Real-time identification of travelling ionospheric disturbances based on high frequency reflected radio pulses

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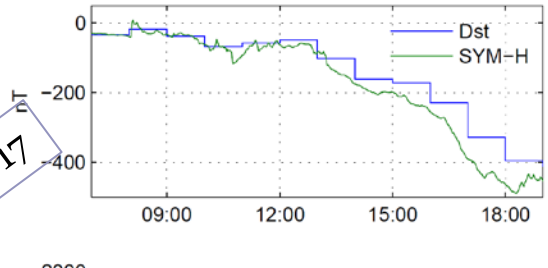
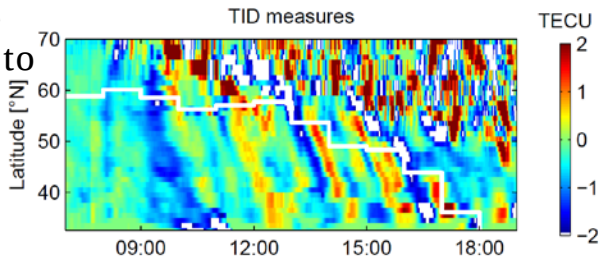
Travelling Ionospheric Disturbances - TIDs

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

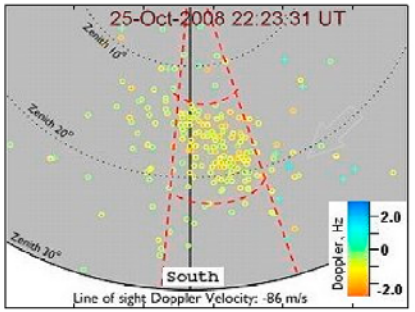
Borries et al., 2017



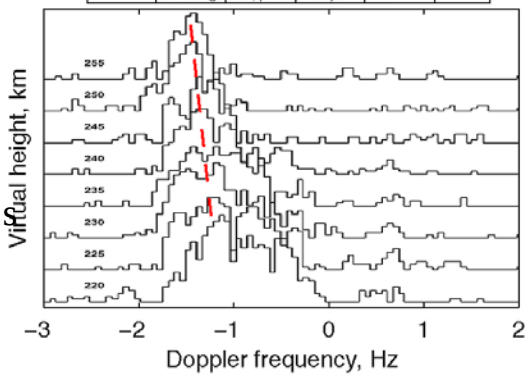


Time-latitude plot of TID estimates (TEC deviations to the 1 h moving average) at 15∘E during the Halloween 2003 storm

Mishin et al., 2012



AGWs generated in the F2 region by high-power HF heating (HAARP) and subauroral polarization streams recorded by the HAARP Digisonde

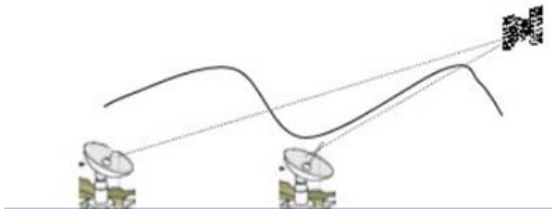


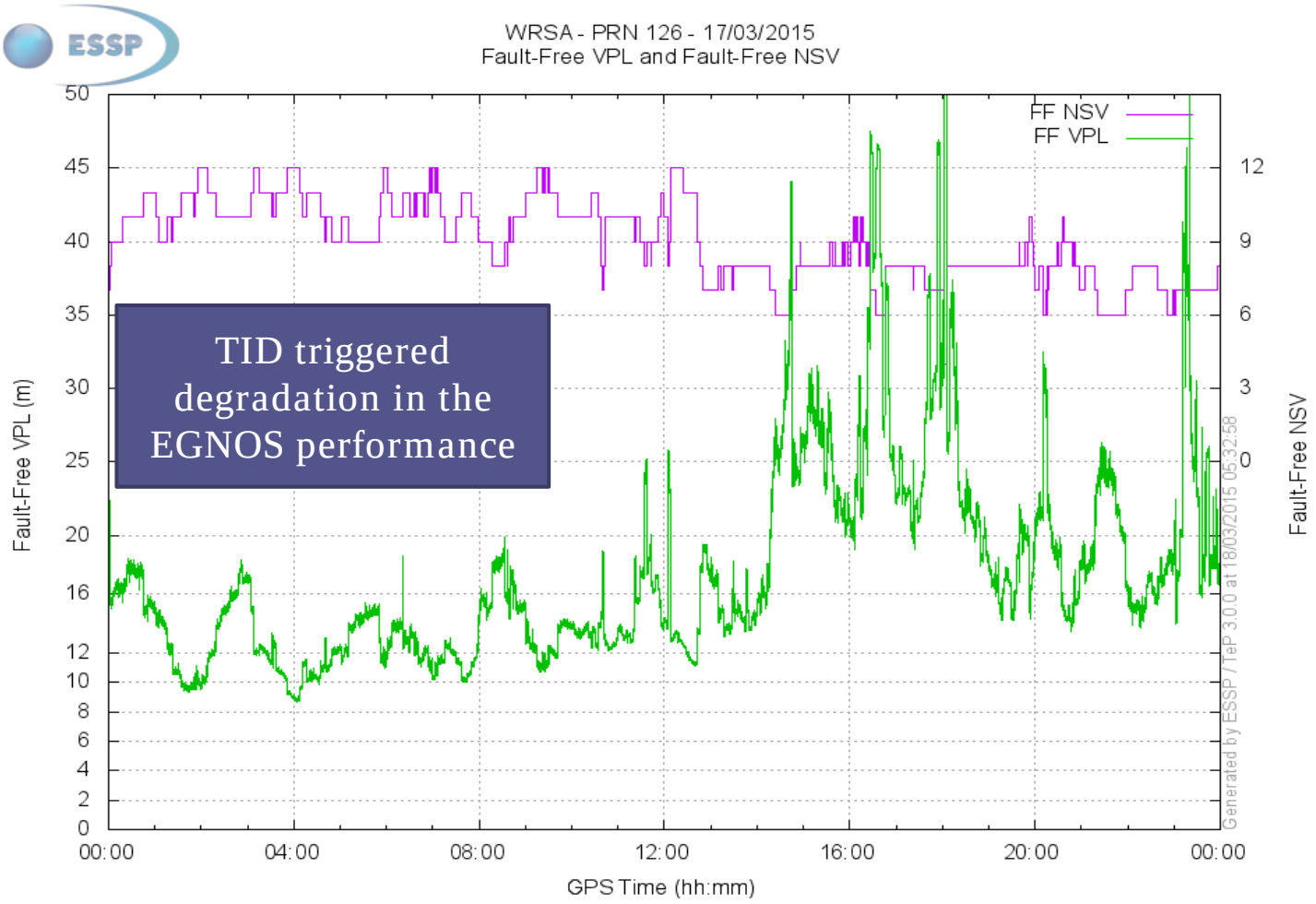
Systems affected by TIDs

TIDs affect all services that rely on predictable ionospheric radio wave propagation. TIDs can impose disturbances with amplitudes of up to **~20% of the ambient electron density**, and a **Doppler frequency shifts of the order of 0.5 Hz on HF signals**.

Multiple effects can be detected in the operation of aerospatial and ground-based infrastructures and especially:

- In the European Geostationary Navigation Overlay Service (EGNOS)
- In the Network Real-Time Kinematic (N-RTK) services
- In High Frequency (HF) communications, in radio reconnaissance operations and in Very High Frequency – Ultra High Frequency (VHF-UHF) radiowave propagation.





An example of recordings from the EGNOS RIMS Warsaw station during the St Patrick's Day storm 2015.

A significant increase of the Vertical Protection Level (VPL) occurred very suddenly at about 14:30 UT. It coincides with the passage of a bulk of LSTIDs reported in Borries et al. (2016).

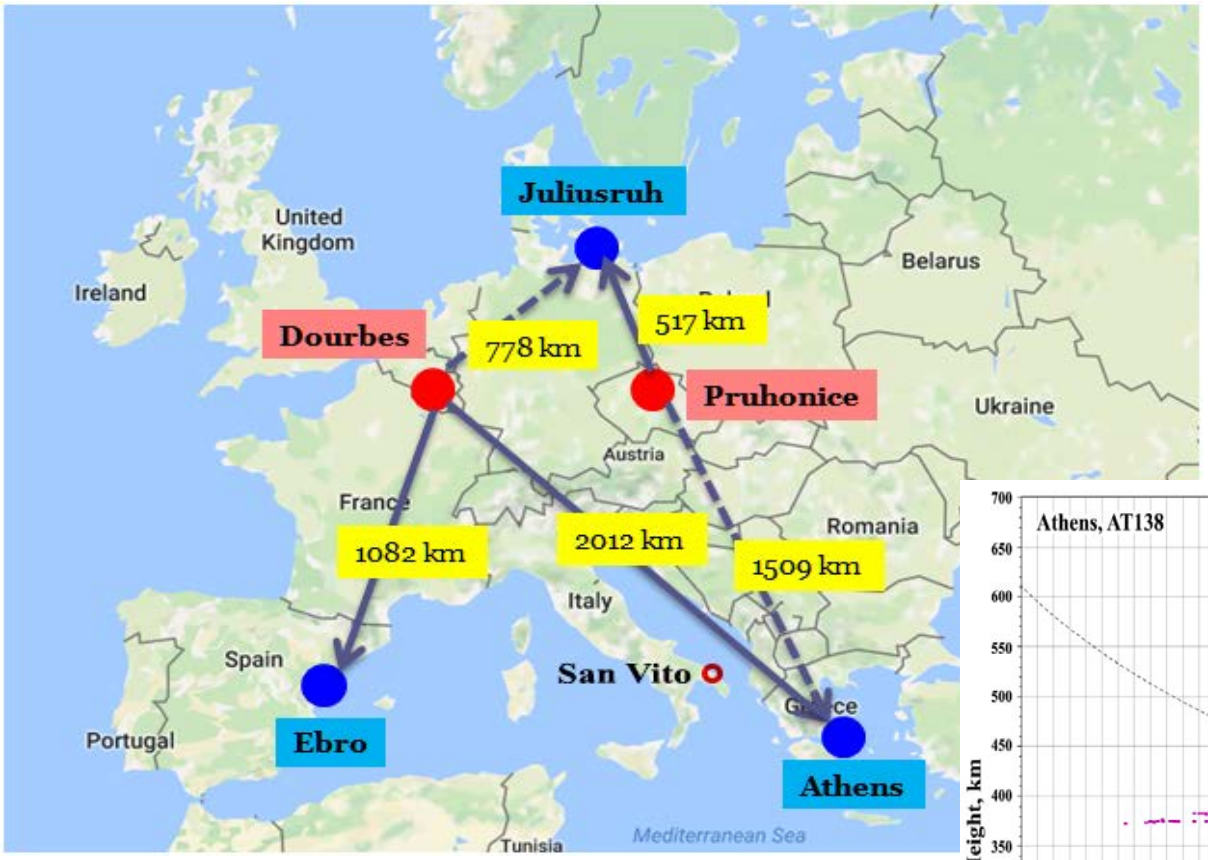
Net-TIDE: Pilot network for identification of travelling ionospheric disturbances

- Net-TIDE exploits for the first time the European network of high precision ionospheric DPS4D sounders and the related software to **directly identify TIDs** over Europe and specify in real-time the wave parameters from bottomside ionospheric measurements.
- Using multi-points measurements we are able to define propagation characteristics of TID waves over Europe and **locate the source**.
- Use of the DPS4D network leads to a **robust, effective, and inexpensive system** for the remote diagnostics of this type of ionospheric irregularities **in real-time**.

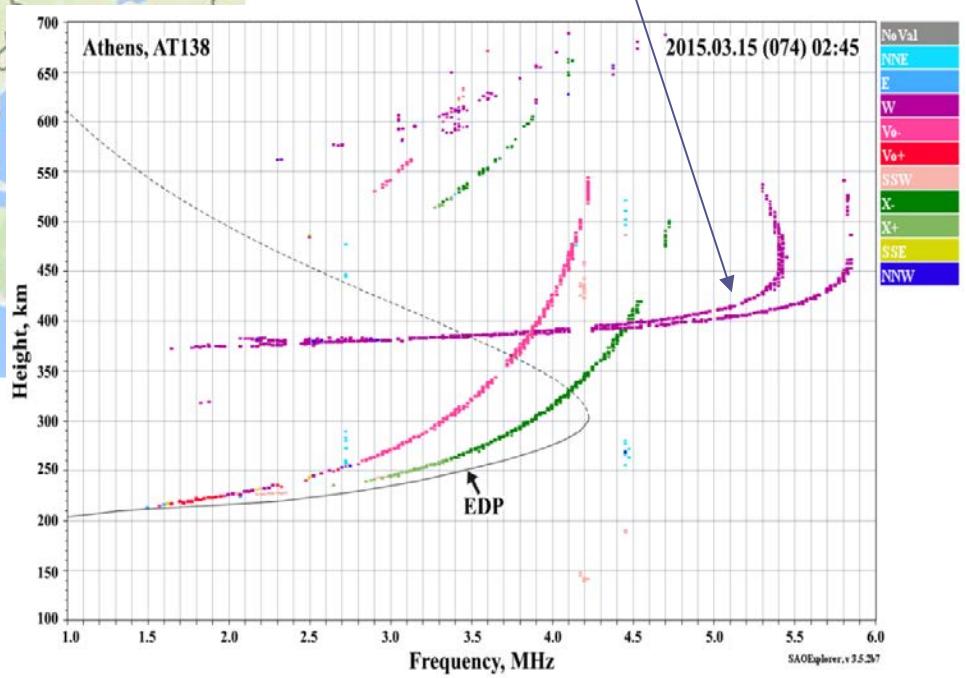
Sounding Types

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



Oblique transmissions from San Vito station recorded in Athens in a synchronized scheduling



DPS4D Transmitters

DPS4D Transmitters

D2D settings for Net-TIDE operations

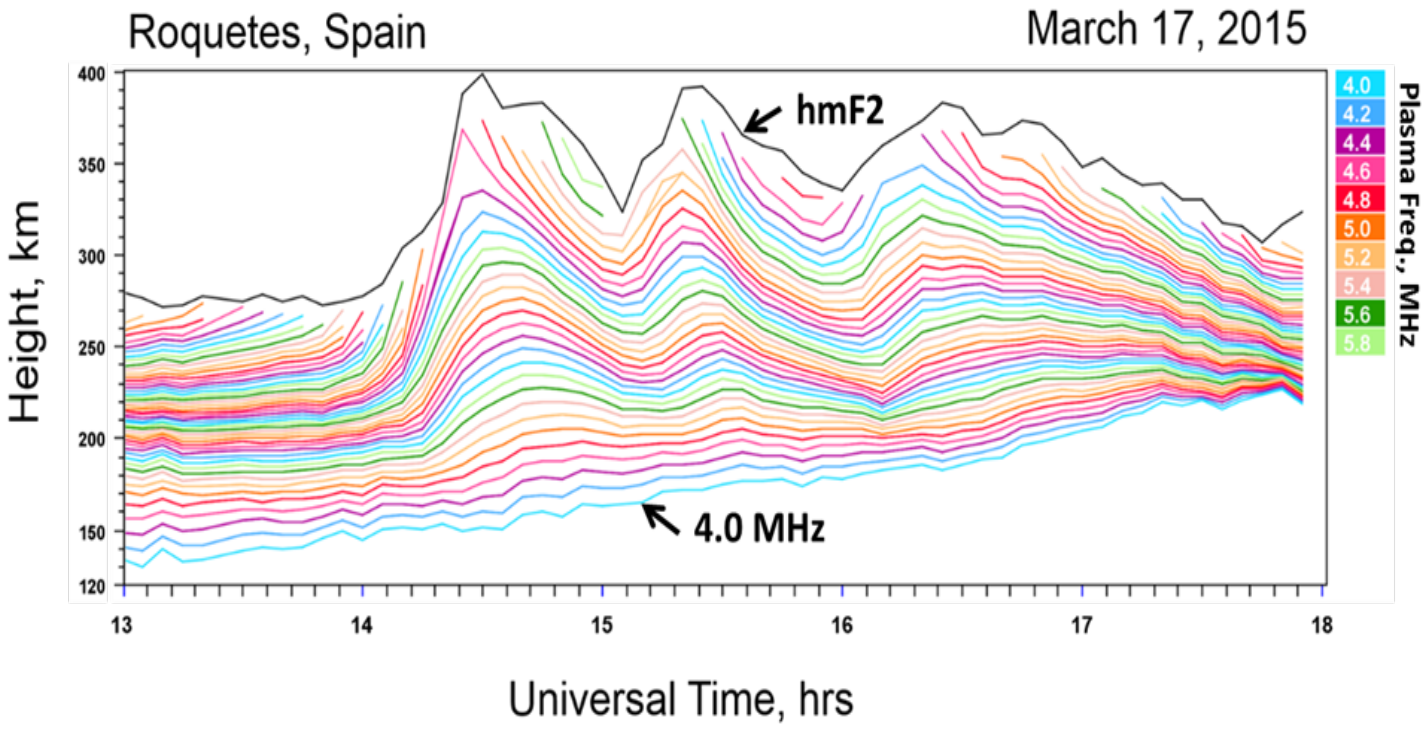
D2D are oblique Digisonde-to-Digisonde “skymap” observations.
For the Net-TIDE project, a 40-sec fixed-frequency D2D skymap measurement has been inserted in the 5-min schedule.

Parameter	Daytime schedule	Nighttime schedule	Twilight Schedule
Operating frequency	10425 kHz	4355 kHz	7825 kHz
Number of pulses	2048	2048	2048
Interpulse period	10 ms	10 ms	10 ms
Measurement duration	40.960 s	40.960 s	40.960 s
Schedule switch times	9:15 to 16:30 UT	19:15 to 6:15 UT	6:15 to 9:15 and 16:30 to 19:15 UT

Operational settings for the Dourbes-to-Roquetes link in October 2016

The reality

The passage of a TID is seen as quasiperiodic height variations of the isodensity contours of the measured vertical electron density profiles (EDPs).

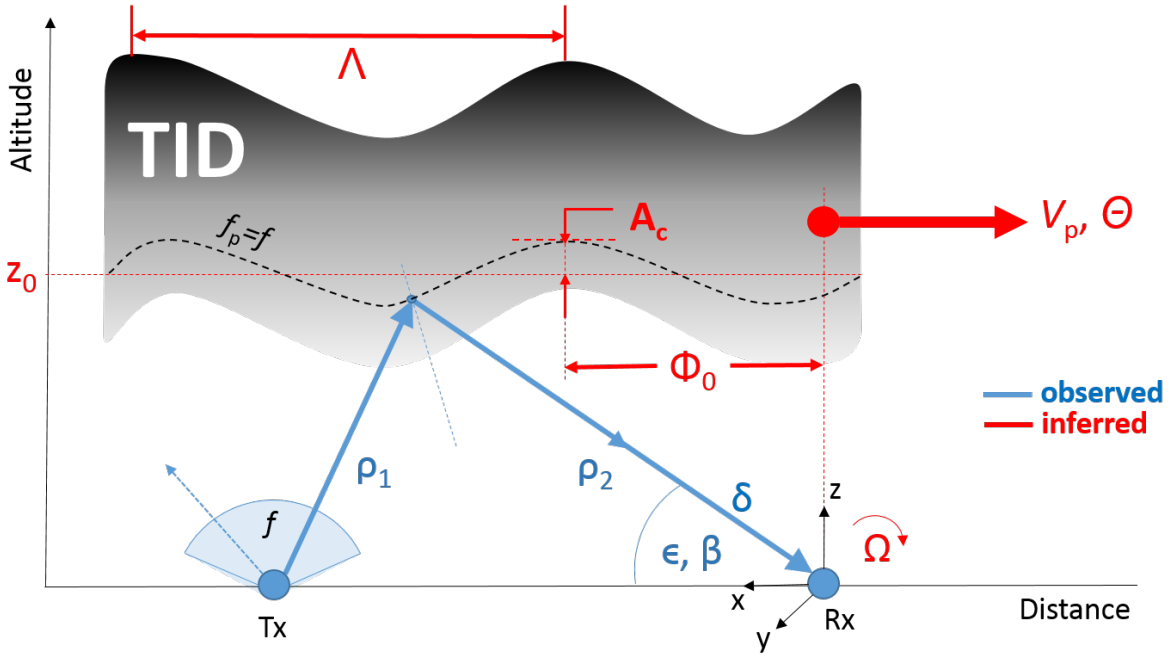


The model

The method is based on the assumption that the ionosphere is represented by a moving undulated mirror, to relate HF signal parameters to TID characteristics, using the Doppler-Frequency-Angular-Sounding (FAS) technique.

signal properties : Doppler frequency, angle of arrival, and time-of-flight from transmitter to receiver

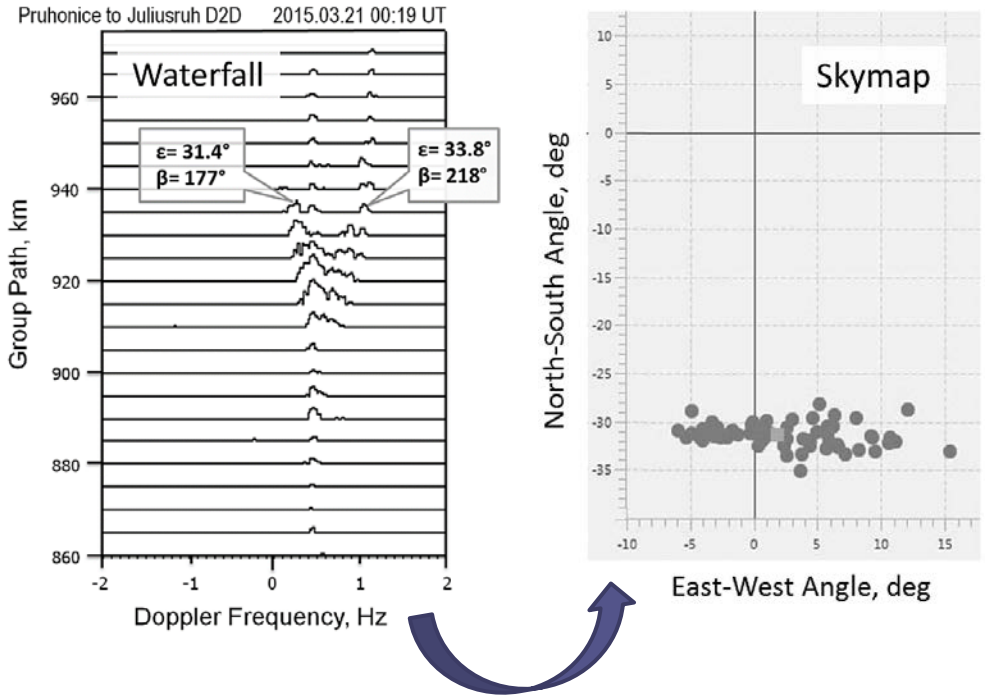
TID parameters: amplitude, wavelength, phase velocity, and direction of propagation.



Intelligent signal processing

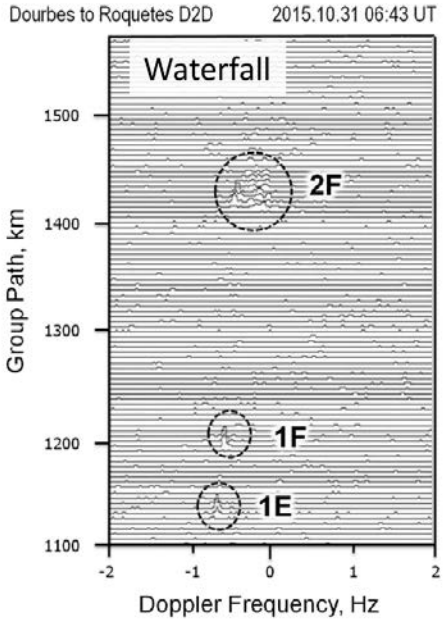
1. **Extract** signals propagated along different paths

Doppler waterfall

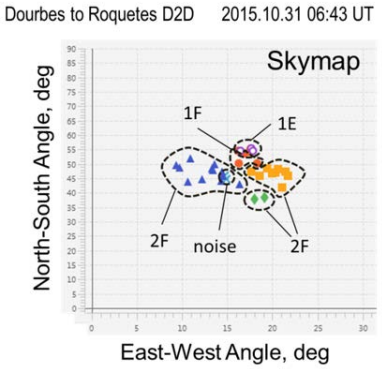


For each signal exceeding the threshold, the angles of arrival ε and β, are determined.

2. **Clustering** signals: hierarchical grouping based on the group path, Doppler frequency and angles of arrival



Clustering with 1E, 1F, 2F propagation modes

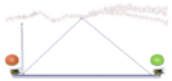


{ρ, δ, ε, β} set of values for each cluster define the "signal"

Transition to operations

Programming Tx and Rx of D2D Skymap

Transmitter	Receiver
• One Fixed Freq	• One Fixed Freq
• 512 ranges, 10 ms IPP	• 512 ranges, 10 ms IPP
• N=2048, $\Delta\Omega$ = 0.024 Hz	• N=2048, $\Delta\Omega$ = 0.024 Hz
• Standard	• Oblique
• Radio Silent OFF	• Radio Silent ON
• No companion station	• Select Tx station from list
• Save data = NO*	• Save data = YES
	• Data format = UMS
	• Full 4 channel data

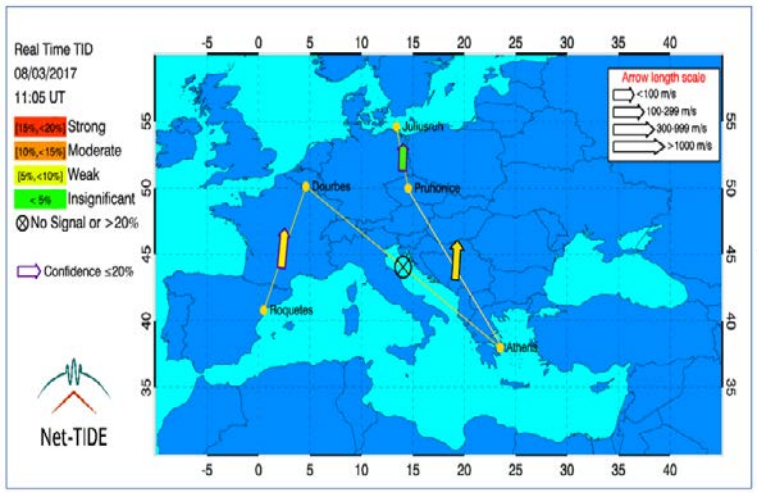


* Vertical echoes, limited availability

D2D Skymaps

D2D skymaps → Skymap- and TAV-derived records

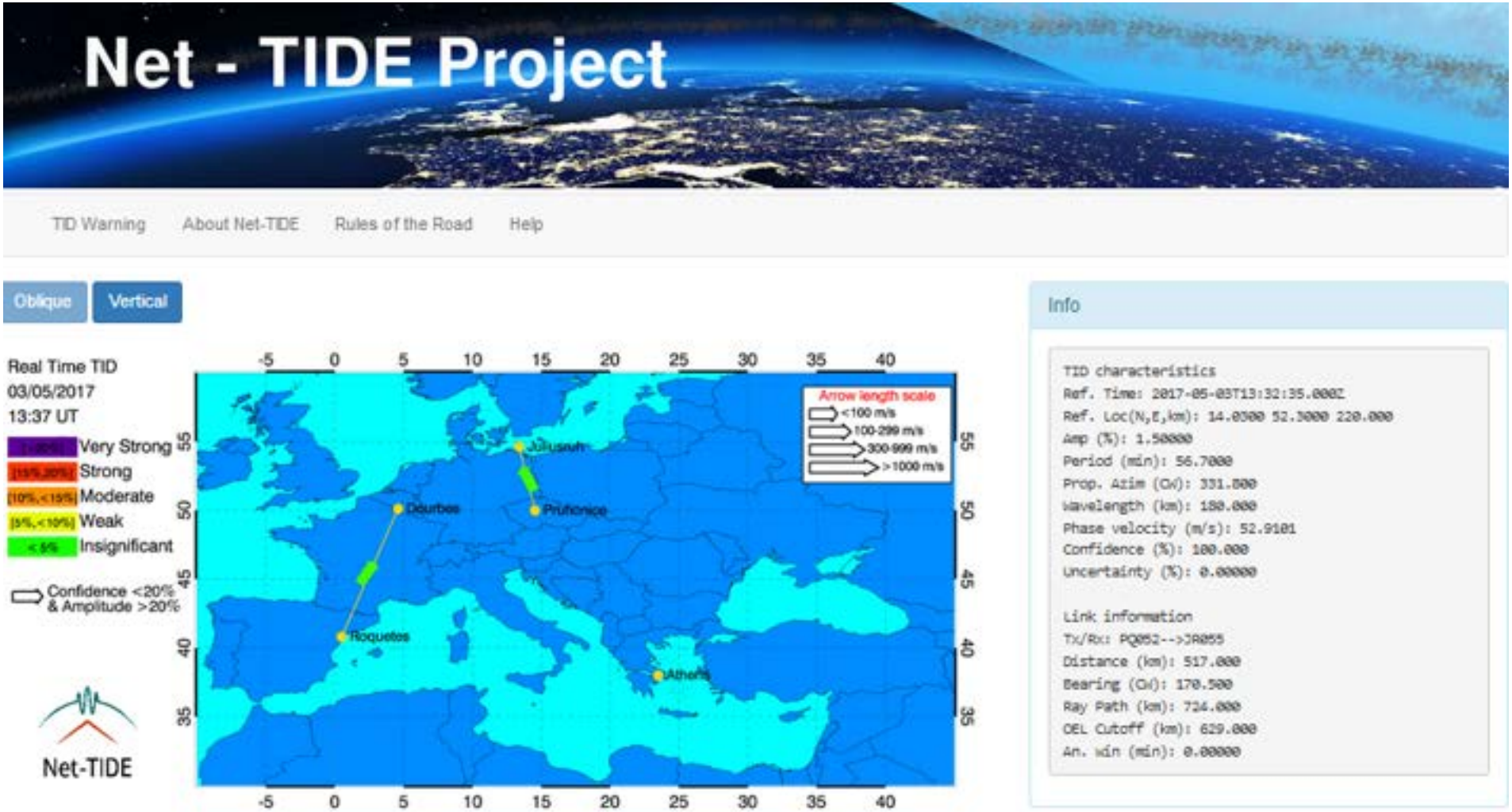
$f_D(t)$, $\varepsilon(t)$, $\beta(t)$



TID base

TID model code

http://tid.space.noa.gr

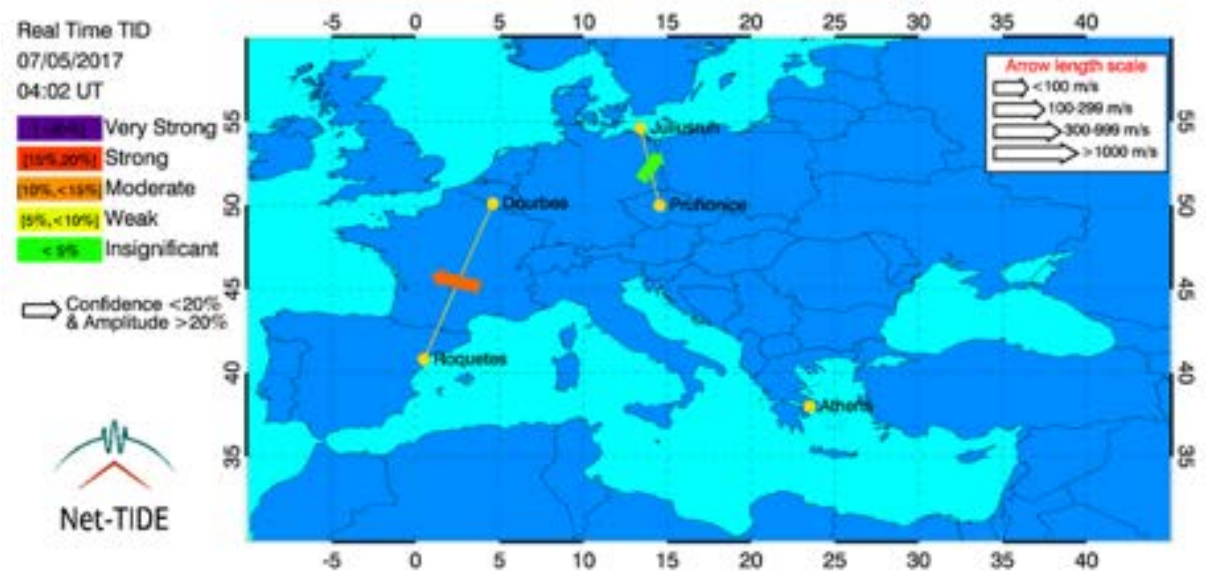


Small scale TID detected on 3 May 2017 at 1330UT with phase velocity ~55 m/s and amplitude 1.5% of the ambient ED

Net-TIDE warning system

TID Warning | About Net-TIDE | Rules of the Road | Help

Oblique | Vertical

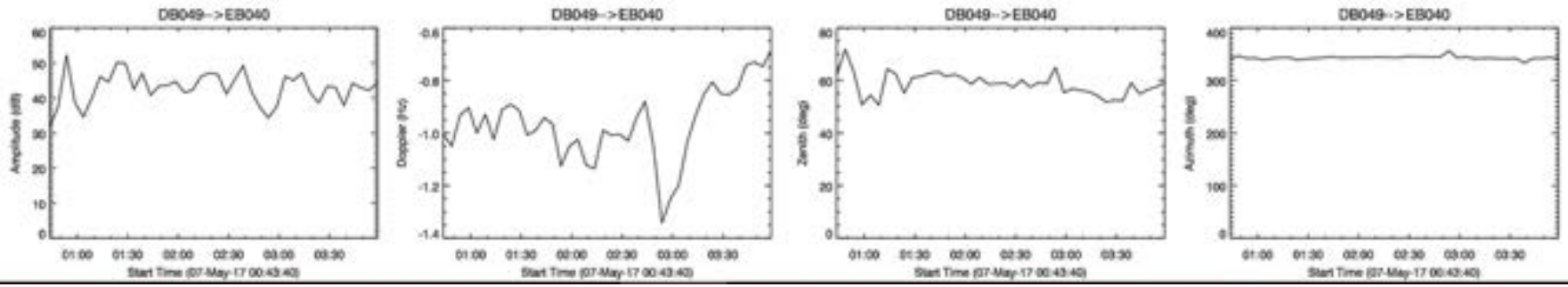


Info

```
TID characteristics
Ref. Time: 2017-05-07T03:58:40.000Z
Ref. Loc(N,E,km): 2.38000 45.4700 332.000
Amp (%): 12.8000
Period (min): 165.000
Prop. Azim (CW): 283.500
Wavelength (km): 1452.00
Phase velocity (m/s): 146.667
Confidence (%): 100.000
Uncertainty (%): 0.00000

Link information
Tx/Rx: DB049-->EB040
Distance (km): 1082.00
Bearing (CW): 15.7000
Ray Path (km): 1262.00
OEL Cutoff (km): 1228.00
An. win (min): 0.00000
```

lick on the arrow to get the TID characteristics.



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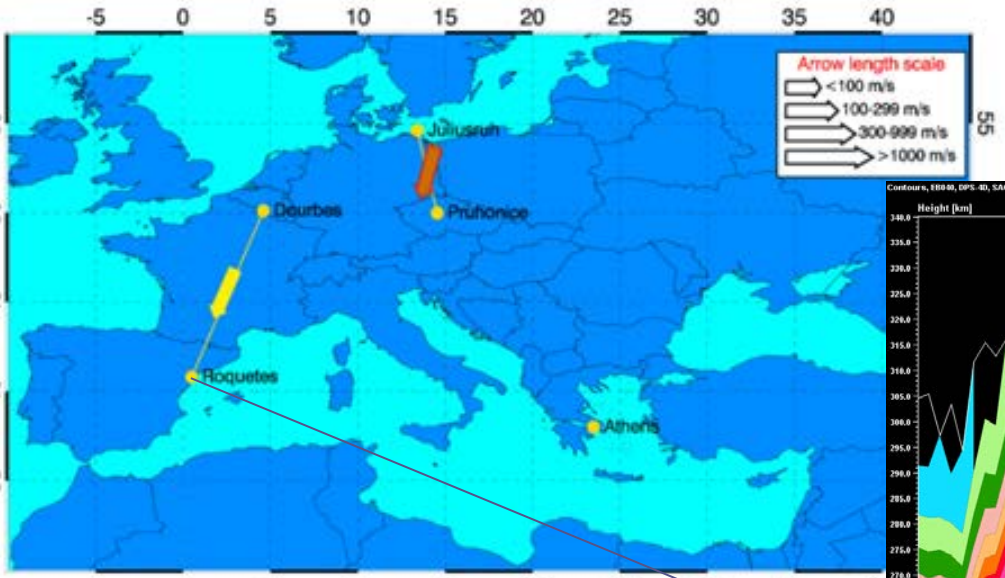
Oblique | Vertical

Real Time TID
07/05/2017
02:07 UT

Very Strong
Strong
Moderate
Weak
Insignificant

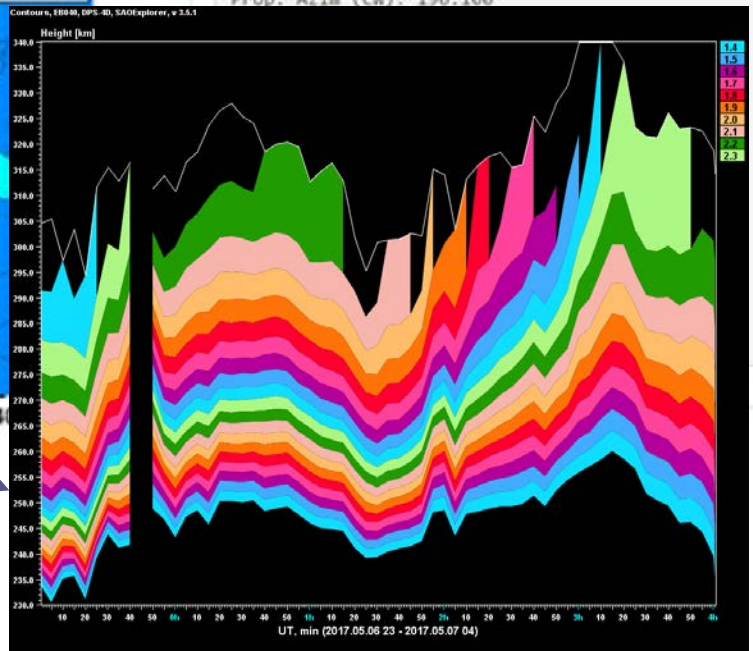
Confidence <20% & Amplitude >20%

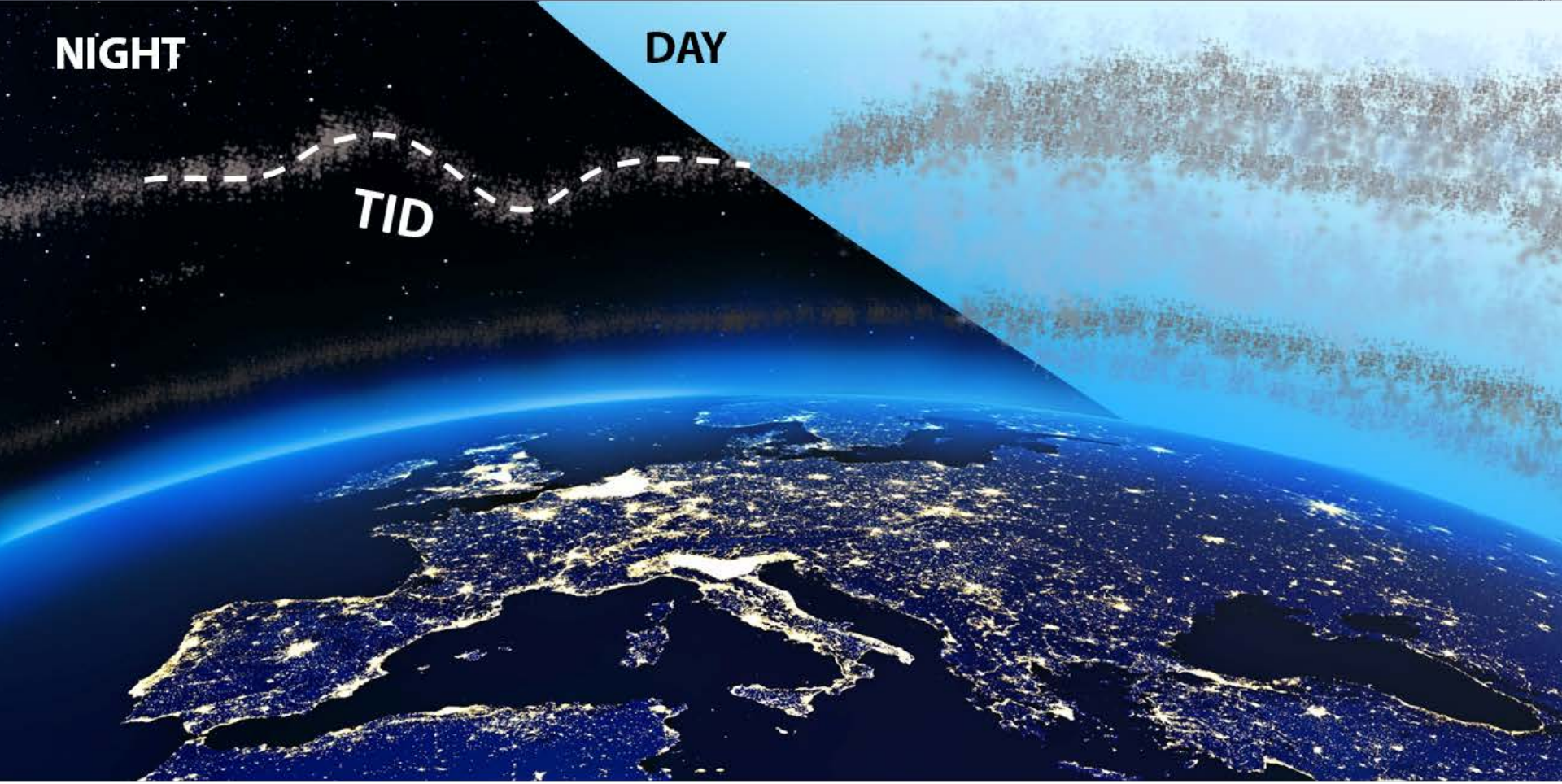
Net-TIDE



Info

TID characteristics
Ref. Time: 2017-05-07T02:02:35.000Z
Ref. Loc(N,E,km): 14.0300 52.3000 221.000
Amp (%): 12.4000
Period (min): 130.000
Prop. Azim (CW): 196.100





Thank you for your attention!

NATO OTAN

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