AURORAL MORPHOLOGICAL SIMILARITIES AT TWO MAGNETICALLY CONJUGATE STATIONS: BUCKLES BAY AND KOTZEBUE*

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Summary

This paper gives a preliminary study of auroral displays photographed by all-sky cameras during November 1962 to March 1963 at the approximately magnetically conjugate stations, Buckles Bay, Macquarie Island, and Kotzebue, Alaska.

Within the degree of accuracy of the plotting method used, the location and shape of clearly discernible simple auroral forms during the initial quiet phase of a display are consistent with magnetic conjugacy in colatitude θ_3 (Bond and Jacka 1962). Increases and decreases in the brightness of corresponding auroral forms occurred simultaneously at both stations, to within 1 min, and were assessed to be of the same order of magnitude. During the later stages of a display the auroral features were slightly displaced in latitude and longitude in a manner possibly related to the angle of attack of the solar wind on the magnetosphere.

This information suggests conformity with the concept that electron precipitation guided along magnetic field lines is a major factor in the morphological pattern of the aurora, and that the visible aurora may portray in miniature the pattern of deformation in the magnetosphere of the magnetic field lines connecting the conjugate phenomena.

I. Introduction

This paper reports a preliminary investigation into the nature of simultaneous auroral displays above the approximately magnetically conjugate points, Buckles Bay (geographic lat. 54·5° S., long. 159·0° E.) on Macquarie Island and Kotzebue (geographic lat. 66·9° N., long. 197·5° E.) in Alaska during the period October 21, 1962 to March 1, 1963. It confirms and extends the findings of De Witt (1962) which were derived from four nights of records at the Campbell Island–Farewell conjugates and one night at the Macquarie Island–Kotzebue pair.

At each station all-sky camera photographs were taken at 1 min intervals, with 10 sec exposure commencing on the minute of Universal Time. Although night conditions occur simultaneously for 8 months of the year and the maximum period of concurrent darkness is about 6 hr (Fig. 1), moonlight and very high incidence of cloud (99% of nights $\geqslant 5/8$) at Macquarie Island, resulted in only 8 nights of effective simultaneous observation. Nevertheless, on these 8 nights similar auroral forms occurred simultaneously above Buckles Bay and Kotzebue. Additional observations under clouded conditions at Buckles Bay were used in the study of intensity variation.

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II. Examination of Film

Two 16 mm film rear projection viewers were set up side by side, a prism being inserted into the viewer used for the Kotzebue film so that directly comparable pictures were obtained (see Fig. 2).

Sets of points on the lower borders of auroral forms were read off in azimuth and great-circle distance and plotted in geographical coordinates, using an assumed auroral height of 105 km. In general, auroral plan positions were prepared for displays at 5 min intervals, but, where the movement of the aurora was rapid, auroral positions relating to shorter intervals were drawn.

Using cinematic mode, the film from Buckles Bay was examined for changes in intensity and the times at which significant increases or decreases occurred were noted. The film from Kotzebue for these time intervals was then examined. It was found that the times of like changes agreed to ± 1 min. The correspondence was such that location and intensity of auroras at Kotzebue corresponded always with predictions made from the more cloud-obscured Buckles Bay.

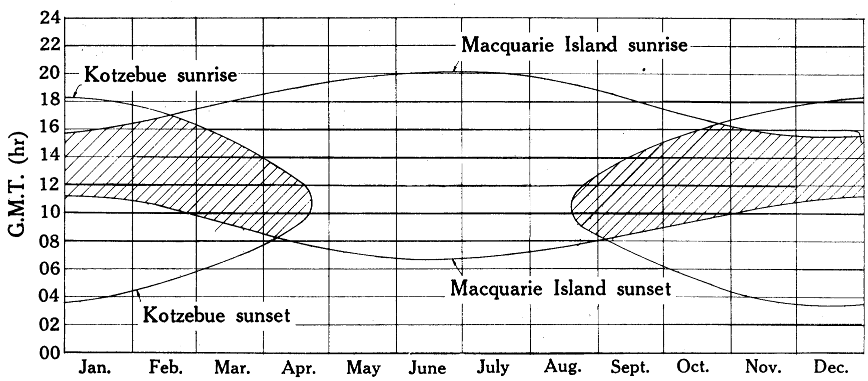


Fig. 1.—Nautical twilight curves for Kotzebue and Macquarie Island, 1962. The shaded areas indicate times of simultaneous darkness.

III. Analysis of Data

The aurora above the two stations can be compared directly if the data are presented in a geomagnetically conjugate system of latitude and longitude.

At the date of this analysis, the conjugate grid available consisted of colatitude θ_3 (Bond and Jacka 1962) and eccentric dipole longitude ϕ_1 (Cole 1963). The Gaussian coefficients used in the ϕ_1 determinations were taken from Finch and Leaton (1957) referring to epoch 1955. Since the auroral observations refer to 1962–63 it is necessary to bring the ϕ_1 longitude system up to date. A convenient approximate method was used.

The point near Kotzebue that is conjugate to Buckles Bay was found by use of a computer programme for determining the value of L (McIlwain 1961), using the

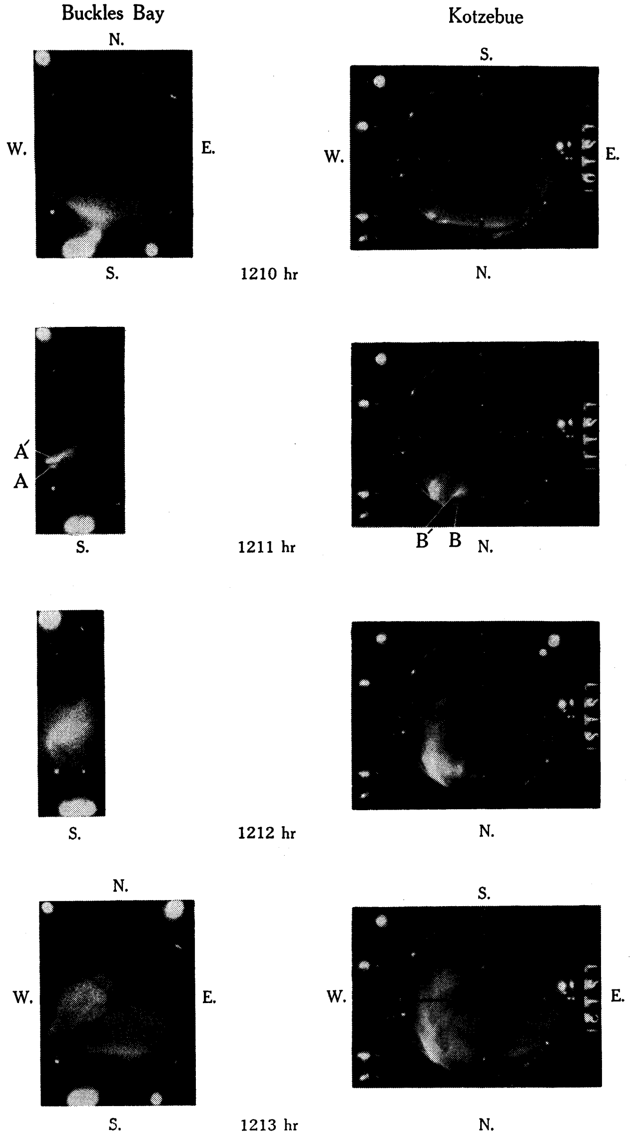


Fig. 2.—Comparison of all-sky camera film from Buckles Bay and Kotzebue as presented for viewing by the rear projection film viewers. The Kotzebue picture is presented as it would appear if transferred along the geomagnetic field lines to the southern hemisphere. The photographs cover the period 1210–1213 hr, March 1, 1963. The pair of photographs at 1211 hr show ray bundles A′, B′ near a short brighter section A, B, of corresponding ⊃ loops. Directions are based on centred dipole north on which both cameras were oriented. In making comparisons visually, account must be taken of the marked compression with increasing radius of the all-sky camera record and the perspective effect due to the fact that the centres of the pictures are not accurately conjugate.

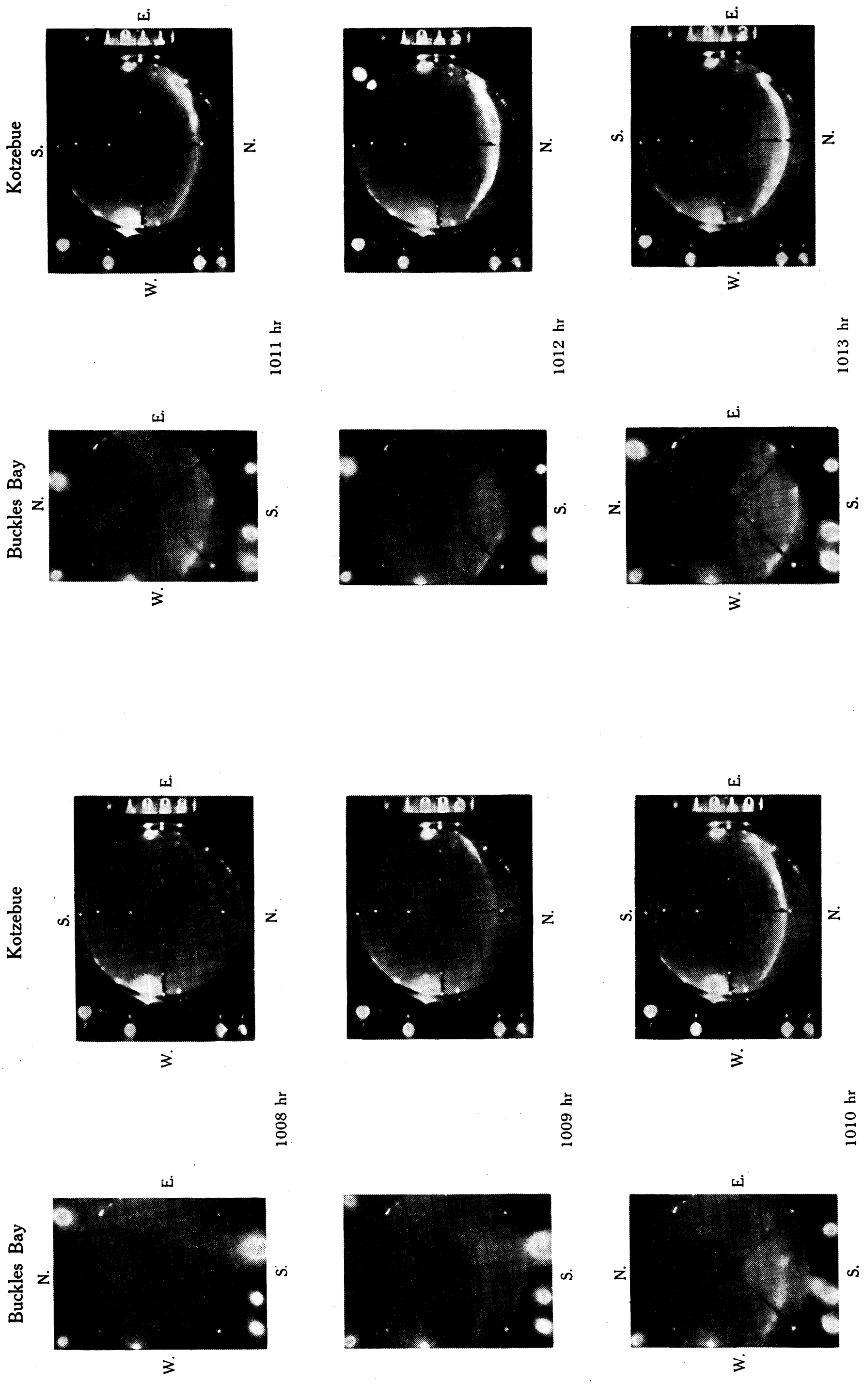


Fig. 3.—Latitude conjugacy of quiet arcs 1008–1013 hr, March 1, 1963. The more intense illumination is first visible east of Kotzebue and west of Buckles Bay.

1960 Gaussian coefficients (Jensen and Cain 1962), the programme being modified to give the conjugate point at the average auroral height of 105 km, together with the geographical location.

Thus the field line from a point 105 km above Buckles Bay is traced to the conjugate point at auroral height near Kotzebue. The geographical coordinates of this conjugate point are lat. 67·32° N., long. 196·16° E., or 0·4° N. and 1·3° W. of Kotzebue.

In Table 1 the θ_3, ϕ_1 coordinates of the conjugate to Buckles Bay in both the θ_3, ϕ_1 system and the McIlwain system are compared with the coordinates of Kotzebue and Buckles Bay.

The two methods of locating the conjugate point differ in colatitude by only 0·5°, and hence the θ_3 colatitude is an acceptable approximation. However, the difference in longitude, 4·5°, requires an adjustment to be made.

Table 1

COMPARISON OF CONJUGATE COORDINATE SYSTEMS

Location	Colatitude θ_3	Eccentric Dipole Longitude ϕ_1
Buckles Bay	25·7° S.	239·0° E.
Conjugate (θ_3,ϕ_1)	25·7° N.	239·0° E.
Conjugate (McIlwain)	25·2° N.	234·5° E.
Kotzebue	26·0° N.	237·0° E.

At this colatitude the lines of eccentric dipole longitude are evenly spaced. The northern hemisphere grid was therefore rotated about the pole of the eccentric dipole so that the longitude of Buckles Bay and its conjugate as determined by the McIlwain programme had the same value in the grid system. In the areas covered by the two all-sky cameras, the grid conjugates are virtually identical with the McIlwain programme conjugates.

The points on the lower border maps for Kotzebue were read off in θ_3, ϕ_1 coordinates, transferred to the magnetically conjugate θ_3, ϕ_1 points in the Buckles Bay region, and the auroral lower borders redrawn.

IV. Results

Information on the auroral lower borders is summarized in Table 2. It will be seen that simple arc forms of the aurora are approximately latitudinally conjugate in the θ_3, ϕ_1 grid. The criterion for conjugacy in these cases was firstly similarity in form, and secondly a latitude difference not exceeding 0·5° in the θ_3 grid. It should, however, be noted that in all cases the Kotzebue conjugate form lies polewards of the Buckles Bay form and in the majority of cases the displacement was very close to the 0·5° limit.

An example of similarity in colatitude is given in Figures 3 and 4(*a*). This example is chosen to illustrate a case of conjugate arcs in which there is also an increase in intensity in only a portion of a simple arc or band form. It will be noted that at

TABLE 2

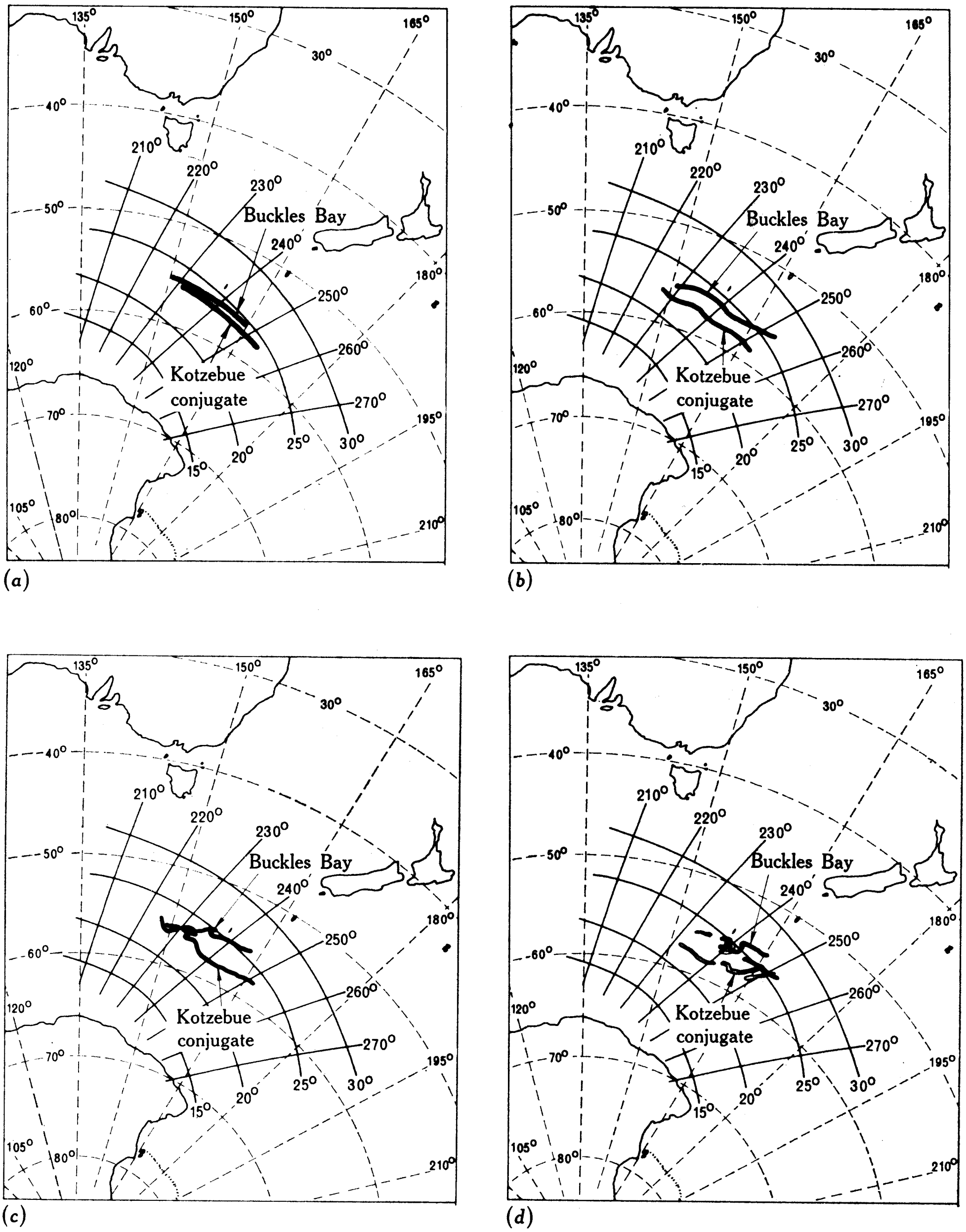
COMPARISON OF BUCKLES BAY AURORAL FORM WITH KOTZEBUE CONJUGATE AURORAL FORM

Date, Time (hr U.T.)	K_p	Cloud at Macquarie Is. (eighths)	No. of Forms and Position*	Coincidence	Similar Forms, Lat. Difference between Forms	Lat. Similarity Only	Long. Shift of Buckles Bay Main Feature	Remarks†
21.x .62								
1530	4^-	4	1	Yes	—	—	—	
1535	4^-	4	1	Yes	—	—	—	
22.x .62								
1520	3^+	7	1	Yes	—	—	—	
1525	3^+	7	1	Yes	—	—	—	
1530	3^+	7	1	Yes	—	—	—	
1535	3^+	7	1	Yes	—	—	—	
1540	3^+	7	1	Yes	—	—	—	
24.x .62								
1331	4^0	8	3(e)	—	Yes, 1°	—	—	
			(z)	—	—	Yes	West	
			(p)	—	Yes, 3·4°	—	—	
1332	4^0	8	3(e)	Yes	—	—	—	
			(z)			Yes	West	
			(p)	—	Yes, 2·5°	—	—	
1333	4^0	8	3(e)	Yes	—	—	—	
			(z)	—		Yes	West	
			(p)	—	Yes, 3·0°	—	—	
1336	4^0	8	2(z)	—	Yes, 2·0°	—	West	
			(p)	—	—	—	—	1
1337	4^0	8	2(z)	—	Yes, 2·0°	—	—	
			(p)	—	—	—	—	1
1400	4^0	8	1	—	Yes, 0·7°	—	West	
28.x .62								
1033	3^0	8	1	—	Yes, 3·0°	—	—	
23.xi.62								
1250	3^+	8	1	Yes	—	—	—	
1254	3^+	8	1	Yes	—	—	—	
1256	3^+	8	1	—	—	Yes	—	2
24.xi.62								
1351	3^0	7	1	—	Yes, 3·0°	—	—	
30.i .63								
1437	4^+	1	1	Yes	—	—	—	
1442	4^+	1	1	—	Yes, 1·0°	—	—	
1534	3^+	3	1	—	Yes, 1·4°	—	—	
1.iii.63								
1010	2^+	2	1	Yes	—	—	—	
1015	2^+	2	1	—	Yes, 1·2°	—	East	
1020	2^+	2	1	—	Yes, 2·0°	—	—	
1025	2^+	2	1	—	Yes, 2·2°	—	—	
1030	2^+	2	1	—	Yes, 2·0°	—	—	
1038	2^+	2	1	—	Yes, 2·0°	—	—	
1108	2^+	2	1	—	Yes, 2·0°	—	East	3
1111	2^+	2	(Breakup)	—	Yes, $\sim$1°	—	—	4
1152	2^+	2	1	Yes	—	—	—	5
1211	2^0	5	"Rays"	—	Yes, 2·0°	—	West	6

* Positions; e, equatorwards; z, zenith; p, polewards.

† Remarks are; 1, cloud at Macquarie obscured southern sky; 2, cloud at Macquarie partly obscured southern sky; 3, spiral form; 4, breakup; 5, simple band re-forms; 6, two ray bundles R2 in association with a $\supset$ band form.

1010 hr U.T., March 1, 1963, an increase in intensity occurs in part of the arc *east* of Kotzebue (i.e. east of the Buckles Bay conjugate point), whereas in the southern hemisphere the corresponding increase in intensity occurs *west* of Buckles Bay. More usually an increase in intensity affects the whole length of the conjugate arcs visible on the respective camera frames.



Figs 4(*a*)–4(*d*).—Stages in the development of the auroral display on **March 1, 1963:**

(*a*) The conjugate quiet arc phase at 1010 hr.

(*b*) The conjugate band phase as it had developed by 1015 hr.

(*c*) The conjugate spiral phase as it had developed by 1108 hr.

(*d*) The conjugate "breakup" phase at 1111 hr.

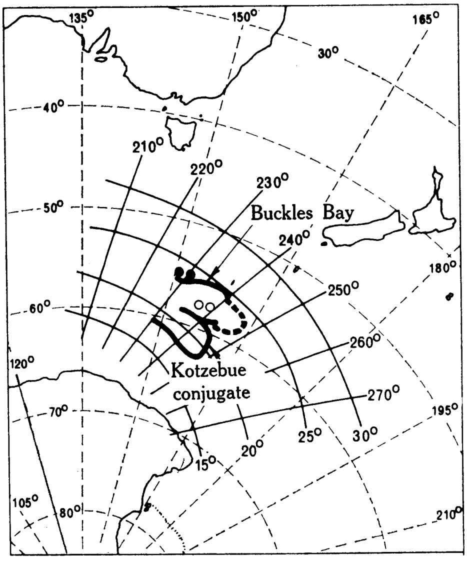


Fig. 4(*e*).—Showing a further stage in the development of the auroral display on March 1, 1963, which occurred after simple conjugate bands had re-formed at 1152 hr. The ray bundles that appeared near a ⊃ loop at 1211 hr are plotted. The dashed portion of the Buckles Bay form is taken from the frame at 1210 hr (see Fig. 2). Ray bundles shown are:

●, Buckles Bay;

○, Kotzebue.

Figures 4(*a*)–4(*e*) illustrate stages in the development of the display on March 1, 1963.

At 1015 hr (Fig. 4(*b*)), when the bands had developed a sinusoidal ribbon-like structure, two aspects assume importance. Firstly, the Buckles Bay form is markedly closer to the equator than the Kotzebue conjugate form, and an inspection of Table 2 reveals that this is the situation always found, during the period when the observations were recorded, when the latitudinal separation between the form and its conjugate was greater than 0·5°. Secondly, above Buckles Bay the band as a whole is displaced *eastwards* while the Kotzebue conjugate form is displaced *westwards*. This displacement is in the opposite sense from the intensity displacement observed earlier in this display.

In Figure 4(*c*), at 1108 hr, a more marked deformation of the arc form is indicated, the principal feature above Buckles Bay again being east of that referring to the Kotzebue conjugate.

The auroral breakup (or pseudo breakup; see Fig. 4(*d*)) had occurred by 1111 hr and the tendency seen is for the Buckles Bay auroral band fragments to be at the same longitude or even slightly west of those of the Kotzebue conjugate.

From Table 2 it can be seen that the simple band situation had reformed by 1152 hr and the situation was similar to that depicted in Figure 4(*a*), but the illumination of the arcs was uniform in intensity.

It should be noted that an increase in intensity is to be found in the ray bundles recorded at 1211 hr (Fig. 4(*e*)). This display was previously shown as a set of photographs in Figure 2. Unfortunately, the Buckles Bay camera produced a part frame at 1211 hr. By comparison with the pair of photographs taken 1 min earlier, it can be seen that at Kotzebue a bright portion A, and at Buckles Bay a bright portion B, developed on a ⊃ loop form near the western end. In each case near the bright

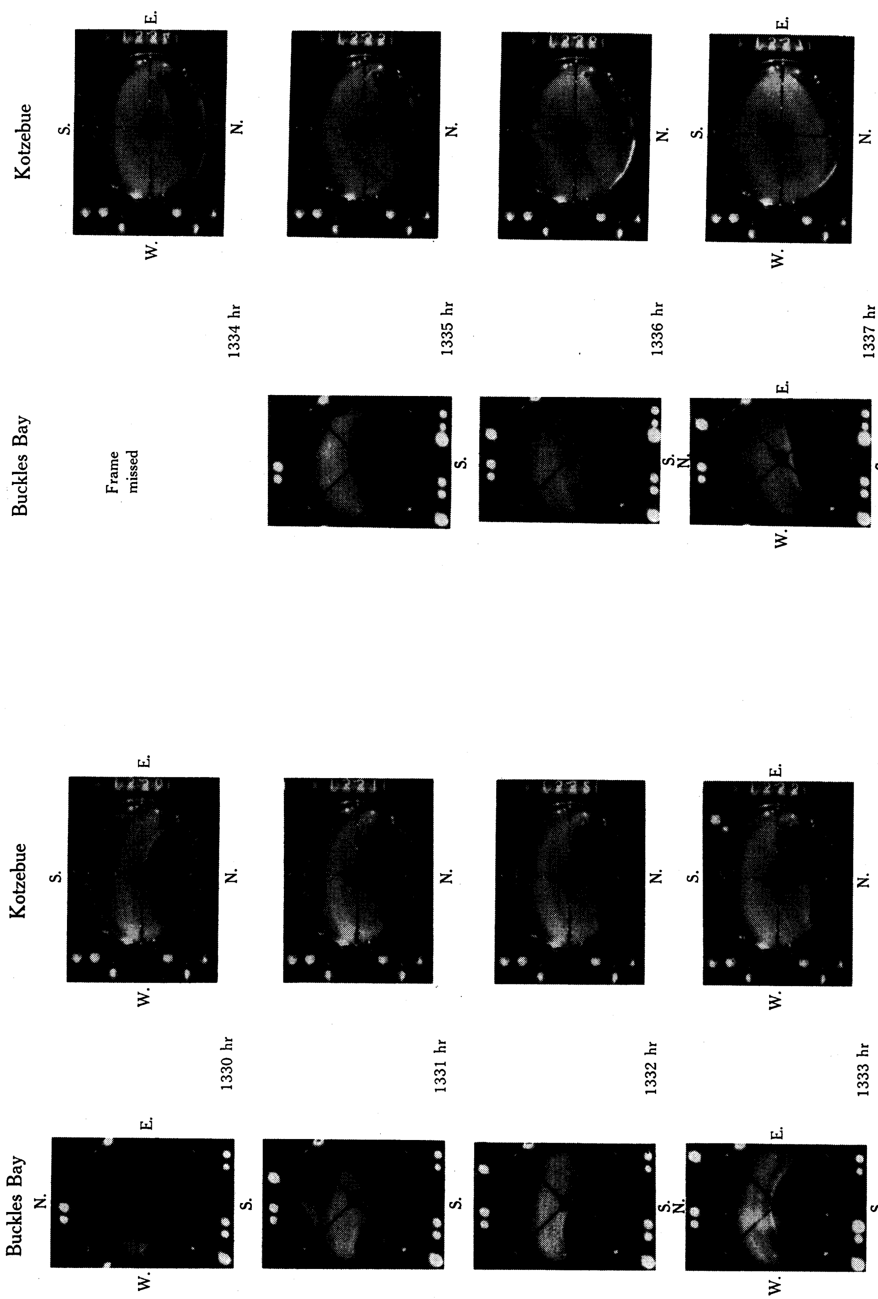


Fig. 5.—Conjugate zenith forms at 1330–1337 hr on October 24, 1962. This figure illustrates the westward longitude displacement above Buckles Bay and the eastward movement of corrugations in the zenithal band forms.

portions A and B can be seen bundles of rays A′ and B′. These ray bundles demonstrate instantaneous conjugacy. However, the rays near Kotzebue are displaced eastwards, and the rays near Buckles Bay are displaced westwards with respect to the mean longitude of the two sets of rays. The bundles of rays corresponding to the additional set on the westernmost part of the 1211 hr Kotzebue frame were presumably further to the west than the portion of the display encompassed by the Buckles Bay frame, but clear correspondence can be seen on the frames at 1212 and 1213 hr.

Figure 5 shows auroral forms near the zenith for the period 1330–1337 hr on October 24, 1962. This display, which occurred after magnetic midnight, shows feature displacement in longitude, the Buckles Bay form being west of the Kotzebue conjugate. The longitude displacement evidence is discussed in the next section.

An example of simple conjugate arcs or bands at a later period of a display is shown in Figure 6 for 1442 hr on January 30, 1963.

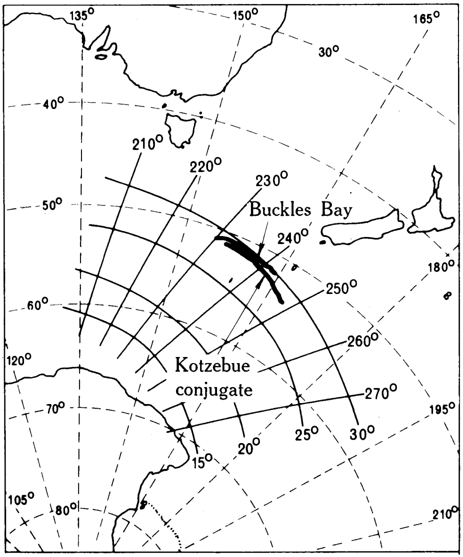


Fig. 6.—Conjugate simple bands at a later period of a display, shown at 1442 hr on January 30, 1963.

V. Discussion

Although numerically limited the data seem to indicate that, during the quiet phases of the auroral display at the θ_3 colatitude considered, a state of conjugacy in the θ_3, ϕ_1 grid system exists at least in relation to latitude.

However, the sample of data from the period October 21, 1962 to March 1, 1963 indicates that as the auroral display became more disturbed the aurora over Buckles Bay was positioned nearer to the geomagnetic equator than the corresponding form near Kotzebue. The auroral forms that could be seen from these approximately conjugate points were similar and, even up to the breakup stage, an instantaneous auroral conjugacy, displaced from the calculated magnetic conjugacy, persisted.

Latitude Displacement

It is pertinent to examine whether any relationship existed between the direction, in relation to the aspect presented by the Earth, of the solar wind and the displacement in latitude. Wilcox and Ness (1965) have reported that during the northern winter, November 1963 to May 1964, the interplanetary magnetic field was directed nearly parallel to the ecliptic plane. Assuming that the solar wind carries its own frozen-in magnetic field, then the solar wind direction will lie parallel to the ecliptic plane.

During the hours of simultaneous darkness at Kotzebue and Buckles Bay, on the solar side the ecliptic plane was below the geomagnetic equator for the whole period under consideration.

Although there does not yet appear to be full three-dimensional confirmation of the shape of the magnetosphere with its geomagnetic tail, the theoretical proposal by Piddington (1960) and the substantial practical confirmation by satellite (Ness 1965) suggest a geomagnetic tail with a θ-shaped cross section, the bar of the θ being a neutral sheet, or having only a weak magnetic field. This situation is illustrated in Figure 7(a), where the geomagnetic equator is in the plane of the ecliptic and X represents the geomagnetic axis.

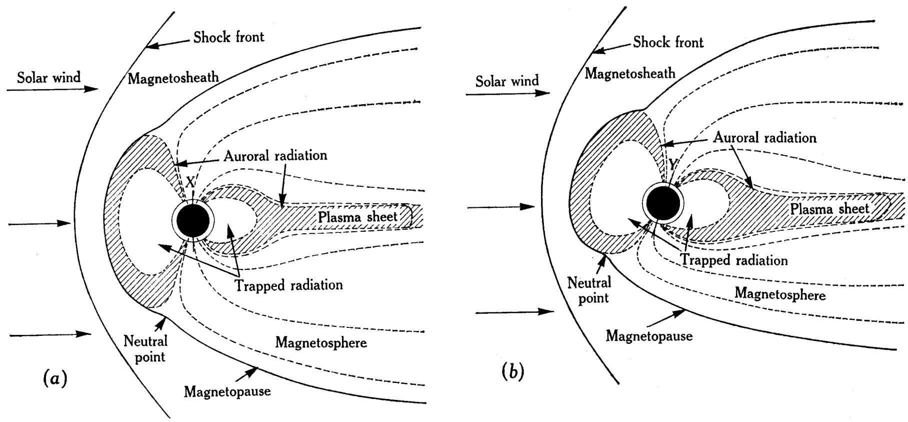


Fig. 7.—Diagrammatic sketch to illustrate the effect of a change in the angle of attack of the solar wind from (a) parallel to the eccentric dipole equator to (b) a direction south of that equator. (a) is based on a modification of O'Brien (preprint 1966).

An impression of the magnetosphere to agree with the displacements observed is indicated in Figure 7(b), with the geomagnetic axis shown as Y.

Longitude Displacement

To identify longitudes it is necessary to locate identifiable points on the corresponding northern hemisphere and southern hemisphere auroral forms. It is desirable to distinguish between the two types of longitude displacement in conjugate auroral forms:

(1) localized increases in intensity;

(2) shaped features.

(1) *Intensity displacements.* Only two clearly distinguishable examples of localized increases in intensity were recorded; the first, 1010 hr, March 1, 1963, occurred before local geomagnetic midnight, and the second, 1211 hr, March 1, 1963, virtually at geomagnetic midnight. In each case the precipitation in the northern hemisphere is east of the average longitude of the conjugate point of precipitation and west of this longitude in the southern hemisphere.

Thus, on the assumption of field line guided precipitation either the field line is distorted, or the precipitation suffers lateral movement onto neighbouring field lines. eastwards in the north and westwards in the south.

(2) *Feature displacements.* The directions of the longitude displacement of the Buckles Bay auroral form in relation to the corresponding identifiable point on the Kotzebue form are extracted from Table 2 and presented in Table 3. Also shown in this latter table is eccentric dipole approximation of geomagnetic time, $\phi_{1,\mathrm{Sun}}-\phi_{1,\mathrm{s}}$, where $\phi_{1,\mathrm{Sun}}$ is the eccentric dipole longitude of the Sun, $\phi_{1,\mathrm{s}}$ is the eccentric dipole longitude of the station, and time is measured westwards from the station to the Sun.

TABLE 3

LOCATED POINTS ON CORRESPONDING AURORAL FORMS

Time (hr U.T.)	Date	$\phi_{1,\mathrm{Sun}}-\phi_{1,\mathrm{s}}$	Relative Longitude Displacement (Buckles Bay rel. to Kotzebue)
1015	1.iii.63	151·7°	East
1108	1.iii.63	164·7°	East
1211	1.iii.63	179·9°	West
1331	24.x .62	208·0°	West
1336	24.x .62	208·3°	West
1400	24.x .62	214·1°	West

These longitude data, referring to only two displays, are too few from which to draw any firm conclusion. However, it is reasonable to speculate that the displacement may be related to the representation of the solar wind in Figure 7(*b*). Since the major effect of the solar wind there is directed against the southern hemisphere, it is to be expected that, prior to local geomagnetic midnight, the relative longitudinal displacement in this hemisphere would be eastwards towards the midnight meridian, and after midnight westwards, again towards the midnight meridian. This is the situation found in Table 3.

The further point arises that the intensity displacement at 1010 hr is opposite in direction to the feature displacement at 1015 hr, March 1, 1963. This suggests that the mechanisms involved may be different in nature.

VI. Conclusions

Within the degree of accuracy of the plotting method used, the location and shape of clearly discernible auroral forms of the arc or simple band type during the initial phase of a display are consistent with latitudinal magnetic conjugacy in the θ_3 grid.

Increases and decreases in the brightness of corresponding auroral forms occurred simultaneously at both camera stations to within 1 min and were assessed to be of the same order of magnitude.

During the developing stages of the display there was an instantaneous auroral conjugacy but the features were displaced from the positions expected from theoretical magnetic conjugacy in a manner possibly related to the angle of attack of the solar wind on the magnetosphere.

The limited data presented here suggest conformity with the concept that magnetic field line guided precipitation is a major factor in the morphological pattern of the aurora, and that the visible aurora portrays in miniature the pattern of deformation in the magnetosphere of the magnetic field lines connecting conjugate phenomena.

In conjunction with the Geophysical Institute, University of Alaska, this study will be pursued with better Buckles Bay data (35 mm SCAR all-sky camera) and more accurate techniques for ascertaining the conjugate grids.

VII. Acknowledgments

The all-sky camera film from Kotzebue was provided by the Geophysical Institute, University of Alaska. The collaboration of Mr. J. Reid, formerly of the Australian National Antarctic Research Expeditions (ANARE), in the modification of Professor C. E. McIlwain's computer programme is acknowledged, as is the assistance by Mrs. D. Lebbon of the Antarctic Division and by university students Miss A. Pearse, Mr. I. Thomas, and Mr. G. Creer during their vacation.

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