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# The morphology of pulsating aurorae

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ANTARCTIC DIVISION
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# THE MORPHOLOGY OF PULSATING AURORAE

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## ABSTRACT

This paper reports the morphological observations of pulsating aurorae from Davis, Antarctica during 1984, and from Macquarie Island during 1980-81 using a twin-channel, wide-angle photometer pointing at the zenith. The data have been analysed to investigate the diurnal variation of the occurrence of pulsating aurorae. The dependence of pulsating aurorae on the level of magnetic activity has also been determined. The diurnal variation and interdependence of the pulsation period and the ratio of the intensities of the 427.8nm and 557.7nm pulsations were examined.

The results are presented in histograms and polar diagrams. These morphological maps show that the pulsating aurora has a close relation to the auroral oval and the phases of the auroral substorm. The occurrence of pulsating aurorae depends strongly on local time.

The comparison of the results from the two stations indicates that the morphology of the pulsating aurora at the higher latitude station, Davis (74.5°S invariant latitude), is more complex than at the lower latitude station, Macquarie Island (64.5°S invariant latitude). There is a double-peak in the occurrence of pulsating aurora at Davis. One peak occurs in the early afternoon and the other at magnetic midnight. For Macquarie Island, pulsating aurora is observed most often in the early morning hours.

At Macquarie Island, the pulsating aurora is generally a post-break-up phenomenon; it has a single occurrence peak at approximately 02-03 local magnetic time.

The average period of the optical auroral pulsations observed at Davis is greater than those recorded at Macquarie Island.

At Macquarie Island, the occurrence of pulsating aurorae depends on geomagnetic activity as well as local time, but no significant dependence on magnetic activity is found for Davis.

An interesting feature of the Davis observations is that pulsations at this latitude may be observed at all hours for which data were collected. This indicates that optical pulsations are a basic characteristic of auroral displays. Pulsating aurora can appear in various forms under quiet or active conditions, and in the afternoon, evening, midnight and morning sectors.

# 1. INTRODUCTION

Pulsations in the optical aurora have been noted for a long time. The term pulsation is generally used to describe a class of aurorae for which the maximum intensity never exceeds 10kR in the 427.8nm band and which undergoes at least one full cycle with a rapid increase followed by a rapid decrease in intensity. The auroral pulsations are usually repetitive and often quasi-periodical (Davis 1978). Their fluctuation periods are generally in the range 2-30s.

Auroral morphology is a television image of solar and magnetospheric activity. The aurora is a radiant manifestation of solar particle emissions and their control by intervening electromagnetic fields. Thus, the size, shape, motion and variation of the aurora must reflect all the forces acting on the auroral particles on their way from the sun to the Earth. The auroral morphology, therefore, is the study of the occurrence of aurora in space and time for the purpose of describing the origin of solar particles and the forces acting upon them between the time of their production on the sun and their loss in the atmosphere (Deehr et al. 1981). Figure 1 shows the generally accepted occurrence of auroral forms as a function of local geomagnetic time and geomagnetic latitude. The occurrence and spatial distribution of various types of aurorae depend strongly on local and substorm time, so there are some effects shown on the diagram which would not be together in time or space in a real situation (Deehr et al. 1981). The morphology of pulsating aurorae is of interest because the temporal variation of observed auroral emissions permits the study of the time variations of particle precipitation. The observed temporal variations are also indicative of the causative acceleration and precipitation processes involved in the generation of pulsating aurorae (Jones 1974). Hence, studies of the pulsating aurora are a useful tool for studying instabilities and oscillations in the magnetospheric plasma.

To trace the origin and mechanism of the intensity modulation of pulsating aurorae, it is necessary to know not only how far out in space the modulations of the flux of the primary particles take place, but also the distribution in latitude and time of pulsating aurorae and its distribution relative to other auroral forms. In most cases observers have relied on single-station observations of pulsating aurorae. In these cases a statistical approach to the problem is necessary (Omholt et al. 1969).

For the complete determination of pulsation morphology, more work is required at high latitudes.

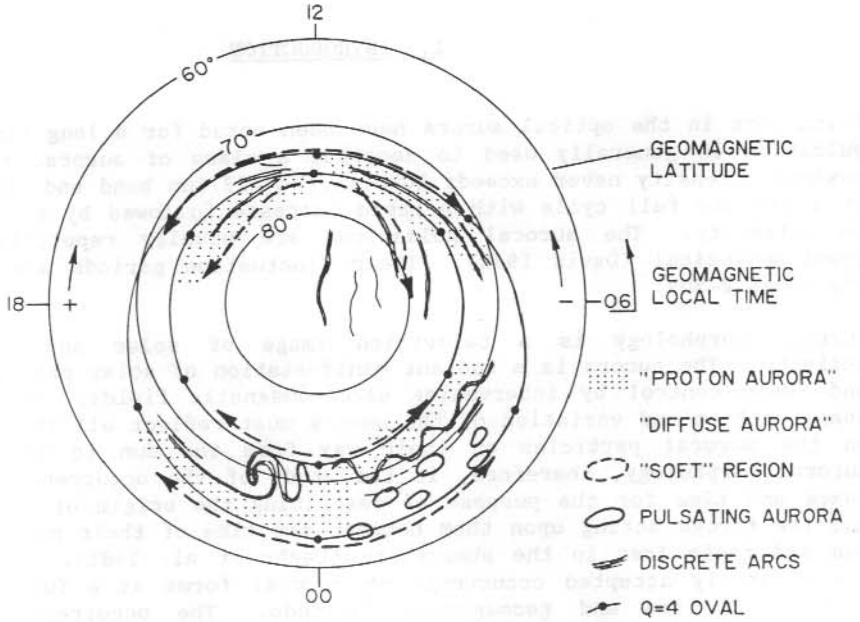

**Figure 1. A composite picture of auroral occurrence (from Deehr et al. 1981).**

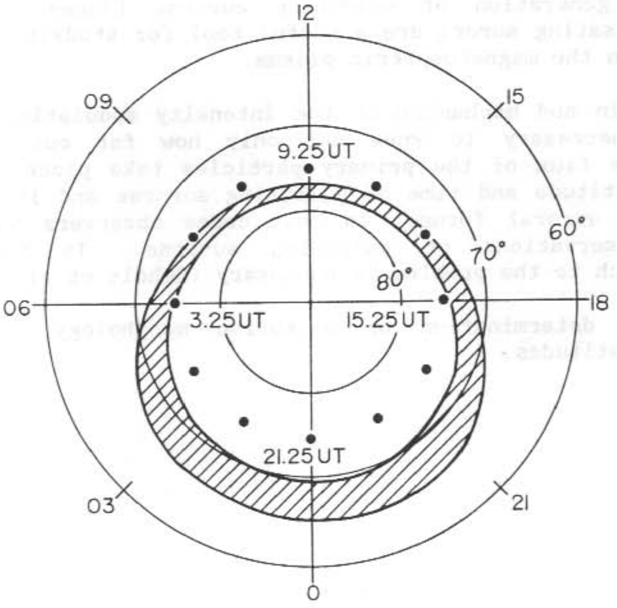

**Figure 2. The approximate locations of Davis at different UT in invariant latitude - magnetic local time coordinates; the average size oval is also indicated (from Akasofu 1978).**

## 2. OBSERVATIONS AND DATA REDUCTION

For this research a twin-channel, wide-angle, zenith-oriented photometer was utilised. The $30^{o}$ half-angle photometer system measured both the 557.7nm $O(^1S - ^1D)$ line emission, and the $N_2^+$ 1NG (0,1) band with a 427.8nm band head. Interference filters were used to separate the two auroral emissions. The intensities of these emissions were recorded on chart at speeds of 2 or 3 cm/minute. Data collected in this form span the period from 26 March to 20 October 1984 for Davis, and from 27 February 1980 to 8 February 1981 at Macquarie Island. Both station's position co-ordinates and time systems are shown in Table 1. Macquarie Island is a typical trans-auroral zone station. It is near the northern edge of the auroral zone, in the subantarctic. Davis is a polar cap station located on the coast of Antarctica. It is inside the polar cusp region near midnoon, and is typically inside the auroral oval during the night. This location means that it crosses the auroral oval twice each day (Figure 2).

The method of data reduction follows Burns (1983). An auroral activity index and an optical pulsation index were determined from the charts for each ten minute interval. When predetermined thresholds were exceeded, the pulse heights and the period of the optical pulses were estimated.

The auroral activity index records any optical auroral activity discernible on the 427.8nm and 557.7nm traces during each ten minutes. Each ten minute sampling period observed defines an event. The auroral activity index is divided into 'weak' and 'intense'. The intense auroral activity is defined as an excursion of the 557.7nm trace, the trace which is less susceptible to lunar contamination, above half a chart width greater than the background value, anytime during the ten minute analysis interval. The optical pulsation index refers to the occurrence of auroral pulsation activity in the 427.8nm and 557.7nm traces anytime during an event. A separate code is used to distinguish optical pulsation activity when the height of the largest 427.8nm band emission pulse above the base level exceeds a pre-determined threshold during the ten minute sample. This arbitrary threshold is 1/20th of the chart width. If this threshold were exceeded, the pulsation was graded as 'intense' and other parameters of the optical pulses were evaluated. These parameters are the height of the largest 427.8nm pulse in the relevant ten minute data; the height of the associated

|  | DAVIS | MACQUARIE ISLAND |
|---|---|---|
| Geographic co-ordinates | -68.60°S, 78.00°E | -54.5°S, 158.95°E |
| Invariant co-ordinates$^+$ | -74.48°S, 29.60°E | -64.47°S, 177.67°E |
| L value | 14.0 | 5.4 |
| Local midnight | 18:48 UT | 13:24 UT |
| Approximate magnetic midnight* | 21:25 UT | 12.14 UT |
| Approximate magnetic noon* | 09:25 UT | 00:14 UT |

+ As calculated for epoch 1977.25 (Boyd 1983).

* Eccentric dipole time (Epoch 1977.25, Boyd 1983) as calculated for a solar declination of 0.0 and a meridian passage of twelve noon.

Table 1. Location and time data for Davis and Macquarie Island.

557.7nm pulse, and an estimation of the period of the pulsations. Only pulsations in the period range two to thirty seconds were studied. Shorter periods are impossible to delineate on the charts, and larger periods are indistinguishable from moving auroral forms.

The number of events within each hour, for which each particular phenomenon is observed throughout the observation period is divided by the total number within each hour for which observations were made. This ratio is converted to a percentage occurrence for that phenomenon for that hour.

The authors conducted the data analysis using three patterns. One involved using all the data. Another used only the data collected when the moon was not above the horizon at the observation station. This was used to determine the extent of the 'cloud and moon' screening of weak auroral events. Thirdly, the data were split on the basis of an associated Kp index to study the effect of varying levels of magnetic activity.

The results calculated for each data set include the percentage occurrences of all optical aurorae, non-pulsating aurorae, pulsating aurorae, 'intense' aurorae and 'intense' pulsating aurorae. The percentage occurrence of a range of pulsation periods and a range of I(427.8nm)/I(557.7nm) intensity ratios was also calculated.

All charts recorded were scaled manually. This may introduce some subjectivity into the chart processing. As a check on the subjectivity of the chart scaling and on the interpretation of events by different persons (Cao Chong, Davis 1984; Gary Burns, Macquarie Island 1980), two months of charts were rescaled for each station and compared with the initial results. The agreement of the results is quite good. This puts the comparison of the different station's data on a reasonable foundation. The check report appears in Appendix I.

# 3. RESULT ANALYSIS

## 3.1 DIURNAL VARIATION

The histograms of the percentage occurrence versus Greenwich Mean Time (UT) and Magnetic Local Time (MLT) of all optical auroral activity and of optical pulsating aurorae are shown in Figure 3. Both phenomena show a single occurrence peak at Macquarie Island and a double peak for Davis. Optical pulsations are a significantly smaller fraction of all optical auroral activity at Davis than at Macquarie Island. Note that while there is considerable variation in the percentage occurrence of pulsating aurorae with local time, pulsating aurorae have been observed during all hours for which observations have been made. This feature has been noted by others Iyengar and Shepherd (1961), Paulson and Shepherd (1965, 1966a, 1966b), Campbell (1970) and Cresswell (1972).

The occurrences of both optical and pulsating aurorae at Davis have two peaks during the interval when observations are possible. The first maximum of pulsating aurorae is at about 15 MLT in the early afternoon, and the first maximum of optical aurorae is at about 14 MLT, earlier by an hour. The second maximum occurs at 23 and 00 MLT for pulsating and optical aurorae respectively. The two-maximum phenomenon was observed in the occurrence of polar cap aurora by Lassen (1969). However, to the authors' knowledge there has been no report of a double-peak phenomenon in the diurnal variation of pulsating aurorae.

The first occurrence peak at Davis is nearly the same magnitude as the second. The first maxima of the occurrences reach 65% for optical aurorae and 14.5% for pulsating aurorae, and second maxima are 58% and 14.3% respectively. The occurrence of optical aurorae at Davis is much higher than the occurrence of pulsating aurorae. The occurrence minimum is near 18 MLT for pulsating aurorae and near 20 MLT for optical aurorae.

Macquarie Island has only a single-peak in the occurrence of these phenomena. The occurrence of auroral activity with no discernible pulsations (obtained by subtraction of the two histograms presented) peaks at 27% just before magnetic midnight, while pulsation activity reaches a maximum of 32% about three hours later. This is consistent with pulsation activity being a post auroral break-up phenomenon. The histogram of optical auroral activity reaches a maximum occurrence of 48% about one hour after magnetic midnight. These features are typical of a trans-auroral station.

Burns (1983) compared the percentage occurrence of pulsating aurorae at Macquarie Island with the figures obtained by Brekke (1971) for Tromso ($67^{O}$N geomagnetic latitude). Although there are differences in the analysis procedures used on the two data sets the values are in good agreement.

From Figure 3, the percentage occurrence of optical aurora at Davis is higher than that at Macquarie Island, and the percentage occurrence of pulsating aurora is reversed. In addition, the pulsating aurora at Macquarie Island is mainly a morning phenomenon, and at Davis an afternoon and near-midnight phenomenon. One aspect contributing to this discrepancy may be the limited hours during which it is possible to make optical observations at each station. At Macquarie Island optical observations are possible from 19 MLT to 07 MLT while at Davis the range is 13 MLT to 05 MLT.

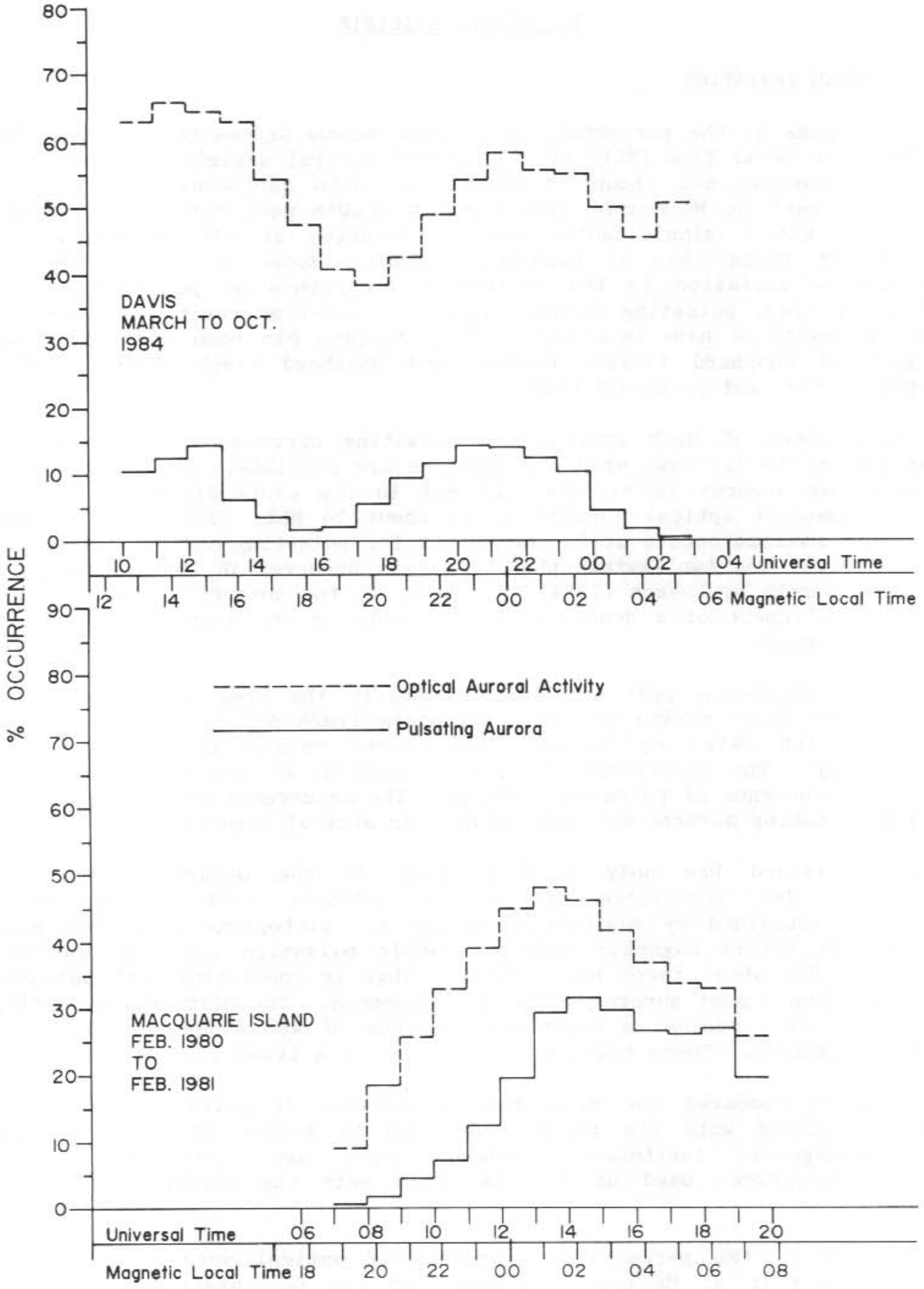

Figure 3. The variation in percentage occurrence of optical auroral activity and pulsating aurorae at Davis and Macquarie Island.

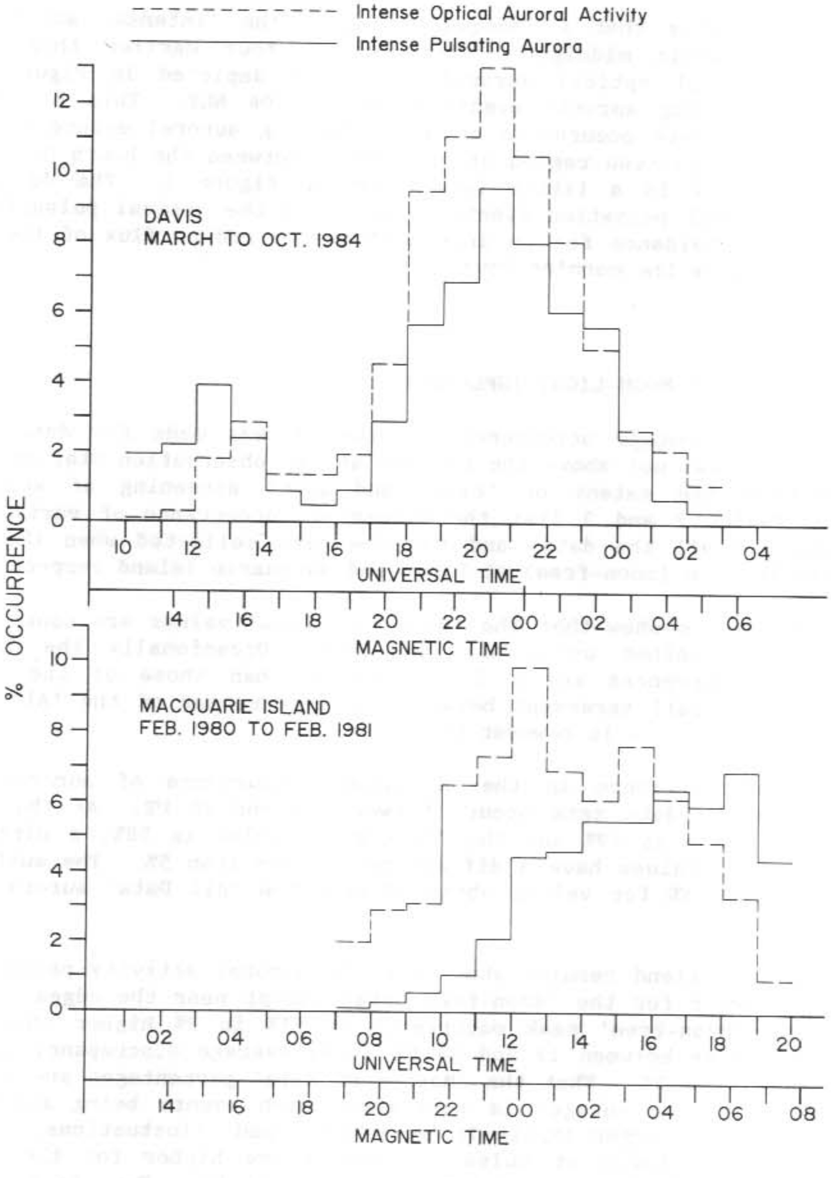

**Figure 4.** The variation in the percentage occurrence of 'intense' optical auroral activity and 'intense' pulsating aurorae at Davis and Macquarie Island.

The variations in the percentage occurrence of 'intense' optical auroral activity and 'intense' pulsating aurora against UT and MLT are shown in Figure 4. The arbitrary definitions of 'intense' optical auroral activity and 'intense' pulsating aurora have been described previously. Although the occurrence variations at Davis still have the double-peak, the afternoon peak is significantly reduced with respect to the midnight peak for both 'intense' optical auroral activity and 'intense' pulsation activity.

Figure 4 indicates that at Macquarie Island the 'intense' auroral events peak near magnetic midnight. This is one hour earlier than the peak occurrence of all optical auroral events as depicted in Figure 3. The 'intense' pulsating auroral events peak near 06 MLT. This is four hours later than the peak occurrence of all pulsating auroral events as depicted in Figure 3. A plateau region of occurrence between the hours 02 and 07 MLT is apparent. It is a little later than in Figure 3. The delay of the 'intense' optical pulsation events relative to the optical pulsation events in general is evidence for an increased energy and/or flux of the incident electrons towards the morning hours.

## 3.2 THE STUDY OF MOON-LIGHT INFLUENCES

A separate percentage occurrence calculation was made for data collected when the moon was not above the horizon at the observation station. This is to determine the extent of 'cloud and moon' screening of weak auroral events. Tables 2 and 3 list the percentage occurrence of various auroral phenomena for all the data, and for the data collected when the moon was below the horizon (moon-free) at Davis and Macquarie Island respectively.

The Davis results show that the 'Moon-Free Data' values are consistent with the results obtained using all the data. Occasionally the 'All Data' percentage occurrences are a little higher than those of the 'Moon-Free Data'. The overall agreement between the occurrences of the 'All Data' and 'Moon-Free Data' sets is however very good.

The maximum difference in the percentage occurrence of auroral activity between the two data sets occurs between 19 and 20 UT. At this time the 'All Data' value is 49% and the 'Moon-Free' value is 58%, a difference of 9%. All other values have a difference of less than 5%. The authors claim an accuracy of 5% for values obtained from the 'All Data' auroral activity data set.

The Macquarie Island results show that the auroral activity percentages are generally larger for the 'Moon-Free Data' except near the edges of the time span. The 'Moon-Free' peak occurrence of 51% is 3% higher than the 'All Data' percentage between 13 and 14 UT. The average discrepancy between the two data sets is 5%. That the 'Moon-Free Data' percentages are higher than the 'All Data' percentages is consistent with events being missed due to being swamped by larger amplitude 'moon and cloud' fluctuations. The hourly occurrence percentages of pulsating aurora are higher for the 'Moon-Free Data', but the differences are minor before 16 UT. From 16 to 19 UT the differences are more substantial. This difference is in part due to a variation in the level of auroral activity between the two data sets. This auroral activity information was obtained from cosmic noise absorption data which was available with the Macquarie Island data but not the Davis data.

| TIME | AURORAL ACTIVITY | | 'INTENSE' AURORA | | PULSATING AURORA | | 'INTENSE' PULSATION | |
|---|---|---|---|---|---|---|---|---|
| (UT) | 'ALL DATA' (%) | 'MOON-FREE' (%) | 'ALL DATA' (%) | 'MOON-FREE' (%) | 'ALL DATA' (%) | 'MOON-FREE' (%) | 'ALL DATA' (%) | 'MOON-FREE' (%) |
| 10-11 | 63.0 | 59.0 | 0.0 | 0.0 | 11.0 | 7.4 | 1.9 | 0.0 |
| 11-12 | 66.0 | 69.0 | 0.2 | 0.5 | 13.0 | 15.5 | 2.2 | 2.3 |
| 12-13 | 65.0 | 62.0 | 1.8 | 1.2 | 15.0 | 14.0 | 3.9 | 2.7 |
| 13-14 | 63.0 | 61.0 | 2.8 | 1.5 | 6.0 | 5.0 | 2.3 | 2.0 |
| 14-15 | 54.3 | 52.0 | 1.4 | 0.7 | 4.0 | 1.1 | 0.8 | 0.2 |
| 15-16 | 48.0 | 45.0 | 1.4 | 0.9 | 2.0 | 1.8 | 0.5 | 0.4 |
| 16-17 | 41.0 | 43.0 | 1.9 | 2.5 | 2.0 | 2.5 | 0.9 | 1.3 |
| 17-18 | 38.0 | 40.0 | 4.6 | 6.0 | 6.0 | 7.6 | 2.9 | 3.8 |
| 18-19 | 43.0 | 48.0 | 9.5 | 10.5 | 10.0 | 13.4 | 5.7 | 7.6 |
| 19-20 | 49.0 | 58.0 | 11.1 | 14.1 | 11.0 | 14.6 | 6.9 | 8.6 |
| 20-21 | 54.0 | 59.0 | 12.6 | 13.1 | 14.0 | 15.3 | 9.6 | 10.5 |
| 21-22 | 58.0 | 60.0 | 10.5 | 9.4 | 14.0 | 13.7 | 8.0 | 8.4 |
| 22-23 | 56.0 | 53.0 | 8.1 | 6.4 | 12.0 | 11.2 | 6.1 | 6.4 |
| 23-24 | 55.0 | 54.0 | 5.0 | 5.3 | 11.0 | 12.8 | 5.7 | 7.0 |
| 00-01 | 50.0 | 51.0 | 2.7 | 2.5 | 5.0 | 4.2 | 2.4 | 2.8 |
| 01-02 | 46.0 | 47.0 | 2.1 | 1.6 | 2.0 | 2.7 | 0.7 | 1.1 |
| 02-03 | 50.0 | 47.0 | 1.2 | 0.8 | 1.0 | 0.4 | 0.3 | 0.0 |

Table 2. A comparison of the percentage occurrences for the 'All Data' and the 'Moon Free Data' divisions at Davis.

| TIME | AURORAL ACTIVITY | | 'INTENSE' AURORA | | PULSATING AURORA | | 'INTENSE' PULSATION | |
|---|---|---|---|---|---|---|---|---|
| (UT) | 'ALL DATA' (%) | 'MOON-FREE' (%) | 'ALL DATA' (%) | 'MOON-FREE' (%) | 'ALL DATA' (%) | 'MOON-FREE' (%) | 'ALL DATA' (%) | 'MOON-FREE' (%) |
| 07-08 | 9.0 | 15.0 | 2.0 | 3.6 | 0.6 | 1.3 | 0.0 | 0.0 |
| 08-09 | 19.0 | 23.0 | 2.9 | 3.4 | 1.5 | 2.8 | 0.2 | 0.4 |
| 09-10 | 26.0 | 30.0 | 3.1 | 4.4 | 4.5 | 6.0 | 0.6 | 1.3 |
| 10-11 | 33.0 | 39.0 | 6.5 | 6.1 | 7.3 | 9.9 | 1.2 | 1.9 |
| 11-12 | 39.0 | 42.0 | 7.3 | 6.0 | 13.0 | 13.0 | 2.2 | 1.5 |
| 12-13 | 45.0 | 48.0 | 10.0 | 10.0 | 20.0 | 19.0 | 4.5 | 3.6 |
| 13-14 | 48.0 | 51.0 | 6.8 | 6.7 | 29.0 | 32.0 | 4.7 | 5.0 |
| 14-15 | 46.0 | 49.0 | 6.2 | 5.1 | 32.0 | 32.0 | 5.5 | 4.9 |
| 15-16 | 42.0 | 48.0 | 7.7 | 7.7 | 30.0 | 33.0 | 5.5 | 6.4 |
| 16-17 | 37.0 | 48.0 | 6.2 | 7.6 | 27.0 | 36.0 | 6.4 | 10.4 |
| 17-18 | 33.0 | 41.0 | 4.9 | 4.5 | 26.0 | 33.0 | 5.8 | 9.0 |
| 18-19 | 33.0 | 39.0 | 3.3 | 2.5 | 27.0 | 33.0 | 6.8 | 9.3 |
| 19-20 | 26.0 | 22.0 | 1.0 | 1.5 | 20.0 | 18.0 | 4.4 | 4.8 |

Table 3. A comparison of the percentage occurrences for the 'All Data' and the 'Moon Free Data' divisions at Macquarie Island.

The general feature of the optical pulsating aurora occurrences, namely a plateau region between 13 and 19 UT, is maintained in the 'Moon-Free Data' values with the exception of the auroral activity percentages, which differ by approximately 5%. The overall agreement between the 'All Data' and 'Moon-Free Data' sets for Macquarie Island is good.

## 3.3 THE VARIATION IN AURORAL OCCURRENCES WITH THE LEVEL OF MAGNETIC ACTIVITY

The co-ordinates used in this research are the invariant colatitude+, the magnetic local time*, and the magnetic disturbance level as indicated by the Kp index. In order to investigate the variation in the occurrence of various auroral phenomena with geomagnetic activity, the data obtained at both stations were sorted into three groups on the basis of the Kp value at the time of observation. The divisions made were $Kp \leq 1^+$, $2^- \leq Kp \leq 2+$ and $Kp \geq 3^-$. For convenience, we call these three groups the low, medium and high magnetic activity groups. To show some characteristics of the optical pulsating aurora occurrences, the data were further split to include the divisions $3^- \leq Kp \leq 3^+$ and $4^- \leq Kp \leq 4^+$. The histograms in Figures 5 and 6 show the results, for these data divisions, for all optical aurorae and for optical pulsations. The Davis results in these figures show little dependence on magnetic activity. Similar results were obtained by Brekke and Pettersen (1971) at Spitzbergen (75.4°N geomagnetic latitude). Their observations were made during the winter 1967-68 and 1968-69 with a photometer having a 10° field of view, and equipped with an interference filter of 200nm f.w.h.m. (full width at half maximum) covering the first negative $N_2^+$ band at 427.8nm. The data they obtained were divided for high and low Kp. The curves, however, were not significantly different.

The result for optical aurora occurrences at Davis (Figure 5) shows a slight dependence on magnetic activity. An increase in occurrence is associated with increasing magnetic activity. However, for pulsating aurorae (Figure 6) there is no confirmed tendency. The $Kp \leq 1^+$ curve in the early afternoon part is higher than for some other Kp levels. All Davis curves in these figures maintain the double-peak and there is a discernible trough in the afternoon hours.

A slight trend shown in the Davis data is that the early afternoon peak (15 MLT) is associated with generally lower Kp values than the midnight (23 MLT) peak. This is true for both auroral activity and pulsating auroral activity. Figure 7 shows histograms of Kp levels associated with the the two peaks for both auroral activity and pulsating auroral activity. For auroral activity, for the time period 19-23 UT, 31% of events are associated with a $Kp \geq 4$ while the value for the 10-13 UT peak is 11%. For pulsating aurorae the corresponding figures are 31% and 15%.

The Macquarie Island results in Figures 5 and 6 show that all auroral activities are significantly dependent on magnetic activity. The 'All Aurora' data of Macquarie Island in Figure 5 shows an increase in the time span for which the optical activity is observed, and an increase in the

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\+ As calculated for epoch 1977.25 (Boyd 1983).

* Magnetic local time in this report is calculated simply in UT hours relative to local magnetic midnight. Local magnetic midnight is determined using an eccentric dipole magnetic field model for epoch 1977.25 with a solar declination of 0.0° and a meridian passage of twelve noon. The data do not warrant greater accuracy.

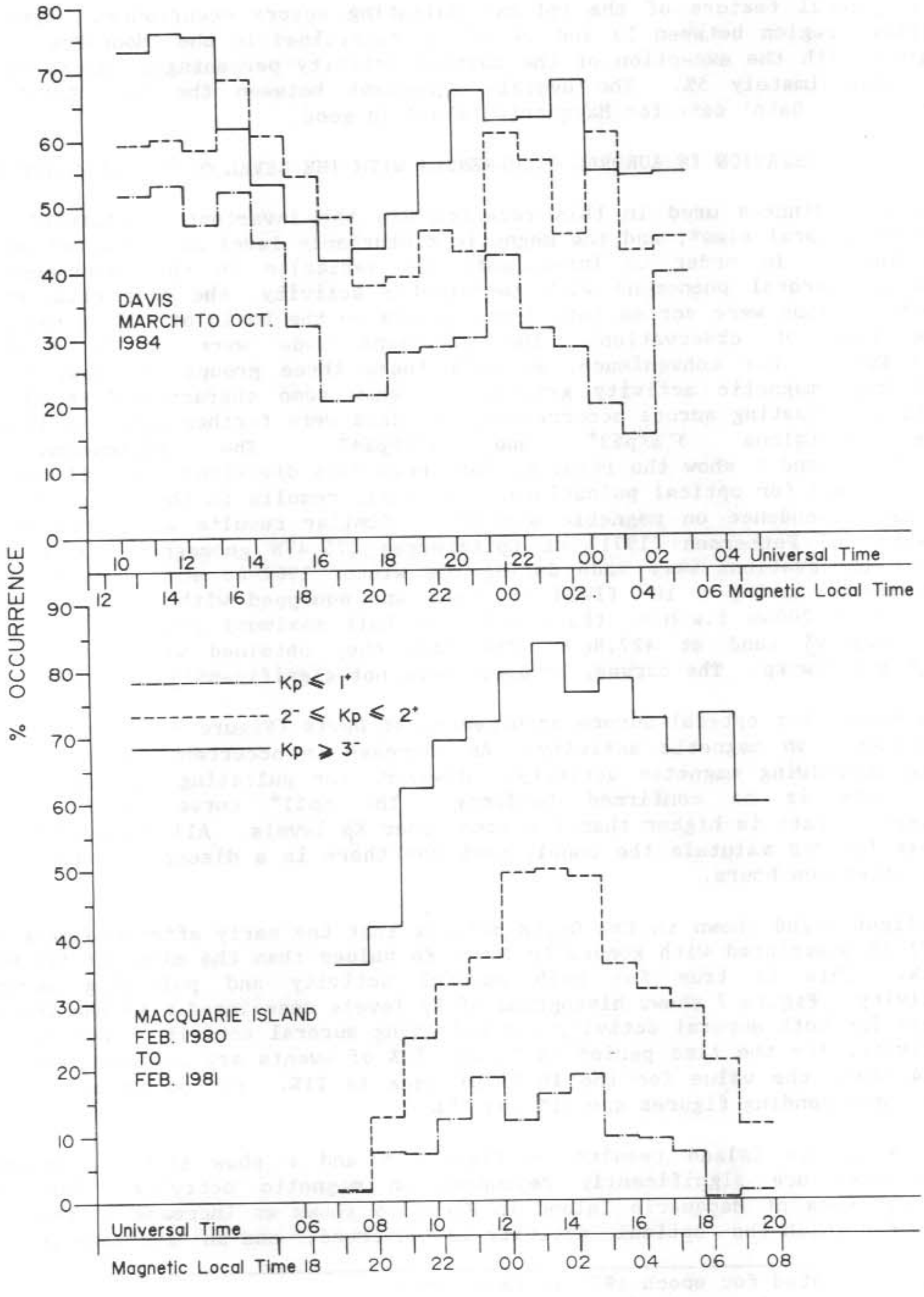


Figure 5. The percentage occurrence of optical auroral activity for three ranges of magnetic activity as defined by the Kp index.

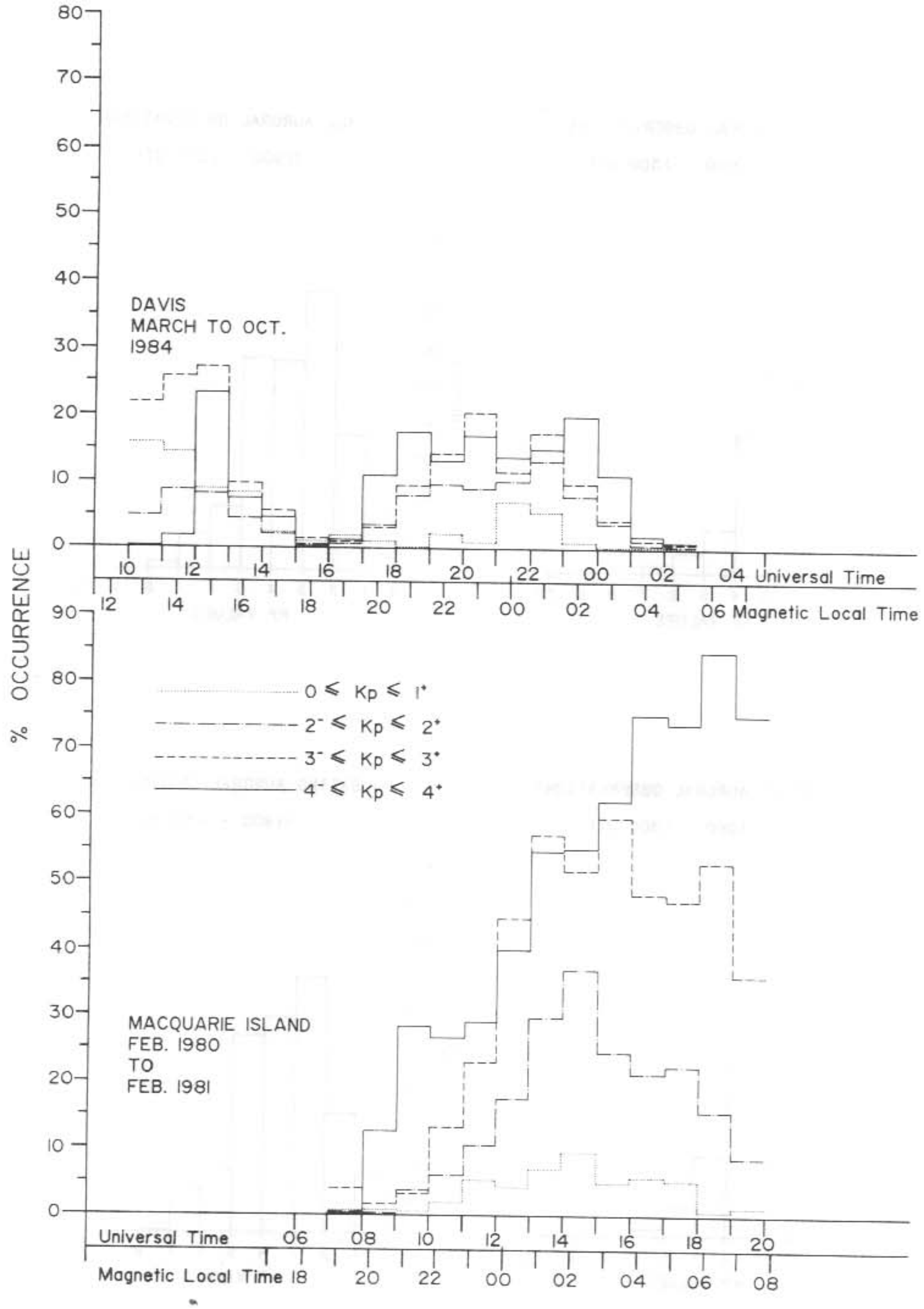


Figure 6. The percentage occurrence of optical pulsating auroral activity for a range of levels of magnetic activity.

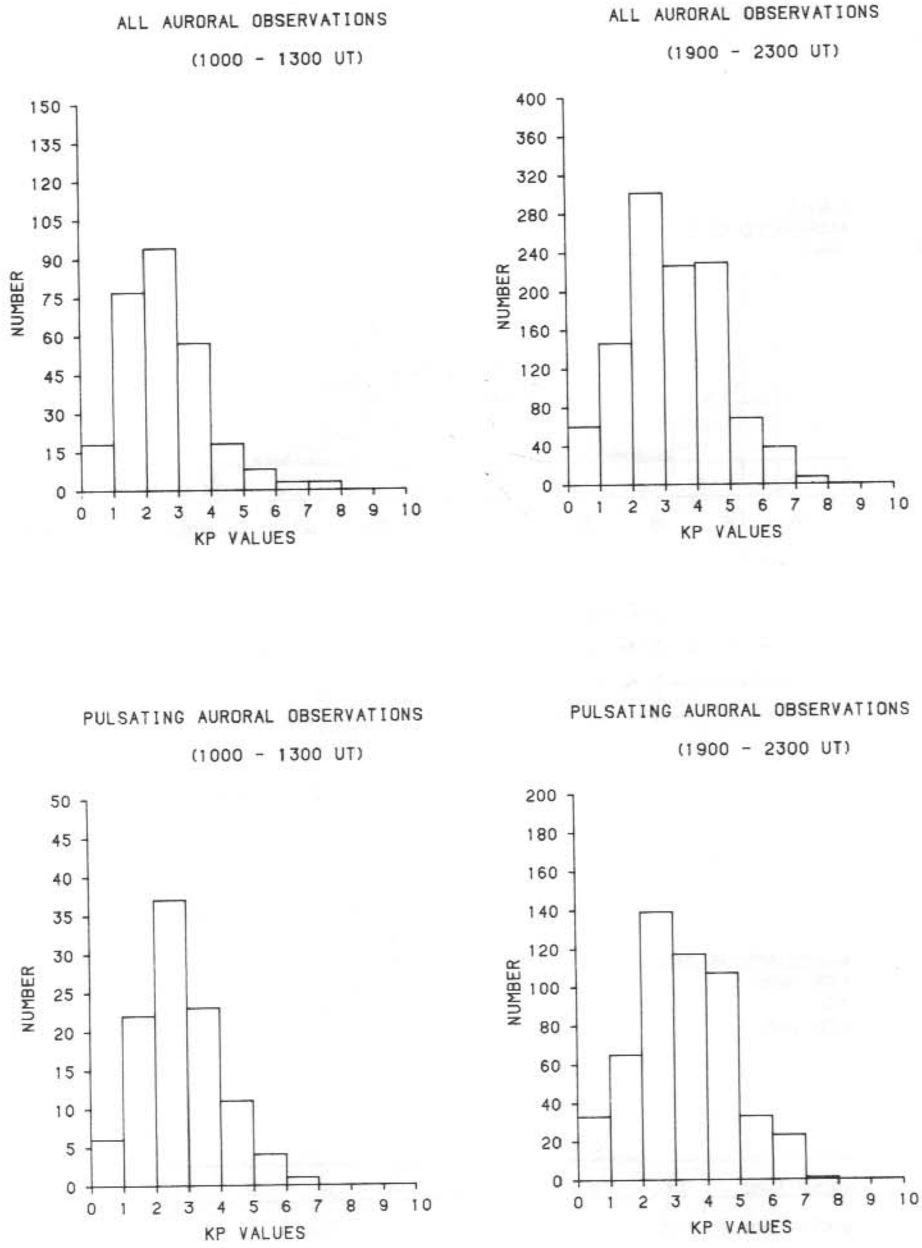


Figure 7. The Kp distribution for both optical auroral activity and pulsating auroral activity for the afternoon peak and the midnight peak at Davis.

percentage occurrence, as the magnetic activity increases. The peak in auroral activity for each of the three Kp divisions occurs between about 01 and 03 MLT. For $Kp \leqq 2^+$, optical auroral activity is negligible until 20 MLT, yet the $Kp \geqq 3^-$ data shows an occurrence of 33% in the hour before 20 MLT. A shift in the occurrence of the peak, in optical auroral activity, from near magnetic midnight towards the evening sector by two hours, occurs as the magnetic activity increases. In all the data divisions for optical pulsating aurora in Figure 6, the occurrence is minimal prior to 20 MLT. For $Kp \leqq 1^+$ and $2^- \leqq Kp \leqq 2^+$ the occurrence is significantly decreased, with respect to peak occurrence values, after about 07 MLT. The times of the peak occurrence are gradually shifted to later in the morning with increasing magnetic activity. The values of the peak occurrence of pulsating aurora are strongly increased as the level of magnetic activity increases. For Macquarie Island data in the $Kp \leqq 1^+$ division, the occurrence peak is 9.4% at about 02-03 MLT; for the $2^- \leqq Kp \leqq 2^+$ division the occurrence peak is 37% at about 02-03 MLT and for $3^- \leqq Kp \leqq 3^+$ division the occurrence peak is 60% at about 03-04 MLT.

For $3^- \leqq Kp \leqq 3^+$ the occurrence rate averages above 50% for six hours in the morning sector. For the $4^- \leqq Kp \leqq 4^+$ division the peak occurrence of 84% occurs at about 06-07 MLT and the occurrence rate exceeds 50% for seven hours in the morning sector.

The morphology of the authors' results is also illustrated in polar diagrams in Figures 8(a), 8(b), 8(c) and 8(d) for four increasing levels of magnetic activity. In these figures the occurrence data are presented with invariant magnetic latitude and magnetic local time as the parameters. The double-peak in the Davis data and the single-peak in the Macquarie Island data are readily apparent.

Kvifte and Pettersen (1969, 1972) divide their data on pulsating aurora into three groups according to the level of geomagnetic activity. The observations were performed with four identical photometers at Tromso (67°N, 117°E geomagnetic co-ordinates) during the winters of 1967-68 and 1968-69. The photometers had a 10° field of view and measured the 427.8nm band emission. To separate the data, the sum of local K indices from 12 GMT to 12 GMT the following day was computed for every night that observations were obtained. The sum values limiting the three groups were set at 14 and 22. These observations show more pulsation activity at high magnetic activity than at low. Note that the Tromso data indicates that pulsating aurora does occur in the evening sector. Normally, the evening pulsation occurrence is low. For high magnetic activity a very low percentage of occurrence is recorded before magnetic midnight and very high values late in the night. The occurrence maximum is also shifted towards the morning hours as the magnetic activity increases. These conclusions are similar to the Macquarie Island observations. Roldugin and Starkov (1970) report pulsations in the latitude interval 60°-64°N geomagnetic latitude during several nights in the winter of 1967/68. At low magnetic activity they found pulsations during a few hours only. These occurred shortly after magnetic midnight. At high activity they observed pulsations during the period 22-06 hours geomagnetic time. This is also in good agreement with the results at Macquarie Island.

Oguti et al. (1981) examined the frequency of occurrence of pulsating aurorae on the basis of all-sky TV data for thirty-four nights from five stations, in a range from 61.5 to 74.3°N in geomagnetic latitude. Their results indicate that pulsating aurorae occur in the morning hours along the

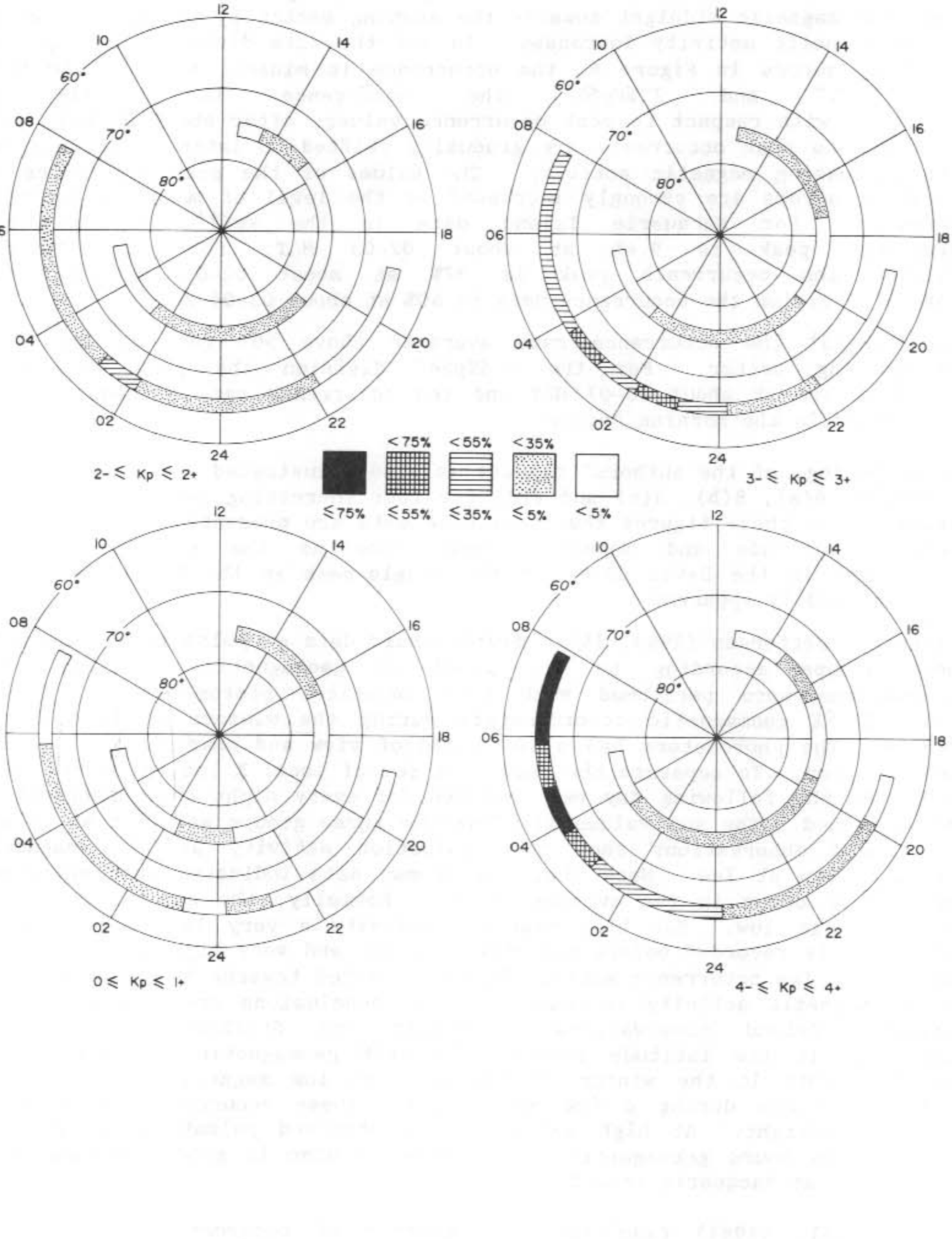


Figure 8. The occurrence of pulsating aurorae at Davis and Macquarie Island presented in geomagnetic coordinates for a range of Kp levels.

auroral oval even when magnetic activity is as small as $0 \leqq Kp \leqq 1^+$. They report that the occurrence region of pulsating aurorae expands equatorwards and the occurrence time expands to the evening side as magnetic activity increases. These observations are supported by Macquarie Island results.

## 3.4 LATITUDE AND DIURNAL VARIATIONS OF AURORAL PULSATING PERIODICITY

Tables 4 and 5 list the diurnal variation of pulsating aurora periods at Davis and Macquarie Island respectively. Figure 9 shows histograms of the total distributions of pulsation periods at both stations. The pulsating aurorae were divided into five groups on the basis of the period of the pulsations. The divisions are 0-5s, 6-10s, 11-15s, 16-20s and above 20s. It should be noted that these periods are estimated by eye and ruler. Although the charts are marked every 20 or 30s, considerable error is associated with the estimates, and only general trends are considered valid. Figure 9 shows that there are very few pulsating events in the 0-5s group. At Macquarie Island 60.8% of pulsating aurora events are in the 6-10s group. As the period increases, the percentage of events gradually decreases. At Davis, however the histogram does not have a sharp peak in the 6-10s range. About 50% of the pulsating events occur in the 6-15s 'plateau' region. Nearly 46% of the pulsating events have periods greater than 15s.

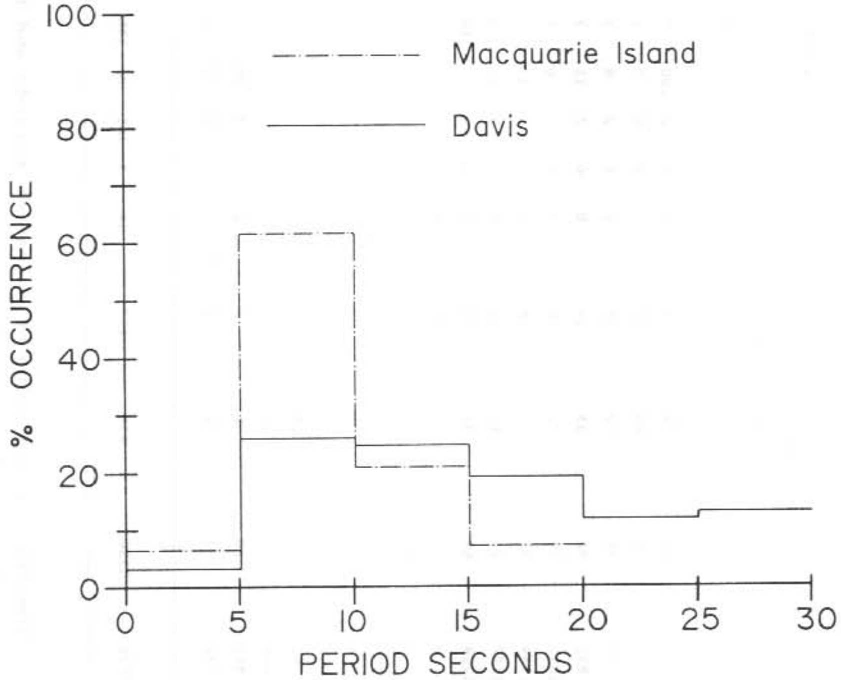


Figure 9. The percentage distribution of the period of optical pulsation aurorae.

* a - number of events b - percentage occurrence

| TIME UT | Total Number of Observed Events | Number of Pulsation Events | Number of 'Weak' Pulsation Events | Number of 'Intense' Pulsation Events | Percentage Contribution of Pulsation Period - Seconds | | | | | | | | | | Percentage Contribution of I(427.8nm)/I(557.7nm) Ratio | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1-5 | | 6-10 | | 11-15 | | 16-20 | | 21 | | 0-0.5 | | 0.5-1.0 | | 1.0-1.5 | | 1.5-2.0 | | 2.0 | |
| | | | | | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| 10-11 | 105 | 11 | 9 | 2 | 0 | 0 | 2 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 100 |
| 11-12 | 456 | 58 | 48 | 10 | 0 | 0 | 0 | 0 | 1 | 10 | 2 | 20 | 7 | 70 | 0 | 0 | 2 | 20 | 7 | 70 | 1 | 10 | 0 | 0 |
| 12-13 | 660 | 96 | 70 | 26 | 0 | 0 | 2 | 8 | 3 | 12 | 4 | 15 | 17 | 65 | 0 | 0 | 8 | 31 | 18 | 69 | 0 | 0 | 0 | 0 |
| 13-14 | 831 | 52 | 33 | 19 | 0 | 0 | 2 | 11 | 3 | 16 | 3 | 16 | 11 | 58 | 0 | 0 | 2 | 11 | 15 | 79 | 2 | 11 | 0 | 0 |
| 14-15 | 1055 | 39 | 31 | 8 | 0 | 0 | 0 | 0 | 2 | 25 | 3 | 38 | 3 | 38 | 1 | 13 | 2 | 25 | 4 | 50 | 1 | 13 | 0 | 0 |
| 15-16 | 1139 | 21 | 15 | 6 | 0 | 0 | 1 | 17 | 2 | 33 | 2 | 33 | 1 | 17 | 0 | 0 | 3 | 5 | 1 | 17 | 1 | 17 | 1 | 17 |
| 16-17 | 1192 | 24 | 13 | 11 | 0 | 0 | 8 | 73 | 3 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 36 | 2 | 18 | 3 | 27 | 2 | 18 |
| 17-18 | 1224 | 69 | 34 | 35 | 3 | 9 | 6 | 17 | 10 | 29 | 8 | 23 | 8 | 23 | 1 | 3 | 9 | 26 | 16 | 46 | 3 | 9 | 6 | 17 |
| 18-19 | 1224 | 120 | 50 | 70 | 4 | 6 | 23 | 33 | 13 | 19 | 16 | 23 | 14 | 20 | 3 | 4 | 13 | 19 | 29 | 41 | 20 | 29 | 5 | 7 |
| 19-20 | 1224 | 140 | 55 | 85 | 2 | 3 | 32 | 38 | 20 | 24 | 15 | 18 | 16 | 19 | 4 | 5 | 10 | 12 | 45 | 53 | 19 | 22 | 7 | 8 |
| 20-21 | 1200 | 171 | 56 | 115 | 2 | 2 | 33 | 29 | 25 | 22 | 31 | 27 | 24 | 21 | 2 | 2 | 20 | 17 | 59 | 51 | 30 | 26 | 4 | 4 |
| 21-22 | 1149 | 163 | 71 | 92 | 3 | 3 | 21 | 23 | 23 | 25 | 16 | 17 | 29 | 32 | 4 | 4 | 9 | 10 | 56 | 61 | 13 | 14 | 10 | 11 |
| 22-23 | 1082 | 134 | 68 | 66 | 0 | 0 | 19 | 29 | 23 | 35 | 7 | 11 | 17 | 26 | 1 | 2 | 6 | 9 | 42 | 64 | 15 | 23 | 2 | 3 |
| 23-24 | 882 | 93 | 43 | 50 | 2 | 4 | 7 | 14 | 23 | 46 | 8 | 16 | 10 | 20 | 0 | 0 | 3 | 6 | 25 | 50 | 19 | 38 | 3 | 6 |
| 00-01 | 698 | 33 | 16 | 17 | 0 | 0 | 4 | 24 | 4 | 24 | 4 | 24 | 5 | 29 | 0 | 0 | 0 | 0 | 14 | 82 | 3 | 18 | 0 | 0 |
| 01-02 | 563 | 10 | 6 | 4 | 0 | 0 | 1 | 25 | 3 | 75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 50 | 1 | 25 | 1 | 25 |
| 02-03 | 342 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 100 | 0 | 0 |
| CUMULATE | 15026 | 1236 | 619 | 617 | 16 | 3 | 161 | 26 | 158 | 26 | 119 | 19 | 163 | 26 | 16 | 3 | 91 | 15 | 335 | 54 | 132 | 21 | 43 | 7 |

Table 4. The diurnal variation of pulsation periods and the I(427.8nm)/I(557.7nm) intensity ratios at Davis.

* a - number of events b - percentage occurrence

| TIME UT | Total Number of Observed Events | Number of Pulsation Events | Number of 'Weak' Pulsation Events | Number of 'Intense' Pulsation Events | Percentage Contribution of Pulsation Period - Seconds | | | | | | | | | | Percentage Contribution of I(427.8nm)/I(557.7nm) Ratio | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1-5 | | 6-10 | | 11-15 | | 16-20 | | 21 | | 0-0.5 | | 0.5-1.0 | | 1.0-1.5 | | 1.5-2.0 | | 2.0 | |
| | | | | | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| 08-09 | 923 | 14 | 12 | 2 | 0 | 0 | 2 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | |
| 09-10 | 1267 | 61 | 53 | 8 | 0 | 0 | 8 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | |
| 10-11 | 1460 | 114 | 97 | 17 | 2 | 12 | 12 | 71 | 3 | 18 | 0 | 0 | 0 | 0 | | | | 24 | | 59 | | 18 | | 0 |
| 11-12 | 1741 | 219 | 181 | 38 | 1 | 3 | 27 | 71 | 8 | 21 | 2 | 5 | 0 | 0 | | | | 32 | | 40 | | 21 | | 8 |
| 12-13 | 2009 | 388 | 298 | 90 | 1 | 1 | 59 | 66 | 29 | 32 | 1 | 1 | 0 | 0 | | | | 41 | | 42 | | 12 | | 4 |
| 13-14 | 2028 | 590 | 495 | 95 | 1 | 1 | 69 | 73 | 20 | 21 | 4 | 4 | 1 | 1 | | | | 33 | | 52 | | 11 | | 5 |
| 14-15 | 1970 | 622 | 514 | 108 | 3 | 3 | 64 | 59 | 37 | 34 | 3 | 3 | 1 | 1 | | | | 38 | | 49 | | 11 | | 1 |
| 15-16 | 1676 | 500 | 407 | 93 | 0 | 0 | 57 | 61 | 26 | 28 | 7 | 8 | 3 | 3 | | | | 46 | | 41 | | 11 | | 2 |
| 16-17 | 1402 | 378 | 288 | 90 | 6 | 7 | 51 | 57 | 9 | 10 | 12 | 13 | 12 | 13 | | | | 36 | | 43 | | 13 | | 8 |
| 17-18 | 1234 | 322 | 251 | 71 | 8 | 11 | 36 | 51 | 4 | 6 | 14 | 20 | 9 | 13 | | | | 34 | | 31 | | 18 | | 17 |
| 18-19 | 931 | 247 | 184 | 63 | 14 | 22 | 29 | 46 | 5 | 8 | 6 | 10 | 9 | 14 | | | | 27 | | 35 | | 24 | | 14 |
| 19-20 | 499 | 97 | 75 | 22 | 9 | 41 | 10 | 46 | 2 | 22 | 1 | 11 | 0 | 0 | | | | | | | | | | |
| CUMULATE | 17140 | 3552 | 2855 | 697 | 45 | 7 | 424 | 61 | 143 | 21 | 50 | 7 | 35 | 5 | | | | | | | | | | |

Note that the value of the I(427.8)/I(557.7) ratio between Macquarie Island and Davis cannot be compared, ie no absolute calibration.

Table 5. The diurnal variation of the pulsation periods and the I(427.8nm)/I(557.7nm) intensity ratio at Macquarie Island.

The mean period of pulsating aurorae recorded at Davis is greater than that for Macquarie Island. The former is about 16.6, and the latter is 11.6s. This difference reflects a latitude variation in the periodicity of pulsating aurorae. Such variation has been reported by Thomas and Rothwell (1979) and Duncan (1981), who suggest that shorter periods are associated with lower latitudes. Duncan (1981), also reports that "more than two-thirds of all pulsations observed had periods in the range of 5-10s inclusive". These results are typical features of auroral and trans-auroral zone stations and are similar to the Macquarie Island results.

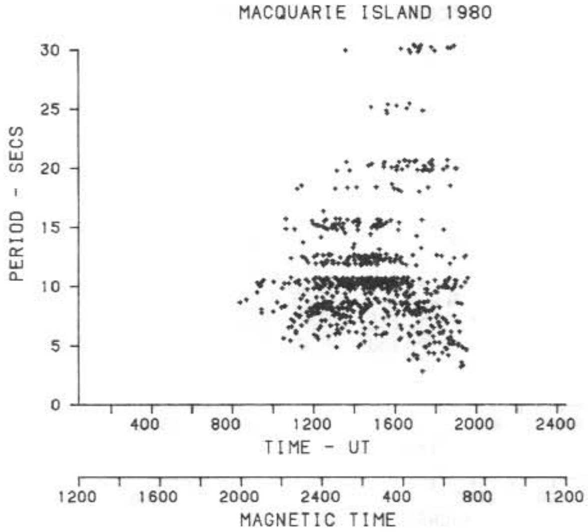
Campbell and Rees (1961) report the percentage occurrences for a range of pulsation periods determined from fifty-eight days of data collected at College, Alaska (65$^{O}$N geomagnetic latitude). The data yield a maximum relative occurrence of greater than 50% for the 6-10s period grouping at 01 local time. For the Macquarie Island data the overall occurrence of the 6-10s pulsations is greater than 60% and reaches a relative occurrence maximum in excess of 70% at local midnight. Campbell and Rees (1961) also report a decrease in the occurrence of pulsations with a period greater than 21s as the night progresses. This is contrary to the Macquarie Island results. There is a low number of these events recorded at Macquarie Island with only thirty five periods greater than 20s. Most of these events occurred in three particular displays on 11 May, 25 May and 16 August. The low number of examples and the difficulty of distinguishing long period pulsations from fluctuations in intensity due to the movement of auroral forms during the auroral break-up phase, may be the cause of this discrepancy.

The plots of pulsating period against time (UT, MLT) of occurrence are shown in Figure 10 for both Davis and Macquarie Island. Figure 10 shows that the pulsation periods recorded in the early afternoon at Davis are often longer than those around midnight.

Figure 10 also shows that the pulsation periods at Macquarie Island divide into two branches after the occurrence peak periods. One branch tends to longer periods and the other tends to shorter periods. The former implies that the period of pulsations is increasing as the night progresses. This result is in general agreement with Tromso (69.7$^{O}$N, 81.9$^{O}$E) results (Johansen and Omholt 1966). The latter is consistent with the results reported by Duncan et al. (1981). Johansen and Omholt indicate that early in the night the higher frequencies ($>0.25s^{-1}$) are dominant, whereas lower frequencies ($<0.25s^{-1}$) dominate in the morning hours. Duncan et al. however conclude that the period tends to decrease near dawn and that this tendency is more pronounced at lower latitudes. These conflicting results indicate that the variations of pulsation periods are complex and that no consistent pattern has yet been discerned.

### 3.5 THE VARIATIONS OF THE I(427.8nm)/I(557.7nm) RATIO AGAINST LOCAL TIME AND PULSATION PERIOD

The relation between the auroral green line at 557.7nm and the $N_2^+$ first negative band at 427.8nm is of considerable importance and has been extensively examined both theoretically and experimentally (Omholt 1971). The I(427.8nm)/I(557.7nm) intensity ratio has been used as a monitor of electron energies (McEwen and Bryant 1978; Davidson and Sears 1980). If the absolute value of the intensities is measured this ratio may yield a meaningful measure of the characteristic energy of the incident electrons



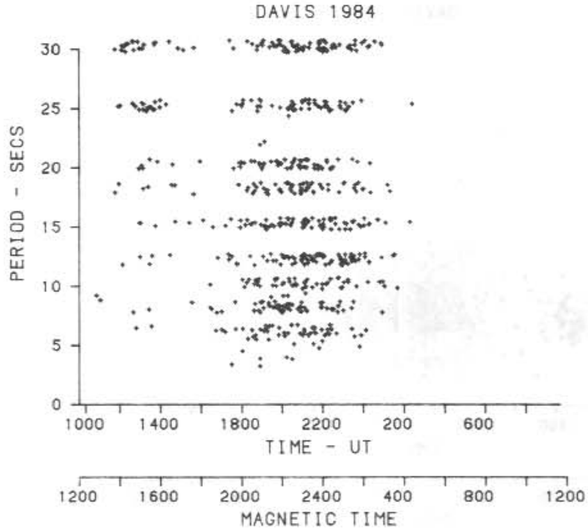


Figure 10. Plots of the pulsation period, as estimated from the chart records, against the time of occurrence for Davis and Macquarie Island.

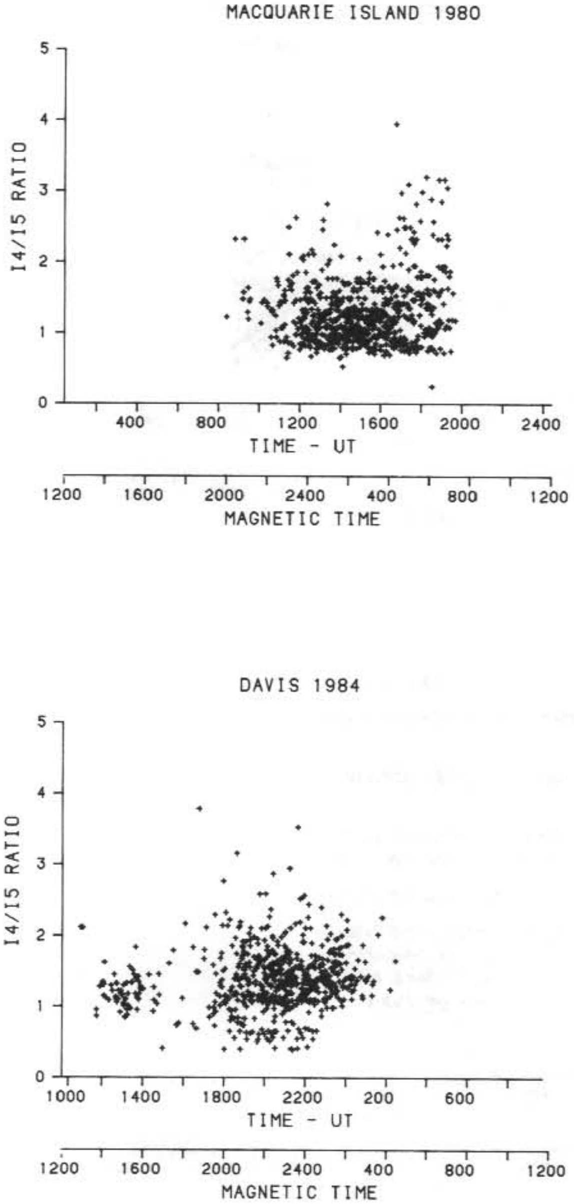


Figure 11. Plots of the I(427.8nm)/I(557.7nm) ratio against the time of occurrence for Davis and Macquarie Island.

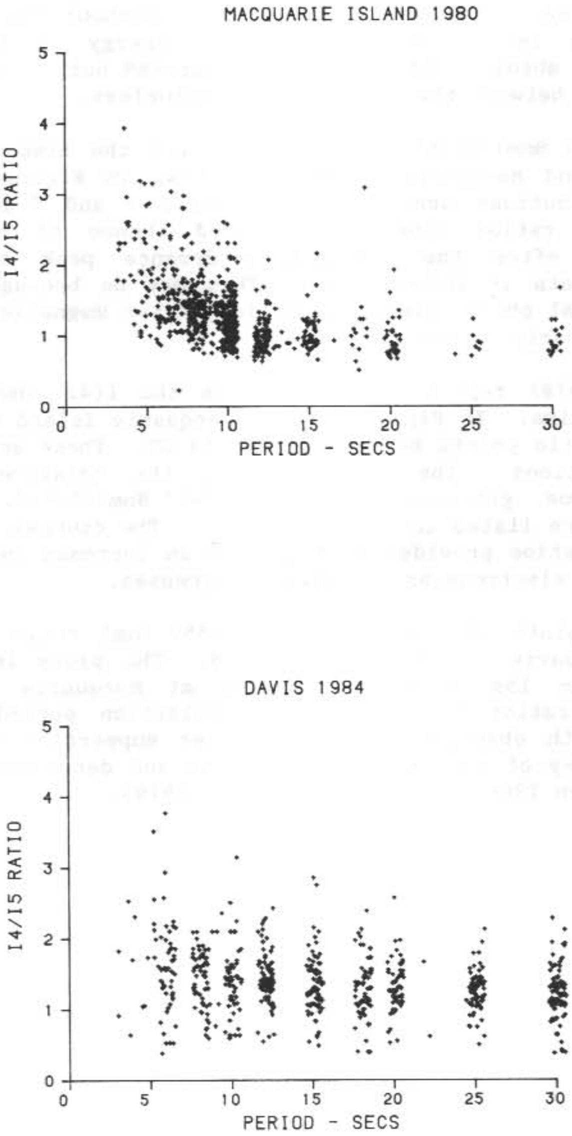


Figure 12. Plots of the I(427.8nm)/I(557.7nm) ratio against the pulse period as estimated from the chart records for Davis and Macquarie Island.

(McEwen et al. 1981). This ratio increases as the energy of the incident electrons increases.

In this experiment the absolute intensity of the emissions was not determined. However the variation in the ratio throughout the night gives an indication of the increasing or decreasing energy of the incident electrons. Because no absolute calibration was carried out, a comparison of the value of the ratio between the stations is meaningless.

The plots of the I(427.8nm)/I(557.7nm) ratio against the time (UT, MLT) of occurrence at Davis and Macquarie Island are shown in Figure 11 and the intensity-ratio distributions are listed in Tables 4 and 5 respectively. The Macquarie Island ratios show an increased chance of higher ratio pulsations occurring after the midnight occurrence peak of pulsating aurorae. The Davis data is inconclusive. This may be because it is not possible to make optical observations for as long after magnetic midnight at Davis as it is at Macquarie Island.

McEwen and Bryant (1978) report an increase in the I(427.8nm)/I(557.7nm) ratio at pulsation maxima. In Figure 11, the Macquarie Island data shows a small group of high ratio points between 11 and 13 UT. These are related to break-up phase pulsations. The variations in the relative percentage occurrence, of various groupings of the I(427.8nm)/I(557.7nm) ratios throughout the night are listed in Tables 4 and 5. The diurnal variation of the Macquarie Island ratios provides evidence for an increase in the average energy of the incident electrons as the night progresses.

Figure 12 shows the plots of the I(427.8nm)/I(557.7nm) ratio against the pulsation period for Davis and Macquarie Island. The plots indicate that for periods less than 15s at Davis and 10s at Macquarie Island, the I(427.8nm)/I(557.7nm) ratios increase as the pulsation periods decrease. This is consistent with observations and theories supporting the relation between increased energy of the incident electrons and decreased periods of the pulsations (Johansen 1966; Thomas and Rothwell 1979).

# 4. DISCUSSION

The data from the higher-latitude station, Davis, and the lower-latitude station, Macquarie Island, reveal different morphological features of pulsating aurorae. These features reflect the different pulsation characteristics of a trans-auroral zone station and a polar cusp station respectively. The data is also of interest in that it is not readily accepted that pulsating aurora occurs at such high latitudes as Davis. Our observations show that the pulsating aurorae are a very common feature of the auroral display, and may be more of a normal, than an abnormal, auroral feature. Pulsating aurorae as a class seem to occur in most auroral forms and at all times. However, they occur in some preferred regions relative to the auroral oval and at preferred phases of the auroral substorm. The pulsating aurorae may be divided into a quiet subclass and an active subclass. Generally, the quiet pulsating aurora is related to the normal auroral oval, and active pulsating aurora is associated with auroral substorm activity. On a statistical basis these two types occur simultaneously.

Consider the occurrence peak near 15 MLT in the Davis data in Figure 3. There is a slow increase before the peak. This shows that the pulsating aurora preferably occur at the equatorward boundary of auroral activity. This has been observed by many researchers but not to the authors' knowledge for this region of the oval.

There is a sudden decrease of pulsation occurrence after the peak at Davis. This is evidence of a deficiency of pulsating forms on the poleward side of the auroral oval. This feature is prominent in the $2^{-} \leq Kp \leq 4^{+}$ curves, shown in Figure 6.

From Figure 2 it can be seen that Davis station rotates under the auroral oval twice a day. On average these crossings occur at 07 MLT and 17 MLT. Observations at Davis cover the period 13 MLT through to 05 MLT. Of the double pulsation occurrence peak at Davis the 15 MLT peak appears to be associated with the equatorward edge of the average auroral oval while the 23 MLT peak may be associated with either poleward surges of the oval or events associated with a contracted oval. Observations at Ny-Alesund (invariant latitude 75°N) by Brekke and Pettersen (1971) indicate a pulsation peak at 10 MLT. This may be associated with the equatorward boundary of the late morning region of the average oval.

Thomas (1971) reports on pulsating aurorae observations at Mawson (70.1°S, 19.6°E invariant co-ordinates). Pulsating aurorae recorded during low levels of optical intensity show a bimodal distribution, centred near local magnetic midnight, with the peaks separated by three hours with only a slight occurrence dip just before magnetic local midnight. For high intensity, pulsating aurorae at Mawson have a broad single occurrence peak. The bimodal distribution of pulsation events for low levels of intensity at Mawson correspond to the equatorward edge of the auroral oval in the late evening and early morning. The weak dip before magnetic midnight may correspond to occasions where Mawson passes under the auroral oval.

In Figure 6 we see that the variation with magnetic activity of pulsating aurora at Davis is more complex than at Macquarie Island. As the Kp value increases, the percentage occurrence of active pulsating aurorae and their occurrence time intervals increase, but in different ways for the two stations. The time intervals spread mainly towards the early afternoon direction at Davis and towards the morning direction at Macquarie Island. The occurrence rates of pulsating aurora at Davis do not vary uniformly as magnetic activity increases, but at Macquarie Island these variations are regular. All these features can be explained by the morphology and the dynamics of the auroral substorm (Akasofu 1968; Oguti et al. 1981).

The substorm consists of two phases, the expansive and recovery phases. The size and the location of the auroral oval changes with magnetic activity, and with substorm phases. The early phase of the substorm includes the poleward expansion of the auroral system located in the midnight sector of the auroral oval. The expansion in the midnight sector of the oval initiates a large-scale auroral display over a substantial portion of the polar cap region. The activity spreads rapidly in all directions. In the evening sector, the western edge of the bulge is seen as the westward travelling surge and in morning sector aurorae disintegrate into patches. This poleward expansive motion is responsible for the midnight peak of pulsating auroral activity at Davis. Royvrik and Davis (1977) report that optical pulsations occur behind the poleward edge of the midnight bulge. This is consistent with the authors' observations at Davis. In many cases, the auroral displays during breakup pass through the Davis magnetic zenith and pulsating aurora is then observed. The poleward expansion of the auroral oval lasts only a short time. This makes the midnight peak of occurrence of pulsating aurorae at Davis sharp compared to the Macquarie Island occurrence peak (Figure 3). Macquarie Island is situated near the equatorward edge of the average auroral oval.

The near midnight peak and the post-peak plateau of pulsating aurorae are typical observations for this latitude. Figure 3 shows that auroral activity generally precedes pulsation activity at Macquarie Island. As the magnetic activity increases, the auroral oval is expanded to lower latitudes. Macquarie Island thus penetrates deeper into the centre of the oval and remains longer in the morning pulsating region (Figure 5). Pulsating aurorae occur more often near the equatorward boundary of the auroral oval. As a result of this, as magnetic activity increases, the peak occurrence of pulsating aurorae at Macquarie Island gradually shifts towards dawn.

Spatially adjacent pulsating patches with widely varying repetition rates have been observed (Jones and Gattinger 1981). A simple direct relationship between pulsation period and geomagnetic latitude or magnetic local time is thus improbable. However average pulsation periods have been related by some researchers to geomagnetic latitude and local time. The relationships reported are not however consistent.

Omholt (1971) reported that the average frequency of pulsating aurorae decreases from about 0.06 Hz (16s) at 65°N geomagnetic latitude to about 0.03Hz (35s) at 75°N geomagnetic latitude (Spitzbergen). Duncan et al. (1981) report that the more equatorward stations contribute more to the shorter periods. Duncan et al. operated photometers at four sites ranging from 67.8°N (invariant latitude) to 61.3°N. The average periods of pulsating aurorae at Davis and Macquarie Island, are 16.6s and 11.6s respectively. The average period of pulsating aurorae at Mawson (Thomas 1971) is 14.8s. The change in period with latitude may be interpreted as being related to the bounce period for 2 Kev electrons (Thomas and Rothwell 1979, Johnstone 1978).

It is now generally accepted that pulsating aurorae are caused by an electron beam that is modulated near the equatorial plane (Johnstone 1983). The mechanism of this modulation is however still the subject of conjecture.

## 5. SUMMARY

The diurnal variation of pulsating aurorae at Macquarie Island consists of a single asymmetric occurrence peak after magnetic midnight with a plateau region of high occurrence in the morning hours. At Davis, a double occurrence peak is recorded, one in the early afternoon (15 MLT) and one near magnetic midnight (23 MLT). The Davis peaks are of approximately equal magnitude.

The overall occurrence of optical auroral activity at Davis is greater that at Macquarie Island, however, pulsating aurorae are less frequent at Davis than Macquarie Island. The Macquarie Island pulsating auroral peak occurrence is 32%, the Davis peaks are both approximately 15%.

As the level of magnetic activity, as determined from Kp index, increases, the pulsating auroral occurrence peak at Macquarie Island increases in magnitude, shifts towards the morning hours and becomes broader in duration. At Davis, while there is a general increase in the percentage occurrence of pulsation activity as magnetic activity increases, this increase is not as large or as consistent as recorded at Macquarie Island. There is no significant change in the time of the peak occurrences at Davis as the magnetic activity increase. It has however been noted that the mid-afternoon peak is associated with a generally lower level of magnetic activity than the midnight peak.

The authors' results are consistent with pulsation activity being generally associated with the equatorward boundary of the auroral oval in all time sectors. To the authors' knowledge this is the first published recording of significant pulsation activity in the early afternoon sector at a high latitude station.

The average pulsation period at Macquarie Island ($64.5^{o}$S invariant latitude) is 11.6s and at Davis ($74.5^{o}$S invariant latitude) is 16.6s. The average pulsation period for Mawson ($70.1^{o}$S invariant latitude) is 14.8s (Thomas 1971).

As the night progresses at Macquarie Island the pulsation periods recorded split into two branches, one tends towards lower values, the other towards higher values, from the near 10s average. At Davis a longer than average pulsation period is found in the afternoon. No other variation at Davis is significant.

Shorter period pulsations are found to be associated with higher energy electron fluxes (as measured by the I(427.8nm)/I(557.7nm) ratio) at both Davis and Macquarie Island.

An increase in the energy of the incident pulsation fluxes (as measured by the I(427.8nm)/I(557.7nm) ratio) towards the morning hours is recorded at Macquarie Island. No such variation is recorded at Davis.

# APPENDIX I

## A CHECK ON THE CHART SCALING

Manual chart scaling is a subjective process. The Macquarie Island data was scaled by Gary Burns and the Davis data by Cao Chong. Two tests were performed in order to test the reliability of the manual scaling. Two months of Macquarie Island data, June-July 1980, were scaled by Cao Chong and compared with data reduced by Gary Burns. Cao Chong also rescaled two months of Davis data, May-June 1984, to check the consistency of the subjective interpretation process.

Table 6 shows a comparison of the percentage occurrence of a range of auroral features for the original and repeat analysis of May-June 1984 Davis data. Column A in Table 6 refers to the original scaling and column B lists the rescaling results.

We can see from Table 6 that the agreement between the A and B columns is good. The maximum error (at 20-21 UT) is a difference of approximately 3% in optical auroral activity. Normally, the difference in all corresponding percentage occurrences are less than 2%. We can thus say that the scaling stability of the Davis data is good.

Table 7 compares the two scalings of June-July 1980 Macquarie Island data. Column A lists the initial scaling and B is the repeat scaling. The maximum error in the percentage estimates of optical auroral activity is a difference of about 3% except for the last hour of observation (at 19-20 UT) when the difference is 5%. A greater difference between the original scaling and the rescaled data is in the measurement of pulsating aurorae. Obviously, the percentage occurrence of pulsating aurorae is underestimated during the rescaling. This is the result of neglecting some very weak optical pulsations. These were never observed at Davis. This underestimation of pulsation occurrence thus does not influence the compatability of the Davis and Macquarie Island data.

The comparison of the pulsation periods and their distributions between the original scaling and the rescaling of Davis and Macquarie Island data is shown in Table 8. For the most part, the results agree. For the Macquarie Island data, the number of events with periods of optical pulsations in the ranges 6-10s and 11-15s are a little different. This is because pulsations with periods of about 10s can belong either to 6-10s range or to 11-15s range.

This rescaling gives the authors some confidence in the conclusions they have drawn from the more extensive data sets.

| TIME (UT) | Total Number of Observed Events | | Optical Aurora | | 'Intense' Aurora | | Aurora with Non-Pulse | | Pulsating Aurora | | 'Intense' Pulsation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B | A | B | A | B |
| 10–11 | 81 | 81 | 62 | 63 | 0 | 0 | 48 | 48 | 14 | 15 | 3 | 4 |
| 11–12 | 284 | 284 | 66 | 66 | 0 | 0 | 52 | 53 | 13 | 13 | 1 | 1 |
| 12–13 | 349 | 349 | 67 | 67 | 1 | 1 | 53 | 52 | 14 | 14 | 2 | 2 |
| 13–14 | 360 | 360 | 58 | 59 | 2 | 2 | 53 | 54 | 6 | 6 | 1 | 1 |
| 14–15 | 360 | 360 | 48 | 47 | 1 | 1 | 46 | 45 | 2 | 2 | 0 | 0 |
| 15–16 | 366 | 366 | 42 | 43 | 1 | 1 | 40 | 42 | 1 | 1 | 0 | 0 |
| 16–17 | 366 | 366 | 36 | 36 | 1 | 2 | 34 | 34 | 2 | 3 | 0 | 0 |
| 17–18 | 366 | 366 | 36 | 34 | 6 | 5 | 31 | 30 | 5 | 5 | 3 | 3 |
| 18–19 | 366 | 366 | 36 | 35 | 8 | 8 | 29 | 27 | 7 | 8 | 4 | 5 |
| 19–20 | 366 | 366 | 40 | 40 | 8 | 10 | 30 | 30 | 11 | 10 | 6 | 6 |
| 20–21 | 366 | 366 | 54 | 51 | 14 | 13 | 39 | 36 | 16 | 15 | 12 | 12 |
| 21–22 | 366 | 366 | 57 | 55 | 11 | 11 | 44 | 42 | 13 | 13 | 8 | 8 |
| 22–23 | 366 | 366 | 49 | 48 | 9 | 8 | 37 | 36 | 12 | 12 | 5 | 5 |
| 23–24 | 366 | 366 | 54 | 51 | 6 | 6 | 40 | 38 | 14 | 13 | 7 | 7 |

* A: Original Scaled Data;  B: Rescaled Data.

Table 6.  The percentage occurrence comparison of optical auroral activity and pulsating aurorae between the original and the rescaled data of Davis station.  The data are from May-June, 1984.

| TIME (UT) | Total Number of Observed Events | | Optical Aurora | | 'Intense' Aurora | | Aurora with Non-Pulse | | Pulsating Aurora | | 'Intense' Pulsation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B | A | B | A | B |
| 07-08 | 307 | 310 | 9 | 12 | 1 | 1 | 8 | 12 | 1 | 0 | 0 | 0 |
| 08-09 | 348 | 347 | 12 | 12 | 3 | 3 | 11 | 11 | 2 | 2 | 1 | 1 |
| 09-10 | 351 | 351 | 18 | 17 | 3 | 2 | 15 | 14 | 3 | 3 | 1 | 1 |
| 10-11 | 354 | 354 | 25 | 27 | 8 | 6 | 22 | 24 | 4 | 2 | 1 | 1 |
| 11-12 | 354 | 354 | 33 | 31 | 8 | 6 | 24 | 25 | 9 | 7 | 1 | 1 |
| 12-13 | 351 | 351 | 37 | 34 | 10 | 9 | 15 | 17 | 22 | 17 | 6 | 6 |
| 13-14 | 350 | 350 | 39 | 40 | 5 | 4 | 9 | 17 | 31 | 22 | 7 | 6 |
| 14-15 | 354 | 354 | 38 | 40 | 6 | 5 | 9 | 21 | 29 | 19 | 3 | 4 |
| 15-16 | 357 | 357 | 40 | 39 | 9 | 8 | 7 | 11 | 34 | 28 | 6 | 6 |
| 16-17 | 360 | 360 | 40 | 38 | 9 | 9 | 13 | 17 | 28 | 24 | 7 | 6 |
| 17-18 | 360 | 360 | 35 | 35 | 8 | 7 | 6 | 8 | 29 | 23 | 9 | 9 |
| 18-19 | 360 | 360 | 32 | 35 | 5 | 6 | 5 | 13 | 27 | 14 | 8 | 8 |
| 19-20 | 320 | 319 | 24 | 20 | 2 | 3 | 6 | 6 | 19 | 6 | 5 | 5 |

* A: Original Scaled Data; B: Rescaled Data.

Table 7. The percentage occurrence comparison of optical auroral activity and pulsating aurorae between the original and the rescaled data of the Macquarie Island Station. The data are from June-July 1980.

| | Total Number of Events | | 1 - 5 S | | 6 - 10 S | | 11 - 15 S | | 15 - 20 S | | 20 S | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STATION | Origin-Scale | Rescale | Origin-Scale | Rescale | Origin-Scale | Rescale | Origin-Scale | Rescale | Origin-Scale | Rescale | Origin-Scale | Rescale |
| DAVIS | 196 | 193 | 3 | 3 | 41 | 43 | 53 | 54 | 46 | 40 | 53 | 53 |
| MACQUARIE ISLAND | 189 | 186 | 16 | 14 | 138 | 124 | 27 | 39 | 7 | 6 | 1 | 3 |

Table 8. The comparison of pulsation periods between the original and rescaled data.

# REFERENCES

Akasofu, S. ¯I. (1968). Polar and magnetospheric substorm. D. Reidel Publishing Co., Dordreht, Holland.

Brekke, A. (1971). On the correlation between pulsating aurora and cosmic radio noise absorption. Planetary and Space Science 19:891-896.

Brekke, A. and Pettersen, H. (1971). Some observations of pulsating aurora at Spitzbergen. Planetary and Space Science 19:536-540.

Bond, F.R. and Jacka, F. (1962). Distribution of auroras in the southern hemisphere II. Nightly probability of overhead aurora. Australian Journal of Physics 15:261-272.

Boyd, J.S. (1983). Invariant geomagnetic coordinates for epoch 1977.25. ANARE Research Notes Number 14.

Burns, G.B. (1983). Pulsating Aurora: Photometer, Riometer and Micropulsation Observations. PhD Thesis, Division of Theoretical and Space Physics, La Trobe University.

Campbell, W.H. (1970). Rapid auroral luminosity fluctuations and geomagnetic field pulsations. Journal of Geophysical Research 75:6182-6208.

Campbell, W.H. and Rees, M.H. (1961). A study of auroral coruscations. Journal of Geophysical Research 66:41-55.

Cresswell, G.R. (1972). The morphology of displays of pulsating auroras. Journal of Atmospheric and Terrestrial Physics 34:549-554.

Davidson, G.T. and Sears, R.D. (1980). Pulsating aurora: Evidence for flux limiting. Geophysical Research Letters 7:185-196.

Davis, T.N. (1978). Observed characteristics of auroral forms. Space Science Review 22:77-113.

Deehr, C.S., Romick, G.J. and Sivjee, G.G. (1981). Auroral morphology: A television image of solar and magnetospheric activity. In: C.S. Deehr and J.A. Holtet (Eds). Exploration of the Polar Upper Atmosphere. D. Reidel Publishing Co.

Duncan, C.N., Creutzberg, F., Gattinger, R.L., Harris, F.R. and Jones, A.V. (1981). Latitudinal and temporal characteristics of pulsating aurora. Canadian Journal of Physics 59:1063-1069.

Iyengar, R.S. and Shepperd, G.G. (1961). Observations of pulsating auroral fluctuations. Canadian Journal of Physics 39:1911-1922.

Johansen, O.E. (1966). A possible relation between Pulsations in the auroral luminosity and the energy spectrum of the primary particles. Planetary and Space Science 14:217-219.

Johansen, O.E. and Omholt, A. (1966). A study of pulsating aurora. Planetary and Space Science 14:207-215.

Johnstone, A.D. (1978). Pulsating aurora. Nature 274:119-126.

Johnstone, A.D. (1983). The mechanism of pulsating aurora. Annales Geophysicae 1:397-410.

Jones, A. V.(1974). Aurora. D. Reidel Publishing Co., Dordrecht, Holland.

Jones, A.V. and Gattinger, R.L. (1981). TV morphology of some episodes of pulsating aurora. Canadian Journal of Physics 59:1077-1082.

Kvifte, G.J. and Pettersen, H. (1969). Morphology of the pulsating aurora. Planetary and Space Science 17:1599-1607.

Kvifte, G.J. and Pettersen, H. (1972). Morphology of the pulsating aurora. In: Proceeding on the Magnetosphere - Ionosphere interactions. Pp.113-116.

Lassen, K. (1969). Polar cap aurora. In: B.M. McCormac and A. Omholt (Eds). Aurora and Airglow. Proceedings of the Nato Advanced Study Institute.

McEwen, D.J. and Bryant, D.H. (1978). Optical-particle characteristics of pulsating aurora. Journal of Atmospheric and Terrestrial Physics 40:871-876.

McEwen, D.J., Yee, E., Whalen, B.A. and Yau, A.W. (1981). Electron energy measurements in pulsating aurora. Canadian Journal of Physics 59:1106-1115.

McEwen, D. J., Duncan, C. N. and Montalbetti, R. (1981). Auroral electrons energies: comparisons of in situ measurements with spectroscopically inferred energies. Canadian Journal of Physics 59:1106.

Oguti, T., Kokubun, S. and Hayashi, K., Tsuruda, K. and Machida, S., Kitamura, T. and Saka, O., and Watanabe, T. (1981). Statistics of pulsating auroras on the basis of all-sky TV data from five stations. I. Occurrence frequency. Canadian Journal of Physics 59:1150-1157.

Omholt, A. (1971). The optical aurora. Springer-Verlag, New York.

Omholt, A., Kvifte, G.J. and Pettersen, H. (1969). Pulsating aurora. In: B.M. McCormac and A. Omholt (Eds). Atmospheric emissions. Van Nostrand Reinhold Co., New York. Pp. 131-143.

Paulson, K.V. and Shepherd, G.G. (1965). A cross-spectral method for determining the mean lifetime of metastable oxygen atoms from photometric observations of quiet aurorae. Journal of Atmospheric and Terrestrial Physics 17:831-841.

Paulson, K.V. and Shepherd, G.G. (1966a). Fluctuations in brightness from quiet form auroras. Canadian Journal of Physics 44:837-846.

Paulson, K.V. and Shepherd, G.G. (1966b). Short-lived brightness oscillations in active auroras. Canadian Journal of Physics 44:921-924.

Roldugin, V.K. and Starkov, G.V. (1970). Zone of pulsating aurora. Geomagnetic Aeronomy 10:72-74.

Royrvik, O. and Davis T.N. (1977). Pulsating aurora: Local and global morphology. Journal of Geophysical Research 82:4270-4740.

Thomas, I.L. (1971). The auroral ovals and the related morphology of optical pulsations. PhD. Thesis, Physics Department, University of Melbourne.

Thomas, R.W. and Rothwell, P. (1979). A latitude effect in the periodicity of auroral pulsating patches. Journal of Atmospheric and Terrestrial Physics 41:1179-1184.

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