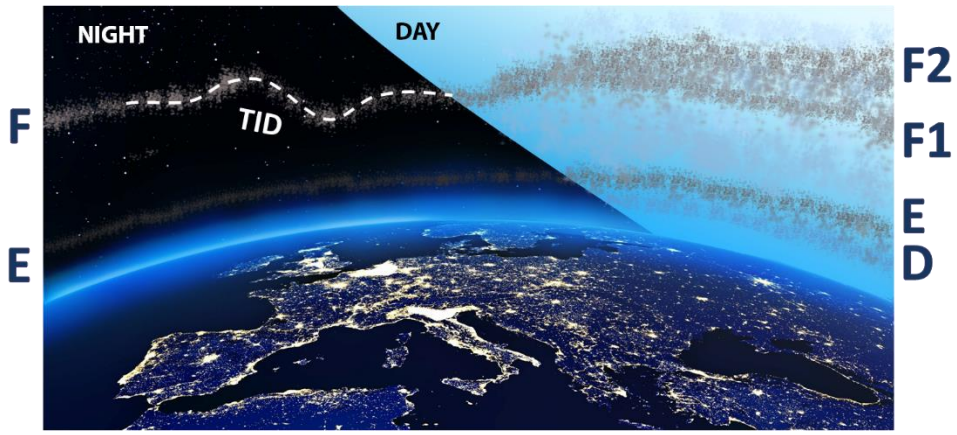


Pilot network for the identification of travelling ionospheric disturbances

GOALS OF THE PROJECT AND CURRENT STATUS

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

TIDs carry along information about their sources of excitations which may be either natural (energy input from the auroral region, earthquakes/tsunamis, hurricanes, solar terminator, and others) or artificial (ionospheric modification experiments, nuclear explosions, and other powerful blasts like industrial accidents). TIDs contribute to the energy and momentum exchange between different regions of the ionosphere, especially during geomagnetic storms. Their tracking is important because the TIDs affect all services that rely on predictable ionospheric radio wave propagation. Although a number of methods have been proposed to measure TID characteristics, none is able to operate in real time for monitoring purposes. In the framework of the current NATO Science for Peace and Security multi-year project (2014 - 2017) we are exploiting 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 TID wave parameters based on simultaneous measurement of the variations of the group path length, angle-of-arrival, and the Doppler frequency of the ionospherically reflected high-frequency (HF) radio signals. The project is running until November 2017 and is expected to result in a pilot network of DPS4D ionospheric sounders in Europe, enhanced by a real-time processing system of the TID observations for diagnostics and warnings purposes of TIDs and associated ionospheric disturbances over the area. Based on these warnings, the end-users will be able to put in action specific mitigation techniques to protect their systems.

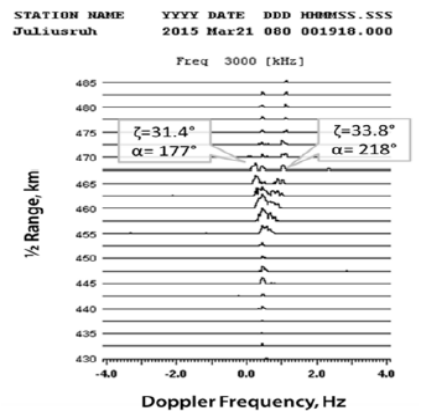
Current Status

The network of European DPS4D sounders has been tested and calibrated to operate with an agreed configuration and schedules. Bi-static HF propagation links have been established between the network DPS4Ds to record synchronous vertical and oblique ionogram and skymap soundings. Automatic processing software has been developed to analyze the data in terms of the parameters of TID waves, employing the *Doppler Frequency and Angular Sounding* (FAS) technique .

IN THIS ISSUE

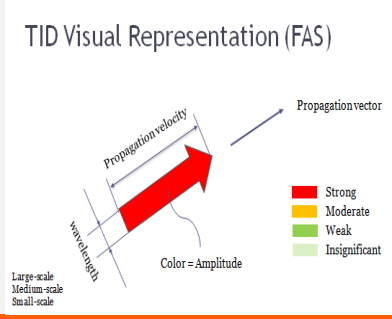
D2D skymap measurements

New UML TIDx software specifies the group path length, angle of arrival and Doppler frequency



TID warning system

A warning system is under development to provide TID characteristics over Europe for users warning.



Scientific sessions organized by the Net-TIDE consortium

- 13th European Space Weather Week, November 2016
- EGU General Assembly, April 2017

Bi-static links

In Europe five routinely operating DPS4Ds meet the specifications to perform oblique skymap measurements, and their Principal Investigators participate in this project. These are the DPS4Ds in Athens (Greece), Ebro (Spain), Dourbes (Belgium), Juliusruh (Germany), and Pruhonice (Czech Republic). These Digisondes are able to operate in synchronized mode, which is required for the pilot network to detect and specify the TIDs (Figure 1).

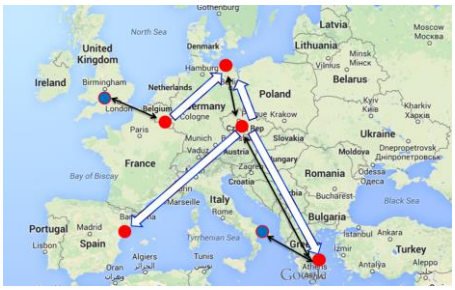


Figure 1: DPS4D locations and potential short and long path links under consideration. Red dots indicate the DPS4D stations already participating in the project. Additional stations to be considered in future experiments are indicated with blue dots. Black arrows denote synchronized vertical and oblique "ionogramming", white arrows denote D2D "skymapping".

Potential TID sensing capabilities have already been reviewed and a preliminary TID measurement schedule has been designed and tested.

The most relevant measurement mode is the **Digisonde-to-Digisonde (D2D) Skymapping**: this is a periodic 40-sec fixed-frequency (selectable) transmission with 4-channel spectral data collected at the receiving DPS4D; a 5-min cadence is currently implemented, and 2 or 2.5 minute cadences are options under consideration. The D2D skymapping where one Digisonde transmits and the other operates in radio-silent reception mode is the main data resource for the FAS calculations of the TID parameters.

Synchronous ionogramming with reception of both vertical incidence (VI) and oblique incidence (OI) echoes is another powerful observing mode to be used in complementarity with D2D. DPS4Ds operating with identical schedule and ionogram programs collect not only their own VI signal, but also the OI signals from neighbouring stations. While OI ionograms are not directly used for the TID calculations, they show signatures of the anomalous propagation caused by TIDs.

Figure 2 shows a VI+OI ionogram at Athens with OI signals (magenta color = West) from the San Vito DPS4D operated by the USA NEXION Network.

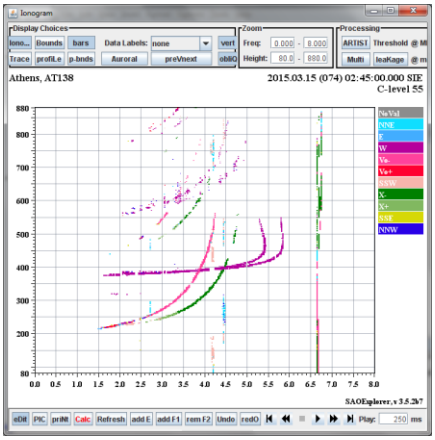


Figure 2: An example of VI+OI ionogramming between the San Vito and Athens DPS4Ds.

First D2D skymap results are shown for the relatively short path from Pruhonice (transmitting) to Juliusruh (receiving). The D2D "waterfall" display of the (Doppler) spectral amplitudes in Figure 3 displays the amplitudes as a function of range for the 8.0 MHz transmissions. The HF pulse arrived at an apparent range, i.e., group path length, of 2x435 km.

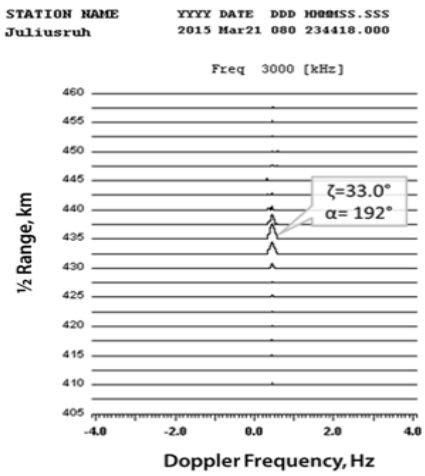


Figure 3a: During quiet conditions on the path between Pruhonice and Juliusruh (the right panel), the HF pulse arrives at an apparent range of 2x435 km, zenith of 33°, and azimuth of 192°.

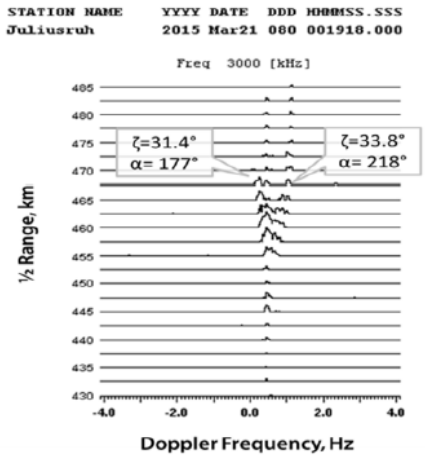


Figure 3b: Under disturbed conditions, as those occurring on 21 March 2015 on the path between Pruhonice and Juliusruh, multimodal propagation is observed with various angles of arrival and Doppler frequencies.

Warning system

The results from the processing of D2D observations are stored in a DOP file format. The collection and processing of the DOP files is managed by the University of Massachusetts, Lowell. The archiving of the DOP files is realized in the Institute for Atmospheric Research of the Academy of Sciences of the Czech Republic. The collection and real-time processing of raw DOP measurements will lead to the Net-TIDE warning system. This is a real-time system that will be openly accessible to all interested users and is under development by the National Observatory of Athens.

The software developed for the analysis of the DOP files can provide calculations of the TID propagation velocity, direction, amplitude and wavelength. First specifications have been presented and discussed in the User Forum held in Prague on 15 April 2016. The proposed TID visualization is given in Figure 4 and in Figure 5.

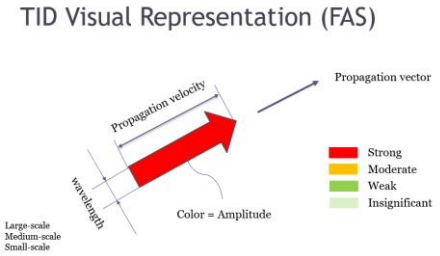


Figure 4: The propagation velocity of the TID at single location in Europe is designed as a vector with specific amplitude, direction and wavelength.

Figure 5 provides a first mockup of the TID activity over Europe. The final system will refresh the map every 5 minutes. Additional information regarding the characteristics of the activity detected at each link, will be also provided.

Figure 5: Preliminary proposal for the visualization of TID propagation, as a basis for the TID warning system setup.

FORTHCOMING EVENTS

13th European Space Weather Week 2016, Oostende, Belgium

Splinter session: "Real-time identification of travelling ionospheric disturbances"

Travelling Ionospheric Disturbances (TIDs) are the ionospheric signatures of atmospheric gravity waves. TIDs carry along information about their sources of excitations which may be either natural (energy input from the auroral region, earthquakes/tsunamis, hurricanes, solar terminator, and others) or artificial (ionospheric modification experiments, nuclear explosions, and other powerful blasts like industrial accidents). TIDs contribute to the energy and momentum exchange between different regions of the ionosphere, especially during geomagnetic storms. Their tracking is important because the TIDs affect all services that rely on predictable ionospheric radio wave propagation. In this working meeting, we will discuss progress in identifying TIDs exploiting the European network of high precision ionospheric DPS4D sounders (and the related software) and to specify in real-time the TID wave parameters based on measuring the variations of the angles-of-arrival and Doppler frequencies of ionospherically reflected high-frequency (HF) radio signals. Experts will also review progress on the real-time processing system of the TID observations for diagnostics and warnings purposes of TIDs and associated potential disturbances over the area. Based on these warnings, the end-users would be able to put in action specific mitigation techniques to protect their systems.

European Geosciences Union, General Assembly 2017, Vienna, Austria

Session ST3.2 "Advances in ionospheric measurement techniques"

The session aims at exploring recent advances in all aspects of measurement techniques, options of data processing, storage, visualization and exchange leading to efficient monitoring, nowcasting and forecasting ionospheric parameters important for communication, navigation, and positioning systems. We invite authors to present results demonstrating novel techniques based on radio sensing methods, radar measurements, optical methods, and in situ measurements, and how the use of these results contributes to advanced empirical assimilative and ensemble modeling techniques. Results presented in this session should target the improvement of our ability to specify and predict ionospheric large scale disturbances, travelling ionospheric disturbances, and scintillations towards a comprehensive space weather monitoring and warning system.

ABOUT THE PROJECT

Pilot Network for identification of travelling ionospheric disturbances

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- Mauro Messerotti, INAF – Astronomical Observatory, Trieste, Italy

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