Potential of an Ionospheric Disturbance Index to Estimate the Ionospheric Impact on GNSS

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Ionospheric perturbations can have a strong influence on the use of global navigation satellite systems (GNSS) and other space-based systems. The detection and estimation of spatial and temporal variations of electron density in near real-time is challenging and subject to current research. Based on former studies on the Disturbance Ionosphere Index (DIX) [1], here we present preliminary results concerning its capability to deduce also directional information on horizontal structures of the ionospheric electron content. Related results are derived from GNSS data sets obtained over Europe during a moderate ionospheric storm in October 2011. Although being limited due to the uneven data coverage over Europe, the derived index indicates the potential of providing valuable information on the actual performance of GNSS applications.

The index is designed to be reliable and robust and allows an easy and objective interpretation. The calculation of the ionospheric disturbance index is based on the Total Electron Content (TEC) which has been confirmed in many publications to be an outstanding parameter for quantifying the range error and the strength of ionospheric perturbations. The quality of the index is dependent on the density of the used GNSS data base. The shown analysis results are calculated using the IGS and EUREF GNSS reference networks. DIX shall be made available to registered users in near real-time via the Ionospheric Monitoring and Prediction Center (IMPC) just established at DLR (http://impc.dlr.de).

The space weather event on October 24th / 25th, 2011

The space weather event started on October 22nd, 2011 when a solar flare of class M1.3 was observed. The eruption started at 10:00 UT and ended at 13:09 UT. Remarkable is the approximately 3 hours duration of the flare showing a maximum at 11:10 UT. The solar flare was associated with a Coronal Mass Ejection (CME) which arrived in the evening hours of October 24th, 2011 at the ACE satellite just before entering the Earth's magnetosphere. It is interesting to note that ACE observed first the velocity and pressure enhancement at the forefront of the CME (around 17:00 - 18:00 UT) and the turning of Interplanetary Magnetic Field (IMF) Bz to negative values took place some 2 hours later (around 20:00 - 21:00 UT).

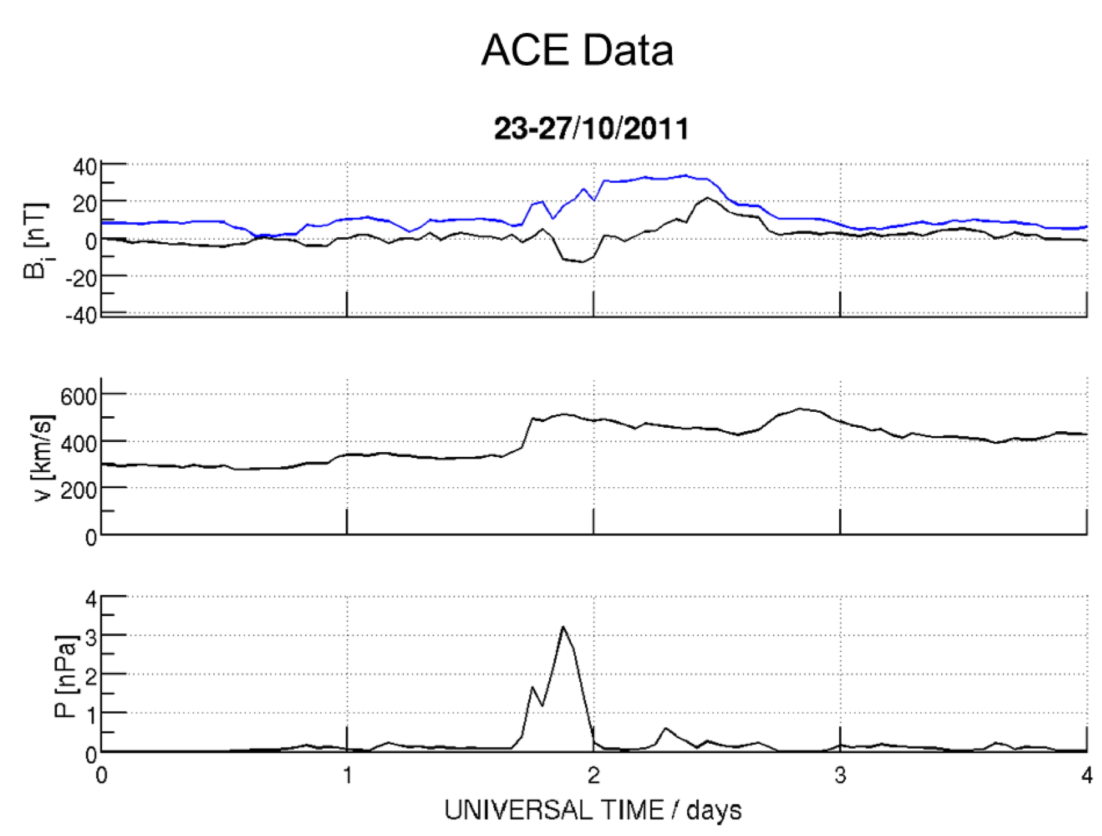

Figure 1: Solar wind measurements at the ACE satellite. Shown are the interplanetary magnetic field, the velocity of the solar wind and the solar wind pressure during the period October 23rd till 27th, 2011. The enhancement of the plasma pressure was guided by a negative Bz component indicating good coupling conditions with the geomagnetic field.

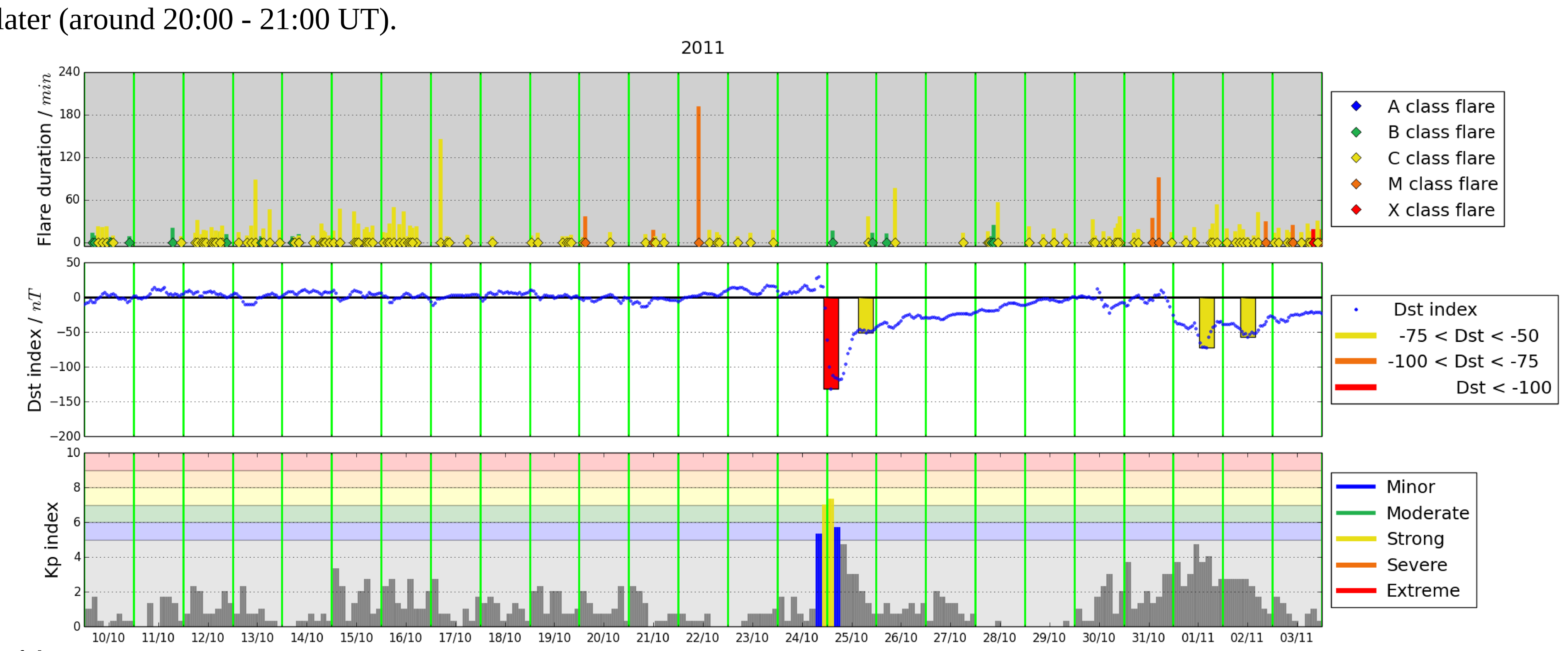

Figure 2: Solar flare time and duration, Dst and planetary Kp-Index for the geomagnetic storm on October 2011.

Ionospheric impact on SBAS

The global deviation on October 24th shows a strong enhancement of the ionization at 21:00 UT during day time over the American sector extending over both hemispheres from high to low latitudes. The ionization over US and Pacific region is enhanced by more than 20 TECU (3.2m at L1) in the vertical direction which may increase up to more than 9.5 meters at low elevation angles.

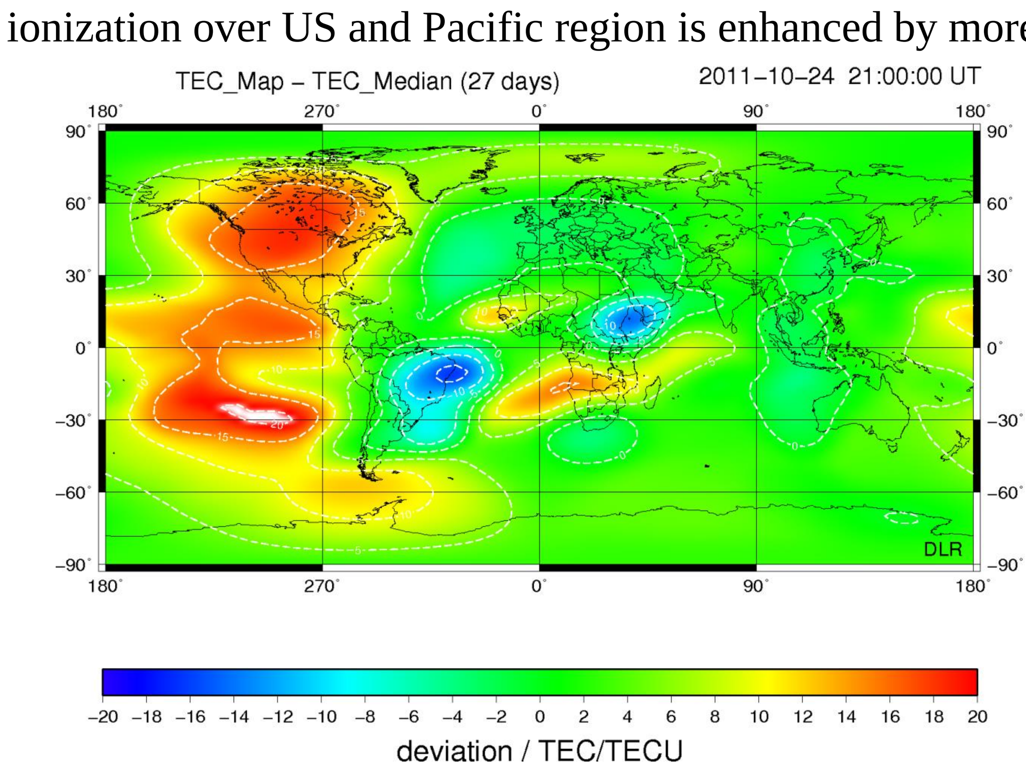

Figure 3: Deviations of global TEC from previous 27 day medians on October 24th, 2011 at 21:00 UT.

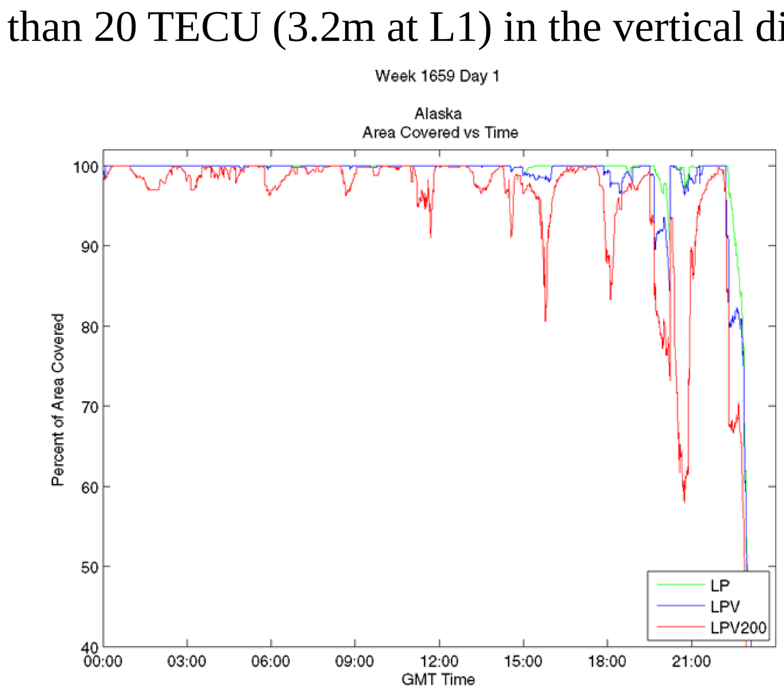

Figure 4: LPV availability of WAAS over Alaska on October 24th, 2011. (http://www.nstb.tc.faa.gov/RT_VerticalProtectionLevel.htm)

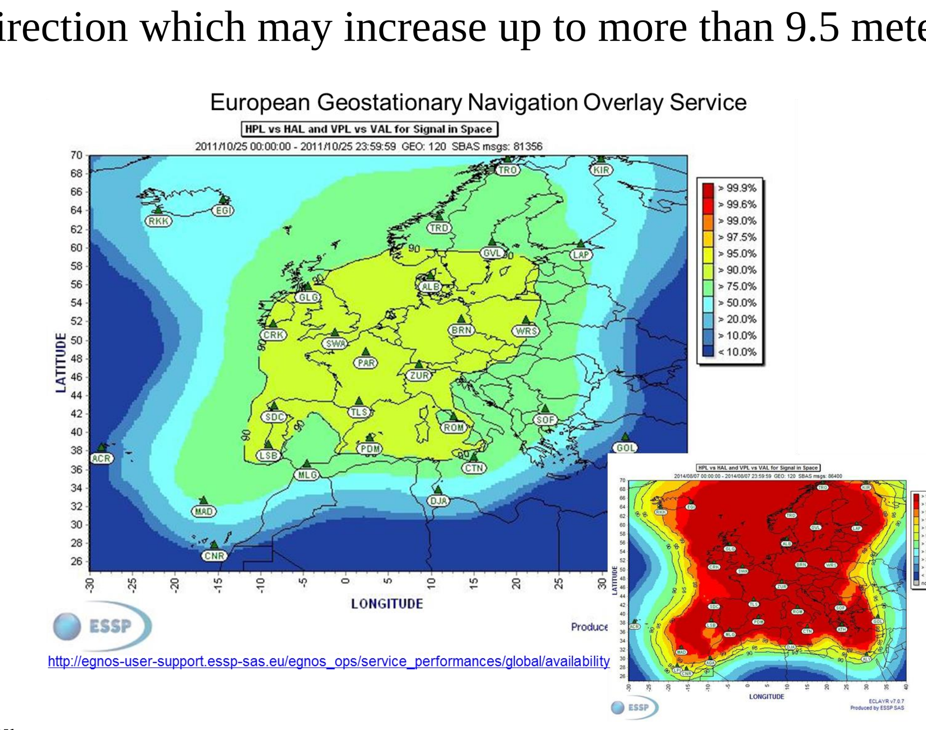

Figure 5: EGNOS availability on October 25th, 2011. For comparison EGNOS availability on an undisturbed day (lower right).

WAAS performance does not depend on the level of deviation but might have some problems related to the dynamics of the perturbation when rapid changes and spatial gradients of TEC occur. It is interesting to note that the LPV (Localizer Performance with Vertical Guidance) performance of WAAS over Alaska is heavily impacted in the evening hours of October 24th obviously in relation to the storm behavior. The performance of EGNOS also reacts sensitive to these perturbations.

The associated Ionospheric Disturbance Index DIX

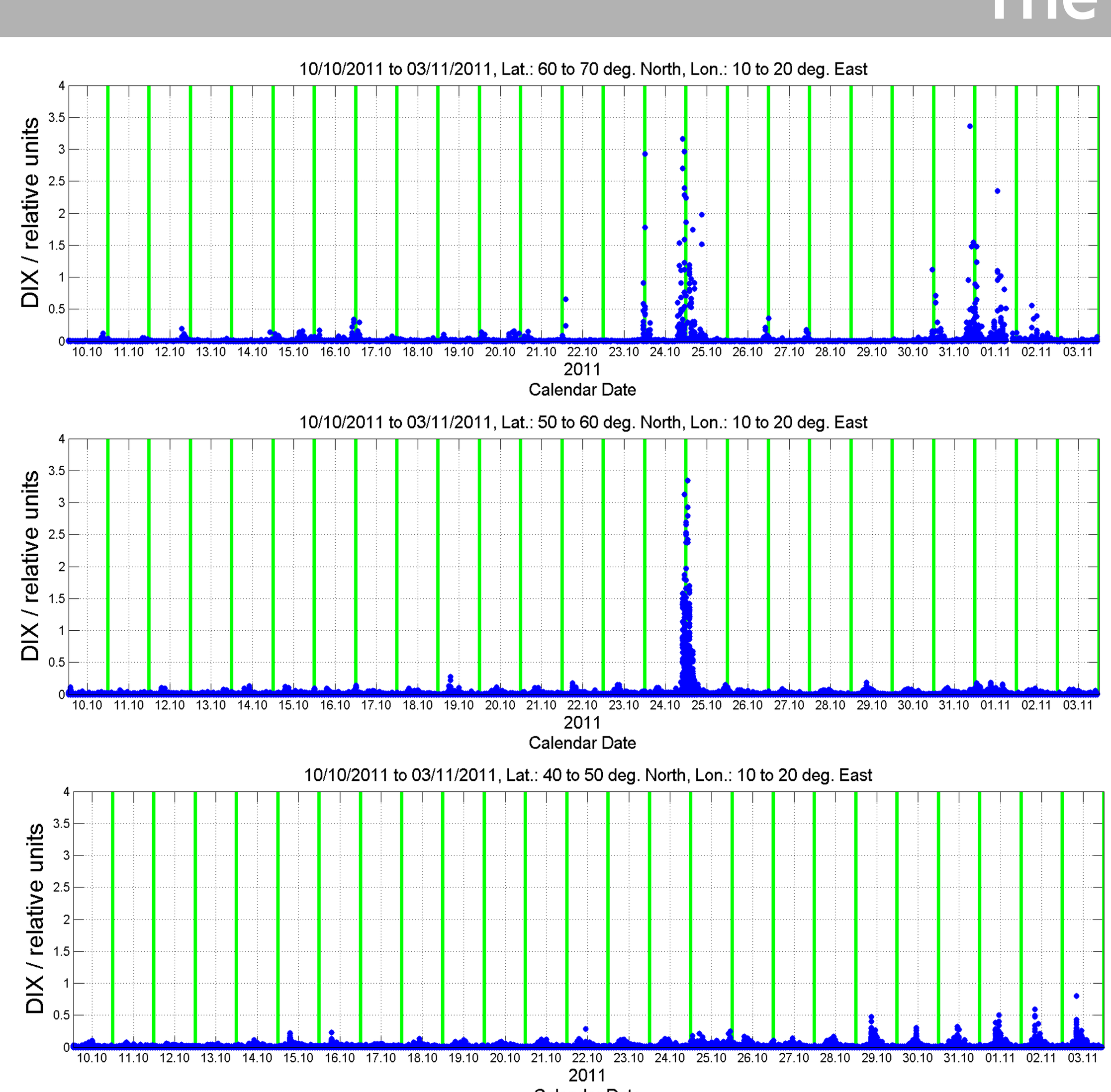

Figure 6: Ionospheric Disturbance Index (DIX) for the geomagnetic storm on October 10th to November 3rd, 2011 at three different latitudes.

The Ionospheric Disturbance Index (DIX) is defined on the basis of dual-frequency carrier phase measurements. The easy computable method uses a combination of TEC rates from two different GNSS receiver stations.

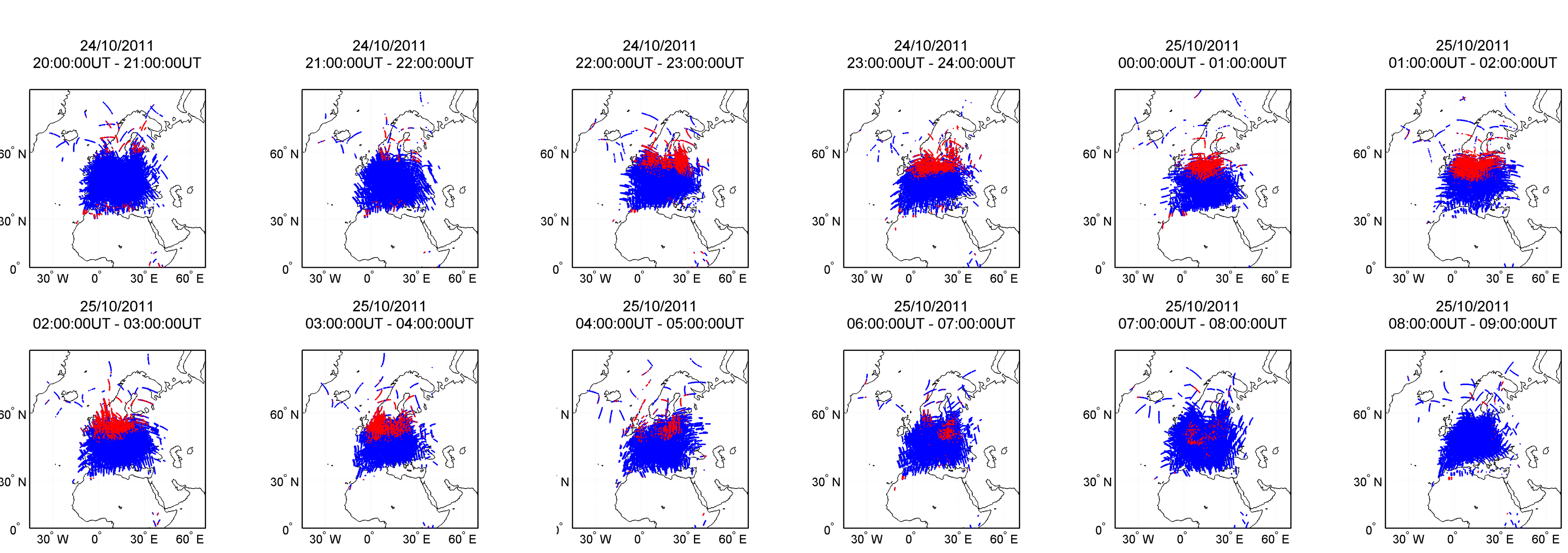

Figure 7: Time series of geo-located DIX estimates on October 24th / 25th, 2011 based on IGS and EUREF GNSS measurements. Blue dots indicate low level DIX values and red dots the enhanced DIX exceeding a fixed threshold value.

The arrival time of the CME and the enhanced geomagnetic activity indicate that ionospheric perturbations should be observable in the evening hours of October 24th. Indeed, enhanced ionospheric activity is indicated by DIX at high latitudes around 60°N (see Figures 6 and 7). GNSS users at lower latitudes are not seriously impacted during the subsequent night.
The coupling of the solar wind after about 20:00 UT on October 24th as seen in ACE, Dst and Kp data (see Figures 1 and 2) is well reflected in the related DIX at high latitudes. The DIX index allows near real-time detection and tracking of ionospheric disturbances with high resolution in space and time including the estimation of their propagation direction.

References:

[1] Jakowski, N. C. Borries and V. Wilken (2012), Introducing a Disturbance Ionosphere Index (DIX), RADIO SCIENCE, 47, doi:10.1029/2011RS004939

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