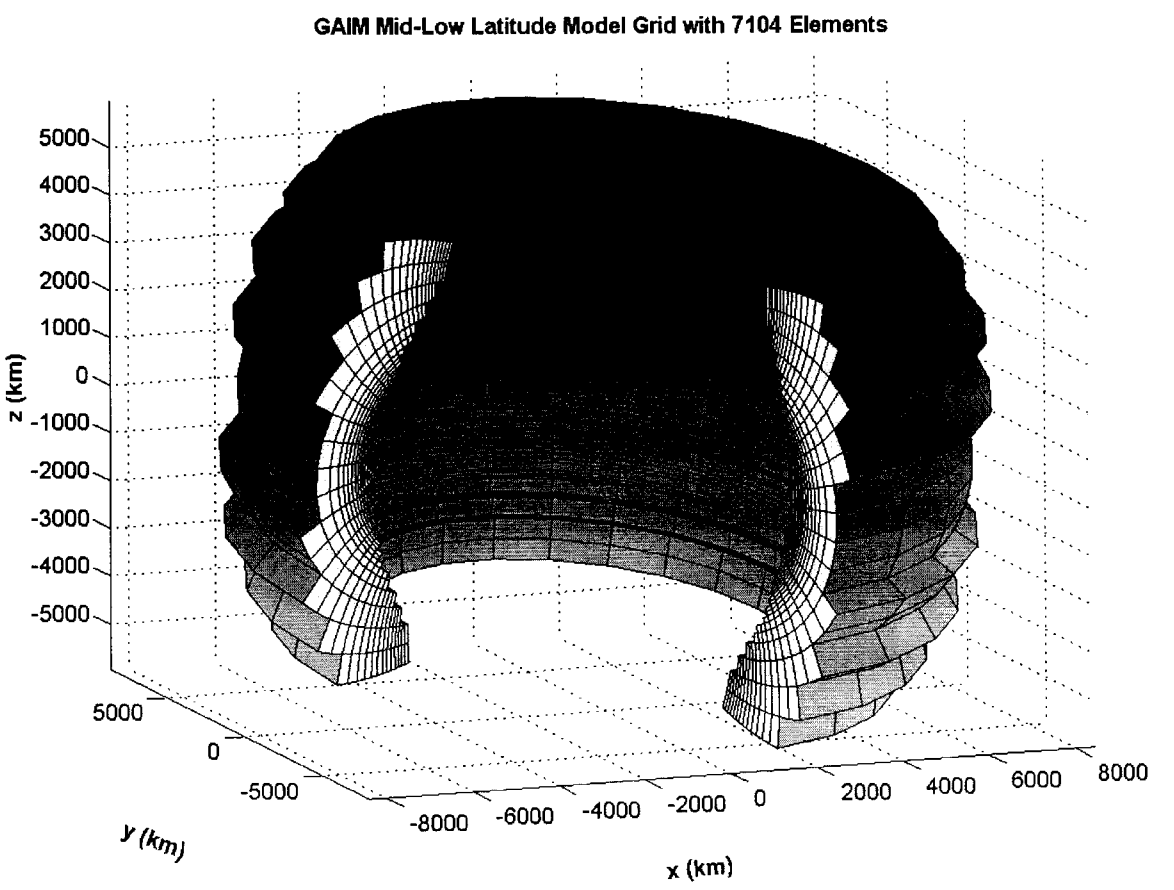
Elements of a 4DVAR Process

Estimation of multiple drivers and improvement of state (n_e)

- Physics-based forward model
- Observation operator
- Parameterization of multiple drivers
- Computation of cost functional
- Calculation of Gradient: $\partial J/\partial \alpha$ (adjoint method)
- Minimization of cost function
- Region of interest
- Data acquisition and selection
- Grid for parameter estimation: dimensions and spacing
- Determining the assimilation cycle length
- Selection of penalty coefficients

GAIM Grid for Low Latitude Simulation Experiments

- **Coverage**
  - Global in longitude: $\Delta\phi = 15°$
  - $\pm 30°$ in latitude: $\Delta\theta = 3°$
  - 120 – 1500 km in altitude
  - $\Delta h = 80, 50$ km



Optimization Approach: 4DVAR

$$J(n;\alpha) = \sum_{k=1}^{m} \left\| y_k - H_k n(t_k;\alpha) \right\|^2 + \beta \left\| n - n_0 \right\|^2 + \lambda \left\| \alpha - \alpha_0 \right\|^2$$

$$\nabla \vec{J}(\alpha)$$

$$\nabla \vec{J}(\alpha) = 0$$

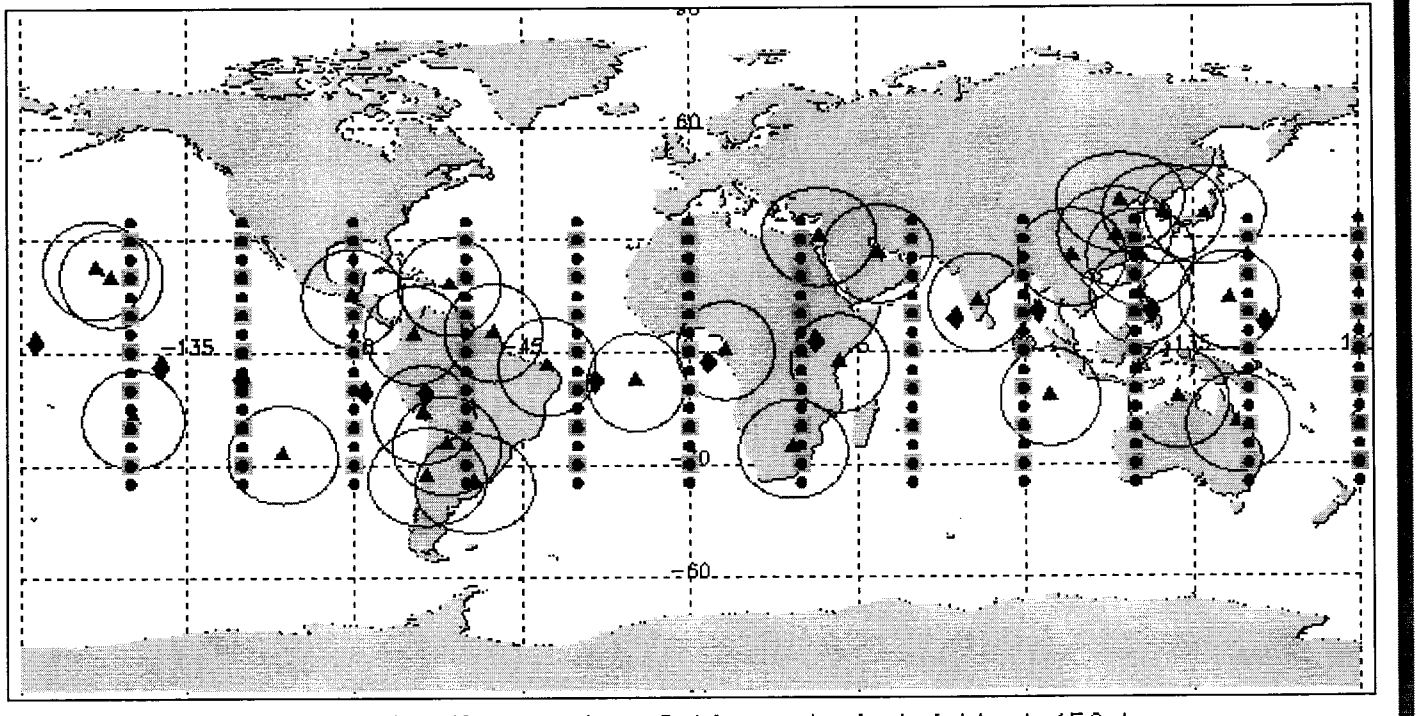
$$v_{eq}(t) = v_{eq,0}(t) + \sum_{k=1}^{N} \alpha_k \phi_k(t)$$

$$F(\mathbf{r}) = F_0(\mathbf{r}) + \frac{1}{\sum_{i=1}^{7} w_i} \sum_{i=1}^{7} w_i(\rho', \sigma) f_i(\mathbf{r}')$$

- **Non-linear least squares minimization**
  - *Cost function* to compute model deviation from observations
  - *Adjoint method* to compute gradient of cost function: computation efficiency
  - *Minimization*: finding roots using Newton's method by estimating driving parameters
  - *Parameterization* of model drivers

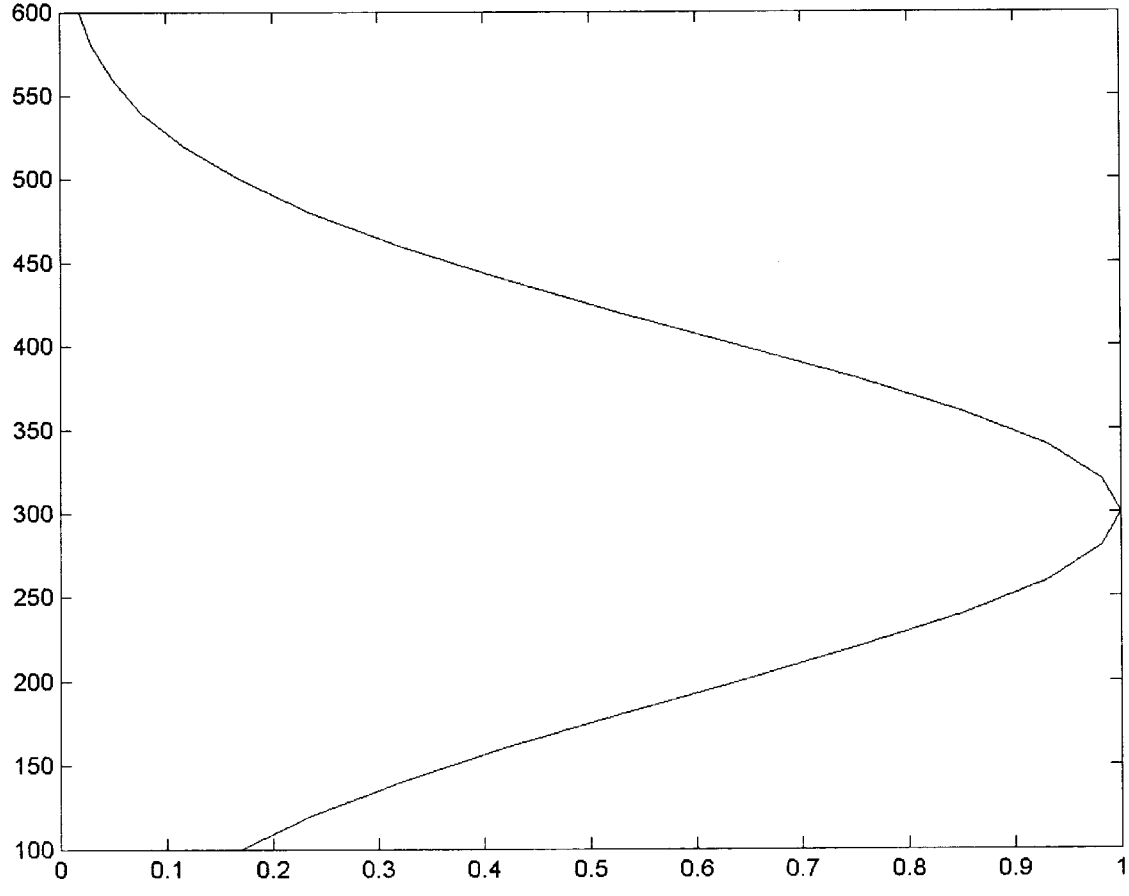
To estimate ionospheric drivers and optimize the state

Parameter Grid and GPS Stations



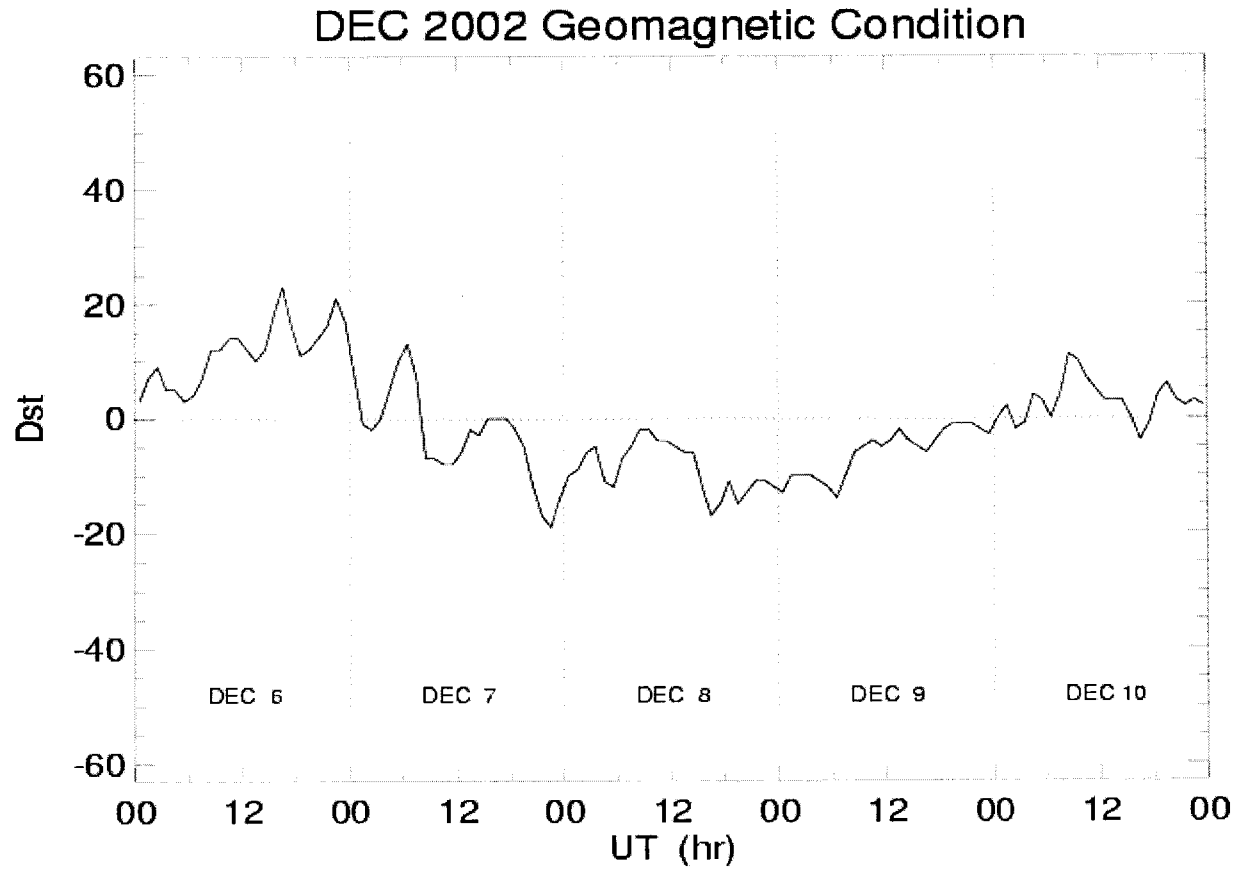
- Number of stations: 12/07/2002: 31
- Observation links: ~2240/ hour, sampled at 5-minute epochs

Wind Perturbation Scale Pattern in Altitude Dimension

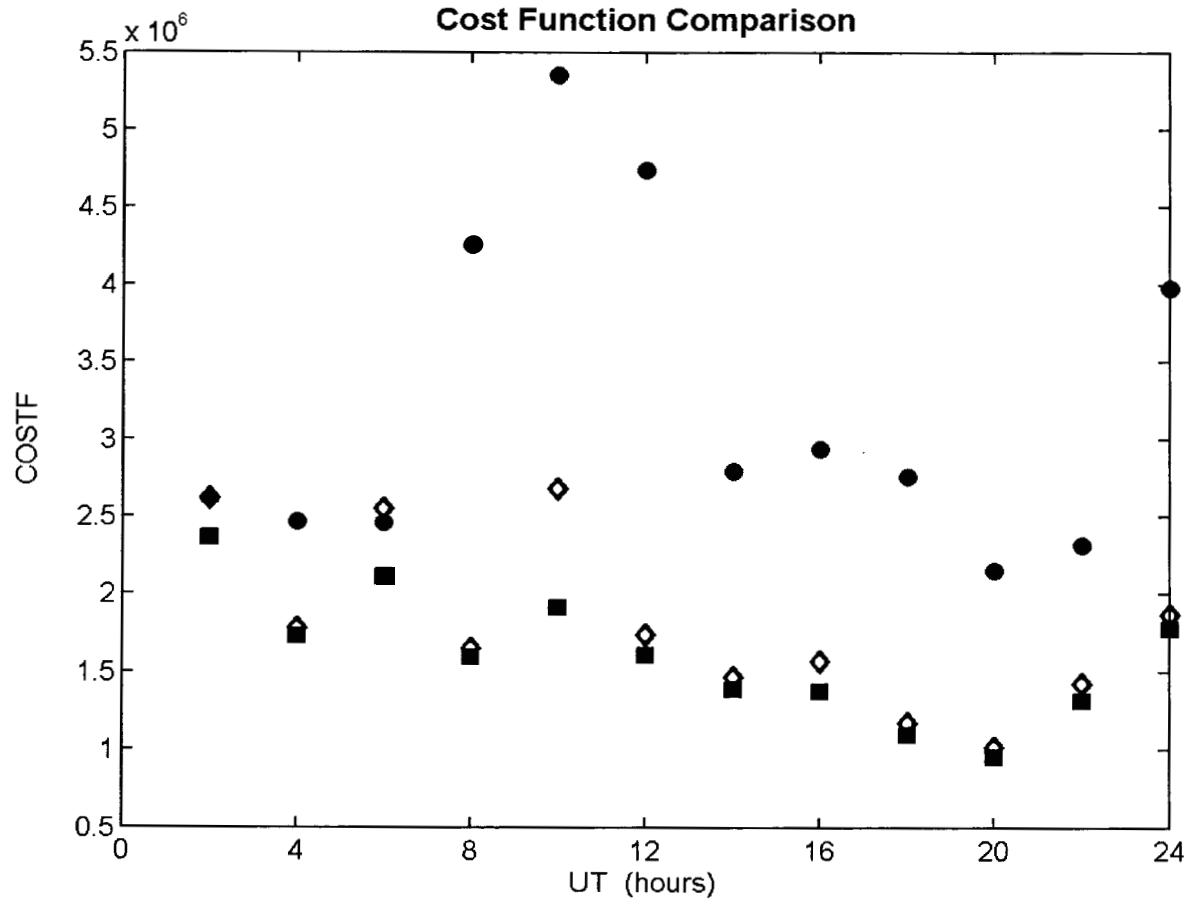


Geophysical Conditions

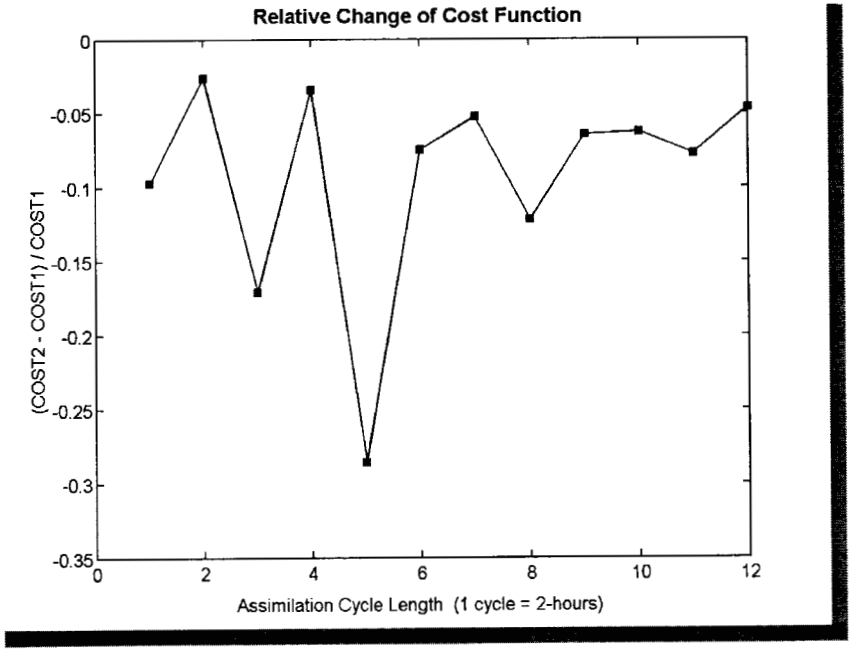
Quiet: 12/07/2002 F10.7=147, F10.7a=152, Ap=18

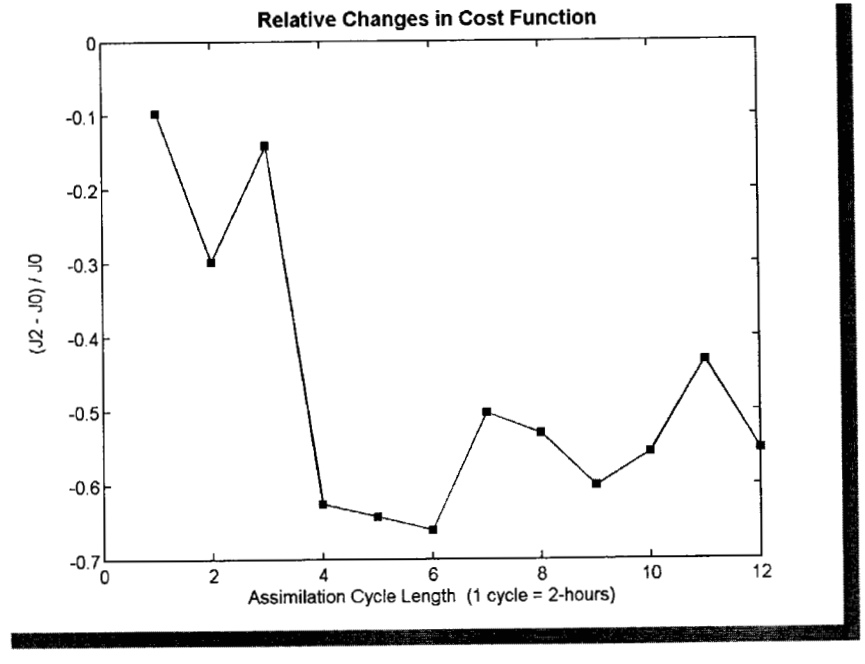


Assimilation Results: Cost Function



Relative Changes in Cost Function

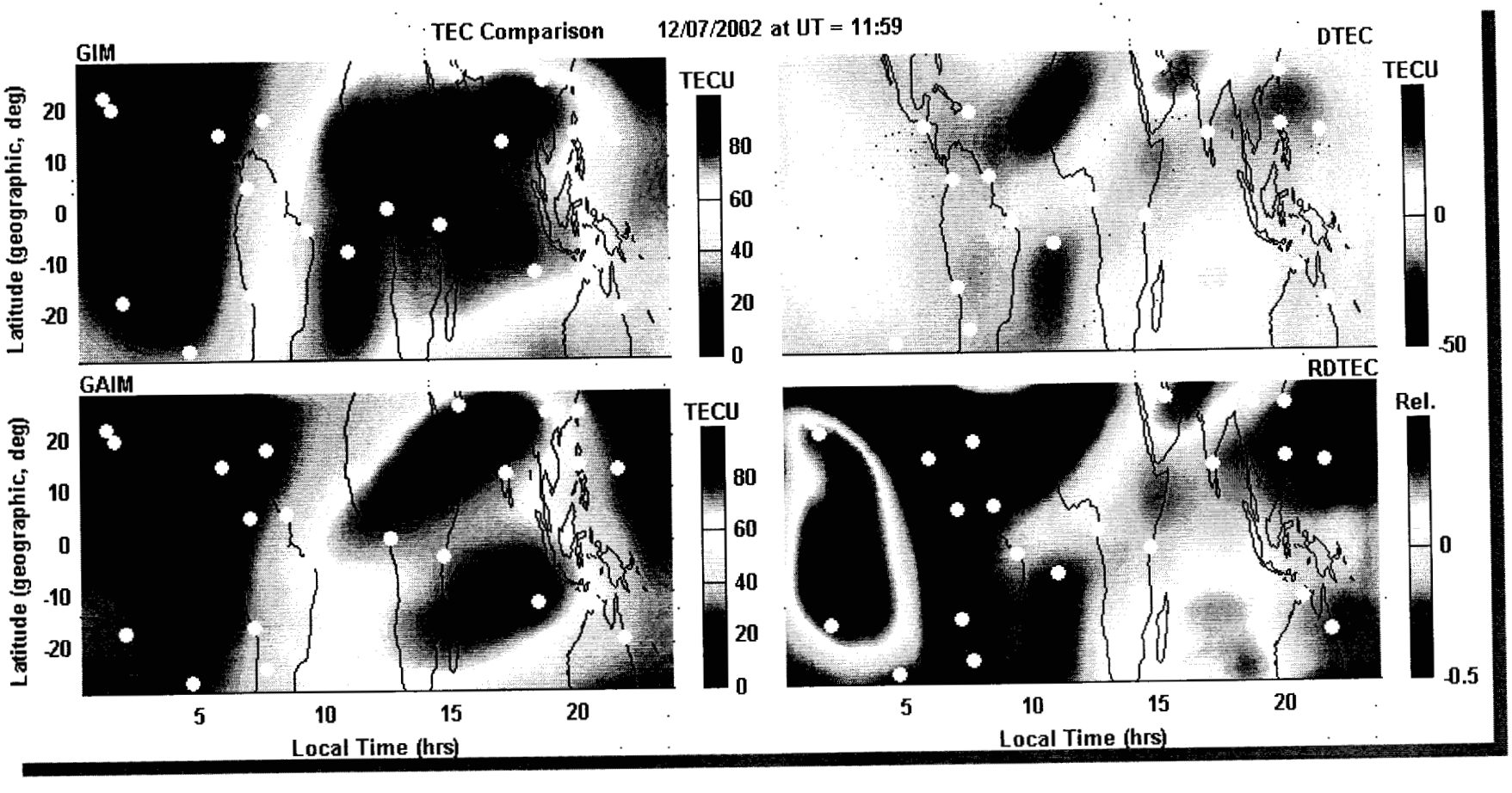




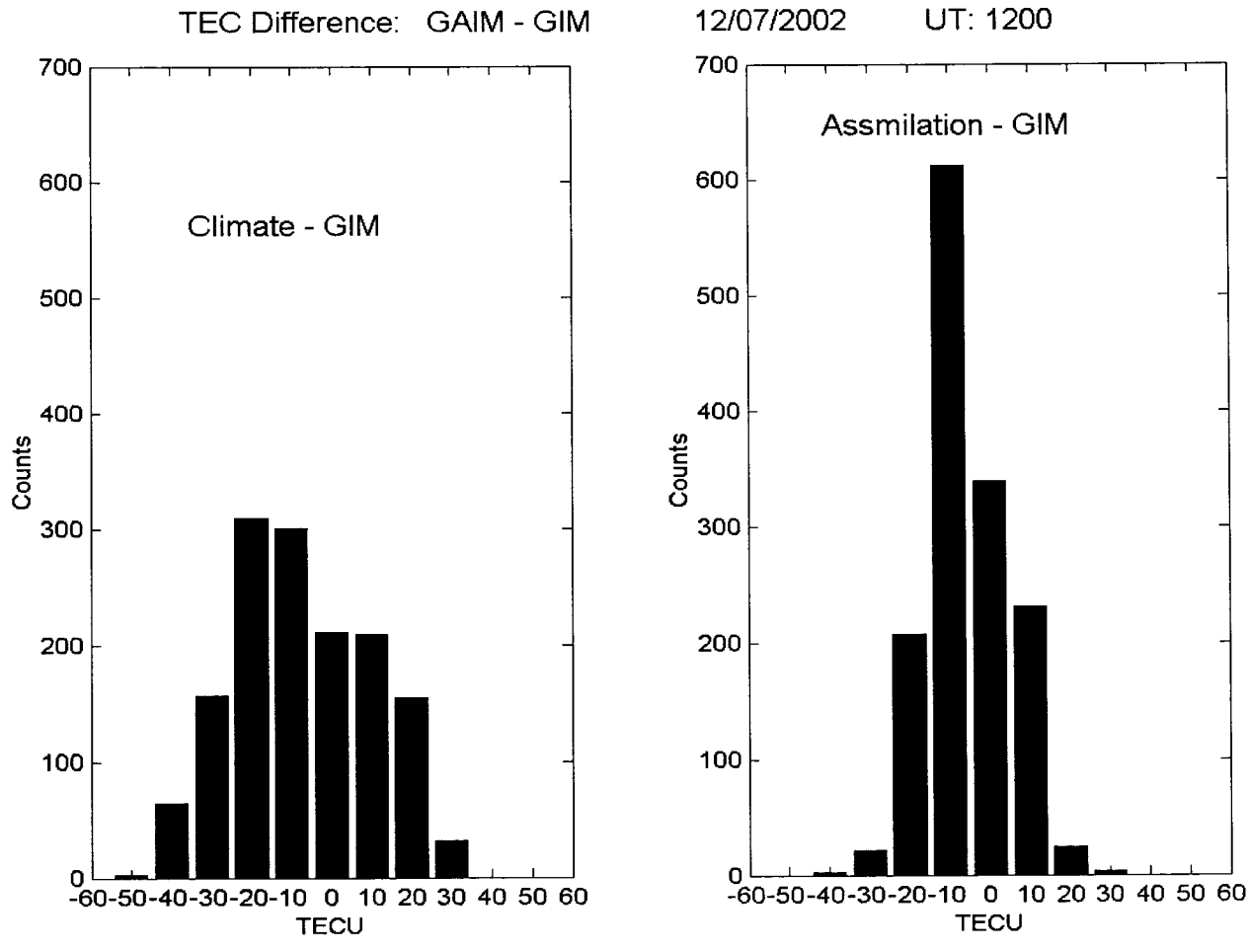
Relative to J_1

Relative to J_0

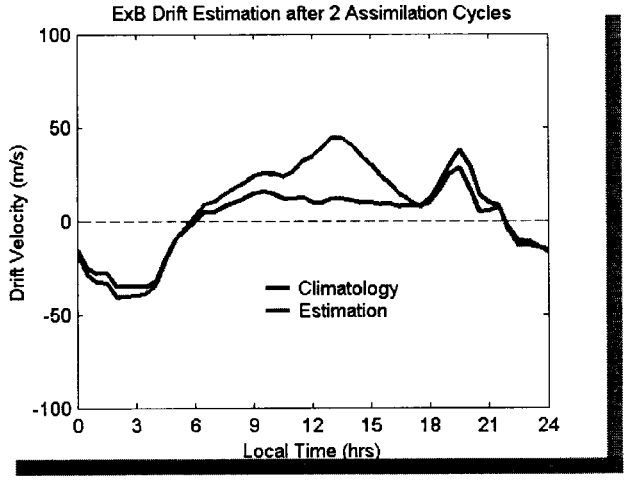
GAIM-GIM Comparison: VTEC

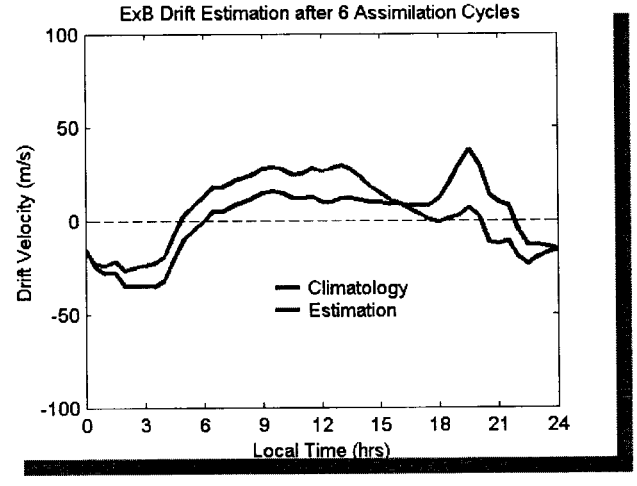


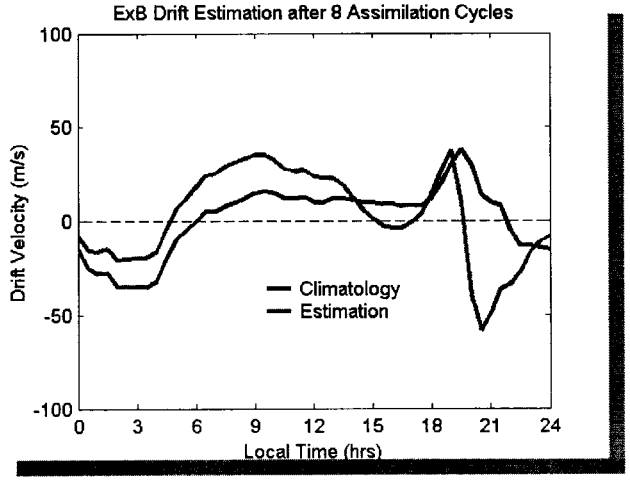
GAIM-GIM Comparison: VTEC

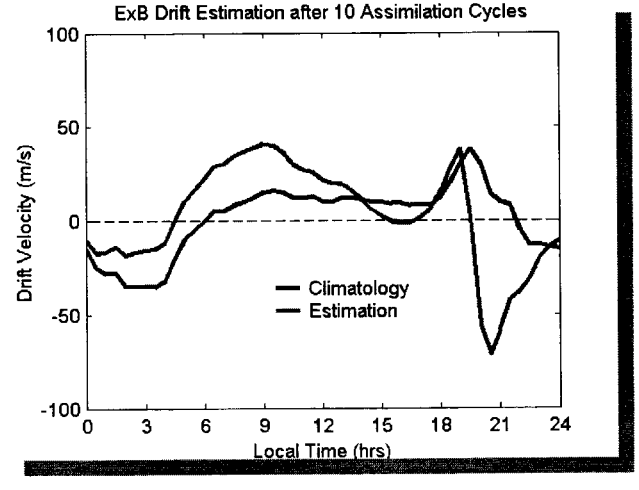


Drift Estimation: 12/07/2002

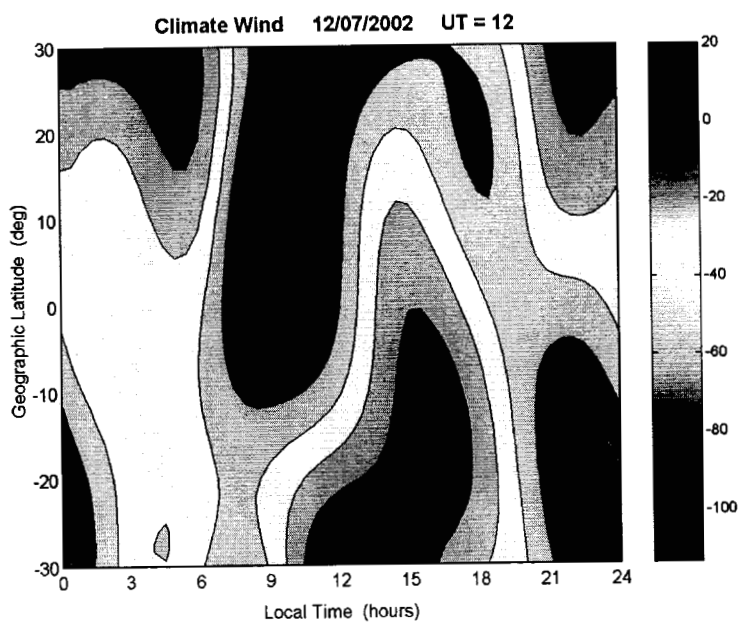


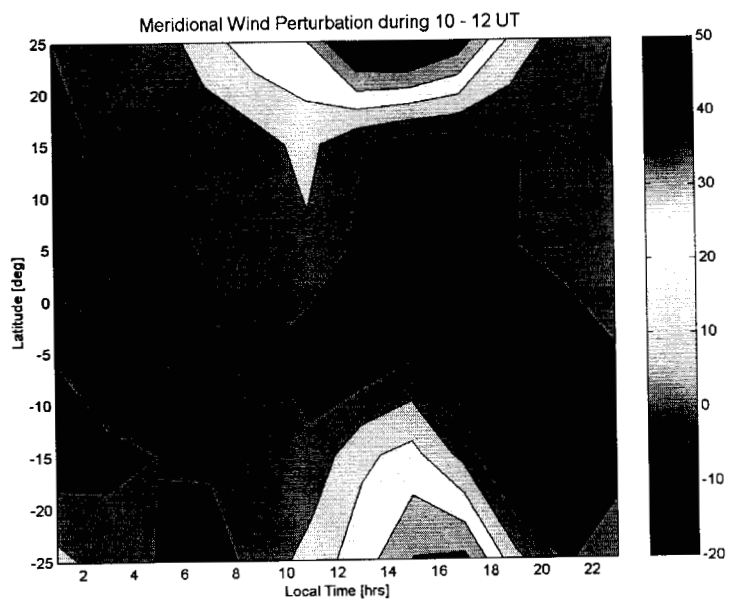




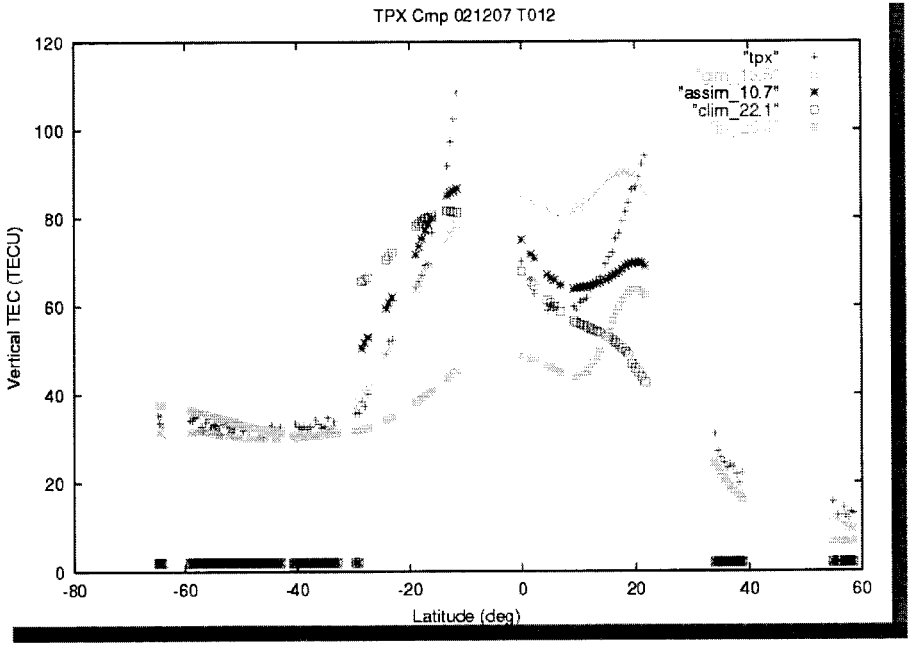


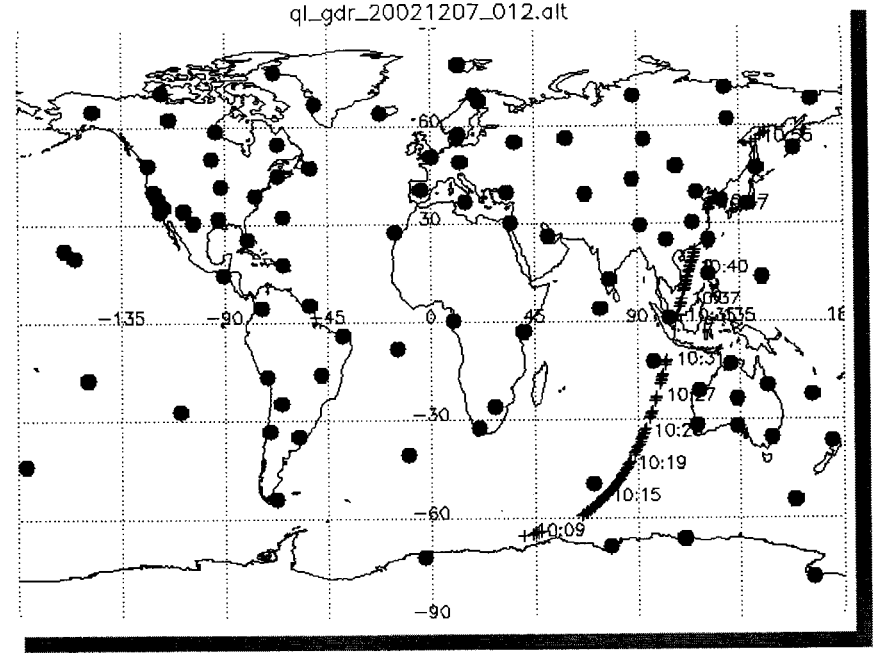
Climatology Wind: 12/07/2002



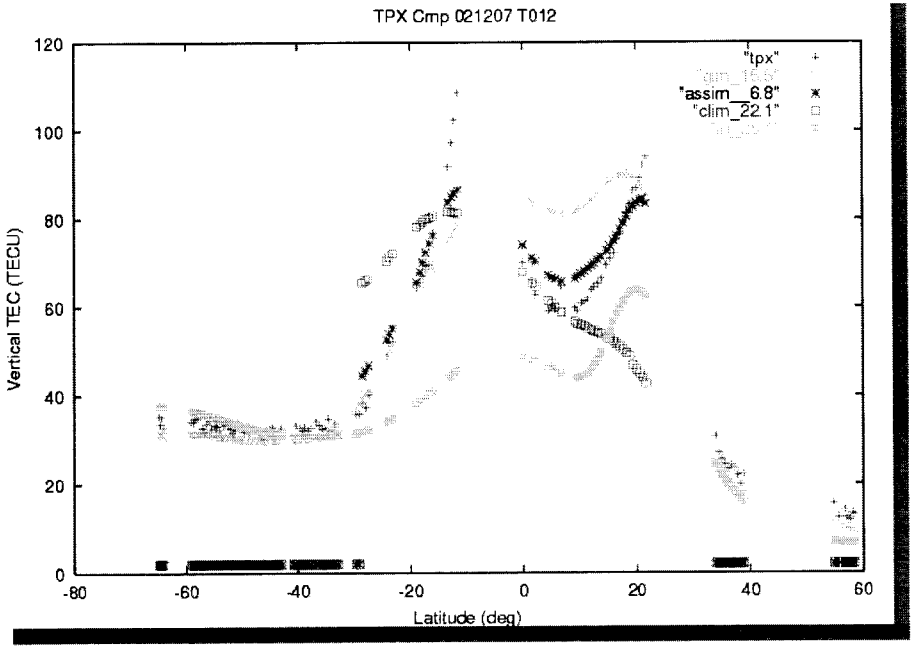


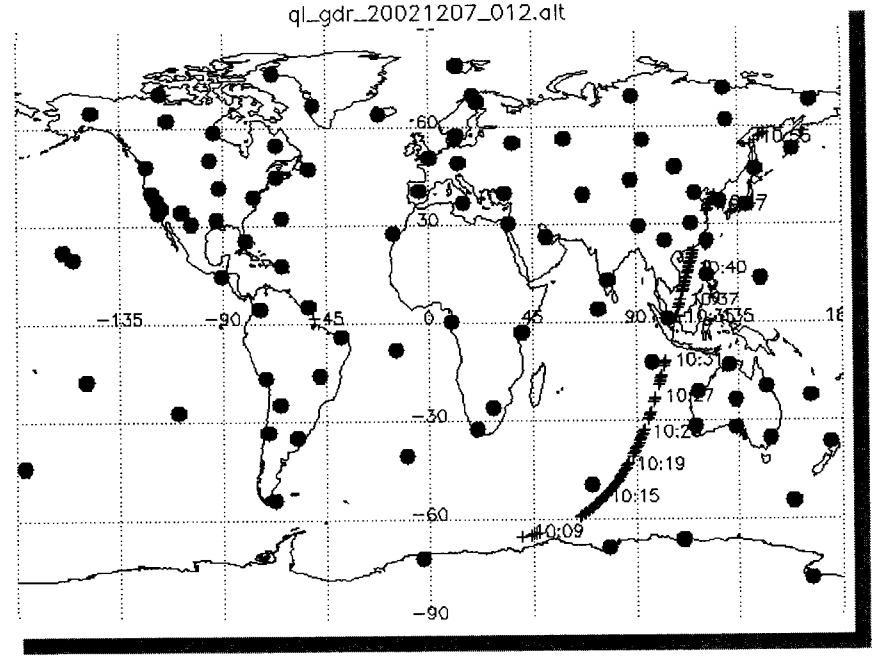
TEC Comparisons



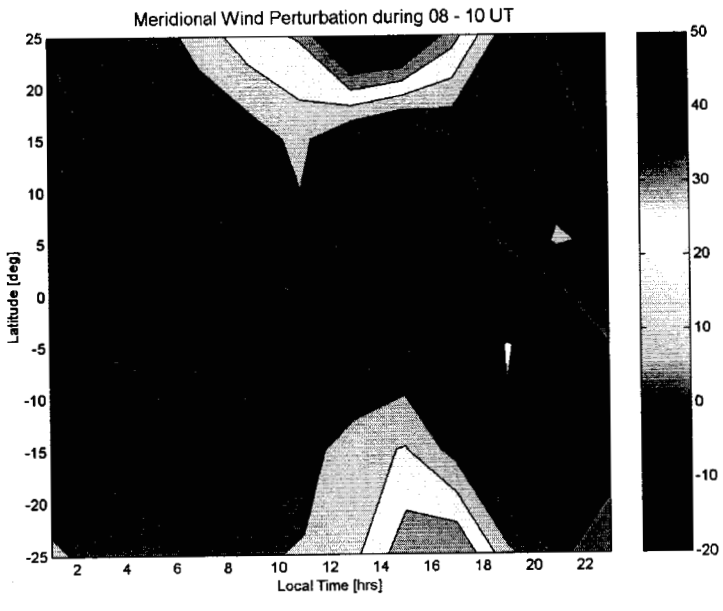


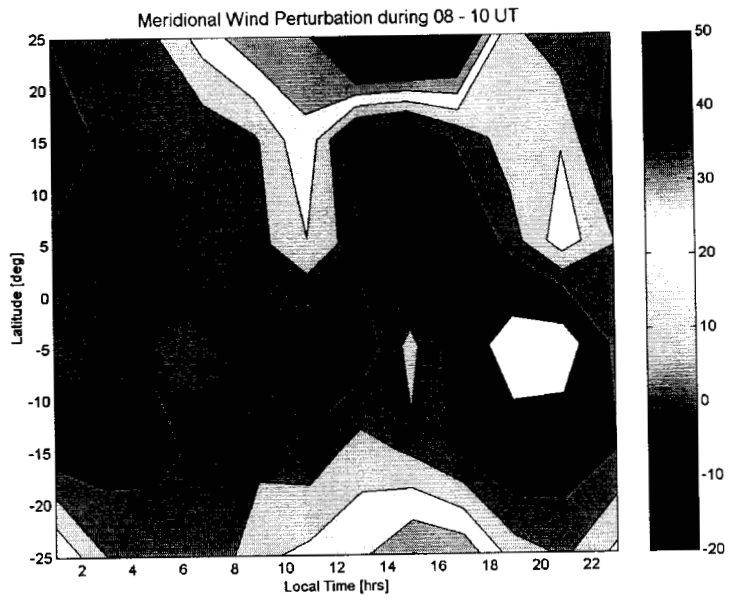
TEC Comparisons:
Test of Penalty Weightings





Dynamical Drivers





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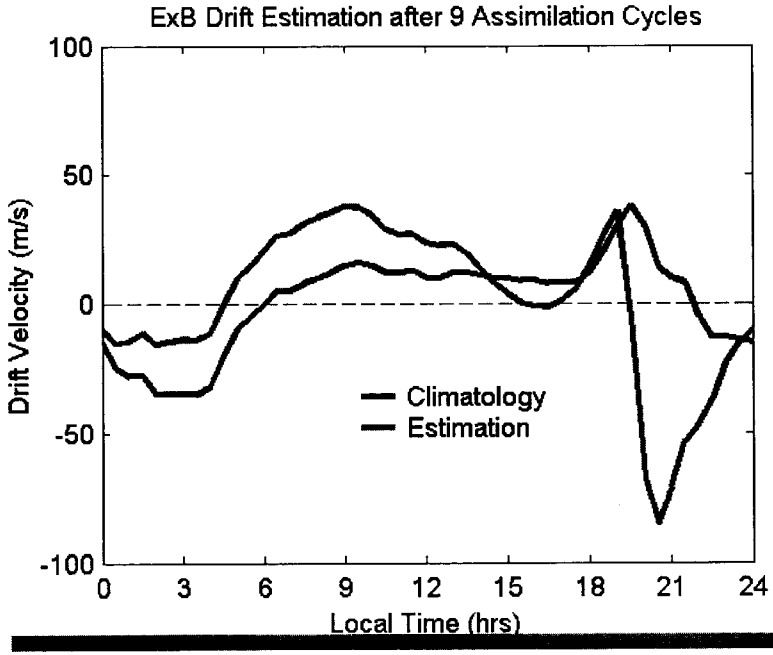

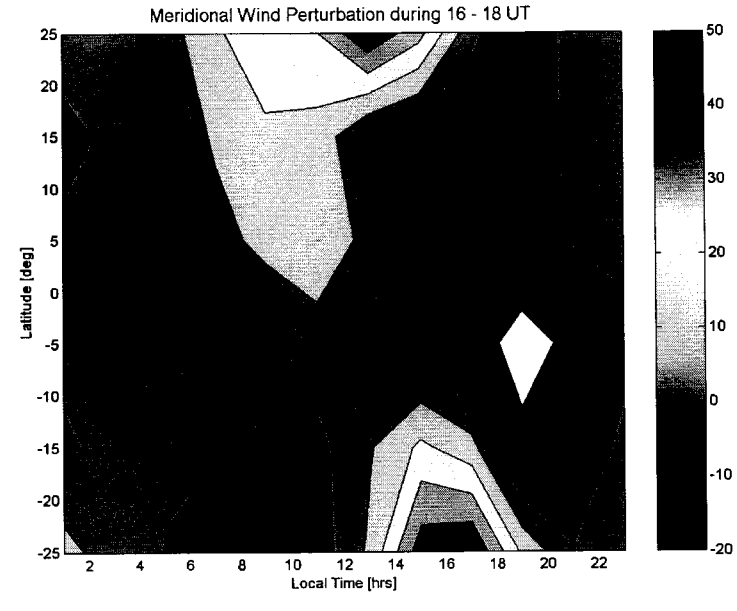

4DVAR Experiments with Ground GPS Data

- Estimation of E×B drift only
- Estimation of E×B drift and wind simultaneously
- Estimation of production alone and with the other drivers to assess the sensibility
- Testing different assimilation cycle lengths
- Testing with and determining regularization coefficients with respect to different types of drivers
- Quiet and storm days

Issues Concerning the 4DVAR Process

$$J(n;\alpha) = \sum_{k=1}^{m} \left\| y_k - H_k n(t_k;\alpha) \right\|^2 + \beta \left\| n - n_0 \right\|^2 + \lambda \left\| \alpha - \alpha_0 \right\|^2$$

- Balance of ACL to catch both LT and UT effects
  - Longer ACL for LT patterns
  - Shorter ACL to capture UT variations/effects
  - Shorter for computing time and operation
  - Overlapping data for more stable solutions and high temporal solution requirements
- Determining regularization weighting coefficients
  - Balance between driver and state adjustment
  - With respect to different kinds of parameters/drivers and initial state
  - Adjusting initial state too
- Number of parameters
  - Finer spatial resolutions require a larger number of parameters