Wind-Induced Magnetic Fluctuations*

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Irregular magnetic fluctuations, with time scales of the order ten minutes to two or three hours, provide a characteristic feature of magnetograms at most latitudes during magnetic storms, and at high latitudes even at times of relatively low world-wide magnetic activity. Their amplitude is of course great at times of high activity, by definition, and decreases with decreasing activity. They have long been believed to yield a measure of the interaction between solar plasma and the geomagnetic field, and this belief has been firmly substantiated by recent observations of a close correlation between the magnetic K_p index and the speed of the solar wind [*Snyder and Neugebauer*, 1964].

It would be a natural extrapolation of this general viewpoint, if the same solar-wind source were invoked to explain the residual magnetic fluctuations, of amplitude 3–6 γ say, that appear on most 'quiet' days even at middle latitudes. The present note is concerned with the possibility that a distinct second source is operative at this low level of intensity, however, and that this source provides a natural background of magnetic noise into which the fluctuations induced by the solar wind may subside on occasion. The source in question is that provided by the irregular winds of the ionospheric dynamo region.

The thought that some magnetic fluctuations might have atmospheric origins is by no means new. Indeed, such a source received major consideration in the years before solar-wind and magnetospheric studies became fashionable. Some attempts were made to test the hypothesis, by seeking a correlation between local magnetic and meteorological conditions. A degree of success in this venture appeared initially to have been achieved, but it has not proved to be statistically significant [*Chapman and Bartels*, 1940, Sec. 6.12]. This null result does little to dispose of the hypothesis, however, for there is no *a priori* reason to suppose that the dynamo region is intimately related to the meteorology of the troposphere directly below.

It has been argued elsewhere [*Hines*, 1960, 1963 a, 1964], and it will be assumed here, that the irregular winds of the ionosphere are attributable to internal atmospheric gravity waves, propagating energy upwards from sources below. Sources as low as the troposphere may be imagined, and these may indeed be variable in intensity according to the meteorological conditions. [See, for one example, *Gossard*, 1962.] But even if such sources should be dominant—and there is no reason as yet to suppose that they are—the null result mentioned above should come as no surprise, for the major irregular winds of the dynamo region are associated with waves whose energy propagates at only a slight inclination from the horizontal, and they should appear in the dynamo region only after suffering a horizontal

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displacement of a thousand kilometers or more from their source.

An unambiguous test of the hypothesis can be made only when magnetic data are compared with directly determined wind measurements in the dynamo region. Ground-based ionosonde and radio-meteor observations might conceivably be adequate for the purpose, though they would retain certain elements of ambiguity that are undesirable. Rocket released vapor trails, though expensive, could be decisive.

These vapor trails actually provide the new data on which the conjectured link between magnetic fluctuations and ionospheric winds is here resuscitated. An extensive analysis by *Kochanski* [1964] shows the irregular winds to be of the order 40 m/s at heights of 90–130 km, where the Hall conductivity of the daytime ionosphere reaches its maximum values. These winds are quite comparable to those of the tidal and prevailing components at the same level. Since the latter are deemed to account for the daily variation (Sq) of magnetic field at ground level, whose amplitude is of the order 30γ at middle latitudes, it is clear that the magnetic effects of the irregular winds cannot be dismissed out-of-hand. On the contrary, there would appear to be a problem in accounting for the *absence* of irregular fluctuations of the order 30γ .

This problem can be resolved by the consideration of two effects. In the first place, it must be recognized that polarization fields can be established in the large-scale wind systems of the daily variation, and that these can result in an effective dynamo-region conductivity some 2 to 5 times greater than the integrated Hall conductivity [*e.g.*, *Baker and Martyn*, 1953]. The irregular winds, on the other hand, would tend to build up competing polarization fields which would discharge one another, with the result that the non-enhanced Hall conductivity would be more appropriate to an assessment of the associated currents.

The second point concerns the irregular nature of the winds themselves. While the currents produced locally may well be strong, they will tend to lie in differing directions and their magnetic effects will then cancel to some extent. We may crudely conceive of N effective wind cells, for ground-level observations at any one point, and we might expect the magnetic deviation observed at that point to be reduced by a factor $N^{1/2}$ from the value that would have obtained, had all the currents been flowing in the same direction. The vertical half-wavelength of the dominant irregular winds is about 6 km at the base of the dynamo region, rising to 12 km or more at the top [*Kochanski*, 1964], in agreement with theoretical limits for atmospheric gravity waves [*Hines*, 1964]. This suggests that perhaps 4–6 ‘cells’ might be stacked vertically within the dynamo region. The horizontal half-wavelength is of the order 200 km, as inferred by *Hines* [1960] from the meteor data of *Greenhow and Neufeld* [1959] for slightly lower altitudes, and this suggests that only two or three ‘cells’, horizontally spaced in each of two directions, need be taken into account for magnetic measurements at ground level. A total of 16–54 ‘cells’ may then be effective, to reduce the amplitude of the magnetic fluctuations by a factor in the range 4–7.

The two reduction factors combine to produce a net reduction which lies in the range 8–35. When compounded with the daily variation of 30γ , they yield finally the range 1–4 γ as a crude estimate of the fluctuations that may be expected from the irregular winds. This

estimate could well be low, since the magnitudes adopted for the reduction factors tend to be generous, and no reductions were considered to be operative in the case of the daily variation (although they might arise: for example, as a consequence of the tidal change of phase with height). The estimate is, however, quite compatible with the observed magnitudes of $3-6\gamma$ on typical 'quiet' days at middle latitudes.

A correlation time scale of about 100 minutes was inferred by *Greenhow and Neufeld* [1959] for meteor-height irregular winds. This was taken to imply dominant waves with periods of the order 200 minutes by *Hines* [1960]. Such periods would then be natural to assign to the dominant dynamo-region winds, at least at the lower levels, since there the observed amplitude and vertical scale sizes are quite consistent with an upward extrapolation from the dominant winds of the meteor level. On the other hand, wave periods as short as 10 minutes are certainly possible [*Hines*, 1960], and have been inferred to be present, both from sporadic-E measurements [*Hines*, 1963b; data from *Heisler and Whitehead*, 1962] and from the existence of small-scale (1 km) irregularities [*Hines*, 1963a]. Thus, time scales of order 10-200 minutes, more or less, are to be anticipated in the irregular winds, and these match the time scales that are observed in the $3-6\gamma$ magnetic fluctuations that are of interest here. (They also match the periods of those gravity waves that can most readily escape upward out of the troposphere [*Gossard*, 1962].)

Quasi-periodic magnetic variations are observed on occasion, with time scales in the same range as the irregular variations; they may well reveal the passage of a single dominant gravity wave through the dynamo region. It is in this context, incidentally, that the possible connection between magnetic variations and gravity waves was first suggested to me, some years ago, by Dr. I. Paghis of Ottawa.

The resolution of wind-induced fluctuations from solar-wind-induced fluctuations may come in part from an examination of diurnal variations. The wind-induced component depends for its existence on dynamo-region conductivity, and therefore should drop to inappreciable levels at night; the others would tend to be damped by dynamo-region conductivity, and so should be enhanced at night unless they are predominantly incident on the daylit hemisphere. The geographical extent, over which an isolated pulse is observed, may provide another clue.

As noted already, there is a substantial degree of correlation between the Kp index and the speed of the solar wind [*Snyder and Neugebauer*, 1964]. The correlation is not perfect, however; there is a spread of some 10-20 units in the daily sum of the three-hourly Kp 's, for any given value of solar wind speed. Some scatter is to be expected, of course, even if the Kp index derives entirely from solar-wind origins. On the other hand, it is also possible that some part of the scatter is due to fluctuations engendered by the irregular ionospheric winds now under discussion. A wind-induced magnetic fluctuation of 6γ would contribute at most one unit to the three-hourly Kp index, or 4 units to the daily sum of Kp 's if allowance is made for a contribution only during a 'daylight' 12-hour period. This is well within the scatter of the Snyder-Neugebauer measurements, but nevertheless constitutes a significant fraction of it. Because of the peculiar manner in which the Kp index is constructed, the wind-

induced fluctuations would be relevant only if they were to vary in concert over a broad range of longitudes, at sub-auroral latitudes in the northern hemisphere. Such a variation is quite conceivable if, for example, the circumpolar jet stream of the stratosphere acts as a major source of gravity waves.

This conjecture can be pursued, perhaps to an unwarranted extreme, in connection with the analysis of *Jacchia and Slowey*, [1964]. They report that the temperature of the *F* region varies with magnetic activity in a different fashion, when $Kp \lesssim 3$, than it does at times of magnetic storms. The temperature is in fact far more sensitive to Kp changes, when Kp is small. It undergoes variations of 10 per cent, approximately proportional to the two-day mean of the three-hourly Kp , as that mean ranges from 0 to 3. The energy flux carried by atmospheric gravity waves into the *F* region, and deposited there, is estimated to be about 10 per cent of the heat requirements of the region [*Hines*, 1965]. That estimate permits the speculation that the altered behavior and increased sensitivity reported by *Jacchia and Slowey* may be associated in part with a common gravity-wave input to the temperature and Kp measurements. This particular speculation is subject to a number of counterarguments, however, and so will not be pursued in detail; it may be subject to a decisive dismissal once simultaneous data on *F*-region temperatures and solar-wind speeds become available.

None of the foregoing discussion stands on truly firm ground, and it is put forward with some diffidence in consequence. One would certainly wish for a more thorough analysis than has been possible here, both from the theoretical and from the observational points of view. We are, however, currently in and soon to depart from the years of the quiet sun, and it is only in those years that conditions favorable to an experimental test are likely to be found. This note is presented in the hope of stimulating such a test, perhaps through the use of ground and rocket-borne magnetometers, united with vapor-trail determinations of wind systems. The IQSY program contains both types of measurement, but the value of their exploitation in unified experiments to study irregular magnetic fluctuations does not appear to have been appreciated widely.

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References

- Baker, W.G., and D.F. Martyn, Electric currents in the ionosphere, I: The conductivity, *Phil. Trans. Roy. Soc. London, A* **246**, 281–294, 1953.
- Chapman, S., and J. Bartels, *Geomagnetism*, Clarendon Press, Oxford, 1940.
- Gossard, E.E., Vertical flux of energy into the lower ionosphere from internal gravity waves generated in the troposphere, *J. Geophys. Res.* **67**, 745–757, 1962.
- Greenhow, J.S., and E.L. Neufeld, Measurements of turbulence in the 80–to 100-km region from radio

- echo observations of meteors, *J. Geophys. Res.* **64**, 2129–2133, 1959.
- Heisler, L.H., and J.D. Whitehead, Rapid variations in the sporadic-E region, *J. Atmospheric Terrest. Phys.*, **24**, 753–764, 1962.
- Hines, C.O., Internal atmospheric gravity waves at ionospheric heights, *Can. J. Phys.*, **38**, 1441–1481, 1960.
- Hines, C.O., The upper atmosphere in motion, *Quart. J. Roy. Meteorol. Soc.*, **89**, 1–42, 1963 a.
- Hines, C.O., Ionization irregularities in the E-region, *J. Atmospheric Terrest. Phys.*, **25**, 305–306, 1963 b.
- Hines, C.O., Minimum vertical scale sizes in the wind structure above 100 kilometers, *J. Geophys. Res.*, **69**, 2847–2848, 1964.
- Hines, C.O., Dynamical heating of the upper atmosphere, *J. Geophys. Res.* **70**, 177–183, 1965.
- Jacchia, L.G., and J. Slowey, Temperature variations in the upper atmosphere during geomagnetically quiet intervals, *J. Geophys. Res.*, **69**, 4145–4148, 1964.
- Kochanski, A., Atmospheric motions from sodium cloud drifts, *J. Geophys. Res.*, **69**, 3651–3662, 1964.
- Snyder, C.W., and M. Neugebauer, Interplanetary solar-wind measurements by Mariner II, *Space Res.* **4**, 89–113, 1964.