Assessment of Radio Occultation Observations to Improve Space Weather Nowcasts Using the JPL/USC Global Assimilative Ionosphere Model

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Session 6 “Ionosphere”
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Outline

1. The radio occultation data set
2. Survey of results
   1. Value of radio occultation to ionospheric space weather: electron density profile shape
   2. Benefit of COSMIC-2: more profiles, and filling in geospatial “holes”
   3. Driver estimation (“holy grail”)
3. Summary and conclusions
GPS Receivers in Low Earth Orbit: Electron Density Maps

COSMIC coverage: 2500 profiles/day
Occultation Locations for COSMIC, 6 S/C, 6 Planes, 24 Hrs

800 km altitude
72° inclination, 6 planes

Six-satellite COSMIC constellation
Launched April 14, 2006

November 4, 2010

ajm/JPL SEASONS Conference 2010

AJM/JPL
Coverage of Daily IGS Network and Regional Networks

(10 degree elevation mask; 450 km shell height)
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
GAIM Magnetic Aligned Grids

Intersections of:
- magnetic field lines,
- magnetic geopotential lines
- and magnetic longitudes
GAIM VTEC RMS Difference Versus JASON Altimeter

06/01/2004 to 11/08/2004    200 stations/day    137 days
Ground and COSMIC Coverage Example (Sept 21, 2006)

- Ground GPS: dense but unevenly distributed coverage
- COSMIC: less dense yet evenly distributed coverage
COSMIC Coverage on Nov 21, 2008
The use of COSMIC+ground-GPS data over ground-GPS only significantly improved TEC predictions for all 3 days processed: 30, 28 and 44% respectively.

Regional Coverage and COSMIC-2 Simulation Experiment

dTEC over ocean (GAIM) - Probability[|dTEC|<10%]

IUGG, Melbourne, Australia
Arecibo ISR Study for June 26, 2006
COSMIC Overflight Jicamarca Radio Observatory

1. UT 15:36

2. UT 15:48

3. UT 16:36

COSMIC UT 15:30

Height km

0 2 4 6 10^{11} \text{el/m}^3

Elevation angle

10 15

UT hours

Sept 21, 2006

October 27, 2009

Formosat-3/COSMIC 2009

AJM/JPL
IRI and GAIM TEC Integrated from ALTAIR to LEOs

LEO altitude: 836 km
Time of pass: 12:30 UT

786 km  11:10 UT

575 km  10:10 UT

757 km  9:50 UT

490 km  8:30 UT
Profile Shape is Critical

**Profile above ALTAIR, 2008-09-17 12:31, lat=9.4, lon=167.5**

**Profile above ALTAIR, 2008-09-17 08:24, lat=9.4, lon=167.5**
Improvement from COSMIC

- Time of ALTAIR track has been shifted to 5:00 UT to coincide with COSMIC pass
- Top-side has improved (to the detriment of NmF2) and the bottom-side remains unchanged
- GPS+COSMIC is the closest to the ground truth
COSMIC Coverage on Nov 21, 2008
Ionosonde Locations in RSA

Green – ground GPS
Red - ionosonde

MU12K  HRAO  RBAY
LV12P  SUTH
SIMO  HE13N  GR13L

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

Courtesy of L. McNamara
Nmf2 (e/m³) Statistics for Nov 21, 2011

Slopes:
Climate: 0.565
Ground: 1.387
G+C: 1.352
G+C2: 1.349
Day-To-Day Ionospheric Variability

Range Delay at L1 (m) for Hamilton, MA 1981:

- JANUARY
- FEBRUARY
- MARCH
- APRIL
- MAY
- JUNE
- JULY
- AUGUST
- SEPTEMBER
- OCTOBER
- NOVEMBER
- DECEMBER

Local Time

TEC
Regions In Geospace: Ionosphere is Near-Earth Space
Variability During Geomagnetic Storms
October 30, 2003

Electron content above 400 km altitude

Mannucci et al., *GRL* 2005

“Global Ionospheric Storm”
Storm Day: Oct 29, 2003, NGAIM and Truth Storm Features at NLIB

VTAC Map from gain_state_rll_20031029_194806.mat

Obs Vertical TEC 031029-1945-2000

First Interplanetary Coronal Mass Ejection

DST -350 nT at 0125 UT on October 30
Storm-time data assimilation
August 6-7 2006

Electron density contours showing the assimilative modeling results in altitude vs. latitude dimensions at 125° longitude, for the quiet day (August 6, 2006; upper left), storm day (August 7, 2006; lower left), and percentage difference between the disturbed and quiet state (upper right). A comparison of sample electron density profiles at the equator is also provided in the lower-right panel. The corresponding local time is 1844 for this longitude. The storm-time disturbance shows clear features of equatorial anomaly enhancement that must be driven by an enhancement of eastward electric field at low latitudes.

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Driver Estimation Using 4DVAR

Prod Estimation 6/1/2002

Estimation Cycles = 12

Production Factor

GAIM++4DVAR Estimation of V & P; 6/1/2002

Vertical E×B drift
Tohoku Tsunami Seen in Ionosphere Using GPS Compared with JPL’s Song Tsunami Model

Gravity Waves

Ocean Tsunami model Observations from ~1200 GPS receivers

- Tsunami generates atmospheric gravity waves that propagate to ionosphere.
- Allows imaging of tsunami using GPS Total Electron Content.

Potential application:
- Real-time tsunami monitoring and early warning

Attila Komjathy (335G), David Galvan (335G), Y. Tony Song (3244), Tony Mannucci (335G)
Galvan et al, 2011, submitted to JGR
Summary & Conclusions

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   1. Value of radio occultation to ionospheric space weather: profile shape
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Earth-Sun System Exploration 5
January 13-19, 2013
Kona, Hawai’i

“Earth Sun System Disturbances: Weak, Moderate, and Extreme”

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E-layer science session