Identification and monitoring techniques of TIDs in the H2020 TechTIDE project

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- Traveling Ionospheric Disturbances (TIDs) are wave-like propagating irregularities that alter the electron density environment and play an important role spreading radio signals propagating through the ionosphere.
- TechTIDE project, funded by the European Commission Horizon 2020 research and innovation program, is establishing a pre-operational system to issue warnings of the occurrence of TIDs over the region extended from Europe to South Africa based on the reliability of a set of TID detection methodologies.
- This contribution aims at presenting the different methods and techniques of identification and tracking the activity of TIDs and their respective performance, that serve to feed the warning system of TechTIDE.
The main objective of the TechTIDE project (Warning and mitigation Technologies for Travelling Ionospheric Disturbances Effects) is the development of an identification and tracking system for Travelling Ionospheric Disturbances (TIDs) which will issue warnings of electron density perturbations over large world regions.

The TechTIDE project has put in operation a real-time warning system that provides the results of complementary TID detection methodologies. The TechTIDE methodologies are able to detect in real time activity caused by both large-scale and medium-scale TIDs and to provide indicators of TID activity.

TechTIDE methodologies are based on the exploitation of data collected in real time from Digisondes, Global Navigation Satellite System (GNSS) receivers and Continuous Doppler Sounding System (CDSS) networks.
Real-Time detection of TIDs

TID detection methods in TechTIDE

- HF-TID model.
- HF-INT method.
- Space & Time GNSS analysis.
- GNSS TEC Gradient method.
- TAD 3D-EDD method.
- HTI algorithm.
- CDSS method.
- AATR indicator.
TID detection methodologies

- **Detectors of LSTIDs:**
  - HF-TID (No TID / Uncertain / TID)
  - HF-INT (No TID / Uncertain / TID)
  - HTI (No TID / Uncertain / TID)
  - LSTID index: 1-D version TAD 3D-EDD (No TID / Uncertain / TID)

- **Detectors of MSTIDs**
  - CDSS MSTID (No TID / Uncertain / TID)
  - MSTID index: Space & Time GNSS Analysis (No TID / Uncertain / TID)

- **Ionospheric disturbance indicators**
  - AATR indicator (Low / Medium / Strong)
  - GNSS TEC Gradient (Low / Medium / Strong)
  - Background Ionospheric Activity (Negative / Median / Positive)
HF-TID method

- Detects perturbations in space from all possible sources (solar and lower atmosphere origin) and it is suitable for identification of both **MS** and **LS** TIDs.

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
<th>PRODUCTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal properties from Digisonde synchronized</td>
<td>TID velocity, amplitude, propagation direction at the signal reflection</td>
<td>• European map indicating the velocity, amplitude and propagation direction at the reflection points between Digisondes operated in bistatic mode.</td>
</tr>
<tr>
<td>operation</td>
<td>point between the stations</td>
<td>• Report of TID characteristics extracted from the analysis of the raw data from the D2D operations, i.e TID propagation Doppler frequency, angle of arrival, and time-of-flight from Tx to Rx, both OI and VI sounding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Plots of amplitude, Doppler, azimuth within the last 45 minutes from the TID detection</td>
</tr>
</tbody>
</table>
Detectors of LSTIDs

HF-TID method

Real Time TID
05/08/2019
16:07 UT

Figure Credits to Belehaki et al., 2020
Detectors of LSTIDs

HF-INT method

- Identifies **LSTIDs** for the monostatic measurements of a given network of HF sensors (i.e. ionosondes) dense enough, separated less that 1000 km.

<table>
<thead>
<tr>
<th>INPUT</th>
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<th>PRODUCTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionospheric characteristics</td>
<td>2D TID vector velocity,</td>
<td>• TID log files with characteristics extracted from the analysis of the</td>
</tr>
<tr>
<td>from VI and OI soundings</td>
<td>amplitude and period</td>
<td>raw data.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Map indicating the velocity and propagation direction of TIDs over</td>
</tr>
<tr>
<td></td>
<td></td>
<td>measuring sites.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Dominant period, Amplitude and Horizontal Vector velocity of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>detected LSTID over the region of interest and over each Digisonde</td>
</tr>
<tr>
<td></td>
<td></td>
<td>location</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Daily plots of TID variability, Period and Azimuth</td>
</tr>
</tbody>
</table>
Detectors of LSTIDs

HF-INT method

Figure Credits to Belehaki et al., 2020

Arrow length scale

Vector velocities estimated on 05 August 2019 at 12:45 UT

TID Strength

- Insignificant
- Weak
- Moderate
- Strong
- Very Strong

DB049

Spectral Contribution (%)
Detectors of LSTIDs

HTI method

- Reconstructs daily plots of the **vertical movement** of the ionospheric layers over measuring sites and detect oscillations from all possible sources.

<table>
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<tr>
<th>INPUT</th>
<th>OUTPUT</th>
<th>PRODUCTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw vertical ionogram binary data from single station</td>
<td>Reconstructed daily variability of F region virtual height</td>
<td>• F region virtual height variation above a given Digisonde station.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Dominant period, Amplitude and Strength of TID.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Daily plots F region virtual height variability.</td>
</tr>
</tbody>
</table>
Detectors of LSTIDs

**LSTIDx: 1-D version TAD 3D-EDD**
- Provides **LSTIDx index** as the absolute values of the residuals of the electron density at given altitude after detrending the 30-day running median.

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</tr>
</thead>
<tbody>
<tr>
<td>Ionospheric characteristics at the hmF2</td>
<td>Analytical function of the electron density</td>
<td>• Residuals of the detrended electron density from the median values,</td>
</tr>
<tr>
<td>altitude and TEC maps</td>
<td>distribution with altitude from 90 km to 22000 km</td>
<td>calculated with the TaD model for heights ranging from 150 up to 900 km</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with 50km step.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The results are provided over specific European Digisondes performing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VI sounding at least every 5min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Map of the height of the maximum electron density disturbance.</td>
</tr>
</tbody>
</table>
Detectors of LSTIDs

LSTIDx: 1-D version TAD 3D-EDD

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Electron Density
Height = 300 km

Max Ne Disturbance on 2019-10-04 09:55 UT

dNe = 16.3%
h = 300km

dNe = 83.6%
h = 200km

dNe = 10.1%
h = 200km

dNe = 22.0%
h = 200km
Detectors of MSTIDs

CDSS MSTID

- Provides **multipoint CDSS** of different frequencies in regions with at least three sounding paths (transmitter – receiver pairs).

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<th>OUTPUT</th>
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</tr>
</thead>
<tbody>
<tr>
<td>CDSS reflected signals, ionospheric</td>
<td>Doppler shift.</td>
<td>• Period, Amplitude of Doppler measurements.</td>
</tr>
<tr>
<td>characteristics and irregularities</td>
<td>Fluctuations associated to the TIDs and</td>
<td>• Observed horizontal velocities and azimuths of MSTIDs.</td>
</tr>
<tr>
<td></td>
<td>estimation of the propagation parameters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(direction, velocity and amplitude)</td>
<td></td>
</tr>
</tbody>
</table>
Detectors of MSTIDs

CDSS MSTID

Figure Credits to Belehabi et al., 2020
Detectors of MSTIDs

Space & Time GNSS Analysis

- Provides **MSTID index** detrending GNSS data of a single receiver and estimates the propagation parameters for a network of receivers.

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
<th>PRODUCTS</th>
</tr>
</thead>
</table>
| GNSS TEC from single receivers over a region | Fluctuations associated to the MSTIDs and estimation of the propagation parameters (direction, velocity and amplitude). | • MSTID index calculated at each GNSS contributing receiver.  
• Daily plots of MSTIDx  
• Maps of MSTIDx  
• Estimated horizontal velocities and azimuths of MSTIDs. |
Detectors of MSTIDs

Space & Time GNSS Analysis

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mstid_idx.YEAR.day Ex: mstid_idx.19.270

MSTID.YEAR.day_day.png Ex: MSTID.19.270_day.png  MSTID.YEAR.day_5m.png Ex: MSTID.19.270_5m.png
AATR indicator

- Provides a **metric for ionospheric activity** at high latitudes, based on the rate of the slant TEC, which causes performance degradation of the EGNOS network.

<table>
<thead>
<tr>
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<th>OUTPUT</th>
<th>PRODUCTS</th>
</tr>
</thead>
</table>
| Slant TEC parameters   | Along Arc STEC Rate, metric to characterize the ionosphere operational conditions of EGNOS | • AATR indicator calculated at each GNSS contributing receiver.  
• Daily plots of AATR indicator  
• Maps of AATR indicator |
GNSS TEC Gradient

- Provides temporal and spatial **TEC gradients** which are indicative of strong ionosphere-thermosphere perturbations and precursors of LSTID activity.

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Grids of TEC maps over a region</td>
<td>Latitude-time maps of TEC gradients and indication of significant gradients</td>
<td>- Maps of TEC gradients for the European region.</td>
</tr>
</tbody>
</table>
Ionospheric disturbance indicators

GNSS TEC Gradient

Figure Credits to Belehaki et al., 2020
# Background Ionospheric Activity

- Provide **indication of ionospheric disturbances** for a region of interest and probability of detection of TIDs produced by Gravity Waves.

<table>
<thead>
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<th>PRODUCTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionogram derived characteristics in the F2 layer from ionosondes</td>
<td>Maps of the electron density at any height in the bottomside and topside ionosphere</td>
<td>- Maps of relative standard deviation of the electron density at each ionospheric altitude with an indication of the probability for LSTIDs detection</td>
</tr>
</tbody>
</table>
Background Ionospheric Activity

Figure Credits to Belehaki et al., 2020
References


References


Acknowledgements

Thank you for your time

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Keep safe and see you at #EGU2021!