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VOLCANIC TREMOR ARRAY OBSERVATION USING THREE-COMPONENT SEISMOMETERS AT IWATE VOLCANO, JAPAN

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ABSTRACT

In order to clarify the source region and mechanism of volcanic tremors which are occurring around Iwate Volcano in northern Honshu, Japan, two arrays of seismometers were deployed at northern area of the volcano. The triangle-shape array which consists of 10 elements is used to estimate incident azimuth of volcanic tremors. The aperture of the array is 300m. The linear array (900m) which consists of 14 elements is used to identify wave types and apparent velocity of volcanic tremor. All elements have a three-component 2 Hz sensor and a portable data recorder.

During an array observation period from 23 July until 11 August in 1998, more than 70 volcanic tremors were observed but many events were low signal to noise ratio. Vertical components of four volcanic tremor events which were relatively high signal to noise ratio were analyzed using frequency-wavenumber method to estimate both the incident azimuth and the horizontal apparent velocity. Three of the four events had the predominant frequency of about 2 Hz. At the 2 Hz running frequency-wavenumber power spectra were calculated. As a result, the incident azimuth of volcanic tremors was the south direction and the horizontal apparent velocity was about 1000 to 2000 m/s.

Ohjigokudani, where several steam eruptions were reported to occur previously and steam and gas generate now, is to the south direction of the triangle array. The direction was consistent with the direction of the linear array. Then we also used the linear array to estimate the apparent velocity and identify wave types. The apparent velocity was nearly equal to or higher than one of the Rayleigh wave which was estimated from the seismic noise. We also estimated shallow velocity structure of the volcano to constrain source depth of volcanic tremors. These results show that volcanic tremors occur at shallow part in Ohjigokudani at western Iwate Volcano not in Yakushi crater at eastern Iwate Volcano.

1. INTRODUCTION

Shallow seismicity has become active around Iwate Volcano in northern Honshu, Japan, since February in 1998. However, the seismicity level had been very low before then. At June in 1998, volcanic tremor event has observed. The observation data implies that the Iwate Volcano activity will become high. It is thought that volcanic tremors relate to the magma activity or hydrothermal activity. However, we can not determine where or how the volcanic tremors occur because the waveform and the first arrival time were uncertain. We try to observe the volcanic tremors with an array to estimate an arrival direction and an apparent velocity of the volcanic tremors.

Two arrays of seismometers were deployed at northern area of the volcano in order to clarify source region and mechanism of volcanic tremors.

2. OBSERVATION

We carried out two seismometer array observations at the northern part of Iwate Volcano at Matsuo Village, Iwate Prefecture, Japan, from 23 July until 11 August in 1998. One was the triangle-shape array which consisted of ten elements seismometers for estimating the volcanic tremor arrival direction and apparent velocity, the other was the linear array which consisted of 14 elements seismometers for estimating mainly its incident dip angle. Figure 1 shows a location map of the observation site. The triangle array is located at Kenmin-no-mori of Matsuo Village, and the linear array is located at the northern slope of Iwate Volcano. Ohjigokudani, where several steam eruptions were reported to occur previously and steam and gas generate now, is located in the south direction of the triangle array. The summit of Iwate Volcano is located in the east-south direction of the triangle array.

The data acquisition system consists of one three-component seismometer and one data-logger. The three-component seismometer was the velocity-type with a natural frequency of 2 Hz(Mark Products L-22D). The data-logger was with a memory of 20 Mb (Hakusankogyo LS8000SH). Data were continuously recorded from 8 p.m. until 6 a.m. with a sampling period of 10 msec because seismic noise level was relatively low in night time. Time was calibrated every hour for keeping less than 3 msec resolution using GPS. Recorded data on memory were retrieved every day during observation period.

Figure 2 shows triangle seismometer array configuration. Solid circles show the seismometer locations. The maximum seismometer spacing of the triangle array was 311 m, and the minimum one was 45 m. The array was used to estimate the direction of volcanic tremor and apparent velocity and to estimate underground velocity structure using microtremor, namely, seismic noise.

The linear array was used for estimating the dip angle of volcanic tremor by drawing particle orbits. However, we could not identify the dip angle clearly because of bad signal-to-noise ratio. The seismometer spacing of the linear array was 70 m. The total length was 900 m, and the maximum altitude gap was 150 m.

3. S-WAVE VELOCITY STRUCTURE ESTIMATION USING MICROTREMORS

Before volcanic tremor analysis, we estimated shallow underground velocity structure using microtremor data. An exploration method using microtremors is used to be a conventional technique for subsurface survey (Yamamoto *et al.*,1997). We used microtremor data at periods during which the volcanic tremor was not observed and during which a traffic noise was contaminated. It is thought that microtremor mainly consists of surface waves which have the dispersive characteristics. The dispersion depends on the underground velocity structure. We can estimate underground velocity structure, especially, S-wave velocity structure, from the dispersion relation of surface waves in microtremors which were observed with an array.

We used the frequency – wavenumber spectral analysis (F-K analysis) to determine the phase velocity of Rayleigh waves in vertical component of microtremors (LaCoss *et al.*, 1969, Horike, 1985, Matsushima and Okada, 1990, Yamamoto *et al.*, 1997). We obtain the horizontal apparent velocity from the horizontal apparent wavenumber at which the power of F-K spectrum is maximum at each frequency.

Figure 3 shows the observed phase velocities of Rayleigh waves as a function of frequency from vertical component of microtremors. Phase velocities were obtained at a range between 1500 and 700 m/s at the frequency range between 2 and 8 Hz. We can find the dispersion relation which the phase velocity decreases with frequency increasing. We can estimate S-wave velocity structure model by Haskell's matrix method using the dispersion relation (Haskell, 1953). Figure 4 shows the estimated S-wave velocity structure model as a function of depth. Solid line is a S-wave velocity structure model, and dashed line is a P-wave velocity structure model. Estimated model consists of 4 layers , and the S-wave velocity of basement is 3000 m/s at a depth below 400 m. P-wave velocity was calculated from the estimated S-wave velocity.

4. VOLCANIC TREMORS OBSERVATION RESULTS

At array observation period from 23 July until 11 August in 1998, more than 70 volcanic tremors were observed but many events were low signal to noise ratio. Therefore, events which we can analyze are four, and all of them have relatively good signal to noise ratios. Figure 5 shows the vertical component array records of waveforms of the typical volcanic tremor observed with the triangle array from 3:23:00 a.m. until 3:26:10 of 26 July in 1998. As the characteristic waveform, expanded waveform of the channel T10 is shown. The record of the channel T1 contains high frequency noise because of the ground site effect. However, other waveforms are similar. Although we can see the characteristics phases of volcanic tremors at a period between 3:23:40 and 3:24:10, we can not detect when the volcanic tremor event starts because the waveform is ambiguous.

Firstly, we computed running power spectra of the volcanic tremor waveforms using FFT. Figure 6 shows three power spectra of waveforms. The first spectrum is estimated from a period between 3:23:00 and 3:23:20, which is thought to be background noise. The second spectrum is estimated from a period between 3:23:50 and 3:24:10, which is though to be the characteristic phase. The third spectrum is estimated from a period between 3:25:00 and 3:25:20, which is thought to be a part of continuous volcanic tremor. We can detect three characteristic peaks at frequencies of 2, 3 and 4 Hz from the second spectrum. However, we can detect only one peak of 2 Hz from the third spectrum. These show that the vibration power of a frequency of 2 Hz had been continuing during the analysis period.

Next, we applied a running F-K power spectral analysis to the vertical component array records waveforms of volcanic tremors. The running F-K spectra are defined by the sequential F-K spectra. One basic F-K spectrum is computed from a period of 20.48 seconds. Overlapping interval is 3/4, that is, the next F-K spectrum calculation is starting after five seconds. We obtained 33 running F-K spectra for the event at 3:23 of 26 July. Figure 7 shows the running F-K spectra as a contour presentation at a frequency of 2 Hz. The time descriptions on each figure are start time and end time, respectively. At the time between 3:23:00 and 3:23:30, namely, at the time before the volcanic tremor event arrival, we can find that the contour peak is wide at each figure. However, after the seventh figure of period from 3:23:30 to 3:23:50, namely, after the time of the volcanic tremor event arrival, we can find that the contour peaks are steep and the wavenumber direction of the peak location shows south. We can see the south peak from 3:23:40 until 3:26:10.

Figure 8 shows both the direction and phase velocity of four volcanic tremors as a function of lapse time at a frequency of 2 Hz. The periods used for analysis were from 3:23:00 until 3:26:10 at 26 July, from 5:19:00 until 5:22:20, from 4:20:30 until 4:23:00 at 31 July and from 1:48:10 until 1:51:30 at 6 August, respectively. The events which were relatively good signal-to-ratio were selected. All four events show that the arrival azimuthes are 180 degree, namely, south direction. These show that the incident azimuth of volcanic tremors was the south direction and the horizontal apparent velocity was about 1000 to 2000 m/s. The apparent velocities were consistent with one observed from surface waves in microtremors. The result shows that the depth of source region is relatively shallow.

Ohjigokudani, where several steam eruptions were reported to occur previously and steam and gas generate now, is located in the south direction of the triangle array. The direction was consistent with the obtained one by F-K analysis. The direction was also consistent with the direction of the linear array, then we also used the linear array to estimate the apparent velocity and identify wave types. The apparent velocity was nearly equal to or higher than one of the Rayleigh wave which was estimated from microtremors, namely, seismic noise. These results show that volcanic tremors occur at shallow part in Ohjigokudani at western Iwate Volcano, not in Yakushi crater at eastern Iwate Volcano. The fact implies that volcanic tremor event observed in this study relates to hydrothermal activity not to magma activity.

5. SUMMARY

Two arrays of seismometers were deployed at northern area of Iwate volcano to clarify source region and mechanism of volcanic tremors which are occurring around the volcano. Vertical components of four volcanic tremor events were analyzed using frequency-wavenumber method to estimate both the incident azimuth and the horizontal apparent velocity. Three of four events had the predominant frequency of about 2 Hz. At the 2 Hz running frequency-wavenumber power spectra were calculated. As a result, the incident azimuth of volcanic tremors was the south direction and the horizontal apparent velocity was about 1000 to 2000 m/s. The apparent velocity was nearly equal to or higher than one of the Rayleigh wave which was estimated from the seismic noise. We also estimated shallow velocity structure of the volcano to constrain source depth of volcanic tremors. These results show that volcanic tremors occur at shallow part in Ohjigokudani at western Iwate Volcano not in Yakushi crater at eastern Iwate Volcano.

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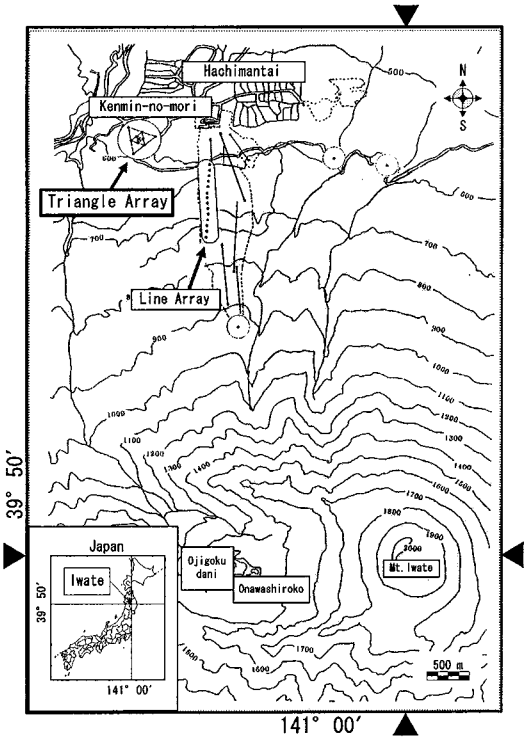

Figure 1. Location map of the observation site. Volcanic tremor array observation were carried out at the northern area of Iwate Volcano. The triangle array is located at Kenmin-no-mori of Matsuo Village, Iwate Prefecture, the linear array locates at the northern slope of Iwate Volcano. Ohjigokudani, where several steam eruptions were reported to occur previously and steam and gas generate now, is located in the south direction of the triangle array. The summit of Iwate Volcano is located in the east-south direction of the triangle array.

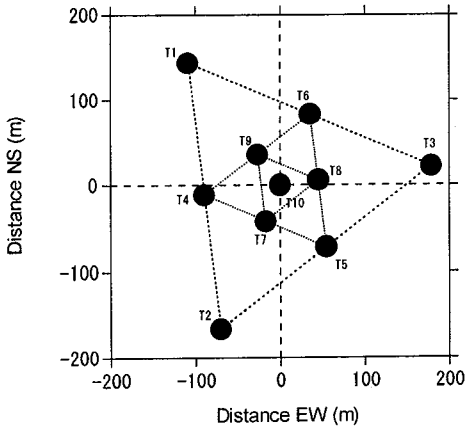

Figure 2. Array configuration for observation. Solid circles show the seismometer element locations. At each point, three-component seismometer and data-logger were set. The triangle array was used to estimate the phase velocity of Rayleigh wave in microtremors and to estimate both the arrival direction and the phase velocity of the volcanic tremor. The maximum distance of seismometer spacing was 311 m, the minimum one was 45 m.

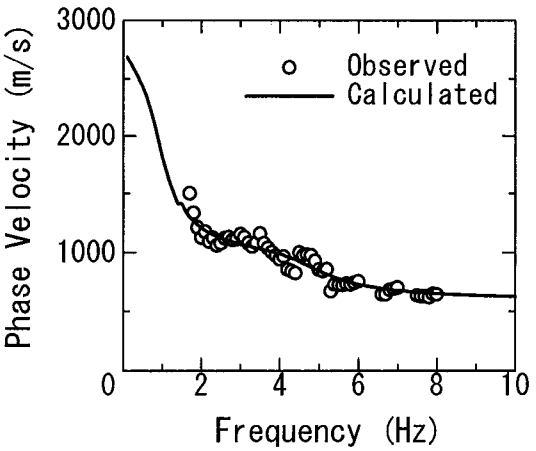

Figure 3. Phase velocities of Rayleigh wave in microtremors. Observed phase velocities of Rayleigh waves were plotted by open circles as a function of frequency. Calculated phase velocity was shown by solid line. The calculated values were obtained from the structure model of Fig. 4.

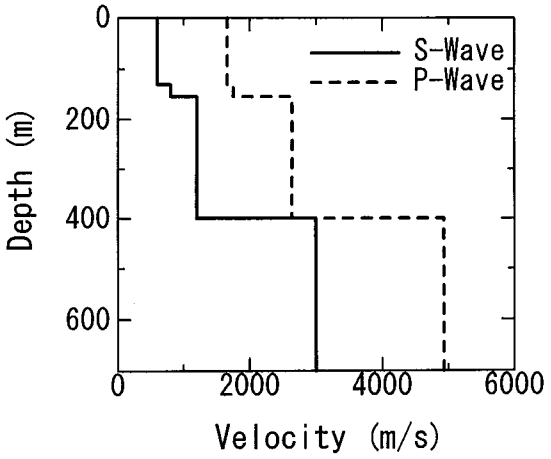

Figure 4. Velocity structure model. Estimated S-wave velocity structure was drawn by solid line as a function of depth. P-wave velocity which was drawn by dashed line was calculated from S-wave velocity. The basement depth was estimated to be 400 m.

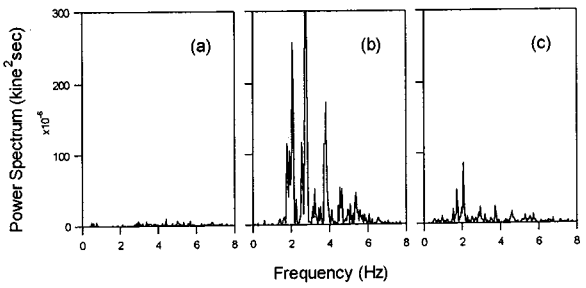

Figure 6. Volcanic tremor power spectra.
(a) Power spectrum at a period between 3:23:00 and 3:23:20.
(b) Power spectrum at a period between 3:23:50 and 3:23:10.
(c) Power spectrum at a period between 3:25:00 and 3:25:20.

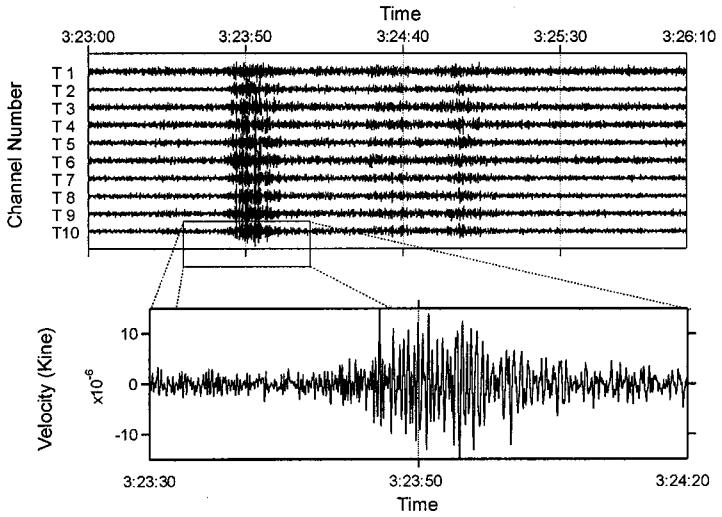

Figure 5. Waveforms of volcanic tremor. Array records of vertical component velocity waveforms of the volcanic tremors observed at a period from 3:23 a.m. to 3:26 of July 26 in 1998 with the triangle array(upper figure). Expanded waveform of the channel T10 is shown as an example in the lower figure. We can find characteristic phases at from 3:23:40 until 3:24:00.

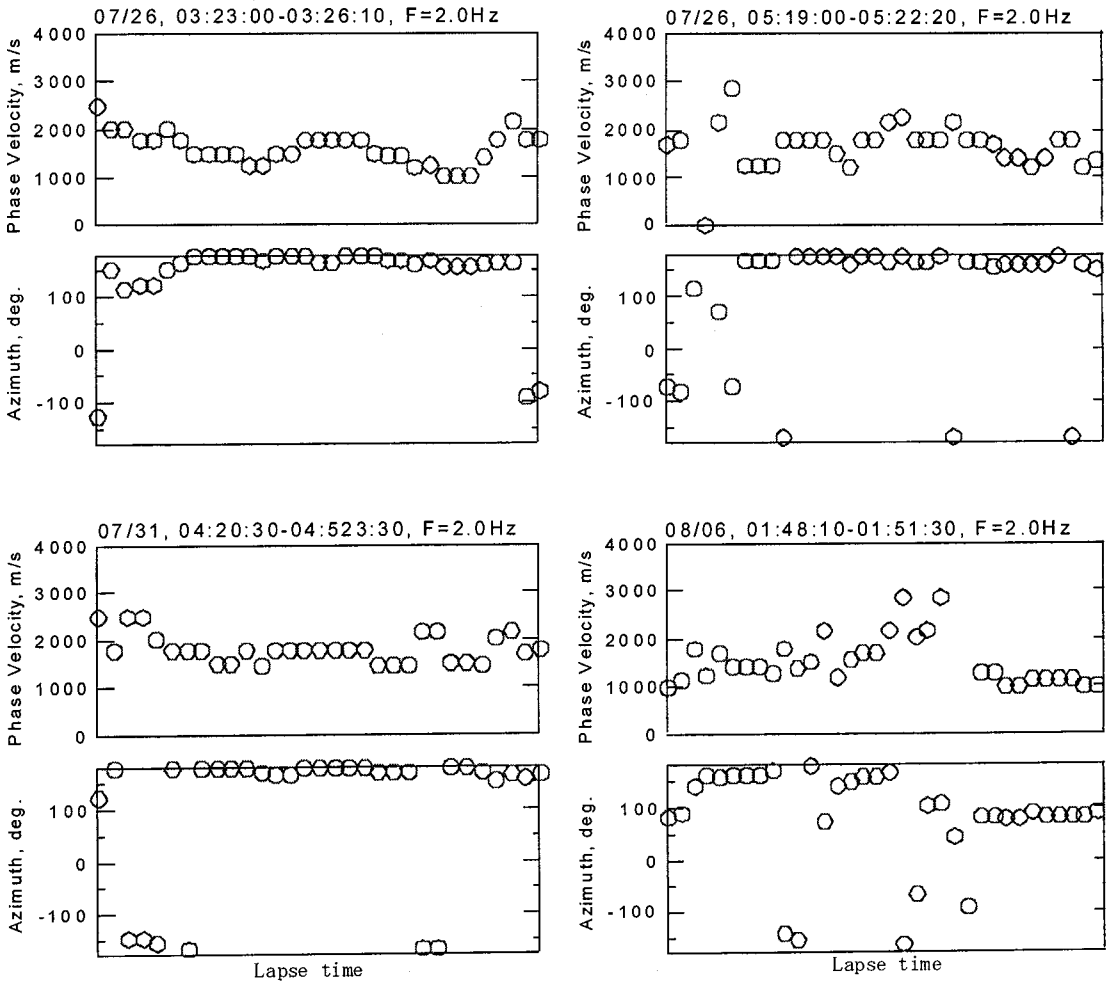

Figure 8. Apparent phase velocities of volcanic tremors and its arrival azimuths. Estimated arrival directions and phase velocities of four volcanic events at a frequency of 2 Hz as a function of lapse time. The periods used for analysis were from 3:23:00 until 3:26:10 at July 26, from 5:19:00 until 5:22:20 at July 26, from 4:20:30 until 4:23:00 at July 31 and from 1:48:10 until 1:51:30 at August 6, respectively. We can find that the direction shows south after the volcanic tremor event arrival time.

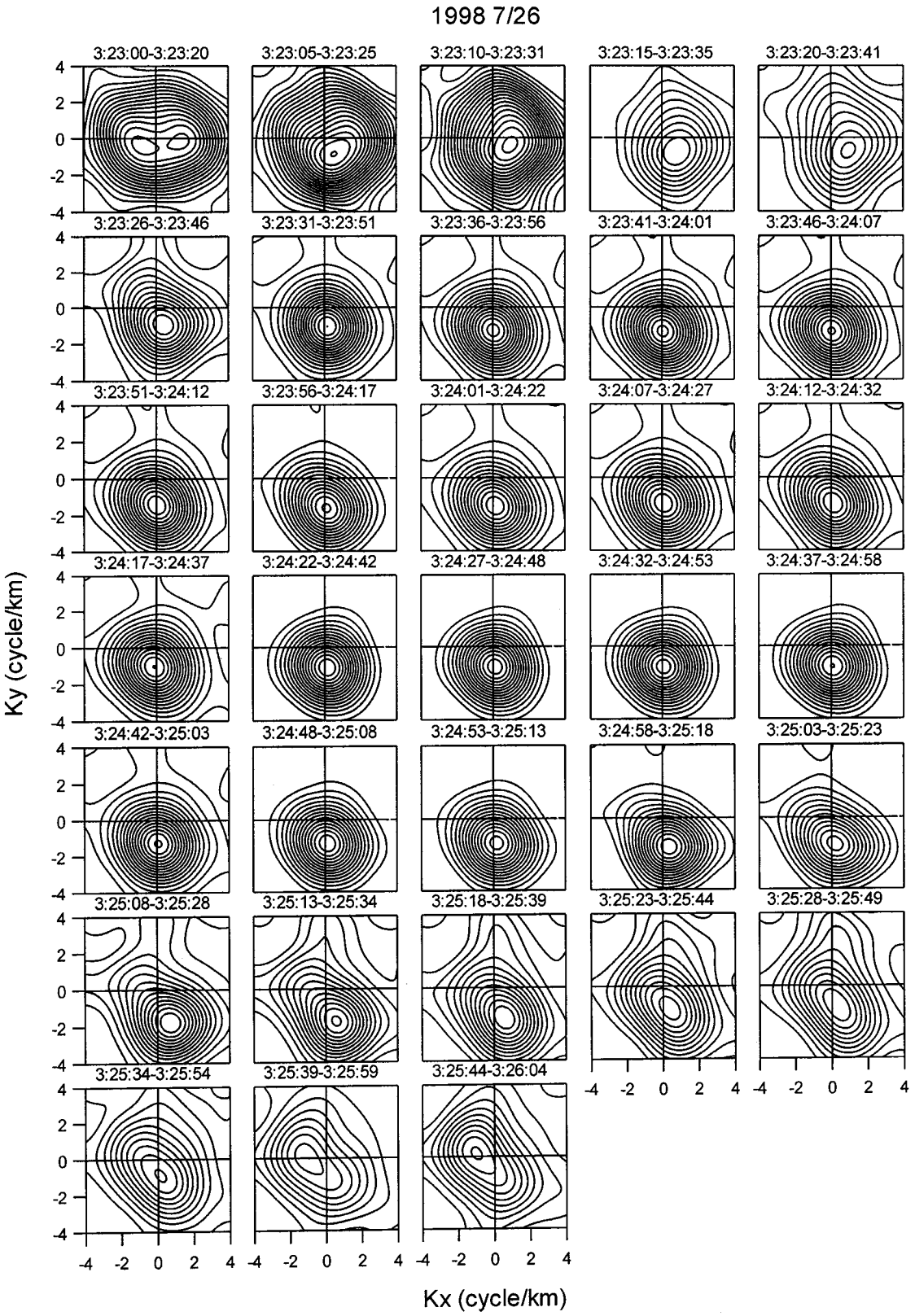

Figure 7. Contours of running F-K spectra of volcanic tremors. Running F-K spectra of vertical components of volcanic tremor event observed at July 26, 1998 at a frequency of 2 Hz. kx is east (+) –west (-) direction wavenumber, ky north (+) – south (-) direction one. One contour is calculated with a period of 20.48 seconds. The arrival direction and apparent velocity of volcanic tremors are estimated from the wavenumber where F-K spectrum is maximum value.