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DIRECTION FINDING EXPERIMENT IN NORTH SCANDINAVIA

JACOBSEN Bjørn

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Torleiv Maseng
Director of Research

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FORSVARETS FORSKNINGSINSTITUTT
Norwegian Defence Research Establishment
P O Box 25, NO-2027 Kjeller, Norway

FORSVARETS FORSKNINGSINSTITUTT (FFI)
Norwegian Defence Research Establishment

P O BOX 25
N0-2027 KJELLER, NORWAY

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8) ABSTRACT

High-frequency (HF) radio wave propagation at high latitudes is greatly affected by geomagnetic and ionospheric conditions, and both civilian and military users need reliable forecasts of the propagation environment. In particular, the presence of large electron density gradients within the polar cap and auroral oval often lead to off-great circle propagation, which can be a serious problem for transmitter locating techniques based on direction finding and triangulation. Based on the large amount of data expected from a new Direction Finding (DF) experiment in North Scandinavia, a statistical classification of signal directional characteristics under various geophysical conditions and for all seasons can be made. In this report, cases of both quiet and disturbed geomagnetic conditions have been studied, and comparisons have been made with data from magnetic disturbance observatories in the same geographic region. In addition a first statistical study of one month of DF data is presented.

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1 INTRODUCTION

High-frequency (HF) radio wave propagation at high latitudes is greatly affected by geomagnetic and ionospheric conditions, and both civilian and military users need reliable forecasts of the propagation environment. In particular, the presence of large electron density gradients within the polar cap and auroral oval often lead to off-great-circle propagation, which can be a serious problem for transmitter locating techniques based on direction finding and triangulation.

The channel scattering characteristics have been studied in detail with the DAMSON sounder system (Davies and Cannon (1); Cannon et al (2)) installed in Northern Scandinavia, and the DAMSON signals were also received on a multichannel, spaced antenna array system, developed by University of Leicester, in Kiruna, northern Sweden (Warrington et al (3)). Transmissions were from Svalbard and Harstad in northern Norway. This technique enabled determination of the direction of arrival of each received signal component, as well as time of flight and Doppler frequency shift. A measurement campaign of 10 days duration was undertaken in March 1998, under relatively benign geomagnetic conditions. The experimental data showed a variation in bearing with Doppler frequency of the received signal, consistent with reflections from ionospheric irregularities drifting across the reflection points of the propagation path. Different modes were at times received with widely separated bearings, and propagation paths well displaced from the great circle direction sometimes occurred for long periods (several hours).

Similar Direction Finding (DF) experiments have also been conducted along paths within the Canadian Arctic and between Canada and Greenland. Large quasi-periodic bearing variations of up to ± 100° from the great circle direction were observed which were attributed to reflection from arcs and patches of enhanced electron density, as well as large deviations attributable to the sub-auroral ionospheric trough (Warrington et al (4), Rogers et al (5)).

Recently, a new network of transmitters and receivers has been installed in northern Scandinavia (including Svalbard), capable of measuring the time delay and Doppler spread characteristics and the directional structure of received signals on three HF paths. Transmitters were first located in Longyearbyen (Svalbard), Kirkenes (northern Norway) and Uppsala (southern Sweden), cf. Figure 1.1. The Uppsala transmitter had a short time of operation and was then moved to Leicester, UK. The receiver is located in Kiruna, where data are stored and later transferred to the University of Leicester. The system has operated nearly continuously over a period of more than one year (since June 2002), and a more detailed technical description of the experiment and data processing is given by Warrington et al (6).

Based on the large amount of data expected from this experiment, a statistical classification of signal directional characteristics under various geophysical conditions and for all seasons can be made. In this report, cases of both quiet and disturbed geomagnetic conditions have been studied, and comparisons have been made with data from magnetic disturbance observatories in the same geographic region. In addition a first statistical study of one month of DF data is presented.

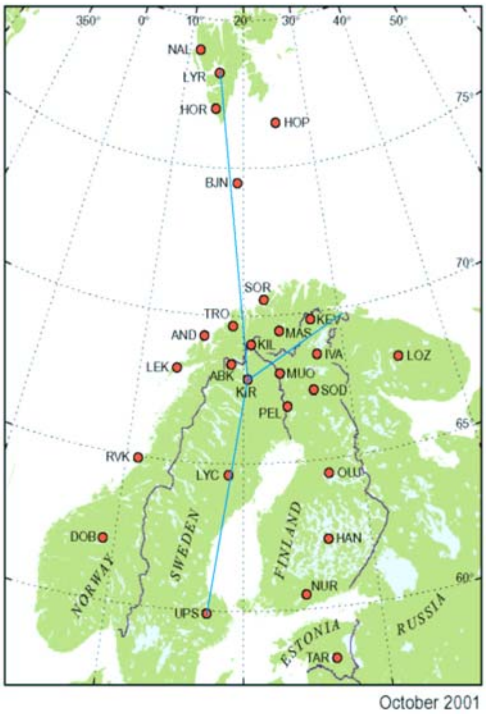

Figure 1.1 *Radio paths used in the DF experiment and magnetic observatories in Scandinavia. LYR is Longyearbyen, KIR is Kiruna, and UPS is Uppsala. Kirkenes is located east of KEV.*

2 DATA ANALYSIS

The signals radiated from the transmitter sites comprise sequences of 13-bit Barker coded PSK pulses. Since the transmitter and receiver systems are GPS-synchronised, the time of flight of the signals may be determined. The signals are received on a six-element spaced aperture antenna array, in which individual elements are connected to individual inputs of a multi-channel receiver. The signal samples received on each antenna within the array are processed to provide a measure of the absolute times of flight of the propagating modes and their associated Doppler spectra. In this way, the signal may be split into complex amplitude components distinguished by time of flight, Doppler frequency and, since a multi-channel receiver with a spaced antenna array was employed, by antenna position. A superresolution direction finding algorithm may then be applied to the spatially resolved information in order to estimate the directional structure of the signals.

The data collected in Kiruna are electronically transferred to the University of Leicester, where they are stored on CD ROM. The raw data are then processed with dedicated software developed at University of Leicester. A typical processing session is run in batch mode and comprises unpacking of data archives, unzipping of data files, calibration, direction finding algorithms and finally writing the result to files in MATLAB format. The raw data files are very large and the batch processing is rather time consuming, and since the University of Leicester performs this part of the data reduction on a regular basis, it is suggested that the much smaller MATLAB files are requested from them rather than the raw data files. The files may then be transferred (by ftp) to a local PC where plotting and/or other subsequent data analysis, e.g., statistics, may be performed.

University of Leicester has also provided some MATLAB routines for plotting the data in various formats. Provided that MATLAB is installed and the data files and routines are stored in relevant directories, the following command sequence in MATLAB will create two plots for one day’s worth of data and all sounding frequencies:

```
SITE='X'
DATE='yyyymmdd"
procsummplot
```

(X can be S for Svalbard Tx or K for Kirkenes Tx, yyyyddmm is the date.)
The first plot shows Doppler spread, azimuth and elevation of the received signals, while the second plot includes time of flight, azimuth on an expanded scale (centred on the nominal great circle bearing of the radio path) and signal-to-noise ratio (SNR). (This format is used for the data examples in the following section.) Similarly, the routine `simpleplot` will create a plot with one day’s worth of data for a single sounding frequency.

3 EXAMPLES OF DF OBSERVATIONS

In order to describe some characteristics of the observed HF signal propagation, we have selected two geomagnetically quiet (K=0-1) and one more disturbed (average K=4.5) day, where K is the magnetic disturbance level at Tromsø (TRO in Fig. 1.1).

3.1 Quiet days: September 23-24, 2002

DF data for the Svalbard-Kiruna path are presented in Figures 3.1 and 3.2, where Doppler spread, azimuth, elevation, time of flight and SNR of the received signals are plotted. The azimuth angle is shown for the strongest identified signal component and is plotted both on a full 360° scale and in more detail, centred on the great circle bearing (-5°) of the path. Due to instrumental effects, multiple traces are seen in the time of flight plots, and the upper traces should be disregarded. The observation interval started at 1100 UT (Sept. 23) and ended at 1330 UT (Sept. 24).

Magnetograms from Tromsø are shown in Figure 3.3 and 3.4 and clearly illustrate the low activity level of this time interval (local K-index for Tromsø varied between 0 and 1). Correspondingly, the radio signals were received from near the great circle (GC) direction at all propagating frequencies from the start of the data interval. However, marked deviations towards the west of GC bearing (negative azimuth angles) were observed after 18UT, first at 11.175 MHz and later at the lower frequencies. Deviations of more than 25 degrees were observed, i.e. exceeding the detailed azimuth scale in Fig. 3.1 (lower panels). Off-great circle propagation was accompanied by a large increase in Doppler spread, increase in time of flight, and reduction in SNR. The return to GC propagation took place after 03 UT (Sept. 24), first at the lower frequencies. The two lowest frequencies (4.455 and 5.795 MHz) were received from near GC throughout the time interval.

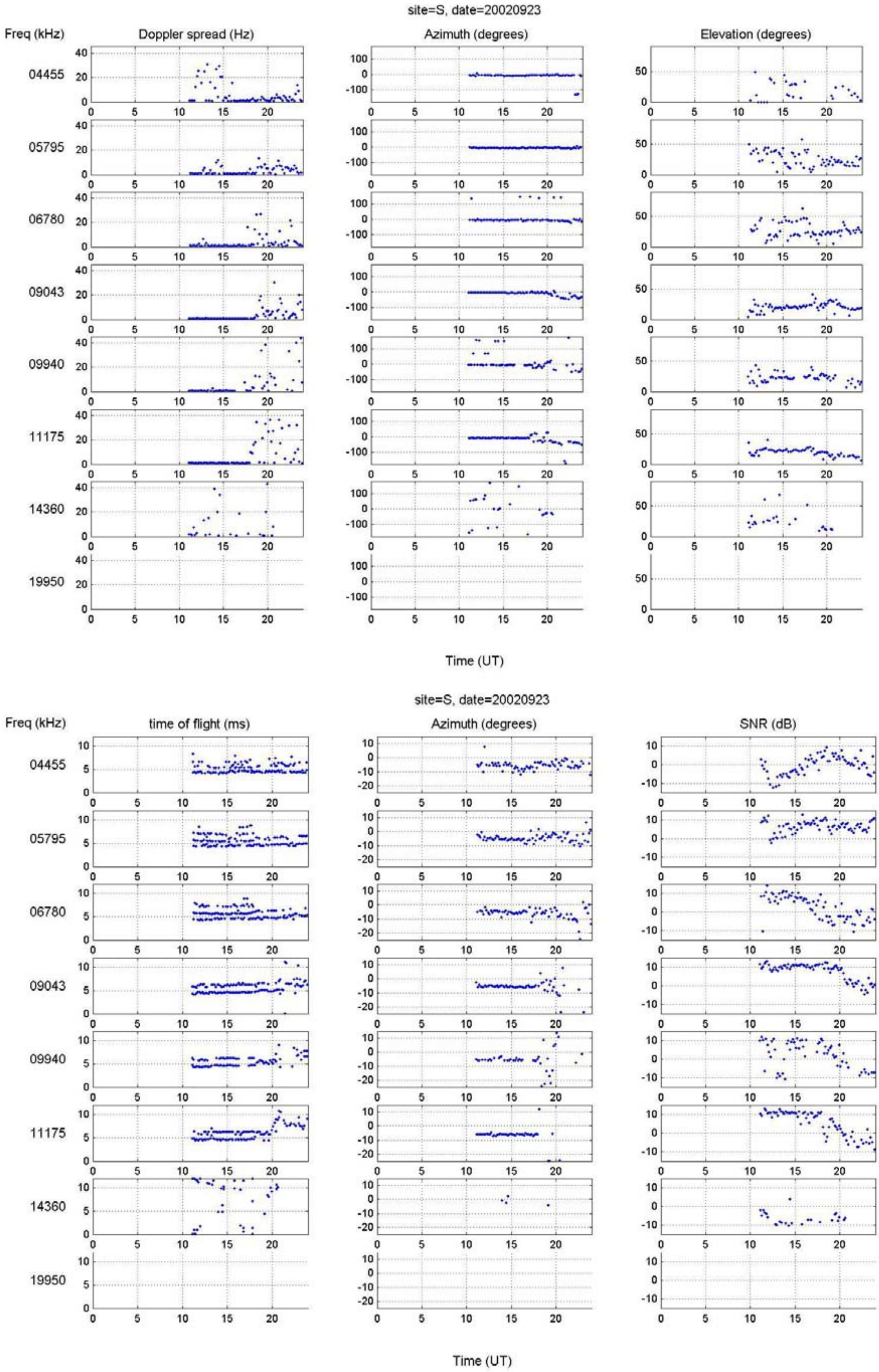

Figure 3.1 *Summary plot of signal characteristics (all frequencies) for Svalbard to Kiruna path on September 23, 2002*

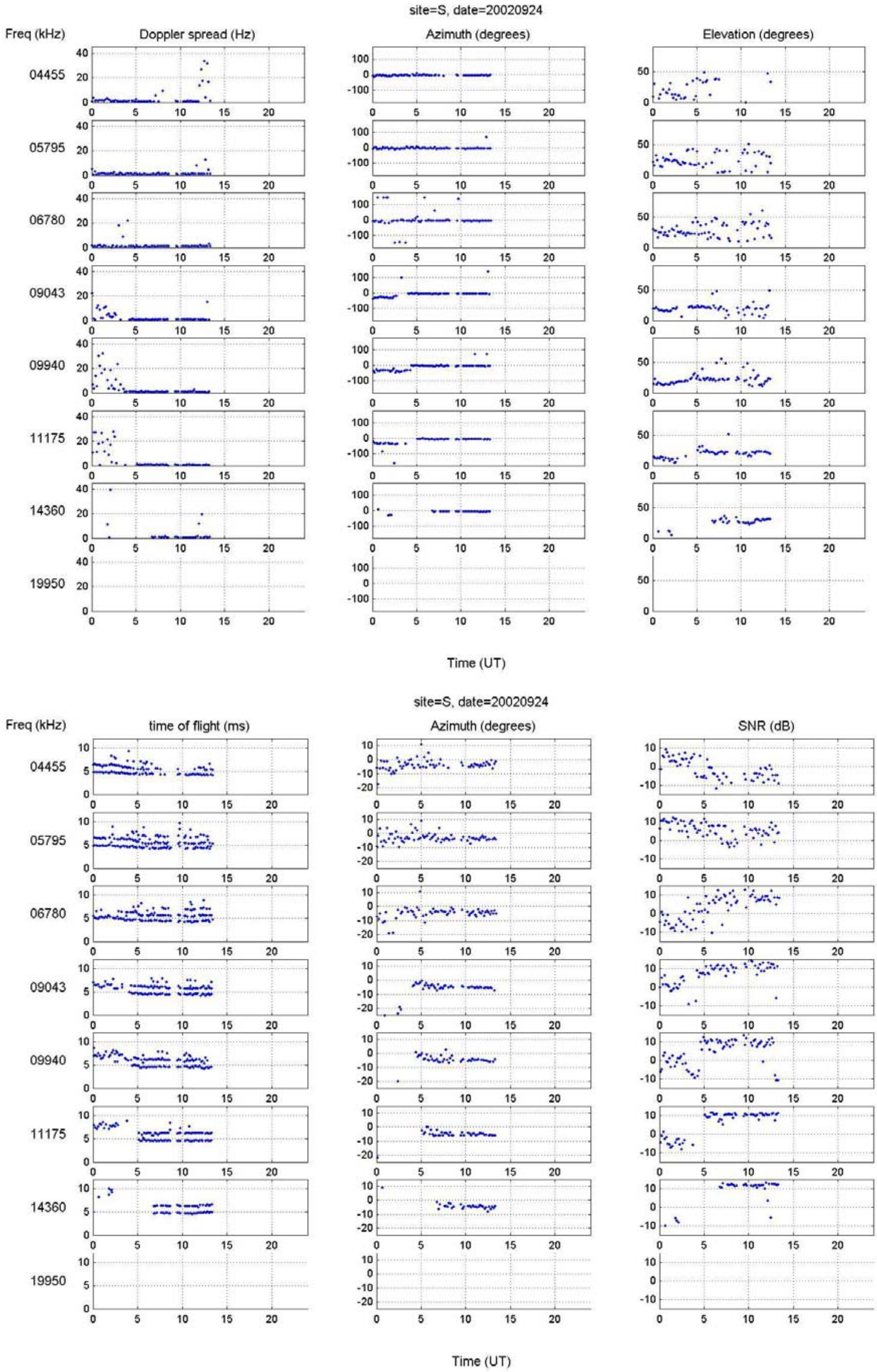

Figure 3.2 Summary plot of signal characteristics (all frequencies) for Svalbard to Kiruna path on September 24, 2002

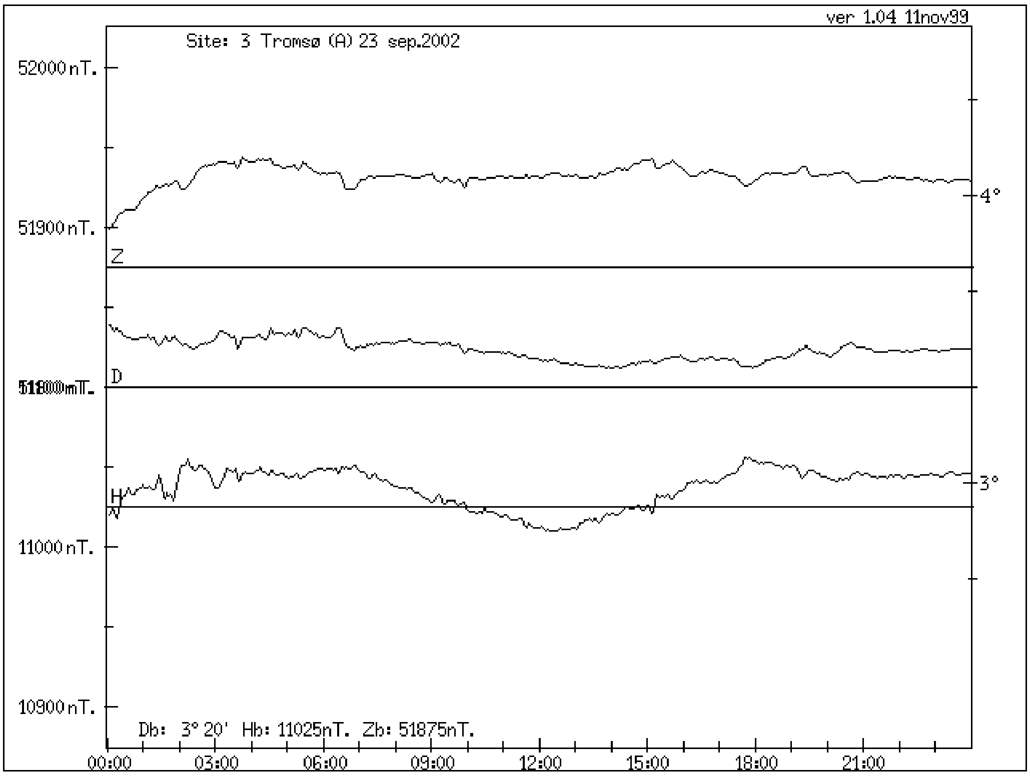

Figure 3.3 Tromsø magnetogram (H,D,Z components) for September 23, 2002

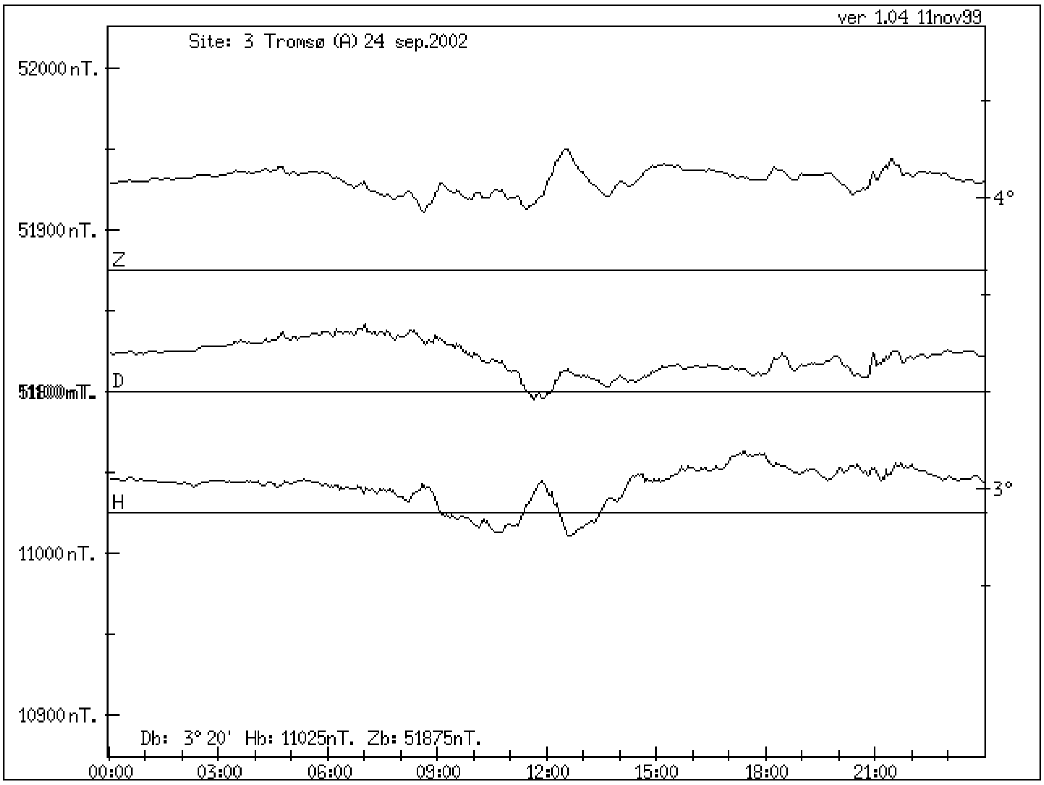

Figure 3.4 Tromsø magnetogram (H,D,Z components) for September 24, 2002

3.2 Disturbed day: October 1, 2002

The DF data for this time interval are plotted in Figure 3.5 in the same format as for September 23-24. Similarly, magnetograms for Tromsø are shown in Figure 3.6 and indicate a higher geomagnetic disturbance level (average K index for Tromsø is 4.5) than for Sept. 23-24 (note the different amplitude scales in Fig. 3.3 and 3.6).

We will not discuss the detailed time history of the signal propagation during this day, but we note that even during magnetic disturbances, there are prolonged time intervals when GC propagation is maintained at several frequencies, associated with high SNR and low Doppler spread. However, these periods are interrupted by intervals of off-GC propagation, increased Doppler and reduced SNR, for instance at 15 hours UT on 9.043 MHz. (The presence of signals with bearings in excess of 100 degrees, for instance as seen at 6.780 MHz, are due to other interfering transmissions within the receiver passband.)

The lack of datapoints between 6 and 9 UT is probably due to increased absorption which is a common feature during geomagnetic disturbances. For this day, propagation conditions are also similar during day and night, as opposed to the quiet days. This can be explained by physical factors other than the solar zenith angle contributing most to the propagation environment.

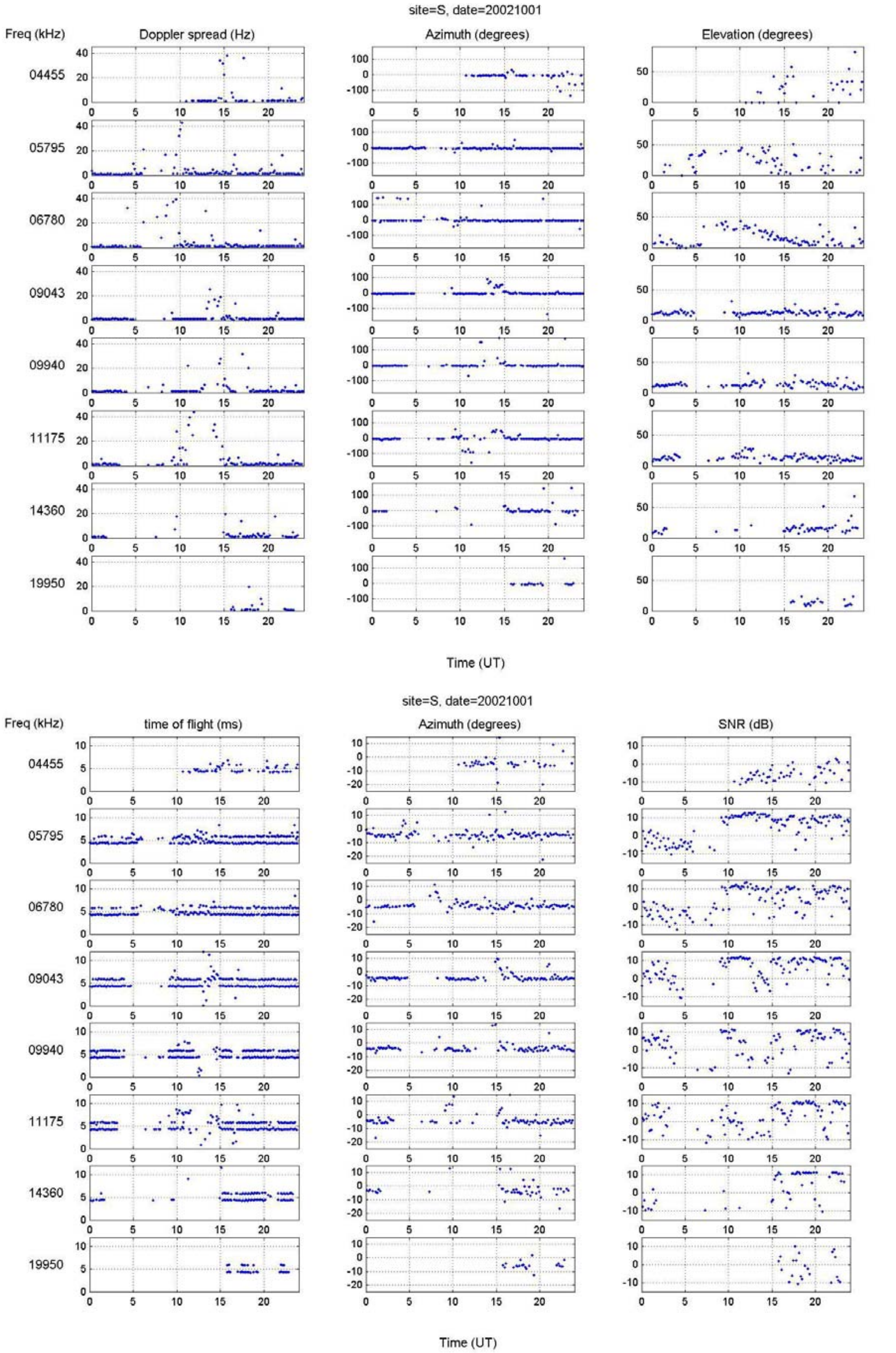

Figure 3.5 Summary plot of signal characteristics (all frequencies) for Svalbard to Kiruna path on October 1, 2002

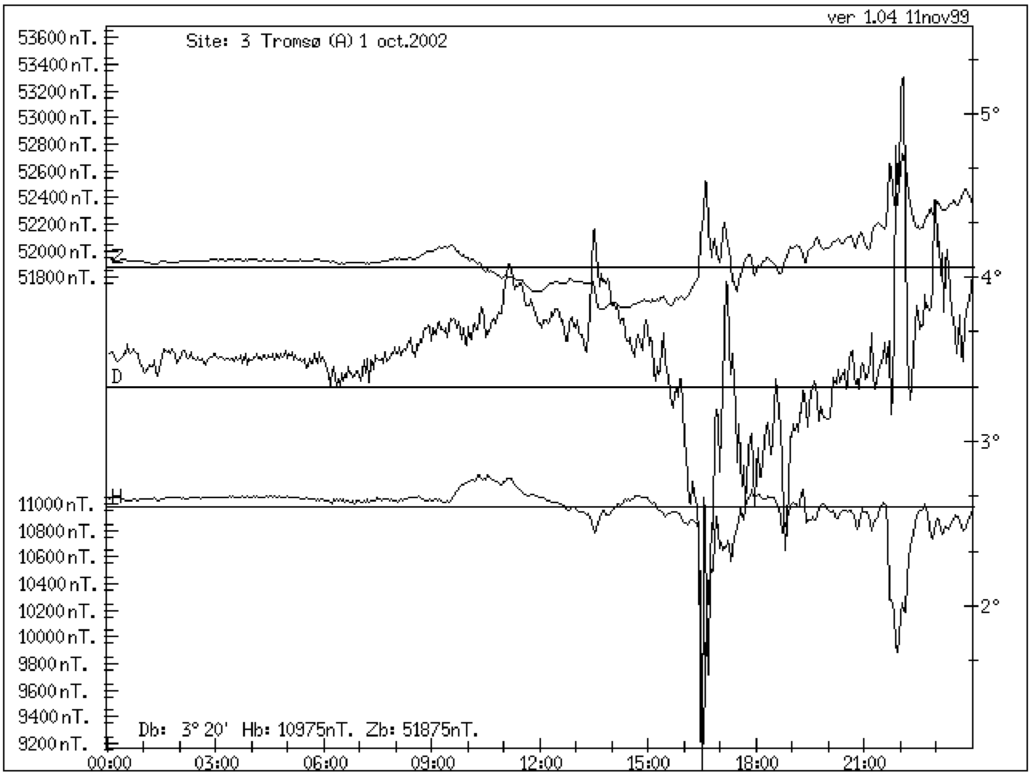

Figure 3.6 Tromsø magnetogram (H,D,Z components) for October 1, 2002

3.3 Discussion of observations

The onset of off-GC and return to near-GC propagation observed during the quiet interval (Sept. 23-24) correspond well in time with local sunset and sunrise. As the electron density is reduced after sunset, the higher frequency signals will be above the Maximum Usable Frequency (MUF) for the Svalbard-Kiruna path, and GC propagation is no longer sustained. However, electron density gradients and irregularities may effectively reflect or scatter the signal, such that off-GC propagation becomes possible. The longer path length for off-GC propagation is consistent with the observed increase in signal time of flight. Irregularity drift motion and turbulence increases the Doppler spread on the received signals. The lowest frequencies (below the MUF) maintain GC propagation even during times of reduced electron density.

For more disturbed conditions, the selected case indicates that GC propagation is still the dominant mode during long time intervals, as long as there is sufficient electron density in the reflection region to support this mode. This may even be the case during the night, since auroral electron precipitation can create the needed additional ionisation, and the signal is received with relatively high SNR.

These two case studies indicate that off-GC propagation modes may sometimes be dominant both during very quiet and more disturbed geomagnetic conditions. On the other hand, strong GC modes may also be present during disturbed time intervals. Signals with strong SNR often arrive at the receiver along the great circle direction, while signals with weaker SNR may arrive from directions well displaced from the great circle. The September 23-24 case may be considered a rare event of long periods of off-GC circle propagation during very quiet conditions, and more data is needed to estimate the probability of this scenario.

4 STATISTICAL STUDY

The large amount of DF data collected from the different paths over an extended time period may be used in establishing statistics on the deviations in azimuth relative to the great circle bearing for the received signals as a function of season (solstice vs. equinox), time of day (sunrise/sunset effects) and magnetic activity (related to charged particle precipitation).

As a first attempt, data for the Svalbard-Kiruna path from one month (September 15 – October 14, 2002) were selected and the corresponding plots were manually inspected. The following parameters were extracted, for two sounding frequencies (5.795 and 9.040 MHz): Signal time of flight, Doppler spread, SNR, and azimuth angle with deviation relative to the great circle bearing.

Representative average values for day and night were estimated for these parameters, even though the data coverage could be as low as 10% for some of the days in the selected time interval, probably due to poor propagation conditions. In addition, the signal parameters were plotted as function of local geomagnetic activity represented by the Tromsø K-index (daily sum).

This limited analysis showed that the azimuth angle of the received signal on average is along the expected great circle direction (from Tx to Rx), which means that large deviations over several hours, as observed on September 23 and 24, 2002, are very rare. The following average values over one month were estimated:

Azimuth deviation relative to great circle bearing: ± 2.7° (day), ± 3.8° (night) for 5.795 MHz, ± 2.8° (day), ± 4.9° (night) for 9.040 MHz

Doppler spread: 3.8 Hz (day), 3.3 Hz (night) for 5.795 MHz, 3.8 Hz (day), 4.3 Hz (night) for 9.040 MHz

SNR: 5 dB (day), -3 dB (night) for 5.795 MHz, 9 dB (day), -1 dB (night) for 9.040 MHz

The azimuth deviation during the night is somewhat larger than during the day, even though the night average value for 9.040 MHz is heavily biased by the two large values for September

23 and 24. The Doppler values are roughly consistent with earlier DAMSON results from the same radio path. The SNR is reduced from day to night and is larger for the highest frequency.

Data for February 2003 were analysed in a similar manner, but these observations were hampered by consistently low SNRs due to as yet undetermined reasons. The average values were not significantly changed when the February data were included.

Finally, no clear functional relationship between azimuth deviations and local geomagnetic activity was found. This is somewhat surprising, since ionospheric disturbances would be expected to give rise to additional signal reflections and off-great-circle propagation. A larger data set is probably needed to establish a possible relationship, e.g. an increase in observed azimuth deviations from great circle bearing with increasing geomagnetic activity. This could prove very useful in future space weather forecasting services based on geomagnetic observations, which are easily accessible via Internet.

5 CONCLUSIONS AND FURTHER WORK

Based on data from a new Direction Finding (DF) experiment in North Scandinavia, cases of both quiet and disturbed geomagnetic conditions have been studied, and comparisons have been made with data from magnetic disturbance observatories in the same geographic region. Off-GC propagation modes were sometimes found to be dominant, both during very quiet and more disturbed geomagnetic conditions. In addition, a first statistical study of one month of DF data has been performed, and average values for azimuth deviation from great circle bearing, Doppler spread and SNR have been calculated.

A statistical study of a larger data set with samples for all seasons and geomagnetic disturbance levels should be performed in the future. Combined with existing physical models of ionosphere convection and HF radar observations from the same geographic region (the CUTLASS radars), this could give a fuller understanding of HF radio signal propagation at high latitudes and its importance in communications and reconnaissance.

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