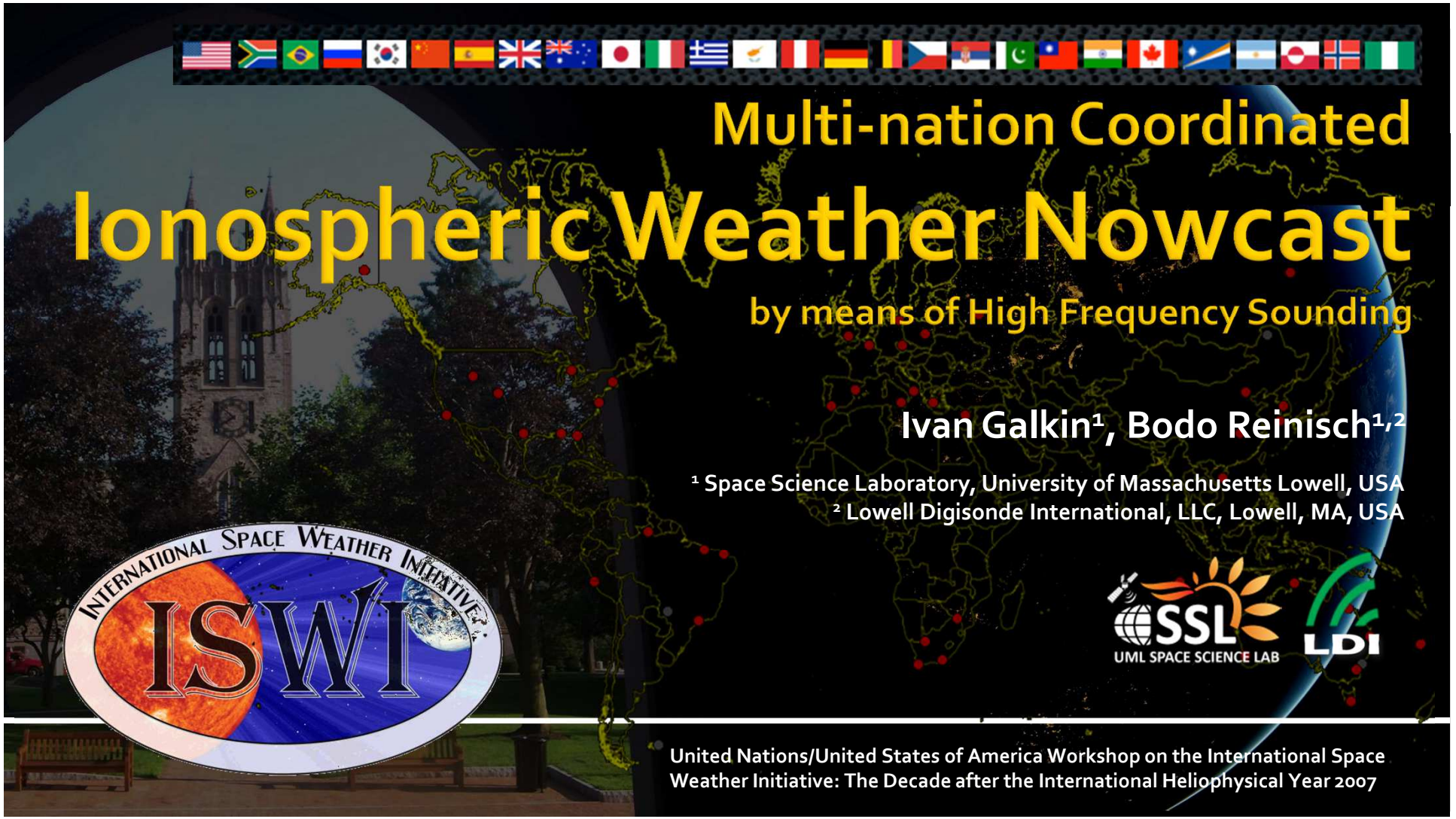

Multi-nation Coordinated Ionospheric Weather Nowcast

by means of High Frequency Sounding

Ivan Galkin[1], Bodo Reinisch[1,2]

[1] Space Science Laboratory, University of Massachusetts Lowell, USA
[2] Lowell Digisonde International, LLC, Lowell, MA, USA

United Nations/United States of America Workshop on the International Space Weather Initiative: The Decade after the International Heliophysical Year 2007

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Acknowledgements

LOWELL TEAM

- GIRO Software IPT
- Digisonde Crew

OTHER SCIENCE TEAMS

- IRI Real-Time Task Force
- Net-TIDE Europe Group
- NASA HPDE and VWO

GIRO PROVIDERS

- 28 countries, 60 observatories

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Motivation

- Ionospheric Weather applications keep emerging
  - High-Frequency (HF) ionospherically reflected radio : is there life after Marconi Noble Prize in 1909…
- New today: unprecedented need for high accuracy of global Ionospheric Weather Nowcast in near real time
  - TID as a "major operational nuisance"
    - PPP (precise point positioning) applications of GNSS
      - TID as a "Silent Killer of PPP Accuracy"
      - Problem more acute than GNSS scintillation/loss-of-lock
    - HF Geolocation of Uncooperative Transmitters
      - "Short-range Catastrophe" : a devastating impact on geolocation (10s km)
  - Academy is tasked to provide new understanding and accurate specification of the ionospheric dynamics

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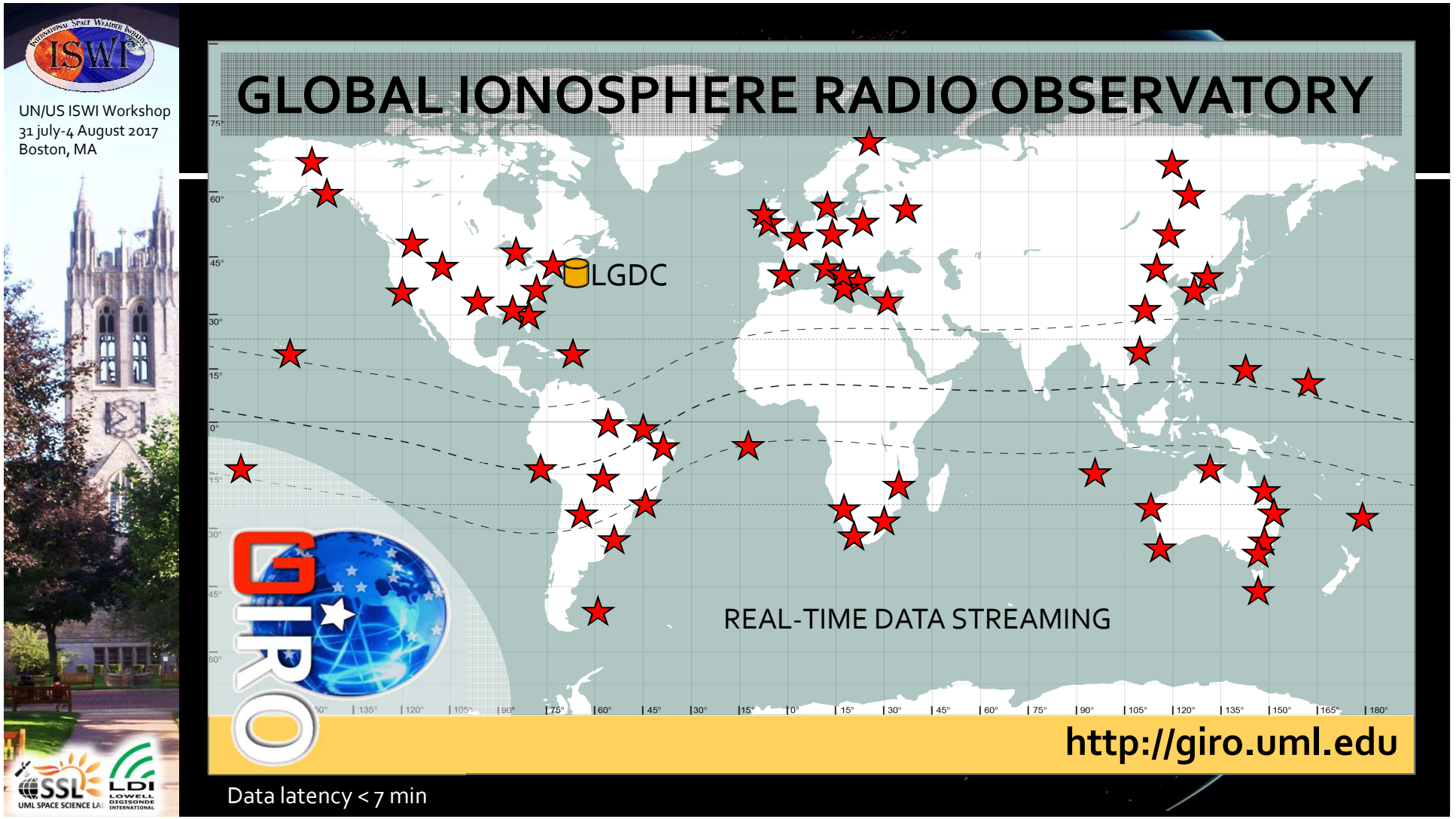
Remote Sensing Capability

- Accurate Nowcast: near-real-time data are needed
  - Ionosphere has a short memory
    - Measurements 1 hour old are 50% useful in nowcast
    - Measurements 4 hours old are not useful
  - Global sensor networks with continuous data streams at <1 hr latency?
    - Space-borne ionosphere observing fleet… not quite ready
    - Ground-based network
      - GNSS “Ultra-rapid” and nRT networks, ~300 receiverss
      - …and then there are HF ionosondes and GIRO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GLOBAL IONOSPHERE RADIO OBSERVATORY
LGDC
REAL-TIME DATA STREAMING
GIRO
http://giro.uml.edu
Data latency < 7 min

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GLOBAL IONOSPHERE RADIO OBSERVATORY

LGDC

REAL-TIME DATA STREAMING

http://giro.uml.edu

Data latency < 5 min

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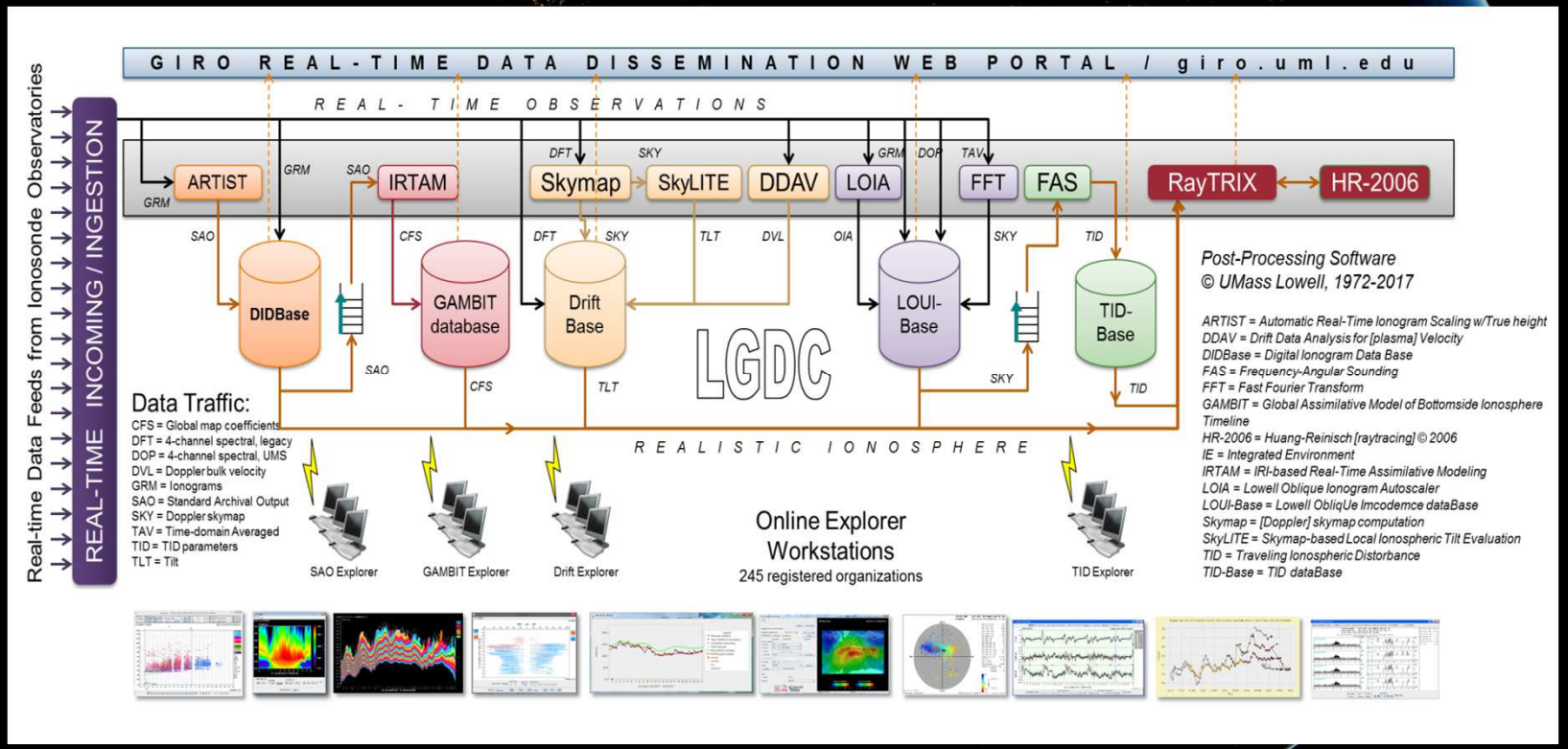
LGDC: ~ 600 Mil records



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Outline

- Next step: Realistic Ionosphere
  - IRTAM 3D: real-time assimilative model
  - TID Explorer: TID detection and forecast
  - RayTRIX: ray-tracing through Realistic Ionosphere
- Transition to Operations
  - Intelligent and expert system research
  - Net-TIDE: pilot network for TID evaluation

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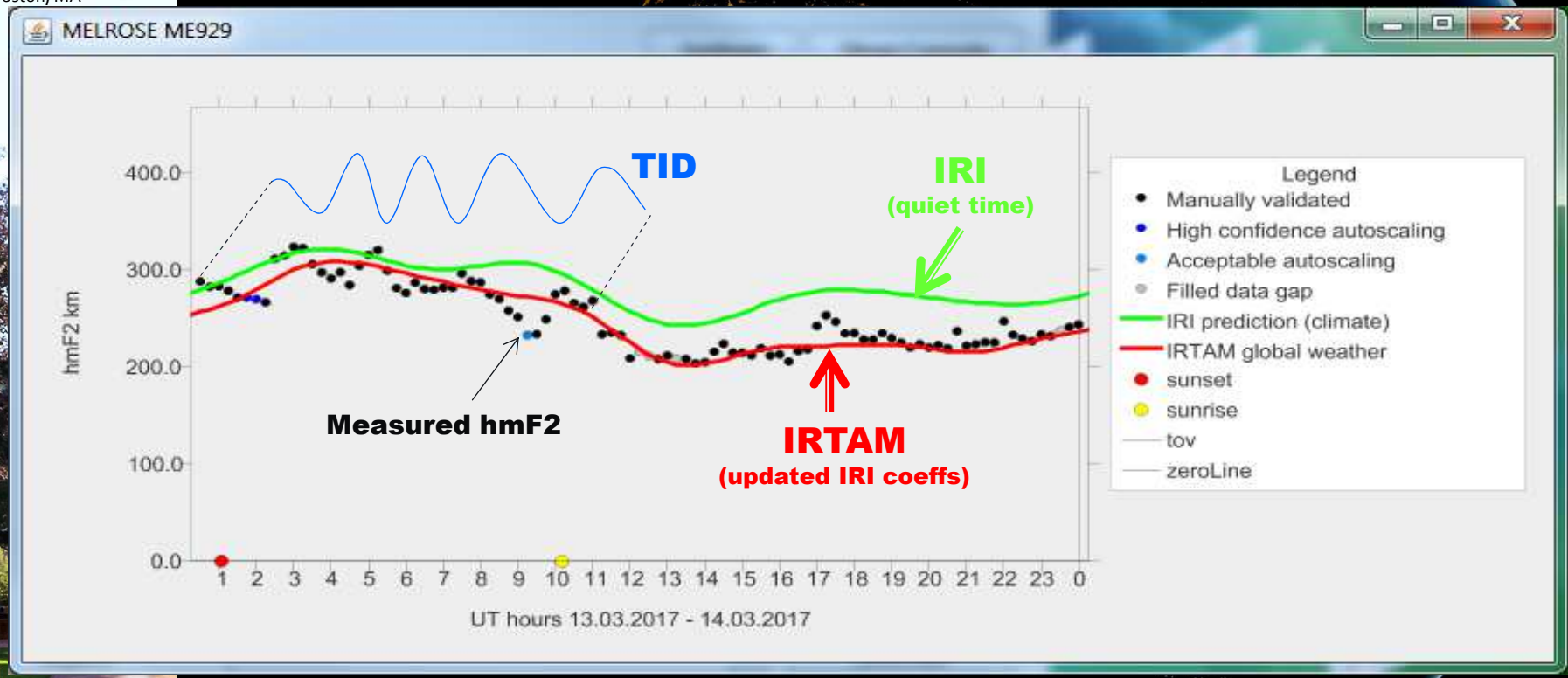
Realistic Ionosphere: IRTAM+TIDx



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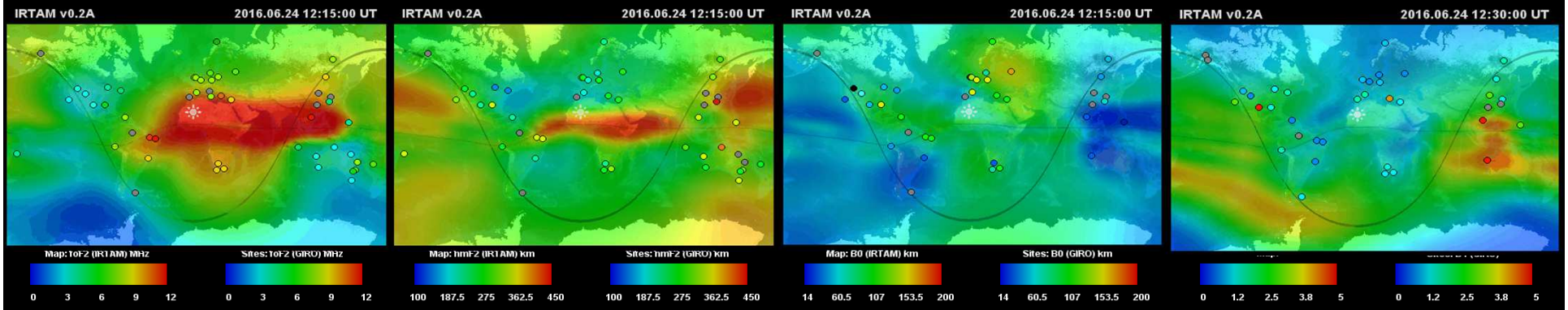
IRTAM 24-hour Animations



f_0F2 h_mF2 *B0* *B1*

Used as input drivers to IRI density profile for 3D specification

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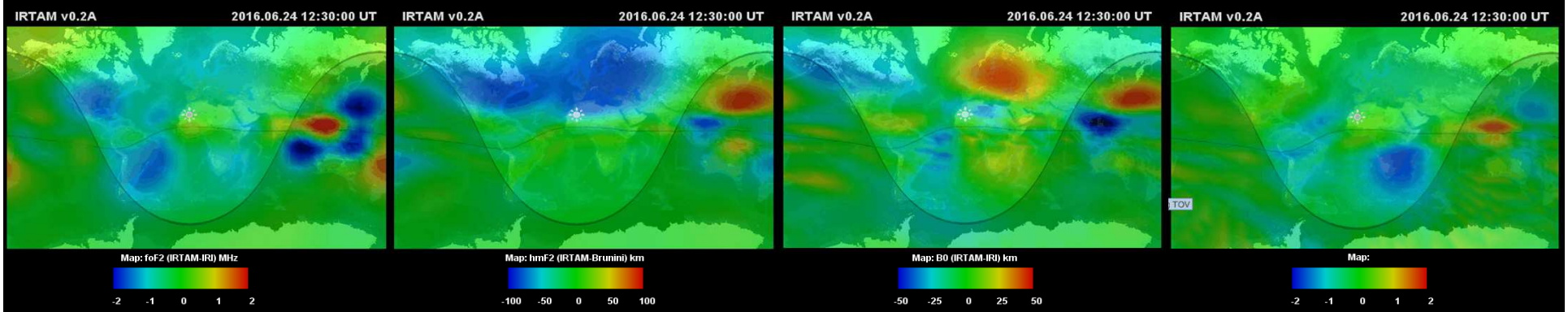
IRTAM Deviation Maps

HOW IONOSPHERE IS DIFFERENT FROM ITS QUIET-TIME STATE



Δf_0F2 Δh_mF2 $\Delta B0$ $\Delta B1$

NECTAR

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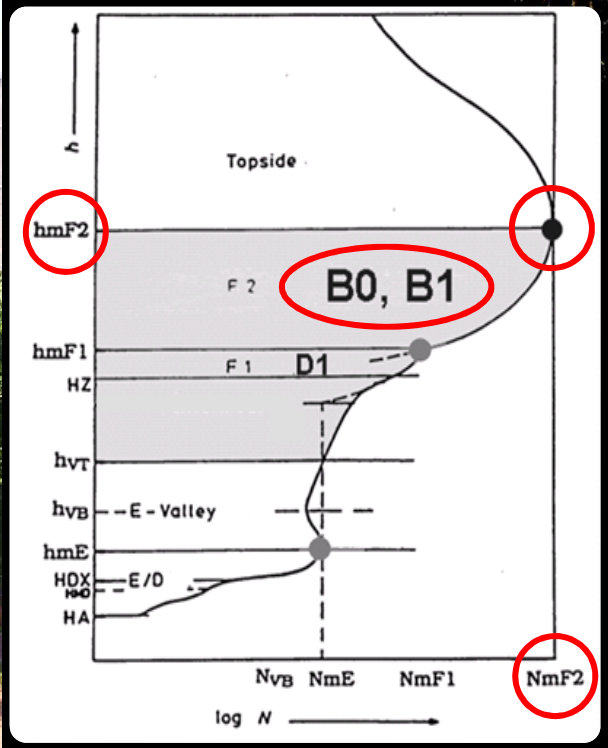
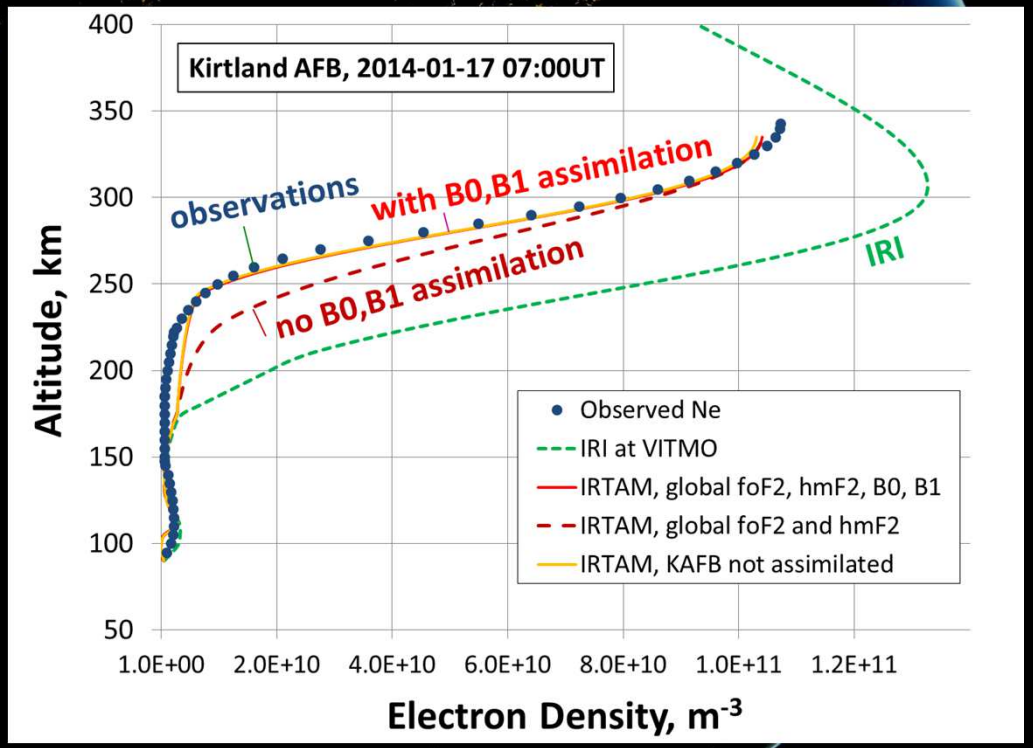
IRTAM 3D





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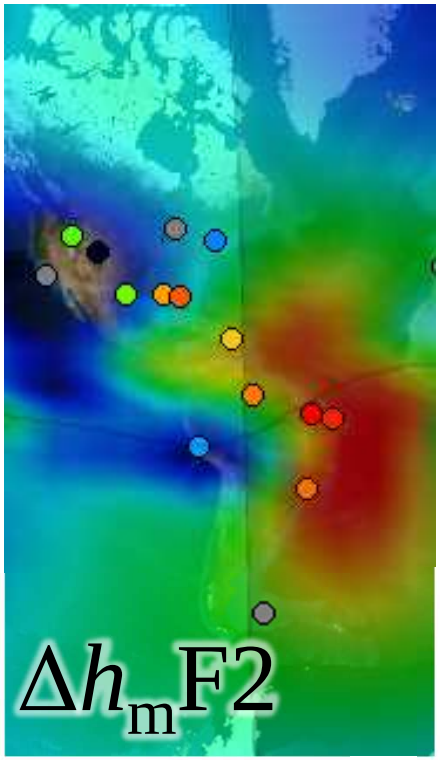
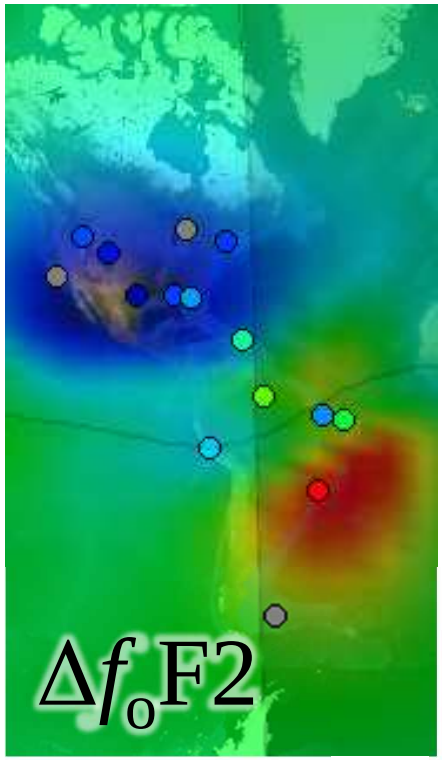
IRTAM paired with GNSS TEC

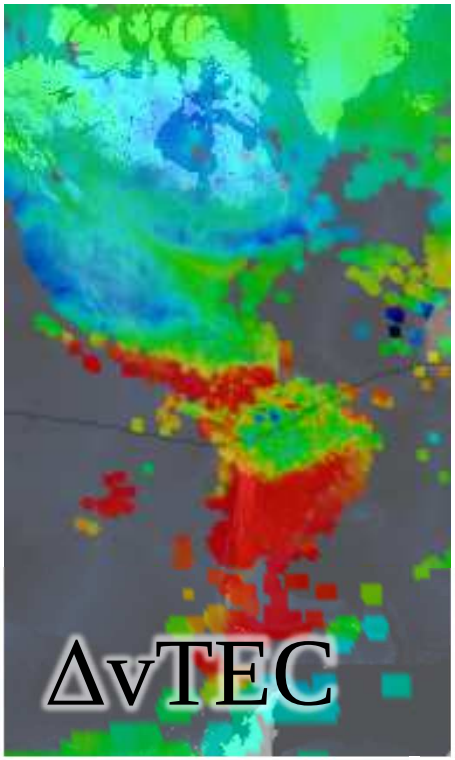
Δ Peak Density Height



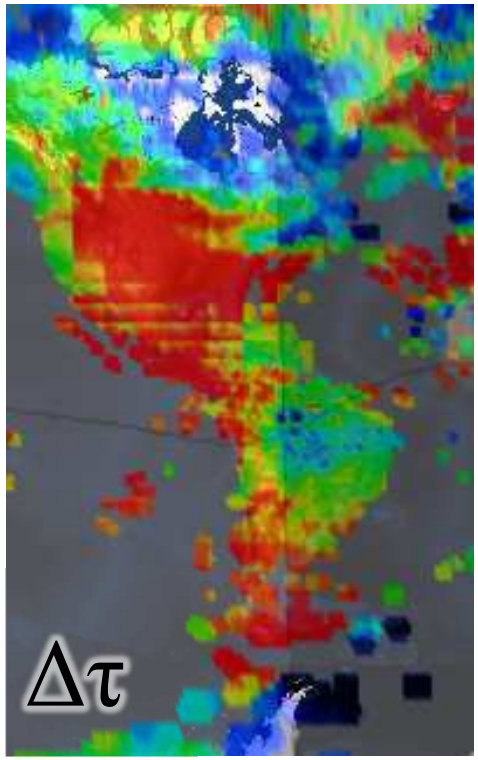
Δ Peak Density



Δ vTEC



Δ Slab Thickness



VTEC data courtesy Anthea Coster, MIT Madrigal

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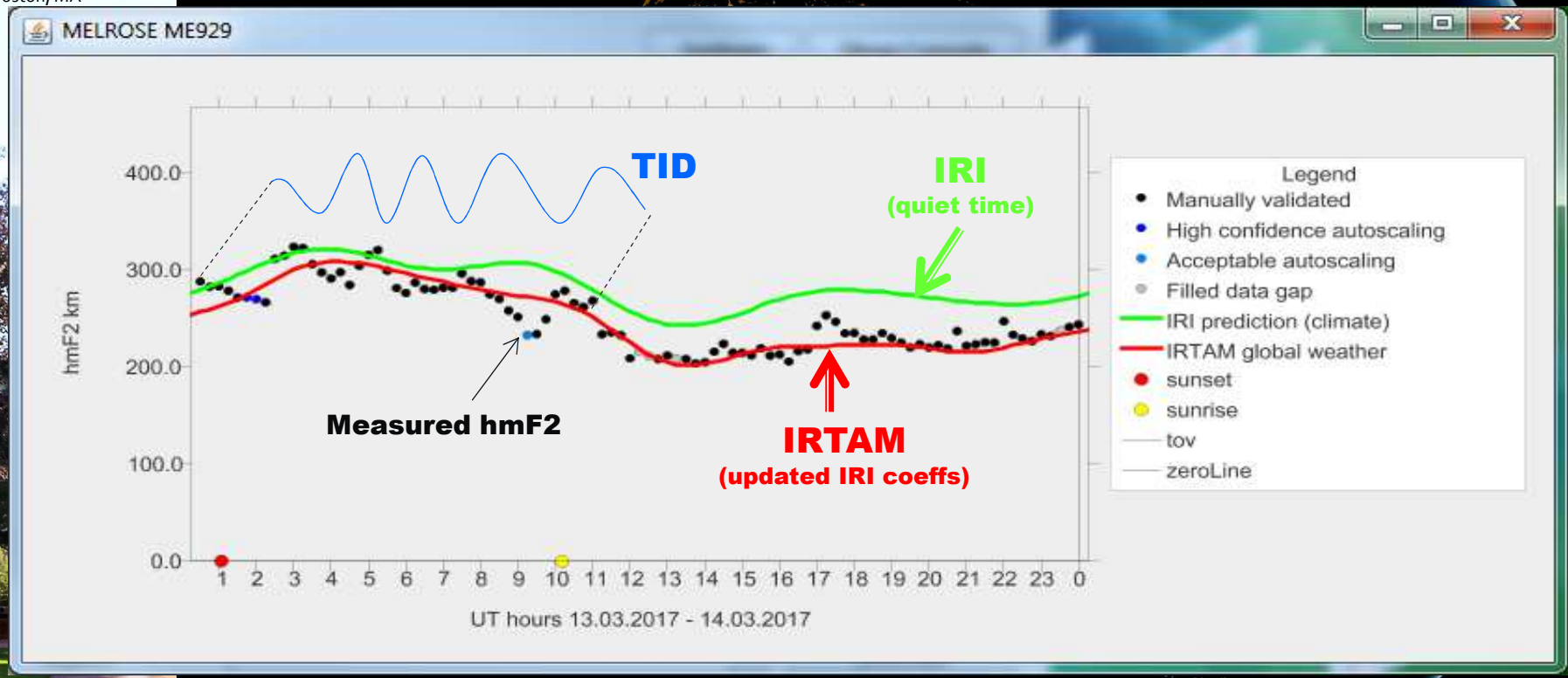
Realistic Ionosphere: IRTAM+TIDx



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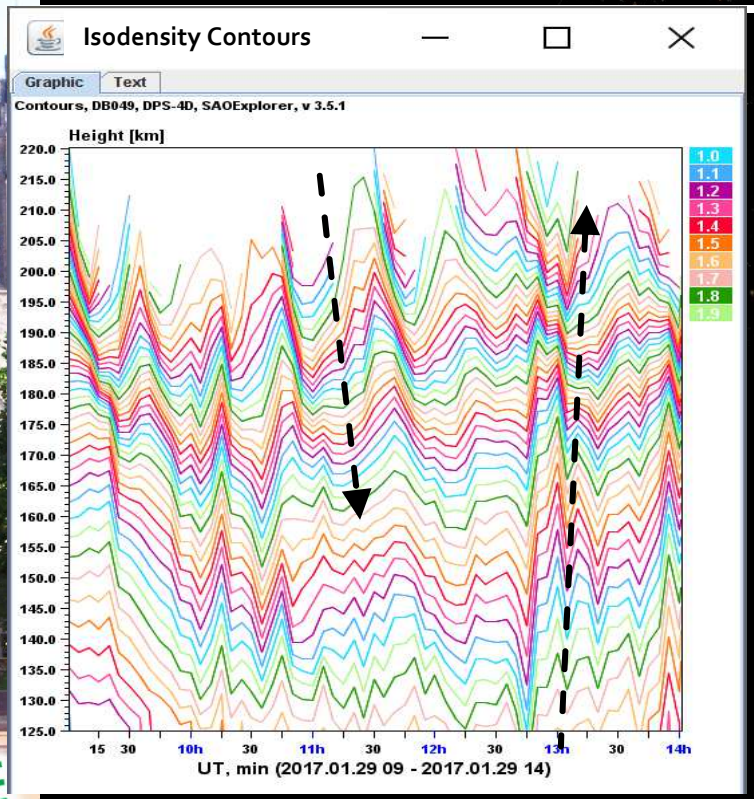
HF versus other TID sensors



Data courtesy Tobias Verhulst, RMI

- **1D Altitude profile of TID**
  - Detailed view of propagation along z-axis
  - Pin-point to particular altitude region
- **Sensitivity**
  - Detection of a 5% TID vs underlying density
  - “TID are always present” < 1%
- **Direction, Velocity, Wavelength**
- **Direct measurement**
  - Static platform
  - No slant-to-vertical transformation needed
- **24/7 operations with automatic intelligent system analysis**
  - Replicate human intelligence

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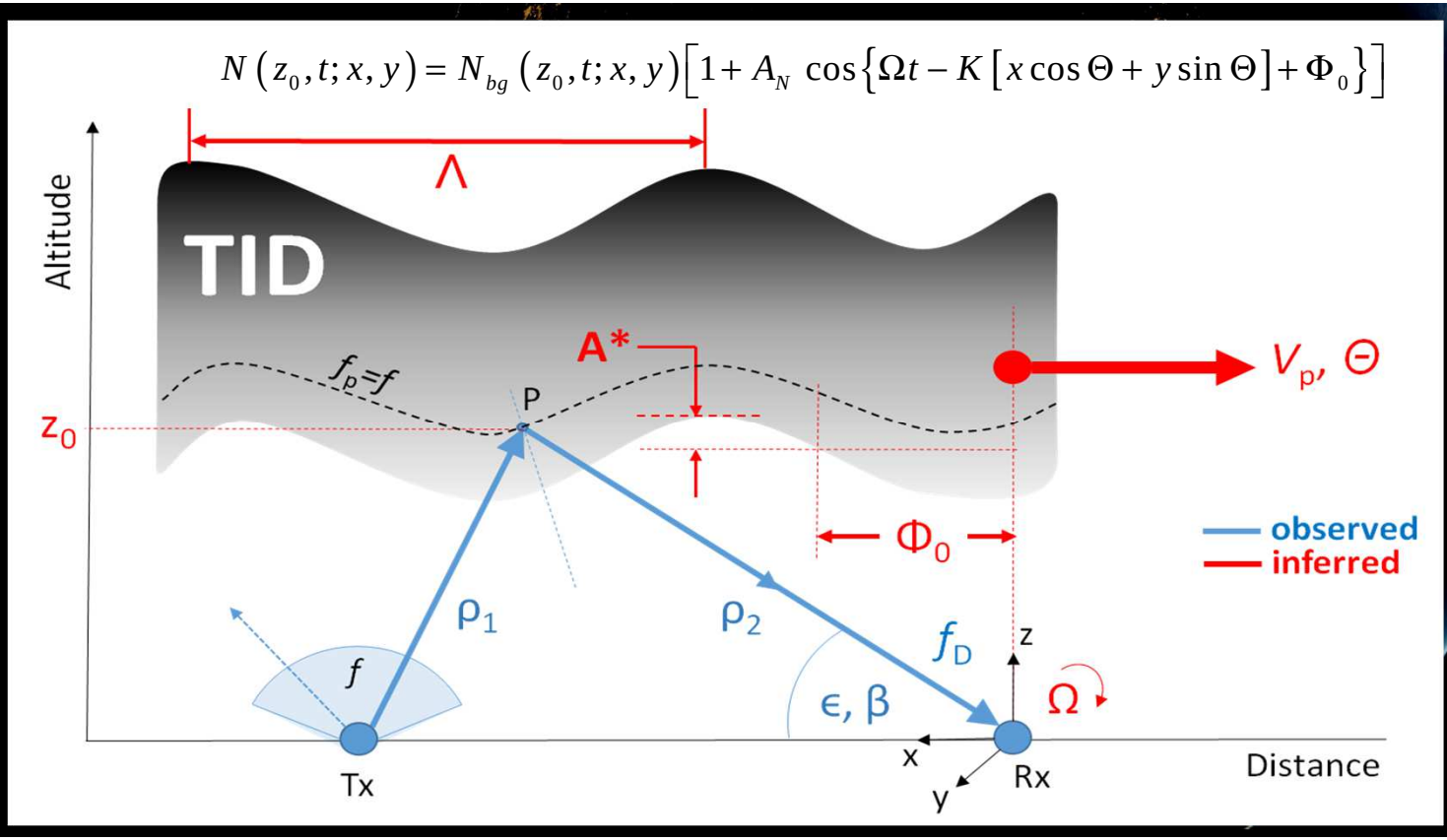
TID Evaluation using D2D and FAS

HF Pulsed sounding with multi-path resolution

$$N\left(z_0,t;x,y\right)=N_{bg}\left(z_0,t;x,y\right)\left[1+A_N\ \cos\left\{\Omega t-K\left[x\cos\Theta+y\sin\Theta\right]+\Phi_0\right\}\right]$$



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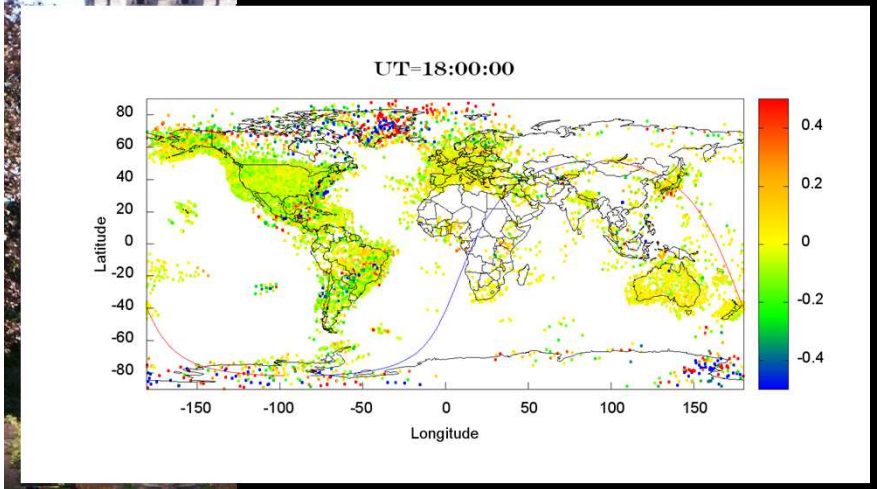
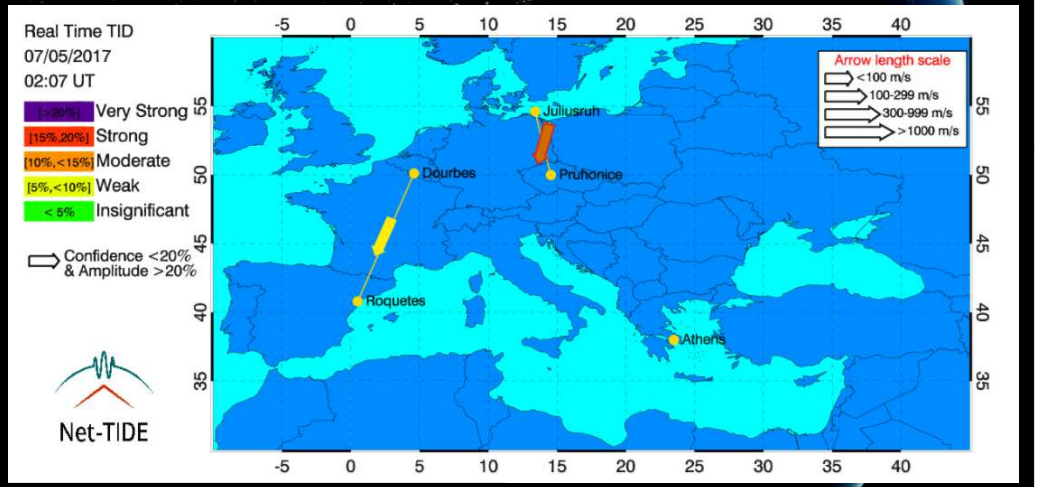
Forecast of TID propagation

TID AS SEEN BY GNSS



TEC Animation courtesy Y.Yasyukevich, ISTP

TID AS SEEN BY NET-TIDE EUROPE



Net-TIDE Pilot Warning System, http://tid.space.noa.gr

Project PI: Anna Belehaki, NOA, Greece

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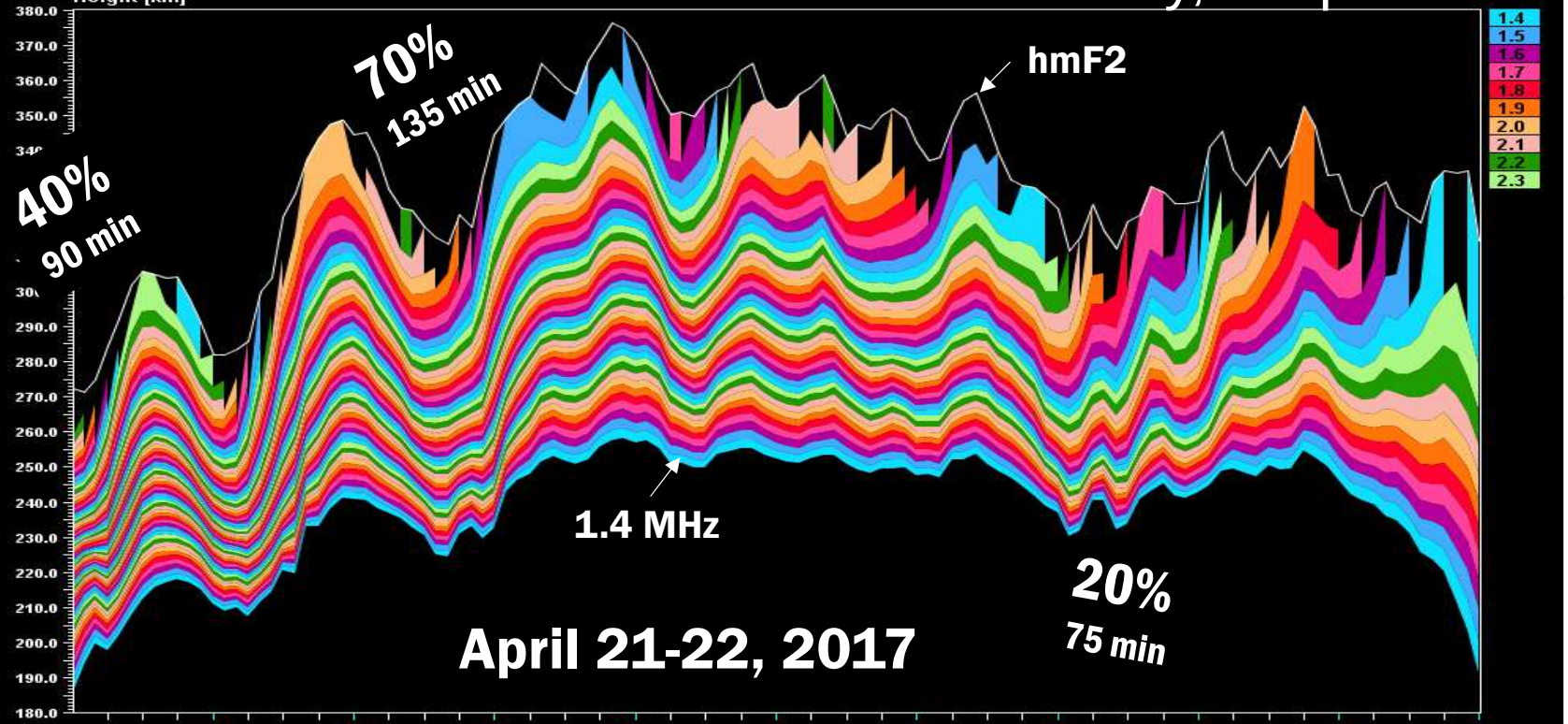
"EGU Opening" TID Event

Ebro Observatory, Roquetes



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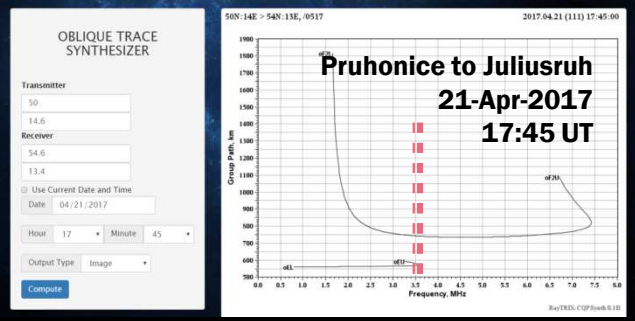
"EGU Opening" TID: April 21, 2017 19:00 UT

Pruhonice to Juliusruh link (513 km)

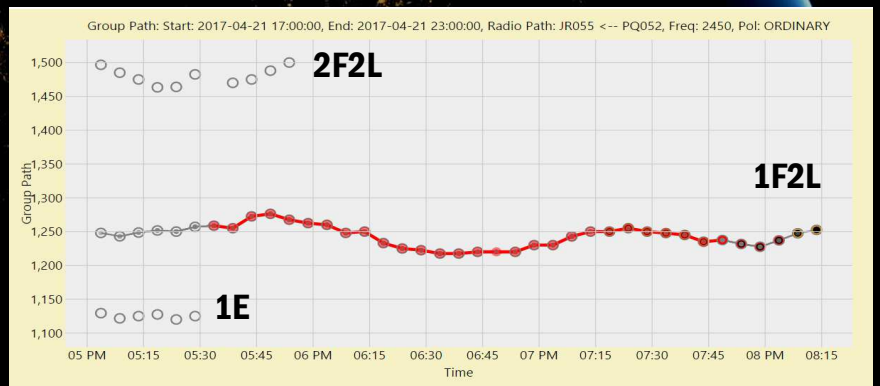
RayTRIX
Ray Tracing through Realistic Ionosphere Explorer



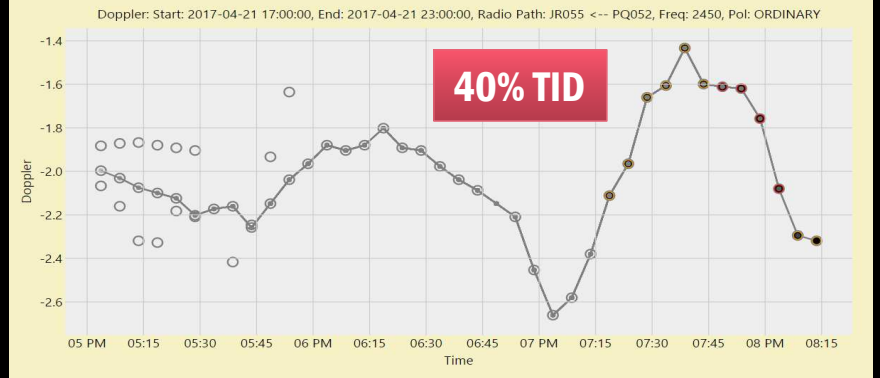
40% TID, 410 m/s
2500 km, 100 min
245° azimuth CW

Accuracy sufficient for a warning system

Group Path



Doppler



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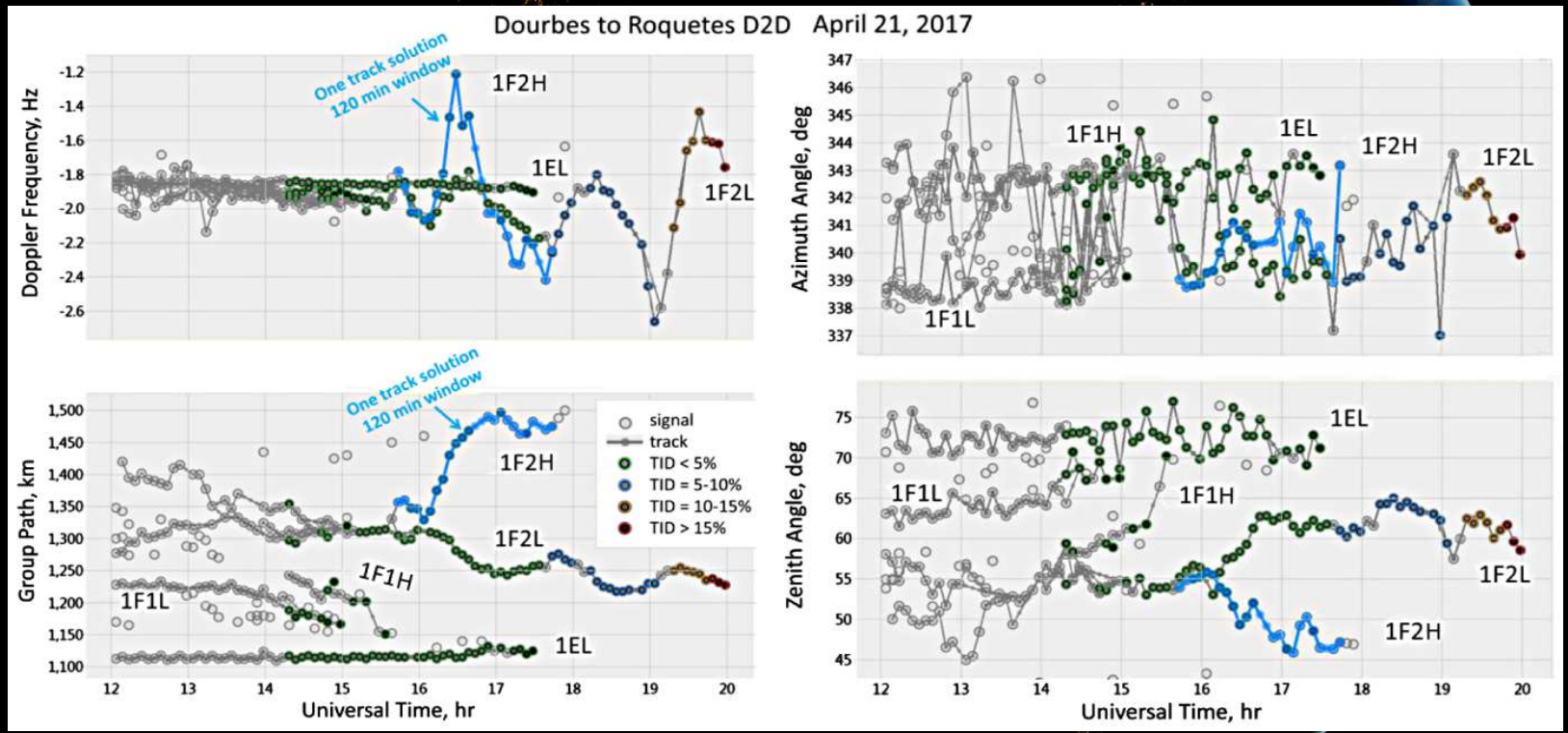
Automatic Signal Tracking

Dourbes to Roquetes link (1082 km) ["southern link"]



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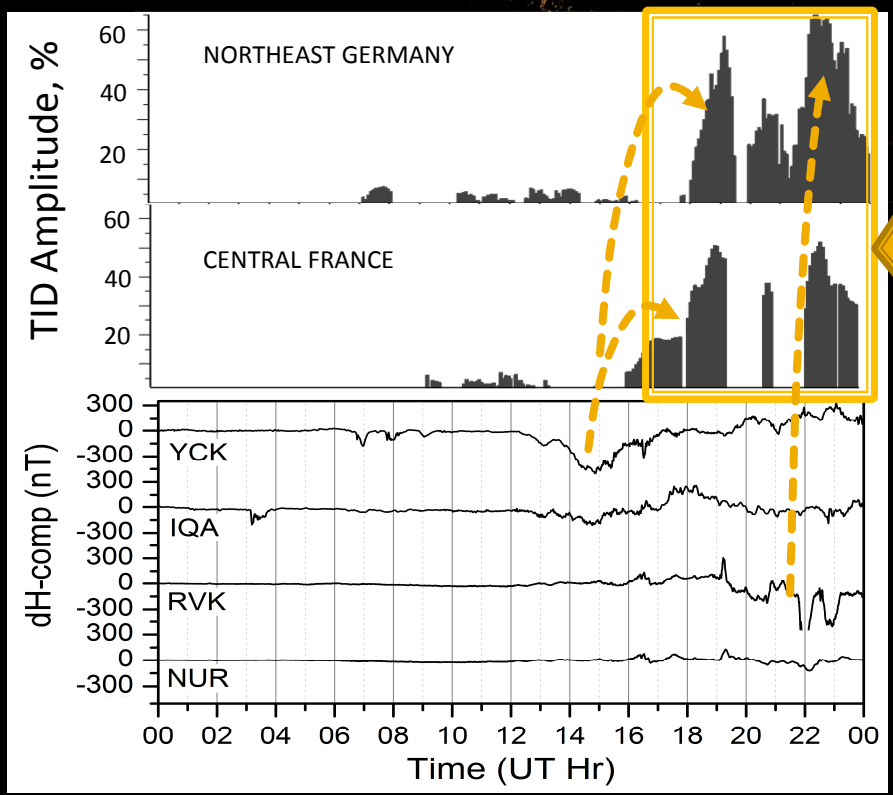
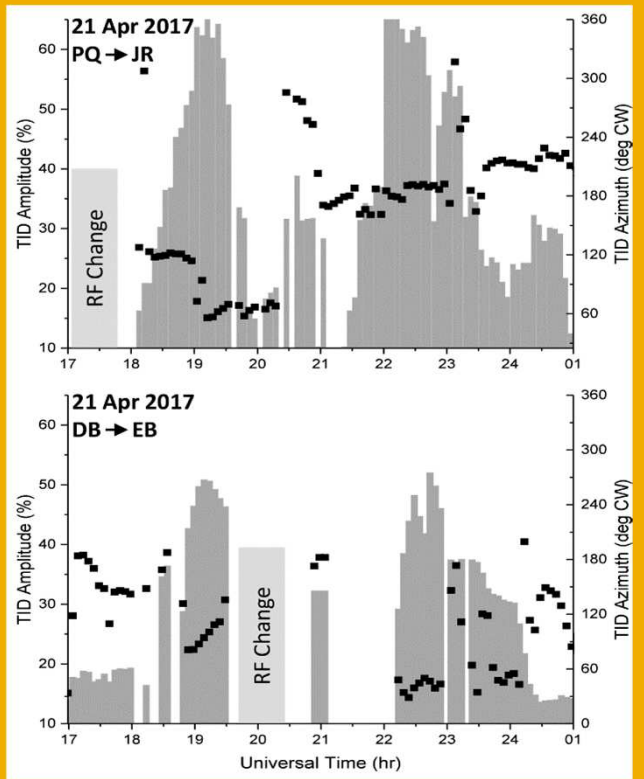
The Case of the Traveling Disturbance…





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Unattended Real-Time Service

- Transition to Operations is ongoing
- Automatic Processors
  - Signal Clustering based on hierarchical clusterization
  - Signal Tracking based on ARTIST vision model
- Uncertainty metrics and Confidence Level
  - Self-attested quality control
  - Similar to ARTIST and QUALSCAN

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Outlook

- Realistic Ionosphere eXplorer (RIX) on the Web
- Components available at http://giro.uml.edu
- Rapid visualization of global 3D ionosphere timeline through some of the most interesting times of ionospheric dynamics

BACKUP SLIDES

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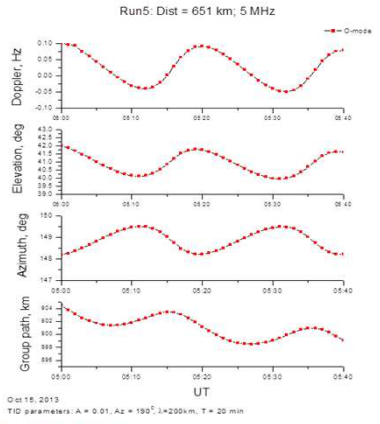
FAS and SAF

2 x 1 km UTR-2
phased array



- **Frequency and Angular Sounding (FAS):**
  - 1995: initial results from the FAS team at RIAN [Beley, Galushko, Yampolsky]
  - 2012: Implemented in Digisonde [Paznukhov *et al.*] for ground-based HF power beacons
  - 2017: Implemented in European Net-TIDE project for D2D links [Reinisch *et al.*]
- **Synthesis of Angles and Frequency (SAF):**
  - 2016: Simulated variations of angles/frequency [Huang *et al.*]
    - Required precision of angle measurements ~1°
    - Required signal-to-noise ratio (SNR) is 30-40 dB
    - Unprecedented fidelity of Digisonde operations needed

Clusterization of Radio Signatures

Custom Signal Processing for FAS

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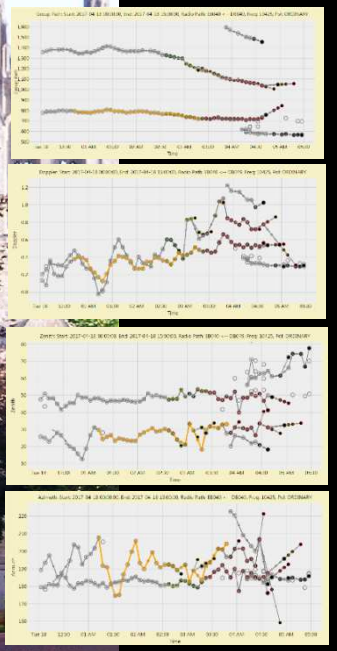

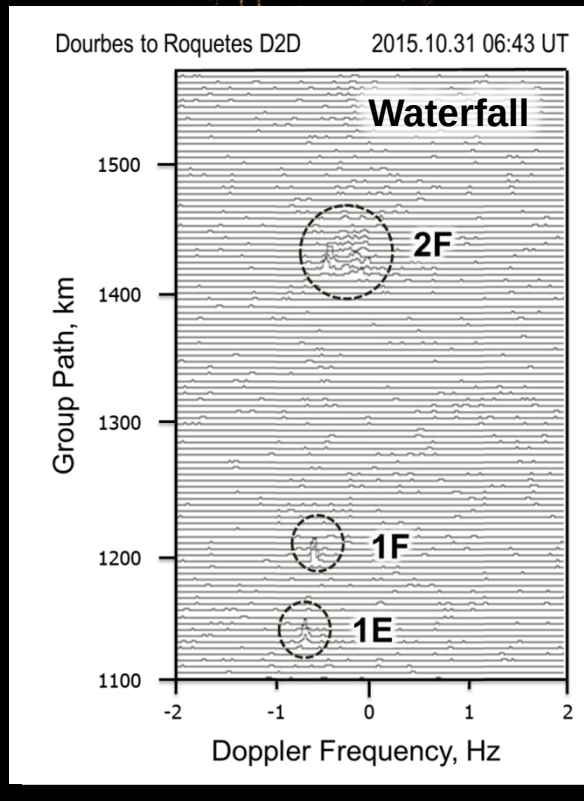

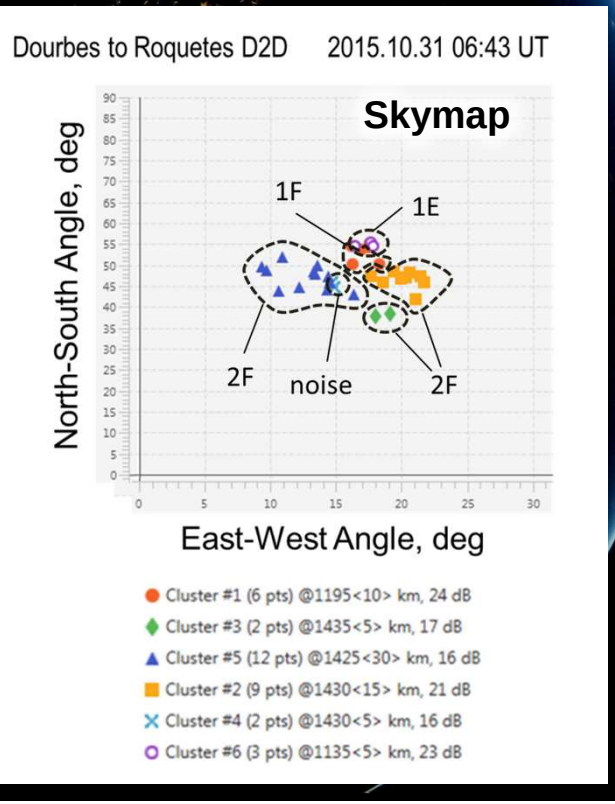

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TID as manifestation of AGW

- Atmospheric Gravity Waves are known since 1883
- Energy/momentum transfers from the lower to the upper regions of atmosphere are involved
  - AGW transfers are comparable to those of the Solar wind
- Sources of AGW: earthquakes/tsunami, volcano eruptions, tornadoes, substorm activities at high latitudes, powerful explosions, rocket launches
- Usually a mixture of waves propagates in all directions

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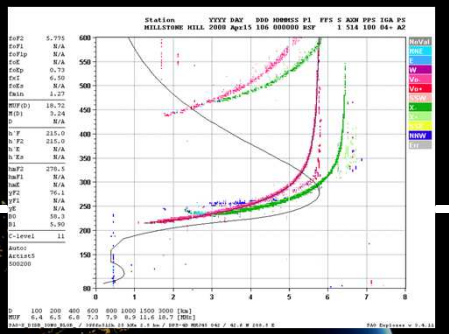
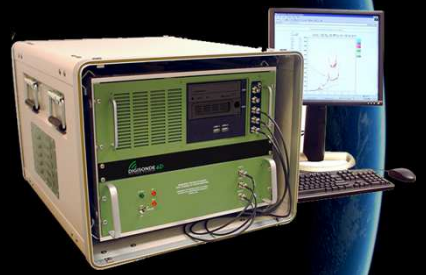
HF Ionosonde

24/7 workhorse of monitoring ionospheric plasma

- First ionosonde ionogram: Jan 11, 1931
- 1936: five ionosondes in the world
- 1957 (IGY): 150 ionosondes in the world
- 2017: <unknown> ionosondes in the world, but
  - 231 ionosonde locations in WDC-A
  - 164 Lowell digisondes
- Latency below 7 min (2017)
  - Lower latency expected as GIRO upgrades IT infrastructure



Ionograms



Digisonde DPS4D

GIRO Wall at LGDC