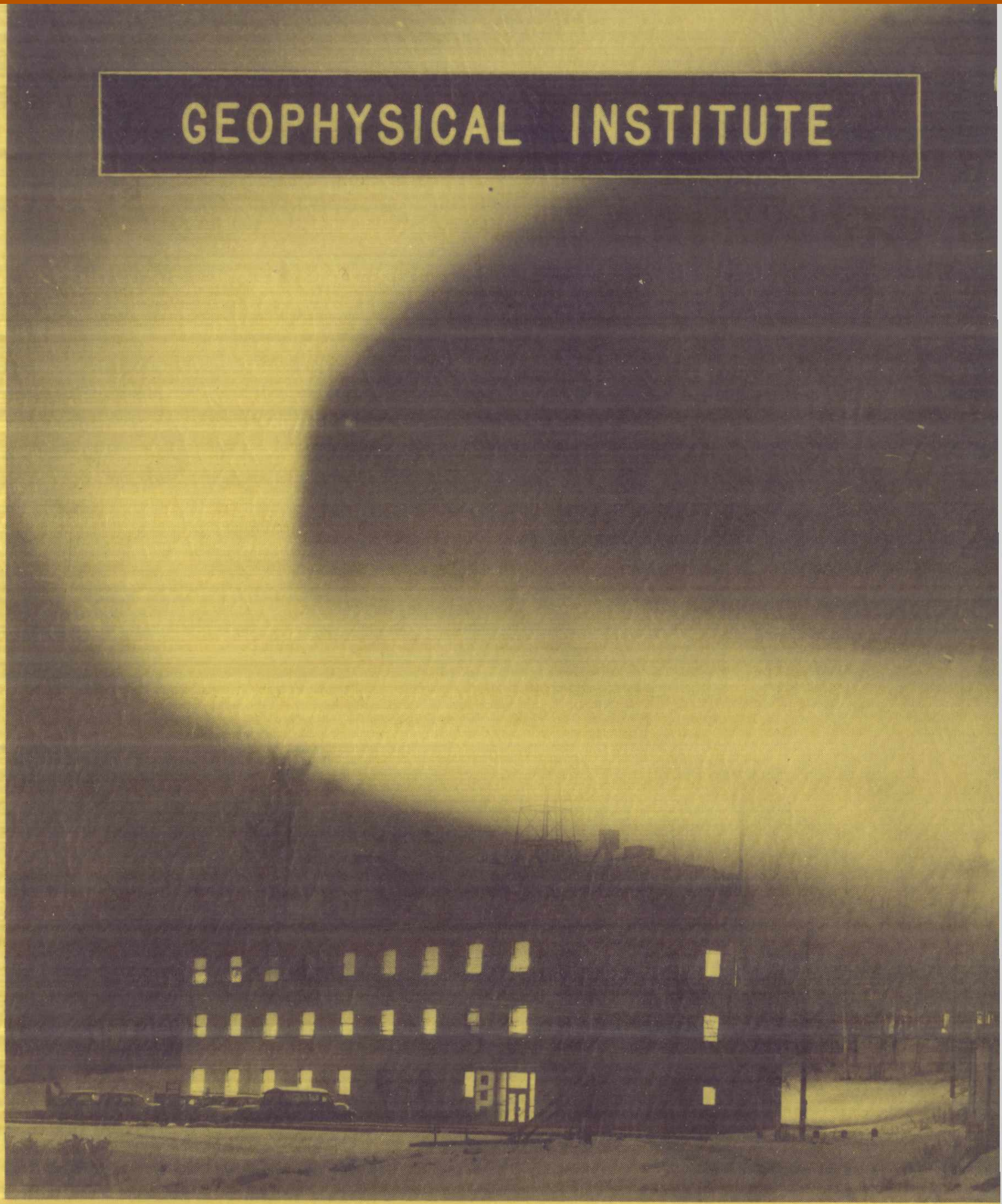

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INCIDENCE OF AURORAS AND THEIR NORTH-SOUTH MOTIONS IN THE NORTHERN AURORAL ZONE

by

T. Neil Davis and Donald S. Kimball

Scientific Report No. 4
NSF Grant No. Y/22.6/327

Principal Investigator: C. T. Elvey

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ABSTRACT

Studies of the incidence of auroral forms and their north and south motions are made by using a close-spaced array of all-sky cameras located in the northern auroral zone at the approximate geomagnetic longitude 250°E. It is found that during the observing season 1957-58 the peak of the average auroral zone occurred at 66-67° geomagnetic latitude. Although the southern extent of auroras retreats northward after local magnetic midnight, the southward motion of the individual forms, observed at the southern edge of the auroral zone, predominates over the northward motion throughout most of the night. The data indicate the existence on any given night of a latitude position near which many auroral forms occur. The first motion of auroras incident north of this position tends to be northward, and the first motion of auroras incident south of this position tends to be southward. A curve showing the occurrence of auroral forms peaks at, and is nearly symmetrical about, local geographic midnight, but the intensity of auroral emissions measured over the celestial hemisphere remains at a high level after midnight.

INTRODUCTION

The increased use of all-sky cameras for auroral photography during the IGY, 1957-58, makes possible new examination of several aspects of auroral morphology. While the all-sky camera has certain disadvantages, such as not being able to make instantaneous recordings, it does allow for permanent recording of auroral forms and uniformity of observation. The all-sky camera is particularly useful in the study of motions and changes in form of most auroras.

The present study makes use of a closely-spaced array of all-sky cameras to determine the shape of the average auroral zone over Alaska and to examine the north and south motions of auroral forms. This array consists of five cameras operated during the IGY at the positions shown in Figure 1. Only the data obtained during the observing season September 1957 to April 1958 are used: The actual operation of the cameras during this period is shown in Figure 2. These cameras were operated to take 15-sec exposures at 1-minute intervals throughout the dark hours. Details of the operation are given by Young (1959).

In order to maintain a reasonable uniformity of observation in this study, only data from that part of the sky within 60° of each camera zenith are used. At zenith distances greater than 60° there is severe distortion in the all-sky photographs. There is also considerable difference in the appearance of the auroral forms when viewed from below as compared to those viewed from a great distance. Markers placed along the all-sky camera meridians at zenith distances of 30° and 60° respectively correspond to overhead positions displaced from the camera location by 1/2 and 1-1/2 degrees in latitude. This correspondence results from assuming an average auroral lower border height of 100 km. As can be seen in Figure 1, the locations of the cameras allow with little error the assignment of each marker to one of the geomagnetic latitude positions between 60° and 70° inclusive.

Most auroras are aligned approximately in the geomagnetic east-west direction. This is true of the simpler forms, homogeneous and rayed arcs; and also to a lesser extent of the bands and other active forms. In fact, both visual observations through a geomagnetic-aligned grid and the all-sky camera observations show considerably more alignment of auroral forms with geomagnetic latitude lines than is readily apparent to the visual observer without the aid of such a grid. Such forms as draperies, ray bundles, and diffuse surfaces may appear to the unaided visual observer to be scattered without pattern, but through a proper grid or the lens of an all-sky camera these are often seen to be parts of discontinuous arcs or bands. Hence, it may be ambiguous to state the number of auroral forms visible from some observing location unless the criterion of counting is also given. If only arcs are visible, little question arises as to the number of forms present, but the determination of the number of irregular forms present, such as draperies, may be more difficult. This problem is avoided in this study by considering only those auroral forms extending across the geomagnetic meridian of the observing location. By assuming that all auroral forms are aligned nearly vertical, or more precisely, along the geomagnetic field, it is possible to consider the lower limit of the auroral form as defining its overhead position. The lower limits may, as in the case of arcs, be sharply defined lower borders, or if these are lacking, the irregular edge of the form can be used to determine the position of incidence. The term "incidence" is used here in the sense that an auroral form incident at a position on the earth's surface is one which has a lower limit above that position. Thus, the term incidence has a more restrictive meaning than "occurrence", which is often used to describe the number of auroral forms visible in the celestial hemisphere above an observing location.

Two methods of scaling are used in this study. One method, to determine the incidence of auroras, involves counting the number of auroral forms incident during each hour along a geomagnetic meridian extending from 60° to 70° geomagnetic north. This is done by viewing each fifth frame of the all-sky film and counting the number of auroral lower limits and noting their latitude position between the camera marker bars. The second method of scaling, by which the north and south motions are determined, involves examining all frames of the all-sky film and observing crossings of auroral lower limits at the markers corresponding to the 11 overhead latitude positions shown in Figure 1. The north or south motion of an auroral form is recorded as a crossing only if the lower limit moves completely across a marker. The markers are of such a size that a minimum horizontal motion of 5 km on the 30° markers and 20 km on the 60° markers is necessary to yield a recorded motion. The techniques of listing and analysis of the scalings allow examination of the details of individual displays as well as statistical study of the auroral incidence and north-south motion.

PRESENTATION OF DATA

Auroras were photographed by one or more cameras on 180 of the 217 nights of the observing season. The lack of photographs of aurora on the remaining 37 nights can be attributed mainly to cloud cover or camera mal-functions. All nights were scaled for north and south motions, and scalings for auroral incidence were obtained for the 60 nights during which observations were complete enough to detect all auroras incident between 60° and 70° latitude The data resulting from adjacent cameras which view common portions of the sky showed general agreement on clear nights. Frequently, however, there were differences caused by partial cloud cover, unequal aspect angles, and by incorrectly assumed heights of aurora. Whenever inequalities existed it was necessary to apply some judgement in the interpretation of the data.

Diurnal Variation of Auroras. Figure 3 shows the diurnal variation of three kinds of auroral phenonoma. They are north and south motions (curves S,N and S+N); incidence of auroras; and the intensity integrated over the entire sky as observed from College.

The curves in Figure 3 result from summing the various types of data and so represent average diurnal variations. The curves are normalized for ease of comparison. Curve S indicates south motion; curve N indicates north motion; and their sum, curve S+N, is total north and south motions. Lying very close to the S+N curve is the curve showing incidence of auroras. The closeness of these two curves except between 03 and 06^h demonstrates a close statistical relation between the incidence and north-south motion of auroras. Further, examination of individual displays shows that the incidence of auroras between two geomagnetic latitude lines during any hour correlates closely with the number of auroral crossings over those latitude lines during that hour. Such correlation decreases as the time interval of comparison is shortened. This time dependence of the correlation gives some information about the north-south mobility of the auroral features It implies that a feature incident upon a one-latitude-degree wide strip of the earth's surface usually will move across one of the boundaries of the strip within an hour. For this reason it is possible to consider the number of north and south crossings over the latitude positions each hour as being an acceptable indicator of auroral incidence between the latitude positions during that hour. This is further shown by comparison of the curves of incidence and S+N motions versus latitude; Figure 4.

Since the southern extent of auroras is known to move southward before local magnetic midnight and then move back northward during the morning, it has often been assumed that the individual auroral features move south before midnight and north afterwards. It is evident that this is not true in the auroral zone. Examination of Figures 3 and 4 shows that during most of the night and at all latitudes between 60° and 70° the south motion exceeds the north motion. There is, therefore, a net southward drift throughout the night, except possibly during the late morning hours. Note that after 06^h, the north motion exceeds the south motion. Although Figures 3 and 4 represent the compilation of more than 10,000 auroral crossings, most of the crossings occurred during the middle of the night, and so the curves are least reliable during the early evening and late morning hours. It will be noticed that those curves of Figure 3 that are discussed above are symmetrical about local midnight. Contrasting with this symmetry is the curve entitled College Intensity Index. This curve is an hourly sum of auroral indices obtained from the College all-sky films for the 1957-58 season by Tryon (1959) and tabulated by Ernest Stiltner of the Geophysical Institute. The indices represent Tryon's evaluation of the intensity of auroral forms present and the "auroral activity" as determined by visual examination of three consecutive all-sky photographs from each 15-minute interval.

Comparison of these curves shows that it is necessary to consider the incidence of auroras and the integrated intensity of auroral radiation as two different aspects of the auroral phenomenon. This statement is strengthened by examination of other curves of diurnal auroral variations published by Murcray (1959), Fuller (1935), and Elvey (1956). Elvey (1956) and Elvey, et. al. (1955) also show several curves of auroral incidence that are not symmetrical about local midnight. The data used in Elvey's investigations came from visual auroral observations, as did that used earlier by Fuller. In comparing the past results with those presented here, the question arises as to whether or not all-sky camera and visual observation data are comparable. A comparative study of all-sky camera and visual observations described by Davis Deehr, and Leinbach, (in preparation) indicates that although there are differences in the descriptions obtained by the two methods, the results should be essentially the same if the visual observations are uniform and continuous. It should be kept in mind in comparing the results of the various investigations that the characteristics of displays may be dependent upon time of occurrence within the sunspot cycle.

Latitude Variation of Auroral Incidence. Figure 4 shows that when the incidence and auroral crossing data are summed over the 1957-58 season that the peak of the auroral incidence and of the auroral motions is a 66-67° north geomagnetic latitude. It is not known whether the slight minimum in the N & S crossings curve at 67° is real or is due to a lack in the uniformity of the observations. The number of auroral features decreases rapidly on either side of the latitude of maximum incidence so that less than half as many auroral features and north-south motions are observed at the 64° and 70° positions as compared to the maximum at 66-67°.

The summed auroral motions data shown in Figures 3 and 4 is also represented in the form of an isometric plot, Figure 5, which shows the north and south motions as a function of latitude and local time. From this diagram it is apparent that during the early evening hours the only aurora (as implied by the crossings data) occurs to the north. Auroras occur farther south as the night progresses, but the long-term average maximum remains north of 64° during all hours of the night. The maximum number of auroras occurs at 66° during the hour beginning at local midnight. After that time there is a broadening in latitude of the curves of north-south motion versus latitude.

Sixty displays are chosen on the basis of completeness of the observations on the nights these displays occurred, and these are divided into two equal groups. Those displays having less than 22 crossings during the most active hour are placed in one group and those having 22 or more crossings are placed in the other. Isometric diagrams of these two groupings are shown as Figures 6 and 7. These diagrams show the same trends as observed from Figure 5, but Figure 6 emphasizes the well-known tendency for the southern extent of the auroral displays to be farthest south near midnight and then to retreat northward during the morning hours.

Southern Extent of Auroras. Figure 8 presents the average southern limit of the auroral displays as a function of local time. The southern limit of a display is here defined as the lowest latitude at which auroral crossings occur. The plotted points are hourly means of the southern edge of the auroral crossings. The numbers adjacent to the plotted points represent the number of displays used for determining the mean position of the southern extent for each hour.

The lower curve represents the combined data for 77 displays which had a maximum southern limit greater than 65°. These could be classified as moderate or large displays. This curve would probably be deeper during the hours around local or magnetic midnight, if observations were extended below 60° latitude. It will be noted that the recovery phase (retreat of the southern limit to the northward) is more rapid than the initial phase.

The upper smoothed curve represents the combined data for 16 displays having maximum southern limits reaching only to 65°. These can be classed as weak displays. The middle curve includes 33 auroras which reached a southern limit of 64°. The straight-line connections between the points of the upper two curves suggest the possibility of two peaks in the southern extent of the weaker auroras. The smoothed curves illustrate that both weak and strong auroras seen in the latitude range 60-70° have their greatest southern extent near local magnetic midnight.

A study of the mean southern limit of 28 auroras seen in the northern United States from 1939 tc 1951 as a part of the Cornell University visual auroral program (Bless, et.al 1959) shows a similar trend with the greatest southern extent near midnight, except that the recovery phase to the north is less rapid.

Time Progression of Latitude of Maximum Aurora. Observing conditions were such that on 71 nights it is possible to locate and follow the progressions of the latitude positions near which more auroras are incident than to the north or south. Examples of the progression of these latitude positions of maximum incidence are shown in Figure 9. On the two nights pictured in Figure 9a, single latitude positions of maximum aurora incidence occur during each hour and these positions progress southward throughout the night. Figure 9b shows a similar pattern except that a second position of maximum incidence moves into the field of view from the north. Of the 71 nights observed, 26 are of the types shown in Figures 9a and 9b. Thirty-three other nights are of the type shown in Figure 9c. On those nights the center of activity remains at approximately the same latitude throughout the night. Figure 9d shows examples of two nights on which the position of maximum incidence is somewhat erratic, but on these nights there is a tendency for the positions of maximum incidence to move southward until midnight and then retreat northward after midnight. Only 10 examples of this type of progression are found. Two of the 71 nights do not fit any of the above patterns; instead they are similar to those nights shown in Figure 9b except that the secondary position of maximum aurora progress considerably farther south.

The displays occurring on those nights illustrated by Figures 9a and 9b tend to extend farther south than on those nights where the position of maximum aurora remains relatively constant as shown in Figure 9c. At least 8 of the 26 displays in the first group extend south of 60°, but only 2 of the 33 displays of the second group definitely extend below 60°.

Width in Latitude of Nightly Displays. The camera array could observe the southern limit of many auroral displays occurring on the above-mentioned 71 nights, but usually the aurora extended beyond 70°, the northern limit of the observations. The least width found for any display is 3 degrees of latitude and most displays have a width of at least 7 degrees during the hour of maximum width. Although it is not always possible to determine the hour of maximum width from these data, it appears that the times of maximum width range from 20 to 05^h, with most maxima occurring with approximately equal frequencies between 22 and 03^h.

Relations between North-South Auroral Motions and Magnetic Activit For those nights of good observational coverage, hourly plots of north and south motions and the College 3-hour K-indices are drawn for each display. Figure 10 shows a comparison of north-south motions and the College K-indices on 15 representative nights. A diagram corresponding to each of the 15 nights indicates the number of north and south crossings observed during each hour and the corresponding College K-indices. The figures in parenthesis following the dates are the apparent southern limits of each display. The nights are arranged in rows of increasing magnetic activity. In each display the aurora moves both north and south during nearly all the hourly periods, with the southern motion being greater most of the time. The number of crossings, and by implication the number of auroral features present, appears to be related to the College K-indices before local midnight, but a similar correlation after midnight is lacking.

The great aurora of February 10, 1958 (See lower right-hand corner of Fig. 10) moved to low latitudes and showed relatively little motion during the periods of great magnetic activity. In northern latitudes this display was characterized by a red glow or veil over much of the sky. The low number of crossings observed during this aurora are in part due to the lack of features with well-defined lower borders and to the obscurement of detail of the features because of the high intensity during much of the display. Further, this display, being red was probably higher than the normal green auroras and so there is no justification for assuming a lower border height of 100 km as was done in reducing the data from this display.

<u>Latitude of Origin of Auroral Displays</u>. Early in the investigation it became evident that the direction of first motions observed at the latitude positions follow definite trends. On many nights the first auroral features seen at any of the geomagnetic latitude positions between 60 and 70° are moving southward. On other nights, there exists a latitude between 60 and 70°, north of which the first motions are to the north and south of which the first motions are to the south. For purpose of discussion we call this the "latitude position of origin" for the display. The auroral features do not necessarily form at this

latitude. Rather, they seem to form in place within one or two degrees on either side of the latitude position of origin and have a direction of first motion determined by whether the features form on the north or the south side of the latitude position of origin. Figure 11 shows the direction of the first motion at each latitude position for those days of the 1957-58 season on which aurora is observed by at least one camera. The solid circles represent the latitude positions north of which the first aurora moves north and south of which the first motions are southward, and the open circles represent similar latitude positions obtained with a lesser degree of confidence. The vertical lines extending across a latitude position in the figure indicate that aurora is seen at that latitude and the arrows on the vertical lines show the direction of first motion. Dashed vertical lines indicate that the first aurora seen probably did not occur during the initial part of the display. In most cases where this symbol is used, the first part of the display is obscured by clouds. Occasionally, at some latitude positions there are two vertical lines indicating for the position conflicting data from two or more cameras.

Often the display extends to latitude positions not observable because of cloudiness. This is shown by single dashes on the ends of the vertical lines. Short horizontal bars at the ends of the vertical lines indicate the apparent northern or southern limits of the displays. Those vertical lines extending to the 60 or 70° positions indicate that the auroras extend to or beyond these positions.

A latitude of origin can be found in the 60-70° latitude zone on 86 of the 180 nights when aurora was seen. On 58 other nights the aurora first moves south across all the latitude positions where it is observed. If the pattern described here holds at higher latitude, the implication is that on these 58 nights the latitude of origin is north of 70°. Approximately 10 nights are found on which the first motions either are without pattern or there is more than one latitude of origin. On those few nights where two latitudes of origin apparently exist, these origins are separated by approximately 4 degrees of latitude

The latitudes of origin occur occasionally as far south as 62-1/2° but most occur north of 66°. It seems likely that most of the latitudes of origin occur between 66 and 69°, but northward extension of observations may show that this is not true. These data explain why observers inside the auroral zone first see the aurora moving away from the zone, as do observers outside the zone. To an observer within the zone the first observed auroral motions may appear quite erratic because of nightly variation of the latitude position of origin. Such an observer may see southward motions at the beginning of one display and northward motions at the beginning of the next.

A plot of the ratio of south to north motions versus geomagnetic latitude for all data, Figure 12a, indicates a greater proportion of southward motion at the lower latitudes. In order to further investigate this, the motion data for each display for which the latitude of origin can be found are rearranged to be functions of the distance from the latitude of origin rather than functions of actual latitude. These data are then summed and the ratios of south to north motions obtained. The results, Figure 12b, clearly show a greater proportion of southward motion south of the latitude of origin and approximately equal south and north motions north of that position. The data have not been sufficiently studied to determine if a latitude of origin persists throughout each display, and if it does, whether or not its position is stationary. Until such a study is made it is not possible to fully describe the direction of auroral motions with respect to the origin position throughout each display. On the basis of the present study it can only be said that both north and south motions occur, but in differing proportions, on the two sides of the origin position.

SUMMARY AND CONCLUSIONS

This study has been accomplished mainly by examining the occurrence of auroras over a geomagnetic meridian extending from 60° to 70° N geomagnetic latitude, and by determining the north-south motion of these incident auroras. The meridian was divided into 10 segments, each one latitude-degree in length. Then by examining the all-sky camera films, a determination was made of the number of auroral forms incident over each meridian segment and of the north-south motions of these forms across the ends of the segments.

The results of this investigation are summarized as follows:

1) There is close statistical and detailed correlation between

the number of auroras incident between adjacent geomagnetic latitude lines during any hour and the number of auroral crossings over those latitude lines during that hour. This implies that few auroral forms occur without exhibiting some north or south motion. Those forms exhibiting the least motion appear to be most likely to occur between 03 and 06^h.

2) The peak of the average auroral zone over Alaska for the 1957-58 observing season was at 66-67° geomagnetic latitude. More than twice as many auroras occurred there as occurred at latitudes 3° north and south of this position.

3) The average incidence of auroras along a geomagnetic meridian extending from 60° to 70° N latitude is a function of the local time and is nearly symmetrical about local midnight. The north-south auroral motion data imply that toward the northern end of this meridian the maximum incidence occurs slightly before local midnight, and toward the southern end of the meridian the time of maximum incidence is after midnight. In comparing the diurnal variation curves obtained in this study with those of other studies, it is seen that there is not always agreement. This lack of agreement may be due to the average characteristics of auroral displays being dependent upon time of occurrence within the sunspot cycle.

4) The incidence of aurora and the auroral intensity integrated over the sky are different aspects of the auroral display. The incidence is symmetrical about its peak at local midnight, but the intensity is greater in the morning hours than it is during the evening hours.

5) Individual auroral features move both north and south, but, with the possible exception of the late morning hours, the south motion exceeds the north motion. Taken over the region 60-70°, the average ratio of south to north motion is approximately 1.5 and varies little from this value throughout most of the night. There is a tendency for greater south motion toward the south edge of the 60-70° latitude zone.

6) There appears to exist on any given night a latitude position near which many auroral features form. The first motion of features forming north of this position tends to be northward, and the first motion of the features forming south of this position tends to be southward. This latitude position of origin occurs many times between 66° and 68° but may occur south of this zone and often occurs north of it. There is relatively more northward motion north of the latitude position of origin than occurs to the south of it.

7) During any hour of a display there usually exists some latitude position near which more auroral forms are occurring than occur to the north or south. This latitude position remains fairly constant during the course of many displays. During other displays, the position near which there is maximum incidence drifts southward, and these displays tend to have greater southward extents. There may be some correspondence between the latitude position discussed here and the latitude position of origin discussed in (6) above, but this has not yet been investigated.

8) Auroral displays reach their greatest southern extent near local magnetic midnight. The southern extent recedes after

midnight at a rate greater than the pre-midnight advance.

9) There appears to be good correlation of the north-south motions and incidence of auroras with the College K-indices only before local midnight.

10) Between 20^h and local midnight, most auroras occur overhead near 67° geomagnetic latitude. After midnight, however, there ceases to be a sharp peak in the curves of incidence versus latitude. Instead, the curves broaden and the aurora appears to be spread more uniformly in latitude.

Probably the most significant of these results are numbers 5 and 6. Number 5 leads to the conclusion that, although the southern extent of auroras retreats north after midnight, the individual features continue to have a net southward drift. This continuance of southward motion appears to be contrary to accepted belief and poses a problem to those theoretical treatments such as Cole's (1959) which depend upon a near-midnight reversal of north-south motion.

The second result implies that there exists at some latitude a discontinuity or critical condition which causes the direction of first north-south motion to be opposite on the two sides of the critical latitude. The position of the critical latitude changes from one display to the next. Hence, its position may depend upon magnetic and electric conditions in or above the ionosphere.

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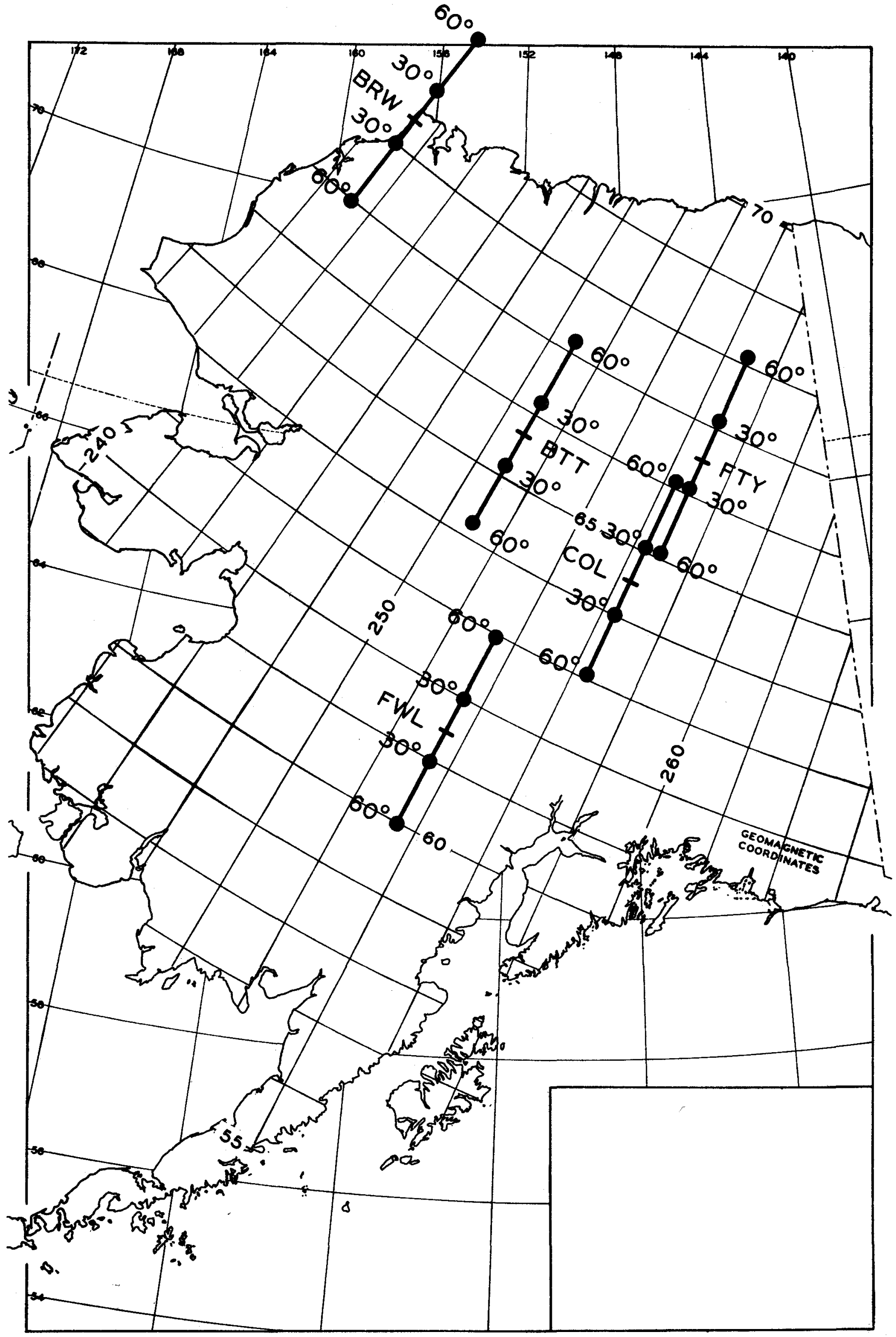


Fig. 1. Locations of the all-sky cameras, Barrow (Brw), Bettles (Btt), Fort Yukon (Fty), College (Col), and Farewell (Fwl) and the corresponding positions of the 30° and 60° markers.

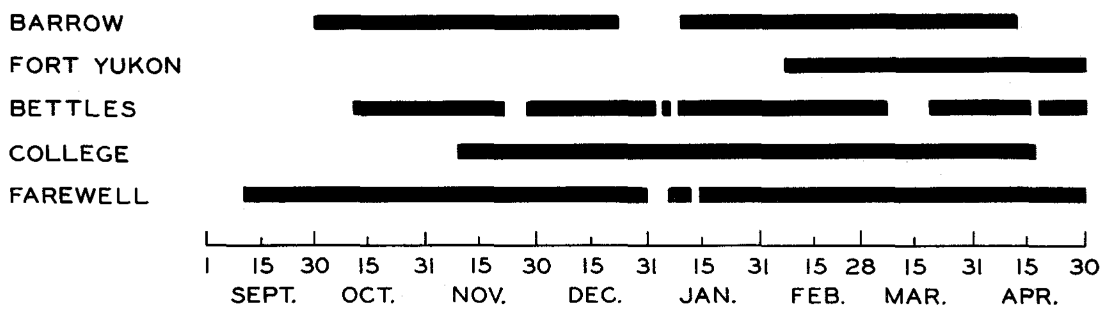


Fig. 2. Actual operation times of the cameras.

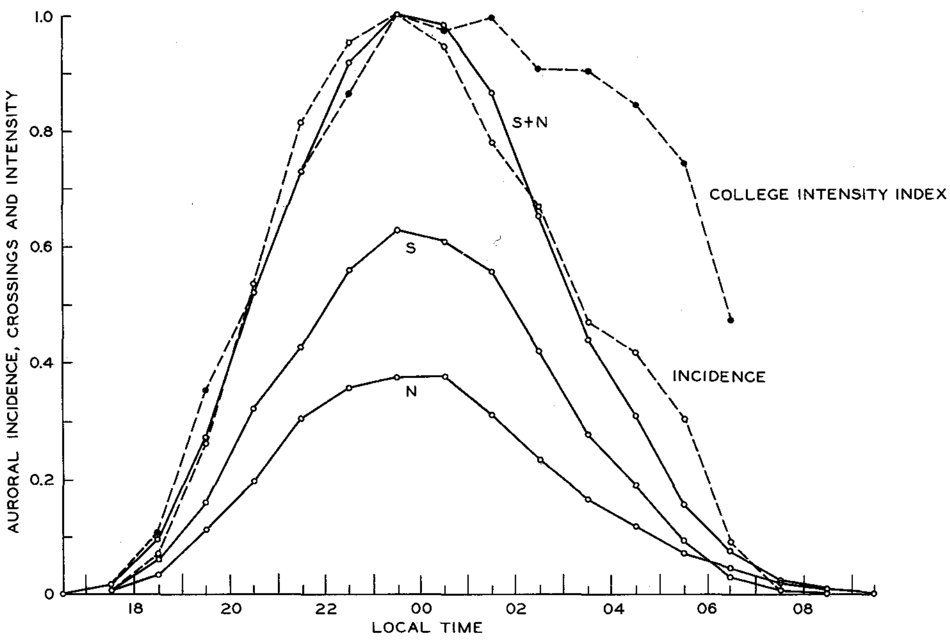


Fig. 3. Average curves of auroral incidence, north-south motions, and intensity versus local time.

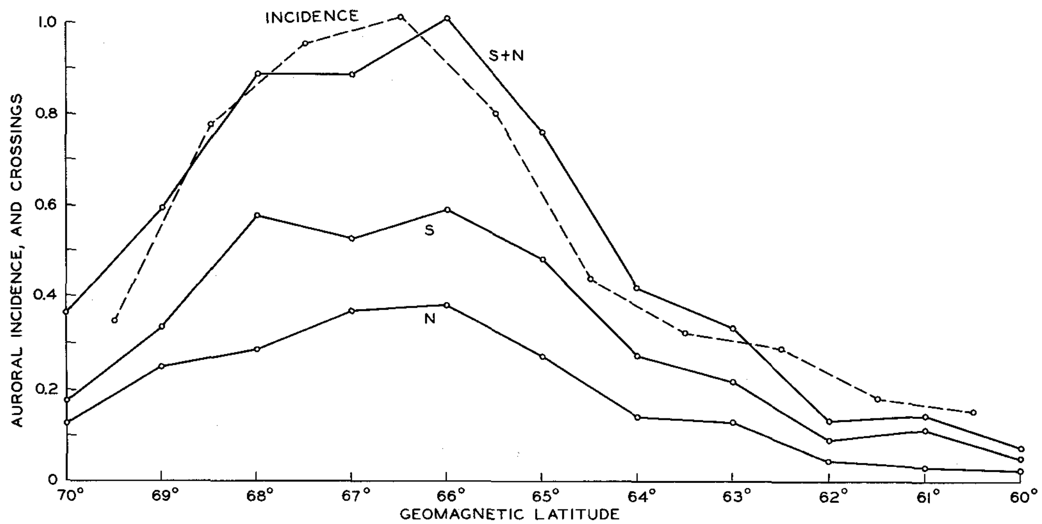


Fig. 4. Average curves of auroral incidence and north-south motions versus geomagnetic latitude.

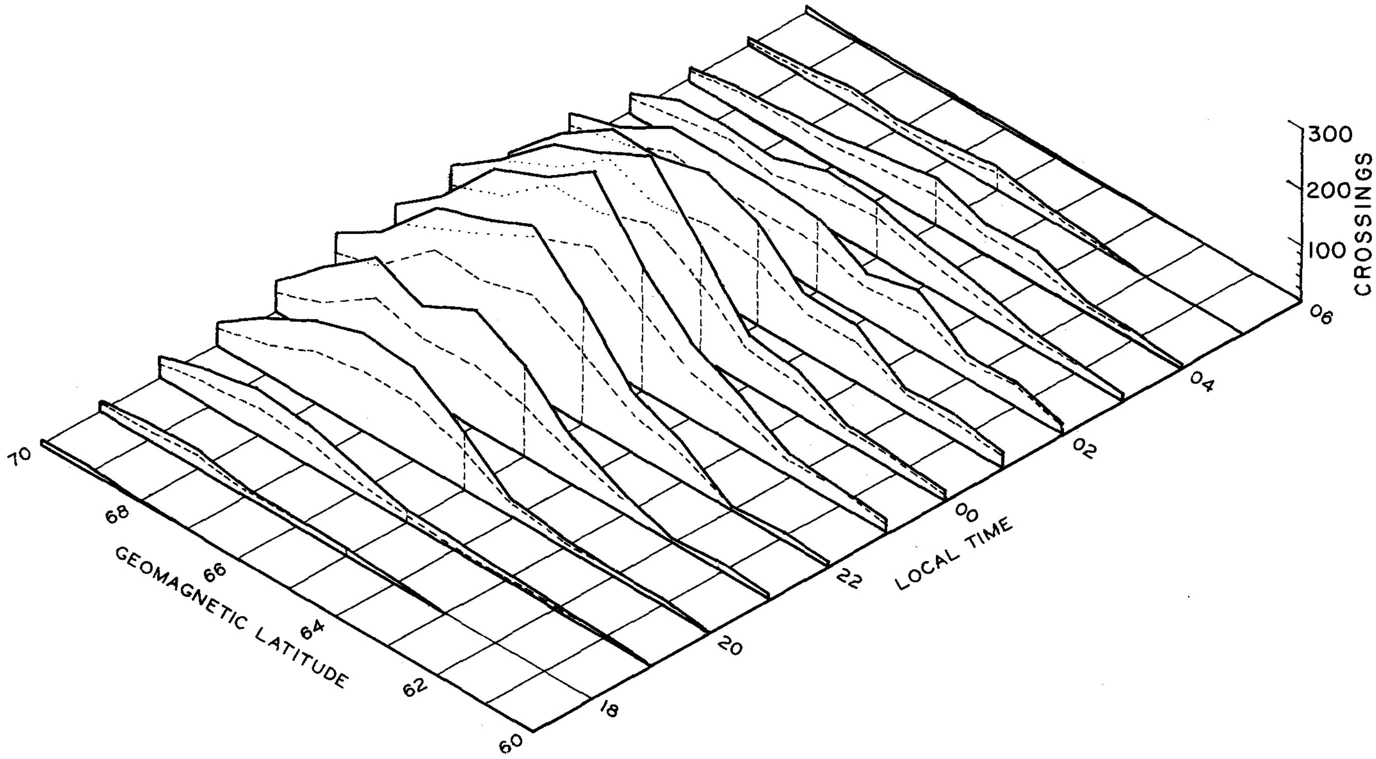


Fig. 5. Isometric plot showing north-south motions versus latitude and local time. Dashed lines are south crossings only; solid lines are south plus north crossings.

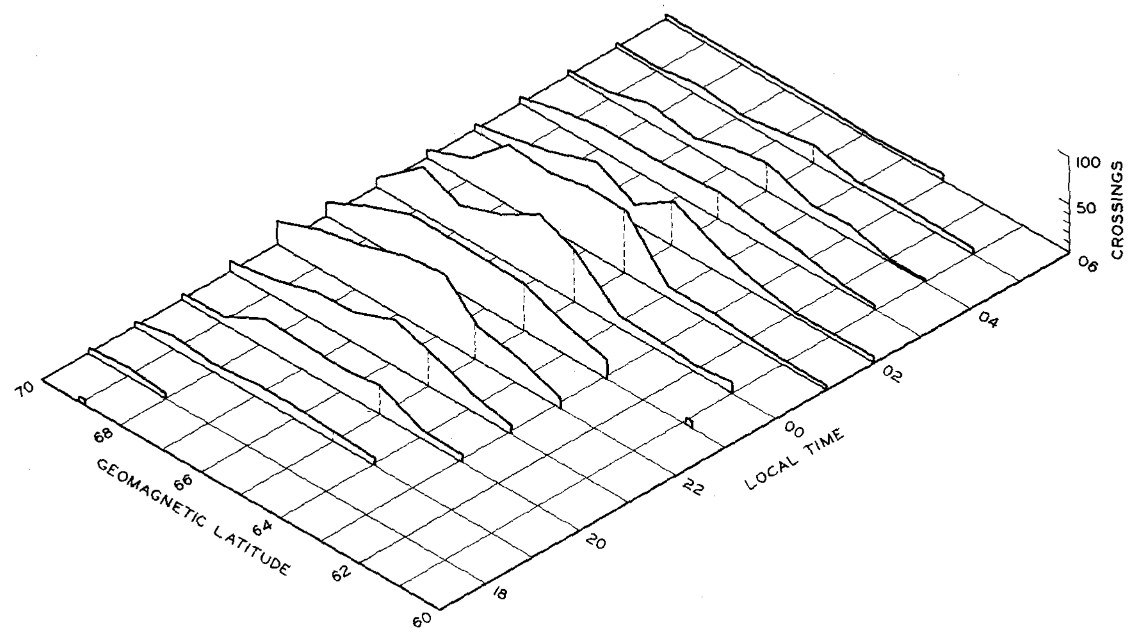


Fig. 6. Isometric plot of north-south motions versus latitude and local time compiled from 30 weak auroral displays.

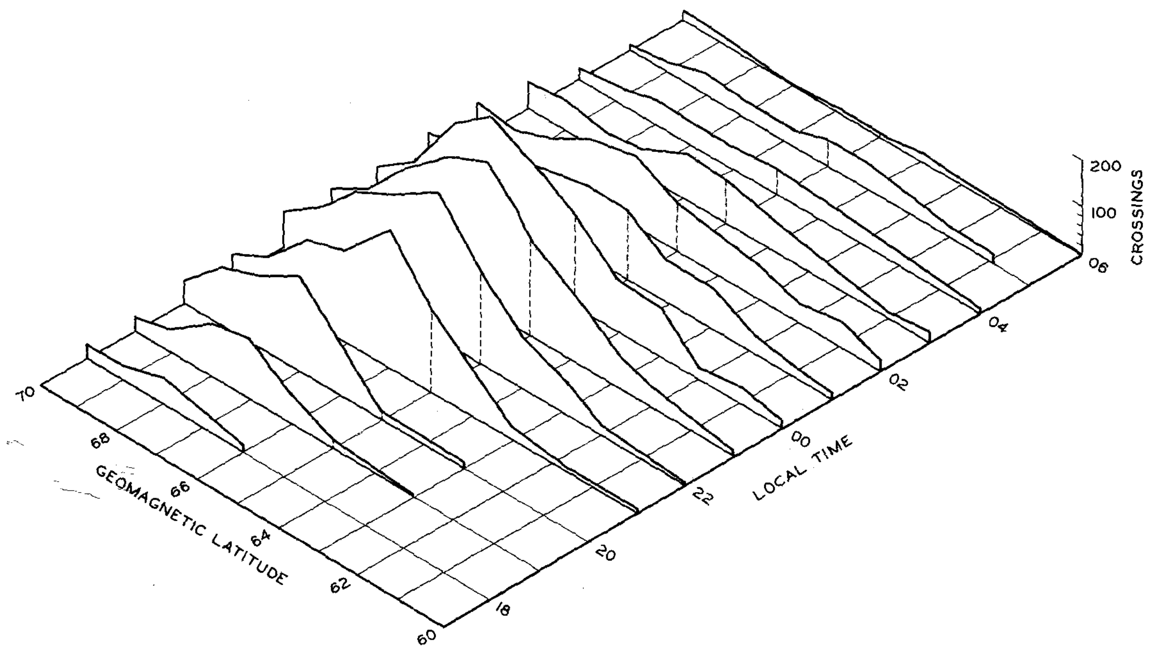


Fig. 7. Isometric plot of north-south motions versus latitude and local time compiled from 30 strong auroral displays.

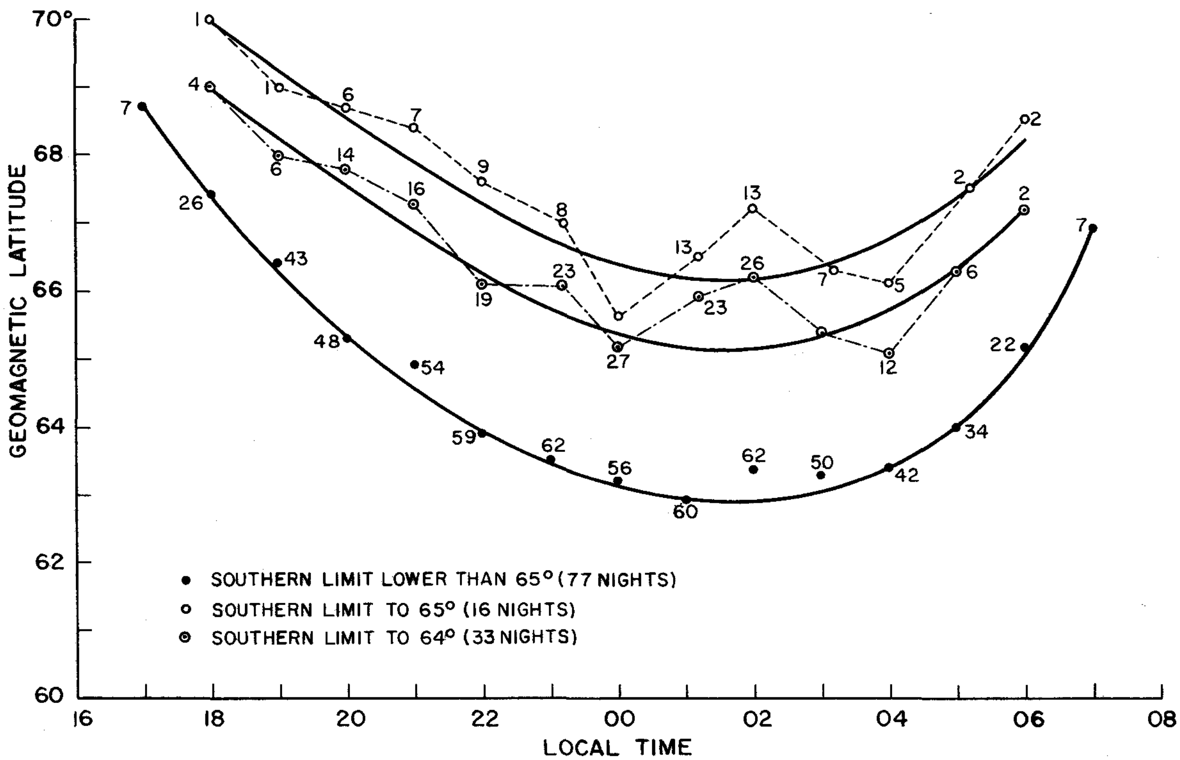


Fig. 8. Average southern extent of three groupings of auroral displays.

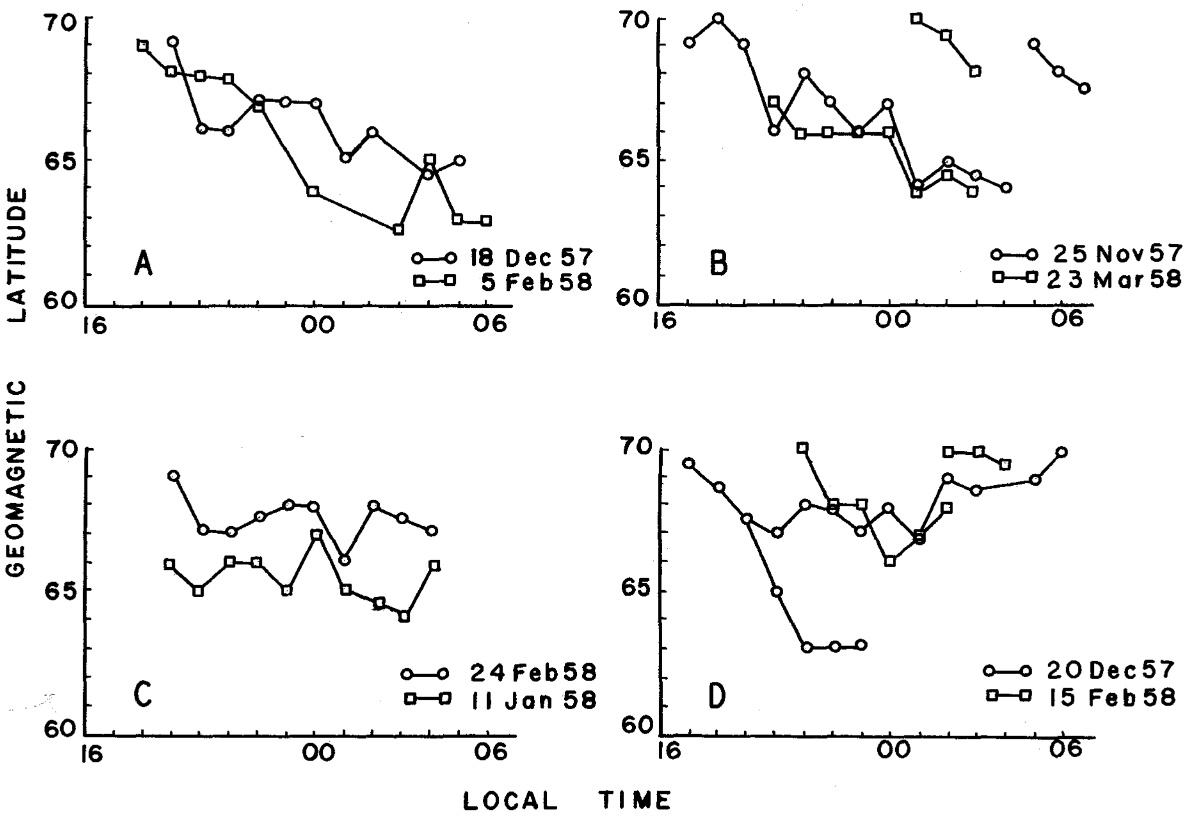


Fig. 9. Examples of the time progression of the latitude position near which maximum auroral incidence occurs.

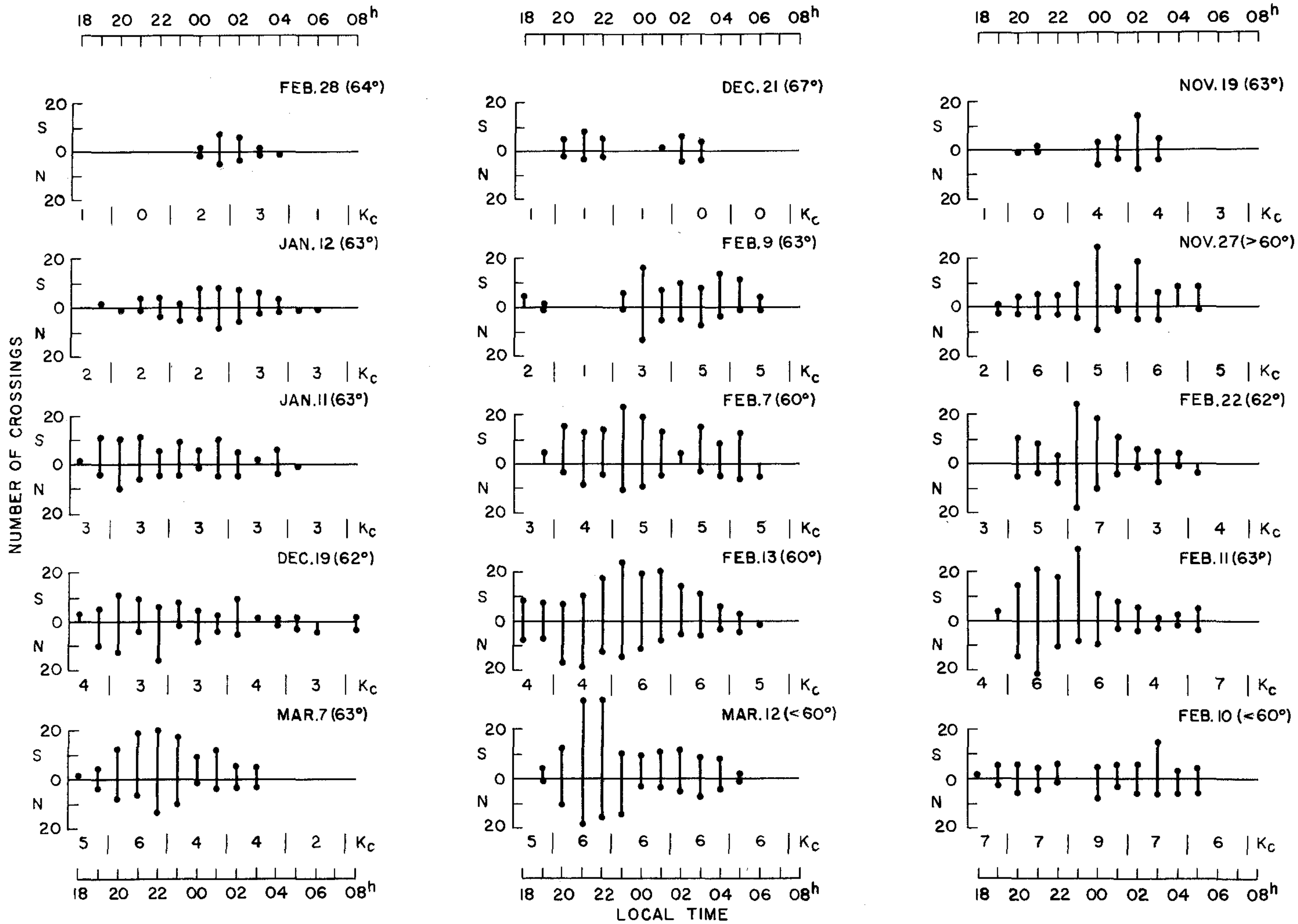
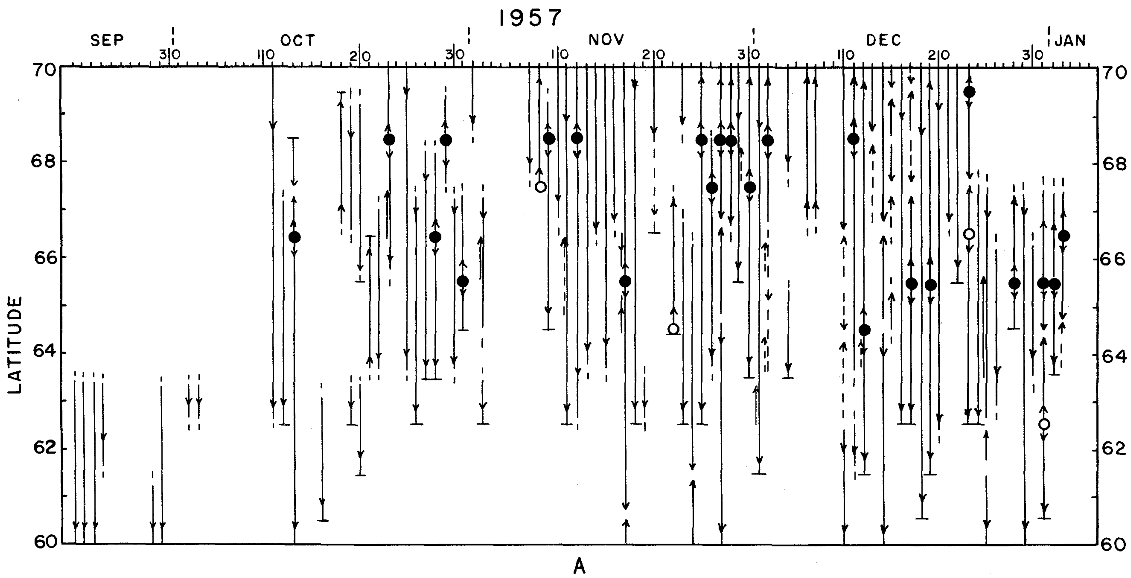


Fig. 10. Fifteen representative displays showing north and south motions and the College K-indices during each hour.



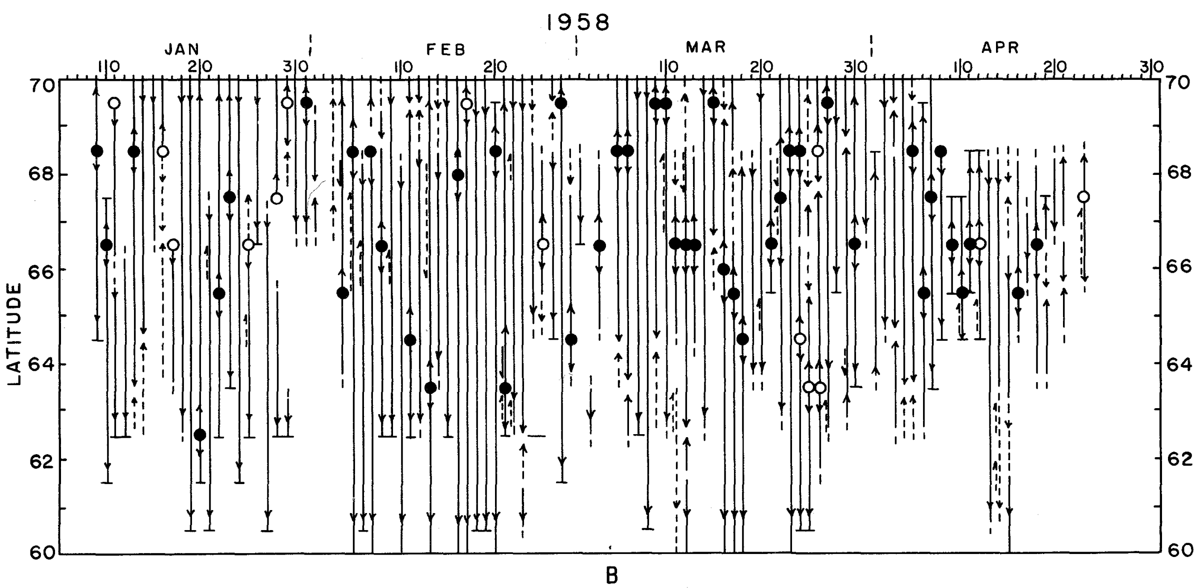


Fig. 11. First north and south motions observed during each display. See text for explanation.

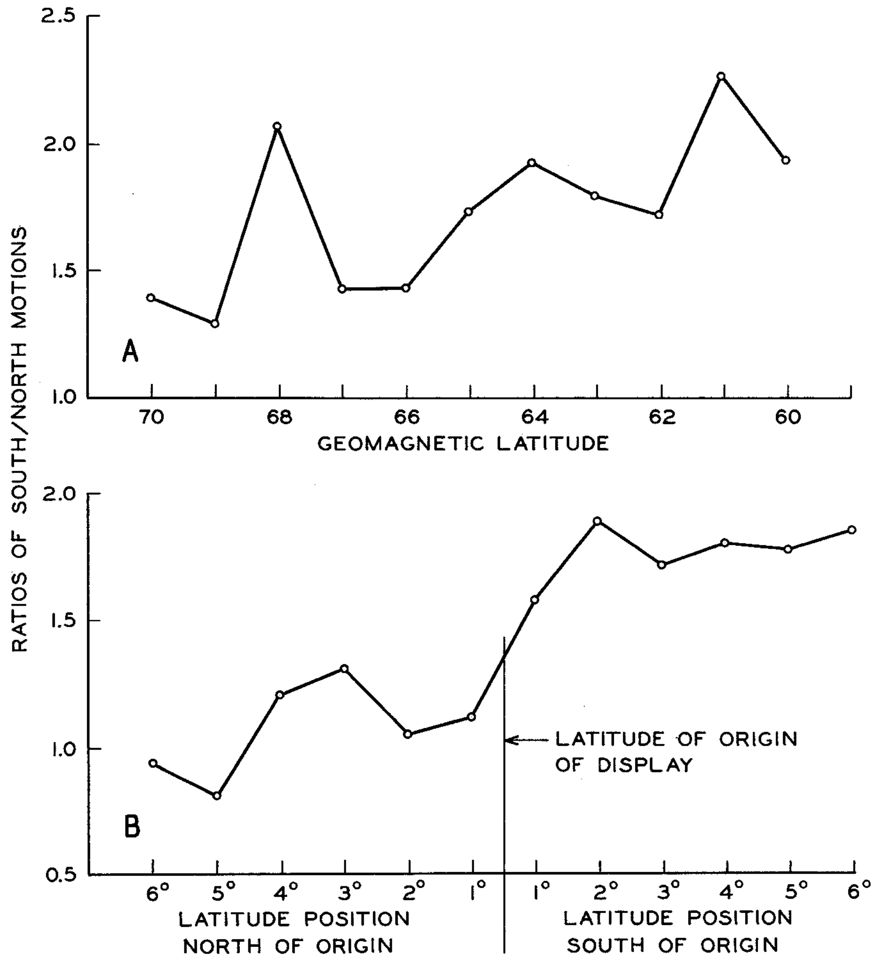


Fig. 12. a) Ratio of south to north motions versus actual geomagnetic latitude, and b) ratio of south to north motions versus distance north and south of "latitude position of origin" for each display.