MARITIME RADIO SYSTEMS PERFORMANCES IN THE HIGH NORTH (MARENOR)

Rico Behlke
Polar Science and Guiding, Longyearbyen, Norway[1]
Beate Kvamstad
Marintek, Trondheim, Norway[2]
Erlend Bjørdal
Electromagnetic Geoservices, Trondheim, Norway[3]
Fred Sigernes and Dag Lorentzen
University Centre in Svalbard, Longyearbyen, Norway[4]

Keywords

Global Navigation Satellite Systems (GNSS), ionospheric disturbances, space weather forecasting, ionospheric scintillation

Abstract

As the activity level is increasing in the Arctic, there is also a growing focus on safety and efficiency of maritime and marine operations. Support systems based on Global Navigation Satellite Systems (GNSS) and digital communication are being developed and taken into use. However, the environmental and space conditions in and over the Arctic influence navigation and communication systems in a way different from other places on Earth. Ionospheric and atmospheric effects, harsh weather conditions leading to rapid vessel movements, icing on antennas and other outdoor equipment, low satellite elevation angles, poor groundbased communication infrastructure and system architectures are elements that have an effect on the total performance of the navigation and communication systems.

The main objective of MARENOR is to quantify the system performance of the most common navigation and communication systems being used by maritime users in the High North. This will be achieved through measurement campaigns and analyses of:

1. System architecture,
2. propagation (L-, C-, Ku-, Ka-band),
3. signal degradation factors (ionosphere, atmosphere, ship movements, location, icing on antennas).

---

1 Polar Science and Guiding, Vei 238-5, 9170 Longyearbyen, Norway (rico.behlke@gmx.net)

2 Marintek, Otto Nielsens veg 10, 7052 Trondheim, Norway

3 Electromagnetic Geoservices, Stiklestadveien 1, 7041 Trondheim, Norway

4 University Centre in Svalbard, P.O. Box 156, 9171 Longyearbyen, Norway

The expected result is a model for the assessment of the quality and performance of navigation and communication systems at high latitudes.

In this paper, we present an overview of the MARENOR project, summarise the processes that exhibit degrading effects on radio signals traversing the Earth's ionosphere and provide an outlook on possible correction and warning/forecasting mechanisms.

Introduction

The Norwegian research project 'MarCom – Broadband at Sea' (2007-2010) analysed the future needs for digital services and supporting communication infrastructure at sea. The constantly increasing efficiency and safety requirements from authorities and ship owners lead to an increased use of information-and-communication-technology-(ICT)-based decision-support and reporting systems on-board ships, and the data rate demands range from a few kilo bytes per second (kbps) to several megabytes per second (mbps) [1]. One major gap identified by the project was that maritime actors operating at high latitudes would have difficulties utilizing such ICT because they have limited or no access to digital communication systems. The project 'MarSafe North – Maritime Safety Management in the High North' (2008-2011), investigated the needs for improved or new technologies necessary to maintain the safety level in the Barents Sea at least as high as the Norwegian Sea. Emerging activities within both the oil & gas and maritime industry in the High North will increase the need for updated and validated data on traffic, weather, sea state, ice and environmental conditions and other navigational aiding data such as for example GPS integrity information [2]. In emergency operations, the real time requirements are high and data integration and sharing amongst the involved parts need to be continuous in order to achieve shared situational awareness. The communication infrastructure in the area cannot meet these demands today. The results from the MarCOM and MarSafe projects were emphasised by the ArctiCOM project initiated by the European Space Agency (ESA) in 2011. The ArctiCOM objective was to analyse and quantify the satellite communication needs in the Arctic in the time scope 2015 and 2020 [3]. Secondary, the project investigated the expected availability of satellite communication systems within the same time scope. The results showed that today's systems are not sufficient to meet the emerging requirements, but if the planned satellite systems such as the Canadian Polar Weather and Communication (PWC) and the Russian Polarstar systems are implemented, the requirements will be covered. However, at best the earliest implementation of such systems will be in 2020. In the meantime it is thus of great importance to obtain profound knowledge on the true performance of existing systems. This provides the possibility to forecast when and where certain operations can be performed within a certain safety framework.

Navigation and communication systems in Arctic regions suffer from a variety of factors that degrade system performance. The most important factors for navigation systems are the ionosphere, icing on antennas and sparse availability of correction services. Communication systems are mostly influenced by a combination of low elevation angles (leading to a longer propagation path through the Earth's atmosphere and thus enhanced impact by rain, snow etc.), limited ground infrastructure and icing on antennas which result in a decrease in signal strength. This can cause loss of signal which subsequently yields information loss and delays. The on-going project MARENOR (2012-2015) will contribute to an improved situation with regard to these challenges by measuring and analysing degrading effects on navigation and communication systems in L-, C-, Ku- and Ka-band in the Arctic. The main objective is to develop a methodology and a tool for real-time assessment and prediction of the quality of services. The partners in the project consist of problem owners and product suppliers such as EMGS (project owner), the shipping company Remøy, Kongberg Seatex and Telenor. The R&D institutes Polar Science Guiding, UniS, SINTEF ICT and MARINTEK will contribute with their competence on atmospheric behaviours and distributions, system designs, link budgets, antenna technology and requirements from maritime applications that need robust navigation and communication systems. The Polish Wrocław University of Technology contributes with their competence on antenna design.

EMGS is an R&D and service provider company that develops and operates equipment for geological surveys by using electromagnetic technology. They have performed over 600 surveys, whereof several of them in the Arctic, and they expect to further develop their services in the area as the oil & gas activity increases. One important prerequisite for the surveys are accurate positions and robust communications. As this is a challenge at high latitudes, it will be of great importance for EMGS to have real-time and predicted information on quality of services. Increased control means increased operational windows, in addition to the possibility of validating survey data.

Theory and Method

The Earth's ionosphere which is a dispersive medium, exhibits a degrading influence on radio signals traversing it. It stretches from roughly 50 km altitude to an upper limit of approximately 2000 km. Ionisation is achieved by solar radiation and produces free electrons and positive ions. In addition, the ionosphere contains a large number of neutral particles. It is the free electrons that are responsible for the degradation of radio signals traversing the ionosphere.

The Total Electron Content (TEC) is given by $N_T = \int_s n_e(s)\, ds$ where s denotes the propagation path (in m) and n_e the electron density (in el/m^3). In general, the TEC is characterised by a great range of temporal and spatial variability ranging from diurnal variations to periods of several years (11-year solar cycle and long-term changes of solar irradiation). In addition, for the ionosphere at high latitudes the temporal and spatial variations are even further emphasised. This is the result of the presence of open magnetic field lines which connect to the highly variable solar wind. Commonly used tools to correct for ionospheric degradations include, e.g., two-frequency GNSS receivers and augmentation systems. Two-frequency GNSS receivers utilise the dispersive character of the ionosphere and can compute the TEC of the ionosphere. However, during events of severe scintillation (see below for a short description of ionospheric scintillation) these receivers might not be able to track GNSS signals any longer [4]. Augmentation systems make use of ionospheric models and data input in order to forecast ionospheric conditions which are broadcasted to the GNSS receiver. Unfortunately, ionospheric models at high latitudes suffer from little data input and large grid sizes. In addition, Satellite Based Augmentation Systems (SBAS) that use geostationary satellites are influenced by the low elevation angle of these satellites. Ground Based Augmentation Systems (GBAS) are impacted by the lack of sufficient radio infrastructure at high latitudes. However, it should be noted that this issue has received increased attention lately, e.g., in terms of the installation of EGNOS RIMS on Jan Mayen and Svalbard, the Arctic Testbed project and an improved version of the International Reference Ionosphere in 2011 with special focus on high latitudes.

The following paragraph gives a short overview of the most important degrading, ionospheric mechanisms [5, 6]. Firstly, scintillations are considered the most severe factor that impacts radio signals traversing the ionosphere. They resemble rapid fluctuations of amplitude, phase, polarisation and other wave parameters when radio waves traverse regions of fluctuating electron density. Ionospheric scintillation is most severe in equatorial, auroral and polar regions. Amplitude scintillations are commonly denoted by the scintillation index S4 which is associated with the peak-to-peak-fluctuations of the signal amplitude. Amplitude scintillations lead to a decrease of the signal-to-noise-ratio. Phase scintillations are given by the phase scintillation index σ. This type of scintillation can cause range jitter and thus loss of precision in range. Digital systems may not suffer from the impact of phase scintillations if the bit rate is much greater than the scintillation rate. Secondly, multipath effects arise when the receiving antenna collects the radio wave via two or more propagation paths. Ionospheric irregularities may cause changes in the refractive index which in its turn can lead to multipath. Thirdly, phase advance and group delay are caused by the presence of charged particles along the signal path. The group delay is proportional to N_T / f^2. Additional mechanisms include Faraday rotation (a rotation of polarisation sense of the wave), polar cap (caused by energetic protons associated with solar flares lasting for days) and auroral absorption events (connected to auroral events lasting hours), angle of arrival variations, dispersion etc.

In addition, navigation and communication installations at high latitudes suffer from icing of the antennas and sudden ship movements as well as magnetic deviations due to the proximity to the magnetic pole.

Variations in the geomagnetic field create magnetotelluric (MT) currents. These variations are enhanced during periods of increased solar activity. Technologies such as CSEM (Controlled Source Electromagnetic) involve the use of active sources, whereas MMT (Marine Magnetotellurics) is based on naturally occurring electromagnetic signals. Strong MMT signals can have a positive and negative impact on CSEM measurements. On one side, they introduce background noise that can shield the CSEM signal. On the other side, they might be used as part of the actual measurements.

Results

Figure 1 displays the impact of a severe geomagnetic disturbance on a low-end GPS receiver, a Garmin 60 installed at the Kjell Henriksen Observatory (KHO) close to Longyearbyen on Svalbard. The first two panels display the deviation of the latitude and longitude from the mean, respectively, for a period of 24 hours. The deviation is of the order of a few meters and is largely dependent on the satellite constellation throughout the day, see panel c). This pattern is relatively constant and is repeated approximately every 24 hours and thus determine the shape of the curves for the relative deviation. Panel d) and e) show measurements from the Longyearbyen magnetometer (operated by the Tromsø Geophysical Observatory), the D component and the deviation of the H component relative to the daily mean. A significant geomagnetic disturbance is clearly visible around UT 17. Comparing with panels a)-c) yields that this geomagnetic disturbance only results in minor signatures in the latitudal and longitudal measurements and the number of used satellites. Clearly, the constellation of the GPS spacecraft has a larger impact on accuracy and availability than geomagnetic disturbances for low-end GPS receivers utilising the L1 frequency [7].

Figure 2 shows typical measurements by a scientific receiver, in this case receiver 5 at the Polish Research Station in Hornsund, Svalbard. Panel a) displays the TEC. From around UT 03:30 to 04:30 gradients in the TEC of up to 5 TECU (1 TECU = 10^{16} electrons/m²) are clearly visible. At the end of the pass, the receiver looses track, probably due to the horizon mask at the station. Panel b) shows the phase of the GPS signal. The jump in phase at the end of the support relates to the loss of lock of the signal. Panel c) displays the power of the received signal. For higher elevations, the received signal strength is significantly stronger. The signal consists of low-frequency wave-like structures and high-frequency spikes, as can be seen in panel d). Here, the signal was highpass-filtered by a Butterworth filter at a stop-frequency of F_s = 20 Hz. Note the spikes around UT 01:30-02:05 and around UT 03:30. These can lead to sudden drops in the signal-to-noise-ration (SNR) and in the worst case to loss-of-lock of the signal. Panel e) shows the declination of the geomagnetic field as measured by the Longyearbyen magnetometer (operated by the Tromsø Geophysical Observatory). The geomagnetic field is relatively quiet during this period, only exhibiting small deviations from ca. UT 03:00 which coincide with some of the gradients in TEC, as shown in panel a).

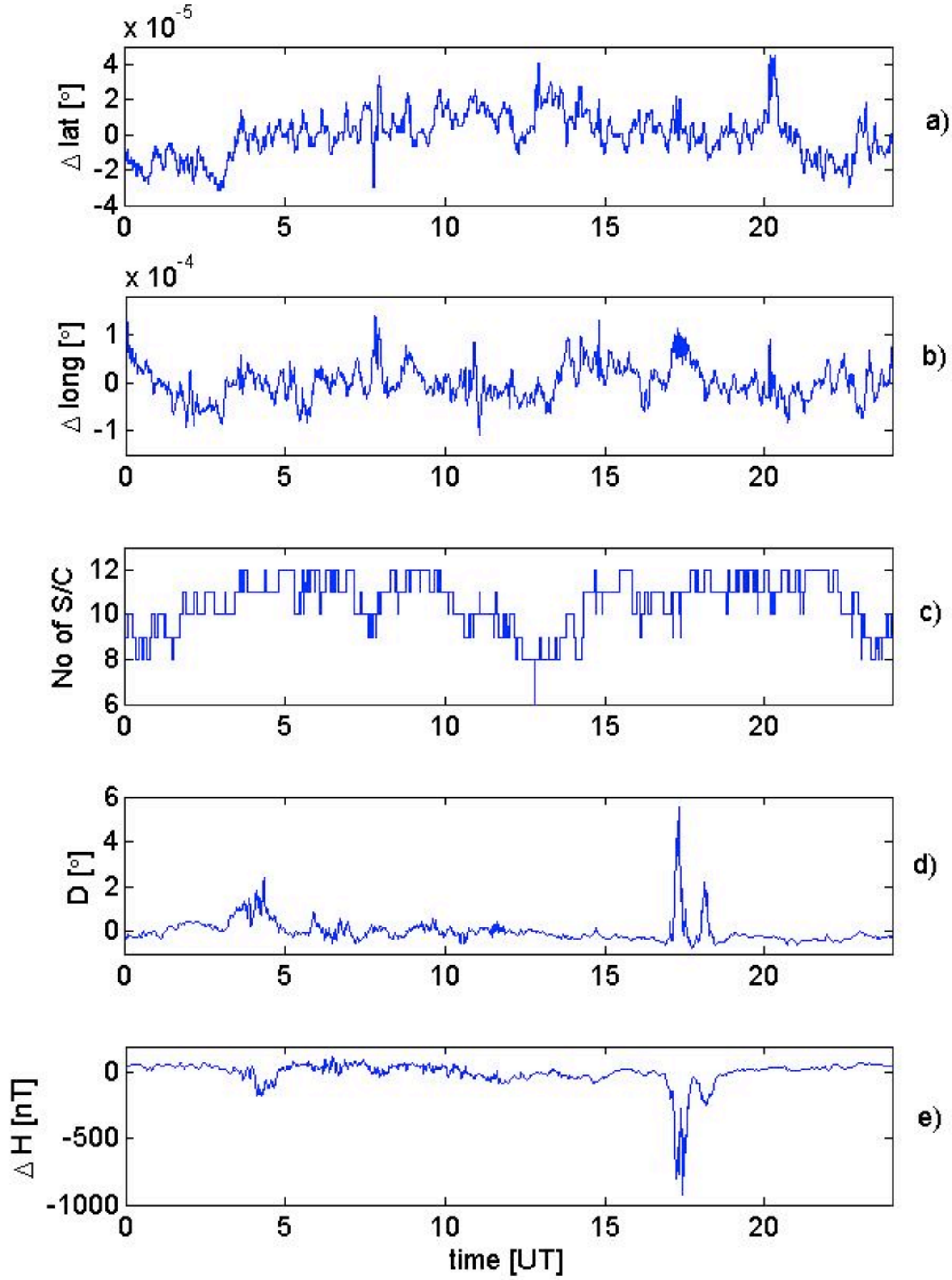

Figure 1. February 11, 2008, UT 00-24. Panel a)-c) display data from a Garmin 60 installed at the KHO (a): deviation of the estimated latitude from the mean value, b): deviation of the estimated longitude from the mean value, c): number of spacecraft used for the position measurement. Panel d)-e) show data from the groundbased magnetometer in Longyearbyen (operated by the Tromsø Geophysical Observatory).

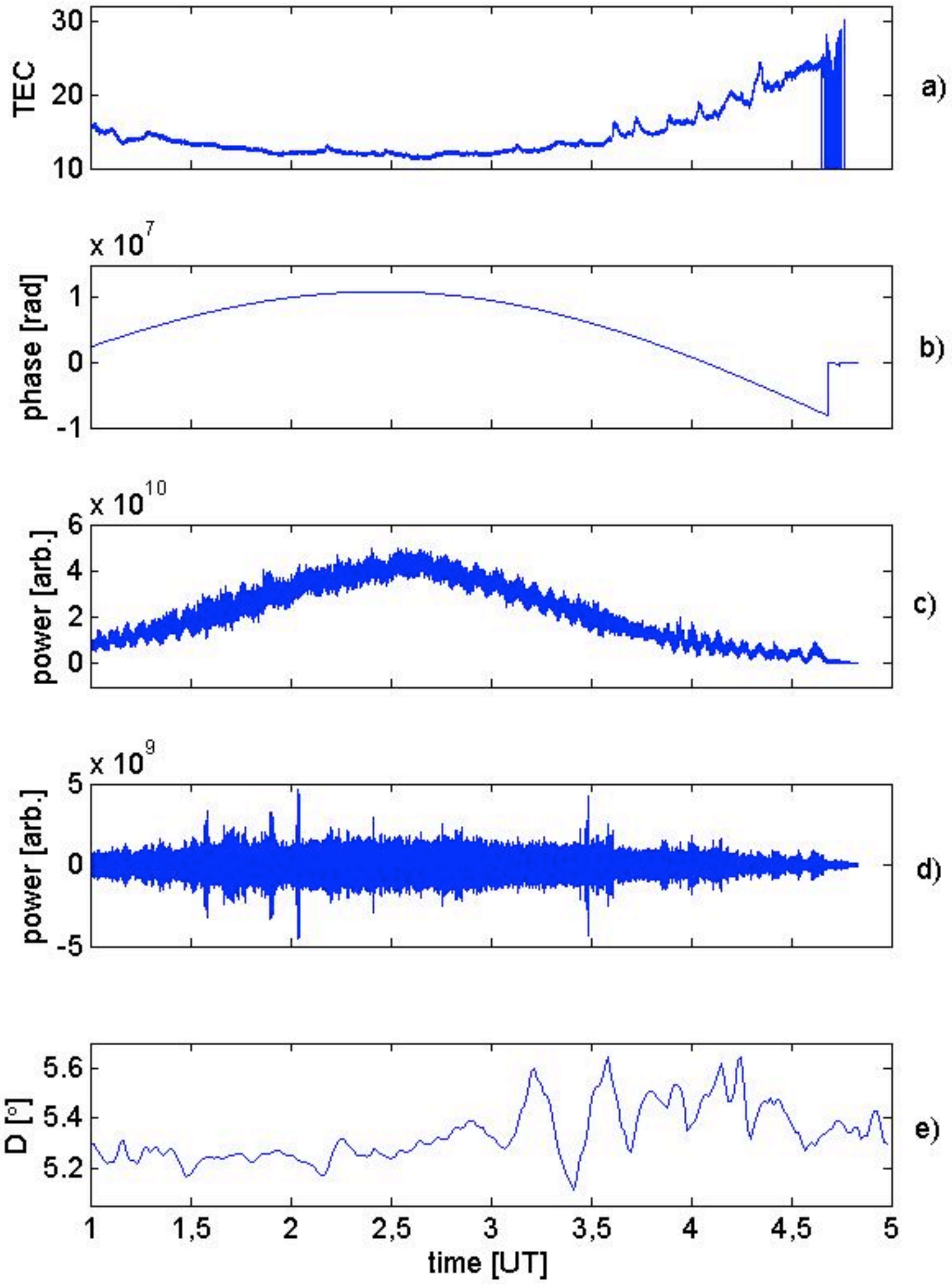

Figure 2. February 21, 2008, UT 01-05. Panel a)-d): Data from receiver 5 at the Polish research station at Hornsund, Svalbard (77 degrees North), GPS satellite PRN 1. Panel a) displays the TEC, panel b) the phase, panel c) the received power and panel d) the received power after utilising a highpass Butterworth filter at F_S=20 Hz. Panel e) shows the D component of the geomagnetic field as measured by the Longyearbyen magnetometer (operated by the Tromsø Geophysical Observatory).

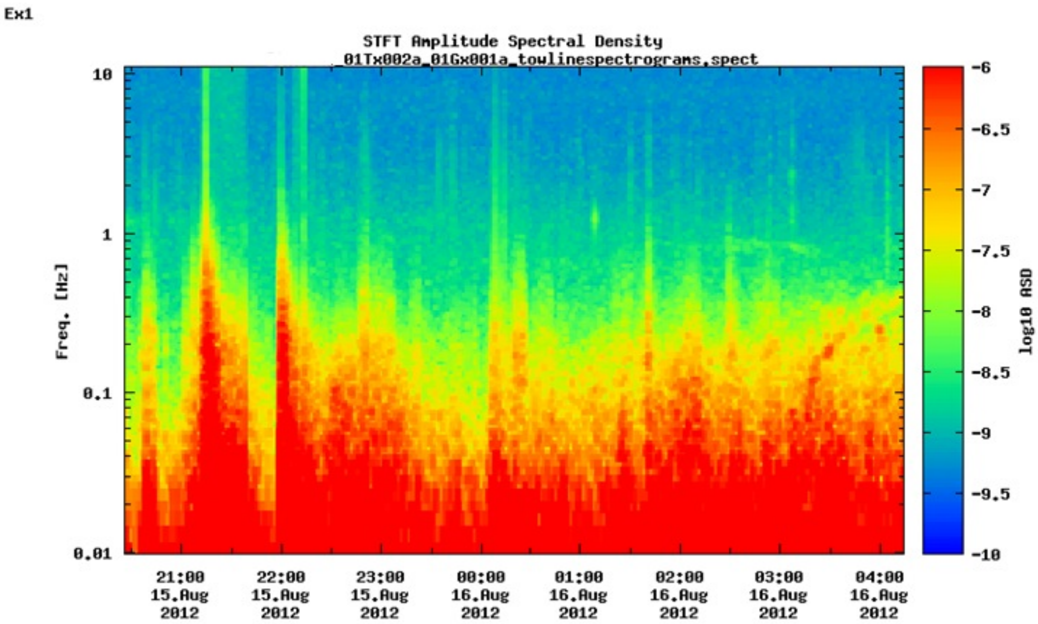

Figure 3. August 15-16, 2012, ca. UT 20:25 - ca. UT 04:10: Towline spectogram containing broadband, erroneous spikes.

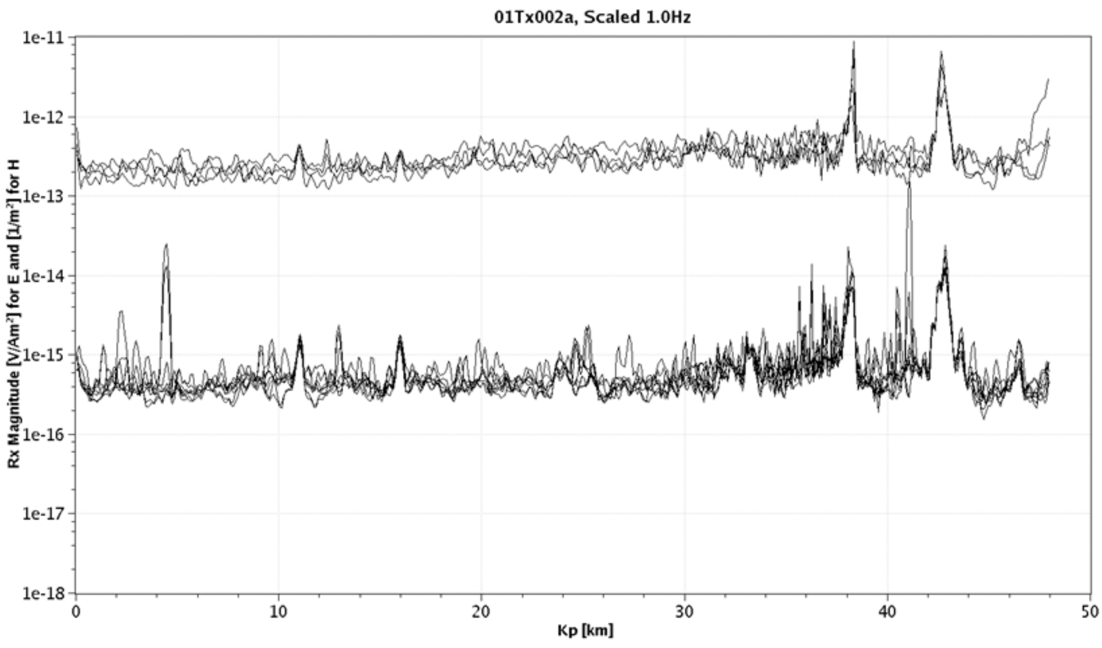

Figure 4. Magnitude of the received E and H components for the data shown in Figure 3. The geomagnetic noise is outside of the QC limits at f = 1 Hz from K_P 37.83 km to K_P 38.39 km (560 m) and from K_P 42.37 km to K_P 43.15 km (780 m). Thus, a retow was advised for this measurement.

Figure 3 gives an example of a CSEM measurement performed by EMGS at high latitudes. This spectrogram exhibits strong broadband signals throughout the measurement period, e.g., around UT 21:15 and 22:00. The occurrence of these signals correlates with moderate excursions of the geomagnetic field (as measured with a groundbased magnetometer in the vicinity of the towed line). Note also the narrow signal close to f = 1 Hz (ca. UT 02:30-03:30). This is the frequency of naturally occurring pulsations of the geomagnetic field.

Figure 4 displays the magnitude of the received E and H components for the same time period as presented in Figure 3. Two simultaneous excursions of both components are clearly visible around $K_P \sim 38$ km and $K_P \sim 43$ km. Here, the geomagnetic noise is outside of the QC limits at $f = 1$ Hz. Subsequently, it was recommended to reacquire the measurement due to the impact of the geomagnetic noise.

Discussion

In the result section of this paper, we have presented examples of GNSS measurements and CSEM investigations that were affected by space-physical processes: In the case of GNSS signals, the dispersive character of the ionosphere and in the case of CSEM measurements, geomagnetic disturbances.

These challenges for navigation, communication and CSEM measurements at high latitudes have not been met satisfactorily until now. Measurement campaigns have mostly been undertaken for short period of times or mostly during solar minimum. In addition, mostly scientific instruments have been deployed without simultaneous measurements from industrial instruments.

The MARENOR program intends to establish a test site including a scientific and industrial GNSS two-frequency receiver in addition to an IRIDIUM Open Port terminal for a duration of approximately 2 years. Simultaneous long-term data collection allows us to (1) identify periods of increased geomagnetic activity in the scientific data and evaluate their impact on the performance of the industrial receiver and IRIDIUM Open Port terminal and (2) identify periods of decreased system performance of the industrial instruments and correlate these with data from the scientific receiver in order to characterise physical parameters that are responsible for the system degradation. In addition, we will make use of a single-frequency GPS receiver (Garmin 60) at the Kjell Henriksen Observatory in order to monitor the system performance of low-end receivers. Furthermore, groundbased magnetometer data (operated by the Tromsø Geophysical Observatory) will be used to identify periods of enhanced geomagnetic activity. The project also plans to install a similar test set-up on ships operating at high latitudes during shorter periods of time.

One goal of the MARENOR project is to describe a simplified warning/forecasting system for communication and navigation solutions at high latitudes that notifies the user of times of decreased system performance. MARENOR aims at evaluating suitable forecasting tools in the context of performance and user-friendliness. Simply speaking, an operator on a maritime vessel in the High Arctic who is already confronted with challenging climatic conditions needs simple forecasting options on navigation and communication solutions during periods of reduced system performance.

The accuracy of CSEM and MMT measurements is also dependent on the accuracy of position estimates. Improved navigation solutions as a minimised error source will also increase the operation accuracy of CSEM and MMT measurements. The combination of CSEM and MMT is considered a promising product in the near future, in particular in the context of mapping the top and bottom of subbasal structures. Here, seismic survey methods struggle when penetrating basal structures. Furthermore, robust communication solutions are essential for operating at high latitudes. In addition, reliable forecasting of the geomagnetic field will make it possible to evaluate windows of operation even better.

Acknowledgements

The authors acknowledge Prof. Truls Lynne Hansen (Tromsø Geophysical Observatory, University of Tromsø) for providing data from the Longyearbyen magnetometer and Dr. Mariusz Pozoga (University of Warsawa) for providing data from the scintillation receiver at the Hornsund station. The Norwegian Research Council supports the MARENOR project as part of the MAROFF program.

References

[1] Fjørtoft K. et al., "Maritime communication to support safe navigation", TransNav - Intern. J. Marine Nav. Safety of Sea Transport., 3, 87-92, http://www.mits-forum.org/communication.html, 2009.

[2] "MarSafe North, Analysis of Maritime Safety Management in the High North", v. 1.3, http://www.sintef.no/marsafe, 2010.

[3] ArctiCOM Final Report, ESTEC Contract Number 4000101171/NL/NR, v 0.1, 2011 (full paper can be obtained from Beate.Kvamstad@marintek.sintef.no, short summary: http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=30581).

[4] Jakowski et al., "Operational space weather services for GNSS precise positioning", Ann. Geophys., 23, 3071-3079, 2005.

[5] Recommendation ITU-R P.531-4: "Ionospheric propagation data and prediction methods required for the design of satellite services and systems", 1997.

[6] Ippolito, "Propagation effects handbook for satellite systems design", 5. edition, Stanford Telecom, 1999.

[7] Skone et al., "Limitations in GPS receiver tracking performance under ionospheric scintillation conditions", Phys. Chem. Earth (A), 26, 613-621, 2001.

Biographies

Rico Behlke received both his Master of Science and PhD in space physics from the University of Uppsala. He has both worked with satellite measurements, e.g., on the Cluster spacecraft, and groundbased measurements, e.g., magnetometer, scintillation and incoherent scatter radar data. In 2009, Rico founded his own company (Polar Science and Guiding) working on ionospheric research and providing scientific lectures for tourists on Svalbard. Since 2010, he works for Kongsberg Satellite Services, Svalbard division, in Longyearbyen.

Beate Kvamstad received her Master of Science in electronics and telecommunications from the Norwegian University of Technology and Science (NTNU) in 2000. Since then she has been working with product development of positioning systems based on GPS and Glonass technology, AIS, EGNOS and Galileo. Since early 2008 she is a research scientist in applied maritime communications at the Norwegian Marine Technology Research Institute (MARINTEK).

Erlend Bjørdal received his Master of Science in numerical mathematics from the Norwegian University of Technology and Science (NTNU) in 2003. He started in EMGS in 2006 and has been involved in various roles related to data quality, processing, hardware, projects and operational management. He is currently working as manager for the Geophysical Support group in EMGS.

Fred Sigernes was the first to obtain a PhD in space physics on Svalbard through UNIS in 1996. He then worked as a researcher at the Norwegian Institute of Fisheries and Aquaculture in Tromsø with focus on industrial processing of fish by hyperspectral imaging. In 1998 he was hired by UNIS as associate professor in the field of middle atmospheric physics. Since 2007, he works as a professor in optics and atmospheric research at UNIS, and is head of the Kjell Henriksen Observatory (KHO) in Longyearbyen.

Dag Lorentzen is a professor of physics at UNIS. He has been the PI of several Research Council projects, the latest ongoing being InfraSpace - an infrastructure project to build auroral optical instrumentation to be located at the Kjell Henriksen Observatory (KHO). He was the Head of the Geophysics Department at UNIS for a total of 3 years, and is currently the Deputy Head of the Department. His research concerns magnetospheric and ionospheric physics, using both ground-based and space-based instrumentation. His science focus the last few years have been polar cap patches, ion outflow and auroral morphology. He has also participated in several sounding rocket launches. Lorentzen is an elected member of the Norwegian Scientific Academy for Polar Research.