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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.

INTRODUCTION TO THE PROJECT

Travelling Ionospheric Disturbances (TIDs) are plasma density fluctuations that propagate as waves through the ionosphere at a wide range of velocities and frequencies. TIDs are driven by the auroral and geomagnetic activity, by lower atmosphere phenomena of non-space origin (e.g., severe tropospheric convection or passages of cold fronts, seismicity, volcanic activity) but also by artificially triggered events such as explosions. TIDs constitute a threat for operational systems using predictable ionospheric characteristics as they can impose significant disturbances in the ambient electron density and Doppler frequency shifts on High Frequency (HF) signals. TIDs can have multiple effects in the operation of aerospatial and ground-based infrastructures and especially in HF radars and direction finding systems, in GNSS-based applications and especially in the European Geostationary Navigation Overlay Service (EGNOS) and in Network Real-Time Kinematic (N-RTK) services.

Because of the multiple triggering mechanisms of TIDs, and because of the variety of their velocity, propagation direction and amplitude, their identification, tracking and especially their forecast is a real challenge.

T-FORS attempts for the first time to forecast TIDs deploying scientific models able to interpret a broad range of observations of the solar corona, the interplanetary medium, the magnetosphere, the ionosphere and the atmosphere.

"T-FORS aims at the transition of the scientific outcome to actionable products in order to address economic and technological challenges, [...] at ensuring the safety and sustainability of space operations in Europe"

The models will provide forecasts and warnings for TIDs several hours ahead and will be based on both empirical and ML learning methods.

T-FORS aims at the transition of the scientific outcome to actionable products in order to address economic and technological challenges by developing novel architectures and technical solutions for ground/space sensors, data processing, networking and operation canters, including critical technological elements for the realisation of crucial future space weather applications and services. T-FORS activities aim at ensuring the safety and sustainability of space operations in Europe as well as by improving EU Space Surveillance and Tracking (SST) services and implementing new ones, such as space debris mitigation and remediation services and space weather services.

If successful, space weather prediction capabilities will be drastically improved in accuracy and availability at a global scale. Given that the T-FORS concept is based on the exploitation of ground-based observing facilities operated by European institutions, such a project strengthens European autonomy in developing an operational space weather prediction system.

STATE OF THE ART

The state-of-the-art standards and capabilities in TID detection and forecast methodologies have been reviewed to strategize the T-FORS priorities. We leveraged the beneficiaries' experience in implementing space weather projects and conducted a literature review of TID detection experiments, methodologies, propagation models, and relevant operational services. Our investigation has confirmed a strong capability for sensing TID activity using various radio, in-situ, and optical instrumentation. Several observational techniques have been noted for their applicability to unattended real-time weather forecasts. Yet, the underlying complexity of physical processes in relevant regions in the atmosphere, ionosphere, thermosphere, magnetosphere, and heliosphere resists their accurate collective description in the consortium of non-linear relations and varying contributions. The science community is only beginning to approach this monumental task; no direct implementations of the operational algorithms for TID forecast have been identified in the literature or practice.

Given the complexity of the problem, Machine Learning (ML) and statistical treatment are proposed for the tasks. When provided with a good historical dataset of the system behavior, ML has a well-recognized capability of gleaning a deep understanding of the otherwise hidden essence of the system dynamics. Combined with another capability to automatically learn and improve its representations from experience, without being reprogrammed, ML can offer superior TID forecasting skills to explore in T-FORS. In particular, one chain of events has been understood to the level that will admit its forecast: during intense geomagnetic storms, associated Joule and particle heating at high latitudes cause significant disturbances in the upper atmosphere and create strong globally propagating LSTIDs. As for the MSTIDs, their prediction appears feasible via statistical considerations that reveal significant patterns of repetitive behavior.

LSTID FORECASTING: BRIDGING THE GAP IN SPACE WEATHER PREDICTION

"We anticipate the development of three distinct versions of the LSTID model: Short-Term High-Accuracy Model, Medium-Term Medium-Accuracy Model, Long-Term Low-Accuracy (LT-LA) LSTID Model"

In the realm of space weather forecasting, one enigmatic phenomenon has eluded precise prediction: Large-Scale Travelling Ionospheric Disturbances (LSTIDs).

These elusive disturbances are a forecasting-challenge due to their intricate triggering mechanisms and the complex multiparametric propagation patterns they exhibit.

LSTIDs are generally regarded as manifestations of atmospheric gravity waves (AGWs) within the ionosphere, often accompanied by auroral and geomagnetic activity. Despite their significance, key aspects of LSTIDs, including their formation mechanisms, energy transformation within the magnetosphere-ionosphere-thermosphere system, trigger mechanisms, fundamental properties, propagation characteristics, and their response to background ionospheric conditions, remain inadequately defined.

However, there is one specific case of LSTID forecasting that offers a simpler outlook—the affected regions of the European continent. The large-scale disturbances responsible for generating LSTIDs span thousands of kilometres, and their atmospheric dynamics can be attributed to two critical regions on Earth: the Polar Ovals. The rapid heating of the Polar Oval atmosphere, induced by energetic particle precipitation, results in instantaneous temperature gradients that initiate plasma disturbances on a scale of a few thousand kilometres.

Predicting the energy dissipation within the Polar Oval provides a promising avenue for determining the timing and location of LSTID triggers. To achieve this, T-FORS develops early forecasting methodologies for solar wind-magnetosphere-ionosphere coupling and their source mechanisms in the solar corona. We envision constructing a Machine Learning forecasting framework that utilizes features derived from geospace regions, whether directly measured or calculated. In line with recent trends in Machine Learning for time series forecasting, we intend to leverage these novel tools to predict LSTIDs.

Our training labels will be drawn from the valuable data series of LSTID characteristics detected and stored in the database from the previous TechTIDE project.

These tools will harness all available prior information, including data measurements related to solar activity, magnetosphere-solar wind coupling, ionospheric conditions, and the geomagnetic field. The resultant architecture will establish a European regional predictive model for detecting Traveling Ionospheric Disturbances (TIDs). Recognizing the complexity of LSTID occurrence, we propose a multifaceted modelling approach within the T-FORS project. This approach entails:

- Forecasting solar wind parameters at L1 based on estimated CME parameters derived from solar images.
- Predicting magnetic disturbances at ground level, using the solar wind parameters at L1 (both measured and forecasted).
- Alerting for the presence of LSTIDs and forecasting their parameters (onset time, period, azimuth, and duration) based on magnetic disturbances at ground level (again, both measured and forecasted).

We anticipate the development of three distinct versions of the LSTID model: Short-Term High-Accuracy Model, Medium-Term Medium-Accuracy Model, Long-Term Low-Accuracy (LT-LA) LSTID Model.

Stay tuned as we embark on this ground-breaking journey to enhance our understanding and forecasting capabilities of LSTIDs, unravelling the mysteries of space weather in the process.

MEDIUM SCALE TRAVELING IONOSPHERIC DISTURBANCES (MSTID) PROBABILISTIC FORECASTING SYSTEM

"We will [...] establish the MSTID climatology information over Europe."

MSTID is a wave-like perturbation in the ionospheric electron density with a horizontal scale size of 100 to 500 km. MSTID is classified into two categories viz. day and nighttime. The daytime MSTIDs are mostly driven by the gravity waves originating in the lower and middle atmosphere, and the nighttime MSTIDs are generated by the electrodynamic coupling processes between the E and F regions. Extreme tropospheric weather events such as cyclones, thunderstorms, and cold fronts, as well as lithospheric disturbances like earthquakes, and tsunamis also can trigger the MSTID in the ionosphere.

MSTID can cause 2 to 10% perturbation in the plasma density depending on the source, and it could be a potential threat to the HAM radio. However, the climatology of the MSTID over the European sector is not understood well.

In this work package, we will be addressing the following three main objectives:

1. Establish the MSTID climatology information over Europe.
2. Develop a probabilistic (empirical) MSTID model.
3. Issue the forecast (warning alert) to the extreme events associated with MSTID.

To attain these objectives we have the work plan in the figure that follows (*Figure 1.*).

Eight of the consortium partners are involved in this work package out of the ten.

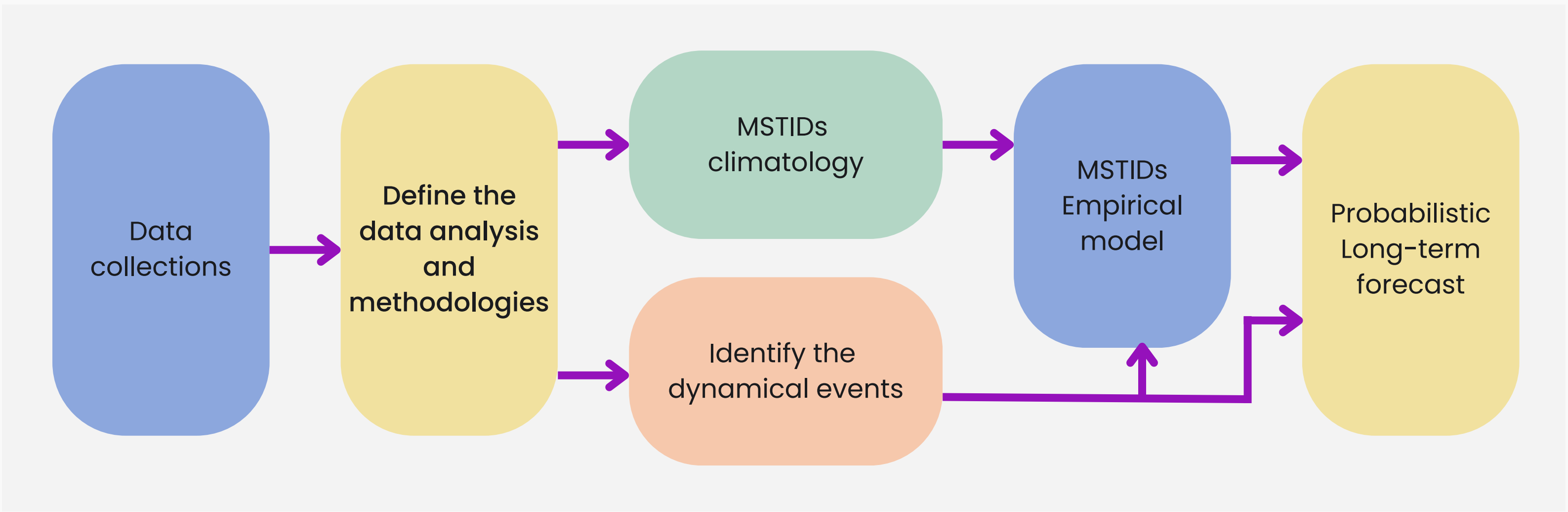


Figure 1. Schematic diagram for the general approach to implement our plans

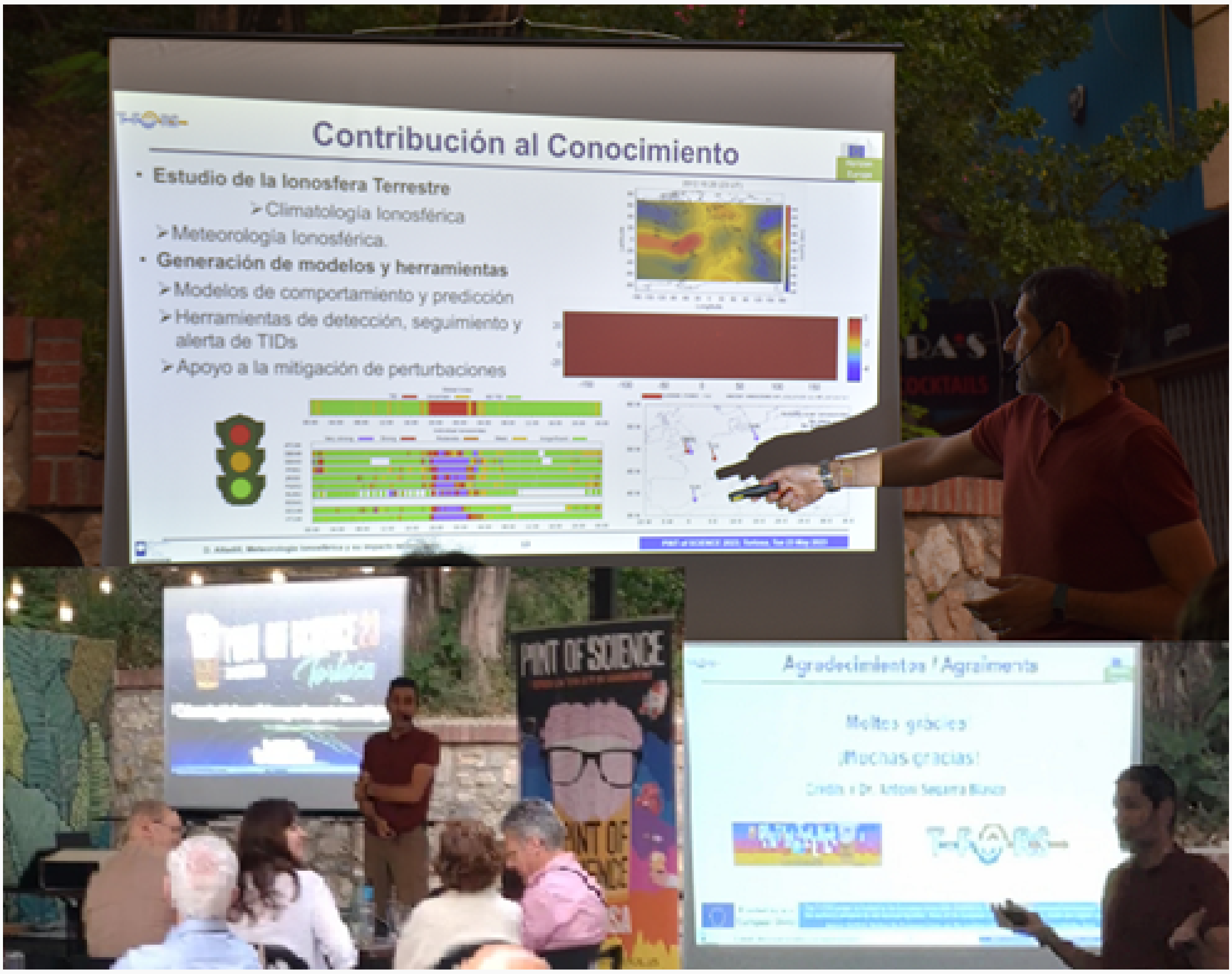
OUTREACH ACTIVITIES

The Observatori de l' Ebre (OE) have contributed to the outreach activity "Pint of Science Spain" presenting to the general public "Ionospheric meteorology and technology impacts" (https://pintofscience.es/event/dia-2; https://www.icsebre.cat/wg/el-festival-de-divulgacio-cientifica-pint-of-science-torna-a-ser-protagonista-a-tortosa-i-amposta-els-dies-22-i-23-de-maig-en-la-seva-8a-edicio/).

The talk have explained what the Ionosphere is, its dynamics and its effects on technological systems of communication and navigation, on which we depend more and more every day.

We have shown the impact of ionospheric dynamics on applications of these technological systems, and the need to have an accurate monitoring and prediction of ionospheric meteorology.

We have also discussed on the contribution of the team to provide the most accurate specification possible of ionospheric dynamics and other value-added products derived from such knowledge, such as detecting volcanic explosions and large earthquakes".



OE also have contributed to the CSIC Day of scientific collaboration in security and defense explaining the assets of the team and projects developed for analysis and modeling of Geomagnetic and Ionospheric Meteorology and its Technological Impact (https://www.youtube.com/watch?v=oyYtnycvrdI (2:00:00 – 2:15:00)).

Institute of Earth Physics and Space Science (Sopron, Hungary) held an open day for primary school students on 8 June 2023. The researchers gave talk about the solar - terrestrial physics, Earth's environment and especially about the ionosphere. The presentations focused on effects of the space weather events on the modern technological systems, thus the necessity of the monitoring and prediction of the mechanisms at the near-Earth space.

The **National Observatory of Athens (NOA)** team contributed to the 28th Summer School of Astrophysics organised by NOA's Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS) from August 31 to September 1, 2023.

The school was attended by fifty high school students attending the first two years of high school (16-17 years old). The students attended general lectures on astrophysics/space physics/ionosphere.

They were then divided into groups, and one of them worked on the laboratory topic on "Broadcasting radio waves into space", under Dr. A. Belehaki's supervision.

Finally, they presented the results of their project (vertical and lateral emission of radio waves – Marconi's experiment) to all students and parents.

CALL FOR THE TOPICAL ISSUE

A Topical Issue (TI) devoted to Traveling Ionospheric Disturbances (TIDs) have been recently announced in the Journal of Space Weather and Space Climate (JSWSC). The initiative for this TI raised in the framework of the project T-FORS. The TI welcomes manuscripts which address the TID identification and tracking, TID nowcasting and forecasting, the methods and technologies capable of mitigating adverse effects of TIDs on the performance of critical space and ground-based infrastructure, as well as feeding the obtained results into ionospheric weather services. The deadline for submissions is 1st June 2024. More details are available at https://www.swsc-journal.org/topical-issues-open-for-submission.

CALL FOR THE TRAINING SCHOOL

A training school for early career scientists will be organised by the T-FORS project between 5 and 9 February 2024 at the premises of the University of Leuven, Belgium. This event will be organised jointly with a training school organised by the Horizon 2020 project PITHIA. The school will consist of a combination of theoretical lectures and hands-on sessions using various models and data-sets related to the ionosphere/thermosphere/plasmasphere environment. Limited funds are available for travel support for selected students. All information can be found on the website: https://t-fors.eu/activities-results/training/training-school.

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.

Papers

- Sergii V. Panasenko, Kateryna D. Aksonova, Dalia Buresova, Oleksandr V. Bogomaz, Taras G. Zhivolup, Oleksandr V. Koloskov, "Large-scale travelling ionospheric disturbances over central and eastern Europe during moderate magnetic storm period on 22—24 September 2020", Advances in Space Research, Manuscript Number: AISR-D-23-00785R2. (accepted)
- Guerra, M., Cesaroni, C., Spogli, L., & Crespi, M. "Traveling Ionospheric Disturbances detection: a TEC detrending techniques comparison and a study of their impact on extracted parameters". Proceedings of URSI GASS 2023, Sapporo, Japan, 19-26 August 2023. Available at: https://www.ursi.org/proceedings/procGA23/papers/YSASummaryGuerraMarcoC.pdf.

Presentations

- Guerra, M., Cesaroni, C., Spogli, L., & Crespi, M. "Traveling Ionospheric Disturbances detection: a TEC detrending techniques comparison and a study of their impact on extracted parameters". URSI GASS 2023, Sapporo, Japan, 19-26 August 2023.
- A. Belehaki, T.G.W. Verhulst*, L. Spogli, C. Cesaroni, D. Altadill, I. Galkin, D. Buresova, S. Mani, S. Unger, V. Barta, P. Brouard (2023): "T-FORS: a project to develop TID forecasting systems". URSI GASS 2023, Sapporo, Japan, 19-26 August 2023.
- D. Buresova, J. Chum, S. V. Panasenko, I. Galkin, K. D. Aksonova, J. Rusz, P. Koucka Knizova, D. Kouba, O. V. Bogomaz, T. G. Zhivolup, A. V. Koloskov: "Results of multiinstrumental observations of traveling ionospheric disturbances triggered by different sources over Europe", URSI GASS 2023, Session G16 - The crucial role of integrated research infrastructures for monitoring and modelling the upper atmosphere, Sapporo, Japan, 19-26 August 2023.
- P. Koucká Knížová, K. Potužníková, K. Podolská, D. Burešová*, Z. Mošna, D. Kouba, J. Chum, P. Hannawald, S. Wüst, M. Bittner: "Ionospheric variability observed in connection to mesoscale systems above Europe", URSI GASS 2023, Session GH2 - Plasma Instabilities in the Ionosphere, Sapporo, Japan, 19-26 August 2023.
- J. Urbář*, L. Rejfek, J. Chum, V. Truhlík, J. Rusz, J. Baše, J. Horký, J. Šimůnek, Z. Mošna, D. Kouba, D. Burešová: "Relations of HF Doppler Ionospheric Monitoring with GNSS Positioning Errors", URSI GASS 2023, Sapporo, Japan, 19-26 August 2023.
- V. Barta, D. Kouba, J. Mielich, D. Burešová, Z. Mošna, P. Koucká Knížová, A. Buzás, A03p-002: "Studying the ionospheric absorption variation using European Digisonde data during intense solar flares in September 2017", 28th IUGG General Assembly, Berlin, Germany (11-20 July 2023). Symposium: A03 - Coupling Processes in the Atmosphere-Ionosphere System.
- P. Koucká Knížová, K. Potužníková, K. Podolská, J. Chum, Z. Mošna, D. Kouba, D. Obrazová, V. Barta, K.A. Berényi, C. Szárnya, A. Buzás, I. Bozsó, A03p-005: "Mesoscale cyclone Zyprian and its signatures within ionospheric plasma", 28th IUGG General Assembly, Berlin, Germany (11-20 July 2023). Symposium: A03 - Coupling Processes in the Atmosphere-Ionosphere System.
- K. D. Aksonova, S. V. Panasenko, D. Buresova: "Characteristics of travelling ionospheric disturbances over the European mid-latitude region during 24 Solar Cycle", 28th IUGG General Assembly, Berlin, Germany (11-20 July 2023).
- C. Cesaroni, M. Guerra, L. Spogli, I. Galkin, H. Haralambous, T.G.W. Verhulst, A. Belehaki, D. Altadill, A. Segarra, V. Barta, D. Kouba, D. Buresova and J. Mielich: "Ionospheric effects of the M7.8 and M7.5 Turkey-Syria Earthquake Sequence on February 6, 2023" 28th IUGG General Assembly, Berlin, Germany (11-20 July 2023). Abstract number IUGG23-3369. Symposium JA08 - Ground and Satellite Electromagnetic Observations Related to Earthquakes, Tsunami's and Volcanic Activity (IAGA, IASPEI (EMSEV), IAVCEI).

T-FORS PARTNERS

ABOUT

Title
Travelling Ionospheric Disturbances Forecasting System (T-FORS)

Topic
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