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Project Overview

Anna Belehaki
Project Coordinator
IAASARS, National Observatory of Athens

T-FORS Second Innovation Day
Radisson Blue Park Hotel, Athens Greece
4 December 2024

Main Objective

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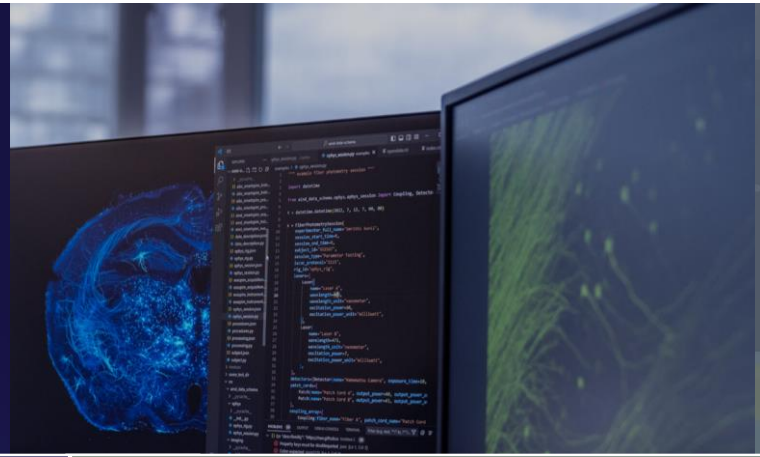
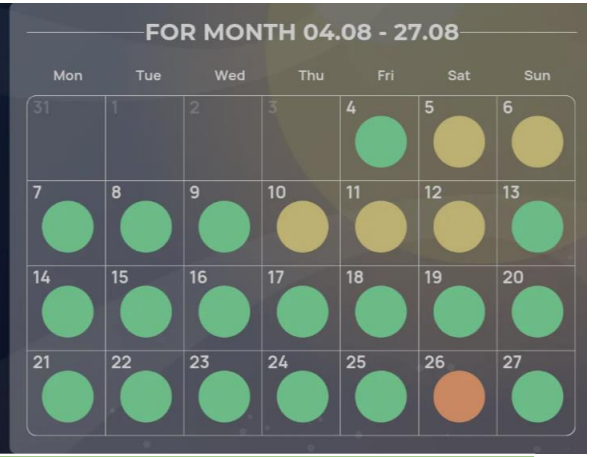
The main objective of the T-FORS project is the ***development of new validated models able to issue forecasts and alerts for TIDs several hours ahead***, exploiting a broad range of observations of the solar corona, the interplanetary medium, the magnetosphere, the ionosphere and the atmosphere.





Databases → Forecast codes → Forecasts & Alerts

Database sources

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	Drivers	Detected TID characteristics	Data for validation
Large Scale TIDs	• Solar Wind Characteristics at L1 • Auroral Electrojet Intensity • GNSS TEC gradients	HF Interferometry results (Spectral Energy Contribution of TIDs)	• Detrended height iso-ionic electron density contours • foF2, hmF2 and MUF deviations • dTEC Keograms
Data provider	• NOAA (DSCOVR, ACE) • FMI (IMAGE network) • DLR (TechTIDE/ESA service)	Observatorio del' Ebre (TechTIDE/ESA service)	• National Observatory of Athens (DIAS service) • GIRO (FastChar) • EUREF
Medium Scale TIDs	Detrended TEC	Deviation of detrended TEC from the range defined between the 1st and 3rd quartiles calculated with monthly values	• Ionogram traces • Continious Doppler Sounding data • Features from TEC keograms
Data provider	Nagoya University (dTEC global maps)	IAP-Leibniz	• EU Digisonde stations • IAP-Prague • IAP-Leibniz

Methodology & Results

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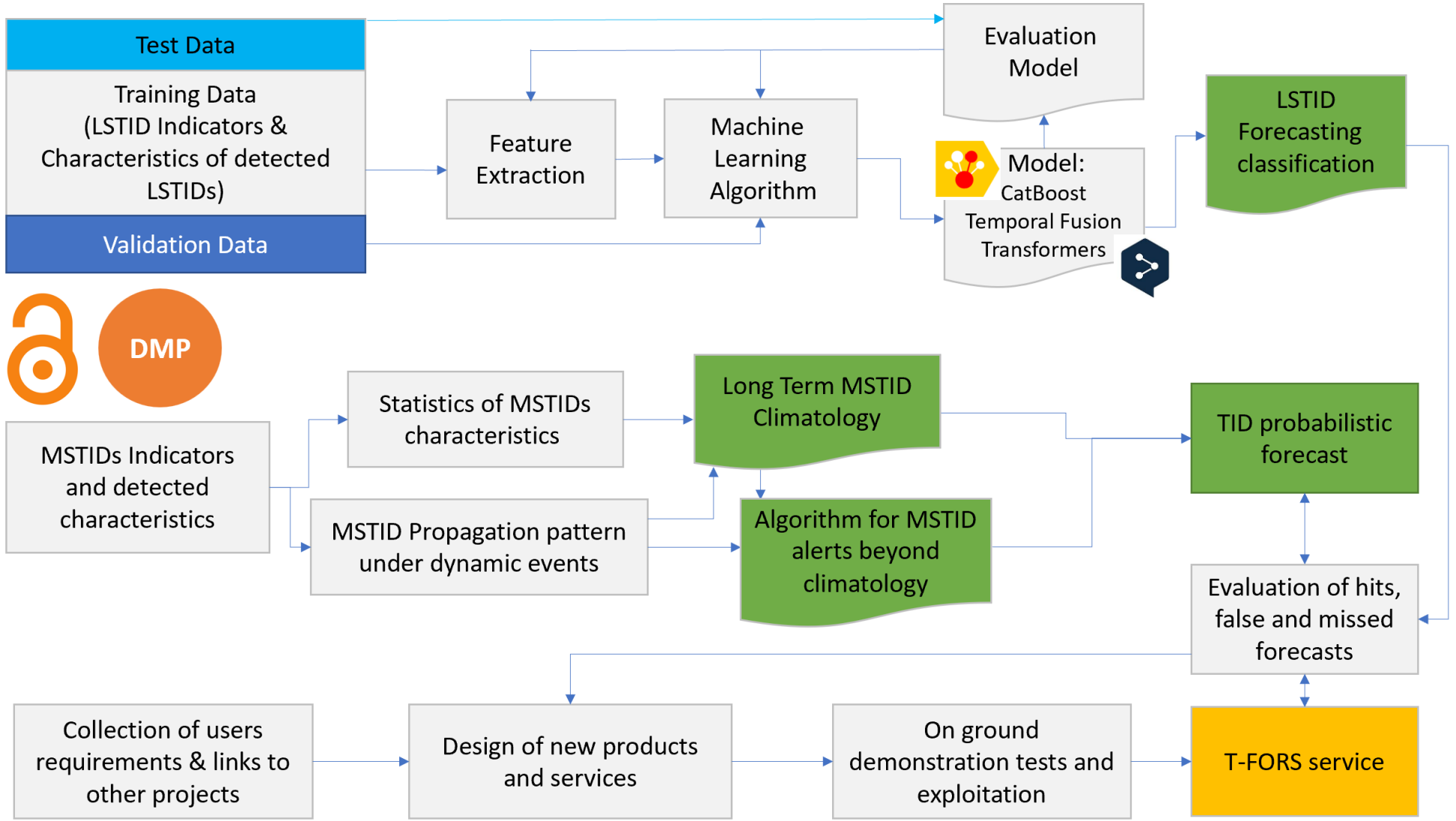

LSTIDs

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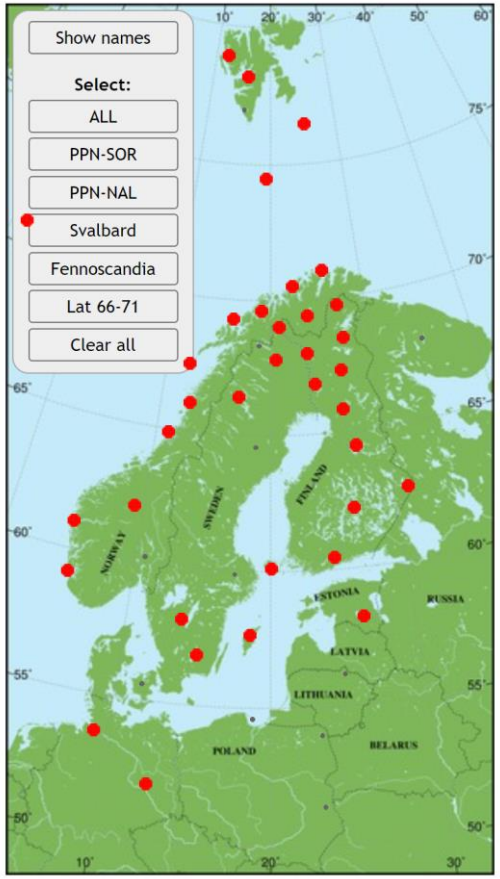
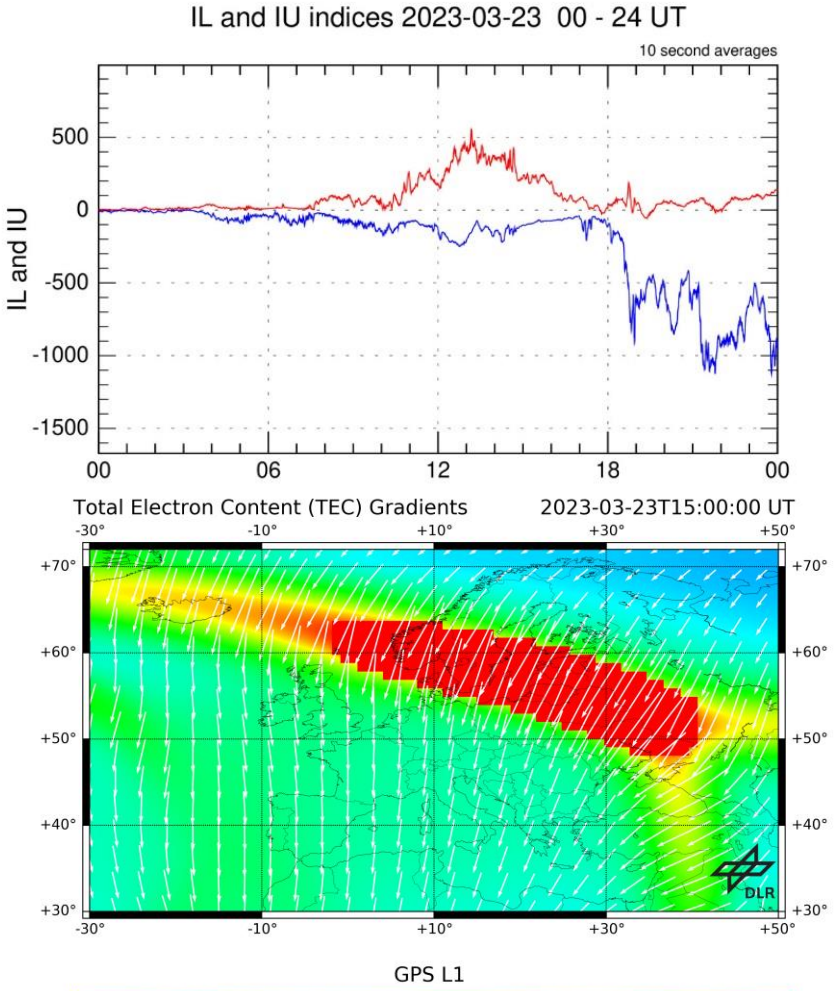
Substorms and geomagnetic storms cause energy injection at high latitudes inducing Joule heating

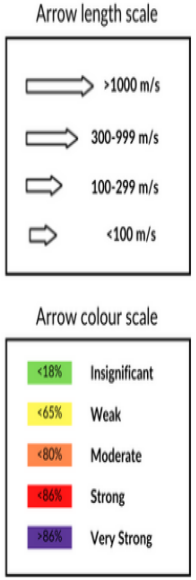
Geomagnetic field disturbances detected along a meridional chain of ground magnetometers

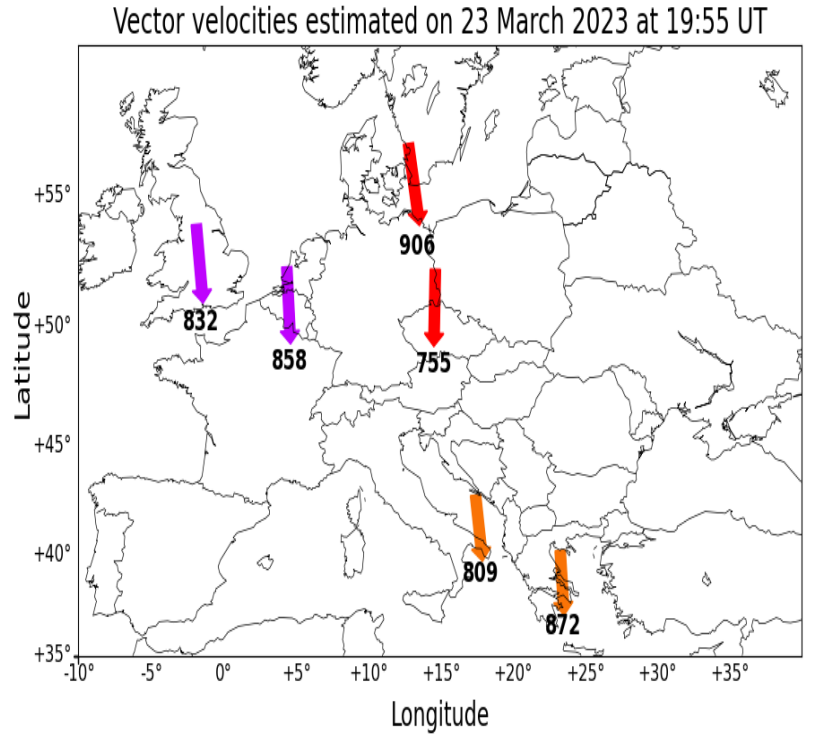
Equatorward Propagation of LSTIDs from auroral latitudes

Detection of LSTIDs by the HF Inteferometry (HF-INT) method over Digisonde stations









The classification of TID activity in the HF-INT method is based on the Spectral Energy Contribution (SEC) of the detected TID.

LSTID forecast models

Multivariate binary time-series classification

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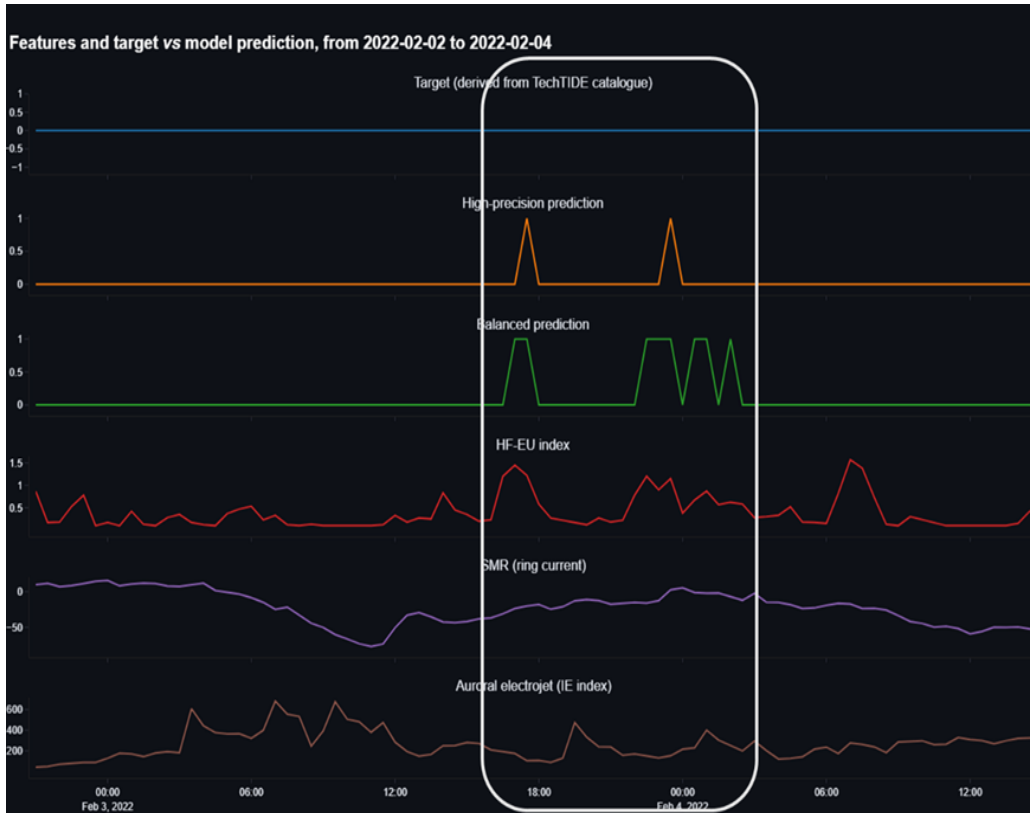
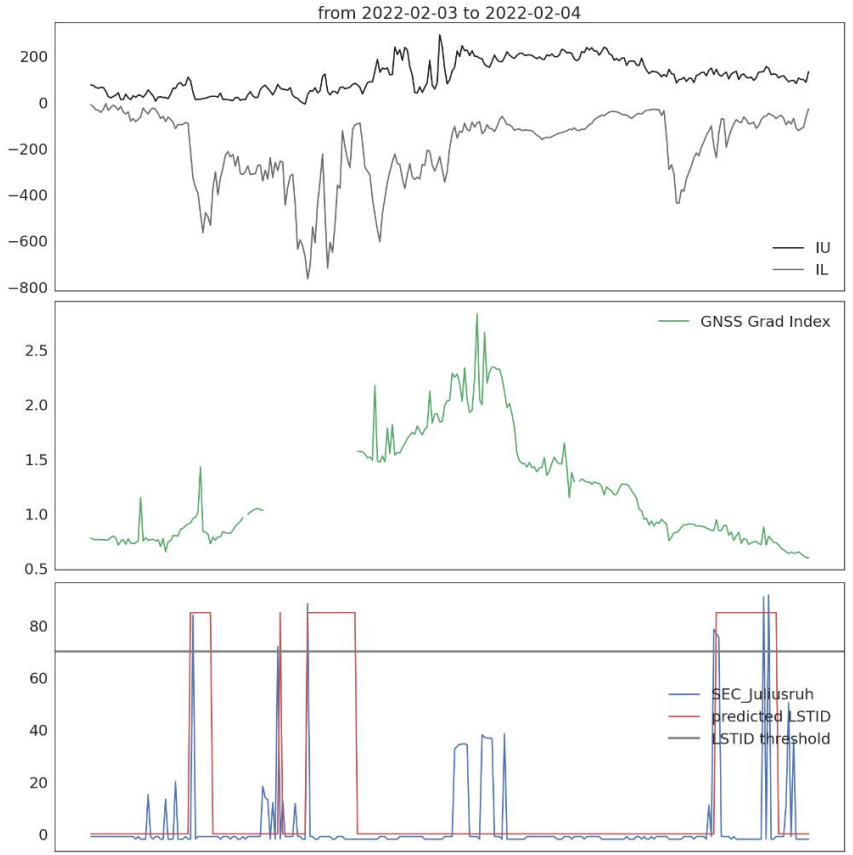
Machine learning methodology – CatBoost & Optuna
Catalogue-based model that forecast **a single value of SEC for the whole EU region**



Machine learning methodology – Temporal Fusion Transformers
HF-SEC-based model that forecast **the SEC over each Digisonde Location**



LSTID forecast key results

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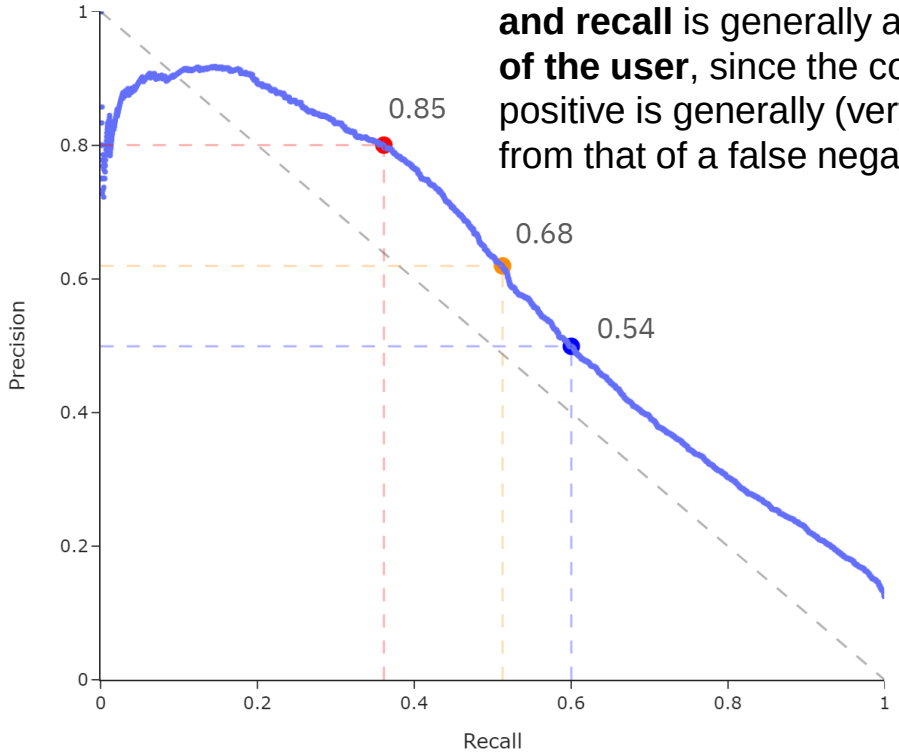
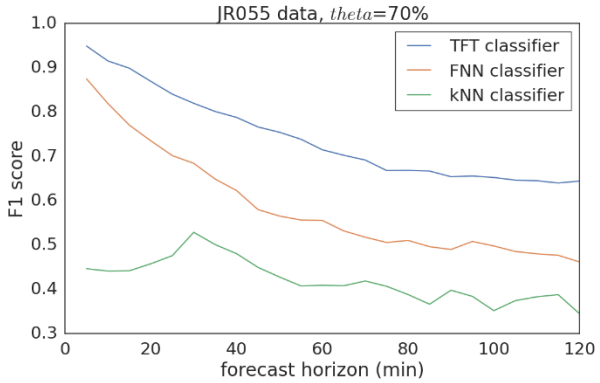
The forecast of the occurrence of LSTIDs is considered as a binary **classification problem**, for a **pre-defined threshold *theta* of the SEC characteristic**, which is computed with the HF-INT method.

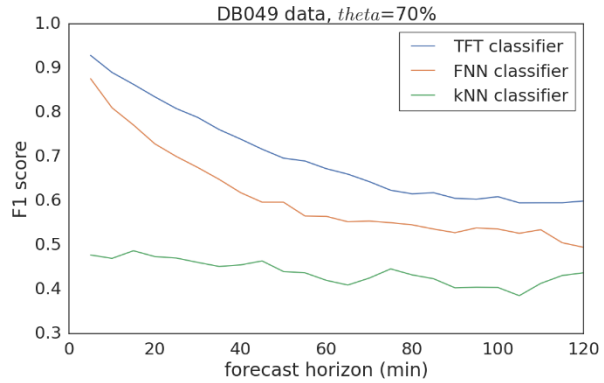
Recall: the percentage of real LSTID disturbance cases correctly classified by the classifier.
Precision: the percentage of cases classified as LSTID disturbances and are indeed LSTID disturbances.

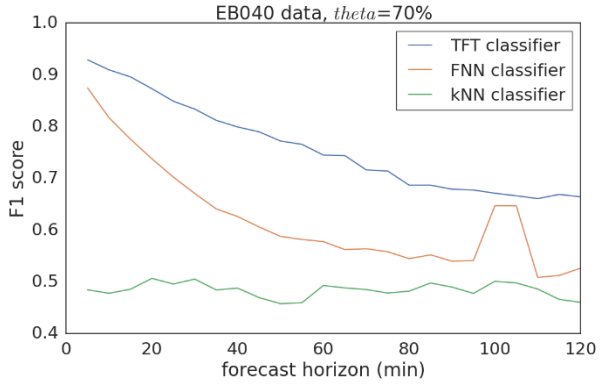


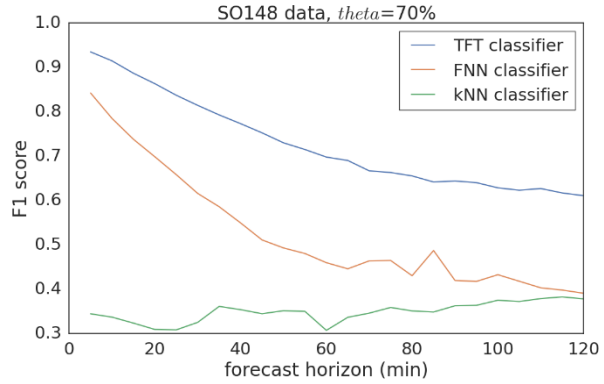
The **trade-off between precision and recall** is generally a **function of the user**, since the cost of a false positive is generally (very) different from that of a false negative

F1-score is the harmonic mean of Recall and Precision.









The performance of the TFT classifier compared to state-of-the-art tools, such as a FNN and a k-NN classifier. LSTID forecasts are performed for a time period up to two hours ahead over Digisonde locations in Europe. The performance is measured in terms of the F1-score for the cases where *theta* takes the values 50% and 70%.

MSTID forecast key results

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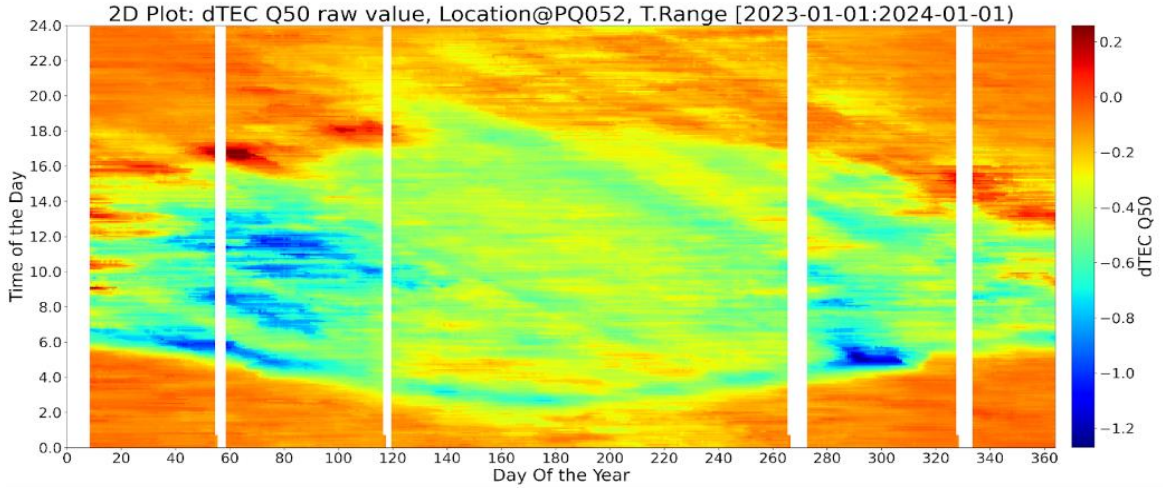
Recurrent physical phenomena such as the solar terminator crossing, the polar vortex, tropospheric jet streams and sporadic E layers are used to develop the MSTID climatology based on detrented TEC keograms.

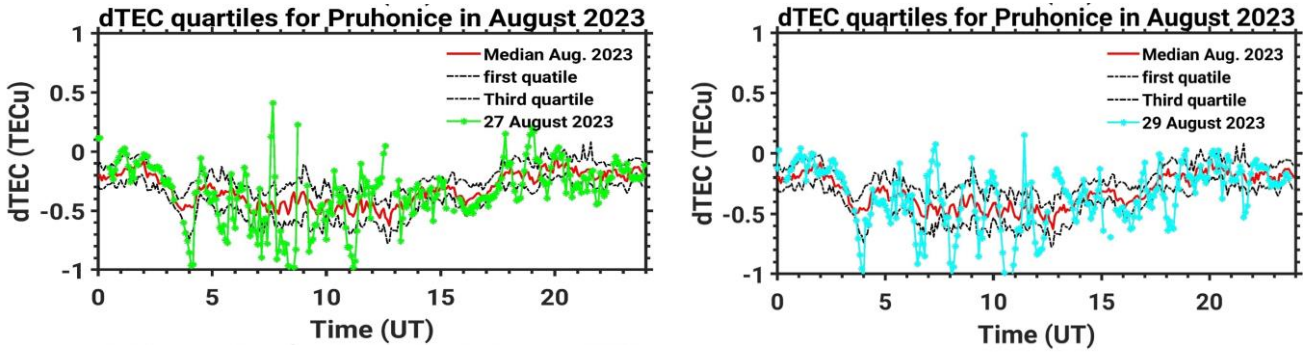
Dynamic phenomena occur randomly (such as geomagnetic storms, tropospheric deep convection, earthquakes, natural and anthropogenic explosions). The resulted disturbances due to MSTIDs often exceed the climatology and an alert can be issued.

Climatology



Small amplitudes of the TEC variation, less than 1 TECu, and the short period oscillation are obtained by calculating the detrended TEC (dTEC): the running monthly median dTEC variation (Q50) for the year 2023 as a function of Day of Year and Time of Day, demonstrates the climatological effect of the solar terminator in Pruhonice, Czechia.

Alert



During a cold front passage occurred on 26-29 August 2023 (DOY 238 – 241), the dTEC exceeds the range defined between Q1 – Q3. In this case an alert for extreme MSTIDs may be issued.

On ground demonstrations

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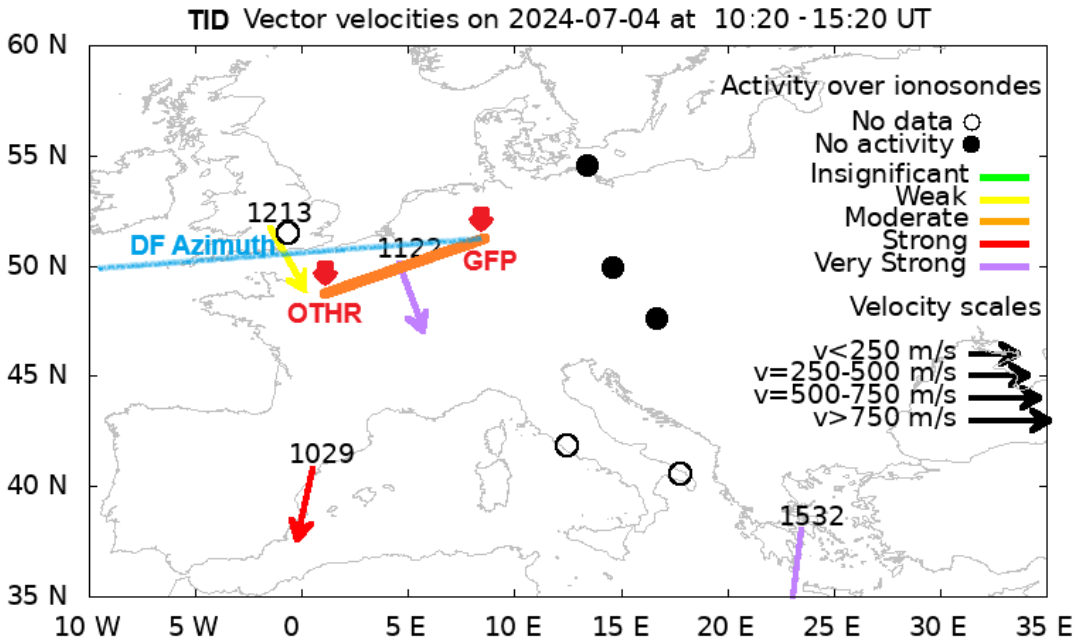
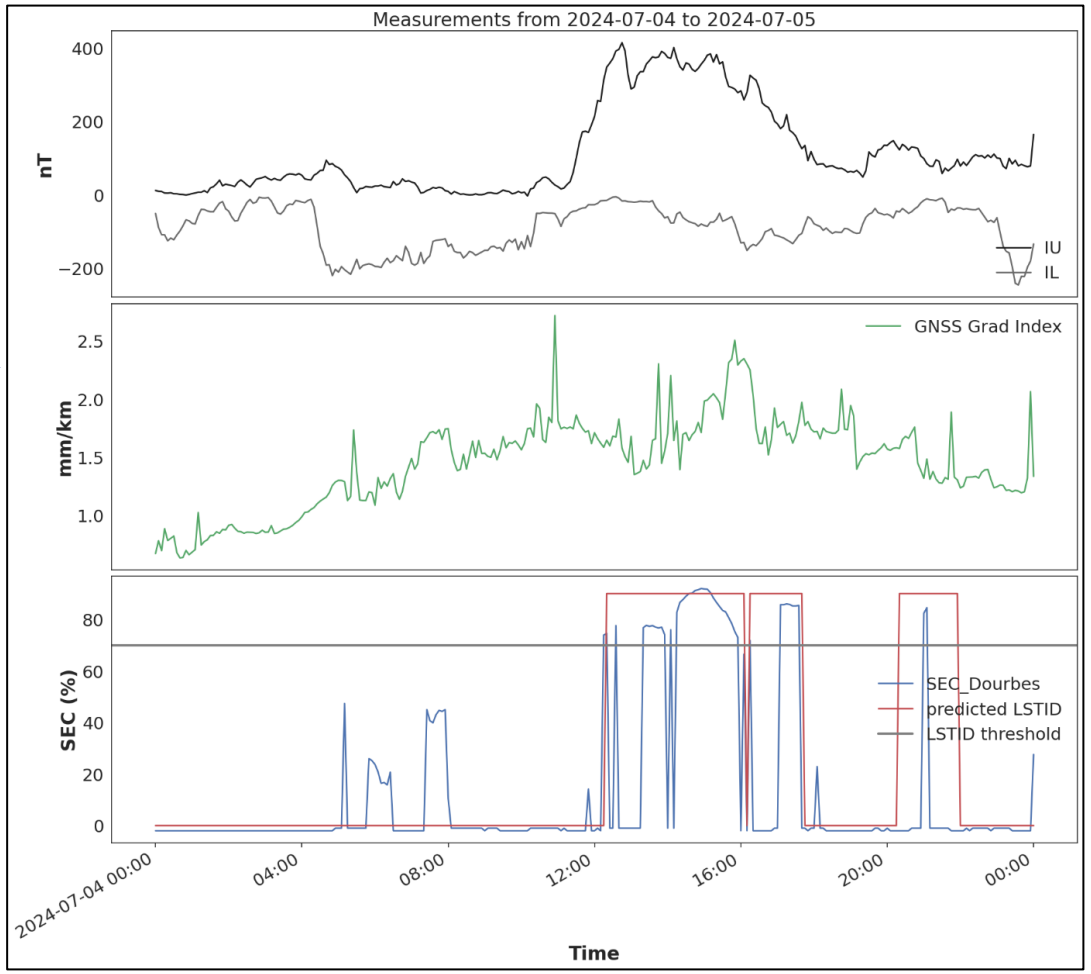
Nostradamus OTHR transmitted a non-modulated frequency with one transmitter at 6.828 MHz. The Direction Finding (DF) system detects azimuth arrival angle of the intercepted signals. Nostradamus signals were detected with an angle of arrival between 269.8° and 270.2°, which gives a deviation from 26.2° up-to 26.6° from the correct one (243.6°).

The deviation is probably due to TID activity over west Europe, forecasted by T-FORS ML algorithms.





Towards a TID forecasting system

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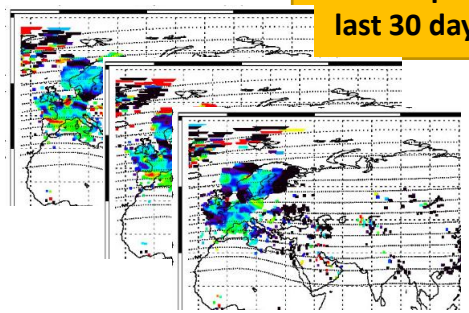
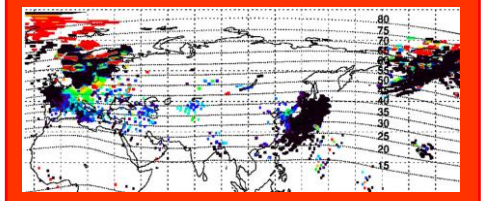
MSTID forecast ← **Backend developer** → **LSTID forecast**



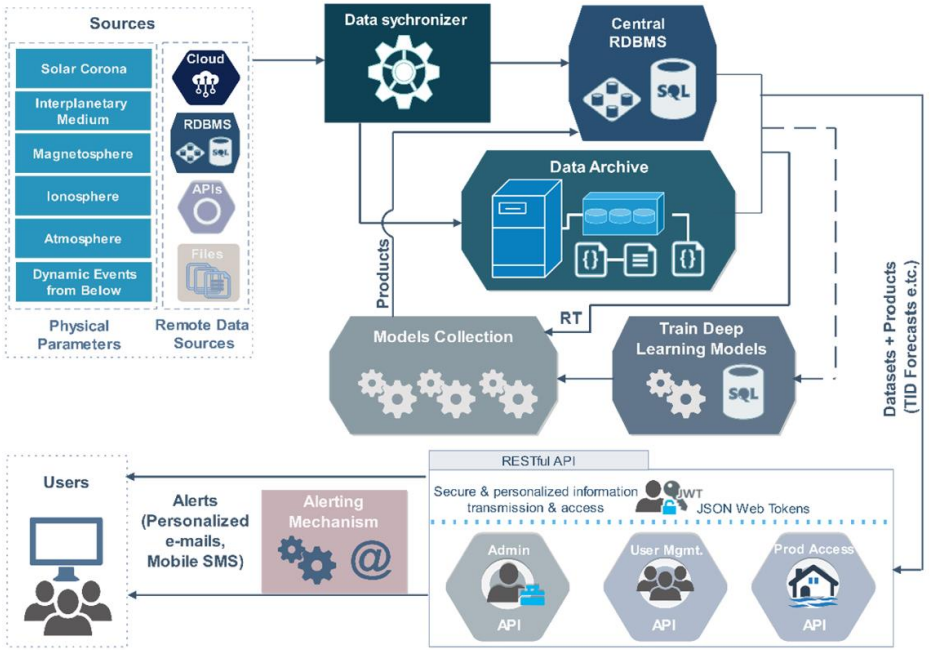
dTEC maps for last 30 days

Current dTEC map

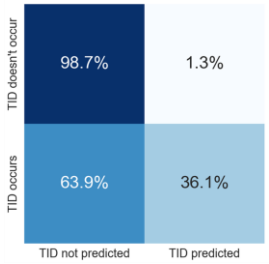


Climatology based on Q1 – Q2 – Q3 variation

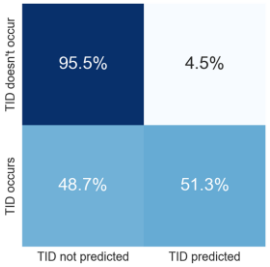
if **dTEC>|Q1-Q3|** ***then*** **alert=*true* presistent for t=MSTID$_T$**



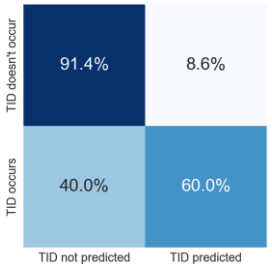
High precision



Balanced



High sensitivity



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Considerations for R2O transition

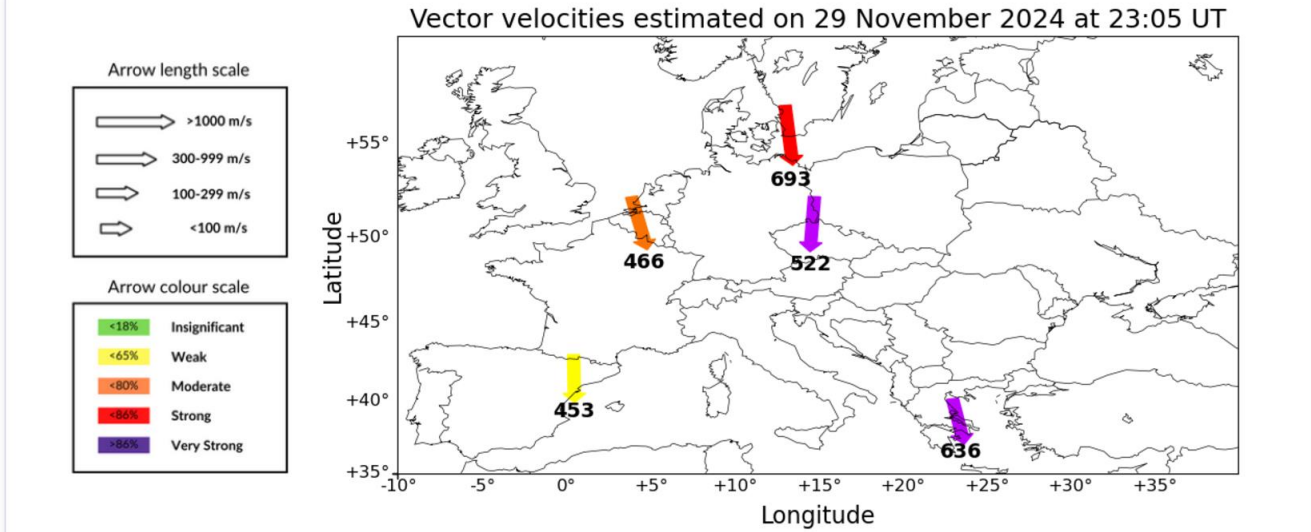
Standards for the design of High Level Data Products (HLDP)	HLDP designer and developer	HLDP end-user
WMO/OSCAR recommendations Domain – Variable name – Definition - Measurement Unit - Uncertainty – Spatial Resolution – Timeliness – Stability – Coverage – Coverage quality – Confidence level **H2020 PITHIA-NRF recommendations** Compliance with the eSC registration standards (ontology) Compliance with the eSC API Compliance with the future ML framework	Data availability (open or under agreement) Latency of data availability in respect to real-time Data storage Data interface Data cleaning Accuracy vs Forecasting horizon Data pre-processing (CPU/GPU) Format of HLDP Model execution time Alert verification time ML Model training time ML Model retraining time	**General requirements** Design of the HLDP Forecast horizon Accuracy Latency in respect to real-time Access technology & policy Interfaces **ESA Space Weather Network requirements** Compliance with Customers Requirements Compliance with the federated services requirements (layout, archive and real-time, quality indicators) Robustness of the IT system

Federated products from the Ionospheric Group of the National Observatory of Athens (NOA)

- TechTIDE Home
- Perturbation maps
- GNSS TEC gradient
- LSTID detector maps
- LSTID station plots
- LSTID activity index
- AATR indicator maps
- AATR daily plots
- CDSS Doppler shift
- MSTID index maps
- MSTID daily plots
- TID activity report
- Acknowledgements

TechTIDE LSTID detector maps

Europe | Latest | Archive | 2024-11-29T23:05:00 | Image | ASCII



- TechTIDE Home
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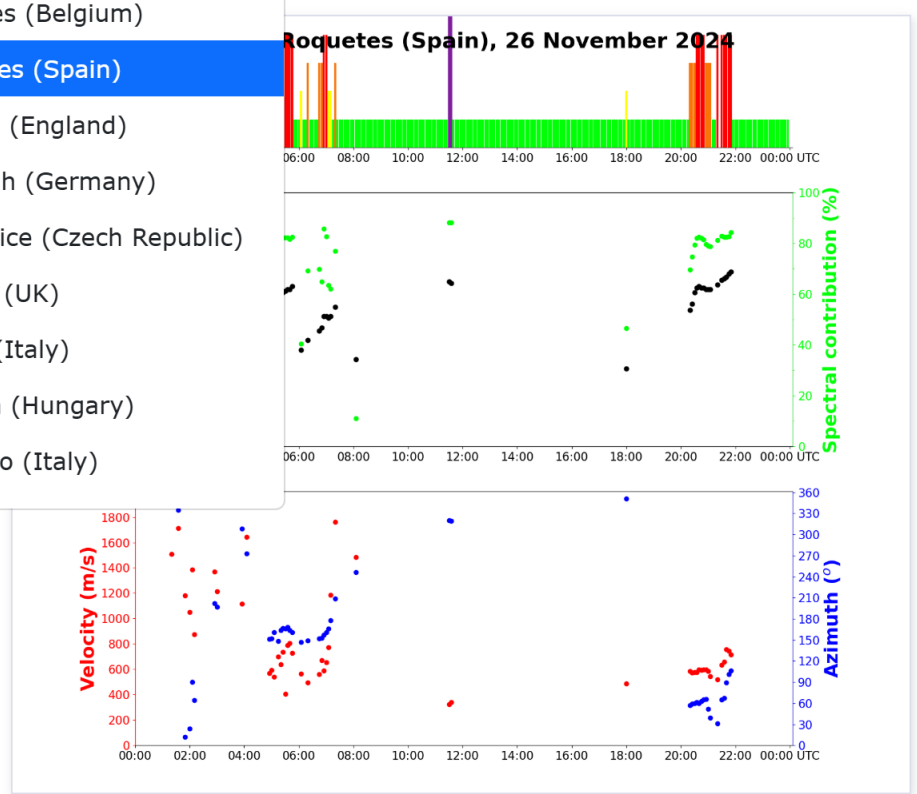
- TID activity report
- Acknowledgements

TechTIDE LSTID parameters over station @ HFI Characteristics: EB040

Stations | Latest | Archive | 2024-11-26T00:00:00 | Image | ASCII

- AT138, Athens (Greece)
- DB049, Dourbes (Belgium)
- EB040, Roquetes (Spain)
- FF051, Fairford (England)
- JR055, Juliusruh (Germany)
- PQ052, Pruhonice (Czech Republic)
- RL052, Chilton (UK)
- RO041, Rome (Italy)
- SO148, Sopron (Hungary)
- VT139, San Vito (Italy)



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Specific Considerations from potential future end-users

- Design and format for High Level Data Products
- Latency in respect to Real-Time
- Access to archive data
- Preferred Transfer Protocol
- Forecasting Horizon versus Uncertainty
- Requirement to specify the scale of the TID, LS/MS
- Access to source code
- Access to input data
- Other information to allow deeper analysis/evaluation of the forecasts

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Thank you for your attention!

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