# STUDY OF THE DECORRELATION OF HF BEAM THROUGH A TURBULENT IONOSPHERE WITH SUPERDARN RADARS


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## ABSTRACT

Interaction between ionospheric HF radar beams and turbulent fluctuations in the auroral zone is studied and shown to affect wave propagation. Middle-scale plasma density irregularities cause the loss of coherence of the wave front as far as it propagates through the medium. This results in a spectral width enhancement of observed signal. SuperDARN spectra are shown to reflect this effect with a frequency dependence. A linear model implemented with Arcad-3 satellite data which provides representative horizontal electron density fluctuations allows to study the role of the plasma frequency over radar frequency ratio and provides quantitative estimates of spectral width enhancement.


## INTRODUCTION

One of the main goals of SuperDARN (Super Dual Auroral Radar Network) is to obtain global convection maps of ionospheric plasma motions driven by solar-terrestrial geophysical processes. The transmitted HF radar waves are refracted in the ionosphere and can therefore achieve perpendicularity to the Earth magnetic field at high latitudes. A part of the wave energy is coherently back-scattered by ionospheric irregularities aligned to the magnetic field. The back-scattered wave undergoes a Doppler frequency shift proportional to the radial component of the plasma velocity and is then received and analyzed by the radar. The amplitude of the signal, the line-of-sight velocity and the spectral width of the signal are then deduced. These parameters are determined both by the plasma instability mechanisms within the sounded volume, and by the large scale convective motions which govern the global ionospheric pattern. In this study, a particular attention is paid to spectral width values observed by SuperDARN, and their dependence upon frequency and range. Numerous studies are making use of spectral width values in order to identify magnetospheric regions or boundaries by their ionospheric footprints. Previous studies [1,2] have applied collective wave scattering theory to radar spectra in order to characterize them in terms of micro-physical processes and to relate them to diffusion processes. A radar frequency dependence of the diffusion coefficient associated with spectral shape has been observed [3]. In this study, a more precise characterization of this effect and the generalization of its observation are conducted.

## STATISTICAL STUDIES

A specific operation mode devoted to multi-frequency studies was run on the Stokkseyri (Iceland) radar between January 1995 and August 2000. This mode allows to have a quasi-simultaneous sounding at 9 MHz, 12 MHz, 14 MHz and 16 MHz and gives a large amount of echoes at each distinct frequency (about 800,000 points for each frequency). Fig.1 shows the contours associated with the relative echo occurence, for each frequency, as a function of range and spectral width.

Each contour represents a 35% level of points. One can notice an organization in frequency: as far as one consider far ranges (more than 1000 km), spectral width values are greater with decreasing frequency. Moreover, at 9 MHz, there is a trend which shows increasing spectral widths as range increases. This trend is observed but less obviously at 12 MHz and is quasi-negligible at higher frequencies.

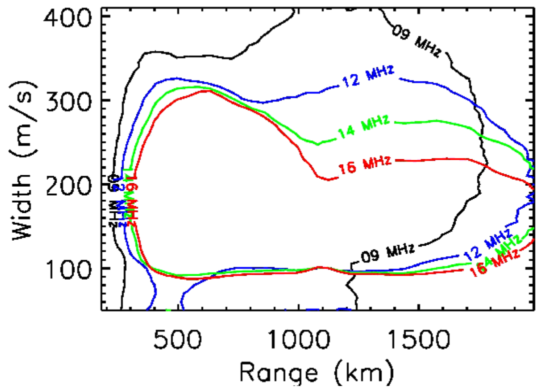


Fig. 1. Contour overplot associated to echo occurence distributions for 9MHz (black), 12MHz (blue), 14MHz (green) and 16MHz (red) in a range-width frame.

Several studies to show the generality of this effect have been performed. In order to consider the role of particular events, distributions have been studied for reduced databases. This effect has been tested for different months and has been shown to affect distributions independently of season. The influence of beam orientation i.e. alignment with the magnetic meridian has also been tested. Indeed, echoes from meridional or zonal beams are greatly and differently influenced by the global convection pattern. The effect was observed whatever beam orientation is considered and thus, is shown not to be caused by the large-scale global convection pattern or propagation conditions. Another study, involving six radars of the Northern hemisphere in standard operation mode has been performed in order to show the generality of the frequency effect. SuperDARN radars are supposed to operate at frequencies between 8 MHz and 20 MHz but in practice, sounding frequencies are around 10 MHz (depending on propagation conditions). The resulting database has been split into two ranges of frequencies: frequencies greater than 10 MHz and those lower than 10 MHz. The corresponding spectral width distributions show a systematically higher value at lower frequency whereas these distributions, plotted in a geomagnetic frame, exhibit almost the same characteristics. As in the previous study, several parameters were tested. These global studies enable to show that the influence of radar frequency on spectral width distributions is global, season independent and beam orientation independent. This shows that global geophysical effects cannot be given for responsible for the frequency effect observed, even if they influence the wave propagation.

## INTERPRETATION AND DISCUSSION

The evolution of spectral width values with range leads us to propose an interpretation in terms of a propagation effect within the turbulent ionosphere up to the point of back-scattering. Large-scale electronic density fluctuations are associated with refraction effects and will bent the wave to achieve perpendicularity. On the other hand, small-scale (of the order of the wavelength or smaller) density structures lead to more isotropic scattering processes and generate the back-scattered wave. Intermediate spatial scales (of the order of some hundreds of meters up to the radar cell size) deviate the wave mainly in the forward direction and result in amplitude and phase fluctuations of the wave front. These fluctuations can be seen as a wave front decorrelation and influence the spectral characteristics of the received signal. This interpretation enables to obtain an effect that depends on the propagation distance within the turbulent medium and on the radar frequency, as observed.

A propagation model, based on the Rytov's method is studied. It is implemented with Arcad-3 satellite data which provides horizontal electron density measurements in the auroral zones with a 8-m resolution. A representative one-dimensional density fluctuation power spectrum is then deduced in the range of spatial scales considered. Under the assumption of field-aligned cylindrical elongated irregularities, the corresponding power-law type three-dimensional power spectrum is computed in order to feed the propagation model. Considering a propagation perpendicular to the magnetic field in the turbulent medium, and under the hypothesis of forward scattering, wave front angle-of-arrival fluctuations are deduced. As the wave front is supposed to be scattered and Doppler shifted in frequency by a small-scale moving auroral irregularity, the angle-of-arrival fluctuations will result in Doppler shift fluctuations. The distribution of Doppler shift fluctuations directly influences the spectral width value deduced from the measurement, resulting in a spectral width enhancement. We study the influence of the propagation distance within the turbulent medium and the influence of the radar frequency to plasma frequency ratio over these fluctuations in order to explain the observed frequency effect and to deduce quantitative estimates of the spectral width enhancement due to propagation.

## REFERENCES


[1] C. Hanuise, J.-P. Villain, D. Grésillon, B. Cabrit, R. A. Greenwald, and K. B. Baker, "*Interpretation of HF radar ionospheric Doppler spectra by collective wave scattering theory*", Ann. Gepohys., 11, pp. 29-39, 1993.

[2] J.-P. Villain, R. André, C. Hanuise, and D. Grésillon, "*Observation of the high latitude ionosphere by HF radars: Interpretation in terms of collective wave scattering and characterization of turbulence*", J. Atmos. Terr. Phys., 58, p. 943, 1996.

[3] R. André, D. Grésillon, C. Hanuise and J.-P. Villain, "Auroral ionosphere plasma turbulence transport coefficient: Direct observations from radar coherent backscattering", *in 1998 International Congress on Plasma Physics*, edited by P. Pavlo, 22C, pp. 1126-1129, ECA, European Physical Society, 1998.