January 1, 1981

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JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 86, NO. A1, PAGES 215-218, JANUARY 1, 1981

F REGION EAST-WEST DRIFTS AT JICAMARCA

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Abstract. F region east-west drifts have been measured at Jicamarca for almost 10 years, using incoherent scatter. The drifts are westward during the day and eastward at night. The daytime drift velocities are about 50 m/s and change very little with season or solar cycle. The evening reversal occurs at about 1600 local time throughout the solar cycle. The maximum nighttime eastward drifts are about 105 and 130 m/s during solar minimum and maximum, respectively. The daytime and nighttime drifts show very litle variation with magnetic activity. These Jicamarca incoherent scatter results (especially the reversal times) differ appreciably from results obtained using other techniques, but there appear to be fairly simple explanations for the apparent disagreements.

Introduction

The large number of ionospheric drift measurements made in the last decade have significantly improved our understanding of the worldwide ionospheric electric fields. These measurements, which have been reviewed in a number of papers [e.g., Balsley, 1973; Testud et al., 1975; Blanc and Amayenc, 1976; Blanc, 1979], have formed the basis of recent detailed worldwide dynamo electric field models [Richmond, 1976; Forbes and Lindzen, 1976; Richmond et al., 1980; Blanc and Richmond, 1980].

F region drift measurements have been made at the Jicamarca Radar Observatory (12°S, 76.9°W; magnetic dip 2°N) for over a decade. The vertical drifts have given us a detailed picture of the variation of the equatorial east-west electric fields [Woodman, 1970; Balsley, 1973; Fejer et al., 1979a, b; Gonzales et al., 1979]. The F region east-west drifts have been observed less extensively at Jicamarca; the only previous study was published by Woodman [1972]. The F region east-west drifts have also been measured at Thumba (magnetic dip 0.5°S), using spaced receiver techniques [Chandra et al., 1970; Rastogi et al., 1972], but drifts measured in this way differ substantially from those observed at Jicamarca [Balsley, 1973], a point we shall return to later. The purpose of this paper is to describe all the east-west drift measurements made at Jicamarca since 1970 and to compare these observations with other related data (such as the Indian results) and with available theory.

Measurement Techniques

The procedure used for measuring the F region drifts at Jicamarca was described in detail by Woodman and Hagfors [1969] and Woodman [1972]. The large Jicamarca antenna is split into two beams, which are both perpendicular to the magnetic field and point 2.45° to the east and 4.33° to the west of vertical, giving a net split of 6.78°. The line of sight drifts from these two directions are then combined to give the F region east-west and vertical drifts. Usually the drifts are measured from 275 to 500 km with a resolution of 25 km. The integration time is typically about 5 min, and the accuracy of the observations is about 1-2 m/s for the vertical drifts and about 12 m/s for the east-west drifts. The drifts are nearly height independent from 275 to 500 km except around reversal times and during the occurrence of spread F. Most of the results to be presented here were obtained by averaging the drifts between 300 and 400 km, where the measurements are most accurate. During periods of mild spread F the altitude region was sometimes shifted somewhat to avoid the echoes from the irregularities; during severe spread F we did not obtain useful east-west drift data.

Results

We have examined all the east-west drift data obtained at Jicamarca from 1970 through May 1977. The drifts from 1970 to 1971 and from 1974 to 1977 were taken to be representative of the results during solar maximum and solar minimum, respectively. The measurements from 1972 to 1973 were very sparse and will not be included in our study.

Fejer et al. [1979a] have shown that the equatorial F region vertical drifts during solar maximum and solar minimum differ substantially. In contrast, the F region east-west drifts change very little with solar cycle, as is shown in Figure 1 (positive drifts are eastward). The triangles in this case indicate the periods when the number of samples used was smaller than or equal to 3. The number of samples per plotted point varies from 45 and 26 at about 2000-2100 local time during solar minimum and maximum, respectively, to only a few in the early morning period. The late night and early morning data were also less accurate because of the small

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Paper number 80A1177.
0148-0227/81/080A1177$01.00

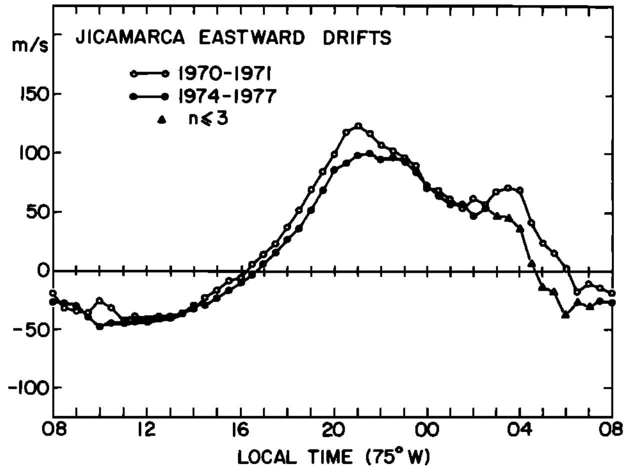

Fig. 1. Daily variation of the average east-west drifts during solar maximum (1970-1971) and solar minimum (1974-1977). The triangles indicate the periods when the average drifts were obtained by using three or less samples.

signal to noise ratios obtained during these periods. The drifts were westward during daytime with a maximum average value of about 45 m/s between 1000-1300 local time. The nighttime eastward drifts are considerably larger during both solar maximum and solar minimum. The maximum eastward drifts are about 130 and 105 m/s, respectively, and occur at about 2100 LT. For the rest of the night the drifts do not change with solar cycle except perhaps in the early morning period. As we just pointed out, however, the early morning results are somewhat uncertain.

The seasonal averages of the data for solar maximum and minimum conditions are shown in Figure 2. The solar minimum averages are slightly different from those presented by Richmond et al. [1980] because of the slightly different definitions used for the seasonal periods. There is no pronounced seasonal variation evident in our data, although there is some indication that daytime drifts are largest in the summer and that nighttime drifts are largest in the summer during solar maximum, but there were only a few data points during most of the solar maximum summer period, and therefore these latter results might not be reliable.

Figure 3 illustrates the day to day variation and wavelike fluctuations of the drifts. The large variability of the nighttime drifts is due in part to the smaller signal to noise ratio. This is especially true during solar minimum. The general characteristics of the daily variation are, however, very clear.

The F region vertical drifts change appreciably with magnetic activity [e.g., Fejer et al., 1979b; Gonzales et al., 1979], but no such effect was seen in these east-west drift data (see Figure 4). The late night and early morning periods were omitted from this figure because of the small number of samples available. During magnetically disturbed periods the equatorial vertical drifts frequently reverse their direction for periods from a few minutes to a few hours [Fejer et al., 1979b], but the east-west drifts show no such reversals, a result which has also been pointed out by Woodman [1972].

Discussion

The equatorial ionospheric drifts are controlled by the neutral wind generated E region dynamo [e.g., Maeda and Kato, 1966; Matsushita, 1969, 1977; Forbes and Lindzen, 1976] and by F region polarization fields [Rishbeth, 1971; Heelis et al., 1974; Matuura, 1974]. The E and F region dynamo theories were recently reviewed by Richmond [1979]. During the equatorial daytime the F region plasma drifts are strongly coupled to the E region at somewhat higher latitudes by the highly conducting magnetic field lines. The daytime equatorial F region east-west drifts are then representative of the E region east-west neutral winds which generate the vertical electric fields in the F region [e.g., Woodman, 1972]. The results presented here suggest that these E region neutral winds are essentially unchanged throughout the solar cycle.

At night the coupling between the E and F regions decreases because of the large decrease in the E region electron density. F region polarization electric fields are set up which the E region cannot short out. As a result the nighttime east-west drifts become nearly equal to the F region neutral winds which generate these fields [Rishbeth, 1971; Woodman, 1972; Heelis et al., 1974]. Our results show that, as was reported previously by Woodman [1972], the nighttime eastward drifts have a maximum amplitude of the order of 120 m/s occurring at about 2100 local time. These drifts at Jicamarca change little with season and solar cycle, and their direction and amplitude are in excellent agreement with the recent neutral wind measurements from airglow observations at Kwajalein (magnetic dip 8.4°N) reported by Sipler and Biondi [1978], which were also observed to decrease late at night. Bittencourt et al. [1976] obtained somewhat larger neutral winds, maximizing at about

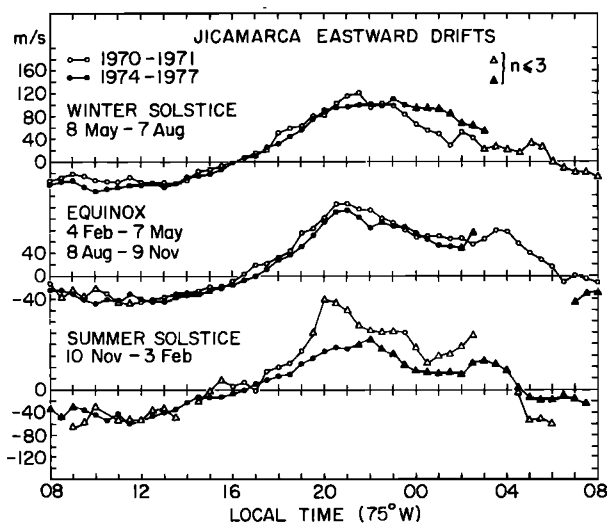

Fig. 2. Seasonal and solar cycle variations of the east-west drifts. The triangles denote that three or less samples were used in the averaging.

2200 local time, from the Ogo 4 O I 630 nm emissions. There is one major difference between the neutral wind and plasma drift measurements which should be recognized. The drifts are usually measured between altitudes of 300 and 400 km, while the winds are measured at the lower edge of the F region, where the airglow is strongest. Therefore as the layer comes down after the reversal of the vertical drifts (at about 2000 local time), the two measurements are made at increasingly different altitudes.

The equatorial vertical drifts are frequently strongly disturbed during periods of high magnetic activity [e.g., Fejer et al., 1976, 1979b; Gonzales et al., 1979]. In contrast, the results shown here indicate that the east-west drifts do not depend on magnetic activity; any electric fields of magnetospheric origin have only a zonal component and directly affect only the vertical drift. However, it is also possible for heating associated with magnetic disturbances to change the equatorial drifts by altering the global thermospheric circulation. These effects would be felt at the equator several hours after the main disturbance observed at high latitudes [Blanc and Richmond, 1980]. This disturbance dynamo effect on the east-west drifts will be considered in a separate paper.

The F region east-west drifts also have been studied in detail in India, using spaced receiver techniques [Chandra et al., 1970; Rastogi et al., 1972]. In this case the velocity is calculated from the time shifts of fading radio waves (frequencies between 2 and 6 MHz) reflected from the ionosphere. The experimental procedures and results using this technique were reviewed recently by Briggs [1977]. Balsley [1973] has compared the early measurements of east-west drifts at Jicamarca with the Indian results. The nighttime eastward drifts measured with the spaced receiver technique are of the same order as the drifts measured at Jicamarca, but the daytime drifts (about 85 m/s for true drifts or 170 m/s for apparent drifts) are appreciably larger. The drifts measured in India decrease with increasing solar activity and are dependent on magnetic activity. Rastogi et al. [1972] have shown a close correlation between the F region east-west drifts measured in India and the equatorial electrojet even during counter electrojet periods. The discrepancy between the daytime Jicamarca and Indian results seems to have a simple explanation: the two techniques are not measuring the same thing. The spaced receiver technique essentially measures the velocity of the diffraction pattern of the reflected wave on the ground. During the day (but not at night) the F region is very smooth, and the pattern will undoubtedly be determined by scattering in the E region due to electrojet irregularities; hence the motion of the pattern will not correspond to F region velocities. This idea is supported by the fact that daytime equatorial scintillations of VHF satellite transmissions are known to be caused by the electrojet irregularities [Basu et al., 1977].

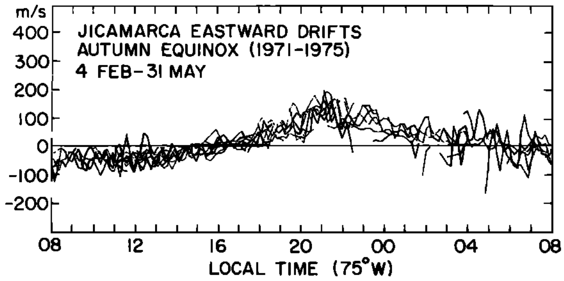

Fig. 3. Daily variation of the F region east- west drifts during the autumn equinox.

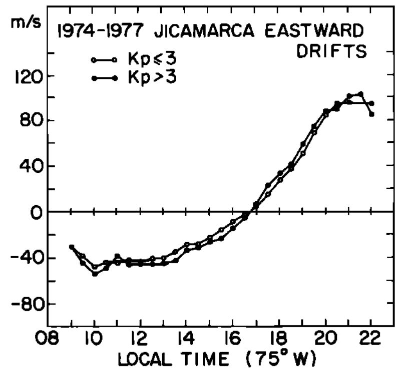

Fig. 4. Variation of the east-west drifts with magnetic activity.

The evening reversal of the Jicamarca drifts from westward to eastward occurs at about 1600 local time, but rocket observations using barium clouds [Rieger, 1974] have indicated the occurrence of large westward drifts at 1900 local time, and spaced receiver measurements have shown a reversal at about 2000 local time. This disagreement can be explained as being a result of the evening circulation pattern recently suggested by Valenzuela et al. [1980]. Electric field measurements from a series of rocket measurements in the equatorial region indicate an evening circulation with westward drifts in the lower F region and eastward drifts near the F region peak and above. In addition, Heelis et al. [1974] have shown that model calculations, including E and F region dynamo fields, result in westward drifts up to about midnight below 220 km, while eastward drifts are present at higher altitudes hours earlier.

The altitudinal variation of the east-west drifts is the result of the combined effect of the E and F region dynamo fields. The efficiency of the F region dynamo is determined by the height of the F layer and by the ratio between the E and F region electron densities, a ratio which changes drastically with altitude in the evening and early night hours. At night the drifts in the equatorial F layer are determined primarily by the F region dynamo; the F region winds rapidly produce a polarization electric field which causes the plasma to drift eastward at very nearly the wind velocity. In the 'valley' just below the F layer, however, the densities are very low, and the plasma drifts will be controlled primarily by E region dynamo fields generated by E region winds north and south of the equator and coupled to the valley region by the curving magnetic field lines. Our data presented here correspond to the F layer itself. Additional numerical studies are needed to understand better the details of the F region dynamo fields. In these calculations the electron density changes resulting from the drifts must be included self consistently (A. D. Richmond, private communication, 1980).

Acknowledgments. We thank the staff of the Jicamarca Observatory for their help with the observations. This work was supported by the Aeronomy Program, Division of Atmospheric Sciences, of the National Science Foundation through grant ATM-78-12323. The Jicamarca Observatory is operated by the Geophysical Institute of Peru, Ministry of Education, with support from the National Science Foundation and the National Aeronautics and Space Administration.

The Editor thanks S. Basu and A. D. Richmond for their assistance in evaluating this paper.

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(Received June 12, 1980;
revised August 12, 1980;
accepted August 13, 1980.)