THE EQUATORWARD EXTENT OF AURORAL ACTIVITY
DURING 1973–1974

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Abstract. The equatorward boundary of auroral activity during 1973–1974 has been derived from DMSP photographs and their associated 'auroral analysis records'. On a time scale of days, the equatorward position of the northern auroral oval varied in phase with the average level of geomagnetic activity. In general, this variation was associated with the occurrence of solar flares and coronal holes. On a time scale of hours, the equatorward position of the oval correlated with the AE index of substorm activity and with the strength of the southward component of the interplanetary magnetic field.

1. Introduction

The high degree of correlation between the occurrence of coronal holes, solar wind streams, and geomagnetic disturbances during the declining phase (1973–1975) of sunspot cycle 20 (Bell and Noci, 1976; Neupert and Pizzo, 1974; Nolte et al., 1976a; Sheeley et al., 1976) provides a basis for improving forecasts of geomagnetic activity. In principle, one monitors the passage of large, low-latitude coronal holes around the east limb onto the solar disk. Then, projecting forward to the central-meridian-passage time of the hole, and allowing approximately three additional days for its high-speed stream to travel from the Sun to the Earth, one can estimate the interval during which geomagnetic activity is likely to be enhanced.

This study is an attempt to correlate these phenomena with occurrences of visible auroras – perhaps the best known and most dramatic indicators of geomagnetic activity. The primary objective is to learn how far equatorward the auroral ovals expand in response to the central-meridian-passage of coronal holes. With such knowledge, one should be able to forecast not only the days during which auroras are likely to occur, but also the latitudes at which they may be seen overhead.

A secondary objective of this study is to measure the expansion and contraction of the auroral ovals with sufficient temporal resolution that this variation can be correlated with the occurrence of individual substorms and the corresponding fluctuations of the interplanetary magnetic field. In this way, it may be possible to test Akasofu's (1976, 1977a) suggestion that the relative size of the oval is a measure of the magnetospheric energy available for substorms. According to his model, the oval should expand and contract as energy is alternately added to (by merging between the geomagnetic dipole field and the interplanetary field) and subtracted from (by the occurrence of substorms) the magnetosphere.
This study is based on the auroral imagery obtained by the polar-orbiting satellites of the U.S. Air Force Defense Meteorological Satellite Program (DMSP) during 1973–1974. It is remarkable that these auroral photographs became available during the declining phase of the sunspot cycle at just the time that the Sun began to produce the large, geomagnetically-effective coronal holes.

2. Observations

The DMSP photographs have been described in detail by Akasofu (1974), Pike (1974), Rogers et al. (1974), Croft (1977), and many others. Briefly, each image consists of an approximately 3000 km-wide swath of the Earth along the satellite subtrack. In general, the satellites were located at altitudes of 815–850 km in 99° Sun-synchronous orbits that were kept in either the noon-midnight or dawn-dusk orbital planes. Auroral images from mid-1972 to the present were made available by the USAF Air Weather Service through the NOAA National Geophysical and Solar-Terrestrial Data Center (NGSDC). They consist of 35 mm films showing 10–20 observations/day depending on the number and location of operational satellites as well as the occurrence of bright auroras. The films also include the USAF ‘auroral analysis records’ which consist of satellite orbital information together with the geographic coordinates of the most equatorward and poleward boundaries of the auroral emission in each photograph.

The negative prints in Figure 1 illustrate the range in the latitude of auroras over North America. Each photograph is a composite of three midnight swaths that were obtained one hour and forty-two minutes apart during consecutive satellite orbits. In the lower photograph, a great band of auroral intensity is visible on November 1 stretching across the United States as far southward as the cities of Philadelphia, Chicago, and Seattle. (The southward-directed features at the swath boundaries are artifacts associated with the non-uniform exposure across each swath.) This aurora followed an interval of solar flare activity that included a 2B flare at 0800 UT on October 30 and a 2N flare only two hours later at 1000 UT on October 30. The corresponding fluctuations of the geomagnetic and interplanetary magnetic fields have been examined recently by Akasofu and Lepping (1977).

The middle photograph shows that by November 2 the auroral oval had contracted poleward where its emission was visible to the north of the cities of Quebec (Q), Winnipeg (W), and Edmonton (E). The upper photograph shows that the oval had contracted even further by November 5 when auroral arcs were visible to the north of Reykjavik, Iceland (R at the extreme upper right) and Fort Rae, Canada (Pt. R.).

In this paper, the equatorward position of the auroral oval is indicated in the invariant geomagnetic coordinate system described by Evans et al. (1969). The principal reason for using this system is the fact that the equatorward boundary of the auroral oval (as determined from the DMSP photographs) tends to lie along contours of constant invariant latitude (\(A\)) rather than along contours of geographic latitude or even geomagnetic dipole latitude. Thus, in each of the photographs in

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Fig. 1. Composite negative prints illustrating the wide range of latitudes at which auroras occurred over North America during November 1–5, 1972. In each case, \( \Lambda \) refers to the invariant geomagnetic latitude of the aurora's equatorward boundary.
Figure 1, it was possible to indicate the southernmost position of the auroral oval by a single latitude – $\Lambda \sim 53^\circ$ on November 1, 1972; $\Lambda \sim 63^\circ$ on November 2; $\Lambda \sim 73^\circ$ on November 5.

Another reason for using this system is to facilitate the interpretation of the auroral observations in terms of the magnetospheric location of the precipitating particles. Specifically, according to McIlwain (1961), the contours of constant $\Lambda$ are the footpoints of geomagnetic field lines that cross the magnetic equator at a distance of $L$ Earth radii from the Earth's center, where $L = 1/\cos^2 \Lambda$. Thus, in Figure 1 the equatorward boundaries of the November 1, 2, and 5 auroras are the northern-hemisphere footpoints of field lines that extend 2.8, 4.8, and 11.7 radii from the Earth's center, respectively, before returning to corresponding footpoints in the southern hemisphere.

Figure 2 is a useful reference for determining the location of auroras. It shows contours of constant $\Lambda$ at the 100 km level superimposed on a geographic coordinate map of the northern hemisphere. This figure is essentially the same as Evans et al.'s (1969) map except that the continents have been shaded for clarity and several cities whose lights are sometimes visible in the DMSP images have been added. With this map, one can compare the geographic locations of a given $\Lambda$-contour in the eastern and western hemispheres. For example, the medium-latitude $65^\circ$ contour passes south of Reykjavik, Iceland, continues through the southern tip of Hudson Bay, lies to the north of Edmonton, and passes near the city of Fairbanks, Alaska in the western hemisphere. In the eastern hemisphere, it passes near Murmansk and Norilsk and continues along the northern boundary of Eastern Siberia.

The negative prints in Figure 3 illustrate the occurrence of auroral displays at several latitudes over Europe and the Soviet Union. The upper photograph is a composite of three consecutive midnight swaths during November 1–2, 1972 and four consecutive swaths on January 25, 1974. In the November 1–2 images, the auroral oval is in a contracting phase following the flare-associated aurora that is visible over North America in Figure 1. The January 25 images show a coronal-hole-associated aurora during the second of twenty-four consecutive solar disk passages of a very long-lived coronal hole. (Figures 4 and 5 show similar great auroras on March 21, 1974 ($\Lambda \sim 58^\circ$) and April 18, 1974 ($\Lambda \sim 57–60^\circ$) during the fourth and fifth disk passages of this same coronal hole.) In Figure 3, the match between the November 1–2, 1972 montage and the January 25, 1974 montage is excellent despite the fact that one of these great auroras was associated with a solar flare and the other was associated with a coronal hole.

While many of the European and Soviet cities have been indicated in Figure 3 by a single letter, Norilsk and Surgut are spelled out because they are useful landmarks for the determination of auroral latitudes. (In this paper, the word Surgut has been used to refer to the general area that includes both the prominent oil field and the group of lights to its west where the city of Surgut actually lies.) Thus, in the upper photograph the equatorward boundary of the oval lies half way between Norilsk
and Surgut at $\Lambda \sim 60^\circ$. In the lower-left photograph, the boundary lies just to the north of Norilsk at $\Lambda \sim 65^\circ$ and in the lower-right photograph it lies well to the north of Norilsk at $\Lambda \sim 68^\circ$.

The photographs in Figures 1 and 3 might lead one to suppose that there is a monotonic relation between the equatorward extent of auroral activity and the magnitude of this activity as determined by its combined brightness and area.
Indeed, Akasofu (1977b) has also used DMSP photographs to illustrate this tendency. However, he noted that the individual measurements (Akasofu and Kamide, 1976) are widely scattered about this relation so that auroras of greatly differing magnitude may occur within the same oval boundary.

Together, Figures 3 and 4 illustrate this scatter as a function of \( \lambda \). (Although variations in detector gain settings can produce apparent variations in auroral brightness, an attempt has been made to minimize this effect by comparing photographs of similar background intensity.) At \( \lambda \sim 68^\circ \), the aurora on December 16,
Fig. 4. Negative prints of auroras over the Soviet Union. Together, Figures 3 and 4 illustrate that the magnitude of auroral activity varies greatly at each latitude.
Fig. 5. The lower panel is a montage of positive prints showing a relatively low-latitude ($A\sim 57-60^\circ$) auroral display over North and Central America on April 18, 1974. This auroral display was associated with the same long-lived coronal hole that produced the January 25–26, and March 21, 1974 auroras in Figures 3 and 4. The upper panel shows an H$\alpha$ flare that occurred on April 14 – approximately 2 days too early to have been able to produce the aurora on April 18. This figure illustrates the difficulty of identifying the source of auroras prior to the use of daily coronal hole observations.
1973, in Figure 4 has a greater magnitude than the aurora on December 17, 1973 in Figure 3. At $\Lambda \sim 65^\circ$, the aurora on January 26, 1974, in Figure 4 has a greater magnitude than the aurora on January 27, 1974 in Figure 3. At $\Lambda \sim 58^\circ$–$60^\circ$, the aurora on March 21, 1974 in Figure 4 has a greater magnitude than the aurora on January 25, 1974 in Figure 3. From these photographs alone one cannot dismiss the possibility that the magnitude differences result from a comparison of auroras in different phases of their evolution. Akasofu (1977c) admits that such phase differences would contribute scatter, but he suggests that most of the scatter results from intrinsic differences in the magnitude of auroras within an oval of a given size.

Finally, the positive prints in Figure 5 illustrate the difficulty of identifying the source of auroras prior to the use of daily coronal hole observations. This figure was obtained from the USAF/AWS by J. Hirman of NOAA/SEL. The lower photograph is a composite of midnight swaths obtained at 0448 UT, 0630 UT, and 0811 UT on April 18, 1974 over North America. The equatorward boundary of auroral emission occurred at $\Lambda \sim 57^\circ$ in the center swath and at $\Lambda \sim 60^\circ$ in the left and right swaths. The upper photograph is an H$\alpha$ solar image obtained at 1205 UT on April 14.

Figure 5 is misleading if it was constructed to relate the April 18 auroral display to the April 14 solar flare. First, based on the 1–2 day transit time of solar flare effects (e.g. Akasofu and Chapman, 1972), the H$\alpha$ flare shown at 1205 UT on April 14 occurred two days too early to have caused the auroral display on April 18. Second, this auroral activity was associated with the solar disk passage of a long-lived coronal hole. (Although the hole was not actually observed during this rotation, it was undoubtedly present because its high-speed stream persisted undiminished through this period and because a hole was still visible when observations commenced during a later rotation (e.g. Sheeley et al., 1976).) This same coronal hole was associated with similar auroral displays during its other transits of the solar disk. Two such displays over the Soviet Union have already been noted in Figure 3 (January 25–27, 1974) and Figure 4 (March 21, 1974) during the second and fourth disk passages of this long-lived coronal hole.

### 3. Data Reduction Techniques

Although some measurements of the equatorward position of auroral activity were obtained directly from the DMSP images, most measurements were derived from the auroral analysis records. These two techniques yielded the same latitude within approximately $1^\circ$, but the indirect method saved considerable time because it relied on the already conducted USAF examination of the myriad of individual photographs.

The indirect technique was based on the observation that in each photograph the equatorward boundary of auroral activity tended to lie along a contour of constant invariant geomagnetic latitude, $\Lambda$. Thus, a single value of $\Lambda$ would characterize each DMSP photograph. In particular, using the maps of Evans et al. (1969) for the 100 km level (see Figure 2), one could choose the value of $\Lambda$ that corresponds to
the tabulated auroral point of most equatorward geographic latitude. In practice, this determination was carried out on a programmable pocket calculator using a closed-form algebraic expression to approximate Evans et al.'s transformation from geographic to invariant geomagnetic coordinates. As expected, the geographic latitude of most equatorward auroral activity changed significantly from orbit to orbit as the satellite surveyed different geographic longitudes at local midnight, but the derived invariant latitude changed relatively little.

The value of \( \lambda \) for the northern hemisphere was plotted on an orbit-by-orbit time scale for the entire interval from February 9, 1973 to February 28, 1974. Southern-hemisphere data were also available and were reduced for selected months. They gave the same average \( \lambda \) values as the northern-hemisphere data, but with greater scatter. Also, the measurements of \( \lambda \) in the southern hemisphere were difficult to verify on the DMSP images due to the lack of convenient reference city lights at high southerly latitudes.

4. Results

Figure 6 illustrates the variation of the equatorward latitude (\( \lambda \)) of the northern auroral oval during October 25–November 9, 1973. For comparison, the auroral electrojet index (\( AE \), Allen et al., 1975) and the northward component (\( B_2 \), King, 1977) of the interplanetary magnetic field (in geocentric solar magnetospheric coordinates) are shown above and below the \( \lambda \)-measurements, respectively. (The \( AO \) index is also shown as the lower of the two electrojet tracings, but it will not be considered in this paper.)

Figure 6 shows a close relation between the temporal variations of the size of the oval and the magnitude of geomagnetic activity. (One would expect a close relation if electric currents in the oval are the source of the geomagnetic variations as, for example, Banks and Douplnik (1975) have reported.) During the relatively inactive period October 25–27.5, \( \lambda \) tended to exceed 65°. The sparsity of measurements during October 25–26 reflects the fact that there were few auroras during this period.

The relatively active period October 27.5–31 shows the influence of a large positive-polarity coronal hole (Nolte et al., 1976b; Sheeley et al., 1976). One can see that as the substorms began to occur, the value of \( \lambda \) began to decrease, first to 62.5° on October 27 and then to 57.5° late on October 28. Except during the lulls in activity at 0000–0700 UT October 28 and 0700–1100 UT October 30, the value of \( \lambda \) remained below 65° until the cessation of activity late on October 31. By early November 1, \( \lambda \) had again reached 70°. As others have often noted (e.g. Burlaga and Lepping, 1977, and references contained therein) these geomagnetically active intervals were also times that \( B_2 \) tended to be large and negative. (In this case \( B_2 \sim -5 \gamma \)).

The oval expanded by a lesser amount (\( \lambda \sim 62.5° \)) on November 1 and 2 during subsequent, but relatively weak, geomagnetic activity. This activity was accompanied by a modest decrease of \( B_2 \) to \(-2.5 \gamma \). During this time, the solar wind speed was approximately 350 km s\(^{-1}\) and still decreasing (King, 1977).
Fig. 6. A 16-day sample of the $\Delta$-measurements that were obtained almost daily for the period February 1973–February 1974. For comparison, the auroral electrojet indices ($AE$ and $AO$) and the northward component ($B_z$) of the interplanetary magnetic field (in geocentric solar magnetospheric coordinates) are shown above and below the $\Delta$-measurements, respectively. The central meridian passage dates (plus 3 days) of two coronal holes are indicated in the nomenclature of the Skylab Coronal Hole Workshop (Bohlin, 1977) as CH4 and CH2 respectively. The onset time of the November 3 solar flare is also indicated.
On November 4, the size of the oval changed in association with flare-induced geomagnetic activity. The value of $A$ decreased twice, first at 1330 UT to $A \sim 62.5^\circ$ and then at 1730 UT to $A \sim 60^\circ$. Corresponding decreases of $B_z$ to $-7\gamma$ are also visible. The associated solar flare had a 2B H$\alpha$ classification and an X-1 X-ray classification. It began at 0014 UT November 3 near 13° S, 82° W on the solar disk. Using Skylab/ATM observations, Sheeley et al. (1975) identified the flare as a long-duration X-ray event complete with post-flare loops and a white light coronal transient. The time difference between the flare onset and the substorm onset was 1.5 days which is consistent with the 1–2 day transit time for flare-induced activity (Akasofu and Chapman, 1972). Characteristics of flare-associated auroras, the oval remained enlarged only briefly compared to the time it had been enlarged under the influence of the coronal hole. Except for some fluctuations late on November 5, the oval contracted northward of 65° until the next coronal hole began to exert its influence late on November 6.

The moderate enhancements of geomagnetic activity during November 6–9 were associated with a negative polarity coronal hole (Nolte et al., 1976a; Sheeley et al., 1976). As one can see in Figure 6, the oval moved equatorward of 65° only briefly compared to the time it had spent below 65° during October 28–31. Furthermore, this second time the southward excursions of $B_z$ tended to be relatively small. These facts seem to be associated with the polarity-dependent seasonal variations of $B_z$ and geomagnetic activity (e.g. see Russell, 1974; Svalgaard, 1977; Sheeley et al., 1977; and references contained therein). According to these references, geomagnetic activity is expected to be greatest when $B_z$ is most negative. This occurs in the northern-hemisphere fall for positive IMF sectors and in the spring for negative sectors as the orbital motion of the Earth changes the orientation of the Earth’s dipole axis relative to the large-scale interplanetary magnetic field lines.

The $A$-measurements for the entire period February 9, 1973–February 28, 1974, have been summarized on a daily basis to facilitate their comparison with the occurrence of coronal holes and solar flares. For this purpose, a new index, $j$, has been chosen to represent the minimum daily value of $A$ according to its location within one of several 2.5° latitude ranges as follows:

<table>
<thead>
<tr>
<th>$j$</th>
<th>$A$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>72.5–75.0</td>
</tr>
<tr>
<td>1</td>
<td>70.0–72.5</td>
</tr>
<tr>
<td>2</td>
<td>67.5–70.0</td>
</tr>
<tr>
<td>3</td>
<td>65.0–67.5</td>
</tr>
<tr>
<td>4</td>
<td>62.5–65.0</td>
</tr>
<tr>
<td>5</td>
<td>60.0–62.5</td>
</tr>
<tr>
<td>6</td>
<td>57.5–60.0</td>
</tr>
<tr>
<td>7</td>
<td>55.0–57.5</td>
</tr>
<tr>
<td>X</td>
<td>no observations</td>
</tr>
</tbody>
</table>

For each day, $j$ was determined conservatively in the sense that isolated data points
were ignored and that the smaller \( j \)-value (larger \( \Lambda \) ) was adopted whenever the minimum daily-value of \( \Lambda \) lay on the boundary between two latitude ranges.

The right section of Figure 7 shows these \( j \)-values in the well-known 27-day Bartels format (Bartels, 1934). For comparison, the left section shows the daily geomagnetic character figures, C9, published by the Institut für Geophysik, Göttingen, Germany. As one can see, the recurrence patterns are visible with much greater ‘contrast’ in the C9 display than in the \( j \) display. Clearly, some modification of the \( j \) index is necessary to increase the visibility of the recurrence patterns of minimum daily \( \Lambda \). However, despite this contrast mismatch, there is a nearly one-to-one correlation between the enhancement of C9 and \( j \), as a detailed examination of Figure 7 reveals.

It is instructive to identify these enhancements with well-known coronal holes using the nomenclature of the Skylab Workshop on Coronal Holes (e.g. Bohlin, 1977). The large pattern in the upper left corner of the C9 display was associated with CH5, a very large extension of the south polar coronal hole. As one can see, the left side of this pattern extends beyond the border of the display and is visible as a second pattern in the upper right corner. The corresponding \( j \)-values lie in the \( j = 4–7 \left( \Lambda = 55–62.5^\circ \right) \) latitude range. A weaker recurrence pattern is visible between the two parts of the CH5 pattern. It was associated with a narrow coronal hole (CH3) that extended across the solar equator. Although there were few corresponding auroral observations, the associated \( j \)-value seems to have been \( j \sim 4 \left( \Lambda = 62.5–65^\circ \right) \).

The large, slanted recurrence pattern just below the upper right corner was associated with two coronal holes. Its upper left end corresponded to CH1, a long coronal hole that extended from the north pole across the equator into the southern hemisphere. Its \( j \)-values lie in the \( j = 4–5 \left( \Lambda = 60–65^\circ \right) \) latitude range. The lower right half of this pattern was associated with CH7, a lobe of the north polar hole. The corresponding auroral activity extended to the \( j = 4–6 \left( \Lambda = 57.5–65^\circ \right) \) latitude range.

The remaining two patterns were associated with two very long-lived coronal holes. The left pattern corresponds to CH4, a low-latitude northern-hemisphere coronal hole that lived until mid-1975. As one can see, its auroral activity extended to the \( j = 4–7 \left( \Lambda = 55–65^\circ \right) \) latitude range during late 1973 and early 1974. The right pattern corresponds to CH2 and its descendant CH2*. This low-latitude southern-hemisphere hole also lived until mid-1975, and was responsible for several of the auroras shown in Figures 3–5 of this paper. Its \( j \)-values were also in the \( j = 4–7 \left( \Lambda = 55–65^\circ \right) \) latitude range.

It is difficult, if not impossible, to relate the remaining non-recurrent enhancements of C9 and \( j \) to the occurrence of solar flares. Some of these enhancements (April 13, September 9, and November 4) were clearly associated with large solar flares that occurred approximately two days earlier. However, other enhancements (June 24) do not seem to be clearly associated with such flares. Furthermore, there is the inverse problem that some large flares (March 12, May 1, July 29) did not
Fig. 7. Comparison of the 27-day Bartels displays of the daily geomagnetic index C9 (left) and an index \( j \) of lowest daily auroral latitude (right). This figure shows that the long-lived patterns of enhanced geomagnetic activity are associated with auroras in the \( j=4-7 \) (A=55–65°) latitude range.
seem to produce geomagnetic effects. Certainly more work will be necessary to improve the forecasting of the non-recurrent enhancements.

Finally, Figure 8 is a graphical illustration of the correlation between the strength of geomagnetic activity and the size of the auroral oval during 1973–1974. In this figure, \( j \) is plotted against the C9 index for the data in Figure 7. The corresponding values of \( A \) have also been indicated. Each circled number is a weighting factor indicating the number of times that a data point occurred at that location. A single data point without a number indicates that the point occurred only once. The straight line is a least squares fit to the data. As one can see, the fit is relatively good. Except at the largest values of C9, few values of \( A \) lie more than 2.5° from the line. (The computed root-mean-square deviation was 1.8°.) Thus, it may be possible to use records of the C9 index to determine past values of the minimum daily latitude of the ovals within ±2.5°.

![Fig. 8. A graphic comparison of the measurements in Figure 7 illustrating the quantitative relation between the daily indices of geomagnetic activity (C9) and auroral latitude (\( j/A \)). The circled numbers are weighting factors indicating the number of times that a measurement occurred at that location.](image)

There have already been numerous attempts to correlate auroral latitudes with geomagnetic activity using satellite observations as well as all-sky camera films (Chubb and Hicks, 1970; Feldstein and Starkov, 1966, 1969; and references contained therein). Chubb and Hicks (1970) used ultraviolet observations from the...
OGO-4 satellite to obtain plots of \( A \) versus the 3-hr magnetic index \( Kp \) for both noon and midnight auroras. Their midnight data are consistent with Figure 8 provided that allowance is made for the difference between the C9 and \( Kp \) indices.

5. Summary

The illustrations and statistical summaries in this paper provide a basis for estimating the equatorwardmost latitude of auroral activity corresponding to given solar conditions. The large, long-lived coronal holes and their associated high-speed solar wind streams during the declining phase of the sunspot cycle produced geomagnetic activity whose auroral displays extended to \( A \sim 60^\circ \). Consequently, these auroras should have been visible nearly overhead from such cities as Montreal, Minneapolis, Edmonton, Anchorage, Leningrad and Oslo. The corresponding daily geomagnetic indices were \( C9 = 6-7 \). When the C9 index was smaller, the auroral activity tended to occur at higher latitudes where it was visible overhead only at auroral zone stations.

As one can see in Figure 8, during the entire period February 9, 1973–February 28, 1974 there were no days for which \( j \) exceeded a value of 7 (\( A < 55^\circ \)). There was only one day for which C9 reached 8 (April 1), and even on that day \( j \) had a value of 6 (\( A = 57.5–60^\circ \)). However, during 1972 there were a few cases for which \( A \sim 53^\circ \). The cities of Washington, Omaha, Portland, Moscow, Amsterdam, and London lie near the \( A = 53^\circ \) contour.

These events had unusually great geomagnetic activity (\( C9 \geq 8 \)) and followed the occurrence of ‘large’ solar flares by approximately 1.5 days. The great auroras of November 1, 1972 (see Figure 1) and August 4–5, 1972 were such events. However, some ‘large’ solar flares were associated with only moderate geomagnetic enhancements and with correspondingly small expansions of the auroral ovals. For example, the November 3, 1973 solar flare was associated with geomagnetic activity having \( C9 = 5 \) and \( A \sim 60^\circ \) on November 4 (see Figure 6).

The fact that auroras occur well above the surface of the Earth means that they are visible away from the zenith at latitudes less than their equatorward latitude \( A \). For example, the contours of constant \( A \) in Figure 2 were constructed for the 100 km level at which many auroras have been observed (e.g., Chapman and Bartels (1962)). At a zenith angle of 45\(^\circ\), such auroras would be visible from locations that are 100 km further toward the equator than the latitude at which they are visible overhead. However, some auroras extend much higher than 100 km above the Earth. According to Chapman and Bartels (1962), Stormer observed auroral rays that extended upward to 800 km on March 22–23, 1920 when \( C9 = 9 \). Such auroral rays should be visible from locations that are more than 1000 km equatorward of their overhead position.

This height effect may account for some (but not necessarily all) of the auroral sightings at very low geomagnetic latitudes. (See Chapman (1957), Adem (1958), and Corzo and Adem (1958) for a summary of low-latitude auroras, two of which
were observed within 10° of the geomagnetic equator.) The most equatorward observation with which the author is personally familiar was obtained by Cole (1967) from the Kitt Peak National Observatory (A \sim 44°). He photographed the auroral rays on May 25–26, 1967 when C9 = 8–9. In view of the large zenith angle (\geq 60°), Cole’s aurora may have been similar to the November 1, 1972 aurora (Figure 1) whose equatorwardmost latitude was A \sim 53°. It will be interesting to examine future DMSP photographs to see how large the ovals become during sunspot maximum when great, geomagnetically-effective flares may be more common.

Measurements of the northern oval’s equatorward boundary have been reduced for the entire period February 9, 1973–February 28, 1974 and measurements of the southern oval’s boundary have been reduced for a few selected months of this period. A preliminary comparison of these data with the AE index and with B_z showed a degree of correlation on a time scale of one to several hours (e.g. Figure 6). In general, these boundaries moved equatorward at times that AE increased and poleward at times that AE decreased. During geomagnetically quiet times, the auroral boundaries tended to occur at A \sim 70°. During extended intervals of B_z \leq −5γ, AE usually exceeded 500γ and A fell below 65°.

These correlations show that one may regard A-variations as changes in the size of the auroral ovals, rather than simply diurnal shifts in the oval positions. This conclusion is supported further by the fact that observations in the northern hemisphere gave essentially the same value of A as observations in the southern hemisphere. Consequently, a detailed analysis of these data may help to test Akasofu’s (1976, 1977a) suggestion that the oval should expand and contract as energy is alternately added to (i.e. when B_z is negative) and subtracted from (i.e. when AE is large) the magnetosphere.

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