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On the production of traveling ionospheric disturbances by atmospheric gravity waves

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ABSTRACT

This paper deals with how atmospheric gravity waves produce the traveling ionospheric disturbances (TIDs) that are observed by ionosondes. It is shown that, rather than directly producing variations of ionospheric height, a likely mechanism involves changes in ionization density by gradients in the horizontal atmospheric gravity wave air motion. These density changes can be observed as variations of the height of an ionospheric isodensity surface (the usual way of measuring TIDs). This mechanism involving enhancement/depletion of ionospheric density requires quite moderate atmospheric gravity wave air motion speeds, and works well at almost all latitudes.

1. Introduction

Traveling ionospheric disturbances (TIDs) are a ubiquitous ionospheric phenomenon. The TIDs are usually divided into the two categories of medium scale and large scale. The large-scale TIDs are excited by high latitude processes in the auroral regions usually associated with geomagnetic storms (Hunsucker, 1982) and have long horizontal wavelengths and high speeds so that they travel long distances and are occasionally observed in equatorial regions. Studies have shown that these large-scale TIDs are only observed at midlatitudes when the Kp index $> \sim 4$ (Tsugawa et al., 2004). In this paper we are concerned with the medium-scale TIDs that are very common at all latitudes and are an everyday occurrence. The amplitude of these TIDs does vary from day to day so that by specifying some threshold size one can talk about the presence or absence of TIDs. However, there are always some, possibly small, medium-scale TIDs present. These medium-scale TIDs have been extensively studied, particularly at middle and high latitudes (Hines, 1960; Francis, 1975; Williams et al., 1988; Samson et al., 1989; Hocke and Schlegel, 1996). There are fewer studies of TIDs near the equator (Bowman, 2001; Pimenta et al., 2008; Candido et al., 2008), possibly because at one time it was thought that TIDs in this region should be small.

One aspect of the TIDs that has been mostly neglected is how the atmospheric gravity waves (AGW) produce the observed TIDs. It is usually assumed that the AGW directly produce height variations. In this paper we first show some measurements of the amplitudes of TIDs at various latitudes, and we then discuss possible mechanisms whereby AGW produce these TIDs.

2. Measurements

In this study we will use data from near equatorial stations: Cachimbo ($\sim -2^\circ$ mag. lat.), Fortaleza (-5.8° mag. lat.), Sao Jose dos Campos (SJC) (-17.8° mag. lat.), and a midlatitude station London, Canada (55° mag. lat.). Fig. 1 shows an example of the virtual height fluctuations due to TIDs at Cachimbo. The TID fluctuations, with periods a fraction of an hour, are very obvious and have amplitudes of a few tens of kilometers. One can verify that these are TIDs by looking at data from two frequencies and checking that the TIDs show downward phase motion (see for instance Lanchester et al., 1993; and Figs. 15, 18 of Hocke and Schlegel, 1996). We have done this for a few sample intervals. There are also some height variations of longer periods that are probably due to other processes, but are difficult to check via the two-frequency method to make sure that they are not TIDs. Therefore when analyzing TIDs we will not include variations with long periods. In our TID analysis we use band pass filtering to remove the periods $> \sim 2$ h that are probably not TIDs but are just daily variations of the ionosphere, and we also remove periods < 15 min (the approximate F region Brunt–Väisälä period) that are probably just 'noise'. We want to have a measure of the amplitude of the filtered quasi periodic fluctuations that are assumed to be TID ionospheric height variations, and because of

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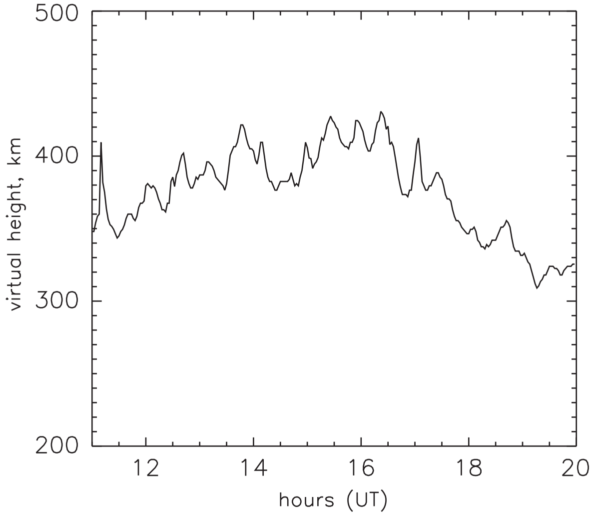

Fig. 1. Example of TID virtual height fluctuations at Cachimbo, Brazil, near the magnetic equator. Frequency is 6.084 MHz and day is July 16, 2005. For local time subtract 3 h.

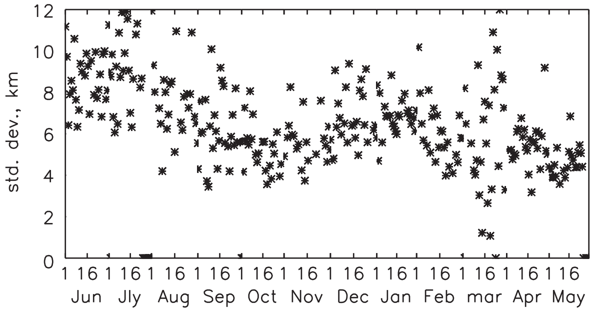

Fig. 2. One year (June 1998–June 1999) measurements of size (standard deviation) of daytime TIDs at Fortaleza, Brazil. Data points on the x axis ($y=0$) are missing days.

their randomness we calculate the standard deviation (SD) of the fluctuations as a measure of the magnitude of the TIDs. Note that if the TIDs were exactly periodic sine waves this standard deviation would be called the root-mean-squared (RMS) amplitude. For the data in Fig. 1, after filtering to remove periods >1.5 h, the SD of the filtered TIDs averaged over the 9 h is 11.1 km.

The measurements reported here use virtual height on a fixed frequency for the TID measurements. At midlatitudes the fixed frequency usually used was 4 MHz, but near the equator a higher frequency, 5 MHz, worked better. For a few sample days we compared TID measurements using real height with the measurements using virtual height. As expected, the amplitude of the TIDs using virtual height was larger than the amplitude using real height (of the order of 20% larger), but for convenience of analyzing large amounts of TID data virtual height was used for the measurements reported here.

Fig. 2 shows the TID measurements at Fortaleza, Brazil (-5.8° dip. lat.). Only daytime measurements were used since at nighttime there were often data gaps due to low critical frequencies, Spread-F, and other effects. The SD values are an average over 10 daytime hours. There appears to be a semiannual variation of the TID magnitude, and possibly a longer time change of amplitude. However, for the purposes of this paper we take the typical size of the TIDs as ~6 km SD at Fortaleza.

In Fig. 3 we show the average SD amplitudes of TIDs at low and midlatitude stations plotted versus magnetic dip latitude. Note that the near equatorial stations all have approximately the same SD amplitude of TIDs, which is surprising because it was generally expected that the TIDs would be weak very close to the equator. The amplitude of the average TIDs at the midlatitude station London is about twice as large as near the equator. Close to the equator Fig. 3 shows that TIDs have typical amplitude ~8 km, and at high midlatitudes the typical amplitude is ~16 km. In the discussion that follows we will, for convenience, take the typical TID amplitude as 12 km, a compromise between midlatitude and equatorial amplitudes. For convenience we also assume a sinusoidal TID height variation so that the 12 km SD variation becomes a 12 km RMS variation in our calculations.

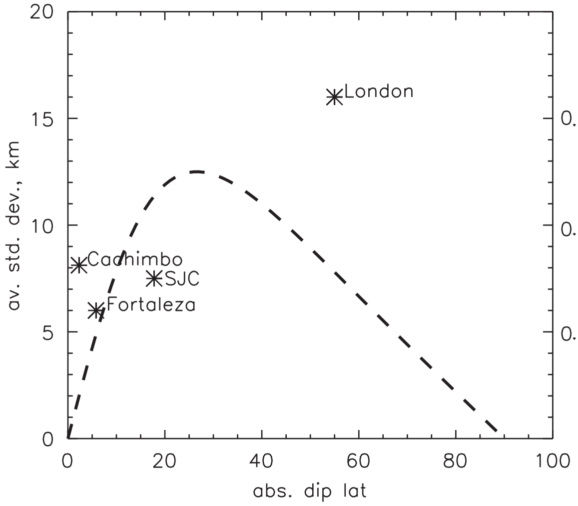

Fig. 3. Size of TIDs at low and midlatitudes. Stations are Cachimbo (mag. lat. -2°), Fortaleza (mag. lat. -6°), Sao Jose dos Campos (mag. lat. -18°), London (mag. lat. 54°). The dashed curve shows $\cos(\text{dip})\times\sin(\text{dip})$ and uses the scale on the right-hand y-axis.

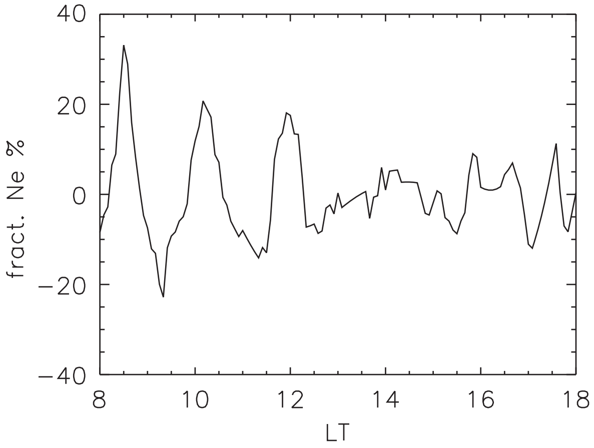

Fig. 4. Fractional daytime changes in NmF2 at London, January 1, 2000. Data have been filtered to remove variation with periods longer than 2 h.

Another property of the TIDs is that they can also be observed as variations of ionospheric density. Fig. 4 shows an example of the fractional electron density changes for the peak of the F2 layer at London for daytime TIDs. It can be seen that fractional electron density changes of the order of 10% are observed. Therefore a suitable TID production mechanism needs to be able to produce a ~12 km RMS virtual height variation and also a ~10% (again assume RMS) electron density variation.

In our calculations we will be using a typical value for the vertical velocity of the ionospheric plasma due to the TID and