ON THE ORIGIN OF ELECTRIC FIELDS IN THE PLASMASPHERE

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Abstract: Whistler data recorded continuously at Sanae, Antarctica ($L=4$) over a 24 hour period of quiet magnetic conditions (average $Kp=1$) have been analysed to obtain plasma convection patterns. A duskside plasmaspheric bulge is present, centered on 1700 UT. The westward electric fields determined for this bulge region suggest that quiet time plasma drift is predominantly controlled by internal ionospheric current systems of dynamo origin, while in a limited local time sector there is some evidence of the magnetospheric dawn-to-dusk electric field being responsible.

1. Introduction

There has been considerable debate over the source of the electric fields observed in the plasmasphere and ionosphere under magnetically quiet conditions. RICHMOND *et al.* (1976) found that the hypothesis of a magnetospheric source (MATSUSHITA, 1971) was not in agreement with observations, and concluded that the fields originated from thermal winds associated with the ionospheric dynamo (MATSUSHITA, 1969). CARPENTER (1978) presented evidence from whistler observations that plasmaspheric electric fields originated from the ionospheric dynamo.

Even though it is well established that the ionospheric dynamo is responsible for the electric fields observed at low latitudes ($L<3$), it is not clear whether this is still the case at $L=4$ and beyond $L=4$ (MOZER, 1973), and to what extent the magnetospheric convection electric field penetrates the plasmasphere under quiet magnetic conditions (RICHMOND *et al.*, 1976).

The need to establish a quiet day reference pattern for use in determining the effects of substorms has been stressed by numerous authors (*e.g.* CARPENTER and SEELY, 1976). RICHMOND (1976) presented a quiet day electrostatic potential function for ionospheric and plasmaspheric electric fields obtained by least-squares fitting a series of spherical harmonics to a variety of electric field data. CARPENTER (1978) used whistler data obtained on four successive quiet days in an attempt to establish a consistent pattern of plasmaspheric electric fields near $L=4$.

In this paper we report on the analysis of 24 h of continuous whistler data recorded at Sanae, Antarctica ($L=4$) during quiet magnetic conditions. We will first compare the plasma convection patterns obtained with those for a similar set of data previously published (RABE and SCOURFIELD, 1977), and then discuss to what extent these data constitute a 'ground state' convection pattern. We will then examine the electric fields derived from this convection for the noon-midnight period and, by examining the variation of electric field with L-value, make some inferences regarding the source of these fields.

2. Evidence for a Ground State Convection Pattern

The data set analysed was recorded at Sanae ($L=4$; LT=UT) on 11 July 1976. It was characterized by a consistently good whistler intensity and rate (1–20 groups per minute) with well-defined whistler components covering a wide range of L-values. The average *Kp* for this 24 h period was 1. [For the previous 24 h the average *Kp* was 2—.] Some 20000 whistler components were scaled in intervals of 15 min. For each such interval 10 whistler groups were selected which contained consistently identifiable components. The dispersion characteristics of the components in successive groups remain essentially unchanged during the interval so that the nose frequency for each component can be averaged over the 10 groups. This average nose frequency then yields (PARK, 1972) an average L-value for the duct associated with that component over the 15 min interval. The resultant plot of duct L-value *vs.* UT for the full 24 h period is shown in Fig. 1.

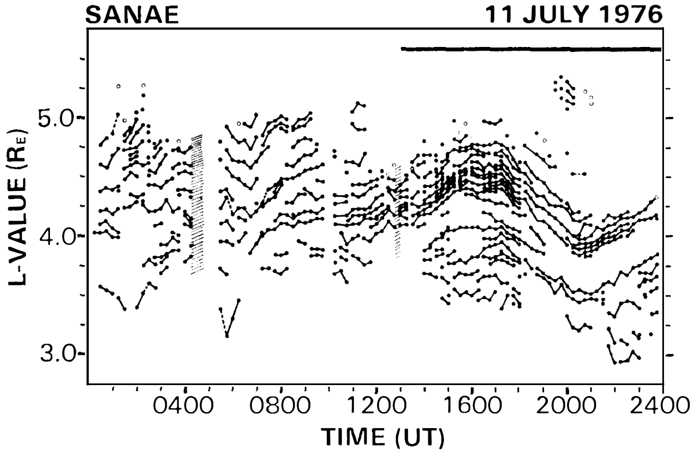

Fig. 1. Whistler duct L-value vs. UT for 11 July 1976. Each solid circle represents a duct averaged over 10 groups in a 15 min interval. Lines joining solid circles represent tracking of ducts between successive 15 min intervals. The horizontal bar in the top right of the figure represents the period for which electric fields were obtained.

In this figure each solid circle represents the L-value of a whistler duct averaged over 10 groups in a 15 min interval and open circles correspond to ducts averaged over fewer than 10 groups. The solid lines connecting the points show where the duct was tracked unambiguously from one 15 min interval to the next. The dashed lines show where some doubt existed in the tracking of the duct. Cross-hatching indicates that whistlers were observed but they were of too poor quality to enable us to identify individual components. The dominant feature of Fig. 1 is the duskside 'bulge' centred on 1700 UT (1530 MLT). Prior to this the plasma flow is outward, followed by an inward flow until 2100 UT, and then another period of outward flow until at least

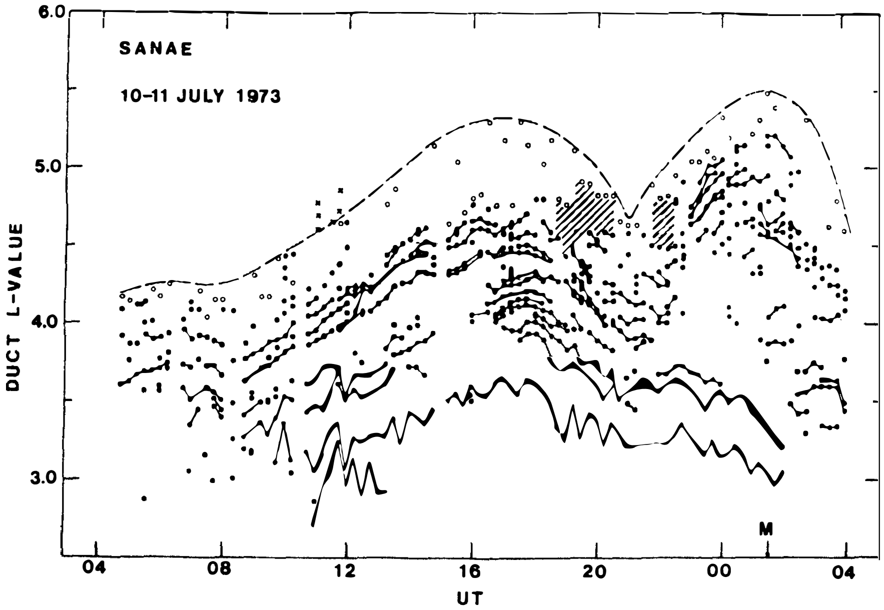

Fig. 2. Whistler duct L-value vs. UT for 0400–0400 UT on 10–11 July 1973. Solid circles and lines joining them have the same meaning as in Fig. 1.

midnight.

Comparison of this figure with a similar plot, Fig. 2, for the 24 h period 0400–0400 UT on 10–11 July 1973, shows similar features. This latter plot, due to Rabe and Scourfield (1977), was obtained for similar magnetically quiet conditions (average $Kp = 1+$). In this case some knee whistlers were observed which allowed the position of the plasmapause to be inferred. The important feature of this plot is the 'double bulge' structure, with the duskside bulge centred on 1700 UT (as in the present data set) and a second bulge centred approximately on magnetic local midnight (denoted by 'M' in Fig. 2) at 0130 UT. This double bulge structure was shown by Woods *et al.* (1979) to be present at two stations, although the structures observed at the two stations did not coincide in magnetic local time. There is some evidence for a second bulge in the present data set also, as the plasma flow is outward prior to 0400 UT

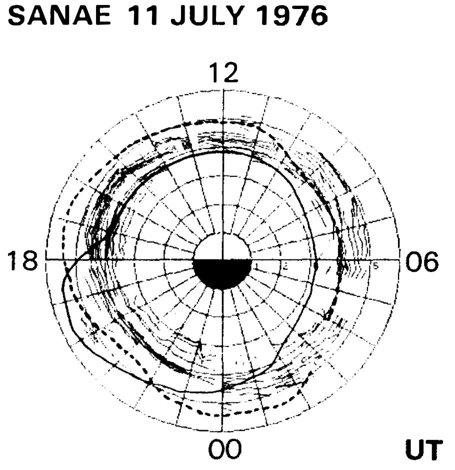

Fig. 3. Polar plot of duct L-value vs. LT (= UT). The Carpenter (1966) [solid line] and Rabe and Scourfield (1977) [dashed line] plasmapauses are superimposed.

and inward from 0530 to 0700 UT. (In this morning sector many of the ducts are short-lived, making tracking for long periods difficult.) This double bulge structure appears to be a consistent feature of the quiet-time plasmasphere (WOODS *et al.*, 1979) so that this represents a 'ground state' from which we can judge the effects of magnetic disturbances.

The convection pattern of Fig. 1 is shown as a polar plot in Fig. 3. Superimposed on this are the plasmapauses of RABE and SCOURFIELD (1977) (from Fig. 2) and CARPENTER (1966). Here we see that the post-midnight bulge occurs later in the present data than in the RABE and SCOURFIELD data, whereas the premidnight bulges are remarkably similar. For the CARPENTER (1966) data we see that the pre-midnight bulge occurs later, but these data correspond to moderately active conditions ($Kp=2$ to 4) whereas the two Sanae data sets are for quiet conditions ($Kp=1$). Thus we believe we have a consistent 'base line' or ground state quiet plasmasphere convection pattern.

3. Electric Fields for the Noon-Midnight Period

Assuming a dipole field, a valid assumption under quiet conditions, the cross-L drift of the whistler ducts yields the westward component of the electric field in the equatorial plane according to the relation (BLOCK and CARPENTER, 1974):

$$E_w = 2.07 \times 10^{-2} \frac{d}{dt}(f_n^{2/3}) \qquad (1)$$

in $V \cdot m^{-1}$ where f_n is the whistler nose frequency in Hz. Positive E_w corresponds to inward plasma flow and negative E_w to outward flow. A typical $|E_w|$ value of 0.1 $mV \cdot m^{-1}$ at $L=4$ corresponds to a flow velocity of approximately 200 $m \cdot s^{-1}$.

We now examine the E_w field for the period 1300–2400 UT, denoted by the bar at the top of Fig. 1. This period was suitable for analysis because it included data which met the selection criteria suggested by CARPENTER (1978)—that ducts should have multipath drifts in the same direction over a range of >1 in L-value and that

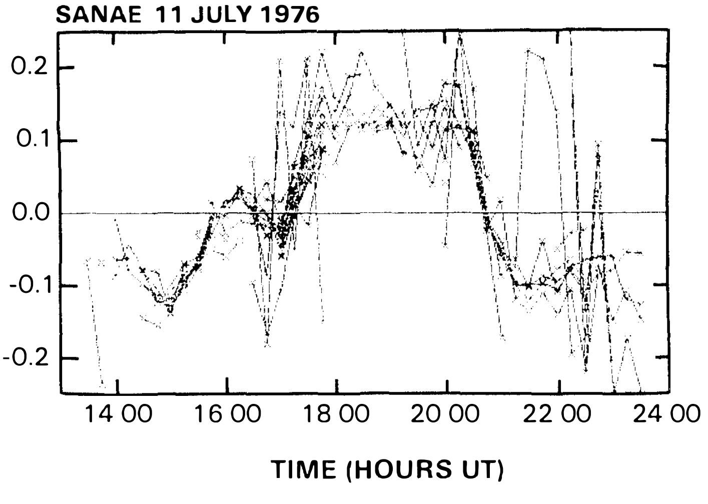

Fig. 4. Westward electric field vs. UT for the period 1300–2400 UT.

$|E_w|$ should be $>0.05\ \mathrm{mV\cdot m^{-1}}$. During this period we have outflow ($E_w<0$) for 1300–1700 UT, inflow ($E_w>0$) for 1700–2100 UT and outflow ($E_w<0$) again for 2100–2400 UT.

To obtain the E_w fields the values of $f_n^{2/3}$ for the tracked ducts were first smoothed using a simple 3-point running mean. The difference in $f_n^{2/3}$ between two successive 15 min intervals then yielded a value for E_w for that duct, according to eq. (1). The resultant plot of E_w *vs.* UT for the period 1300–2400 UT is shown in Fig. 4. Again, a line joining two points indicates that the same duct was tracked unambiguously from one interval to the next. Here we see negative E_w from 1400 to 1600 UT (outflow), positive E_w from 1730 to 2100 UT (inflow) and negative E_w from 2100 to 2400 UT (outflow), corresponding to the three flow periods suggested in the portion of Fig. 1 below the bar.

Two points are of interest here: firstly, the values of $|E_w|$ during the steady flow periods are equal to or slightly greater than $0.1\ \mathrm{mV\cdot m^{-1}}$. Secondly, in terms of MLT (=UT−1 h 30 min) the outflow ($E_w<0$) period is centred on 1330 MLT, while the inflow ($E_w>0$) period is centred on 1730 MLT. By comparison, CARPENTER's (1978) values are generally slightly less than $0.1\ \mathrm{mV\cdot m^{-1}}$ and the respective flow periods are approximately 3 h earlier. The difference in magnitude compared to CARPENTER's (1978) values is not considered significant. The difference in time is consistent with the results of WOODS *et al.* (1979) and is approximately equal to the difference in LT between Sanae and Siple; the reason for this difference is not clear and warrants further investigation. This difference occurs even on the first of a sequence of quiet days, as here; the outflow period apparently occurs later on succeeding quiet days (CARPENTER, 1978).

4. The Source of the Electric Fields

In order to infer something about the source of these electric fields we need to examine the variation of E_w with L-value; if $|E_w|$ varies as a positive power of L, this implies that the source is polewards of the observation point, and if $|E_w|$ varies as a negative power of L, this implies that the source is equatorwards of the observation

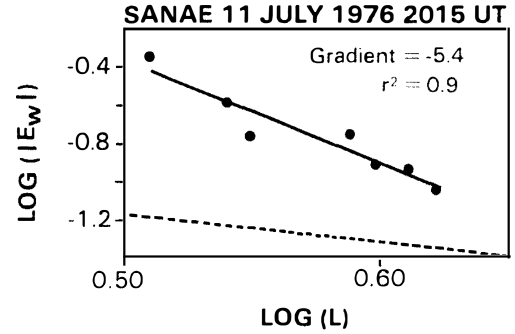

Fig. 5. A typical plot of $\log_{10}(|E_w|)$ vs. $\log_{10}(L)$ with the best-fit straight line. The dashed line corresponds to a gradient of $-3/2$.

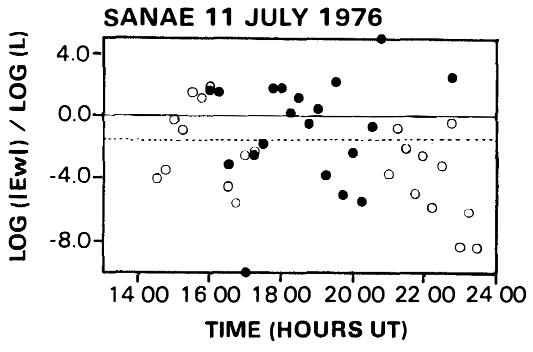

Fig. 6. Gradient of $\log_{10}(|E_w|)$-vs.-$\log_{10}(L)$ regression line vs. UT for the period 1300–2400 UT. The dotted line corresponds to the value $-3/2$.

point. For each 15 min interval $\log_{10}|E_w|$ was therefore plotted against $\log_{10}L$, and where there were 3 or more points corresponding to the same flow direction (inward or outward) a straight line was fitted by regression analysis. An example of such a plot is shown in Fig. 5, with the best-fit straight line. In this case the gradient of the regression line is negative (—5.4) and highly significant (regression coefficient $r^2=0.9$). The dashed line corresponds to a gradient of —3/2, which is what an electric field constant with L at ionospheric heights would map up to in the equatorial plane.

We now examine how this $|E_w|$-*vs.*-L gradient varies with time during the period 1300–2400 UT. This is shown in Fig. 6, where closed circles denote inward plasma flow ($E_w>0$) and open circles outward flow ($E_w<0$). However, not all these points are significant; some correspond to a low regression coefficient r^2, or a small range of L-value, or a small number of components.

Table 1. Variation of E_w with L for selected intervals in the three plasma flow periods, when the flows were consistent and well established, and the gradient $\log_{10}(|E_w|)/\log_{10}(L)$ was significant.

Period (UT)	Flow	Av. Gradient	Equatorial	Ionosphere
1430–1530	Outward	-3.7 ± 0.3	$\|E_w\|\propto L^{-4}$	$\|E_w\|\propto L^{-5/2}$
1800–1930	Inward	$+1.3\pm0.5$	$\|E_w\|\propto L$	$\|E_w\|\propto L^{+5/2}$
2100–2400	Outward	-4.5 ± 1.5	$\|E_w\|\propto L^{-4}$	$\|E_w\|\propto L^{-5/2}$

Averaging the significant values of the $|E_w|$-*vs.*-L gradient for each of the three periods (out-, in- and out-flow) we obtain the values given under 'Av. Gradient' in Table 1. This suggests that the westward electric field varies with L in the equatorial plane as shown under 'Equatorial'. These results confirm and extend the findings of CARPENTER (1978) that generally $|E_w|$ varies as a power of L of order —4. This is considerably more rapid than the power —3/2 suggested by a dynamo field constant with L in the ionosphere. In particular we note from Fig. 6 a significant trend for the $|E_w|$-*vs.*-L gradient to become more negative towards midnight, presumably as the effects of the daytime ionospheric currents diminish. For the outward flows the negative exponents suggest that the ionospheric dynamo electric field, with its source region equatorwards of the observed range of L-value, predominates. For the inward flows the positive exponents (over a short interval) suggest that in this case the magnetospheric dawn-to-dusk electric field dominates the dynamo-generated field. We thus have a scenario where the afternoon quiet day electric fields associated with outward plasma convection are ionospheric dynamo in origin, with intrusions of the dawn-to-dusk magnetospheric electric field—even under such quiet magnetic conditions and at such relatively low L-values as $L=4$—causing inward flow.

When mapped down to the ionosphere (MOZER, 1970) the variation with L is as shown under 'Ionosphere'. These results suggest that for the ionospheric dynamo field, the variation with L in the ionosphere at these latitudes is rather different from that suggested theoretically by, for instance MOZER (1973). They also suggest that the source of the dynamo electric field lies equtorwards of $L=3.5$, since the field increases with decreasing L down to this lowest observed value of L.

4. Conclusion

We have examined 24 h of whistler data and concluded that they constitute the basis of a quiet day reference pattern. During periods of plasma outflow on such a quiet day the electric fields are found to vary as L^{-4} and are deduced to be ionospheric dynamo in origin. There is some evidence of the magnetospheric dawn-to-dusk electric field being responsible for the inward flow of plasma when the field varies approximately as L.

Acknowledgments

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