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T-FORS NEWSLETTER

TRAVELLING IONOSPHERIC DISTURBANCES FORECASTING SYSTEM

IN THIS ISSUE

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T-FORS AT A GLANCE

Travelling Ionospheric Disturbances (TIDs) constitute a specific type of space weather disturbance affecting the performance of critical space and ground infrastructure by disrupting operations and communications in multiple sectors. T-FORS aims at providing new models able to interpret a broad range of observations of the solar corona, the interplanetary medium, the magnetosphere, the ionosphere and the atmosphere, and to issue forecasts and warnings for TIDs several hours ahead. Machine Learning techniques are used to train the models based on existing databases developed in the frames of past Horizon 2020 projects, to estimate the occurrence probability of medium scale TIDs and to forecast the occurrence and propagation of large scale TIDs. Prototype services are developed based on specifications from the users' community and following harmonized standards and quality control similar to the best practices of meteorological services. On ground demonstration tests are organised, by aerospace and civil protection agencies, to validate the performance of the T-FORS prototype services. A comprehensive architectural concept is proposed, including the densification of ground instrument networks, and new space missions, and possible future adjustments in order to develop a real-time operational service fully compliant and complementary to the ESA Space Weather services.

FIRST INNOVATION DAY

The First Innovation Day of the T-FORS project was organised in Toulouse during the "European Space Weather Week" conference (https://t-fors.eu/t-fors-users/t-fors-first-innovation-day). The latter event, bringing together the main European experts in the field of space meteorology and ionosphere, it was a great opportunity to present the T-FORS project and discuss its relevance with specialists in the field. The innovation day was divided into three parts. First the objectives and progress of the T-FORS project were presented, then various stakeholders of the domain, such as European Space Agency, Thales Alenia Space or PECASUS alert service (providing space weather advisories), presented their needs in term of TIDs forecasting. Finally, a round table was held to discuss the relevance of the work in progress.

The event brought together about thirty people. During the round table, feedback from stakeholders of the domain was very positive and the T-FORS project appeared relevant, covering the expectations of end-users. It appeared particularly interesting for different electromagnetic systems such as all systems using satellite positioning (GNSS with or without integrity information produced by SBAS systems), producing forecasts in the form of alert levels to TIDs. The interest of T-FORS outputs for electromagnetic systems in HF band (typically communications links or over the horizon sky wave radars) were also discussed. The impact of TIDS on low frequency SAR systems onboard satellite and very low frequency astronomical observations was also discussed, with a need more focused on a posterior classification of observations.

In conclusion the First Innovation Day has been considered as very successful by the community and appointment is made for the end of the project, where the achievements will be very expected by the community.

FUNCTIONALITIES

T-FORS expects to develop prototype services based on specifications from the users' community with a comprehensive architectural concept allowing for possible future adjustments in order to develop a real-time operational service.

Therefore, the system requirements are driven by a review of user's initial requirements and by the community standards.

The requirements are established according to 3 different user levels: Public Operator (PO), Premium Operator (PrO) (professional use) and Scientist Operator (SO). The PO refers to a basic usage of the T-FORS service, with access to TID alarms and a dedicated interface. The PrO is set for a professional use (e.g. telecom company) with access to a local dataset in addition. The SO gives access to the entire current and past database.

Each type of users calls for specific *functional requirements*:

- PO: Provide alarms, Provide dedicated interfaces, Provide standardised data format, Performance, Documentation.
- PrO: Provide alarms, Provide dedicated interfaces, Provide local real time data, provide standardised data format, Performance, Documentation.
- SO: Provide alarms, Provide archived data and access to entire database, Provide dedicated interfaces, Provide local real time data, provide standardised data format, Performance, Documentation.

The *non-functional requirements* are common to the 3 users' level:

- Legal and regulatory (open access data).
- Security (data protection comply with European laws, protected against manipulation).
- Maintenance (data exchange history, system maintainable throughout his lifetime).
- Infrastructure (to host the service - provided by NOA).
- Operation (minimal direct human intervention, English is official language).
- Design (all processing elements of the system located within the territory of the European member states, info and data are UTC time tagged).

MSTID CLIMATOLOGICAL MODEL

The T-FORS team works on establishing Medium Scale Travelling Ionospheric Disturbances (MSTID) climatology over Europe based on the available observations and developing an empirical model for the probabilistic forecasting of the extreme events associated MSTID.

MSTIDs are mostly associated with ionospheric coupling with the lower atmosphere and have no clear correlation with geomagnetic activity.

However, the occurrence characteristics (diurnal, seasonal, solar cycle, and latitudinal dependency of the MSTIDs occurrence) and climatology of the MSTID are not explored well over the European sector. Therefore, prior to the development of a climatological model we have established the climatology of the MSTID over Europe using the dTEC and ionosonde network data sets.

The concept of the climatological model is constructed based on the following assumptions:

1. The prediction for the MSTID occurrence is assumed to rely exclusively on extreme dTEC values.
2. The dTEC value depends on the geographical location (GL), local time (LT), ap index and solar proxy (SP: F10.7 cm).
3. The dependence of dTEC from GL, LT, ap index and SP is linear.

In the light of the above assumptions, we use linear regression technique to develop the model considering the geographical location (GL), local time (LT), ap index and solar proxy (SP: F10.7 cm) as predictor variables, and the detrended total electron content dT (dTEC) as the response variable.

This model consists of two phases: (1) development phase and (2) validation and implementation phase, in which the model outcome will be validated with the observed occurrence climatology of the MSTID.

The basic idea is displayed in the schematic diagram of Figure 1, whereas a detailed schematic of MSTID occurrence climatology estimation, comparison and validation with the linear regression model results is given in the flow chart of Figure 2. It is noted that in the schematic diagrams, blue colour indicates the tasks already completed, green colour indicates the tasks completed very recently or in progress, and the red colour indicates the work to be carried out in the upcoming days or the expected results.

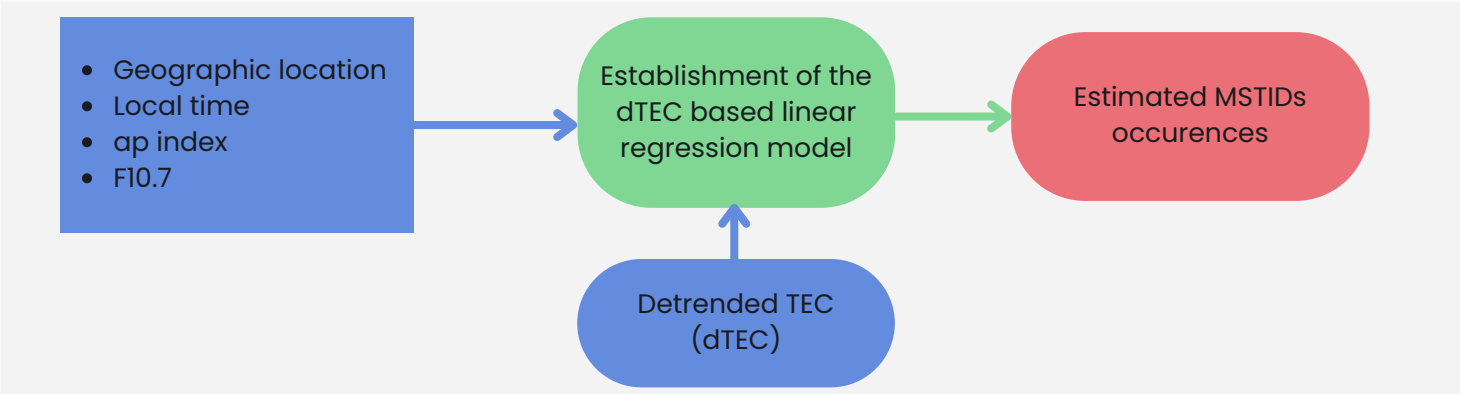


Figure 1. Flow chart of the input parameters for the dTEC based linear regression model

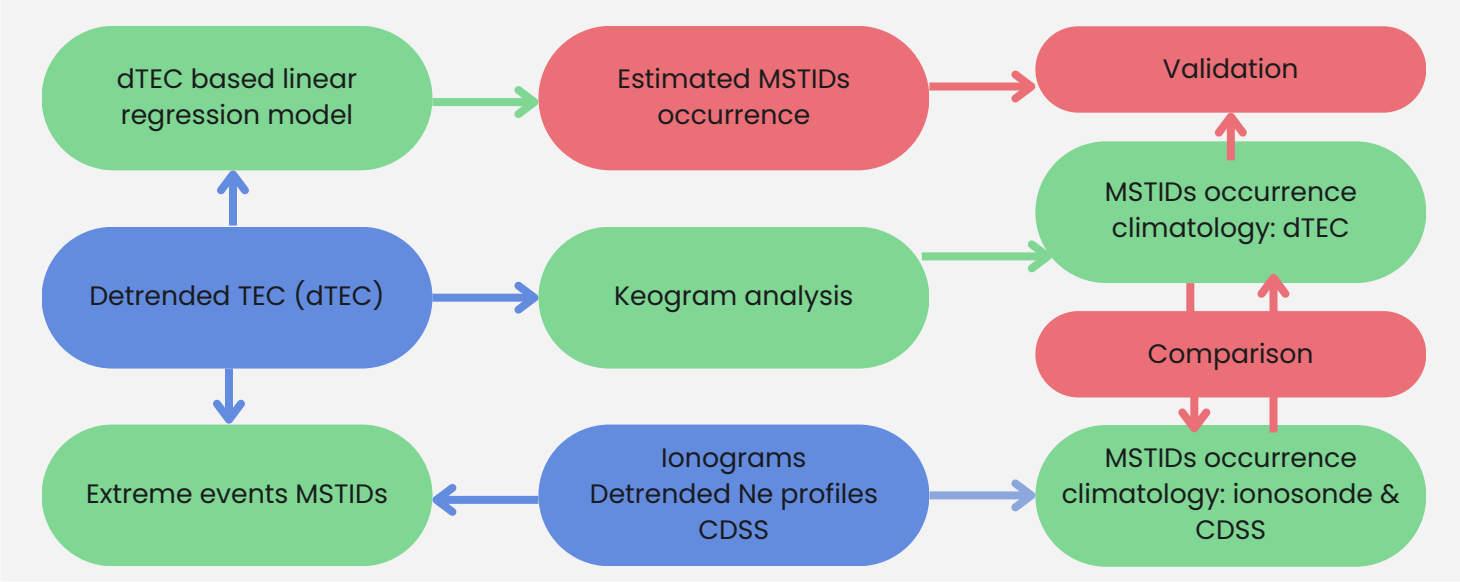


Figure 2. Flow chart of the comparison and validation of the observational results with the model outcome

KNOWLEDGE HUB

T-FORS has made available a Knowledge Hub addressed to different audiences, school children and students, the general audience and targeted groups, providing materials to enhance knowledge on the effects of TID and awareness of their in certain types of applications (https://t-fors.eu/t-fors-users/knowledge-hub).

Three types of leaflets have been designed for General Public, Technical Public and School Students (https://t-fors.eu/t-fors-users/knowledge-hub/leaflets).

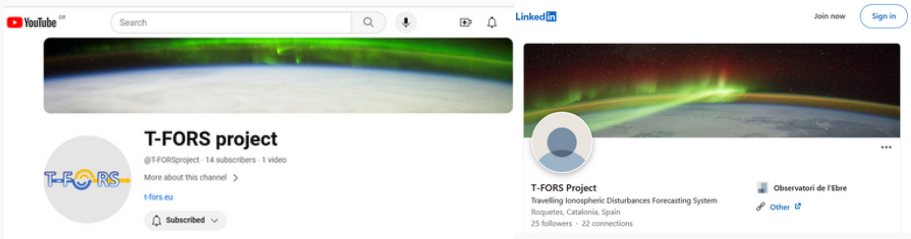
It has been prepared training material about the basic principles of the ionosphere as observed in ionograms, which are specific measurements of the ionosphere. Several handbooks and manuals for scaling, interpretation and reduction of ionograms to measure the ionospheric characteristics were added to the Knowledge Hub.

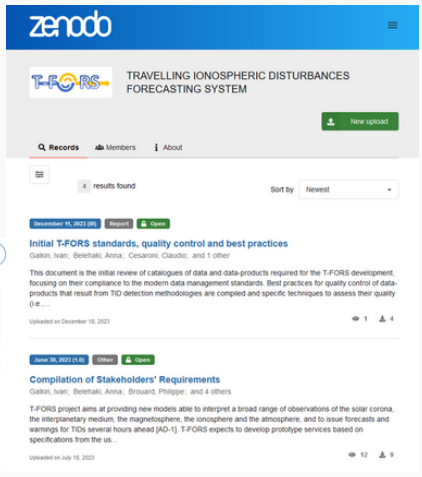
SOCIAL NETWORKS

T-FORS developed dissemination and communication activities through social networks:

- LinkedIn account (https://www.linkedin.com/company/t-fors)
- Zenodo account (https://zenodo.org/records/8085475)
- YouTube Channel (https://www.youtube.com/@T-FORSproject)

Different materials, reports and video presentations are being shared via the social networks to enhance knowledge on the effects of TID and awareness of their in certain types of applications.





REVIEW VIDEO

A video promotion introducing T-FORS, travelling ionospheric disturbance forecasting system, designed and developed with the support of the Horizon Europe programme to generate space weather warnings and alerts, has been released (https://www.youtube.com/watch?v=DbbsH123Yic).

The video provides an overview of the project objectives, and several interviews with experts explaining the different types of TIDs and effects, the capabilities in Europe to measure and track such disturbances, the modelling and predictions of TIDs to anticipate and manage the impact of TIDs on our technology-reliant systems, and the participation of users to address practical experience in operating radio communication systems and to discuss the TIDs impacts on them.

OUTREACH ACTIVITIES

The Ionospheric Group of the Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS) of the National Observatory of Athens (NOA) contributed to the "Athens Researcher's Night 2023" on 29 September 2023 (https://researchersnight.gr/).

The NOA team talked with school and university students about the observations of the Athens Digisonde, the Ionosphere, the Solar Storms, and the Aurora, and has demonstrated Athens Digisonde operations in real-time.

In the framework of the Hungarian Science Day the Space Science Unit of **the Institute of Earth Physics and Space Science (FI)** organised a lecture series about the space weather and its impact to the manmade infrastructure on 9 November, 2023. The "Hungarian Science Day" is a feast in November every year to celebrate the foundation of the Hungarian Academy of Sciences.

One of the presentations was dedicated to the Travelling Ionospheric Disturbances - as one type of space weather risk - and to the T-FORS project. The programme of the lecture series and the above-mentioned presentation is available (in Hungarian) at https://epss.hun-ren.hu/mtu-rendezvenyek-2023/.

TRAINING SCHOOL

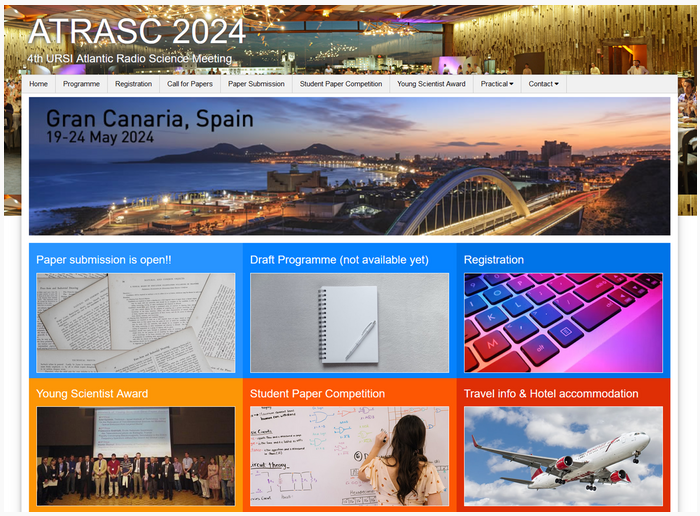
T-FORS supports the Second Training School of the PITHIA-NRF Plasmasphere Thermosphere and Ionosphere Integrated Research Environment supported by Machine Learning models (https://t-fors.eu/activities-results/training/training-school).

T-FORS teams contribute to the programme of the school by preparing lectures on the physical mechanisms acting in the Earth's Ionosphere, Thermosphere and Plasmasphere as parts of the coupled Sun-Earth system and theoretical lectures on the TIDs triggering mechanisms and detection methodologies.

The school has been promoted by a poster at the ESWW2023 (T-FORS Poster) and at the First Innovation Day of the T-FORS project.

URSI AT-RASC 2024

A conference session into the Union Radio Scientifique Internationale (URSI) meeting URSI AT-RASC 2024 (https://www.atrasc.com/home.php) devoted to Travelling Ionospheric Disturbances (TIDs) has been organised (Session G2). The initiative for this conference session raised in the framework of the T-FORS project and will focus on the nowcasting and forecasting Travelling Ionospheric Disturbances for ionospheric weather and mitigation services. The session G2 invites contributions on TIDs identification and tracking experiments and methodologies, on models for nowcasting and forecasting TIDs and corresponding ionospheric weather services, descriptions of operational issues caused by TIDs, and possible mitigation technologies able to prevent degradation of the applications concerned and it is co convened by experts involved in the T-FORS projects.



Session	Title	Convener names & e-mails	Number of slots
G02	**Nowcasting and forecasting Travelling Ionospheric Disturbances for ionospheric weather and mitigation services**	Geoff Crowley, David Altadill Felip, Anna Belehaki, Sivakandan Mani geoff.crowley@orionspace.com, david_altadill@obsebre.es, belehaki@noa.gr, mani@iap-kborn.de	10 / 15

Description: Travelling Ionospheric Disturbances (TIDs) are plasma density fluctuations that propagate as waves through the ionosphere at a wide range of velocities and frequencies and play an important role in the exchange of momentum and energy between various regions of the upper atmosphere. TIDs are the ionospheric manifestation of internal atmospheric gravity waves (AGW) in the neutral atmosphere and are associated with auroral and geomagnetic activity and with lower atmosphere phenomena of non-space origin (e.g., severe tropospheric convection or passages of cold fronts, seismicity, volcanic activity, and artificially triggered events such as explosions). The exact physical mechanisms of TID formation, the trigger mechanisms, the basic properties and parameters of TIDs and their propagation direction from the source, how they dissipate with distance and how background ionospheric conditions affect their propagation, have still not been fully characterized or understood. Nevertheless, it is confirmed that TIDs constitute a threat for operational systems that use simple predictions of ionospheric characteristics and especially in ground-based and aerospace applications. The session invites contributions on TIDs identification and tracking experiments and methodologies, on models for nowcasting and forecasting TIDs and corresponding ionospheric weather services, descriptions of operational issues caused by TIDs, and possible mitigation technologies able to prevent degradation of the applications concerned.

SCIENTIFIC REVIEW

The first scientific review of the T-FORS project was organized by HaDEA on 13 December 2023. Several members of the project met in Brussels with the EC Project Officer and the Scientific Observer in a special meeting where progress and main results were presented.

Our consortium received congratulations for the good progress and we all look forward to the final review where the prototype T-FORS system will be presented.

PUBLICATIONS

Here we list indicative articles. A full list of publications, presentations and reports related to T-FORS can be found on the project website.

Conference Meetings

- Fabbro, V., Garcia, A., Molinié, J.-Ph, Brouard, Ph., Belehaki, A., Themelis, K., et al. (2023). T-FORS: Travelling Ionospheric Disturbances FORecasting System. ESWW19, Toulouse, France, November 2023.
- Segarra, A., Altadill, D., de Paula, V., and Navas, V. (2023). Climatological Characteristics of Large Scale Travelling Ionospheric Disturbances Detected by HF-Interferometry Method. ESWW19, Toulouse, France, November 2023.
- Barta, V., Kouba, D., Mielich, J., Burešová, D., Mošna, Z., Koucká Knížová, P., Studying the ionospheric absorption variation using European Digisonde data during intense solar flares in September 2017, ESWW19, Toulouse, France, November 2023.
- Berényi, K.A., Opitz, A., Dálya, Zs., Kis, Á., Barta, V., Impact of ICME- and SIR/CIR-Driven Geomagnetic Storms on the Ionosphere over Hungary, ESWW19, Toulouse, France, November 2023.

Papers

- Haralambous, H., Guerra, M., Chum, J., Verhulst, T. G. W., Barta, V., Altadill, D., et al. (2023). Multi-instrument observations of various ionospheric disturbances caused by the 6 February 2023 Turkey earthquake. Journal of Geophysical Research: Space Physics, 128, e2023JA031691. https://doi.org/10.1029/2023JA031691.

T-FORS PARTNERS

ABOUT

Title
Travelling Ionospheric Disturbances Forecasting System (T-FORS)

Topic
HORIZON-CL4-2022-SPACE-01-62

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Observatorio del Ebro Fundación

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