VHF Radar studies of the Migrating and Nonmigrating Diurnal and Semidiurnal Tides Over a Tropical and an Equatorial Station

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1. Abstract

VHF radar measurements of winds are utilized to study the diurnal and semi-diurnal tides over Gadanki and Kotatabang. The tidal amplitudes exhibit maxima in UTLS region during June-September over Gadanki and during March and September over Kotatabang. The vertical wavelength is 3-5 km (Gadanki) and 25-30 km (Kotatabang), which reveal the existence of nonmigrating and migrating tides, respectively. Brightness temperature shows that over Gadanki(deep) and Kotatabang(shallow) convective clouds. Release of latent heat due to deep-clouds is found to be the main source mechanism for nonmigrating tides. The present study brings out the differences in tides over equatorial and low latitude.

2. Introduction

Atmospheric tides are global scale oscillations with periods equal to the harmonics of one solar day. The absorption of solar radiation by water vapor in the troposphere and ozone in the stratosphere sets up a thermal forcing which sets the atmosphere in to oscillations with a period of integral fractions of a day [1]. Migrating tides are sun synchronous with their phase propagating to the west traversing the globe in one solar day. Non-migrating are non synchronous with the sun and they are generated due to the asymmetry in the distribution of water vapor and ozone. In order to understand the tidal characteristics long term measurements of winds with high temporal and height resolution is required. The main objective of the present study is to establish the monthly variability of both diurnal and semidiurnal tides using four years of observations from Indian MST Radar (IMSTR) located at a low-latitude station Gadanki (13.45^{o}N and 79.18^{o}E). The second objective of the present study is to compare the amplitudes and phases of the tides at low latitude with that of the equator, where the observations were utilized using Equatorial Atmosphere Radar (EAR) located at Kotatabang (0.2^{o}S and 100.2^{o}E), Indonesia.

2. IMSTR and EAR

The present analysis is based on measurements of winds made by two powerful VHF wind profilers – IMSTR and EAR over 4 (2002-2005) and 1 (2003) years, respectively. Complete details of the IMSTR [2] and EAR [3] are given respectively. Specifications of both the radars are given in Table 1.

Table 1: Specifications of IMSTR and EAR

Frequency	53 MHz	47 MHz
Peak Power	2.5 MW	100 KW
Maximum Duty Ratio	2.5 %	5%
Beam width	3^{0}	3.8^{0}
Inter pulse period	1000 µs	400 µs
Number of coherent integrations	512	32
Number of FFT points	256	256
Range resolution	150	150
Temporal Resolution	4 min	10 min

3. Results

The diurnal and semi diurnal oscillations were determined for each day from the hourly averaged diurnal data by subjecting least square fitting with of 24 hr and 12 hr components at each height levels. The reconstructed time height section of zonal, meridional and vertical wind for both semidiurnal and diurnal components over Gadanki for a typical day is shown in figures 1a-1f respectively. The phase fronts of the wave can be easily identified from the figures. The downward (upward) phase propagation indicates the presence of an upward (downward) propagating wave. The amplitudes in the meridional wind are relatively less than that of zonal wind. The vertical winds are an order of magnitude less than that of the zonal and meridional wind. Detailed study of the diurnal variability of vertical wind is studied by [4].

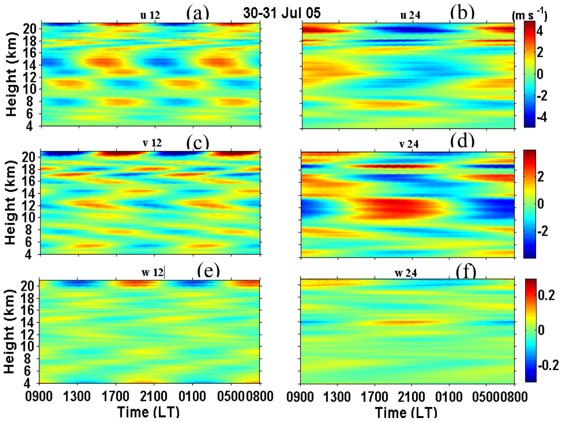

Figure 1(a-f): The reconstructed height-time intensity map of zonal, meridional and vertical winds for 12 and 24 hrs respectively

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3.1. Tropical Station

Figures 2 and 3(a-f) shows the monthly variation of amplitude and phases of the diurnal and semi diurnal tides in the zonal, meridional and vertical wind for all the months. The amplitudes show an increasing trend with height for all the months. In the upper troposphere and lower stratosphere (UTLS) (16-20 km), the amplitudes are high during June to September compared to other months. The amplitudes ranged from 4-6 ms $^{-1}$ during the above months with maximum in the month of June. The amplitudes are showing maxima near the tropopause. In the middle troposphere (8-12 km), during March and September, increase in amplitude is observed but less in magnitude. In the lower troposphere (4-5 km) amplitudes are relatively high during the months of April and May. The amplitudes are comparable with the magnitudes obtained by [5] for a single day in the month of September.

The corresponding phase profiles are given below the amplitude for each month in figure 3a-f. The height profile of phase shows large variations in all the months. The semi diurnal amplitude shows similar variation as that of diurnal tidal amplitudes but their magnitudes are less compared to diurnal tides. The variability in the semi diurnal tidal phase structure is more than the diurnal tide. In the vertical wind it is very interesting to note that during the month of June and July, the amplitudes are showing significant peak from middle troposphere and extending to lower stratosphere. This dominant amplitude is seen in the UTLS region during August and September. The amplitudes are in general an order of magnitude less than that of the zonal and meridional diurnal and semi diurnal amplitudes. This is because the magnitude of the vertical wind itself an order of magnitude less than that of zonal and meridional wind[4].The phase profiles are almost constant during all the months except for the month of August, where some variability is seen in the lower troposphere. The vertical wavelength is found to be ~ 3 km for both diurnal and semi diurnal tides in the zonal, meridional and vertical wind. The vertical wavelengths are comparable numerical simulations [6].

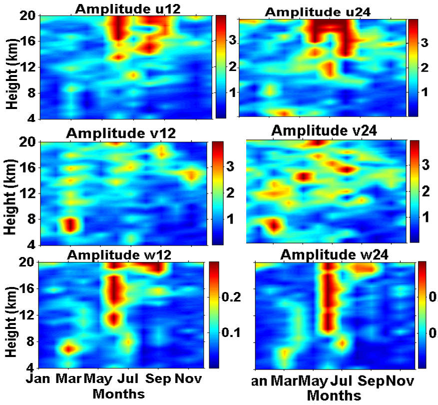

Figure 2(a-f): Monthly height variation of amplitude of Diurnal and semidiurnal tide in zonal, meridional and vertical respectively

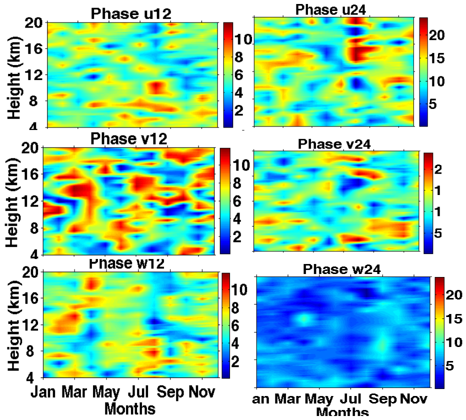

Figure 3(a-f): Same as Figure 2 but for phases

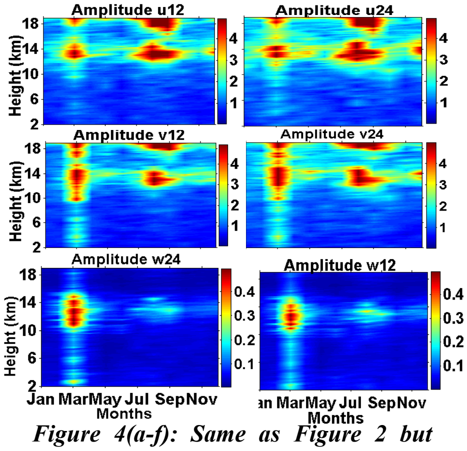

Figure 4(a-f): Same as Figure 2 but over Kotatabang

3.2. Equatorial Station

Figure 4a-f and 5a-f shows the monthly variation of amplitude and phases of the diurnal and semi diurnal tides for all the months over Indonesia. One can observe from the figure that the diurnal and semi diurnal oscillations are having maximum amplitude during March and September in the middle troposphere and in the UTLS region, which is in contrast to Gadanki. The amplitudes are in the range of 5-6ms^{-1} and it is slightly greater than that observed over Gadanki. The features in the meridional wind are similar to zonal wind but during the month of March the amplitude maxima is observed throughout the depth of the troposphere. In the vertical wind the dominant amplitude is seen only in the month of March in the middle troposphere, unlike zonal and meridional wind, where it is observed in September also. The phase profiles given below the amplitudes (5a-f) of the diurnal and semi diurnal tide in zonal, meridional and vertical wind respectively do not show much irregular structure as Gadanki and they remain constant throughout the observational altitude in a month. The vertical wavelength calculated from the phase profiles varied ~25-30 km. The wavelength that is observed is consistent with that of the migrating diurnal component [7].

4. Discussion

The above results indicate that migrating tides are dominant Kotatabang and non migrating tides are dominant over Gadanki. The heating due to water vapor and ozone gives rise to migrating tidal modes and latent heat release due to convection gives rise to nonmigrating tidal modes. Generally precipitation can be used as a proxy for latent heat release as it involves phase transformation of water vapor. Hence we measured the rainfall using surface optical rain gauge (ORG) over Gadanki and Kotatabang. The monthly accumulated rain rate from 2002-2005 is shown in figure 6a and 6b for Gadanki and Kotatabang respectively along with their mean and standard deviation. It is clearly observed that during June–September, the accumulated rain rate is maximum compared to the other months over Gadanki. So it is expected that optimum release of latent heat will be more during these months. This may be the plausible reason for the dominance of nonmigrating modes in the UTLS region over Gadanki.

On the other hand, if we observe the rainfall pattern over Kotatabang in figure 6b, it clearly exhibits that it rains throughout the year over this region. There is little variation in the observed rainfall with respect to months, but that variability seems to be of little significance. Even though the rainfall, was observed throughout the year over Kotatabang, surprisingly we could not observe nonmigrating tides in the UTLS region which raised a question in our mind that whether this rainfall is caused by deep convective clouds or shallow convective clouds.

The vertical extent of the cloud is very important in estimating the latent heat release. Shallow clouds (warm clouds) involves only phase transformation of water vapor to water (latent heat of condensation), where as in deep clouds (cold clouds) phase transformation of water to ice (latent heat of freezing) also involves thus releasing large latent heat. To explore this we processed the cloud top brightness temperature. The data used for the present study is derived from the Infrared channels (IR1) of GMS5 and GMS6 and GOES 9 [8]. We have followed the criteria [9] to define the convective clouds over both the study regions and the monthly variability of T_{bb} is given in figure 7a for Gadanki and 7b for Kotatabang. Over Gadanki during June – August, T_{bb} is less than 240 K. During September the value of T_{bb} is 242 K just above the threshold. It is clearly evident that, during June – September, deep convective clouds prevail over Gadanki, which releases large amount of latent heat thereby triggering the nonmigrating tidal modes over this location. On the other hand, over Kotatabang, the value of T_{bb} is always greater than 260 K. During January-April, it varies from ~275 to280 K and from May-December the variability is very less and it is around 263 K.

This clearly reveals that the rainfall over Kotatabang is mostly due to the shallow convective clouds, and so the

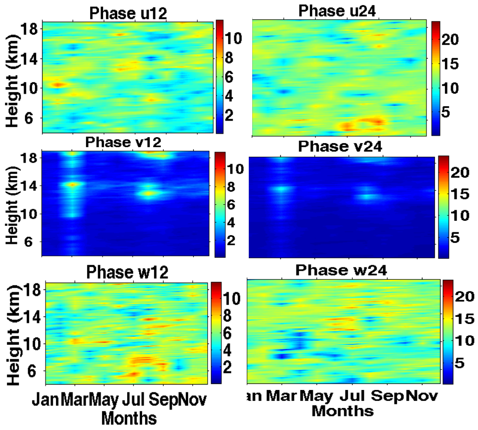

Figure 5(a-f): Same as Figure 4 but over Kotatabang

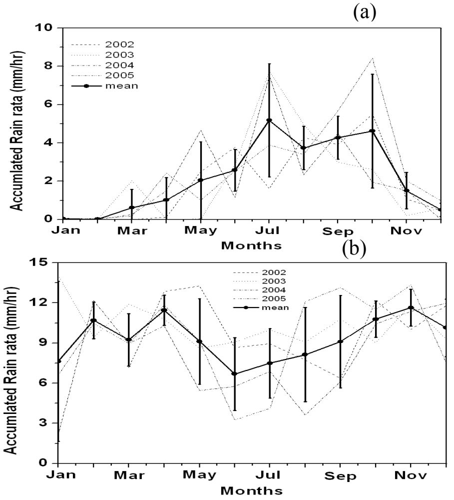
(a)
(b)

Figure 6: (a) Monthly mean of Accumulated rain rate from 2002-2005 along with mean and standard deviation. (b) Same as (a) but for Kotatabang

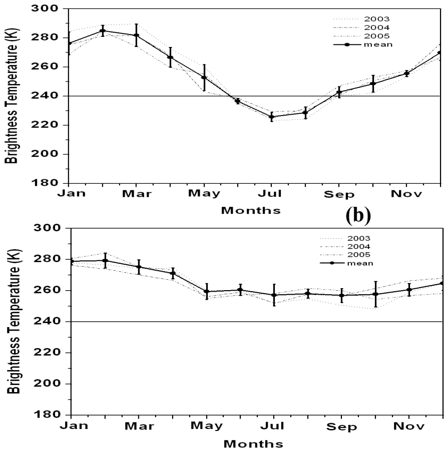
(b)

Figure 7: (a) Monthly mean of Brightness Temperature from 2003-2005 along with standard deviation. (b) Same as (a) but for Kotatabang

possibility of source (latent heat) triggering the nonmigrating tidal modes is expected to be lesser compared to Gadanki. Thus, the presence of shallow convective clouds may be one of the plausible reasons for the absence of nonmigrating modes; thereby the dominance of migrating components observed over Kotatabang.

As a next step we calculated the zonal wavenumber of the nonmigrating tidal mode over Gadanki. Figure 8 shows Fourier spectra of OLR as a function of longitude from June-September, as the dominant non-migrating tidal mode is seen particularly during these months in the UTLS region over Gadanki. It is clearly evident from the figure that over Gadanki the dominant tidal mode of zonal wavenumber (s) between 3 and 4 is observed. So the zonal wavenumber observed over Gadanki gives additional evidence that the nonmigrating tides are dominant over this tropical region.

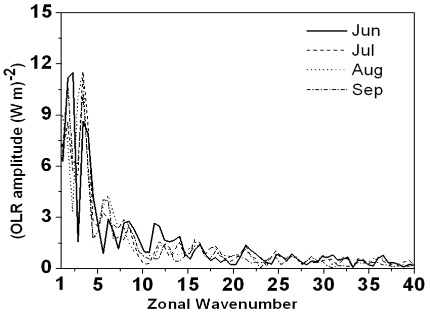

Figure 8: Fourier spectrum of Outgoing Long-wave Radiation (OLR) from June-September over Gadanki.

5. Conclusion

VHF radar observations have been utilized to study the diurnal and semi diurnal tides over Gadanki and Kotatabang. The amplitudes were dominant in the UTLS region over Gadanki during June-September, whereas over Kotatabang it is during March and September. The phase profiles revealed a vertical wavelength of ~3-4 km over Gadanki and ~25-30 km over Kotatabang. Further, the brightness temperature analysis revealed that deep cloud dominated during the monsoon season over Gadanki whereas over Kotatabang most of the time shallow clouds were observed. The zonal wave number calculated using OLR was also found to be between 3 and 4 over Gadanki, which corresponds to a nonmigrating tidal mode. Thus the analysis showed that nonmigrating tides are dominant over Gadanki and migrating tides are dominant over Kotatabang. The present observations revealed the tidal characteristics over two geographical locations within the tropics, which will have implications on modeling of tides and their variability.

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