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Midlatitude Ionospheric density depletion and its impacts on GNSS

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Ionospheric disturbances are the source of accuracy degradation of Global Navigation Satellite System (GNSS) observables and they can cause harm to GNSS positioning techniques, especially for standalone users. The disturbance effects can be rapid and most enhanced by large geomagnetic storm that is still challenging to predict and model. Higher resolution measurement is one of the keys to better understand the storm time impacts on GNSS. During the geomagnetic storm on 17.03.2015, known as St. Patrick's Day storm, large perturbation of geomagnetic fields was observed even in middle latitudes in European region. In northeast Germany, the largest magnetic disturbances and accompanying plasma density changes were observed from afternoon to evening hours. Multiple GNSS satellites measured unusually large drops of Total Electron Content (TEC) in negative phases of the storm. We demonstrate the performance of GNSS positioning in Single Point Positioning (SPP) and Precise Point Positioning (PPP) techniques for the different phases of ionospheric disturbances. The large errors seems to be occurred when the electron density drops sharply compared to quiet time conditions.

Measurements overview and the changes in electron density

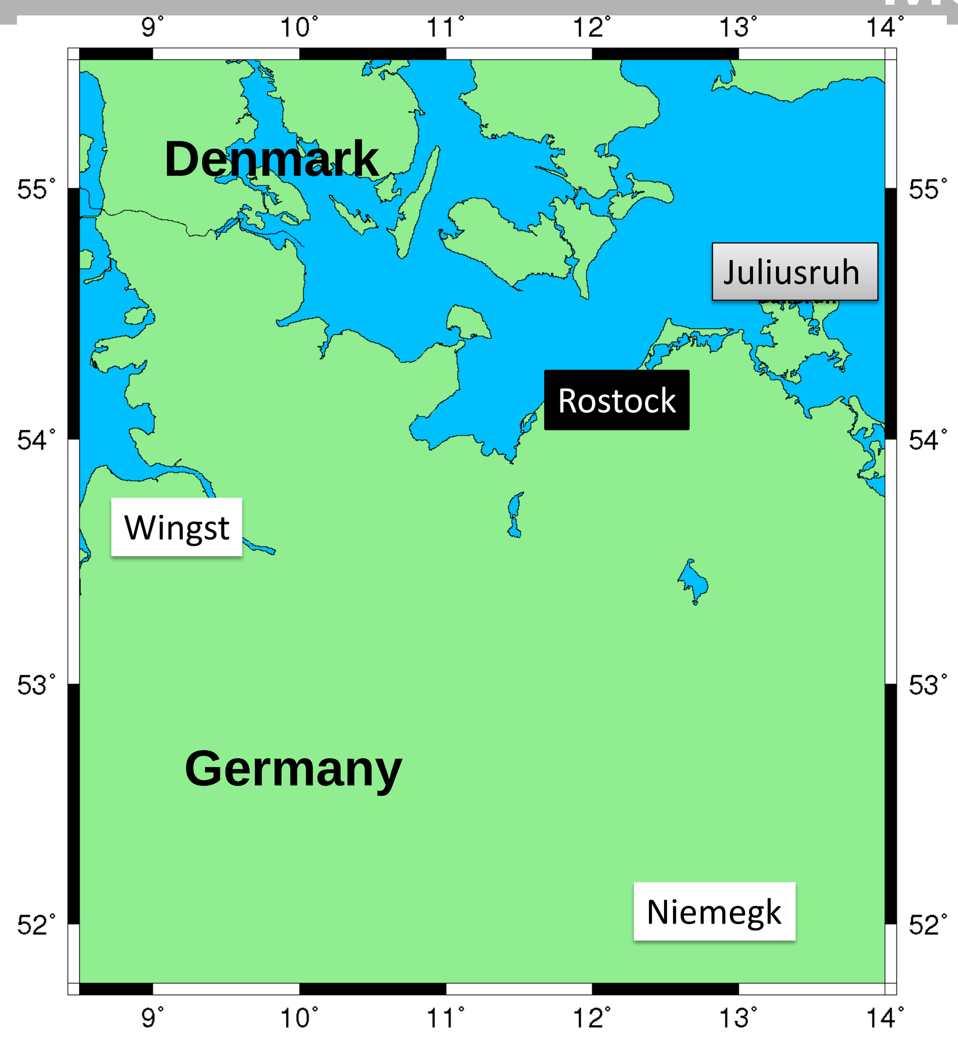

Figure 1. *Locations of the measurement stations.*

The measurement data used are GNSS receivers in Rostock, Ionosonde in Juliusruh, magnetometers from Wingst and Niemegk in Germany. **Figure 1** is an overview map of measurement locations. Several GNSS satellites detected depletions of TEC at Rostock on 17.03.2015. The satellite geometry of GPS12 seen from Rostock is shown in **Figure 2**. The relative slant TEC values from GPS12 are compared with the previous day in **Figure 3**. Both TEC decrease as the elevation angles increase and the values become flat when the satellite flew into the evening sector. On the storm day, this satellite link sees sharp TEC depletions after 16:30 and the flatting occurred much earlier. The TEC values drops up to approximately 30 TEC in 5 minutes when the elevation angles for are more than 50 degree.

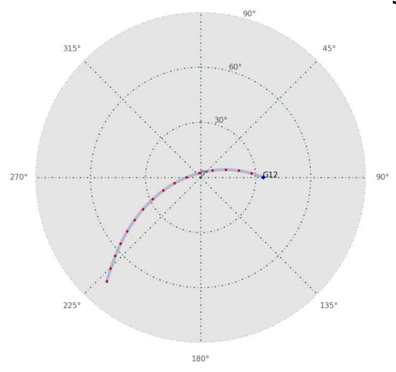

Figure 2. *GPS 12 geometry from Rostock represented in elevation and azimuth angles for Figure3. The satellite flew from west to east. The dots mark every 15 minutes between 15:00 and 19:00.*

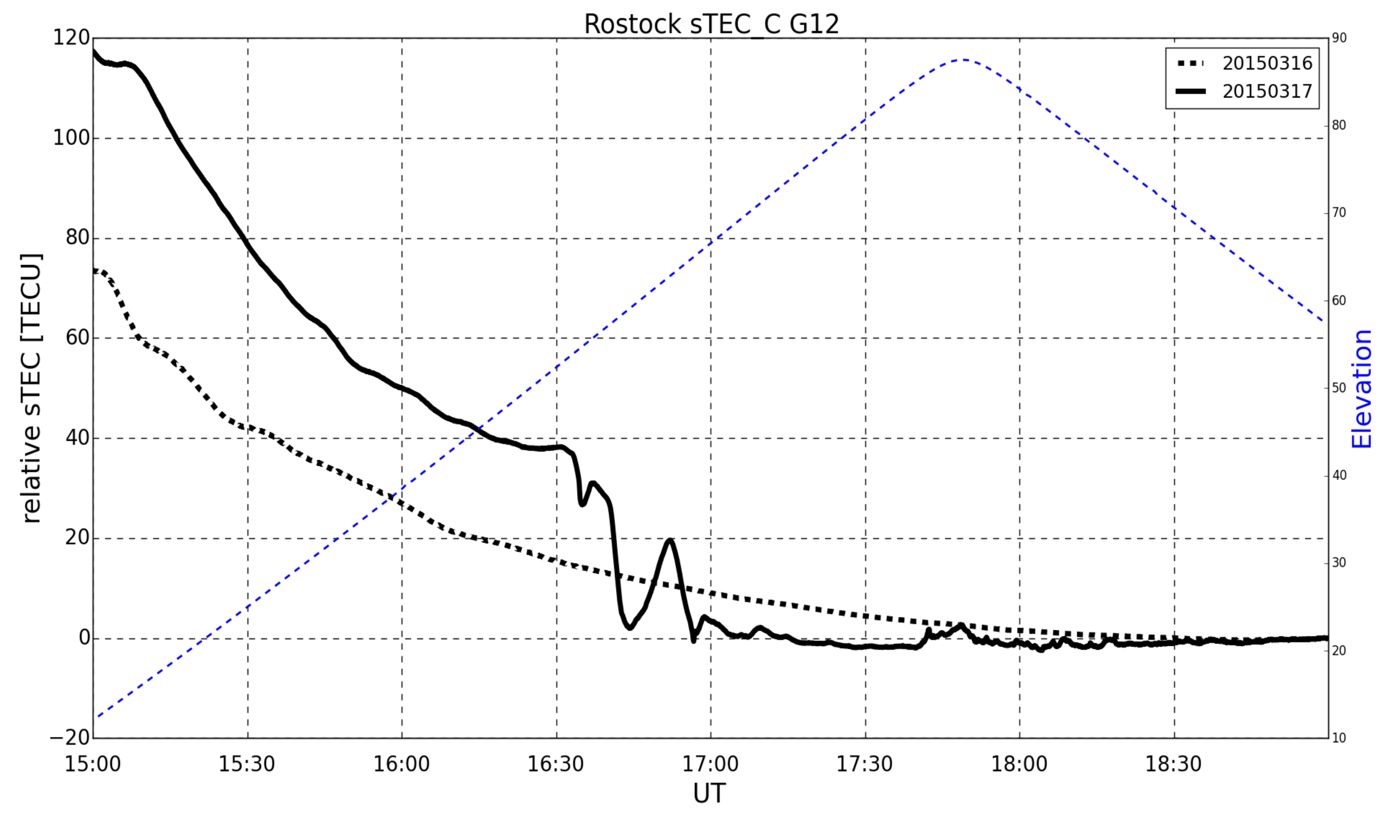

Figure 3. *The relative slant TEC between Rostock and GPS 12 satellite. The TEC is in TECU [10^{16} electrons/m^2]. The elevation angle in degree (blue) is shown on the right. The dotted line is the TEC values on 16.03.2015 from the same satellite for comparison.. The reference values at 19:00 are set as 0 for each day.*

GNSS Positioning Solutions at Rostock (54°08'43 N, 12°06'52 E) on 17.03.2015

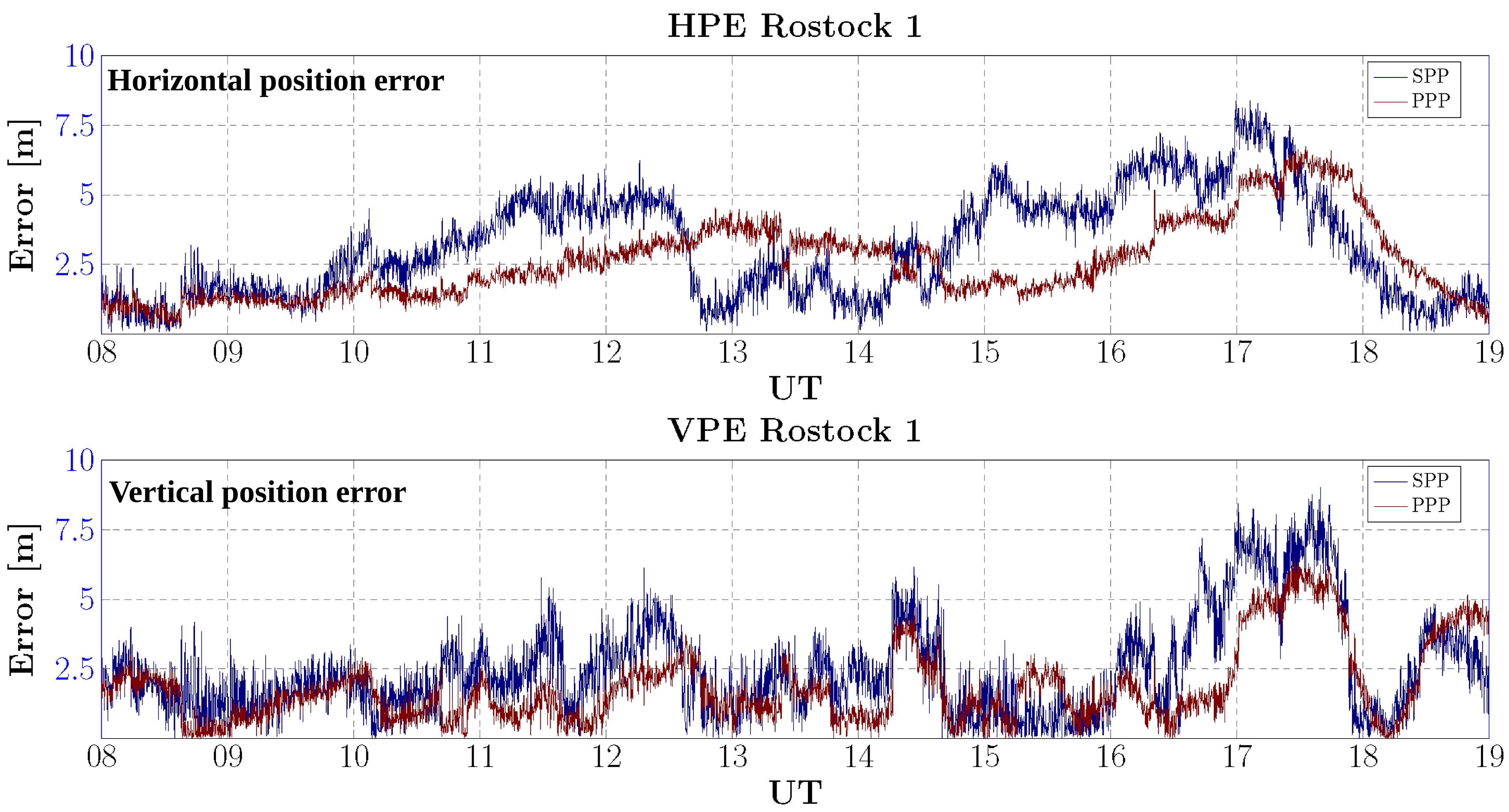

Figure 4. *Positioning solutions from the GNSS station at Rostock on 17.03.2015. PPP (red) and SPP (blue) positioning errors from the true values are shown in horizontal (top) and vertical directions.(bottom).*

We demonstrate Single Point Positioning (SPP) and Precise Point Positioning (PPP) solutions from DLR GNSS station in Rostock on 17.03.2015. SPP uses the pseudorange while PPP also uses the carrier phase. The horizontal component is important for maritime applications and the vertical component has relevance to aviation. In **Figure 4**, the positioning errors are computed with regard to the true values in horizontal and vertical directions.

- SPP and PPP are behaved similarly in vertical direction. In the horizontal component, PPP are usually better except early afternoon hours.
- Several sharp changes are seen from 16:00 to 18:00
- The largest errors are recorded up to 7.5 m in both directions between 17:00 and 18:00 when the large magnetic disturbances occurred.
- The horizontal errors decreased in evening while the vertical error still shows variations.

The ionospheric F2 layer peak electron density from Juliusruh is shown in **Figure 5**. The storm has the positive phases before noon and the negative phases in the afternoon. The large positioning errors are seen in the negative phase.

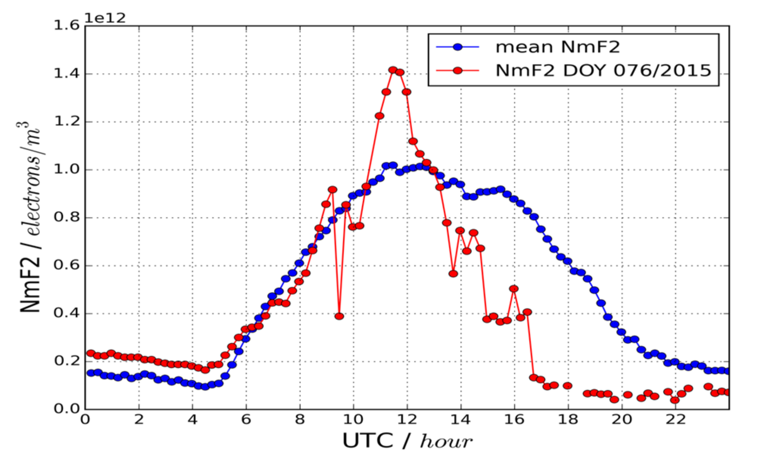

Figure 5. *The F2 peak electron density from Juliusruh Ionosonde on 17.03.2015 (red) and average values from previous 16 days (blue). The data is preliminary and automatic scaled.*

Ground magnetic fields variation

The time derivative of ground magnetic field from Wingst (WNG) and Niemegk (NGK) are shown in **Figure 6**. The coordinate system XYZ are pointing geographic north, east and vertical down.

- The disturbances become larger after13:30.
- The XY components behave very similarly for most of the day.
- The similarity breaks after 16:00 and it is recovered at ca. 17:00, indicating that small scale fluctuations of magnetic fields occurred in this period.
- The largest shock recorded after 17:00. The XY components are synchronized while it is not the case for Z component. The same behaver is seen just before midnight.

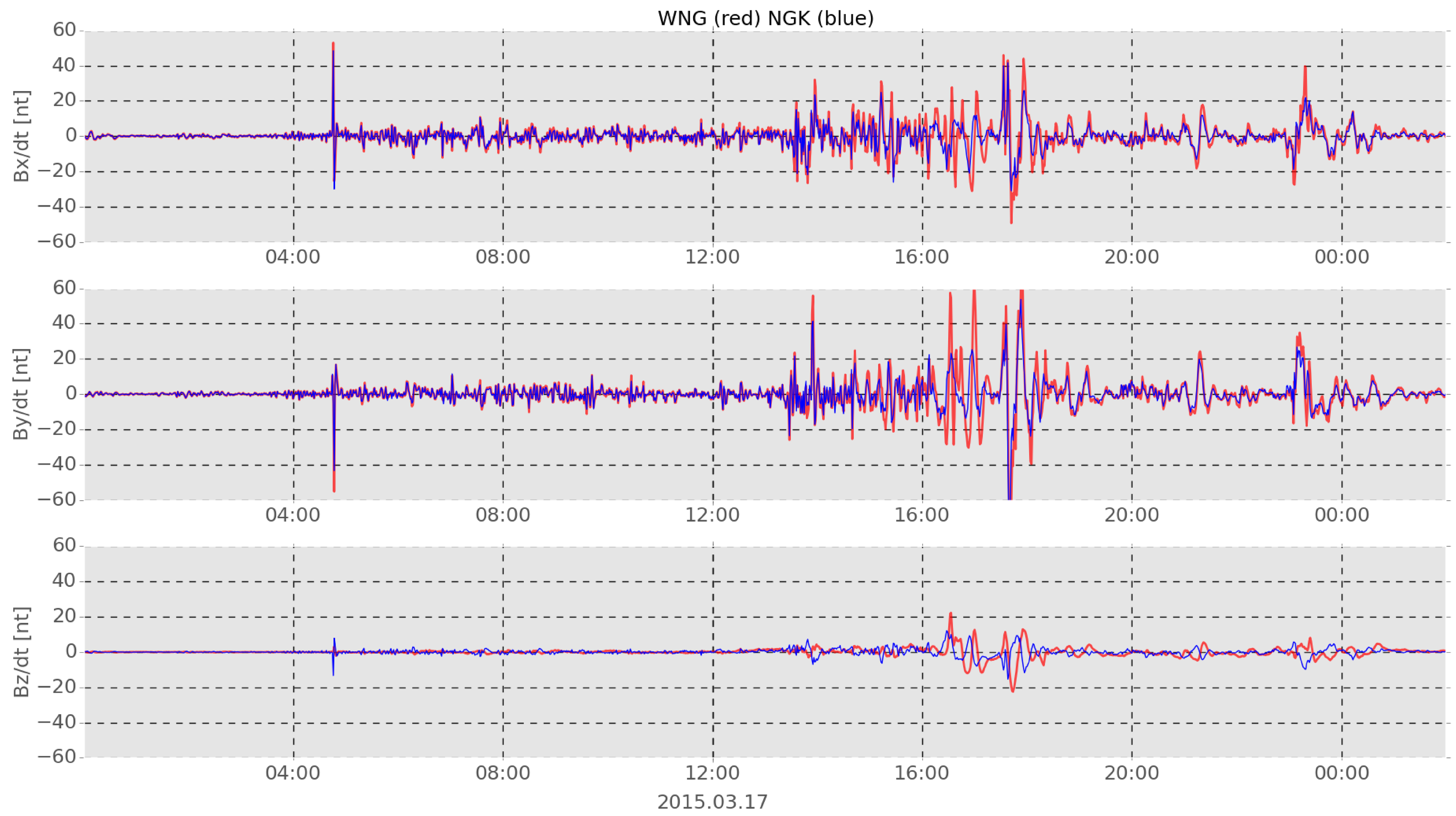

Figure 6. *1-minute time derivative of magnetic fields from the ground magnetometer from Wingst (red) and Niemegk (blue). The X component is pointing the horizontal geographic north, Y is horizontal eastward and Z is vertically downward.*

Discussion and Conclusions

- GNSS positioning solutions shows the directional responses to the different phases of ionospheric conditions in midlatitude during the 2015 St. Patrick day storm.
- The positioning solutions may reflect the horizontal and vertical changes in the electron density and the effects on carrier and phase signals, which can be used as an indicator of storm time density dynamics.
- The large electron density drops are found in link based GNSS TEC on the negative phases of the storm. The density depletions seem to be related to regional magnetic activity seen on the ground.

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