GNSS probing of local ionospheric disturbances in high latitude

H. Sato[1], V. Wilken[1], C. Borries[1], J. Berdermann[1], M. Rietveld[2] and N. Jakowski[1]

[1] DLR/German Aerospace Center Institute of Communications and Navigation, Germany

[2] EISCAT Scientific Association, Norway

ABSTRACT

We present study of regional ionospheric perturbations in high latitude by monitoring dual frequency signals transmitted by Global Navigation Satellite Systems (GNSS). The variations in Total Electron Content (TEC) are identified from high rate GNSS receivers placed in Ramfjordmoen and in Tromsø, Norway. During the experiments in winter 2010, HF electromagnetic pumping waves from EISCAT heating facility in Ramfjordmoen were transmitted along the geomagnetic field lines. The modification of ionosphere was observed by EISCAT UHF radar. We analyze TEC measurements from GLONASS satellite with regard to the distance between the Ionospheric Piercing Points and estimated heated center at 200 km. TEC data shows background increases over the heating cycles as well as some localized variations which may be associated with heating on/off intervals. The largest variations from the background TEC are seen during the longer heating intervals in the vicinity of the heating beam direction.

1. INTRODUCTION

Signal delays of L band frequencies in Global Navigation Satellite Systems (GNSS) are effective tools to study link-related ionospheric disturbances. Recent reports have shown that the effect of small plasma irregularities caused by powerful HF waves are observable in Total Electron Content (TEC) deduced from GPS signals during ionospheric modification experiments by HAARP (Milikh et al. 2008; Najmi et al. 2014). By using single GPS satellite-receiver link, these authors confirmed TEC response against 10 second heating on/off cycle after some time delay from the beginning of the heating.

The objective of this paper is to present observation of TEC variations from a GLONASS satellite and two receivers during an active experiment by EISCAT heating facility (Rietveld et al. 1993). The receiver positions were separated with a comparable distance to the estimated heated region size in order to track TEC variation along different links. On December 4 2010, the heating intervals were programmed to be varied from 10 to 120 seconds to study TEC response to total energy input from HF waves along with changing Ionospheric Piercing Points (IPP).

2. EXPERIMENTAL SETUP

The experiment setup is illustrated in Figure 1. The center of the experiment is the EISCAT heating facility located at the geographic coordinates 69.5836°N/ 19.212°E. During the experiment the heating facility produces a heater beam which is directed southwards with an elevation angle of 78° respectively -12° from the vertical. The open width of the heater beam is 14°. Therefore the center of the heating in 200km height is approximately 42 km south of the EISCAT heating facility at 69.2132°N/19.212°E.

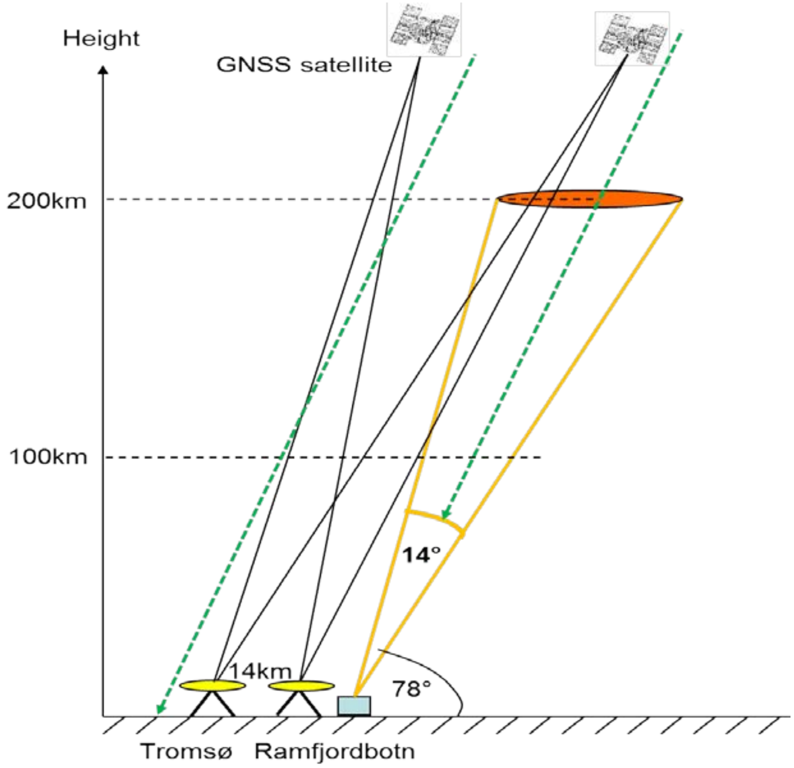

Figure 1. Schematic diagram of the experiment setup. The distance between receivers is approximately 14 km. The green dashed line indicate geomagnetic field lines. The area with orange color is estimated heated ionospheric volume.

We have chosen two GNSS receiver locations to fulfil technical requirements such as power supply and internet as well as satellite visibility for higher elevations. The first receiver is located at the Geophysical Observatory in Tromsø and the second directly at the EISCAT facility at Ramfjordbotn. The station in Ramfjordbotn is approximately 14km south east of the Tromsø receiver station. Two Topcon Legacy EGGDT 50Hz receivers with Leica AR 25 antennas have been installed at both measurements stations. The receivers are able to receive GPS (L1/L2), GLONASS (L1/L2) and WAAS/EGNOS. The receiver coordinates are summarized in Table 1. The receivers were operated at 20Hz during the experiment.

Table 1. Location of GNSS receivers

Location	**Geophysical Observatory Tromsø**	**Ramfjordbotn**
Operational Frequency [Hz]	20	20
X[m]	2103063.589	2107196.773
Y[m]	721638.770	734556.024
Z[m]	5958156.552	5955086.204
Latitude [°N]	69.66147	69.58358
Longitude [°N]	18.93899	19.21825
Height [m]	147.452	99.579

The EISCAT heater was operated at a frequency of 4.544 MHz. The heating frequencies were chosen from the actual plasma densities to effectively heat the plasma. The effective radiated power (ERP) was approximately 185 MW using 80kW power per transmitter. The ranges of the heating intervals are from 10 to 120 seconds. The heating modulation uses a slow pump cycle. The heating experiment started at 09:45 and ended 12:00 UT. The heating intervals were programmed as follows: 10 seconds on-off cycle for the first 60 seconds, 20 on-off seconds for the next 120 seconds, 40 seconds on-off for the next 240 seconds and then 120 seconds on-off for the next 480 seconds. One heating cycle lasts for 15 minutes. Table 2 summarizes the HF heating information.

Table 2. EISCAT heating information on December 04 2010

START (UT)	END (UT)	Frequency (MHz)	Description of Modulation
09:45	12:00	4.544	10s on /10s off for 60s, 20s on/20s off for 120s 40s on/40s off for 240s, 120s on/120s off for 480s

3. SLANT TEC ESTIMATION

For the presented study the relative carrier phase slant TEC was calculated in order to detect variations in the ionospheric plasma. The slant TEC is the path integral over the electron density along the line-of-sight (slant) from the earth bound receiver to the corresponding GNSS satellite. Furthermore the calculation is based on the available carrier phases of the dual frequency receivers only. The adjective ‘relative’ indicates that no bias estimation and ambiguity correction was applied. This approach has the advantage of being quite simple; it avoids additional error sources and completely satisfies the requirements since only variations of TEC are of interest in the frame of the study.

The ionospheric range error $\mathrm{d_{iono}}$ for a signal frequency f is calculated from the corresponding time delay:

$$d_{iono} = c \cdot \Delta t_{iono} = \pm \frac{40.3}{f^2} \int_{rec}^{sat} N_e \, ds = \pm \frac{40.3}{f^2} TEC$$

Two GNSS carrier phase observation of wavelength λ_1 and $\lambda_2$are:

$$\phi_1 = \rho + c(dt - dT) + d_{iono} + d_{tropo} + \lambda_1 N_1 + \varepsilon_1$$

$$\phi_2 = \rho + c(dt - dT) + d_{iono} + d_{tropo} + \lambda_2 N_2 + \varepsilon_2$$

where d_{tropo} is tropospheric range error, N is cycle ambiguity, ε_1 is residual errors of carrier phase while dt and dT are receiver and satellite clock error and ρ is geometric range.
By differencing the two equations and ignoring furthermore ambiguities and biases, we get the equation of the relative carrier-phase slant TEC:

$$sTEC_{rel} = \left(\frac{1}{40.3}\right) \cdot \frac{f_1^2 f_2^2}{f_2^2 - f_1^2} \cdot (\phi_1 - \phi_2)$$

4. OBSERVATION RESULTS

During this active heating experiment, several satellite signals were visible from the two stations. Our interest here is satellite-receiver link when IPP at is within the estimated heated volume 200 km for both Ramfjordbotn and Tromsø stations. This requirement excludes most of the visible satellites in the earlier portion of the experiment. The signals transmitted by GLONASS R23 satellites satisfy the requirements for the last two heating cycles. In this paper our analysis focus on R23 signals recorded at two GNSS stations.

Figure 2 shows the relative distance between the IPP and estimated heating center. The right axis is the corresponding elevation angle. The Ramfjordbotn link (above) is within 25 km distance from 11:28 to 11:50 (UT). During the 120 seconds heater on period starting from 11:37, this link was the closest to the heating center and the distance was approximately 1.5 km at 11:38:10. The link to Tromsø receiver (below) came to the heated volume several minutes later. The closest distance was 1.6 km at 11:44:47 when the heater was off for 120 second relaxation. The elevation angles were between 82 and 70 degree for the current analysis period.

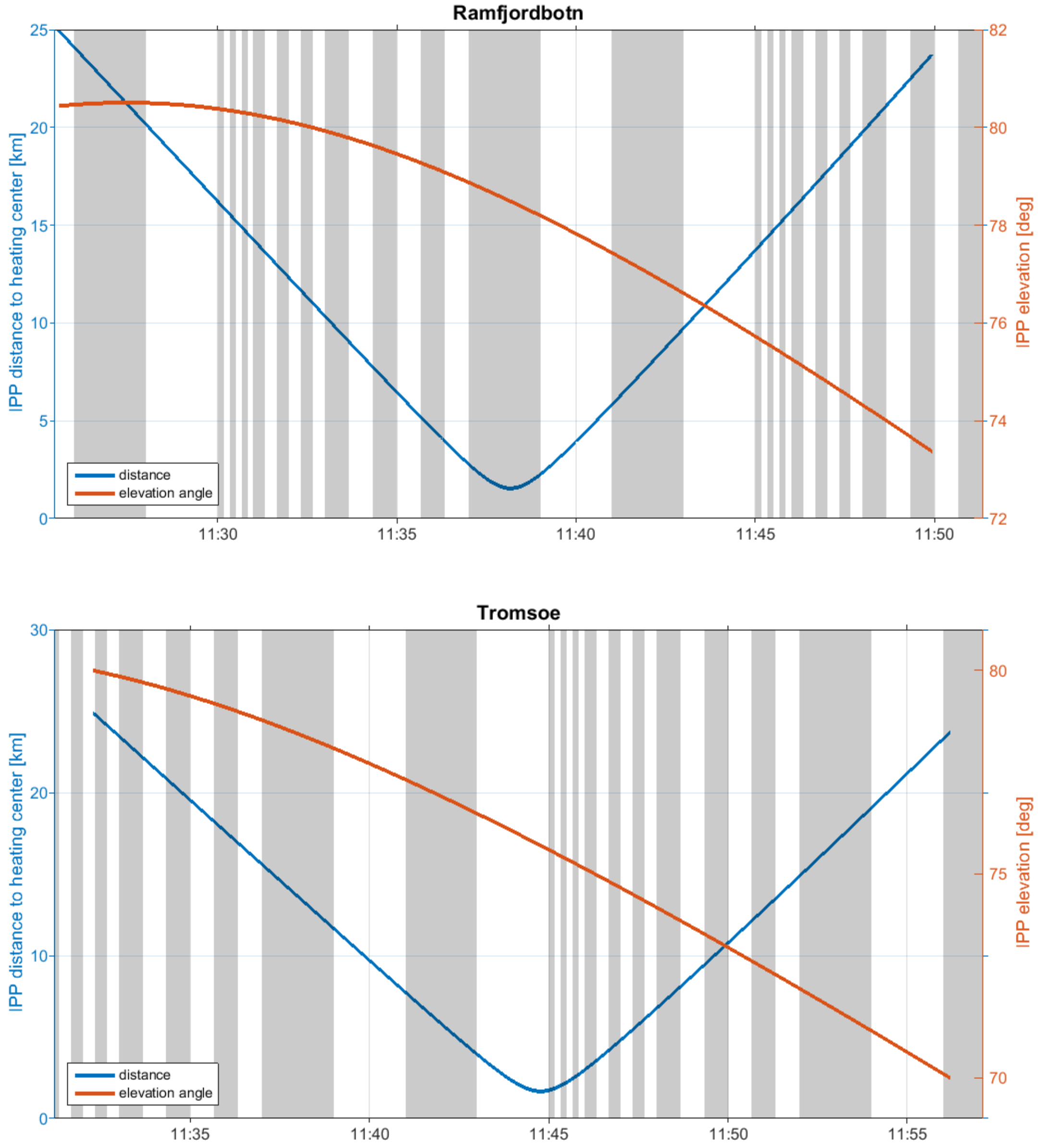

Figure 2. Distance between Ionospheric Piercing Point and center of estimated heated volume at 200 km altitude for Ramfjordbotn receiver and GLONASS R23 (above) and Tromsø receiver and GLONASS R23 (below). The right vertical axis shows corresponding elevation angles. The gray and white area indicates heating on/off intervals described in Table 2.

The dataset presented here covers nearly two full heating cycle when two IPPs are within the estimated heating center estimated from HF wave elevation angle. EISCAT UFH radar has observed strong back scatter from altitude around 200 km and enhanced electron temperature over this period (not shown).

The comparison of relative slant TEC from the two GNSS receivers is shown for the last three heating cycles in Figure 3. The base line of the relative TEC is the mean value during heating off interval before 11:30. In addition to a trend of general increases in TEC as expected for morning ionosphere, several oscillational features were observed from both links, which may be associated to the modulation by the heating. This is most clearly seen in 120 second heating on/off cycle starting from 11:37. Note that a sharp decrease in Ramfjordbotn TEC was observed right after the heating off at 11:39 and it was followed by Tromsø TEC approximately 1 minute later. Thereafter the two TEC curves seem to be in phase over next 120 seconds heating on/off. Both TEC curves reached maximum around 11:49 then decreased almost monotonically over next several heating intervals and the last 120 second heating seems to have had less effect in TEC. Although small oscillations can be seen during the heating on/off for less than 40 seconds, TEC response was not as sharp as in the longer modulation time. This could be associated with heating frequency and power which was not sufficient to cause direct effect in TEC.

The difference in two slant TEC values may be mirroring the trans-ionospheric paths along witch the satellite signals traveled. Compared to the heating cycle in the middle of the figure 3, the TEC difference was relatively small before 11:34, where the distance between two IPPs and the heating center were larger than 10 km. This distance implies the border of the disturbed region in which GNSS signal phase is group delayed, which is nearly half the size of the area estimated by the heating beam width. A sharp drop of both TEC is observed at 11:49 followed by monotonic decrease. We can not provide clear explanations for this behavior at this moment. This could be related to natural background origin rather than effect of the modulation. The position of IPP s in Ramfjordbotn and Tromsø links were 20 km and 10 km away from the heating center when the drop occurred, which implies that both links passed over the disturbed region.

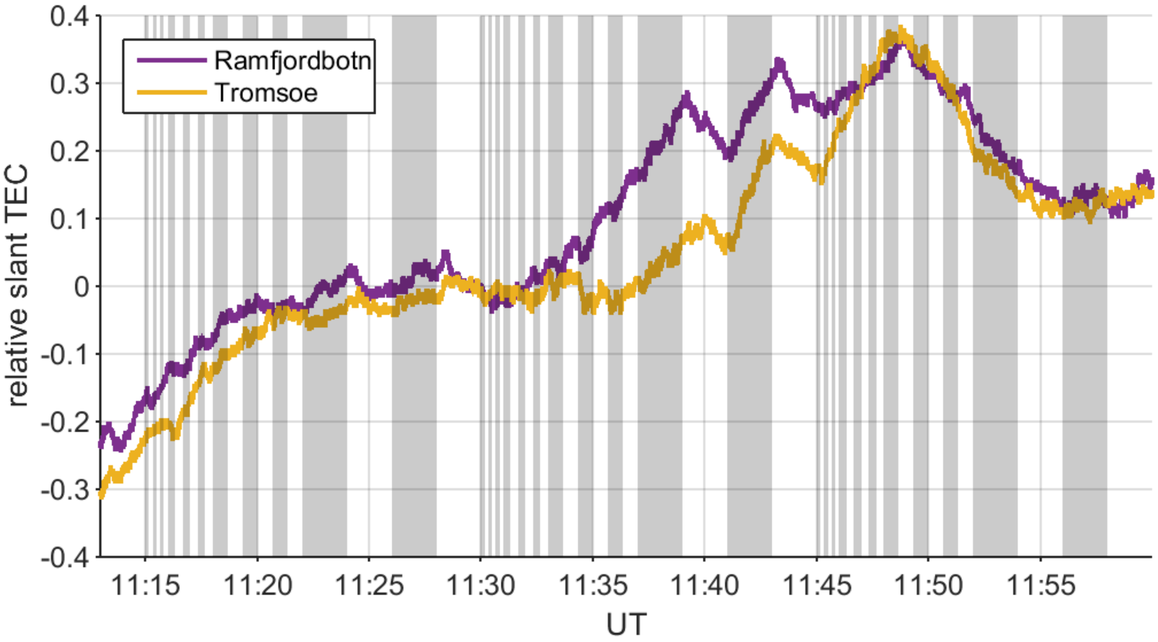

Figure 3. Relative slant TEC observation of GLONASS R23 signals measured at Ramfjordbotn (purple) and Tromsø (yellow). The gray and white areas indicate heating on/off intervals described in Table 2

5. SUMMARY AND CONCLUSION

In this paper, we have presented GNSS signal observation from two satellite-receiver links during the HF heating experiment in high latitude. Slant TEC measurements were investigated when two Ionospheric Piercing Points were crossing the disturbed ionospheric volume.

Our current analysis indicates that slant TEC responds most sensibly to the termination of the HF waves after longer perturbation time. It is implied that the size of disturbed ionosphere which perturbs GNSS signals may be smaller than the region estimated by the heating beam width. Future study will include comparison of TEC temporal variation from GNSS and EISCAT radar (Forte et al. 2013). We also estimate to upgrade receiver facilities with higher sampling rate to acquire higher resolution in GNSS data.

REFERENCES

Forte, B., N. D. Smith, C. N. Mitchell, F. Da Dalt, T. Panicciari, A. T. Chartier, D. Stevanovic, et al. 2013. Comparison of temporal fluctuations in the total electron content estimates from EISCAT and GPS along the same line of sight. Annales Geophysicae 31:745–753.

Milikh, G., A. Gurevich, K. Zybin, and J. Secan. 2008. Perturbations of GPS signals by the ionospheric irregularities generated due to HF-heating at triple of electron gyrofrequency. Geophysical Research Letters 35:n/a–n/a.

Najmi, A., G. Milikh, J. Secan, K. Chiang, M. Psiaki, P. Bernhardt, S. Briczinski, et al. 2014. Generation and detection of super small striations by F region HF heating. Journal of Geophysical Research: Space Physics 119:6000–6011.

Rietveld, M. ., H. Kohl, H. Kopka, and P. Stubbe. 1993. Introduction to ionospheric heating at Tromsø—I. Experimental overview. Journal of Atmospheric and Terrestrial Physics 55:577–599.