Ionospheric Effects on Aviation

Recent experience in the observation and research of ionospheric irregularities, gradient anomalies, 'depletion walls', etc. in USA and Europe

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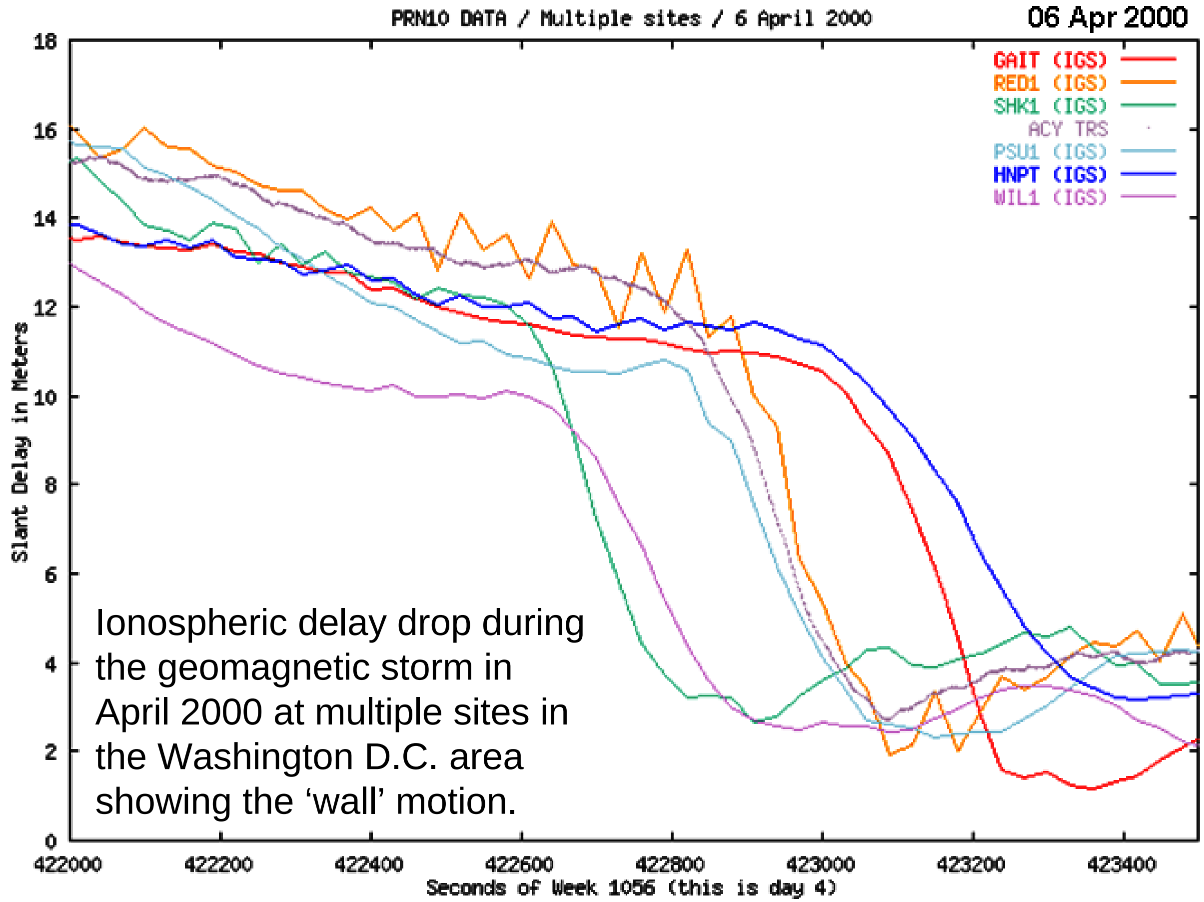
GALOCAD (GALILEO LOcal Component for detection of Atmospheric Disturbances in high accuracy GNSS applications)
is a project funded by ESA / GALILEO Joint Undertaking (GJU) under contract GJU/06/2423/CTR/GALOCAD

Motivation

- **Ionosphere** is the **largest remaining error source** affecting GPS applications
- Accuracy and reliability of GNSS high precision applications strongly affected by:
  - **geomagnetic storms** leading to strong ionospheric disturbances
  - **small-scale structures** in the ionosphere-thermosphere system
- Although **satellite-based navigation for aviation** has capabilities and advantages above conventional navigation aids, the **ionospheric effects** on various aviation applications/services are **still poorly investigated** / **understood**
- **Accuracy, reliability, integrity, safety** - important aspects of the GALILEO system development
- RMI team have **comprehensive research experience** in atmosphere, ionosphere, geomagnetism, and geodesy



Ref.: Dehel et al, 2004: Satellite navigation vs. the ionosphere: where are we, and where are we going? Proc. ION GNSS, Sep. 21-24, 2004, Long Beach CA, 375-386.

Observations of such ionospheric anomalies remain limited and the explanation of the underlying physics is still not well understood

Approach / Methodology

For a given GPS satellite ***i*** , the code measurement made by the user (e.g. aircraft) affected by an ionospheric error (a.k.a. slant ionospheric delay):

$$I_u^i = 40.3\frac{TEC_u^i}{f^2}$$

Code measurement made by the reference station on the same satellite ***i*** also affected by an ionospheric error:

$$I_r^i = 40.3\frac{TEC_r^i}{f^2}$$

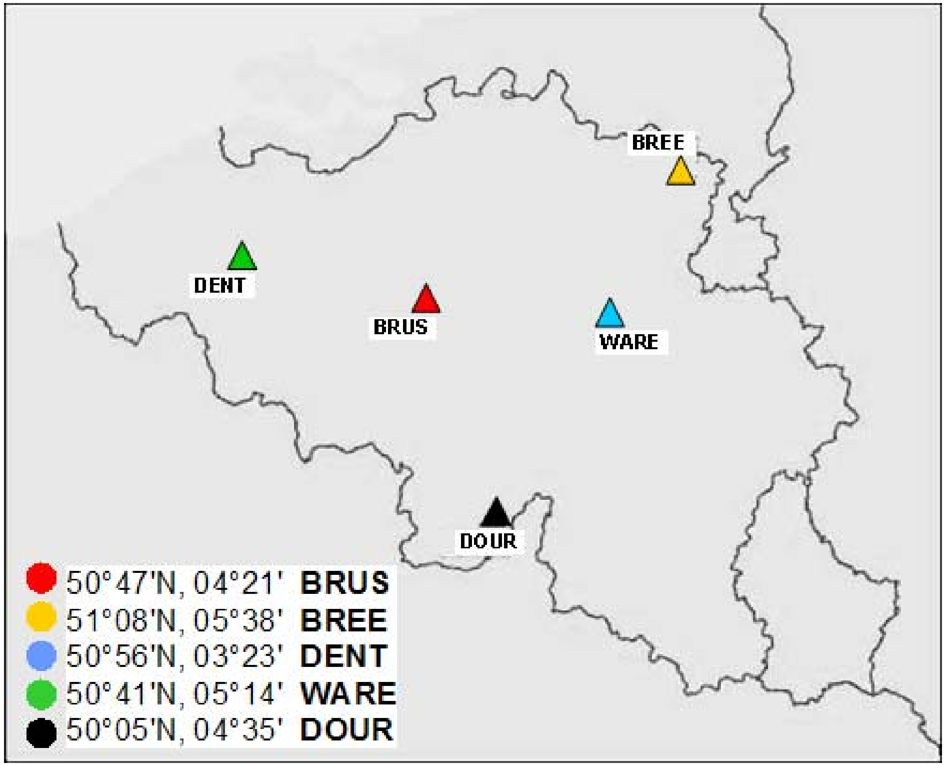
The reference station provides the value of I_r^i as ionospheric correction to the user.

Quality of differential ionospheric correction depends on the value of $I_u^i - I_r^i$

(i.e. the difference between the slant delays measured at the user and at the reference station).

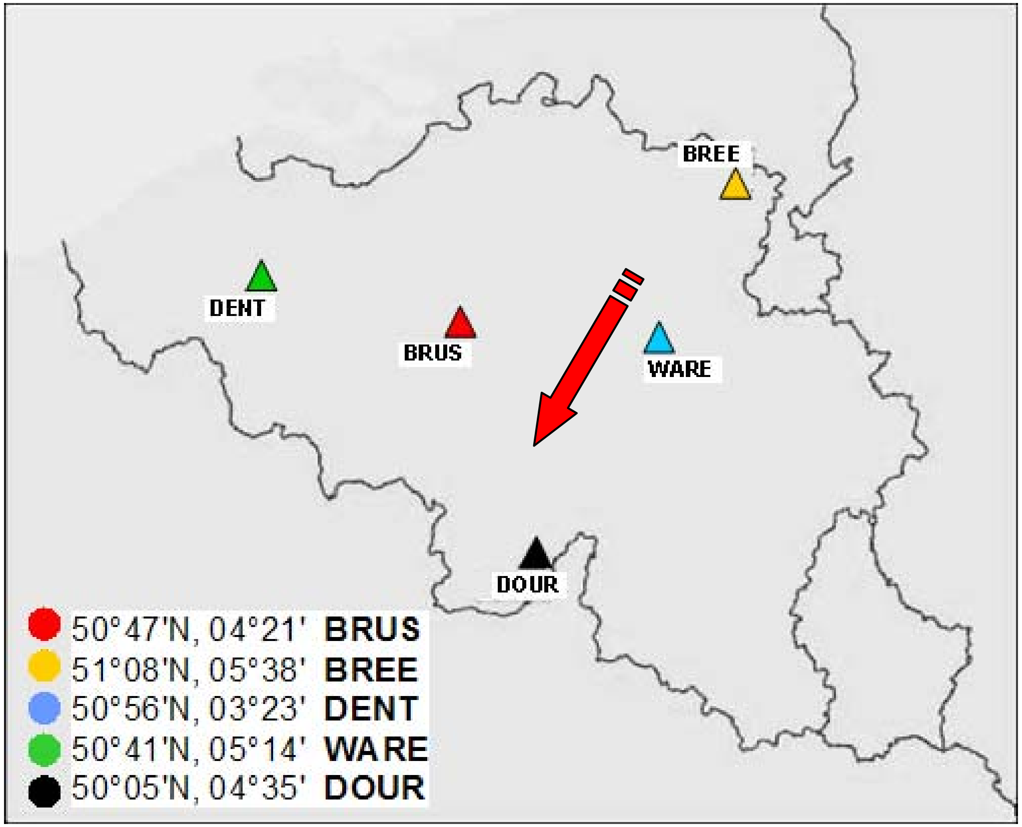
This difference depends on

$$TEC_u^i - TEC_r^i$$

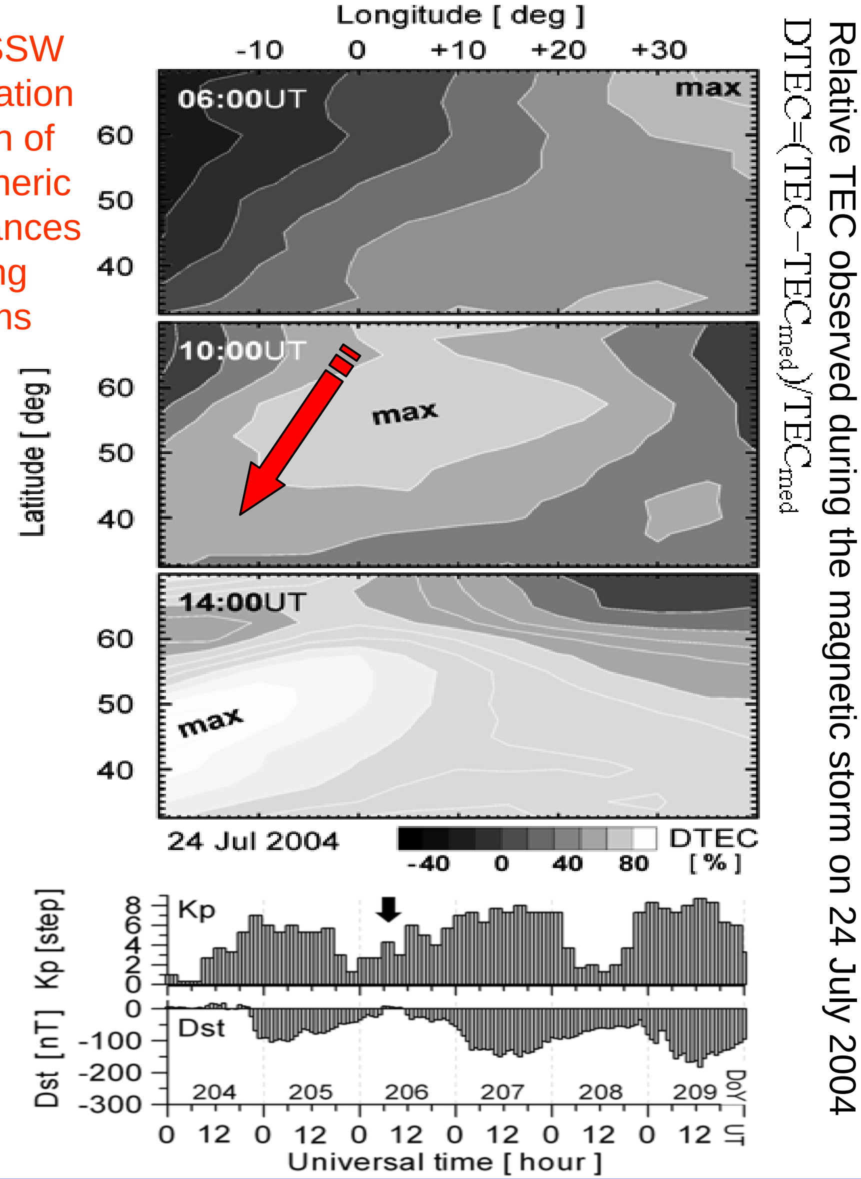


Map of Belgium with the GPS stations used for studying the ionospheric gradient anomalies

Methodology / Tools



NNE-SSW propagation pattern of ionospheric disturbances during storms

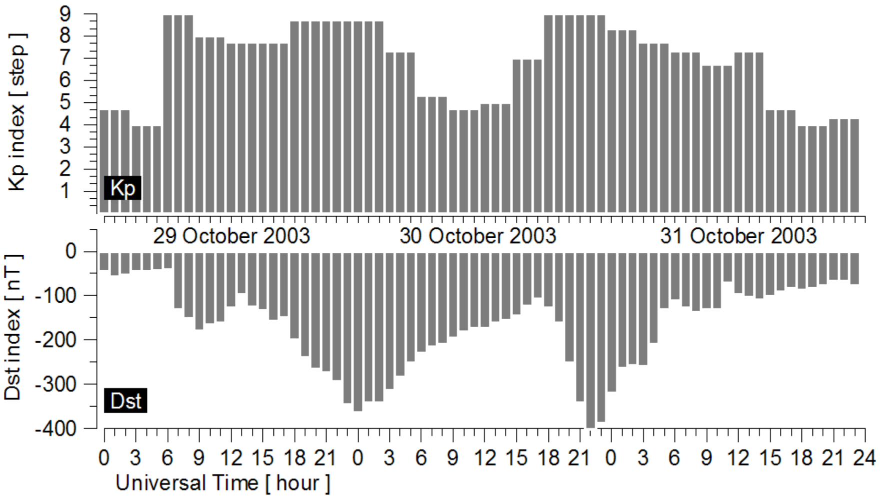


Ref.: Stankov et al., 2005: Generation and propagation of ionospheric disturbances studied by ground and space based GPS techniques. Proc. Ionospheric Effects Symposium (IES), May 3-5, 2005, Alexandria VA, USA, Paper No. A064/9B2.

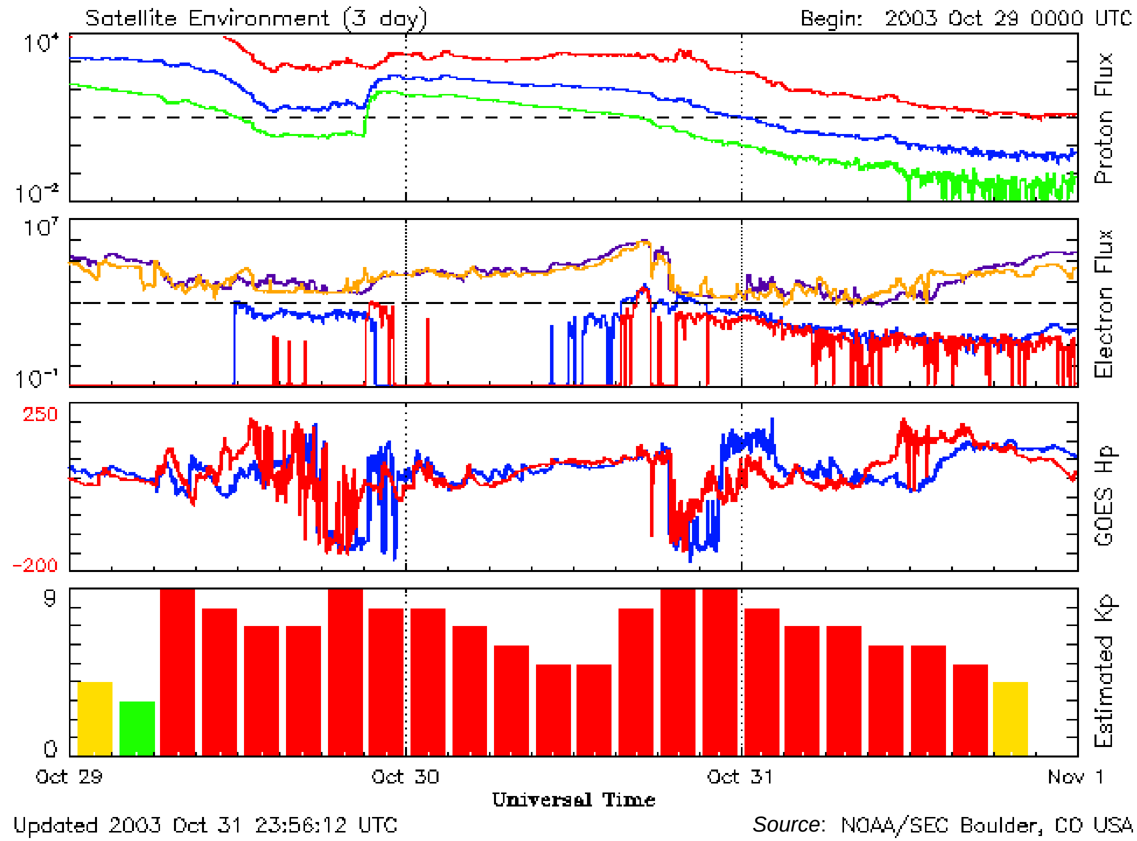
The 29-31 October 2003 ionospheric storm background

During the whole month of October 2003 the geomagnetic activity was low except during the last 3 days when a large storm took place. The events at the end of October 2003 were characterized by a series of large radiation bursts at the Sun and huge coronal mass ejections causing severe perturbations in the geomagnetic field and in the geo-plasma (magnetosphere-ionosphere) environment.

The CME reached the Earth magnetosphere at 06:00UT on 29 October and the subsequent geomagnetic storm continued well into 30 and 31 October 2003.



The 29-31 Oct 2003 ionospheric storm development, represented by the Kp and Dst geomagnetic indices.



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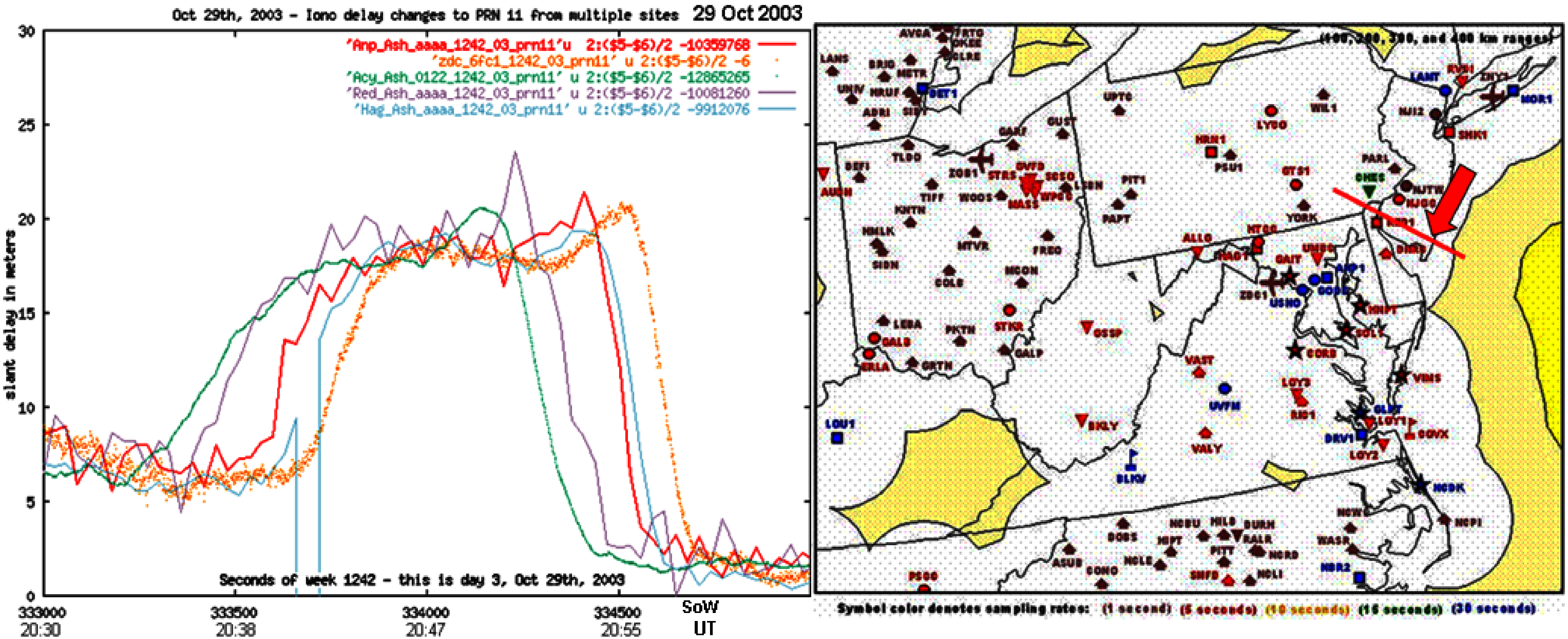

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Large ionospheric delay gradients (‘walls’) (left panel) observed among CORS clusters in the Washington D.C. area (right panel) on 29 October 2003

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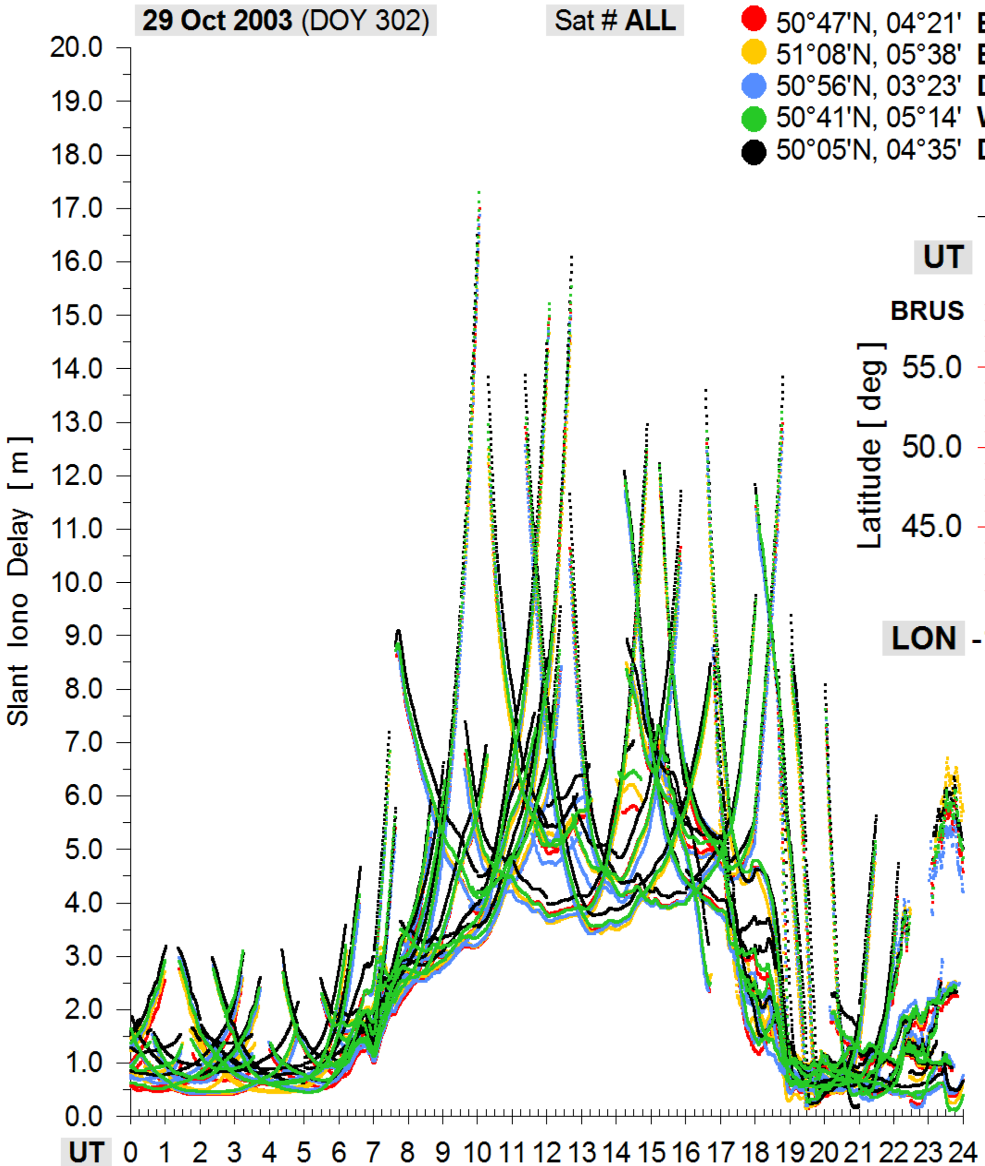
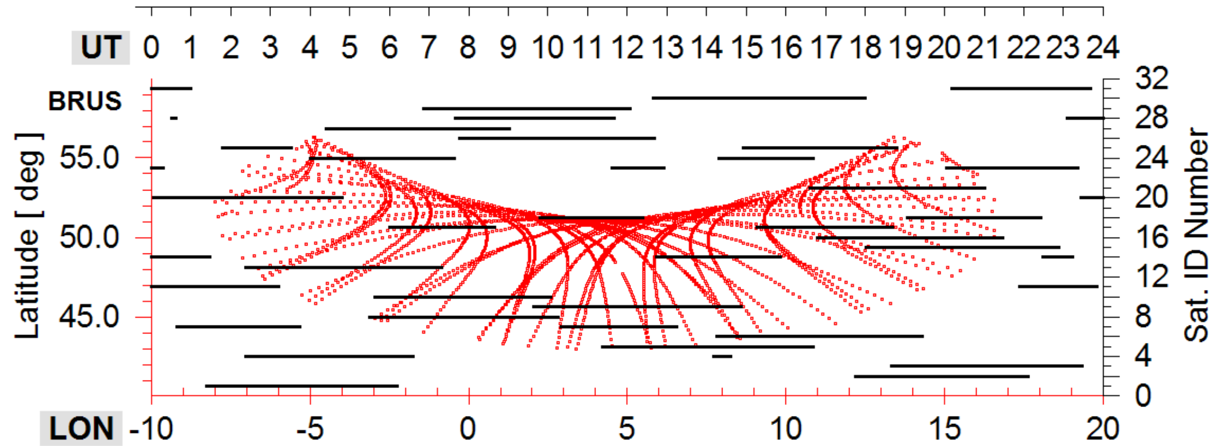
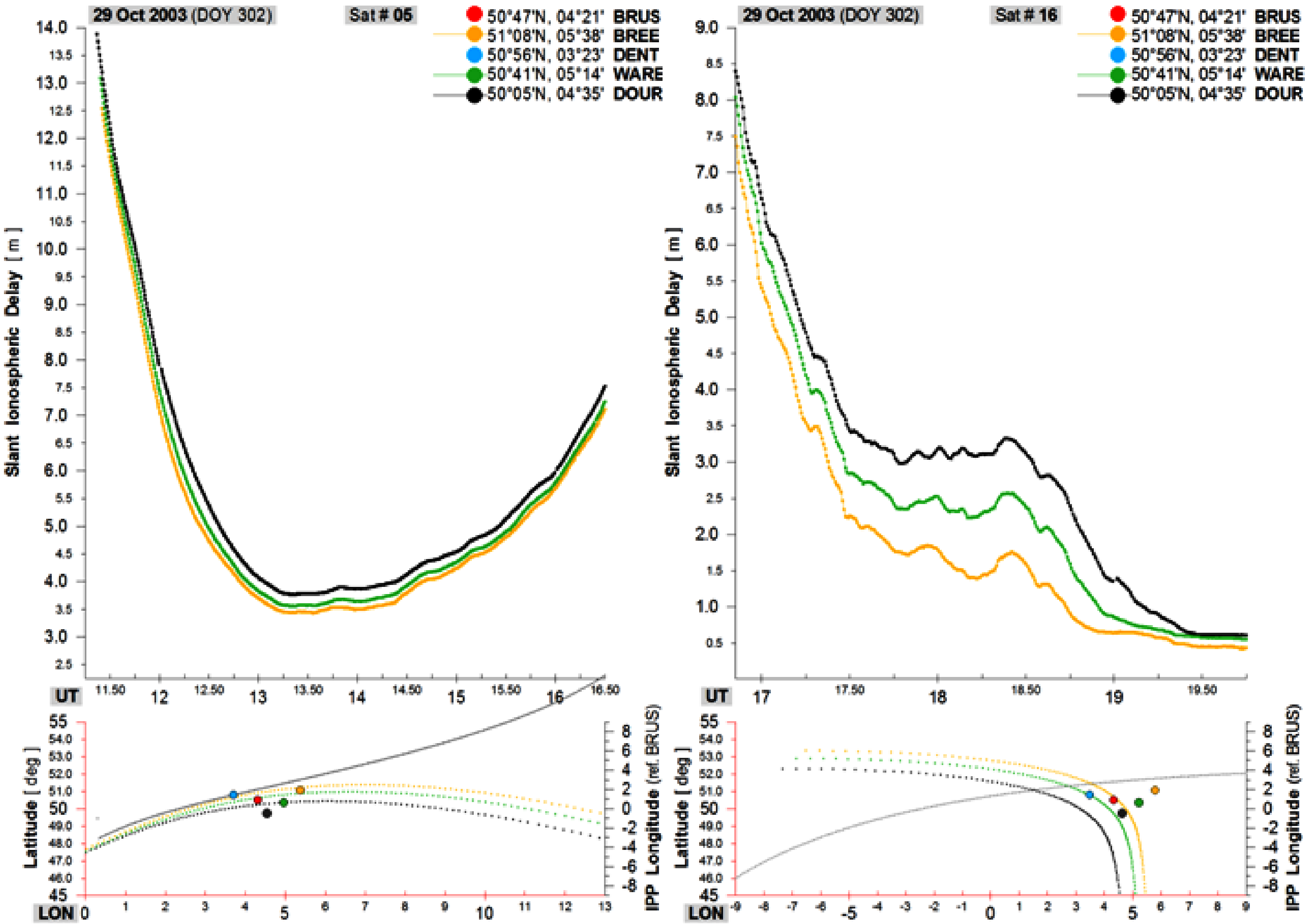




The satellite IPP traces over Europe (ref. station BRUS) plotted in **red** colour. Period of 'visibility' of each GPS satellite, plotted with solid **black** lines.

Ionospheric delays during the storm on 29 October 2003 measured via the GPS satellites 'visible' from the selected GPS stations in Belgium.

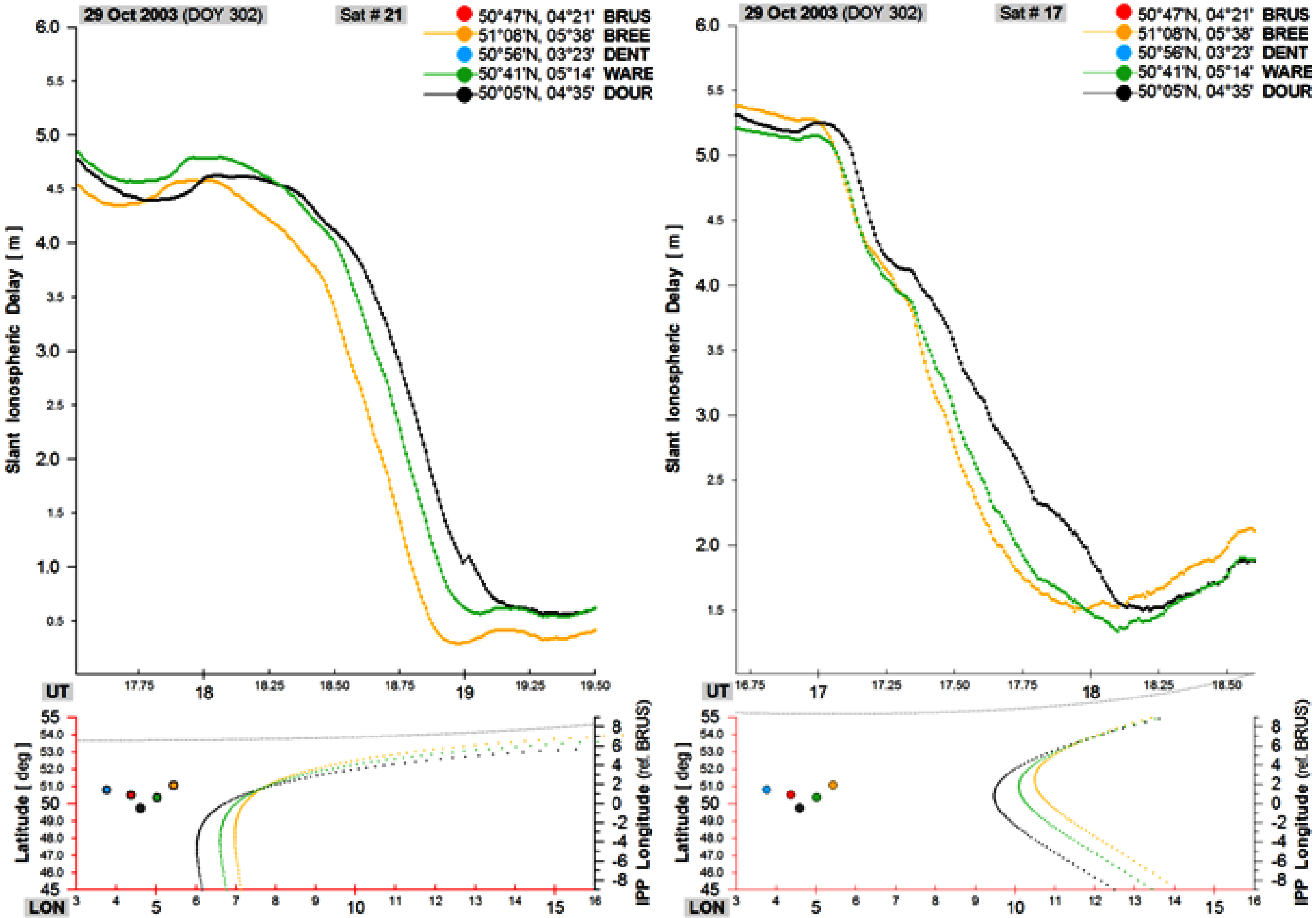
Case study / 29-31 October 2003



Ionospheric delays during the storm of 29 October 2003 as measured via GPS satellites No.5 (left panel) and No.16 (right panel). The bottom panels show the satellite IPP traces (colour corresponding to station) on a geographic longitude vs. latitude map.

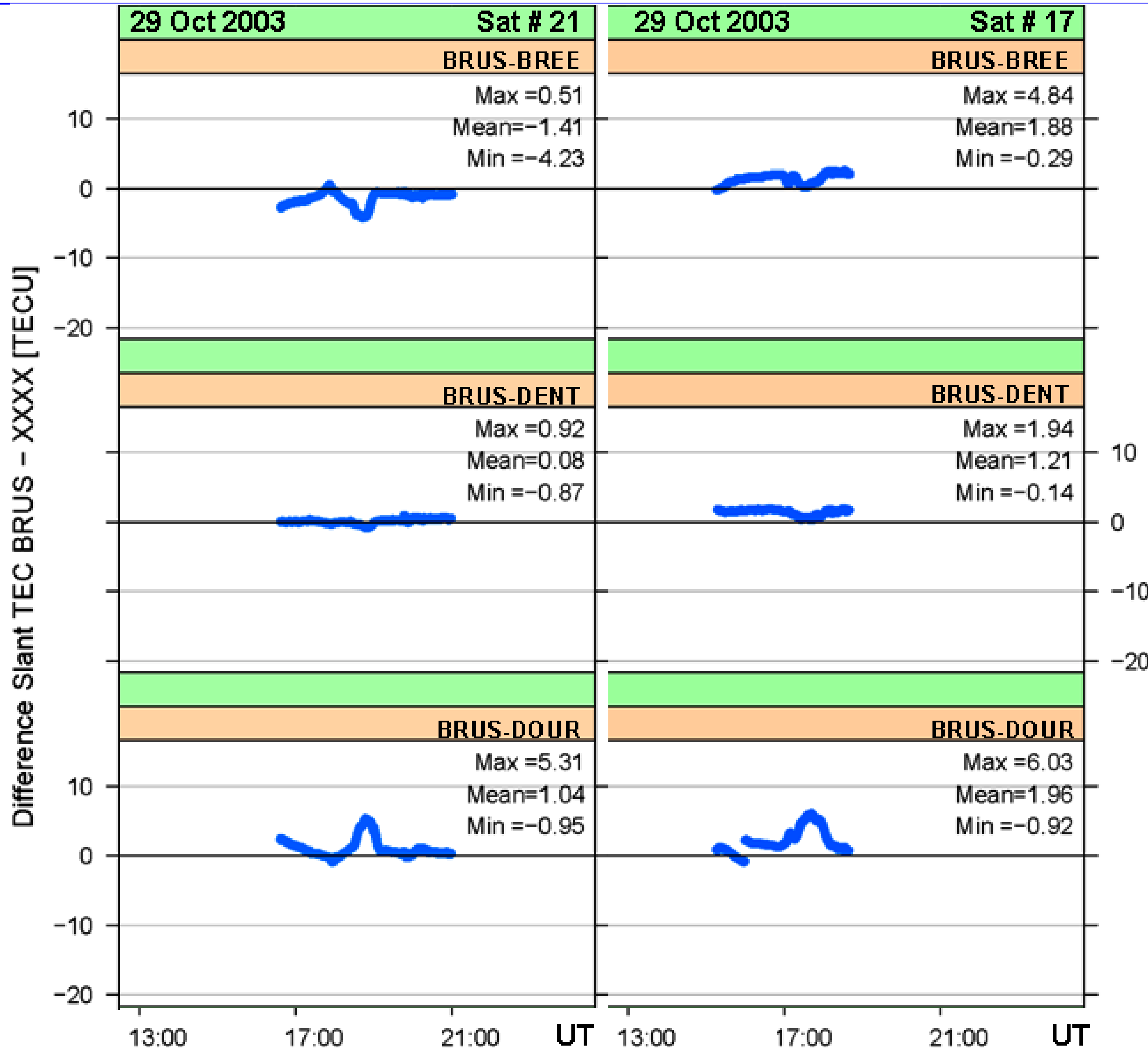
The longitudinal excursion of the satellite IPP (reference station BRUS) during the selected UT period is plotted with solid line (grey colour).

Case study / 29-31 October 2003



Ionospheric delay drops ('depletion walls') during the storm of 29 October 2003 as measured via GPS satellites No.21 (left) and No.17 (right) over Europe.

Case study / 29-31 October 2003

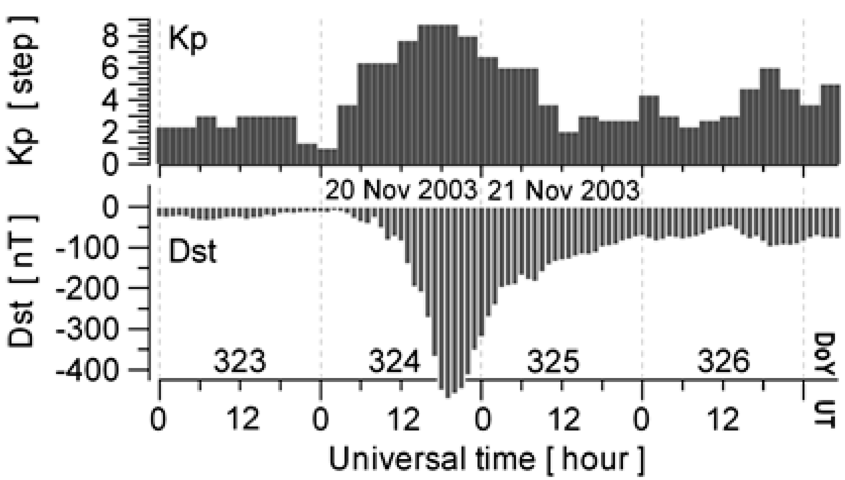


Slant TEC differences between BRUS and 3 other stations during the storm of 29 October 2003 as measured via GPS satellites No.21 (left) and No.17 (right).

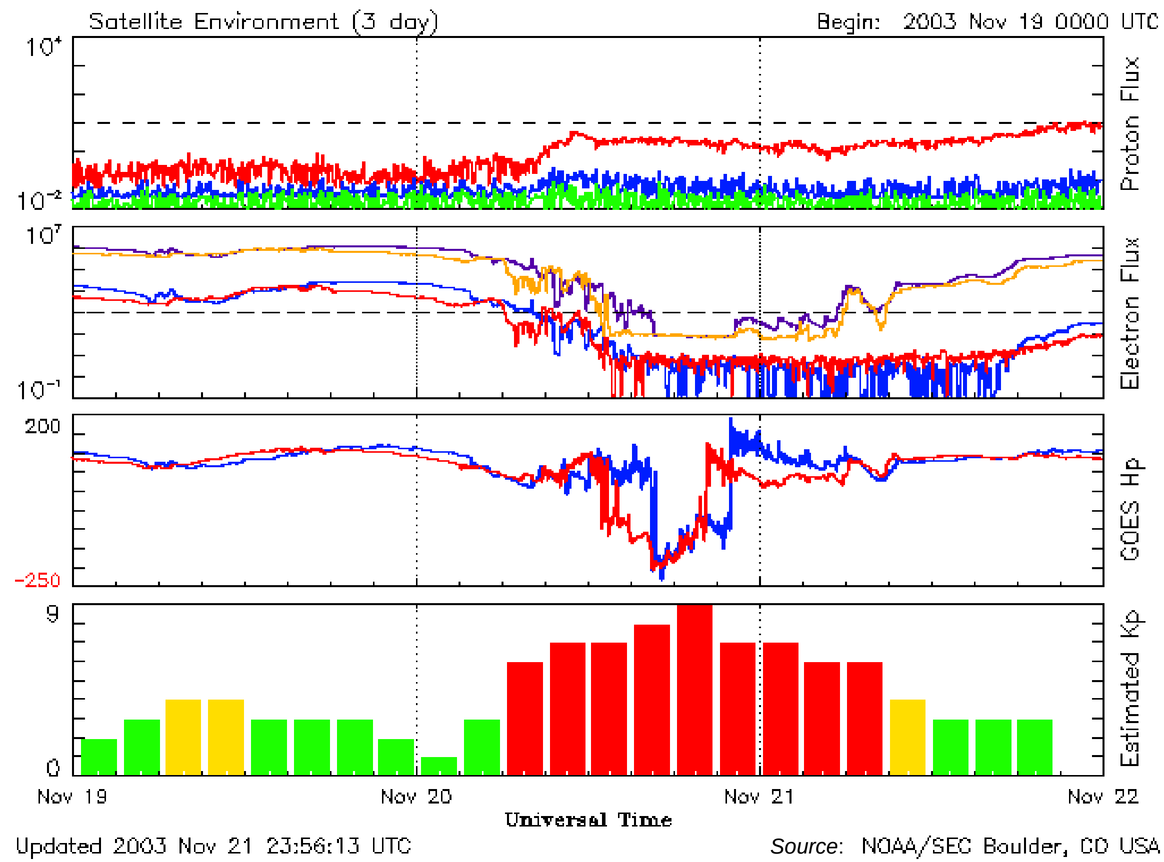
The 20 November 2003 ionospheric storm background

Another major geomagnetic storm occurred on 20 November 2003, beginning with a sudden storm commencement (SSC) at 08:03 UT as a result of the coronal mass ejection (CME) originating from sunspot 484, released into space earlier on 18 November 2003, and travelling at a speed of more than 1000 km/s .

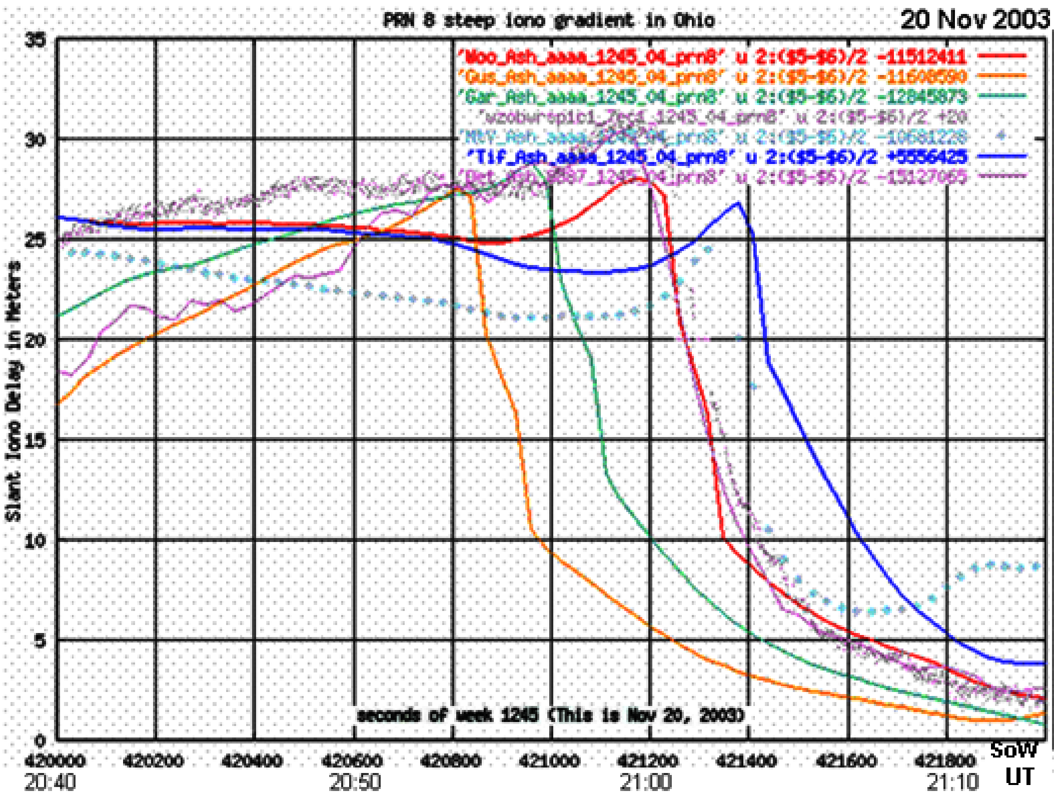
Storm enhanced ionospheric density was widely observed and degradations of GPS based positioning accuracy reported.

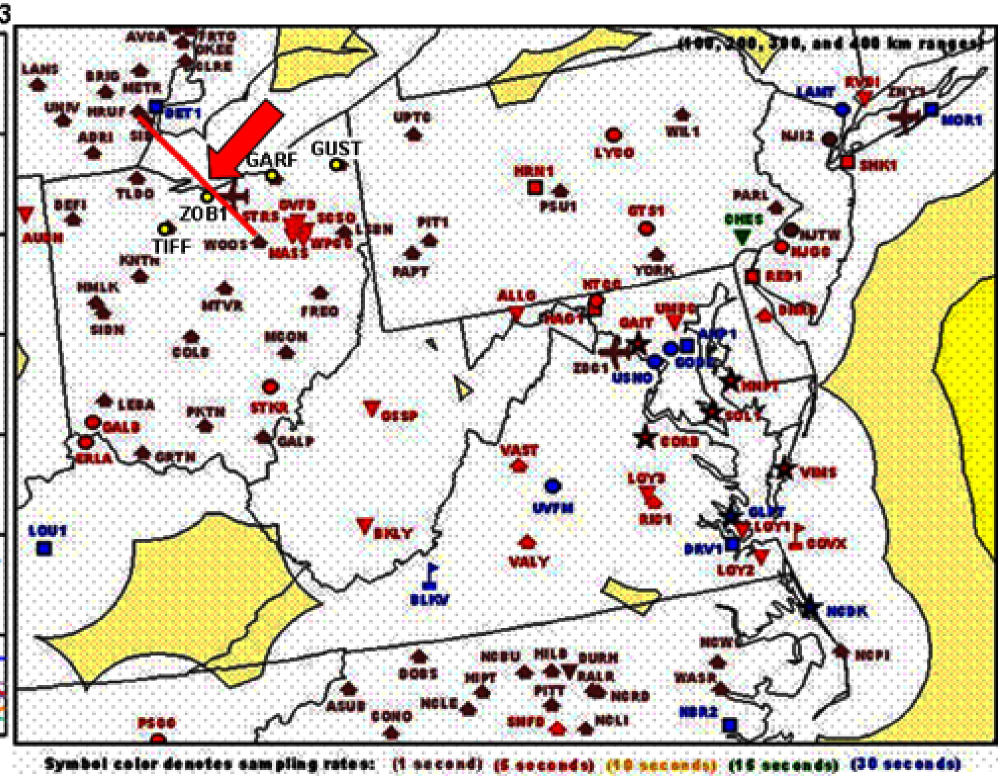


The 20 Nov 2003 ionospheric storm development, represented by the Kp and Dst geomagnetic indices.



Case study / 20 November 2003

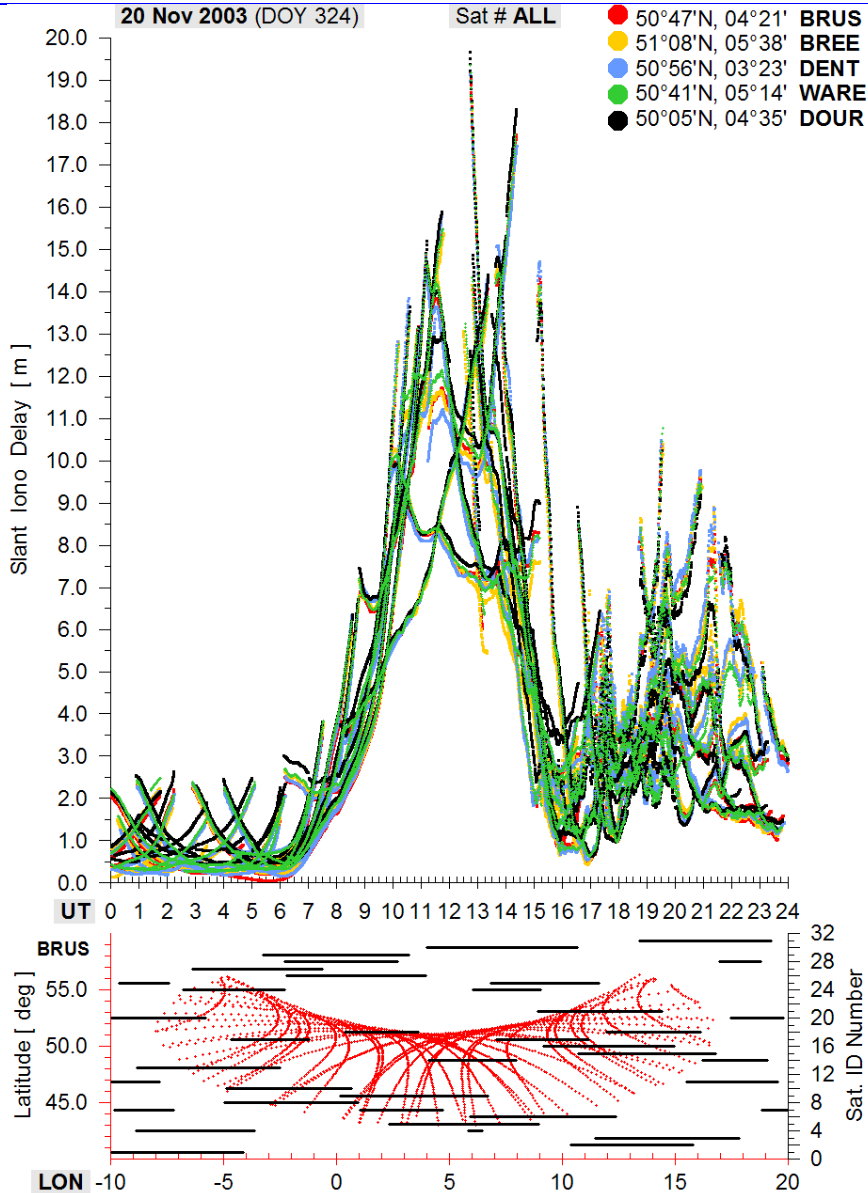


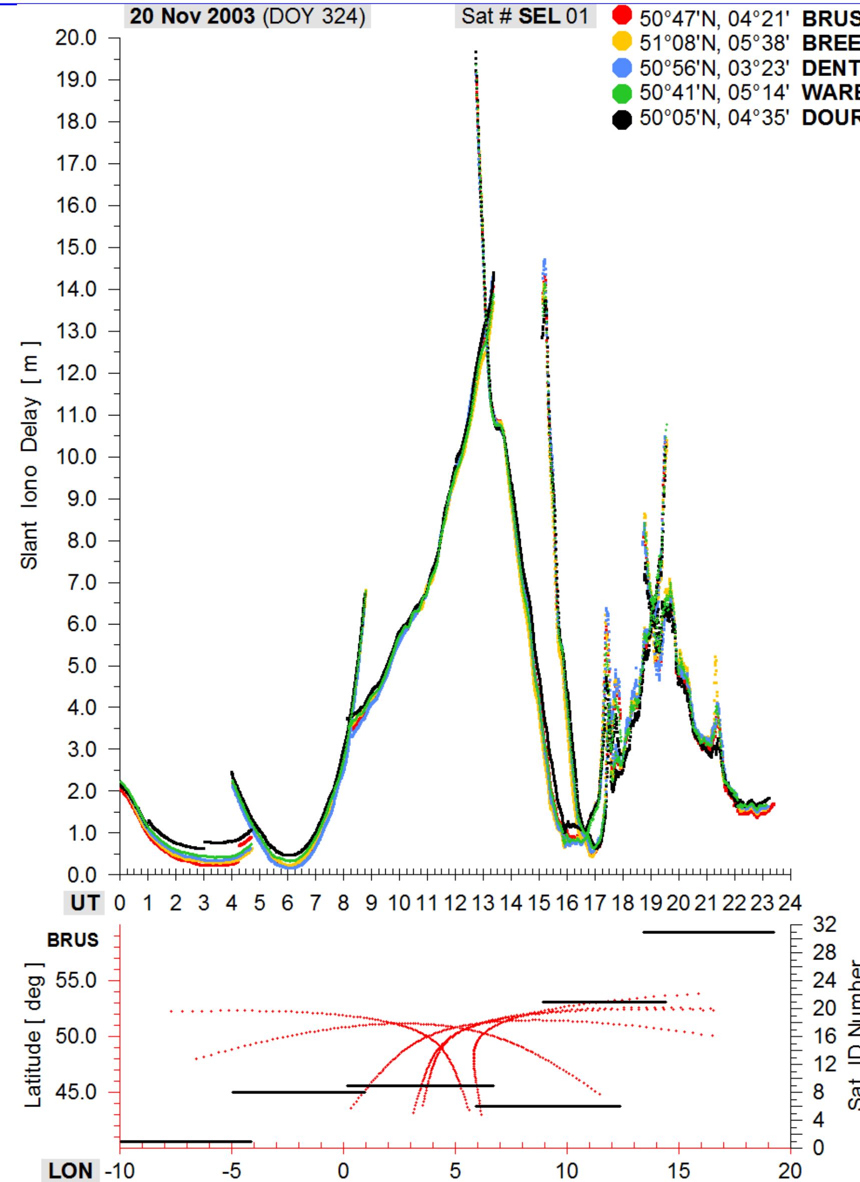


Ref.: Dehel et al, 2004: Satellite navigation vs. the ionosphere: where are we, and where are we going? Proc. ION GNSS, Sep. 21-24, 2004, Long Beach CA, 375-386.

Large ionospheric gradients ('depletion walls') (left panel) observed among CORS clusters in the Ohio area (right panel) on 20 November 2003.

Case study / 20 November 2003





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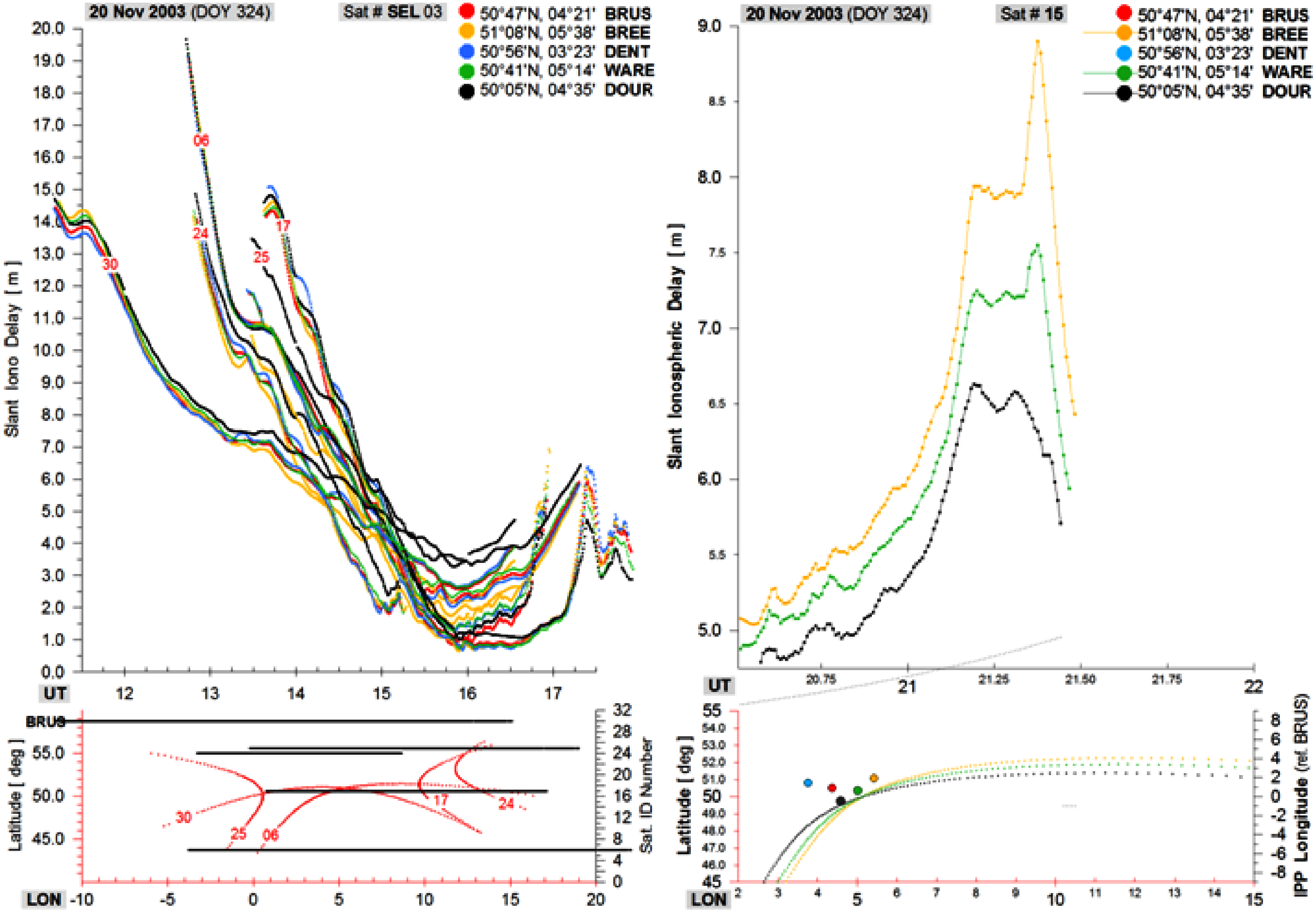
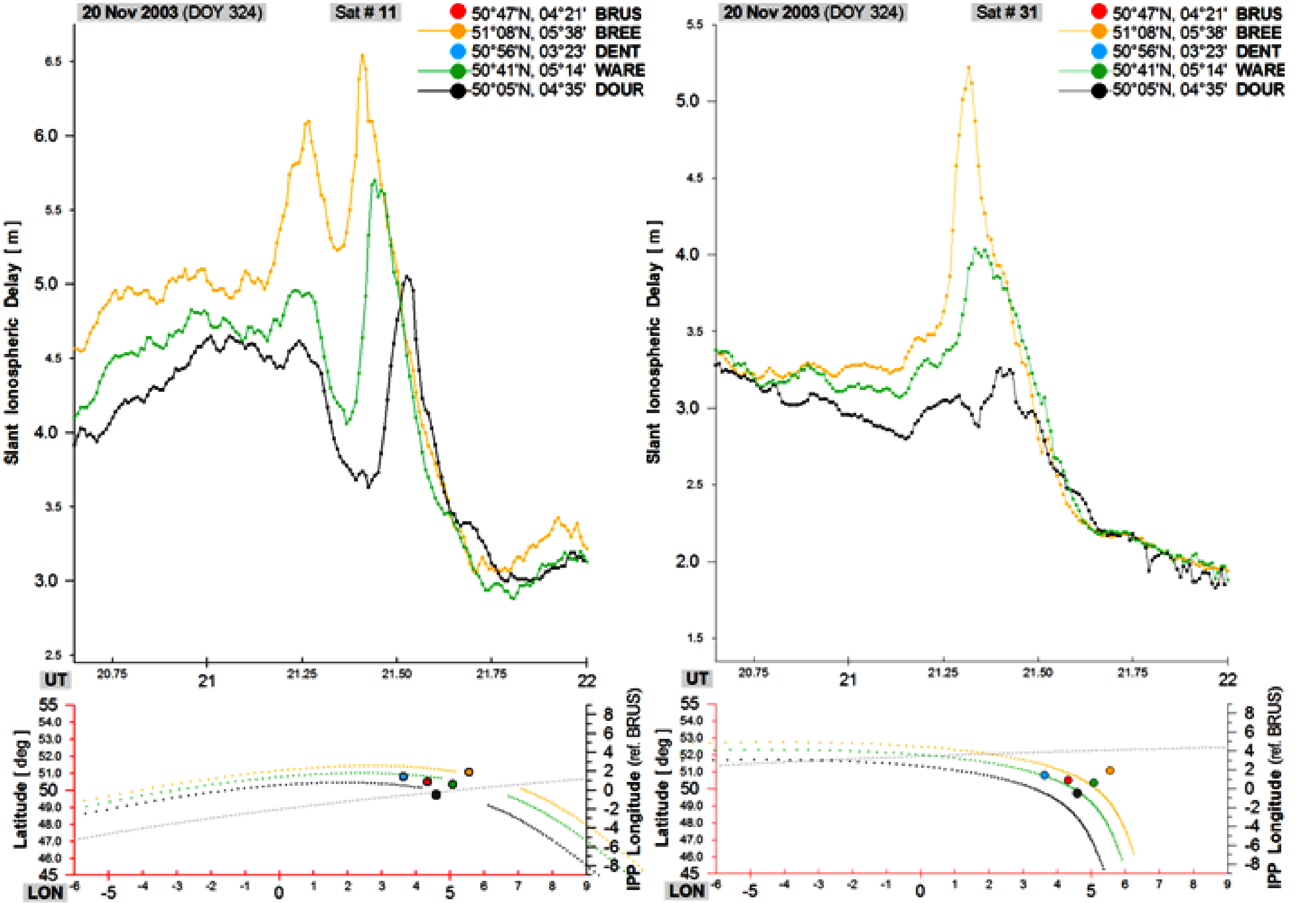


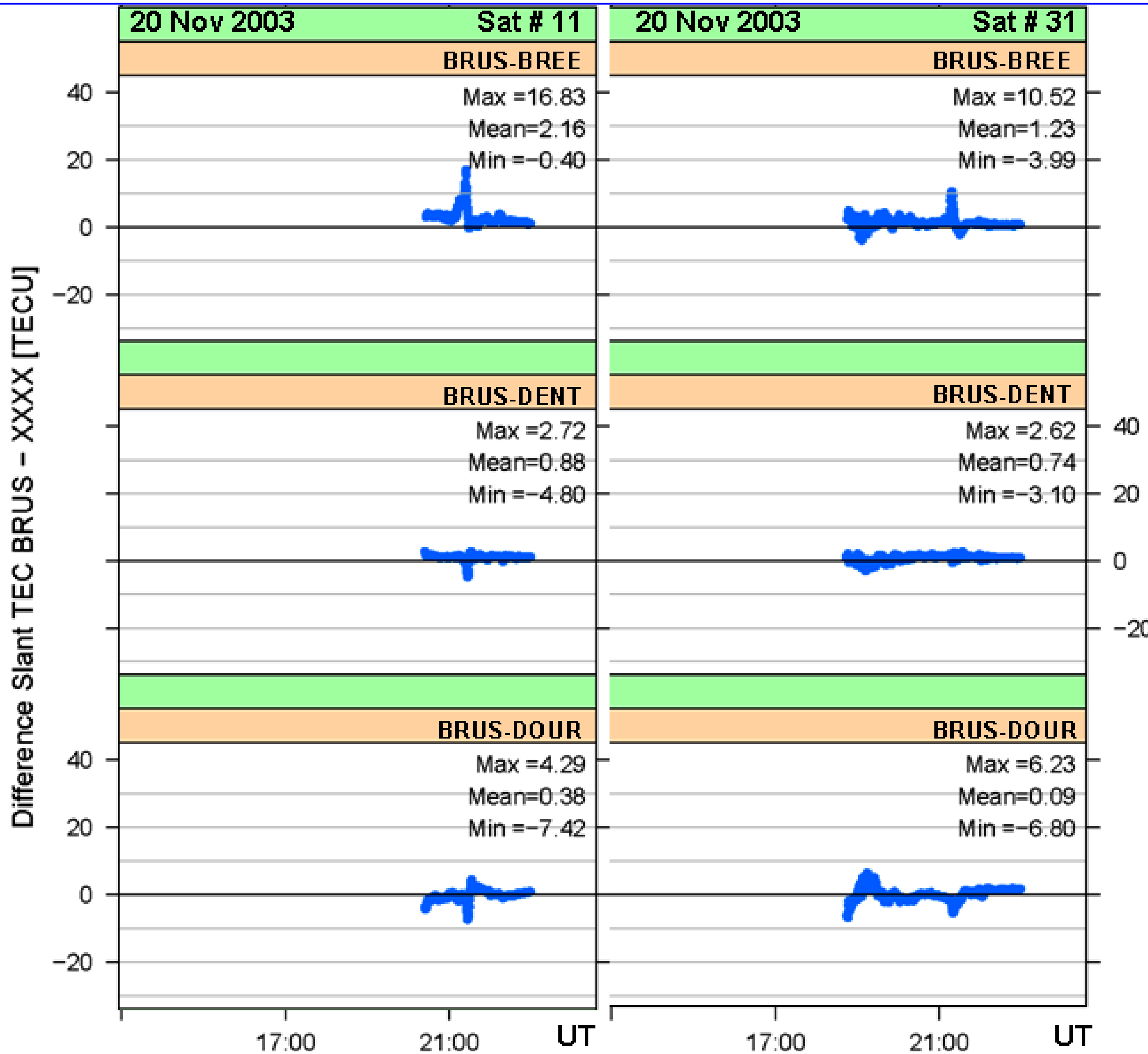
Ionospheric slant delays during the storm of 20 November 2003 as measured via GPS satellite selection # 3 (6, 17, 24, 25, 30) (left) and satellite No.15 (right).

Case study / 20 November 2003



Ionospheric delays during the storm of 20 November 2003 as measured via GPS satellites No.11 (left) and No.31 (right).

Case study / 20 November 2003

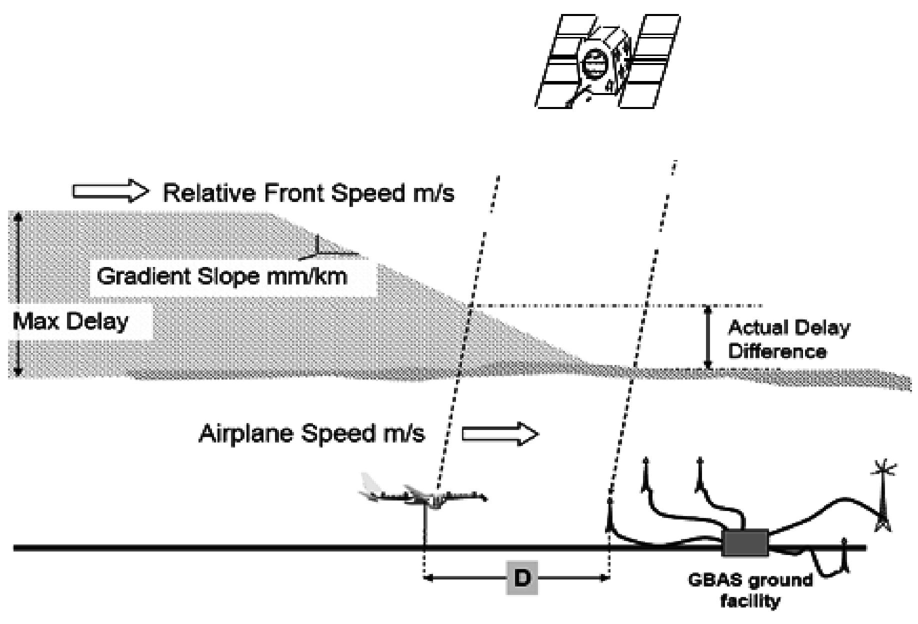


Slant TEC differences between BRUS and 3 other stations during the storm of 20 November 2003 as measured via GPS satellites No.11 (left) and No.31 (right).

Summary and Outlook

- Ionospheric gradient anomalies observed in Europe during the major storm events on 29 October and 20 November 2003

- Observed phenomena similar to those observed in the USA although not so pronounced



Ionospheric Anomaly/Threat Model

Source: Murphy and Harris, 2006: Mitigation of Ionospheric Gradient Threats for GBAS to Support CAT II/III, ION meeting, 26-29 Sep 2006, Forth Worth, TX, USA.

- Investigate possible role of TIDs and other phenomena that may also be responsible

- Investigate ionospheric irregularities effects outside geomagnetic storm periods

- Improve methodology - consider ray tracing algorithms, TEC / gradient mapping

- Develop techniques/algorithms for detecting, monitoring, and estimating key characteristics of the ionospheric gradients (e.g. front shape, slope, velocity, direction, etc.)

- Improve the iono-threat model