Net-TIDE project

Pilot network for identification of Travelling Ionospheric Disturbances

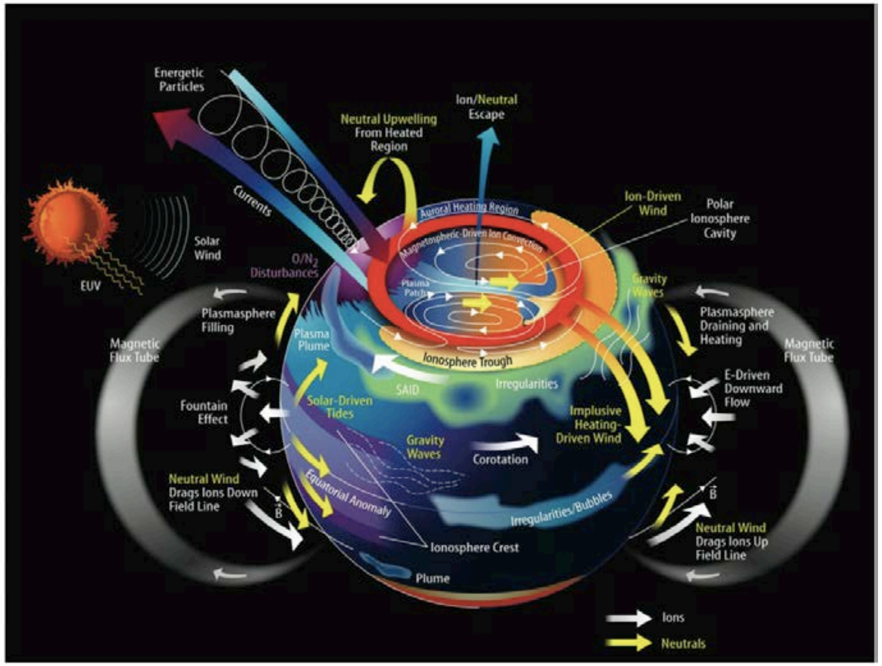
Anna Belehaki (Greece), Bodo Reinisch (USA), Ivan Galkin (USA), David Altadill (Spain), Dalia Buresova (Czech Republic), Matthew Francis (Australia), Jens Mielich (Germany), Vadym Paznukhov (USA), Stanimir Stankov (Belgium)

Travelling Ionospheric Disturbances - TIDs

Travelling Ionospheric Disturbances (TIDs) are the ionospheric signatures of atmospheric gravity waves.

TIDs have various sources of excitations

- **natural** : energy input from the auroral region, earthquakes, hurricanes, solar terminator, and others
- **artificial** : ionospheric modification experiments, nuclear explosions, and other powerful blasts like industrial accidents

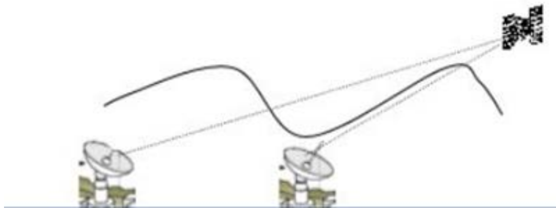


Credit: NASA / J. Grobowsky

Systems affected by TIDs

TIDs affect all services that rely on predictable ionospheric radio wave propagation. The disturbance imposed in the ionosphere is usually measured with the TEC parameter (1 TECU=10^{16} el/m^2).

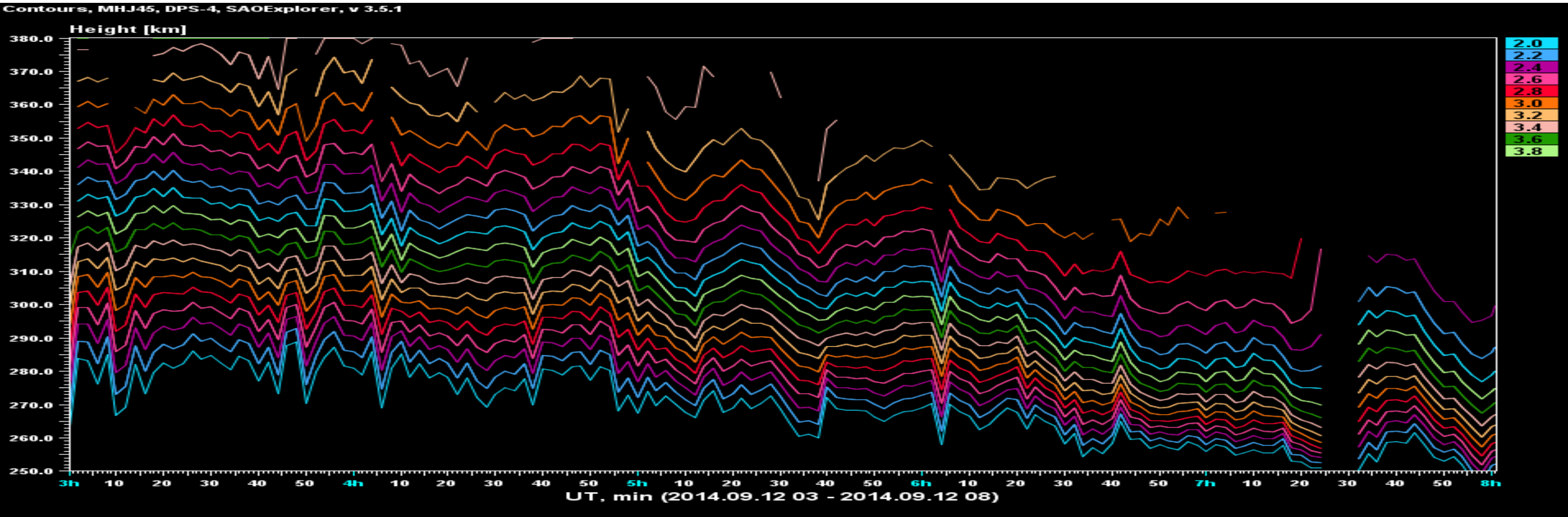
- In general TIDs affect the **HF propagation**:
  - The accuracy of HF transmitter geolocation, especially at short distances (HF/DF is a radio wave direction finding technique)
  - The over-the-horizon radars
- **Large scale ionospheric biases** caused by TIDs affect:
  - High precision differential GPS applications, requiring accuracy > 2TECU
  - Single base RTK and network RTK positioning



Characteristics of TIDs

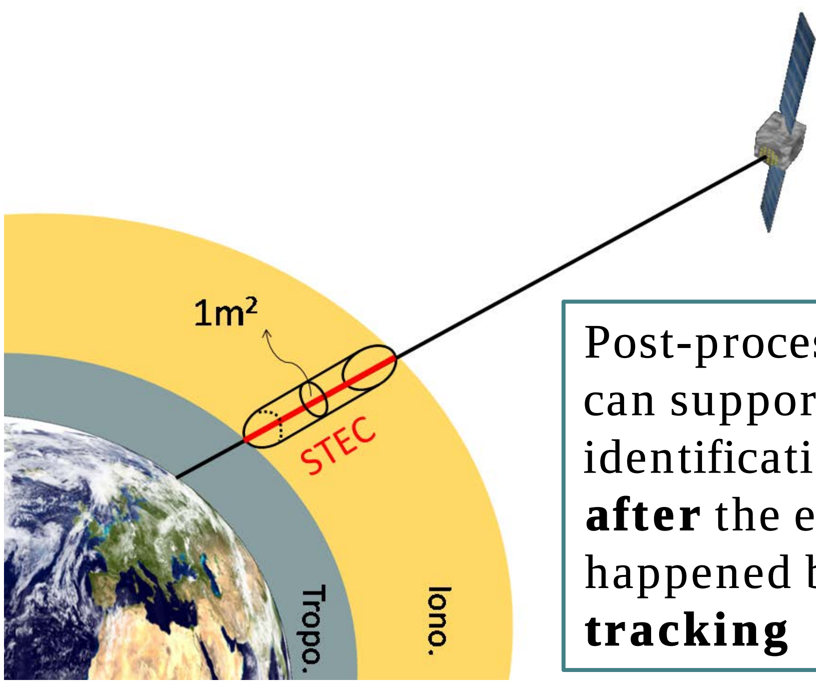
- Large scale TIDs propagate with **wavelengths of 1000 - 3000 km**, velocity of 300 – 1000 m/s and amplitudes up to 10 TECU. LSTIDs are associated with auroral and geomagnetic activity

- Medium scale TIDs propagate with **wavelength of 100-300 km**, velocity of 100m/s and amplitude of 1 TEC, occasionally 10 TECU. MSTIDs are mostly associated with ionospheric coupling from below, no clear correlation with geomagnetic activity.

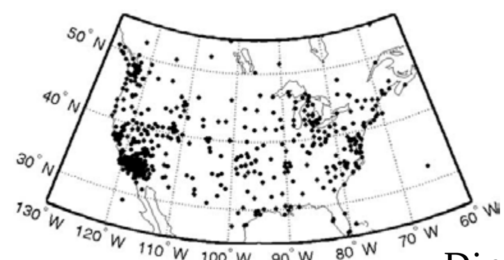


Past efforts to identify TIDs using the Total Electron Content from GPS receivers

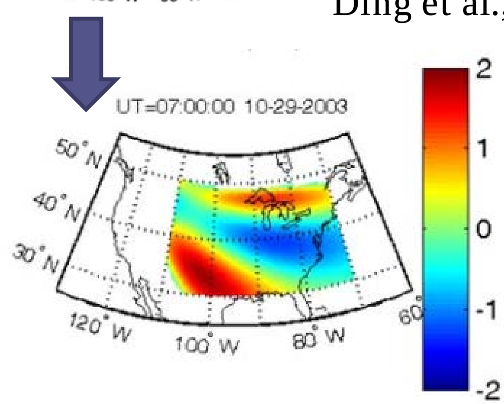
- Algorithms for calculation of TEC and its mapping contain a number of assumptions.
- Redistributions of the ionization due to TID might be not be detected by TEC.
- The real-time analysis of high resolution TEC data is still a challenge.



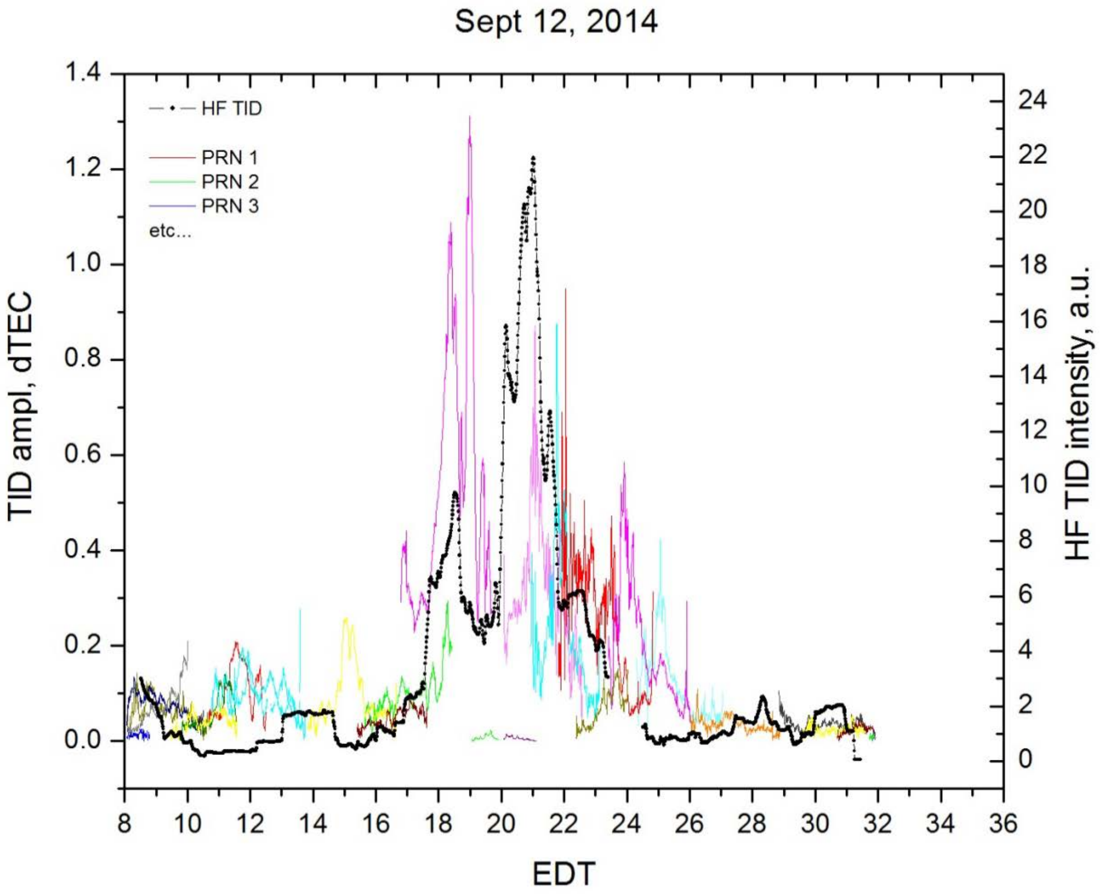
Post-processing analysis can support the identification of TIDs **after** the event happened but **not the tracking**



Ding et al., 2007, JGR



HF and GPS Data Comparison



from Paznukhov, 2015

- Ratio of responses on GPS and HF varies significantly
- Note large GPS signature at 19:00 corresponds to relatively modest signature on HF; conversely, at 21:00 HF response exceeds GPS

What needs to be done?

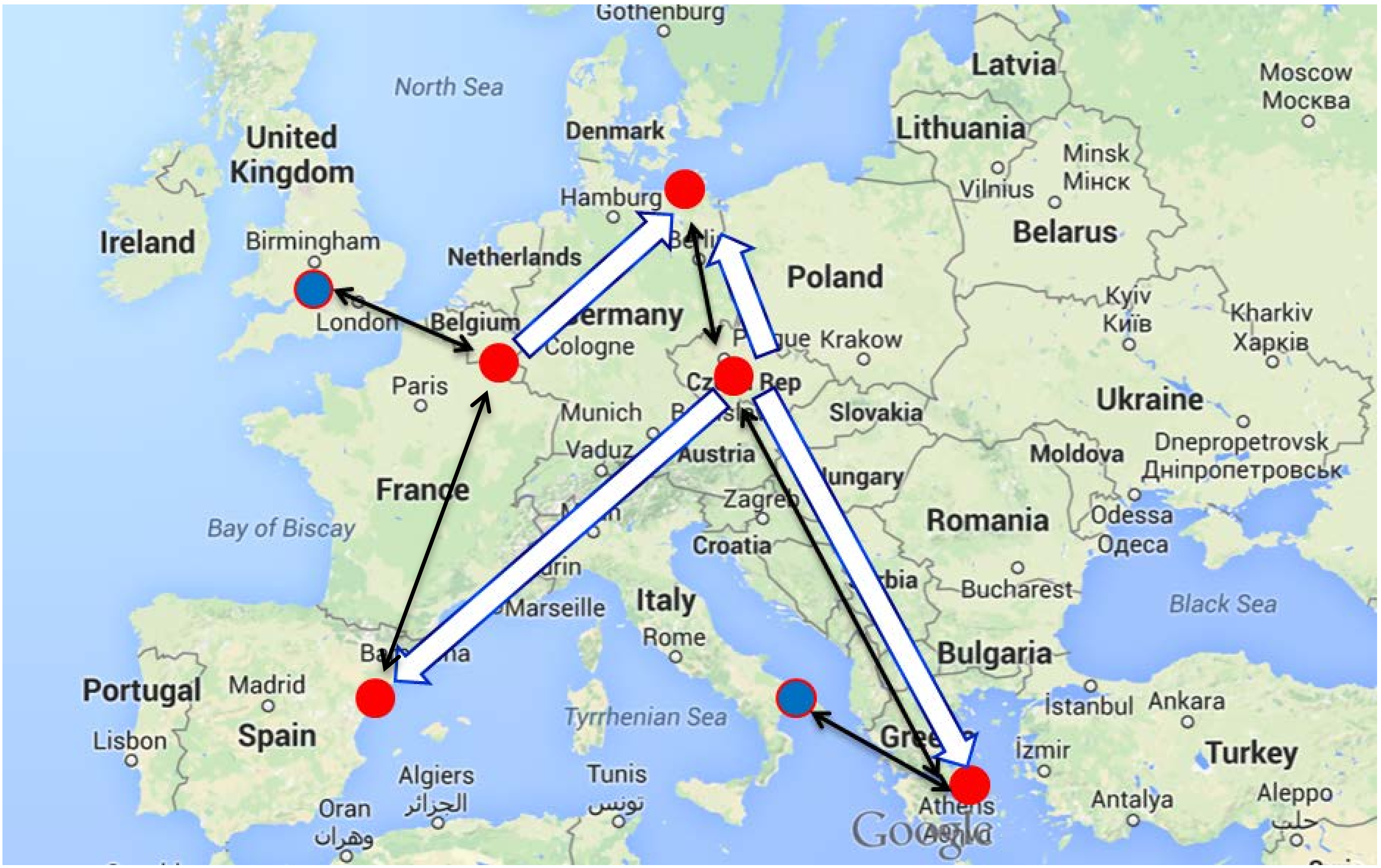
- The TEC TID identification approach is indirect and approximate, and a **more direct and accurate system** to identify and track TIDs in **real-time** must be developed.

→ Based on the exploitation of real-time observations obtained from ionospheric sounders

Sounding Types

D2D Skymaping Oblique drift	Synchronous Ionogramming Vertical Ionogram and Oblique Ionogram VI+OI
Dedicated Oblique Ionogram	Reception of Transmitters of Opportunity (ToO)

The DPS4D network in Europe
Preliminary settings



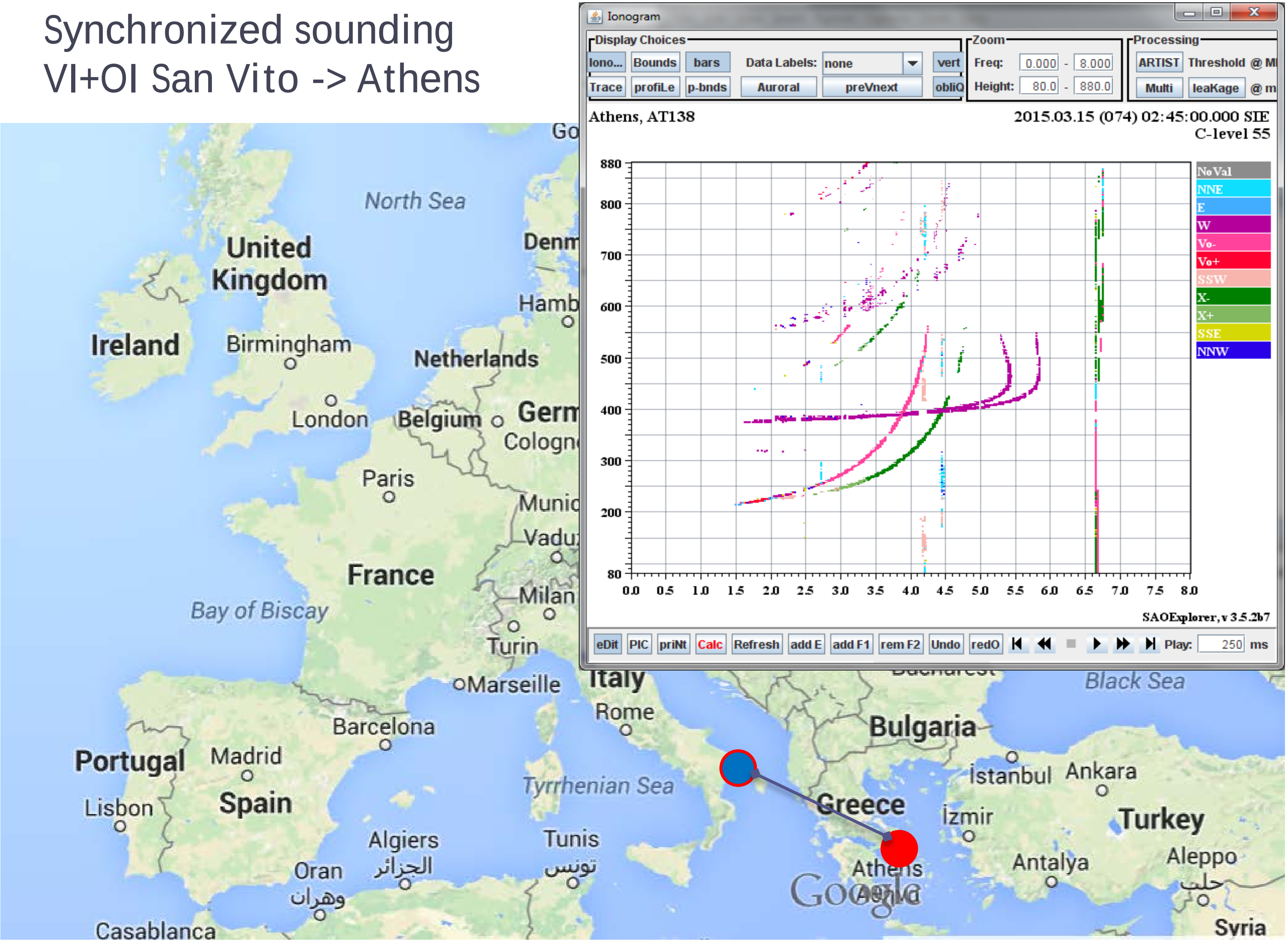
DPS4D operated from partner institutes

NEXION operated by AFWA

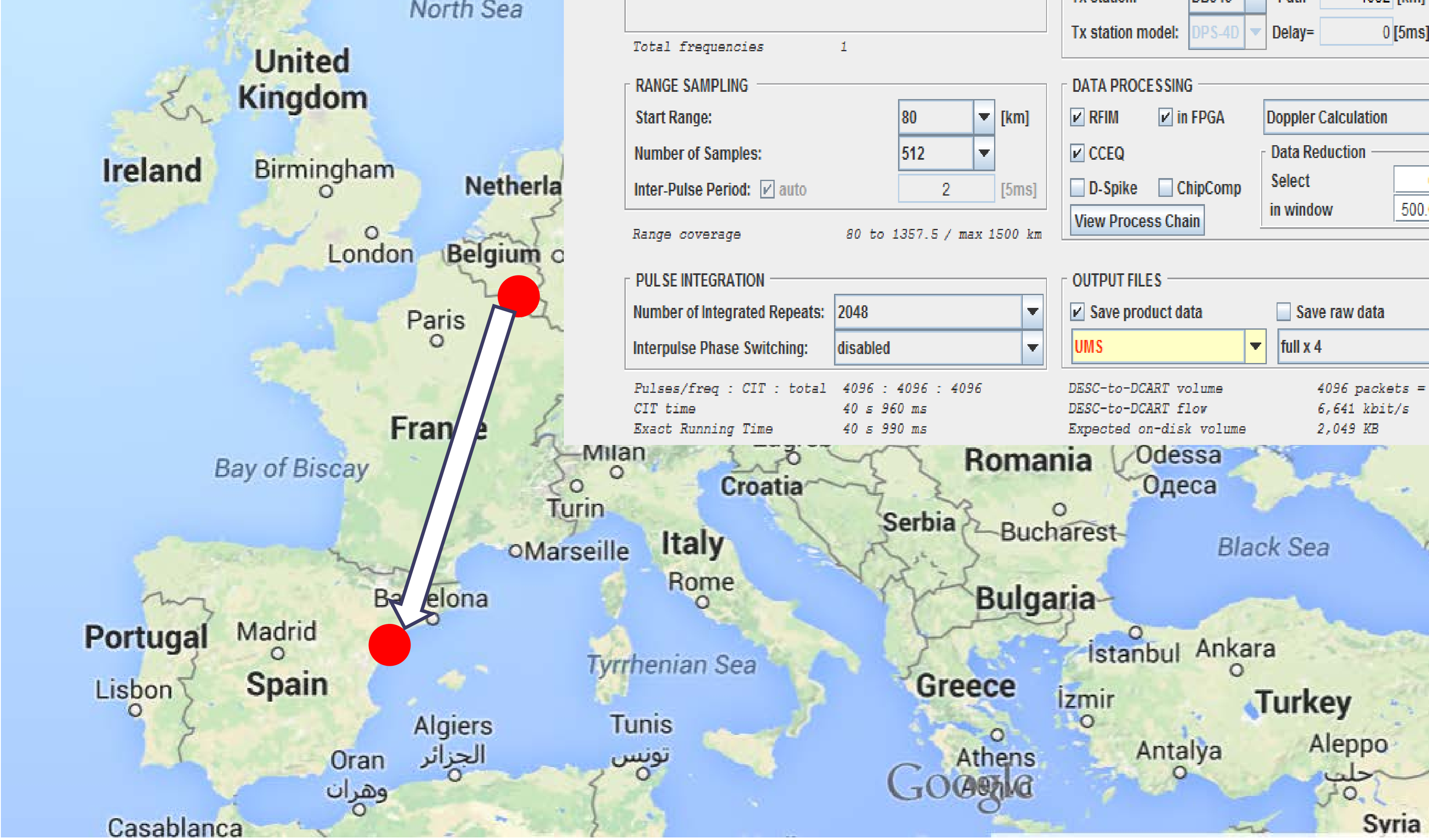
D2D skymaping

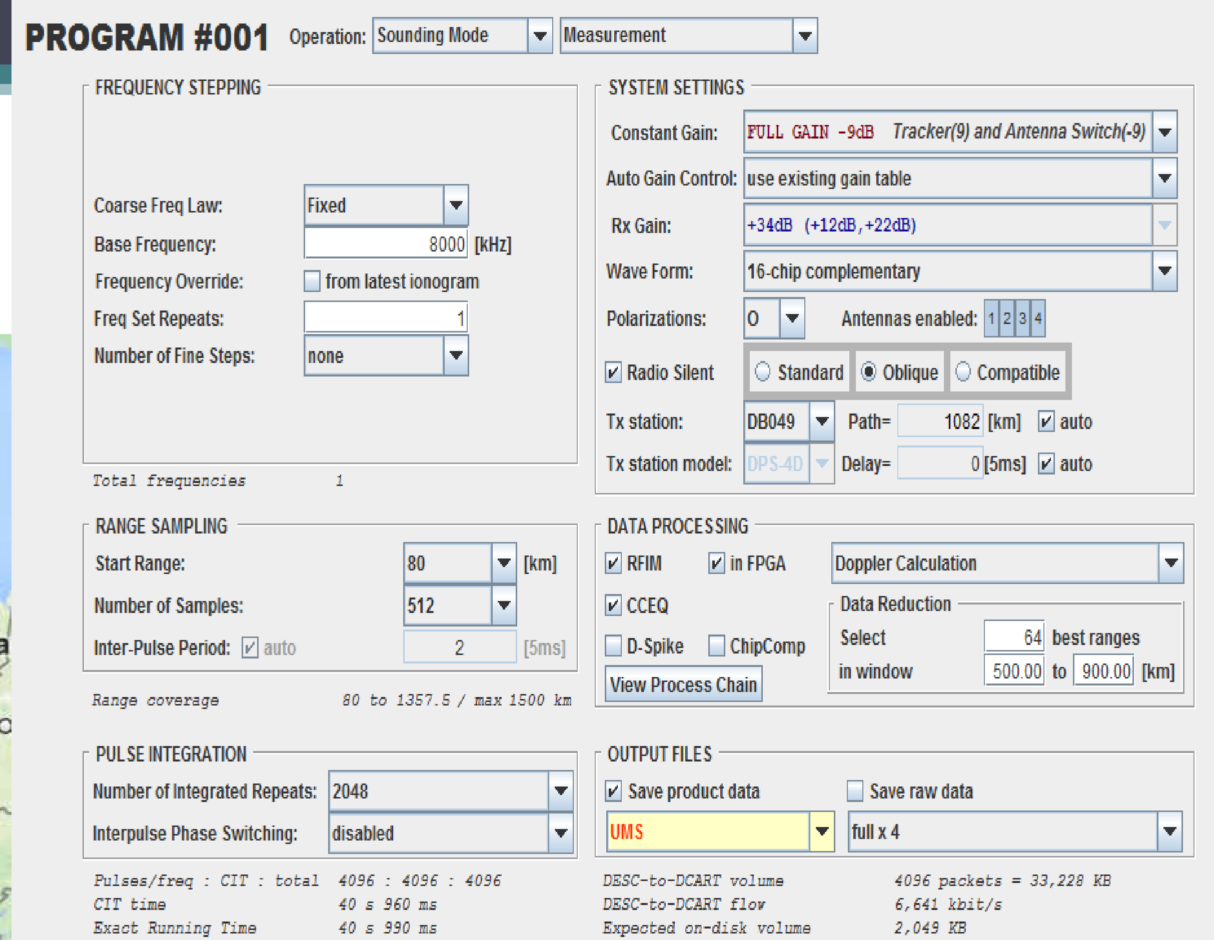
Syncronous VI+OI

Synchronized sounding VI+OI San Vito -> Athens

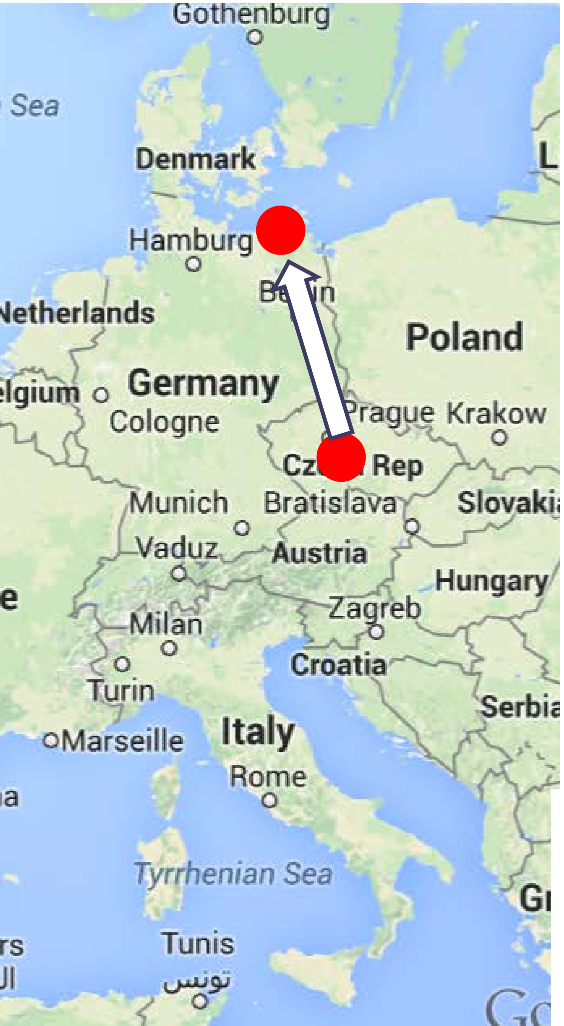


D2D settings for the link Ebro -> Dourbes



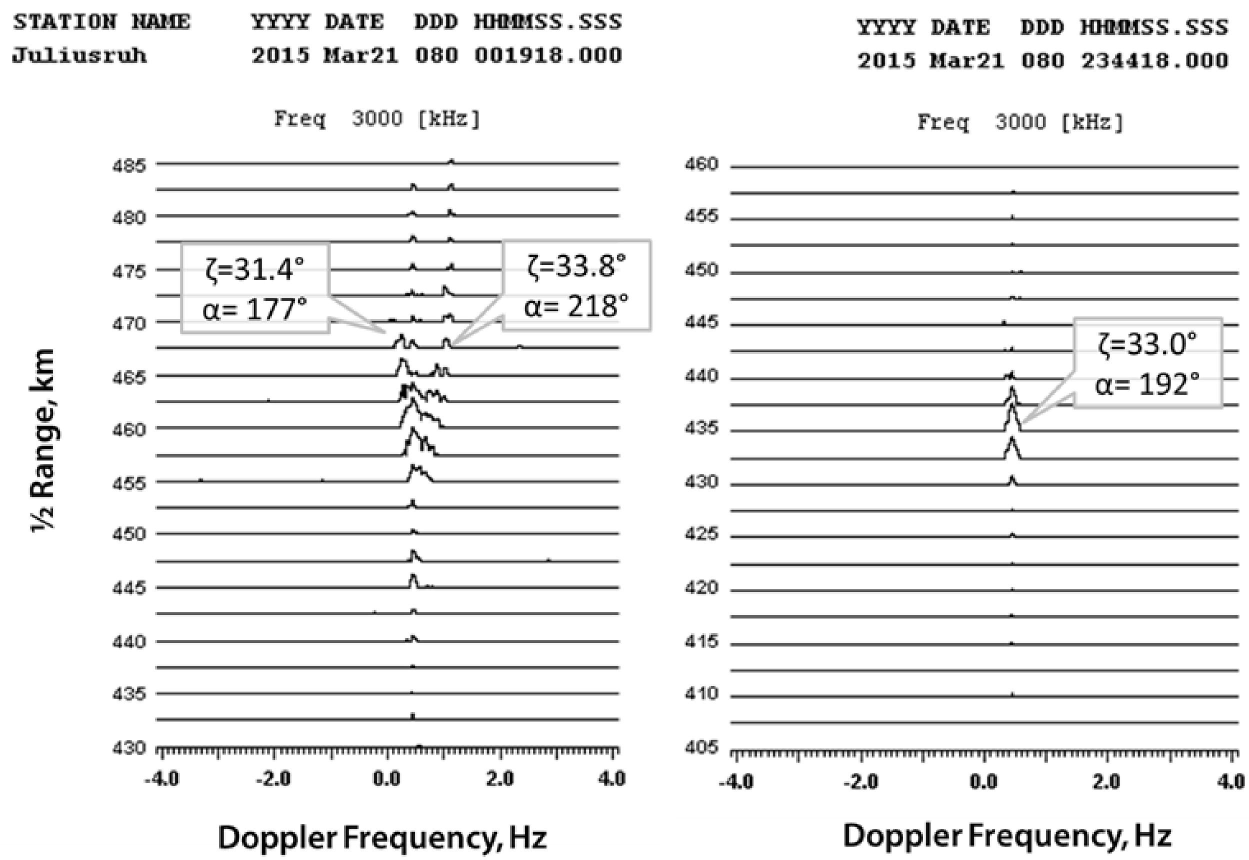


D2D waterfall displays at Juliusruh listening to the 3.0 MHz transmissions from Pruhonice



Disturbed

Quiet



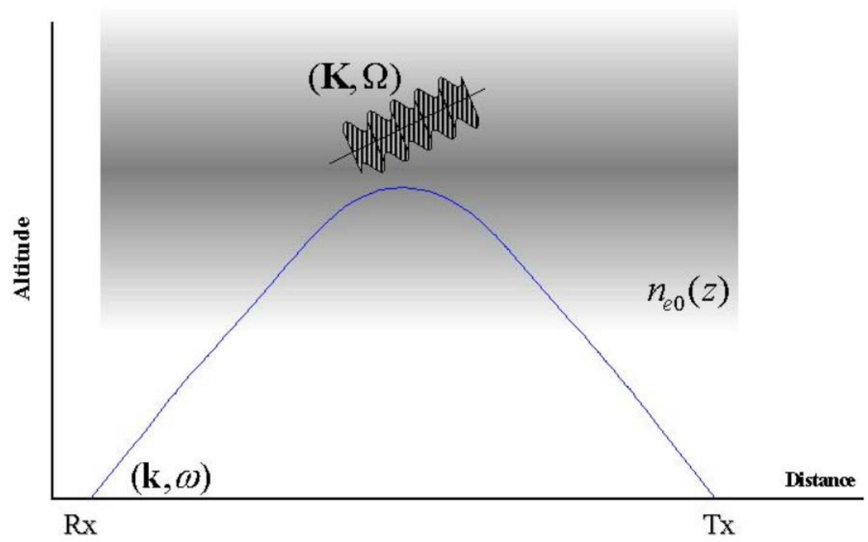
During quiet conditions on the path between Pruhonice and Juliusruh (the right panel), the HF pulse arrives at an apparent range of 2x435 km, zenith of 33° and azimuth 192°.

The left panel shows substantially multimodal propagation of signal during disturbed conditions at various angles of arrival and Doppler frequencies.

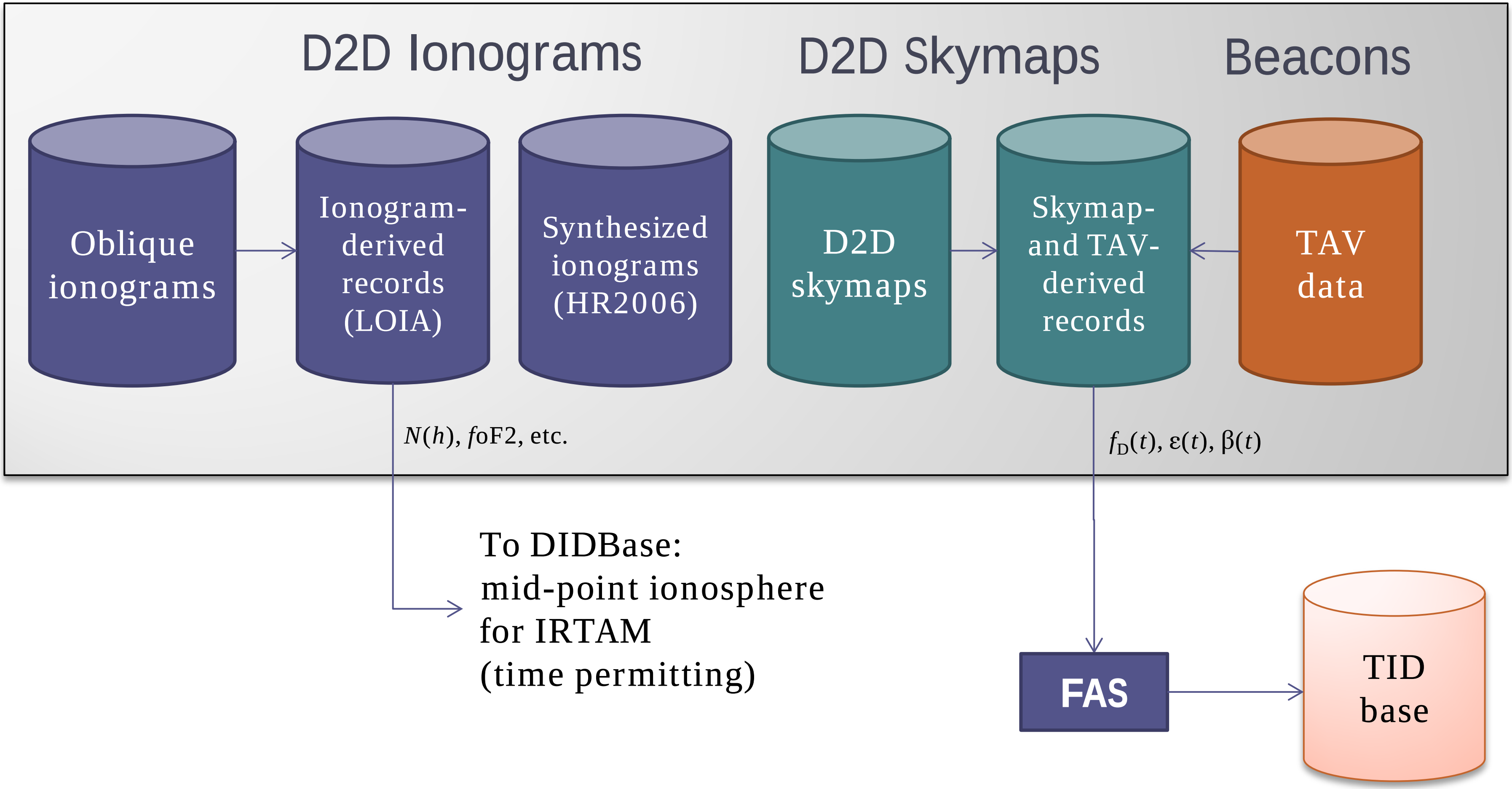
Frequency Angular Sounding (FAS) Technique

- <u>The idea</u>: Use bistatic (or vertical) HF measurements of trajectory signal parameter variations (AoA+Doppler) to determine TID parameters

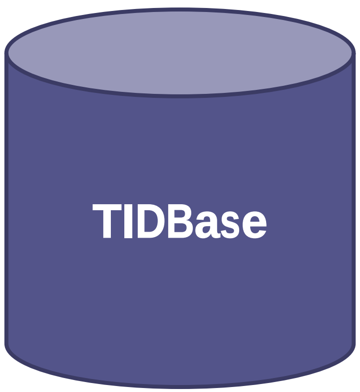
Measured signal parameters:
e(t) elevation angle
j(t) azimuthal angle
f_D(t) Doppler shift
t(t) Signal delay (vert. sound.)



LOUI-Base: Lowell ObliqUe Incidence



TIDBase design



- Reference time UT
- Location of TID (lat, lon, altitude)
- Location of Instruments
- Input $f_D(t)$, $\varepsilon(t)$, $\beta(t)$ series and metadata
  - Frequency and virtual range
  - Uncertainty of input data
  - SNR per point
- Multiple records of derived sets of
  - Ω – TID wave period
  - N – Amplitude of TID perturbation
  - K – k-vector of TID wave propagation
  - Φ – phase of TID wave
- Uncertainty metrics
- Metadata
  - FAS and DFT2Sky versions
  - Computation timestamp

Project schedule

First Year
Kick off meeting: **21 November 2014**
First consortium meeting
Network calibration – Establishment of bi static links – First results on TID identification

Second Year
Establishment of the TID DB and real-time analysis system
Contacts with end-users – requirements collection
Second consortium and users meeting
Release of first warning system prototype

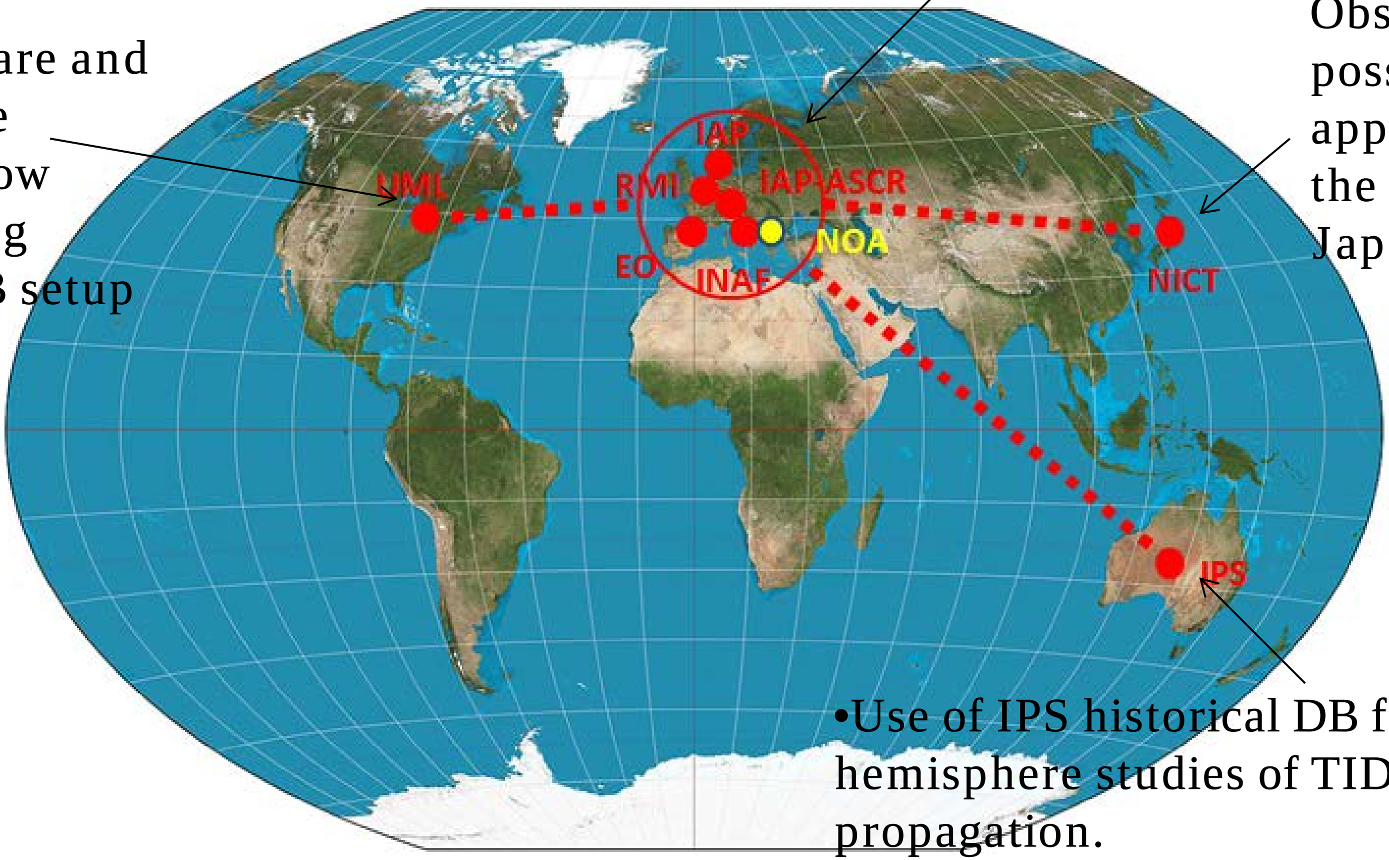
Third Year
Improving the functionality of the warning system
Meeting with users for final assessment of the warning system
Final release of the warning system : **October 2017**

The project team

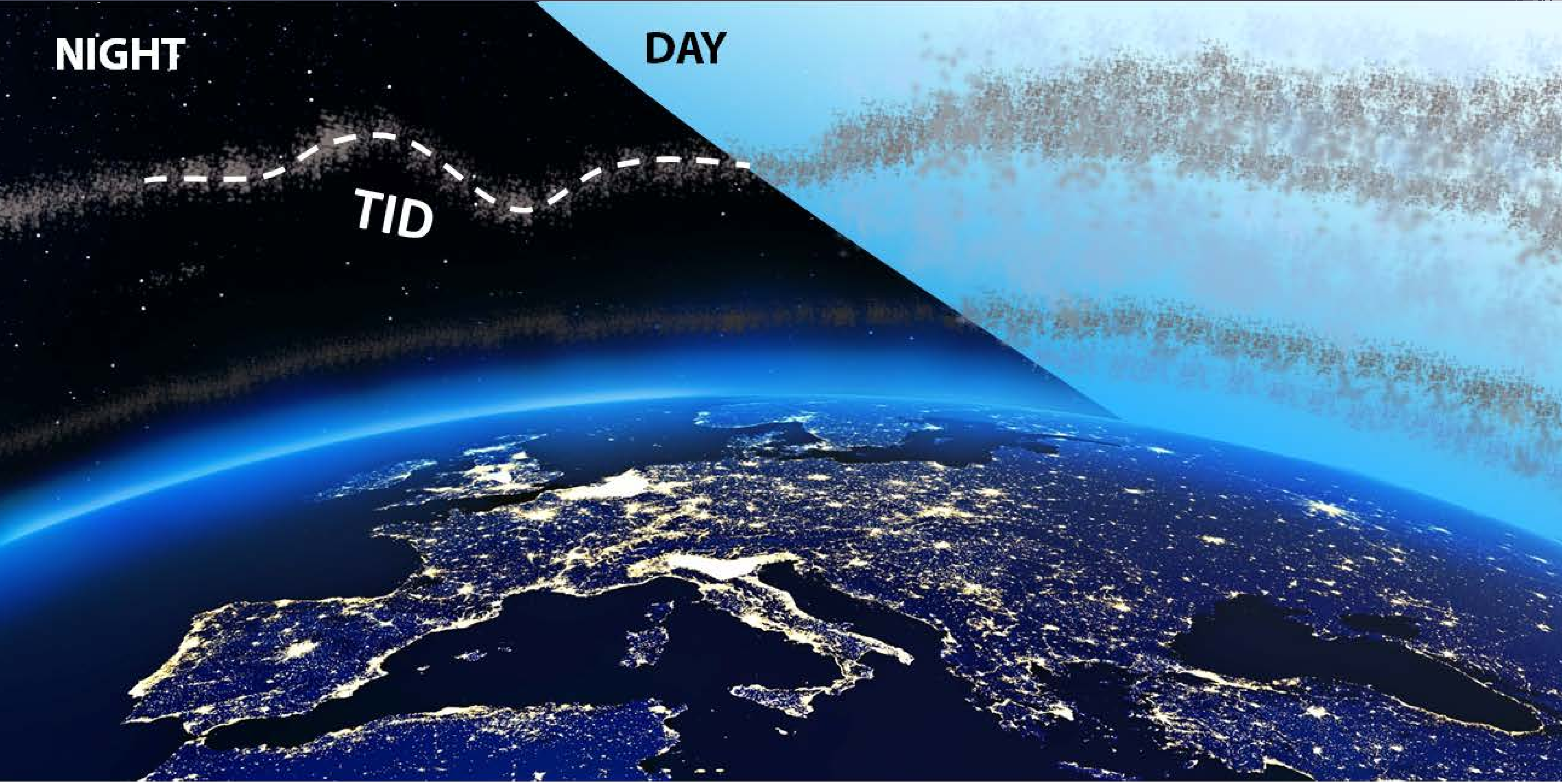
•Observing platforms DPS4D
•Network operation
•NOA will set up the warning system

•Hardware and software know-how
•Training
•TID DB setup

Observer – possible application of the method in Japan

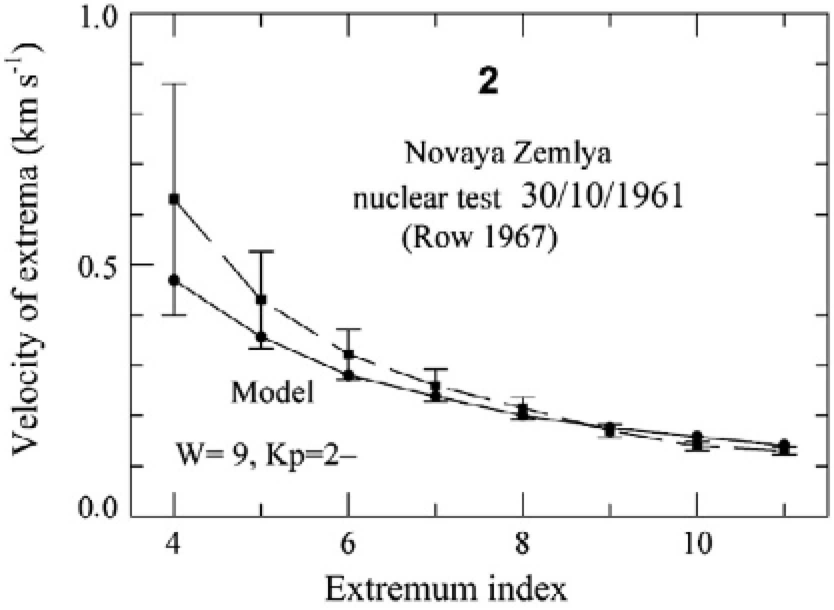


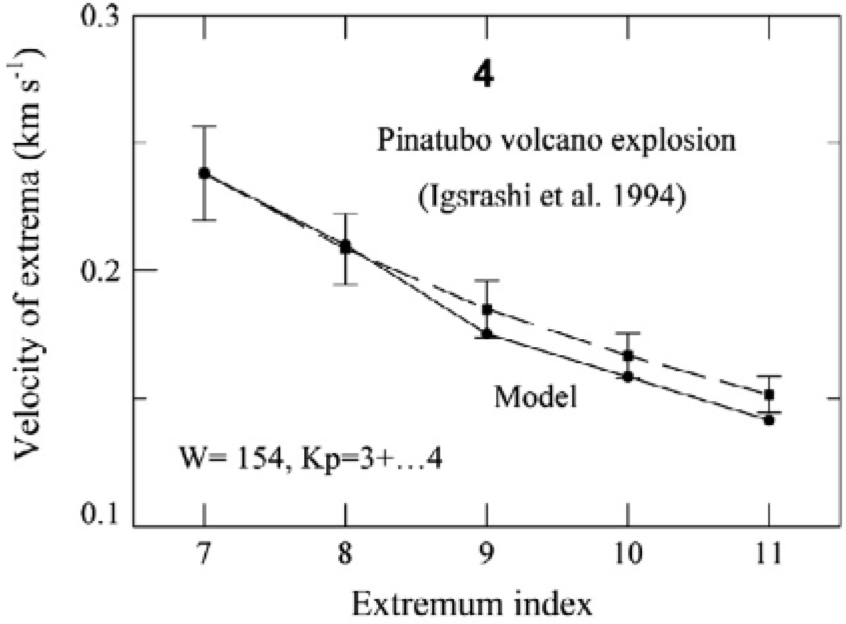
•Use of IPS historical DB for inter-hemisphere studies of TID propagation.
•Links with IPS users for the specification of warning system specs



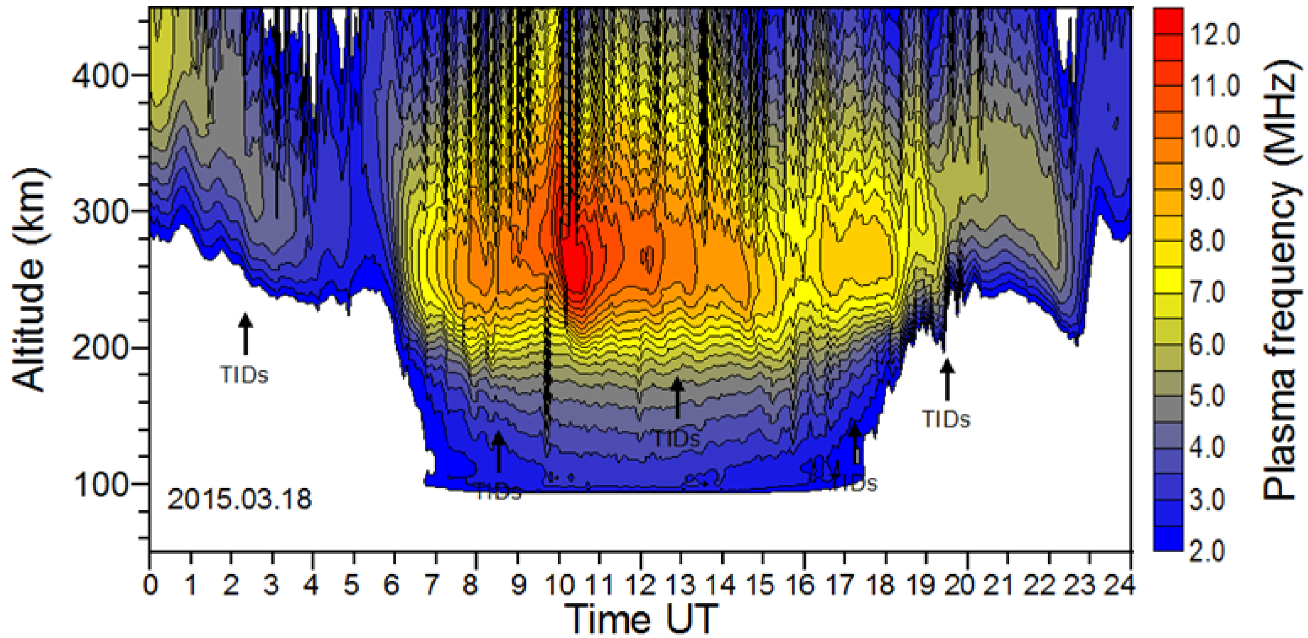
Thank you for your attention!

NATO
OTAN
This project is supported by: The NATO Science for Peace and Security Programme





Extrema velocities of a TID train versus its index for surface **nuclear explosions** and **volcano eruption** (Fedorenko et al., JSWSC, 2013).



Geomagnetic storm in progress