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GROUND OBSERVATIONS OF KINETIC ALFVÉN WAVES

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ABSTRACT

Ground observations of locally confined, very intense, drifting current systems by the EISCAT magnetometer cross in correlation with GEOS 2 measurements will be explained in terms of kinetic Alfvén waves. In the ground based magnetograms the events are characterized by strong pulsations with amplitudes in the horizontal component up to 1000 nT and periods of about 300s and longer. They occur in the evening hours adjacent to the poleward side of the Harang discontinuity with the onset of a substorm. At the same time the inner edge of the plasma sheet passes the GEOS 2 position, magnetically conjugate to ground stations. The common features of four events during Nov and Dec 1982 will be discussed.

INTRODUCTION

During recent years several attempts have been made to analyze the formation mechanism of high latitude Pi2 pulsations (Samson, 1982). In all models shear Alfvén waves play an important role. They transmit any dynamic change of the electric potential distribution in the magnetosphere-ionosphere system along magnetic field lines. If the perpendicular scale lengths of the waves are comparable to the ion gyroradius or the electron inertial length then the parallel electric field becomes strong enough to accelerate particles up to a few keV. These waves are called kinetic Alfvén waves and have been analyzed in connection with the generation of auroral arcs by Fejer and Kan (1969), Goertz and Boswell (1979), and Lysak and Dum (1983). Now ground based observations near the Harang discontinuity and coherent measurements made on GEOS 2 provide in our opinion direct evidence of kinetic Alfvén waves.

The event on 2 November 1982 is as far the best analyzed of the four events presented here. A detailed description of a set of ground observations of this event is given by Lühr et al. (1984).The publication of the associated GEOS 2 observations together with a comparison with theoretically derived quantities is in preparation by Klöcker et al. (1984). The aim of this paper shall be to derive the general characteristics of the pulsation events on ground and on GEOS 2 in order to get a more reliable picture of the processes for their physical interpretation.

OBSERVATIONS

The Figures 1 to 4 show stacked plots of observations made on ground and on GEOS 2 during four time intervals on Nov and Dec 1982. Beginning at the top the figures combine plots of the energetic particle flux, the integrated power of the magnetic flux variations in the frequency band from 0.32 to 1.5 Hz in the z-direction, and the magnetic field component DX in the magnetospheric equatorial plane. The measurements were made on GEOS 2 in the local time sector of Kiruna. The lower panels show the horizontal north component of the magnetic field on ground at one station of the EISCAT magnetometer cross. Fig. 1 also containes the riometer registration of the Finnish station Rovaniemi.

The configuration of the ionospheric currents of the individual pulses can be derived from the latitudinal magnetic profiles shown in the Figures 5 to 8. The shape of the X- and Z-component can in most cases be explained by a narrow westward directed current band on the poleward side adjacent to a broad eastward directed current. Typical values for the width of the narrow ionospheric currents and their total strength are 30 ± 20 km and (3±1) · 10^5A, respectively.

Comparing all four ground observed pulsation events we can realize the following common features:

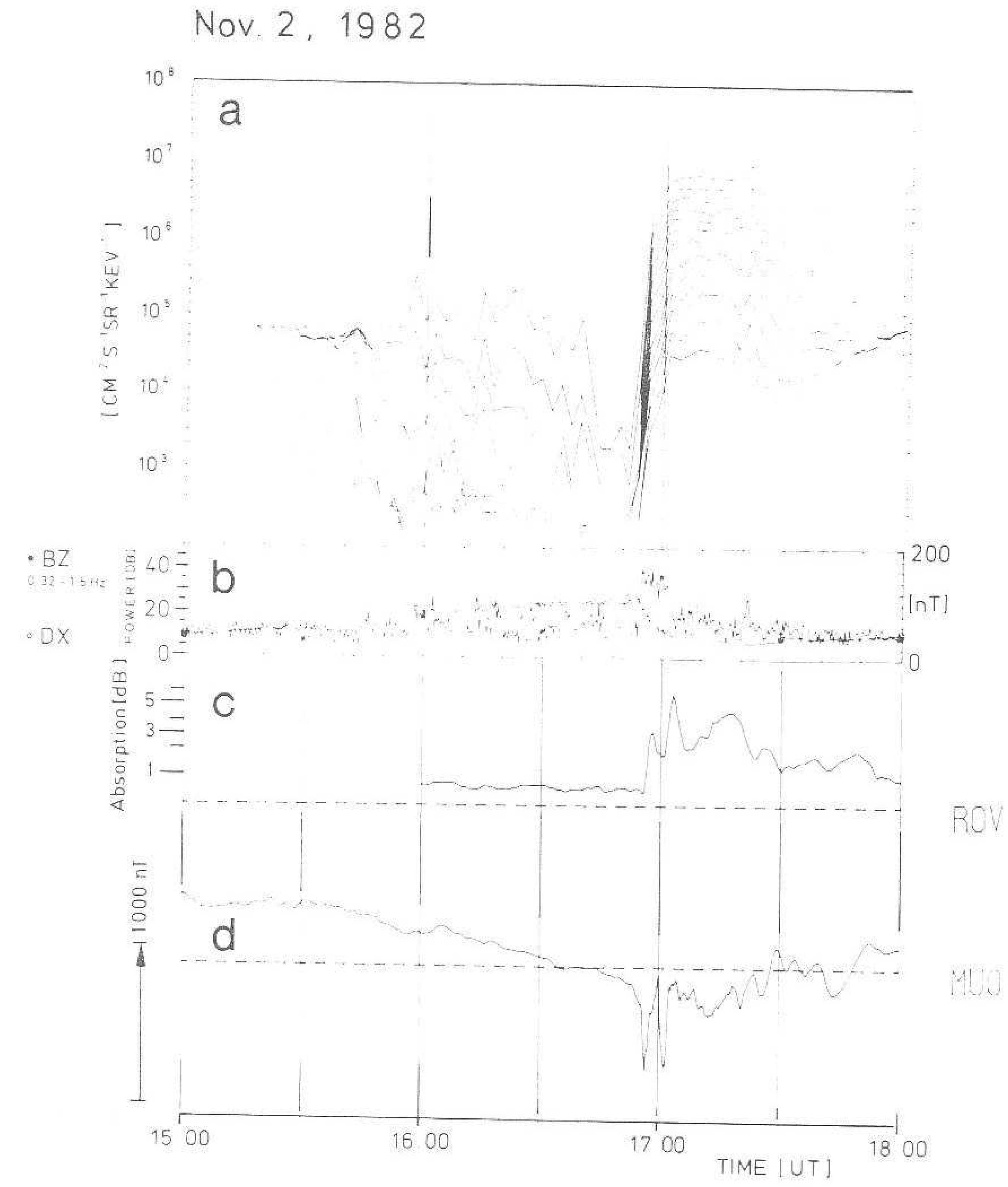

Fig. 1. Stacked plot for the pulsation event on 2 Nov 1982. a The electron flux measurements on GEOS 2 between 20 and 200 keV. GEOS 2 was located in the same local time sector as the ground stations. b The integrated power of the magnetic ULF waves between 0.32 and 1.5 Hz in the z-direction, marked by asterisks. The other curve shows the magnetic field component DX in the equatorial plane. c The radio noise absorption curve of Rovaniemi in northern Finnland. d shows the north component of the magnetic field on ground.

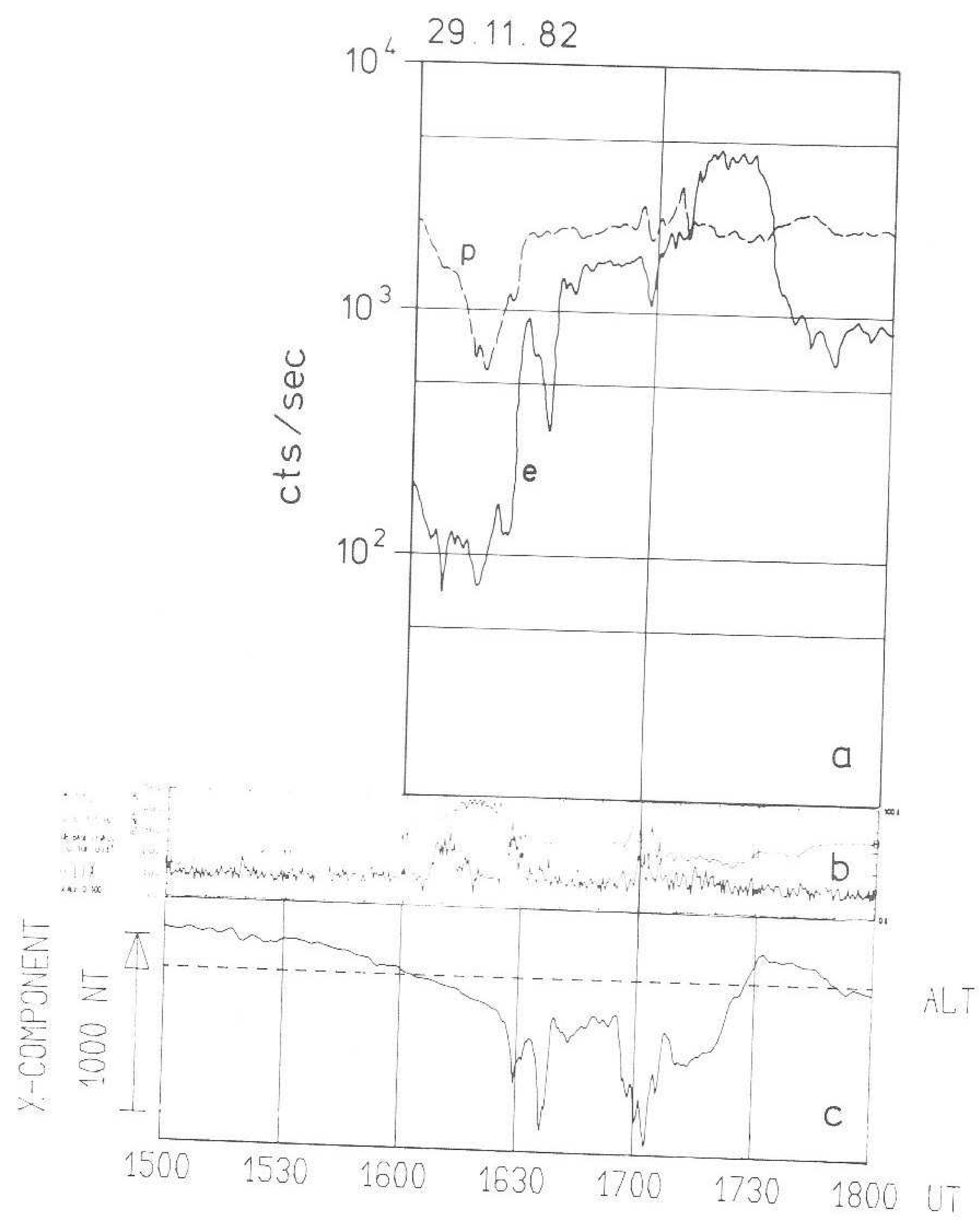

Fig. 2. Panel a shows the electron and proton fluxes for the event on 29 Nov 1982 at the geostationary orbit in the local time sector of Kiruna. b is equal to Fig. 1b, and c equal to Fig. 1d.

a) The time period of the pulsations ranges from 250s to 400s. Shorter periods near 150s can also be identified, especially on 11 Dec.
b) The amplitude of the horizontal disturbance vector can reach 1000 nT. The strongest observed event happened on 2 Nov 1982.

c) All events occur around 1700 UT, i.e. around 2000 MLT. During the whole very disturbed winter 1982/83 we could not find any similar variations at other local time periods.
d) The magnetosphere is in an excited state indicated by a positive deflection in the magnetic north-component in the afternoon sector, in most cases a well developed Harang discontinuity in the ground magnetic field signature, and in addition at the geostationary orbit a tail-like imposed magnetic field. On 11 Dec 1982 these characteristics are less expressed. But this event differs from the others in another aspect, which will be mentioned later. On 20 Dec 1982 the southern-more stations show a strong positive X-component.
e) The pulsations occur in the vicinity of the Harang discontinuity on its poleward side. Projected along the field lines on the equatorial plane this is the region with earthward directed plasma convection.
f) The magnetic perturbations on ground originate from almost two-dimensional narrow ionospheric current bands directed to west or north-west along the Harang discontinuity. In most cases the mean horizontal disturbance vector points 10^{o} to the west of the magnetic south direction. Only for the event on 2 Nov this angle made 45^{o}.
g) The ionospheric currents drift as well in poleward as in equatorward direction with velocities up to 2.5 km/s. This is true for 2 Nov. For the other events v_d is much smaller.
h) The drifting current bands are accompanied by locally confined enhancements in ionization, which was directly observed by riometer stations on 2 Nov.
i) Except the event on 11 Dec the onset of the pulsations coincides with the beginning of a substorm. Due to the limited space the plots of Pi2 registrations of a mid-latitude station can not be shown.
j) At the same time GEOS 2 is passed by the inner edge of the expanding plasma sheet and observes the reconfiguration of the dipolar field.

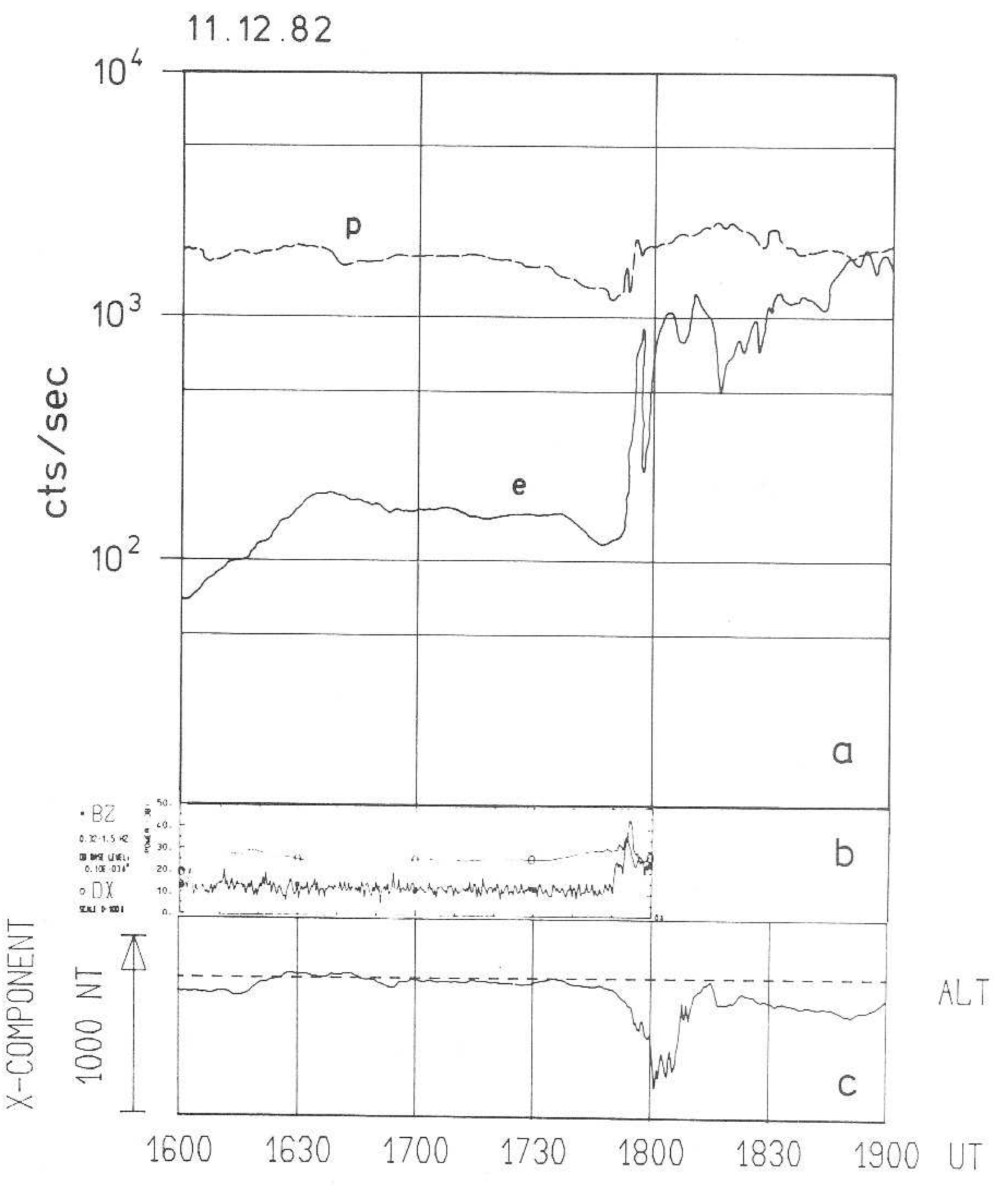

Fig. 3. Same as Fig. 2 for 11 Dec 1982.

DISCUSSION

A comparison of observational results of the event on 2 Nov 1982 with derived quantities from Hasegawa's (1976) theory have led to an excellent agreement. In this theory Hasegawa explaines the generation of narrow structures like auroral arcs and small-scale ionospheric current bands in terms of resonant mode coupling of kinetic Alfvén waves to large-scale MHD surface waves. Since the coupling does not depend on the frequency of the surface wave the nearly constant $\partial B/\partial t$ of the reconfiguration of the dipolar field at the inner edge of the expanding plasma sheet can be regarded as the source of the Alfvén waves.

The pulsation events presented here support our interpretation. In all cases the main conditions for the excitation of kinetic Alfvén waves are given, i.e. a strong density gradient of warm plasma near the equatorial plane, and a large-scale magnetic field variation along this boundary layer. These observations coincide with the onset of strong irregular pulsations on ground.

Furthermore the kinetic Alfvén waves propagate also across the ambient magnetic field, but in the warm plasma case exclusively into the higher-density side of the boundary sheet (Goertz, 1983). This is in agreement with the observations. The pulsations occur only on the poleward side of the Harang discontinuity. Their drift velocity relative to the earth's surface results from the difference between the velocity of the earthward plasma sheet convection and the oppositely directed propagation of the kinetic Alfvén waves. Depen-

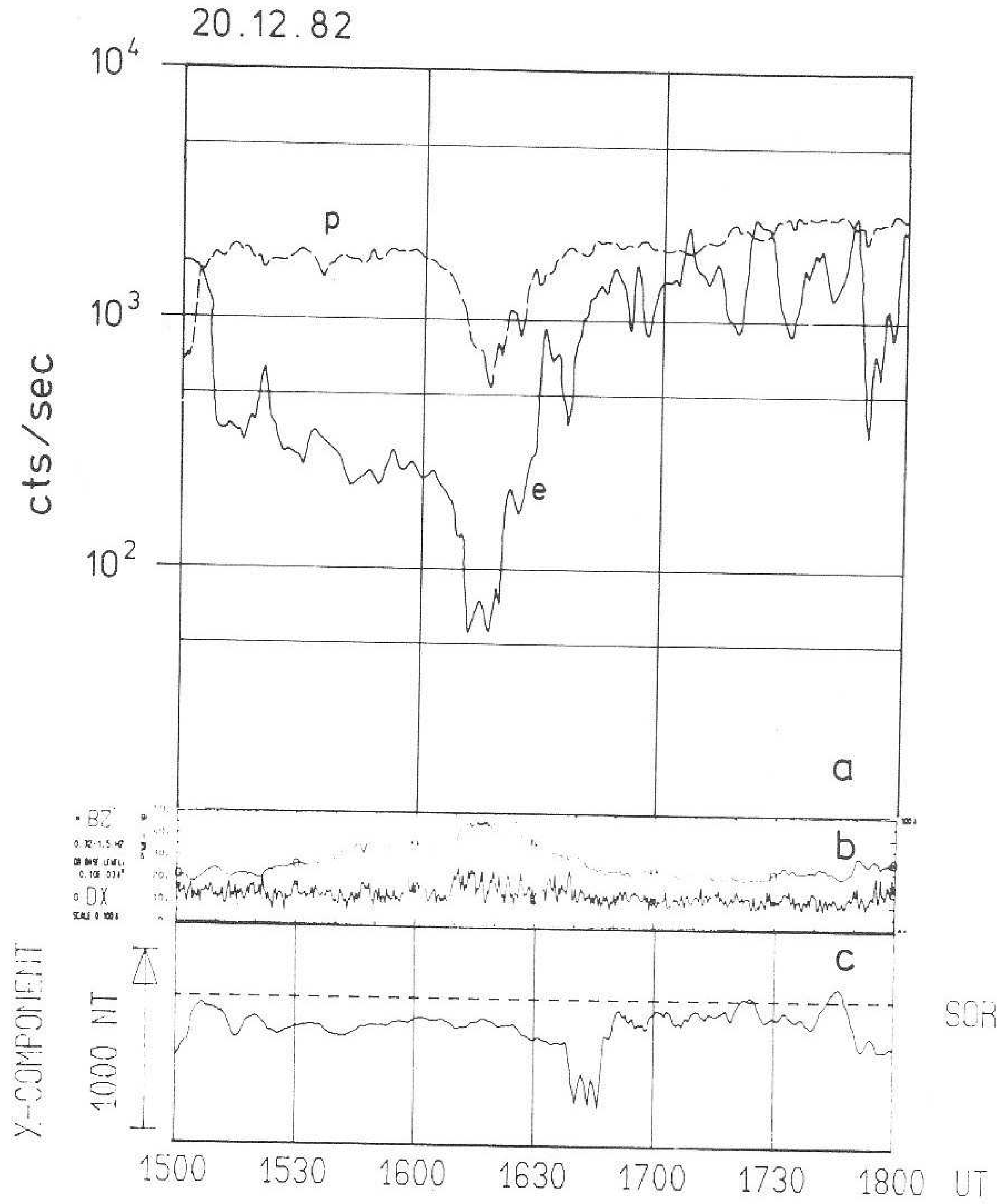

Fig. 4. Same as Fig. 2 for 20 Dec 1982.

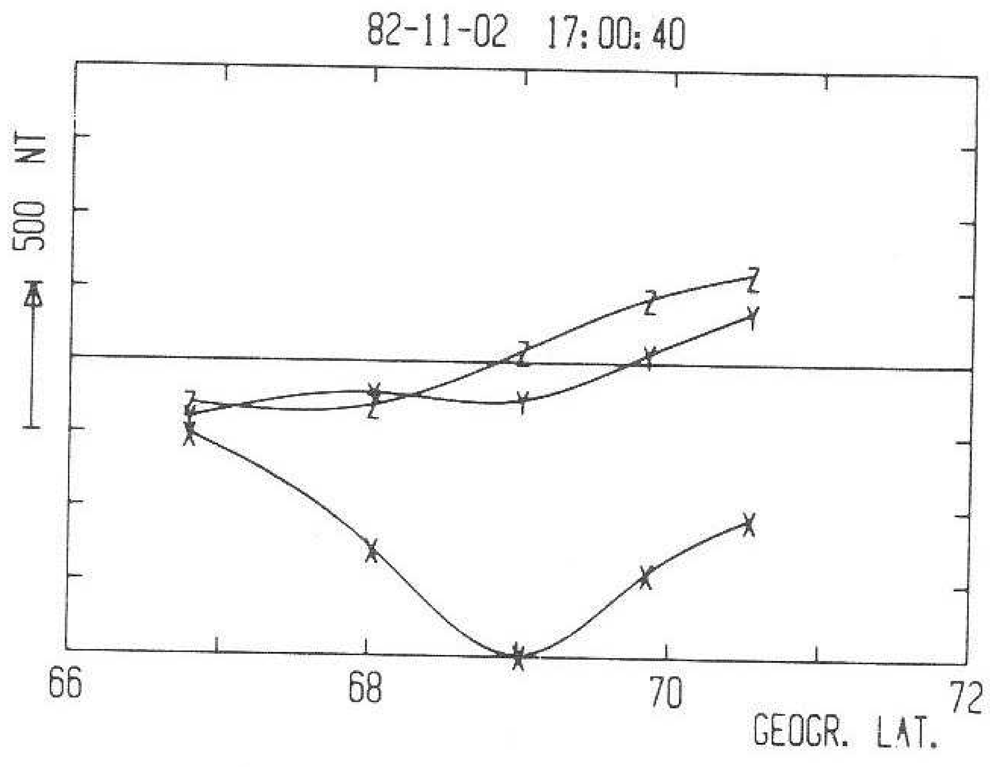

Fig. 5. Latitude profiles of the components X,Y, and Z along the EISCAT magnetometer chain. The coordinate system is turned around Z by 35° to the east. By this way the projected distance of one latitudinal degree reduced to 75 km.

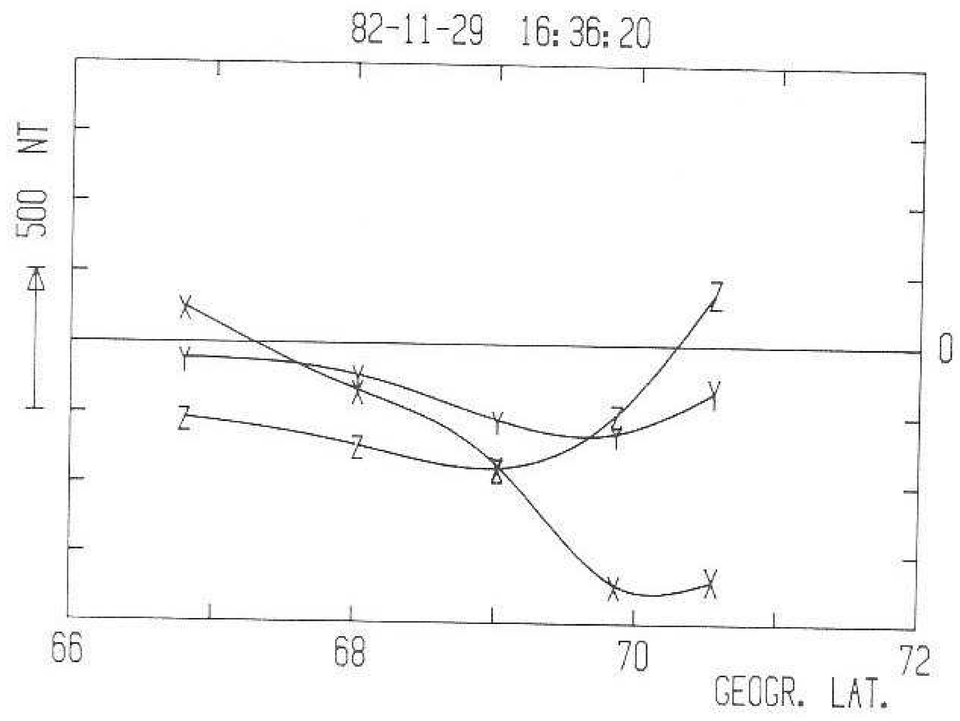

Fig. 6. Same as Fig. 5 for 9 Nov 1982, but without rotation. The X-component points to geographic north.

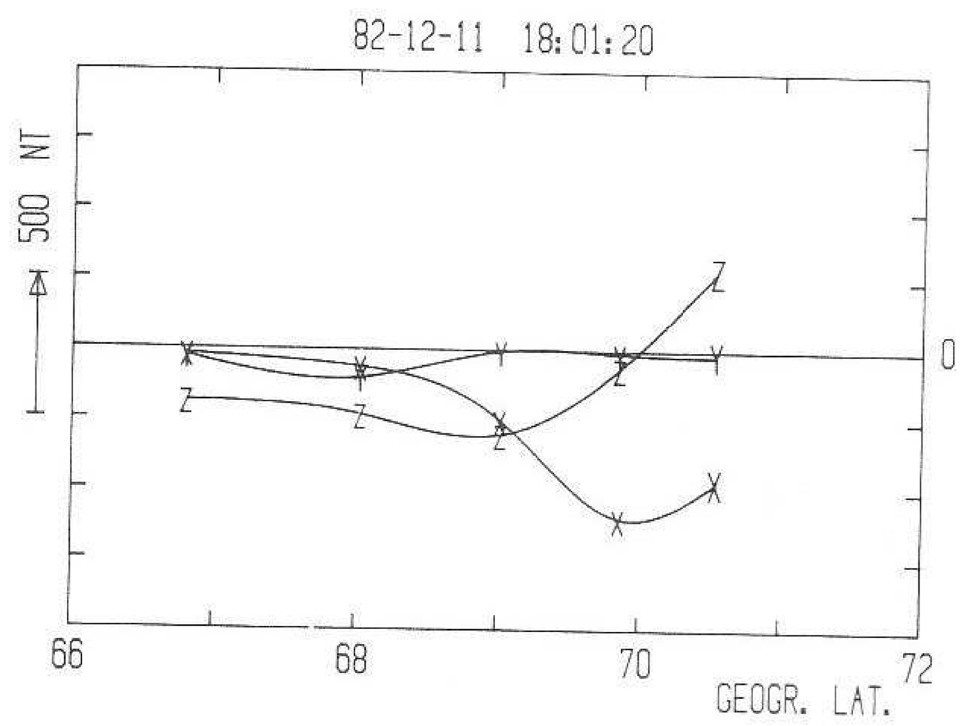

Fig. 7. Same as Fig. 6 for 11 Dec 1982.

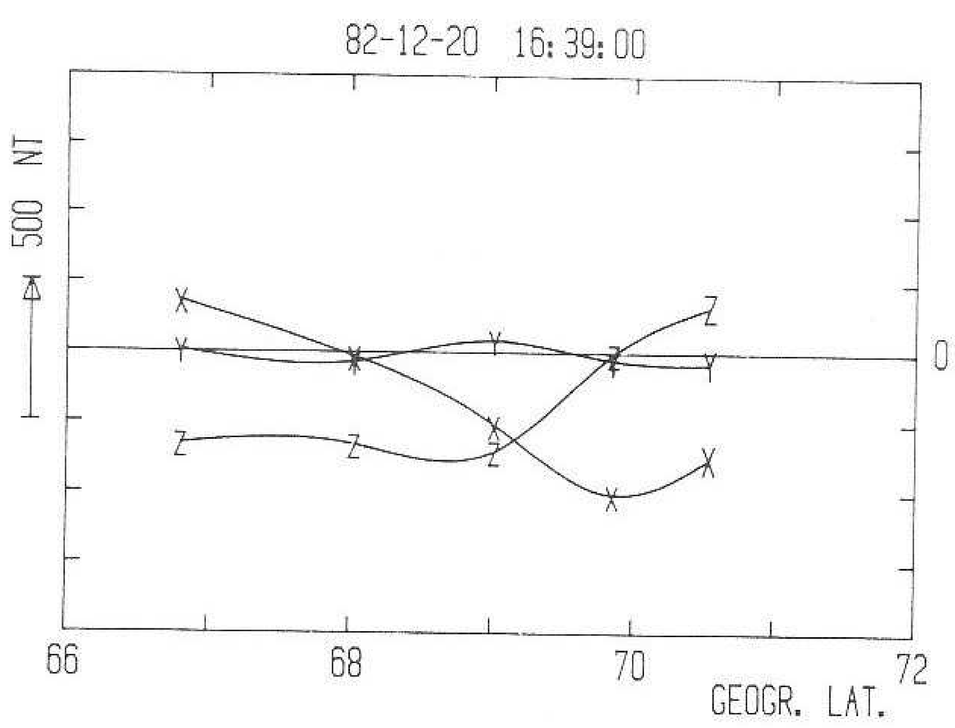

Fig. 8. Same as Fig. 6 for 20 Dec 1982.

ding on their relative magnitude we either observe a poleward or an equatordrift on ground. Both directions have been met. For the strongest event on 2 Nov, where we assume the largest convection velocity of the plasma sheet, we observed an equatorward drift with $v_d \approx 2.3$ km/s at least down to latitudes $L \approx 3.3$.

On ground two characteristic features for kinetic Alfvén waves appear in all events. At first, the width of the ionospheric current bands is very narrow. If we take the width as the perpendicular wave length of the wave fronts we get $\lambda \approx 30 \pm 20$ km, which gives $\lambda \approx 900 \pm 600$ km near the equatorial plane for $L = 6$. The gyroradius of a 20 keV-proton in a magnetic field of flux denstiy $B = 100$ nT is of the order of 200 km. Thus the condition for kinetic Alfvén waves in a warm plasma is given.

The second characteristic is the highly ionized ionosphere in the wave front caused by accelerated particles. Only directly observed for the event on 2 Nov we can deduce this fact from the high ionospheric current densities in the other cases. If we take $I = 3 \cdot 10^5$A and $\lambda = 30$ km as mean values we get for the height-integrated Hall current density along the wave front j_H=10A/m. Such a value can only be achieved with a very large height-integrated Hall conductivity of the order of 50 Ω^{-1} and more.

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