Recent Advances in Ionospheric Specific Specifications and New Applications Using GNSS Measurements

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Introduction

• Global Assimilative Ionosphere Model (GAIM)
• Regional study of the Republic of South Africa (RSA) on November 21\textsuperscript{st}, 2008
• Data sources
  • Ground based GPS measurements
  • Space-based (COSMIC and C/NOFS)
• Comparison to ionosonde measurements in the RSA
• Other recent advances:
  • GAIM prediction accuracies
  • Nested grid capabilities
  • Real-time GAIM assimilations
  • Ionospheric TEC perturbation imaging
• Conclusions
Data Sources

- Ground-based GPS Data
  - High-precision TEC data from 200+ sites
  - 30-sec sampling
- Space-based ionospheric radio occultation data
  - COSMIC/FORMOSAT-3 data (10-sec cadence)
  - CNOFS data (10-sec cadence)
- First time assimilation of COSMIC and C/NOFS has been performed
Global Assimilative Ionospheric Model
Data Assimilation Process

- **4-Dimensional Variational Approach**
  - Minimization of cost function by estimating driving parameters
  - Non-linear least-square minimization
  - Adjoint method to efficiently compute the gradient of cost function
  - Parameterization of model “drivers”

- **Kalman Filter**
  - Recursive Filtering
  - Covariance estimation and state correction
  - Optimal interpolation
  - Band-Limited Kalman filter

4DVAR
Kalman Filter

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COSMIC Coverage on Nov 21, 2008

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CNOFS Coverage on Nov 21, 2008

: 2008/11/21,16:00:00 to 2008/11/21,18:00:00
Ionosonde Locations in RSA

Green – ground GPS
Red - ionosonde

MU12K
LV12P
HRAO
RBAY
SUTH
SIMO
HE13N
GR13L

Louisvale
(28.5°S, 21.2°E)
Hermanus
(34.4°S, 19.2°E)
Grahamstown
(33.3°S, 26.5°E)
Madimbo
(22.4°S, 30.9°E)

Courtesy of L. McNamara

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Profile Examples – C/NOFS Impact

Climate @ HE13N : 191500

Ground

Ground + Cosmic

Ground + Cosmic + CNORS

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Profile Examples – C/NOFS Impact

- Climate @ GR13L: 211500
- Ground
- Ground + Cosmic
- Ground + Cosmic + C/NOFS
Nmf2 (e/m³) Statistics for Nov 21, 2011

Slopes:
Climate: 0.565
Ground: 1.387
G+C: 1.352
G+C2: 1.349
Recent GAIM Prediction Accuracy for SELE on Feb 1, 2011

GAIM – ground-GPS only assimilation

Prediction Residuals at SELE on Feb 1, 2011

Predictions:
GIM RMS = 1.94 TECU
GAIM RMS = 1.71 TECU
Recent GAIM Prediction Accuracy for SELE on Feb 1, 2011

Prediction Residuals at SELE on Feb 1, 2011

Predictions:
Climate RMS = 3.41 TECU
GIM RMS = 1.94 TECU
GAIM RMS = 1.71 TECU
GAIM Prediction Accuracy Using Ground and COSMIC Assimilation on Feb 1, 2011

Station SELE
On Feb 1, 2011

Ground-only GAIM Predicts
Ground + COSMIC GAIM Predicts
Notice the Improvement!

10:45 to 11:00

UT: 10:45-11:00

60°E

2011/02/01, 10:45:

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GIM, GAIM, Predictions for KIT3 on Feb 1, 2011

Included

Removed

Prediction Residuals at KIT3 on Feb 1, 2011

Predictions:
GIM RMS = 2.53 TECU
GAIM RMS = 2.71 TECU

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Climate, GIM, GAIM Predicts for KIT3 on Feb 1, 2011

Predictions:
- Climate RMS = 4.25 TECU
- GIM RMS = 2.53 TECU
- GAIM RMS = 2.71 TECU

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Nested Grid (NGAIM)

- NGAIM grid resolutions:
  - Global grid resolution: 2.5 x 10 degrees lat/lon, 40 km altitude
  - Nested grid resolution: 1 x 2 degrees lat/lon, 20 km altitude
- Forward physics models are coupled at boundary of nested region
  - Global grid provides density and flux on nested boundary using ghost cells
  - Two forward physics models, two Kalman filter runs
  - Both density grids used to properly model TEC links
- Show results from two periods:
  - Halloween storm (Oct 29-31, 2003)
    - ~300 CORS stations in US
  - Florida feature on Oct 31, 2003
    - 200 GPS stations globally, plus ~40 CORS stations near/in Florida
- Advantages:
  - Near real-time execution
  - Can run multiple nested regions at one time (on separate CPUs)
GAIM and Nested GAIM Grids

Inner region

Slant TEC

Outer region

GAIM Nested Grid

Regular GAIM Grid

Intersections of:
- magnetic field lines,
- magnetic geopotential lines
- and magnetic longitudes

Eccentric tilted dipole

Magnetic equator
Nested Grid Capability (NGAIM)
Storm Day: Oct 29, 2003, NGAIM and Truth Storm Features at NLIB
Nested GAIM Validation Near Eglin Radar

- NGAIM run with TAEM only, Jan 16, 2010
- Predict observed slant TEC for surrounding CORS GPS sites
- Prediction RMS error of 3 – 4 TECU
Real-Time GAIM: Assimilating Ground TEC and COSMIC

Global ground network data: 5-minute and 1-hour latency
COSMIC data: 20 - 120 minutes latency

Time
0
150 min

Start of orbit
End of orbit: data downloaded
Data received at CDAAC
CDAAC: COSMIC Data Analysis and Archiving Center at UCAR

Profiles (Abel) available
Limb TEC available

GAIM Thread

GAIM Real Time Daemon

Two way exchange of states (15 min)

100-minute cadence

3-D global electron density grids
15-minute cadence
Stations Used for Real-Time GAIM

All Processed Streaming Versus Delivered Site Locations on May 11, 2011 DOY = 131

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GAIM Real-Time System:
Multipath Weighting

G04 <-> COSM1 arc # 1

- Ionosphere (LI/PI)
- Iono-free (LC/PC)
- Multipath
- Elevation
- Azimuth
- Latitude

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Real-Time GAIM: Web Interface
Real-Time GAIM TEC Residuals for Tohoku Earthquake on March 11, 2011

Acoustic wave generated TEC perturbations at USUD
GIM residuals (a) and band-pass filtered slant TEC measurements. Panel (b) indicates an example for filtered TEC observations.
Acoustic and Gravity Waves Detected in Ionosphere

Song Model overlaid on TEC observations
Japan Tsunami 2011/3/11, Song Model

At a given distance from epicenter
Ionosphere signature appears about 24 minutes after ocean wave.

Note main model tsunami wavefront parallel to strongest ionosphere wavefront.

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Conclusions

- Assimilation of Ground + COSMIC + C/NOFS shows improved agreement with ionosonde measurements of Nmf2 and Hmf2.
- Though limited in quantity, C/NOFS does make improvements to vertical structure.
- Future plans: extend analysis to a global scope to better gauge the improvements made by C/NOFS.
- We would like to acknowledge Leo McNamara (AFRL) for his ionosonde data from the Republic of South Africa.
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October 31, 2003 NGAIM VTEC Map, the Florida Feature

~800 miles North of MIA3

MIA3