Real Time Scintillation Observation at the Norwegian Mapping Authority

Sebastian Schäfer[1], Knut S. Jacobsen[1]

[1]Geodetic Division, Norwegian Mapping Authority, Norway

Kartverket

What is Scintillation?

The ionosphere is the upper region of the Earth's atmosphere, where the neutral gas is ionized by the extreme ultraviolet sunlight. Due to the complex interaction of the solar magnetic field and the geomagnetic field, the high-latitude ionosphere is particulary disturbed under increased solar activty. Amongst other effects, small scaled irregularities occur in the ionospheric plasma leading to a scattering of GPS signals while propagating through the thin ionosphere layer (see Fig.1). This effect is known as scintillation.

Ionospheric irregularities usually occur locally and disturb both phase and amplitude of GPS signals. Intense scintillation affects the processing of the GPS signal in the receiver, which results e.g. in a decreased accuracy in the determination of the position. The worst case scenario is that the signal is shielded by scintillation and cannot reach the receiver at the ground (see Fig.2).

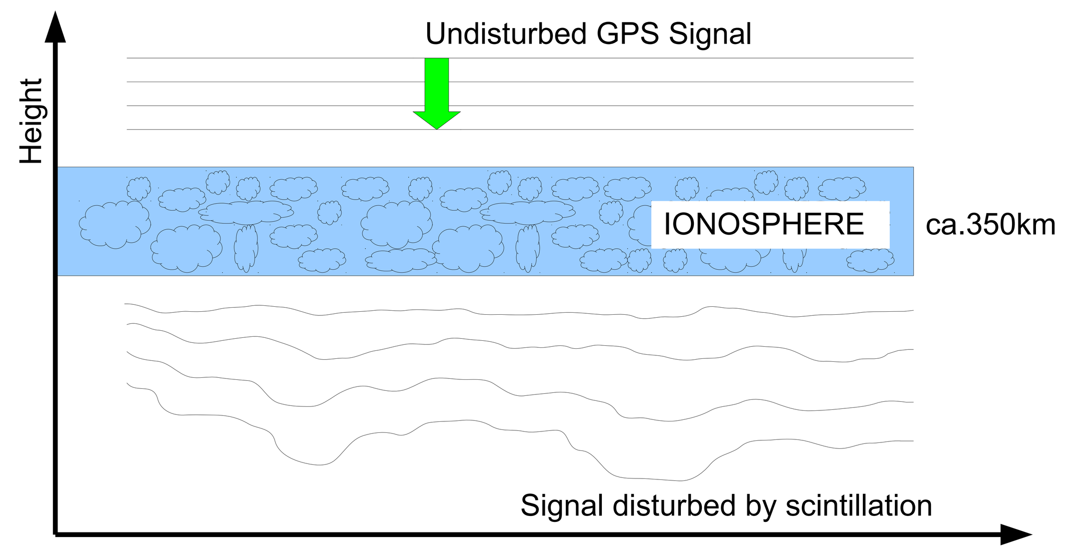

Figure 1: Scintillation effect on satellite signals. Amplitude and phase of the signal are disturbed by irregularities in the ionosphere.

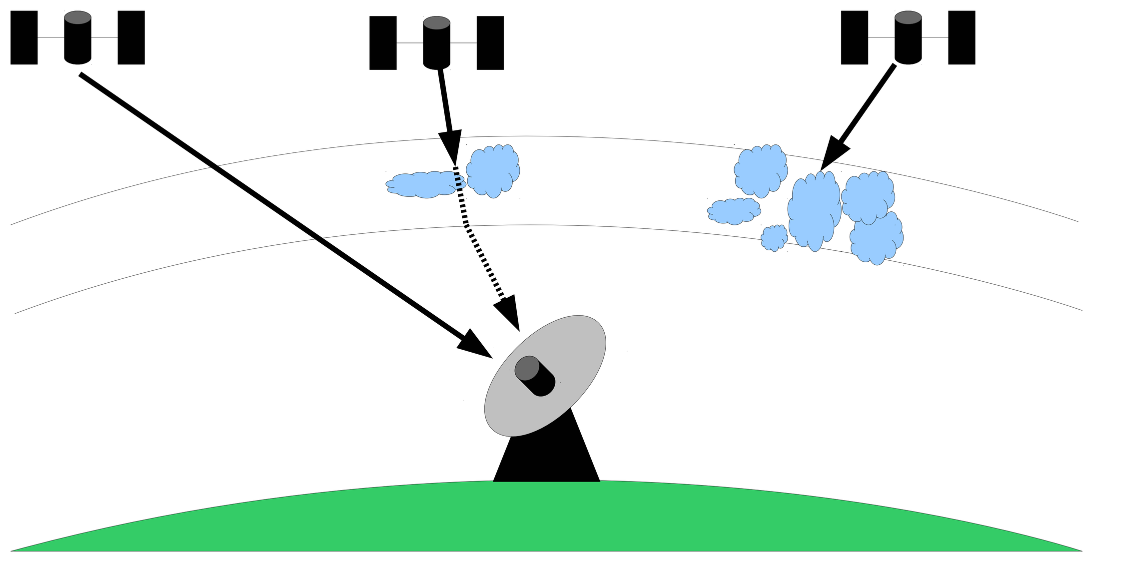

Figure 2: Left: Undisturbed signal path. Middle: Scintillation disturbes the signal path. Right: Intense scintillation shields the signal.

Ionospheric Disturbances

On March 9, 2012, the geomagnetic field was disturbed by a strong coronal mass ejection propagating from the sun towards the Earth. The intensity of the geomagnetic variation at high latitude is represented by the AE index that is induced from $AE = AU - AL$ (see Fig.3). The shape of the AE index indicates geomagnetic activity between 03:00 UT and 18:00 UT.

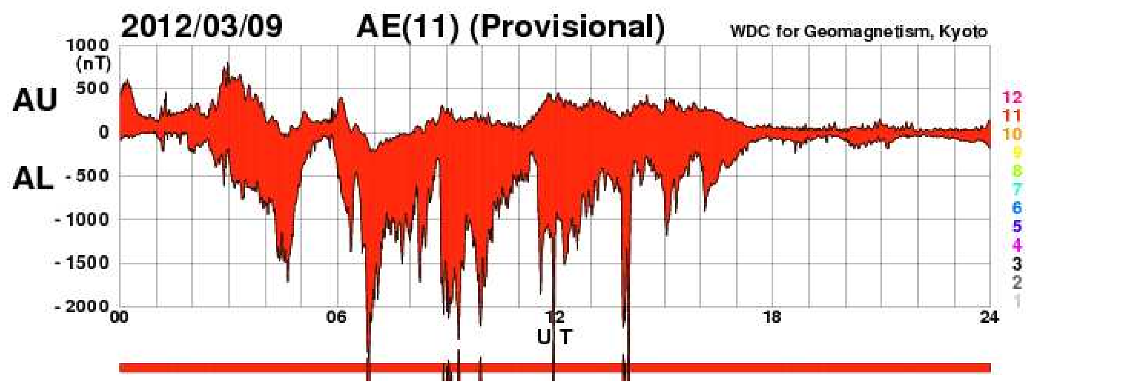

Figure 3: Auroral Electrojet index AE on March 09, 2012, representing the geomagnetic activity.

A useful indicator for the presence of small-scaled structures in the ionospheric plasma causing scintillation is the so-called Range-of-TEC-Index (ROTI). It represents the small-scale variations of the total number of electrons (TEC) remaining in the signal way between satellite and receiver. The distribution of ROTI values over northern Europe are determined in real time at the NMA on a regular basis using data from the network of around 140 geodetic ground receivers (see Fig.6).

The result of the NMA Real-Time Ionospheric Monitor (RTIM) before the onset of the geomagnetic storm on March 9, 2012 is shown in Figure 4. The distribution of ROTI values is uniform and on a low level, which is typical for quiet ionospheric conditions.

Figure 5 displays the ROTI distribution shortly after the onset of the geomagnetic activity at 03:15 UT, which consists of a pattern typical for strong ionospheric disturbances. The ROTI distribution indicates the presence of small-scaled ionospheric disturbances covering latitudes down to 65°N.

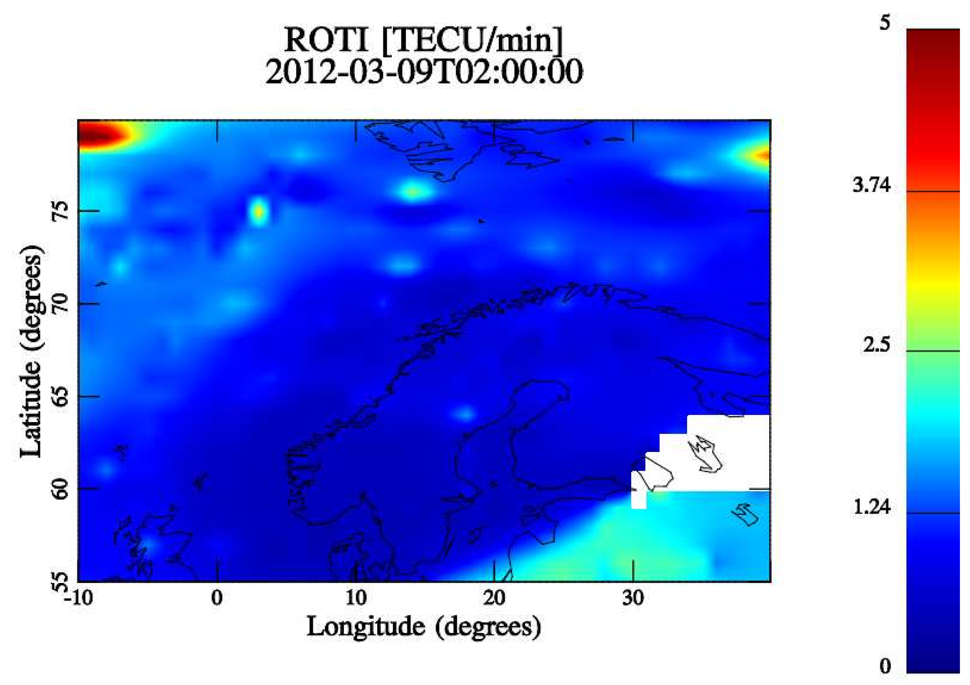

Figure 4: Distribution of ROTI values before the onset of the ionospheric activity.

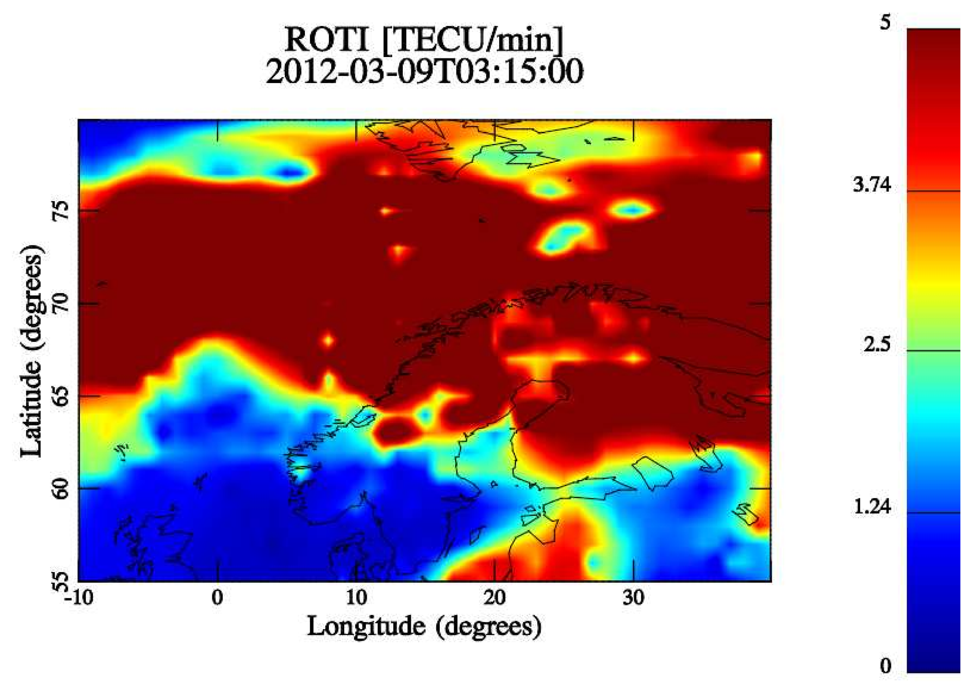

Figure 5: Distribution of ROTI values during intense ionospheric activity.

Real Time Scintillation Monitoring

Two methods are in operation at the NMA to monitor scintillation in real-time. GPS data from the 140 ground receivers with a resolution of 1s are used to determine ROTI values with an update rate of 5 minutes. The direct observation of scintillation is made by two Septentrio PolaRxS receivers located on Vega and in Tromsø, which are used to determine indices that cover the presence of both phase and amplitude scintillation with a 60s update rate based on the 100Hz measurements.

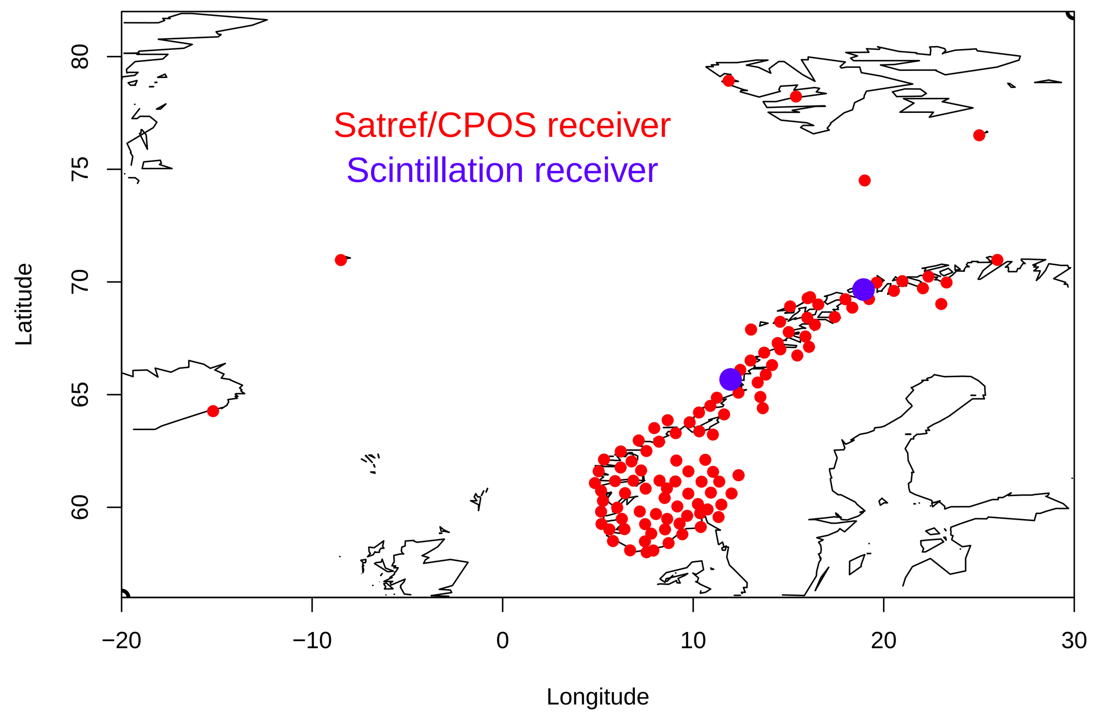

Figure 6: Location of the NMA scintillation monitor stations. The Septentrio PolaRxS receivers in Tromsø and Vega are operational since February 2012

The observation of phase scintillation is accomplished by monitoring the standard deviation σ_ϕ of the detrended carrier phase from received from satellite signals. The strength of amplitude scintillations is typically quantified by a metric called the S4 index. The total S4 index is the ratio of the standard deviation of the signal power to the mean signal power computed over a 60s interval.

Time series of the real-time scintillation observations are shown in the Figures 7 and 8 for both Septentrio PolaRxS receivers.

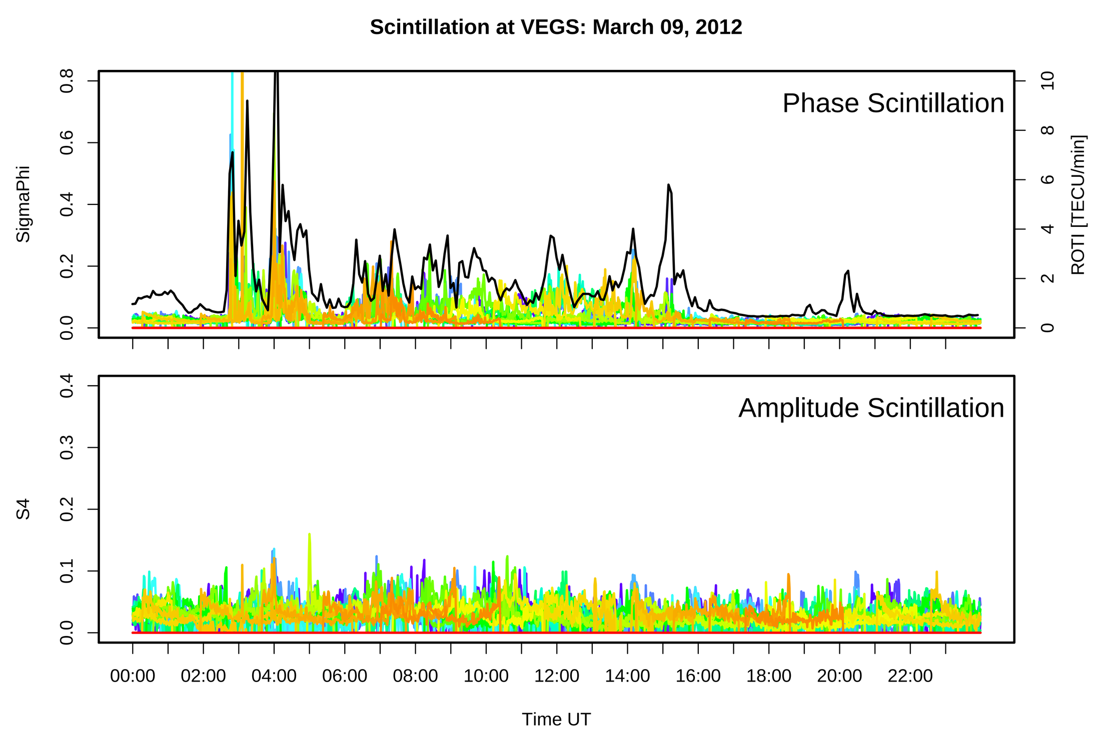

Figure 7: Real time observations of phase (top) and amplitude scintillation (bottom) for the Vega site. The black line in the top panel is the ROTI time series.

The coloured lines indicate individual satellite-receiver links, while the black line shows the time series of the ROTI index for the given location.

In general, the on- and offset times of scintillation agrees very well with the identified time period of geomagnetic activity. In particular, intense phase scintillation has been observed and the correlation with the ROTI index can be confirmed. The general level of phase scintillation is higher in Tromsø. The presence of amplitude scintillation is less obvious, but it can be observed with the Tromsø receiver.

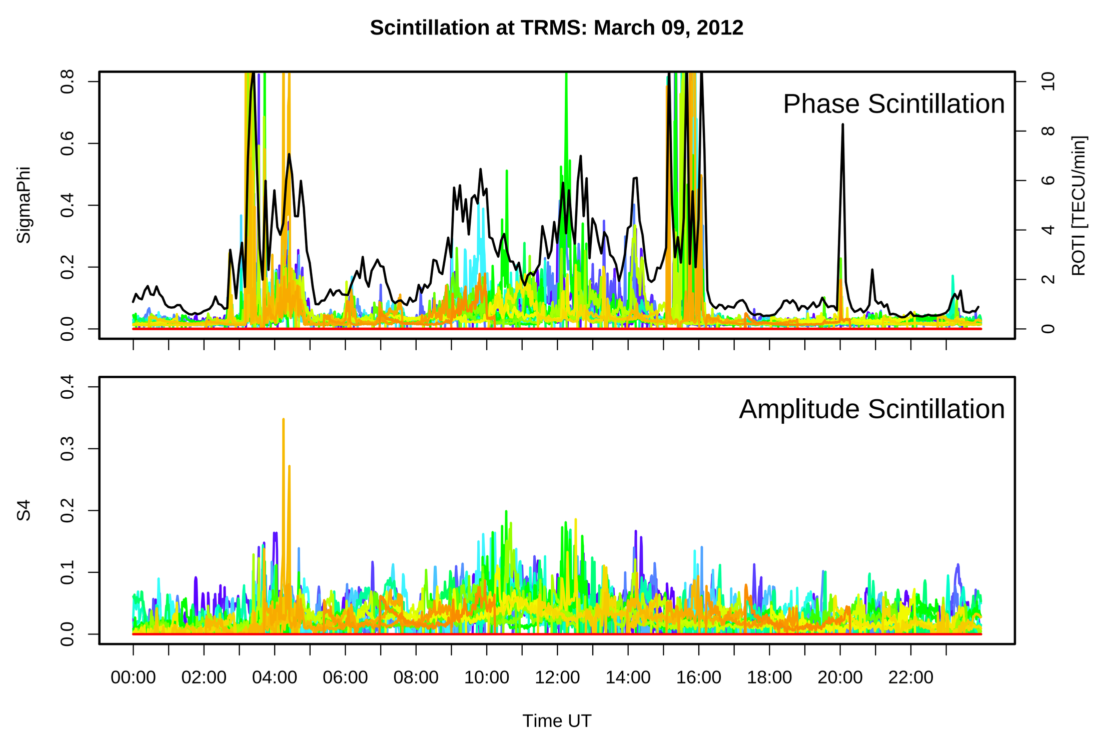

Figure 8: Real time observations of phase (top) and amplitude scintillation (bottom) for the Tromsø site. The black line in the top panel is the ROTI time series.

Impact on the NMA Receiver Network

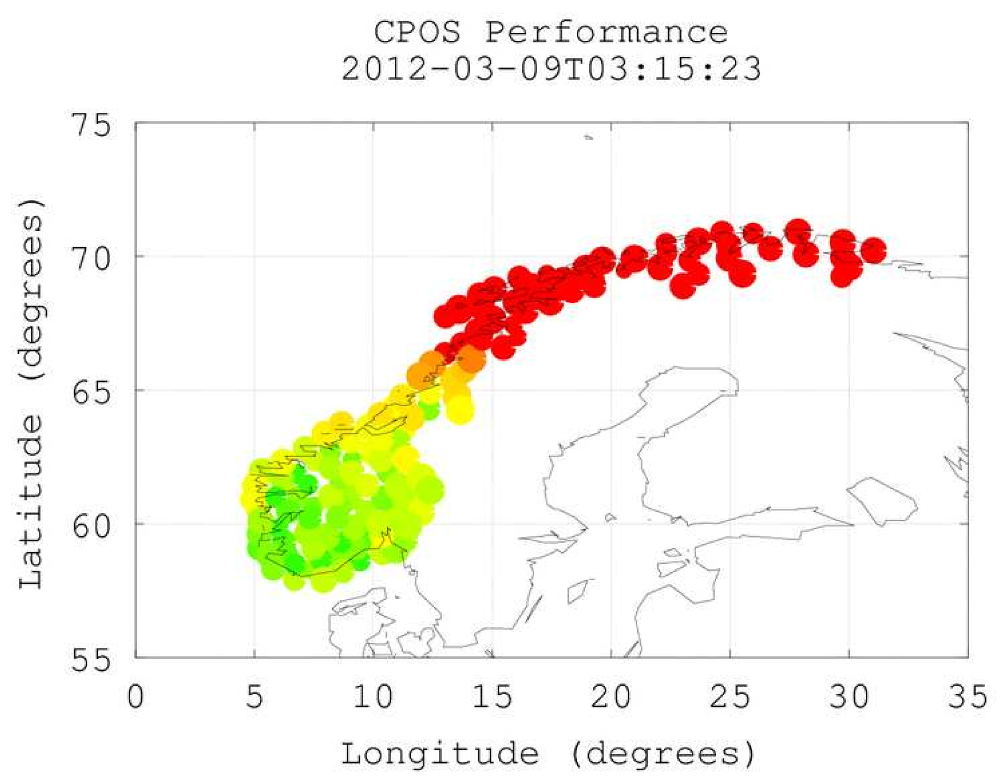

Figure 9: The plot shows the percentage of tracked satellites that are included in the positioning solution, where a pure green indicates 100%, pure yellow 70% and pure red 0% with a linear scale between each colour.

The presence of phase scintillation over large regions can degrade the performance of a positioning service, such as the CPOS network RTK service of the NMA. The visualisation of the CPOS performance (see Fig.9) indicates the unavailability of the position service at latitudes to the north of 65°N. The region correlates with the identified occurrence of phase scintillation.

Impact on Precise Positioning

The NMA is testing the operation of monitor stations to simulate the position results of a CPOS user by running the positioning algorithm in short time intervals. The height solution during increased geomagnetic conditions is shown in Fig.10, together with the time series of σ_ϕ and ROTI. When phase scintillation is more intense, the precision of the position determination decreases.

Summary

Ionospheric scintillation is the main threat for satellite based navigation and positioning systems. The Norwegian Mapping Authority (NMA) establishes a real time scintillation monitor system based on data from multi-frequency, multi-constellation receivers located at high latitudes. The system provides time series of scintillation indices, such as S4 and σ_ϕ, with an update rate of one minute. Scintillation events has been monitored during increased geomagnetic activity. The observed spatial and temporal occurrence of scintillation has been compared with the performance of CPOS network RTK service operated by the NMA. It has been shown that the occurrence of scintillation reduces the performance of such positioning services.

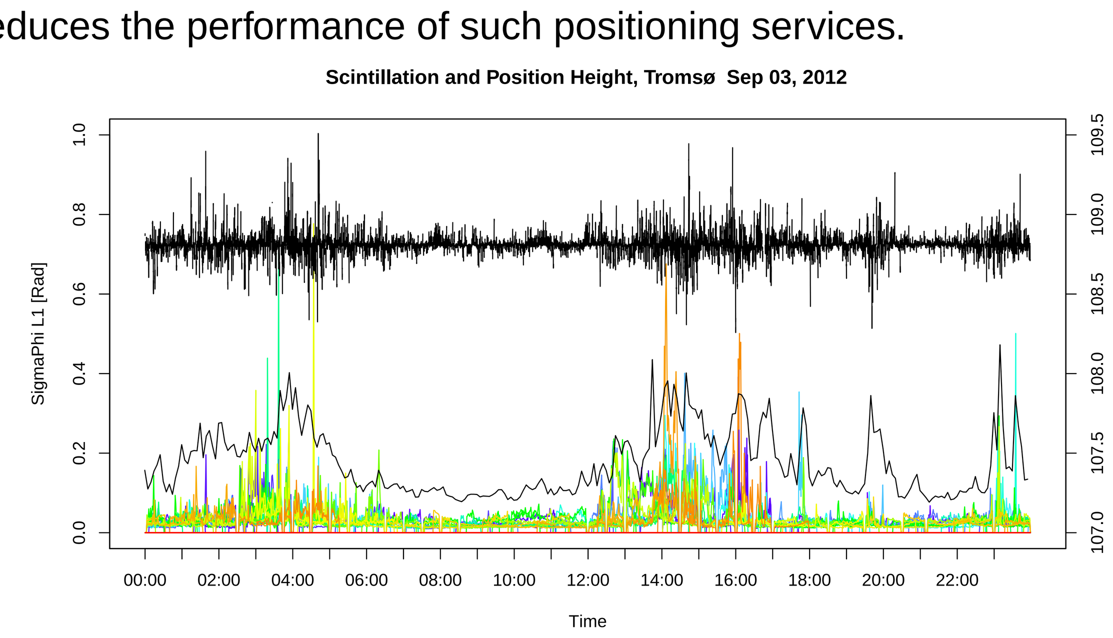

Figure 10: Phase scintillation (coloured lines for each satellite-receiver link), ROTI values (black line) and position height (black line on the top).

Acknowledgements

We thank AE stations (Abisko [SGU, Sweden], Dixon Island, Cape Chelyuskin, Tixie Bay, Pebek [AARI, Russia], Barrow, College [USGS, USA], Yellowknife, Fort Churchill, Sanikiluaq (Poste-de-la-Baleine) [GSC, Canada], Narsarsuaq [DTU Space, Denmark], and Leirvogur [U. Iceland, Iceland]) as well as the RapidMAG team (NiCT, JHU/APL, UoA, AARI, and IDG) for their cooperations and efforts to operate these stations and to supply data with us for the provisional AE index.

Contact

Sebastian Schäfer; *email: sebastian.schaefer@kartverket.no*

Knut Stanley Jacobsen; *email: knut.stanley.jacobsen@kartverket.no*