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ON A POSSIBLE RING CURRENT EFFECT IN THE DENSITY OF THE NEUTRAL UPPER ATMOSPHERE

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ABSTRACT

The neutral post-storm effect is reconsidered by means of accelerometric data. Since $\Delta\rho$ has proved to be different function of Kp during and outside recovery phases, but a unique function of Dst, the latter is considered as a better index for correcting the effect of geomagnetic activity in models, i.e. it seems that the ring current plays an important role in the geomagnetic effect of the equatorial thermosphere.

INTRODUCTION

It has been demonstrated in former papers that a density increase not previously considered in upper-atmospheric models occurs in the upper atmosphere after geomagnetic storms /1,2/. This phenomenon has been called "neutral post-storm effect" (NPSE) and has been found by means of f-values representing the ratio of density values determined from satellite orbital drag to model values corrected even for geomagnetic activity. The excess density has been attributed to heating due to energetic particles precipitating into the upper atmosphere as a consequence of charge exchange between ring current ions and neutral H atoms in the geocorona (ENA) /3/.

It is well known that atmospheric data based on the orbital decay method have a limited time resolution. In the present paper the NPSE is reconsidered by means of accelerometric data of much better time resolution.

DATA, METHOD AND RESULTS

Our recent investigations were based on the measurements of the French CASTOR/CACTUS accelerometer around minimum solar activity. The accelerometric density data have been compared with corresponding total density ρ values of the DTM model /4/ substituting Kp=0; the difference between observed and calculated densities was formed. In the first step, CACTUS data of the interval MJD 42590–43010 (July 1975 through August 1976) referring to altitudes between 400 and 403 km were selected and analysed (their time-resolution consequently decreased to only 8–15 data per day). Since the orbital inclination of the satellite was $\sim 30^\circ$, our investigations refer only to the reaction of the equatorial region to geomagnetic heating. The observed values belong to two groups according to LST (Local Solar Time), because upleg and downleg crossings are separated by $\sim$ 6 hours. The variation of LST within each leg is negligible, therefore daily average means could be calculated giving two separate $\Delta\rho$ values each day. Such series of mean values correspond better to the frequency of Kp and Dst and consequently to deduced model density values.

At first our intention was to verify the existence of the NPSE – based on this kind of observational data as well. The cross-correlation between the $\Delta\rho$ values and the geomagnetic indices Kp and Dst indicate an increase in the correlation if a shift of 6–8 days was applied (Fig. 1a). In the case of Dst the correlation proved to be significant at the 99% significance level. (As it is known the Dst index indicates the intensity of the ring current.) The autocorrelation functions of the indices Kp and Dst also indicate a small increase on the 6th day (Fig. 1b), i.e. the geomagnetic activity has a slight recurrence tendency of 6 days during the NPSE time interval – the cross-correlation analysis can not decide which part of the excess density is due to the recurrence and which part to the NPSE.

Therefore the $\Delta\rho$ values have been separated into two groups according to their epoch with respect to geomagnetic storms, viz.: those belonging to one of the recovery phases and those in any other remaining time interval (except the main phase). In each group the dependence on Kp and Dst has been studied separately forming mean values of Δρ in appropriate Kp as well as Dst intervals ($\overline{\Delta\rho}$). The results are demonstrated in Fig. 2a.

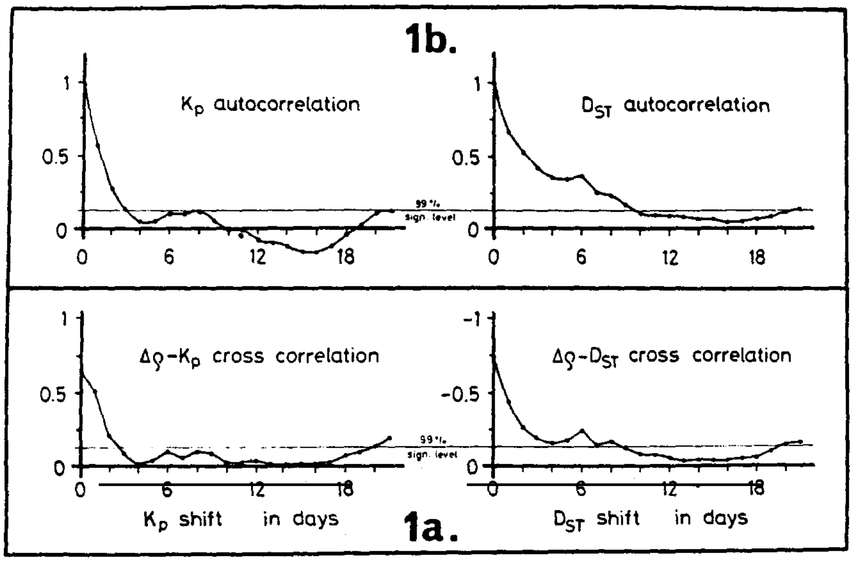

Fig. 1a. Cross-correlation functions between measured deviations from DTM model total density (putting Kp=0): Δρ and Kp, Dst geomagnetic indices respectively.
1b. Autocorrelation functions for Kp and Dst values.

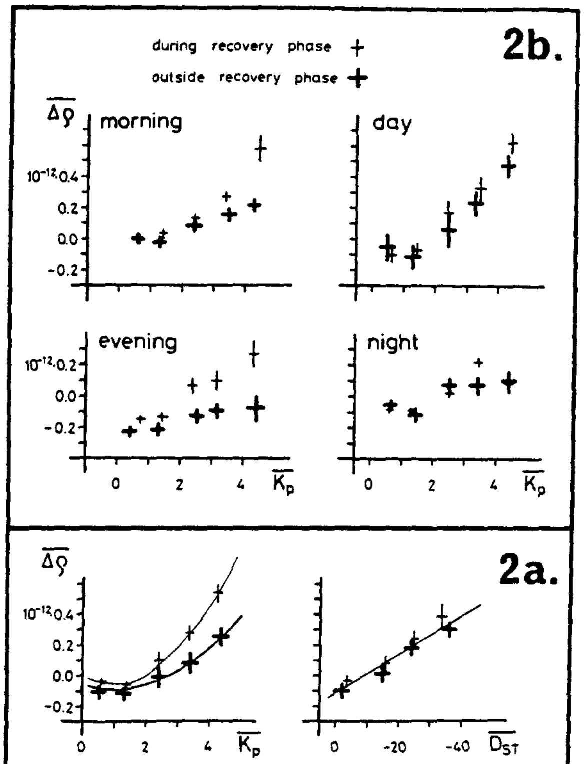

Fig. 2a. $\overline{\Delta\rho}$ versus $\overline{Kp}$ and $\overline{Dst}$ for time intervals inside and outside recovery phases separately
2b. Separation of $\Delta\rho(\overline{Kp})$ function (see first part of 2a) according to local solar time: morning (4–10 hours); day (10–18 hours); evening (18–22 hours); night (22–4 hours).

The two $\overline{\Delta\rho}$ curves are different in the case of Kp; $\overline{\Delta\rho}$ has a steeper increase with Kp during the recovery phase than in the remaining time interval:

$$\Delta\rho = [0.054\ (K_p - 1)^2 - 0.047]\ 10^{-12}\ \mathrm{kg.m^{-3}} \qquad \text{recovery phase} \qquad /1/$$

$$\Delta\rho = [0.030\ (K_p - 1)^2 - 0.079]\ 10^{-12}\ \mathrm{kg.m^{-3}} \qquad \text{remaining time interval} \qquad /2/$$

while the dependence of $\Delta\rho$ on Dst in the recovery phase does not differ from its variation in the remaining time interval.

Since the density is a double valued function of Kp, but a unique function of Dst, it is obvious that at low latitudes Dst is a better index with regard to the geomagnetic effect in the neutral thermosphere than Kp. This can also be seen from Table 1, that gives the correlation coefficients between $\Delta\rho$ measured on the n-th day after geomagnetic disturbances and the corresponding Ap or Dst respectively.

TABLE 1 Correlation Coefficients

No. of days after storm n	number of points	correlation coefficients with Ap	with Dst
1	40	0.636	−0.644
2	34	0.760	−0.631
3	30	0.729	−0.627
4	25	0.665	−0.602
5	19	0.436	−0.580
6	10	0.448	−0.617
7	5	−0.139	−0.537

In the case of Dst the correlation is almost constant until the 7th day, but it strongly decreases for Ap. It means that in the recovery phase the correlation with Ap of the same day vanishes with time, but remains almost constant for Dst.

The material was further separated according to diurnal phase (LST). The dependence on local time is plotted in Fig. 2b. The $\overline{\Delta\rho}(\overline{Kp})$ curves diverge more in the evening hours and less during daytime. It is also obvious that the response of the atmosphere to strong geomagnetic heating is more pronounced in the daytime than at night – a conclusion stated previously by Berger et al. /5/. A detailed analysis of the diurnal behaviour of the geomagnetic effect will be the topic of another paper.

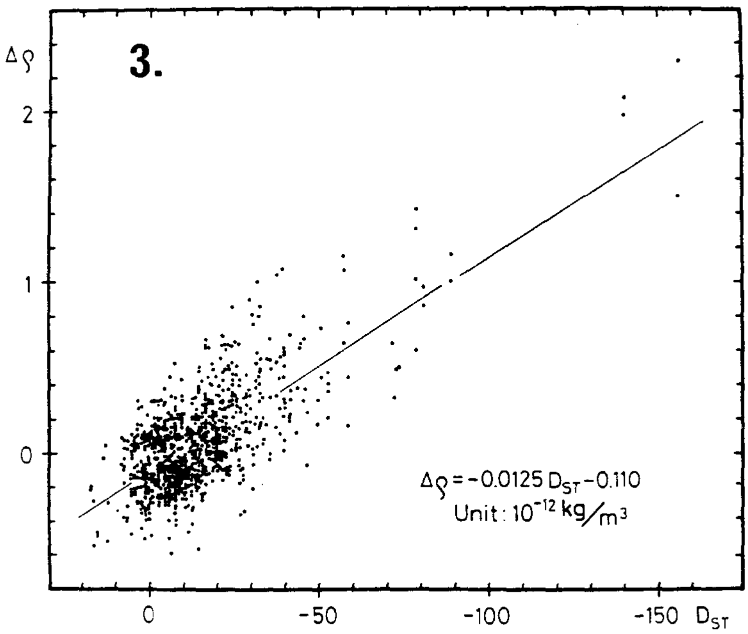

Fig. 3. $\Delta\rho$ versus Dst. A least squares linear fit is also given.

USE OF Dst FOR MODELLING

Using the single valued dependence of $\Delta\rho$ on Dst (Fig. 3) the Kp=0 version of the DTM model can be complemented as a first approximation by a simple linear term for the geomagnetic activity effect. (The model is, however, limited to the altitude and latitude interval in question.) The proposed term is

$$\Delta\rho = (-0.0125 \text{ Dst} - 0.110).10^{-12} \text{ kg.m}^{-3} \qquad /3/$$

determined as a best fit to points in Fig. 3. Using equation (3) a histogram of the residuals is plotted a./ for the original 420 days (Fig. 4a)
b./ for an additional 309 day control interval (Fig. 4b).
The control interval indicates that equation (3) can be extrapolated in time, hence at low latitudes Dst is a comprehensive and appropriate index for the geomagnetic activity effect.

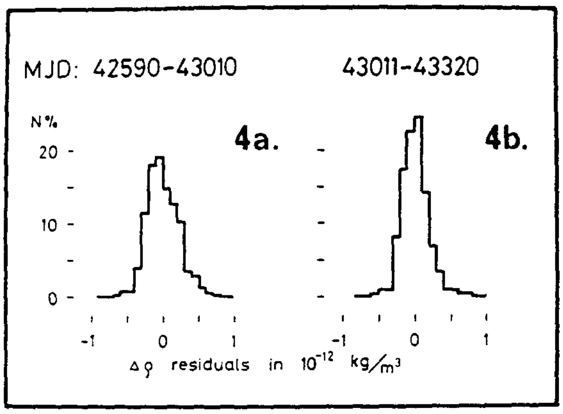

Fig. 4. Histogram of deviations from Kp=0 model values corrected by $\Delta\rho$ from equation (3)
a. in the original time interval MJD 42590-43010
b. in the control time interval MJD 43011-43320

CONCLUSION

In our former studies it was found that in post-storm periods a density excess occurs compared with model values (using the Kp index to consider the geomagnetic effect). Therefore it has been named a neutral post-storm effect and attributed to an additional heating process. The present investigation indicates, however, that the geomagnetic effect can, at low latitudes, be described as a function of the Dst index also in the post-storm period (in contrast to the Kp index). It seems that in this case there is some sort of process which is linked with the ring current and thus it is not restricted solely to post-storm periods. The double valued character of the $\overline{\Delta\rho}(\overline{Kp})$ function in Fig. 2a indicates different behaviour during and outside recovery phases respectively. Therefore it is clear that straightforward use of the Kp or Ap index is not sufficient to characterize the geomagnetic effect in atmospheric models. On the other hand we have good reason to believe that at least at low latitudes a more appropriate description of the geomagnetic effect is possible utilizing the Dst index, because of the better correlation of $\Delta\rho$ with Dst, and, furthermore, because of the identical dependence of $\Delta\rho$ on Dst inside and outside the recovery phase. Our results also imply that a more suitable correction for the geomagnetic effect in the neutral upper atmosphere is necessary - considering not only high but also medium and low latitudes. This might be realized by taking into account the complex nature of the geomagnetic activity consisting of polar and equatorial sources.

We plan to extend the time and height interval of our analysis as well as thoroughly investigate the connection between the diurnal and geomagnetic effect in the upper atmosphere.

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