Equatorial F-region neutral winds and shears near sunset measured with chemical release techniques

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Abstract

The period near sunset is a dynamic and critical time for the daily development of the equatorial nighttime ionosphere and the instabilities that occur there. The pre-conditions necessary for the development of Equatorial Spread F (ESF) plasma instabilities are a region of rapid transition of the ionosphere during these hours. The neutral dynamics of the sunset ionosphere contribute greatly to the generation of currents and electric fields; however, the behavior of the neutral dynamics is experimentally uncertain, and our understanding of single-altitude measurements or measurements that provide weighted altitude means of the winds as a function of time. Vertically-resolved neutral wind measurements in the F region at sunset are very limited. We present two sets of sounding rocket chemical release measurements, one from a launch in the Marshall Islands on Kwajalein atoll and one from Alcantara, Brazil. Analysis of the chemical tracer motions has yielded vertically-resolved neutral wind profiles that show strong vertical gradients in the zonal wind that are unexpected by classical assumptions about the behavior of the neutral wind at these altitudes at sunset near the geomagnetic equator. In addition, these observations show that the direction of the neutral wind reverses over a period of approximately 20 minutes, indicating that the neutral wind may be responding quickly to the rapidly changing solar conditions during sunset.

Introduction and Motivation

Due to the abrupt change in solar heating across the terminator and the associated rapid change in the E-region plasma density, the equatorial ionosphere undergoes significant changes over a short period near sunset. The resulting rapid changes in the E-region plasma density strongly affect the F-region electric fields due to mapping of the fields from lower to higher altitudes. The transition from day to night thus drives a number of processes, including the pre-conditioning of the bottomside F region that can lead to the initiation of Equatorial Spread F (ESF). The dynamics of Spread F have been the subject of many theoretical and experimental studies over the past several decades. Our understanding of many of these processes has improved significantly, but there is still a sparsity of observational data of some of the critical parameters, including the characteristics of the neutral winds in the important bottomside F region.

Experimental Technique

Sounding rocket chemical release experiments have provided accurate in-situ neutral wind measurements in the mesosphere and thermosphere for five decades. In the experiments described here, the chemical releases were photographed from three spatially-separated camera sites, providing simultaneous imaging from three different angles. Wind profiles were obtained for each launch by combining images from pairs of cameras located at different sites. The star field present in each image was used to map the image pixels to equatorial coordinates, i.e., right ascension and declination, based on the known positions of the stars from a star catalog. Software combines the photographs from a pair of sites to compute the intersection point for lines-of-sight to different points within the releases. The output from this procedure is a full three-dimensional position for each cloud point. Vertical profiles are obtained by computing a linear fit from the position data obtained from the image sequence.

Results and Discussion

The goal of the Equatorial Vortex Experiment (EVEX) was to obtain simultaneous E and F region wind measurements, electric fields, and plasma densities in order to better understand the evening pre-reversal vortex [Kudeki et al., 2007]. Launch took place from Roi-Namur, with camera sites at the launch site as well as two remote sites on Lifou and Rongelap (see map below). Sounding rockets released a two consecutive lithium clouds in the F region as well as up-leg and down-leg TMA releases. A composite image of the combined lithium cloud and the down-leg TMA trail is shown below. For this dataset, clouds obscured vision of the trail for approximately 10 minutes, resulting in two distinct observation windows (see fig. 2 (c)).

In the early observation windows, approximately 40 minutes after sunset in both campaigns, we see consistent vertical shear in the zonal component of the neutral wind. Both measurements indicate that the F-region neutral winds are much more structured than previously expected. The reversal from westward flow during the day to eastward flow near sunset appears to occur gradually with altitude. Though comparable vertical wind profiles are scarce, Jicamarca radar measurements indicate that the evening reversal time of equatorial F region zonal plasma drifts from westward to eastward is highly variable [Fey et al., 1991], and a vertical shear and structure is also present in zonal drifts [Fey et al., 1985].

One possible explanation for the observed gradients is the motion of the solar terminator. The terminator moves westward across the Earth as the planet rotates, but it also propagates vertically, as the Earth’s rotation begins to shield lower parts of the atmosphere. The altitude of the terminator can be described by simple geometric considerations [Shah, 1970]. A plot of this function is sketched in Fig. 3 (right), along with its rate of change in km/min. At the time of the earlier EVEX measurement, the shadow height was approximately 100 km. Just 20 minutes later, during the second EVEX observation period, the shadow height has risen to almost 400 km, resulting in significantly different solar conditions at the observed altitudes.

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References


Fig. 2: Neutral wind profiles derived from the Guara campaign (top) and the EVEX campaign (left). The lower profiles in each plot were obtained from the TMA releases, while the upper profiles were obtained from the Ba/Sr and Li trails, respectively.

Fig. 3: The solar shadow height as a function of time, in minutes after local sunset at the equator. Releases for both experiments occurred near 40 minutes after local sunset and persisted for 60 to 120 minutes.