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Estimating wave height using the difference in percentile coastal sound level

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ABSTRACT

This study investigated the correlation between sound level and wave height using field experiments conducted from July 14, 2009, to November 2, 2009, at the Hasaki coast in Ibaraki, Japan. We modeled wave height using the observed data from the first half of the study period to calibrate our model, and validated it using wave height from the latter half of the study period. Based on our results, we propose a model for estimating wave height using sound level and differences in sound level. The model predicted wave height with good accuracy ($R = 0.87$), and accurately described wave heights during the validation time period ($R = 0.87$). By comparing field data and each of the parameters utilized, it is clear that percentile sound level is a more accurate parameter for estimating wave height.

1. Introduction

Once we stand on a sandy beach, we can hear the sound of wave breaking, wind, wave uprush and down rush periodically. How acoustic waves travel in water, the behavior of air bubbles caused by wave breaking, and underwater noise have all been investigated (e.g., Bass and Hay, 1997; Deane, 1997; Means and Heitmeyer, 2002). Graćes et al. (2006) reported a correlation between low-frequency sound in water and wave height, and Bass (2013) found a correlation between wave-generated noise and dissipation of wave energy. Nadaoka and Tokumi (1991) investigated the physical and rhythm characteristics of wave sounds observed on land, and Nadaoka and Tamashima (1991) outlined the spatial distribution of such wave sounds. Murakami et al. (1996) not only reported the tone features and rhythm of wave sounds but also the effects of sediment diameter and bed slope using physical and field experiments. However, these investigations of the on-land wave sound were observed at the close to the shoreline or above the wave breaking point, and mostly they considered the characteristics of the sound.

In this study, the sounds that characterize the coastal aural landscape, which consists of sounds from both wind and waves, were observed on land on a sandy beach. Then we attempted to calculate wave height from these sounds using a simple equation.

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2. Outline of field experiments

2.1. Field experiment data

The field study was conducted over two periods, one spanning July 30 to September 14, 2009 (total = 46 days), and the other from September 14 to November 2, 2009 (total = 50 days), at the Hasaki Oceanographical Research Station (HORS), a research facility of Port and Airport Research Institute on the Pacific Coast of Japan (Fig. 1, Picture 1). The HORS facility includes a 427-m-long pier located perpendicular to the shore; the cross-shore distance along the pier was defined relative to the HORS facility located near the entrance of the pier, and the seaward direction was set as positive. The median sediment diameter was almost uniformly 0.18 mm along the pier (Kuriyama, 2002). The Hasaki coast is stable, and the bathymetry around HORS is uniform alongshore (Katoh et al., 1990).

Fig. 2 shows the mean beach profile and its standard deviation within the first period investigated (from July 30, 2009 to September 14, 2009). High, mean, and low water levels, based on data from the Hasaki Coast (Tokyo Peil −0.687 m), were 1.25 m, 0.65 m, and −0.20 m, respectively. In this study, the shoreline position was defined as the cross-shore location where the elevation is equal to the mean water level. The seaward position at the intersection between the mean beach profile and the mean water level was $x = 15.9$ m, and the beach slope was about 1/60.

To record coastal sounds, a sound level meter (NL-21, RION) was affixed to an array located at the top of the research facility (Picture 1). The location of the sound level meter was $x = -100$ m (115 m landward from the averaged shoreline position), and the

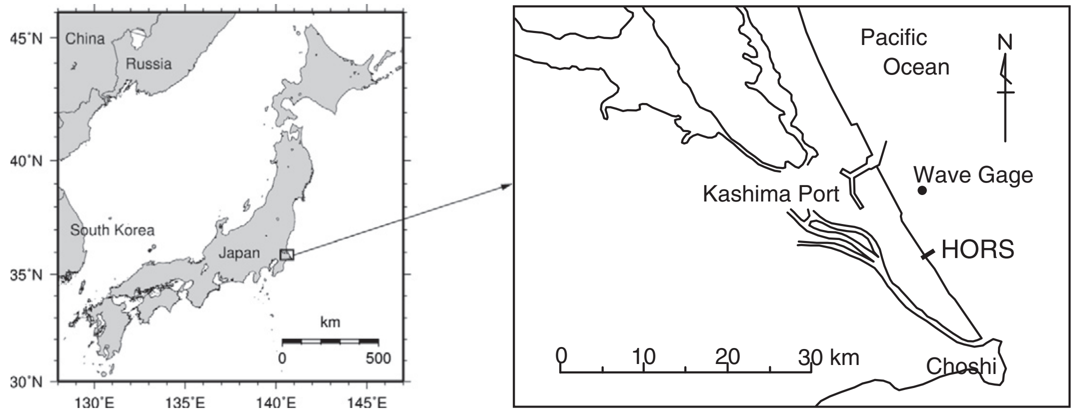

Fig. 1. Location of Hasaki Oceanographical Research Station (HORS).

elevation was D.L. = +12.6 m (11.9 m above the M.W.L.). All data from the sound level meter was recorded using a data recorder. To reduce background sounds of wind and rainfall, an all-weather windscreen was used (WS-03S01, RION). The noise reduction effect of the windscreen is approximately 19 dB. The observed sound level data were averaged sound level, and 5% and 90% percentile sound levels. Data were recorded every 5 min, to create 5 min averaged values, and the frequency-correcting circuit was set as the flat characteristic. In this analysis, data averaged every 20 min on the hour every hour was used.

Wave characteristics, which were used to calibrate and validate our model, were recorded using an ultrasonic wave gage (UH-401, KENEK) at x = 378 m (362 m seaward from the averaged shoreline position); the average water depth at this point was 5.3 m, and 20 min averages of wave data on the hour every hour was calculated. Significant wave height and the corresponding significant wave period were also calculated from the data. Wind was measured using a propeller style vane anemometer (N-363, Nippon Electric Instrument), which was fixed to the tip of the pier; the resultant data were averaged to every 10 min on the hour every hour.

2.2. Statistics of observed data

In this analysis, we attempted to develop a wave height estimation equation using observed data from the first period (from 12:50 JST July 30, 2009, to 12:10 JST September 14, 2009); to validate the accuracy of our equation, we used data from the second period (from 14:00 JST September 14, 2009, to 10:00 JST November 2, 2009).

Time series data, including significant wave height, significant wave period, sound level, wind speed, wind direction and air pressure during the first period, are shown in Fig. 3. Fig. 3e shows the wind direction positive for clockwise rotation where the zero degree denotes the direction parallel to the pier from offshore to onshore. The wind with −59° blows from north to south. The minimum, maximum, average, and standard deviation of each dataset are listed in Table 1. As shown in the figure, the values for all data types were relatively small from the beginning of this time period until the 30th day of observation (August 29). The averaged values of significant wave height, sound level, and wind speed over these 30 days were 0.92 m, 67.1 dB, and 5.0 m/s, respectively. During this period, three typhoons approached Japan. However, all of them occurred far from the observation site, and did not affect significant wave height or wind speed.

During the 31st and 32nd days of observation (August 30 and 31), typhoon Krovanh passed just east of the observation site, heading north. Maximum values for significant wave height, sound level, and wind speed were observed during this event. Over the 31st to the 40th day (from September 1 to 8), relatively high waves were observed, with average values for significant wave height, sound level, and wind speed of 1.73 m, 72.1 dB, and 7.23 m/s, respectively. On the 40th day

Picture 1. Location of the sound meter near HORS.

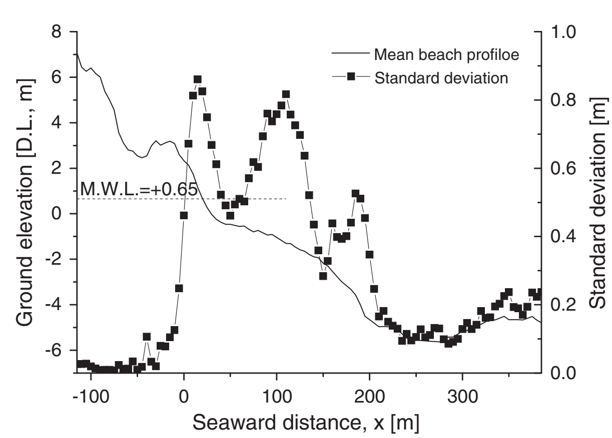

Fig. 2. Mean beach profile and its standard deviation (first period: from July 30, 2009 to September 14, 2009).