Two Possible Mechanisms for Relating Terrestrial Atmospheric Circulation to Solar Disturbances

C. O. HINES
University of Toronto

During geomagnetic storms, which are initiated by solar disturbances, two cells of circulatory motion are established in the polar ionosphere. The torques that contribute to either cell might conceivably be as great as 10^{24} dyne cm, and may persist for times of the order 10^5 sec. The angular momentum contributed to a cell may then conceivably be as great as 10^{29} g cm^2/sec. This is roughly of the order required to account for the changes of vorticity area that are claimed by Wilcox et al. (1973) to be correlated with reversals of solar magnetic sector structure. Transfer of the angular momentum from ionospheric heights to the vicinity of the tropopause might be accomplished either by viscous effects or by planetary waves with delay times of the order of days. A solar-wind source of angular momentum then constitutes one possible mechanism for relating terrestrial atmospheric circulation to solar disturbances.

The vorticity variations studied by Wilcox et al. (1973) may themselves be analyzed in terms of planetary waves. During winter, these waves propagate energy upward into the lower thermosphere. Some reflection may occur there, with the reflected energy returning to the lower altitudes and causing constructive or destructive interference with the initial disturbance. Changes in the reflection process, which might be induced by thermospheric circulation or other effects introduced during geomagnetic storms, would then alter the interference and so alter the observed vorticity. This second mechanism, in contrast to the first, makes active use only of energy derived from the lower atmosphere itself, where energy is in abundant supply. Moreover, in contrast to hypothetical "triggering" processes, the magnitude of the variable energy is a priori matched to the energy of the atmospheric circulation system being studied, albeit by unknown emission, transmission and reflection coefficients.

Mechanisms that require planetary-wave coupling between troposphere and thermosphere, such as the first may require and the second must require, could not be effective during the summer months because of absorption of the waves at intervening "critical" levels during those months. Such mechanisms would then contain a built-in explanation for the conclusion of Wilcox et al. (1973) that the correlation they report is available only during winter months.

None of the foregoing should be taken to imply that the present author is convinced that claimed correlations between terrestrial atmospheric circulation and solar disturbances (or sector structure) are in fact established as being physically valid, nor should it be thought that the suggested mechanisms are free from serious difficulties in aspects of the problem that are not discussed here.

Circumstances and my own reservations about the mechanisms outlined in the foregoing abstract have combined to prevent my presentation here of an extended development of the abstracted material. The following comments may be of some interest to those who wish to pursue the matter, however.

The estimate of maximum potential torque as 10^{24} dyne cm derives from an extension of the analysis by Hirshberg (1972) to take into account the angular momentum of solar plasma prior to capture by the magnetosphere. It allows for the effect of capture of solar plasma on one flank of the magnetosphere at a time, in a process that could give rise to one cell (at a time) of the traditional two-cell magnetospheric circulation pattern (for example, Axford and Hines, 1961). Equal capture on both flanks simultaneously could give rise to a symmetrical two-cell circulation pattern (if various complexities are ignored), with no net transfer of total angular momentum, whereas significant departures from strictly equal capture could give rise to a net transfer of angular momentum of a sense either to speed up or to slow down the rotation of the magnetosphere, the underlying atmosphere, and (to an inappreciable degree) the Earth. (See Hines, 1974*a*.) The statement in the foregoing abstract referred to the torque acting on a single cell at a time, and it would be operative whether or not a second cell were being established simultaneously.

The statement that an angular momentum of 10^{29} g cm^2/sec is roughly of the order required to account for reported changes of vorticity area index corresponds to the calculation made by Dessler in these proceedings, that a change of angular velocity of 2×10^{-5} rad/sec is imposed upon a disk of air whose moment of inertia is 2.9×10^{26} kg m^2, which implies a change of angular momentum of 5.8×10^{21} kg m^2/sec $= 5.8 \times 10^{28}$ g cm^2/sec.

Among the difficulties under contemplation in my abstract for this mechanism was inefficient coupling. My own estimates in the problem of magnetospheric rotation (Hines, 1974*a*) would indicate an inefficiency marked by a reduction factor of 10^2 at least, and more likely 10^4, based upon observations of maximum wind speeds observed in conjunction with magnetic storms. A quite independent calculation of Dessler in these Proceedings yields a maximum angular acceleration of 10^{-13} rad/sec^2, which, when combined with the moment of inertia cited above, implies a maximum operative torque of 2.9×10^{13} kg m^2/sec^2 $= 2.9 \times 10^{20}$ dyne cm and hence an inefficiency of the order 3×10^3 relative to my estimated maximum potential torque. Dessler and I are therefore in reasonable agreement on the degree of unlikelihood of my first mechanism being operative.

I did not reject this mechanism entirely, however, for two reasons: (1) The manner in which the vorticity area index is computed does not demand that the changes of angular momentum should be as great as is indicated above. Indeed, angular momentum might in fact be fully conserved, and the reported variation of vorticity index might simply expose a redistribution of the conserved angular momentum. The question of available torque would then simply not arise; all of the foregoing discussion of torques would be irrelevant. The truth might be thought to be somewhere between the two extremes, somewhere between a required zero torque and a required torque of 10^{24} dyne cm, that is. Just where, I could not possibly say. But to get within two or three orders of magnitude of the maximum torque that might be required seemed to me to be something of an achievement in this general area of study, and therefore an achievement worth reporting, at least orally. (2) In conjunction with my second mechanism, greatly reduced torques might be sufficient. The second mechanism comes into play if the reflection of planetary waves is altered sufficiently at heights well above the 300-mb level, for example at heights of 60 to 80 km. The moment of inertia of the disk of air overlying those levels is reduced by a factor of 10^3 to 10^4 from the value previously cited, and the torques that are likely to be available then become adequate to effect appreciable changes of circulation and hence, it would seem, adequate to effect appreciable changes of planetary-wave reflection coefficient.

The discussion of the planetary-wave reflection mechanism is pursued a short distance beyond that given in the foregoing abstract (Hines, 1974*b*).

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