Data assimilation of FORMOSAT-3/COSMIC using NCAR Thermosphere Ionosphere Electrodynamic General Circulation Model (TIE-GCM)

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Outline

Introduction
- NCAR TIE-GCM
- FORMOSAT-3/COSMIC
- DART (Ensemble Kalman Filter)

Result
- Electron density profiles
- 3D electron density structures
- Improvement and forecasting

Discussion & Conclusion
Thermosphere Ionosphere Electrodynamic General Circulation Model (TIE-GCM)

- A self-consistent system
- Solving the three-dimensional momentum, energy and continuity equations for neutral and ion species
- Forcing dependent model

The model domain:
- Latitude: -87.5° to 87.5°
- Longitude: -180° to 180°
- Lower boundary: ~97 km
- Upper boundary: ~500 to ~700 km
- Resolution: 5°×5°×0.5level (75,168 grids)
- Time step: 120 seconds
The FORMOSAT-3/COSMIC system is a constellation of 6 LEO micro-satellites. Each satellite carries 3 payloads:
- GPS occultation receiver
- Tiny Ionospheric Photometer
- Tri-Band Beacon

Global observation of pressure, temperature, water vapor, refractivity, ionospheric electron density, and scintillation for weather and space weather research as well as climate monitoring.
Data Assimilation Research Testbed (DART)

- An open-source community facility
- **A software environment** that makes it easy to assimilate observations to various models.
- A modular programming approach to apply an Ensemble Kalman Filter.
- **A forward operator** is applied to model states to generate the prior estimate of the observation.

http://www.image.ucar.edu/DAReS/DART/
FORMOSAT-3/COSMIC (Electron Density Profile)

TIE-GCM

Model State:
- NE
- O
- O₂
- $F_{10.7}$

Observations (ionPrf)

initial state

another cycle?

Yes

Diagnostics

state vector

model to dart

new model states

advance model states

initial model states

Dart to model

Done.

assimilate

Fortran namelist

restarts

No

http://www.image.ucar.edu/DARES/DART/

DATA ASSIMILATION OF FORMOSAT-3/COSMIC USING NCAR TIE-GCM
Real F3/C GOX Observation Experiments

Observations: FORMOSAT-3/COSMIC electron density profile

- **Quite time** condition of the ionosphere
- Date: 2008.04.08 (099), total 2437 profiles of the day
- From 200 to 450km, resample to 10 km resolution

Forecasting model: NCAR TIE-CGM Ver. 1.93

Assimilation window: **60 minutes** (+/- 30min.)

Localization function: Gaspari-Cohn with a half-width of 0.1 radian

- Horizontal impact region: 15° × 15° (3x3 grids in model)
- Vertical impact region: 100 km (vertical normalization=1000km)

Ensemble members: 90 members

Perturbing solar flux, Hemispheric power, Cross-tail potential, Zonal electric potential

Introduce the Abel inversion error to observation variance.
Date: 2008-04-08 08:00UT
Ensemble members: 90,
Assimilation window: 60 min,
Outlier threshold = 4.0 std.,

GOX profile
Prior mean
Posterior mean
Prior ensembles
Posterior ensembles

Data Assimilation of FORMOSAT-3/COSMIC using NCAR TIE-GCM
Prior

Level 12
~200KM

Level 18
~300KM

Level 22
~400KM

Level 26
~500KM

Posterior
DATA ASSIMILATION OF FORMOSAT-3/COSMIC USING NCAR TIE-GCM
TIE-GCM v1.93 Electron density ~300km

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DATA ASSIMILATION OF FORMOSAT-3/COSMIC USING NCAR TIE-GCM
Over 5 Hours Forecast RMSE and Bias
Over 5 Hours Forecast RMSE

DATA ASSIMILATION OF FORMOSAT-3/COSMIC USING NCAR TIE-GCM
Discussion & Conclusion
Date: 2008-04-08 08:00UT  
Ensemble members: 90,  
Assimilation window: 60 min,  
Outlier threshold = 4.0 std.,  

- GOX profile  
- Prior mean  
- Posterior mean  
- Prior ensembles  
- Posterior ensembles  

DATA ASSIMILATION OF FORMOSAT-3/COSMIC USING NCAR TIE-GCM
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Conclusion

Successful to assimilate the F3/C GOX observations with TIE-GCM to assimilate global 3D electron density structures by using DART.

Assimilating F3/C GOX observations into TIE-GCM improves the electron density distribution and ionospheric parameters such as NmF2 and HmF2 mainly in the low- and mid-latitude ionosphere during daytime period.

Other Forcing parameters (tide, wind...etc) are needed to be perturbed to diversify the span of the ensemble members and may also need to be tuned to eliminate systematic model biases.
Thank you~

Contact: Lee, I-TE  [ite@ucar.edu]

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Assimilation Window

15 minutes (18)

30 minutes (38)

45 minutes (64)

60 minutes (87)

90 minutes (139)

120 minutes (184)

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Localization Function

Members

Lon-Lat map

Lon-Alt slice

Lat-Alt slice

Vertical normalization

Horizontal distance
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Data Distribution and Impact Region
Abel Inversion Error Estimation

[Image showing various plots and graphs related to Abel inversion error estimation.]

Liu et. al., 2011

Data Assimilation of FORMOSAT-3/COSMIC Using NCAR TIE-GCM
Real observation covariance

- Abel inversion error
- 3D matrix (37x15x25)
- Lat: -90:5:90 in magnetic
- Alt: 100:50:800
- LT: 0:1:25
- Value=999.999 >ignored
Tuning the zonal electric potential can affect the peak height and peak density at all latitudes during the daytime ionosphere.
Future work(II) – Next assimilation cycle?