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INVESTIGATION OF THE THERMOSPHERE–IONOSPHERE INTERACTION BY MEANS OF THE NEUTRAL POST-STORM EFFECT

E. Illés-Almár,* I. Almár,* P. Bencze** and A. Horváth*

**Konkoly Observatory, H-1525 Budapest, Box 67, Hungary*
***Geodetical and Geophysical Research Institute, H–9401 Sopron, Box 5, Hungary*

ABSTRACT

Previous investigations of the authors based on the decay rates of many satellites have demonstrated the existence of a post-storm effect in the neutral atmosphere after geomagnetic storms. Its maximum appears 4-6 days after the storm onset. It generally lasts 8-10 days, but if there is also an ionospheric post-storm effect, then it is about twice as long at mid-latitudes and in the evening hours. The observed characteristics of the post-storm effect seem to indicate that it is related to the precipitation of ring current particles due to charge exchange and wave-particle interactions.

INTRODUCTION

In a former paper /1/ it has been demonstrated that the density (ϱ) deduced from atmospheric drag on satellites is increased after geomagnetic storms as compared to semiempirical models (CIRA 72). We call this "the thermospheric post-storm effect". This phenomenon was observed in the height range 200 - 600 km, and is similar to the well-known after-effect in the mean ionospheric absorption of radio waves (MIA). The density maxima occur four to six days after the onset of geomagnetic disturbances. In this paper we investigate different aspects of this thermospheric post-storm effect.

DATA

Our data base contains about 16000 density values (from 1965 to 1972) based on the decay of 20 satellites having appropriate orbital eccentricities ($0.05<e<0.20$). Some decay rates have been partly determined by our PERLO program /2/, and partly taken from publications of ephemeris centres. The time resolution was sometimes as good as 2 days, but generally not better than 3-5 days. Time intervals were omitted when a time resolution at least as good as 5-10 days could not be guaranteed.

The f-curves were derived for each satellite separately, where $f = \varrho_{obs}/\varrho_{model}$. All remaining long-term variations were eliminated from the f-curves of each satellite. In order to remove the effect of inadequate knowledge of satellite cross-sections, all f-values were divided by $\bar{f}$ (the mean of all density values of a given satellite).

METHOD

The well-known method of superposed epochs (MSE) has been used with Dst minima as key days. Altogether those 109 events were selected during the 7 years which had Dst minima exceeding -40γ. Both the events and the measured density values were separated according to criteria described as follows:

Separation of events according to geophysical parameters

We applied MSE to all events together (Case 1) as well as to events separated according to different geophysical parameters (altogether 40 cases:
Ap -- planetary geomagnetic index; MIA -- mean ionospheric absorption;
HSPS -- high speed plasma stream; SSC -- storm sudden commencement;
C_{DR} -- galactic cosmic ray intensity measured at Deep River.

The following types of separation proved to be the most interesting:

Case 2: those events when Ap maxima corresponding to Dst minima were lower than 20 (marked by -Ap, 26 events);

Case 3: Ap maxima exceeding 40 (marked by +Ap, 61 events);

Case 4: when $Ap > 40$ combined with an ionospheric post-storm effect (marked by +Ap +MIA, 33 events);

Case 5: when $Ap > 40$ with no ionospheric post-storm effect (marked by +Ap -MIA, 20 events).

Separation of density data according to the position of the perigee

The averaged f-curves were plotted using MSE for all density data (denoted by "unseparated" in Fig. 1) and for those separated by the position of the perigee respectively.
All f-values were separated according to the latitude of the perigee into three groups: low latitude ($|\varphi| < 30^\circ$), midlatitude ($30^\circ < |\varphi| < 60^\circ$) and polar ($|\varphi| > 60^\circ$).
Another four groups were formed according to the local solar time (LST) of the perigee: daytime ($10^h < LST < 14^h$), evening ($18^h < LST < 22^h$), night ($22^h < LST < 2^h$) and morning ($4^h < LST < 8^h$).

RESULTS

Altogether 320 curves were plotted using MSE with the Dst minima as key days. There is a well-pronounced minimum on almost every curve around the key day. In our opinion this phenomenon is a simple consequence of the inadequacy of the time resolution of the density curves which are not sensitive enough to follow the profile of quick geomagnetic variations; i.e. our experimental density curves cut off the peaks of sharp density maxima.

The main results are summarized in Fig. 1 and Fig. 2, where the departures of experimental densities from corresponding model values are plotted as a function of time elapsed after each key day. In the case of a perfect model the scatter would be around a constant value.

In Fig. 1, in column 1, MSE curves for case 1 are plotted: at the bottom different geophysical parameters, above them the unseparated f-curve, then those belonging to different sections of the day and latitudes respectively. In the next two columns events of case 1 have been separated according to the absence or presence of Ap storms (case 2 and 3). The thermospheric post-storm effect is seen on every curve with a maximum around the fifth day. Comparing the unseparated curves, it is obvious that the post-storm effect has a longer duration in case 3 than in case 2. On separated curves it is conspicuous that the longer duration is characteristic of the midlatitudes and of the evening hours.

In Fig. 2, in column 1, the MSE curves are separated according to φ and LST together (i.e. the combined latitudinal and LST effect is treated). Evening curves indicate a long-lived post-storm effect lasting about 18 days at midlatitudes. Separating the events of case 3 according to the presence (+MIA) or absence (-MIA) of an ionospheric post-storm effect (case 4 and 5) we can conclude that the long-lived thermospheric aftereffect is characteristic only of +MIA cases (column 2, case 4, plotted with heavy line) and it is short-lived even at midlatitudes and evening without a MIA effect (column 3, case 5, dashed line).

DISCUSSION

The required energy source must not be limited to the recovery phase. The observed conditions, i.e. the time of the increased density with its lag behind the geomagnetic activity, the height range and the latitude region concerned suggest that the energy comes from the precipitation of ring current (radiation belt) particles. The precipitation of particles depends on the loss processes, charge exchange and wave-particle interaction.

Considering the scenario of the thermospheric post-storm effect, it appears at low latitudes in the early recovery phase and is restricted to the interval from 3 days to 10 days after the onset of the disturbance. On the basis of other experimental data, charge exchange is probably responsible for the particle precipitation at these latitudes. Energetic protons have lifetimes against charge exchange long enough to produce the observed effects, but do not transfer enough energy in inelastic collisions in the height range considered /3/. On the other hand, soft protons have short charge exchange lifetimes /4/. Moreover, according to recent investigations, during the re-

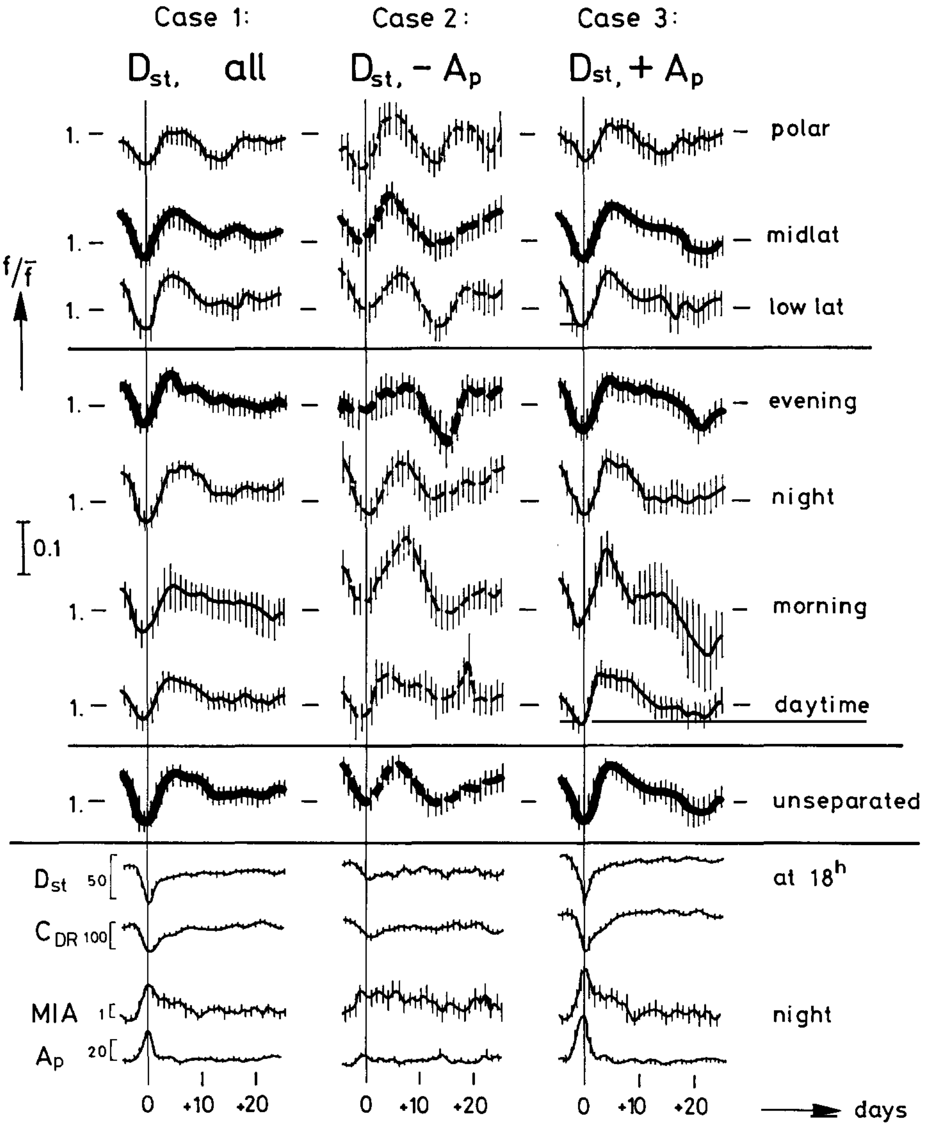

Fig. 1. Demonstration of the thermospheric post-storm effect by means of the method of superposed epochs (MSE). After geomagnetic storms (Dst minimum used as key day) there is a density excess which lasts longer in midlatitudes and in the evening hours.

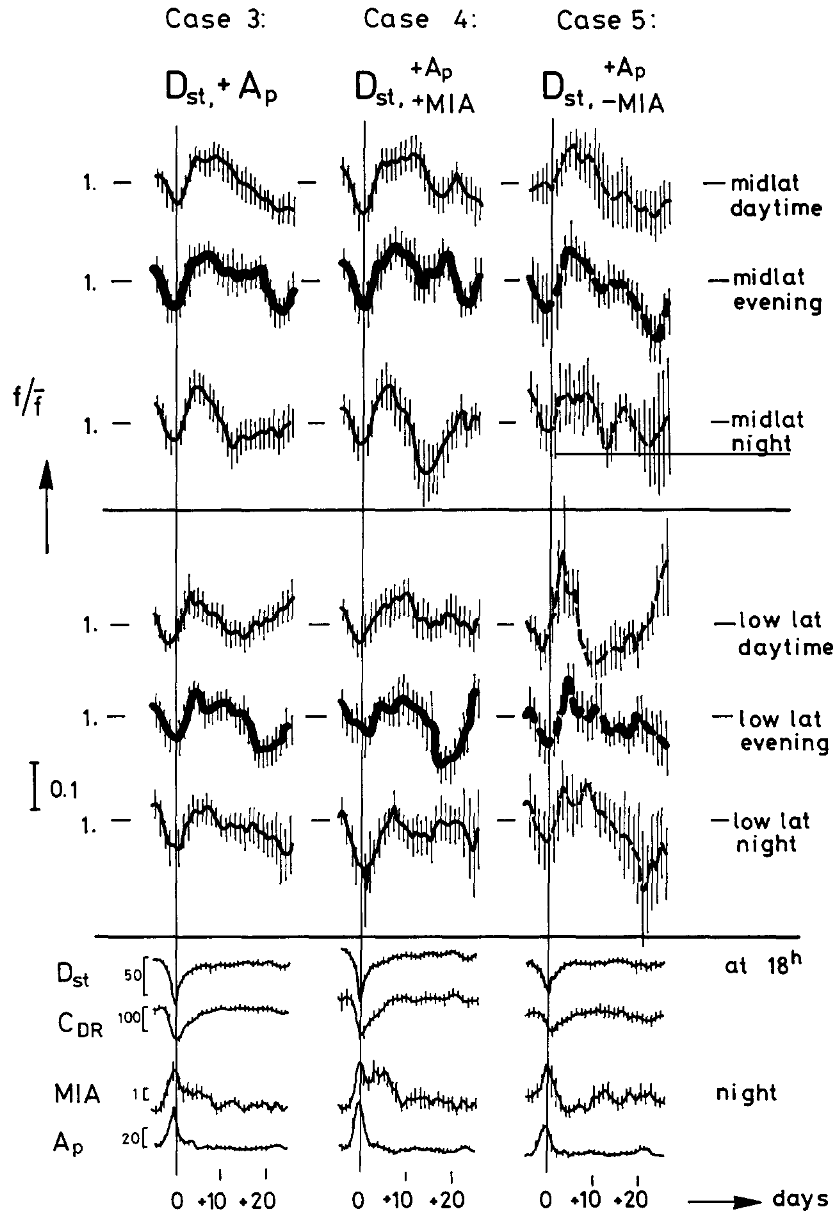

Fig. 2. The thermospheric post-storm effect is long-lived when midlatitude plus evening cases are combined and there is an after-effect in mean ionospheric absorption (MIA) as well.

covery phase, O^+ decays rather rapidly (~1 day) in the bulk of the energy density (>20 keV), but not at lower energies /5/. Since low energy O^+ ions have long charge exchange lifetimes and show the greatest magnetic activity dependence, they might be considered as candidates for the energy source.

Precipitating particles can directly and indirectly affect the upper atmosphere at low latitudes. The direct effect can be the result of precipitating neutrals, produced by charge exchange between the ring current ions and the geocorona. The neutrals directed towards the Earth impact at latitudes determined by the geometry of the pitch angle distribution; i.e. within 30° of the dip equator /6/. The O atoms of low energy (<10 keV) which have lifetimes long enough to produce the post-storm effect are thermalized by ionizing (stripping) and excite the ambient atoms in the height range 200-600 km. This process results in the heating of the upper atmosphere /7/. The indirect effect can be attributed to a process suggested by Moritz /8/ and confirmed by Mizera and Blake /9/ and by Scholer et al. /10/. According to Moritz /8/, the energetic neutral atoms formed in a charge exchange of ring current ions with neutral hydrogen in the geocorona and moving freely in the upper atmosphere are reionized. These particles can be neutralized by charge exchange and untrapped and temporarily trapped at lower altitudes in the low latitude upper atmosphere (double charge exchange). The flux of these particles depends on the flux of the incident energetic neutrals. Our hypothesis seems to be supported by the observation of increased intensity of H Lyman alpha emission /11/, /12/. The H Lyman alpha emission measured during the recovery phase of a geomagnetic storm at low latitudes indicates that the radiation could be attributed to the precipitation of protons in the energy range 10-300 keV observed by Moritz /8/ and Mizera and Blake /9/. Since the asymmetric ring current is concentrated in the evening hours, the circumstance that the thermospheric post-storm effect is more developed in this time interval may also hint at the ring current origin of this effect.

At midlatitudes the thermospheric post-storm effect has been found more long-lived than at low latitudes -- in the presence of MIA in particular. Other observations show that plasma waves (periodically structured Pc1 type micropulsations) are enhanced inside the plasmasphere in the late recovery phase /13/, /14/, /15/. Thus, at midlatitudes, wave-particle interactions can also contribute to the observed post-storm effect, when the plasma waves are amplified by ion cyclotron instability. Theoretical investigations indicate that the stable trapping limit for a given flux of energetic particles is decreased as the ambient cold plasma density increases /16/. Such conditions occure, where, during the recovery phase, the plasmapause moves outward into the ring current due to the filling of the plasmasphere. The intersection of the ring current with the increasing cold plasma density of the plasmasphere produces the ion cyclotron instability. Concerning the local time dependence of the thermospheric post-storm effect at midlatitudes, our results seem to show that such intersections are more effective at the bulge of the plasmasphere located in the evening sector. It should again be noted that the asymmetric ring current is concentrated also in the evening hours during the recovery phase. The observation that the thermospheric post-storm effect is not a regular phenomenon may also be a proof of the working of the wave-particle interaction. Thus, it has been found that the unmodelled thermospheric density increase can be due to the long-lived dissipation of the energy of the geomagnetic storm into the thermosphere.

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