Spatial structure of high-latitude Pc5 pulsations via SuperDARN data

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1. Introduction

ULF waves propagating from the magnetosphere must pass through the ionosphere to be detected on the ground. Several studies have shown how signals detected on the ground are influenced by the anisotropic ionosphere [*Hughes,* 1974; *Hughes and Southwood,* 1976; *Glassmeier,* 1984]. In addition to a rotation of the wave disturbance vector, small scale features with scale sizes less than the ionospheric E region altitude ($\simeq 120km$) are smoothed. A simpler model using empirical formulations for ionospheric currents and the Biot-Savart law to obtain the ground magnetic signature was described by *Poulter and Allan* [1985]. This study was concerned with damping properties of FLRs and concentrated on latitudinal spatial structure. In the present paper we use a similar model to *Poulter and Allan* [1985] to investigate the two dimensional spatial structure of ULF waves.

Following the observations of large m-number signals in SuperDARN data [*Fenrich et al.,* 1995], a comparison of latitudinal and azimuthal spatial structure of ULF waves obtained from CANOPUS and SuperDARN was reported by *Ziesolleck et al.* [1998]. They showed several events where the FLR amplitude and phase structure measured by the radar was 'smeared' at the ground. This was explained in terms of spatial integration introduced by the ionosphere, modelled by *Hughes and Southwood* [1976] and *Poulter and Allan* [1985]. However, the discussion of the azimuthal structure focused on the phase where the m numbers obtained from the magnetometer data were found to be much smaller than those obtained from the radar. The data for 23 October, 1994 were presented as an example where the radar and magnetometer data did not agree too well. In the present work we re-examine the 23 October, 1994 data set and show that the spatial amplitude structure must also be included alongside with the phase structure in order to interpret the ground compared with radar (ionospheric) signals for both latitude and longitude.

2. Analysis of data

The time series, power spectra for selected ranges and phase data for 0232-0402 UT, 23 October, 1994 obtained from the SuperDARN radars at Saskatoon and Kapuskasing and the CANOPUS magnetometers are presented in Figures 6 to 9 of *Ziesolleck et al.* [1998]. The magnetometer data showed a dominant spectral peak near 1.7 mHz. Unfortunately, we found that the Saskatoon and Kapuskasing merged radar data had insufficient spatial coverage to be useful for comparison with the magnetometer data in this case. This does not allow us to restore a full horizontal vector of the Doppler velocity in the ionosphere, and we used data obtained from only the Saskatoon radar. Of course, one should always keep in mind that this is only line-of-sight velocities, and polarization effects might affect the results (e.g., *Fenrich et al.,* [1995] or *Ziesolleck et al.,* [1998]). However, in the absence of any other alternative we were forced to use these data as a zero approximation for the ULF wave field structure in the ionosphere. We have taken the data set for the time interval 0235-0335 UT, 23 October, 1994 from selected CANOPUS magnetometers and the Saskatoon radar.

The spatial variations of amplitude and phase for the 1.7 mHz spectral component are shown in Figure 1(a) and (b) respectively. The larger amplitudes appear at the western edge of the radar field of view and most certainly extend further westward. The small latitudinal extent is consistent with FLR structure. The phase shows a gradient in both latitude and longitude. The longitudinal phase change is used to determine the m number and would usually be interpreted as tailward propagation of Kelvin-Helmholtz generated waves at the magnetopause. From this figure, the resulting m-number in the ionosphere over RAB-BAC is $\sim$ 12. Furthermore, the amplitude of the radar signal is larger in the western region while the magnetometers are located more to the east. The phase differences obtained from the three ground magnetometers (Table 1) shows that the signal at RAB is leading which agrees, in sign, with the radar data. However, the phase difference with longitude is $\sim$ 3 times smaller for the magnetometer data, which gives an estimate of $m = 3-5$ for the RAB-BAC pair.

Table 1. Phase difference values for the H and D components of the three CANOPUS magnetometers

Stations	H	D
RAB-BACK	42^o	67^o
RAB-GILL	6^o	-47^o

3. Modelling of data

The aim of modelling the data is to highlight changes in m that occur due to ULF wave interaction with the ionosphere rather than providing a detailed mapping from the magnetosphere to the ground.

Approximating the data in Figure 1, the ionosphere signal with magnetic latitude was modelled using a Gaussian shaped amplitude function and an arctangent phase distribution arising from FLR properties as shown in Figure 2. The longitudinal distributions were also Gaussian in amplitude and linear in phase to model azimuthal propagation. Using the equations of *Poulter and Allan* [1985], the ionosphere signal was integrated to obtain the 2-D structure at the ground. Figure 3 shows the ionosphere and ground distributions of the ULF amplitude and phase along magnetic latitude and longitude across the amplitude maximum at -50^oE, 70^oN. In addition to the expected broadening of the amplitude, the phase has a flatter slope just beneath the region of largest amplitude (active region) and additional extrema near its edges. Detailed analysis of 1-D model curves obtained for different values of horizontal scale size of the active region in the ionosphere, L_i, shows that the ground phase gradient directly under the active ionospheric region becomes smaller than in the ionosphere, and distortions of the phase-amplitude distribution on the ground decrease with increase of the ratio L_i/H, where H is effective height of the ionospheric E-layer. Also, additional extrema of the phase distribution occur at the edges of the active region (Figure 3).These results show that azimuthal wavenumber discrepancies between the ground and ionosphere in both the magnitude and sign of m may occur. In general, the magnitude of the phase gradient on the ground should be smaller than in the ionosphere, which leads to smaller m values. If at least one of the ground sensors lies outside the footprint of the active ionospheric region, then even the sign of the phase gradient may be altered.

The 2-D structure calculated over is shown in Figure 4. The amplitude functions have 'smeared' as shown by previous authors. Also, there are two extrema of the phase gradient, one to the north-east and the other to the south-west of the center of the active region. Figures 3 and 4 show that while the azimuthal phase gradient (i.e., m-number) in the ionosphere does not depend on the longitude, its value on the ground depends on both the latitude and longitude structure.

4. Discussion

Modelling the 23 October, 1994 event in this paper has shown how radar and magnetometer data can give different estimates of ULF spatial structure. It is important to recognize that the ionosphere does not change the ULF wave spatial structure and yet there would be no alteration to the ground signal if the ionosphere were absent. The process is made clear if we follow an incident, anisotropic propagating (field aligned) shear Alfvén wave with a specific m number from the magnetosphere to the ground signal (Figure 5). In the lower ionosphere (where the conductivity is largest), the wave generates Hall currents which produce an isotropic (in the neutral atmosphere) propagating electromagnetic signal. The structure has the same m as in the magnetosphere. Since ground magnetometers do not have angular selectivity (wavelength $\gg$ sensor size), the magnetometer signal is an integrated view over the sky, each spatial contribution weighted according to the Bio-Savart law. It is here that m differs from the magnetosphere and ionosphere.

The 2-D spatial integration can explain the difference in azimuthal wave numbers obtained from radars and ground magnetometers. Ground measurements provide estimates of m which are always smaller than values in the ionosphere. The predictions of the model may be improved by obtaining estimates of the electric field polarization over the ionospheric spatial grid. This can be achieved by using data from two radars that cross beams and this is being pursued, as it has been done in [*Walker et al.,* 1979]. The most important finding is the confirmation that the spatial structure of both amplitude and phase of induced ionospheric currents affect the azimuthal characteristics of ULF waves estimated from ground magnetometer data. The latitudinal structure associated with FLRs is quite well understood. As more work is directed toward understanding ULF azimuthal structure it is important to realize that similar constraints apply in the longitudinal direction as well.

5. Conclusion

For many years, ground based magnetometer measurements of the spatial phase structure of ULF waves has been used to estimate their generation and propagation mechanisms. Even though it was known that the ionosphere smears the spatial structure, most studies have focused on the latitudinal aspects associated with FLRs. The modelling presented in this paper shows that (i) the total horizontal structure (amplitude and phase) is modified by the presence of the ionosphere, (ii) this occurs for both latitudinal and longitudinal structure and (iii) both the incident wave amplitude and phase spatial structure as well as the height of the current layer contribute to the ground signal. Thus, in using m-numbers measured by ground based magnetometers, one should keep in mind that they could be significantly underestimated or even have the wrong sign. SuperDARN provides data that can quantify the spatial distribution of both amplitude and phase and should be used where possible with any ground data when azimuthal wave numbers are inferred.

References

Fenrich, F.R., J.C. Samson, G. Sofko, and R.A. Greenwald, ULF high- and low-m field line resonances observed with the Super Dual Auroral Radar Network, *J. Geophys. Res., 100,* 21535, 1995.

Glassmeier, K-H., On the Influence of Ionospheres with Non-Uniform Conductivity Distribution on Hydromagnetic Waves, *J. Geophys. Res., 89,* 125, 1984.

Hughes, W.J., The effect of the atmosphere and ionosphere on long period magnetospheric micropulsations, Planet. Space Sci., *22,* 1157, 1974.

Hughes, W.J., and D.J. Southwood, The screening of micropulsation signals by the atmosphere and the ionosphere, *J. Geophys. Res., 81,* 3234, 1976.

Poulter, E.M., and W. Allan, Transient ULF pulsation decay rates observed by ground based magnetometers: The contribution of spatial integration, Planet. Space Sci., *33,* 607, 1985.

Walker, A.D.M., Greenwald, R.A., Stuart, W.F. and Green, C.A., STARE Auroral Radar Observations of Pc5 Geomagnetic Pulsations, *J. Geophys. Res., 84,* 3373, 1979.

Ziesolleck, C.W.S., F.E. Fenrich, J.C. Samson, and D.R. McDiarmid, Pc5 field line resonance frequencies and structure observed by SuperDARN and CANOPUS, *J. Geophys. Res., 103,* 11771, 1998.

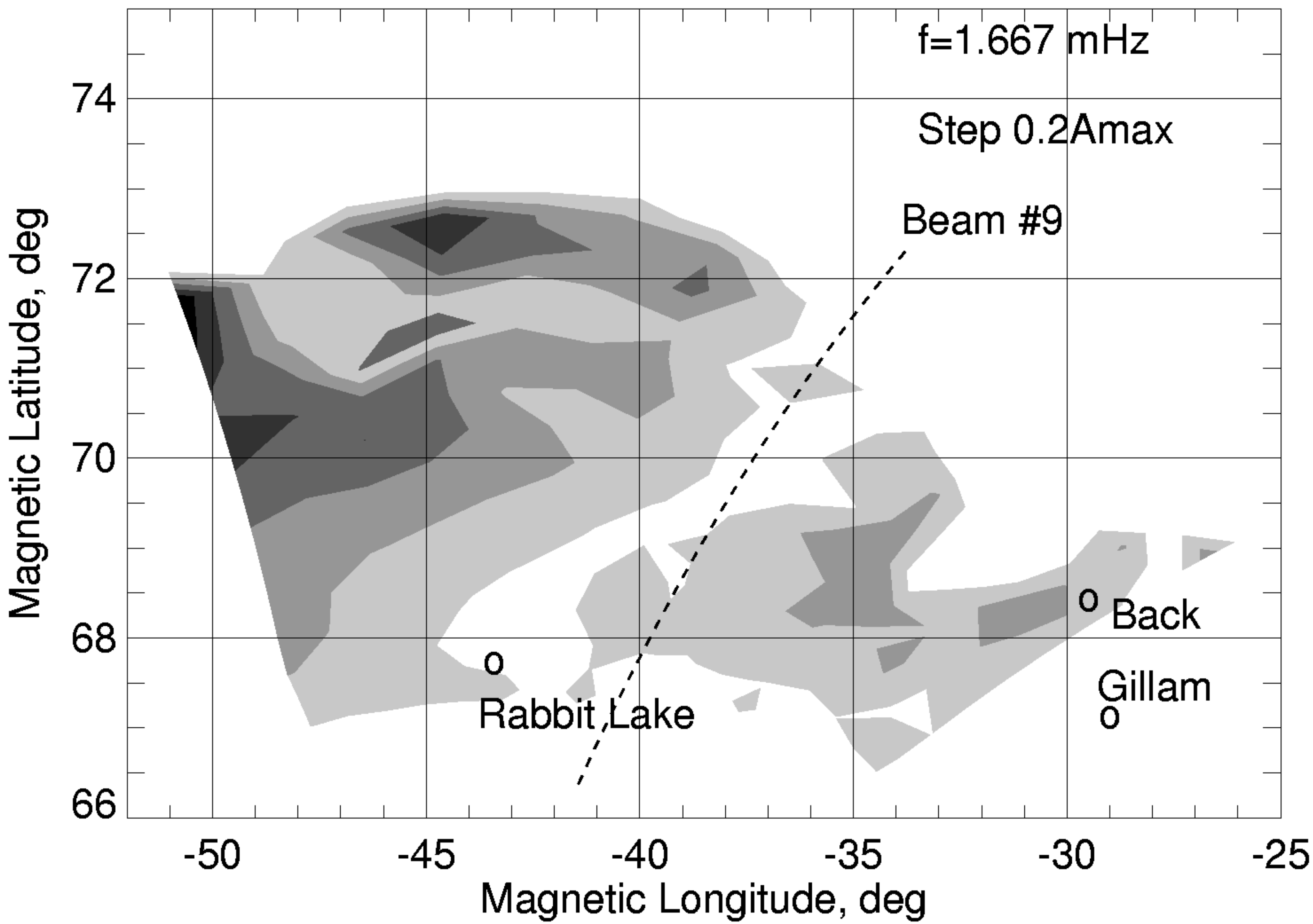

Figure1a. The spatial amplitude for the 1.7 mHz Doppler velocity data from Saskatoon for 0235-0335 UT, 23 October, 1994. The westward FLR region is seen around 70^{o} latitude.

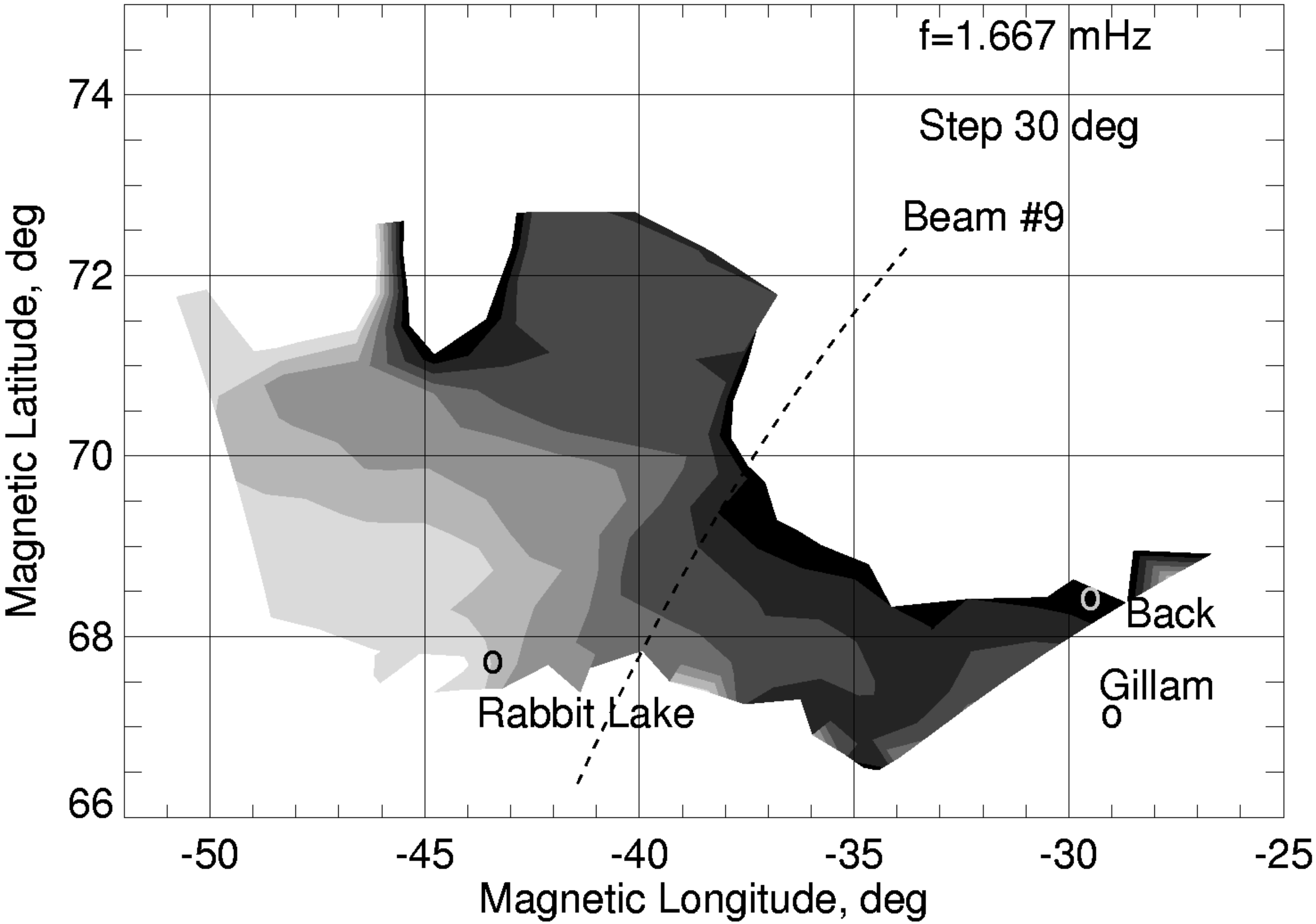

Figure 1b.The spatial phase for the 1.7 mHz Doppler velocity data from Saskatoon for 0235-0335 UT, 23 October, 1994. The lighter colour means a higher phase value, i.e., phase decreases estward.

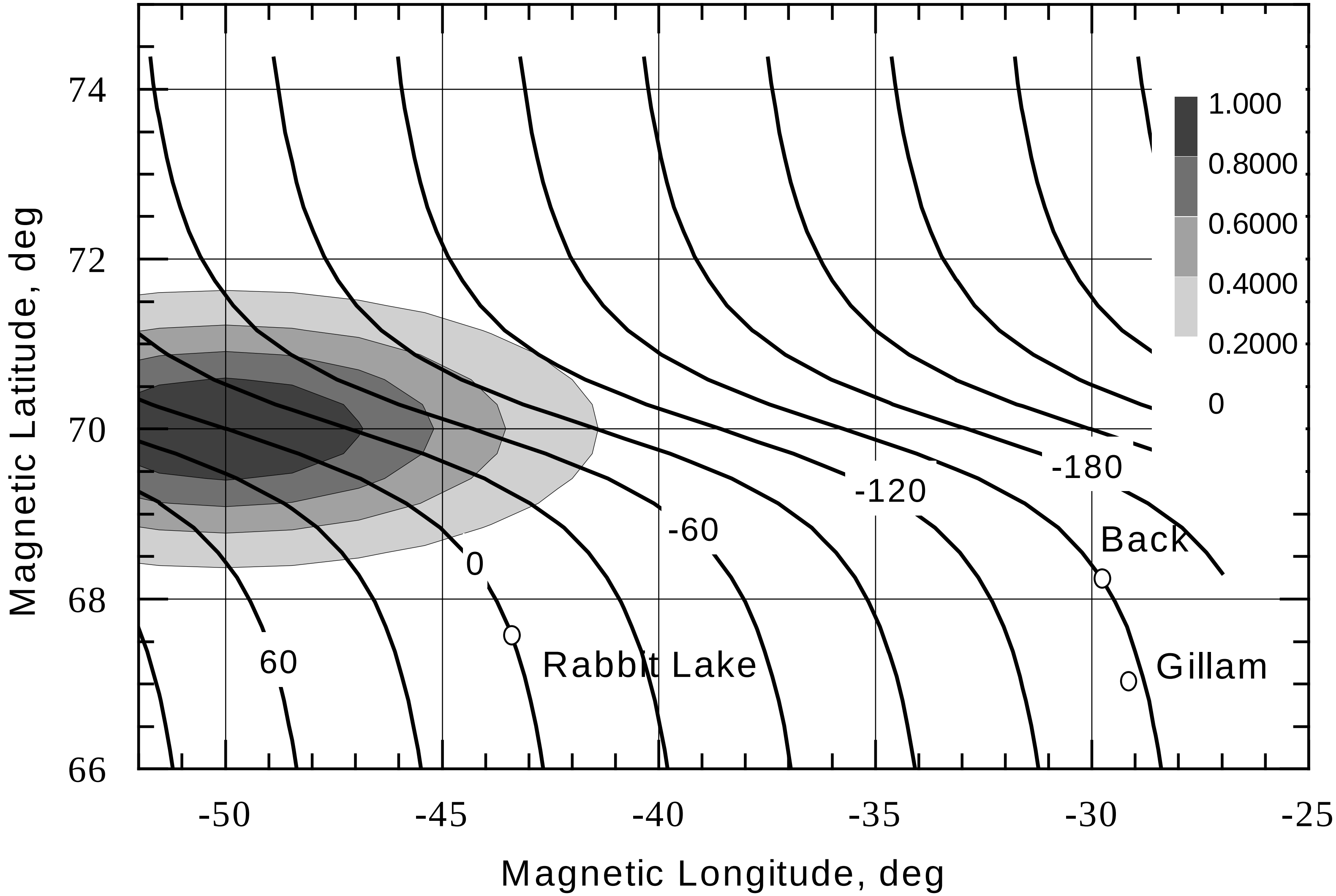

Figure 2. The modelled ionospheric data which reproduce the main features of the data in Figure 1.

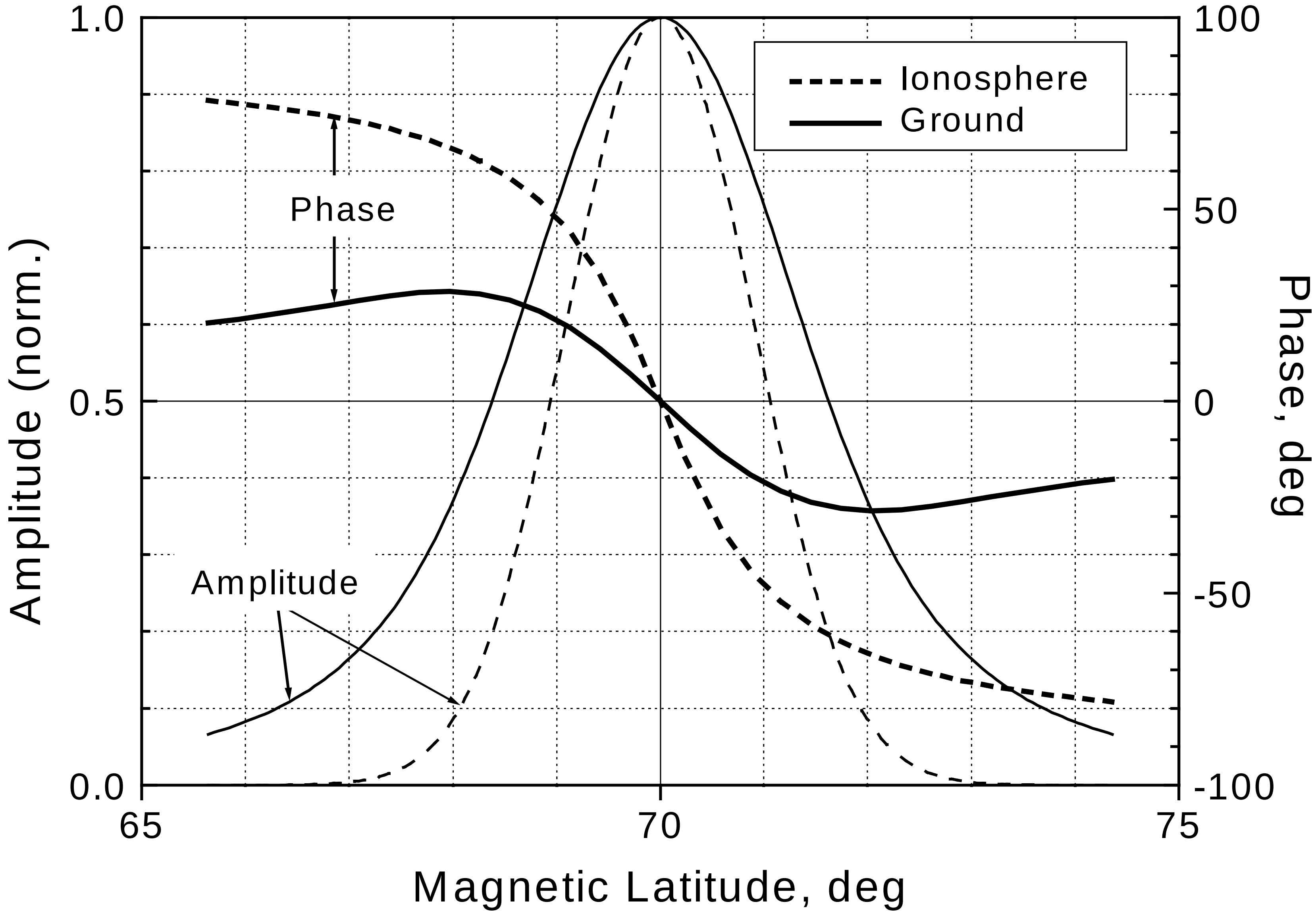

Figure 3a.Modelled 1D ionospheric and ground amplitude-phase distributions along magnetic latitude.

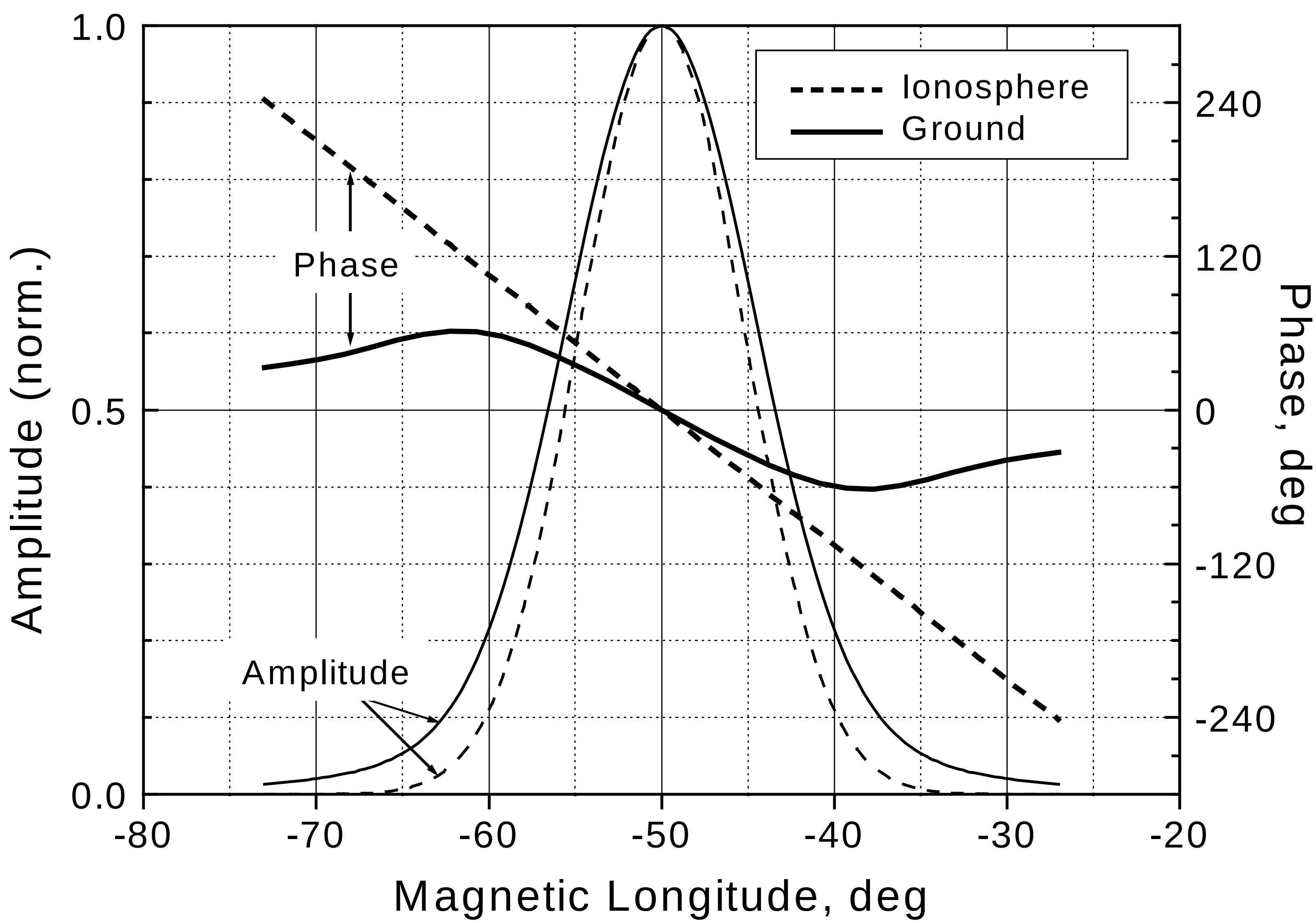

Figure 3a.Modelled 1D ionospheric and ground amplitude-phase distributions along magnetic longitude.

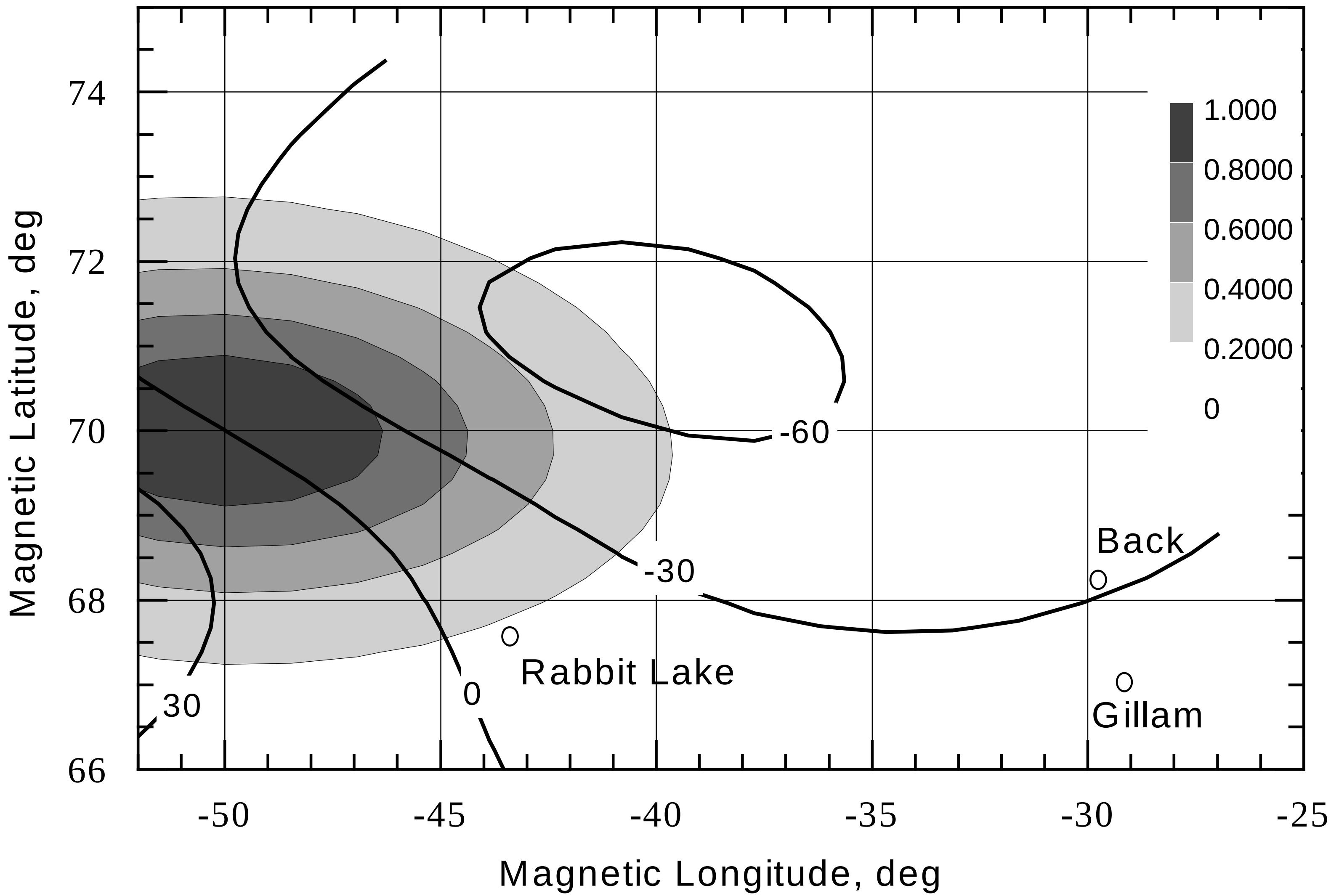

Figure 4. The expected amplitude and phase distribution seen at the ground due to the data in Figure 2. Both the amplitude and phase of the signal in the ionosphere contribute to the spatial distribution seen at ground level.

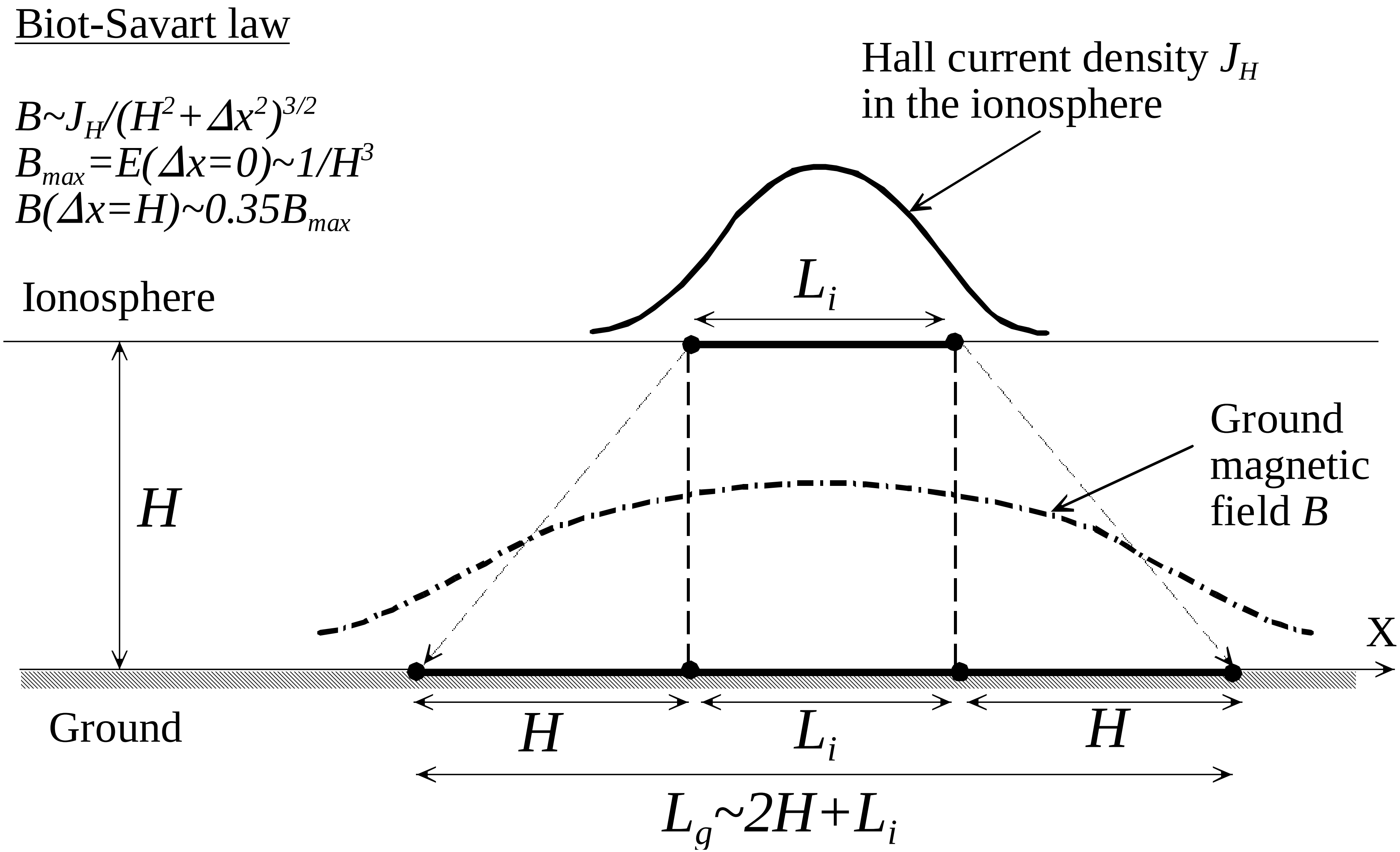

Figure 5. Sketch of ULF wave amplitude and phase modification due to the presence of the ionosphere.