Travelling Ionospheric Disturbances studied in the EU H2020 TechTIDE project

Outline

• Introduction

• TechTIDE objectives and approach

• Case study – September 2017

• TechTIDE results

• Summary
Atmospheric waves and ionospheric signatures

Medium Scale TIDs

- MSTIDs are mostly associated with ionospheric coupling from below through AGW
- Periods: < 60 minutes, Wavelength: < 1.000 km

Large Scale TIDs

- LSTIDs are associated with auroral and geomagnetic activity
- Periods: >= 60 minutes, Wavelength: > 1.000 km

LSTID signatures during 23rd May 2002 geomagnetic storm

Tsugawa et al. (2011), Earth Planets Space

Borries et al. (2009), Ann. Geophys.
Why do we care about TIDs

Operations at middle and low latitudes depending on predictable ionosphere characteristics are affected by TIDs:

• Systems using the ionosphere as part of their operations such as HF communication, HF geolocation operations
  ➢ direction finding systems
  ➢ radio communication and broadcasting operations
  ➢ humanitarian aid organizations and radio amateurs

• Systems for which the ionosphere is a noise
  ➢ radio-astronomy experiments such as LOFAR and SKA
  ➢ ground and space-based augmentation systems (EGNOS and GBAS)
  ➢ enhanced precision positioning systems (such as N-RTK) which are extensively used in agriculture and drilling operations
The overarching objective of TechTIDE is to design and test new viable TID impact mitigation strategies for the technologies affected by the TIDs and in close collaboration with operators of these technologies, to demonstrate the added value of the proposed mitigation techniques which are based on TechTIDE products.
TechTIDE working approach

- TID detectors that provide near-real time measurements of TIDs
- Estimation of ionosphere background conditions
- Generation of TID activity metrics and information for non-scientific users

First line algorithms

- **TID detector**
  - HF-TID method
  - HF interferometry
  - Spatial & Temporal GNSS analysis
  - GNSS TEC gradients method
  - TaD 3D-EDD model
  - HTI method
  - CDSS TID detector
  - AATR indicator

Extracted characteristics

- TID velocity, propagation direction, amplitude at the reflection points between the sounders
- 2D TID vector velocity
- Propagation parameters (propagation direction, velocity and amplitude)
- Rate of change of TEC with latitude and time
- Electron density distribution from 90 to 22000km and height of max perturbation
- Daily variability of the electron density over stations
- Doppler shift
- Slant TEC perturbations over a region

Second line algorithms: TID activity metrics calculation and warning release

- IMF data @ L1, CME, ICME, CCIR detectors
- Magnetospheric indices AE, PCN, PCS, Dst
- Atmospheric dynamics and infrasound signatures from natural and anthropogenic sources
- Seismic data (strong earthquakes)

- Inter-hemispheric circulation warning
- Astronomical almanac data
- Solar flare detection
- Ionospheric background

TID activity metrics
- Cross comparison of TID results in respect to current and forthcoming geophysical conditions (drivers)

TID nowcasting verification
- Warnings for TID occurrence over the European-African sector
Event Analysis September 2017

• GNSS based TID detection used for assessment and validation of TechTIDE products
• Many LSTIDs have been observed during 7th and 8th Sept. 2017

Set of LSTIDs:
- Wavelength ~ 6000 km
- Period ~ 130 min
- Phase speed ~ 850 m/s

Set of LSTIDs:
- Wavelength ~ 2400 km
- Period ~ 110 min
- Phase speed ~ 350 m/s

Set of LSTIDs:
- Wavelength ~ 2700 km
- Period ~ 110 min
- Phase speed ~ 415 m/s

High latitude perturbations due to auroral activity and auroral expansion
Theoretical Background

- Very sudden intensive heating generates large scale atmospheric gravity waves in the winds. They are observed in the Total Electron Content (TEC) as Large Scale Travelling Ionospheric Disturbances (LSTIDs).

- Source region of LSTIDs is characterized by strong spatial gradients, depletion and significant fluctuations of the electron density and TEC.
LSTID activity – GNSS precursors

Along Arc TEC Rate (AATR)

• This index based on TEC estimates derived from ground based GNSS measurements
• used to identify the conditions where a degradation in the user performance of the SBAS systems is expected

TEC Gradients

• This product is derived from near real-time TEC maps
• Spatial horizontal gradients between the TEC maps (1°x1°) grid points are calculated
AATR during 8 September 2017

Strong perturbations in auroral region

perturbation TEC 2017-09-08, LON: 15°E
TEC gradients during 8 Sept 2017

- Weak TEC gradients in high latitudes co-located with TEC depletion

**TEC rate, 08-08 Sep 2017, 10°E**

**IGS TEC map, 08-09-2017 12:15 UT**

**IGS TEC gradient map, 08-09-2017 12:15 UT**
Europe
The LSTID activity as observed by the HF-Interferometry reports a dominant disturbance for all the European stations with a periodicity of about 2-h and clear southward propagation occurring in the day-time and in the evening to mid-night hours.

South Africa
Stations in South Africa observe a dominant disturbance with a periodicity close to 1.5-h and clear northward propagation occurring in the evening.
September 7:
Strong TID activity in the evening hours. Propagation: north-to-south, velocity: 300 – 1000 m/s

September 8:
Strong TID activity in the early morning and daytime hours. Propagation: north-to-south, velocity: 300 – 1000 m/s
Positive storm effects (ionization increases) over Europe from 08:00 UT onwards: wave-like disturbances, probably attributed to TADs (Travelling Atmospheric Disturbances)
Background ionosphere

8 September 2017

Negative storm effects (ionization decreases) over Europe after dawn that are more intense in the middle-to-high European latitudes.
1st Release of TechTIDE system

TechTIDE Project

Real-Time Conditions

www.tech-tide.eu
TechTIDE activity report

- All results of TID detection are collected in an overview table
- Differences do result from different affected regions/altitudes in the ionosphere
- It illustrates the complexity of TID propagation in the ionosphere

<table>
<thead>
<tr>
<th>Activity</th>
<th>Method/Indicators</th>
<th>September, 6</th>
<th>September, 7</th>
<th>September, 8</th>
</tr>
</thead>
</table>
| Overall  | • Solar flare indicators  
• Geomagnetic activity (Kp, Dst)  
• Magnetospheric activity (AE)  
• AATR  
• Ionospheric characteristics (SNR, foF2, TEC) | Solar flare activity | • Enhanced geomagnetic and magnetospheric activity  
• Enhanced ionospheric activity: Positive storm effects over Europe from 08:00 UT onwards | • Enhanced geomagnetic and magnetospheric activity  
• Enhanced ionospheric activity: Negative storm effects over Europe after dawn |
| TIDs     | AATR              | -            | -            | Weak LSTIDs that propagate southwards from the auroral region (15:30 - 16:00 UT). |
| HF-Interferometry | -         | Europe: LSTIDs with a periodicity of about 2-h and southward propagation (600-800 m/s) occurring in the day-time and in the evening to midnight hours  
South Africa: LSTIDs with a periodicity close to 1.5-h and northward propagation occurring in the evening (200-1000 m/s). | Europe: LSTIDs activity in early hours (until 2:00 UT) - azimuth of 180º (from true north) and a velocity of about 400m/s.  
South Africa: LSTIDs with a periodicity of about 1.5-h and northward propagation occurring in the day-time hours. The disturbance propagated with an azimuth of 0º (from true north) and a velocity of about 450m/s. |
| HF-TID   | -         | Europe: Strong TID activity in the evening hours. Propagation: north-to-south, velocity: 300 – 1000 m/s | Europe: Strong TID activity in the early morning and daytime hours. Propagation: north-to-south, velocity: 300 – 1000 m/s |
| TaD      | -         | -            | Disturbances in the daytime hours that are maximum in lower altitudes |

- Enhanced geomagnetic and magnetospheric activity
- Enhanced ionospheric activity: Positive storm effects over Europe from 08:00 UT onwards
- Weak LSTIDs that propagate southwards from the auroral region (15:30 - 16:00 UT).
- Europe: LSTIDs activity in early hours (until 2:00 UT) - azimuth of 180º (from true north) and a velocity of about 400m/s.
- South Africa: LSTIDs with a periodicity of about 1.5-h and northward propagation occurring in the day-time hours. The disturbance propagated with an azimuth of 0º (from true north) and a velocity of about 450m/s.
- Europe: Strong TID activity in the evening hours. Propagation: north-to-south, velocity: 300 – 1000 m/s
- Disturbances in the daytime hours that are maximum in lower altitudes
Summary

• TechTIDE is a project which aims to help users in the GNSS and HF application domains to mitigate the impact of TIDs
• Many different techniques for detection of TIDs have been implemented. They use different instruments and complement each other in the detection of different types of TIDs
• The first release of TechTIDE near real-time services has been issued in May 2019
• Second and third release are planned for October 2019 and April 2020. We will add:
  • Activity reports
  • Alarms
  • User friendly navigation
  • …

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ResearchGate: https://www.researchgate.net/project/TechTIDE-2
Thank you for your attention
Backup slides
AATR during 8 September 2017

Strong perturbations in auroral region
How do we detect TIDs?

CDSS for MS TID detection

Digisonde – to – Digisonde (D2D) oblique skymaps for MS and LS TID detection

Gradients of TEC maps for LS TID detection
HF interferometry method

8 September 2017

Typical characteristics of LSTIDs whose origin might be auroral.

Europe
LSTID activity was also observed in early hours of 8 September (until 2:00 UT) for all the European stations, as continuation of the event reported for 7 of September - azimuth of 180º (from true north) and a velocity of about 400m/s.

South Africa
Dominant disturbance with a periodicity of about 1.5-h and northward propagation occurring in the day-time hours. The disturbance propagated with an azimuth of 0º (from true north) and a velocity of about 450m/s.
• During geomagnetic storms, large amounts of energy is transferred from the solar wind into the Earth system.
• The energy is deposited in high latitudes, via convection electric fields and particle precipitation in the auroral region.
• The electric fields drive currents in the auroral region.
• Dissipation of currents and precipitation result in significant heating in the auroral region.
• Electrojet heating has very large horizontal extension while.
• Heating through precipitation is very localized.
Both heating effects have impact on thermosphere-ionosphere system.

Precipitation causes strong localized fluctuations in the thermosphere composition, winds and hence strong fluctuations in the electron density. It is associated with scintillation effects.

Current heating generates large scale wind systems and cause the expansion of the thermosphere.
  - The electron density in the auroral region decreases
  - The electron density in mid-latitudes increases
  - There are significant gradients in the electron density at the border of the auroral region.
Validation of method with published events

- Extreme TEC gradient published in Mayer et al. (2008)
- Max. gradient at around 10:55 UT at 63°N (Iceland)
- Max amplitude: 2.5 TECU/min
- Speed 117 m/s in North-South direction

Validation of method with published events

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- Max. gradient at around 10:55 UT at 63°N (Iceland)
- Max amplitude: 2.5 TECU/min
- Speed 117 m/s in North-South direction

- TEC maps can identify significant gradient
- Gradient moves equatorward
- Speed ~ 154 m/s → roughly same magnitude
- Max amplitude ~ 0.2 TECU/min → one magnitude less

→ Method applies to identify gradients correctly
→ However, the gradients are a lot sharper/ steeper than what can be identified in the TEC maps
TID activity observed in TEC

High latitude perturbations due to precipitation and current activity

TID activity after moderate perturbations in high latitudes
Time-latitude plots of TEC gradients

More perturbations in high latitudes, but no significant TEC gradients.

Low latitude gradients might be a result of TID activity.