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AFTERNOON ABSORPTION AND THE ROTATION OF THE POLAR CAP CONVECTION PATTERN

by

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Abstract

Based on evidence from STARE drift velocity measurements it is shown that many short-lived absorption events in the afternoon at auroral and subauroral latitudes, as well as other ionospheric phenomena accompanying them, are associated with a transient rotation of the previously predominantly westward electron drift in the ionosphere towards south, followed by a return to the westward drift. This rotation is explained by a temporary clockwise rotation of the polar cap convection pattern, so that phenomena usually encountered in the night sector appear in the afternoon sector. The cause of these phenomena might be found in changes of the ratio of region 1 and region 2 field-aligned currents and of the conductivities in the auroral zone, associated with a magnetospheric disturbance.

1. *Introduction*

The auroral absorption exhibits, on the average, a deep minimum in the afternoon hours, obviously due to the fact that energetic electrons (the main cause of increased ionization in the D region during this type of absorption), injected during substorm near the midnight sector, relatively seldom reach, in the course of their eastward drift, the afternoon sector and become precipitated there. As an exception from this rule, shortlived peaks of afternoon absorption are relatively frequently observed in the auroral and subauroral zone. Magnetic pulsations of the types IPDP (irregular pulsations with diminishing period) and Pi2 (irregular short-lived pulsations) are usually observed simultaneously with this absorption (see, *e.g.*, LUKKARI and KANGAS, 1976; NOVIKOV *et al.*, 1980; RANTA *et al.*, 1983). As an explanation for these phenomena, a westward drift of aurorally injected protons and subsequent parasitic interaction between the ULF waves, generated by the protons via the ion-cyclotron mechanism in the plasmapause region, and the high-energy electrons in the radiation belt has been suggested (LUKKARI and KANGAS, 1976; NOVIKOV *et al.*, 1980).

We propose here an alternative explanation, for at least a part of these events, based on additional data from an ionosonde and an auroral radar. We were led to this study by the fact that, while examining ionograms obtained at Sodankylä during several afternoon absorption occurrences, we very often found the following pattern.

More or less simultaneously with an afternoon absorption event, as observed by means of the Finnish riometer chain, a short-lived ionospheric disturbance takes place at Sodankylä, with the ionograms resembling those obtained during a disturbed night. The disturbance usually decays in less than an hour, and the ionosphere returns to the late-afternoon state. After dusk the disturbance starts again in a manner usual during a disturbed night. Sometimes, when the afternoon disturbance has occurred very near dusk, it goes over to a night disturbance without the temporary return to quiet conditions.

Of the numerous cases following the pattern described above, we have picked up two events from the first year or so when the STARE auroral radar system was operating in Northern Scandinavia. The reason for using STARE data is that they deliver, among others, information on the drift of auroral electrons in STARE viewing area, and we wanted to study variations in the drift direction, reflecting changes in the perpendicular convection electric field, associated with these afternoon phenomena.

In what follows, we shall show our observational results in detail and discuss their interpretation.

2. *Observations*

September 28, 1977

Riometer data. The variation of ionospheric absorption, as measured by means of the Finnish riometer chain between 14 and 17 UT on September 28, is shown in Figure 1. A small absorption increase is seen from Ivalo to Oulu between 14.15

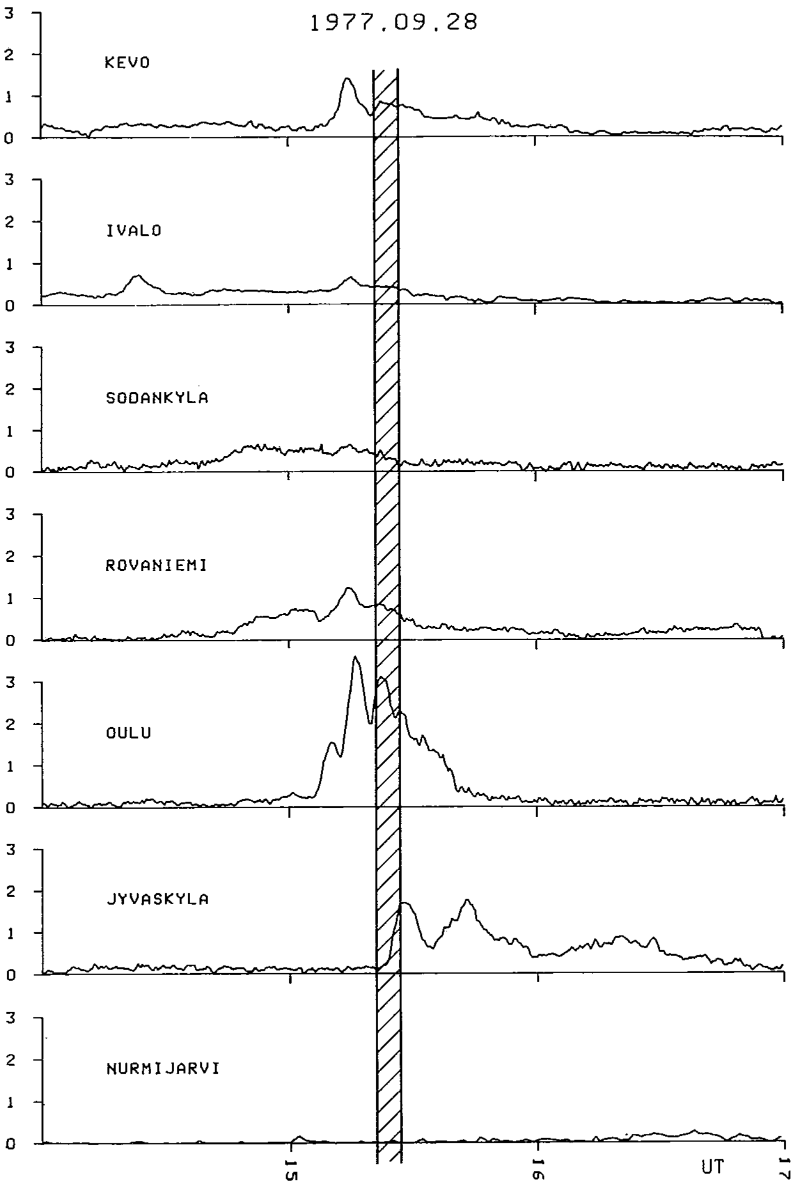


Figure 1. Temporal variations of ionospheric absorption, as measured by the Finnish riometer chain between 14 and 17 UT on September 28, 1977. The vertical hatched stripe indicates the time of southward drift in Figure 4.

and 15.15 UT, with maxima increasing and appearing later with decreasing latitude. Our main concern here is the second increase of absorption, observed after 15 UT at six stations, viz. at Kevo, Ivalo, Sodankylä, and Rovaniemi (with maxima at 15.14), at Oulu (at 15.15 and 15.21), and at Jyväskylä (at 15.27 and 15.41). The increase of absorption is generally steep and the decrease more gradual. The maximum absorption decreases when going south from Kevo and starts then to increase again, attaining its highest value (about 3 dB) at Oulu, L = 4.4. The four northern stations Kevo, Ivalo, Sodankylä, and Rovaniemi observe a simultaneous absorption increase but a shift to slightly later times is seen at Oulu and, especially, at Jyväskylä. Nurmijärvi, a station at the southern end of the chain, does not record any remarkable absorption increase.

Ionosonde data. Half-hourly ionograms were obtained with the ionosonde at Sodankylä on the day in question. An f-plot, containing information on some important frequencies on an ionogram (the critical frequencies of the F and E layers, as well as the minimum frequency of echoes), is shown in Figure 2 for the period 13...18 UT.

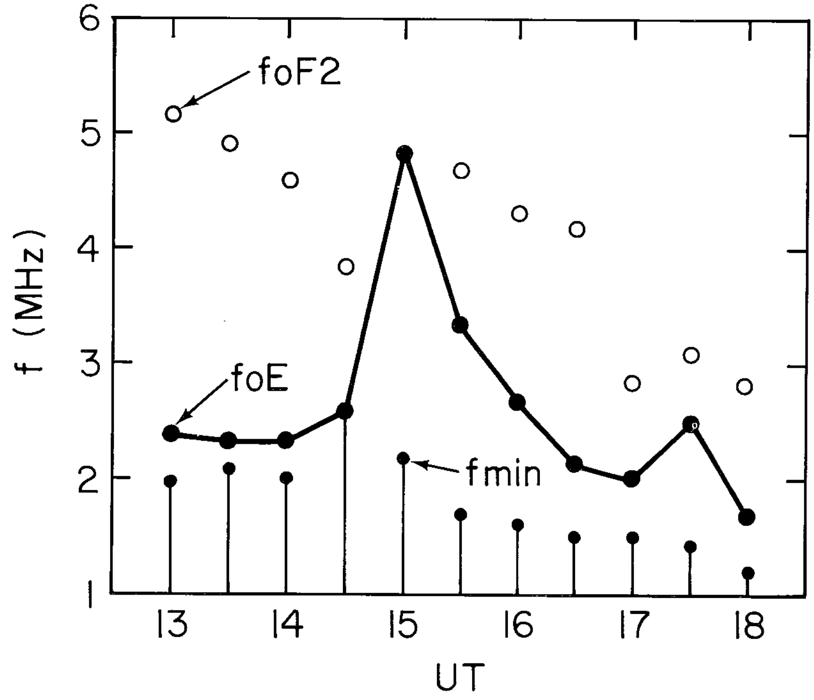


Figure 2. f-plot for the period 13 to 18 UT on September 28, 1977, based on ionospheric soundings at Sodankylä. At 14.30 no Es layer was visible, thus *foE* = *fmin*.

In the beginning of the period the ionosphere is normal, with *foF2* and *foE* decreasing at their usual rates with approaching night. Between 14.00 and 14.30 a sudden drop in *foF2* (a troughlike feature) and a small increase in *fmin* has occurred and the E layer disappeared. At 15.00 UT the F layer is completely blanketed by a thick sporadic E layer (Esk layer or particle Es layer), the critical

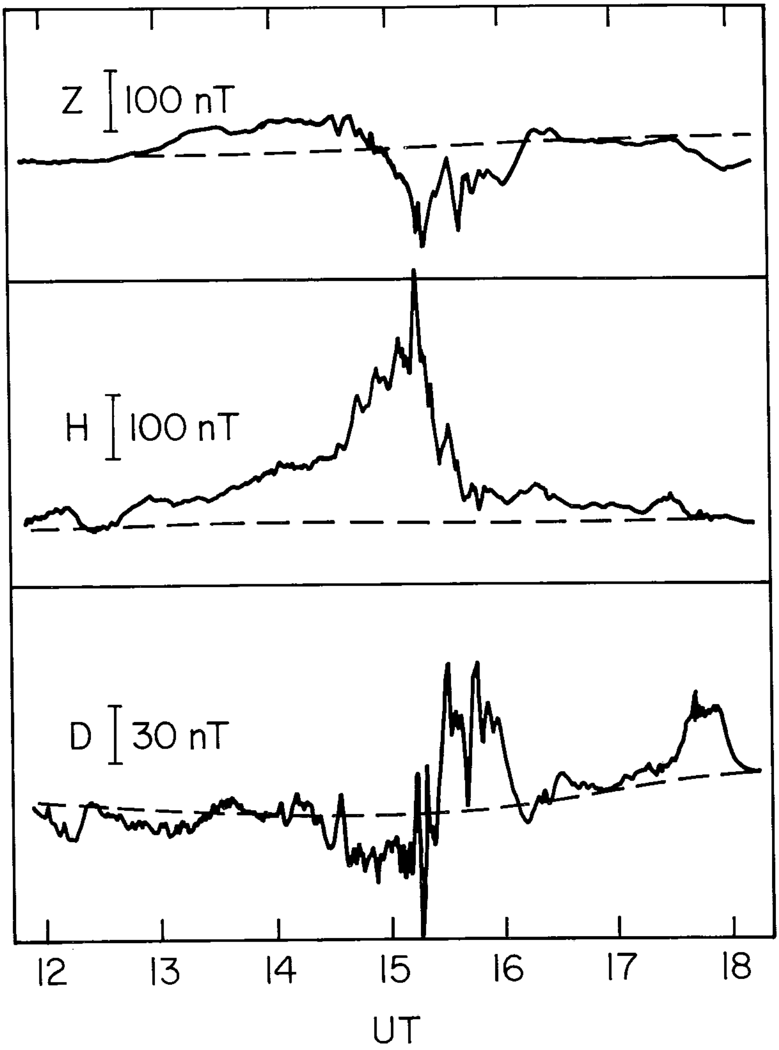


Figure 3. Geomagnetic recording from Sodankylä for the period 12 to 19 UT on September 28, 1977. The positive direction of all components is upwards. The quiet day curves are shown by means of dashed lines.

frequency of which is 4.8 MHz.

At 15.30 the *F* layer is visible again, and the critical frequency of the Es layer has the value of 3.3 MHz. At 16.00 and thereafter the ionosphere is returning to normal but the effect of the disturbance is (on the original ionograms, not shown here) visible in the irregular structure of the E and F layers. Later on, an ionospheric storm begins.

Geomagnetic data. An excerpt of the geomagnetic recording obtained at Sodankylä on the day in question is shown in Figure 3. As seen from the H (horizontal component) trace, an eastward electrojet was flowing above the area between 12 and 18 UT. The sign reversal of ΔZ (change in the vertical component) shortly before 15 UT from positive to negative reveals that the centre of the electrojet passed Sodankylä at that time while the electrojet was moving south. ΔD (change in the declination), in turn, tells us that the direction of the electrojet had a northward component (causing a negative or westward deflection in D) before about 15.15 and a southward component after that.

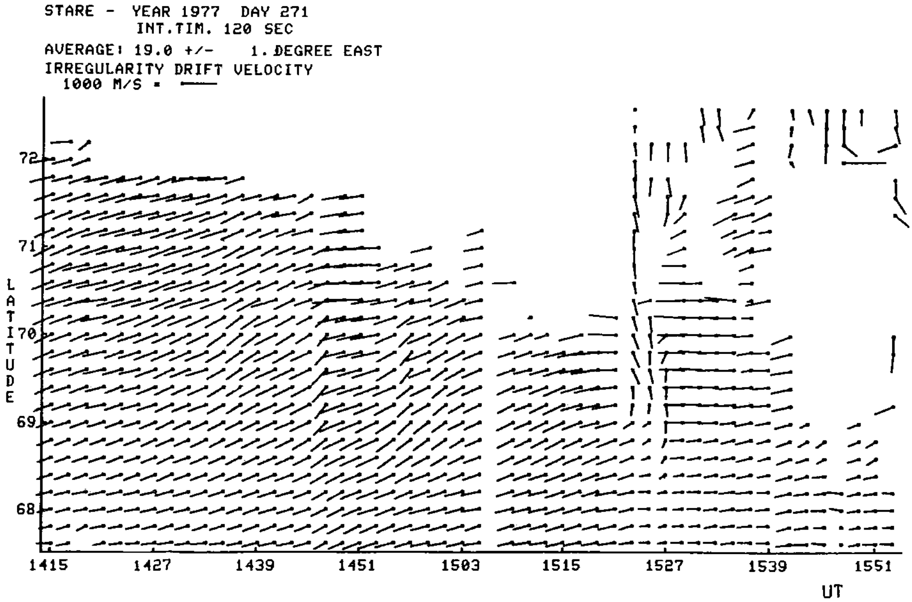


Figure 4. STARE drift velocity plot (mean drift velocity in the longitude range 19° to 21° E as a function of latitude and time) for the period 14.15 to 16.00 UT on September 28, 1977. The line segments starting at the grid points give the direction and magnitude of the velocity at each point. An integration time of 2 minutes was used.

STARE data. The STARE drift plot (mean drift in the longitude interval 19.0... 21.0°E as a function of latitude and time) for the period in question is shown in Figure 4. The drift is seen to be directed mainly to the west, as normal at this time of the day. A tendency to turn to south is seen at 14.45...14.47 and 14.55... 14.57, *i.e.* around the time of the first absorption increase, but a clear rotation to the south is observed later, starting at 15.21 and lasting for about six minutes. This time interval lies inside the time of increased absorption at the stations Kevo to Oulu, as shown by the hatched stripe in Figure 1.

February 27, 1978

Riometer data. The temporal variation of ionospheric absorption at the Finnish stations between 12 and 17 UT on this day is shown in Fig. 5. Two consecutive increases of absorption are seen to occur at each station down to Oulu. The first increase between 13 and 15 UT is growing in intensity (down to Rovaniemi) and appearing at a later time with decreasing latitude. It also has a complicated temporal structure which varies from station to station. The second increase occurs approximately simultaneously around 15.30 at all stations down to Oulu. Its strength decreases monotonously with decreasing latitude down to Rovaniemi and increases thereafter, the maximum appearing at Oulu as during the previous event. A second peak is observed about ten minutes later at Kevo and Ivalo but is absent at the other stations.

Ionosonde data. The f-plot for the period in question is shown in Figure 6. *foF2* is seen to behave roughly similarly as during the previous event: a smooth decrease towards evening is followed by blanketing by an Esk layer and a return to a more normal state again. *fmin* has high values in the period 12 to 15 UT, indicating a relatively high absorption. The maximum absorption is achieved at 14 UT when a complete black-out of ionospheric echoes (denoted by the symbol B) occurs. The E layer cannot be seen during this period of increased absorption (except at 12.30 and 13.30 when *fmin* has somewhat lower values). After 15 UT the absorption is low and the E-region ionization strong, leading to a total blanketing of the F layer at 16 UT. At 17 the ionosphere is relatively quiet again but becomes disturbed at night due to an ongoing magnetospheric storm (not shown here).

Geomagnetic data. The geomagnetic recording from Sodankylä for the period in question is shown in Figure 7 (A less sensitive »storm» recording was used this time because the disturbance was more severe than in the previous event.)

Again, an eastward electrojet flows above the area, as shown by the H trace. Two enhancements of the electrojet occur, the first, between 12.30 and 14 UT;

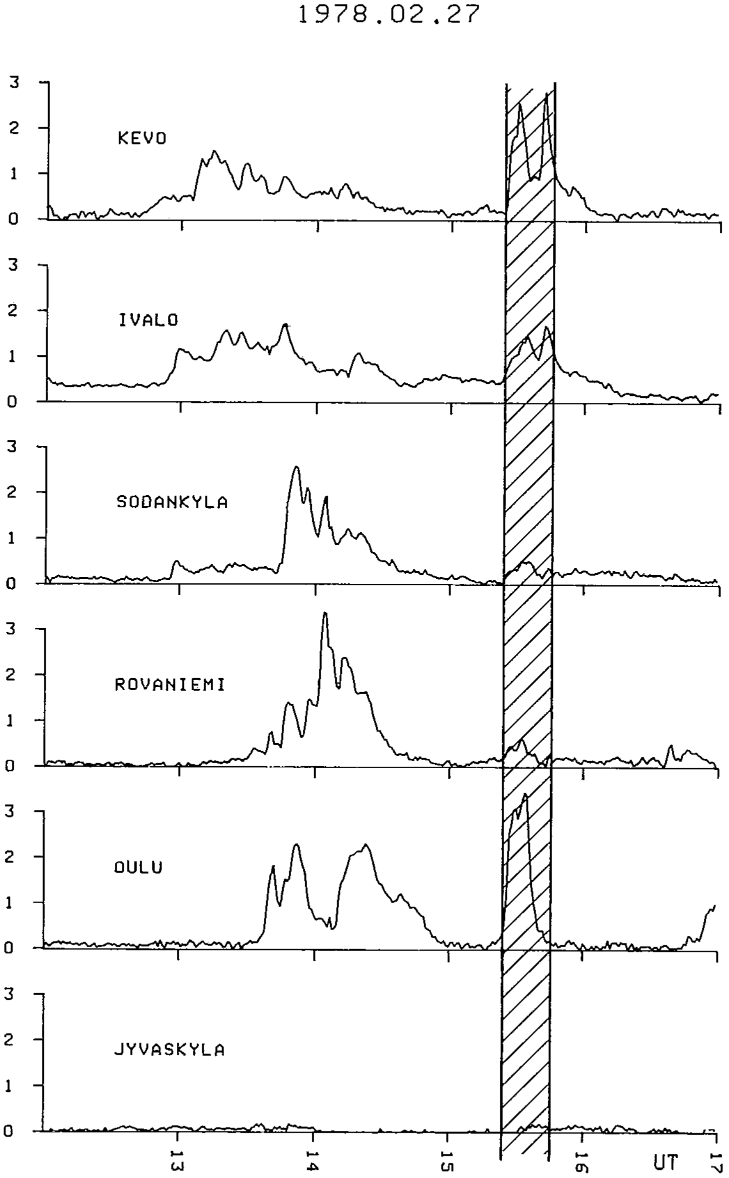


Figure 5. Temporal variation of ionospheric absorption between 12 and 17 UT on February 27, 1978, at the Finnish riometer stations. The vertical hatched stripe indicates the time of the southward drift in Figure 8.

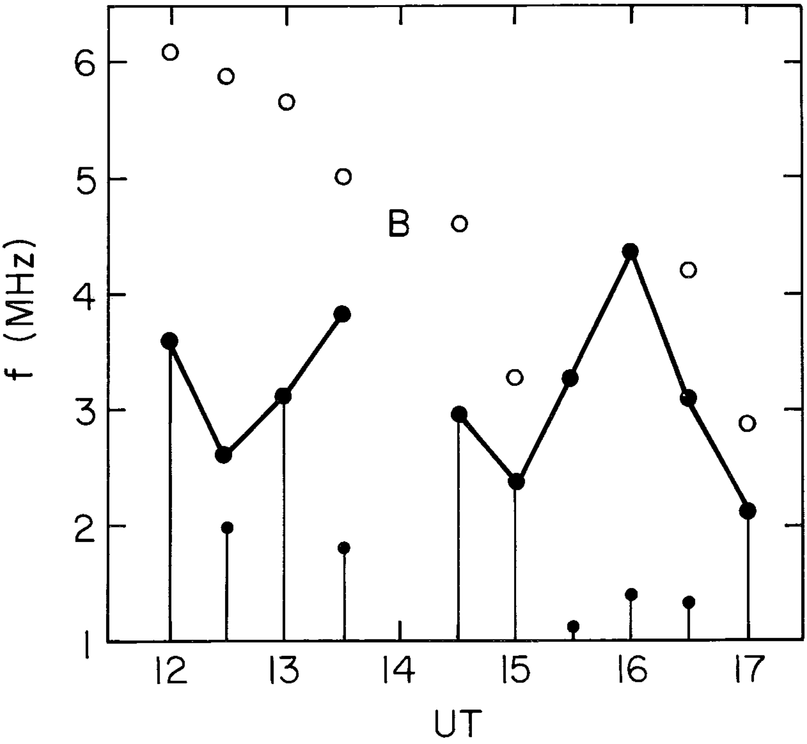


Figure 6. f-plot from Sodankylä for the period 12 to 17 UT on February 27, 1978. The symbols are the same as in Figure 2; in addition, B denotes a complete absence of echoes (black-out) at 14.00 UT.

to the north of Sodankylä (as indicated by equal signs of ΔH and ΔZ), the second, after 14.30 UT, above and to the south of Sodankylä. The sharp, strong negative peak in D indicates a brief appearance of an almost northward current above Sodankylä around 15.30 UT, at the time of the second absorption increase in Figure 5.

STARE data. The STARE velocity plot for the period in question is shown in Figure 8. The predominantly westward flow visibly tends to rotate before 15.18 UT, in part of the latitude range covered by STARE, towards south but the most clear southward direction is attained between 15.28 and 15.45. The drift seems to preserve its well-ordered westward pattern during the first absorption increase, observed at Ivalo between 14 and 15 UT.

A more detailed picture of the changes in the drift pattern is given in Figure 9

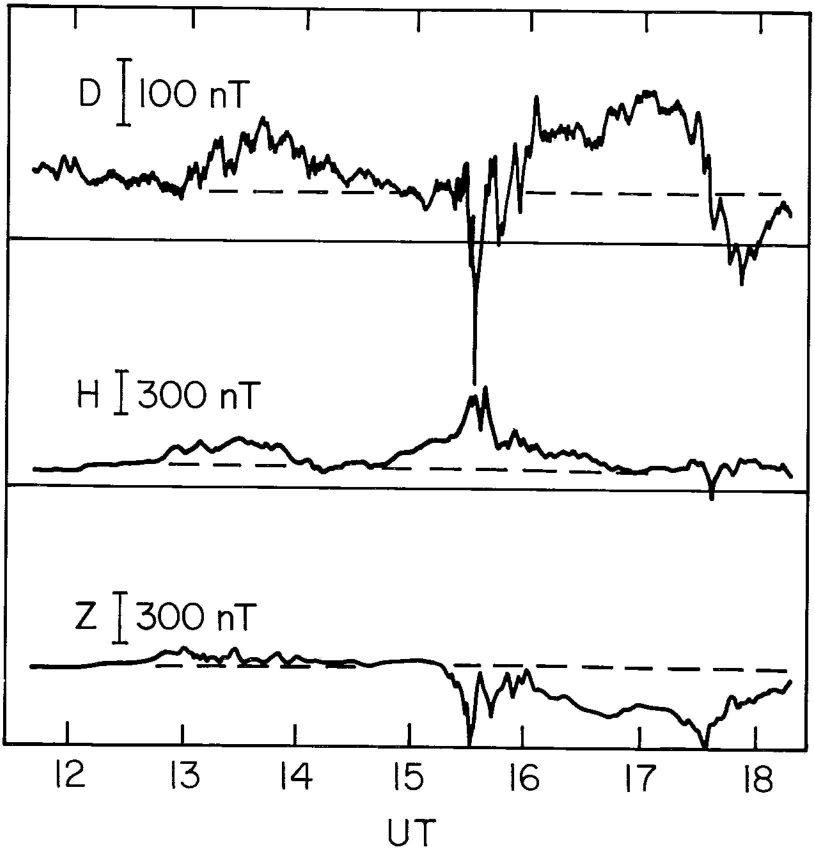


Figure 7. Geomagnetic (»storm») recording from Sodankylä for the period 12 to 18 UT on February 27, 1978.

where eight representative latitude-longitude charts of drift velocity are shown. The drift is seen to be directed in the geographic SW (≈ geomagnetic W) direction at 15.29. The direction has turned to S in the northern portion of the plot at 15.29. Rotation of the drift from SE to SW with decreasing latitude is obvious at 15.31, and at 15.33 a southward drift is seen in the whole area of coverage. A return to the rotational pattern occurs at 15.36...15.44 but a general southward drift prevails again at 15.48. At 15.52 the situation is normal again, with a SW drift in the whole area.

The hatched stripe in Figure 5 shows that the period 15.28...15.45 of a predominantly southward flow in Figure 8 very well coincides with the second in-

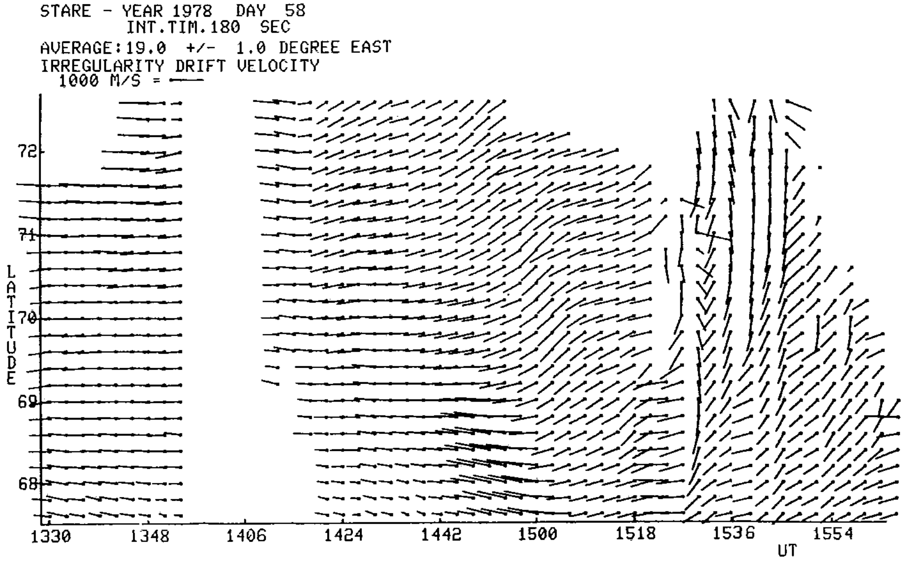


Figure 8. STARE velocity plot for the period 13 to 166 UT on February 27, 1978. The integration time is 3 minutes.

crease in absorption. The two occurrences of purely southward drift in Figure 9 (at 15.33 and 15.48) seem to correspond to the two absorption peaks at Kevo and Ivalo in Figure 5.

3. *Discussion and Conclusions*

The observations presented above, as well numerous other observations we have made, can be summarized as follows:

A short-lived (with a duration less than or equal to one hour) absorption increase is relatively frequently observed during the afternoon hours in the auroral and sub-auroral zones between the approximate L values of 4 and 6. It occurs practically simultaneously, but with varying intensity, at several stations in the same longitude zone but dispersed in latitude. The absorption has normally two latitudinal maxima, one at higher ($L \approx 6$) and the other at lower ($L \approx 4$) latitudes (see also RANTA *et al.*, 1983).

The absorption increase is accompanied by a transient disturbance in the ionospheric E and F layers. During this disturbance the critical frequency of the F layer is suddenly decreased and that of the E layer increased. After the absorption event

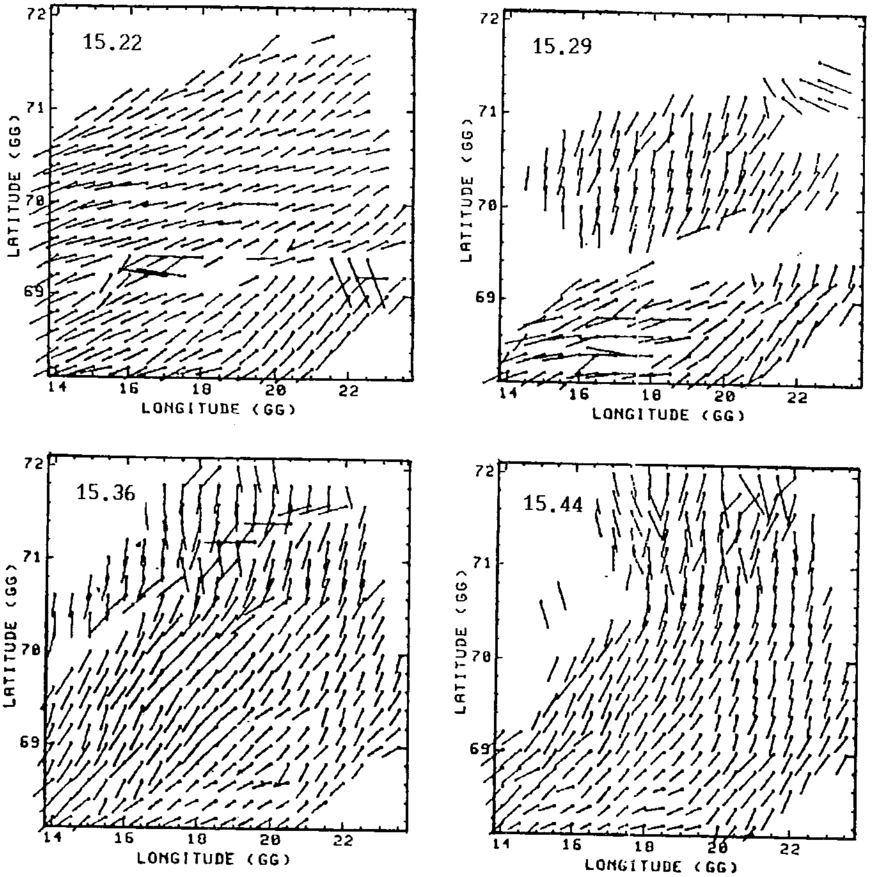


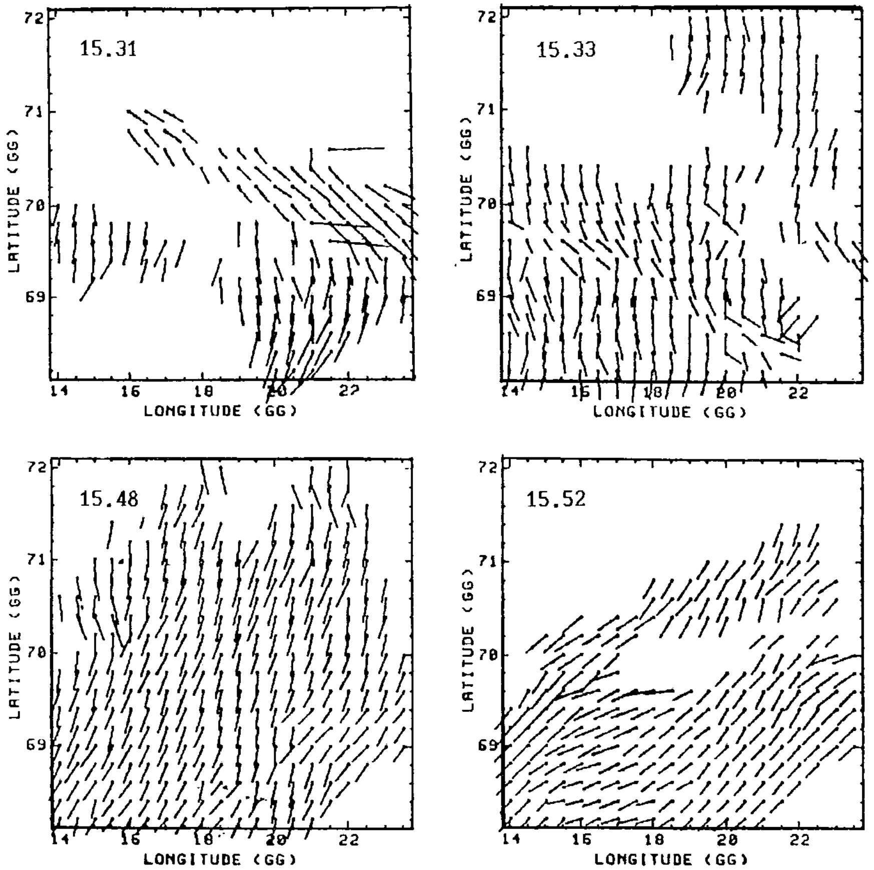
Figure 9. Some representative STARE velocity charts (velocity vs. latitude and longitude) for February 27, 1978.

the ionosphere usually returns, for a short period, to a relatively undisturbed state, until the nightly disturbance takes over.

The ionospheric disturbance takes place in the region of an eastward electrojet. A sudden change in the direction of the electrojet towards north during the disturbance is indicated by the D component of the geomagnetic field.

These phenomena coincide with a transient southward turning of the previously predominantly westward electron drift in the ionosphere.

This set of phenomena is usually preceded by another absorption increase in approximately the same latitude range but with different characteristics: the absorption starts later at lower latitudes and is not accompanied by any major changes



in the E and F layers or in the drift velocity. The two absorption increases roughly resemble those seen in the same latitude range preceding a substorm and during it (*e.g.* RANTA *et al.*, 1981).

We suggest that these observations can be explained by assuming that the convection pattern of the polar cap and the adjoining auroral zone experiences, during such events, a strong clockwise rotation so that the tip of the clockwise convection cell (where the convection turns from an eastward to a westward direction), normally located near local midnight, arrives in the pre-dusk sector. The precipitation causing the observed D- and E-region ionization might be the result of injected protons and electrons which normally would be precipitated in the night sector but due to the rotation of the polar cap (and the associated twisting of the geomagnetic field lines) arrive in the late afternoon sector.

The fact that the equatorward absorption maximum is associated with IPDP and the poleward maximum with Pi2 pulsations suggests that the former maximum is due to proton precipitation near the plasmapause, whereas the latter is associated with a substorm-type current wedge (SINGER *et al.*, 1983). Because the electron density is enhanced in both D- and E-regions, the precipitation must have a broad energy spectrum.

Due to the rotation of the polar cap, the late afternoon F layer would be temporarily replaced by a weaker nightly one, resembling the appearance of the F-region through above Sodankylä much earlier than normal. When the convection pattern would rotate anticlockwise again, normal pre-dusk conditions would return, until the stations arrive at the nightside of the magnetosphere were a disturbance is going on.

The rotation of the convection pattern must be observable, in one way or the other, around the whole polar cap. We have not investigated this question extensively but an examination of some sets of magnetograms from auroral stations has revealed simultaneously with an afternoon absorption event in Scandinavia the appearance of a negative magnetic bay in Canada or Alaska.

We have examined whether the afternoon absorption events correspond to some characteristic changes in the solar wind but have failed to find any simple pattern.

A look into the electric field data from the GEOS-2 satellite in the Scandinavian sector has revealed that outward directed electric fields in the equatorial plane (corresponding to a sunward plasma drift) are associated with these afternoon events, suggesting that the clockwise rotation in the auroral ionosphere can be felt also at $L = 6.6$ in the equatorial plane.

The idea of a rotation of the polar cap is not new after all. For instance, there is a lot of experimental evidence that certain features of the convection pattern, such as the convection reversal (often called the Harang discontinuity) appear earlier in local time with increasing magnetic activity (see *e.g.*, ZI *et al.*, 1982).

Also theoretical calculations on the rotation have been made. NOPPER and CAROVILLANO (1979) suggest that the polar cap convection pattern would be rotated clockwise when the ratio of region 2 and region 1 field-aligned currents increases during magnetospheric disturbances. In extreme cases they predict a rotation of more than 90°.

YASUHARA *et al.* (1983) explain the rotation as a result of the space charge which develops due to conductivity gradients along the boundaries of the auroral oval. Their maximum value of rotation is 33°.

KAN *et al.*, (1984) explain the westward traveling surge as a result of a clockwise rotation of the convection pattern, caused by a partial blockage of the substorm-enhanced Hall current from closure in the magnetosphere.

In all these explanations the auroral ionosphere is assumed to be partially decoupled from the magnetosphere so that the ionospheric and magnetospheric convection patterns are not replicas of each other. This state of affairs can be described by stating that the magnetic field lines are twisted so that certain phenomena in the magnetospheric tail are projected, instead of the midnight sector, into the late afternoon sector. A strong twist like this is obviously possible during exceptionally strong disturbances only; during afternoon absorption phenomena discussed here we have fould *AE* values up to 1000 nT or even higher. Smaller twists are obviously more frequent and might be responsible for many apparent rapid east-west movements in the auroral ionosphere.

Another possible cause for afternoon absorption phenomena could be found in flux transfer events (FTEs) at the magnetopause (for a thorough discussion see BERCHEM and RUSSELL, 1984). FTEs could cause corrugations to occur in the boundary between the auroral zone and the polar cap, where the flow direction would be locally perturbed. Localized absorption could result from this perturbation.

The extension of absorption in these two mechanisms would be different: a rotation of the polar cap convection pattern would be observed all around the polar cap, whereas the effect of an FTE would be more localized.

Also other mechanisms for generating short-lived absorption events in the afternoon might exist. It is possible that different mechanisms cause different subsets of these phenomena. Further studies are clearly needed in this respect.

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