Ionospheric Density Variations in the F Region and Trans-ionospheric GHz Radio Propagation - the View with the Swarm Langmuir Probes and Lantmäteriets SWEPOS

Stephan C. Buchert <scb@irfu.se> (IRF), Tim Abrahamsson (Uppsala University) and Martin Håkansson (Lantmäteriet, Gävle)

Abstract

The ionosphere affects trans-ionospheric radio signals even at GHz frequencies and in the bands that are used for satellite based positioning and navigation. Density measurements by Langmuir probes on the Swarm satellites at altitudes between about 450 and 510 km can be used to roughly characterize the total effects on GNSS signals during a period of about 12 years since the Swarm launch. Comparison with data from SWEPOS system and scintillation receivers on the ground reveals both, a ionospheric delay which is largest in the hours before and after local noon and seen at all latitudes over Sweden, as well as irregular disturbances which are normally seen in the Northern parts of Sweden in the night, but expand to the south of Sweden and beyond in the large geomagnetic storms which have occurred around the most recent solar maximum.

Introduction

Satellite-based positioning is ubiquitously available, for example, with many mobile phones. For high accuracy, $\Delta x \sim 1$ cm, special systems are required. Real-Time Kinematic (RTK) is widespread and used by, among others, the Swedish cadastral office (Lantmäteriet) for the SWEPOS: Reference stations with known fixed positions record the carrier phase of the satellite signal and communicate to mobile RTK 'rovers' receiving signals of both GNSS and a reference station. With the phase information from one reference station $\sim$ 1 cm positioning accuracy is achieved.

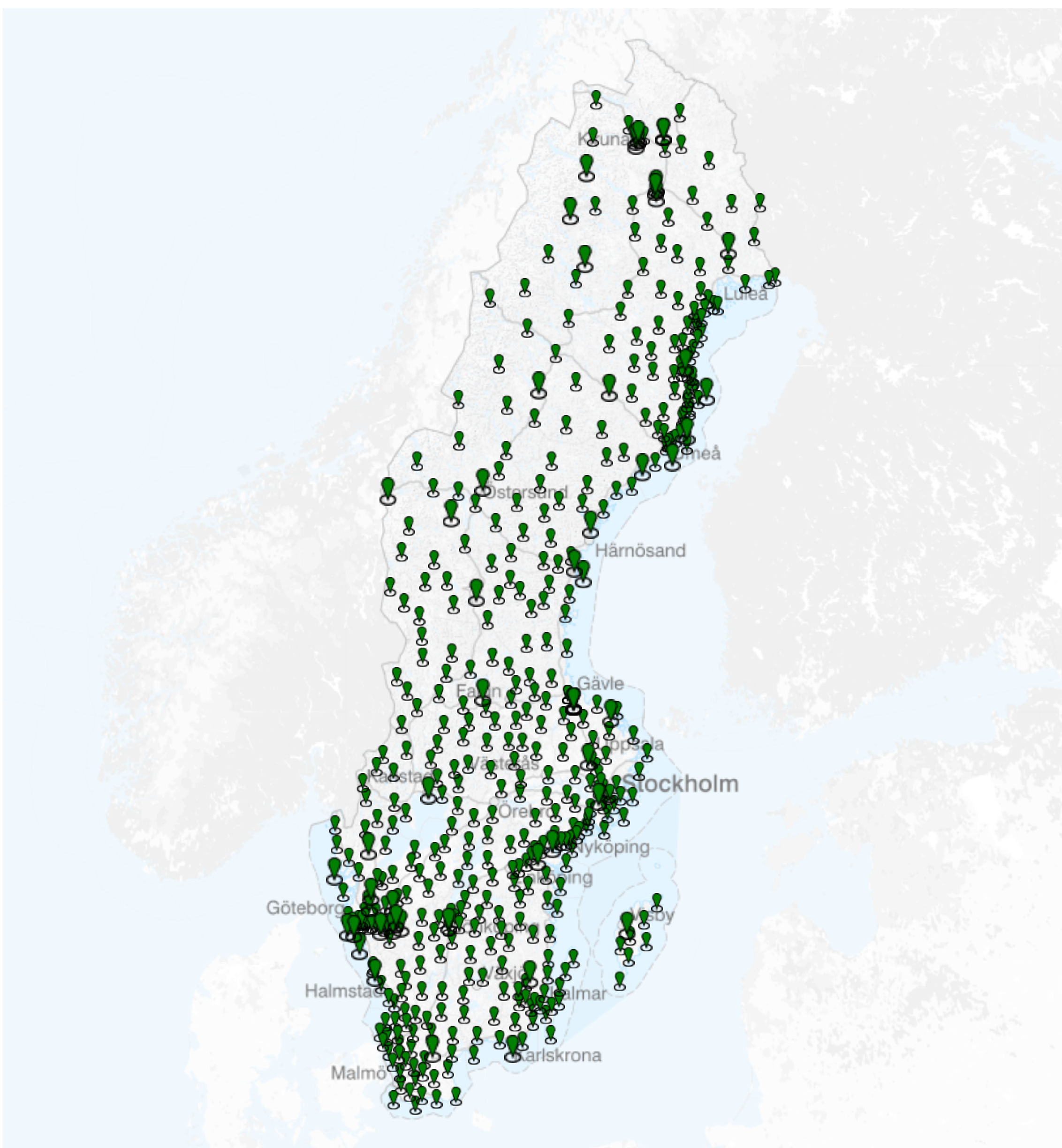


Figure 1: Map of the SWEPOS reference stations

Jonosfärmonitor

Some selected stations receive the phases from three (or more) references and so provide three independent estimates of the position and an estimate of its uncertainty. The main source of the uncertainty comes from the trans-ionospheric signal. Therefore the positioning uncertainty can indicate ionospheric effects, namely delay and disturbance, on the satellite signal. This is realized in Lantmäteriets 'Jonosfärmonitor' presenting a color-coded positioning uncertainty in real-time at a cadence of 30 seconds.

Ionospheric effects

While an effect of the ionosphere on the L-band (∼1–2 GHz) is well established, the actual causes could be

- unmitigated ionospheric delay
- scintillations from small-scale density variations

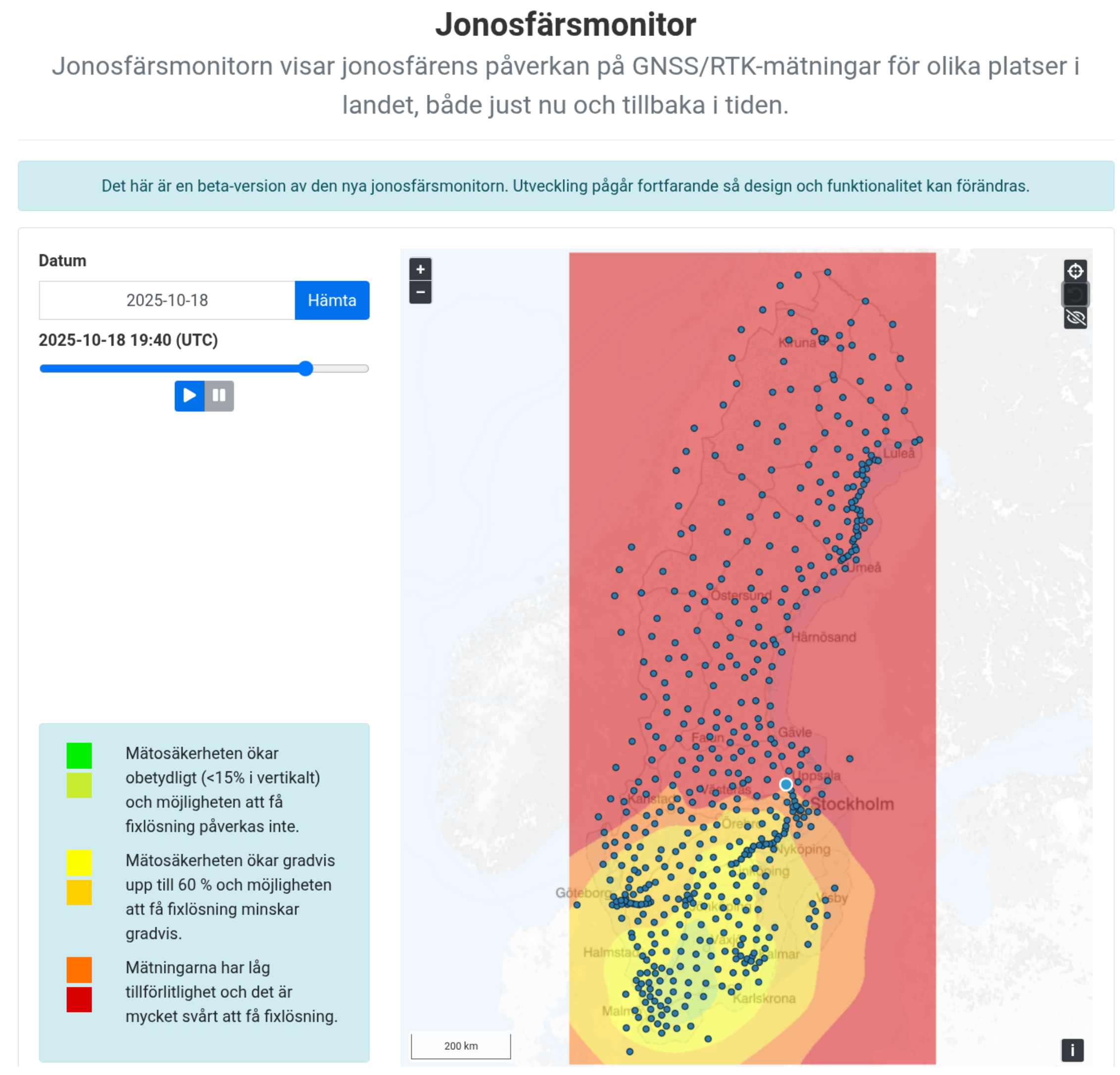
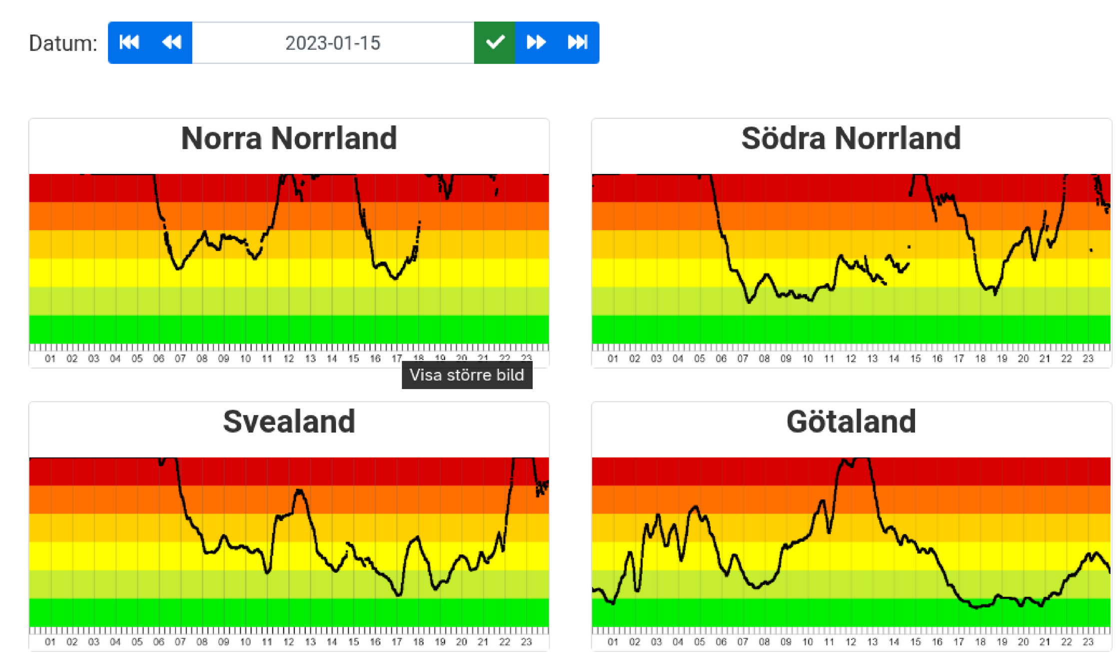


Figure 2: The monitor warns in red color during the recent geomagnetic storm in 2025 even in the Svealand (Stockholm) area of Sweden.

(https://swepos.lantmateriet.se/services/ionomonitor.aspx)

Swarm over Sweden

The polar orbiting ESA Swarm satellites pass over a region of the size of Sweden 1-2 times/day/satellite on each of the ascending and descending legs (for a better coverage in time a satellite constellation akin StarLink would be needed).



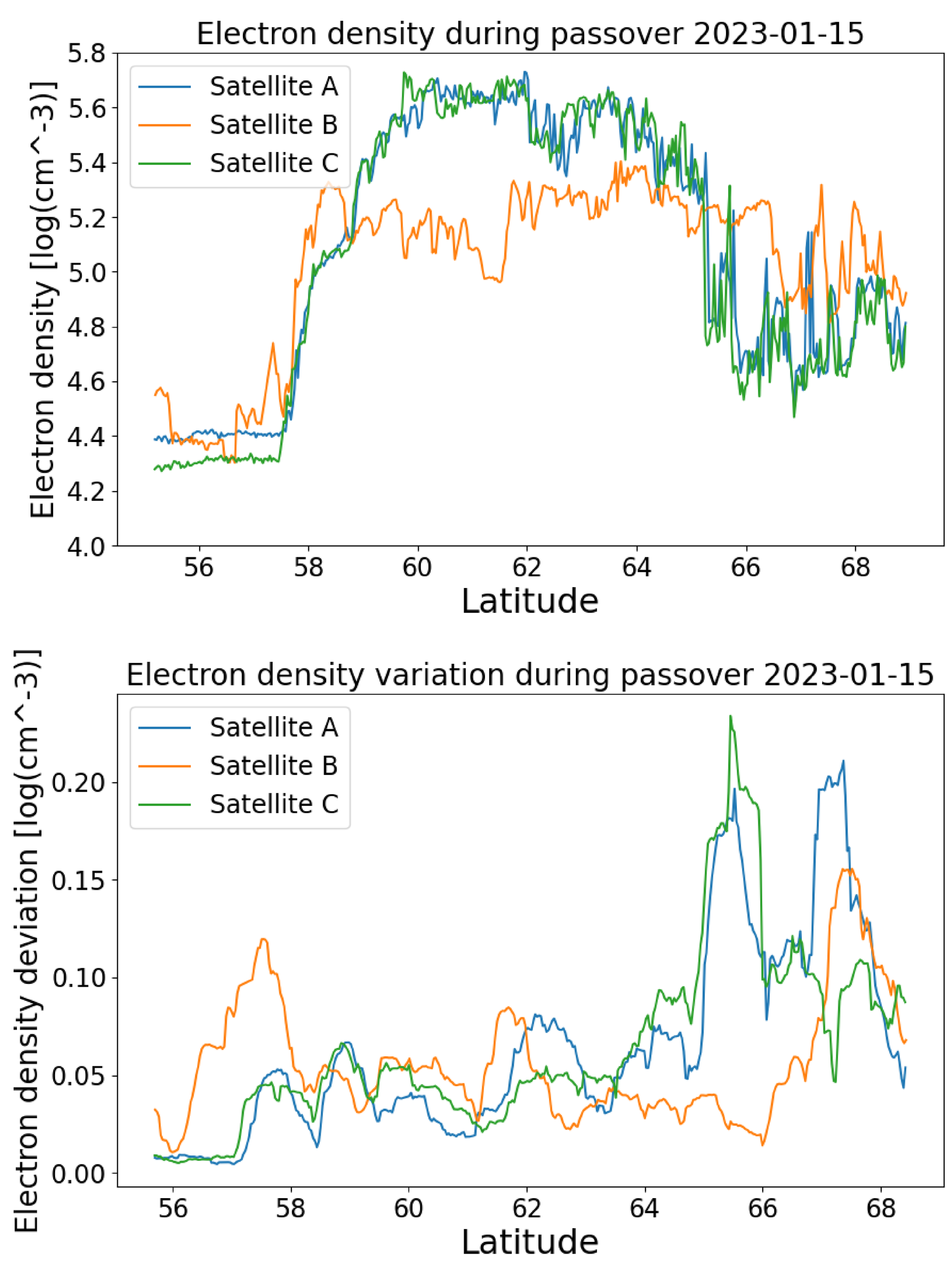


Figure 3: The electron density and its deviation during an event of high positioning uncertainty (red color in Jonosfärmonitor). Note the elevated level of electron density in the south to middle regions as well as the elevated level of deviation in the northernmost region.

Statistics over a solar cycle

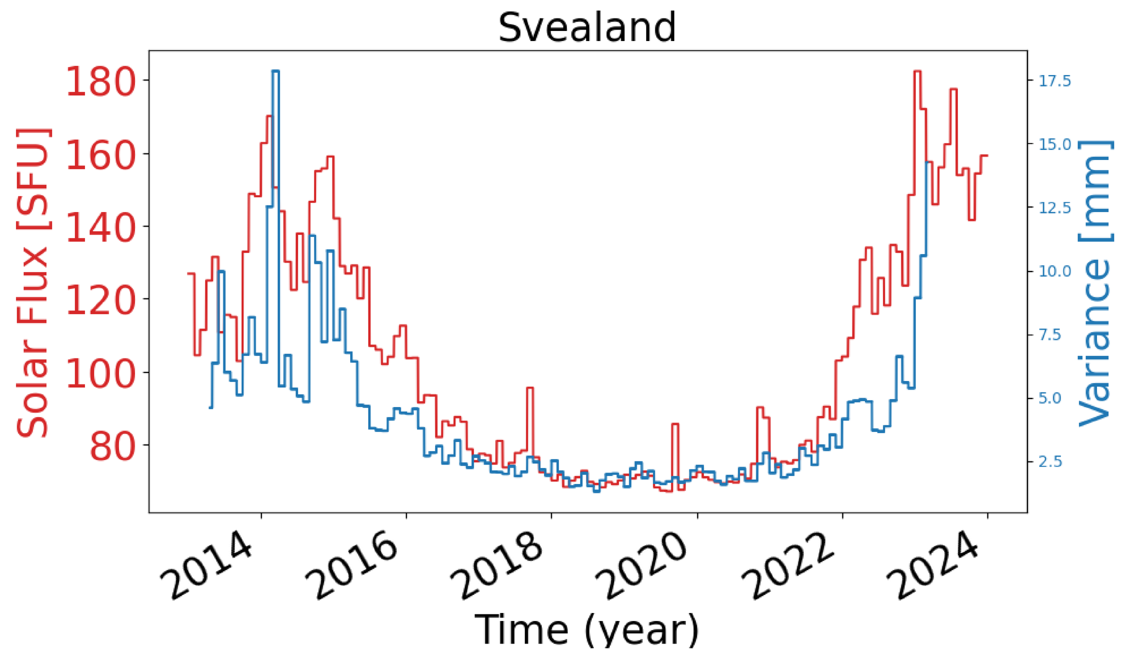


Figure 4: The SWEPOS Δx in mm and solar F10.7

Variation over a Day

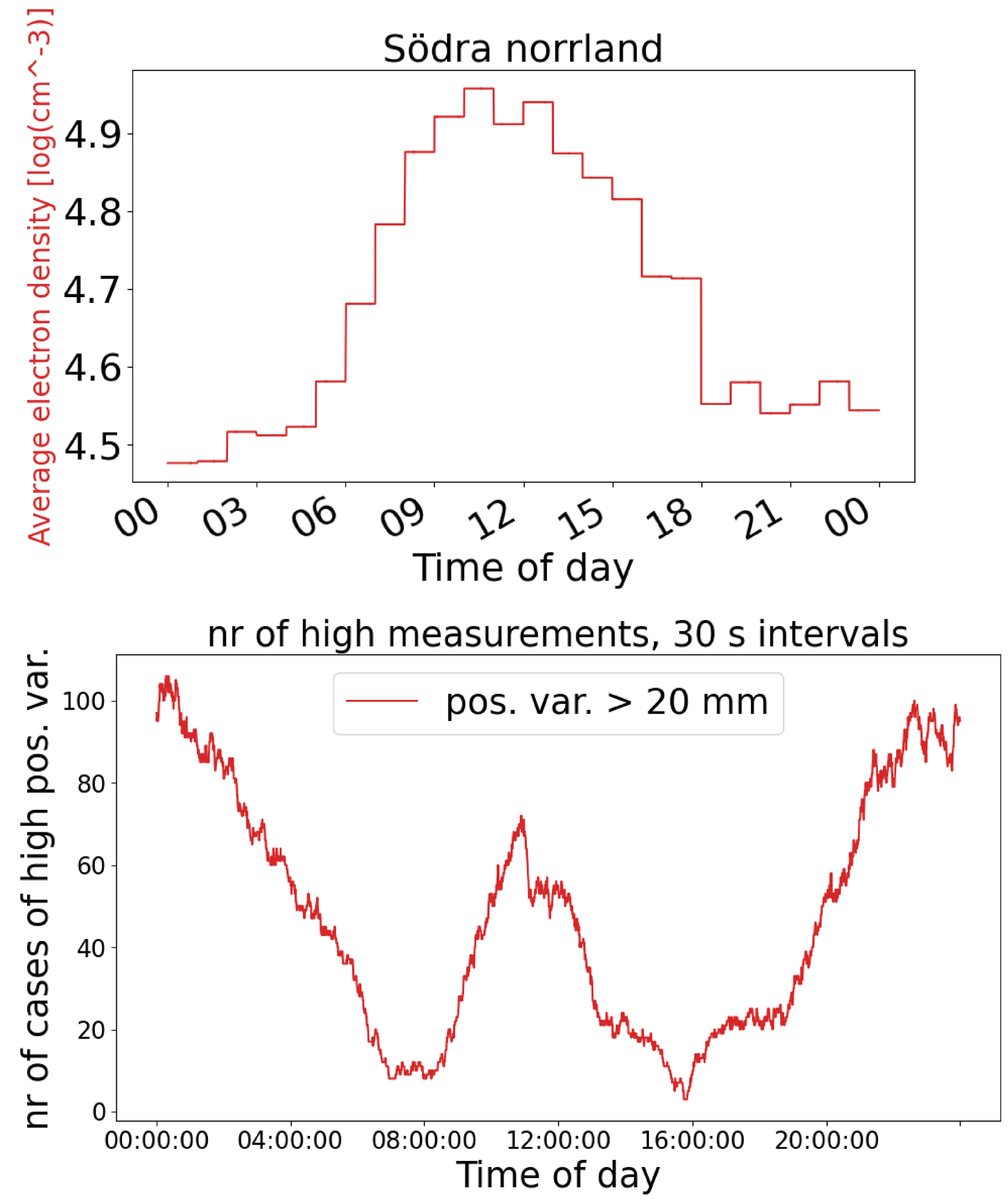


Figure 5: The average electron density (upper panel) and nrs of low positioning accuracy (lower panel) in the Södra Norrland (Umeå) region over the time of day. The $|Deltax$ is affected by auroral disturbances in the night, but also increases around noon when the electron density is high.

Conclusions

- positioning uncertainties of the SWEPOS system correlate with ionospheric electron density measurements by the Swarm Langmuir probes at passes over Sweden,
- two effects can be distinguished:
  1. mainly night-side effects of the ionosphere on GNSS signals are typically seen when variations of the ionosphereic density as seen by Swarm at altitudes between abut 400 and 510 km are enhanced;

     These occur typically mainly in Norrland, but during strong geomagnetic activity can expand over the whole of Sweden.

     Probably signal scintillations caused by irregular density variations affect the positioning. Fresnel theory, re- and diffraction would apply.
  2. Results also indicate that an increase of the positioning uncertainty around noon at all regions is perhaps related to unmitigated ionospheric delay when the density is high.