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A case study of the mesospheric 6.5-day wave observed by radar systems

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[1] In this paper, analysis of wind data detected by six ground-based radar systems located in equatorial and midlatitude belts shows that a strong mesospheric 6.5-day wave event occurred during April–May 2003. We compared the global distribution of the observed 6.5-day wave event with the theoretical wave structure (Rossby normal mode (s, n) = (1, −2)). Additionally, we investigated several important wave characteristics to understand the mesospheric 6.5-day wave event, i.e., wave period, vertical structure, relationship with background wind, propagating direction, and the zonal wave number. Our results are summarized into three points: (1) the latitudinal structure of the mesospheric 6.5-day wave during April–May 2003 is basically in agreement with the theoretical Rossby mode (s, n) = (1, −2), although the wave amplitude of zonal wind peaked at the subequatorial latitude of Northern Hemisphere but not at the theoretical place, equatorial region; (2) the main wave periods and the altitude distribution of large amplitude of this wave event varied with latitude; (3) the downward propagating wave phases indicated that this wave event originated in the lower atmosphere and propagated upward to the upper region.

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1. Introduction

[2] The quasi 6.5-day wave, with periods between 5 and 7 days, in the mesosphere/lower thermosphere (MLT) region has been the subject of interest that has a long history. The 5-day wave is well known as a Rossby normal mode. If no continuous forcing acts on this wave mode, it does not transport heat, momentum, or energy [*Andrews et al.*, 1987] and the wave phase shows no variation with altitude [*Chapman and Lindzen*, 1970]. The observed 6.5-day wave in the MLT region displays a horizontal feature consistent with the 5-day wave; however it has a distinct vertical wave structure (the downward propagating phase tilt) and a different period range. Many earlier studies have investigated the source and the relevant mechanism for the generation of the mesospheric 6.5-day wave by model simulations [*Meyer and Forbes*, 1997; *Liu et al.*, 2004; *Riggin et al.*, 2006]. In the past three decades, this wave was identified by both ground- and satellite-based observations [*Wallace and Chang*, 1969; *Madden and Julian*, 1972; *Geisler and Dickinson*, 1976; *Wu et al.*, 1994; *Kovalam et al.*, 1999; *Talaat et al.*, 2001, 2002; *Clark et al.*, 2002; *Sridharan et al.*, 2003; *Lieberman et al.*, 2003; *Kishore et al.*, 2004; *Lima et al.*, 2005; *Riggin et al.*, 2006; *Jiang et al.*, 2008].

[3] At present it is believed that the mesospheric 6.5-day wave propagates westward with zonal wave number 1 and is particularly strong during the equinoxes [*Talaat et al.*, 2001, 2002; *Lieberman et al.*, 2003; *Kishore et al.*, 2004; *Liu et al.*, 2004; *Riggin et al.*, 2006; *Jiang et al.*, 2008]. Three mechanisms have been proposed to explain the origin of the 6.5-day wave observed in the MLT region. The first is that the 6.5-day wave is closely associated with a normal mode or resonant mode of oscillation on a sphere, that is, the Rossby mode (s, n) = (1, −2) referred to as the 5-day wave [*Wu et al.*, 1994; *Lieberman et al.*, 2003; *Liu et al.*, 2004; *Riggin et al.*, 2006]. The second is that the 6.5-day wave in the MLT region is an unstable mode, distinct from the normal mode 5-day wave, drawing energy from the unstable regions in the upper mesosphere, and whose realization is global in scale [*Meyer and Forbes*, 1997]. The third is that the mesospheric 6.5-day wave can be excited by the nonlinear wave-wave interaction between a

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Table 1. Simple List of Radar Systems and Wind Data Used

Station	Instrument[a]	Location	Height Range (Data)	Time Interval for Plotting (Data)
Platteville	MF	(40.18°N, 104.7°W)	79–97 km	20 April to 31 May 2003
Yamagawa	MF	(31.2°N, 130.6°E)	78–98 km	20 April to 31 May 2003
Wuhan	MWR	(30.5°N, 114.3°E)	78–98 km	20 April to 31 May 2003
Maui	MWR	(20.75°N, 156.43°W)	80–98 km	20 April to 31 May 2003
Tirunelveli	MF	(8.67°N, 77.82°E)	78–98 km	20 April to 31 May 2003
Adelaide	MF	(35°S, 138°E)	78–98 km	20 April to 31 May 2003

[a] MF, medium frequency; MWR, meteor radar.

quasi-sationary planetary wave and zonal wave number 2 planetary wave [*Pogoreltsev et al.*, 2002].

[4] During late April and early May 2003, a large mesospheric 6.5-day wave was seen by the SABER instrument aboard the TIMED satellite and the ground-based radar systems at equatorial and midlatitudes in both the Northern and Southern Hemispheres [*Riggin et al.*, 2006; *Jiang et al.*, 2008]. *Riggin et al.* [2006] found that the global structure of this wave event was consistent with the theoretical waveshape (Rossby mode (s, n) = (1, −2)). They compared the results of the observations and the NCAR thermosphere–ionosphere–mesosphere–electrodynamics general circulation model (TIME-GCM) simulation and showed that the observed 6.5-day wave in April–May 2003 had a major source in the Southern Hemisphere, and was amplified by baroclinic instability in the Northern Hemisphere. They argued that the waves in the mesosphere with periods of 5–7 days are best understood in the framework of the gravest symmetric Rossby planetary wave (1, −2) (known as the 5-day wave), although these waves are vertically propagating and have been modified and amplified by instability.

[5] Though *Riggin et al.* [2006] presented well the global and vertical structures of this wave event observed by the SABER instrument, they did not make a detailed presentation of results from the radar systems. In fact, radar systems have an advantage of studying the fine structure of the waves in a certain height range, because of their high temporal and spatial resolution. For example, the ground-based radar observation can give the main wave periods and the continuous temporal evolution of a wave event, while the detection of the instrument on satellite cannot provide this kind of information. In addition, the 6.5-day planetary wave belongs to the global-scale atmospheric waves, and so it would be fruitful to use the network of ground-based measurements to investigate this wave.

[6] In this paper, we chose the wind data observed by six radar systems located in equatorial and midlatitude belts to study the mesospheric 6.5-day wave in April–May 2003. The main purpose of our present work is to identify a possible wave source of this wave event through analyzing its spatial characteristics, i.e., latitudinal structure, vertical structure, and zonal wave number. In order to show more information about this wave event, wave period variation with latitude and the relationship between the 6.5-day wave and background wind are investigated.

[7] The results in the present work are important, since this all-around comparison of ground-based radar observations has not been previously done in this zone. The radar systems that were made use of in this work and data analysis are described in section 2. The results are given in section 3. We then discuss the results in section 4. Finally, the conclusions of our study are briefly drawn in section 5.

2. Radar Systems and Data Analysis

2.1. Radar Systems

[8] The wind data analyzed in this paper were obtained from six radar systems. Four medium frequency (MF) radars are located at Platteville (40.18°N, 104.7°W), Yamagawa (31.2°N, 130.6°E), Tirunelveli (8.67°N, 77.82°E), and Adelaide (35°S, 138°E). Two meteor radars (MWR) are located at Wuhan (30.5°N, 114.3°E) and Maui (20.75°N, 156.43°W). The detailed descriptions of the six radar systems configuration, technical features, and method of wind determination can be found in the work of *Manson et al.* [2003], *Murayama et al.* [2000], *Rajaram and Gurubaran* [1998], *Vincent and Lesicar* [1991], *Xiong et al.* [2004, 2006], and *Franke et al.* [2005], respectively. Here, we just list the radar locations and wind data used in this paper (see Table 1). Figure 1 shows the locations of these radar systems on the world map.

2.2. Data Analysis

[9] The wind data averaged in 4-h time bins of each radar system are used for studying the mesospheric 6.5-day wave in April–May of 2003. Though the time interval for plotting is from 20 April to 31 May 2003, the amount of data analyzed is much longer than these 42 days. In order to ensure that our results are accurate and representative, a time series of several years were applied to statistical data analysis. The gaps in wind data were filled by the following method. When the length of the data gap is small ($\leq$ 2 days), the gaps are filled by linear interpolation. When the missing data are longer than 2 days but less than 6 days, they are replaced by Gaussian random values with the means and standard deviations matching the rest of the available data. If the gap is still longer, we kept it unfilled and no further analysis was done. This process was also described by the first author in an earlier paper [*Jiang et al.*, 2008].

[10] Wavelet analysis method is used to derive spectral information of the wind data [*Pancheva et al.*, 2000, *Kishore et al.*, 2004]. The Morlet wavelet consisting of a plane wave modulated by a Gaussian envelope $\psi_0(\eta) = \pi^{-1/4} e^{i\omega_0}\eta\, e^{-\eta^2}/2$ is used in the present work, where η is a nondimensional time parameter and ω_0 represents nondimensional frequency, here taken to be 6 to satisfy the admissibility condition. Wavelet analysis method has an advantage of determining both wave frequency information and how these frequencies vary with time evolution at the same time. The detailed depiction of wavelet analysis method can be found in the paper of *Torrence and Compo* [1998].

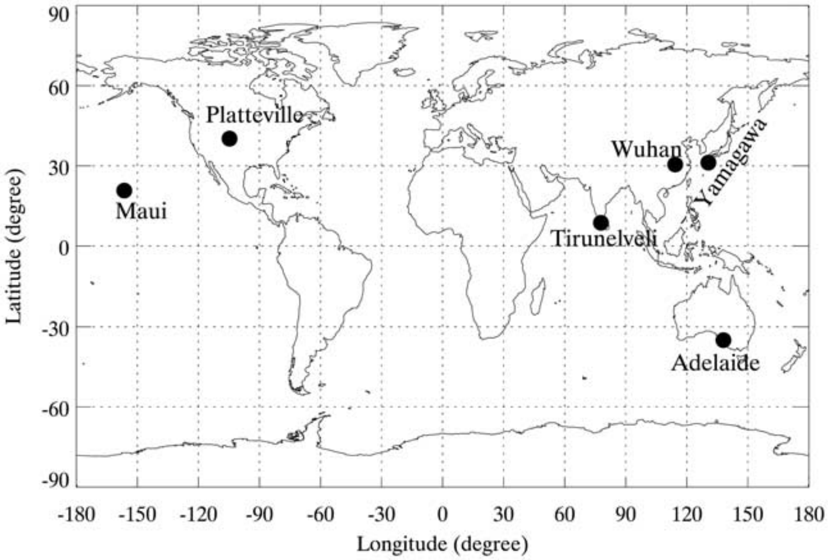


Figure 1. The locations of six radar systems used.

[11] A band-pass Butterworth filter [*Xiong et al.*, 2006] with cut-offs at 5 and 7 days is used to show the rough variation of 6.5-day waves in the time domain. For band-pass filter and wavelet analysis, either method has its own advantage to analyze the characteristics of the investigated wave: The former can show us the rough feature of the wave amplitude varying with time; the latter can reveal the elaborate wave feature, for example, the wave period, besides the wave amplitude.

[12] The background wind was obtained by using the second-order polynomial fit to the long trend in the data [*Luo*, 2002; *Namboothiri et al.*, 2002]. The polynomial fitting was applied to a 150-day window within each time series, and the window was then advanced through the data in 75-day increments. Harmonic fitting with 30-day window centered at the middle of the selected time interval gives an estimation of the height variations of the wave amplitudes, phases, and background winds, and 6.5 day is selected as the fitted period.

[13] Finally, a cross-spectral method [*Luo*, 2002] based on the Fourier transform was applied to check the general spectral relationships and average phase differences between the wind oscillations over Yamagawa and those over the other three stations (Wuhan, Maui and Tirunelveli). The phase differences were used to estimate the zonal wave number of the 6.5-day disturbance from 20 April to 31 May 2003.

3. Results

3.1. Morphologic Comparison on Wave Latitudinal Structure in Observation and Theory

[14] Figures 2 and 3 show the zonal and meridional wind components of 6.5-day wave during 20 April to 31 May 2003, at six different radar sites, respectively. Results were derived using wavelet analysis. Units of the colorbar are in meters per second. White spaces in Figures 2 and 3 denote the places with no data. From left to right, radar stations are Platteville, Yamagawa, Wuhan, Maui, Tirunelveli, and Adelaide, respectively.

[15] First of all, we focus on the latitudinal variations of the zonal 6.5-day wave presented in Figure 2. During about 25 April to 20 May 2003, intense wave signatures in the zonal wind can be noticed in the MLT region over the equatorial station (Tirunelveli (8.67°N)), the low-latitude station (Maui (20.75°N)), and midlatitude stations (Yamagawa (31.2°N), Wuhan (30.5°N), and Adelaide (35°S)); however, in Platteville (40.18°N), the wave activity was weak. Figure 2 reveals another 6.5-day wave event that appeared during the last week of May at 79–82 km over Platteville; because of the different time of its occurrence, this wave event was regarded as another wave event rather than the same one observed at the other five stations. The largest zonal component of the 6.5-day wave was observed by Maui meteor radar, where the amplitude exceeded 26 m/s.

[16] We now focus on the latitudinal variation of the meridional 6.5-day wave presented in Figure 3. It is worth noting that an evident 5- to 7-day wave existed in the meridional wind at Platteville, while no wave with a 5- to 7-day period appeared in the zonal wind. At Tirunelveli, no wave with a 5- to 7-day period appeared in the meridional wind, while a strong 6.5-day wave existed in the zonal wind. Over the other four stations, a meridional 6.5-day wave was obvious but weaker than the zonal component.

[17] Finally, the observed latitudinal structure of the mesospheric 6.5-day wave in April–May 2003 was compared with the theoretical Rossby wave mode $(s, n) = (1, -2)$ (known as a 5-day wave; see Figure 4). The vertical wind and temperature would theoretically follow the shape of the Hough function solution (solid line), and the variations of zonal wind and meridional wind are represented by a dashed line and a dotted line, respectively. Thus, in theory Platteville (40.18°N) is located at the zero node in the Hough mode of the zonal wind, while Tirunelveli (8.67°N) is located close to the zero node of the meridional wind. In the observations, we found that the zonal 6.5-day wave over Platteville and the meridional 6.5-day wave over Tirunelveli were very weak during April–May 2003. The

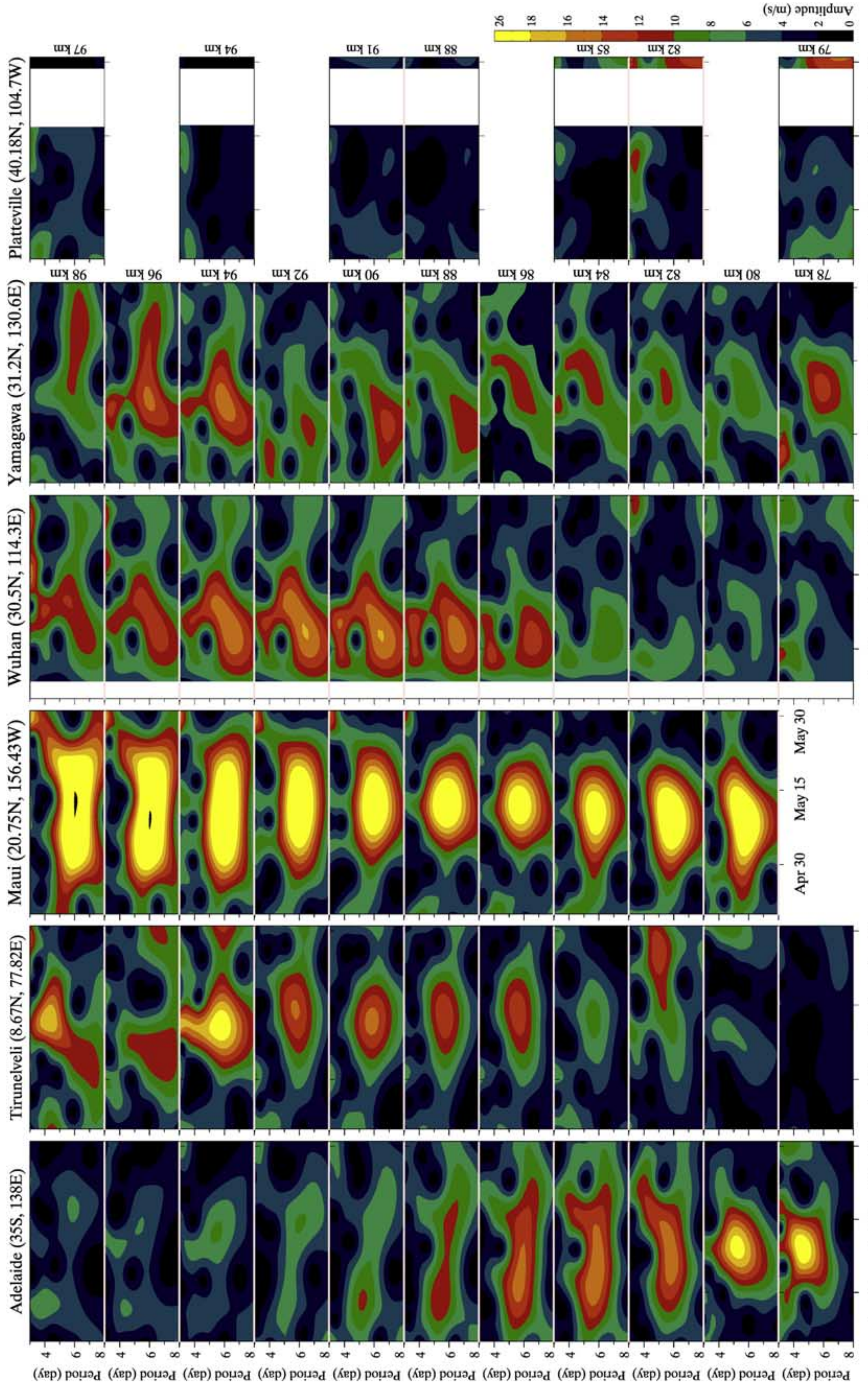


Figure 2. Zonal wind components of the 6.5-day wave from 20 April to 31 May 2003, at six different radar stations. Results were derived using wavelet analysis.

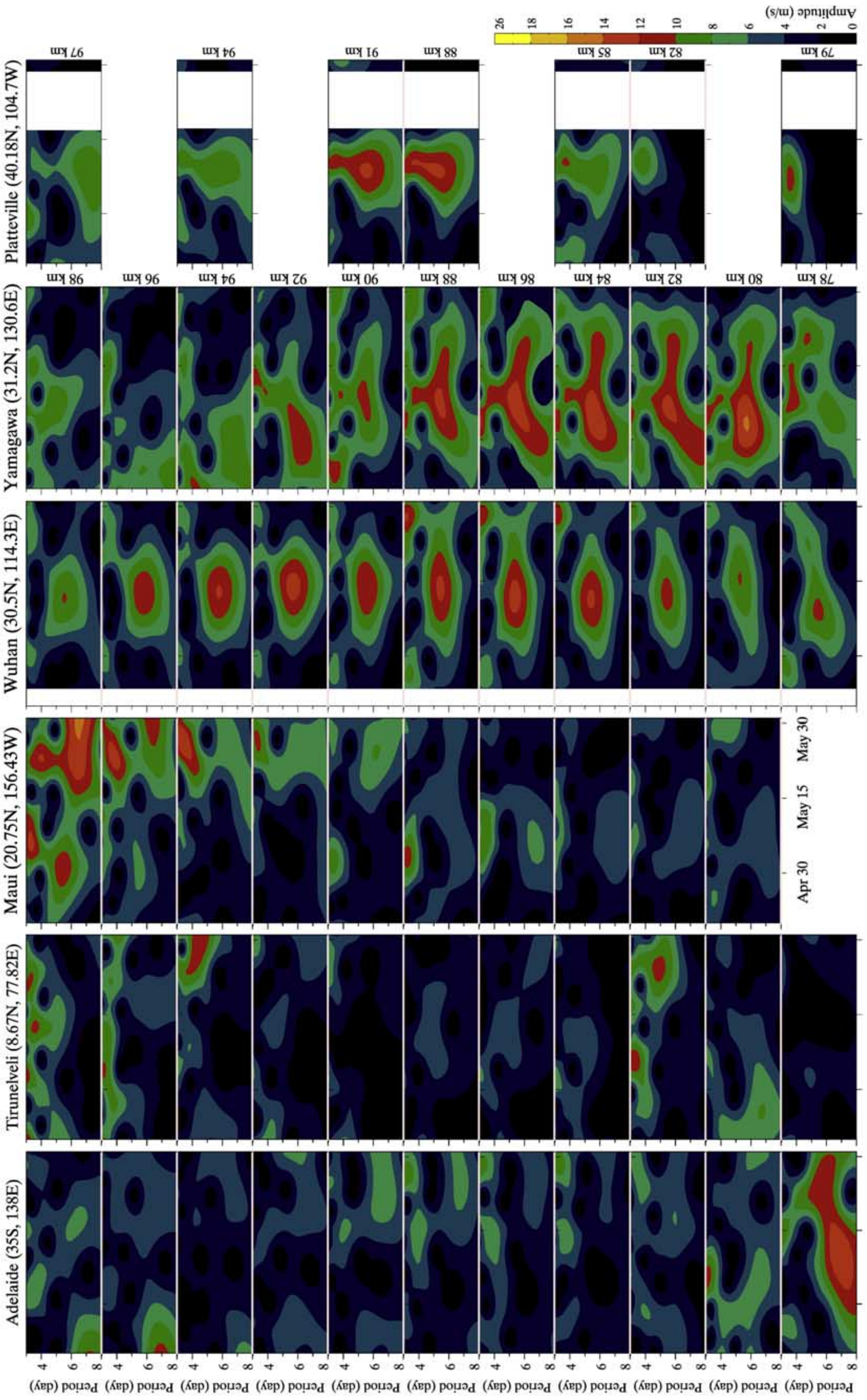


Figure 3. Same as in Figure 2 but for the meridional components.

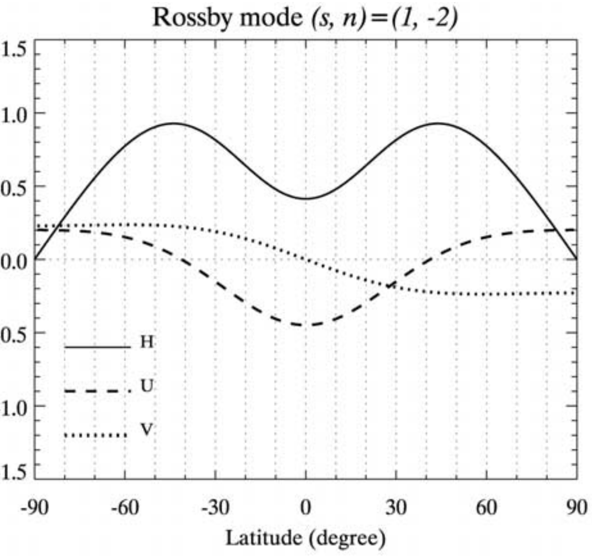


Figure 4. Theoretical Rossby mode (s, n) = (1, −2) (known as the 5-day wave) with Hough function solution (solid line), zonal wind (dashed line), and meridional wind (dotted line).

latitudinal structure of the mesospheric 6.5-day wave in April–May 2003 is approximately in agreement with the theoretical waveshape, although the wave amplitude of zonal wind peaked at the subequatorial latitude of Northern Hemisphere but not at the theoretical place, that is, the equatorial region. Our results are consistent with the same wave event study of the satellite (TIMED/SABER) and ground-based radar observations by *Riggin et al.* [2006].

3.2. Variations of Wave Period

[18] The 6.5-day wave is a quasi-periodic wave, whose period range is 5–7 days [*Talaat et al.*, 2001, 2002; *Liu et al.*, 2004; *Riggin et al.*, 2006]. The main wave period varies with latitude [*Sridharan et al.*, 2006]. Figure 5 gives the periods of the maximum wavelet amplitudes of the mesospheric 6.5-day wave during April–May 2003 over Yamagawa (blue solid square), Wuhan (green solid circle), Maui (yellow star), Tirunelveli (red open circle), and Adelaide (brown solid upward triangle). From Figure 5 we can see that the main periods of this wave event were between 6 days and 7 days. Wave period variation with latitude was also indicated in Figure 5. At equatorial site Tirunelveli and southern midlatitude site Adelaide, the main period was 5–6 days, while at the stations near northern midlatitude (~20°N to 31°N) Maui, Wuhan, and Yamagawa, the periods were in the range of 6–7 days.

3.3. Vertical Structure

[19] Figure 6 shows the 5- to 7-day band-pass-filtered zonal winds during 20 April to 31 May 2003, at six different radar sites. We can see that the altitude distribution of the strong mesospheric wave is different in two hemispheres, at a higher altitude in the Northern Hemisphere and at lower altitudes in the Southern Hemisphere (84–98 km over Tirunelveli (8.67°N), Wuhan (30.5°N), and Yamagawa (31.2°N), 80–98 km over Maui (20.75°N), and 78–88 km over Adelaide (35°S)). The filtered result also indicated the very weak wave in the MLT region over Platteville (40.18°N). Referring to the wave variation with height in Figures 6b, 6c, 6d, 6e, and 6f, it is confirmed that the phase of the 6.5-day wave propagated downward.

[20] Figure 7 gives more vertical structure information of this 6.5-day wave event. Here, we chose only the four stations where a strong wave appeared. The amplitude, phase, and zonal mean wind were derived from a harmonic fitting analysis with a 30-day data window centered at the middle of the interested time interval; the time epoch used for analysis is 24 April to 23 May 2003; the fitted period is 6.5 days, and the phases are with respect to the maximum amplitudes. In the MLT region of the six radar stations, the largest amplitude of ~25.7 m/s occurred at 96 km over Maui. The maximum amplitudes of Yamagawa, Wuhan, Tirunelveli, and Adelaide were roughly 12.34 m/s at 94 km, 12.05 m/s at 92 km, 12.02 m/s at 94 km, and 11.3 m/s at 84 km, respectively. The global 6.5-day wave event in April–May 2003 had a different altitude distribution in the MLT region over different latitudes. The strong wave appeared at a higher altitude in the equatorial and midlatitude Northern Hemispheric sites, while it appeared at a lower altitude in the midlatitude Southern Hemispheric site.

[21] The downward phase progression in time can clearly be seen in Figure 7. For a Rossby planetary wave, the downward phase progression corresponds to upward energy propagation [*Riggin et al.*, 2006]. So, the radar detections implied that the 6.5-day wave in the MLT region during April–May 2003 came from the lower atmosphere. This result is consistent with the same wave event study of the satellite measurements (TIMED/SABER) by *Riggin et al.* [2006].

3.4. Relationship Between Background Wind and 6.5-day Wave

[22] Figure 8 illustrates the zonal mean wind of 20 April to 31 May 2003, over six different radar sites. The mean wind

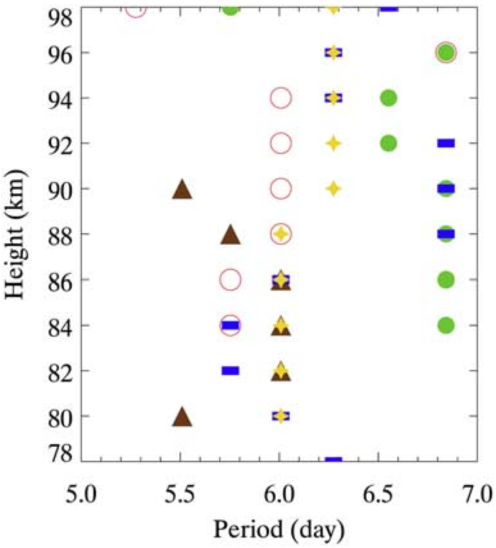
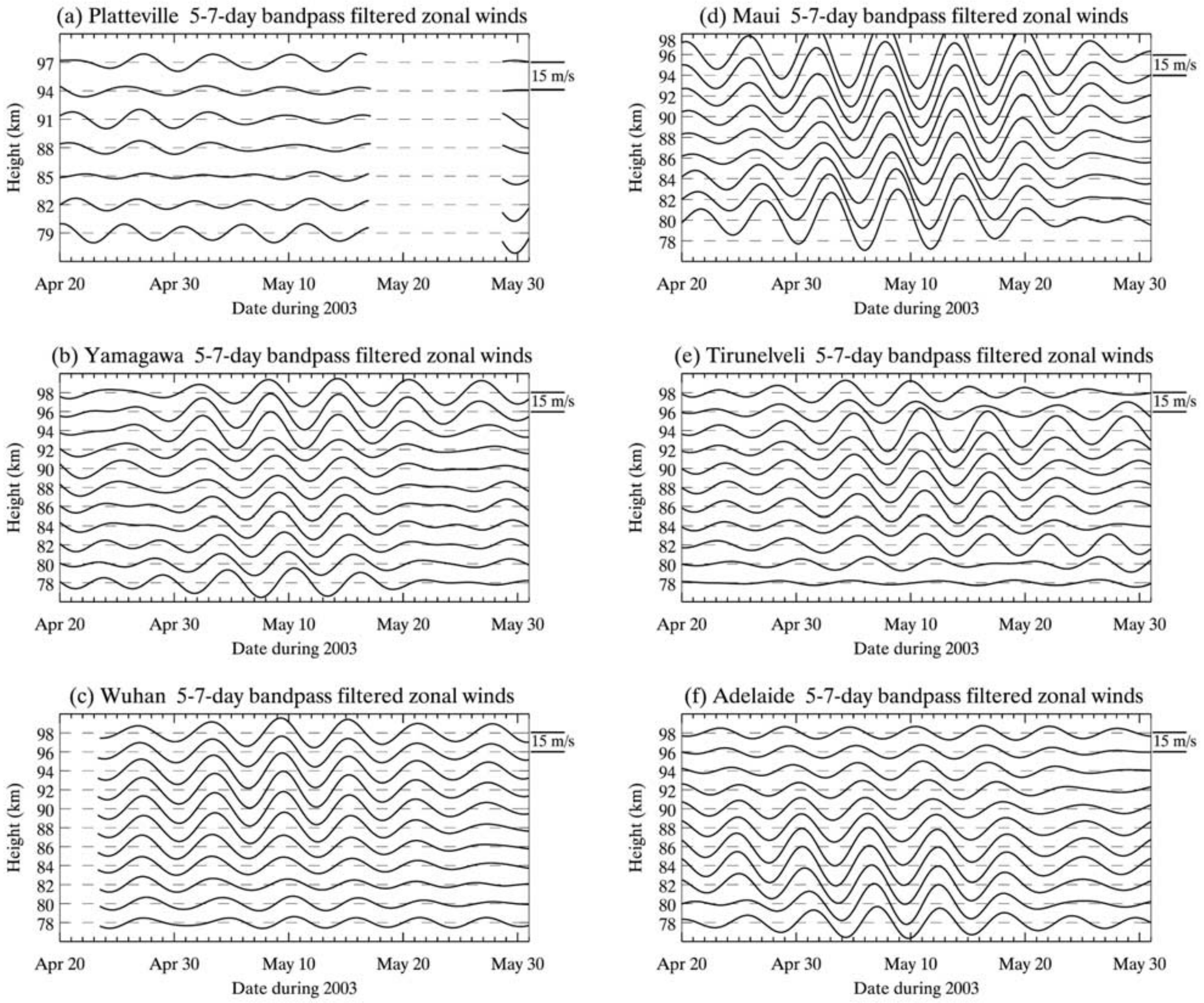


Figure 5. Periods of the maximum wavelet amplitudes over Yamagawa (blue solid square), Wuha (green solid circle), Maui (yellow star), Tirunelveli (red open circle), and Adelaide (brown solid upward triangle).


(a) Platteville 5-7-day bandpass filtered zonal winds

(b) Yamagawa 5-7-day bandpass filtered zonal winds

(c) Wuhan 5-7-day bandpass filtered zonal winds

(d) Maui 5-7-day bandpass filtered zonal winds

(e) Tirunelveli 5-7-day bandpass filtered zonal winds

(f) Adelaide 5-7-day bandpass filtered zonal winds

Figure 6. The 5- to 7-day band-pass-filtered zonal winds 20 April to 31 May 2003, at six different radar stations.

was calculated by the polynomial fitting method. After carefully comparing the 6.5-day wave over each station (see Figures 2, 6, and 7) with their background wind (shown in Figure 8), we found that this wave event was robust in eastward background wind.

[23] *Kishore et al.* [2004] showed that the 6.5-day wave over Tirunelveli during the years 1995–1997 was an equinoctial phenomenon when the background wind was westward. However, in our study of the 6.5-day wave during April–May 2003, a strong wave event also existed

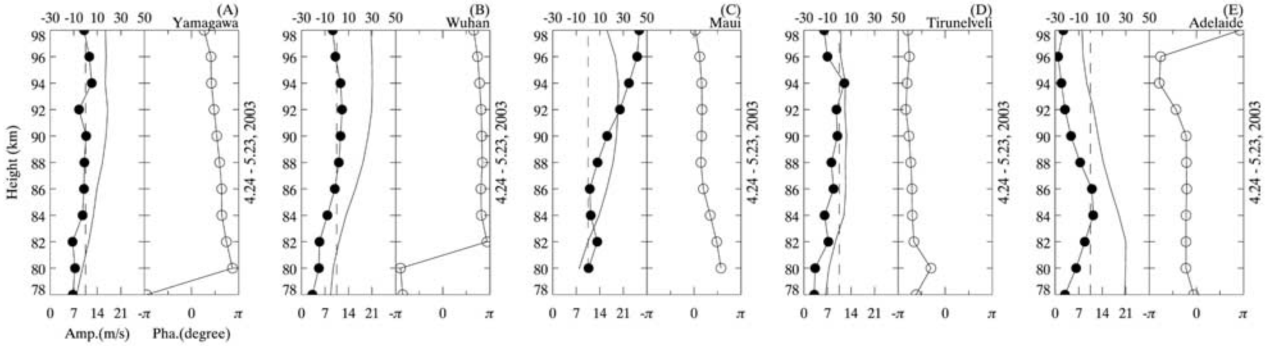


Figure 7. Vertical profiles of the 6.5-day waves in zonal wind at six different radar sites. In each panel the left half denotes wave amplitude (solid line with solid circle) and zonal mean wind (solid line), and the right half illustrates wave phase (solid line with open circle). The dashed line represents zero mean wind.

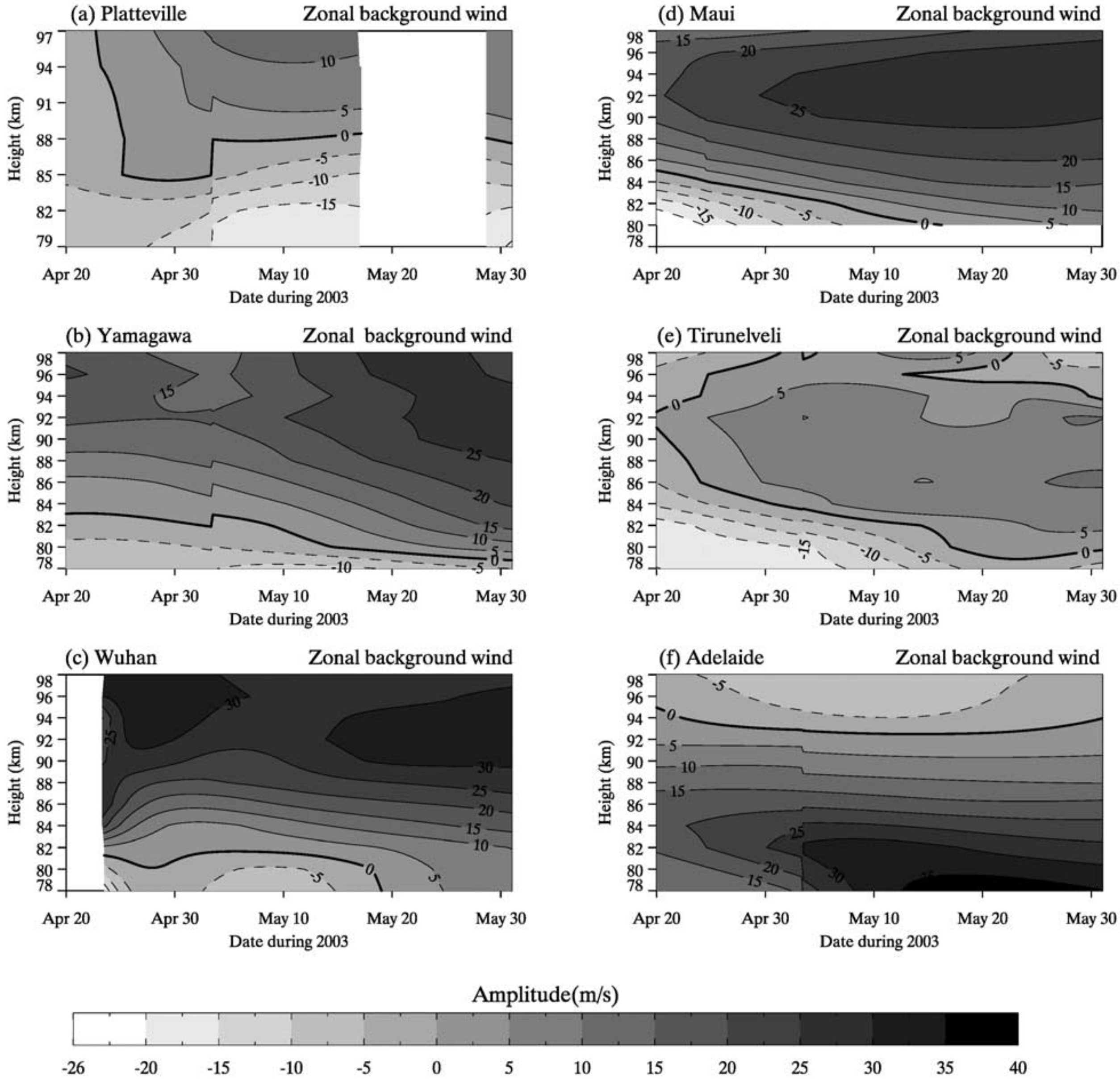


Figure 8. The zonal mean wind 20 April to 31 May 2003, over six different radar stations. The thin solid line represents eastward/northward, the dashed line westward/southward, and the thick line zero wind.

when the background wind was eastward. In fact, we used the wind data detected by the same Tirunelveli MF radar to investigate the 6.5-day wave in January 2002 to June 2003 and found that a large wave event appeared not only in the westward background wind but also in the eastward background wind in the equatorial MLT region (not shown in this paper). It seems that the background wind does not significantly affect the vertical propagation of a 6.5-day wave. The interpretation of *Sridharan et al.* [2003] should help us clearly understand this phenomenon. They pointed out that the phase speed of a 6.5-day wave is ~65 m/s for zonal wave number 1, so this wave generally can overcome the stratospheric quasi-biennial oscillation (QBO) wind speed and reach mesospheric heights.

3.5. Estimation of Propagation Direction and Zonal Wave Number

[24] The observations of four radar systems in the Northern Hemisphere, that is, Yamagawa, Wuhan, Tirunelveli, and Maui, were used to estimate the propagation direction and zonal wave number of the 6.5-day wave event during April–May 2003. Figure 9 presents the band-pass-filtered (5–7 days) outputs for the zonal wind at 90, 92, and 94 km over four selected sites. The 6.5-day wave over Yamagawa, Wuhan, Tirunelveli, and Maui is represented by a green solid line, red dotted line, black dotted line, and blue dashed line, respectively. From Figure 9, the phase relation between the four sites is roughly: Yamagawa leads Wuhan, Wuhan leads Tirunelveli, and Tirunelveli leads Maui. In other words, the mesospheric 6.5-day wave during

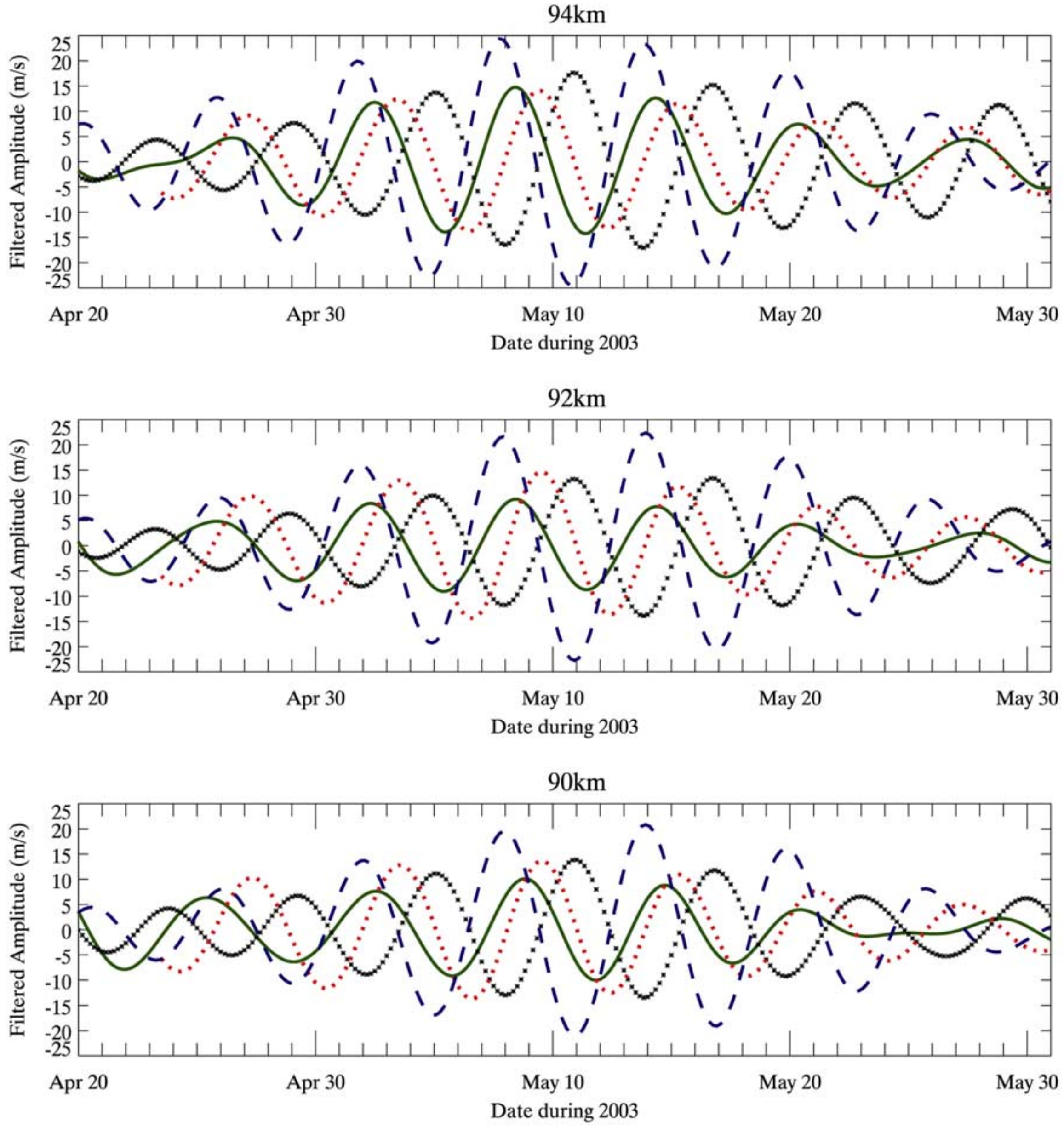


Figure 9. The band-pass-filtered (5- to 7-day) outputs for the zonal wind at 90, 92, and 94 km over four selected stations.

April–May 2003 propagated westward. The result from cross-spectral analysis more distinctly shows this phase relation (see Figure 10). The dashed line represents the phase component of the cross-spectrum. Positive values indicate that Yamagawa leads the other three stations at the periods of the 6.5-day wave. It should be noted that the negative cross-spectrum phase value between Maui and Yamagawa indicates a phase difference of over 180°.

[25] Figure 11 shows the wave phase difference (derived from cross-spectral analysis) versus longitude difference between Yamagawa and the other three stations. Yamagawa is the reference station, at (0, 0), in the origin of coordinates shown in Figure 11. The zonal wave number can be determined by the slope of the line 1.05, and the minus sign indicates westward propagation. The radar observations thus show that the mesospheric 6.5-day wave during April–May 2003 was a westward traveling global oscillation with wave number 1.

4. Discussion

[26] Predicted by atmospheric tidal theory [*Longuett-Higgins*, 1967], the Rossby (s, n) = (1, −2) normal mode, generally regarded as 5-day wave, shows that the zonal wind component has a symmetric meridional structure with respect to the equator (see Figure 4).

[27] In this paper, our study of the mesospheric 6.5-day wave during April–May 2003 shows that this wave event propagated westward with zonal wave number 1 and had a meridional structure similar to the Rossby (s, n) = (1, −2)

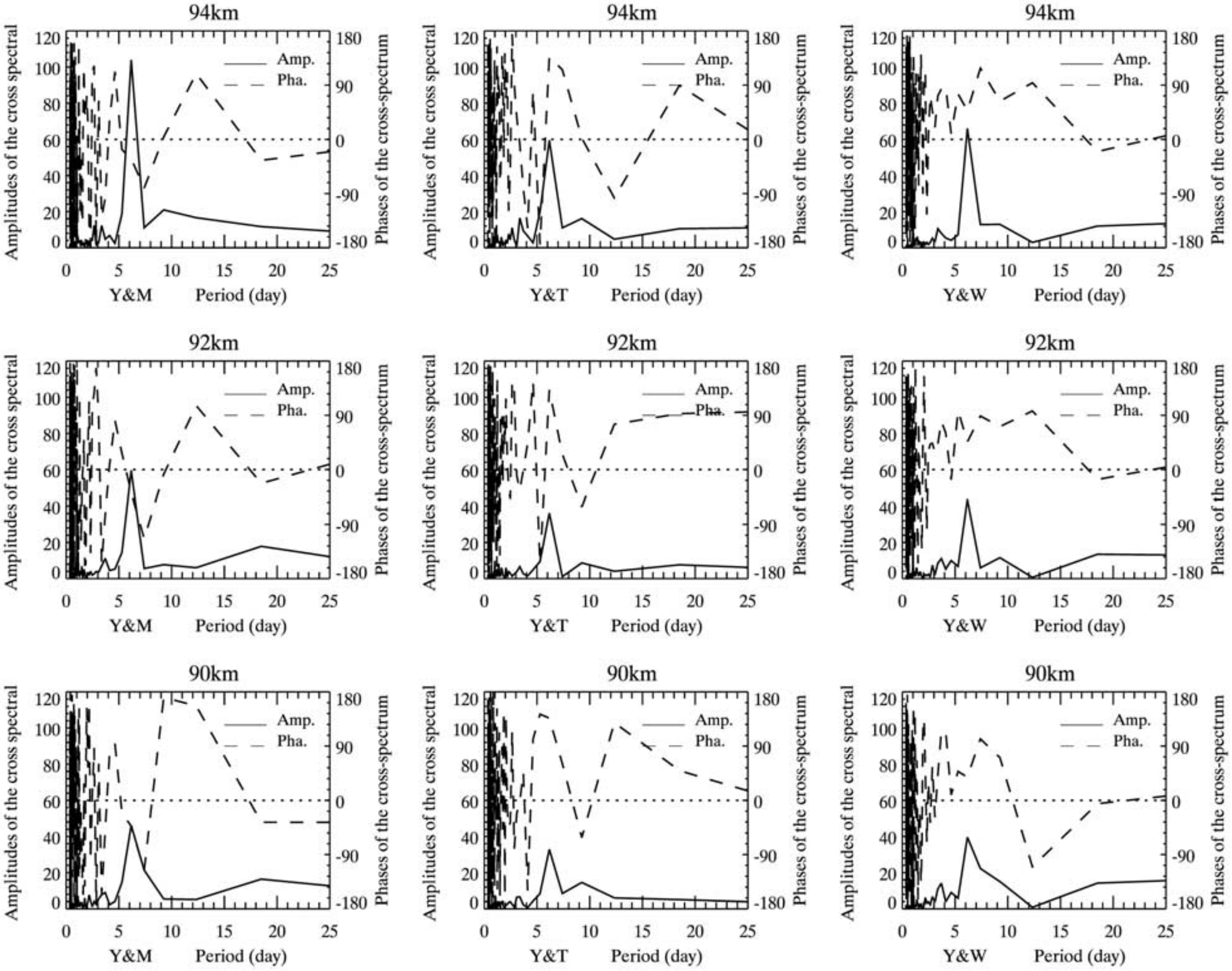


Figure 10. Cross-spectrum analysis for the zonal wind at 90, 92, and 94 km between Yamagawa and other three sites in the Northern Hemisphere. Yamagawa is the reference station. The time interval for calculation is 24 April to 31 May 2003.

normal mode. But the wave amplitude of zonal wind peaked in the Northern Hemisphere and not at the equator and was larger in the higher altitudes in the Northern Hemisphere and at lower altitudes in the Southern Hemisphere, which is not consistent with the theoretical prediction. These differences between the observations and the theoretical prediction imply that in the real atmosphere, the 6.5-day wave possibly underwent the forcing region with baroclinic/barotropic instability when propagating in the Northern Hemisphere, and then was amplified to the stronger wave. This supposition has been proved by the same wave event study of *Riggin et al.* [2006]. The analogical wave amplification due to instability of the mesospheric wind was earlier propounded by *Lieberman et al.* [2003] and *Liu et al.* [2004]. Our inference is that the 6.5-day wave in the MLT region during April–May 2003 could be an atmospheric Rossby normal mode (1, −2). So we agree with the viewpoint in *Riggin et al.* [2006]: The waves in the mesosphere with periods of 5–7 days are best understood in the framework of the gravest symmetric Rossby planetary wave (1, −2), although these waves are vertically propagating and have been modified and amplified by instability.

5. Conclusion

[28] A strong mesospheric 6.5-day wave of a global scale occurred during April–May 2003. In the present work, we study this wave event by using the wind data of six radar systems located at equatorial and midlatitude sites, Platteville (40.18°N, 104.7°W), Yamagawa (31.2°N, 130.6°E), Wuhan (30.5°N, 114.3°E), Maui (20.75°N, 156.43°W), Tirunelveli (8.67°N, 77.82°E), and Adelaide (35°S, 138°E). The results are summarized as follows:

[29] 1. We investigated the latitudinal structure, zonal wave number, and vertical structure of this wave event, and further explored the possible wave source. The latitudinal structure of this 6.5-day wave event is basically in agreement with the theoretical Rossby wave mode (s, n) = (1, −2), although the wave amplitude of zonal wind peaked at the subequatorial latitude of Northern Hemisphere and not at the theoretically expected location, namely, the equatorial region. Cross-spectral analysis demonstrated a significant coherence between the waves with 5- to 7-day

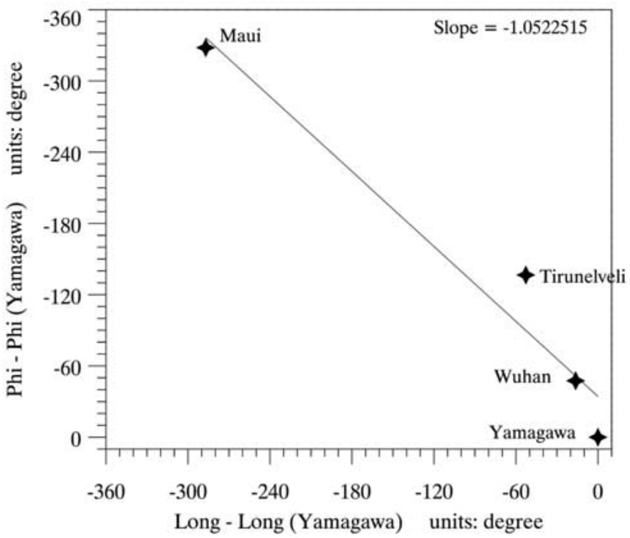


Figure 11. Wave phase difference versus longitude difference between Yamagawa and the other three stations. The slope of the line provides the planetary zonal wave number, and the minus sign indicates westward propagation.

periods observed at the chosen sites, and confirmed that this wave event propagated westward with zonal wave number 1. The downward progressing wave phase indicated that the mesospheric 6.5-day wave came from the lower atmosphere. Our opinion is that the 6.5-day wave in the MLT region during April–May 2003 should be regard as an atmospheric normal mode.

[30] 2. The main periods of the observed wave event were in the range of 6–7 days at the stations near northern midlatitude (∼20°N to 31°N) Maui, Wuhan, and Yamagawa, and they were between 5 days and 6 days at the equatorial site Tirunelveli and southern midlatitude site Adelaide.

[31] 3. The relationship between the 6.5-day wave and background wind was examined, through analyzing the observations of several radar systems located in different sites. We found that the background wind does not significantly affect the vertical propagation of the 6.5-day wave because of its faster phase speed (∼65 m/s).

[32] Our investigation should help us further understand the 6.5-day wave appearing in the MLT region during April–May 2003. However, the results of a case study cannot represent the universality of the mesospheric 6.5-day wave. For this reason, we suggest that more wave events should be collected to study this wave phenomenon in detail.

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