JPL/USC GAIM: New Developments in Using COSMIC and Ground-Based GPS Data to Estimate High Precision Ionospheric Products Including VTEC

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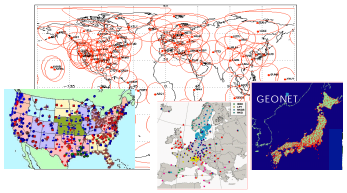
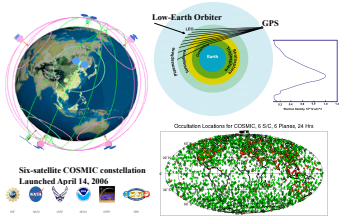
Data assimilation techniques for space weather are finding increasing success in ionospheric remote sensing due to the growing abundance of data from ground and space-based GPS receivers and new UV remote sensing satellites. The COSMIC 6-satellite constellation, launched in April 2006, now provides unprecedented global coverage from GPS occultation measurements (~1700 per day as of June 2007), each of which yields electron density information with up to ~1 km vertical resolution. Calibrated measurements of ionospheric delay (total electron content or TEC) from COSMIC suitable for input into assimilation models are currently made available in near real-time (NRT) with latencies between 30 and 120 minutes.

In this research, we discuss the impact of assimilating COSMIC occultation and ground-based TEC measurements into the JPL/USC Global Assimilative Ionospheric Model (GAIM). Electron density profiles from GAIM are compared to radar measurements obtained from the Incoherent Scatter Radar (ISR) at Arecibo, Jicamarca and Millstone Hill.

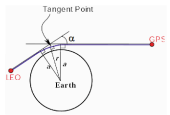
GPS Ground Networks

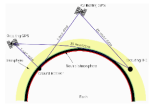


COSMIC Ionospheric Weather Constellation



Occultation Geometry



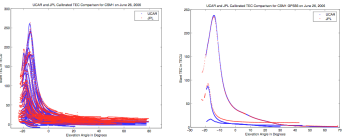


- Single Frequency Retrievals
- Dual Frequency Retrievals
  - TEC = const. x (L1 – L2)
  - α ~ dTEC/dt

$$\alpha(a) = 2a\int_{r}^{\infty} \frac{1}{\sqrt{a^2 - a^2}} \frac{d\ln(n)}{da'} da'$$

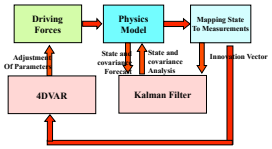
$$\ln(n(r)) = \frac{1}{\pi}\int_{r}^{\infty} \frac{\alpha}{\sqrt{a^2 - r^2 n^2}} da$$

Comparison of Calibrated Slant TEC Measurements: An Example



- An example of comparison of calibrated TEC between JPL and UCAR
- Currently there appears to be a 1-2 TECU bias between JPL and UCAR slant TEC
- Similar data volumes between JPL and UCAR

Global Assimilative Ionospheric Model Data Assimilation Process



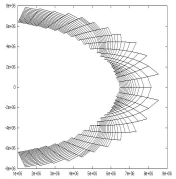
- 4-Dimensional Variational Approach
  - Minimization of cost function by estimating driving parameters
  - Non-linear least-square minimization
  - Adjoint method to efficiently compute the gradient of cost function
  - Parameterization of model "drivers"
- Kalman Filter
  - Recursive Filtering
  - Covariance estimation and state correction
  - Optimal interpolation
  - Band-Limited Kalman filter

GAIM Input Data Files:

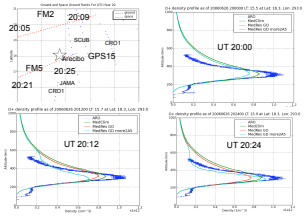
- Ground GPS Data (Absolute TEC)
  - >150 Esmin. to Hourly Global GPS Ground Stations
  - Assimilate >300,000 TEC points per day
- Space GPS Data (Relative TEC)
  - CHAMP (@ 440 km)
  - SAC-C (@ 700 km)
  - IOX (@ 800 km)
  - GRACE (@ 350 km)
  - Topex/Poseidon (@1330 km) (Upward looking only)
  - Jason 1 (@1330 km) (Upward looking only)
  - C/NOFS & COSMIC constellation
- UV Airglow: Limb & Nadir Scans
  - LORAAS on ARGOS, GUVI on TIMED
  - SSUSI/SSULI on DMSP and NPOESS
- Other Data Types
  - TEC from TOPEX & JASON Ocean Altimeters
  - Ionosonde
  - DMSP, CHAMP, C/NOFS in situ density
  - C/NOFS Electric fields
  - GRACE Cross links
  - ISR

Kalman Assimilation Runs: Three Case Studies

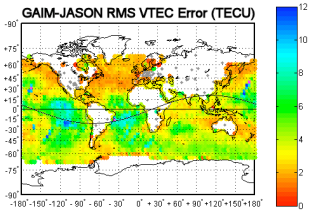
- Three runs:
  - GAIM Climate (no data)
  - Ground GPS TEC (200 sites)
  - Ground + COSMIC links (upward & occultation)
- Medium and Low Resolution runs:
  - 2.5 Vs. 5.0 Lat. In Deg.
  - 10.0 Vs. 15.0 Lon. in Deg.
  - 40 Vs. 80 Alt. in km
  - 100,000 Vs. 18,000 voxels
- Sparse Kalman filter:
  - Update & propagate covariance
  - Truncate off-diagonal covariance that is beyond physical correlation lengths



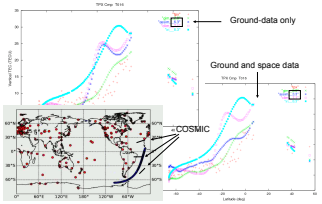
Case 1: Arecibo ISR Study for June 26, 2006



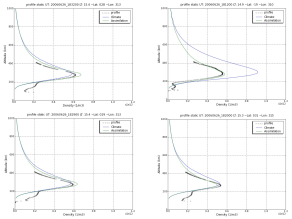
GAIM-JASON RMS VTEC Error (TECU)



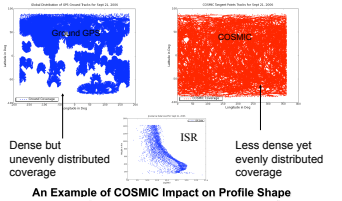
GAIM Validation Using Jason-2 Vertical TEC for June 26



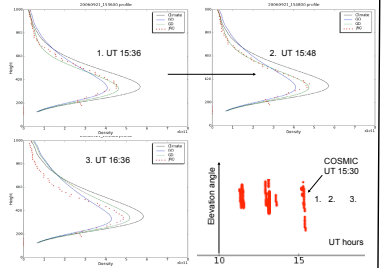
GAIM versus Abel Profiles

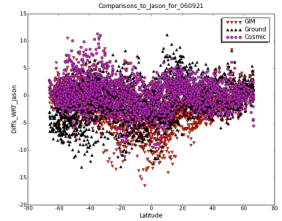


Case 2: Ground, COSMIC and Jicamarca ISR Coverage for Sept 21, 2006



An Example of COSMIC Impact on Profile Shape

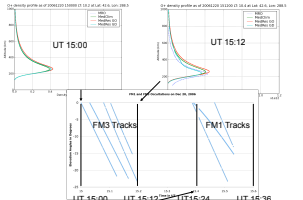


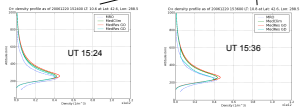


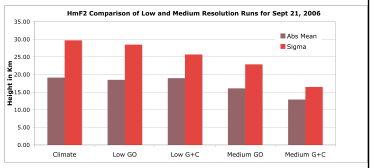
Summary and Conclusions

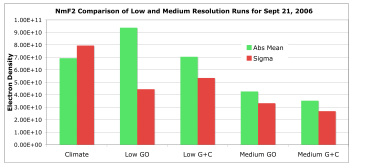
- JPL now routinely generates calibrated TEC and Abel electron density retrievals using COSMIC data.
- Performed GAIM assimilation using data from 200 ground-based GPS and six COSMIC satellites for World Days June 26, Sept 21 and Dec 20, 2006.
  - Ground-only, ground+COSMIC and climate GAIM runs performed.
  - GAIM profiles are validated using Arecibo, Jicamarca, Millstone Hill ISR, Jason VTEC and Abel profiles.
- ISR validation results show that assimilating COSMIC data improves VTEC, NmF2 and Hmf2: i.e., resulting in improved profiles shapes. Assimilating COSMIC does seem to improve TEC accuracy potentially leading to more accurate IGS ionospheric products.

Case 3: Millstone Hill Radar Validation for Dec 20, 2006









GAIM VTEC Accuracy Assessment Using Jason Data

		Mean	Sigma	RMS	Min	Max
	GIM	-1.61	2.88	3.31	-12.5	9.1
06/26/06	Ground	-0.24	3.26	3.27	-17.26	11.7
	Ground+COSMIC	-0.29	2.26	**2.28**	-10	8.72
		Mean	Sigma	RMS	Min	Max
	GIM	-2.01	3.48	4.02	-13	11.2
09/21/06	Ground	-1.08	3.45	3.62	-13	11.2
	Ground+COSMIC	-0.31	2.66	**2.67**	-10.16	11.36
		Mean	Sigma	RMS	Min	Max
	GIM	-1.95	2.58	3.24	10.7	8.2
12/21/06	Ground	-1.3	4.32	4.51	-17.9	10.8
	Ground+COSMIC	0.49	2.45	**2.54**	-18.8	9.36

Take-Away Message

- **Advent of global ground & space-based GPS is revolutionizing the accuracy of Ionospheric specification, nowcast and forecast.**
- **Promise of Global Ionospheric Data Assimilation (GAIM) is near.**