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LOW LATITUDE THERMOSPHERIC HEATING IN GEOMAGNETICALLY DISTURBED PERIODS: DYNAMICAL OR PARTICLE HEATING

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ABSTRACT

The density increase of the thermosphere in geomagnetically disturbed periods called geomagnetic activity effect indicates a temporal variation at low latitudes, which can be described more correctly by the Dst index, than by the Kp or Ap indices. This circumstance hints at the partially ring current origin of the density increase. So far the density increase at low latitudes was attributed to heating caused by circulation disturbances propagating equatorward from high latitudes in both hemispheres. The source of the density increase is investigated by considering the heating corresponding to the height variation of the measured density disturbance and comparing it with the height variation of the heating due to solar electromagnetic radiation, precipitating energetic particles and dynamical sources.

INTRODUCTION

In earlier papers [1,2,3] it has been shown that the morphology of the density increase in geomagnetically disturbed periods, that is the geomagnetic effect $\Delta\rho$ at low latitudes is similar to that of the geomagnetic disturbance field: it has a storm time (reckoned from the beginning of the disturbance) and a disturbance daily variation. This behaviour and the circumstance that the temporal variation of the density increase can be described better by the Dst index, characterizing the density of the equatorial ring current, than Kp suggests a relation to the ring current. The study of the disturbance daily variation indicated characteristics, which can confirm the ring current origin of the geomagnetic effect at low latitudes. It has been found that the storm time variation in the time of the maximum of the disturbance daily variation of $\Delta\rho$ is similar to that of the geomagnetic horizontal component. A slight phase change of the disturbance daily variation with latitude showing a trend similar to that of the geomagnetic horizontal component reveals itself too [3]. The investigation carried out at first with data of the neutral density referring to 400 km, was extended to higher altitudes. Thus, the height variation of the geomagnetic effect could also be studied [4]. As the course of the height variation of the geomagnetic effect depends on the energy source, it has been attempted to use this information for the determination of the origin of the geomagnetic effect at low latitudes.

DATA AND METHOD

For the determination of the height dependence of the geomagnetic effect in the neutral density, the data measured by the French CACTUS accelerometer on board of the satellite CASTOR were used. The values obtained in three km height intervals around the heights 400, 425, 450, 500, 550 and 600 km were included in the computations. Both the storm time and the disturbance daily variations have been determined. The geomagnetic effect is defined as the difference between the measured density and the model value uncorrected for the geomagnetic effect $\Delta\rho$ - supposing that every other effect (diurnal, seasonal, semiannual)is described correctly in the model. The storm time variation is that part of the geomagnetic effect, which correlates with the Dst index. The disturbance daily variation is obtained by subtracting from the measured density the model values corrected for the geomagnetic effect by means of the Dst index and the residuals ordered according to local time. The height variation of the storm time component of the geomagnetic effect has been determined using the relations between $\Delta\rho$ and Dst established for different altitudes.

From the height variation of the storm time component of the geomagnetic effect obtained on the basis of measured values using Dst indices, the height variation of the heating related to the density increase has been computed and compared with calculated profiles of the heating due to solar electromagnetic radiation, to particle precipitation and to circulation disturbances propagating from auroral latitudes, using the results of model calculations, respectively.

The heating related to the solar electromagnetic radiation can be determined by the well known formula, which describes the absorption of the solar electromagnetic radiation, multiplying the absorbed energy by the heating efficiency [5]. It is to be noted that the height variation of the heating caused by the solar electromagnetic radiation depends on the one hand on the height variation of the density, on the other hand on the variation with height of the solar electromagnetic radiation. The former decreases with increasing height, while on the contrary the latter increases with height in consequence of the diminishing absorption. Thus, the height variation of the heating is smaller than that of the density itself.

The heating related to particle precipitation can be obtained by known formulas, which describe the energy deposition of the particle flux multiplying the absorbed energy by the heating efficiency [6]. In this case the height variation of the heating depends on the one hand on the height variation of the density, on the other hand on the variation with height of the precipitating particle flux. However, the height variation of the precipitating particle flux is reduced by the circumstance that the decrease of the particle flux in a given energy range with decreasing height is compensated by the energy loss of particles of higher energy ranges. Thus, in the height range considered here the height variation of the heating approximates that of the density.

The density increase connected with circulation disturbances originating from auroral latitudes has been obtained by using a theoretical atmospheric model. For this purpose a relatively simple model has been chosen considering the results of [7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17]. The height variation of the heating due to circulation disturbances originating in the auroral zones has been computed on the basis of this model for solar minimum conditions corresponding to the period of the measurements, for the latitude 15° (since the density was measured by the satellite in the latitudinal belt $\pm 30^{\circ}$) and the height interval 400-600 km. Concerning the response of the thermosphere to a heat input of impulse form to the auroral zones, as dissipative processes vertical heat conduction, horizontal ion drag, as well as viscosity were taken into account. The latitudinal and longitudinal variations of the total density were determined by spherical harmonics (P_n^m). The small scale (large wave domain number) variations are strongly damped in the thermosphere by adiabatic heat transfer and appear only during the first hour after the beginning of the disturbance. Besides the inverse relation between the amplitude of the density disturbance and the decay of the heat input indicates that short period polar disturbances do not produce a significant geomagnetic effect. Thus, only the large scale (small wave number) components were used.

RESULTS AND DISCUSSION

In Fig. 1 the height dependence of the heating rate due to the storm time component of the geomagnetic effect found in the measured density values has been compared with the height variation of the heating rate caused by the solar electromagnetic radiation on the dayside, with the heating rate profile related to the nightside storm time energetic O^+ energy deposition and with the height variation of the heating rate due to circulation disturbances originating in the auroral zones, respectively. The heating rate produced by the solar electromagnetic radiation on the dayside was computed for solar maximum conditions by Torr et al. [18] using the Atmosphere Explorer solar flux measurements. The heating rate resulting from the nightside storm time influx of energetic O^+ ions was determined by the same authors from the energy spectrum observed by Shelley et al. [19] near L=3,4 during the December 1971 storm. The conversion of the energy of energetic O^+ ions to energetic O atoms was computed assuming charge exchange and momentum transfer (due to elastic collisions). Both the heating rate profile of the measured density increases and the height dependence of the heating rate connected with circulation disturbances according to the model refer to the same level of geomagnetic activity.

As can be seen from Fig. 1, the height variation of the heating due to the solar electromagnetic radiation is smaller than that of the heating caused by precipitating particles as it has been indicated in the previous section. The height dependence of the heating, which is due to circulation disturbances originating in the auroral zones and which is computed by means of the model mentioned above, is also less steep than the height variation of the heating related to particle precipitation. The height variation of the heating related to the height dependence of the measured density increase, however is similar to the height variation of the heating connected with particle precipitation, though below 450 km less steep, than the latter. It is to be noted that in case of the heating rate profile of energetic O^+ ions, the height of the maximum depends on the elastic scattering cross section and on the vertical distribution of the density, that is on solar activity. Consequently, the height of the maximum heating rate decreases with decreasing solar activity. Thus, in case of the height variation of the heating, due to the measured density increase at solar minimum and assumed to be related to energetic ring current O^+ ions, the maximum heating rate is also located at a lower altitude, than that of the heating rate profile of energetic O^+ ions corresponding to solar maximum. This can be the reason for the different slope of these two curves at lower heights.

Thus, the comparison of the height variations of the heatings related to the solar electromagnetic radiation, to particle precipitation, to circulation disturbances respectively with the height dependence of the heating connected with the measured density increase shows that the heating rate profile derived from the measured density increase approximates mostly that of the storm time energetic O^+ energy deposition. This indicates that the formation of the measured density increase can at least partly be attributed to particle precipitation. As to the heating connected with the circulation disturbances originating in the auroral zones, the decrease of the disturbance with latitude [17] suggests that these circulation disturbances seem not to be of determinative nature at low latitudes. Namely, according to the model the heating rate due to circulation disturbances amounts only to a fraction of the energy rate indicated by the measured density increase. This is due partly to the circumstance that the upwelling produced by the heat input is confined to a small area at high latitudes as compared with the area of subsidence at middle and low latitudes (ratio of the areas 0.07). Although at high latitudes temperature effects increase, but the wind induced diffusion of atomic oxygen reduces the total density enhancement, while at low latitudes the transport of atomic oxygen and thermal expansion are reinforcing the effect of each other. Another phenomenon, which cannot be explained by circulation disturbances of polar origin is the broad maximum around midday in the disturbance daily variation of the geomagnetic effect. The circulation set up by the disturbance should namely reduce the geomagnetic effect by day decreasing the meridional circulation in the thermosphere and increase it by night enhancing the equatorward circulation. It is also to be noted that the modelling indicates a slight density increase at low latitudes in the morning, 6-7 hours after the onset of the disturbance.

There are also new observations of phenomena supporting the idea of heating related to energetic particles precipitating at low latitudes. Following severe magnetic storms, measurements at low latitudes show average ionization enhancements of more than 10 % in the E region of the ionosphere, which is partly attributed to the precipitation of energetic particles produced by charge exchange [20]. The measurement of night UV spectra at middle and low latitudes indicated that significant precipitation of neutral O atoms, originating from ring current O^+ ions by charge exchange, can take place in periods of large Dst [21]. Using a theoretical model for the ring current interaction with the plasmasphere it has also been found that MHD waves generated by energetic ring current protons can transfer energy to plasmaspheric electrons and ions resulting in the heating of the thermal plasma in the plasmasphere at equatorial latitudes [22]. The produced heat flux can heat the upper atmosphere. These observations and computations give evidence once more of the energy deposition at low latitudes in geomagnetically disturbed periods.

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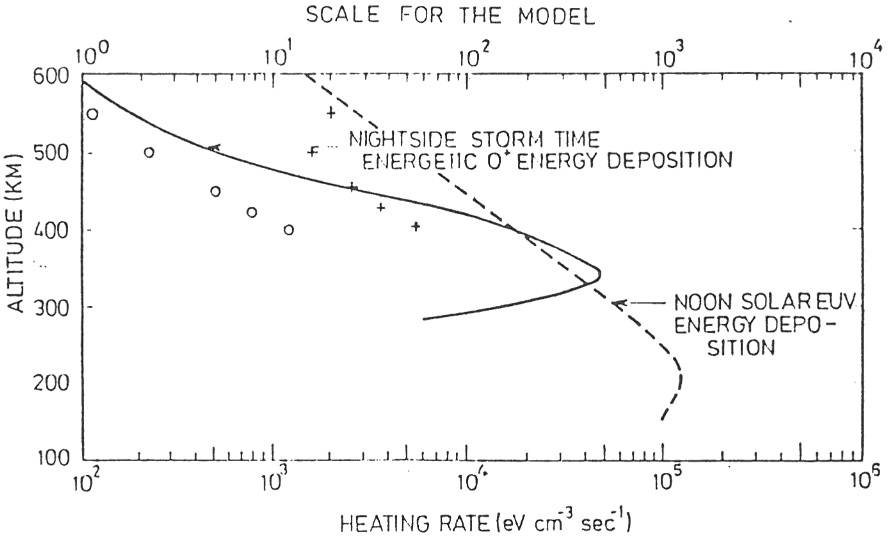

Fig. 1. Heating rate profile of the dayside solar electromagnetic radiation and that due to the nightside storm time energy deposition by energetic O^+ ions both computed for solar maximum conditions, as well as the height variation of the heating rate related to measured density increases in geomagnetically disturbed periods (o) and model values (+) representing the effect of circulation disturbances at low latitudes originating in the auroral zones during solar minimum.