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High resolution OI (630 nm) image measurements of F-region depletion drifts during the Guará campaign

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Abstract.
A high performance, all-sky, imaging system has provided data on the evolution and drift motions of F-region depletions above the magnetic dip equator at Alcântara, Brazil, (2.3° S, 44.5° W). Monochromatic images of depletions in the OI(630 nm) nightglow were recorded on eight nights during 1-16 October, 1994, as part of the Guará campaign. The drift motions of the depletions were typically 80-100 m/s eastward prior to local midnight and reduced to a minimum of ~30-50 m/s in the morning hours, in accord with previous observations. However, on October 2–3 and 12–13 the depletions were observed to reverse direction for ~60–90 min, achieving westward speeds of ~30 m/s before the motion reverted to eastward around 0100 LT and accelerated to 35-45 m/s near dawn. Magnetic activity and other evidence suggests that these reversals in the motion of the airglow depletions probably result from reversals in the F-region dynamo rather than from shifts in the altitude of the shear in the nighttime F-region plasma drift.

Introduction

For about thirty years, it has been known that the high altitude (250–300 km) equatorial OI(630 nm) nightglow emission often exhibits irregularities associated with spread-F. Weber et al. [1978] recorded the first images of magnetically N-S aligned bands of diminished 630 nm intensity (termed depletions) coincident with ionosonde measurements of spread-F. Since then, several groups have reported measurements of depletions at low magnetic latitudes [e.g Mendillo and Baumgardner, 1982; Tinsley et al., 1995]. These observations establish that depletions are the bottomside signatures of flux-tube aligned plasma bubbles and provide measurements of their horizontal sizes, shapes, and drift speeds.

Almost without exception, previous observers have reported eastward drifts during nighttime hours, consistent with the downward electric field which predominates in the nighttime equatorial F-region. Relatively high eastward velocities (100-200 m/s) are usually observed in the early evening hours, but during the post-midnight period the depletion drift speeds reduce significantly to 20-100 m/s, reflecting the well known diurnal dependence of the vertical electric field. Weber et al. [1978] report a single observation (26 March 1978) at ~16° N in which the eastward drift of the depletions reversed and turned westward. There are two possible interpretations for such a reversal in the zonal velocity of the depletions: the F-region dynamo itself may reverse; or the natural shear in the zonal drift (which in the evening sector creates a boundary between westward drift at low altitudes dominated by the E-region dynamo and eastward drift at higher altitudes) may shift to higher altitudes, placing the airglow layer in the influence of the E-region dynamo. Electric field studies show that at 200-600 km altitude, the drift is usually eastward throughout the night, reversing to westward near 0600 LT [Fejer et al., 1991], although the reversal time depends on season, geomagnetic activity and phase of the solar cycle. The drift reversal observed near midnight by Weber et al. [1978], though unusual, is not inconsistent with this pattern as airglow features at 16°N map up to ~500 km altitude above the equator where the onset of drift reversal from eastward to westward has been observed as early as local midnight in some electric field measurements [e.g., Coley and Heelis, 1989]. Nighttime reversals in the motion of depletions at low latitudes, where the field lines map to lower altitudes above the equator, have not been previously reported.

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Data Presentation

During October 1–16, 1994, high resolution (512 x 512 pixel) all-sky, monochromatic image measurements of F-region depletions in the 630 nm nightglow emission were made using a high quantum efficiency CCD detector ~80% at visible wavelengths. The camera was fitted with an all-sky telecentric lens system and a narrow-band interference filter (bandwidth ~2.4 nm) permitting high signal-to-noise ratio (SNR≈ 20 – 50) images of the depletions to be obtained using an exposure time of 180s. These measurements were incorporated into a 5–9 minute sequence of observations that also included OI(557.7 nm), which also exhibited signatures of the depletions.

The imager was operated from the INPE Satellite Tracking Station at Alcântara, Brazil, (2.33°S, 44.5°W). Assuming a peak emission altitude of 280 km for the OI emission the useful field of view of the instrument was 1000 km radius.

Depletions were evident on 8 out of 15 nights during period 1-16 October but, due to variable cloud conditions the duration of the measurement was often restricted. A clear preference for sightings prior to local midnight consistent with previous measurements from higher latitude sites was found. Depletions were sighted most frequently to the west and appeared generally brighter in this direction. However, high contrast events extending over an area significantly greater than the all-sky field-of-view of several million km^2 were common.

Figure 1 shows four examples of OI(630 nm) depletions recorded during the campaign. Due to the favorable location of the imager on the magnetic equator the depletions exhibit marked magnetic N-S symmetry. The first two images (*a,b*) were recorded at 2355 and 0004 LT on October 9–10 and show several high contrast depletions to the west of Alcântara. Before 2300 LT and after 0100 LT cloud obscured these observations. Analysis of this display indicates motion towards the east with an average speed of 40 m/s during this period. The narrow striations and the enhanced 630 nm intensity towards the north were typical of several of the depletion events observed during this campaign.

Figure 1c-d shows a sequence of two 630 nm images recorded near local midnight on October 12–13, 1994, when reversal to westward motion was observed. Depletions were imaged continuously for more than eight hours (1951–0439 LT) on this night. Initially, the observations were limited by the high elevation moon which was masked out in later images by the large dark spot evident in the figures. Figure 1c shows several well-defined, narrow depletions imaged at 22:58 LT during the period of rapid eastward motion. Figure 1d shows the depletion pattern at 00:35 LT which is equally extensive but has now reversed its direction of motion to westwards. Towards dawn the separation between depletions increased considerably and only three depletions were evident (not shown).

By comparing successive images like those shown in Figure 1, the speed and direction of the airglow features were measured as a function of local time. Figure 2*a*

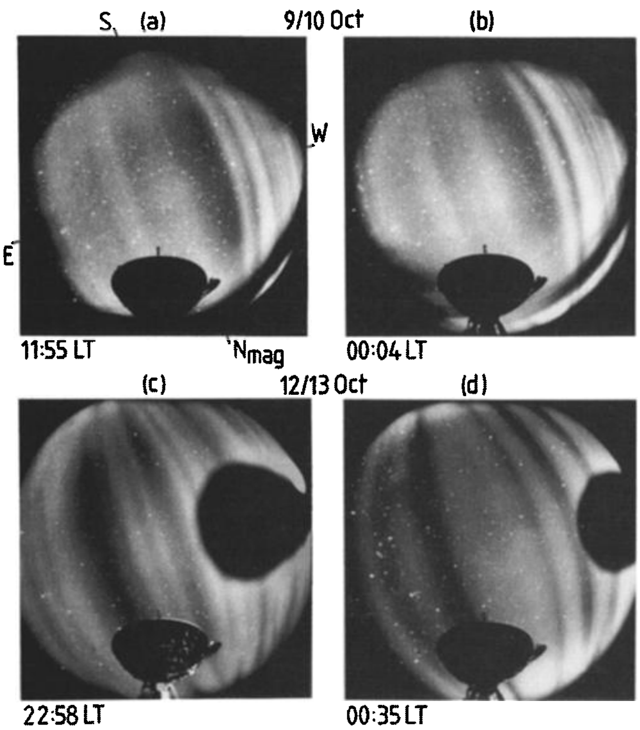

Figure 1. Four all-sky CCD images showing OI(630 nm) depletions from Alcântara, Brazil.

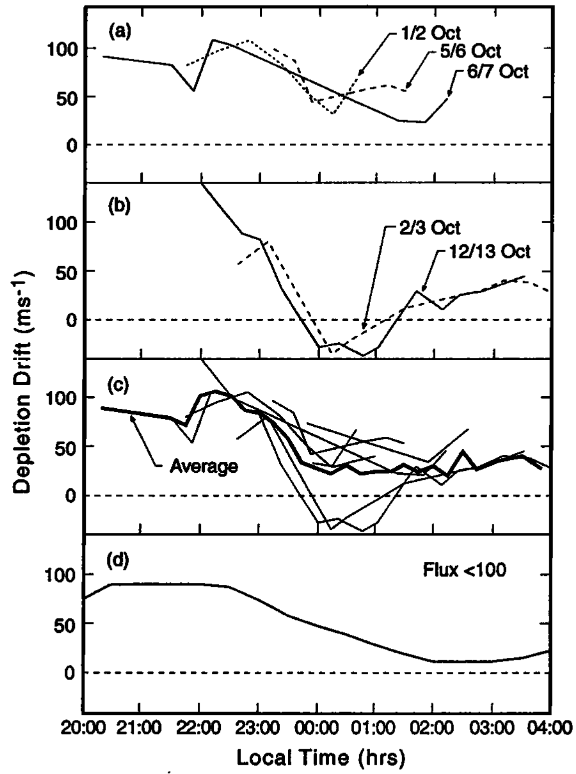

Figure 2. Summary of depletion drift measurements indicating (a) typical nighttime behavior, (b) westward motions, (c) average zonal behavior, and (d) comparison with Jicamarca average zonal drifts for low solar f10.7 fluxes (after Fejer et al. [1991]).

shows three typical drift profiles for which the eastward drift in the evening sector (2000–2300 LT) is ~100 m/s, and thereafter the drift speed decreases steadily reaching ~50 m/s in the post-midnight hours. Figure 2*b* shows the drift profile for the two "anomalous nights". On October 12–13, initial measurements around 2200 LT indicate eastward drifts of ~150 m/s which decrease steadily until 2345 LT, when the drift reverses to westward. The reversal is quite prompt, occurring within the 9-minute sample interval, and the westward drift is relatively low (~30 m/s) but lasts for about 90 min. At 0115 LT the motion reverts back to eastward for the remainder of the night and accelerates up to 45 m/s. Measurements on October 2–3 indicate a somewhat lower eastward drift (80 m/s) in the pre-midnight period prior to the westward reversal, which again occurs near local midnight. The westward drift again reaches a similar maximum value of ~30 m/s shortly after midnight but reverts to eastward at about 0100 LT. In both cases the drift motion at the end of the observations (0300–0400 LT) was 35-45 m/s eastward, comparable to the drifts measured at the same local time on other nights.

Figure 2c shows a superposition of all seven drift profiles. The dark trace indicates the average drift speed as a function of local time as determined from this data set. For comparison, Figure 2d shows the average zonal drift extracted from the Jicamarca incoherent scatter radar (ISR) data base for solar 10.7 radio flux index < 100 [Fejer et al., 1991]. This index was generally in the range 70-90 during the 15 day campaign. The average airglow drift profile agrees remarkably well with the Jicamarca average profile in both magnitude and shape, given the small number of samples comprising the airglow data set. In both profiles a distinct downward trend in eastward drift speed is evident in the evening hours followed by a broad post-midnight minimum. This minimum occurs a slightly earlier local times in the airglow profile (near 0100 LT compared with 0230 LT in the Jicamarca data). The phase of the minimum in the averaged airglow profile was clearly affected during the two anomalous nights.

To investigate the ionospheric conditions during the two anomalous nights, Figure 3 shows the virtual height bottomside of the F-layer (h′F) scaled from the INPE digital ionsoundings measured from Sao Luis (located ~40 km from the camera site). The virtual height of the F-peak was obscured by spread F during most of the time, but h′F was observed continuously. Changes in this parameter provide a measure of vertical motions of the ionosphere over the altitude range 225- 325 km, roughly coincident with the height of the airglow layer (~280 km). In each panel, the time of the reversal from eastward to westward drift, as inferred from the image data, is indicated by a vertical line. On both nights, this reversal in the zonal motion of the depletions occurs when the vertical motion of the F-layer inferred from h′F reduces to nearly zero and also appears to reverse. This observation is reminiscent of spaced receiver scintillation drift measurements, which show that reversals in the zonal drift of F-region irregularities, near the peak of the F-layer are associated with times when the vertical drift nearly vanishes [Abdu et al., 1985]. The coupling between the zonal and vertical plasma drifts, whereby the zonal drift decelerates as h′F decreases (e.g., during 2200-0000 on October 2) and accelerates as h′F increases (e.g., during 0000-0300 on October 3), has been demonstrated in a model of the low-latitude electric fields [Eccles, 1996]. Curl free requirements on the electric field cause the vertical plasma drift to respond in proportion to the rate of change of the zonal drift, which is strongly coupled to the zonal neutral wind dynamo.

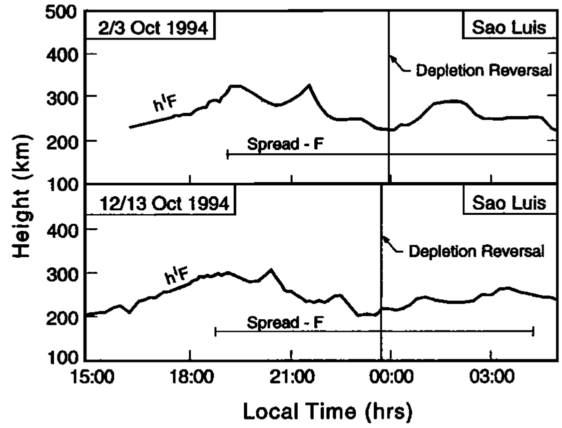

Figure 3. Plots of h′F for 2/3 and 12/13 October, 1994. The vertical line in each plot indicates the time of drift reversal determined from the image data. The horizontal bars show when spread-F occurred.

Discussion

There are two possible mechanisms for reversing the zonal velocity of the airglow depletions: First, the nighttime F region plasma drift may have reversed direction; second, the boundary between eastward drift in the F-region and westward drift below the F-region may have shifted to higher altitude, placing the airglow layer in westward-drifting region.

The zonal F region wind dynamo drives Pedersen currents and creates a vertical polarization electric field, which forces the plasma to drift at nearly the neutral wind velocity [Rishbeth, 1971]. The reversal of the nighttime plasma drift to the west may suggest an unusual reversal in the F region dynamo. High-latitude magnetic activity can alter low-latitude drifts [Fejer, 1993] though high latitude electric field penetration and thermospheric wind disturbances. Though October 1-16 had only moderate magnetic activity, the Kp index increased significantly several hours before the drift reversal on October 2–3 (from ≤ 1.7 preceding 1200 LT to ≥ 5.3 after 1800 LT on October 2.) The significant magnetic activity may have altered the neutral wind dynamo. Due to the delay between the increased Kp and the drift reversal, field penetration is not a likely cause. The reversal of October 12–13 is not accompanied by the same level of Kp activity as October 2–3. However, a significant change in Kp, from 1.7 to 4.0, occurs at

1800 LT on October 12. No other nights during October 1–16 have comparable increases in Kp in the early evening when a magnetic disturbance could contribute to the observed reversal.

The second possibility for the drift reversal is the shear in the nighttime zonal plasma drift. The altitude profile of the zonal drift has a strong eastward flow at F region altitudes and weaker westward flow below the F-ledge. The shear is created by the competing E and F region dynamo winds which are directed oppositely near sunset [Haerendel et al., 1992]. At altitudes equal to or above the F-peak, the field-line-integrated Pedersen conductivity is dominated by the F region, so the F region dynamo controls the drifts. Below the F-peak peak the E region dynamo dominates. The altitude of the shear rises and falls with the F region ionosphere. The 630 nm airglow region of 260–300 km might generally lie above the shear so that the depletions drift eastward. One might suggest that the shear may have moved above the airglow region causing depletions to move westward during the anomalous westward drifts near midnight.

The dominant E region winds below the shear altitude are represented well by atmospheric tidal modes with the dominate mode being the [-1,2] diurnal mode [Tarpley, 1970]. The near-equator zonal winds move westward in the evening with speeds of ~20 m/s near sunset and decreasing to zero near 0200LT. The resulting westward plasma drift below the shear near local midnight would be much smaller than the observed 30 m/s in the airglow irregularity drift. There are other E region wind modulations upon the [-1,2] diurnal tide that could produce the observed westward drifts below the shear. However, since the shear height rises and falls with the F region ledge, it is difficult to see why the anomalous zonal drifts occur near midnight when h'F is near its minimum (Figure 3). When h'F is near its minimum the shear is most likely to be below the airglow region, which would suggest eastward flows. Additionally, during 2200-2300LT the h'F is much higher than at local midnight, yet the depletions show no hint of a westward drift. Together these arguments suggest that the anomalous westward drifts near local midnight on Oct 2/3 and Oct 12/13 are actual reversals in the F region dynamo winds, possibly due to impulsive magnetic activity earlier in the evenings.

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