Warning and Mitigation technologies for Travelling Ionospheric Disturbances Effects

H2020-COMPET-2017

Monitoring and analysis of the TIDs triggered by magnetic storms and their impact on EGNOS availability degradation

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Outline

- Brief introduction to the techniques applied to detection of LSTID
- Brief information on EGNOS
- Results of analysed space weather events
- Summary

TID detection method	Brief description of the method
HF-TID	A new technique, based on the exploitation of DPS4D ionosondes, is implemented to directly identify TID in real-time. For the real-time detection and evaluation of TIDs remote-sensing data from synchronized, network coordinated HF sounding between pairs of DPS4D ionosondes are exploited. (*Reinisch et al., 2017; Huang et al., 2016)*
HF Interferometry method	The method identifies coherent TID activity at different sites and sets bounds to time intervals for which such activity occurs into a given region. *(Altadill et al., 2017)*
TID activity monitoring using GNSS data	TEC observations used for the analysis are calculated utilizing L1 and L2 Global Positioning Systems (GPS) frequency measurements (i.e. 1575.42 and 1227.60 MHz, respectively) in an algorithm developed at Boston College.

TechTIDE project HF-TID network (including possible extension)

1D Altitude profile of TID

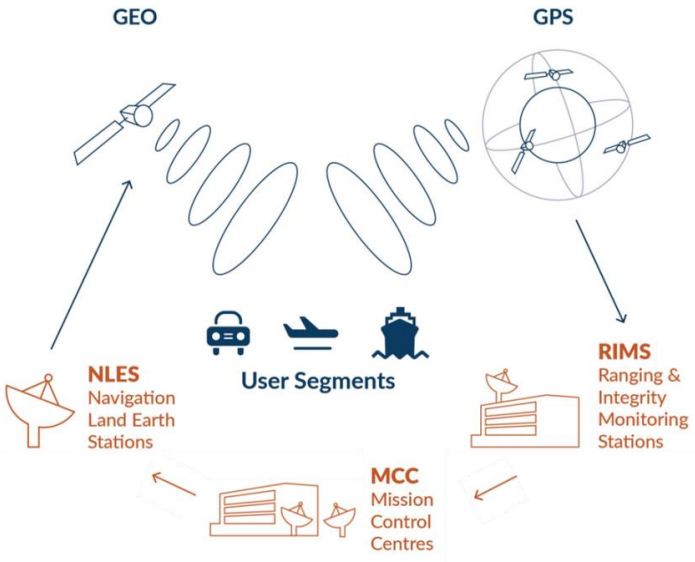
- Detailed view of propagation along z-axis
- Pin-point to particular altitude region

Sensitivity (amplitude)

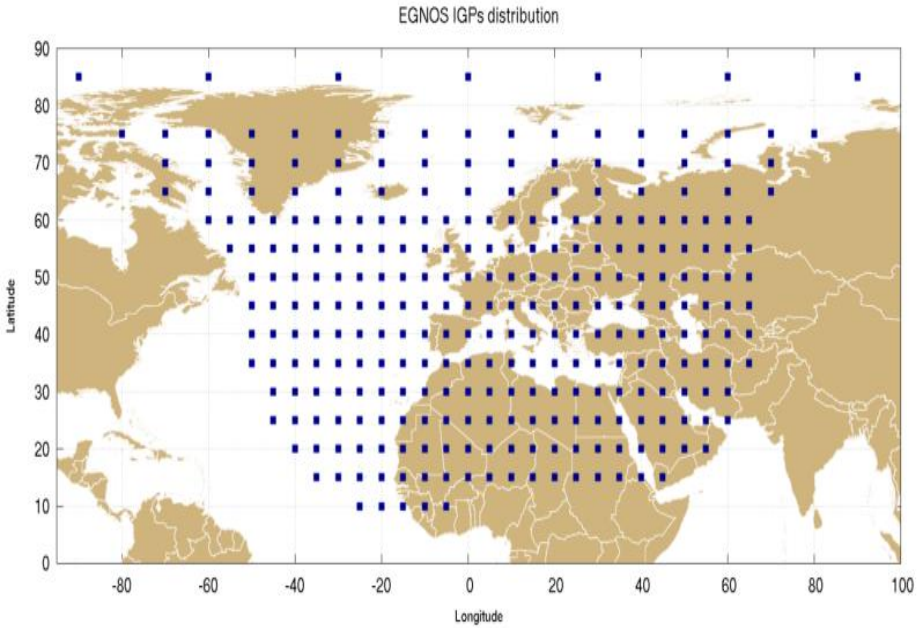
- Detection of a 5% TID vs underlying density
- "TID are always present" < 2%

Direction, Velocity, Wavelength

- Direct measurement
- Static platform
- No geometric transformation needed
- 24/7 operations with automatic intelligent system analysis



Scheme of EGNOS infrastructure



The map of IGPs where EGNOS computes the ionospheric corrections

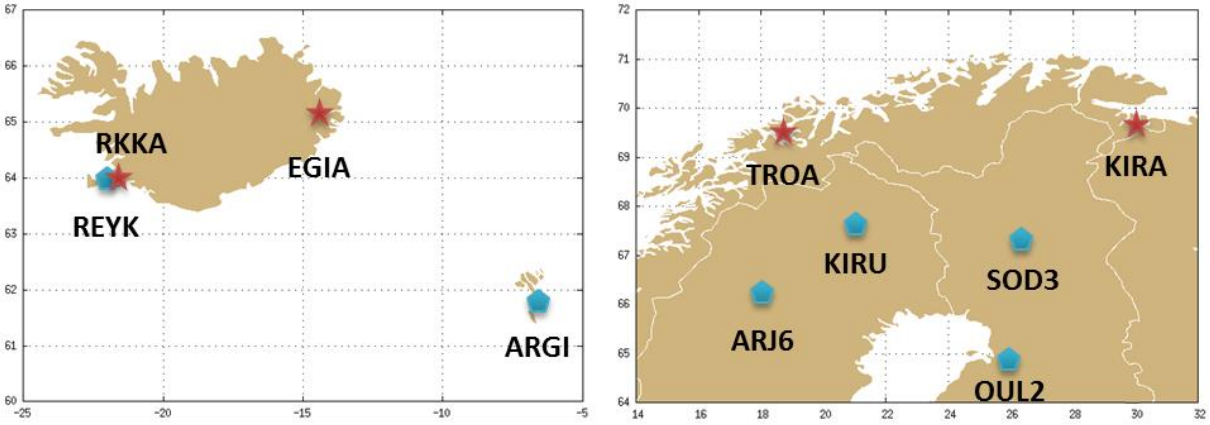
The **European Geostationary Navigation Overlay Service (EGNOS)** is Europe's regional satellite-based augmentation system (SBAS). EGNOS computes the ionospheric information distributed in a grid of pierce points, called **Ionospheric Grid Points (IGP)**, located at an altitude of 350 km.

The ionospheric information provided by EGNOS is:

- **Grid Ionospheric Vertical Delay (GIVD)**: Ionospheric vertical delay at the IGP for L1 frequency;
- **Grid Ionospheric Vertical Error (GIVE)**: Ionospheric Vertical Error at the IGP.

The GIVD is related with the TEC value. This parameter indicates the delay of the signal (in meters) due to the transition through ionosphere. On the other hand, the GIVE is the bounding of the GIVD estimation, that is, is the sigma (at 99.99999%) of the ionospheric delay. Any disturbance in the ionosphere would increase the width of the distribution error around the IGP and, therefore, would lead to an increase of this value.

The **Along Arc TEC Rate (AATR) index** is computed from dual-frequency GNSS measurements and serves as an ionospheric activity indicator. The higher AATR value means the larger ionospheric perturbation is in the area (Juan, M. et al, SWSC, 2017)



Locations of EGNOS RIMS (red starts) and IGS stations (blue pentagons)

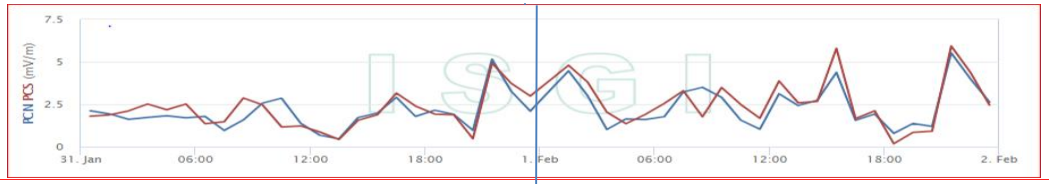
- Performance at EGNOS **Ranging Integrity Monitoring Stations (RIMS)** is computed as representative of user performance. The data used from the RIMS are:
  - EGNOS APV-I availability at RIMS;
  - Horizontal and Vertical Protection Levels (HPL and VPL, respectively).

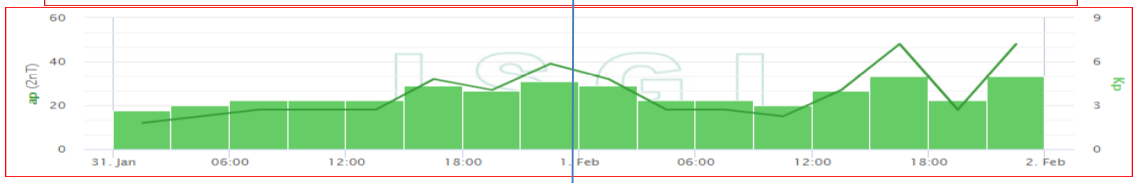
- IGS stations: dual-frequency multi-constellation receivers used for the computation of the AATR values.

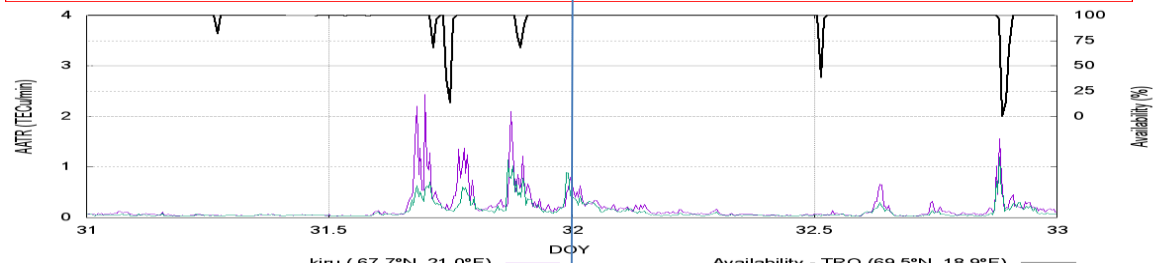
RIMS station	IGS station
EGI (65.1°N, 14.4°W)	ARGI (61.8°N, 6.8°W)
RKK (64.0°N, 22.0°W)	REYK (64.0°N, 22.0°W)
KIR (69.6°N, 29.9°E)	KIRU (67.7°N, 21.0°E)
	ARJ6 (66.2°N, 18.1°E)
TRO (69.0°N, 18.9°E)	OUL2 (64.9°N, 25.9°E)
	SOD3 (67.3°N, 26.4°E)

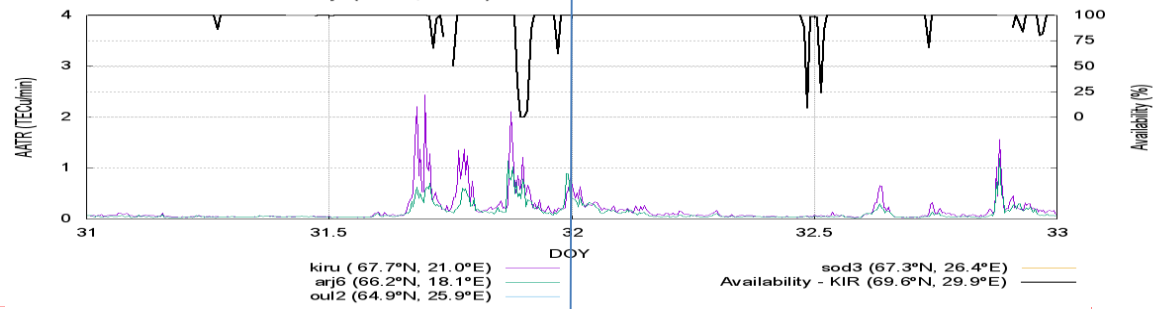
EGNOS APV-I Availability is defined as the percentage of epochs in which the **Protection Levels are below Alert Limits** for this APV-I service (**HPL<40m and VPL<50m**) over the total period.

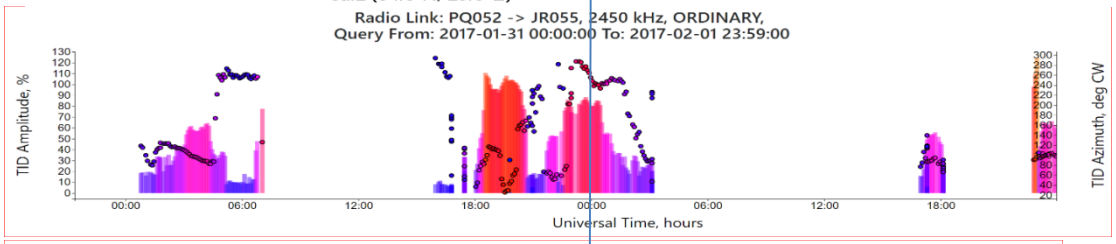
31 January -1 February 2017

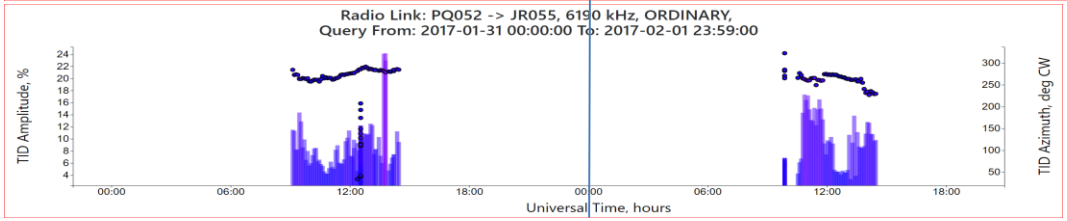






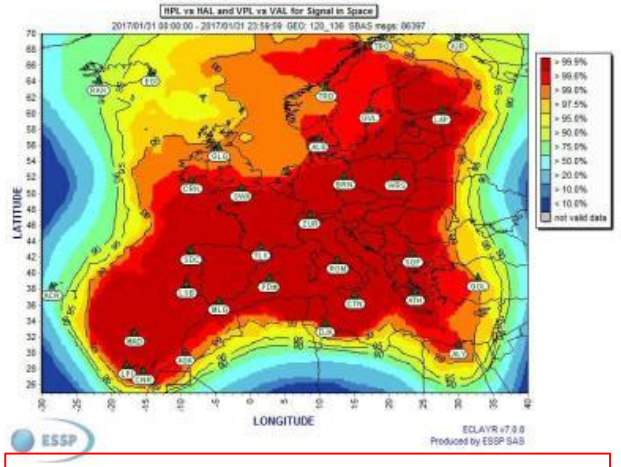




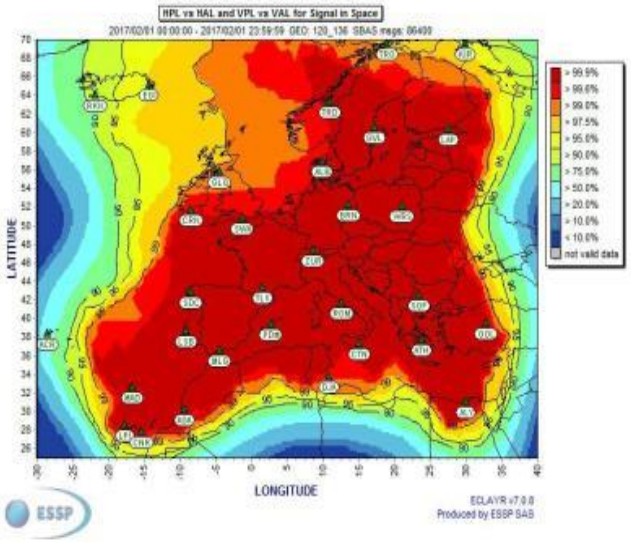


Time (UT)	WA, %	WAz, deg	WL, km	WP, min
PQ-JR path (2450 kHZ)				
31/01/ 01:30-05:00	64	88	1110	155
31/01/ 05:00-08:00	78	126	1188	150
31/01/ 18:00-20:00	77	149	4270	160
31/01/ 20:00-24:00	83	265	2484	105
31.01-01.02/ 23:00-03:00	39	251	913	65
01/02/ 20:00-23:00	60	98	1204	115

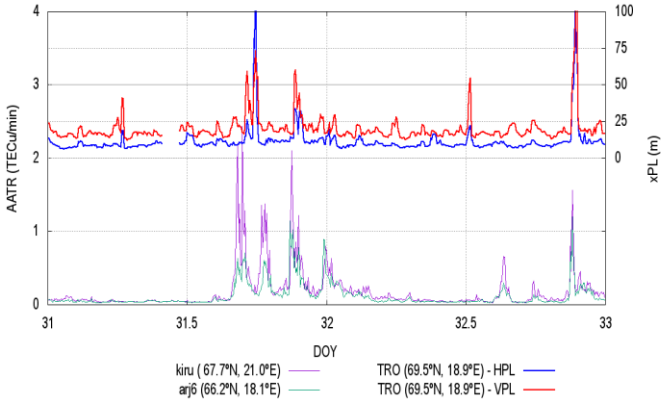
31 January -1 February 2017 event

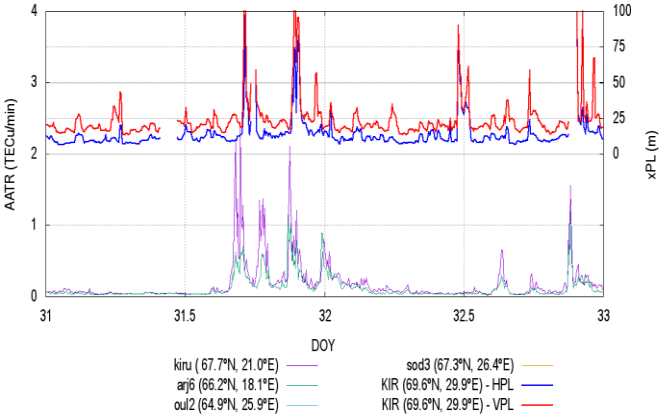


APV-I 99% Availability Degraded Area
12.8% -moderate degradation



APV-I 99% Availability Degraded Area
9.5% -moderate degradation

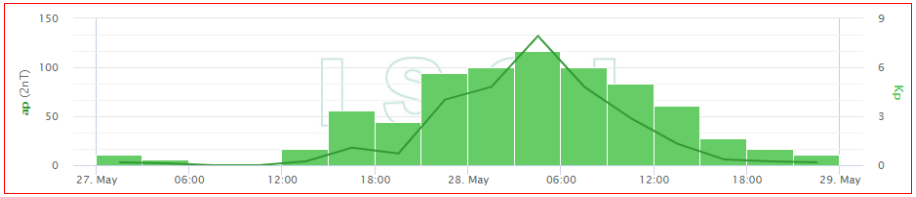


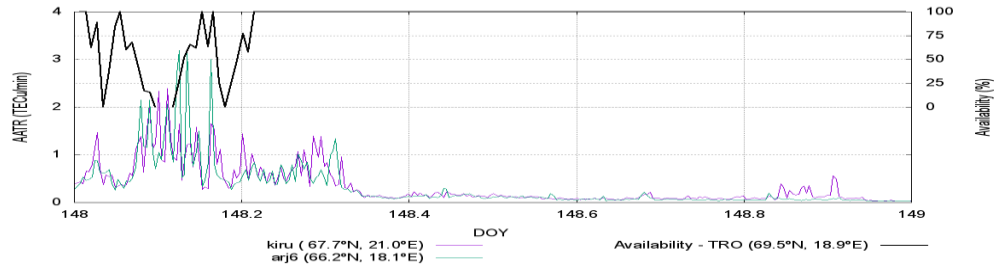


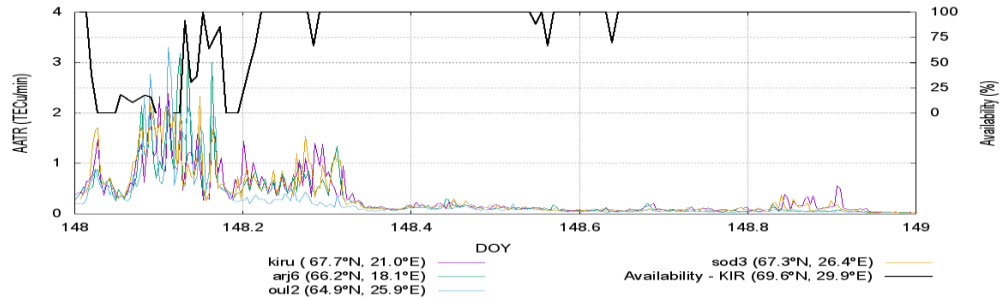
HPL variation (blue), VPL variation (red) at RIMS TRO and KIR, AATR values at IGS station KIRU (purple), ARJ6 (green), OUL2 (blue) and SOD3 (orange).

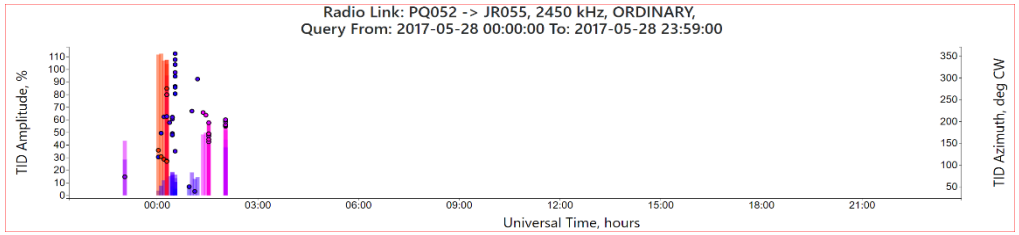
On **31/01/2017** the high geomagnetic activity has been observed by the end of the day which leads to degradation in EGNOS performance in the North West part of service area.

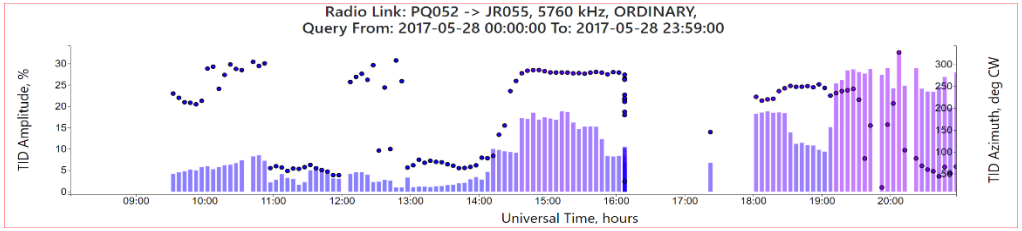
On **01/02/2017** the geomagnetic activity was still enhanced and continued impacting the EGNOS availability in the northern part of the service area.







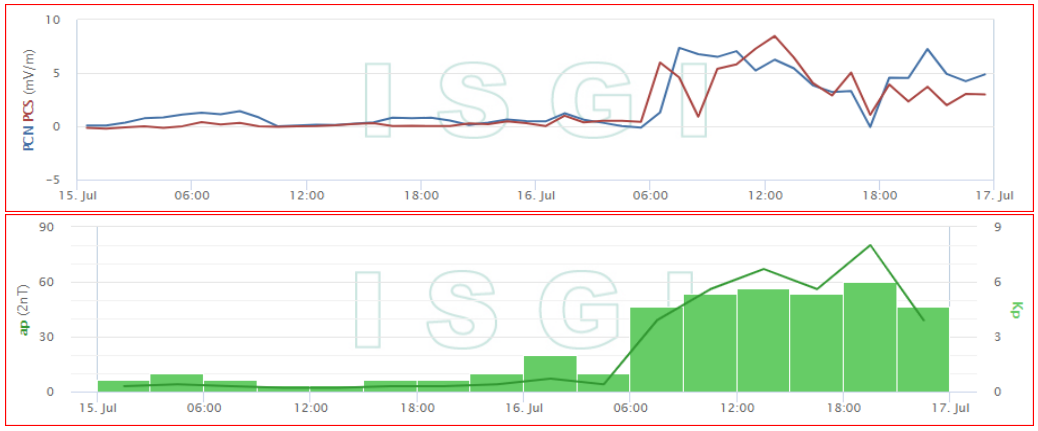


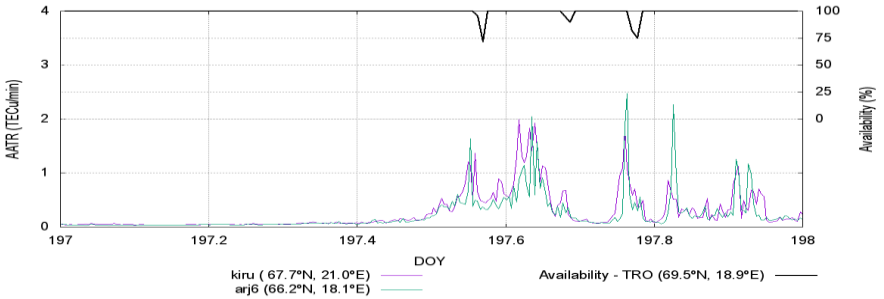


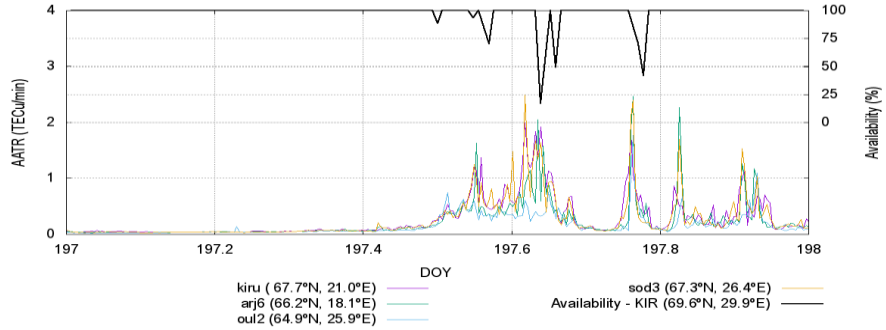
28 May 2017 event

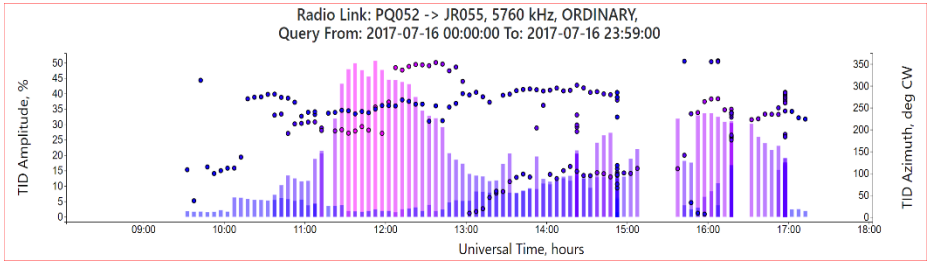
Parameters of LSTIDs observed on the PQ-JR sounding paths of 2450 KHz and 5760 kHz

Time (UT)	WA, %	WAz, deg	WL, km	WP, min
PQ-JR path (2450 kHZ)				
27.05-28.05/ 22:00-00:30	84	261	3774	130
27.05-28.05/ 23:30-02:00	59	172	2076	120
PQ-JR path (5760 kHZ)				
28/05/ 18:30-22:30	28	66	330	120



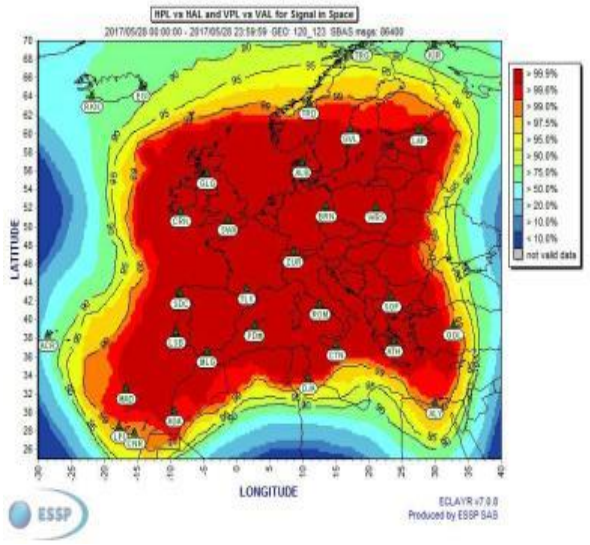




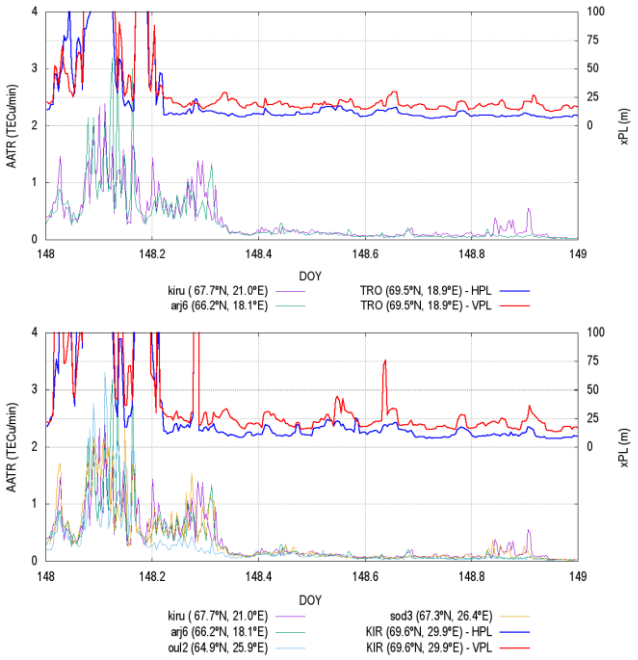


16 July 2017 event

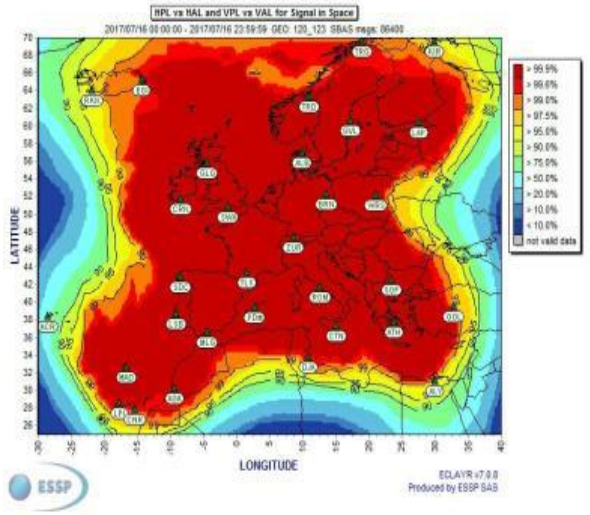
Time (UT)	WA, %	WAz, deg	WL, km	WP, min
PQ-JR path (2450 kHZ)				
01:30-03:00	29	26	896	90
PQ-JR path (5760 kHZ)				
10:00-12:50	21	335	2113	78
12:30-15:10	22	111	1392	60
14:20-16:50	23	235	1148	105
EB-DB path (4725 kHZ)				
21:10-23:50	80	117	1705	135
EB-AT path (4725 kHZ)				
21:30-23:50	51	111	2021	56



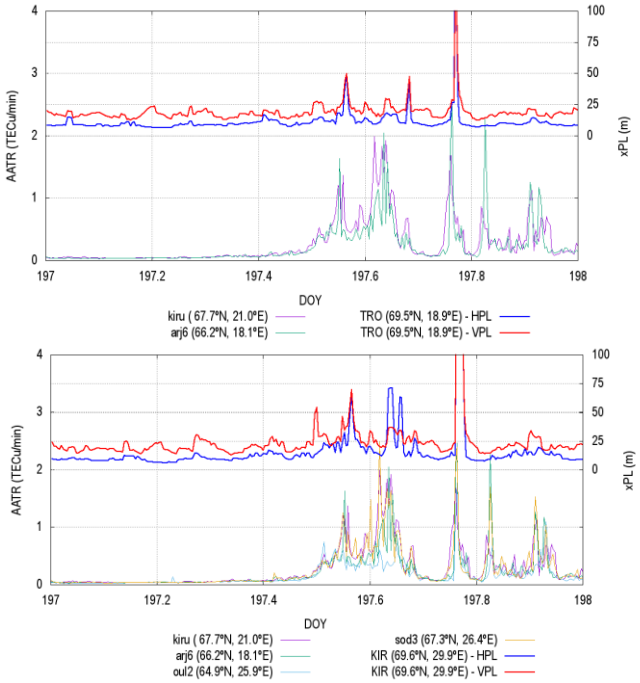
APV-I 99% Availability Degraded Area
21.7% - high degradation



On **28/05/2017** very strong geomagnetic activity has been observed at the beginning of the day which had a strong impact in the North part of EGNOS service area.

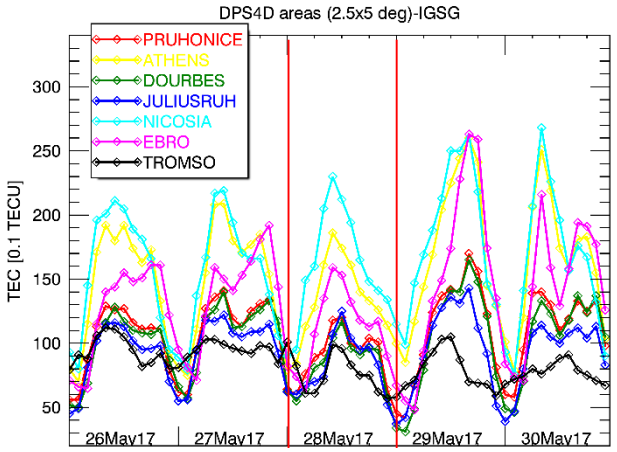


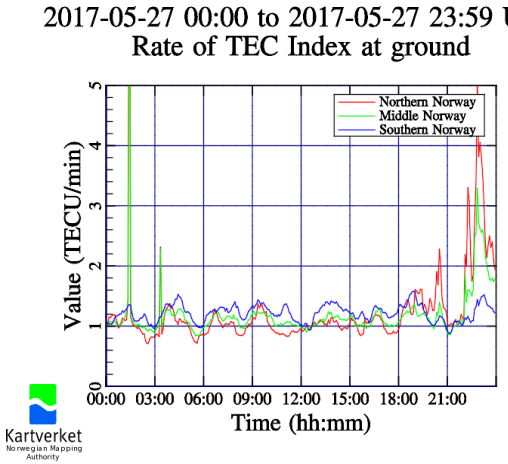
APV-I 99% Availability Degraded Area
1.8% - low degradation

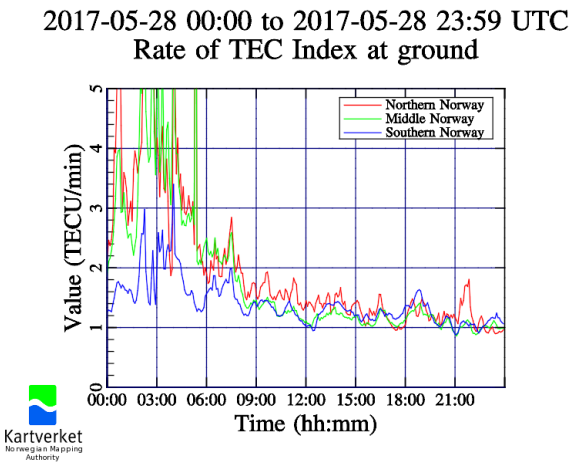


On **16/07/2017** geomagnetic impact has been present especially in the second part of the day degrading EGNOS performance in the North part of service area.

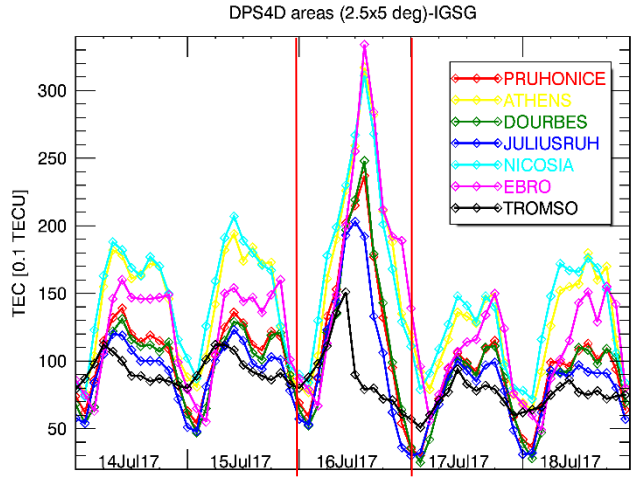
28 May 2017 event

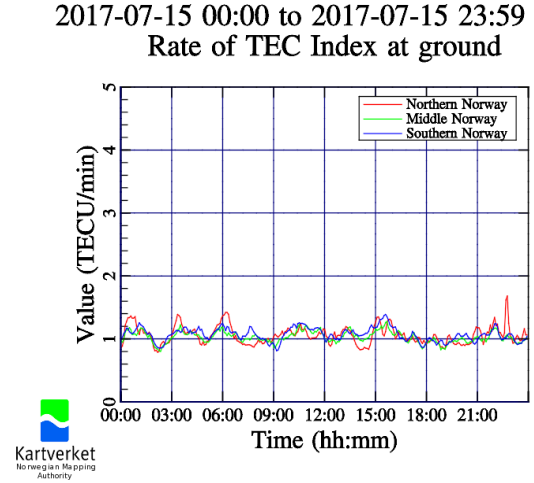


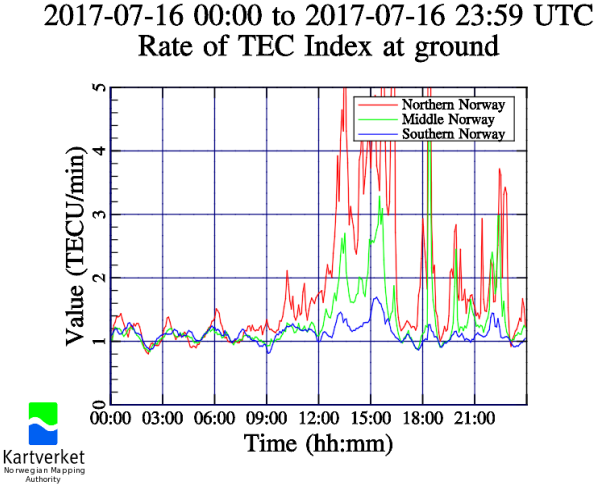




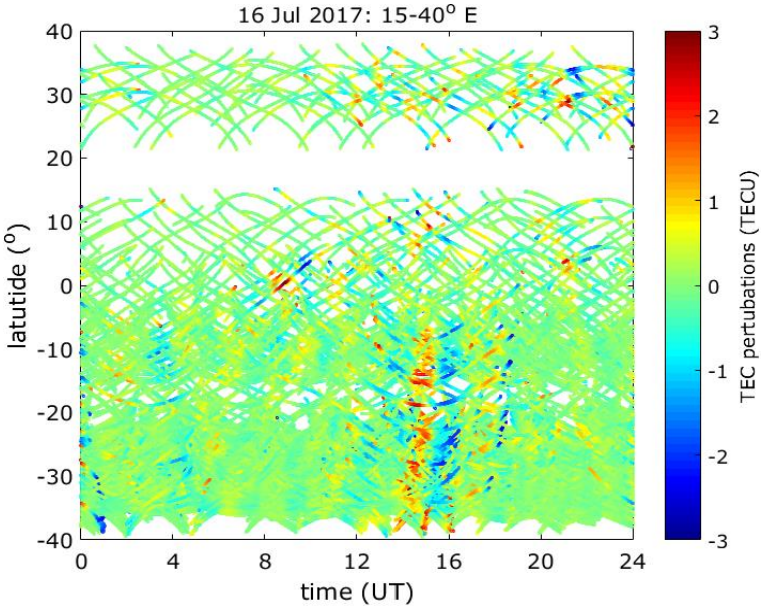
16 July 2017 event

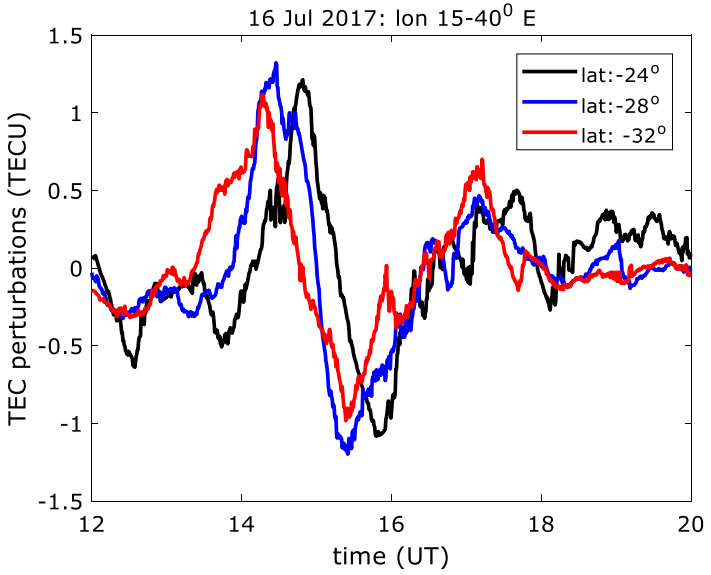






LSTIDs observed over both hemispheres based on GNSS data for 16 July 2017





Map of TEC perturbations over South Africa show TID observed between 14:00 and 18:00 UT during the storm's main phase.

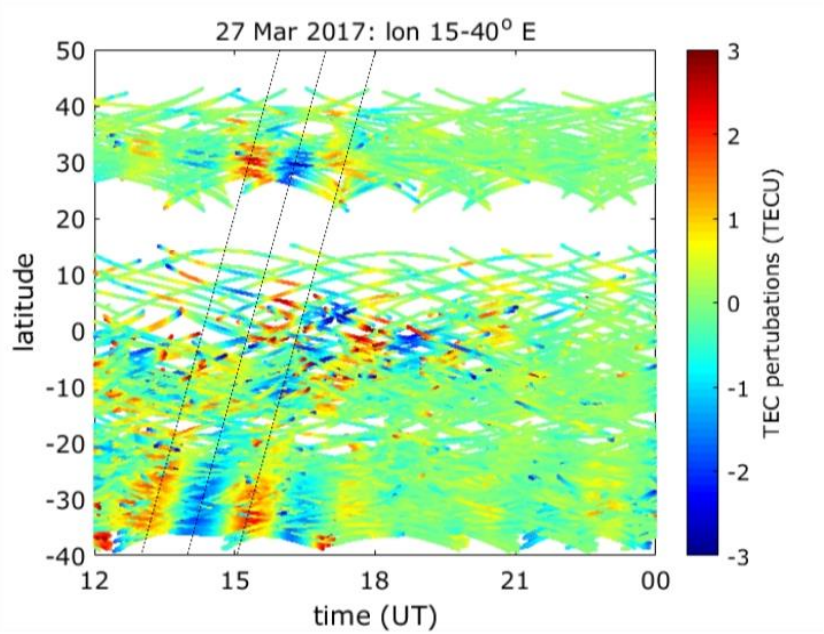
Observed TID propagating equatorward over the southern middle latitudes and dissipate in the equatorial region.

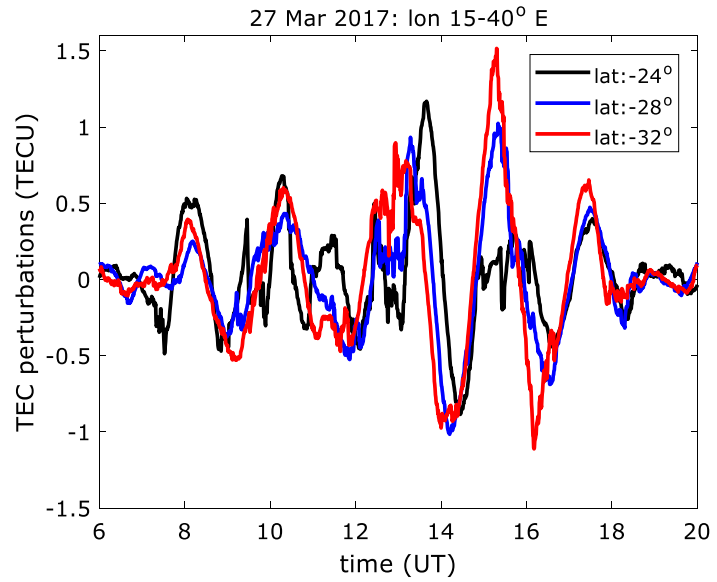
Sampled TEC perturbations at three different latitudes in order to estimate horizontal propagation speed:

- Succession of peak appearance with latitude around 14 UT confirms equatorward propagation;
- Mean speed = 418.7 m/s.

Period of the LSTID is roughly 3 hours.

LSTIDs observed over both hemispheres based on GNSS data for 27 March 2017





The slant TEC is mapped to vertical TEC by using a thin shell model at ionospheric altitude of 350 km. In order to reduce the impact of multi-path, only data from satellites with elevation angle 30˚ are used.

Map of TEC perturbations over African southern middle latitudes shows TID activity between 8:00 and 20:00 UT that is intensified between 12:00 and 16:00 UT.
TID propagating equatorward.

LSTID amplifies during course of main phase of the storm:

Mean velocity = 772 m/s
Period of wave roughly 2 hours

APV-I 99% Availability Degraded Area
10.5% -moderate degradation

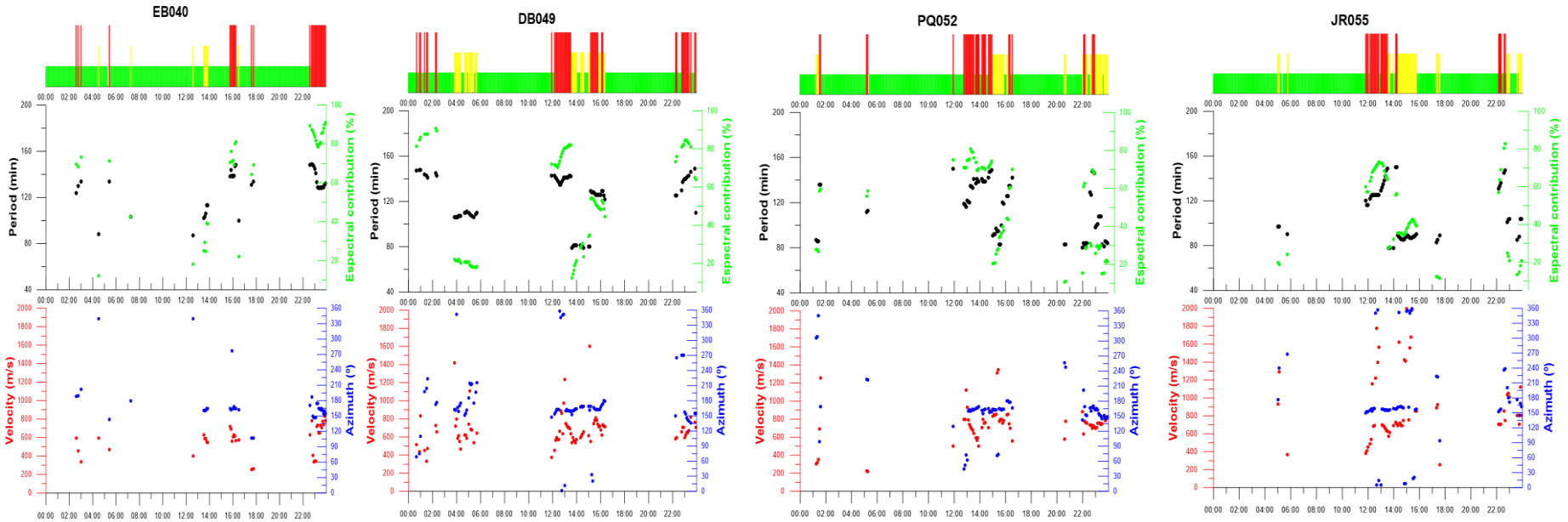
Comparison of the results of the HF Interferometry and HF-TID techniques

16 July 2017

HF-TID

Path	Time, UT	Frequency, kHz	WA, %	WAz, deg	WL, km	WP, min
EB-DB	02:30-04:30	4725	41,8	176	1816	110
JR-PQ	12:30-15:10	5760	22	111	1392	60

HF Interferometry



Appearance of LSTIDs in both hemispheres and interhemispheric circulation

38 TID events from the TechTIDE project event catalogue were analysed

26 events indicated LSTID occurrence

The 26 events in detail (each of the three groups below sums up to 26)

16 events: LSTID in both hemispheres, no interhemispheric propagation
4 events: interhemispheric propagation of LSTID
6 events: LSTID occurrence in one hemisphere (insufficient data coverage of the other hemisphere)
NOTE: no case of LSTID observed in one hemisphere and definitely excluded in the other one

14 events: LSTID originating at high latitudes and propagating equatorward
3 events: LSTID originating near the geomagnetic equator and propagating poleward
9 events: LSTID origination at high latitudes and near the geomagnetic equator

13 events: LSTID during stronger storms (*SYM-H* exceeding -90 nT) during or immediately after the main phase
8 events: LSTID during weak storms (*SYM-H* not exceeding -90 nT)
5 events: LSTID during absence of storm conditions or late in the recovery phase of a storm

The reaming **12** events
4 events: no LSTID during weak storm periods (*SYM-H* not exceeding -90 nT)
8 events: no LSTID during storm-free periods or late in the storm recovery phase

Summary of what we observed:

TID driver	Number of analysed events	Magnitude of EGNOS availability degradation	Range of EGNOS availability degradation
CME	5	2 - high degradation 2 – moderate degradation 1 – low degradation	22.7% - 33.9% 8.7% - 12.0% 1.8%
CIR/CH HSS	25	23 – moderate degradation 2 – low degradation	5.4% - 15.7% 4.1% - 4.3%
SSBS	1	moderate degradation	6.8%

- Both CME- and CIR/HSSS-related events are significant sources of the LSTIDs.
- The CIR/HSSS-related LSTID activity has longer duration.

ACKNOWLEDGEMENTS

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TechTIDE

Warning and Mitigation Technologies for Travelling Ionospheric Disturbances Effects

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Funded by:

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COMPET – Space Weather 2017

Contract Nº 776011

Program COMPET-5 Space Weather

Horizon 2020 Research and Innovation

CONSORTIUM

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- Deutsches Zentrum für Luft- und Raumfahrt (DLR)
- Ustav Fyziky Atmosfery AV CR (IAP)
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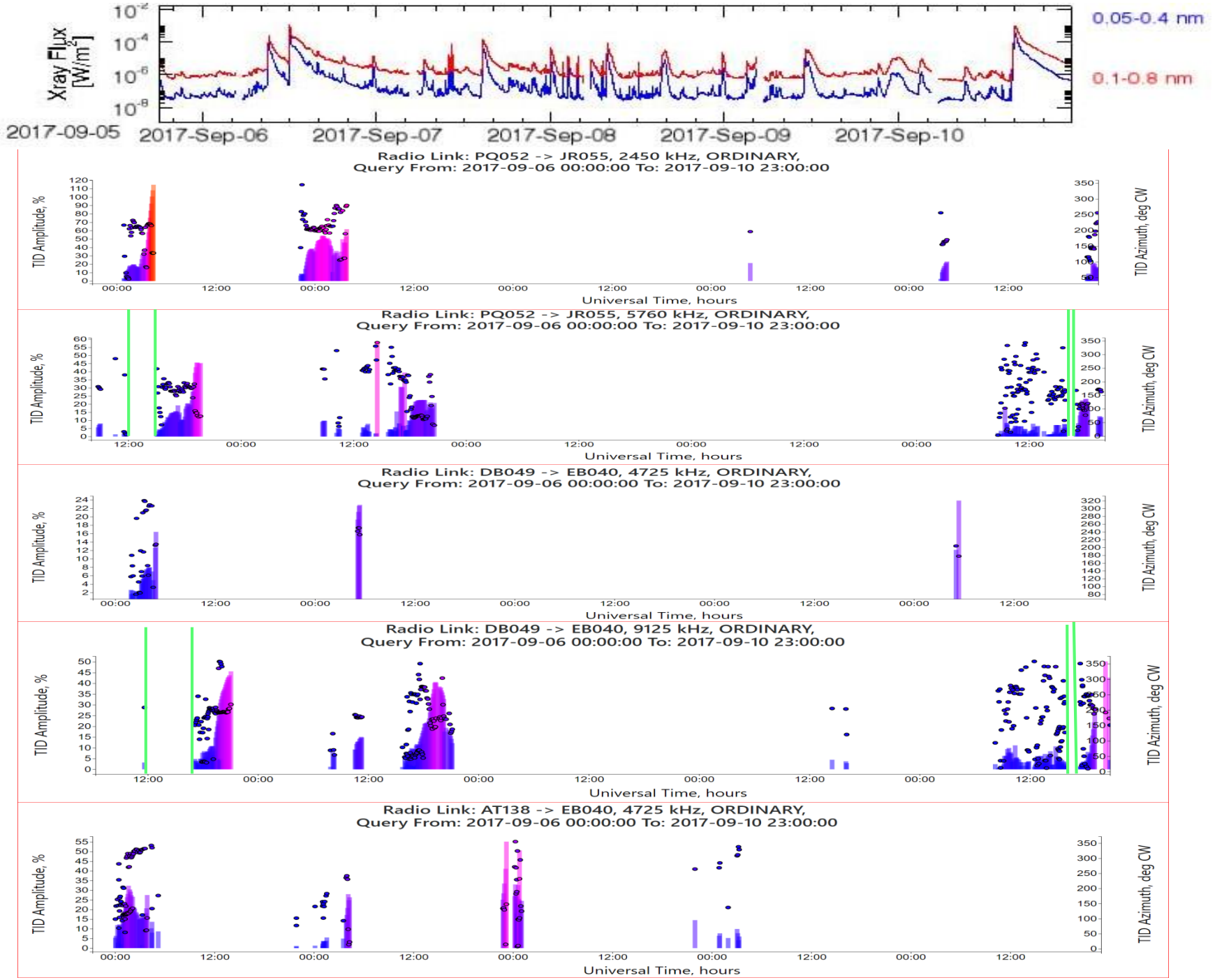
- Borealis Global Designs Ltd. (BGD)
- Leibniz Institute of Atmospheric Physics, Rostock University (L-IAP)
- Universitat Politecnica de Catalunya (UPC)
- European Satellite Services Provider (ESSP)
- South Africa National Space Agency (SANSA)
- Watermann Juergen Friedrich Wilhelm (JFWCONSULT)
- Frederick University (FU), Cyprus
- German Federal Police (GFP)


Xray Flux [W/m²]
0.05-0.4 nm
0.1-0.8 nm
2017-09-05
2017-Sep-06
2017-Sep-07
2017-Sep-08
2017-Sep-09
2017-Sep-10
Radio Link: PQ052 -> JR055, 2450 kHz, ORDINARY,
Query From: 2017-09-06 00:00:00 To: 2017-09-10 23:00:00
Radio Link: PQ052 -> JR055, 5760 kHz, ORDINARY,
Query From: 2017-09-06 00:00:00 To: 2017-09-10 23:00:00
Radio Link: DB049 -> EB040, 4725 kHz, ORDINARY,
Query From: 2017-09-06 00:00:00 To: 2017-09-10 23:00:00
Radio Link: DB049 -> EB040, 9125 kHz, ORDINARY,
Query From: 2017-09-06 00:00:00 To: 2017-09-10 23:00:00
Radio Link: AT138 -> EB040, 4725 kHz, ORDINARY,
Query From: 2017-09-06 00:00:00 To: 2017-09-10 23:00:00
TID Amplitude, %
TID Azimuth, deg CW
Universal Time, hours