Cooperative IGS and GIRO Monitoring for Rapid Real-Time Insight into Global Ionospheric Weather

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Outline

- Real-Time Assimilative Modeling with GIRO and IRI
  - GIRO /Global Ionosphere Radio Observatory/
  - IRI /International Reference Ionosphere/
  - NECTAR assimilation algorithm
  - GAMBIT analysis environment for IRTAM
- 3D Real-Time Ionosphere with IRTAM
- Cooperation: IGS VTEC and GIRO NmF2 & hmF2
  - Slab thickness
  - Adding B0
    - 3D accuracy
    - Topside half-thickness
  - Outlook

GIRO + IRI + NECTAR = IRTAM
(IRI-based Real-Time Assimilative Modeling)
HF Ionosonde

- First multi-frequency ionogram: 1931
- 1936: five ionosondes in the world
- 1957 (IGY): 150 ionosondes in the world
- 2016: <unknown #> ionosondes…
  - 231 ionosonde locations in NOAA SPIDR
  - 160 Lowell Digisondes®
Global Ionosphere Radio Observatory

~ 50 contributing ionosonde stations

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Current real-time GIRO sites, Sep 2014
3D Ionosphere by IRI

Monthly median climatology

1D vertical profile of Ne

- **3D specification of Ne = 1D vertical profile** with 2D maps of its anchors
- **NmF2 and hmF2** – most important anchor that changes the whole profile
- **B0, B1, D1** – profile shape parameters
- E-layer, F1-layer, and E-F valley anchors are less sensitive to space weather dynamics

IRI Climatology success:
- foF2 error is 0.01 MHz ($\sigma = 0.78$ MHz)
- hmF2 error is 1.51 km ($\sigma = 25$ km)
- 1.5+ million monthly medians
- 7 solar cycles, 250+ ionosondes
- [Damboldt and Suessmann, 2011]

**foF2:** 200 kB worth of expansion coefficients

→ To capture real-time SPACE WEATHER:
- 1. Keep 3D formalism of IRI
- 2. Use ionosonde data to adjust anchor maps

Assimilative 2D Mapping
2D+Time Mapping of Anchors
Combination of global and diurnal expansions

[Jones and Gallet, 1962-1966]

One-time snapshot
76 coefficients $C_k$

One-day of each $C_k$
13 coefficients

One day in the life (DITL)
988 coefficients $C_{ik}$
Single-site Data Assimilation

- **4DDA algorithm**
  - 24 hour history used to perform one real-time assimilation
  - Robust to autoscaling mistakes
  - Slight improvement in hindcast mode
    - Day boundary filter of discontinuity

- **Output**: 13 adjustments $\Delta C_{0-12}$ to diurnal harmonic coefficients
  - Adjustments to IRI can be extrapolated spatially
    - Short-path modeling

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This chart makes use of IARPA data from the HFGeo program. The IARPA Program Manager is Chris Reed.”
Real-Time IRI Configurations

A. Single-Site Assimilation

13 real-time adjustments to IRI coefficients in the vicinity of ionosonde (corrections valid for ~200 km)

No TIDs

B. Single-Site Assimilation with local tilt measurement

Local tilt evaluation by Digisonde HF skymapping for IRI transformation
Sensitive to TID passages within ~300 km area

C. Global Assimilation

988 real-time adjustments to IRI using all available Digisondes

IRTAM

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Next Step: Above Peak Sensing

SLAB THICKNESS $\tau$

Fig. 1. Schematic view of the vertical electron density profile with key characteristics such as the peak density ($N_m F_2$), peak height ($h_m F_2$), upper ion transition level (UTL), scale height ($H_{sc}$) and slab thickness ($\tau$).

Stankov and Warrant, 2009
Complementing GIRO with GNSS

Total Electron Content  Peak Electron Density  Peak Density Height  Slab Thickness

Deviation from expected quiet-time behavior
GAMBIT Database and Explorer

Public access to IRTAM retrospective and current results

Early release User Version 0.1C download (64-bit Java 7 or higher is required)
Early release GAMBIT Explorer User Guide 0.1C

http://giro.uml.edu/GAMBIT
Importance of B0 assimilation

- B0 parameter is needed to represent profile shape correctly
  - Without B0 assimilation up to 20 km height error in this example
- Warning: Observed Ne profile may have errors
  - IRTAM’s 24-hour 4DDA assimilation mitigates autoscaling errors
    - No autoscaling errors in this example

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Outlook

- **Cooperative real-time newscast using GNSS VTEC and GIRO F2 layer profile**
  - Implementation is imminent
  - Current objective at GIRO: assimilate shape parameter B0
  - Current objective at IGS: Service integration with IRTAM
  - Services at Lowell GIRO Data Center and UWM IGS RTS node

- **Applications to space weather research and practice**
  - Intriguing capability of sensing topside ionosphere using ground observatories

- **GAMBIT environment in open source domain for data access and visualization**