Study of Spatial Variation of Ocean Surface Waves by Using SAR Images in Coastal Area

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Abstract. A temporal pattern or characteristic of the ocean surface wave can be learned from buoy observation. In terms of spatial variations, the use of Synthetic Aperture Radar (SAR) image is considered to be the most efficient as SAR is not weather dependent. This paper aimed to study the pattern of ocean waves with study area in Jakarta coast by using SAR image. We focused on spatial variation so that we emphasized in the study of the wave pattern in the area close to the coastline and away from the coast. The low pass filter was applied to reduce the noise and the discontinuity in wave images can be removed as well. The two dimensional Fast Fourier Transform and the dispersion relation were applied to get the wave spectrum and then the amplitude of ocean wave was successfully obtained. By comparing the spectral ocean wave model, the pattern of ocean waves can be understood. The results showed that in the area close to the coastline, the random wave behavior was not dominant, where a single wave pattern as a result of the nonlinear process or the wave-wave interaction appeared. Meanwhile, in the offshore area, the random effect was very dominant.

1. Introduction

The growth of coastal town will give the change of shoreline so that the detailed information about the pattern of ocean waves is needed. The shoreline dynamic is mostly influenced by ocean waves. Therefore, the knowledge of ocean wave climate and dynamics are indispensable for developing shoreline management plan. The information of ocean wave can be obtained by using wave gauge measurement. This measurement gives detailed information temporally but weak spatially [1]. This weakness can be handled by distributing many wave gauges onto the ocean but this is not a cost-effective way. The use of radar satellite for observing ocean surface wave fills this weakness.

The spatial and temporal variation of ocean surface waves can be retrieved from SAR images. In this image, mesoscale phenomena can be observed i.e. waves with the periods between 3s~30s (wind sea to swell). The SAR image consists of two-dimensional electromagnetic backscatter of the ocean surface. The wave backscatter energy from SAR image depends on wavelength, polarization, geometry, and roughness of ocean surface [2]. The wave provides the change of ocean surface so that following the fundamental principle, by knowing roughness generated from SAR image, the information of ocean surface wave can be obtained.

Currently, the knowledge of extraction of surface wave from SAR image was already developed [3,4]. In this paper, we used similar manner to investigate the ocean surface wave dynamics in Jakarta Bay. Jakarta is the largest coastal city in Indonesia that is growing rapidly so that the information of ocean
wave is very important. The wave information of wave climate usually is obtained by wave gauge measurement which has good temporal variation but less on spatial variation. This lack may be equipped with the satellite data. The satellite data that is often used for the wave information is Topex-Poseidon but it had a low resolution so that not adequate for Jakarta bay. The satellite data most adequate to this proposed is SAR. We used the SAR images to see the behavior of the wave dynamics for both offshore areas and the onshore area in Jakarta Bay. The paper is organized as follow, the data and data processing are presented in sec-2. The data analysis and discussion are described in sec-3. The paper is ended by a conclusion

2. Method

2.1. Data

The study area was in Jakarta bay that is located in the north coast of Java with latitude around 106°50E and longitude 05°09S. The bay is relatively shallow and flat, with an average depth about 15m. It has many coral islands, reef-flats and related shallow-platforms occur in this bay. We used ALOS-Palsar II with HH polarization image on January, 26 2015 that is depicted in Figure 1. The data was provided by JAXA under ALOS Research Announcement Project number PI417002 entitle “Sea Surface Roughness Identification based on Synthetic Aperture Radar Data in Indonesian Waters”. The study area are represented in white box for both offshore and close to shoreline.

![Figure 1. SAR images of ALOS Palsar II with HH polarization on January, 26 2015.](image)

2.2. Data Processing

The Data processing chain for ScanSAR mode (wide-swath dual polarization, 1.5 level) was started by converting the ALOS-2 CEOS data format to EAM-DIMAP data format. To reduce the speckle noise after radiometric calibration then the Refined Lee filter was applied [5]. The result was a normalized radar cross section (sigma naught σ0) in terms of decibel (dB) value that is depicted in Figure 1. The first step was to capture the study areas in the offshore region and close to shoreline region (see the white box in Figure 1). The statistical behavior of surface wave was investigated from backscatter distribution of sigma naught along with the wave crest. Then the probability function (pdf) can be calculated.
A single SAR image contains a lot of kind of ocean surface waves that are described in the form of its wavelength. The characteristic of each wave can be seen from the spectrum of the wave numbers. But the SAR image spectrum does not represent the real ocean surface displacement spectrum. The relation between them is expressed by the modulation transfer function $T(k)$ (MTF) where $k = \frac{2\pi}{\lambda}$. The relation is usually not linear and difficult to obtain. From one SAR image (radar cross section $\sigma_0$), we can observe the directional wave spectrums in which the ocean wavelength and direction are evaluated. It means that from SAR image, we evaluate the wave number spectra rather than frequency spectra which are intensively observed by wave gauge. The 2D Fast Fourier Transform (FFT) is used to get wave number spectrum $S(k_x,k_y)$ that represents the wave energy. The relation between SAR spectrum and ocean surface wave spectrum $\Psi(k_x,k_y)$ is given by [4],

$$S(k_x,k_y) = T(k)\Psi(k_x,k_y)$$  \hspace{1cm} (1)

In two dimensional, the wave has the energy and the direction that is represented in term of directional spectrum $\Psi(f,\theta)$. This relation is between spatial wave spectrum and temporal wave spectrum [3]

$$\Psi(f,\theta) = \Psi(k_x,k_y) \cdot \frac{4\pi k \sqrt{gk \tan(h/k) \text{ tanh}(kh) + gh \sec^2(kh)}}{gk \tan(h/k) + gh \sec^2(kh)}$$  \hspace{1cm} (2)

where $g$ is the acceleration of gravity and $h$ is water depth. The 2D FFT is applied to get dominant wavelength before applying the averaging filter. The band pass filter is constructed based on the equation (2). We use MTF linear Equation (1) with $T(k)=105$ to get ocean wavenumber spectrum. Finally, the inverse Fourier transform is applied to get the wave amplitude.

3. Result and Discussion
We studied two interest areas i.e. offshore and close to the shoreline. They are depicted in Figure 2 and Figure 3. The wave that is observed by SAR image is usually generated by wind force that propagates from offshore and dissipated by the change of bathymetry and wave breaking. The previous measurement showed that the wave characteristics of Jakarta bay were determined by the wind velocity [6]. Most of the wave had 1-10 dm for wave height, 1-8 sec for wave periods and 20-30 m for the wavelength [6]. When the waves propagate close to the coast then the wave direction is perpendicular to the shoreline. The behavior of radar cross-section of the offshore and near coastline region is depicted in Figure 2 and Figure 3.

![Figure 2: Offshore](image1)

![Figure 3: Close to shoreline](image2)
a) The capture of offshore region corresponds to white box in Fig.1. b) The backscatter value of white line and c) represents the probability density function of backscatter distribution of white line.

Figure 2.

For the offshore region the radar cross section had pdf in the form of $\rho = 1/(2\pi\sigma) \exp(-((x-\mu)/2\sigma)^2)$ where the mean of deviation standard $\sigma$ was about 0.0038 and the peak displacement $\mu = 0.31$ m$^{-1}$. This form was a Gaussian distribution. In the other hand, for the region close to the shoreline the pdf had the form of $\rho = 1/(2\pi\sigma) \exp(-((x-\mu)/2\sigma)^2)-0.01$ where the mean of deviation standard $\sigma$ was about 0.0046 and the peak displacement was $\mu = 0.34$ m$^{-1}$.

The 2D FFT and the wave amplitude of offshore are depicted in Figure 4 where area close to the shoreline is depicted in Figure 5.

Figure 4.

b) The 2D FFT for an offshore area where a horizontal axis is a wave number and the vertical axis is energy, b) The wave amplitude as result of 2D IFFT with linear MTF where horizontal axis in m and the vertical axis in da.
The results showed that for an offshore region the wave fields had average amplitude about 0.85 m and it had a random distribution. The significant wave high measurement based on Altimetry satellite and modeling show that for inter-island waters of Indonesia (such as Jakarta bay) had less than 1.2 meters wave height in January, which increased in February and March and reaches about 1.5 meters height [7,8]. It can be inferred that the wave fields had the wavelengths which a bit random but the amplitude is relatively uniform. This is consistent with the radar cross section that has Gaussian pdf. Contrasts with the offshore, for the nearshore the wave fields had amplitude with the average 0.8 m and appeared to tend to be a single wave. The Figure 5 b) also shows that there are two single waves with the amplitude is about 1m among the smaller wave high.

4. Conclusion
The spatial variation of ocean surface wave fields from SAR images in Jakarta Bay was investigated. We used ALOS-Palsar II images with HH polarization images on January, 26 2015 in this study. By using linear MTF then the ocean surface wave fields were obtained. The result showed that the area closes to the coastline, the wave appeared to be a single wave but in the offshore region the wave has random wavelength and the amplitude tend to uniform. 2017.

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