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Equatorial disturbance dynamo electric fields

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EQUATORIAL DISTURBANCE DYNAMO ELECTRIC FIELDS

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Abstract. F-region vertical drift data from Jicamarca, Peru show that equatorial east-west electric fields are sometimes perturbed 16-24 hours after the onset of geomagnetic storms. These disturbance dynamo electric fields, which must be caused primarily by the action of neutral winds at low and middle latitudes, decrease and sometimes even reverse the quiet time electric field pattern during both daytime and nighttime. The long delay excludes the possibility that gravity waves are responsible and suggests that the thermospheric circulation is disturbed. The data also show that after some storms there are no such delayed disturbances, a fact which may be due to the longitudinal structure of the disturbances at high latitudes and/or that only very strong storms can produce major thermospheric perturbations that extend to middle and low latitudes.

Introduction

Studies of low latitude ionospheric electric fields have shown close coupling between low and high latitude fields during magnetically disturbed periods [e.g., Fejer et al., 1979; Kelley et al., 1979, Gonzales et al., 1979]. The east-west electric field, which drives the equatorial electrojet and the F region vertical drifts, is frequently correlated with large and rapid temporal variations in the high latitude current system. Radar observations have shown examples of nearly simultaneous changes in the equatorial east-west electric field and the zonal component of the auroral electric field during magnetic storms [Gonzales et al., 1979]. A review of recent progress in the study of equatorial electric fields is given in Fejer [1981].

The main effect on low latitude electric fields of large enhancements in the high latitude fields is a fast change, usually in the opposite sense to the quiet time east-west electric fields. But these changes are not the subject of this paper. Rather, we will discuss F-region vertical drift data from Jicamarca, Peru and the corresponding auroral AU and AL indices to show that sometimes, but not always, there is an additional delayed disturbance dynamo electric field associated with large scale perturbations in the thermospheric circulation and conductivity. We believe that this field, which decreases and sometimes even reverses the quiet-time electric field, is associated primarily with changes in the low and middle latitude thermospheric circulation. Conductivity changes have a longer time scale and can affect only the magnitude of the electric fields. The amplitude of the disturbance winds, driven primarily by Joule heating, has a nearly linear dependence on the high latitude energy input [e.g., Mayr and Volland, 1973; Richmond and Matsushita, 1975; Roble et al., 1979], which can be estimated from the time variation of the auroral indices [e.g., Ahn et al., 1982]. We find, however, that a large energy dissipation in the high latitude ionosphere is only a necessary, not a sufficient condition for the generation of disturbance dynamo electric fields at Jicamarca. The equatorial disturbance dynamo electric fields can be identified most clearly when a large magnetic disturbance is followed by a quiet period, since otherwise the disturbance pattern may be masked by the direct penetration electric fields that occur nearly simultaneously with perturbations in the high latitude current system.

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Experimental Results

Equatorial electric fields at Jicamarca are determined by measuring the F-region drifts using the incoherent scatter radar technique [Woodman, 1970]. Over Jicamarca an upward F-region drift of 40 m/s corresponds to an eastward electric field of about 1 mV/m. The integration time is usually 5 min and the accuracy of the measurements is of the order of 1-2 m/s.

We have examined the F-region vertical drift data from 17 magnetically disturbed periods from 1968 to 1978 to determine the importance of disturbance dynamo effects. We have found examples of four clear effects and four more possible effects, usually but not always corresponding to the largest storms. The clearest illustration of the difference between the signatures of direct penetration of magnetospheric electric fields and disturbance dynamo fields was observed at Jicamarca on 8-10 August 1972. The auroral electrojet indices and the Jicamarca vertical drift data for this period are shown in Figure 1. The solid lines in the lower part represent the average quiet time diurnal variation of the vertical drifts. Large excursions in AL began at about 03 UT on August 9; the maximum AE index was close to 1200 gammas at about 11 UT. Geomagnetic conditions had returned to a low level by 13 UT of the same day and remained quiet during the next 24 hours. At 23 LT (04 UT) rapid, large-amplitude variations in the Jicamarca vertical drifts occured in response to the onset of the substorm as discussed in detail by Fejer et al. [1979] and Gonzales et al. [1979]. On August 9 the daytime drifts were close to their undisturbed values, but at 22 LT a much slower variation in the vertical drift pattern began, and led eventually

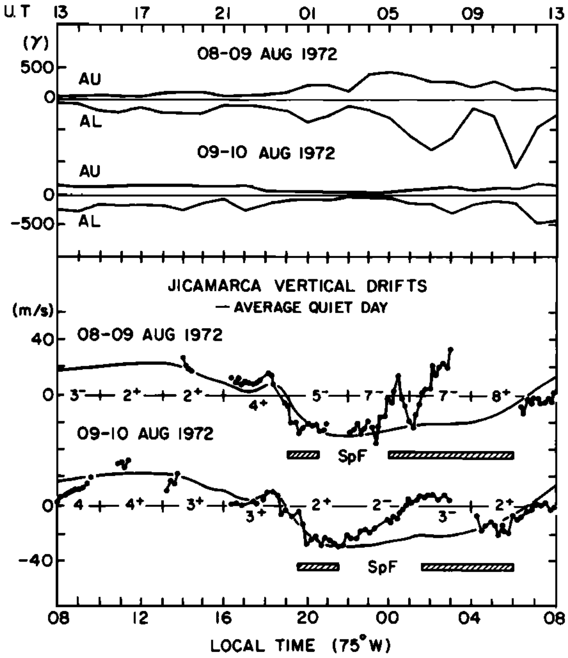

Figure 1. Auroral electrojet indices and F-region vertical drifts at Jicamarca on August 8-10, 1972. The solid curves in the lower panel show the average quiet time diurnal variation. Deviations from this pattern beginning at 2300 LT on August 8 are due to direct penetration effects, whereas the slower deviations starting at 2200 LT on August 9 are due to the disturbance dynamo.

to a reversal in the drift direction. Since the activity level at this time was low the effect cannot be attributed to direct penetration electric fields. Furthermore, the variation was much slower than that characteristic of direct penetration. The maximun amplitude of the disturbance dynamo field was about 1 mV/m in this case, and the delay between the onset of the storm and the beginning of the deviation in the equatorial vertical drifts was between 20 and 24 hours.

The disturbance dynamo electric fields occurred most frequently in the post midnight-prenoon period at Jicamarca. Figure 2 shows the auroral indices and the vertical drift data during the strongest such daytime event seen at Jicamarca. The AU and AL data for the period February 10-14, 1969 show a large storm beginning at 20 UT on February 10 and lasting until 00 UT on February 12. Drift data were not available prior to 14 LT on February 11, but the measured drifts at that time show that a disturbed pattern already existed. A normal pattern was not reestablished until about 20 LT or later on the following day. This example also shows the difficulty that is often encountered in determinig the timing of the event.

The data for May 27-30, 1970, shown in Figure 3, represent an example of a pattern during an extended period of magnetic activity, a situation more common than the examples in Figures 1 and 2. In such an extended storm it is usually very difficult to separate the effects of disturbance dynamo and penetration fields. A large magnetic storm was already in progress at 13 UT on May 27 when the drift measurements were started. Although there was a brief quiet period between 05 and 09 UT on May 28, geomagnetic conditions were fairly active at least until 18 UT on May 28. The daytime drifts on May 28 were smaller than the quiet time values before about 13 LT and larger afterwards. Beginning at approximately 22 LT, the drifts show a departure from the quiet-time behavior somewhat similar to that seen on August 10, 1972. However, there are also rapid variations associated with direct penetration effects, particularly around 03 LT. Thus, the vertical perturbation drifts in this case may be due to a combination of direct penetration and disturbance dynamo electric fields.

Our final example, shown in Figure 4, is representative of several magnetic storms (about half of the cases examined) which do not seem to generate appreciable delayed effects in the equatorial electric fields, at least not at Jicamarca. The auroral electrojet indices for May 14-16 show that a storm began at 17 UT on May 14 and lasted until 12 UT on May 15. Based on the other cases presented here, a disturbance dynamo perturbation would be expected at the equator, but the drifts throughout the period

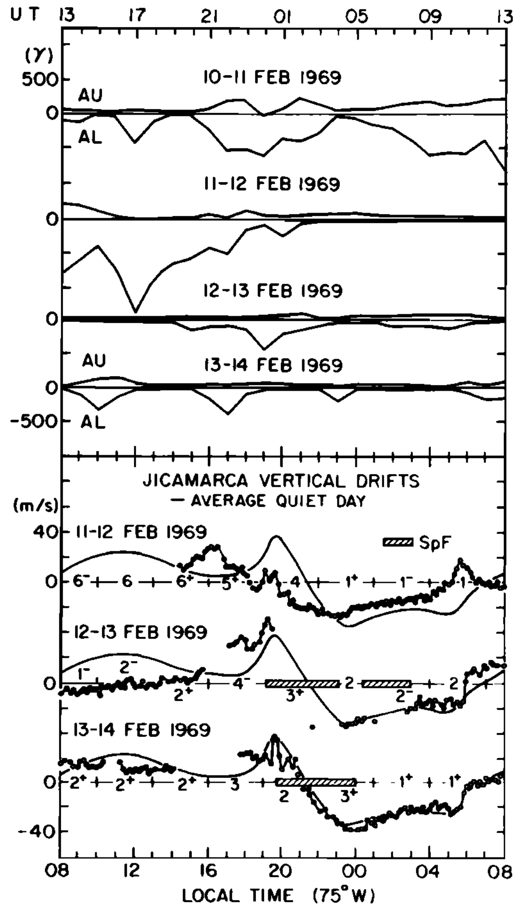

Figure 2. Same as Figure 1 but for February 10-14, 1969. The vertical drifts were disturbed over 24 hours in response to the very large magnetic storm that lasted from 2100 UT on February 10 to 2200 UT on February 11.

were not significantly different from the quiet time pattern. Hence we see that a large high-latitude disturbance is not by itself sufficient to cause a disturbed dynamo effect at Jicamarca.

Along with the electric field data, we have also examined foF2 data from two northern hemisphere ionosonde stations (Wallops Island, Virgina and Boulder, Colorado) and two southern hemisphere stations (Tucuman, Argentina and Concepcion, Chile) to determine if the slowly varying disturbance dynamo electric fields were indeed associated with global thermospheric perturbations. The results were not inconsistent with the results of Park and Meng (1976) who studied the response of foF2 to isolated magnetic substorms, not large storms. A response was observed at Jicamarca only if daytime foF2 depressions appeared near the same longitude further north or south. For example, when the perturbations appeared at Wallops Island or Concepcion, a disturbed dynamo pattern would also appear at Jicamarca, but if the pattern was perturbed at Boulder, but not at Wallops, no effect was seen at Jicamarca.

Although these ionosonde data show that the longitudinal structure of the disturbance is important in determining where the effects will be observed, foF2 could not be used to trace the propagation of the perturbed circulation from high to low latitudes. As Park and Meng (1976) have shown, substorm related changes in the F-region peak electron density occur primarily during daytime, beginning at sunrise, giving the disturbance an apparent westward velocity component. The disturbance in the vertical drift at Jicamarca can begin at any time, as the cases presented here show. Thus, although the longitudinal structure of both types of disturbances appear to be related, there are clear differences in the electric field and

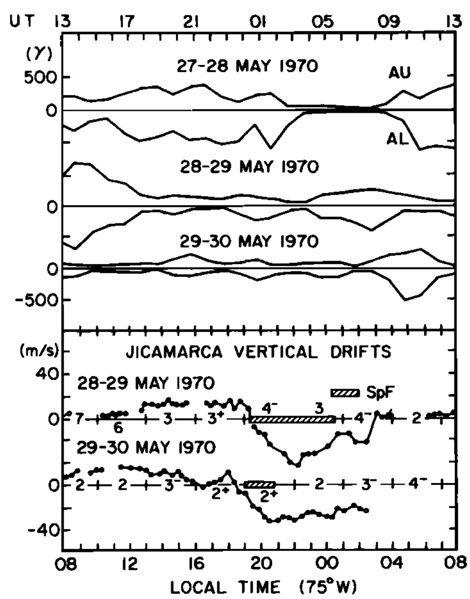

Figure 3. Same as Figure 1 but for May 27-30, 1969. The long duration of the storm makes it difficult to separate the disturbance dynamo and direct penetration effects.

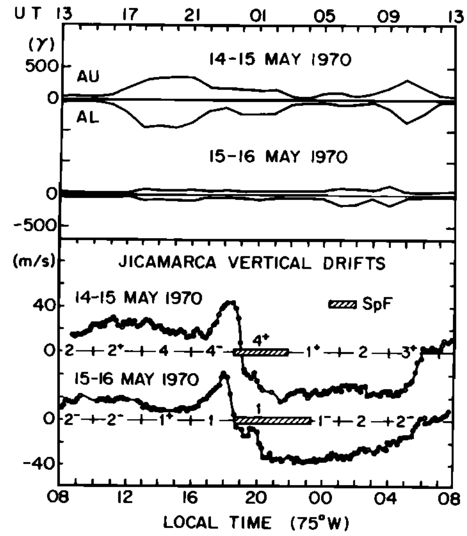

Figure 4. Data for the period May 14-16, 1970. The characteristics of the storm appear to be suitable for creating a disturbed dynamo pattern at low latitudes, but no effect was seen.

electron density effects. Unfortunately, we had electric field data from only one longitude and a relatively small data set which did not allow us to determine the longitudinal extent of the phenomena. The electric field measurements, however, do seem to be a more sensitive indicator of the disturbance at nighttime than are the foF2 observations.

Discussion

Our results show that the time delay between the onset of energy deposition at high latitudes and the onset of equatorial disturbance dynamo effects is of the order of 16-24 hours for the cases we examined, although it was frequently diffficult to make an accurate estimate. This delay is considerably longer than the estimated 3-4 hours taken by large scale thermospheric waves such as gravity waves to reach middle and low latitudes [Francis, 1975], but it is of the order of the characteristic time for the establishment of a steady circulation pattern [Richmond and Matsushita, 1975].

Some large magnetic storms do not seem to generate detectable disturbance dynamo electric fields at Jicamarca. The highly localized nature of ionospheric disturbances associated with large geomagnetic storms is well known from the study of ionospheric storms [e.g., Kane, 1973] and from corresponding composition changes detected by satellites [e.g., Prolss, 1981]. The auroral indices used in this study give an estimate of the high latitude energy input [Ahn et al., 1982], but only on a global scale. A more detailed study should take into account the time dependent global distribution of energy input associated with magnetic storms.

Blanc and Richmond [1980] have studied a two-dimensional numerical model of ionospheric disturbance electric fields and currents driven by auroral Joule heating during magnetic storms. They showed that the low latitude electric fields and currents driven by the high latitude heat input are in the opposite sense to the quiet time patterns, in agreement with our observations. The calculations indicate that with an energy input of 8.2×10^{11} W for 12 hours, a maximum eastward disturbance electric field of about 1.5 mV/m in the postmidnight-presunrise sector and a nearly constant westward electric field of about 0.6 mV/m during daytime would be expected. Our results show disturbance electric fields of this magnitude. However, if we use the relationship between the Joule heating rate and the AE index given by Ahn et al. [1982], i.e. $U_J=2.1 \times 10^8$ AE(γ) W, then our results would imply that a smaller energy input than that of Blanc and Richmond could generate the disturbance fields reported here. For example, the average energy input during the period shown in Figure 1 would be less than 2×10^{11} W, about one quarter of the value used as input in the numerical model. In addition, our study indicated a time scale about twice as long as the low latitude time scale (6-12 hours) in the Blanc-Richmond model.

It is clearly important to include the temporal and spatial distribution of the heat source in any future disturbance model, as Roble et al. [1979] have done. In their study, however, the numerical model was only two dimensional, and no electric field calculations were performed.

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