Hearing the ultra-low frequency sound from the 2024 Noto Peninsula earthquake

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Introduction

Atmospheric acoustic wave can exist only above its cutoff frequency defined by the return period (˜300 s) of acoustic speed relative to the scale height. Acoustic propagation around 0.01Hz is strongly dispersive and the waveform changes rapidly through the propagation, accordingly. This situation makes it challenging to detect coexistence of acoustic and boundary (Lamb) waves and their progressive separation, which are expected to occur near the source of ultra-low frequency sound. The coseismic uplift associated with the Noto Peninsula earthquake provided a unique opportunity for such a detection to be feasible.

Observed air pressure records

We used 11 microbarograph stations equipped with Paro absolute pressure gauges, 7 operated by NIED and 4 operated by JWA. We divided them into the Asama-array of 4 stations at distances around 150km from the epicenter, Fuji-array of 4 stations at distances around 270km and Toyohashi array of 3 stations around 300km. Fig.1 shows the locations of these arrays and the epicenter of the Noto Peninsula earthquake along with a simplified fault model of the Noto Peninsula earthquake.

Fig.2 shows the records (highpass-filtered at 600s) of the Asama-array and the Fuji-array. The pulse of our interest is characterized by a positive amplitude of a few Pa with an apparent duration of 100s as observed across the Asama array (Fig.2A) to 200s as observed across the Fuji array (Fig.2B). The onset is sharp and can be interpreted by a straight line with a typical acoustic speed of 0.34 km/s all the way from the epicenter to the most distant station of the Fuji array. On the other hand, the arrival of the first peak (=the largest peak) is better fit by a straight line with an apparent speed of 0.31 km/s. This apparent speed coincides with the propagation speed of the Lamb wave. Such a difference in the apparent speed between the onset and the peak of the wave motion implies the coexistence of the acoustic and Lamb waves in the pressure waves generated by the Noto Peninsula earthquake.

Analysis

Bearing this implication in mind, we made a simple waveform calculation to see how the atmosphere responds to the pressure force applied from bellow across the bottom boundary. The applied force is a centroid force over a temporal spread of 30 s and over a spatial spread of 10km. The atmosphere was approximated to be the isothermal ideal gas at a fixed temperature of 273K for which tsound speed is 0.33km/s. The Fig.3 shows the lowpass-filtered waveform change as a function of epicentral distance in case where only the acoustic branch (the fundamental mode with the one-dimensional horizontal propagation) is taken into account. The Lamb and gravity wave branches are excluded from modeling. The arrival of the positive peak almost exactly follows the straight line with the input sound speed of 0.33km/s. No significant arrival is associated with the straight line with a speed of 0.31km/s.

The most striking feature of Fig.3 is the progressive loss of low frequency components from the propagating pulse. Although not shown, the waveform at the origin is a lowpass-filtered boxcar function rich in the near-zero frequency components. The acoustic pulse loses its low-frequency components rapidly enough to change the waveform from a boxcar-type to its time-derivative-type only within an epicentral distance of 150km. We note such a loss of low-frequency components and the resultant waveform change are not observed on the real records (Fig.3). This implies that the low frequency components visible on the observed records are not the low-frequency residuals of the acoustic wave but are mostly the components carried as the Lamb wave.

Implications

1.The coseismic uplift of the Noto Peninsula produced a pressure force acting on the atmosphere. The time-integral of this pressure force is the “impulse” (Force x Time = Pressure x Area x Time)”, which can be used as a quantitative measure of the total impact of the coseismic vertical ground motion.

2.The resultant pressure pulse propagates away from the source. The pulse on the acoustic branch little loses the high frequency energy but rapidly loses the low frequency energy. Such dispersion does not occur on the the Lamb wave branch of the pulse. The observed records are understood as the snapshots of the stage where the pressure wave from the Noto Peninsula begins to be separated into the higer-frequency acoustic wave and the lower frequency Lamb wave.

Acknowledgement
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Keywords: Acoustic wave , Crustal deformation, Atmosphere, Atmospheric pressure

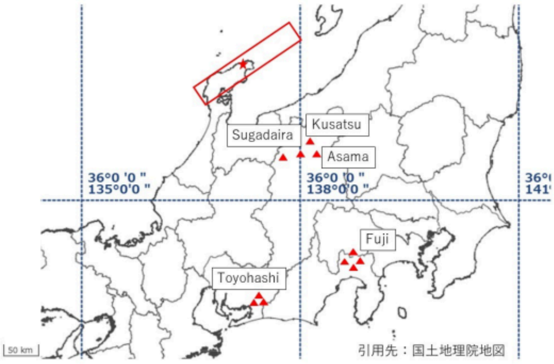

Figure 1

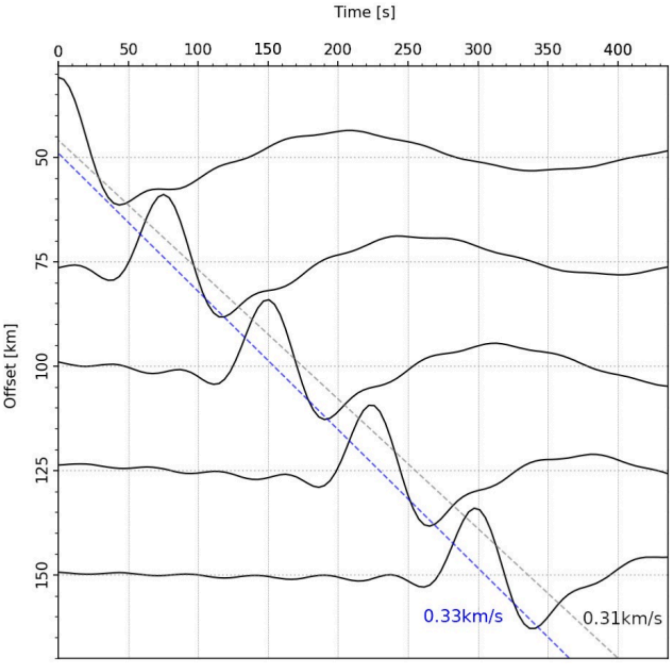

Figure 3

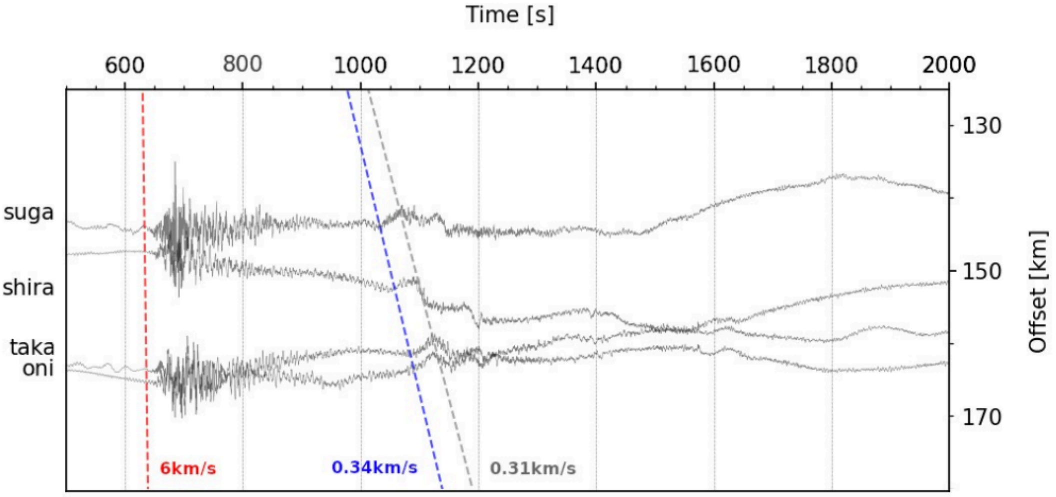

Figure 2A

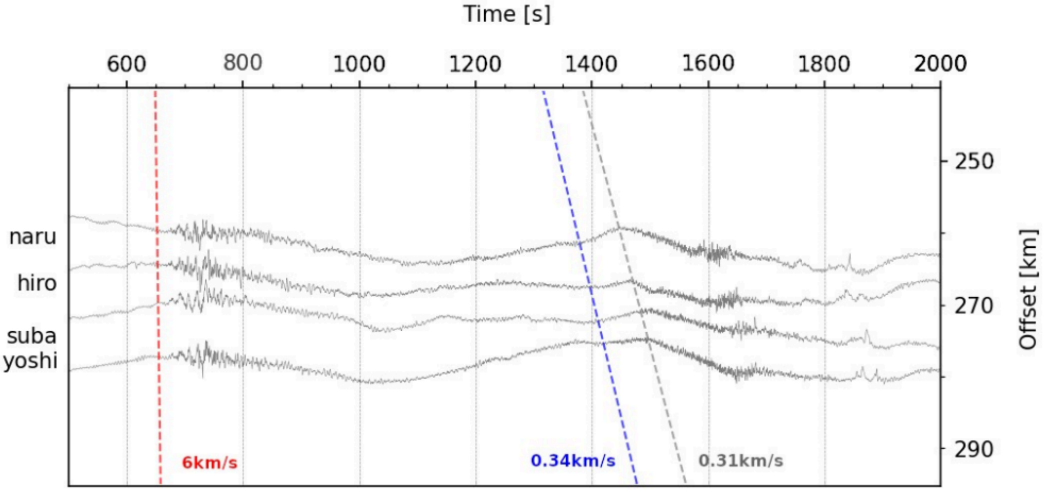

Figure 2B