

Ground-based and space-born monitoring systems

AND THEIR DATA PROCESSING TECHNIQUES

DISPEC

Presented by Ivan Galkin

BOREALIS GLOBAL Designs

Chania, Greece
21 September 2026

Historical Reference: High Frequency

skywave

The world goes wireless, most extraordinarily

Ionosonde Weather Service

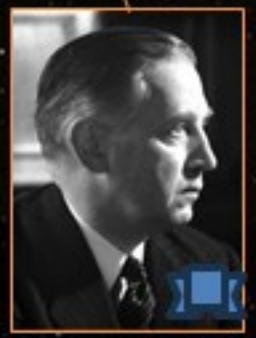
The world goes into space, most extraordinarily

1901 | 1920 | 1925 | 1930s | IGY 150 ionosondes | ISR era | 1990 | RO era

1922 | WW2 radar era | 1956-1957 | GPS era with tomography | TID era



Marconi



Appleton

First ionosondes!

1970s peak of interest in ionospheric radio

HF Dead declarations

22 SEPTEMBER PRE-FORUM SCIENCE DAY
23-26 SEPTEMBER XVI INTERNATIONAL GIRO FORUM
IGF 2025

Modern sensors for monitoring ionosphere

Instrument	Measures/Derives	Missions/models	Strength
GNSS Ground	TEC, Electron density via tomography and fusion with other sensors	GPS, Galileo, GLONASS, BeiDou	Global coverage
GNSS RO	Electron density	COSMIC-1,2; SPIRE	Global coverage, vertical structure
In-situ flyby	Electron density, etc.	Swarm, ICON	Cross-sections
Spaceborne UV Imagers	O/N_2 ratio	GUVI, SSUSI, SSULI	Scanning sensor with detail coverage



Classic sensors for monitoring ionosphere

Instrument	Measures/Derives	Missions/models	Strength
Ionosonde	Electron density profile	GIRO: Digisonde, Parus A, 5D, AIS-INGV, VIPIR/Dynasonde. Also OI, GBS	Vertical structure, high sensitivity to irregularities of all scales (incl. TiD)
ISR	Full specification	Unique installations	
Coherent scatter radar	Doppler velocities	SuperDARN, JULIA	Field-aligned irregularities in space.. Convection patterns at high-lats
Magnetometer	Magnetic disturbances	SuperMAG, INTERMAGNET, CARISMA	Geomagnetic activity
Riometer	Cosmic noise absorption	..	D-region
VLF	Lower ionosphere	..	SID
CW HF Doppler Radar	Doppler frequency variation	CDSS, TIDDBIT, TRIDENT	High sensitivity to Irregularities such as TID

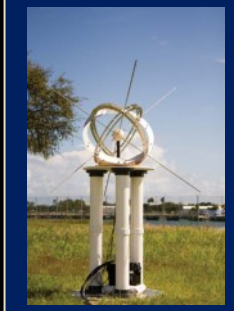
Why ionospheric weather?

GNSS PPP / RTK

- Affected systems: autonomous vehicles and machinery
- TID as a ***Silent Accuracy Killer***
  - Worse than the loss of lock and scintillation
  - (Hard to detect)



HF Geo



- Geolocation of uncooperative HF transmitters
- Tens of km positioning errors
- **Short-range catastrophe**

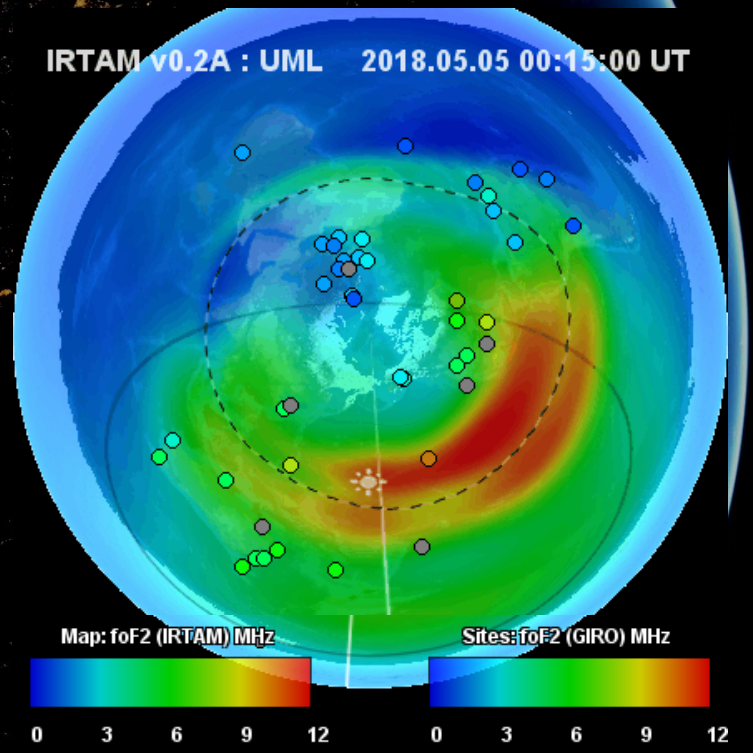
HF Communications

- Negative storm phase: plasma losses lead to **MUF depression** and communications failures
- Aviation, rescue teams, stock markets

Space walks on ISS

- Positive storm phase or ionosphere uplifting lead to higher plasma density and excessive ISS surface charging
- Spacewalk scheduling affected

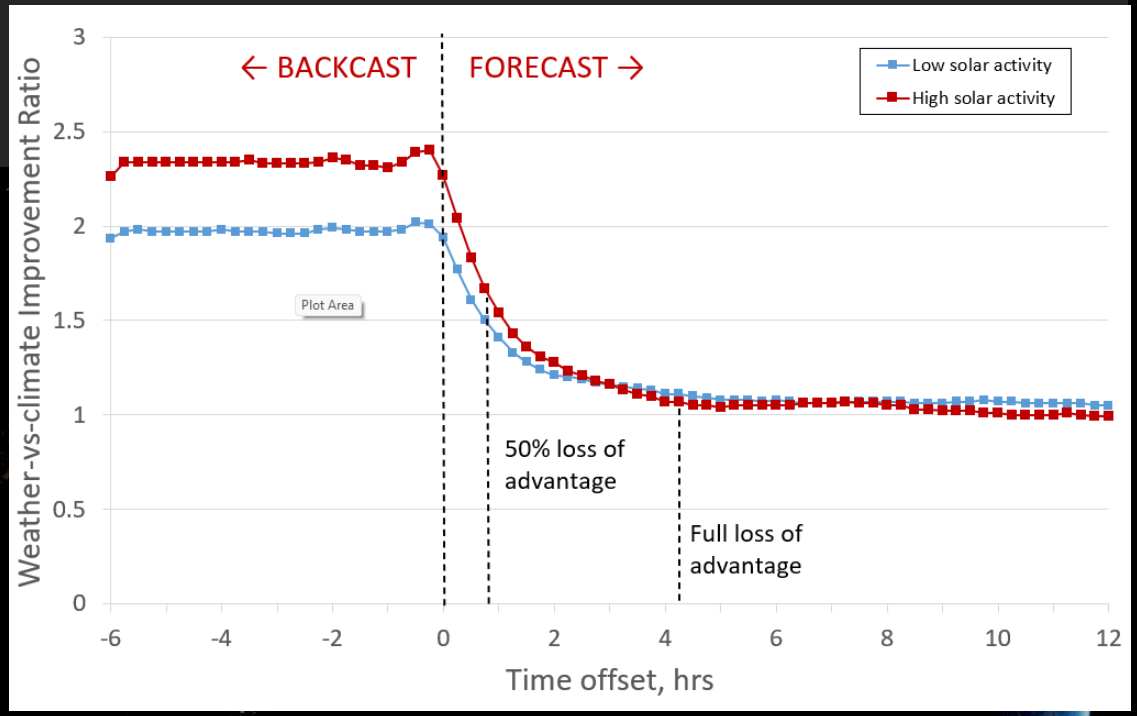




Ionosphere (*def.*): A major operational nuisance. © US Air Force

Path forward

- Forecasting ionosphere
  - Forecast vs prediction
  - Tomorrow's L2.1 lecture
- Space weather needs prompt data!
- Overall tendency
  - No longer a single-sensor research
    - Networks
    - Multiple types of sensors
    - Data fusion with other instrumentation
    - Many co-authors!
- Ionosondes
  - Exotic uses
    - Teach an old dog new tricks
    - DFAS, D-region, skymaps/velocities
  - Oblique sounding
  - Low-cost equipment: folks keep trying



Ionosphere has a short memory!

Compact and low-cost ionosondes

- SDR (software-defined radio) + radio amateur amps + compact antennas
- RFsIONO1 (Finland)
- Juha Vierinen (Haystack O.)
- Known problem is in secondary analysis software
  - Autoscaling
  - Data validation tools/editors
- Licensing is important
  - Known violations



Magnetic Loop Tx Antenna (Finland)



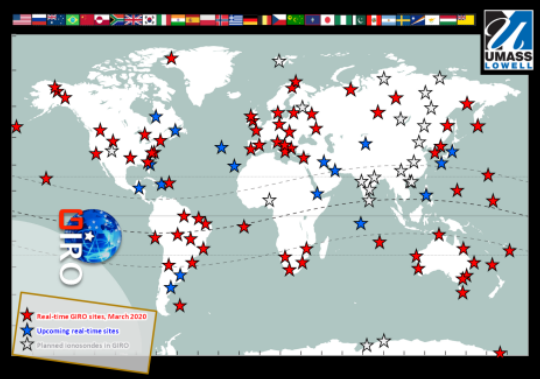
6-axis Colocated Rx Array (USA)



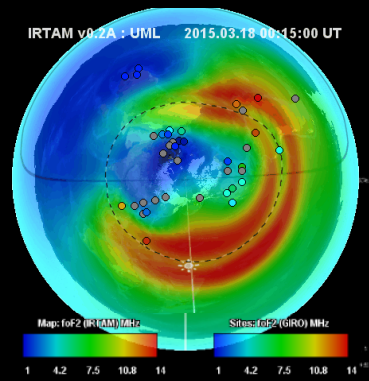
UML Realistic Ionosphere

RION

RION is member of United Nations Space Weather Initiative
http://www.iswi-secretariat.org/

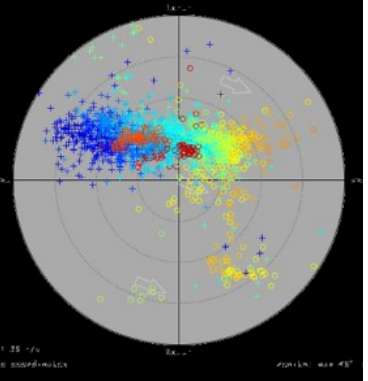


GIRO



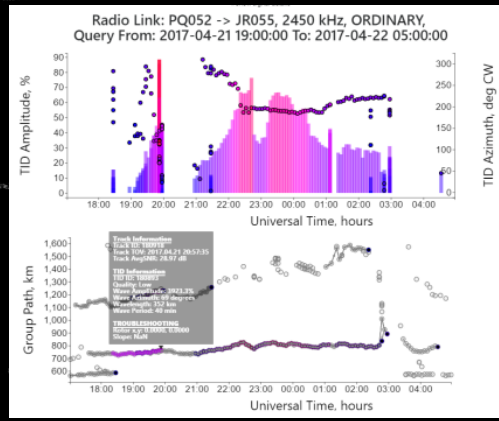
IRTAM 3D

Jicamarca



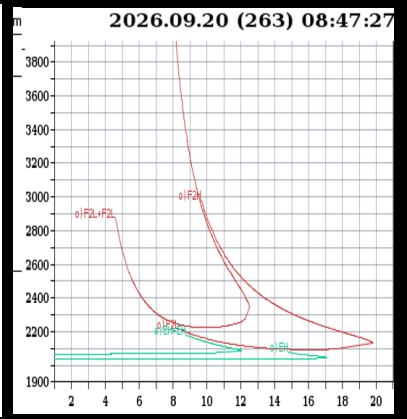
SkyLITE

Pruhonice to Juliusruh



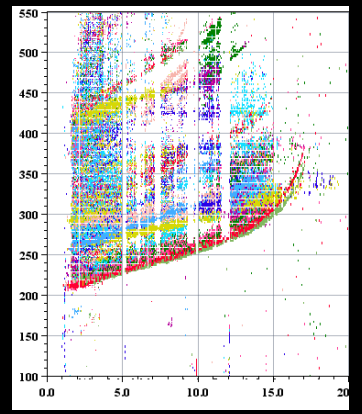
TID Explorer

Dourbes to Athens



RayTRIX

Ascension Island



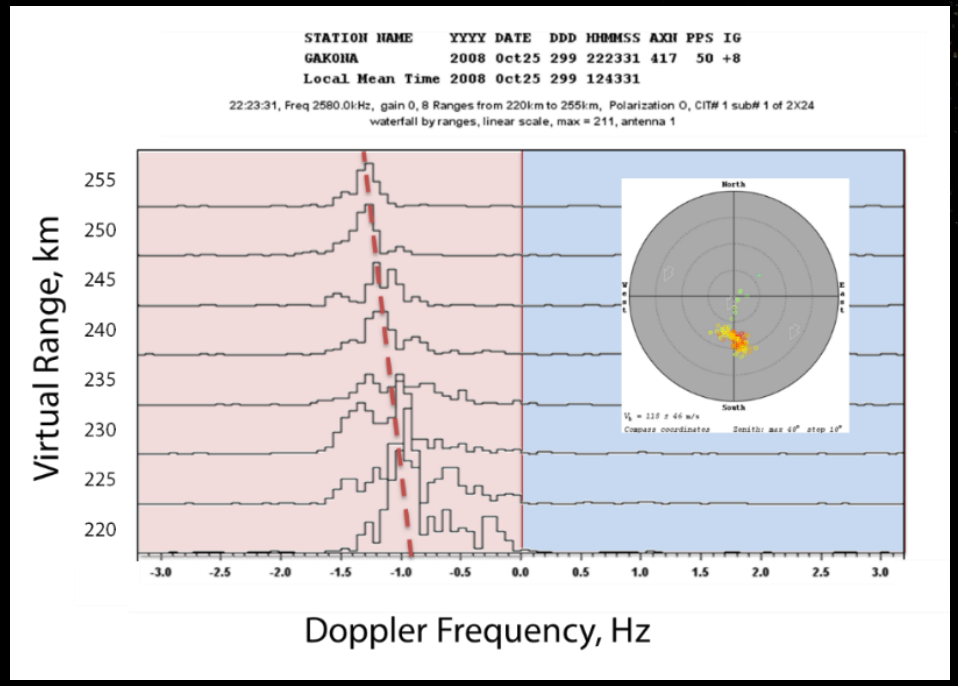
IDI

Measurements	Global Model	Plasma Drifts	TID Warnings	Raytracing	Disturbance Indicator

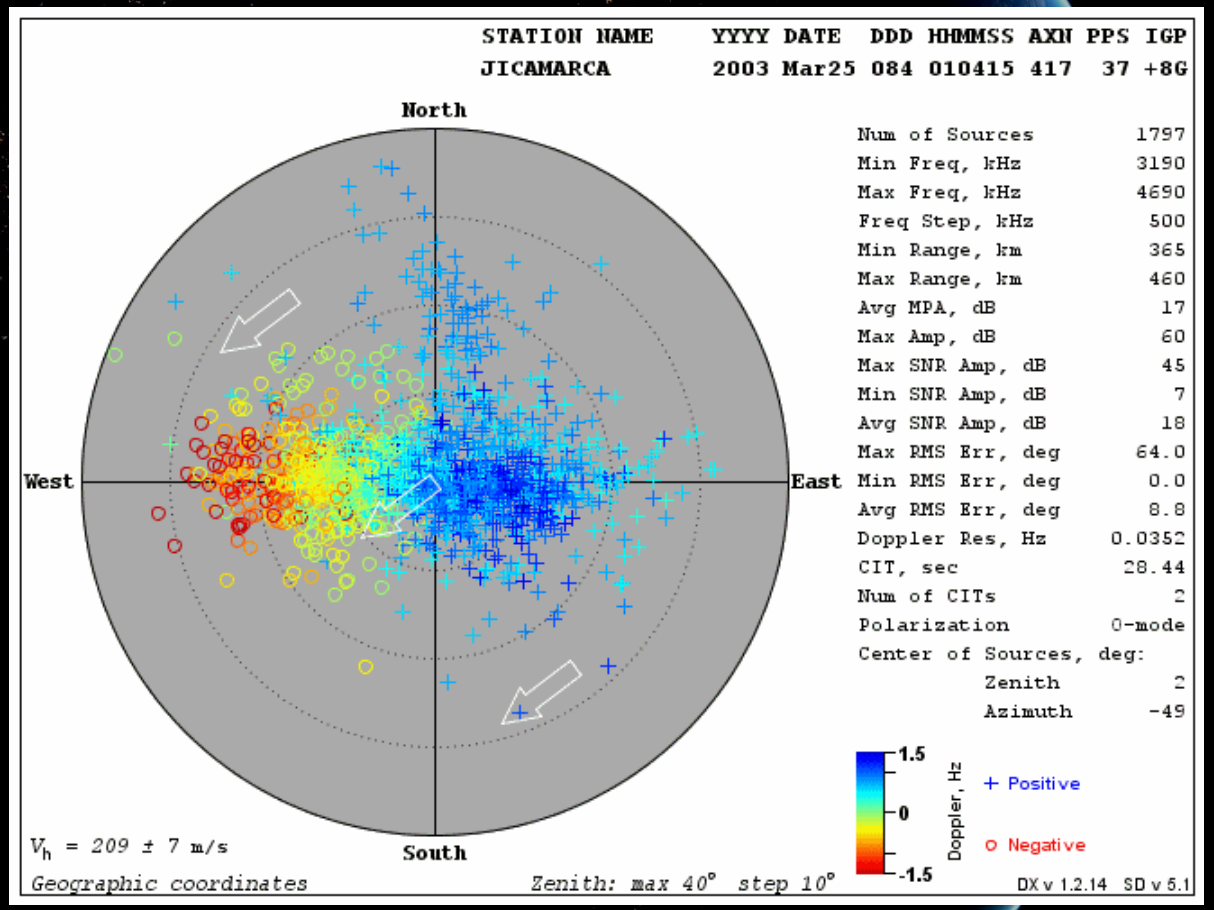
Doppler Skymapping (exotic?..)

HIGH SENSITIVITY TO PLASMA MOTION

- **Doppler Skymapping**



Plasma acceleration above the HAARP-heated area



Digisonde's view of the equatorial bubble passages

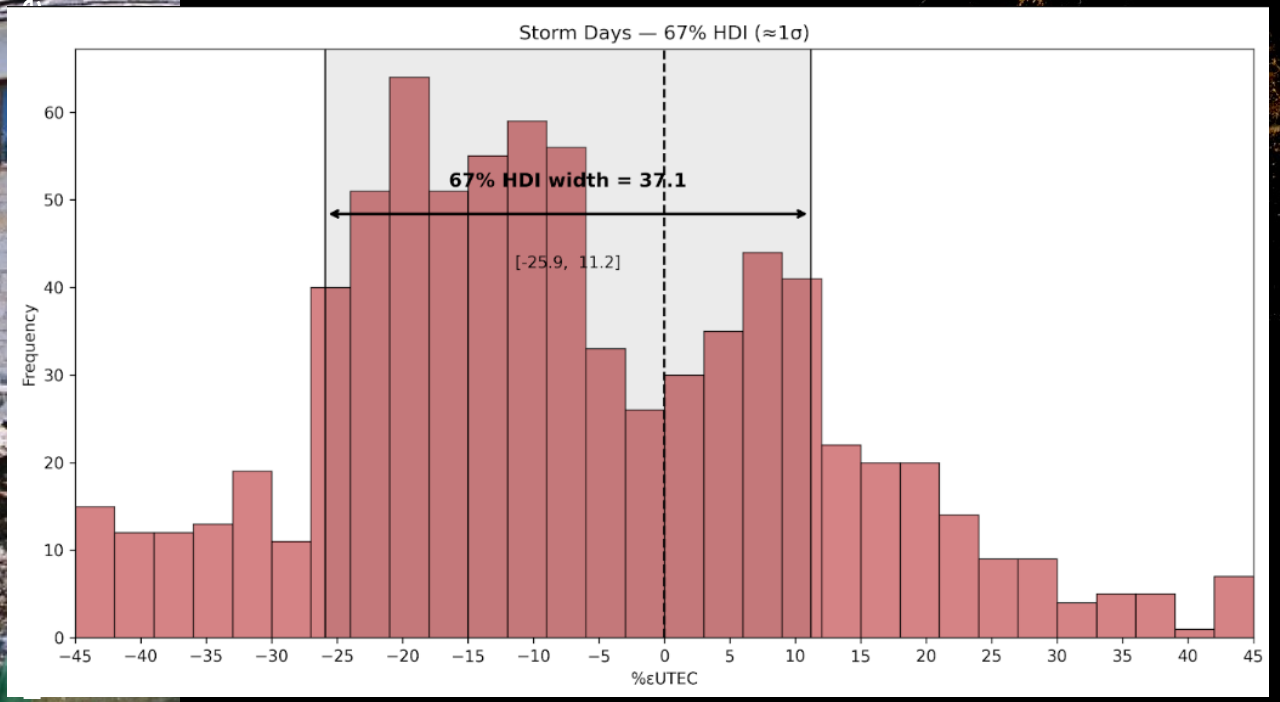
Digisonde skymap data courtesy: AFRL Gakona and JRO

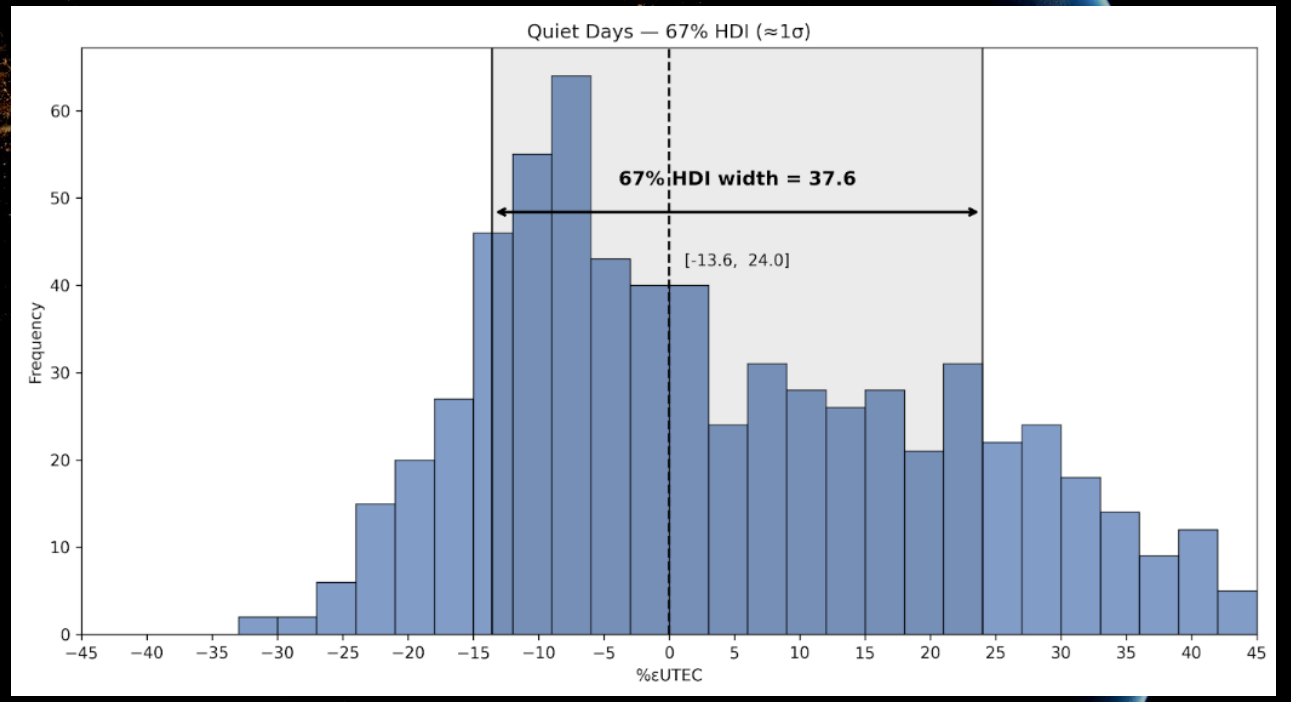


MUF and Raytracing applications

- Maximum Usable Frequency (MUF)
  - ICAO and PECASUS project
    - Every Airbus and Boeing airplane has HF antenna
      - Used for low-bandwidth reliable communications
  - MUF(D) computations?
    - Needs raytracing algorithm
    - Needs good global model of ionospheric bottomside (sub-peak) plasma
      - GIRO: ionosondes
      - RO (radio accultation)
      - GNSS: not without additional tomography-like analysis
- Why not use ALE?
  - Automatic Link Establishment
  - Expensive radios that exchange knowledge which frequency is optimal
    - Have a pool of frequencies assigned to them
    - Exchange messages about SNR
  - Work ok during moderately disturbed times
- Raytracing: standby for upcoming presentation by Vincent

Percent deviation of supra-peak contribution (from empirical model)





Storm day: -45..+45%

Quiet day: -32..+45%

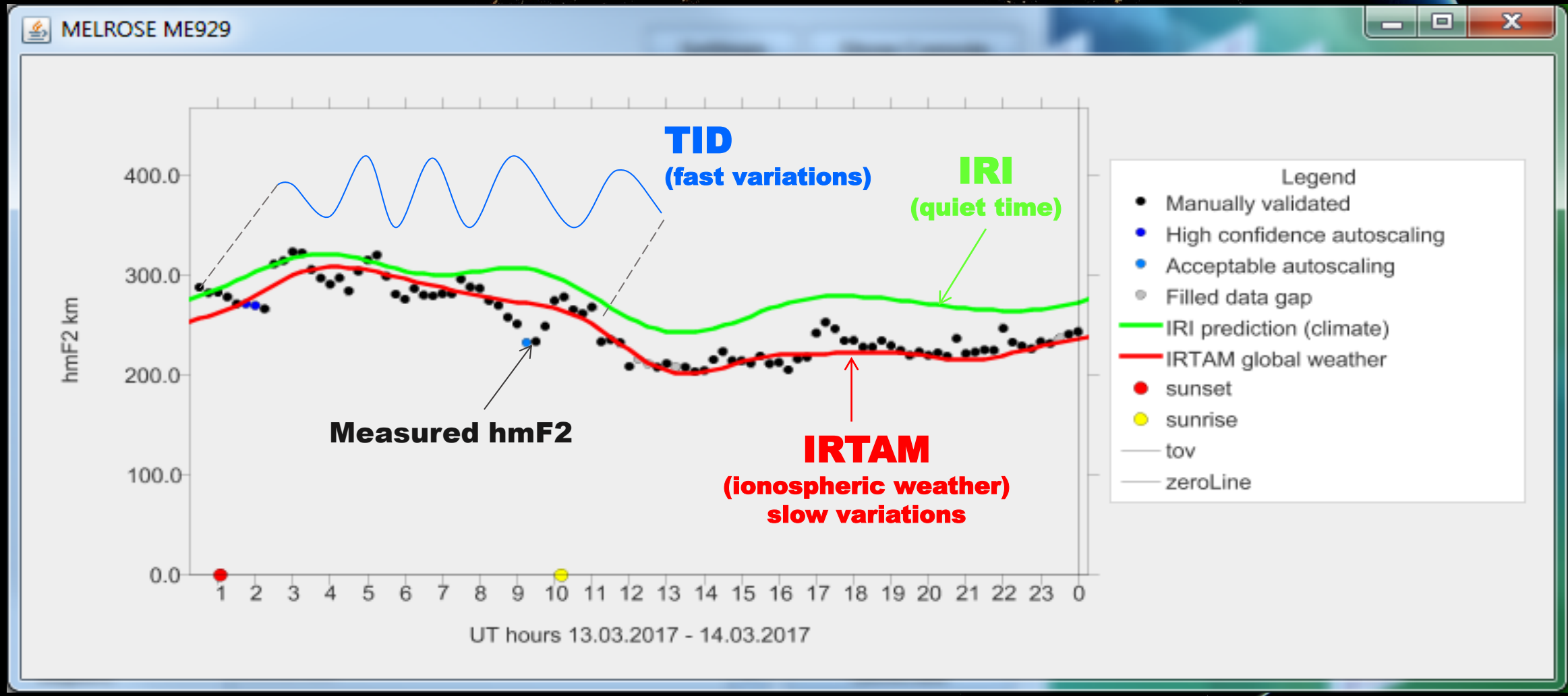
$$\varepsilon VTEC_{supra}[\%] = \frac{\left(cVTEC_{supra} - oVTEC_{supra}\right)}{oVTEC}$$



Traveling Ionospheric Disturbances

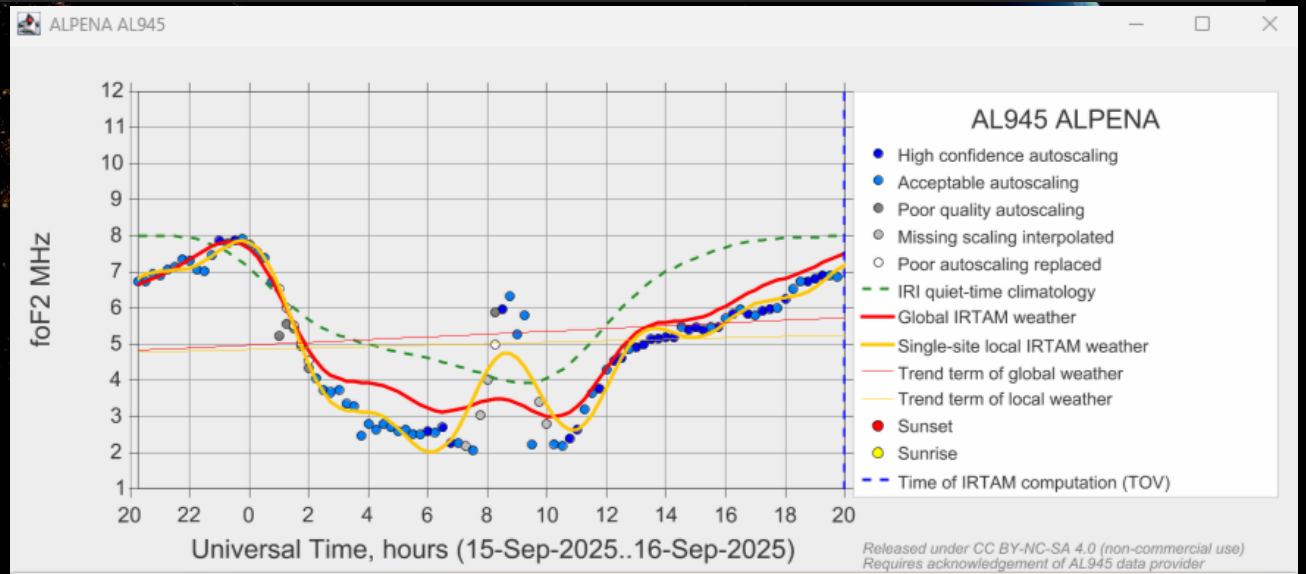
Ionosondes as an extremely sensitive sensor

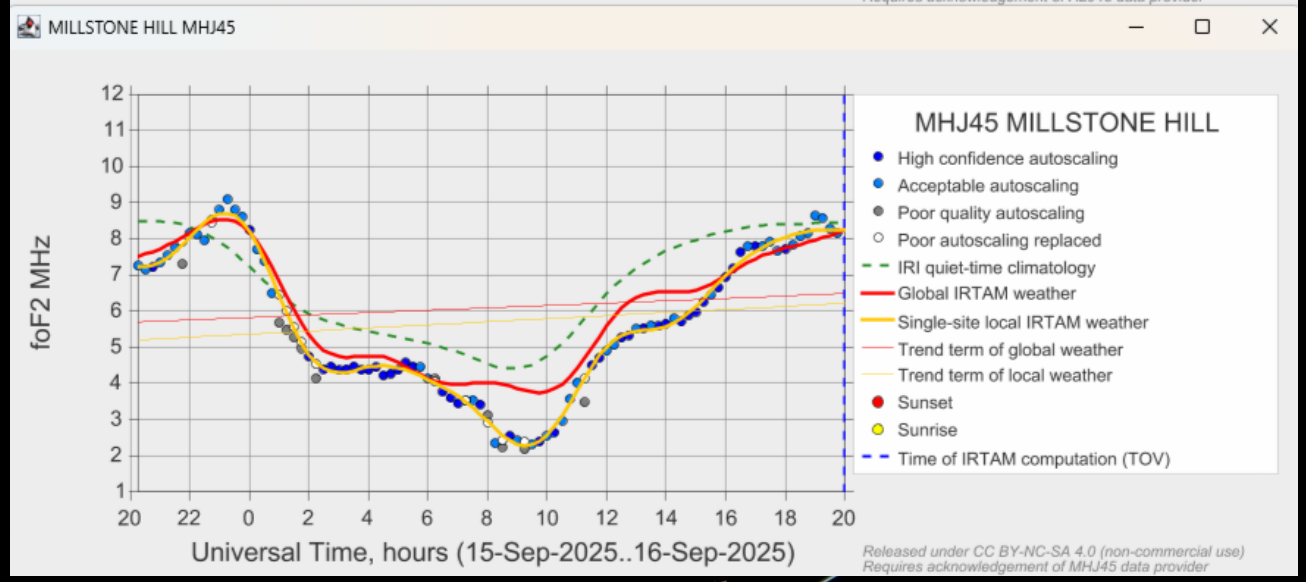
Realistic Ionosphere: IRTAM+TIDx



IRTAM: Real-Time Assimilative IRI

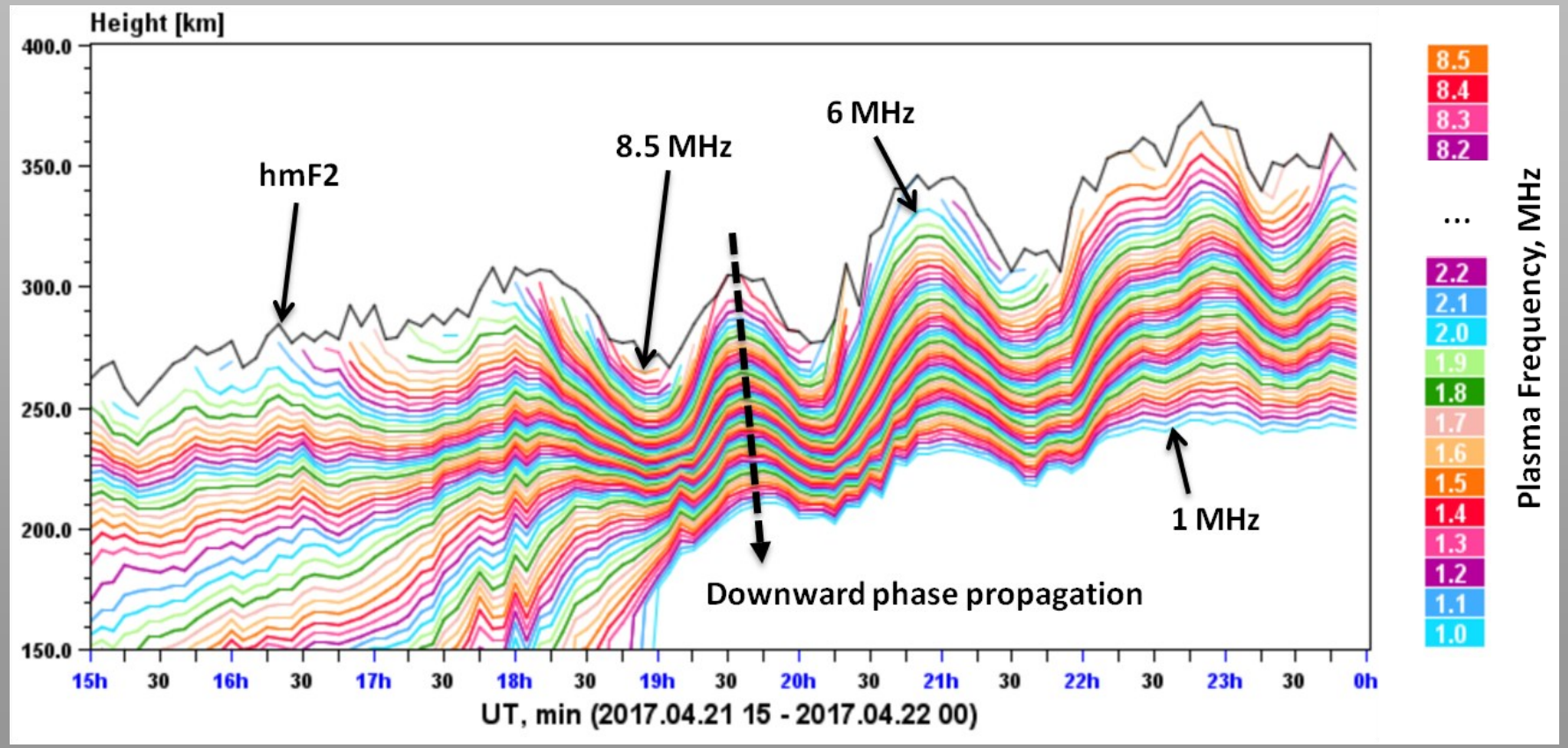
- Assimilative IRI:
  - IRI whose coefficients are adjusted for a better match with measrements
- Real-time IRI:
  - IRI driven by real-time measurements
    - Excluding other types of data…
- Underlying engine of the quiet-time empirical IRI
  - Temporal resolution: 4 hour period (6th order)
  - Spatial resolution: 76 Jones-Gallett expansion basis





GIRO capability to detect TIDs

1. Single-site Ionogramming, circa 1980s



Pan-European TID Warning Service

DISPEC

DISPEC Training School • 21-25 September, 2025 • Chania, Greece

UMASS LOWELL

Cooperation of GNSS, Digisondes DPS4D, HF Radars



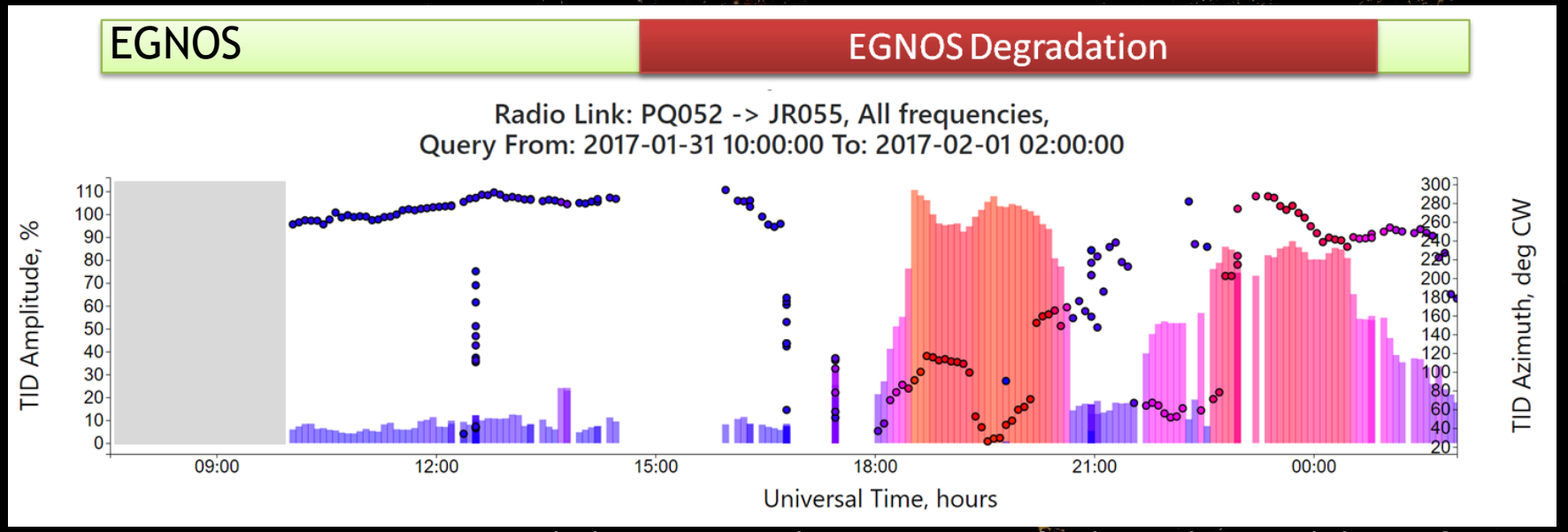
TechTIDE Digisondes



[*Belehaki et al.*, 2020; *Reinisch et al.*, 2018]

+ T-FORS: forecasting TID activity in Europe

EGNOS to HFTID Comparison



Digisonde data courtesy Dalia Buresova, UFA (Czechia) and Jens Mielich, IAP (Germany)
ESNOS "AATR" alerts courtesy José Miguel Juan, UPC (Spain)

Northern D2D link (515 km)

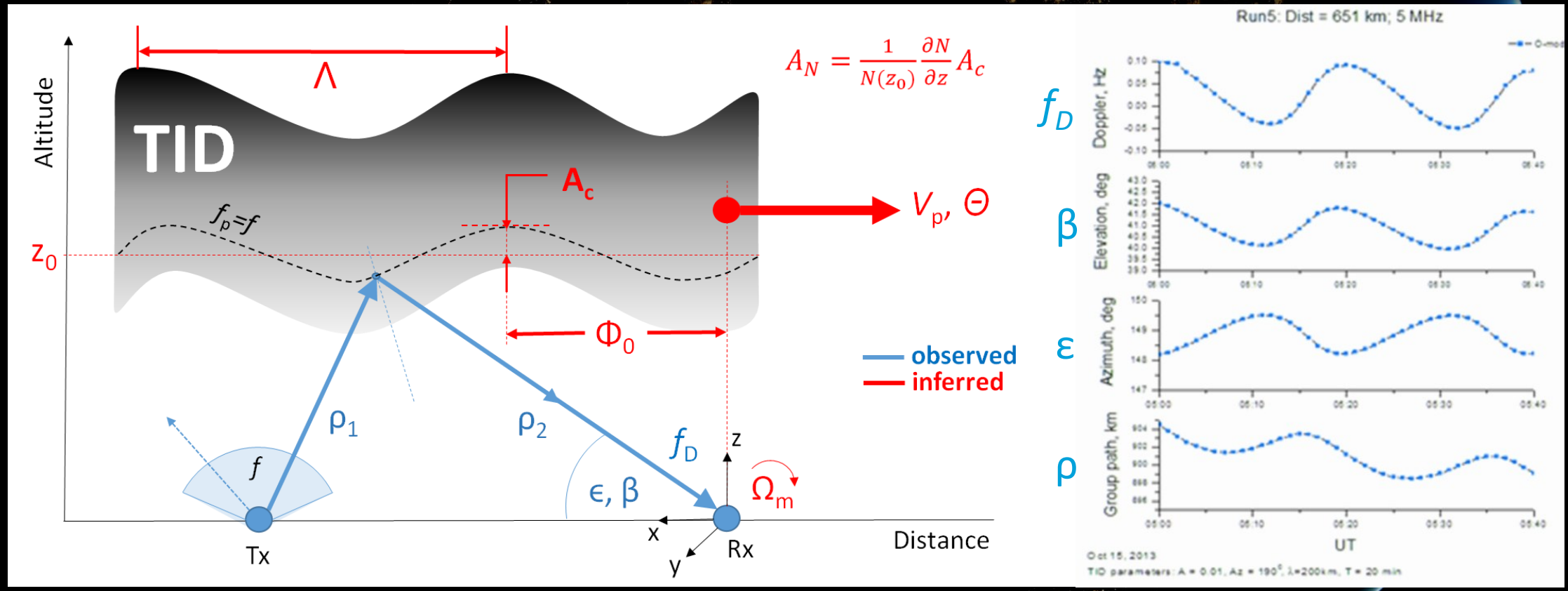
Pruhonice to Juliusruh, mid-point in North-East Germany

EGNOS: GNSS augmentation service in Europe

HFTID: Full-specification TID evaluator based on Digisonde-to-Digisonde (D2D) sounding

HFTID: Full TID Specification

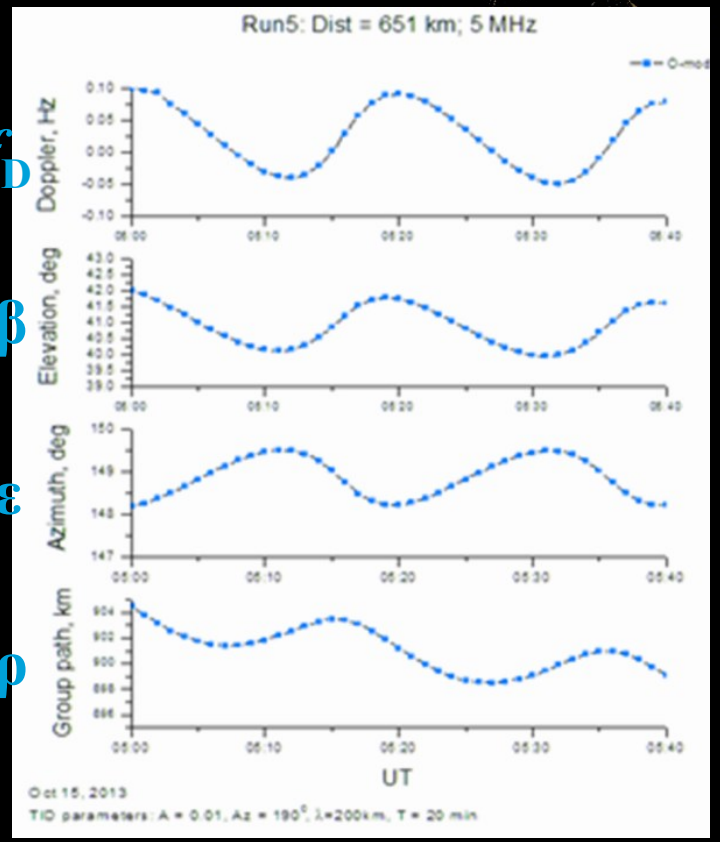
$$N(z_0,t,x,y) = N_{bg}(z_0,t,x,y)\left[1 + A_N cos\left\{\Omega t - \frac{1}{\Lambda}(xcos\Theta + ysin\Theta) + \Phi_0\right\}\right]$$



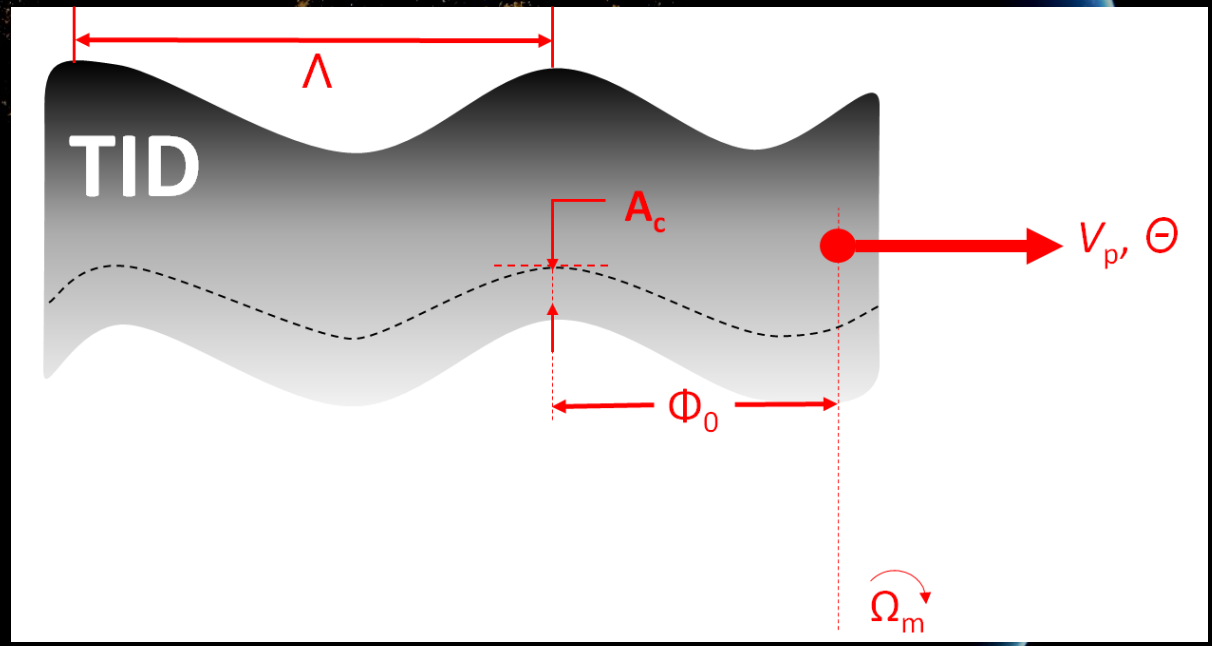
TID Model and D2D signal measurands

RayTRIX synthesizer output

Inverse problem



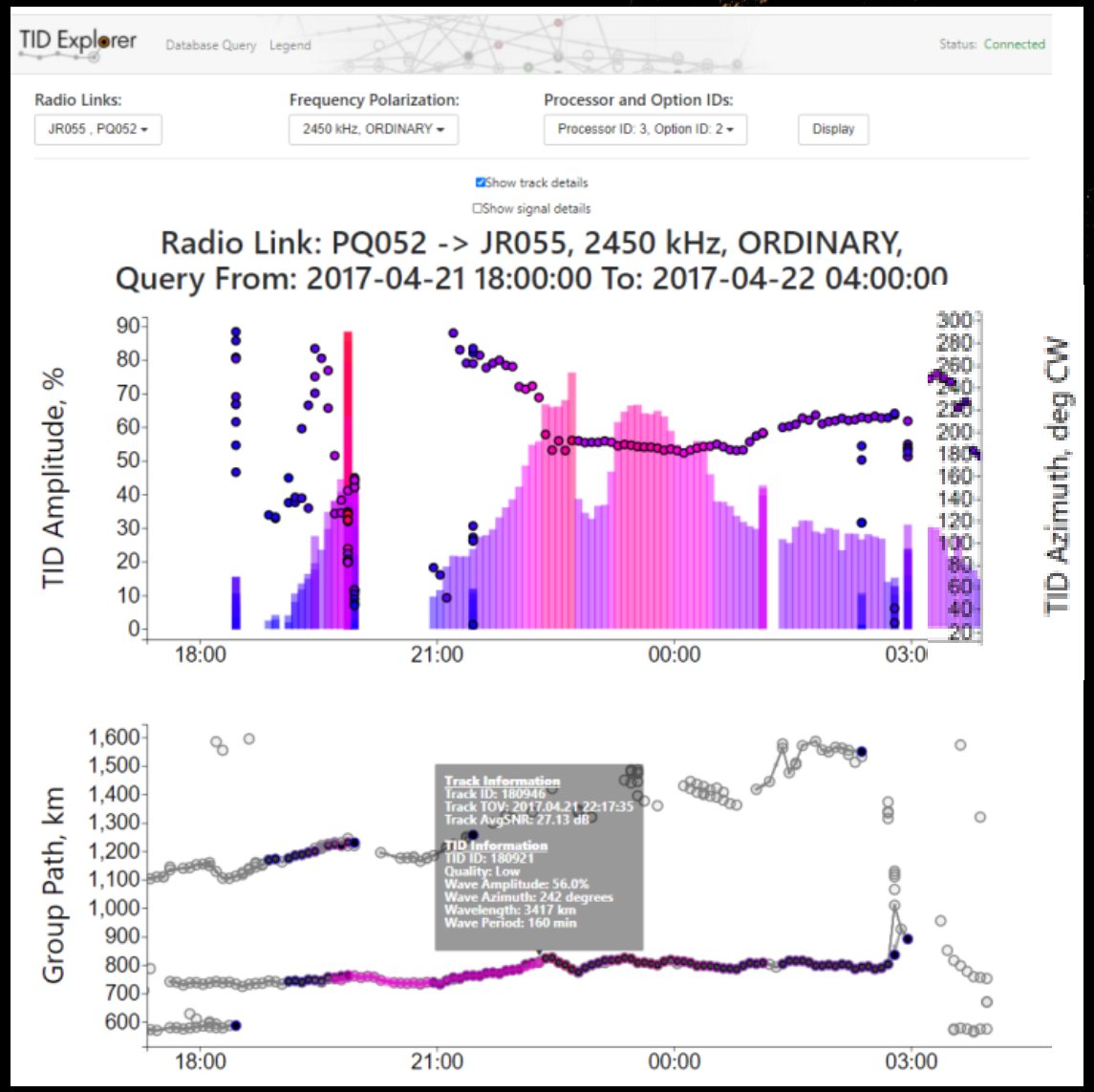
Observation

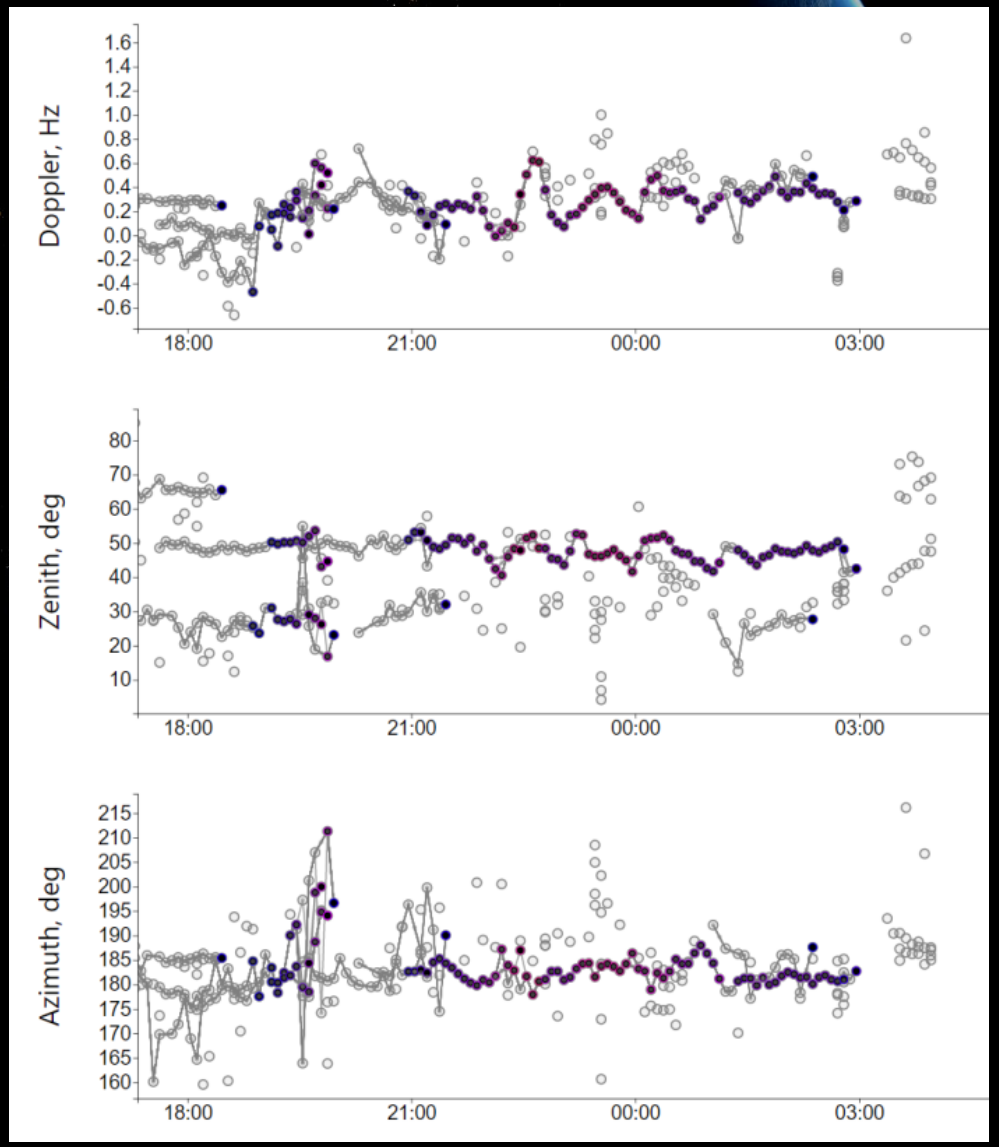


TID Wave Parameters

TID Explorer

http://backends.giro.uml.edu/tidx





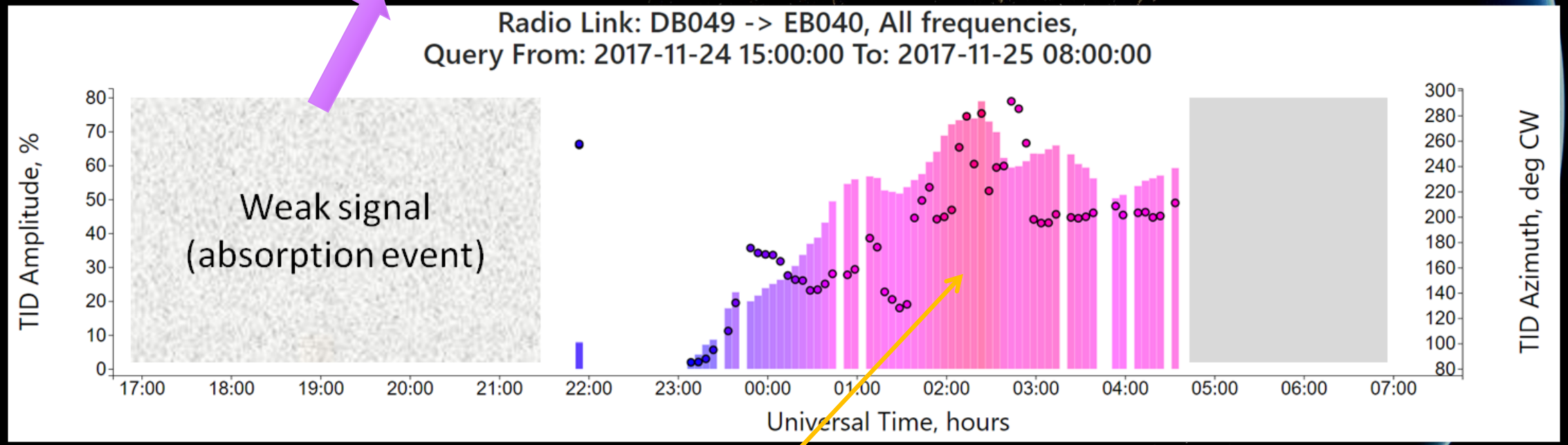
HFTID, GNSS, HF Radar

- GNSS dense networks are great for capturing TID in spatial domain, cos(kr)
  - But typical TID amplitudes seen in VTEC are ~0.1 TECU, which is well below 1%
    - TEC cancels +/- plasma deviations along the path
- HFTID is sensitive to even minor TIDs
  - TIDs are always present, with ~3% noise floor
  - Mid-strength TIDs are 40-60%, detected unmistakably
  - MSTID evaluation: work in progress
- HF Doppler Radar with distributed receiver array
  - Works best for MSTID detection (TechTIDE outcome)

TIS is Silent Accuracy Killer

Western D2D link (1080 km)

EGNOS DEGRADATION



Digisonde data courtesy David Altadill, Ebro Obs. (Spain) and Tobias Verhulst, OMA (Belgium)
ESNOS "AATR" alerts courtesy José Miguel Juan, UPC (Spain)

"Invisible" TID

Real-life Problems using HFTID

- Multi-path signal propagation
  - Small scale irregularities
- Multiple overlapping TID waves
  - Mix of multi-scale waves
- Precision of measured signal properties
  - Signal-to-noise requirements: ~35 dB
- Measurement scheduling conflicts
  - Medium-scale TID detection requires higher cadence
    - TechTIDE D2D experiments at 20-sec runs every 2.5 minutes



Intelligent Systems

Source Clustering

- Clustering of “sources” (signatures of signal) into “signals” on the skymap
  - Bottom-up hierarchical clusterization algorithm
  - “Nearness” criteria

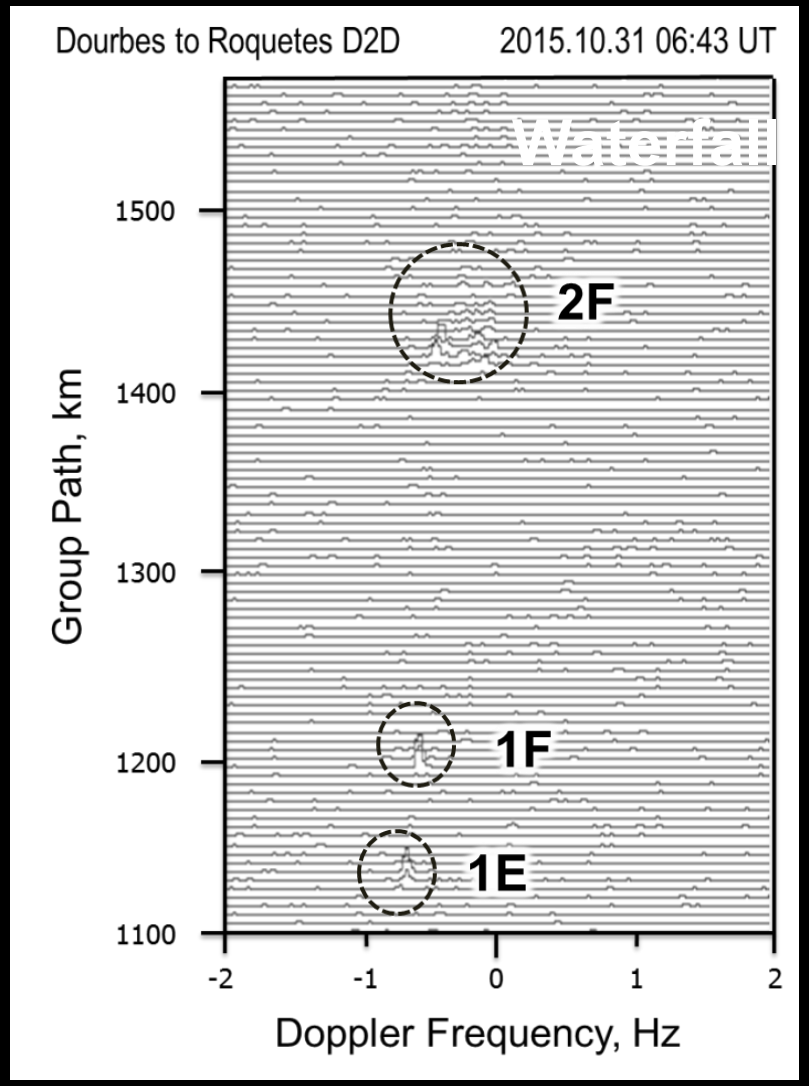
Signal tracking

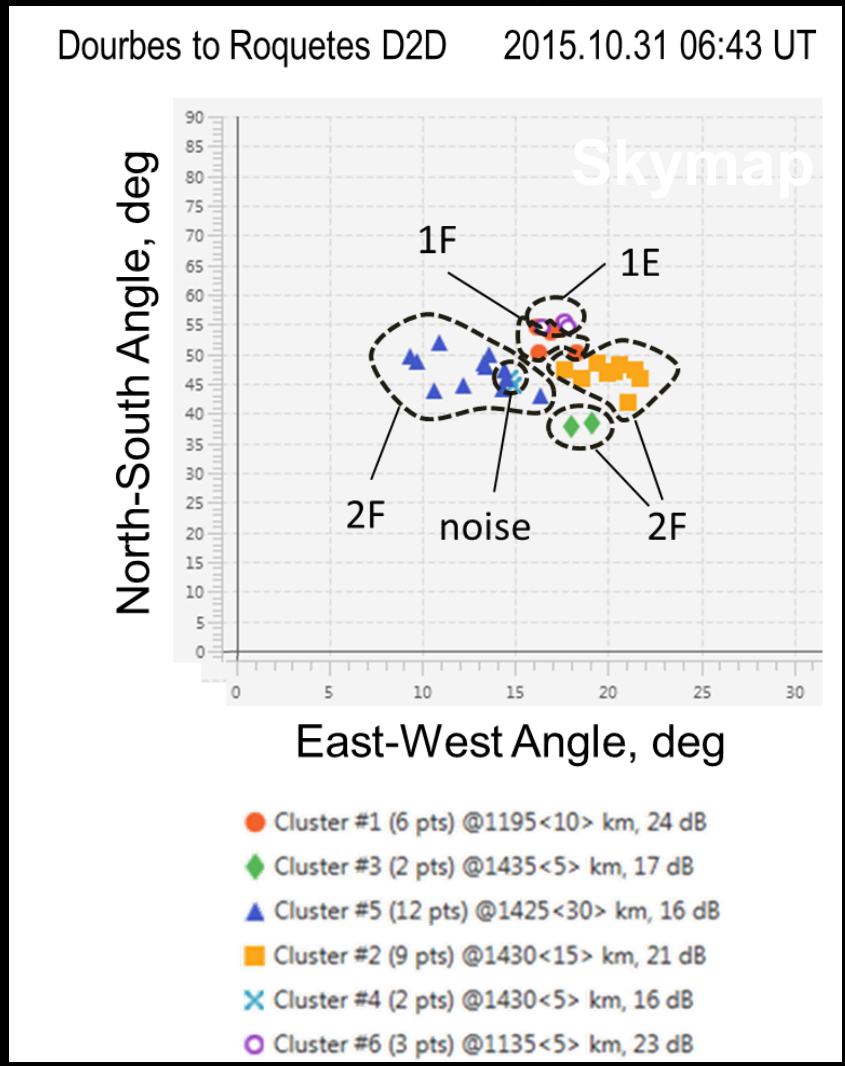
- Stringing of signals into tracks of the same mode
  - Human vision model “ANNAE”
    - Artificial Neural Network pre-Attentive Eye
  - Based on a Hopfield neural network (bio-plausible)





Clusterization





Digisonde data courtesy David Altadill, Ebro Obs. (Spain) and Tobias Verhulst, OMA (Belgium)

Multi-path scenarios… AI needs to sort these out

