CONJUGATE CONDUCTIVITY ASYMMETRY AND THE PRECIPITATION OF MAGNETOSPHERIC ELECTRONS

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Abstract

Using a simplified model of the atmosphere, a calculation is made of the wind-induced vertical redistribution of ions derived from the 100 km level. Assuming the effect to be dissimilar in magnitude at the conjugate point, a potential difference will be set up in this way between the ends of the magnetic field line. For various values of the parameters involved, an estimate is made of the consequent precipitation to ionospheric heights of previously trapped electrons of the magnetosphere.

I. Introduction

An important source of additional ionization in the upper atmosphere is provided by the spiralling electron content of the magnetosphere. One means by which a significant displacement of its previously mirroring component can be effected is by the superposition of an electric field along the magnetic field line. This possibility has been investigated by Catchpoole (1966). In that paper an estimate was made of the proportionate increase in precipitation to ionospheric heights (arbitrarily, below 600 km) of electrons of various equatorial energies and pitch angles. These previous results were in terms of parameters which involve the conjugate point potential difference V and the energy of the spiralling electron. The control of such an electric field over the spatial and energy distributions of incident electrons might also be expected to have further consequences on processes deeper still within the atmosphere. This has recently been considered in respect to auroral ionization by Catchpoole (1970).

Although quite small in magnitude, such a parallel electric field would always be present unless the angular distributions of the spiralling ion and electron velocities coincided at each point (Alfven and Falthammar 1963). However, the electric field considered has hitherto been attributed rather to a potential difference which is due in turn to asymmetric dynamo effects at conjugate points. Patterns of magnetospheric electron precipitation have been derived on this basis by Catchpoole (1967) from a transformation of assumed controlling wind patterns.

In the present paper, consideration is given to the possibility of a parallel electric field resulting from a difference in charge accumulation at the two conjugate points. If of sufficient magnitude, the field produced by such a mechanism would, of course, be equally effective in the subsequent magnetospheric precipitation.

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Further, it could provide a means of particle displacement even when the conjugate dynamo effects were equal. The specific mechanism now envisaged is a wind-induced vertical redistribution of ionization. At the outset, possible asymmetry can be imagined by conjugate dissimilarity either in the forces themselves producing the redistribution or in the available initial ionization. The latter possibility is inherent, for instance, in near sunrise or sunset conditions. At such times one point might be sunlit while its conjugate point is in the dark with the accompanying differences in lower (E region) ionization conditions (Ratcliffe 1960).

II. Vertical Redistribution of Ions

A section of the atmosphere is considered in which it is supposed that there occurs a net vertical transport of ions produced at lower levels. A very simplified model for this process is described in the next section and this is followed by the results of calculations estimating the magnitude of the effect for some particular cases. The transport is effected by means of a vertical wind, or, more generally, a vertical component in the neutral particle motion.

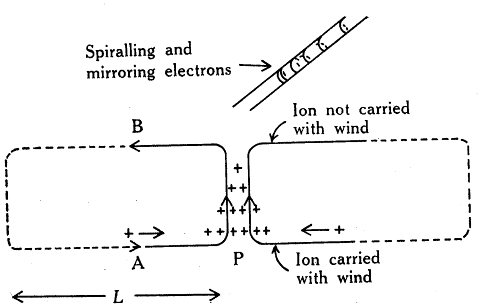


Fig. 1.—Schematic diagram of wind circulation and ion transport resulting in the accumulation of positive ions above the point P in the atmosphere.

It can be shown that the motion of charged particles relative to the neutral gas is determined by the collision frequency ν and by the particle gyrofrequency, involving the charge to mass ratio $\omega = qB/m$ (Chapman 1956). In addition to its dependence on the appropriate external force components, the drift velocity in the direction of the magnetic field B is inversely proportional to ν, whilst those in the directions of both the other Cartesian axes (one perpendicular to the total external force) depend on the ratio ν/ω. The collision frequency decreases with height in the atmosphere so that the extent to which the charged particle is carried along by the wind is similarly altitude dependent. Here, attention is directed to conditions in which ion drift rather than electron motion is important, that is, to altitudes from 100 km upwards. At 100 km, the (positive) ion drift velocity relative to the neutral wind is virtually zero. In other words, the ions are carried along with the wind. The relative velocity changes progressively with height until at some altitude B (Fig. 1) it can arbitrarily be said that the ion is no longer carried by the wind.

Figure 1 illustrates the general circulation envisaged, which results in an accumulation of positive ions near and above the point P in the atmosphere. This is at the foot of some magnetic tube of force in which the mirroring height of the spiralling electrons will be consequently altered, supposing that this effect at the conjugate point is dissimilar in magnitude.

Once clear of the lowest (source) level, the density of this *excess* ion accumulation rapidly falls well below that of the ambient ionization density. It is therefore supposed that its equilibrium will be determined primarily by local conditions of density and recombination rate. That is to say, no immediate compensating inflow of electrons from within the ionosphere itself is considered at these higher altitudes where the overall neutrality is not appreciably disturbed. Any such polarization field set up at the lower level (A) will be determined by the wind dimension L and by the nature (sense) of adjacent wind systems. For present purposes, the relevant part of the excess ion profile is its magnitude at the upper level B. However, in view of the possible neutralizing effects, values found will certainly be, on the basis of the model used, the maximum available for the production of a conjugate point potential difference.

The vertical redistribution of transported ions will be critically controlled by their recombination rate. This will be rapid in the lower, denser regions, whereas at the higher altitudes the ions will persist longer. However, this situation is further modified by the supposed decrease in the upward velocity of the ions, as they progressively fall further behind the neutral gas.

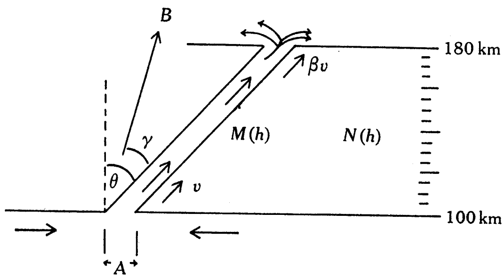


Fig. 2.—Schematic diagram of the model atmosphere adopted.

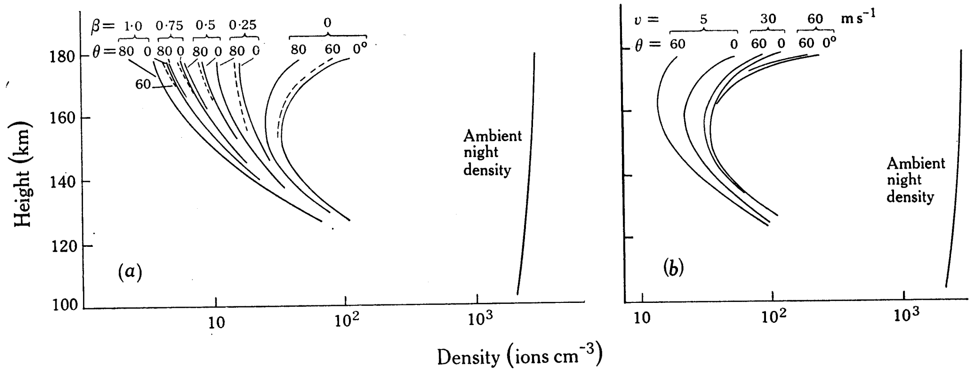
III. Model and Data Used

The first objective of the following calculations has been to determine $M(h)$, the profile over the relevant upper height range of the excess ion density which results from an assumed pattern of vertical ion transport. A simplified model for the ion velocity has been adopted in which only the component in the direction of the wind is considered. This is v as the ion leaves the source level, and uniform deceleration is supposed to reduce it to βv at the upper boundary of the model. Beginning with the wind velocity, the transported ions thereafter retain only its (constant) direction (θ to the vertical).

This restriction of the model will also differ from actual atmospheric conditions in two other important regards. Firstly, the velocity of the neutral particles, or of the wind itself, is not explicitly included. In general, an important and independent height relation might be expected for this. Then there also exists a significant non-linear height variation of the three components of ion motion with respect even to the neutral gas. All of these factors are replaced here by the supposed uniform deceleration which reduces the ion velocity to a fraction β of its initial value by the time the model is traversed.

It is briefly noted that the more complete expression for the component of ion velocity in the direction of the wind is a geometric function of γ, the angle between it and the magnetic field line B. It also includes the dimensionless drift component quantities given by Fejer (1965), one of which (that in the direction of B) predominates above about 150 km. These drift velocities are in turn dependent on the "total electric field", one component of which is the polarization field. This latter component is itself dependent on the charge redistribution now being investigated.

The model atmosphere adopted is illustrated in Figure 2. The ion stream has a lateral dimension of A, its source is the 100 km layer, and its flow ($v-\beta v$) is at an angle θ across the model, so producing an excess ion density $M(h)$ against the ambient background $N(h)$. The flow is terminated at 180 km, either by complete dissociation of the ion–wind dependence ($\beta = 0$) or by the end of the vertical component of the wind motion itself.



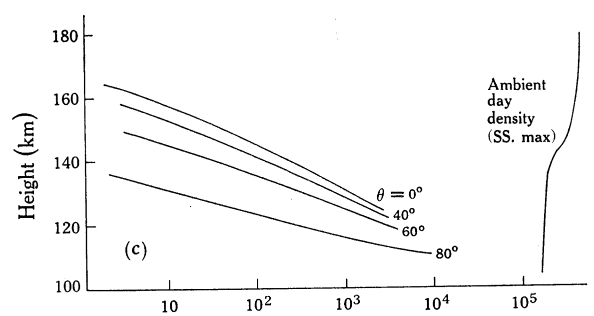


Fig. 3.—Ion redistribution profiles:
(a) night, $v = 30 \text{ m s}^{-1}$
(b) night, $\beta = 0$
(c) day, $v = 30 \text{ m s}^{-1}$, $\beta = 0$

It is supposed that the dimensions A, L, and v are such that the 100 km reservoir can supply the ions required to set up the equilibrium redistribution profile. The main interest centres on sunrise and sunset times when one of the conjugate points will be sunlit at low solar zenith angle. Photoionization rates to sustain ion production of the order of 10–10^2 $\text{cm}^{-3}\,\text{s}^{-1}$ might then be expected (Watanabe and Hinteregger 1962).

Data on pressure and temperature values for each of the height intervals are taken from the U.S. Standard Atmosphere (1962) and those on recombination coefficients from Bates and Massey (1946) and Ratcliffe (1960), while the typical day and night ionization profiles $N(h)$ used in the calculations are from Hanson (1961).

The calculation procedure involved dividing the height range of 100–180 km into 16 equal intervals. The excess ion density was found for each interval in turn.

This was done by taking the contribution from the next lowest interval, allowing for both the flow modifications referred to above and the changing atmospheric parameters. The procedure began with the ambient value of the 100 km source.

IV. Results

Figure 3 shows the resulting excess ion profiles $M(h)$, alongside the appropriate ambient density profiles $N(h)$ on which they are based. Figures 3(a) and 3(b) show results based on a typical night-time background, in which a specified wind redistributes ions derived from the 100 km level.

Figure 3(a) is for an initial velocity of 30 m s^{-1}. Except for large values, it is seen that the M dependence on θ is not very important. However, the degree to which the ion is slowed down in traversing the model is significant. A flow which just gets the ions to the upper boundary results in an excess ion density there of the order of 10^2 cm^{-3}, whereas in the opposite hypothetical case in which the ions remain with the (constant) wind all the way, this density is only about 5 cm^{-3}.

All the curves in Figure 3(b) are for the more relevant case of $\beta = 0$ in which a maximum high-level density might result. They are for different initial velocities and show also the θ limits of 0° (vertical) and 60°.

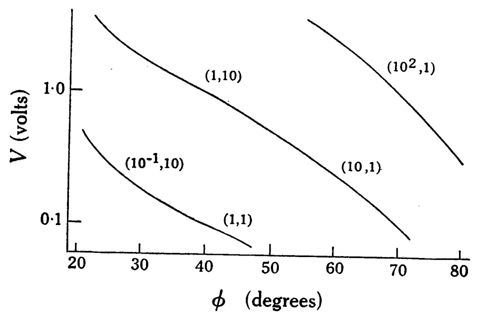


Fig. 4.—Potential differences V between conjugate points at geomagnetic latitudes ϕ. The curves are for the indicated (M, D) values, $M(h)$ being the excess ion profile and D (km) the assumed depth of the accumulated ionization.

Both Figures 3(a) and 3(b), then, show results based on the night-time ambient density which near dawn or for a very low solar zenith angle might still be fairly appropriate. Figure 3(c), on the other hand, shows a redistribution obtained from the same source level with an ambient density corresponding to full day-time ionization. Comparing this with Figure 3(a) (both are for $v = 30$ m s^{-1}), it is seen that the greater recombination now results in a generally much lower excess ion density despite the greater source value; in fact, virtually none of the ions reach the upper boundary of the model. Transported charge available for setting up a conjugate point potential difference is practically zero in such a case. If the (early) daylight end of a sunlit–dark field can ever be supposed to approximate this condition at all, then the night-side ions will alone set the potential. It is equivalent, in fact, to no wind-inducing effect at the sunlit end.

The potential difference between the conjugate points was next calculated; it was supposed that, from the top of the model atmosphere, a depth D of this additional accumulated ionization was effective in its production. The magnitudes of these potentials for a dipole field are illustrated in Figure 4, where a wind (or ion-stream) cross section of $A^2 = 1$ km^2 is also implicit. The figure shows the potential differences between conjugate points at the geomagnetic latitudes ϕ indicated. The curves are for particular M values which can be related to the earlier model parameters by the previous graphs. A zero conductivity effect at the conjugate point is assumed.

V. Magnetospheric Electron Precipitation

With $V = V(v,\beta,\theta,A,D,\phi)$, the actual magnitude of the conjugate potential differences due to the present mechanism is by now very parameter dependent. However, Figure 5 shows the results of an application of the above treatment to the question of precipitation of magnetospheric electrons. Conditions relating only to an increase in this precipitation by the mirroring displacement are illustrated.

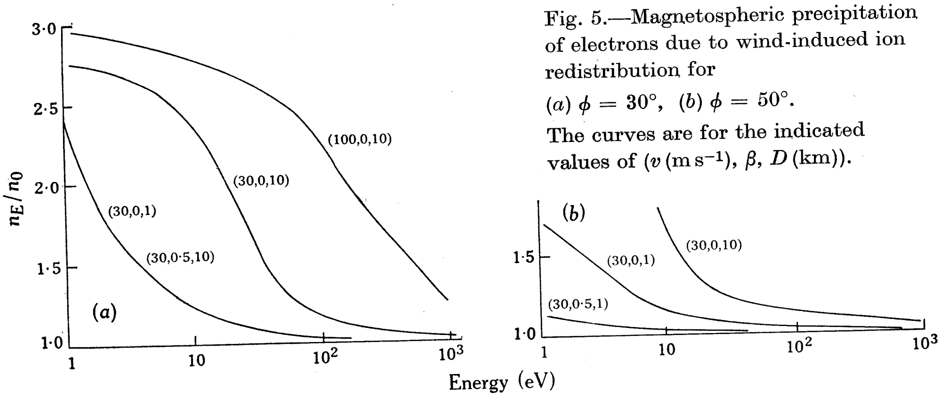


Fig. 5.—Magnetospheric precipitation of electrons due to wind-induced ion redistribution for (*a*) $\phi = 30°$, (*b*) $\phi = 50°$. The curves are for the indicated values of (v (m s^{-1}), β, D (km)).

Figures 5(*a*) and 5(*b*) are for latitudes ϕ of 30° and 50° respectively and they show the increase in precipitation into the ionosphere of magnetospheric electrons of various energies. This increase is designated n_E/n_0. It is the same ratio as that used by Catchpoole (1966), namely that of the number of electrons precipitated in the presence of the field E (resulting now from the V of the present context) to that in its absence. This relates to the 600 km level, so the curves give the increased precipitation across that boundary due ultimately to the redistribution of ions now envisaged at the lower E-region level. The curves were obtained from the results of the above paper using the conjugate potential differences indicated here by Figure 4. Examples of the primary parameter values (v,β,D) are given for the curves; equivalent combinations can be found from the other figures.

From the results it is concluded that a significant change in the magnetospheric precipitation might be expected to be brought about by such a wind-induced conjugate conductivity asymmetry. This is dependent, of course, on actual atmospheric conditions, which need to be both equivalent in their production and maintenance of ion redistribution to those used in the present model and also similarly asymmetric at the conjugate points.

VI. Acknowledgments

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