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RING CURRENT HEATING OF THE LOW LATITUDE THERMOSPHERE CONNECTED WITH GEOMAGNETIC DISTURBANCES

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ABSTRACT

The excess thermospheric density at low latitudes during the recovery phase of geomagnetic disturbances found in earlier studies has been related to the ring current belt. This would mean that the geomagnetic effect is due not only to an auroral but also to an equatorial source. The low latitude excess density could be separated into a storm time dependent and a local time dependent component. Thus, the morphology of this effect is similar to that of the geomagnetic disturbance field. The heating can be attributed mainly to the precipitation of energetic neutral particles produced by charge exchange, as well as to the dumping of energetic charged particles due to wave-particle interaction. The local time dependent component could be connected also with the asymmetry of the composition of the ring current and with the irregular shape of the plasmasphere.

INTRODUCTION

In previous studies it has been found that at least at low latitudes the geomagnetic effect in the neutral density of the thermosphere can be represented by a storm time (reckoned from the commencement of the disturbance) dependent and a local time dependent component [1,2]. These features of the geomagnetic effect are similar to the characteristics of the horizontal component of the geomagnetic disturbance field, which shows also a storm time dependent and a local time dependent component [3]. Besides, similar variations have also been revealed in the electron density of the F region of the ionosphere [4]. Thus,considering these conditions it is reasonable to take into account the results obtained in the interpretation of geomagnetic and ionospheric variations for the explanation of the geomagnetic effect.

STORM TIME DEPENDENT COMPONENT

The storm time dependent component of the geomagnetic effect at low latitudes manifests itself in the close correlation between the difference of the density measured by the CACTUS accelerometer [5] minus the model value uncorrected for the geomagnetic effect $\Delta\rho$ and the Dst index characterizing the intensity of the ring current. This correlation is especially remarkable in the recovery phase of geomagnetic disturbances decreasing much slower with storm time than Ap [1]. Thus, the storm time dependent variation of the total density can be related to the ring current. As it is known the decay of the ring current is due mainly to charge exchange between ring current ions (H^+,He^+,O^+) and neutral atoms of the geocorona [6]. In this process energetic neutral atoms are formed, which uncontrolled by the geomagnetic field a part of them precipitates into the upper atmosphere and deposits its energy in collisions producing there heating [7].

That some type of heating should play a role here is also indicated by the results of modelling. The conservation of mass, namely, demands that at lower latitudes a sinking of air must correspond to the upwelling of air (rich in molecular constituents) caused by auroral heating at high latitudes [8]. The sinking air (being rich in atomic constituents) would accomplish a composition change contrasted with satellite measurements [9]. Thus, thermal expansion could compensate the effect of sinking air and create an unchanged composition.

Wave particle interaction can also contribute to the loss of ring current ions, electrons [10]. During this process pitch angle diffusion and fall-out of ions and electrons from the ring current belt is caused by plasma waves. Nevertheless, because of the position of the loss cone as compared to the dense atmosphere determined by the geometry of the geomagnetic field, the effect of the particle precipitation due to wave-particle interaction can substantially be effective at latitudes greater than 20° [11]. Thus, at low latitudes ($<20^{\circ}$) first of all the charge exchange process, at mid-latitudes ($>20^{\circ}$) wave-particle interaction can provide for particle precipitation.

LOCAL TIME DEPENDENT COMPONENT

In addition to the close correlation between the neutral density ($\Delta\rho$) and Dst the similar behaviour of the local time dependent component of the geomagnetic effect to that of the disturbance daily variation of the geomagnetic field could also support the ring current origin of the geomagnetic effect at low latitudes. The local time dependent component of the geomagnetic effect has been revealed in the residuals obtained by substracting from the measured density data the model values corrected for the geomagnetic effect by means of the Dst index and the residuals ordered according to local time [2]. The investigation of geomagnetic disturbances has shown that the local time variation of the geomagnetic disturbance field called the disturbance daily variation could be attributed partly to the asymmetry of the ring current, partly to auroral sources [12]. At low latitudes ($<30^{\circ}$), which are considered in this paper, the effect of the auroral sources is less pronounced. Note that the Dst-indices represent mean values of the depression in the geomagnetic field due to the ring current observed at equatorial stations [13]. Thus, in the diurnal variation of the Dst index the effect of the asymmetry is eliminated but not in the residuals of the density. The reality of the local time dependent component of the geomagnetic effect, or the disturbance daily variation of $\Delta\rho$ as it is called here, is demonstrated by the increase of its amplitude with rising geomagnetic activity [2].

Relating the source of the local time dependent component of the geomagnetic effect to the disturbance daily variation of the geomagnetic field, the former could be explained by the asymmetry of the ring current. As it has been shown, the disturbance daily variation of the geomagnetic field has some characteristics, by means of which the assumed origin of the local time dependent component of the geomagnetic effect can be checked [12].

One feature of the disturbance daily variation of the geomagnetic field (horizontal component) is the change of the time of its maximum (during a geomagnetic storm) with storm time. According to the investigations of Sugiura and Chapman [14], at low latitudes the maximum of the disturbance daily variation of the geomagnetic horizontal component occurring during the first 6-hour interval in the midday hours is shifted in course of the following 6 hour interval to the morning hours (Fig.1). As the geomagnetic activity decreases with increasing storm time, in the study of this phenomenon the storm time change of the phase can be replaced by the dependence of the phase on the geomagnetic activity. For this reason the residuals mentioned above were separated on the basis of the geomagnetic activity into two groups characterized by $Kp<2$ and $Kp>4$, respectively. Considering the above correspondence, the second group ($Kp>4$) would be connected with the earlier, the first group ($Kp<2$) with the later storm time period. The relation between the disturbance daily variation of $\Delta\rho$ and of the geomagnetic disturbance field can be demonstrated by the phase change of the diurnal component because of the shape of the local time variation of the latter. Thus, from the results of a Fourier analysis only the diurnal component is used. A tendency of the phase change with storm time similar to that of the geomagnetic disturbance field has also been found in this case as it is demonstrated in Fig. 1. It can be seen that the maximum of the disturbance daily variation of $\Delta\rho$ in the group corresponding to the higher activity ($Kp>4$) around 15 h is shifted to earlier hours 12 h in the low activity group ($Kp<2$).

The disturbance daily variation of the geomagnetic horizontal component shows also a latitudinal variation its maximum being shifted from the morning hours at low latitudes to the afternoon hours at mid-latitudes (Fig.2) [14]. It should be noted that the same phenomenon can be observed in case of the disturbance daily variation of the F-region electron density (foF2) [4]. As the total density data refer to the geographical latitude belt of $\pm 30^{\circ}$, endeavouring for reliability, the residuals were separated into only two groups. Into the first group those data were included which belong to magnetic latitudes less than $\pm 20^{\circ}$, while in the other group the data referring to magnetic latitudes greater than $\pm 30^{\circ}$ are considered. Taking into account again only the diurnal component in the spectrum, the maximum of the disturbance daily variation of $\Delta\rho$ occurring at 13 h in the magnetic latitude belt $<\pm 20^{\circ}$ is shifted to the later forenoon hours (11 h) at magnetic latitudes $>\pm 30^{\circ}$ (Fig.2). Note that in this case the phase is strongly influenced by the development of the other peaks in the local time variation (Fig.3).

Thus, it can be stated that at low latitudes not only the storm time variation, but also the characteristics of the disturbance daily variation of $\Delta\rho$ hint at a relation between the geomagetic effect in the neutral density and the asymmetric ring current.

DISCUSSION AND CONCLUSIONS

The ring current is asymmetric from the point of view of both its intensity and its composition. The asymmetry revealed in the intensity of the ring current is mainly due to the partial ring current on the night side formed by field aligned currents entering into the ionosphere at dusk in the auroral zone and leaving it at dawn (region 2 currents) [15]. The asymmetry of the composition of the ring current consists of a larger concentration of O^+ ions on the day side as compared to the nightside during the recovery phase [16]. Charge exchange and also wave-particle interaction can be considered as loss processes the latter being dependent on the interaction between the hot ring current plasma and the cold plasma of the plasmasphere [10]. As it is known, the plasmasphere has an irregular shape having a larger extension on the dayside than on the nightside (noon-midnight asymmetry) and a bulge in the afternoon sector [17, 18].

Taking into account the duration of the different phases of a geomagnetic storm, the largest contribution to the geomagnetic effect at low latitudes can be attributed to the recovery phase. Thus, those ring current ions can be responsible for the geomagnetic effect, which have the greatest life time against charge exchange. The ions having this property are low energy O^+ and high energy H^+ ions [19]. Since the energy loss by collisions of low energy oxygen atoms produced by charge exchange to the ambient atmosphere is more effective than that of the high energy H atoms, the disturbance daily variation of $\Delta\rho$ with its maximum around noon could be explained by heating due to energetic oxygen atoms being the O^+ ions the dominant ions on the dayside and in the recovery phase (Fig.3). The post midnight (02 h) maximum occurring in it can be connected with the injection zone (or with the polar thermospheric disturbance zone?) while the evening maximum (at 19 h) can be due to the effect of enhanced wave-particle interaction, related to the position of the bulge of the plasmasphere.

As regards the change of the disturbance daily variation with storm time it can be attributed on the basis of the above mentioned to the storm time variation of the asymmetry of the ring current, to that of both its intensity and composition.

Considering that charge exchange and wave-particle interaction are latitude dependent processes, the latitudinal variation of the disturbance daily variation can be related to the latitudinal variation of the loss processes the charge exchange at mid-latitudes becoming insignificant as compared to the wave-particle interaction. As this would mean also a change of the local time variation of the particle precipitation with latitude, modulating the heating and the local time conductivity variations in the ionosphere it could produce the observed disturbance daily variation of $\Delta\rho$, the geomagnetic field and the F region electron density. The latter idea seems also be supported by the latitudinal structure of the storm effects in density indicating the same character as that of the latitudinal structure of the particle precipitation (Fig.4) [20, 21, 22, 23].

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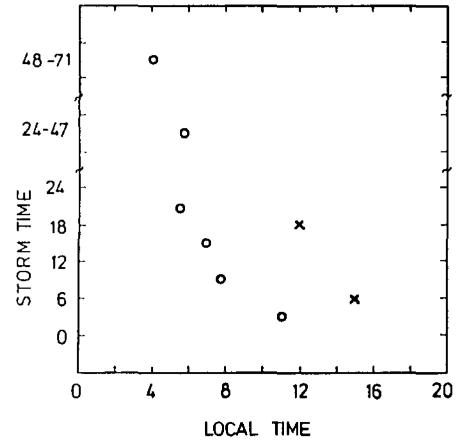

Fig.1. Storm time variations in the phase of the disturbance daily variations of the geomagnetic horizontal component (circles) (after[14]) and that of $\Delta\rho$ (crosses).

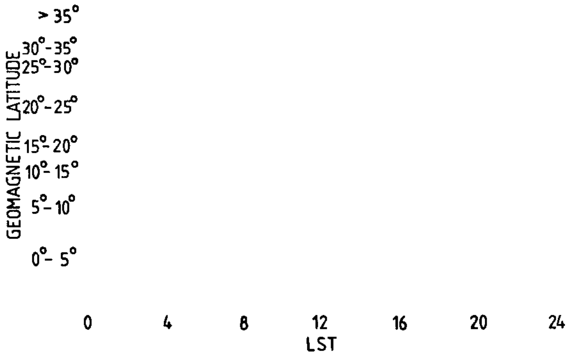

Fig. 3. Disturbance daily variation of $\Delta\rho$ as function of geomagnetic latitude.

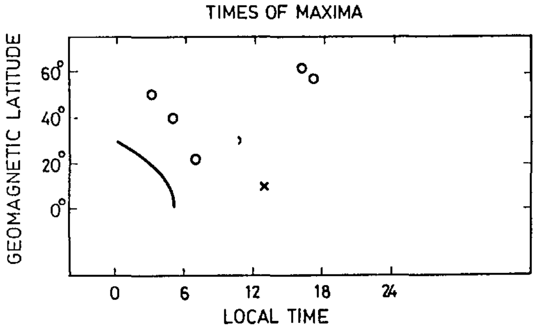

Fig.2. Latitudinal variations in the phase of the disturbance daily variations of the geomagnetic horizontal component (circles) (after[14]) $\Delta\rho$ (crosses) and foF2 (full line) (after 4).

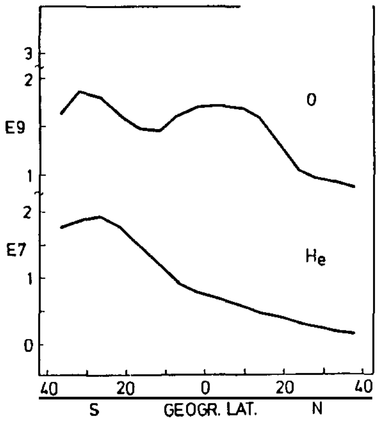

Fig.4. Nighttime zones of precipitating electrons and ions (after[23]), as well as storm effects in the density of O and He (after [22]).