IGS INTERNATIONAL GNSS SERVICE

IGS Workshop, 8-12 Feb 2016
Sydney, NSW, Australia

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

Ivan Galkin
University of Massachusetts Lowell, USA
Bodo Reinisch,
Xueqin Huang
Lowell Digisonde International, LLC, USA
Dieter Bilitza
George Mason University, USA

Andrzej Krankowsi
University of Warmia and Mazury, Poland
Manuel Hernandez-Pajares
Universitat Politècnica de Catalunya, Spain
Adam Froń and Kacper Kotulak
University of Warmia and Mazury, Poland

IGS Workshop 2016

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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

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

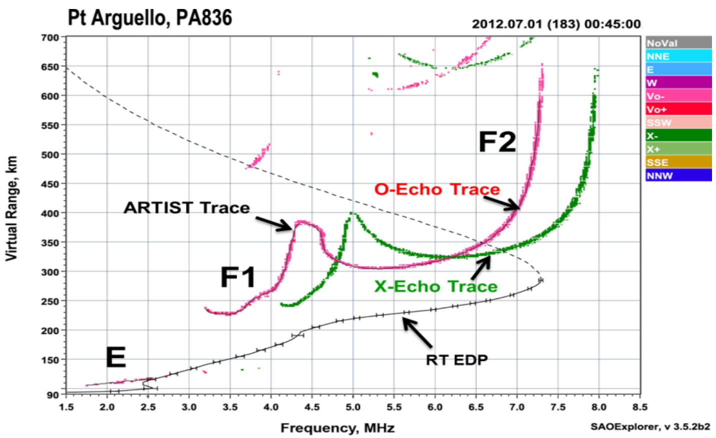
- **3D Real-Time Ionosphere with IRTAM**
- **Cooperation: IGS VTEC and GIRO NmF2 & hmF2**
  – Slab thickness
  – Adding **B0**
    • 3D accuracy
    • Topside half-thickness
  – Outlook

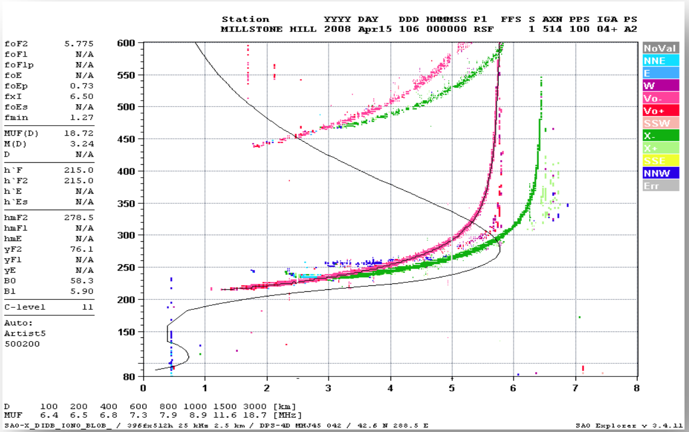
HF Ionosonde

- 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®

Wannalancit Building
Lowell, Dec 2015
Home to Digisonde®

Digisonde DPS4D





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Global Ionosphere Radio Observatory

~ 50 contributing ionosonde stations

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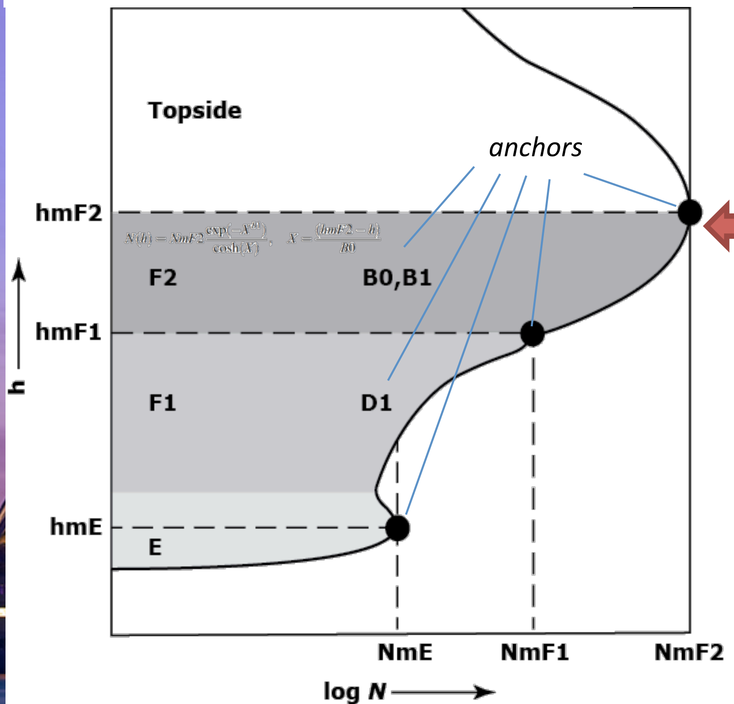
3D Ionosphere by IRI

Monthly median climatology

INTERNATIONAL REFERENCE IONOSPHERE

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 (σ = 0.78 MHz)
hmF2 error is 1.51 km (σ = 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**

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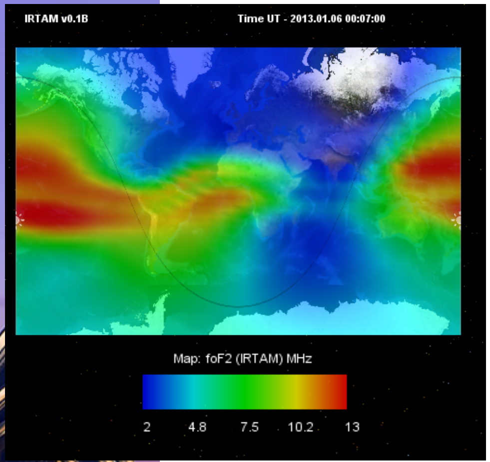
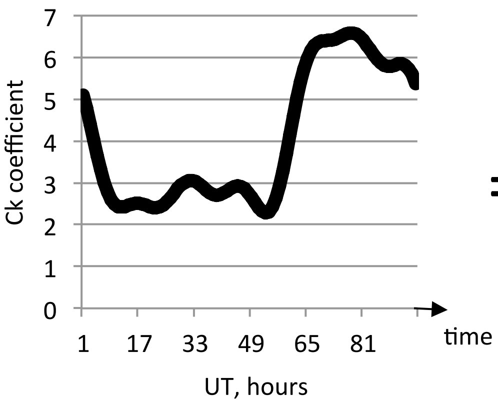
2D+Time Mapping of Anchors

Combination of global and diurnal expansions

[Jones and Gallet, 1962-1966]



X



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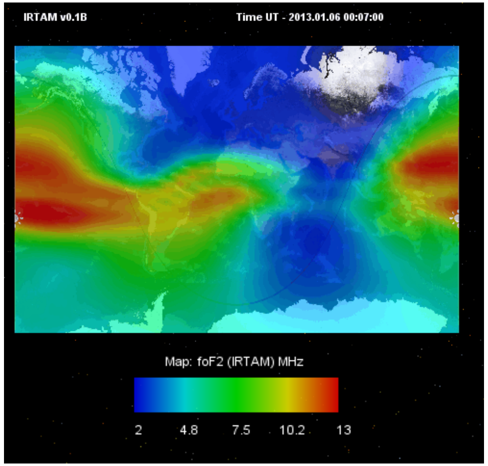


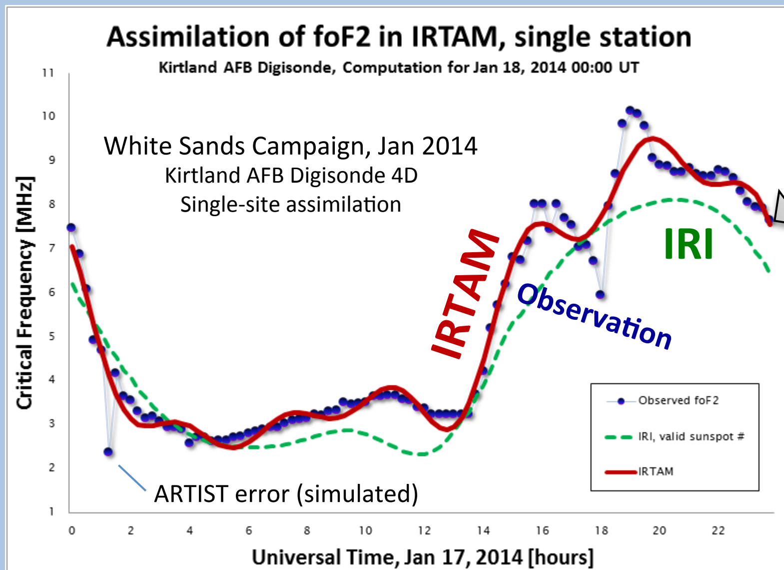
One-time snapshot
76 coefficients C_k

One-day of each C_k
13 coefficients

One day in the life (DITL)
988 coefficients C_{ik}

Single-site Data Assimilation

REAL TIME IRI Assimilative Mapping
IRTAM



REAL-TIME IRI UPDATE : 13 VALUES

6^{th} order diurnal harmonics

4 hour fastest harmonic, **hence no TIDs**

Robust to ARTIST autoscaling errors

- 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 ΔC_{0-12} to diurnal harmonic coefficients
  - Adjustments to IRI can be extrapolated spatially
    - Short-path modeling

This chart makes use of IARPA data from the HFGeo program. The IARPA Program Manager is Chris Reed."

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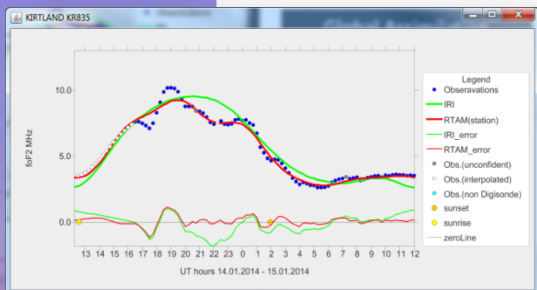
Real-Time IRI Configurations

REAL TIME IRI Assimilative Mapping
IRTAM

NECTAR

A. Single-Site Assimilation

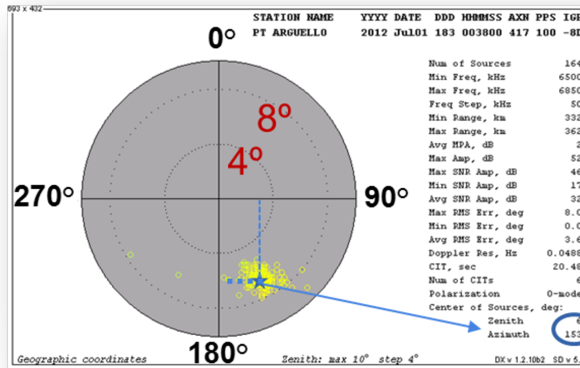


13 real-time adjustments to IRI coefficients *in the vicinity of ionosonde*

(corrections valid for ~200 km)

No TIDs

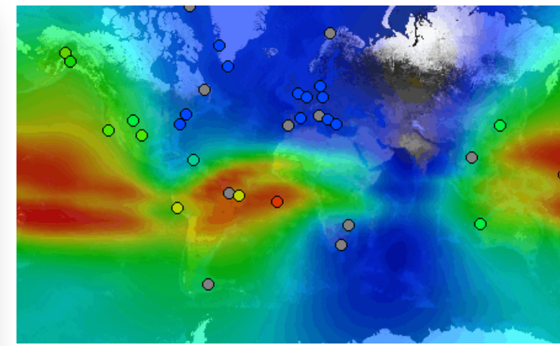
B. Single-Site Assimilation
with local tilt measurement



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

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Next Step: Above Peak Sensing

SLAB THICKNESS τ

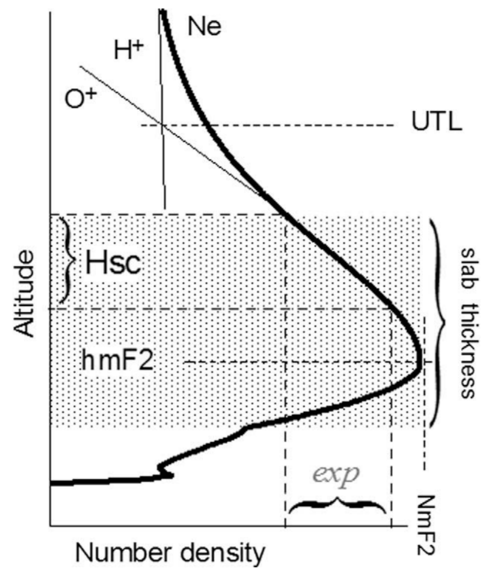
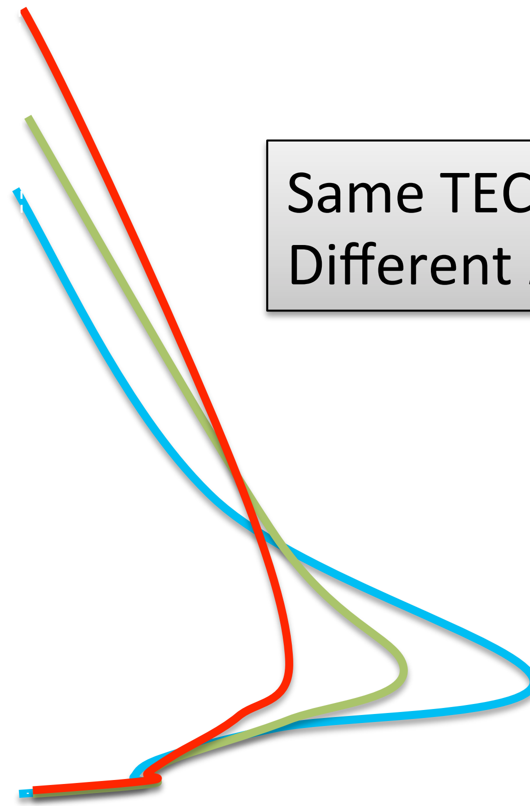


Fig. 1. Schematic view of the vertical electron density profile with key characteristics such as the peak density (NmF2), peak height (hmF2), upper ion transition level (UTL), scale height (Hsc) and slab thickness (τ).

Stankov and Warrant, 2009



Same TEC
Different N_mF2

Thicker slab
Thinner slab

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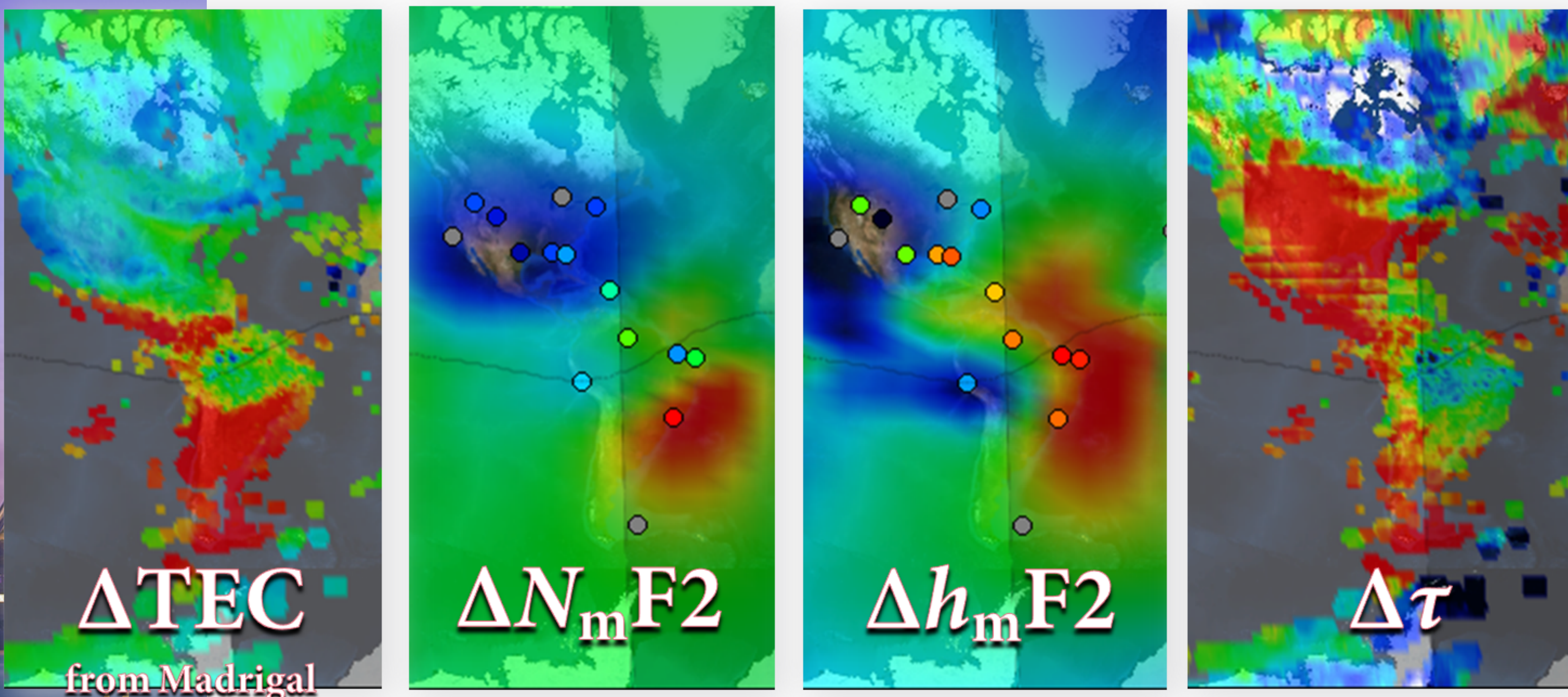
Complementing GIRO with GNSS

Total Electron Content | Peak Electron Density | Peak Density Height | Slab Thickness



Deviation from expected quiet-time behavior

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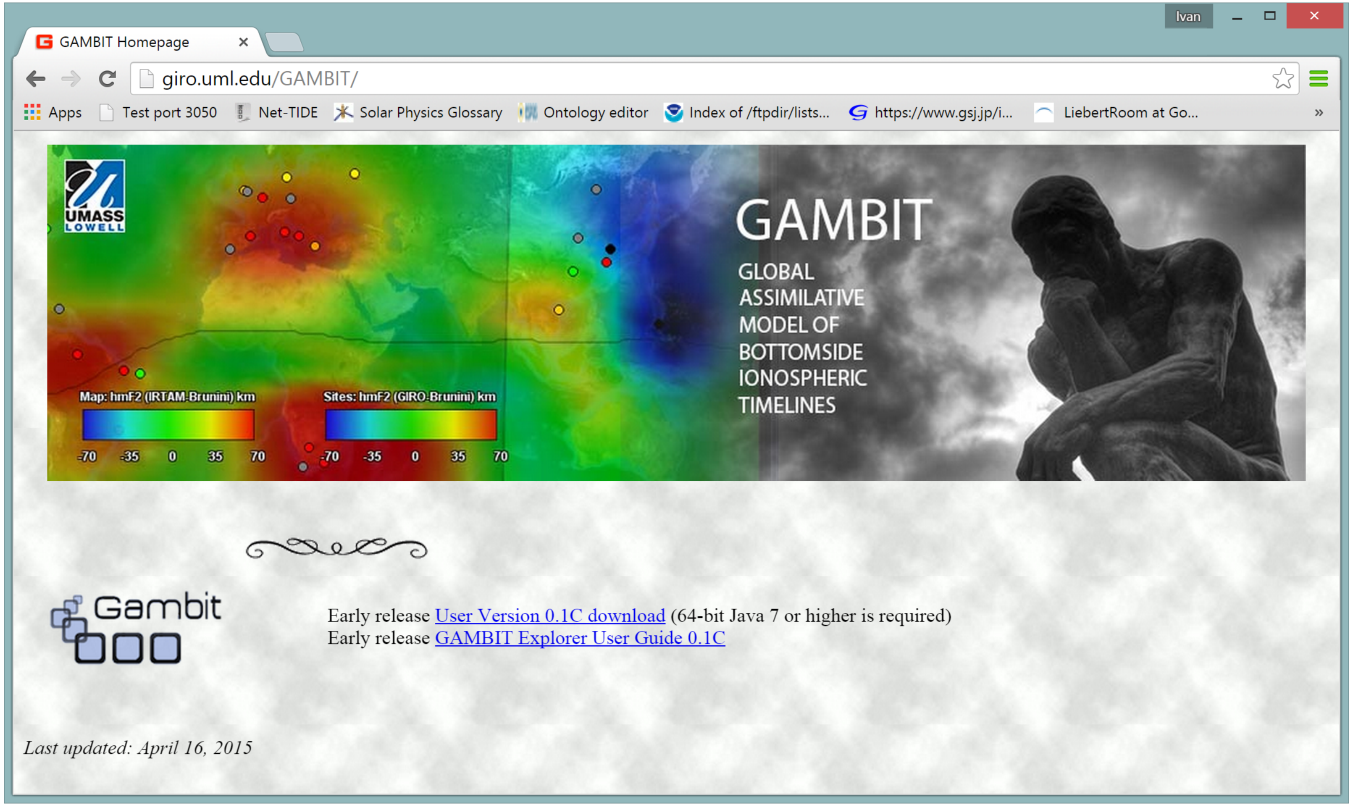
GAMBIT Database and Explorer

Public access to IRTAM retrospective and current results



http://giro.uml.edu/GAMBIT

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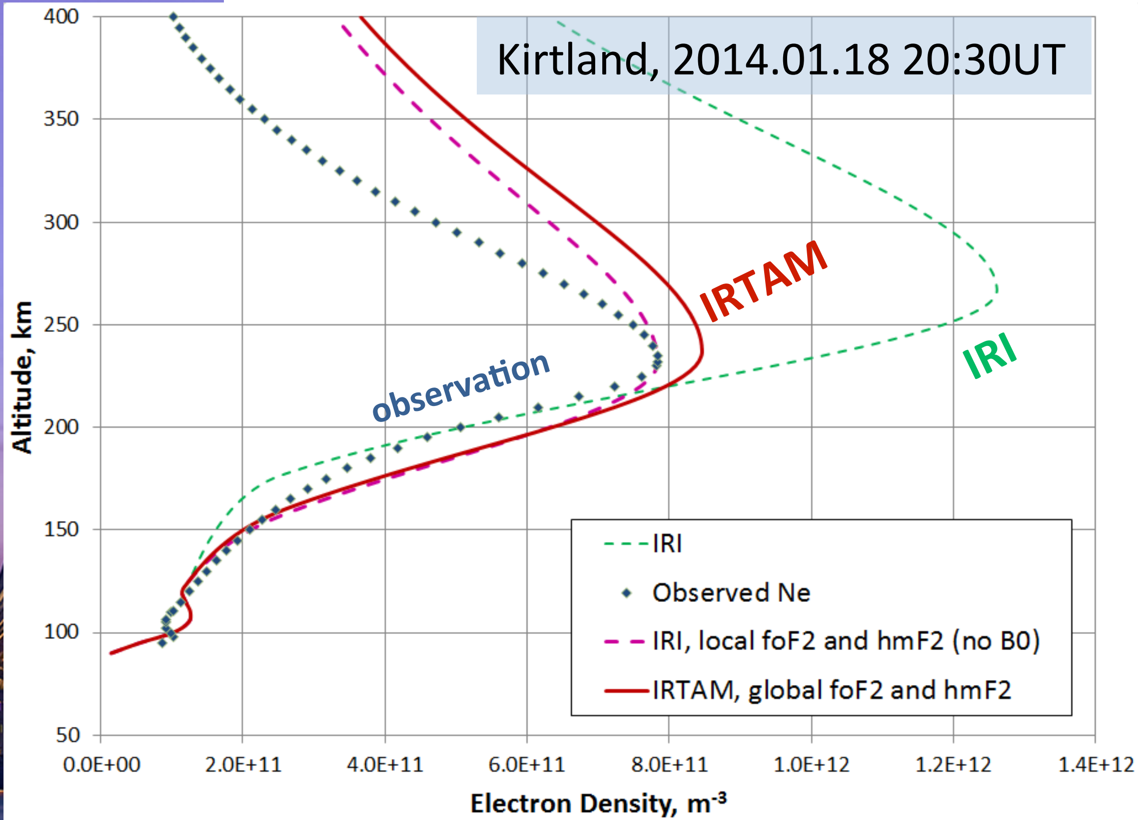
Importance of B0 assimilation



- 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**

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