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EQUATORIAL AIRGLOW DEPLETIONS INDUCED BY THERMOSPHERIC WINDS

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Abstract. Interferometric observations of the 630.0 nm nightglow brightness at the equatorial station of Arequipa, Peru [16.2°S, 71.4°W geographic, 3.2°S dip latitude] have revealed widespread areas of airglow depletion, with reductions in intensity as large as factors of 3 or 4. These depletions correlated closely with large increases of the equatorward (northward) wind and the 630.0 nm kinetic temperature. On occasion, the usually small meridional wind reached a velocity of 100 m/s near 22^h LT lasting for 1 to 2 hours. The temperature increases of 100 K or more existed only in the poleward (southward) direction. Comparisons with modelling calculations suggest that this effect results from an upward movement of the ionosphere along the inclined magnetic field lines, driven by the equatorward neutral wind. The airglow column integrated emission rate is consequently decreased by the slower rate of formation and subsequent dissociative recombination of molecular oxygen ions within the higher F-layer. We conclude that the transient period of equatorward wind is a result of the passage of the midnight pressure bulge.

Introduction

Optical studies of the 630.0 nm brightness distribution of the airglow emanating from the bottomside of the equatorial F-region often show regions of significant depletion [Weber et al., 1982; Mendillo and Baumgardner, 1982; Sipler et al., 1981; Malcolm et al., 1984] that are usually aligned in the meridional geomagnetic direction and have widths ranging between 50 and 200 km. The 630.0 nm airglow line is emitted by $O[^1D]$ atoms produced by the dissociative recombination of O_2^+ ions with F-region electrons. These airglow intensity depletions are believed to be associated with reduced electron density zones in F-region "plasma bubbles" which result from vertical plasma transport driven by the gxB Rayleigh-Taylor instability [see review by Fejer and Kelley, 1980]. Initially the bubbles contain an excess of O_2^+ and NO^+ molecular ions from the lower thermosphere which rapidly capture F-region electrons by dissociative recombination.

In this paper we present several examples of equatorial airglow depletions observed near solar minimum that do not fit this description of an airglow reduction associated with the plasma depletion regions. Accordingly, we suggest an alternative explanation, namely, an upward motion of the F-region along inclined magnetic field lines induced by meridional neutral wind flow. In this case the plasma is not depleted but is shifted to higher altitudes.

Our consideration of the latter possibility is prompted by the opposite effect, airglow enhancements observed near local midnight at Arecibo [Nelson and Cogger, 1971; Herrero and Meriwether, 1980], at the time of the "midnight collapse" in which the ionosphere descends between one and two scale heights. Work over the last few years has established that this downward motion of the ionosphere is caused by the reversal or abatement of the neutral thermosphere equatorward flow to a countervailing poleward flow from the nighttime midnight pressure bulge, which was formed previously by thermospheric winds converging towards the midnight sector or by tidal forcing from below [Mayr et al., 1979; Herrero and Spencer, 1982]. The amplitude of the bulge-related meridional wind was found to be 50 to 100 m/s [Friedman and Herrero, 1982].

The same mechanism was invoked earlier by Chandra et al. [1973] to explain the asymmetry across the equator in the 630.0 nm airglow brightness between 15°N and 15°S observed by the OGO-4 photometer for the American sector.

Our interferometric observations of the 630.0 nm airglow intensity and the thermospheric neutral wind at Arequipa, Peru [16.2°S, 71.4°W geographic, 3.2.°S dip latitude], a station able to observe the 630.0 nm airglow layer from a point over the geomagnetic equator southward to 7°S dip latitude, exhibit examples of significant airglow depletion events overhead and to the South, when there is an equatorwards wind of about 100 m/s. We have modelled the Arequipa observations to determine whether the equatorward neutral wind driving the F-region plasma up the magnetic field lines can raise the plasma sufficiently to account for the intensity depletions. (Since the rate of production of O_2^+ ions by the $O^+ + O_2$ charge transfer reaction is reduced by the smaller concentration of O_2 molecules at the higher altitude, the production of $O(^1D)$ by dissociative recombination is correspondingly reduced.) Although the dip angles are small near the magnetic equator, a 100 m/s equatorward wind at 5°S dip lat. (−10° dip angle) will cause a vertical plasma transport component of $100 \times \sin(10°)\cos(10°) = 17$ m/s. This vertical transport is comparable with the typical vertical ExB drift velocity seen at equatorial latitudes [Fejer et al., 1979].

Measurements

The 100 mm Fabry-Perot interferometer operating automatically at Arequipa, Peru has been described by Biondi and Meriwether [1985], and Meriwether et al. [1985]. A multiple

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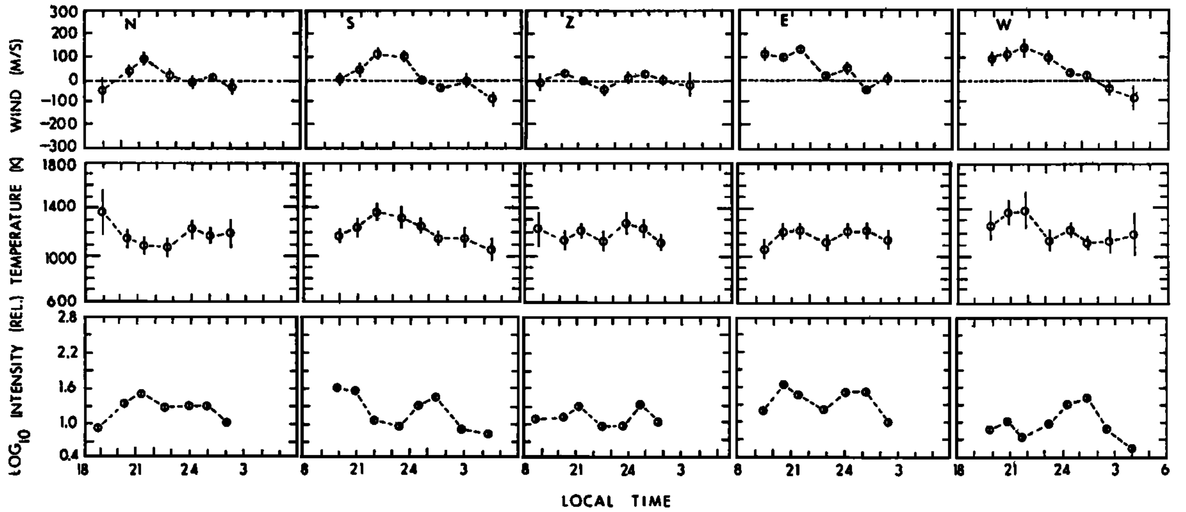

Fig. 1. 28/29 September 1984 (World Day 272) observations of thermospheric wind, 630.0 nm kinetic temperature, and relative intensity ($\log_{10}$) for the directions North, South, zenith, East, and West, respectively. Northward and eastward winds are positive.

aperture exit plate designed to transmit light from several interference orders increases the sensitivity by a factor of four over that provided by a central aperture instrument [Biondi et al., 1985]. The measurements of the spectral profile of the 630.0 nm emission were obtained by sweeping the Fabry-Perot etalon chamber in pressure with argon gas through 60% of one order in about 30 s, and successive up/down scans were summed separately in the mini-computer memory. The pointing head of the instrument was directed by the computer to look, in succession, towards the four cardinal positions at 30° elevation and vertically. Observations in a given direction are terminated either after reaching a signal-to-noise ratio yielding a precision of 15-25 m/s in the velocity determination or after a specified number of pressure scans have been completed.

Figure 1 presents the observed thermospheric winds, temperatures, and intensities seen for the five geographic directions of North, South, East, West, and zenith on 28/29 September, 1984, World Day 272. The sensitivity of the interferometer was not calibrated absolutely, so only relative intensity values are shown. The most striking feature in Figure 1 is that, between 21 and 24^h LT, the usually small (< 50 m/s) meridional wind increased to a speed of about 100 m/s both North and South of Arequipa. During this equatorward flow, there was a decrease in the 630.0 nm surface brightness at the latitude of Arequipa by a factor of 2.1 (see the Z, E, and W observations in Fig. 1) and by an even larger factor, 3.7, poleward of Arequipa (see the S observations). While the neutral temperatures T_n measured in the N, Z, E, and W directions remained at a level of 1050-1100 K during the equatorward flow, the S observations showed a 300 K increase in T_n at this time. The zonal velocity of the thermospheric wind was eastwards until local midnight and became westwards in the early morning hours between 2 and 5^h LT; this result agrees with the seasonal behavior of the Arequipa zonal winds reported by Meriwether et al. [1985] and with the expectation of zonally-converging winds associated with the midnight pressure bulge formation [Mayr et al., 1979].

Other observations obtained during late September and early October 1984 also detected the evening transient in the

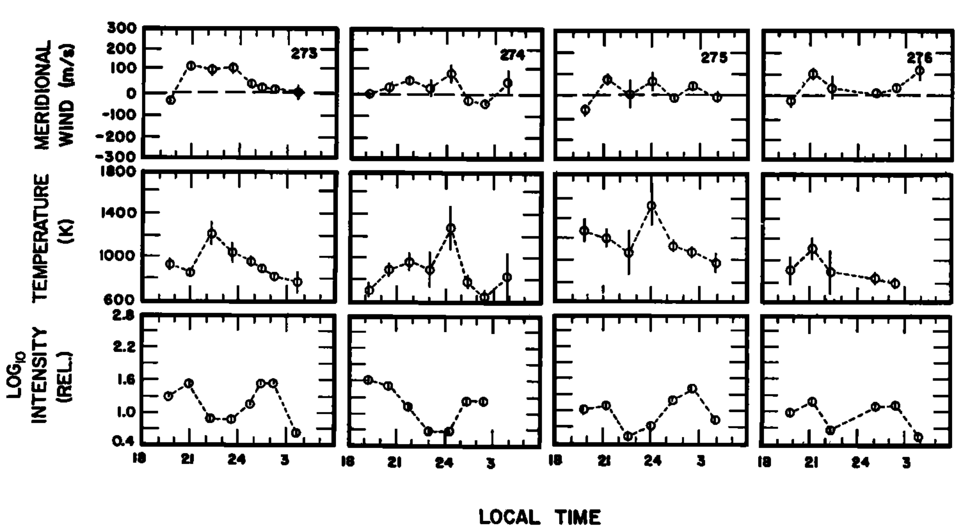

Fig. 2 Meridional winds, kinetic temperatures, and the 630.0 nm relative intensity ($\log_{10}$) for four nights in late September and early October, 1984 for the South direction only; World Day numbers are given.

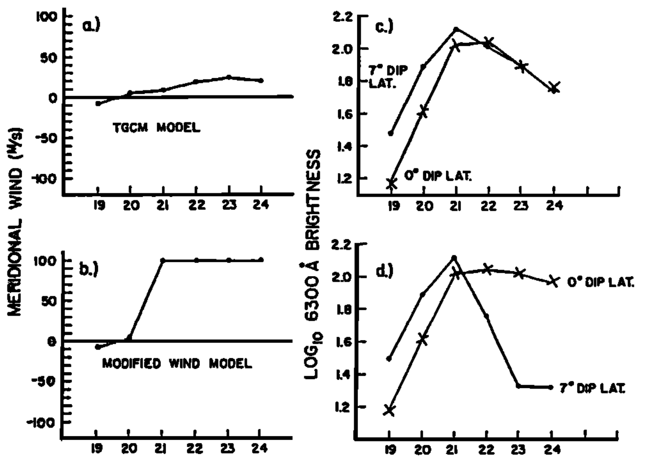

Fig. 3.a) The TGCM-equivalent meridional neutral wind model used in calculation of predicted zenith airglow intensities shown in c); b) the TGCM wind model as modified to simulate the equatorward flow noted in Figs. 1 and 2; c) relative airglow intensities ($\log_{10}$) calculated for directions North (0° dip latitude) and South (7°S dip latitude) of the Arequipa station using the neutral wind model of 4a; d) same as c) but using the modified wind model of b).

meridional wind, although not so clearly defined as on the World Day 272. Figure 2 shows the meridional wind, the 630.0 nm kinetic temperatures, and the relative intensities for the South-directed observations on days 273-276. The increase in the equatorwards meridional wind noted in Figure 1 occurred each night at about the same local time between 21 and 24^h LT. While the amplitude of this transient varied substantially, the depth of the airglow depletion remained constant.

This meridional wind behavior at Arequipa is somewhat similar to the summertime wind pattern observed at Arecibo in that the wind shifts from polewards to equatorwards around 20^h LT, reaches a peak meridional flow of 50-100 m/s between 22^h and 24^h LT, and then abates as the neutral pressure bulge passes [Burnside et al., 1981]. This similarity is not surprising since Arequipa is located at almost the same geographic latitude as Arecibo but in the southern hemisphere. What is surprising is the extent to which the 630.0 nm airglow intensity decreases in response to the increase in the equatorward wind.

Further evidence for the passage of the midnight pressure bulge comes from the temperature data. The thermal enhancement seen in the southward direction in Figure 1 for day 272, together with similar enhancements seen on other nights, is consistent with the thermal signature of the pressure bulge. It is known from the satellite observations reported by Herrero and Spencer [1982] that the thermal enhancement within the nighttime bulge is typically about 100 K, but may be as large as several hundred degrees.

Theoretical Simulation

To assess whether the transient equatorward wind seen in Figure 1 can lead to the observed airglow depletion, we have calculated the expected nighttime zenith 630.0 nm intensities for two locations. The first is a region located at 7°S dip latitude, and the other is at the magnetic equator. The former represents the region seen from Arequipa when the Fabry-Perot instrument looks southward, and the latter the area seen looking northward. For the purpose of this comparison, it is simpler to determine zenith airglow brightness. The latitudinal width introduced by the slant path of the observations is small, about 1 degree, and the conclusion based upon the comparison of our relative intensity observations with calculations carried out for either geometry would not change.

To calculate electron and ion (O^+) densities as a function of altitude, latitude, and local time, the ion continuity equation,

$$\frac{\partial N_i}{\partial t} + \nabla \cdot (N_i V_i) = P_i - L_i \qquad (1)$$

is solved numerically. Here, $N_i (= N_e)$ is the O^+ ion density, P_i the ion production rate, L_i the ion loss rate, and V_i the mean ion transport velocity. The procedure for solving this equation and the transformations required have been reviewed by Moffett [1979], and the input models which must be assumed are given by Anderson and Klobuchar [1983]. These models include: 1.) the MSIS [Hedin et al., 1977] neutral atmosphere appropriate for an equinoctal, solar minimum period; 2.) a photoionization production coefficient at the top of the atmosphere, $P_\infty = 2.8 \times 10^{-7}\ s^{-1}$; and 3.) loss rate coefficients adopted from Torr and Torr [1979]. The vertical ExB drift velocity observed at Jicamarca, Peru that is characteristic of the September equinox, solar minimum period [Fejer et al., 1979] is assumed to be representative of the ion drift motion needed in these calculations. We also assume it to be independent of altitude.

The basic model of the meridional neutral wind adopted for this study is patterned after the one used to model total electron content observations above Ascension Island [Anderson and Klobuchar, 1983]. We designated this model in Figure 3a as the "TGCM" model because it is similar to the nighttime NCAR/TGCM results reported by Meriwether et al. [1985] for Arequipa at the equinox. Our model is assumed to be independent of altitude and symmetric about the geographic equator. Effects of the zonal wind component are neglected, because the geomagnetic field line declination is close to zero at Arequipa. The modified wind model, displayed in Figure 3b, is based upon the Fabry-Perot observations taken at Arequipa on day 272 in 1984. It is identical to the TGCM wind model except between 21 and 24^h LT, when the wind is directed northwards with a speed of 100 m/s, independent of latitude and altitude.

The predicted zenith intensities for the two models are shown in Figs. 3c and 3d, the 0° (dip latitude) curves corresponding to the North-looking observations and the 7° curves to the South-looking observations. Until 21^h LT, the 630.0 nm zenith brightness at 7°S is larger than that at the magnetic equator, since not only is the F-layer higher at the equator, but also the peak electron density is lower. In the case of the modified wind model, after the shift to 100 m/s northwards flow for 3 hours, the predicted brightness at 7°S decreases by a factor of 3, while that at the equator increases slightly.

These results compare favorably with the observations shown in Figure 1. It appears that the ionosphere responds somewhat more rapidly than indicated by the modelling work, but the magnitude of the brightness decrease agrees well with the observed depletion. A more realistic simulation of the time-dependent behavior would require that the vertical ExB drift velocity be measured simultaneously with the neutral wind, so that the two vertical transport effects could be separated. A coordinated Jicamarca/Arequipa campaign to measure both drifts and winds is planned for November, 1985.

Discussion and Conclusions

We conclude from these results that the normal global thermospheric wind patterns may cause significant 630.0 nm airglow depletions in the near-equatorial ionosphere. Our results indicate that the zonal extent, unlike the events reported by Weber et al. [1982], is of order of 1000 km or larger, at least five times greater than the largest width reported in the AFGL aircraft observations.

The lack of any observed airglow depletion in the direction towards the magnetic equator is consistent with the modelling simulation. This suggests that the rise of the ionosphere was not induced by the ExB vertical drift but rather by the equatorward enhancement of the meridional wind. This conclusion is supported by the results of vertical ion drift measurements reported by Fejer et al. [1979], which indicate that the magnitude of the pre-midnight reversal enhancement is not very large for solar minimum conditions. Further, the vertical ion drift usually occurs earlier in the evening, just after twilight or before, whereas the airglow depletion we observed came later in the evening, between 21 and 23^h LT.

Identification of the meridional wind enhancement with the midnight pressure bulge seems reasonable, but the details of the relationship are not well understood. It seems likely that there is an equatorward flow from the pressure bulge created by the secondary temperature maximum noted by Herrero et al. [1982] to lie at a latitude 20° south of the geographic equator for all seasons. This relationship will be examined further when we have acquired more equatorial wind measurements for summer in the southern hemisphere.

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