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MAGNETOSPHERIC CONVECTION PATTERNS INFERRED FROM HIGH LATITUDE ACTIVITY

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I. Introduction

This paper is a sequel to the presentation on "High Latitude Magnetic Disturbances" (Heppner, 1967) given at the Aurora and Airglow, 1966, Institute at Keele, England. In that presentation the geomagnetic time and latitude distribution of magnetic disturbance at latitudes > 51° was illustrated by means of a motion picture. Each frame of the motion picture displayed in polar projection the disturbance vectors in the horizontal plane simultaneously from 25 high latitude observatories for each 2.5 minutes of universal time for a period of 16 consecutive days. The detailed (i.e., frame by frame) study of the vector plots permitted a number of impressions and conclusions to be drawn concerning the pattern and behavior of ionospheric currents at high latitudes. Many of these are summarized in the paper (Heppner, 1967) and it will be assumed in the present paper that the reader will refer to the previous paper for information to substantiate points that might otherwise appear to be unjustified assumptions.

The discussion here is directed toward magnetospheric convection in terms of the information provided and restrictions imposed by the distribution of ionospheric currents. Historically, following Axford and Hines (1961), patterns of magnetospheric convection have been inferred from distributions of ionospheric currents under the premise that the Hall conductivity, σ_2, is much greater than the Pedersen conductivity, σ_1, in the lower ionosphere and that above roughly 180 km magnetic field lines are essentially lines of infinite conductivity and thus equipotential lines. The electric field $\underline{E} = -\underline{v} \times \underline{B}$, perpendicular to the electric current $\underline{j}$ in the reverse direction,

- $\underline{v}$, of the plasma flow, maps directly along magnetic field lines everywhere above a 80 to 100 km lower limit with the above and other, more detailed, assumptions regarding the difference between electron and ion interaction with neutrals in the 80 to 180 km region. Theoretical justifications for these assumptions and the general concept of "frozen fields" have been discussed in numerous articles (e.g., Hines, 1964; Axford, 1967; Piddington, 1967) and will not be repeated here. One of the reasons for writing this brief article is to point out that however valid, or invalid, this procedure may be, various investigators have deviated considerably from the observed current systems and consequently one is confronted with numerous convection patterns that may be misleading. The motive here is not criticism but rather: (1) to illustrate a more representative pattern with the hope that getting closer to reality will bring forth ideas that will assist in eventual understanding of magnetospheric convection, (2) to note substantive points as well as the pitfalls of existing pictures, and (3) to note that irregularities in the convective medium are such a common property that one should question the reality of any model until either the irregularities are properly explained or shown to be of little consequence relative to the use of the model. The discussion will however proceed under the assumption that the basic concepts of convective motion are valid.

Recent auroral zone rocket experiments involving the study of motion of Ba^+ clouds (Föppl, et al., 1968; Wescott, et al., 1968; Lüst, 1969) and direct probe measurements of electric fields (Aggson, 1969) substantially support some of the theoretical predictions relating behavior in and above the ionosphere to magnetospheric convection. These findings and the findings from an electric field probe carried by the OV1-10 satellite (Heppner, et al., 1968; Aggson, 1969) are used both directly and indirectly here to supplement the information from magnetic disturbances.

II. Convection Models

Figure 1 provides a representative sample of convective models for later reference (also see review by Obayashi and Nishida, 1968) including both closed (A, B, C, D) and open (E, F) magnetospheric models. The reconnection model of the Dungey (1961) type is assumed to be represented by (E). In all models: (1) the electrical equipotential lines are also the flow lines, giving the direction of $\underline{v}$, and (2) only the solar wind induced flow produces current in the reference frame of the earth. Thus, only (A) and (E) can be compared directly with magnetospheric mapping of the electric field driving ionospheric currents and only (B), (C), (D) and (F) give the distribution of potential seen by a particle entering the magnetosphere from a reference frame not rotating with the earth. Comparison of (A) with (B) and (E) with (F) indicates the comparatively small effect on the total pattern that results from adding the co-rotating potential, $\approx -90 \sin^2 \theta$ in kilovolts where θ is the co-latitude. However, to compare the Taylor and Hones (C) and Nishida (D) constructions with those of Section III here, this difference should be recognized.

III. Convective Pattern of This Study

A. Current Pattern from Magnetic Disturbance Plots

Any attempt to illustrate the distribution of high latitude ionospheric currents with a few simple pictures might appear presumptuous. Perhaps surprisingly at the level of generalization here, which could be called a first approximation, a simple representation is achieved, Figure 2, which is highly consistent with the motion picture disturbance plots (Heppner, 1967) for disturbance conditions in the range $Kp \approx 3$ to 4. It can similarly be made representative for $Kp < 3$ by shrinking the pattern such that all lines are displaced poleward, and for $Kp > 4$ by expanding the pattern such that all lines are displaced equatorward. Before explaining how the three pictures of Figure 2 can be viewed as one pattern further explanation is required.

The objectives in the Figure 2 construction were: (1) to produce a pattern that could only be criticized for its omissions and not for its content, and (2) to represent only the geometry and not the magnitude of the current. The principal omission is obviously the omission of current continuity within and between the three regions: the eastward, or evening, current producing positive ΔH; the westward, or morning, current producing negative ΔH; and the polar cap current directed into the 6^h to 12^h local time quadrant. Ignoring the magnitude, (2) above, is related to the omission of continuity (for a discussion of the continuity using the same data base, see Heppner, 1967) but involves an important additional consideration when the object is to find the convection pattern. The consideration is that the current density is directly dependent on the integrated Hall conductivity, σ_2, and hence without reasonable detailed knowledge of the electron density distribution with altitude, simultaneously over the entire high latitude pattern, it is relatively futile to attempt to get the simultaneous magnitude of $\underline{v}$ throughout the pattern. Obtaining the direction of $\underline{v}$ (or $\underline{j}$) from the vector magnetic disturbance is, however, much less uncertain as it is primarily dependent on the reasonable assumption that the Hall conductivity is the dominant transverse conductivity.

This is not to say that the transverse conductivity σ_1 in the direction $\underline{E}$ is completely negligible. It is quite possible that σ_1 and and σ_3 $(=\sigma_1 + \sigma_2^2/\sigma_1)$ play key roles in the detailed dynamics. In a static representation like Figure 2, however, it seems unlikely that very significant errors in direction result from assuming only Hall currents-especially considering the scale of the picture. Also, the results from various Ba^+ release experiments (Föppl, et al., 1968; Wescott, et al., 1968, Lüst, 1969) provide extensive evidence to justify the assumption that the magnetic disturbance is primarily from Hall currents in auroral regions.

The principal difficulties encountered in arriving at the most representative pattern were: (a) in the auroral breakup (or current reversal) region, $\sim 22^h$ to 00^h local time, one can encounter three different conditions: an overlap in latitude of the east and west currents, an abrupt transition, and an interval of very little disturbance; (b) when the overlap in latitude near 22^h is prominent it sometimes extends westward to the dayside, at other times the polar cap and eastward current regions are adjacent; (c) in the 9^h to 12^h local time zone, between 70^o and 75^o, the disturbance may be very small and directions questionable however on numerous occasions the disturbance is clearly an extension of the east and west cells.

It was found, however, that the above variations in pattern could be readily taken into account through rotation in local time of the east and west current regions by letting the regions slip over each other in latitude and spread in longitude with the rotation. This is illustrated in Figure 2 by taking 2 (A) as the basic pattern and producing two extremes 2 (B) and 2 (C) through rotation and slippage of the cells. A third extreme (not shown) would combine the 17^h to 0^h geometry of 2 (C) with the 8^h to 13^h geometry of 2 (B). In this case, the east and west current cells primarily spread in longitude.

B. Convective Boundary from OV1-10

Using only the magnetic disturbance data difficulty would be encountered in placing a low latitude limit on the current cells. Because of the current integrating nature of the magnetic measurement, average errors of 2° to 5° are likely and further uncertainty would be involved in assuming that the lowest latitude of concentrated (auroral associated) current was really the lowest latitude in which the current (or convective flow) had the same geometry. The electric field data from an experiment on the OV1-10 satellite shows a distinct boundary in latitude and time which in turn is found to be compatible with the disturbance distribution within the errors, noted above, in picking a low latitude limit for the current cells. This boundary, explained below, was used in constructing Figure 2.

Briefly stated, the OV1-10 experiment used two 51 foot booms to make a one axis electric field measurement by the double probe technique (Aggson, 1969) along a polar (Incl. = 93.4°) orbit between altitudes 647 and 777 km. The quantities that were to be measured included the d.c. electric field, changes in the electric field having a time constant < 60 seconds presented on a logarithmic scale, and the r.m.s. of electric field fluctuations in 3 bands; 3 - 30 Hz, 30 - 300 Hz, and 300 - 3000 Hz. A short circuit between one boom and the spacecraft made the measurements of d.c. electric fields useless. The outputs of the other channels, however, provided consistent data from orbit to orbit throughout the satellite life on the global distribution of irregularities and low frequency VLF signals. The irregularities appear as a low frequency signal as a consequence of the satellite moving at a high velocity across the irregularity structure. For example, a series of 500 meter striations would produce a frequency of 16 Hz for a satellite velocity of 8 km/sec.

Interpretations and details will be published elsewhere (Heppner, et al., 1968). The purpose here is to note the existence of a boundary in the sense that the signal suddenly rises well above a detection threshold as illustrated in Figure 3 near 73^o at 7.6 hours and 64^o at 18.1 hours. Signals are observed on every polar crossing and although the maximum signal usually occurs at much higher latitudes than the minimum latitude of occurrence, the minimum latitude is usually quite definite and varies systematically with magnetic activity. Figure 4 shows the average location of this boundary drawn between Kp = 2 and Kp = 3 and between Kp = 4 and Kp = 5. Using a value between these two lines gives the Kp = 3 to 4 boundary used in Figure 2.

It is hypothesized that the existence of extensive irregularities with marked contrast in the electric field and electron density between adjacent magnetic field aligned striations is directly related to the existence of d.c. electric fields. Thus, it is implied that the irregularity boundary is also a discontinuity between regions of strong and weak electric fields.

C. Magnetospheric Convection Pattern

In principal the only uncertainty in mapping the ionospheric flow into the magnetosphere is in tracing a flux tube. Mathematical field models can be used as in the Taylor-Hones (1965) extrapolation but there are presently not any models that fit magnetic field observations in all areas of the magnetosphere and for the first approximation approach here it is doubtful that little would be gained. Use of some models (e.g., those that produce open field lines on auroral shells) could in fact produce geometries which the author believes would be completely misleading. The approach taken here is obvious comparing Figures 2 (B) and 2 (C) with Figures 5 and 6, respectively.

It assumes the following: (1) a solar wind distorted dipole within a slightly asymmetric magnetopause boundary, (2) inflation of the field by internal plasma pressures on the nightside such that tubes of equal flux at equal day and night radial distances for $R_e > 4$ have greater radial dimensions on the night side, (3) that distortion of the dipole along the trace of the low latitude convection boundary is negligible for the pattern extrapolation with the exception that at the large radial distances encountered on the day side the field compression by the solar wind locates the trace closer to the earth than for a dipole -- an obvious condition for keeping the trace inside the magnetopause, and (4) that meridian planes of the dipole are approximately preserved, as discussed below.

There is a substantial body of satellite data that can be reasonably interpreted as supporting these assumptions from both the standpoint of field geometry and surface and satellite correlation of events that are restricted in local time and distance. Space will not permit detailing these here. The most questionable aspects in Figures 5 and 6 are: the location of the dashed line to distinguish between polar cap and auroral belt flow, and the exact orientation of the convective flow corresponding to flow in the polar cap. It is estimated that the average position of the dashed line could lie within a radial distance range, relative to the position shown, of -2 to +5 R_e near midnight, and -1 to +2 R_e near the twilight meridians. The question of the exact orientation of the convective flow along polar cap flux tubes is related to the assumption, (4) above, that magnetic meridians are approximately preserved. The likely error involved in this assumption is probably not significant for the auroral belt flow on the scale of Figures 5 and 6. At greater distances (i.e., for polar cap flow) in the near tail region the convective flow arrows have been drawn such that they are either in direct agreement with dipole meridians or biased by small angles in a direction compatible with meridian planes being bent toward the anti-solar direction with increasing distance from the earth. Errors are likely to be in the sense of not sufficiently bending the meridian planes in this manner. If so, the principal correction to Figures 5 and 6 would be between 17^h and 01^h where the corrected flow would be the direction obtained by adding a small vector toward the sun to the existing vector. A second correction would be to add an even smaller vector in the anti-solar direction in the early morning hours.

The magnetospheric convection shown does not include any flux tubes from magnetic latitudes > 76^o, or between 76^o and 74^o (Figure 5) near midday, as only the near tail region is considered. Continuing the same geometrical projection to greater tail distances would give a flow between that of Figure 1 (b) (expanded for a more cylindrical tail) and that of Figure 1 (c). More detailed considerations of the convection pattern are included in the discussion of the next section.

IV. Convection Implications of the Disturbance Pattern

A. Relating the Plasmapause to Convection

Two of the most recent convection pictures, Nishida (1966) and Brice (1967), picture the plasmapause discontinuity in electron density as being the inner boundary of magnetospheric convection. In the Brice (1967) model, Figure 1 (E), convection extends inward from the magnetopause to the plasmapause at all local times. In the Nishida (1966) picture, as initially stated, convection extends inward to the plasmapause location only on the nightside of the earth and it is calculated that the shells depleted at that location do not refill during one rotation of the earth such that they remain depleted after passing out of the convecting region. The Nishida portrayal of convection although supposedly based on the distribution of ionospheric currents does not however follow the systems assumed (e.g., symmetric solar wind convection is shown as accompanying asymmetrical currents) and thus the implications are difficult to follow (also see Section IV here.) Brice (1967) did not consider ionospheric currents in any detail in his model and coincidence of the plasmapause and inner boundary of convection from this standpoint appears to be an assumption.

The pertinent points of the present study relative to the plasmapause question are as follows: (1) If strong solar wind induced convection did in fact extend to the plasmapause at all local times one would expect intense ionospheric currents on the dayside of the earth in the region L = 4 to 8 as a consequence of the conductivity also being high. This directly conflicts with the distribution of magnetic disturbance. (2) The hypothesis, Section III. B., that the OV1-10 irregularity boundary also represents a discontinuity between strong and weak electric fields is consistent with the distribution of magnetic disturbance and is more logically treated as an inner boundary than the plasmapause. This does not mean that the convection, $\underline{v}$, goes completely to zero inside, but it must drop abruptly to a much lower magnitude. An upper limit to this lower magnitude could be reasonably estimated from middle latitude disturbances but this is beyond the present paper. (3) The original Nishida (1966) premise that the plasmapause is created through loss processes involving the nightside convection is not in conflict with the disturbance data although his mechanism for explaining the loss is questionable. Also, the data does not conflict with Carpenter's (1966) proposal that new plasma is added in the 17^h to 24^h sector. In brief, if there is a relationship between the convection discontinuity and the plasmapause it is probably in the form of nighttime dynamic processes and not a geometrical coincidence of boundaries. The most logical place to look for a loss mechanism in the time-latitude morphology would appear to be at the auroral breakup transition between + and $-\Delta H$ bays.

Historically, it should be noted that Axford and Hines (1961) showed a circular convective boundary near L = 4.5. This does not, however, appear to have any direct relationship with the observed plasmapause, but instead resulted from use of a symmetric Chapman S_D current for illustration purposes with the additional consideration that the outer radiation belt might prevent deeper penetration. The authors recognized that the actual pattern was likely to have a day-night asymmetry.

B. Solar Wind, $-\underline{v}_{sw} \times \underline{B}_{ip}$ as the Driving Field for Magnetospheric Convection

Following Dungey (1961) a number of advocates of the field line reconnection process have assumed that magnetospheric convection is driven by the electric field $-\underline{v}_{sw} \times \underline{B}_{ip}$ that appears in the earth frame of reference as a consequence of solar wind flow, $\underline{v}_{sw}$, across the interplanetary magnetic field, $\underline{B}_{ip}$. For a southward directed $\underline{B}_{ip}$, penetration of this field through field line reconnection gives a potential distribution like that of Figure 1 (E). Statistical correlations (e.g., Schatten and Wilcox, 1967) showing that the average Kp value is higher when $\underline{B}_{ip}$ is southward than when northward have been quoted frequently as support for this hypothesis. It is to be noted, however, that this correlation is not independent of other parameters, such as the magnitudes of $\underline{B}_{ip}$ and $\underline{v}_{sw}$, and also that the correlation could relate to other coupling mechanisms. Also, it could relate to a more restrictive form of reconnection than appears in Dungey's (1961) model.

Whatever the exact role of the interplanetary field really is, it is untenable to assume that the basic convective pattern is determined by the direction of $-\underline{v}_{sw} \times \underline{B}_{ip}$. As discussed in the earlier paper, Heppner (1967), and repeated in III (A) and IV (E) here, the pattern of high latitude magnetic disturbance is essentially the same at all levels of activity, except for shifts in latitude. If dependent on the direction of $-\underline{v}_{sw} \times \underline{B}_{ip}$ this could not be the case.

It should also be noted (see Heppner, 1967) that high latitude disturbances do not begin impulsively with sudden negative bay onsets as sometimes assumed. Instead, proceeding from quiet conditions the disturbance grows gradually but intermittently in intensity on a scale that is usually hours synchronous with increasingly greater intensity of individual bay activations. An origin point in time and location is not obvious. The decay of a disturbance is similarly a gradual but intermittent process involving hours. These features evident from examination of successive 2.5 minute disturbance diagrams, are usually apparent even in 1-hour AE indices and 3-hour Kp indices. The implication relative to the convective process is obviously that it takes time to build up plasma pressure and pressure differentials leading to a greater $\underline{v}$ within the magnetosphere and similarly it takes time to deplete the magnetospheric reservoir. On this time scale it is difficult to conceive that the switching on and off of an electric field across the tail proportional to $-\underline{v}_{sw} \times \underline{B}_{ip}$ is directly applicable. A more restrictive form of reconnection could however be applicable as one of the processes that permits solar plasma to enter the magnetosphere.

(C) Nishida's DP-1 and DP-2 Convective Patterns

Nishida (1966) (also see Obayashi and Nishida, 1968) has proposed that in addition to convection of the type discussed here, which he calls DP-1, there is a second convective system, called DP-2, which is evident only during quiet times. His description will not be repeated here except to note: (1) that unlike his assumption that the DP-1 field is highly variable in its pattern, the pattern found in this study is probably just as stable, if not more so, than the DP-2 pattern which he regards as stable, and (2) that the present study has not indicated a second type of pattern which is not surprising considering the similarity of the DP-1 and DP-2 patterns at high latitudes and the fact that the present study does not include the low latitude variations that define his DP-2. It is important, however, to note that a convection of the DP-2 type may be superimposed on the convective patterns considered here and to inquire as to why this convection has such a negligible effect on the consistency of the high latitude disturbance pattern. The answer proposed here is that fluctuations of Nishida's DP-2 type result directly from variations in the total (i.e., B^2 and p) pressure tensor at the magnetopause, both in time and magnetopause location, and that these pressure changes are transmitted uniformly (comparitively speaking) through the magnetosphere. The consequence is that they do not markedly affect the existing internal pressure gradients and thus the flow pattern of $\underline{v}$ is not greatly altered. In effect they are thus regarded as a form of convection similar to the convection accompanying sudden impulses as discussed by Sugiura (1965) but representing slower changes than those designated as s.i.'s. As shown previously (Heppner, 1968) the fast convection accompanying s.i.'s can cause premature triggering of bay onsets in the auroral break-up region. Similarly, one might anticipate enhanced DP-2 effects in regions where a perturbation in $\underline{v}$ from a change in boundary pressure is significant.

In summary, Nishida's DP-2 convection can be viewed as being distinct from the convective patterns considered here, as can the s.i. convection, but the effects of this superimposed convection are of a transient nature.

(D) Mid-day Auroral Belt Convection

As indicated in Figure 2 and Section III the electrojet flow often, but not always, exists along a thin strip in latitude in the late morning and noon hours. At other times, Figure 2 (c), the same region indicates only a very weak extension of the polar cap current. The existence of day-time electrojets and aurora is, of course, one of the strong arguments against assuming that the auroral belt occurs on open field lines. As pictured in the present study the existence of a mid-day electrojet indicates the presence of a thin convective layer adjacent to the dayside magnetopause. This layer is envisaged as temporarily disappearing within the time sector 8^h - 13^h for various periods of time. The OV1-10 data, Section III (B), indicate a similar behavior in that orbits are encountered which do not show the occurrence of irregularities on the dayside in this sector. For example, passing from day to night over the pole the first irregularities encountered in these cases are at much higher latitude or even on the nightside and are of low intensity such as frequently encountered in the center of the polar cap.

(E) Dawn-Dusk and Noon-Midnight Asymmetries

As noted previously, Heppner (1967), the $+\Delta H$ to $-\Delta H$ auroral breakup region is most frequently in the 22^h to 23^h hour local time sector rather than at magnetic midnight. This is further supported by statistics on the magnetic local time dependence of maximum positive and negative deviations of the horizontal component at College (64.7^{o}N) and Kiruna (65.3^{o}N) whose local times lead and lag magnetic time by about 1.5 hours, respectively. This is illustrated in Figure 7. Figure 7 also shows that the time is essentially statistically independent of the level of activity. (Note: The two peak behavior for the time of maximum $| -\Delta H |$ for Kp = 0 or 1 results from the $|-\Delta H|$ of Sq currents near noon frequently being greater than the $|-\Delta H|$ of the westward electrojet under quiet conditions).

There is similarly an asymmetry in the dusk-dawn plane in the sense that the pattern, Figures 2 and 4, extends to lower latitudes near 18^{h} than near 6^{h}. This is contrary to some electrojet representations based on magnetic disturbances as a consequence of the current integrating error, noted in III (B) previously, and the fact that the westward current near 70^{o} may be intense enough to be observed at much lower latitudes. The OV1-10 boundary clarifies this asymmetry. Between 4^{h} and 6^{h} in individual cases of bay activity the westward current region often appears to die out rapidly near 65^{o} as the low latitude boundary moves poleward. Figure 7 indicates this feature statistically in that it is very rare for the maximum disturbance, minimum H, to occur after 05^{h}. In contrast maximum $+\Delta H$ disturbances frequently appear near 18^{h} at the same latitude.

The deviation from noon-midnight symmetry is even greater over the polar cap in that the flow alignment is in general skewed relative to the meridian near 22^{h} - 23^{h} separating east and west electrojet flow. This skew angle ranges from 0^{o} to 60^{o} such that the alignment is in the range 15^{o} to 90^{o} west of the earth-sun line with a definite preference for values near 60^{o}.

These features clearly show that the assumption of noon-midnight symmetry in the solar wind driven convection is incorrect. This point was emphasized by Taylor and Hones (1965) relative to the Axford and Hines (1961) picture. Unfortunately Taylor and Hones went to the opposite extreme of using the Silsbee and Vestine (1942) current model which does not properly represent the auroral belt disturbance in the evening hours (see Heppner, 1967). Their representation of the polar cap region is not however greatly different from that shown here. All other investigators have incorrectly assumed a noon-midnight alignment of the polar cap current in modeling the solar wind driven convection.

V. Reservations Regarding Convective Models

Only large scale features of the convection pattern have been treated in the preceding discussion, and on this scale it is believed that extrapolation from the pattern of ionospheric currents is valid. It should be noted, however, that in polar cap regions there have not been measurements of electric fields to verify the assumption that the integrated σ_2 exceeds σ_1. This is an assumption that is particularly important to note for two reasons: (a) the alignment of auroral forms over the polar cap has often been stated to be along the sun-earth line. If this was indeed true in general they would be skewed relative to the current flow and it would cast serious doubt on the conductivity assumption, and (b) plasma measurements in the magnetospheric tail have not to date demonstrated a systematic change in energy spectra as a function of location such as one might expect from the distribution of equipotentials (e.g., cross-wise to the tail in models such as Figure 1 (E) or primarily as a function of radial distance in models such as Figures 5 and 6). Thus in terms of present knowledge there are some reasons to doubt the validity of all convective models in regions connected to the polar cap. Experiments such as barium vapor releases in polar cap regions are sorely needed to test the conductivity assumption.

The smaller scale features of convection and the intricate dynamic features accompanying rapid time and spatial changes are beyond the scope of this discussion and beyond the current state of understanding to permit discussion much beyond mere speculation. One example, is the anti-correlation between the electric field and the auroral luminosity shown by Aggson (1969). Another example, is whether or not the "frozen field" concept is still applicable at the time of auroral break-up or does a sudden break-up involve ionospheric shorting as proposed by Heppner, et al. (1967). These and other dynamical features place emphasis on ionospheric loading of the convection dynamo.

Feedback effects of irregularities, assumed to be generated directly or indirectly by the convective field, are also likely to alter the subsequent convection. A minimum of three scales of irregularity structure are obvious: (1) as shown by the simultaneous motions of multiple Ba+ clouds (Wescott, et al., 1968) factors of two in velocity are observed between clouds separated latitudinally by < 100 km. Also, factor of two changes in velocity of a given cloud have been observed to occur within several minutes of time along the drift track, (2) magnetic field aligned filaments of 0.1 to 2 km thickness are a prevalent feature as shown by auroral measurements (Maggs and Davis, 1968), striations in Ba+ clouds (Wescott, et al., 1968, Lüst, 1969), the OV1-10 measurements previously noted, and numerous studies of radio wave scintillations, and (3) the dimensions of many auroral forms fall in-between the above two scales. It appears likely that polarization fields will accompany at least the small scale irregularities but there magnitudes, ionospheric attenuations, dependence on the height distribution of ionization, etc. are essentially unknown.

Solutions to many questions involving auroral morphology, explanation of the various discrete auroral forms, and post break-up particle acceleration, probably lie in the understanding of the smaller scale features of the convective process.

FIGURE CAPTIONS

Figure 1: Models of magnetospheric convection: (A) and (B) Axford and Hines (1961), (C) Taylor and Hones (1965), (D) Nishida (1966), (E) and (F) Brice (1967). (A) and (E) omitting rotational flow; (B), (C), (D) and (F) including rotational flow.

Figure 2: High latitude ionospheric electric currents (first approximation omitting continuity): (a) basic pattern, (b) and (c) pattern modifications produced by rotation of east and west current cells of (a). To obtain the convective flow, reverse all arrows. Coordinates are geomagnetic time and invariant latitude.

Figure 3: Example of response in the 3 - 30 Hz and < 60 sec bands from OV1-10 for a polar crossing (Kp = 3).

Figure 4:

Figure 5: Magnetospheric convection in the equatorial plane corresponding to Figure 2 (B). Tic marks are at 2 R_e intervals.

Figure 6: Magnetospheric convection in the equatorial plane corresponding to Figure 2 (C).

Figure 7: Geomagnetic Time of maximum and minimum intensity of the horizontal component of the magnetic field at College and Kiruna. Selected once per Greenwich day by computer from 2.5 minute scalings of 334 consecutive days.

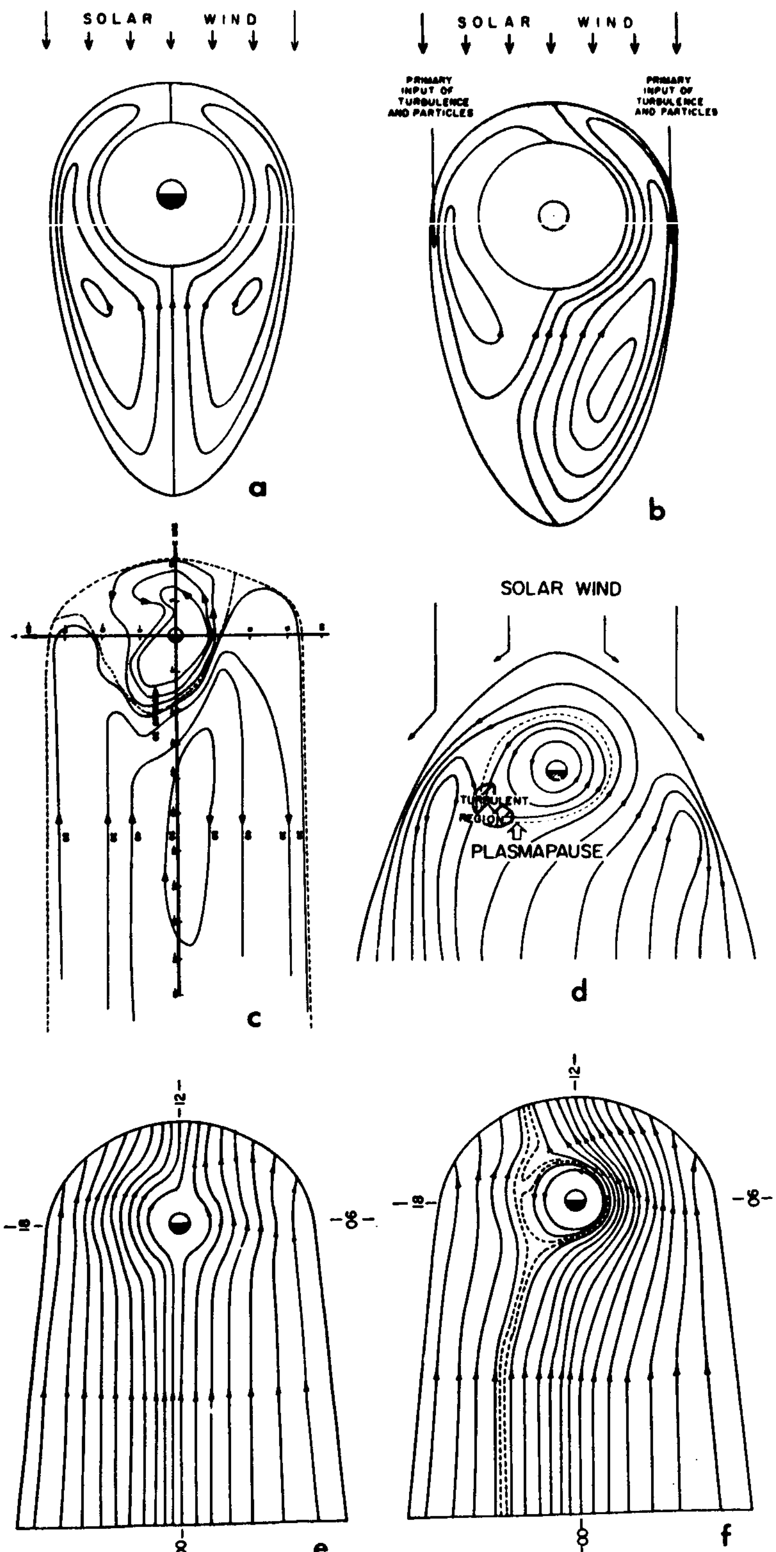
SOLAR WIND
a
SOLAR WIND
PRIMARY INPUT OF TURBULENCE AND PARTICLES
PRIMARY INPUT OF TURBULENCE AND PARTICLES
b
c
SOLAR WIND
TURBULENT REGION
PLASMAPAUSE
d
12
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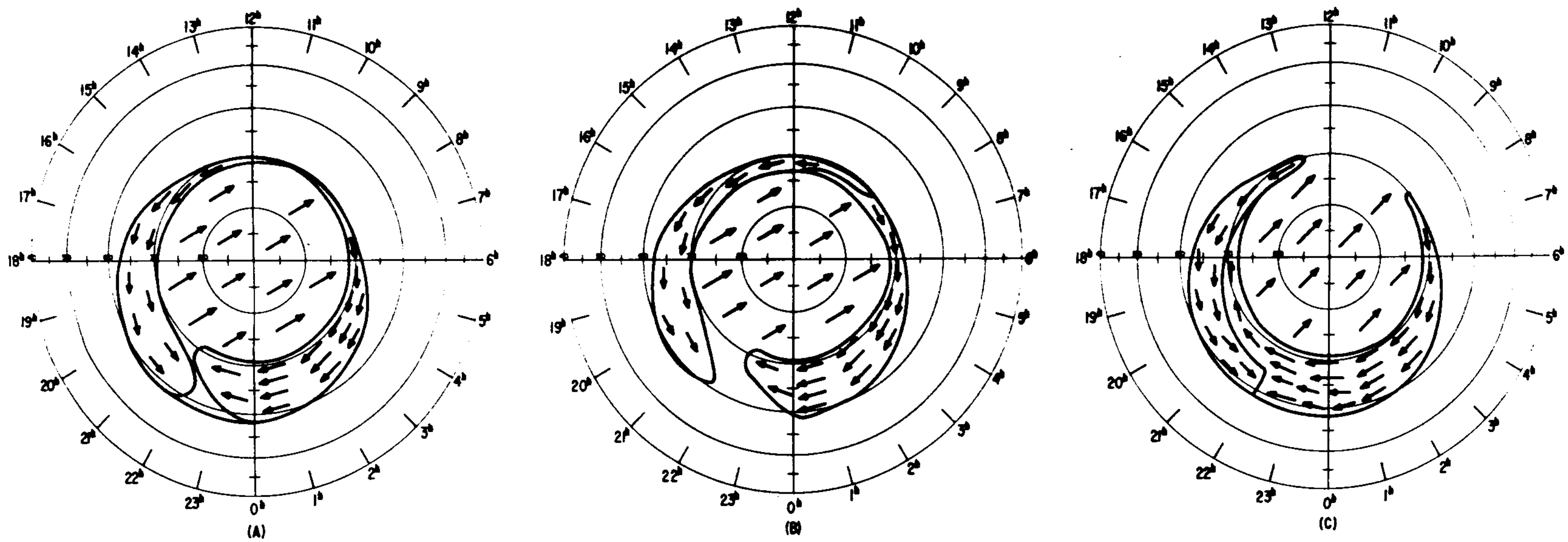
Figure 1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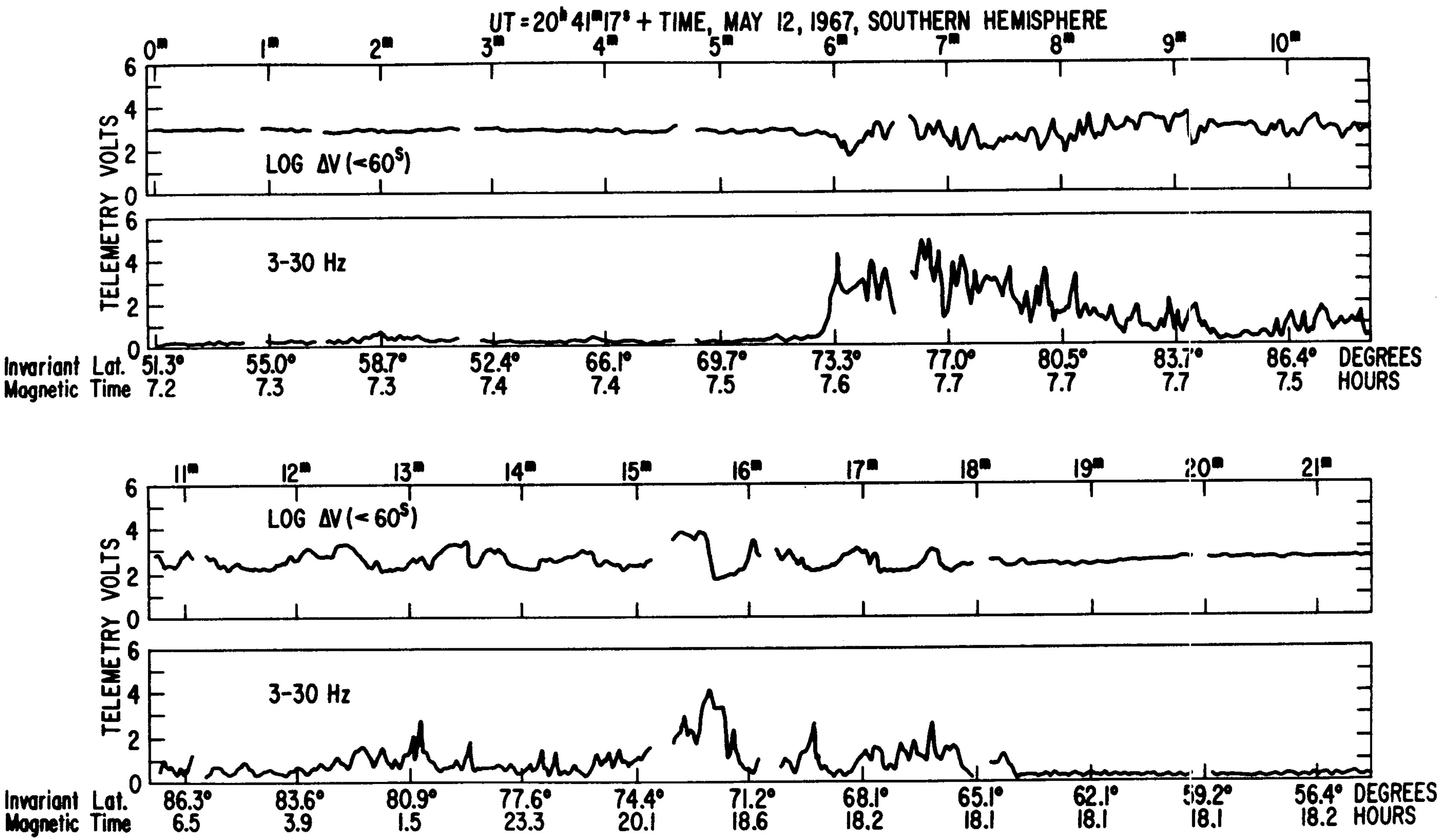
(C)

Figure 2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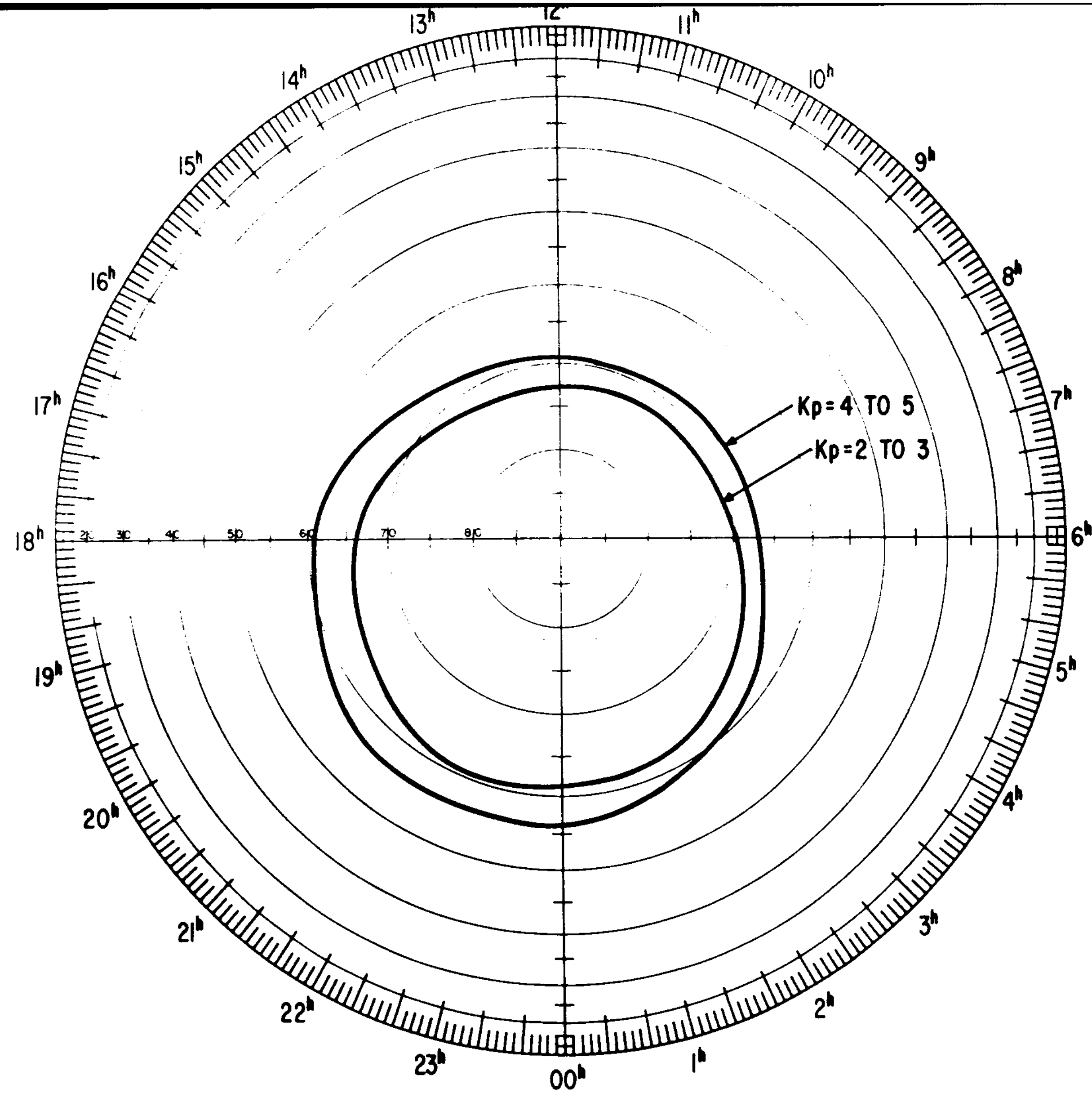
1m
2m
3m
4m
5m
6m
7m
8m
9m
10m
TELEMETRY VOLTS
LOG ΔV (<60S)
3-30 Hz
Invariant Lat.
Magnetic Time
51.3° 55.0° 58.7° 52.4° 66.1° 69.7° 73.3° 77.0° 80.5° 83.7° 86.4° DEGREES
7.2 7.3 7.3 7.4 7.4 7.5 7.6 7.7 7.7 7.7 7.5 HOURS
11m
12m
13m
14m
15m
16m
17m
18m
19m
20m
21m
LOG ΔV (< 60S)
3-30 Hz
86.3° 83.6° 80.9° 77.6° 74.4° 71.2° 68.1° 65.1° 62.1° 59.2° 56.4° DEGREES
6.5 3.9 1.5 23.3 20.1 18.6 18.2 18.1 18.1 18.1 18.2 HOURS

Figure 3



"AVERAGE" LOCATION OF MINIMUM LATITUDE OF 3-30 Hz IRREGULARITY SIGNAL
INVARIANT LATITUDE vs. MAGNETIC LOCAL TIME
FOR Kp=2 TO 3 AND Kp=4 TO 5

Figure 4

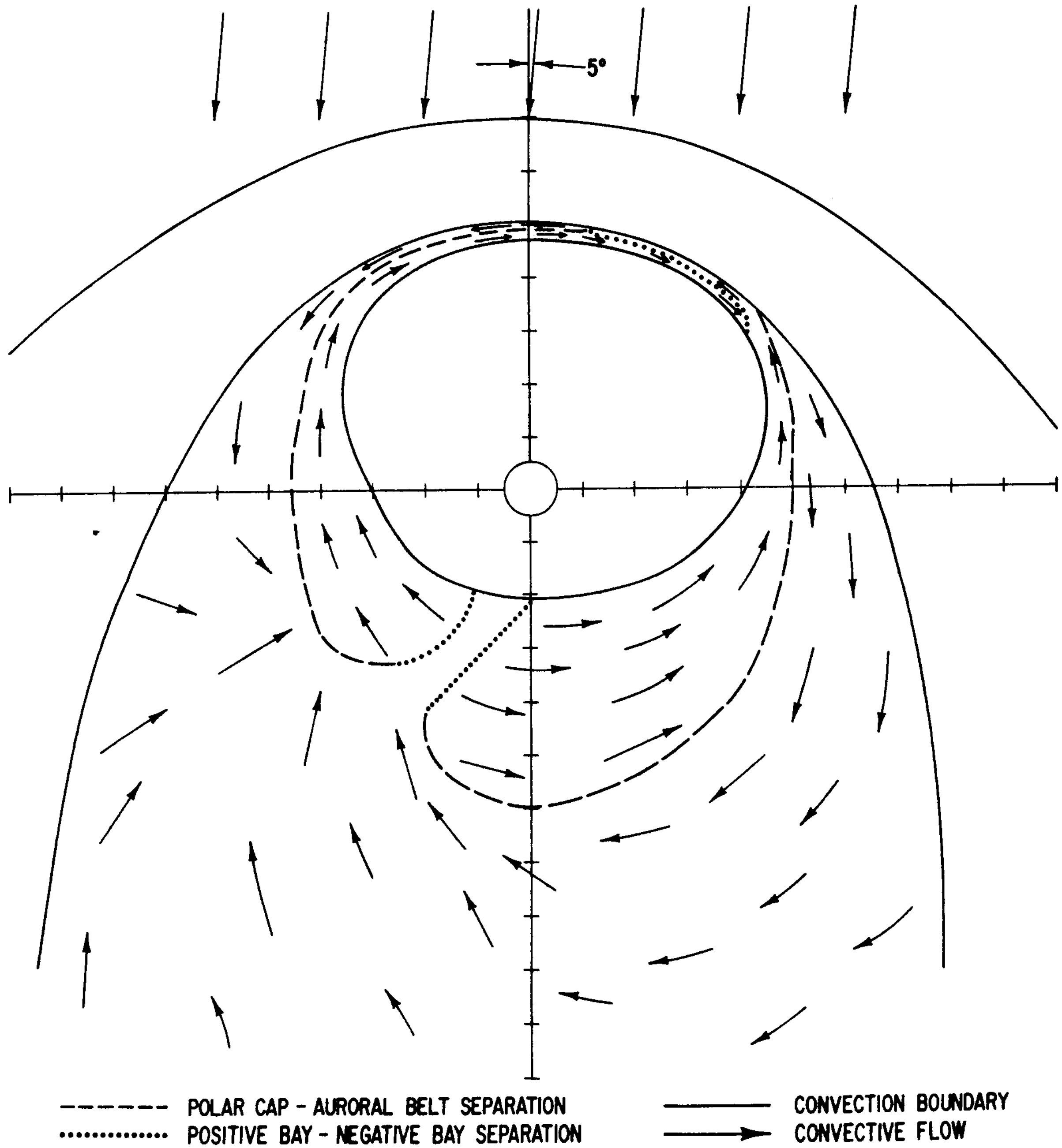

5°
POLAR CAP - AURORAL BELT SEPARATION
POSITIVE BAY - NEGATIVE BAY SEPARATION
CONVECTION BOUNDARY
CONVECTIVE FLOW

Figure 5

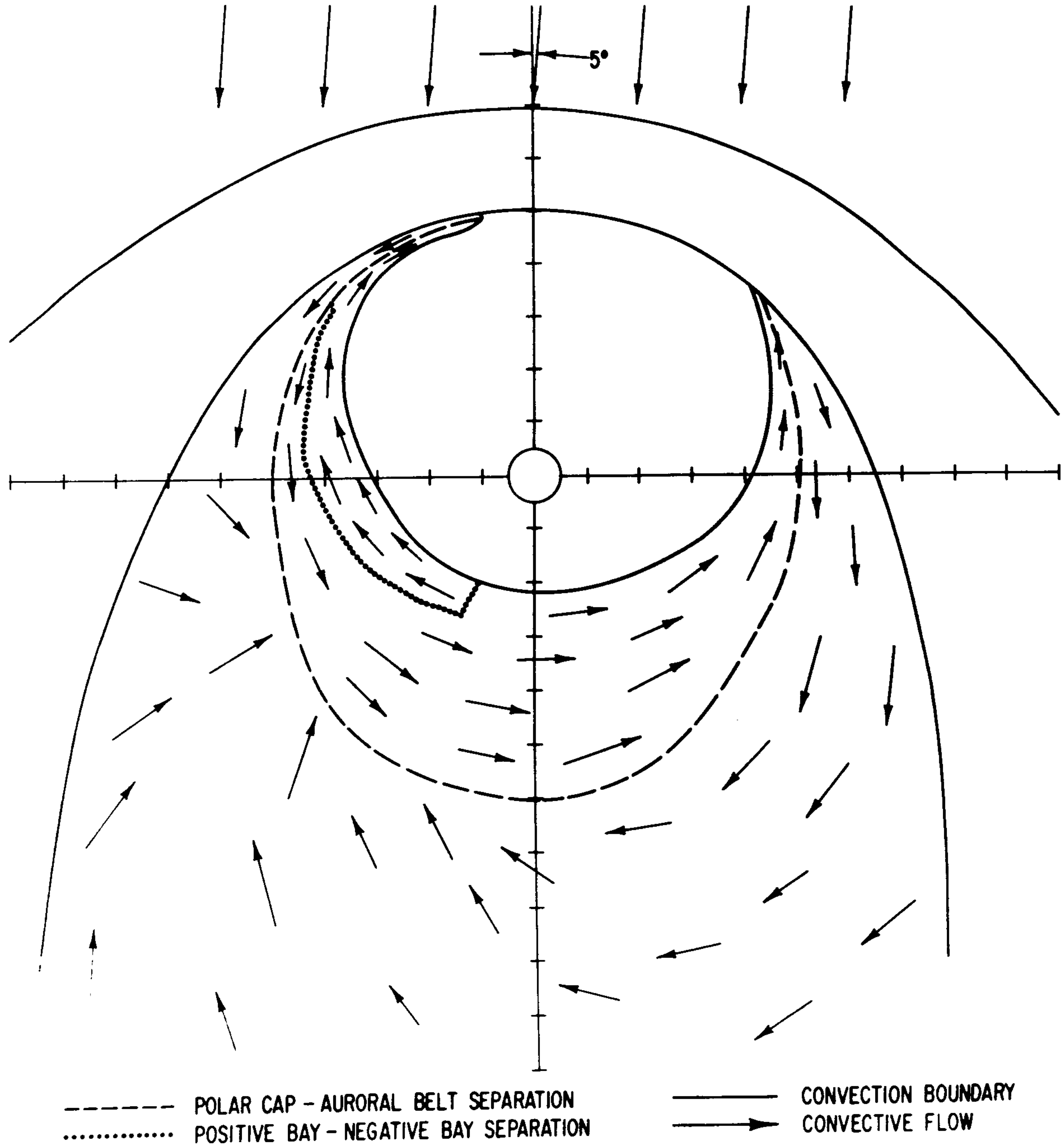

5°
POLAR CAP - AURORAL BELT SEPARATION
POSITIVE BAY - NEGATIVE BAY SEPARATION
CONVECTION BOUNDARY
CONVECTIVE FLOW

Figure 6

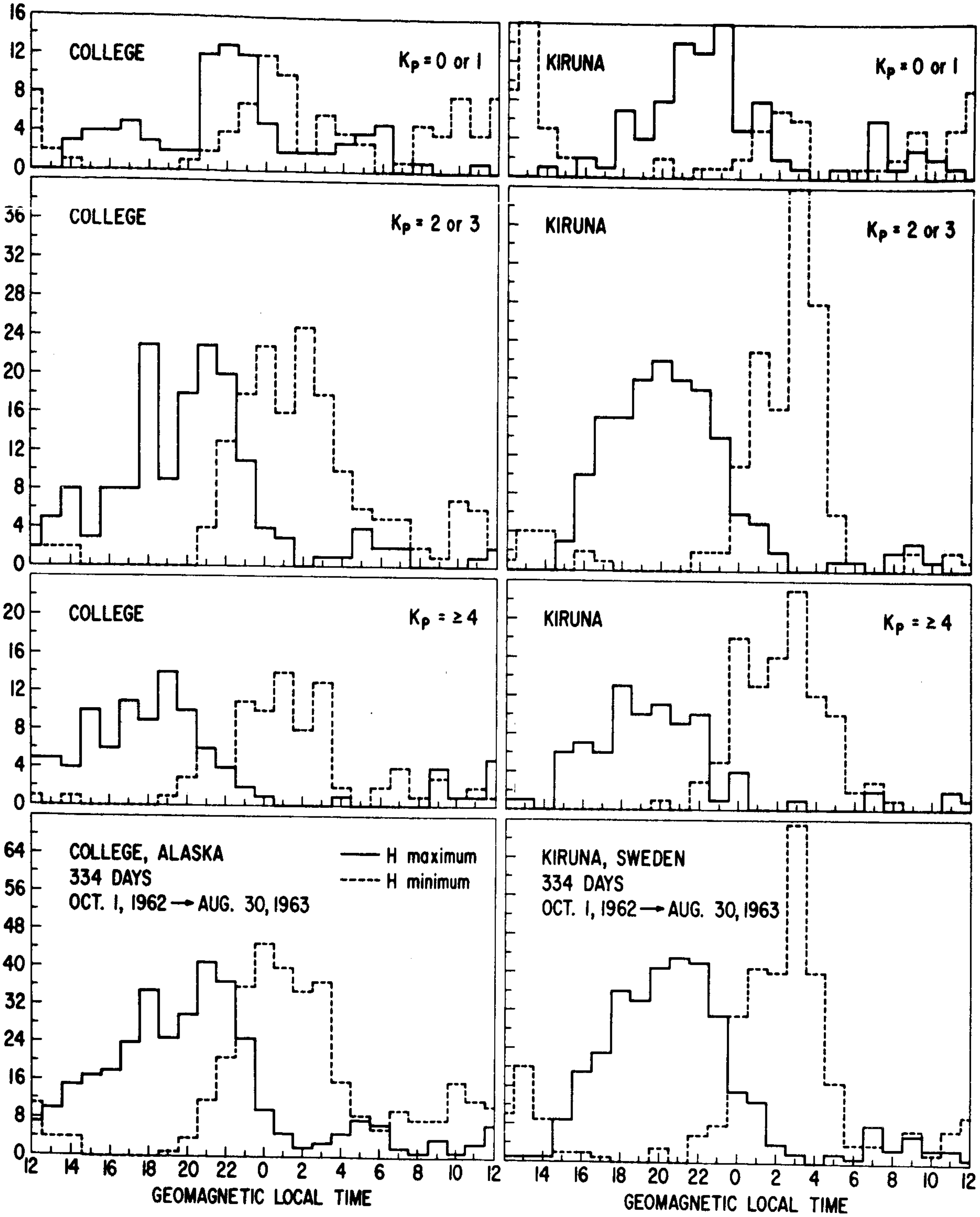

COLLEGE
K_p = 0 or 1
KIRUNA
K_p = 0 or 1
COLLEGE
K_p = 2 or 3
KIRUNA
K_p = 2 or 3
COLLEGE
K_p = ≥ 4
KIRUNA
K_p = ≥ 4
COLLEGE, ALASKA
334 DAYS
OCT. 1, 1962 → AUG. 30, 1963
H maximum
H minimum
KIRUNA, SWEDEN
334 DAYS
OCT. 1, 1962 → AUG. 30, 1963
GEOMAGNETIC LOCAL TIME
GEOMAGNETIC LOCAL TIME

Figure 7

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