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Overview of the 2015 St. Patrick's day storm and its consequences for RTK and PPP positioning in Norway

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ABSTRACT

The 2015 St. Patrick's day storm was the first storm of solar cycle 24 to reach a level of "Severe" on the NOAA geomagnetic storm scale. The Norwegian Mapping Authority is operating a national real-time kinematic (RTK) positioning network and has in recent years developed software and services and deployed instrumentation to monitor space weather disturbances. Here, we report on our observations during this event. We study the ionospheric disturbances in relation to the auroral electrojet currents, showing that the most intense disturbances of GNSS signals occur on the poleward side of poleward-moving current regions. This indicates a possible connection to ionospheric polar cap plasma patches and/or particle precipitation caused by magnetic reconnection in the magnetosphere tail. We also study the impact of the disturbances on the network RTK and Precise Point Positioning (PPP) techniques.

Key words: Positioning system, Space weather, Storm, Ionosphere (auroral), Irregularities.

Introduction

On St. Patrick’s day 2015, the first storm of solar cycle 24 to reach the G4 level on the NOAA scale occurred. The storm was notable for two reasons; the first that it was at that point the strongest storm of the solar cycle, the second that space weather agencies around the world failed to predict it. Geomagnetic storm warnings had been issued, but only for a minor storm, which would not be a concern to most users.

Please note that the contents of this extended abstract are largely based on the work published in Jacobsen, K. S. and Andalsvik, Y. L. [2]. That paper contains more information, results and details than what is included in this paper. Any reference to this work should cite that paper.

Data Sources

Equivalent ionospheric currents were calculated by the Finnish Meteorological Institute (FMI), using magnetometer measurements from the IMAGE network (http://space.fmi.fi/image/). The currents were calculated using a 2D equivalent current model [1].

GNSS data were collected by NMA’s receiver networks. GNSS data from the archive have been used to calculate PPP coordinates using the GIPSY software, provided by NASAs Jet Propulsion Laboratory (JPL), in kinematic mode. The data have also been used to calculate the Rate-Of-TEC-Index (ROTI), which is a measure of ionospheric fluctuations in the GNSS phase data.

Some of the NMA receivers, referred to as RTK monitors, are receivers set up to mimic users of NMA's RTK service. They receive the RTK data stream in the same way as a normal user would and calculate their position every second.

In this paper, we quantify position error by the standard deviation of the vertical coordinate over a 60-second interval. Thus, the position error seen in this paper reflects the noise level of the position solution, but not the long-term position stability.

Observations & Discussion

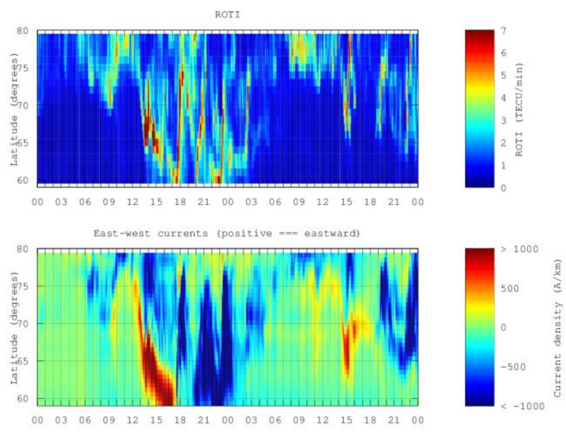

Figure 1 : Data for 2015-03-17 and 2015-03-18. **Top**: Average ROTI as a function of time and latitude, for the longitude range 20 - 24 deg East. **Bottom**: Equivalent ionospheric currents in the east-west direction as a function of time and latitude, at 22 deg East.

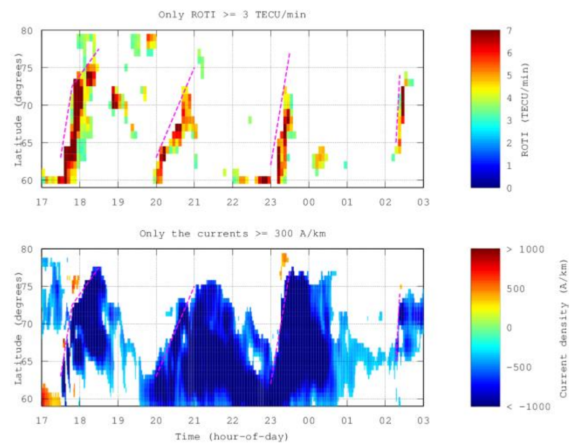

Figure 2 : This figure contains a subset of the data shown in the top two panels of Figure 1, filtered to show only strong disturbances and currents. The dashed magenta lines are visual aids drawn on the poleward edge of the poleward-moving westward electrojet.

The top panel of Figure 1 shows ionospheric ROTI as a function of time and latitude. The bottom panel shows the East-West component of the equivalent ionospheric, calculated based on ground magnetometer measurements. The time and latitude axes are the same as for the first panel. Strong ROTI values and strong currents were observed between 12:00 UT on the 17th and 01:00 UT on the 18th.

The top two panels of Figure 1 clearly indicate that there is at least a co-variation between equivalent ionospheric currents and ionospheric density irregularities. However, while the general pattern is similar, they also clearly demonstrate that there is not a simple linear relationship between current density and irregularity strength. To take a closer look at this, we made a plot focusing on the strong currents and disturbances before and around midnight.

Figure 2 show a zoomed-in view for times from 17:00 UT on the 17th to 03:00 UT on the 18th. The color scales are the same as in Figure 1 but low ROTI (< 3T ECU/min) and currents (< 300A/km) values are not shown, in order to emphasize the high values. The figure reveals that the disturbed area was located at the poleward edge of poleward-moving areas of westward current. This is most clearly seen around 18:00 UT, 20:00 to 21:00 UT and around 23:30 UT. The poleward edge of the electrojet is located just equatorward of the open-closed magnetic field line boundary.

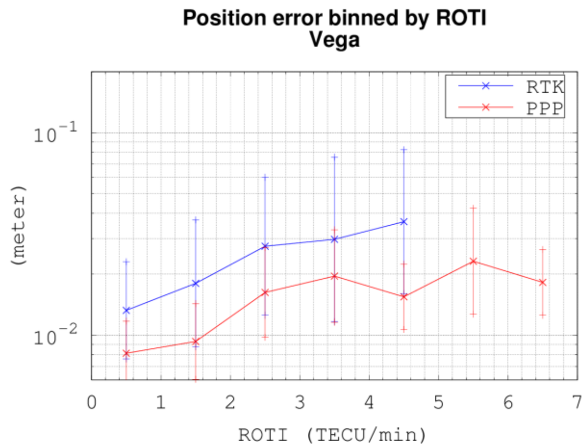

Figure 3 : Vertical position errors binned by ROTI, for Steinkjer (RTK) and Vega (PPP). The blue line shows RTK error and the red line shows PPP error. Crosses mark the average value in each bin, while the vertical lines shows +- one standard deviation.

Vega and Steinkjer are sites in the middle of Norway. Moderate or stronger geomagnetic storms tend to expand the auroral oval enough to disturb these sites, which did indeed occur during this storm. Figure 3 shows the relation between ROTI and positioning errors. The positioning errors increase rapidly with increasing ROTI. The curves for the RTK and PPP techniques appear to be approximately parallel, meaning that the PPP technique yields more precise coordinates than RTK regardless of the ionospheric disturbance level.

Conclusions

– Strong GNSS disturbances were observed at all latitudes in Norway on March 17th and early on the 18th. Late on the 18th, strong disturbances were only observed in the northern parts of Norway.

– GNSS disturbances, measured by ROTI, were most intense on the poleward edge of poleward-moving electrojet currents. This is possibly related to patches and/or particle precipitation activity caused by active tail reconnection. The relative importance of these phenomena, or the importance of having both simultaneously, cannot be determined from our data.

– Regions with less intense currents and/or equatorward motion of the current region were associated with less severe GNSS disturbances.

– Positioning errors increased rapidly with ROTI for both the RTK and PPP techniques. PPP was most precise regardless of disturbance level.

Acknowledgements

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References

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[2] Jacobsen, K. S. and Y. L. Andalsvik, (2016), Overview of the 2015 St. Patrick's day storm and its consequences for RTK and PPP positioning in Norway, Journal of Space Weather and Space Climate, (Accepted, Not yet published)