INTERTIDAL MORPHOLOGY AND WAVE RUN-UP OBSERVATIONS DURING A STORM EVENT WITH X-BAND NAUTICAL RADAR

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Abstract: A X-band nautical radar system has been employed to observe sea surface patterns of shallow coastal waters during a storm event. Wave gauges and current meters are employed in a conventional field test; however, the deployment of the instruments is limited, especially in the surf zone. In this context, a radar system is introduced here, which can remotely and broadly infer the sea surface state even during a severe sea conditions. The radar system was operated at the research pier HORS and radar echo images were collected during a passage of a storm in the vicinity of the pier. Analyses on radar echo images were done and the results demonstrate the potential of the system in observation of sea states, especially for discussion on morphological features and wave run-up motions. Analyses on radar echo images were done and (i) longshore distribution of mean shoreline positions and intertidal foreshore slopes, and (ii) temporal and spatial variation of wave run-up, are discussed.

INTRODUCTION

Applications of X-band nautical radars for coastal studies have become popular recently (e.g., Bell 1999; Borge and Soares 2000; Ruessink et.al. 2002; Takewaka 2005). The present paper reports the results of intertidal morphology and wave run-up observations with a nautical X-band radar during a storm event to show the effectiveness of radar system in coastal measurements under high wave conditions.

The radar system was operated at the research pier HORS, Hasaki Japan, and radar echo images were collected during a passage of a typhoon. Analyses on radar echo images were done and (i) longshore distribution of mean shoreline positions and
intertidal foreshore slopes and (ii) temporal and spatial variation of wave run-up are shown, and link between morphology and wave run-up motions are discussed.

EXPERIMENTAL SETUP

X-band radar measurements were conducted at the research pier HORS, of Port, Harbor and Airport Research Institute located in Hasaki, Japan (Fig. 1). HORS is located on a 17 km long and almost straight sandy coast stretching from north to south. A 400 m pier facing Pacific Ocean and a research building on the backshore, which is located approximately 100 m backwards from the mean shoreline position.

The radar employed in this study is a conventional marine or nautical X-band radar for commercial use (JMA-3925-9 Japan Radio Co. Ltd., 3 cm wavelength, transmitting power 25 kw, HH-polarization, radar pulse length 0.08 ms), which is usually installed
on a fishery or pleasure boat. The 2.8 m antenna rotates with a period of approximately 2.6 s and transmits with a beamwidth of 0.8° in horizontal and 25° vertical (Photo 1).

Back scatter or echo signals from the sea surface, which so-called sea clutters, are grabbed with a specially designed AD-board with sampling rate of 20 Mhz, installed on a Windows PC. The echo signals were sampled with 8 bits along the radial direction and then converted to a rectangular image with 1024 pixels in horizontal and 512 pixels in vertical. Each pixel corresponds to a square of 1.8 m, which is smaller than the theoretical spatial resolution 7.5 m of the radar system determined from pulse length of the emitted beam. Figure 2 show samples of radar echo image for a stormy condition. The radar is located at the center of the bottom of the diagram. The horizontal extent of the image is 1,852 m, or 1 Nautical Mile (NM), and vertical extent is 926 m. The gray images have pixel intensities between 0 and 255, with brighter pixel corresponding to a point with higher signal returns.

There are two main scattering mechanisms providing backscatter or echo signals from sea surface as response of transmission of the radar pulses (e.g. Skolnik, 1990). The
first is the Bragg scattering from capillary roughness on sea gravity waves. Bragg scatters occurs when the length of the roughness is half of wavelength of radar beam, which is 1.5 cm in this study. The second is specular spikes that come from steep and breaking waves. In an horizontally polarized radar, or an HH-polarization radar, sea spikes cause stronger backscatter signals than the Brag scattering.

These image samplings are done with 2 s intervals; part of the image is not renewed since the imaging intervals are shorter than the rotation time of the antenna. This may arise high frequency noises in time domain but does not affect analyses for wave motions, since they have lower dominant frequencies both in time.
A huge typhoon traveled through the western edge of the Pacific Ocean on 10th and 11th of June 2002. Radar echoes were collected continuously for 20 hours. Wave station of Kashima Port at depth of 28 m, which locates 4 km north from the pier, recorded a maximum significant wave height of 2.9 m with significant wave period of
7.4 s, as shown in Fig. 3. Bottom profile along the pier changed slightly due to this storm event as shown in Fig. 4; the off shore bar (y ~ 350 m) reduced slightly its height and migrated shorewards.

**SHORELINE POSITIONS AND FORESHORE SLOPES**

Individual echo images are averaged into a time-averaged image, as shown in Fig. 5. Determination of foreshore profiles, i.e., shoreline positions and foreshore slopes, is done by analyzing the averaged images for different tide levels (Takewaka, 2005). Cross-shore profile estimated from radar measurements are depicted in Fig. 4 with rectangular and triangular symbols, which agree reasonably well with results of bathymetric survey.

Longshore distribution of averaged shoreline positions in the tidal range and foreshore slopes are shown in Fig. 6. Wavy structure with length of order of 500 m in the
shoreline configuration remained almost unchanged after the storm, since the duration of high-energy state was short. Foreshore slopes have a tendency to be relatively large at regions where shore positions are located relatively off-shorewards and vice versa, however, this relationship doesn't stand for the entire region.

**RUN-UP MOTIONS**

**Digitization of Run-up Motion**

Pixel intensities along a cross-shore line are extracted from every echo image and stacked in time, as shown in Fig. 7. Local gradients of the oblique lines correspond to wave propagation speeds; change of local inclinations of the lines shows retardation of the wave celerity during shoaling and merger of waves occurs at intersections of the lines in the final surf zone. Lower end points of the lines are the maximum run-up points, which fluctuate in cross-shore direction with an interval of 30 to 90 s suggesting that low frequency motion exists in the surf zone. Here, the border of run-up bore and dried shore is defined as instantaneous run-up front. Figure 8 shows the run-up motions at different stages during the storm. At 4:00, run-up variation became most intensive during the storm although this period is not the most energetic wave condition.
Run-up motions were digitized as shown in Fig. 9 and a sample of the results are shown in Fig. 10., which suggests that there was longshore propagation of large-scale run-up and -down. The nature of this motion is discussed below.

**Run-up variation during the storm**

The mean of run-up at each location corresponds to the shoreline position that is shown already in Fig. 4. No simple relationship has been found between intensities of run-up variation and local foreshore slopes as shown Fig. 11.

Figure 12 shows the variation of intensities of run-up motion and mean period of them estimated from Fourier analyses of the run-up front variations shown in Fig. 10. Run-up motion became most intensive at 4:00, whereas the maximum significant wave height was recorded at 2:00 as shown in Fig. 3. The lower frequency components in the incident wave increased after the passage of the storm, which was recorded at depth of 28 m as shown in Fig. 13. Here, bandpass filter was adapted to the wave records to estimate wave heights of frequency bin. The run-up motions were amplified in accordance with the lower frequency components of the incident waves.

Propagations of large-scale run-up and -down in the negative longshore direction were observed in the sequence of radar images. A two-dimensional diagram, with vertical axis for time, lateral for longshore extent and local intensities correspond to run-up deviation from the mean, was processed to show this clearly as shown in Fig. 14, where longshore propagations of run-up and downs are clearly observable.
Fourier analyses in time and longshore domain were conducted for run-up point variations to assess this motion. The result shown in Fig. 15, with edge wave dispersion relationship depicted for mode $n = 0$ to $2$ (Scaeffer and Jonsson, 1992), suggests that the longshore run-up variation is a trace of edge waves passing of mode 1 or 2.

The amplitude of this longshore motion increased after the passage of the storm as already described: total incident wave energy decreased but the wave components of lower frequencies increased at this stage.

CONCLUSION

X-band radar measurements have been conducted during a storm event. Analyses on radar echo images were done to estimate longshore distribution of mean shoreline positions and intertidal foreshore slopes, temporal and spatial variation of wave run-up, and link between morphology and wave run-up motions. Rhythmic features of the beach in longshore extent were preserved during the storm, since the duration of high-
The energy state was short. Run-up fronts were digitized and longshore distributions of their variational intensities and means were analyzed. Variational intensities had no distinct correlation between foreshore slopes. Low frequency variances in run-up motion, which traveled alongshore, were observed. The wave numbers and frequencies of this motion satisfied the dispersion relationship of edge waves. The amplitude of this longshore motion increased after the passage of the storm; total incident wave energy decreased but the wave components of lower frequencies increased at this stage.

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REFERENCES

![Figure 15. Edge wave dispersion relationship and wave number - frequency of run-up variations. Components with negative 1/L propagate negative longshore direction.](image-url)