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Doppler Shift of Auroral Backscatter Signals*

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Abstract. The analysis of backscatter signals recorded during the observation of radio auroras on Feb. 23 and Feb. 24/25, 1971 at the receiving station Lycksele and the comparison of these data with values derived from parameters of the disturbed polar E-layer indicate, that the measured Doppler shift Δf of backscatter echoes is caused by moving field-aligned column-like inhomogeneities or by plane waves generated by the drift gradient instability. Furthermore at the same time the condition which leads to the excitation of wavelike electron density inhomogeneities by the two-stream instability was fulfilled, but the angular interval in which these density waves can propagate was too small to explain a scatter process of radio waves in the direction parallel to the antenna of the receiving station Lycksele. In addition to this, Doppler spectra of the observed scattered signals are presented.

Key words: Polar E-Region — Radio-Aurora — Backscatter Measurements — Scatter Mechanism — Electron Density Inhomogeneities — Frequency Shift.

Introduction

The backscattering of HF- and VHF- radio waves during earth magnetic disturbances in connection with auroral occurrences is controlled by the generation and propagation of electron density inhomogeneities, which depend on the velocities of charged particles. Therefore, in the first part of this paper the calculation of the velocities of ions and electrons will be outlined briefly. (For details see Czechowsky, 1974). In the second part three models of possible scatter mechanisms will be compared with each other, in order to explain and discuss the Doppler shift of the backscattered radio signals which are observed during radio aurora events.

Experimental Arrangement

For about five years auroral observations have been carried out by the institute at Lindau with transmitting and receiving stations in Norway and

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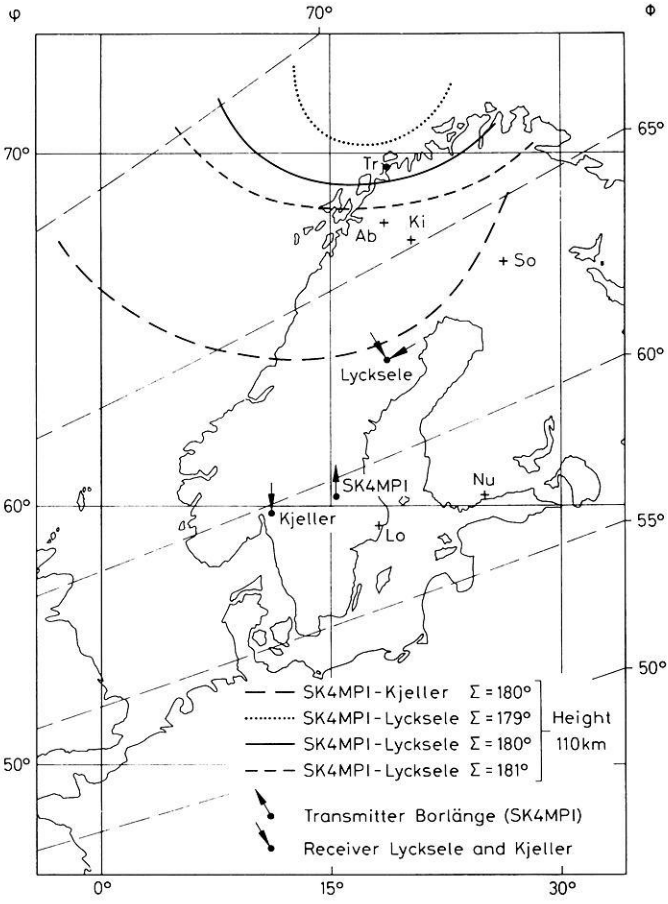

Fig. 1. Location of transmitting and receiving stations with the corresponding antenna directions (arrows), and the backscatter curves for all pairs of stations. Magnetic observatories: Tr = Tromsö, Ab = Abisko, Ki = Kiruna, So = Sodankylä, Ly = Lycksele, Lo = Lovö, Nu = Nurmijärvi

Sweden and with optical instruments at Tromsö. The geographical location of these stations is given in Fig. 1.

The transmitter SK4 MPI near Borlänge, Sweden, on a frequency of 145.96 MHz has a power output of about 150 Watts. During radio aurora events the amplitude and the Doppler shift of the backscattered signals are recorded at the receiving stations Oslo-Kjeller (Norway) and Lycksele (Sweden). The Borlänge-Lycksele pair of stations is particularly well located for this purpose because the backscatter curve (cf. Czechowsky, 1966) overlaps that part of the E-layer which can be seen directly from

Tromsö. There the intensities and structures of visible auroras were recorded with a filter photometer and an all-sky-camera.

Movements of Charged Particles

The frequency shift Δf of backscatter echoes of up to ±500 Hz, observed during radio auroras is caused by the motion of the auroral structures. These scattering centers can be described as column-like inhomogeneities or as electron density waves (Booker, 1956; Farley, 1963; McDiarmid and McNamara, 1969; Knox, 1972; Unwin and Baggaley, 1972). The excitation and propagation of these auroral structures depend on the velocities of ions and electrons, which can be derived from the equation of motion for a plasma in a magnetic field (cf. Lucas and Schlüter, 1954) taking into account the special conditions in the disturbed E-layer. The resulting velocities of the charged particles depend on the electron density, the collision frequencies, the conductivities and the electric field strength. These quantities can be derived from the parameters of the disturbed polar E-region.

In this analysis the maximum electron density is deduced from the absolute intensity of the negative nitrogen bands of visible auroras. According to Omholt (1955) the total photo emission of the negative nitrogen band observed at the surface of the earth is proportional to the square of the maximum electron density. The height distribution of the electron density is approximated by Chapman profiles.

In order to calculate the collision frequencies it is necessary to introduce an atmospheric model since, in addition to the electron density, the collision frequencies depend on the temperature, the neutral gas density and the molecular weight. Then, from the gyrofrequencies, the collision frequencies and the electron density, the Pedersen-, the Hall- and the parallel conductivities can be derived. In the entire height range the parallel conductivity ie several orders of magnitude greater than both the other ones. Hence the component of the electric field strength parallel to the magnetic field B is small compared to the component perpendicular to B so that the electric field strength can be assumed independent of height. In this case the electric field strength can be calculated from Ohm's law using the height integrated values of the current density and of the conductivities.

The height integrated current density can be derived from the measured disturbance vectors ΔH, ΔD, and ΔZ taken from the magnetograms of several observatories located in a geomagnetic north-south direction. Based on a variable model distribution, nine parameters of an equivalent current system can be determined using an iterative method, such that the calculated and measured components of the magnetic field are in good agreement. Details of this method are given by Czechowsky (1971). Thus all important parameters are known for the calculation of the velocities of charged particles.

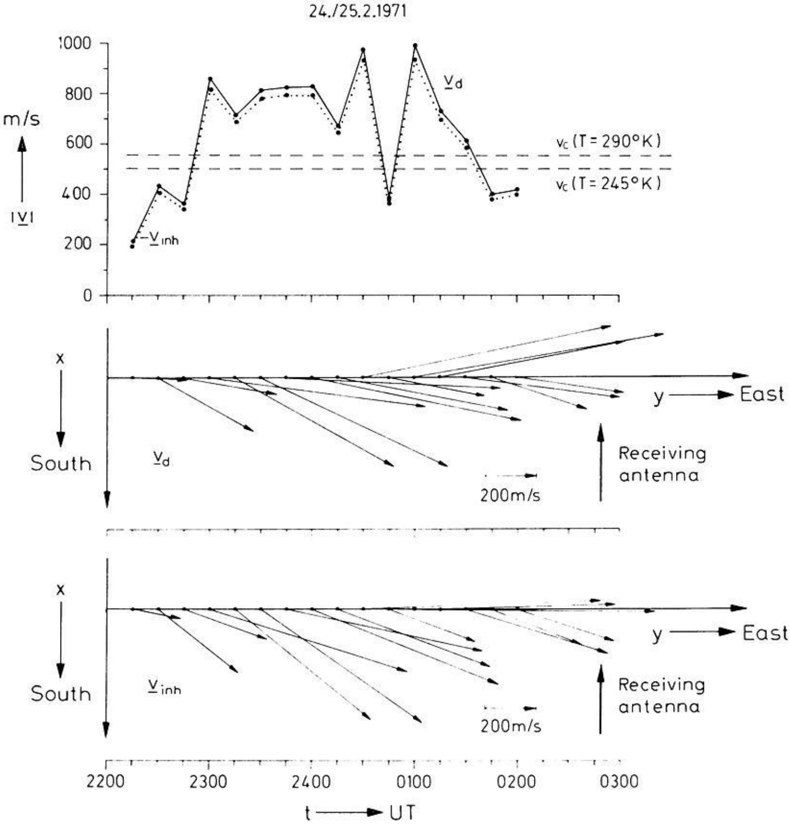

Fig. 2. Magnitude and direction of the relative drift velocity v_d and of the velocity of inhomogeneities v_{inh} on Feb. 24/25, 1971

Excitation and Propagation of Electron Density Waves and Inhomogeneities

By radar observations Bowles *et al.* (1963) discovered structures in the equatorial E-layer in a height range from 90—130 km which were interpreted by Farley (1963) as electron density waves caused by the two-stream instability. Since inhomogeneities in the electron density which are coupled to a current system are also observed in the polar E-layer it was suggested that the excitation mechanisms are identical and that Farley's results can be applied to polar regions. These wavelike inhomogeneities are generated in a limited angular range, if the component of the electron-ion drift velocity v_d exceeds a critical threshold value v_c which is somewhat greater than the ion thermal velocity. These excited primary density waves propagate perpendicular to the ambient geomagnetic field.

Two radio auroral events were analysed. One will be discussed in detail and is shown in the following figures. First the relative drift velocity v_d is calculated and presented in Fig. 2. In the upper diagram the magnitude of v_d is plotted at 15 min. intervals for Feb. 24/25, 1971 (solid line). These values exceed the critical velocity v_c from about 2300—0130 UT except at 0045 UT. On the other hand the components of v_d parallel to the direction of the receiving antenna which is almost identical with the direction of the bisector of the scattering angle in this special case are shown in the second diagram. These values are always smaller than 360 m/s which is clearly below the necessary threshold to excite wavelike inhomogeneities in that direction. In this special case this model yields no explanation for the strong auroral backscatter echoes which were observed at Lycksele during that period. Therefore another type of scattering inhomogeneities ought to exist which is not coupled to a direction depending exciting mechanism.

The study of field-aligned column-like inhomogeneities indicates that the scatter process of radio waves is not influenced by the generation or by the propagation of these structures. The spatial distribution of the scattered power is characterised by a cone with the axis parallel to the local geomagnetic field lines. In this case a backscatter communication between the transmitter and the receiver can be expected whenever field-aligned structures occur in the region of the corresponding backscatter curve. The velocity of this type of inhomogeneities in a plasma under various conditions has been studied by Baker and Martyn (1953), Clemmow and Johnson (1959) and Kato (1963). The propagation direction of these structures is perpendicular to the electric and to the magnetic field strength. For the event on Feb. 24/25, 1971 the variation of this velocity v_{inh} is presented in the upper part of Fig. 2 by the dotted line and differs only slightly from the relative drift velocity v_d, whereas the propagation direction shown in the lower diagram differs from that of v_d by up to 20°.

For a comparison the velocity components of these inhomogeneities parallel to the receiving antenna and the velocity values derived from the Doppler shift of the scattered signals received at Lycksele are given in the upper part of Fig. 3. The error bars represent the measured values including the superimposed noise level and the dashed line shows the calculated values. A positive sign indicates that the scattering structures are moving in a direction towards the receiver. On Feb. 24/25 the magnitude and the variation of the measured and calculated values agree in several cases. In addition to this the dotted line represents the component of the electron drift velocity parallel to the receiving antenna. According to Whitehead (1969), Knox (1972) and Unwin and Baggaley (1972) field-aligned plane wave irregularities can be excited by the drift gradient instability in a limited angular range. In this range which depends on how much the threshold for the onset of the instability is exceeded the magnitude of

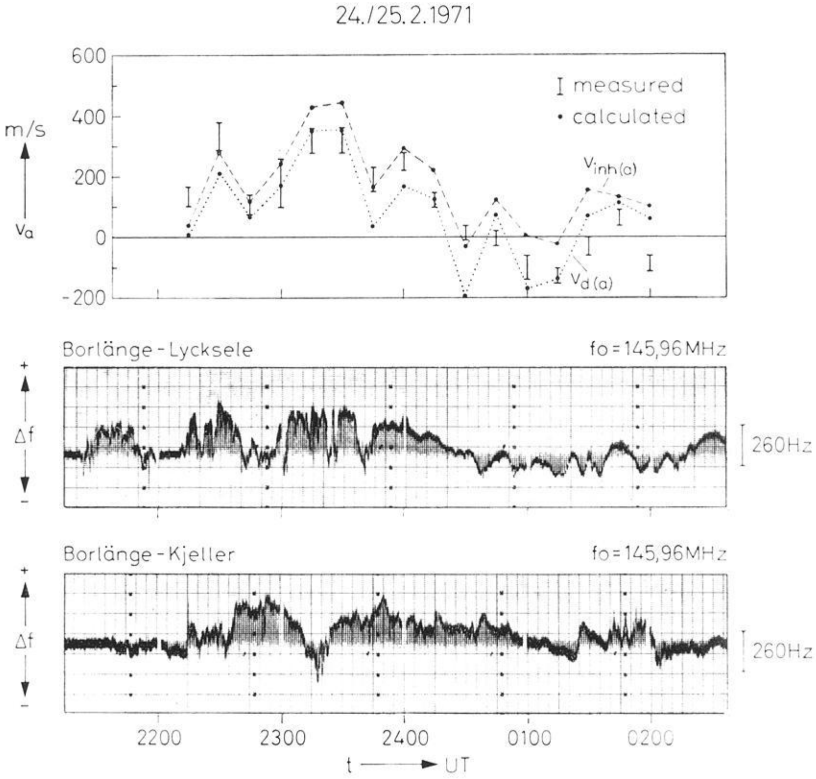

Fig. 3. Velocities derived from Doppler shift recordings on Feb. 24/25, 1971 in comparison with calculated velocity values v_d and v_{inh}

the wave phase velocity is equal to the component of the electron drift velocity parallel to the direction of propagation. The threshold value is a function of the radio wave frequency, of the electric field strength, and of the ionisation density gradient. In this investigation we can only compare the predicted velocity of the waves generated by the drift gradient instability with our measurements. Since the complete set of data of the presented event was not available, it was impossible to examine whether the threshold condition was fulfilled or not. Therefore we cannot finally prove whether the measured backscatter signals and the Doppler shift are caused by this type of inhomogeneities. The recordings shown in the lower diagram present the Doppler shift variation of the scattered signals with maximum field strength.

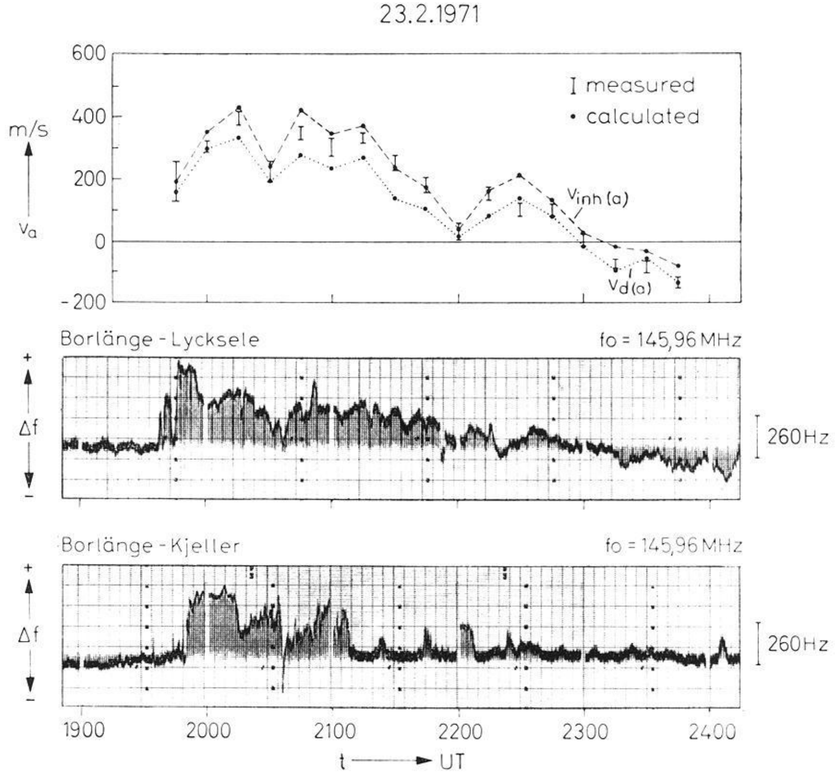

Fig. 4. Velocities derived from Doppler shift recordings on Feb. 23, 1971 in comparison with calculated velocity values v_d and v_{inh}

The second radio aurora event on Feb. 23, 1971 was analysed in the same way and the results are shown in Fig. 4. Measurements and calculations agree very well over a period of about 4 hours.

Both examples demonstrate that two types of inhomogeneities may cause the observed Doppler shift. Differences between the measurements and the calculations may result from the fact that the neutral gas velocity was neglected in this analysis. More details about the above mentioned mechanisms are hoped to be available next year when our narrow beam rotating antenna system is in operation and when the measured Doppler shift is Fourier-analysed.

First results of analysed Doppler measurements, which were observed on Dec. 4, 1972 at about 2207 UT are given in Fig. 5. Both examples present

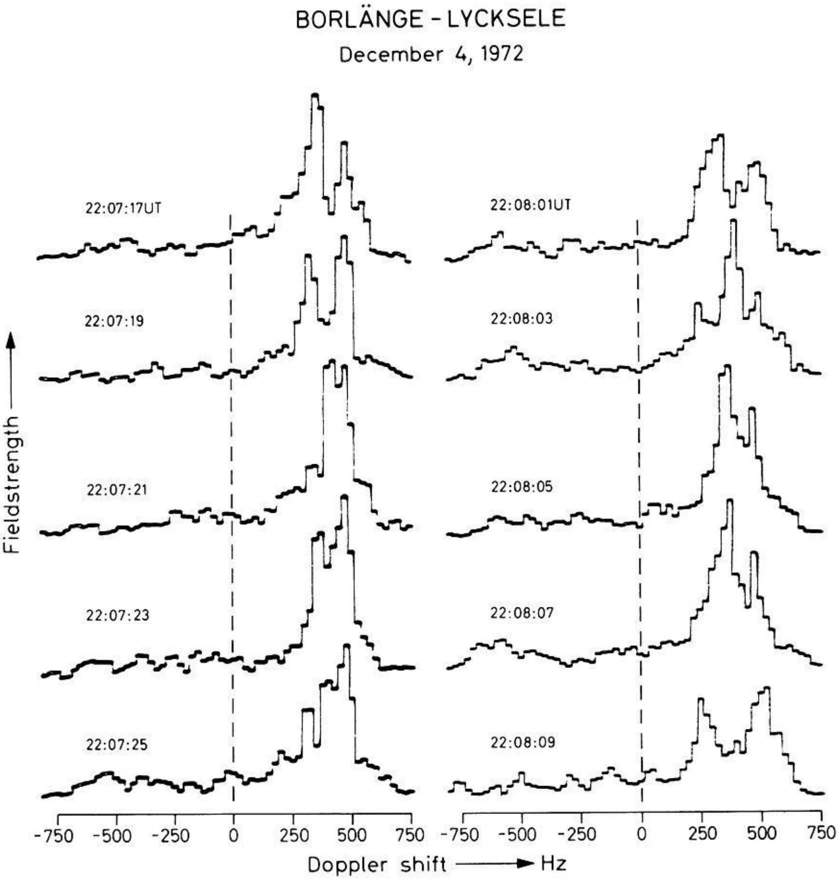

Fig. 5. Two examples of Doppler spectra observed on Dec. 4, 1972 at about 2207 UT

five spectra in intervals of 2s, in this case with two pronounced maxima. One peak, at a constant frequency shift of about 475 Hz, has the character of a line spectrum, which can be caused by electron density waves excited by the two-stream instability. The second maximum of each spectrum varies between 200 and 450 Hz. This part of the Doppler shift may result from the movement of field-aligned inhomogeneities or from plane waves generated by the drift gradient instability.

More details may be derived from the Doppler shift measurements carried out with the projected rotatable antenna system. From the predicted threshold values and from the frequency shift of the received signals as a function of the angle of incidence conclusions can be drawn on the source of the inhomogeneities.

References

Baker, W. G., Martyn, D. F.: Electric currents in the ionosphere. I. The conductivity. Phil. Trans. Roy. Soc. London, Ser. A, No. *913*, 281—294, 1953

Booker, H. G.: A theory of scattering by nonisotropic irregularities with application to radar reflections from aurora. J. Atmospheric Terrest. Phys. *8*, 204—221, 1956

Bowles, K. L., Balsley, B. B., Cohen, R.: Field-aligned E-region irregularities identified with acoustic plasma waves. J. Geophys. Res. *68*, 2485—2501, 1963

Clemmow, P. C., Johnson, M. A.: A contribution to the theory of the motion of weak irregularities in the ionosphere. J. Atmospheric Terrest. Phys. *16*, 21—36, 1959

Czechowsky, P.: Analyse von Rückstreubeobachtungen ultrakurzer Wellen an Polarlichtern. Kleinheubacher Ber. *11*, 165—171, 1966

Czechowsky, P.: Calculation of an equivalent current system in the polar E-region. Radio Science *6*, 247—253, 1971

Czechowsky, P.: Movement processes of auroral structures. J. Atmospheric Terrest. Phys. *36*, 61—77, 1974

Farley, D. T.: A plasma instability resulting in field-aligned irregularities in the ionosphere. J. Geophys. Res. *68*, 6083—6097, 1963

Kato, S.: Theory of movement of irregularities in the upper atmosphere. Planetary Space Sci. *11*, 823—830, 1963

Knox, F. B.: A theory of discrete radio aurora. J. Atmospheric Terrest. Phys. *34*, 747—764, 1972

Lucas, I., Schlüter, A.: Plasmatheorie der Ionosphäre. A. E. Ü. *8*, 27—30, 1954

McDiarmid, D. R., McNamara, A. G.: A physical model of a radio aurora event. Can. J. Phys. *47*, 1271—1281, 1969

Omholt, A.: The auroral E-layer ionisation and the auroral luminosity. J. Atmospheric Terrest. Phys. *7*, 73—79, 1955

Unwin, R. S., Baggaley, W. J.: The radio aurora. Ann. Géophys. *28*, 111—127, 1972

Whitehead, J. D.: Low frequency plasma instabilities in the ionosphere. J. Atmospheric Terrest. Phys. *30*, 1563—1579, 1968

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