REPRESENTATION OF THE GEOMAGNETIC EFFECT IN THE UPPER ATMOSPHERE AT LOW LATITUDES BY MEANS OF THE Dst INDEX

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Abstract: Density values obtained from the measurements of the CACTUS accelerometer around 400 km altitude at low latitudes are compared with corresponding DTM model values. It has been shown that the density increase $\Delta\rho$ during geomagnetic disturbances is a double valued function of Kp but a unique function of the Dst index. Consequently the density increase within this region can be directly connected with energetic particles precipitating from the equatorial ring current.

Резюме: Сравнивались значения плотности, полученные микроакцелерометром "КАКТУС" на высоте 400 км в зоне экватора, с соответствующими данными модели "ДТМ". Повышение плотности $\Delta\rho$ вследствие геомагнитной активности двухзначно зависит от индекса Кр, но однозначно от Dst. Следовательно допускаем, что повышение плотности связанно с энергетическими рассеянными частицами экваториального кольцевого тока.

INTRODUCTION

It has been previously reported that in the neutral upper atmosphere an excess density (detected by means of the orbital decay method) as compared to atmospheric models appears in a few days after geomagnetic storms (Illés-Almár et al., 1984). As the phenomenon occurs almost simultaneously with the well-known ionospheric post-storm effect, it has been called the Neutral Post-Storm Effect (NPSE). The period of this post-storm effect corresponds to the recovery phase of geomagnetic disturbances characterized by a slow increase of the Dst indices (Illés-Almár et al., 1988). The limited time resolution of the orbital decay method did not allow a detailed analysis of the effect.

By the courtesy of CNES CACTUS accelerometer data of much better time resolution above 400 km from the period 1975-77 were used. The CACTUS material refers to latitudes ± 30° around the Equator. Altogether 6840 density values measured between 400 and 403 km altitudes have been selected for further analysis.

METHOD

DTM model values (Barlier et al., 1978) have been computed for each point and time of measurement assuming no geomagnetic disturbance (Kp=0). The differences between the corresponding measured and computed values

$$\Delta\rho = \rho^{CACTUS} - \rho^{DTM(Kp=0)} \qquad (1)$$

were calculated. If the density profile of the quiet upper atmosphere is correctly represented by the DTM model, then $\Delta\rho$ depends only on the geomagnetic activity. Taking into account earlier results concerning the post-storm effect, the $\Delta\rho$ data corresponding to recovery phases have been separately studied.

RESULTS

As it has been pointed out previously $\Delta\rho$ proved to be a double valued function of both the Kp and Ap indices showing that $\Delta\rho$ is systematically larger during recovery phases (Fig. 1 left) (Illés-Almár et al., 1988). This indicates that the upper atmosphere reacts more intensively to a disturbance level characterized by a given Kp during recovery phases than at other times which corresponds to the previously revealed neutral post-storm effect.

Analysing several geophysical parameters (Illés-Almár et al., 1987) it has been found that using Dst as an index of geomagnetic activity (Solar Geophysical Data) $\Delta\rho$ is its unique function (Fig. 1 right) (Illés-Almár et al., 1988). In Fig. 1 the $\Delta\rho$ values have been averaged for different Kp and Dst ranges respectively. The single-valued character of the function $\Delta\varrho$(Dst) indicates that - at least at low latitudes Dst is a more suitable parameter for the description of the density increase in the neutral upper atmosphere during geomagnetic disturbances than Kp or Ap used almost exclusively in upper atmospheric models till-now.

If all $\Delta\varrho$ values are plotted as a function of Dst, then the following linear function can be fitted to the points:

$$\Delta\varrho = (-0.0125 \text{ Dst} - 0.110)\ 10^{-12} \text{ kg m}^{-3} \qquad (2)$$

(Fig. 2). The above investigation refers to a time interval of 420 days (MJD 42590-43010). All $\Delta\varrho$ data of a given day have been averaged for the upleg and downleg separately, since in each leg LST hardly changed within one day. The validity of eq. (2) has been checked in different ways.

First the time interval has been extended to the whole 730 day period (MJD 42590-43320). It has been found that eq. (2) fits suitably the points of the extended time interval. Figure 3 shows the daily averages of $\Delta\varrho$ in this extended time interval before and after the reduction by eq. (2). Figure 4 illustrates the distribution of the residuals in the original (a) and in the additional or control (b) time interval.

As a second step the dependence of the instantaneous $\Delta\varrho$ values (without averaging) on the hourly Dst index has been studied (Fig. 5, upper part). Reducing the instantaneous $\Delta\varrho$ values using hourly Dst values and eq. (2), the dependence of the residuals on Dst varished (Fig. 5, lower part).

Finally, the validity of eq. (2) has been controlled for separate sub-groups of the whole material as quiet periods, storm main phase and recovery phase periods. It has been found that the residuals do not indicate any dependence on Dst also in case of these sub-groups

On the basis of the detailed analysis it is suggested to use eq. (2) for the representation of the geomagnetic effect in the DTM model - at about 400 km altitude in the equatorial zone. Figure 3 shows that as a consequence of the use of eq. (2) the scatter decreased, but some fluctuations of different periodicity remained. It is probable that the residuals are connected partly with solar activity (in spite of the fact, that the DTM model eliminated this effect by the $S_{10.7}$ index), partly with changes in local time - though the model removed already the influence of the bulge (Fig. 6).

It is to be noted that sometimes a strikingly similar trend appears in one of the galactic cosmic ray intensity indices, C_{DR}, suggested previously for the characterization of changes in the density of the upper atmosphere (Illés, 1983; Illés-Almár, 1984). The analysis of this phenomenon remains to be done yet. A detailed investigation of the dependence on LST is the topic of another paper in this volume (Illés-Almár et al., 1989).

DISCUSSION AND CONCLUSIONS

The investigations of the authors called the attention to the circumstance that the Dst index characterizing the intensity of the equatorial ring current is a better index for the description of the geomagnetic effect in the neutral upper atmosphere at low latitudes ($<30^{\circ}$) than Kp (Illés-Almár et al., 1987, 1988). This result suggested that the decay of the ring current can be responsible for the geomagnetic effect at these latitudes. The previously found neutral post storm effect (Illés-Almár et al., 1984) in the density data corrected even for the geomagnetic effect could be the consequence of using in the correction Kp, instead of Dst. The latter idea is supported by the results of a correlation analysis between $\Delta\rho$ and Ap, as well as between $\Delta\rho$ and Dst (Illés-Almár et al., 1988).

The circumstance that the dependence of $\Delta\rho$ on Kp is different during the recovery phase than in the other phases and that at the same time $\Delta\rho$ is a unique function of Dst suggests that the morphology of the geomagnetic effect in the density of the upper atmosphere is similar to that of the geomagnetic disturbance itself. This means that the former can be considered as consisting of a ring current effect at low and mid-latitudes, as well as of an auroral (polar) effect at high latitudes. The $\Delta\rho$ data used in this investigation refer only to low latitudes. Therefore, the data are a unique function of Dst, but not of Kp and better correlated to the Dst index than to Kp.

It is known from the analysis of ESRO-4 satellite measurements that on the one hand at geomagnetic latitudes greater than 30° a large increase of the molecular component's (N_2, Ar) concentration and a smaller increase or decrease of the atomic component's (O, He) concentration can be observed during geomagnetic storms at least in the height range 240-320 km (Prölss, 1980). The increased geomagnetic activity results also in an enhanced total density. These composition changes can not be the consequence of increased temperature (Prölss, 1987). The large storm time reduction of the F region electron density extends to the same latitude zone. This explains the formation of negative ionospheric storms at mid and high latitudes, the large increase of the N_2/O concentration ratio enhancing dissociative recombination. On the other hand at low latitudes ($\varphi < 30^{\circ}$) the measurements do not indicate composition changes during geomagnetic storms - except at the longitudes of the geomagnetic poles (101° W, 141° E) in certain periods - but an enhanced total density (Prölss, 1987; Berger and Barlier, 1981). At these latitudes the storm time increase of the electron density in the F-region can be observed (positive ionospheric storm) which extends in winter to the lower mid-latitudes.

According to the results of the modelling of thermospheric storm effects, the thermospheric composition changes can be due to an upwelling of air which is caused by an energy input (strong electric fields and particle precipitation) in the auroral ovals (Rishbeth et al., 1985). Upwelling transports air rich in molecular components from lower altitudes to greater heights where the atomic components are more abundant. Thus, the concentration of the molecular components is increased as compared to that of the atomic components. This would explain the composition disturbance only at high latitudes, namely in the model it does not spread farther than 5° in latitude from the energy sources. An increase of the concentration of the molecular components as compared to the concentration of the atomic components at lower latitudes can be produced by thermal expansion but not by transport. At low latitudes the former could be compensated by sinking of air (enrichment in atomic components) which corresponds to the upwelling of air at high latitudes. Thus, additional energy sources are needed equatorward of the auroral ovals in the model to assure unchanged composition corresponding to the satellite measurements.

There have also been other investigations which indicate the insufficiency of the only energy input to the auroral ovals and the necessity of the assumption of an equatorial energy source respectively. As regards the insufficiency of an energy input only to the auroral ovals, modelling of thermospheric composition changes caused by a severe magnetic storm has shown that particle heating at latitudes lower than the auroral ovals are needed during magnetic storms to produce the composition changes at mid-latitudes (Rishbeth et al., 1985). Further studies have confirmed the finding that composition changes at mid-latitudes can not be explained by an energy source at high latitudes and assume as an additional energy source the ring current (Fuller-Rowell et al., 1988).

Considering observations, which show the necessity or presence of an equatorial energy source, Prölss and his colleagues could explain 30 per cent of the temperature increase at low latitudes deduced from satellite drag data by particle precipitation from the storm ring current (Prölss et al., 1973). Many observations demonstrated the precipitation of energetic particles at low latitudes by direct or indirect observations. Quasitrapped particles (2-20 keV electrons or protons) were observed by rocket measurements at above 200 km (Goldberg, 1974; Kelley et al., 1977; Guzik et al., 1989) supporting the idea of Scholer et al. (1975) based on the charge exchange between radiation belt ions and neutrals. The precipitation of energetic charged particles (protons, He^+ ions at low latitudes) has also indirectly been shown by the measurements of atmospheric emissions (H Lyman α, H Balmer α, N_2^+ 4278 Å, 304 Å) (Cazes and Emerich, 1980; Thomas, 1980; Levasseur and Blamont, 1973; Meriwether and Walker, 1980; Meier and Weller, 1975). The existence of energetic neutral hydrogen atoms originating from charge exchange reactions has been demonstrated at these latitudes indirectly by the observation of H Balmer β, OI 1304 Å and 1356 Å (Tinsley and Burnside, 1981; Abreu et al., 1986; Tinsley et al., 1986). It has also been found that these particles are an important source of nighttime ionization in the upper E region of the ionosphere at low latitudes (Lyons and

Richmond, 1978).

A study of Tinsley et al. (1988) comparing optical observations of ring current particle precipitation in the vicinity of the equator with the Dst and AE indices further confirms the suggestion mentioned at the beginning of this section. They found that particle precipitation occurs in every case when both Dst (ring current injection) and AE are large, but in case of large AE and no ring current injection little precipitation has been observed.

The changes in the thermosphere at low latitudes connected with geomagnetic disturbances can not fully be explained by simple sinking of air and particle heating, which would compensate each other's effect. Satellite measurements (AE-E) during geomagnetically disturbed periods indicate, namely, in addition to temperature increases also composition perturbations at low latitudes (Gross, 1985). However, the perturbations were observed in a limited longitude range. Thus, the interplay of the processes mentioned above can change in space and time.

Summarizing it can be concluded that the variations of the total density at low latitudes can not be attributed only to an energy input in the auroral ovals. It seems that it can be attributed much rather to an other energy source, to energetic particles originating from the ring current, which are precipitated due to charge exchange or wave-particle interaction. The energy input in the auroral ovals could only indirectly affect the low latitude neutral upper atmosphere. The processes considered from this point of view are propagation of energy by gravity waves and equatorward wind due to heating at the auroral ovals resulting in compressional heating. As a severe argument against the effectiveness of transport the small diffusion time as compared with the velocity of the equatorward wind can be mentioned (Rishbeth et al., 1985).

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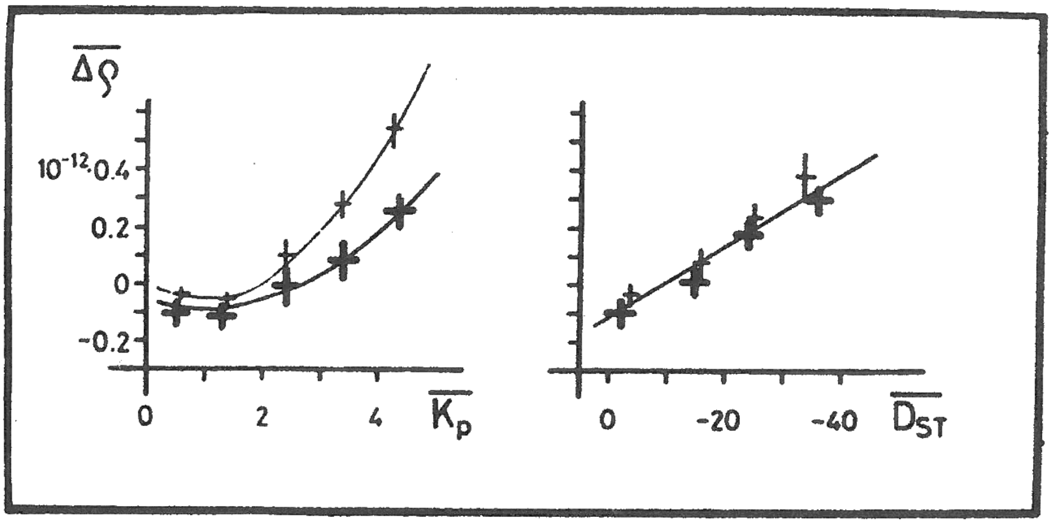

Fig. 1. Deviation of measured density values (averaged for Kp and Dst intervals) from the corresponding model values with Kp=0 ($\Delta\varrho$) as a function of geomagnetic indices. Measurements apart from storm-time refer either within (thin crosses) or outside (heavy crosses) the recovery phases

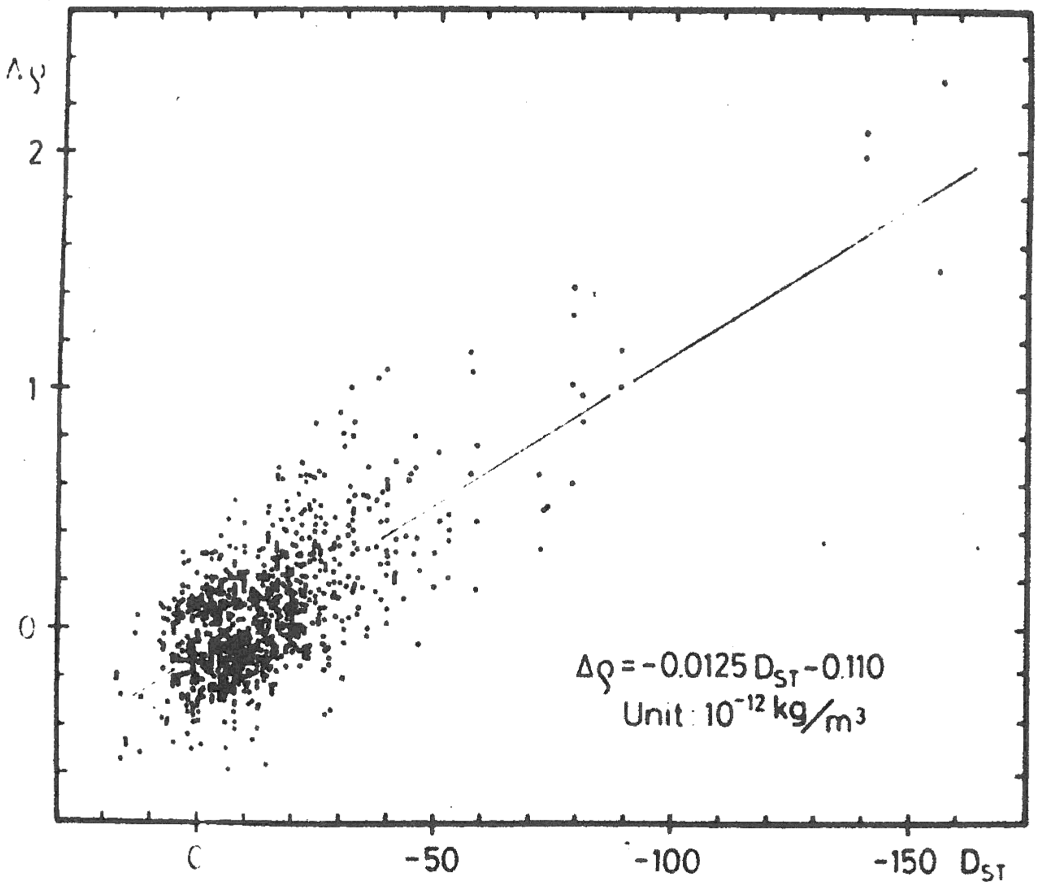

Fig. 2. Daily average values of $\Delta\varrho$ as a function of Dst in the original time interval (MJD 42590-43010)

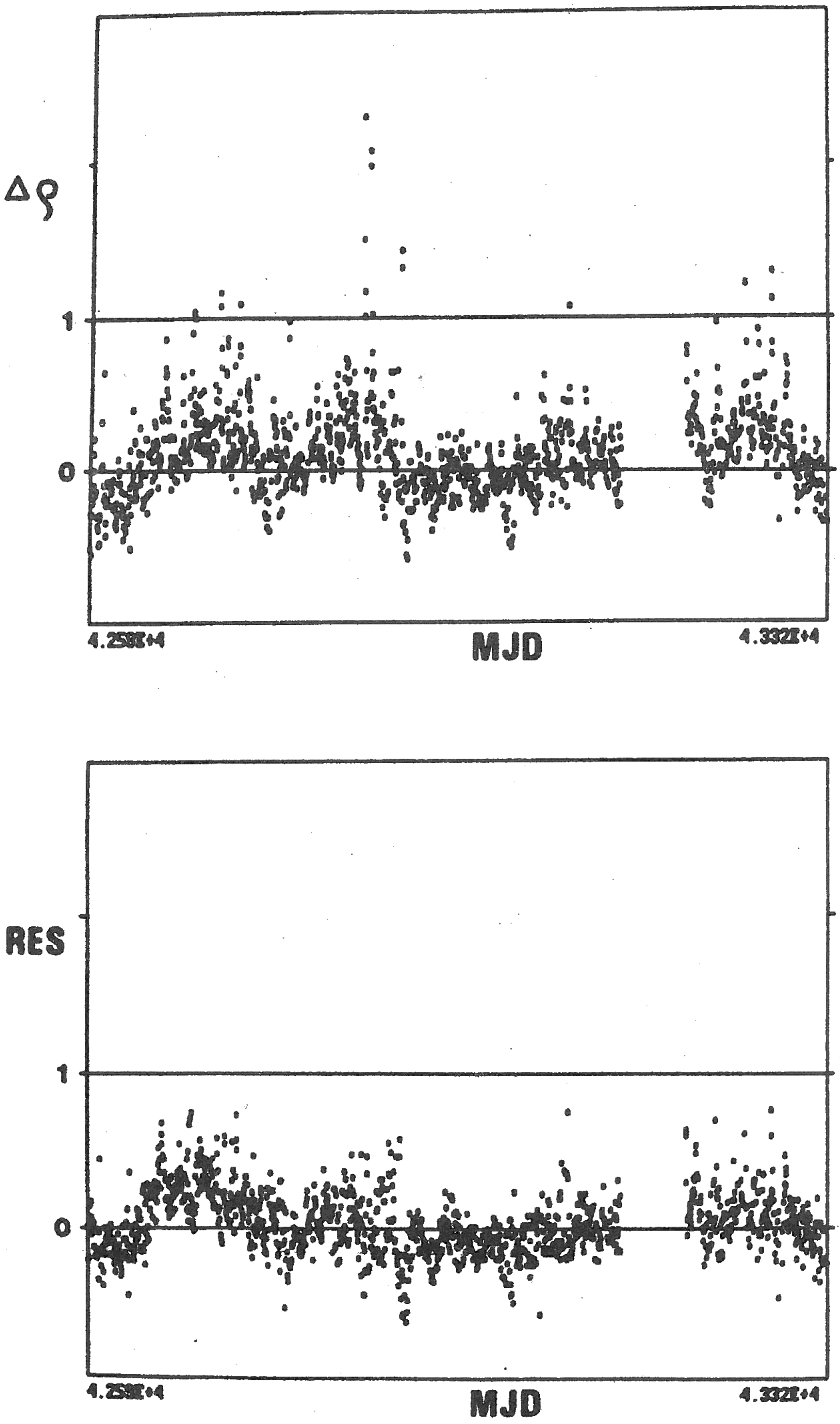

Fig. 3. Daily average values of $\Delta\varrho$ and residuals after a reduction by eq. (2) (RES) plotted as a function of time in the extended time interval (MJD 42590-43320)

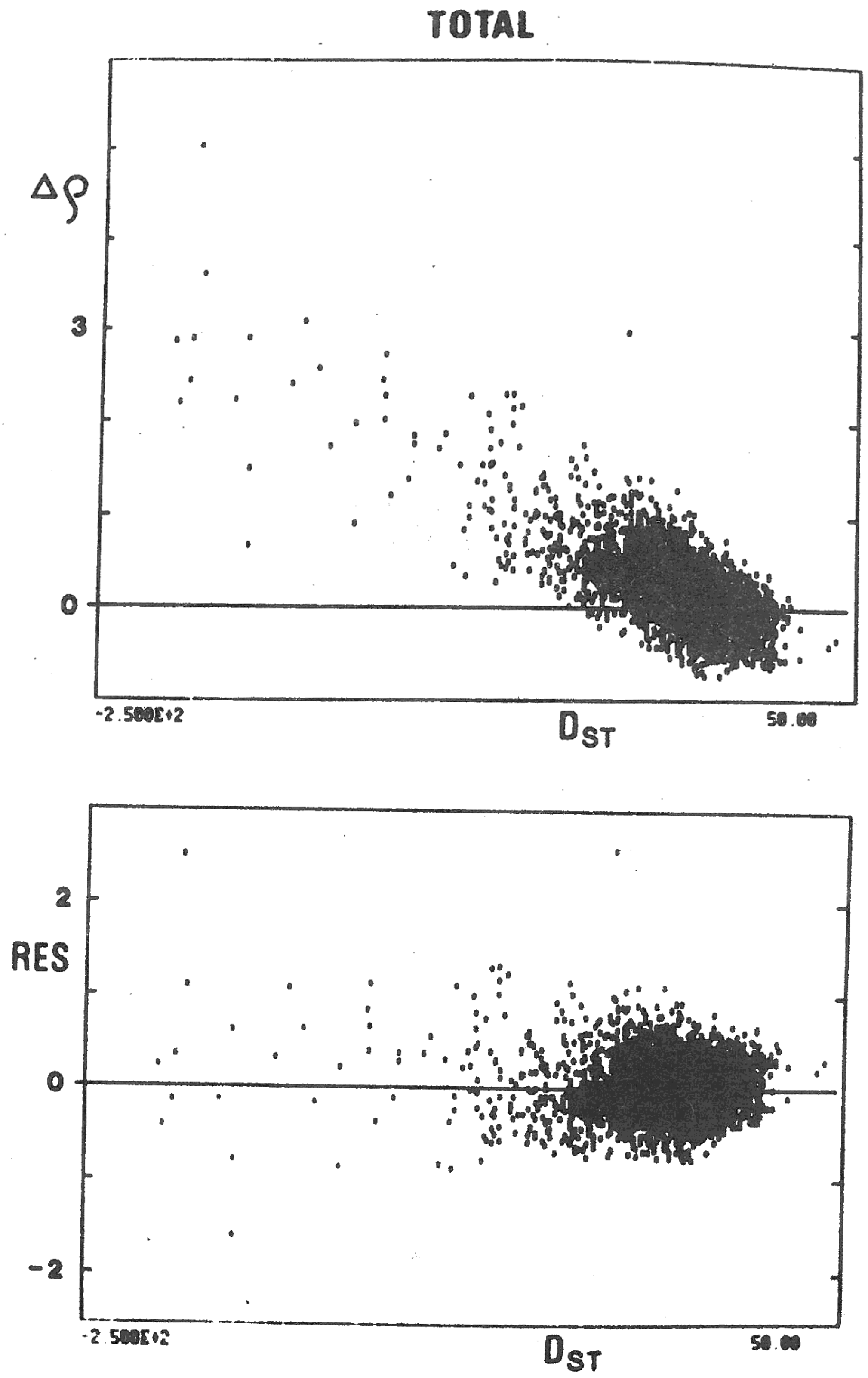

Fig. 5. Momentary values of $\Delta\rho$ and RES plotted as a function of Dst

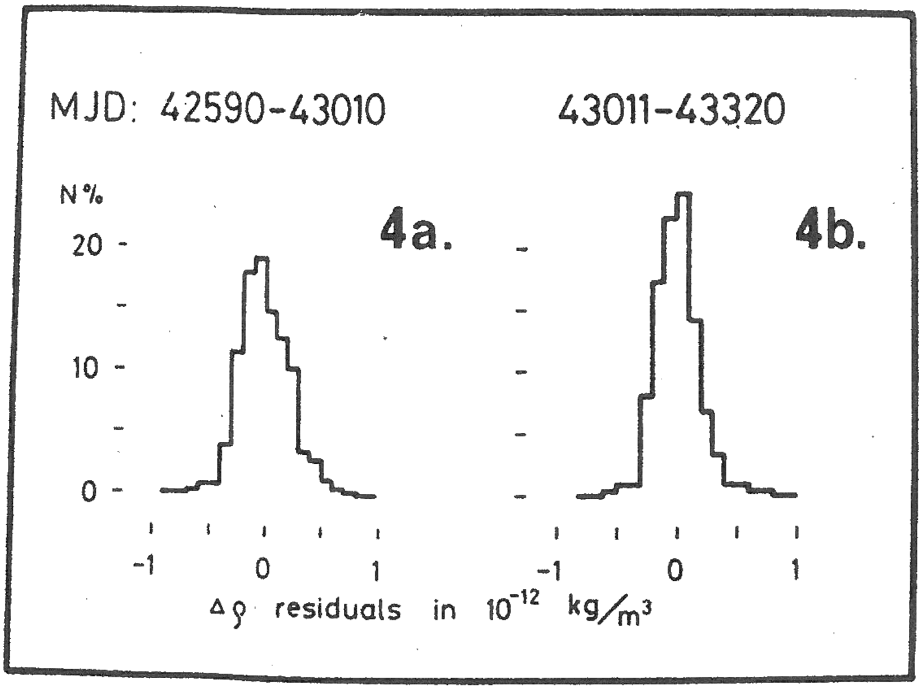

Fig. 4. Histogram of RES values in the original (4.a) and control (4.b) time interval respectively

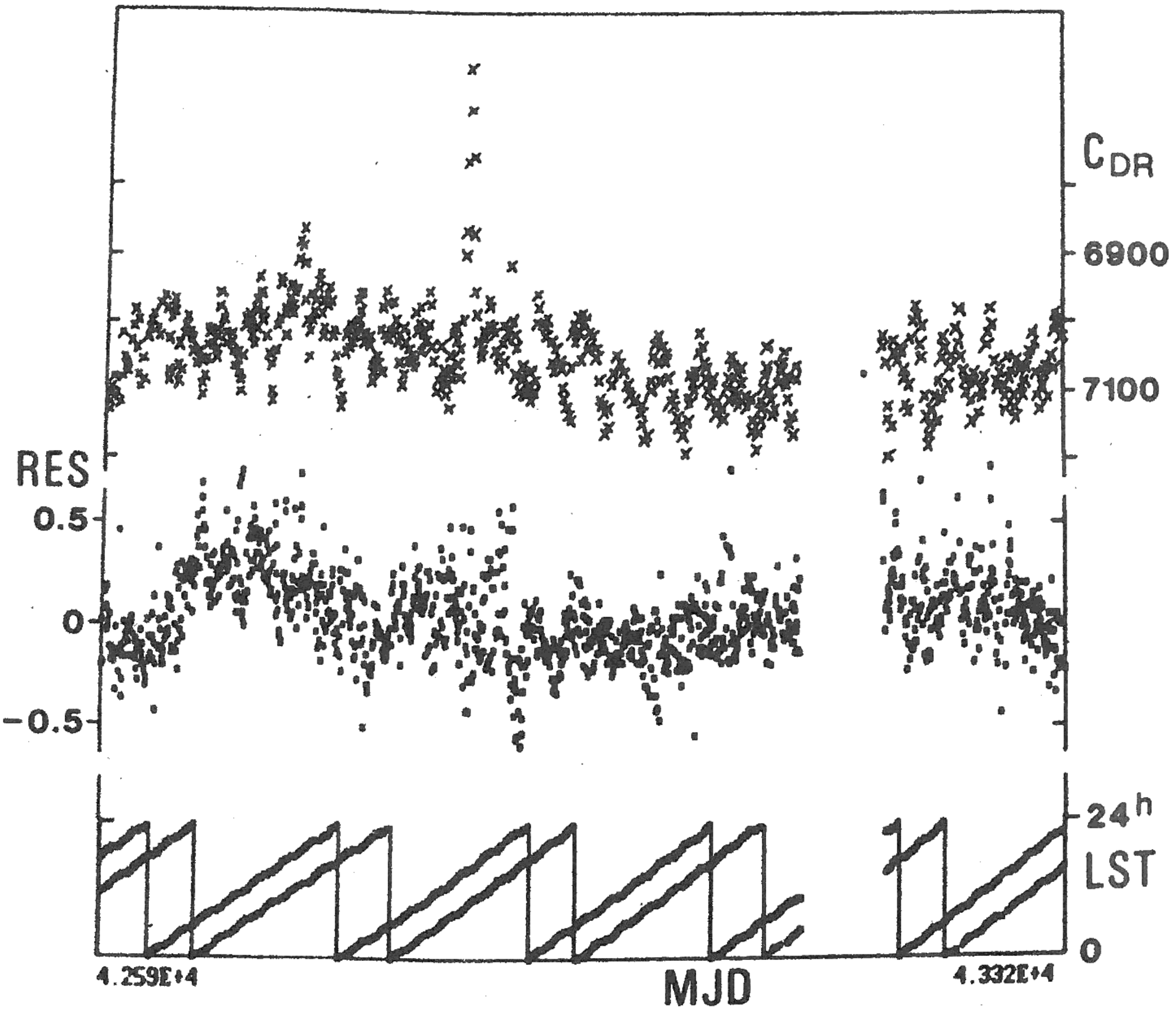

Fig. 6. RES as a function time displays sometimes a trend parallel with the index C_{DR} modulated by solar activity and indicates sometimes a diurnal variation