NOTES AND CORRESPONDENCE

Middle Atmosphere Tides Observed by Incoherent-Scatter-Type Radars

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Recent successes in measuring the middle atmosphere motion by the Jicamarca VHF radar and the Arecibo UHF radar have proved that the radar technique is of vital importance in the study of the middle atmosphere, the region which remained as “ignorosphere” for long time. This paper will review briefly a few important results of observation of tides by the aforementioned two facilities. Although similar facilities in other places have made various contributions in the middle atmosphere observation, the atmospheric tides in the middle atmosphere have been suc-

cessfully detected only by these two facilities. The Jicamarca radar operates in the frequency 50 MHz and the Arecibo one in the frequency of 400 MHz. These radars are Doppler radars, producing Doppler spectrum of radar echoes. The spectrum spreads about the radar frequency due to motions of the scatterers which are refractive index irregularities. The irregularities are those of free electrons in the mesosphere and those of temperature and humidity in the stratosphere.

Fig. 1 Mesospheric diurnal tides over Arecibo. Detailed plots of amplitudes and phase progression in altitude. The solid line on the left and on the right over the open circles (labeled $\lambda_z=25$ km) is the best fit to the first day southward data. The open circles and squares represent fitting at each altitude to all data available at that altitude. The solid and dashed lines over the open squares are best fits to the full data eastward phase component, the solid line best representing the full altitude range, and the dashed line that below 94 km. The two plots in phase with double- and triple-dashed lines are from Lindzen (1967) and are for the eastward (left) and the southward (right) diurnal tide at 15° latitude.

Fig. 2 Mesospheric periodic winds over Jicamarca. The broken curve gives the best fit by diurnal and 48 hr period components, whilst the chain gives the best fit by diurnal and 120 hr period components.

Fig. 3 Stratospheric diurnal tidal winds over Jicamarca. a) Zonal winds. Vertical profiles of the amplitude and phase (hr of max) of the diurnal eastward wind in 3-4, Oct. and 6-8, December, 1977. Solid lines are theoretical result (Lindzen, 1967). b) Similar to a) except for meridional winds. c) Similar to a) except for vertical winds.

The free electron irregularities in the mesosphere can be due to thermal fluctuation for the Arecibo radar as is the case of the ionosphere plasma whilst the irregularities for the Jicamarca radar can be due to turbulence and sharp gradients in the electron density distribution. The temperature and humidity irregularities in the stratosphere for the both radars occur due to turbulence and sharp gradients of temperature and humidity. All of these irregularities move with local winds, the principle on which the technique to measure winds ultimately depends. The Doppler shift of the radar echo spectrum corresponds to this motion.

It is Mathew who successfully detected at Arecibo mesospheric diurnal tides whose existence had long been suspected (Fig. 1), because Harper (1977) had found diurnal tide just above the mesosphere. One difficulty for the detection is due to the fact that observation is limited only to daylight hours; the mesospheric electron density is too low to be detected at night. Quite recently, there was an attempt to find out long period components of the mesospheric motion

over Jicamarca by Fukao *et al.* (1980). Although they were successful to obtain a systematic phase progression of the 120 hr and 48 hr components, no such a feature was found in the tidal components. Note that there was diurnal components with irregular phase at each height (Fig. 2). No long period observation for the mesospheric tides has been done at Arecibo.

As to the stratospheric tide we are much more informed than the mesospheric one. The lower half of the stratosphere (<30 km) has been probed by balloons which provide with fairly systematic informations on tidal winds (Wallace and Tadd, 1974). However, more precise measurement becomes available now by the radars, which can obtain the stratosphere echoes throughout day, thereby enabling to detect various components of tides. Fukao *et al.* (1978) have shown clearly an existence of diurnal tides in horizontal winds over Jicamarca. Peculiarity was in the shorter wavelength than that expected from tidal theory. Further analysis showed that the situation seems changeable. Fig. 3 illustrates that in December, 1977 the observed diurnal wind both in meridional

Fig. 4 Stratospheric semidiurnal winds. a) Similar to a) in Fig. 3. b) Similar to b) in Fig. 3. c) Similar to c) in Fig. 3. The solid and broken lines are based on calculation by Lindzen and Hong's result (1974).

Fig. 5 Stratospheric tidal winds over Arecibo. a) Diurnal tides. The contour spacing is 2.5 m/s, the shaded part showing eastward winds. b) Semidiurnal tides, similar to a).

and zonal components had those wavelength which is consistent with classical tidal theory, much longer than those obtained in 1974 by Fukao *et al.* (1978). This is the case also for semidiurnal components, though no clear existence was found in 1974 (Fig. 4). However, in October, 1977, only two months prior to that period just mentioned (Fukao *et al.*, 1980), the observed data showed that both diurnal and semi-

diurnal winds had wavelengths much shorter than those the theory expects to be (Figs. 3 & 4). This may suggest that the situation may vary depending on some circumstances perhaps on the prevailing winds in the troposphere and stratosphere; the source exciting tides seems to be located below the height of observation because of the downward phase velocity observed (Figs. 3 & 4). The Arecibo observation (Harper *et al.*, 1980) is

revealing now certain features of stratospheric tides (Fig. 5). It is clear that the pertaining wavelength is fairly short (~ 10 km).

The observed tides as shown here in this paper are fairly novel and would challenge theoretical interpretations.

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