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PARAMETERS INFLUENCING THE GROWTH AND DECAY OF *AE* INDEX

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Abstract. The temporal behavior of the *AE* index is examined with using of hourly data for 22-year period. The current-hour magnitude of the index appeared to depend not solely on solar wind parameters but also on the previous-hour *AE* index, the latter dependence being approximately linear. Such a behavior can be described by the following first order linear differential equation: $dAE/dt = Q - (AE - AE_0)/\tau$ where Q is a solar wind coupling function, τ is the relaxation time, AE_0 is a constant. The best fitting is provided by the coupling function $Q = -0.10\ VB_s + 0.041\ pV$, where the solar wind velocity V is in km/s, dynamic pressure p in nPa, AE index and B_s (the IMF southward component) in nT, Q in nT/hr, time t in hr. The relaxation time appeared to be $\tau = 2.1$ hr.

1. Introduction. Electric currents are known to flow permanently in the ionosphere. At the auroral latitudes they reach especially large densities forming electrojets, eastward in the evening sector and westward in the midnight-morning sector. Sometimes the electrojet intensity increases several times as compared to the quiet level. *Davis and Sugiura* [1966] suggested *AU*, *AL*, and *AE* indices as a measure of the electrojet intensity. The indices are calculated from *H* component of several standard auroral-zone observatories. Their upper (*AU*) and lower (*AL*) envelopes characterize the maximum eastward and westward electrojets. Summary intensity of these two currents is measured by the *AE* index defined as

$$AE = AU - AL\,. \tag{1}$$

Note that the *AL* index is negative. When being averaged over several years $|AL|$ exceeds about factor of 2 the averaged *AU*, so that the westward electrojet yields the main contribution to *AE*.

The auroral electrojets are caused by the large-scale electric field applied to the conducting ionosphere. The electric field is generated due to the solar wind-magnetosphere interaction. Two components can be found in the temporal behavior of the *AE* index [*Pytte et al.*, 1978; *Bargatze et al.*, 1985]. One of them (a direct-driven component) is closely related to the solar wind parameters, mainly to the interplanetary magnetic field (IMF) southward component. The other component (an unloading one) is manifested as short-time (<1 h) spikes not connected directly to any variations in the solar wind and probably caused by the development of the so-called current wedge during the substorm explosive stage. In this paper we study the direct-driven *AE* component related to the solar wind, the unloading component being eliminated under statistical processing.

In a number of studies *AE* or *AL* indices were found as a function of solar wind parameters at a certain time [*Murayama and Hakamada*, 1975; *Murayama et al.*, 1980; *Pudovkin et al.*, 1980; *Vorobjov and Zverev*, 1982; *Murayama*, 1982; *Kuznetsov and Sergeev*, 1983; *Goncharova et al.*, 2000]. Sometimes the solar wind parameters with different weights were taken for several preceding times [*Arnoldy*, 1971; *Takalo and Timonen*, 1994; *Gleisner and Lundstedt*, 41997], which improved the correlation. This suggests a kind of memory in the mechanism governing auroral electrojet dynamics. A similar memory was revealed in the behavior of the *Dst* index which is a measure of magnetic storm intensity. The *Dst* index also depends on the IMF southward component at several preceding moments. However its temporal behavior is commonly described by the differential equation which includes only the current values of the Dst index and solar wind parameters [*Burton et al.*, 1975; *Feldstein*, 1992; *Gonzalez et al.*, 1994]

$$\frac{dDst_o}{dt} = F - \frac{Dst_o}{\tau_{Dst}}\,, \tag{2}$$

where Dst_o is the ram pressure corrected *Dst* index, F is a solar wind coupling function, τ_{Dst} is the relaxation time of the electric currents responsible for a storm-time disturbance. The typical value of τ_{Dst} is ~10 hours.

Goertz et al. [1993] suggested an equation for *AE* index variation similar to the equation (2). They statistically processed one-minute data for several days and obtained $\tau = 75$ min and coupling function proportional to the refined dawn-to-dusk interplanetary electric field $E_y^{ref} = -VB_s$ where B_s is the IMF southward component. In this paper we try to obtain such an equation using a more representative data set.

2. Data. We used the hourly solar wind data and geomagnetic indices from the OMNI database. The *AE* index was available for 22 years (1964-1975 and 1978-1987). The B_z IMF component (in the GSM system), solar wind velocity V, and proton number density n were chosen as geoefficient parameters. Their average values and standard deviations of the parameters as well as the number of observations are given in Table 1.

Table 1. Average parameters studied with their standard deviation and observation number

Parameter	Unit	Average	Standard Deviation	Number of Hours
B_z	nT	0.03	3.3	121,653
V	km/s	446	104	118,196
n	cm^{-3}	8.35	6.6	105,866
AE	nT	210	205	192,838

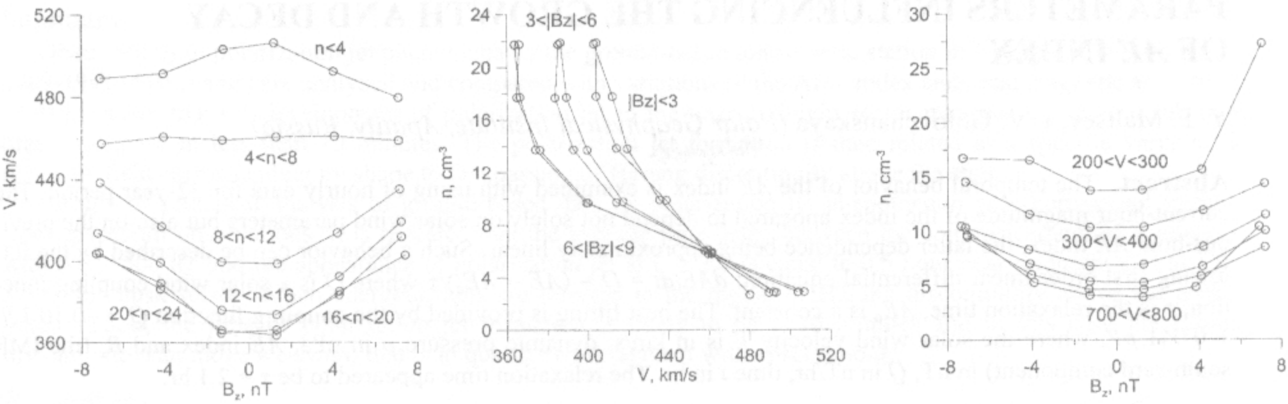

Figure 1. Interrelation of the solar wind parameters.

The solar wind parameters are strongly interrelated (Figure 1) so we shall find the dependence of the AE variation by a certain parameter with the other ones kept invariable. We assume $dAE/dt = AE(t+1) - AE(t)$ where t is the time in hours. In order to decrease the data scattering we averaged the observations in bins with the sizes of 100 nT in AE, 3 nT in B_z, 100 km/s in V, and 4 cm^{-3} in n. The bins containing less than 10 data points were excluded. As a result we obtained 505 "integrated" data points.

3. Results. Figure 2 shows the dAE/dt dependence on AE for several values of B_z IMF. When building it we used the data in the ranges of $400 < V < 500$ km/s and $8 < n < 12$ cm^{-3}. One can see that dAE/dt subsides approximately linearly with growing AE. One can see the linear growth of dAE/dt with the increasing southward IMF. The northward IMF is much less geoeffective. Low geoefficiency of the IMF northward component also results from Figure 2 where the three curves $dAE/dt(AE)$ built for $B_z > 0$ are practically coincident.

The dependence of dAE/dt on B_z IMF is shown in Figure 3 under several values of V (the left) and AE (the right), with respectively, either AE or V being fixed. The density range ($8 < n < 12$ cm^{-3}) is fixed in both cases.

Figure 4 shows the effect of the velocity V on dAE/dt under the northward (the left) and southward (the right) direction of the IMF. When the IMF is southward the dependence on V is more pronounced and close to linear. The slope is almost the same for all the AE except $AE < 100$ nT when the number of data is small. For the northward IMF the dependence is weaker and looks like parabolic.

The effect of the proton number density on dAE/dt is shown in Figure 5 under several AE for the northward (the left) and southward (the right) IMF. For better presentation the lines corresponding to $AE < 100$ nT and $100 < AE < 200$ nT in the right panel are dashed. The solar wind velocity V is kept invariable. The dependence is comparatively weak and approximately linear. Exceptions are the marginal ranges $500 < AE < 600$ nT and $AE < 100$ nT (the latter under negative B_z) but this can be explained by the small number of data.

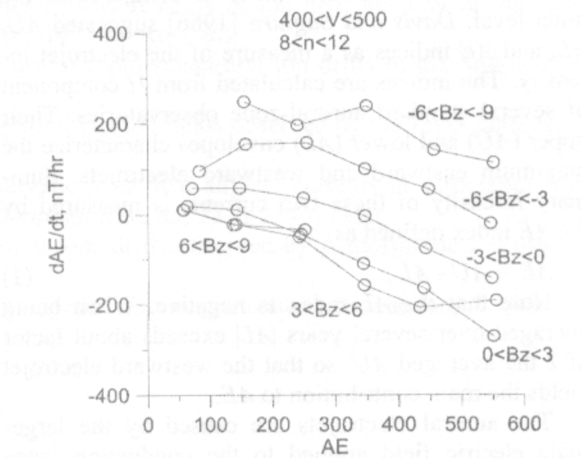

Figure 2. Dependence of dAE/dt on AE in several ranges of B_z IMF.

The linear dependence of dAE/dt on AE (see Figure 2) enables us to find an approximation formula as follows

$$\frac{dAE}{dt} = Q - \frac{AE - AE_o}{\tau} \qquad (3)$$

where Q is the solar wind coupling function, AE_o is the magnitude of AE under steady-state conditions ($d/dt = 0$) in the absence of the coupling ($Q = 0$), τ is the relaxation time. As one can see from Figures 2 and 3, the coupling function Q must nearly linearly depend on the IMF southward component B_s ($B_s = B_z$ under $B_z < 0$ and $B_s = 0$ under $B_z > 0$). If Q were a product $B_s V^\alpha n^\beta$ with α and β being constant coefficients it would be equal to zero under $B_z > 0$. However, as seen from Figure 4 (the left) dAE/dt grows with the velocity under positive B_z. Hence one can expect the following dependence

$$Q = f_1(n,V)\, B_s + f_2(n,V)\,. \qquad (4)$$

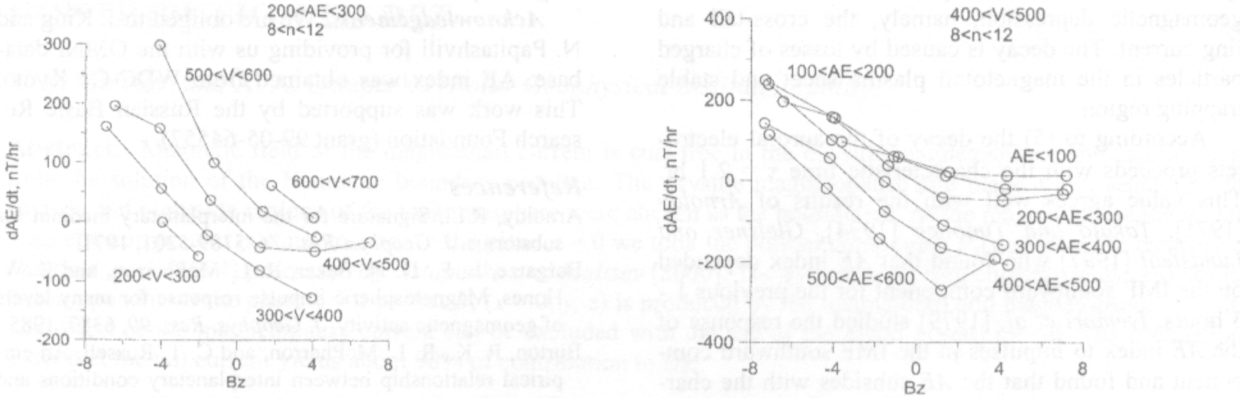

Figure 3. Dependence of dAE/dt on B_z IMF in several ranges of V (the left) and AE (the right).

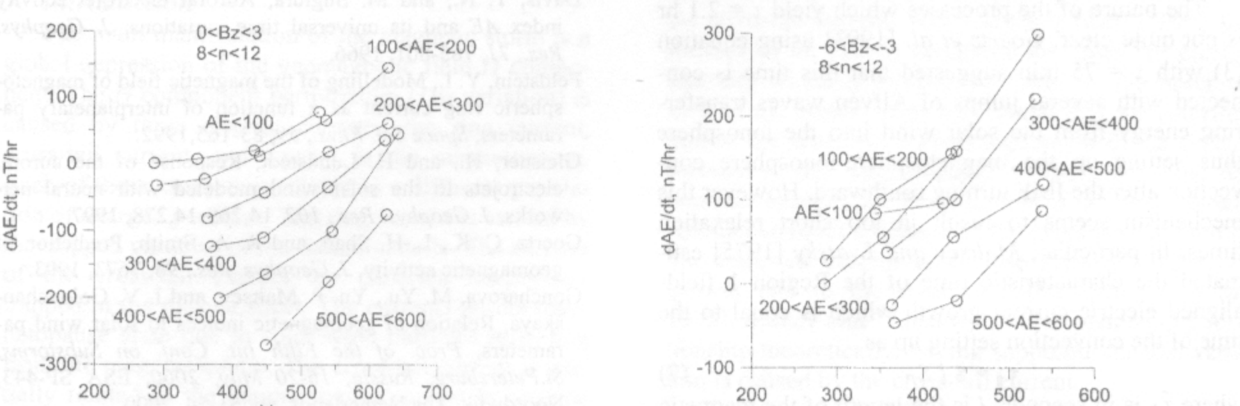

Figure 4. Dependence of dAE/dt on V in several ranges of AE under northward (the left) and southward (the right) B_z IMF.

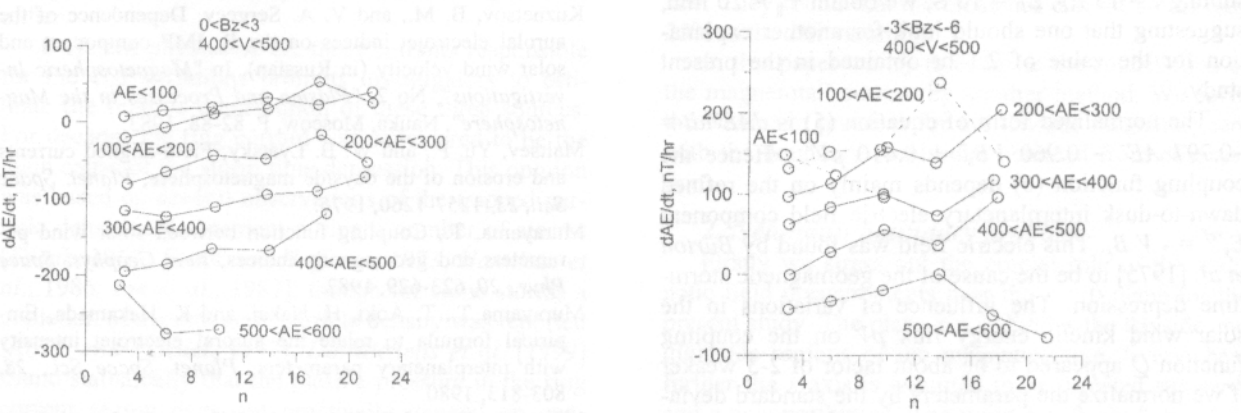

Figure 5. The same as in Figure 4 but with dependence on n. The lines of $AE < 100$ nT and $100 < AE < 200$ nT on the right are dashed.

By using the least squares technique we examined several possible types of $f_1(n,V)$ and $f_2(n,V)$, such as $f_1 = \text{const}, f_1 \propto V, f_2 \propto V, f_2 \propto V^2, f_2 \propto n\,V, f_2 \propto n\,V^2, f_2 \propto n\,V^3$. The best correlation was obtained for the couple $f_1 \propto V$ and $f_2 \propto n\,V^3 \propto p\,V$, where $p = m\,n\,V^2$ is the solar wind dynamic pressure, m is the proton mass. As a result we have

$$\frac{dAE}{dt} = Q - \frac{AE+2}{2.1}, \tag{5}$$

$$Q = -0.10\,VB_s + 0.041\,pV, \tag{6}$$

where the time t is expressed in hr, V in km/s, AE and B_s in nT, p in nPa, Q in nT/hr.

4. Discussion. Equations (3) and (5) in the present research appeared to be similar to the equation (2) for Dst_o with a discrepancy in the relaxation time. *Feldstein* [1992] reviewed the values of τ_{Dst} found in a series of papers. The typical τ_{Dst} is about 10 hr, though varying with geophysical conditions from ~1 to ~20 hr. This time characterizes the decay of the magnetospheric electric currents responsible for the storm-time geomagnetic depression, namely, the cross-tail and ring current. The decay is caused by losses of charged particles in the magnetotail plasma sheet and stable trapping region.

According to (5) the decay of the auroral electrojets proceeds with the characteristic time τ = 2.1 hr. This value agrees well with the results of *Arnoldy* [1971], *Takalo and Timonen* [1994], *Gleisner and Lundstedt* [1997] who found that *AE* index depended on the IMF southward component for the previous 1 - 3 hours. *Iyemori et al.* [1979] studied the response of the *AE* index to impulses in the IMF southward component and found that the *AE* subsides with the characteristic time of 1-2 hr.

The nature of the processes which yield τ = 2.1 hr is not quite clear. *Goertz et al.* [1993] using equation (3) with τ = 75 min suggested that this time is connected with several jumps of Alfvén waves transferring energy from the solar wind into the ionosphere thus setting up the magnetosphere-ionosphere convection after the IMF turning southward. However this mechanism seems to result in too short relaxation times. In particular, *Maltsev and Lyatsky* [1975] estimated the characteristic time of the Region 1 field-aligned electric current growth which is equal to the time of the convection setting up as

$$\tau_{\parallel} = 8\, l\, \Sigma_P \tag{7}$$

where $\tau_{\parallel}$ is in seconds, l is the length of the magnetic field line in the Earth radii (R_E), Σ_P is the height-integrated conductivity of the ionosphere in S. Assuming l = 15 R_E, Σ_P = 10 S, we obtain $\tau_{\parallel}$ = 20 min, suggesting that one should look for another explanation for the value of 2.1 hr obtained in the present study.

The normalized form of equation (5) is $dAE^{\sim}/dt = -0.797\, AE^{\sim} - 0.960\, VB_s^{\sim} + 0.410\, pV^{\sim}$. Hence the coupling function (6) depends mainly on the refined dawn-to-dusk interplanetary electric field component $E_y^{ref} = -V B_s$. This electric field was found by *Burton et al.* [1975] to be the cause of the geomagnetic storm-time depression. The influence of variations in the solar wind kinetic energy flux pV on the coupling function Q appeared to be about factor of 2-3 weaker if we normalize the parameters by the standard deviations given in Table 1. Since $pV \propto nV^3$ we get that the Q dependence on the solar wind density n is rather weak. Earlier *Murayama et al.* [1980] statistically found a similar weak dependence $AL \propto n^{0.13}$. Somewhat stronger dependence on n ($AE \propto n^{0.5}$) was suggested by *Gleisner and Lundstedt* [1997].

5. Conclusions. The temporal behavior of the *AE* index can be described by the first order linear differential equation in the form of (3) or (5). The coupling function (6) is the linear combination of the refined dawn-to-dusk interplanetary electric field and the solar wind kinetic energy flux. The characteristic time $\tau \approx$ 2.1 hr appears to be too large to be explained by any conventional mechanism of the solar-wind-magnetosphere interaction.

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