Travelling Ionospheric Disturbances studied in the EU H2020 TechTIDE project

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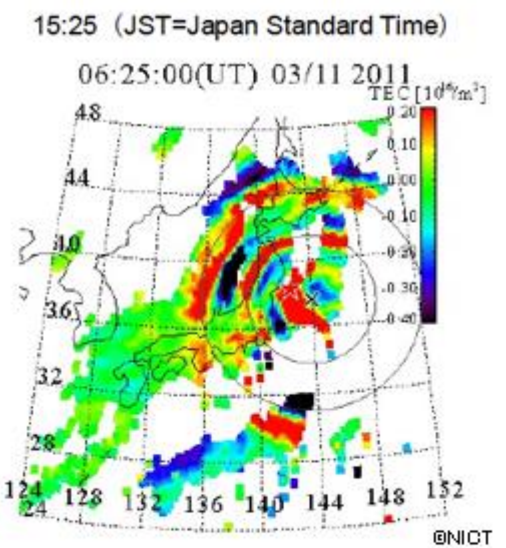
Outline

- 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

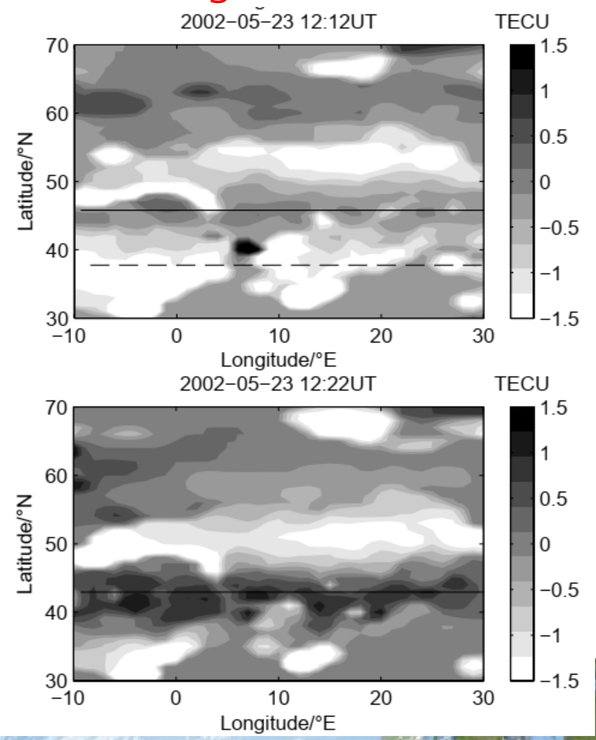


TEC variation about 38 minutes after the earthquake (EQ).

Tsugawa et al. (2011), Earth Planets Space

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

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**

TechTIDE objectives

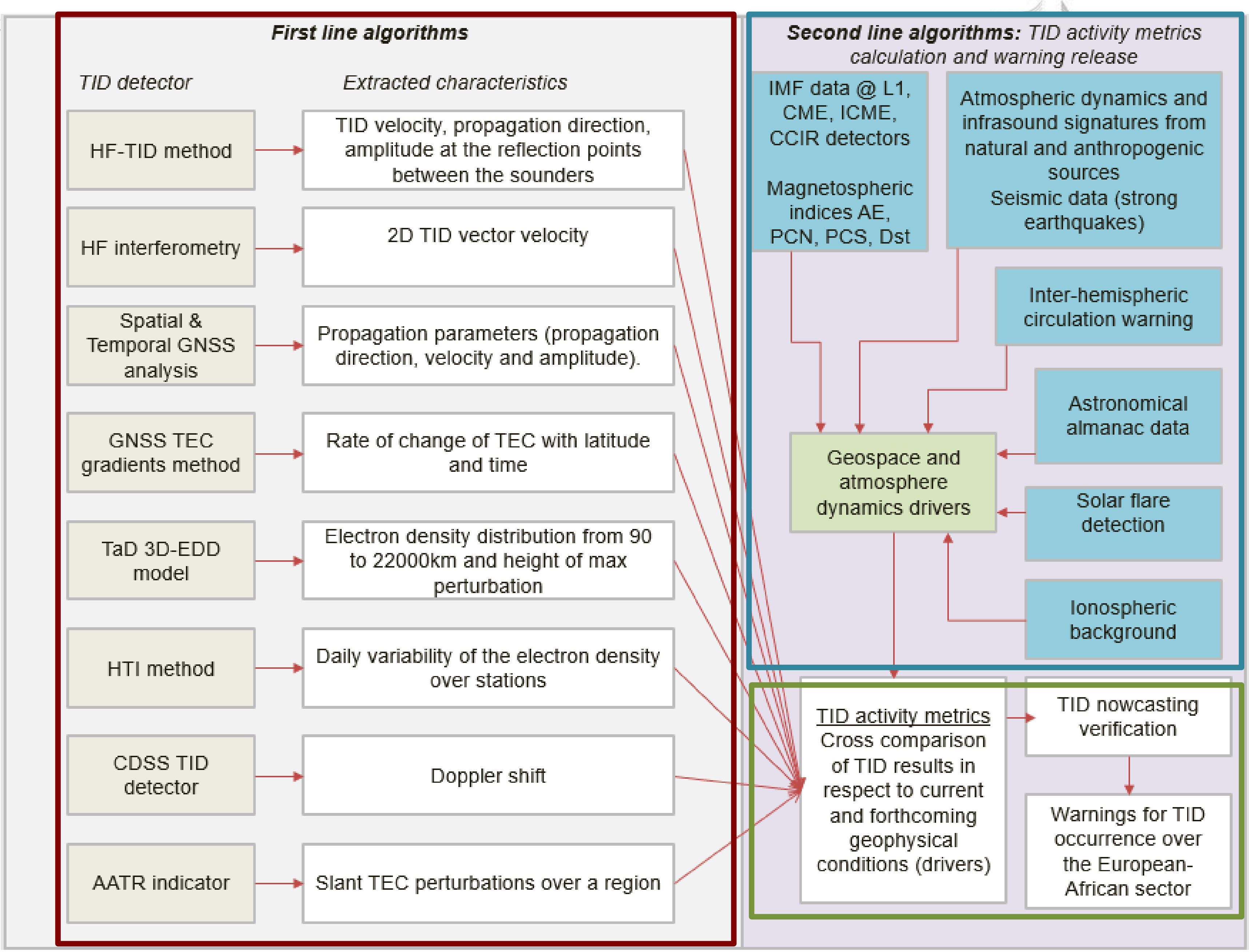
The overarching objective of TechTIDE is to design and test new viable TID impact mitigation strategies for the technologies affected by the TIDs and in close collaboration with operators of these technologies, to demonstrate the added value of the proposed mitigation techniques which are based on TechTIDE products.

- National Observatory of Athens (NOA), Greece
- Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany
- Ustav Fyziky Atmosfery AV CR (IAP), Czech Republic
- Institut Royal Meteorolgique de Belgique (RMI), Belgium
- Observatorio del Ebro Fundacion (OE), Spain
- Borealis Global Designs Ltd. (BGD), Bulgaria
- Leibniz Institute of Atmospheric Physics, Rostock University (L-IAP), Germany
- Universitat Politecnica de Catalunya (UPC), Spain
- European Satellite Services Provider (ESSP), France
- South Africa National Space Agency (SANSA), South Africa
- Watermann Juergen Friedrich Wilhelm (JFWCONSULT), France
- Frederick University (FU), Cyprus
- German Federal Police (GFP), Germany

Funded by EC H2020 COMPET Space Weather Call 2017

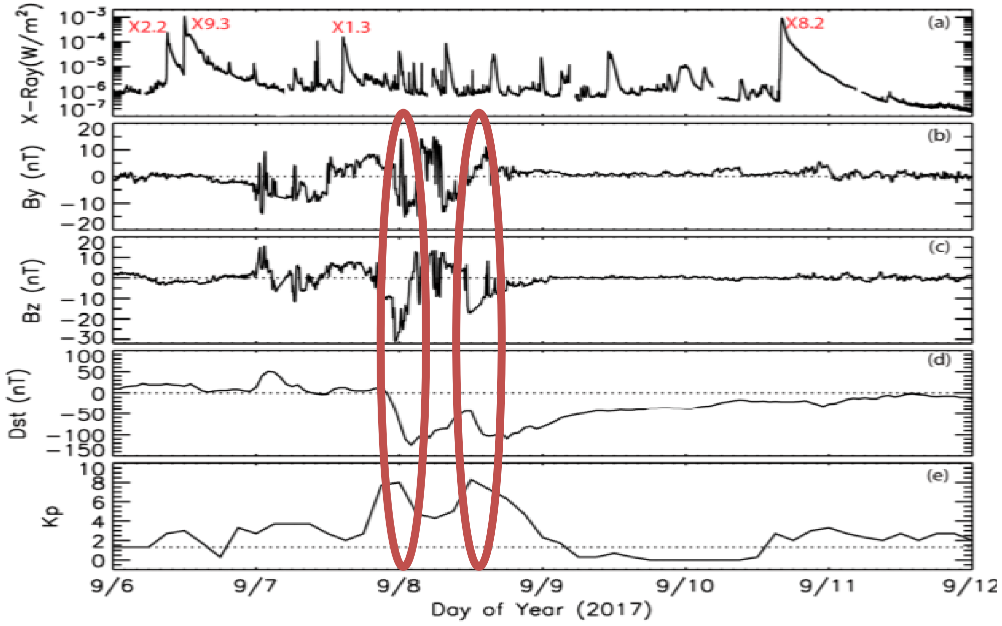
TechTIDE working approach

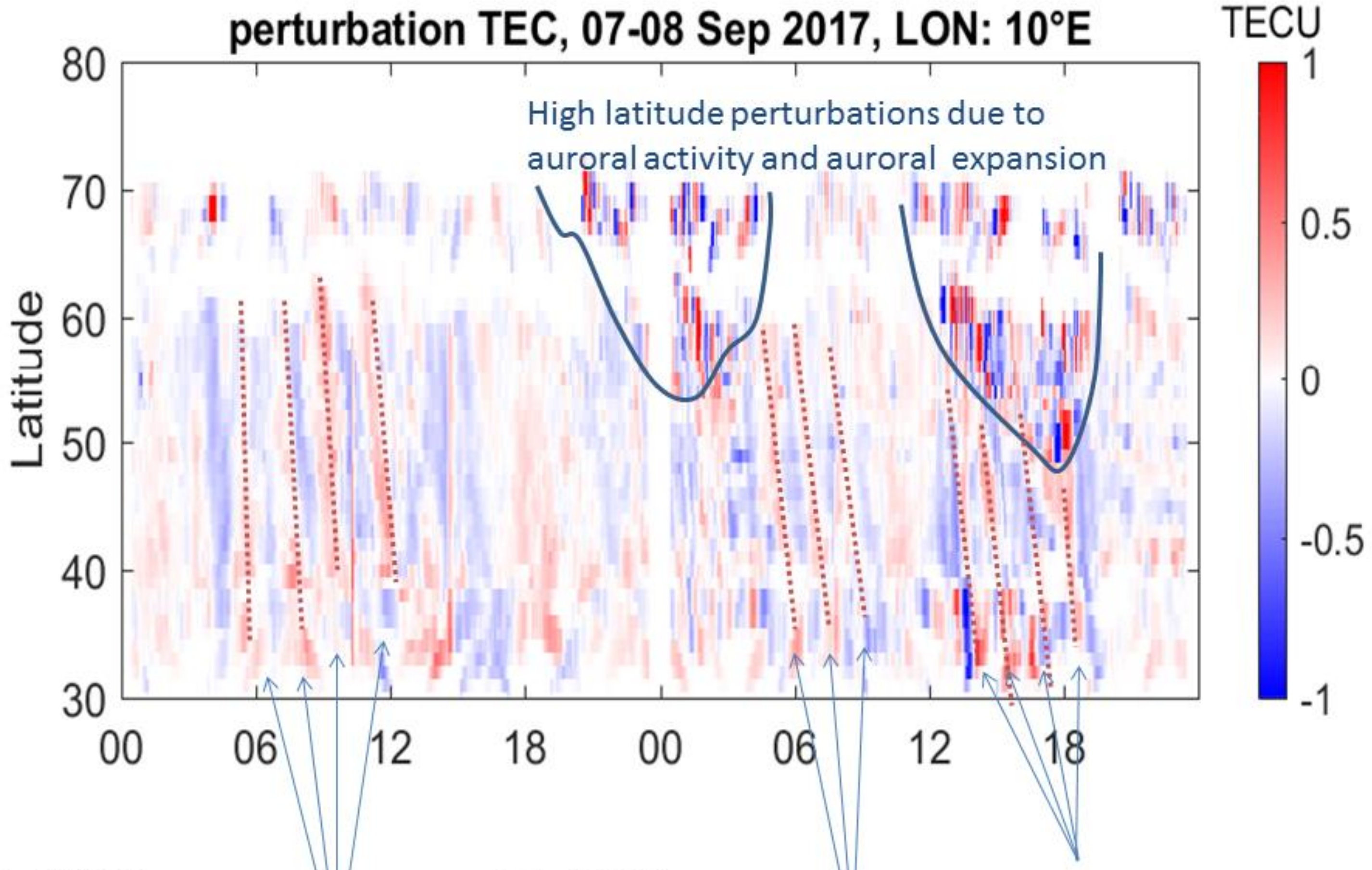
- TID detectors that provide near-real time measurements of TIDs
- Estimation of ionosphere background conditions
- Generation of TID activity metrics and information for non-scientific users



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



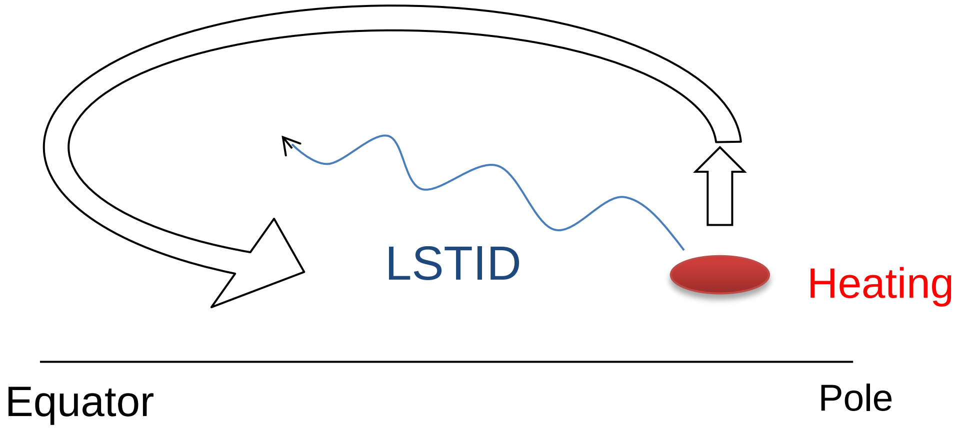


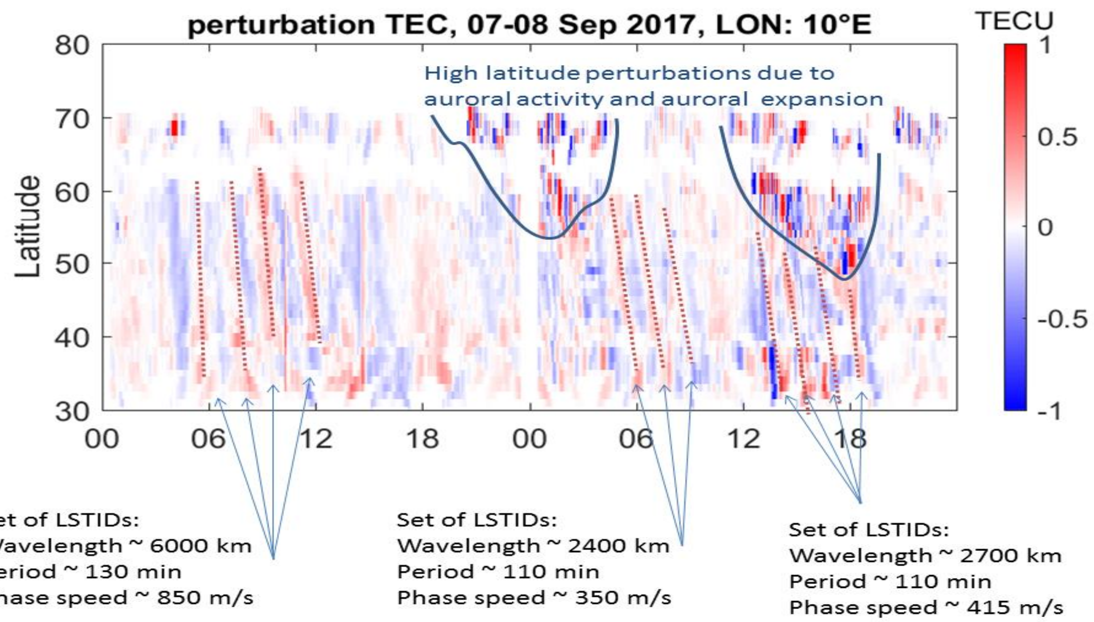
Set of LSTIDs:
Wavelength ~ 6000 km
Period ~ 130 min
Phase speed ~ 850 m/s

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

Theoretical Background



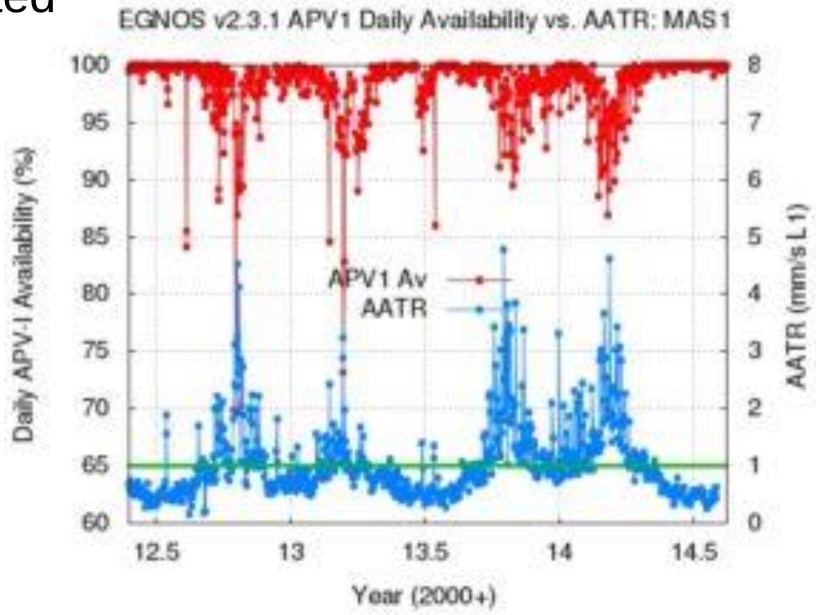


- Very sudden intensive heating generates large scale atmospheric gravity waves in the winds. They are observed in the Total Electron Content (TEC) as **Large Scale Travelling Ionospheric Disturbances (LSTIDs)**
- Source region of LSTIDs is charicterized by strong spatial gradients, depletion and significant fluctuations of the electron density and TEC

LSTID activity – GNSS precursors

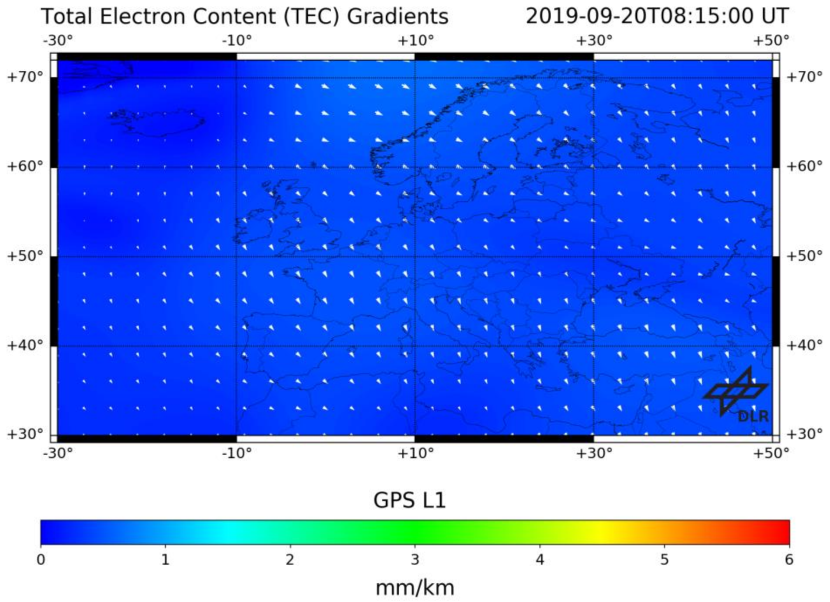
Along Arc TEC Rate (AATR)

- 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



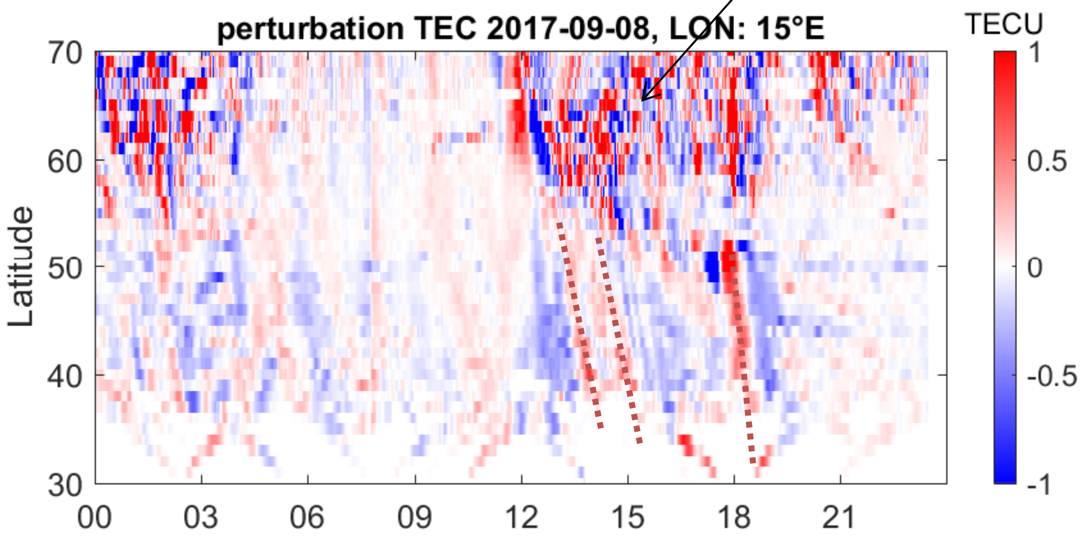
TEC Gradients

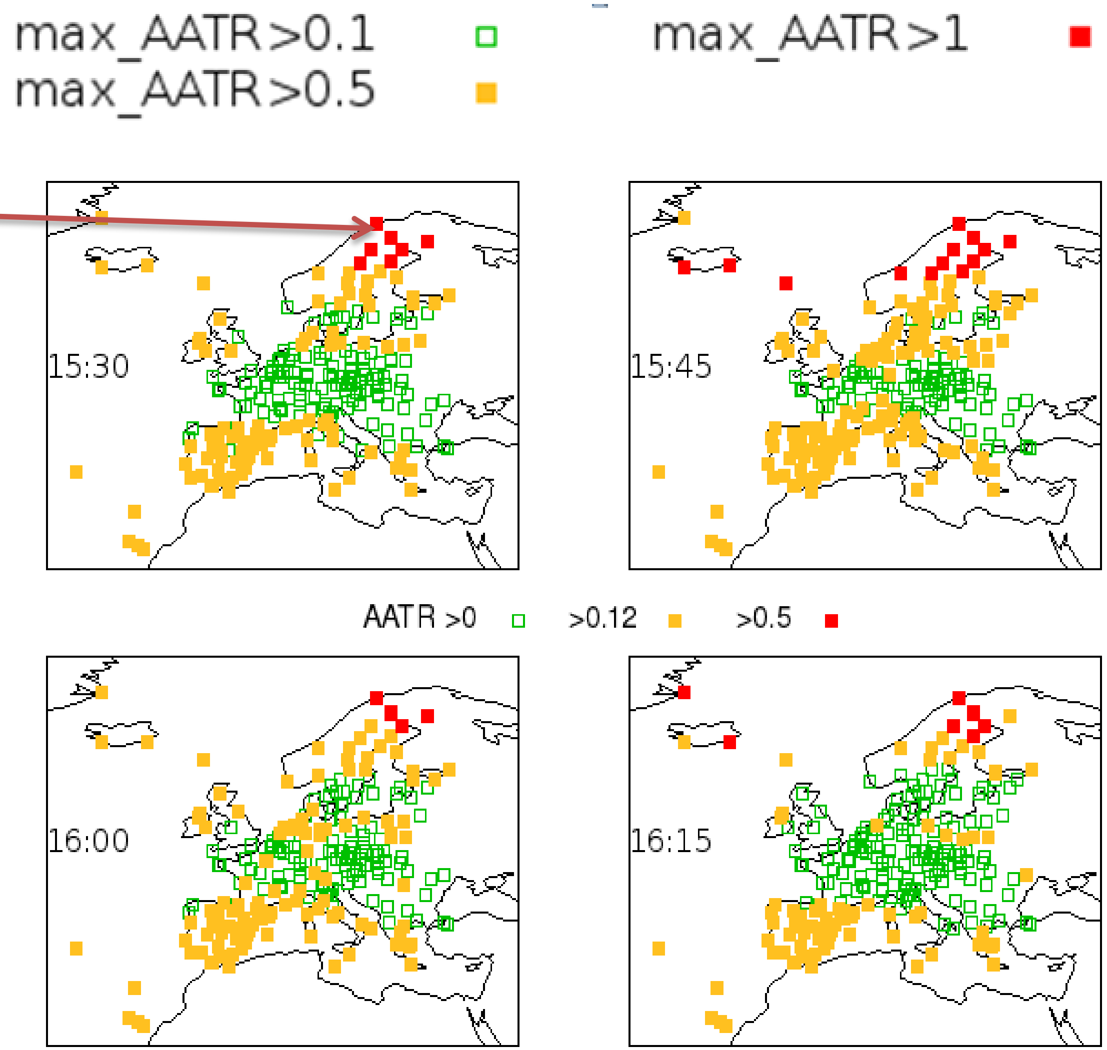
- This product is derived from near real-time TEC maps
- Spatial horizontal gradients between the TEC maps (1°x1°) grid points are calculated



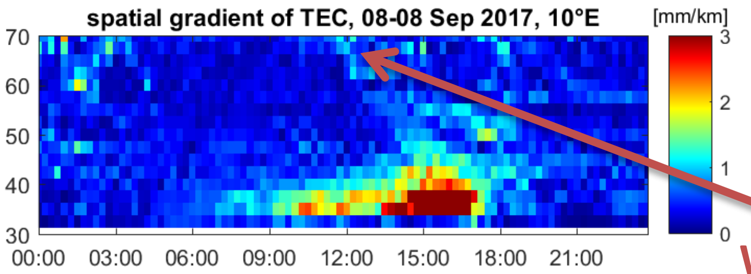
AATR during 8 September 2017

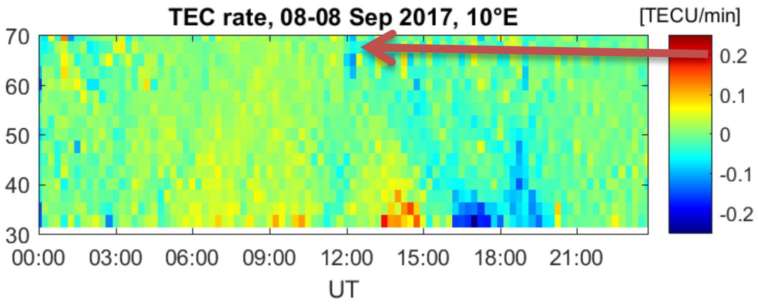
Strong perturbations in auroral region





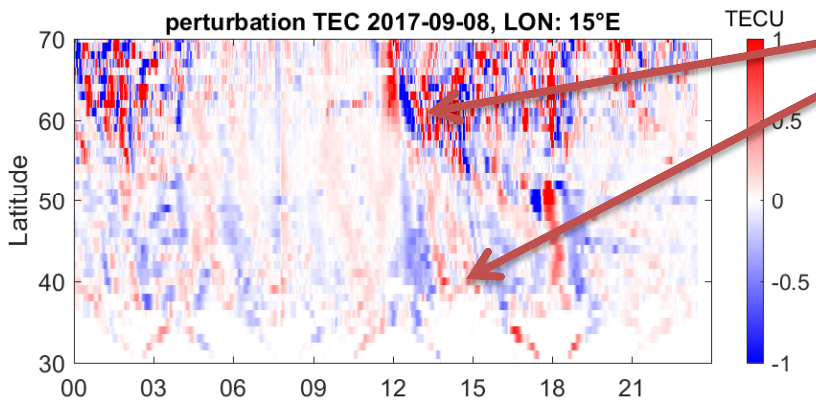
TEC gradients during 8 Sept 2017

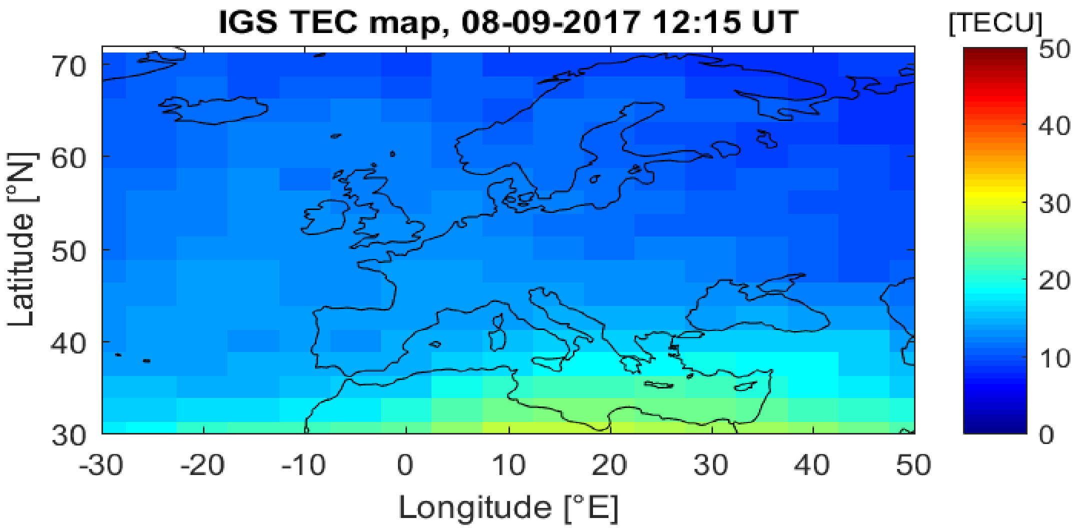


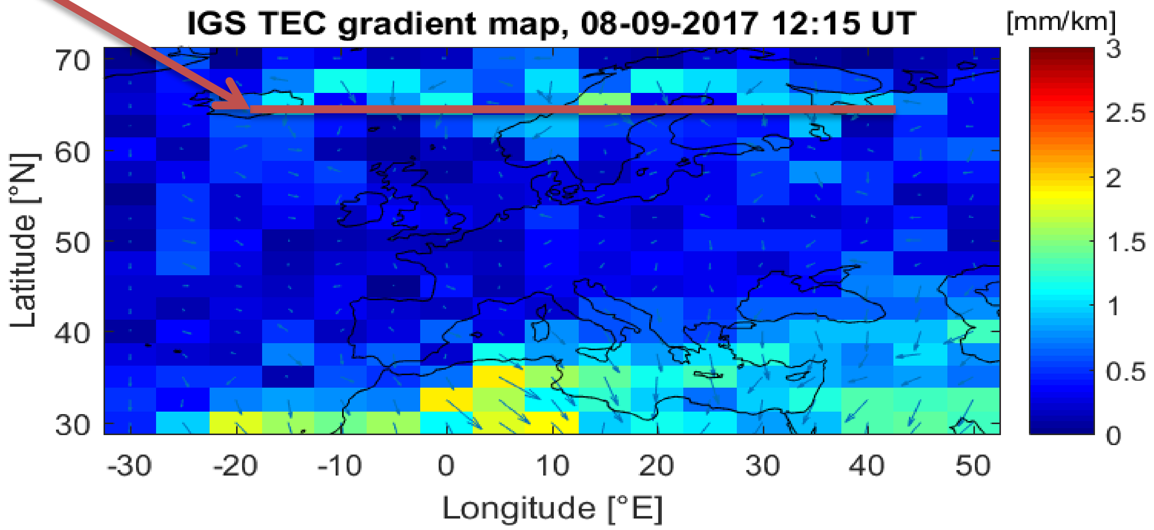


Weak TEC gradients in high latitudes Co-located with a TEC depletion

TIDs







HF Interferometry method performance

7 September 2017

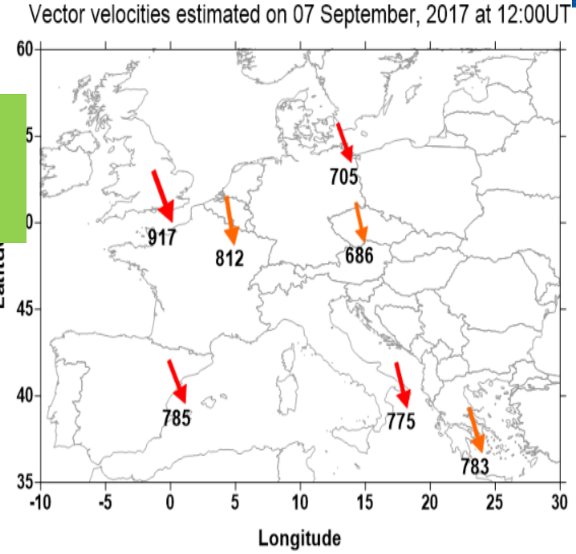
Typical characteristics of LSTIDs whose origin might be auroral.

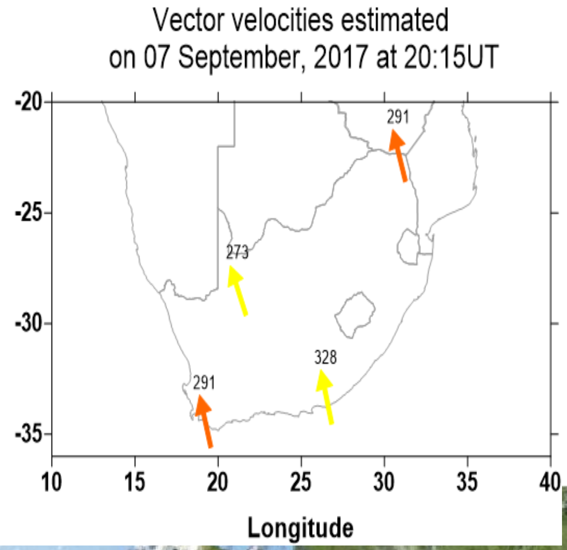
Europe

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.

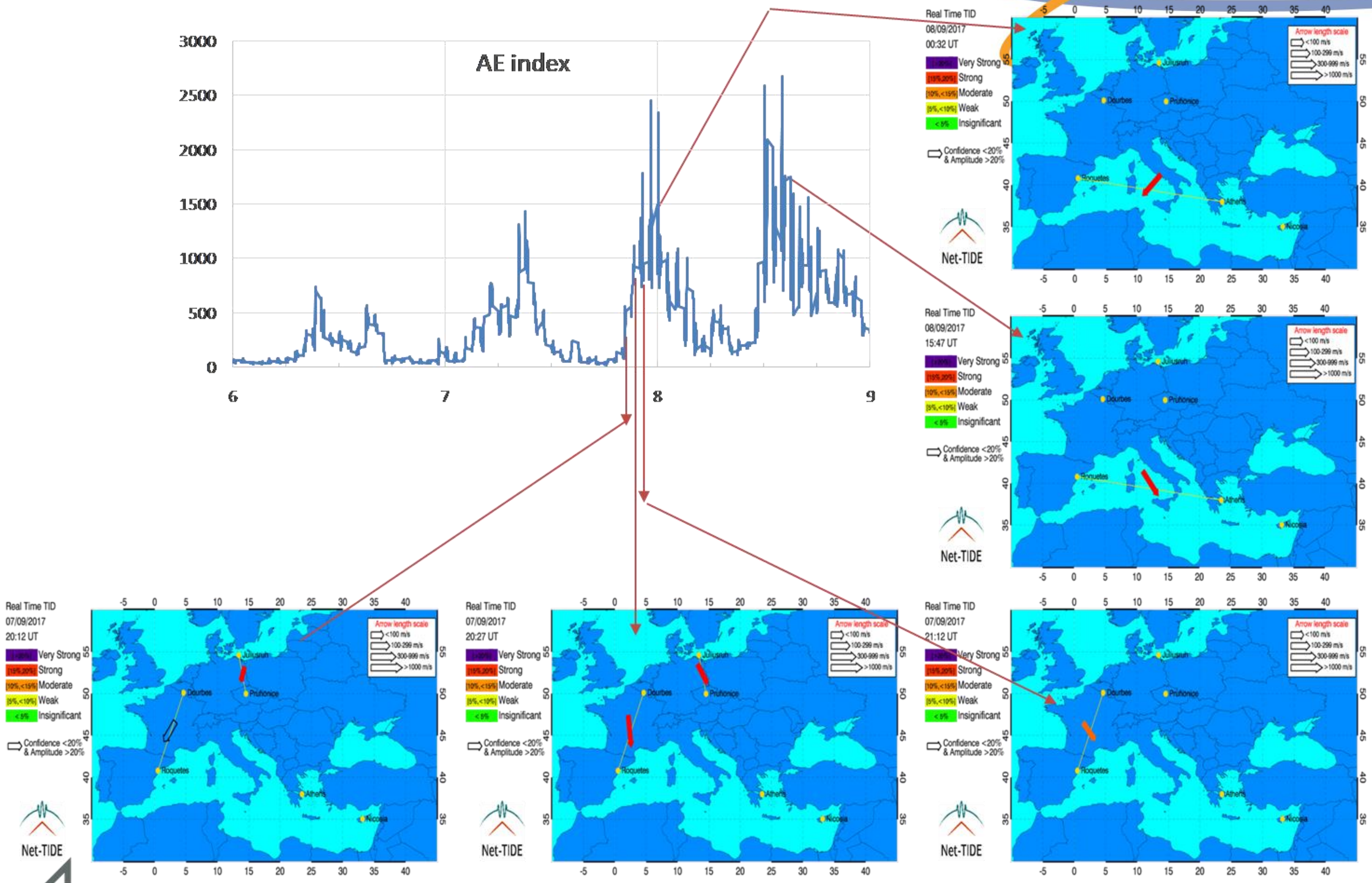
South Africa

Stations in South Africa observe a dominant disturbance with a periodicity close to 1.5-h and clear northward propagation occurring in the evening.





HF-TID method



September 7:

Strong TID activity in the evening hours.

Propagation: north-to-south, velocity: 300 – 1000 m/s

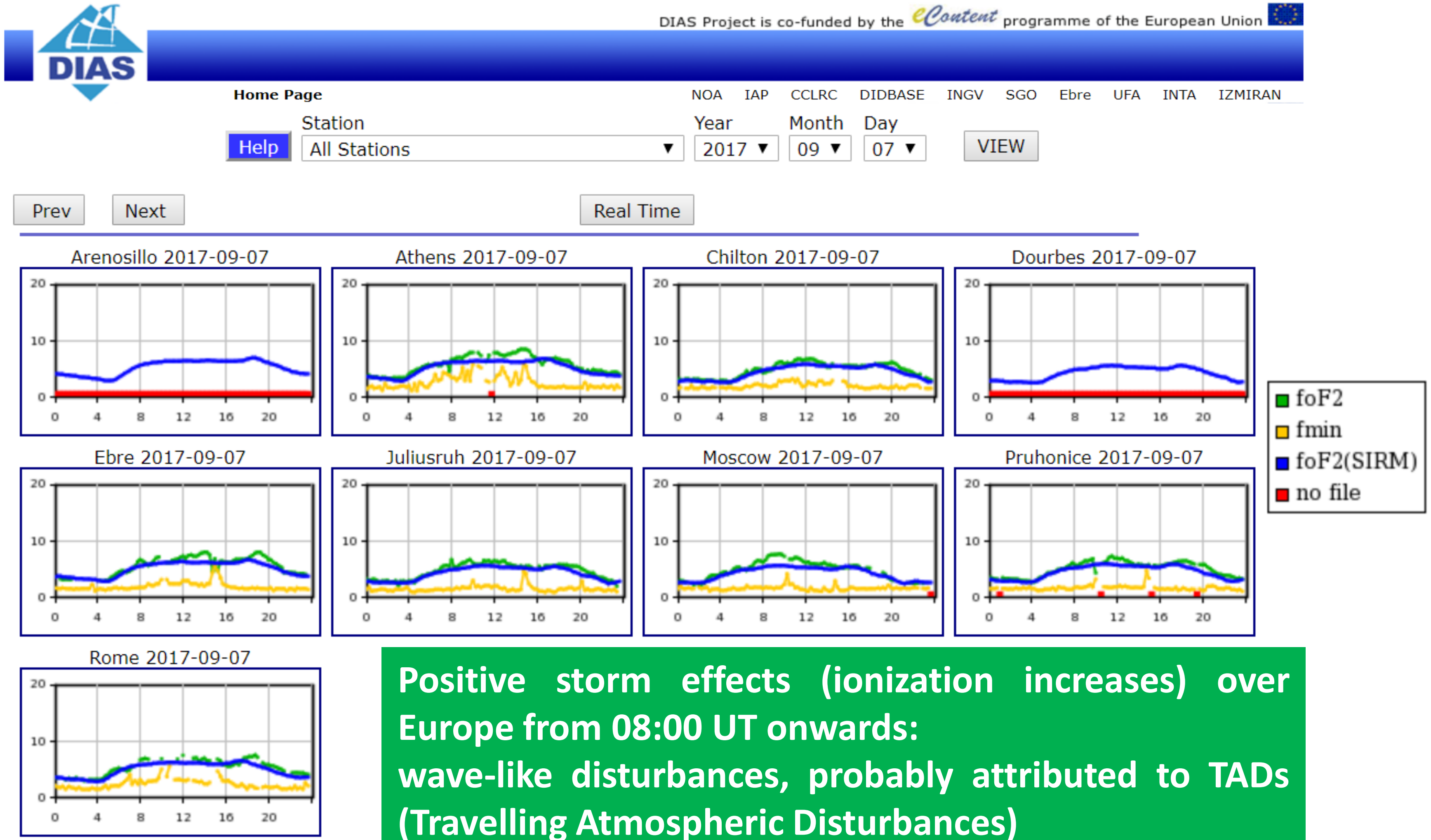
September 8:

Strong TID activity in the early morning and daytime hours.

Propagation: north-to-south, velocity: 300 – 1000 m/s

Background ionosphere

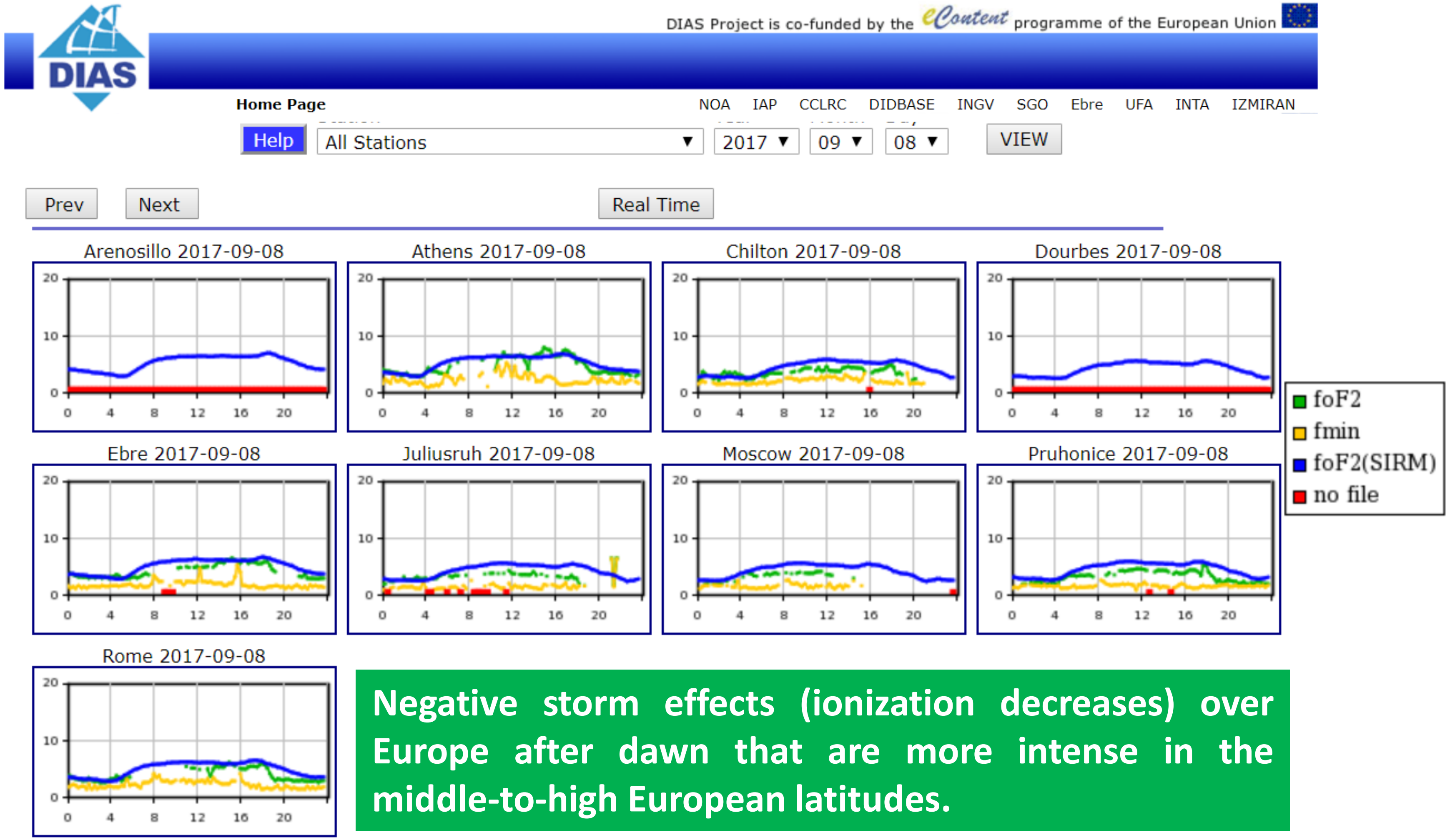
7 September 2017



Positive storm effects (ionization increases) over Europe from 08:00 UT onwards: wave-like disturbances, probably attributed to TADs (Travelling Atmospheric Disturbances)

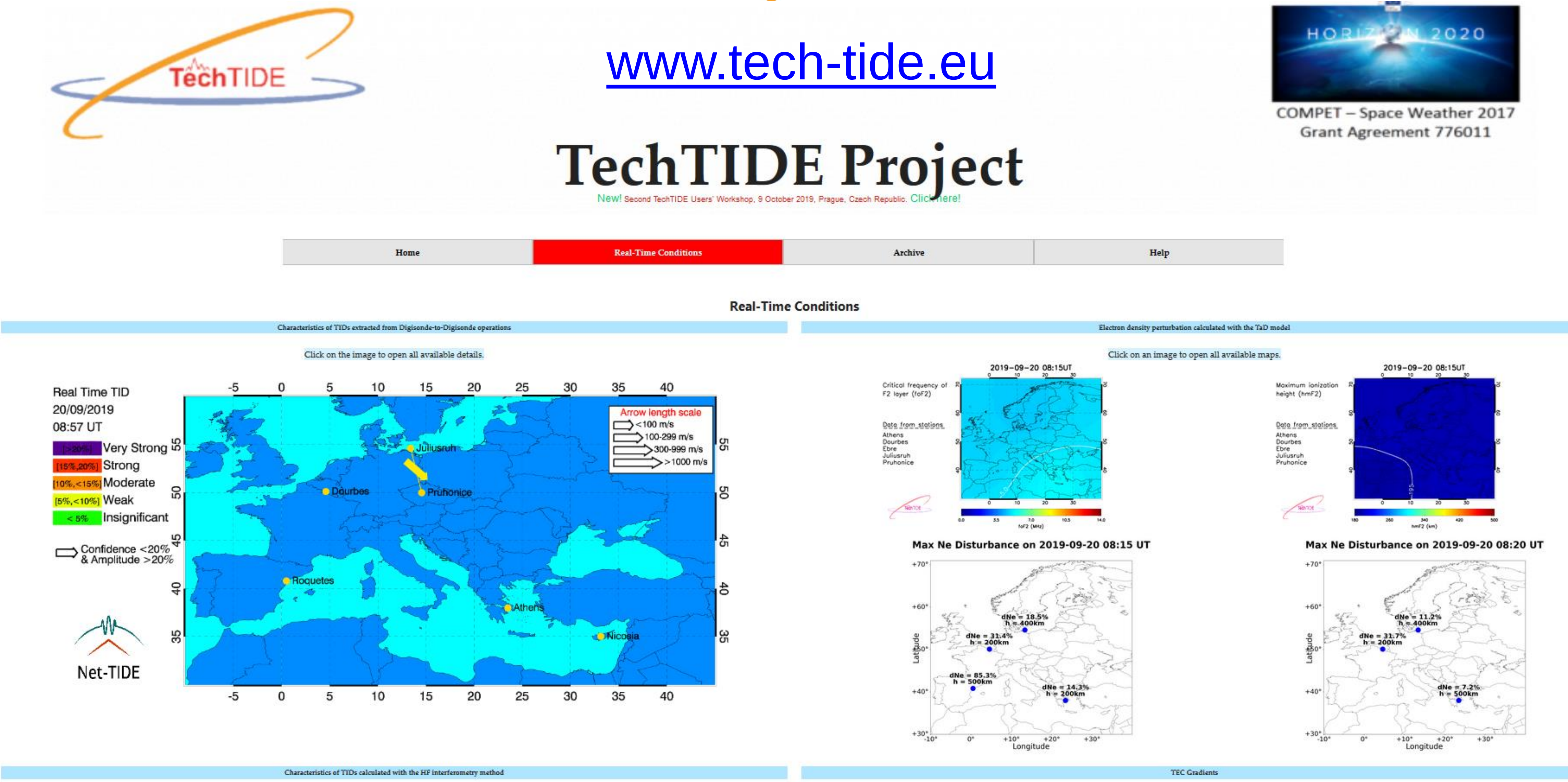
Background ionosphere

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 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

Activity	Method/Indicators	Time interval		
		September, 6	**September, 7**	**September, 8**
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 mid-night 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

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 eachother 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
  - …

Overall coordinator:

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Twitter: @Tech_TIDE https://twitter.com/Tech_TIDE

ResearchGate:

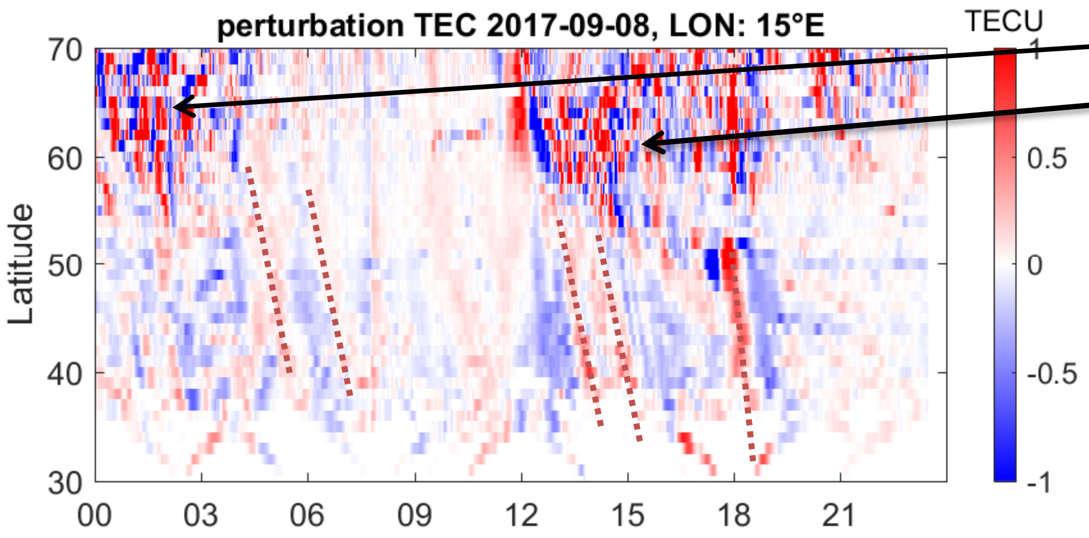
https://www.researchgate.net/project/TechTIDE-2

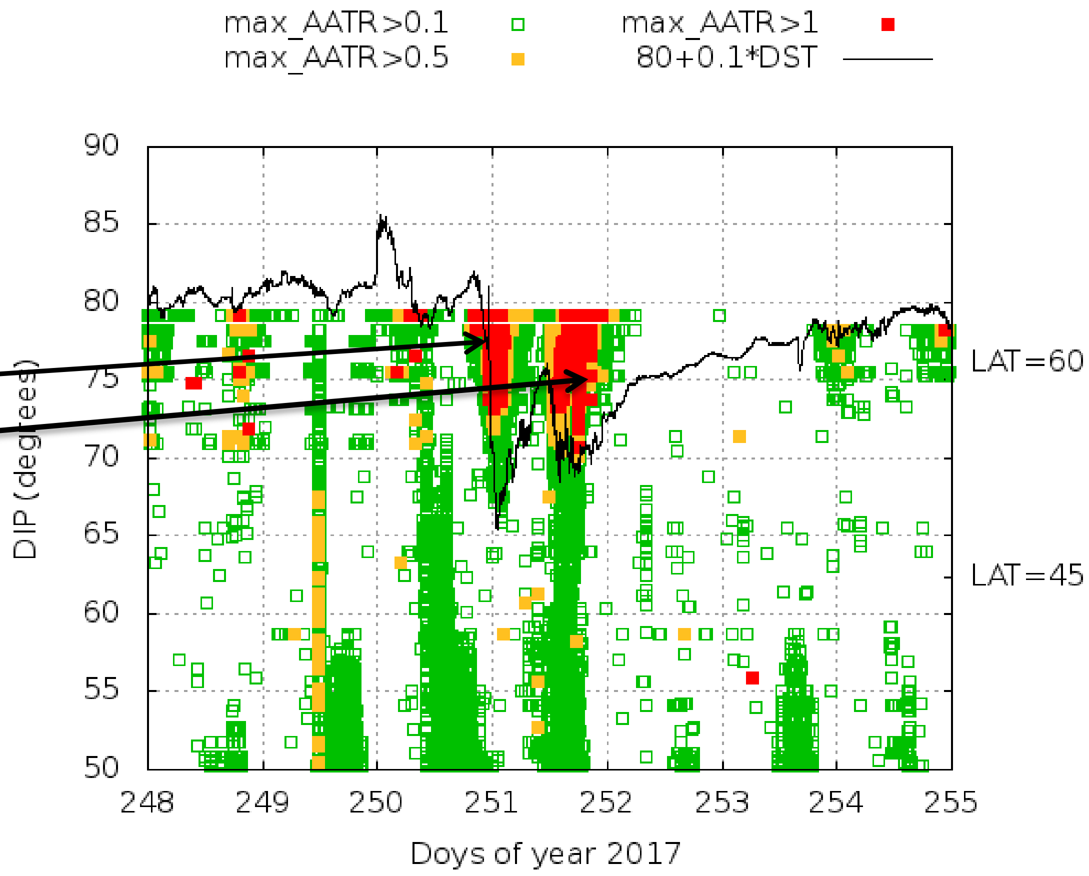
Thank you for your attention

Backup slides

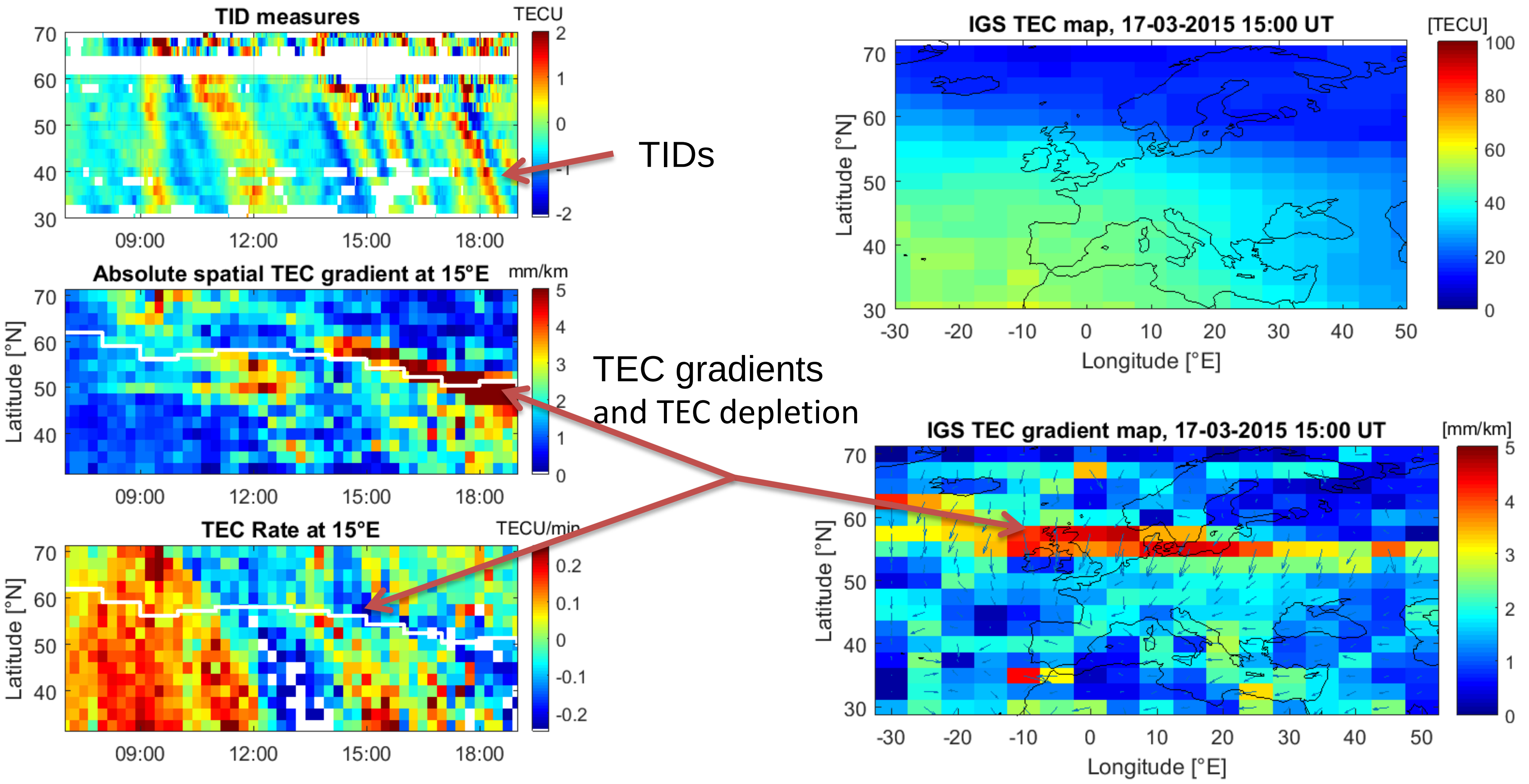
AATR during 8 September 2017

Strong perturbations in auroral region





Event 17 Mar 2015

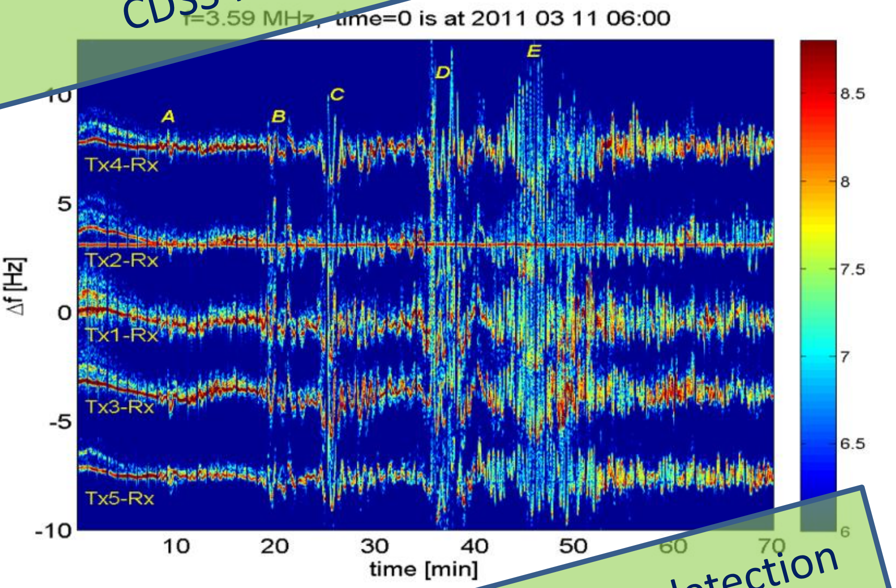


Borries, C., A. M. Mahrous, N. M. Ellahouny, and R. Badeke (2016), Multiple ionospheric perturbations during the Saint Patrick's Day storm 2015 in the European-African sector, *J. Geophys. Res. Space Physics*, *121*, doi:10.1002/2016JA023178.

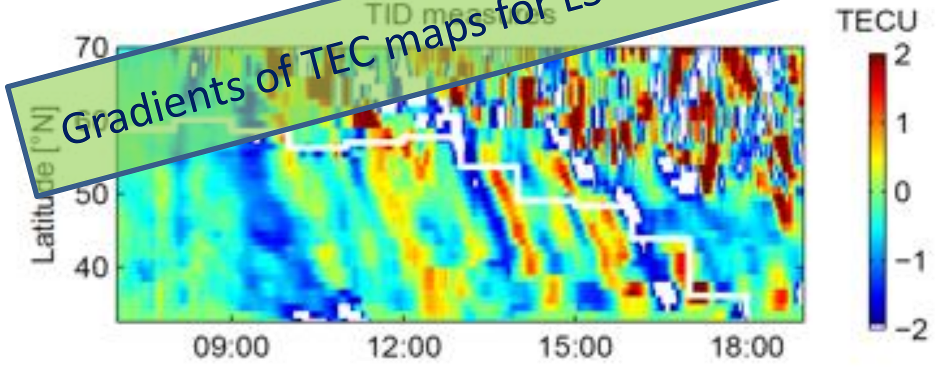
DLR

How do we detect TIDs?

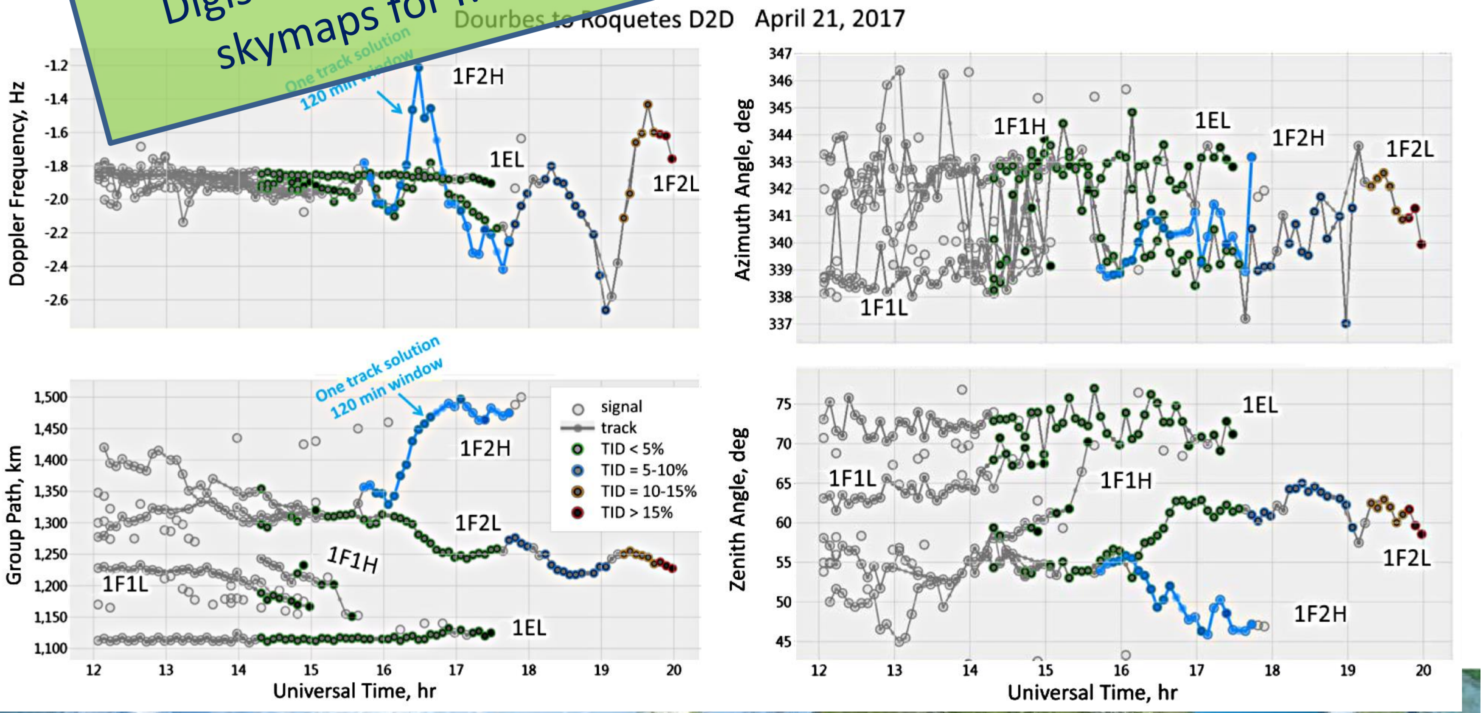
CDSS for MS TID detection



Gradients of TEC maps for LS TID detection



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



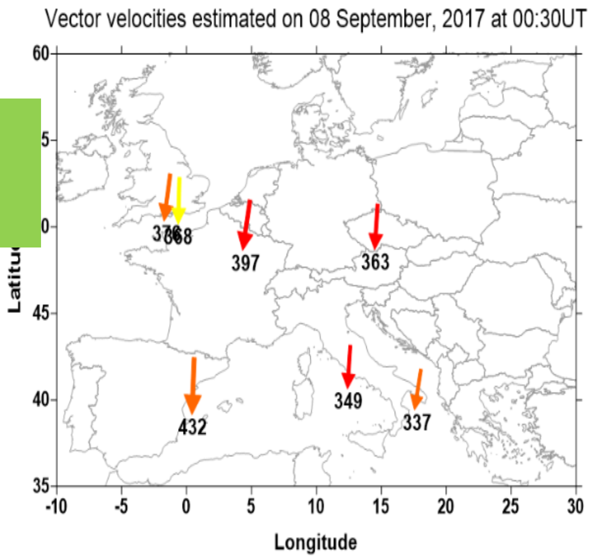
HF interferometry method

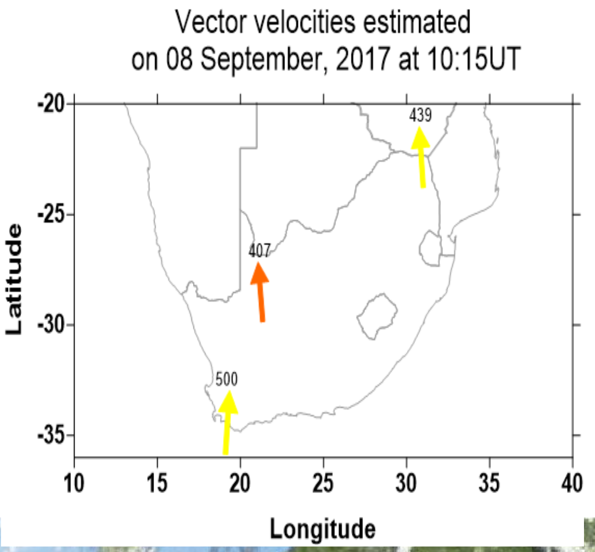
8 September 2017

Typical characteristics of LSTIDs whose origin might be auroral.

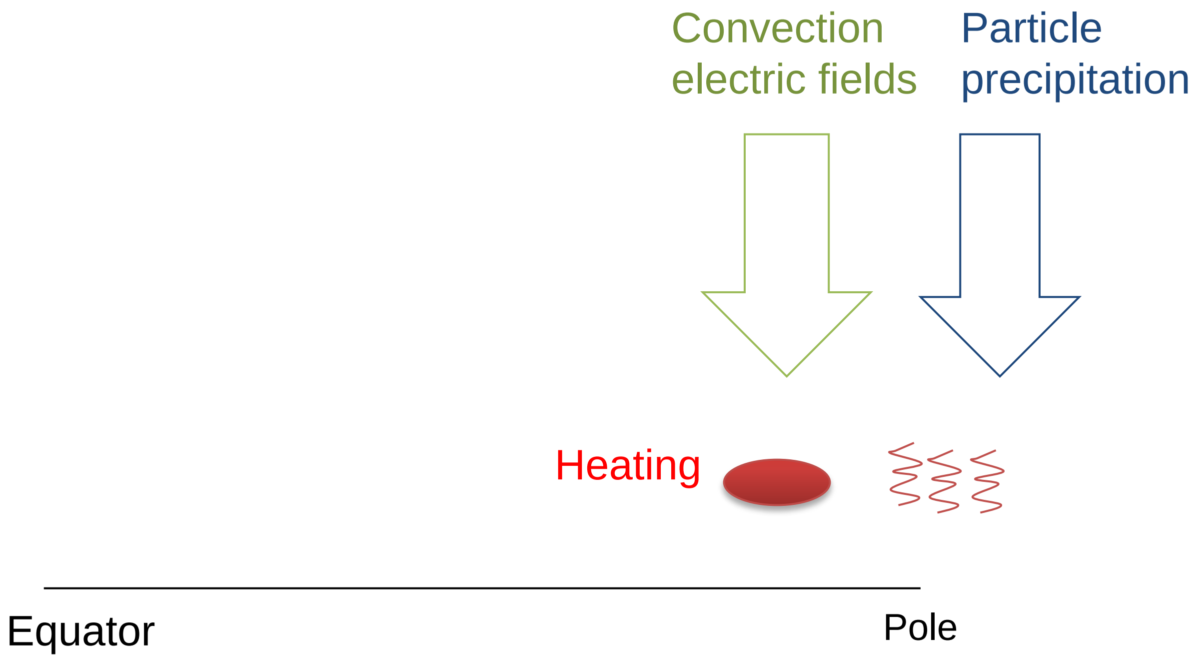
Europe
LSTID activity was also observed in early hours of 8 September (until 2:00 UT) for all the European stations, as continuation of the event reported for 7 of September - azimuth of 180º (from true north) and a velocity of about 400m/s.

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.



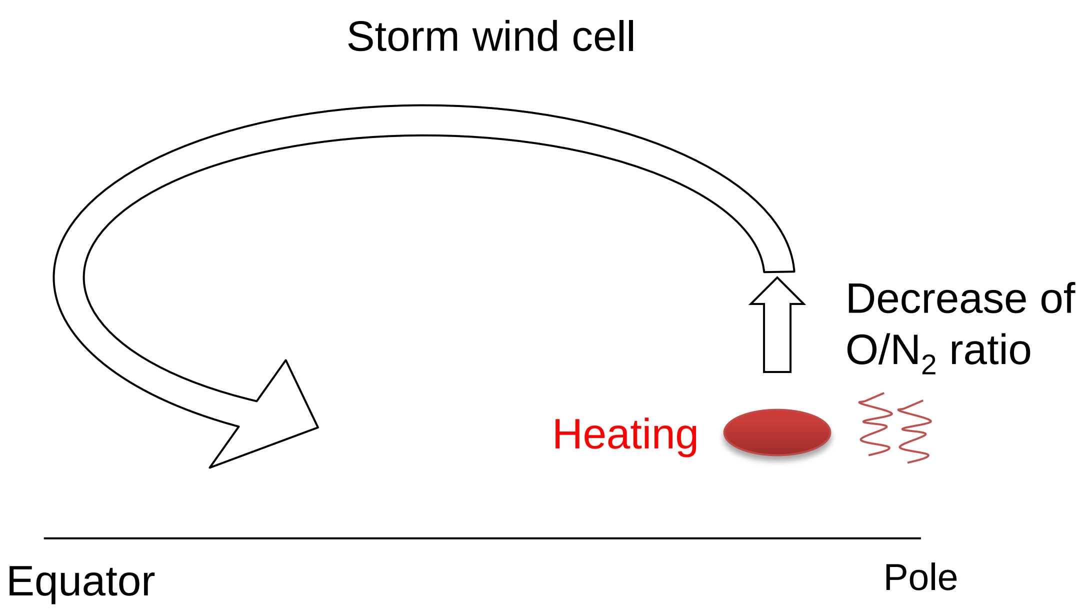


Theoretical Background



- 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

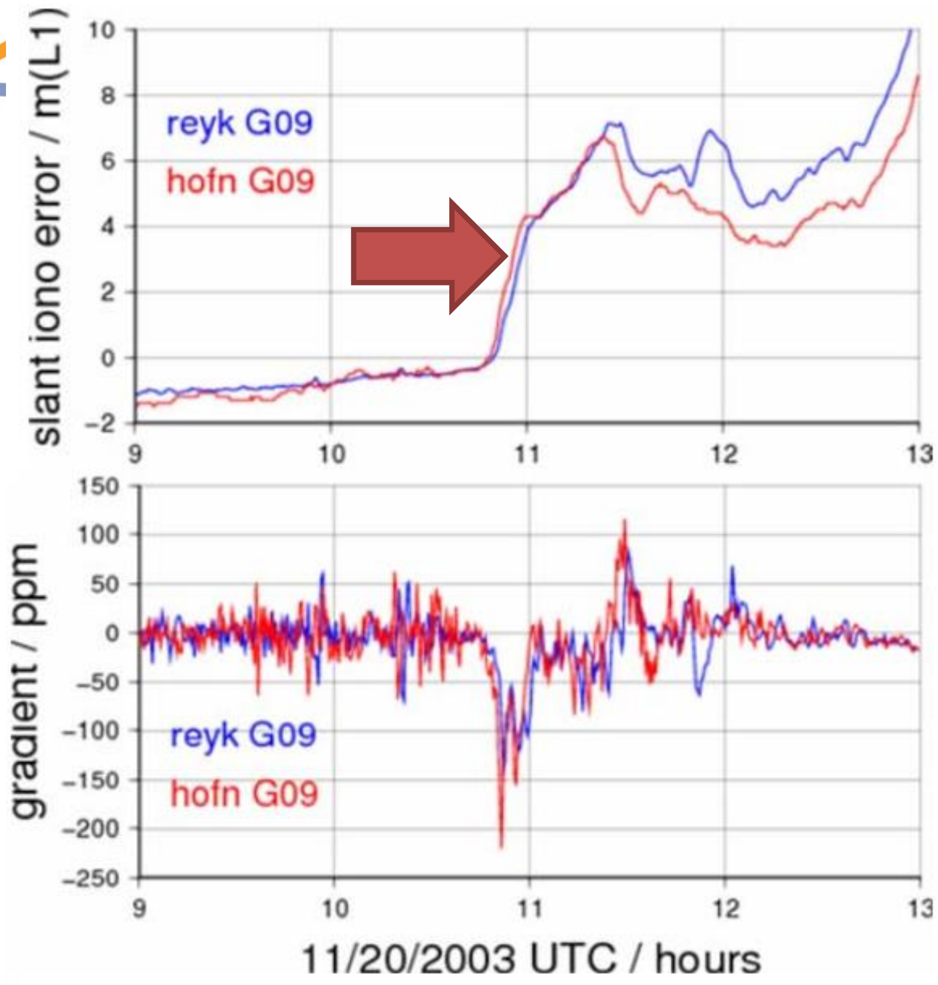
Theoretical Background



- Both heating effects have impact on thermosphere-ionosphere system
- Precipitation causes strong localized fluctuations in the thermosphere composition, winds and hence **strong flucutuations 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



Mayer, C. and Jakowski, N. and Borries, C. and Pannowitsch, T. and Belabbas, B. (2008) Extreme ionospheric conditions over Europe observed during the last solar cycle, *Proceedings of the 4th ESA Workshop on Satellite Navigation User Equipment Technologies*

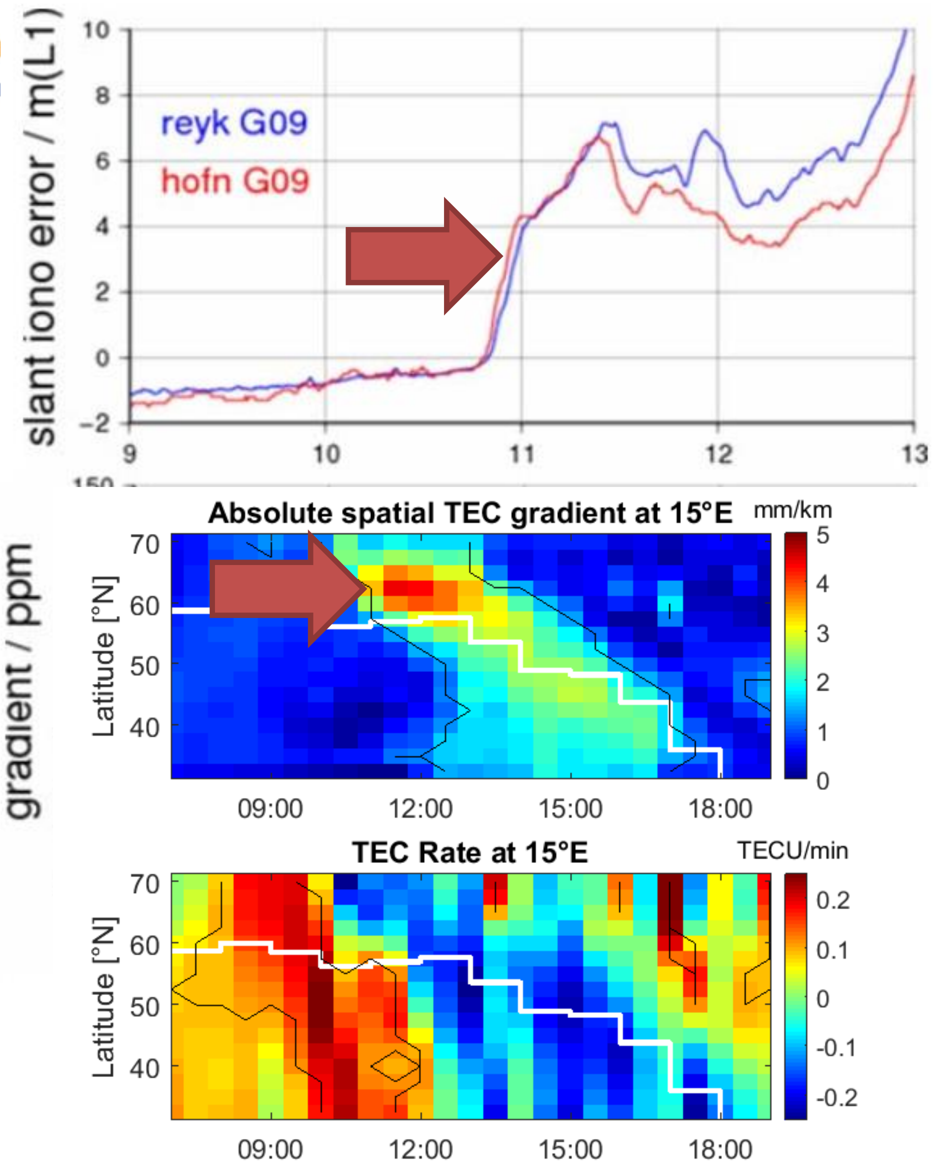
Validation of method with published events

- 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

- 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

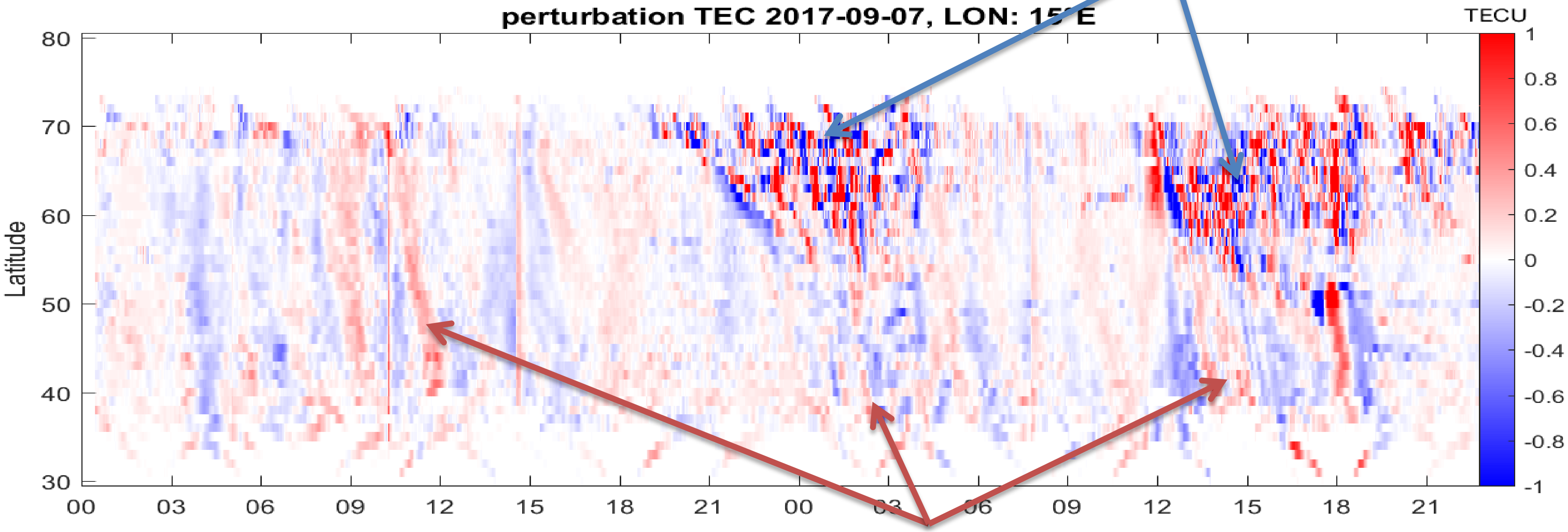
→ Method applies to identify gradients correctly

→ 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



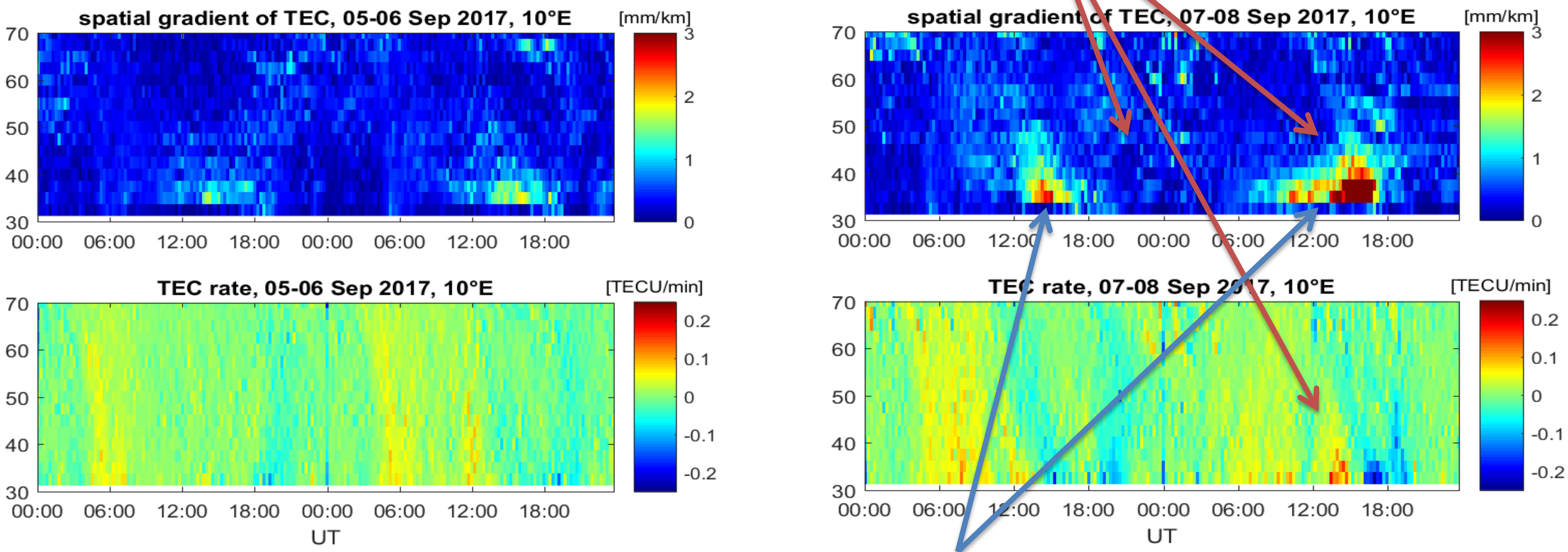
TID activity after moderate perturbations in high latitudes

Time-latitude plots of TEC gradients

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

Quiet

Disturbed



Low latitude gradients might be a result of TID activity