MOTION OF THE AURORA AND MAGNETIC BAYS

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Summary

Observations from the ANARE station at Macquarie Island show that the development of an auroral display is characterized by a slow northward drift, east to west longitudinal motion, and an associated positive bay in the horizontal component magnetogram in the evening hours. This is followed by a sudden change in structure of the aurora and appearance of a negative bay. The negative bay persists for some hours, accompanied by west to east longitudinal motion and slow southward drift of the aurora.

The co-latitude of the northern limits of the aurora is shown to be strongly dependent on level of geomagnetic disturbance.

It is suggested that the observed motions are the mass motions of electrons which constitute the magnetic bay producing current within the boundaries of the auroral form.

I. Introduction

The data used in this paper are from the records of visual observations of the aurora at the Australian National Antarctic Research Expeditions' (ANARE) station at Macquarie Island and from volunteer observers' reports in eastern Australia collected by the Auroral Data Centre.

The auroras considered were located on or to the north of the southern auroral zone which lies approximately 1° south of Macquarie Island (Bond and Jacka 1960). In this region auroras are usually aligned or extended roughly along parallels of geomagnetic latitude. The observations were recorded mainly during the period of the International Geophysical Year 1957–58.

Attention is confined to the large-scale motions of the aurora as a whole across the sky and associated geomagnetic disturbance. Changes of internal structure such as movements of rays along an "arc" or "band" are not considered.

II. Magnetic Bays

A study of magnetic bays recorded at Macquarie Island during 1954 has been reported by Robertson (1960). Examination of the magnetic records for 1958 showed trends similar to the records for 1954.

Positive bays in the horizontal component H occurred less frequently than negative bays, their duration was shorter and their amplitude less. Many positive bays commenced during daylight, mainly between $14^{h}\,30^{m}$ and $18^{h}\,30^{m}$ local time; while negative bays occurred during the night hours, commencing mainly between $18^{h}\,30^{m}$ and $04^{h}\,30^{m}$. The time of change-over from positive bay to negative bay most frequently occurred between $21^{h}\,00^{m}$ and $22^{h}\,00^{m}$.

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III. Motion of the Aurora

(a) *Typical Development of a Display*

Climatic conditions at Macquarie Island are extremely unfavourable for auroral observing; the sky is very rarely clear for more than a few hours at a time. However, an examination of the Macquarie Island observations over the period 1951–1959 indicates that the main pattern of auroral behaviour may be described in terms of two phases.

The first phase commences as a succession of one or more arcs or bands appearing above the southern horizon. Aligned roughly along parallels of geomagnetic latitude, these arcs or bands may show rayed structure of intensity 1 or 2 and very rarely intensity 3 (on the usual 0–4 scale). There is, then, a general northwards progression of the display. This may be a continuous drift, sometimes with a succession of advances or retreats; or it may be a discontinuous progression involving fading of the aurora at one position and a new appearance at another. A new arc or band may form in advance of an existing display. An arc or band may disappear only to be replaced by another further to the south and the advance be repeated. When this phase has a duration exceeding 30 min it is almost invariably associated with a positive bay in the H magnetogram.

In general, the northward drift continues until the beginning of the second phase which is characterized by a quite sudden increase in intensity and development of bright rayed structure. This may be followed by flaming. The discrete structure is replaced by moving diffuse rayed forms and pulsating and diffuse surfaces which latter slowly drift or progress to the south. This second phase is always associated with a negative bay in the H magnetogram.

This main sequence may be halted at any stage and one or more stages may be absent. Occasionally after the second phase has begun arcs reappear for a short time interval and the whole or part of a sequence may be repeated one or more times.

The lateral drifts of individual forms and lateral progression of the display as a whole referred to above, take place typically at a rate of a few degrees of latitude per hour (cf. Jacka 1953) corresponding to speeds of the order of 100 m/sec. Canadian observations by Kim and Currie (1958) on individual auroral forms show a modal value of north-south drift speed of 50–100 m/sec. They also find some evidence for an increase of drift speed with increase in geomagnetic disturbance.

During times of very marked geomagnetic disturbance the complicated auroral situation over Macquarie Island is difficult to interpret in detail, but in these cases the pattern of the aurora as described above seems to apply to the observations from southern Tasmania and, for the major magnetic storms, to the observations from further north in Australia.

The patterns of the auroral display as observed at Macquarie Island appear to be very similar to those described by Heppner (1954) and Elvey (1957) for the approximately magnetically conjugate location, College, Alaska Heppner notes that in general the first appearing arcs and bands approximately coincide in time with the recording of a positive bay in H, while the change-over to a negative bay is associated with the appearance of bright rayed structure and subsequent break up in the arc nearest the equator.

The Macquarie Island 1958 aurora records were examined in detail, in conjunction with the magnetograms to see to what extent a detailed correspondence, similar to that recorded by Heppner, existed.

Auroral reports for 62 nights were examined. It was found that on 11 nights auroral behaviour was quiet and positioned well to the south of Macquarie Island; these were all nights of little magnetic activity. On 46 nights, auroral behaviour and magnetic behaviour did not contradict the Heppner patterns, although in some cases the auroral record was somewhat meagre. Of the remaining 5 nights, on 3 of them the auroral behaviour is difficult to classify, while on 2 nights bright rayed displays occurred at times when the magnetograms showed positive bays. On both occasions these bright rayed displays were at least 1° of latitude to the south, rather than overhead or to the north, which is more usual.

(*b*) *Co-latitude of Auroras and* K_p

Using data obtained during the I.G.Y., synoptic maps have been prepared showing, at 15-min intervals, the distribution of auroras in the region of Macquarie Island and eastern Australia. Auroral positions were computed from recorded elevations and azimuths of points on the lower border, assumed at a constant height of 105 km.

From the maps the co-latitude of the most northerly lower border crossing geographic longitude 152° E. was extracted for each quarter hour and tabulated against the prevailing K_p-index. These data are represented in Figure 1, which shows clearly the equatorwards appearance of the northernmost auroral form with increasing magnetic disturbance. Over the range of K_p values 1–7, the mean co-latitudes in Figure 1 are comparable with those reported for homogeneous arcs at Macquarie Island by Jacka (1953). A similar relation with the K-index recorded at Macquarie Island is apparent in the radio-echo observations tabulated by Gadsden (1959*a*).

(*c*) *Longitudinal Motion*

Observations of longitudinal motion of auroras were made by G. Cowling, a member of the ANARE at Macquarie Island in 1958. Mr. Cowling also carried out a preliminary analysis.

Measurements of elevation and azimuth to points on the lower border were made using an open sights theodolite and successive positions of the aurora were plotted on grids showing reference lines for elevation and azimuth. When, due to rapid movement of the auroral form, measurements were not possible, the initial position of the aurora was estimated and the direction of movement noted. Longitudinal motion, that is, motion in the direction in which the aurora is aligned or extended, was recorded in 33 cases.

Of these 33 cases, 6 were of east to west motion and 27 of west to east motion. The former occurred at or before $22^h\ 36^m$, the latter between $22^h\ 01^m$ and $06^h\ 01^m$ local time. In 5 cases only was it possible to estimate speeds of longitudinal motion; these estimates lay in the range 200–1000 m/sec. Comparable speeds are reported by Kim and Currie (1958), who also find an increase in speed with increase in magnetic disturbance.

Direction of longitudinal motion of auroral fo ms was compared at corresponding times with the H component magnetogram. In general it was found that positive departures ($+\Delta H$) from the quiet-day curve corresponded with east to west motions of the aurora, while negative departures ($-\Delta H$) corresponded with west to east motions. This trend is illustrated in Table 1.

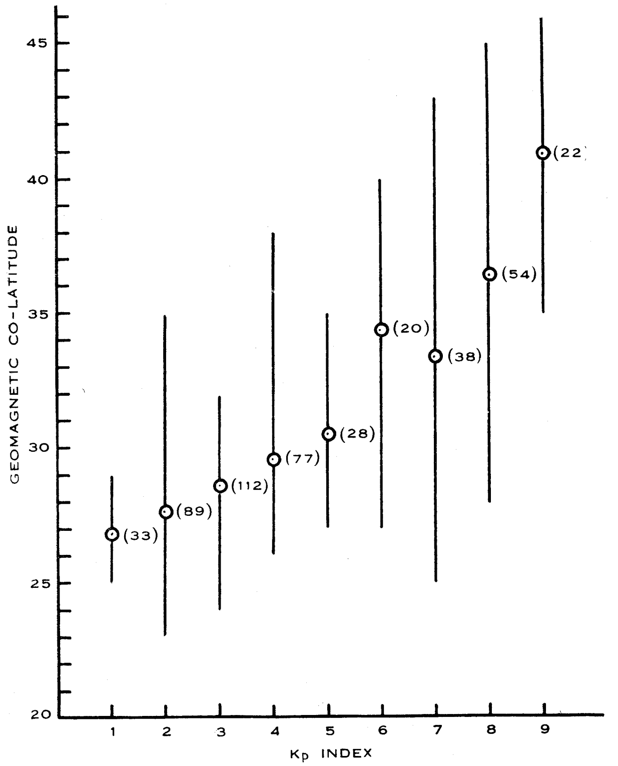

Fig. 1.—Co-latitude of the northernmost auroral lower border versus K_p. The circle represents the mean, the line represents the total range, of co-latitude, and the numbers give the total of quarter-hourly observations, for each value of K_p. (Data from gg. longitude 152 °E.)

It should be noted that in the arc or band type of aurora present during a positive bay, longitudinal motion is virtually along itself and can be recognized only when a discontinuity can be discerned. Discontinuities of recognizable size or shape are not of frequent occurrence. Moreover, it has already been noted that a proportion of positive bays commence during daylight, and that positive bays are of shorter average duration than negative bays. It is presumably for these reasons that the number of recorded cases of east to west motion is small.

These limitations are not present when radio-echo methods are used to trace the motion of ionization at auroral heights. Unwin (1959) has reported such motions over Macquarie Island and has shown that the echoes come from a layer, a few to 25 km thick, centred between a height of 110 km and a little more than 120 km. Unwin found that east to west moving echoes occurred between about $15^{h}\,30^{m}$ and $01^{h}\,30^{m}$ local time, while west to east moving echoes occurred between about $18^{h}\,30^{m}$ and $09^{h}\,30^{m}$ local time. On any one occasion the change from westerly to easterly motion was quite distinct. Velocities ranged from about 200 to 4000 m/sec. Unwin reports a distinct increase in velocity with increasing values of the Macquarie Island K-index.

A summary of some observations of auroral motion and motion of auroral ionization in the northern hemisphere is given in Table 2. The marked similarity with the data of this paper and with those of Unwin is clear.

TABLE 1

MOTION OF THE AURORA, MACQUARIE ISLAND 1958

Direction of Auroral Motion	Number of Cases		
	$+\Delta H$	$-\Delta H$	No Departure
East to west	4	1*	1
West to east	—	27	—

* Value -15γ, a small value for this station.

IV. DISCUSSION

The results of this and quoted works may be summarized as follows. Northward lateral drift or progression and westward longitudinal motion of auroral luminosity and auroral ionization are each associated with positive magnetic bays. Southward drift or progression and eastward longitudinal motion are associated with negative bays. Whether there is a direct association of lateral drift and longitudinal motion of individual auroral forms cannot be ascertained from the present data. These are not precise enough to enable detection of slow lateral drift during the relatively short time intervals in which longitudinal motion is usually discernible. Speeds of longitudinal motion are an order of magnitude greater than lateral drift speeds.

Positive magnetic bays and associated auroral movements northwards and westwards are characteristic of the evening hours. Negative bays and associated movements are characteristic of the night and early morning hours. The transition is usually rapid and may occur within a time range of several hours (but usually within a range of about 1 hr) centred a little before midnight.

The maximum co-latitude and the speed of longitudinal motion and possibly of lateral drift increase with geomagnetic disturbance.

It is apparent that the longitudinal motion takes place in the direction of an electron current which would produce the observed sign of magnetic bays.

TABLE 2

LONGITUDINAL MOTION OF THE AURORA AND MAGNETIC BAYS—SUMMARY

Observers' Location	Approx. Gm. Lat. of Auroras	Time of E. to W. Movement	Time of W. to E. Movement	Type of Bay during Movement		Longitudinal Speed (m/sec)	Reference
				E. to W.	W. to E.		
Yerkes	53 °N	Prior to $24^h\ 00^m$	After $24^h\ 0\ ^m$			100–1400	Meinel and Schulte (1953)
Saskatoon	61 °N	Prior to $02^h\ 00^m$	Throughout the night				Meek (1954)
College	65 °N	$16^h\ 00^m$–$02^h\ 00^m$	$23^h\ 00^m$–$08^h\ 00^m$		—		Heppner (1954)
Ithaca	61 °N	Early in the night	Late in the night				Bless, Gartlein, and Kimball (1955)
Jodrell Bank	55 °N	Prior to $21^h\ 00^m$–$22^h\ 00^m$	After $21^h\ 00^m$–$22^h\ 00^m$	+	—	0–2800	Bullough *et al.* (1957) Bullough and Kaiser (1955)
College	65 °N	Mainly prior to $22^h\ 00^m$	Mainly after $22^h\ 00^m$	+	—	350–2000	Nichols (1957)
Saskatoon, Flin Flon, Uranium City	61 °N, 64 °N, 56 °N	$18^h\ 00^m$–$02^h\ 00^m$	$22^h\ 00^m$–$04^h\ 00^m$			90–1183	Kim and Currie (1958)
Saskatoon	61 °N	Mainly prior to $24^h\ 00^m$	Mainly after $24^h\ 00^m$	+	—	0–670	Lyon and Kavadas (1958)
Invercargill	61 °S	$15^h\ 30^m$–$01^h\ 30^m$	$18^h\ 30^m$–$09^h\ 30^m$			200–4000	Unwin (1959)
Macquarie Island	61 °S	Prior to $22^h\ 30^m$	$22^h\ 00^m$–$06^h\ 00^m$	+	—	200–1000	This paper

Gadsden (1959*b*) has shown that the occurrence of auroral ionization (giving rise to radar echoes) and of visible auroral luminosity are statistically independent events. However, the morphologies of these phenomena are similar.

The simplest hypothesis consistent with the observations is that the radio and optical methods detect different attributes (produced by different causes, either of which may be absent) of the one basic auroral phenomenon. This is characterized by a slow lateral drift and more rapid longitudinal motion. This motion of patterns of ionization and/or luminosity is identified with the mass motion of electrons which constitutes a magnetic bay producing electric current within the narrow confines of the auroral phenomenon. At any one time several such phenomena, generally roughly parallel to one another, may be observable from the one station.

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VI. References

Bless, R. C., Gartlein, C. W., and Kimball, D. S. (1955).—*Astrophys. J.* **122** : 205.
Bond, F. R., and Jacka, F. (1960).—*Aust. J. Phys.* **13** : 610.
Bullough, K., and Kaiser, T. R. (1955).—*J. Atmos. Terr. Phys.* **6** : 198.
Bullough, K., Davidson, T. W., Kaiser, T. R., and Watkins, C. (1957).—*J. Atmos. Terr. Phys.* **11** : 237.
Elvey, C. T. (1957).—*Proc. Nat. Acad. Sci., Wash.* **43** : 63.
Gadsden, M. (1959*a*).—*Ann. Géophys.* **15** : 395.
Gadsden, M. (1959*b*).—*Ann. Géophys.* **15** : 403.
Heppner, J. P. (1954).—Thesis, California Institute of Technology.
Jacka, F. (1953).—*Aust. J. Phys.* **6** : 219.
Kim, J. S., and Currie, B. W. (1958).—*Canad. J. Phys.* **36** : 160.
Lyon, G. F., and Kavadas, A. (1958).—*Canad. J. Phys.* **36** : 1661.
Meek, J. H. (1954).—*Astrophys. J.* **120** : 602.
Meinel, A. B., and Schulte, D. H. (1953).—*Astrophys. J.* **117** : 454.
Nichols, B. (1957).—Sci. Rep. No. 1, Air Force Contract No. AF 19(604)—1859, Geophysical Institute, University of Alaska.
Robertson, C. S. (1960).—*Aust. J. Phys.* **13** : 470.
Unwin, R. S. (1959).—*Nature* **183** : 1044.