Beacon Satellite SYMPOSIUM 2016

International BSS Symposium
27 June – 1 July 2016
Trieste, Italy

Assimilation of Sparse Continuous Ionosonde Data into Real-Time IRI

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REAL TIME IRI Assimilative Mapping
IRTAM

Beacon Satellite Symposium 2016
Trieste, Italy • 29 June, 2016

Outline

- **Real-Time Assimilative Modeling with GIRO and IRI**
  - GIRO /Global Ionosphere Radio Observatory/
  - IRI /International Reference Ionosphere/
  - NECTAR assimilation algorithm

GIRO + IRI + NECTAR =

IRTAM

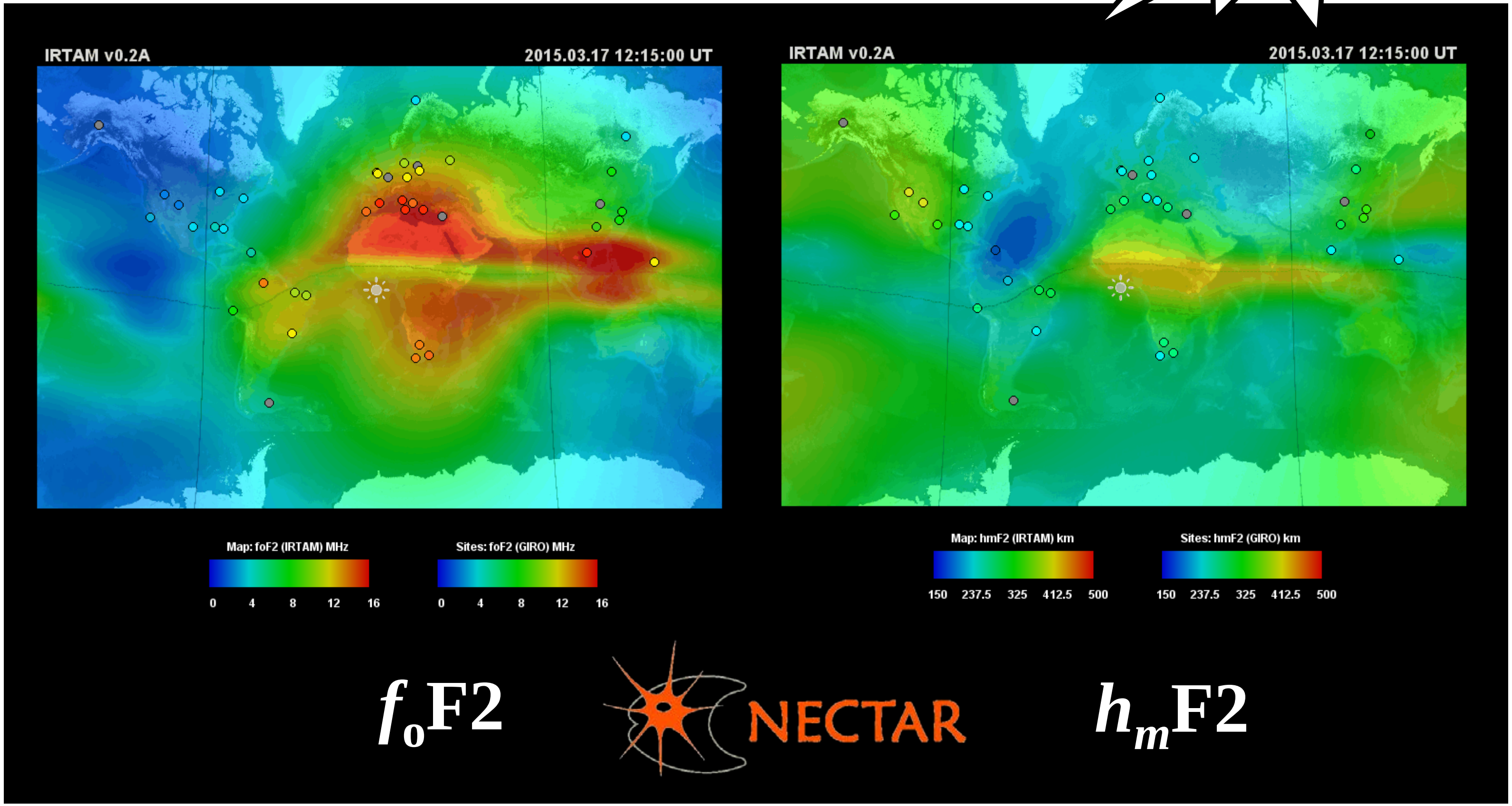
(IRI-based Real-Time Assimilative Modeling)

- **GAMBIT data analysis environment for IRTAM**
  - http://giro.uml.edu/GAMBIT
- **3D Real-Time Ionosphere with IRTAM**
  - Mapping anchor points of Ne profile: foF2, hmF2, B0
- **Outlook**

Real-Time IRI

24 hour history of assimilation

Global Nowcasting



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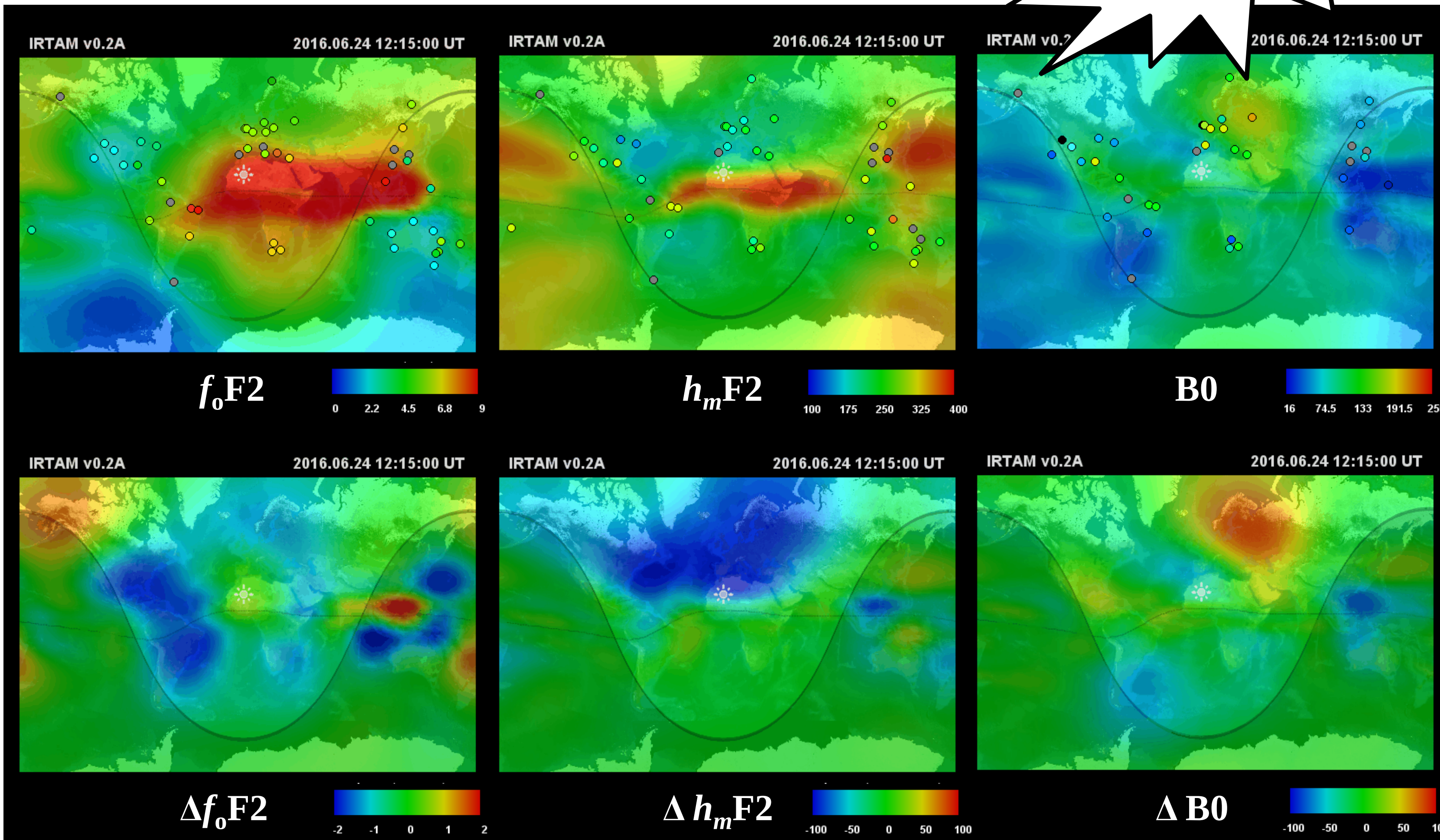
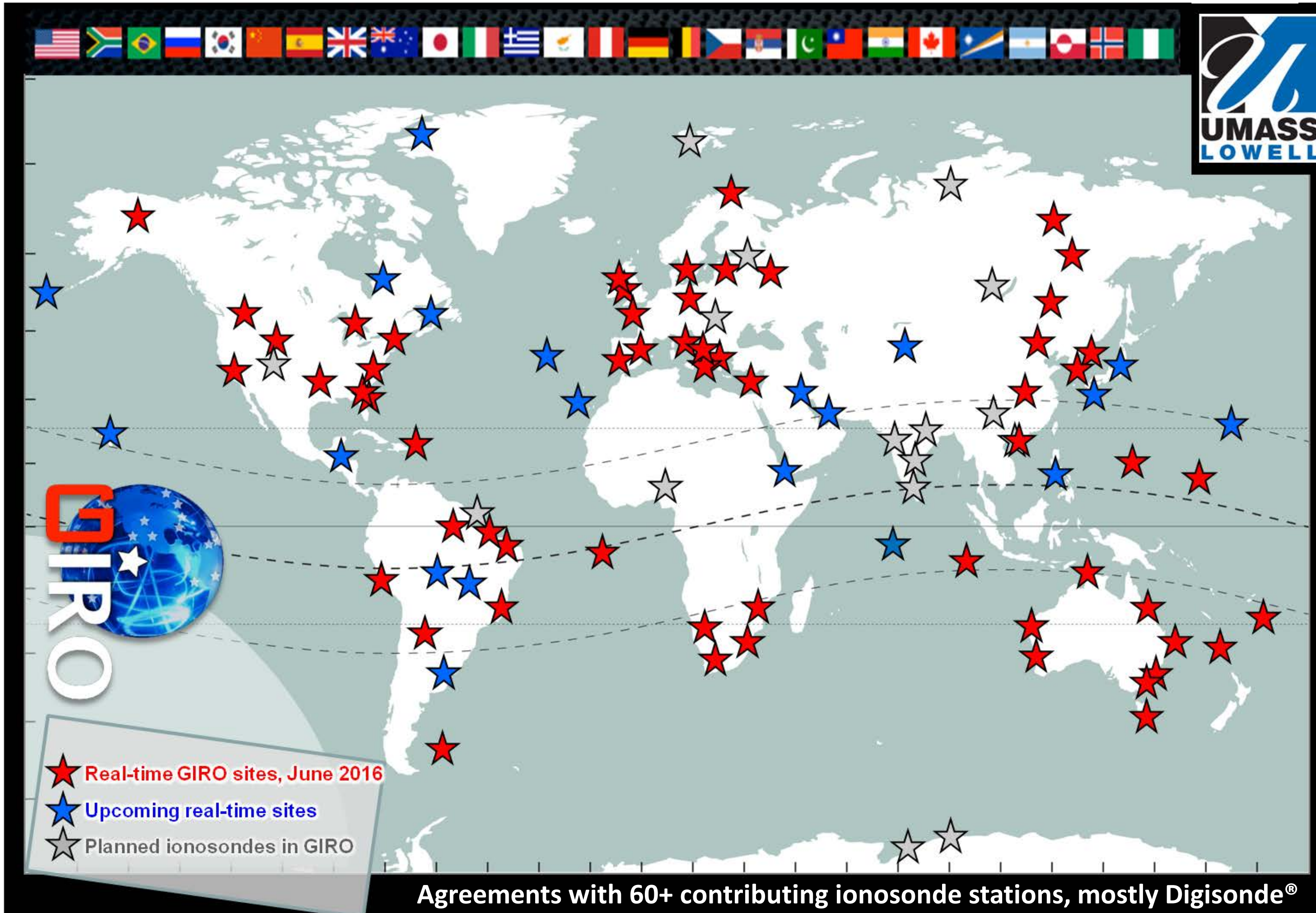


Global Ionosphere Radio Observatory

Digital ionosondes providing real-time data to IRTAM



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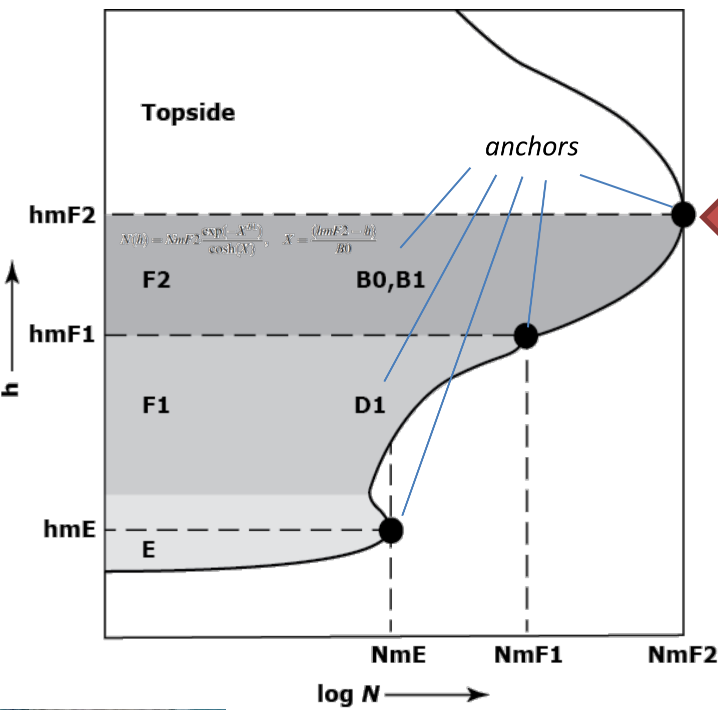
Concept of 3D Real-Time IRI

Use 2D updated maps of Ne profile parameters

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

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 GIRO data to update 2D anchor maps

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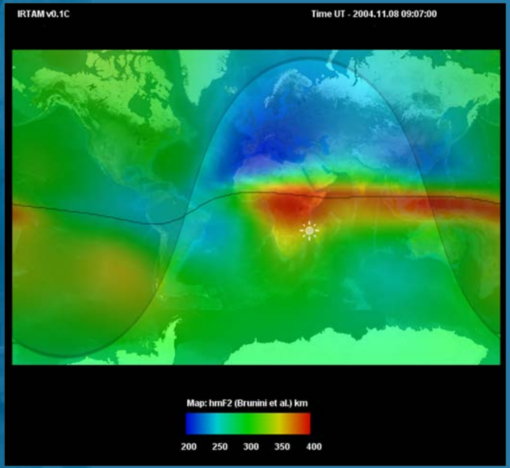
Updating IRI with GIRO data:

Build weather map from monthly average climate map

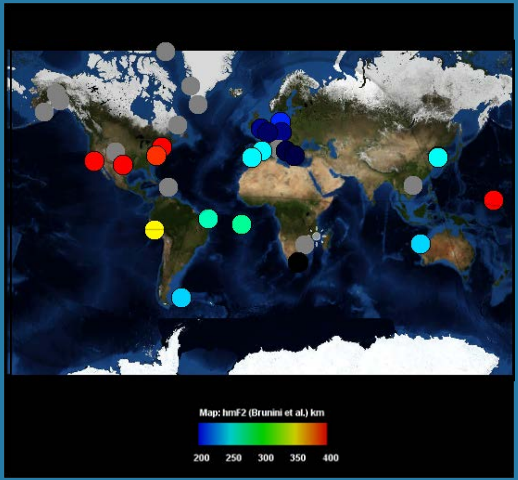
UPDATES EVERY 15 MINUTES

Example: updated hmF2 map



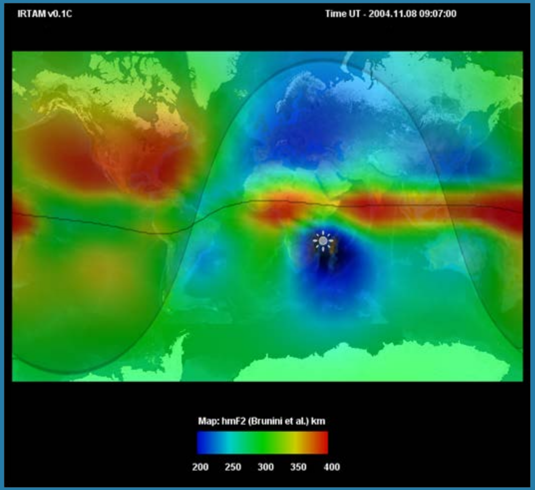
Global hmF2 Climate by IRI

+



GIRO Network Real-Time hmF2

=



Global hmF2 Weather Map

Concept credit: Real-Time IRI Task Force (2009)

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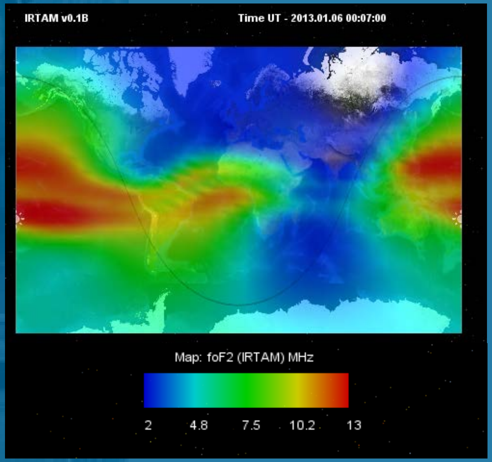
IRI Concept of Mapping

Combination of global and diurnal expansions

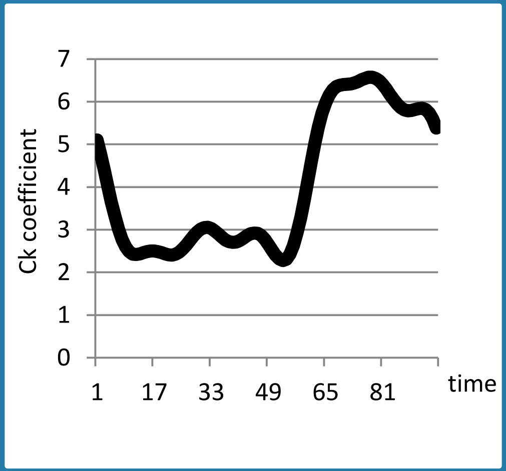
[Jones and Gallet, 1962-1966]

INTERNATIONAL REFERENCE IONOSPHERE

76 x 13 = 988



x



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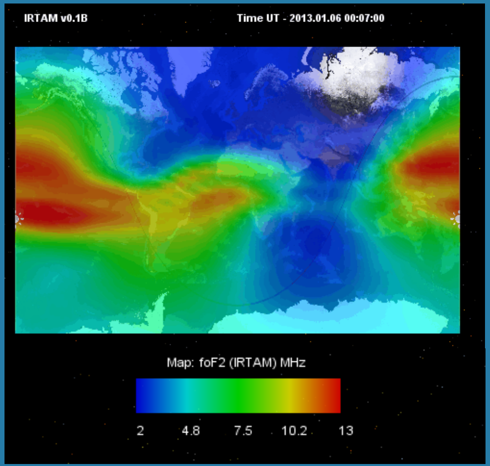


One-time snapshot
76 coefficients C_k

One-day of each C_k
13 coefficients

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

Assimilative IRI technique:

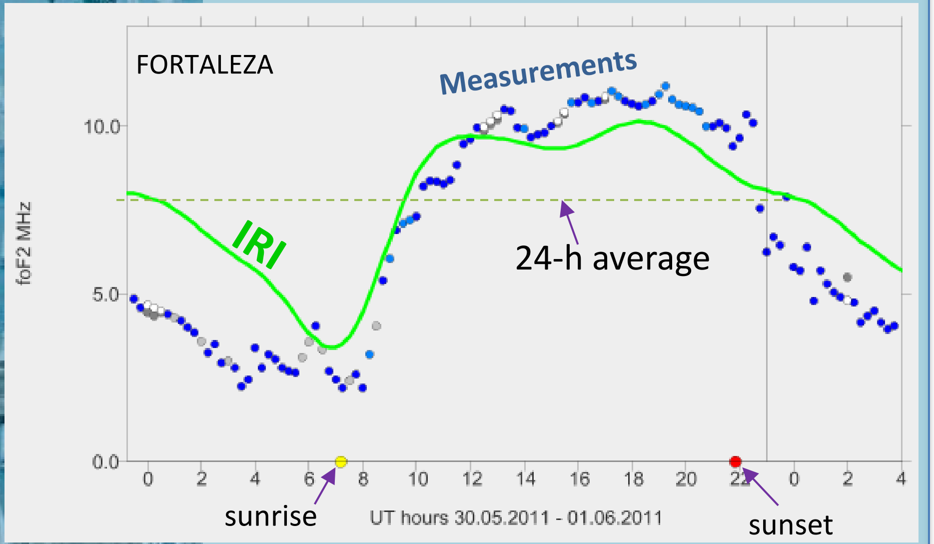
- **One "weather map" is computed using the measurements from all available GIRO ionosondes during the last 24 hrs**
  - This is a 4DDA assimilation technique with 24-hour analysis window
  - The 24-hour analysis window mitigates the effects of ARTIST autoscaling errors
- **Temporal analysis is done first for each GIRO site**
  - using the 96 measurements each station makes during 24 hrs
- **Spatial analysis is done second**
  - Each diurnal harmonic is expanded individually
  - Potential for detecting and capturing planetary scale processes (low-order diurnal harmonics)

I. Temporal analysis: IRI vs IRTAM

single-location 24-hour representation

IRI: average + variations

(13 coefficients for harmonic expansion)

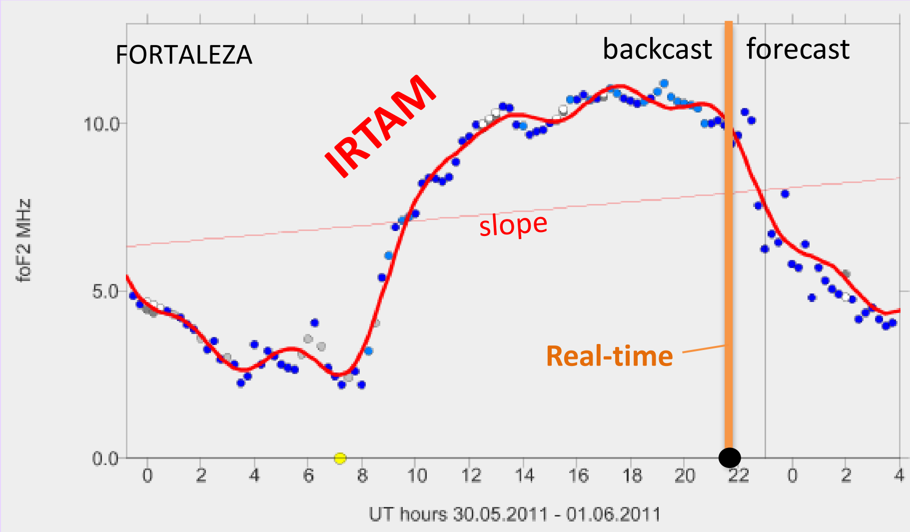


No slope in 24-hour climate prediction

(loops indefinitely)

IRTAM: average + slope + variation

(14 coefficients for detrending and harmonic expansion)

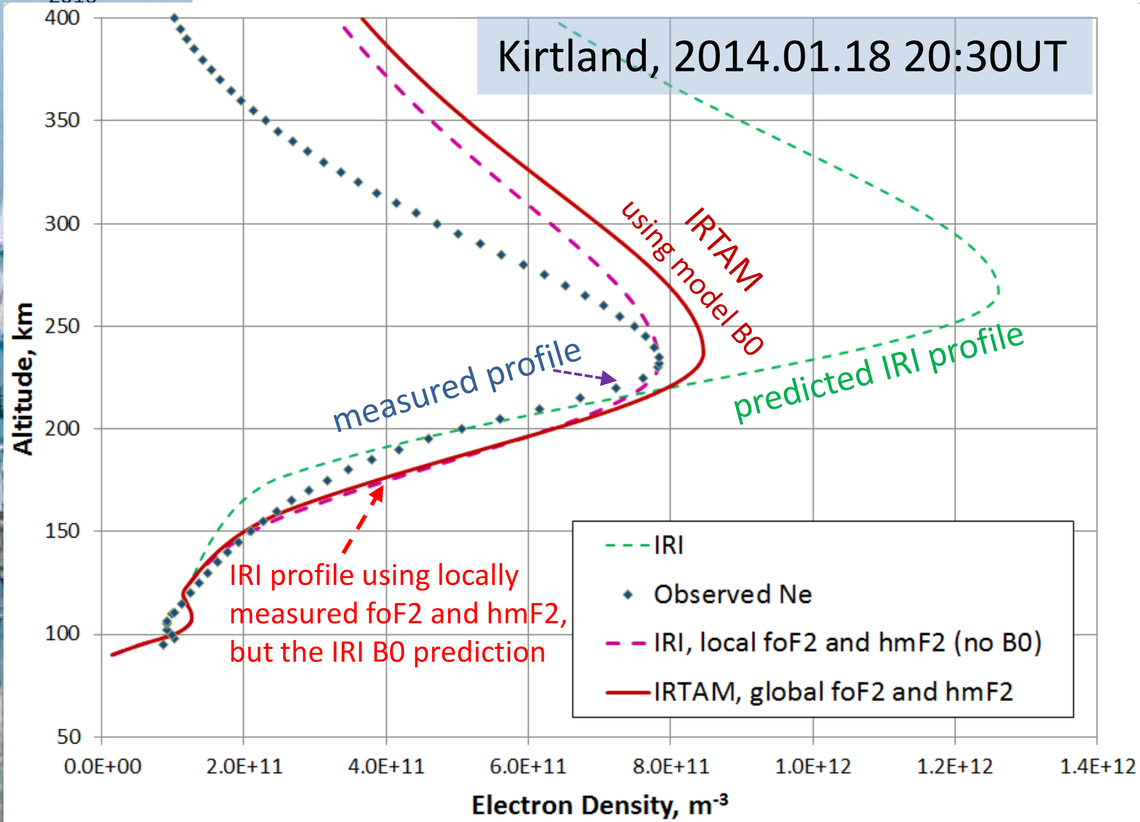


Slope in 24-hour weather timeline

(no need for smooth return to beginning 24 hrs ago)

Fortaleza Digisonde data courtesy Inez Batista, INPE, Brazil

Importance of B0 assimilation



- The model profiles on the left use the IRI model B0 value, <u>not the measured or assimilated B0</u>.
  - Clearly, the bottomside profile is too thick!
  - Using <u>assimilated B0</u> makes bottomside thinner (not shown)

This chart makes use of IARPA data from the HFGeo program. The IARPA Program Manager is Torreon Creekmore.

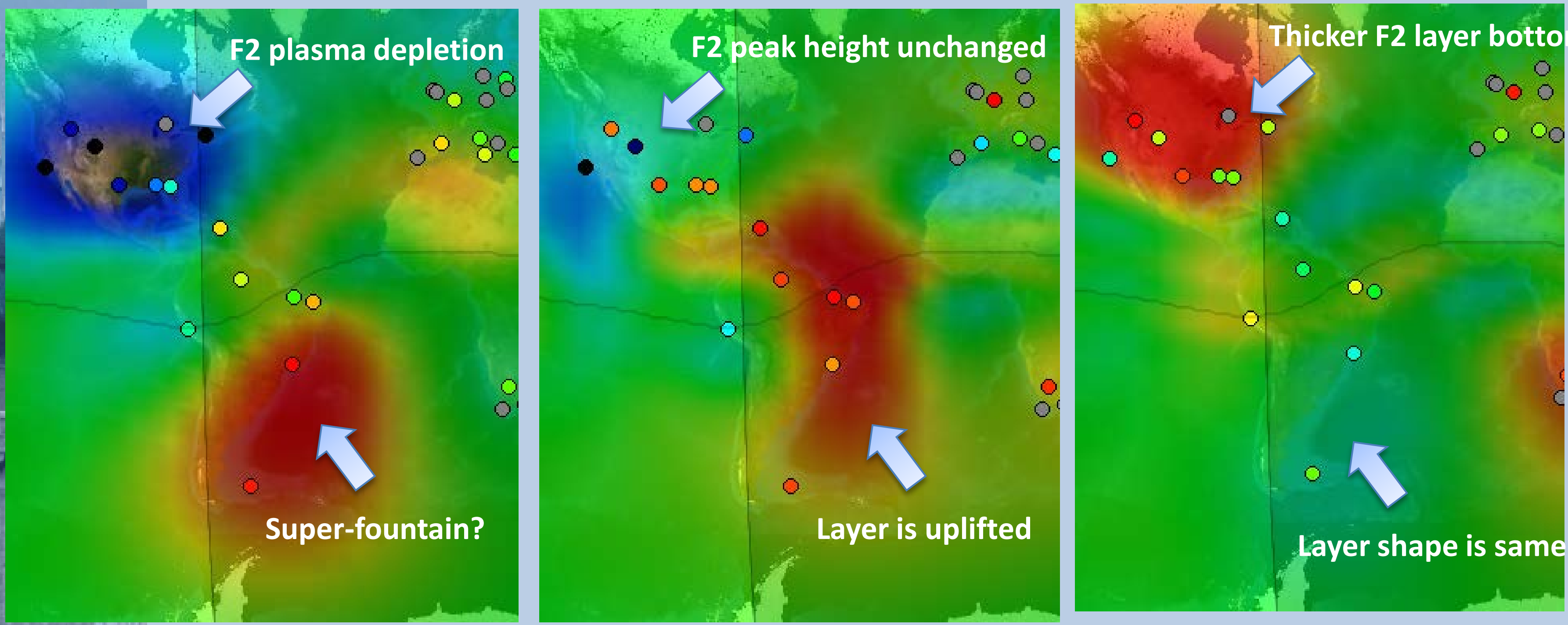
2. Spatial analysis in IRTAM

- **2A. Data interpolation between GIRO sites**
  - Interpolation of *corrections* to IRI background determined by comparing IRI predictions with GIRO observations
  - Interpolation of coefficients to *diurnal harmonic* expansion
    - Longer covariance radii for low-order harmonics
  - NECTAR interpolator based on Hopfield neural network
    - Multi-cell iterative optimization for interpolation smoothness via neuron computations with fading synoptic weights
- **2B. IRTAM Spatial representation of full grid:**
  - Update the 76 ITU-R coefficients in the Jones-Gallet formalism (which is optimized for the Appleton anomaly representation)
  - Algorithm for least-square-error fit of 76th order

Summary: IRTAM + GIRO Capability

Example of March 17, 2015 substorm, very peculiar

DEVIATION FROM EXPECTED QUIET-TIME BEHAVIOR



ΔfoF2 ΔhmF2 ΔB0

IRTAM data from Lowell GIRO Data Center, GAMBIT Database

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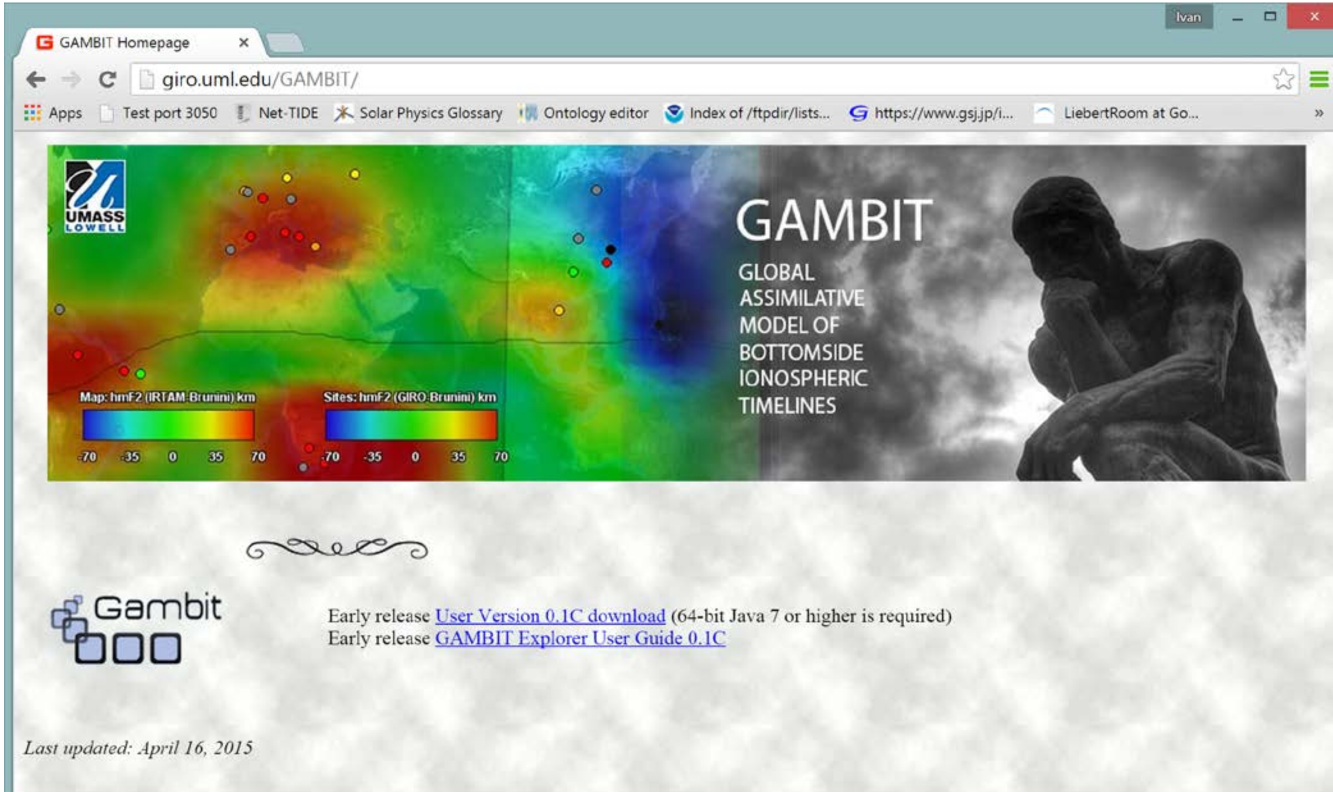
GAMBIT Database and Explorer

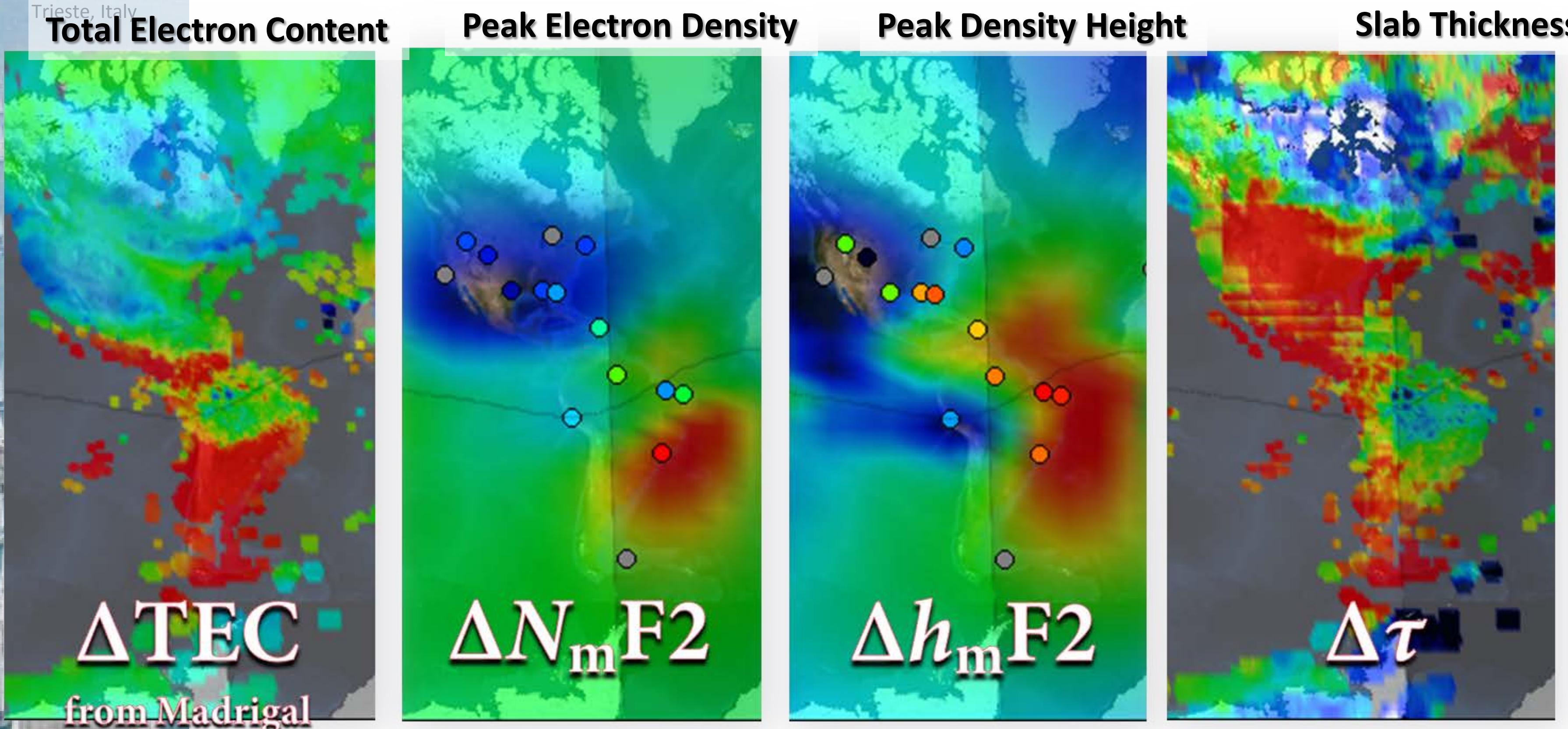
Public access to IRTAM retrospective and real-time results



http://giro.uml.edu/GAMBIT

Complementing GIRO with GNSS TEC

Concept was presented separately at Monday's Session 1



Deviation from expected quiet-time behavior

Red: larger than model Blue: smaller than model

Outlook

- **Cooperative real-time nowcast using GIRO profile data and GNSS TEC**
  - Implementation is imminent
  - Latency of GIRO data: 7 min, working to reduce to < 3 min
  - Current objective at GIRO: 3D profile specification
  - Current objective at IGS: Service integration with Services at Lowell GIRO Data Center and UWM IGS RTS node
- **Applications to space weather research and practice**
  - Ratio of slab-thickness τ to bottomside half-thickness B0 is measure of topside electron content.
- **GAMBIT environment in open source domain for data access and visualization**
  - GAMBIT Consortium is open for membership