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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.

ADVANCEMENTS IN LSTID FORECASTING

We're excited to share the latest developments on the forecasting of Large-Scale Travelling Ionospheric Disturbances (LSTIDs). Our primary objective remains steadfast: to predict the occurrence and propagation characteristics of LSTIDs across various atmospheric regions. The first version of the models have been released and they are able to predict the LSTID occurrence with an horizon of 1 to 3 hours. Here's a glimpse into our recent progress and methodologies:

Catalogue-based Forecasting Model: In our first approach, detected TID characteristics are provided by an improved version of the TechTIDE catalogue based on the network of ionosondes over Europe and covering the period 2014-2022.

We devised a multivariate time-series binary classification model to predict the occurrence of LSTIDs. The developed model stems from an efficient, fast, and scalable gradient-boosting on decision trees framework (CatBoost). The algorithms, including CatBoost, have achieved predictions of LSTID events within the 3 hours. Notably, our explanatory framework (SHAP) aids in deciphering feature influences, enhancing both interpretability and model refinement. To explore the code and methodologies further, visit our GitHub repository here. It also includes a link to a timeline viewer of the model results (*see Figure 1 below*).

Figure 1. Timeline viewer of Catalogue-based Forecasting Model showing main features and target variable vs. model output

HF-Interferometry Based Forecasting Model Over Digisonde Locations: In our second strategy, we have tackled LSTID forecasting through a multivariate time-series binary classification paradigm. Leveraging PyTorch, we've developed a Temporal Fusion Transformer (TFT) classifier, adept at capturing intricate relationships within the data. By meticulously pre-processing data and optimising model parameters, we've achieved promising forecasting accuracies, even up to a two-hour horizon. To delve into the code and datasets utilised, explore our open research repository here.

The figure below (*Figure 2*) displays the performance of the proposed TFT classifier for the location of the Ebro Digisonde, as compared to state-of-the-art tools, such as a Forward Neural Network and a k-Nearest Neighbor classifier.

In our experiment, LSTID forecasts are performed for a time period up to two hours ahead using as features the Spectral Energy Contribution of the MUF calculated with the HF Interferometry method, the auroral electrojet indices derived from the IMAGE network operated by the Finnish Meteorologic Institute (FMI) and the GNSS TEC gradients at high latitudes calculated by the German Aerospace Center (DLR) and provided by the TechTIDE service. The performance is measured in terms of the f1 score, which is the harmonic mean of the precision and recall of the binary classifier.

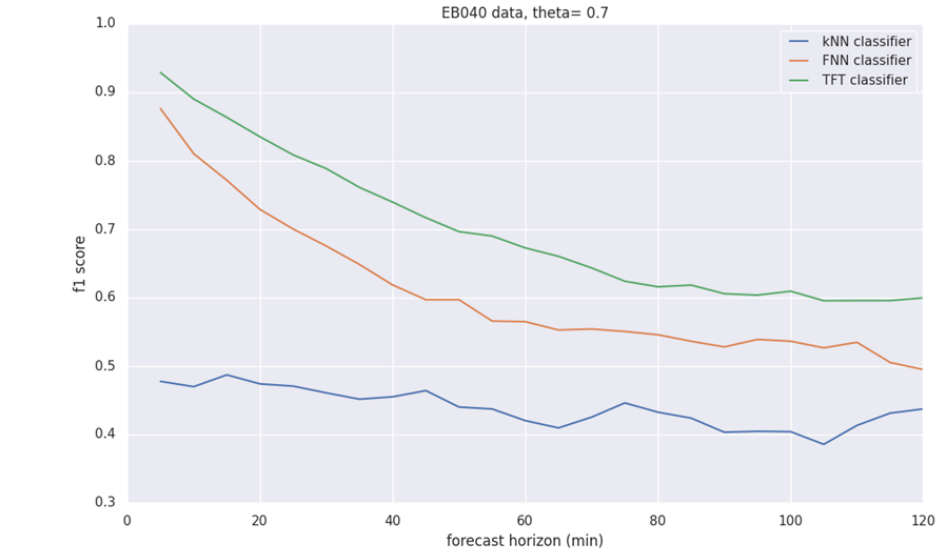


Figure 2. Performance of the proposed TFT classifier for the location of the Ebro Digisonde

These advancements mark significant strides in our quest to enhance LSTID forecasting capabilities and thorough validation of the proposed models will be provided very soon to the community. Stay tuned for more updates and insights from the T-FORS project!

LSTID Forecast Data products

The T-FORS forecasting models for LSTIDs are the basis for the design of data products tuned to the users' needs. More specifically, the following data products are under development:

- Forecast (Yes/No) of LSTID activity over each Digisonde location and over the whole European region with occurrence probability, based on helio- and geospace activity indicators.
- Forecast of LSTID characteristics with a horizon of 24 hrs, 3hrs, and 1hr.
- Large Scale TID activity alerts, issued when the results obtained from the AI/ML models forecast that the expected TID activity exceeds a certain threshold.
- The current values of the TIDs drivers.

Demonstration based on event-cases are expected to be released through the T-FORS portal within the second half of 2024.

PROGRESS IN MSTID CLIMATOLOGY MODEL AND ALERT ISSUING SYSTEM

Here we review the latest activities regarding the development of a climatological model for MSTIDs and the determination of the alert criteria and early activity indicators.

Review of the climatological model

In order to provide the forecasting, we planned to develop a detrended total electron content based multiple linear regression model. Nevertheless, it is clear that the model can't reproduce 100% reliably the observed dTEC.

This suggests that the variability in the dTEC is not fully controlled by neither the auroral electrojet nor the geomagnetic disturbances in the mid-latitude. Thus, we believe that the lower atmospheric sources could be the potential powerful drivers for the MSTIDs. Therefore, we follow a new approach based on the quartiles estimation. As a first step we applied the quartile approach for the month of August 2023. The preliminary results are impressive. The revised climatology reproduces quite well the diurnal pattern of MSTID and the deviation from the interquartile range can provide the basis for alerts definition. Therefore, we will extend our analysis for different seasons and solar activity conditions. The alerts will be validated following the methodology for probabilistic predictions, based on the analysis of cases not included for the derivation of alerts criteria.

MSTID activity during intense tropospheric events and under disturbed geomagnetic conditions

Then we investigated in detail the MSTID activity detected by different observational techniques during severe tropospheric events and under disturbed geomagnetic conditions. MSTID occurrence characteristics were analysed during the extreme tropospheric events using the ionosonde network (7 ionosondes) over Europe. The occurrence and intensity of MSTID activity presented in the ionograms at the different stations were carefully investigated at an hourly rate during the tropospheric events and it has been compared with the analysis used for the climatology. In the case of the less intense tropospheric event the MSTID occurrence basically agreed well with the climatology, except for some stations where activity exceeded it during the passage of the front. The occurrence rate and the intensity of the MSTIDs were much higher in the case of the more intense tropospheric event, very high activity with extremely distorted F trace on the ionograms were detected at the higher mid-latitude stations (Dourbes, Juliusruh, Pruhonice, Sopron). Consequently, the presence of the extremely strong tropospheric event had a great impact on the occurrence of MSTID activity based on the analysis of the ionograms.

Inventory of activity indicators

In the next step we compared the MSTID activity observed during severe tropospheric events and under disturbed geomagnetic conditions with the different meteorological, auroral and geomagnetic activity parameters that can be taken into account as enhanced MSTID activity indicators.

A detailed list of the meteorological maps and local meteorological parameters were presented that can be taken into account as activity indicators for the mechanisms (like front passage, large convection, and jetstream) that can trigger MSTIDs. The peak time of the MSTID activity observed on the ionograms and by single station dTEC measurements agree well with the period when the jetstream reached its highest values (80-90 m/s) during the two investigated events. Consequently, the jetstream seems to be a good activity indicator for the MSTIDs that can be observed also in the dTEC measurements. On the other hand, comparing the MSTID activity detected by other observational techniques (CDSS and D2D measurements and further developed HF-INT method (*see Figure 3 below*) with the lightning activity nearby (< 500 km) and with the local meteorological data we can conclude that they agree well with the passage of the front and the large convection over the region. Thus, different activity indicators can be used for the MSTIDs observed at different heights in the ionosphere by different observational techniques.

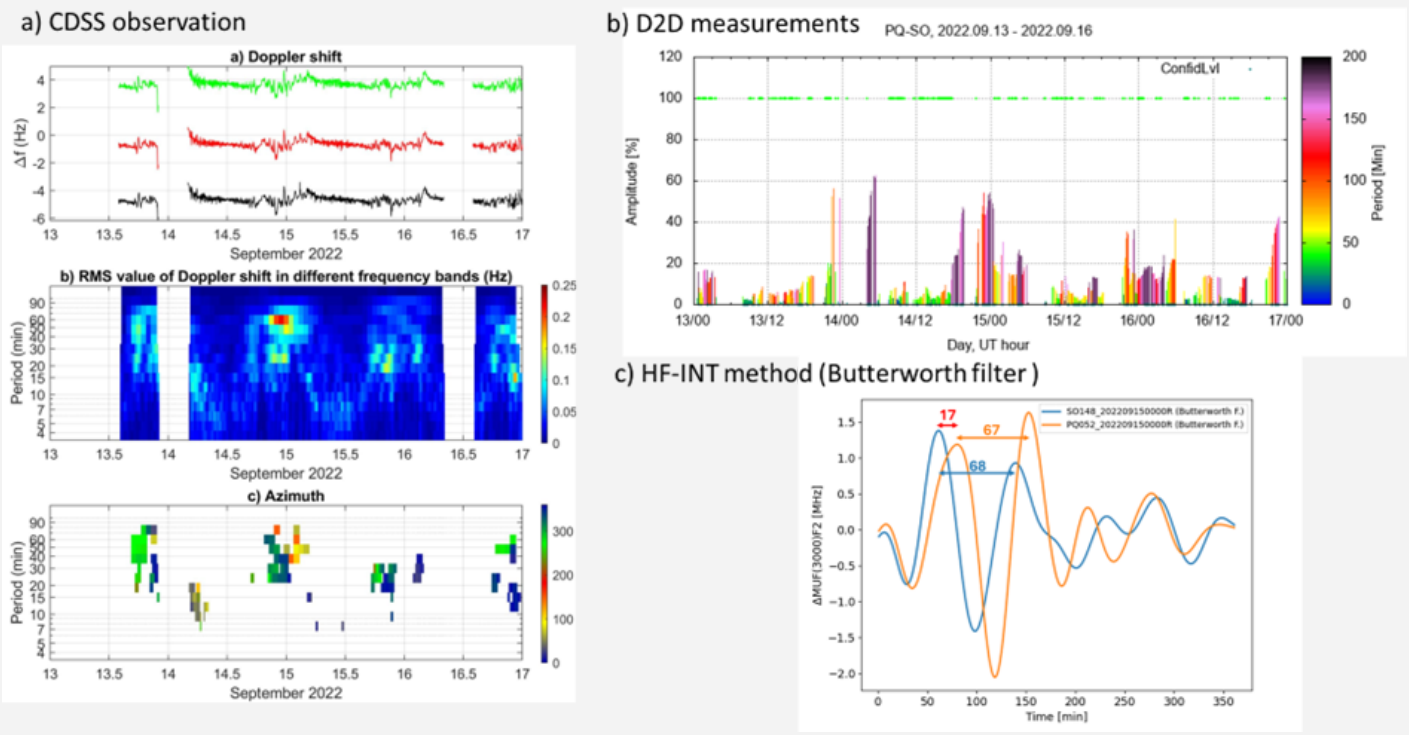


Figure 3. MSTID activity with periods 20-60 min was observed by the Czech CDSS network at 4.65 MHz in the evening of 14 September and nighttime hours of 15 September (a) when the cold front began to penetrate intensively into central Europe. The D2D sounding data also indicates higher activity of MSTIDs with periods up to 60 min in the nighttime and morning hours of 14/15 September (b). The HF Int method has been modified to focus on a shorter period range (20 - 80 minutes), which is attributed to the MSTIDs, for the nighttime of 14-15 September and to the closest stations in central Europe (PQ052, and SO148). SO148 and PQ052 indicated coherent periodicities at 68 and 67 minutes respectively on the investigated night (c).

As for the geomagnetic activity indicators IU, IL and IE indices (source: https://space.fmi.fi/image/www/index.php?page=il_index) could be suitable indicators of the enhanced TID activity over the European region based on our analysis.

Very often it is very difficult to identify MSTIDs independently because especially in the case of strong geomagnetic disturbances many LSTIDs are generated in the auroral region and move towards low latitudes. Therefore, for the purpose of our analysis, we chose medium-sized disturbances and were also successful in observing MSTID storm-time activity.

TRAINING SCHOOL OF THE T-FORS PROJECT

In February the Training School of the T-FORS project was organised at the Katholieke Universiteit Leuven, Belgium. This school was organised as a joined activity between T-FORS and the consortium of the PITHIA-NRF project, another project funded by the EC focusing on research (e-)infrastructure for space weather in Europe. Because of the close relation and complementary of both projects, it was decided to join forces for this event and provide one week-long school.

Fifteen students from nine different countries (Belgium, Brazil, Egypt, Germany, Ghana, Greece, Hungary, Italy and Spain) attended the school. They attended both general, introductory lectures on various aspects of space weather and lectures specifically concerning travelling ionospheric disturbances (TIDs).

At the end of the school, the students also did some practical exercises, including about TIDs.

The lectures given during the Training School were recorded and are now accessible to everyone via the T-FORS YouTube channel. Additionally, the complete program of the school and lecture slides, provided in PDF format, can be accessed on the T-FORS website.

URSI AT-RASC 2024 MEETING

T-FORS members have actively contributed to organize a conference session into the Union Radio Scientifique Internationale (URSI) meeting URSI AT-RASC 2024 (https://www.atrasc.com/home.php).

Session G02 will focus on the Nowcasting and forecasting Travelling Ionospheric Disturbances for ionospheric weather and mitigation services.

The session G02 will have 11 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. The G02 session of the URSI AT-RASC 2024 is co convened by Dr. Anna Belehaki, Dr. David Altadill Felip, and Dr. Sivakandan Mani.

Members of the project consortium will be presenting their scientific research at URSI AT-RASC 2024:

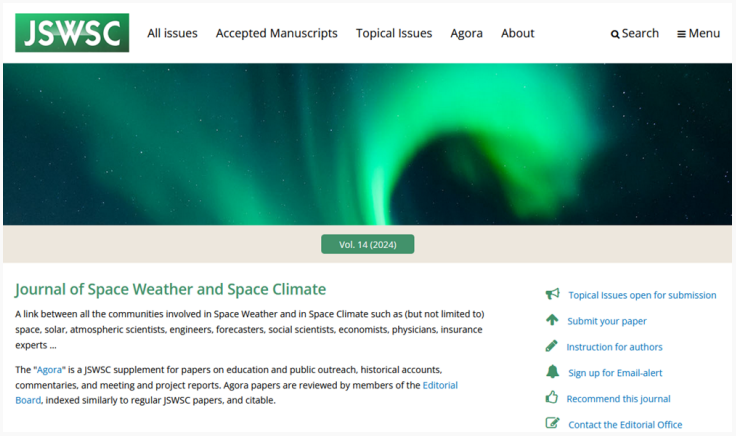
- Themelis, K., K. Koutroumbas, A. Belehaki, D. Altadill, A. Segarra, Short-term forecast of Large Scale Travelling Ionospheric Disturbances in Europe using traditional and advanced Neural Network Classifiers, Accepted for presentation in session G02.
- Barta, V., D. Buresova, S. Mani, J., Chum, A. Belehaki, J. Mielich, T. Verhulst, D. Altadill, A. Segarra, D. Kouba, Z. Mosna, J. Urbar, O. Koucka-Knizova, K. Berenyi, M. Guerra, C. Cesaroni, L. Spogli, Multi-instrument analysis of MSTIDs generated by extreme tropospheric events in Europe, Accepted for presentation in session G02.
- Mani, S., J. Mielich, J. Chau, Climatology of the Traveling Ionospheric Disturbances over Europe, Accepted for presentation in session G02.
- Guerra, M., H. Haralambous, J. Cum, T. Verhulst, V. Barta, D. Altadill, C. Cesaroni, I. Galkin, M. Kiszely, J. Mielich, D. Kouba, D. Buresova, A. Segarra, L. Spogli, J. Rusz, J. Zednik, Multi-Instrument detection of the ionospheric response to the 6 February 2023 Turkey Earthquake, Accepted for presentation in session G02.

SPECIAL ISSUE

T-FORS project supports the initiative of the Journal of Space Weather and Space Climate (JSWSC) to open a Topical Issue (TI) devoted to Traveling Ionospheric Disturbances (TIDs).

The TI **"Observing, modelling and forecasting TIDs and mitigating their impact on technology"** 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.

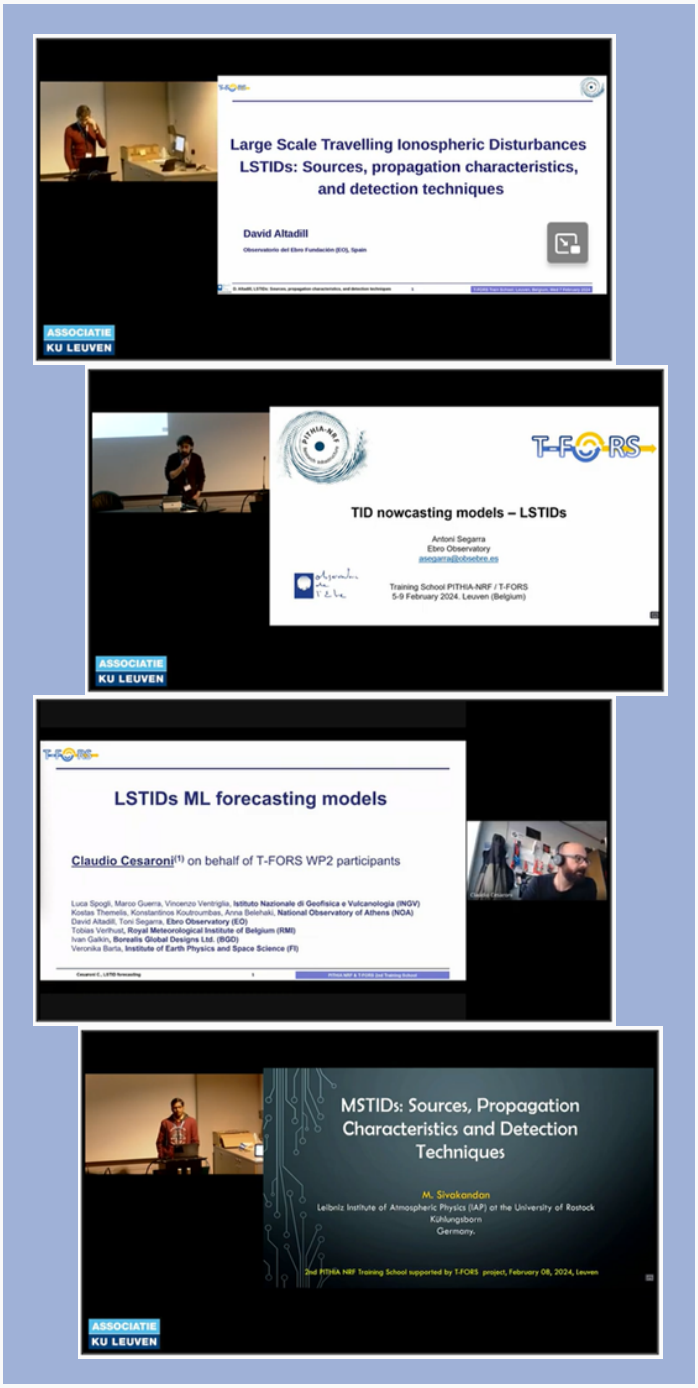
Manuscripts on methods and technologies capable of mitigating adverse effects of TIDs on the performance of critical space and ground-based infrastructure are also welcome in this TI. The deadline for submissions is 1st June 2024.



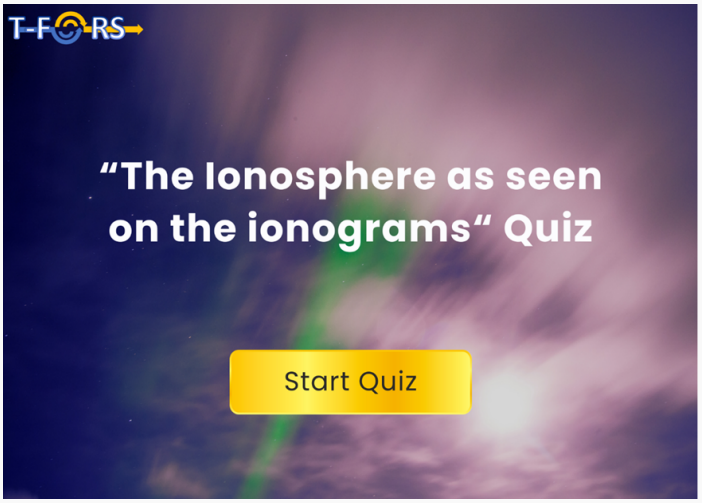
KNOWLEDGE HUB

The T-FORS Knowledge Hub has been populated offering new material.

We have created a Webinar section within the Knowledge Hub dedicated to lectures specifically focusing on TIDs recorded during the T-FORS training school. Future plans envisage to incorporate more presentations as webinars as they are conducted.



The Knowledge Hub has also been completed by a quiz about the different features detected on the ionograms. The quiz has been added to the end of the training about the basic properties of the Ionosphere recorded by the ionograms, thus after the training one can test the acquired knowledge. Take the quiz to assess your comprehension of the Ionosphere!



T-FORS PARTNERS

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