Multi-nation Coordinated Ionospheric Weather Nowcast by means of High Frequency Sounding

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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
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
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 receivers
    - ...and then there are HF ionosondes and GIRO
GLOBAL IONOSPHERE RADIO OBSERVATORY

REAL-TIME DATA STREAMING

Data latency < 7 min

http://giro.uml.edu
GLOBAL IONOSPHERE RADIO OBSERVATORY

REAL-TIME DATA STREAMING

Data latency < 5 min

http://giro.uml.edu
LGDC: ~600 Mil records
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
Realistic Ionosphere: IRTAM + TIDx

Measured hmF2

IRTAM (updated IRI coeffs)

TID (quiet time)

Legend
- Manually validated
- High confidence autoscaling
- Acceptable autoscaling
- Filled data gap
- IRI prediction (climate)
- IRTAM global weather
- sunset
- sunrise
- tov
- zeroLine

UT hours 13.03.2017 - 14.03.2017
IRTAM 24-hour Animations

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

\[ f_{0}F2 \quad h_{m}F2 \quad B0 \quad B1 \]
IRTAM Deviation Maps

HOW IONOSPHERE IS DIFFERENT FROM ITS QUIET-TIME STATE

$\Delta f_0 F2 \quad \Delta h_m F2 \quad \Delta B0 \quad \Delta B1$
IRTAM 3D

Observations with B0, B1 assimilation

Kirtland AFB, 2014-01-17 07:00UT

Electron Density, m⁻³
Δ Peak Density Height  Δ Peak Density  Δ vTEC  Δ Slab Thickness

Δ$h_mF_2$  Δ$f_oF_2$  Δ$\nu$TEC  Δ$\tau$

VTEC data courtesy Anthea Coster, MIT Madrigal
Realistic Ionosphere: IRTAM + TIDx

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HF versus other TID sensors

- **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

Data courtesy Tobias Verhulst, RMI
TID Evaluation using D2D and FAS

HF Pulsed sounding with multi-path resolution

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

TID AS SEEN BY GNSS

TID AS SEEN BY NET-TIDE EUROPE

TEC Animation courtesy Y. Yasyukevich, ISTP


Project PI: Anna Belehaki, NOA, Greece
“EGU Opening” TID Event

Ebro Observatory, Roquetes

April 21-22, 2017

40% 90 min

70% 135 min

1.4 MHz

20% 75 min
"EGU Opening" TID: April 21, 2017 19:00 UT

Pruhonice to Juliusruh link (513 km)

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

Accuracy sufficient for a warning system
Automatic Signal Tracking

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

Dourbes to Roquetes D2D  April 21, 2017

- Doppler Frequency, Hz

- Azimuth Angle, deg

- Group Path, km

- Zenith Angle, deg

Universal Time, hr
The Case of the Traveling Disturbance...
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
Outlook

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

- 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
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
**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