HF RADIO PROPAGATION AT HIGH LATITUDES: OBSERVATIONS AND PREDICTIONS FOR QUIET AND DISTURBED CONDITIONS

Bjorn Jacobsen and Vivianne Jodalen
Norwegian Defence Research Establishment (FFI)
P.O. Box 25, N-2027 Kjeller
Norway
bjorn.jacobsen@ffi.no

Paul S. Cannon, Matthew J. Angling, and Oliver Smith
Defence Evaluation and Research Agency (DERA)
St Andrews Road, Malvern
Worcs., WR14 3PS
United Kingdom

SUMMARY

High-frequency (HF) radio communications at high latitudes are greatly affected by geomagnetic and ionospheric conditions, and both civilian and military users need reliable forecasts of the propagation environment. In recent years, a network of channel sounders known as DAMSON (Doppler and Multipath Sounding Network) has been operated in Scandinavia (including Svalbard) on a nearly continuous basis. We have analysed DAMSON measurements of multipath spread, Doppler shift and spread, and signal-to-noise ratio on four HF paths under both quiet and disturbed geomagnetic conditions. Correlations have been made with data from other ground-based installations in the same geographic region. Long signal delays (several ms) are regularly observed at frequencies well above the predicted MUF and could possibly be caused by ground scatter. Large Doppler spreads (tens of Hz) are observed during disturbed conditions (substorms), when the ionospheric reflection point is located within the auroral oval. We suggest that forecasts of the HF multipath and Doppler environment based on sounder measurements could be utilized as additions to the regular HF predictions of e.g., the MUF and LUF of a propagation path.

1 INTRODUCTION

Radio communications at high latitudes are greatly influenced by auroral and geomagnetic activity, in particular during geomagnetic storms and substorms. Reflections off auroral density walls introduce large multipath delays to the received signals, and fast plasma drifts in the ionospheric medium give rise to Doppler spreads and shifts. These difficulties can cause the breakdown of digital communications systems (i.e., an increase of the bit error rate to intolerable levels).

The DAMSON (Doppler and Multipath Sounding Network) system was developed to measure propagation characteristics over high latitude propagation paths; see Davies and Cannon (1). The system utilises low-power, pulse compression waveforms and digital signal processing techniques to measure the time delay of modes, Doppler spread and shift, and signal-to-noise ratio. Measurements in Northern Scandinavia have been made since 1994. Transmitters are located in Isfjord (Svalbard) and Harstad (Northern Norway), while receivers are located in Kiruna (Northern Sweden) and Tuen (Southern Norway).

The DAMSON system cycles through a list of ten frequencies between 2.8 and 22 MHz. One minute is spent at each frequency and various sounding pulses are transmitted, of which the delay-Doppler (DD) Barker-13 waveform is of particular importance to our study (cf. (1) and (2)). From the DD spectrograms, propagating modes are identified and important parameters such as time delay, Doppler spread/shift and SNR are calculated.

Statistical studies of channel characteristics based on DAMSON have been presented in a number of papers; see Angling et al. (2), Jodalen et al. (3), Willink et al. (4). In the present study, we present detailed case studies of the correlation between Doppler spread and simultaneous disturbances in the local magnetic field near control points for the various DAMSON paths. The rationale is that geomagnetic variations are created by ionospheric currents, which in turn are the result of charged particle motions in the regions where HF radio wave reflection takes place.

2 DATA SELECTION AND ANALYSIS

Magnetic disturbances are regularly monitored by a large number of magnetometer stations in Scandinavia (including the Svalbard islands), which constitute the IMAGE network. The IMAGE magnetometer stations and the four DAMSON paths are shown in Figure 1. We have selected eight stations that are thought to represent geomagnetic conditions near control points for the various DAMSON paths and in the surrounding regions. For example, ABK (Abisko) is located near the midpoint between Harstad and Kiruna, and may also represent the midpoint between Isfjord and Tuen, assuming that longitudinal variations are small over ~200 km. In the present study, we have concentrated on the horizontal north-south (X) component of the magnetic disturbance field, which represents ionospheric east-westward currents (e.g., the westward electrojet current observed during the substorm breakup phase).

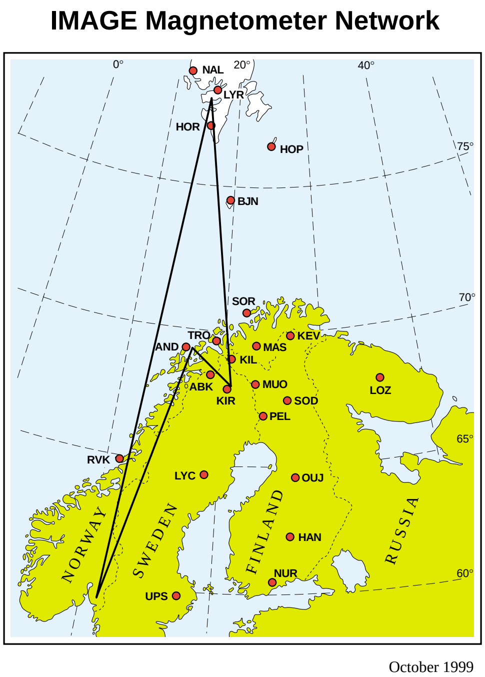

Figure 1: Magnetometer stations and DAMSON paths. Isfjord is located near LYR (Longyearbyen), while Harstad is near AND (Andøya).

3 CASE STUDIES

We have selected two cases representing both quiet and disturbed geomagnetic conditions.

3.1 March 21, 1998

Magnetometer data for this day are presented in Figure 2. The negative deviations seen from 00 until ~02 UT at SOR, ABK and KIR are remnants of substorm activity before midnight. A positive deviation, starting ~07 UT at NAL propagated southward and reached SOR, ABK and KIR around noon. This variation was probably due to an overall expansion of the auroral oval and the corresponding current systems in and around the polar cap. A distinct substorm onset was observed 1915 UT, nearly simultaneously at all stations.

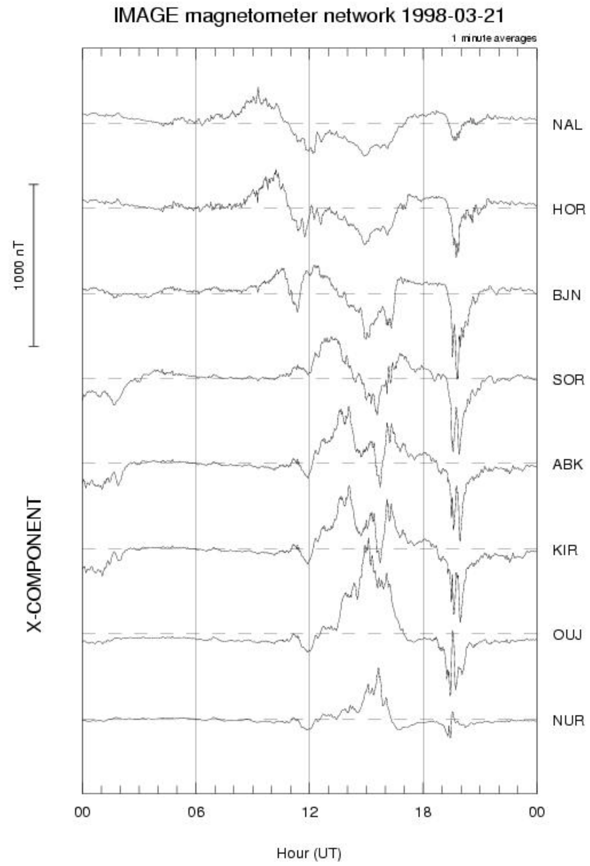

Figure 2: Horizontal north-south component of magnetic variations for selected stations for March 21, 1998.

Plots of time delay and Doppler spread for the propagating modes at 6.8 MHz for all four DAMSON paths are presented in Figure 3 and 4. Comparing with the magnetic observations in Figure 2, we note the following correlations:

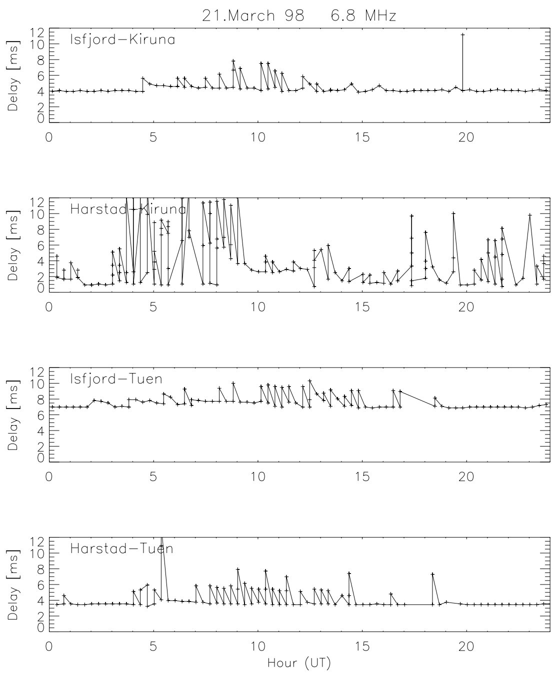

Figure 3: Time delay of propagating modes at 6.8 MHz for all four DAMSON paths for March 21, 1998. Two or more simultaneously observed modes are connected by a vertical line.

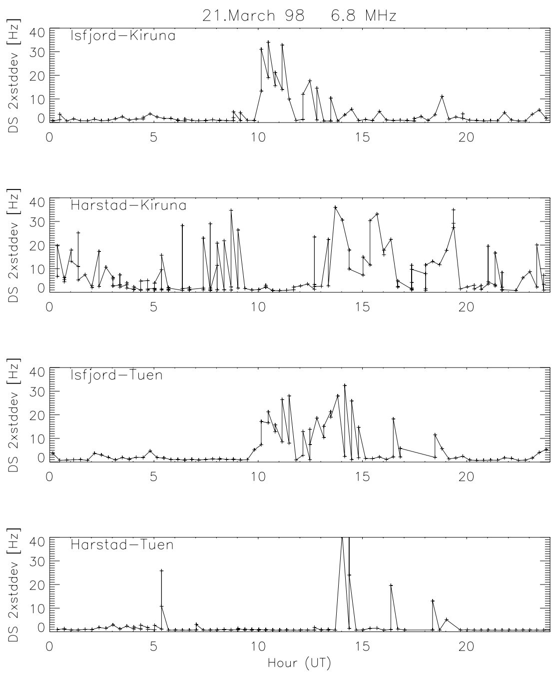

Figure 4: Doppler spread of propagating modes at 6.8 MHz for all four DAMSON paths for March 21, 1998. Two or more simultaneously observed modes are connected by a vertical line.

- Doppler spread strongly increases on the Isfjord-Kiruna (I-K) and Isfjord-Tuen (I-T) paths at ~10 UT, when the southward propagating magnetic disturbance reaches BJN. This station is closest to the 1-hop control point for the I-K and 2-hop control point for the I-T path. The observed time delays also indicate that multi-hop propagation, possibly along with off-great circle propagation, takes place at this time.
- Similarly, when the southward propagating disturbance is over ABK and KIR, a strong increase in Doppler spread is seen on the Harstad-Kiruna (H-K) path (~13 UT). The latest response is on the Harstad-Tuen (H-T) path, consistent with its most southerly control point location.
- Substorm onset at 1915 UT results in increased Doppler spread on the H-K path, but no clear response on the other paths (at 6.8 MHz). The H-K path is nominally located within the auroral oval at this local time, and since the substorm current system (auroral electrojet) is rather localized in latitude, this path suffers greatest Doppler variations. (The observed magnetometer deviations are the integrated results of ionospheric currents within a large field-of-view, and X component variations are observed even when the currents are not overhead.)
- Signals with time delays up to 10 ms are seen on the H-K path during the time interval 04-09 UT, and Doppler spread increases for some of these modes after 0730 UT. Very long delay echoes with low SNR and low levels of Doppler spread are regularly observed on this path and on frequencies well above the expected MUF. Based on directional information and ray tracing simulations, Warrington et al. (5) suggested that these modes result from ground backscatter reflections arriving at the receiver from a generally southerly direction. In the present study, we are left with observations of long delay modes with rather large Doppler

spreads, which could result from off-great circle propagation to the north and scattering off the auroral boundary.

3.2 March 24, 1998

Magnetometer data for this day are presented in Figure 5. The first 11 hours are relatively quiet at all stations, except for some pulsation activity seen at NAL, HOP and BJN. Positive deviations started after 11 UT, first at the northernmost stations, and propagated southward. Substorm onset occurred ~21 UT and was clearest seen at the stations SOR, ABK and KIR.

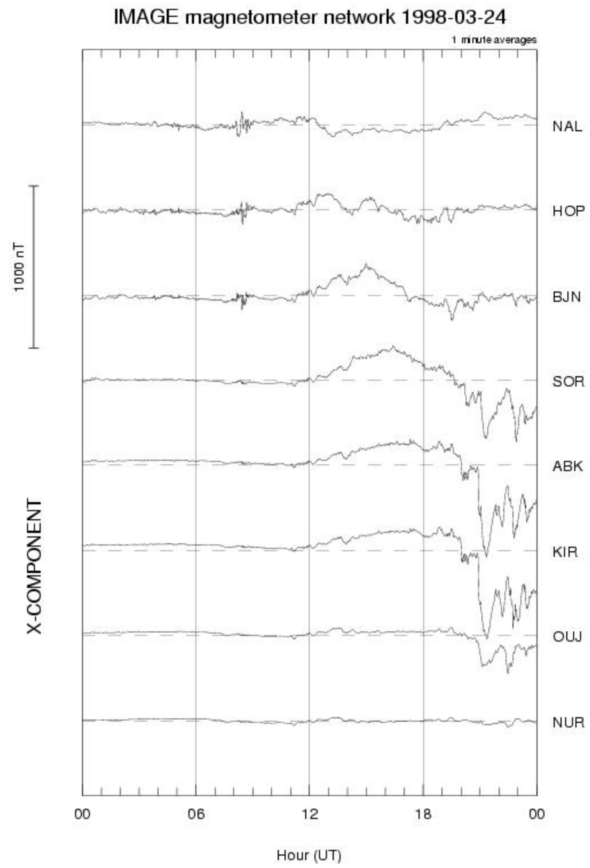

Figure 5: Horizontal north-south component of magnetic variations for selected stations for March 24, 1998.

Time delay and Doppler spread at 6.8 MHz for all four DAMSON paths are presented in Figures 6 and 7.

- Again, we note the onset of enhanced Doppler spreads as the positive magnetic variations expand southward, first seen on the I-K and I-T paths (~13 UT) and later on the H-K path (~15 UT). The H-T path suffered very weak Doppler spread at this time, consistent with the rather quiet magnetic field observed at the southernmost magnetometer stations (OUJ and NUR).
- However, Doppler spreads up to 20 Hz were observed in the early morning hours on both the H-T and H-K paths, coinciding in time with long delays on both paths. Again, we suggest that these modes were scattered by features associated with the auroral boundary in

the north, although directional information would be necessary to fully understand their propagation characteristics.

- Doppler spread on the H-K path was weak around the time of substorm onset but increases 90 min later, even though large magnetic variations were observed near the path midpoint. However, enhanced Doppler spread at the time of substorm onset was seen at higher frequencies (not shown).
- A small detail of interest is the brief increase in Doppler spread on the I-K path as magnetic pulsations appear at the northernmost stations (08-09 UT).

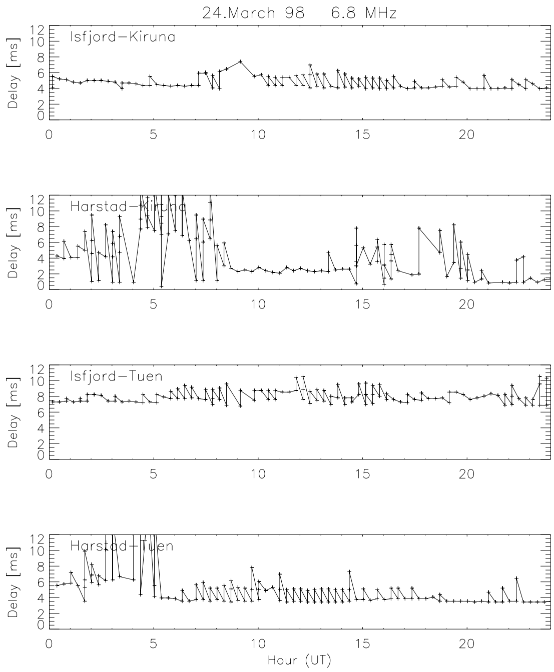

Figure 6: Time delay of propagating modes at 6.8 MHz for all four DAMSON paths for March 24, 1998. Two or more simultaneously observed modes are connected by a vertical line.

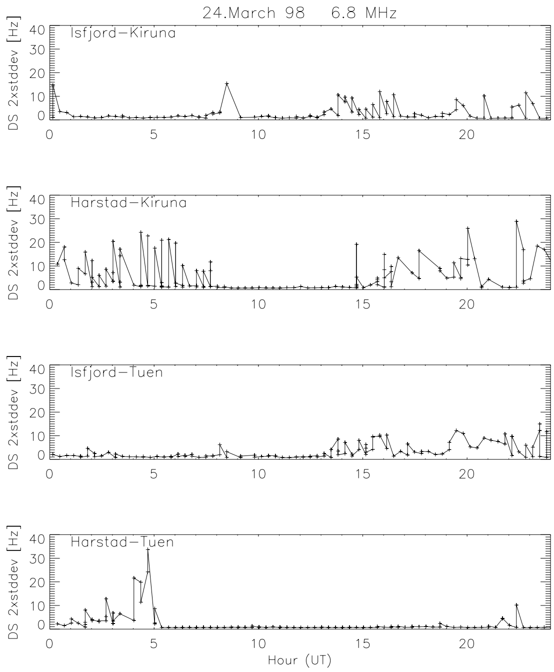

Figure 7: Doppler spread of propagating modes at 6.8 MHz for all four DAMSON paths for March 24, 1998. Two or more simultaneously observed modes are connected by a vertical line.

4 DISCUSSION AND CONCLUSIONS

The previous examples were for one frequency only (6.8 MHz), which is a propagating frequency most of the time on all four path. When all DAMSON frequencies are taken into account, the correlations between Doppler spread at the propagating frequencies and magnetic variations are generally similar, and the observed Doppler spread increases with increasing frequency, as expected from the Doppler equation.

Although several cases of good correspondence in time between increases in Doppler spread and magnetic disturbances were found in the two examples presented here, the correlation is not always present. One important problem is that the magnetometer observations result from integration over ionospheric current systems within a large field-of-view, weighted by their distance from the station (Biot-Savart´s law). Furthermore, there is not always a magnetometer station located near the path control points. HF radar systems, such as

CUTLASS in Northern Scandinavia, yield direct observations of ionospheric drift velocities over large geographic areas, and comparison with DAMSON data should give better insight into radio wave propagation during disturbed periods. However, the magnetometer method applied here does have its advantages, since the data are continuos in time and readily available over the Internet, while HF radar data need more processing and may be lacking due to unfavourable propagation conditions (e.g., ground backscatter).

In conclusion, we note that good correspondences between Doppler spread and magnetic variations may be found, and future studies will take into account more of the vast data set collected over half a sunspot cycle. Hopefully, this will lead to a better understanding and perhaps a prediction capability for multipath and Doppler spread/shift in high latitudes.

5 ACKNOWLEDGEMENTS The DAMSON project is an international collaboration between the Defence Evaluation and Research Agency, UK, the Communications Research Centre, Canada, the Norwegian Defence Research Establishment and the Swedish Defence Research Establishment. The IMAGE magnetometer data are collected as a Finnish-German-Norwegian-Polish-Russian-Swedish project with the Finnish Meteorological Institute as principal investigator.

6 REFERENCES

1. Davies N.C. and Cannon P.S., 1993, "DAMSON - A system to measure multipath dispersion, Doppler spread and Doppler shift on multi-mechanism communications channels", *CP-543, AGARD Multiple Mechanism Propagation Paths (MMPPs): Their Characterisation and Influence on System Design*, The Netherlands, paper 36.
2. Angling M.J., Cannon P.S., Davies N.C., Willink T.J., Jodalen V., and Lundborg B., 1998, "Measurements of Doppler and multipath spread on oblique high-latitude HF paths and their use in characterizing data modem performance", *Radio Science, 33,* 97-107.
3. Jodalen V., Bergsvik T., Cannon P.S., and Arthur P.C., 1998, "The high latitude performance and availabilities of robust and non-robust modems using multiple frequencies", *Proc. Nordic Shortwave Conf., HF98,* paper 4.3.
4. Willink T.J., Davies N C., Angling M.J., Jodalen V., and Lundborg B., 1999, "Robust HF data communications at high latitudes", *IEE Proc.-Microw. Antennas Propag., 146,* 263-268.
5. Warrington, E M., Jackson, C A., Stocker, A J., 1999, "DF as a beneficial addition to DAMSON data analysis", report from Department of Engineering, University of Leicester, UK.