STUDY ON THE OCEANIC PHENOMENA IN THE SEA AROUND JAPAN USING PALSAR ON BOARD ALOS

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ABSTRACT

Retrieval methods of coastal surface wave parameters are studied using the PALSAR images. For developments of the retrieval frameworks, C-Band SAR images have been used together with in situ data of the Japanese coastal wave gauges. Using the surface wave parameters, oceanic phenomena in the Japanese coastal seas have been studied. Throughout this study, five full scientific papers are generated as shown in the REFERENCE.

1. INTRODUCTION

Synthetic aperture radar (SAR) has proved to be a useful and efficient remote-sensing tool for observing ocean surface wave fields at high spatial resolution. SAR images contain vast amounts of information on surface waves, which enables us to retrieve surface wave parameters. SAR imaging mechanisms of surface waves are based on a two-scale model, in which small-scale Bragg waves (i.e., the scattering facets) are modulated by large-scale surface waves. Three modulation mechanisms (tilt modulation, hydrodynamic modulation, and velocity bunching) have been presented, which are modeled by modulation transfer functions (MTFs) in SAR wave imaging.
Retrieval methods for surface wave parameters have been proposed for C-band SARs. On the basis of MTFs, Hasselmann and Hasselmann proposed a nonlinear imaging relation connecting the SAR image spectrum and the surface wave spectrum that has been widely used by many researchers.

Sun and Kawamura [1] developed a scheme to retrieve surface wave parameters (wave height, wave length, and wave direction) from European Remote Sensing Satellite (ERS) SAR image mode data for coastal seas around Japan. They treated the swell and wind-wave dominated cases with linear and nonlinear imaging mechanisms, respectively. They used the wind speed retrieved from the SAR image to generate the first-guess wind-wave spectrum. The significant wave heights derived from SAR were validated with in situ observations. Their results demonstrated that the SAR surface wave parameters retrieved by their algorithm can be used to monitor the surface wave field in the coastal seas around Japan.

Applying these methods, Sun and Kawamura [2] studied the characteristics of the high-resolution coastal wave field near a wind front off the Kii Peninsula using ERS SAR images. Further, using the C-Band SAR image, Yamaguchi and Kawamura [3] have investigated the spiral eddies in Mutsu Bay and developed a physical model for explaining the spiral mechanism of slicks advected by the underneath geotropic oceanic circulation.
Swells dominate in coastal seas and can travel long distances across an entire ocean with small energy loss. When propagating into the coastal seas, swells interact with the coastal bottom topography and swell refraction, diffraction, and depth-induced breaking occur. Due to their long wavelengths, the swells are easily affected by the bottom topography in coastal seas, and the phenomena are generally considered to be well explained by linear wave theory.

Retrieval algorithms for surface wave parameters have been proposed in both open oceans and coastal seas for C-band SARs. In contrast, there has been no such study using L-band SAR images. Satellite-borne L-band SARs are now observing surface waves, and while L-band surface wind retrieval is well established using accumulated L-band SAR images, retrievals of surface wave parameters have not yet been performed. We developed methods to retrieve the swell parameters (wavelength, wave direction, and wave height) from L-band SAR images around Japanese coastal seas [4]. Using the retrieved swell wavelength and wave direction for investigating 2-D characteristics of the swell in Sendai Bay [5]. The infinite amplitude surface wave theory is used for their explanation, and its applicability is examined.

2. RETRIEVAL OF SURFACE WAVE PARAMETERS FROM SAR IMAGES AND THEIR VALIDATION IN THE COASTAL SEAS AROUND JAPAN [1]

We have developed a scheme to retrieve surface wave parameters (wave height and wave propagation direction) from European Remote-Sensing Satellite (ERS) Synthetic Aperture Radar (SAR) image mode data in coastal seas around Japanese coastlines. SAR spectra are converted to surface wave spectra of swell-dominated or wind-wave dominated cases. The SAR spectrum and SAR-derived wind speed are used to derive the surface wave spectrum. The wind-wave dominated case and swell-dominated case are differentiated by a wind speed of 6 m/s, and processed in different ways because of their different degree of nonlinearity. It is indicated that the cutoff wavelength for retrieval of the wind-wave dominated spectrum is proportional to the root of significant wave height, which is consistent with the results of previous studies.

We generated 66 match-ups using the SAR sub-images and the in-situ surface wave parameters, which were measured by wave gauges installed in near-shore seas. Among them, there are 57 swell-dominated cases, and 9 wind-wave dominated cases. The significant wave heights derived from SAR and from in-situ observation agree with the bias of 0.09 m, the standard deviation of 0.61 m and the correlation coefficient of 0.78 (Fig.1). The averaged absolute deviation of wave propagation directions is 18.4° , and the trend of the agreement does not depend on the wave height. These results demonstrate that the SAR surface wave spectrum retrieved by the present system can be used to observe the surface wave field in the coastal seas around Japan.

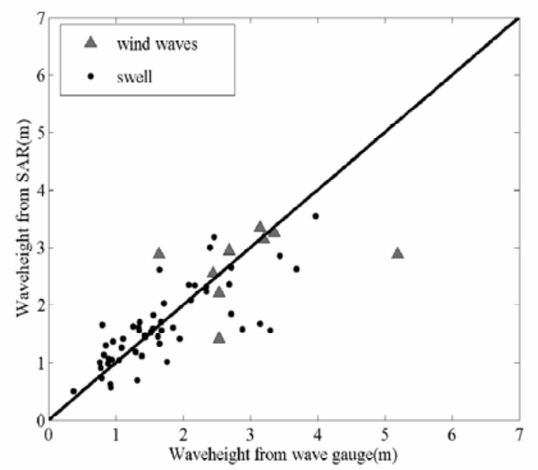

Fig.1 Comparison between gauge-measured and SAR-derived significant wave heights. Solid line indicates perfect correlation. Solid circle dots indicate the significant wave heights of swell cases and the triangles indicates that of wind wave cases.

3. MODIFICATION OF SAR SPECTRA ASSOCIATED WITH SURFACE WIND FIELDS IN THE SEA OFF THE KII PENINSULA: A CASE STUDY [2]

Using surface wave parameters and a high-resolution surface wind field derived from Synthetic Aperture Radar (SAR) image mode data, we have investigated the spatial modification of SAR spectra. We found a surface wind front, formed by sheltering effect of the Kii Mountains, separating high and low wind-speed regions in a sea area of an European Remote-Sensing Satellite (ERS) SAR image off the Kii Peninsula. A swell system propagating westward dominates in the whole sea area covered by the SAR image. The wavelength retrieved from the SAR spectra (Fig.2) in the sheltered (non-sheltered) region is longer (shorter).

Since the distributions of surface wave parameters and surface wind speed are so well correlated, it can be considered that the SAR spectra are modified differently by the sheltered/non-sheltered surface winds. In order to examine the phenomena observed on the SAR image we have estimated the wind-wave SAR spectrum using the SAR surface winds, a wind-wave spectrum model and a SAR wave imaging model. We assume that the SAR spectrum related to the swell is homogeneous in the area imaged by SAR, and that the SAR spectrum of the wind-wave components causes the observed SAR spectra modification. Differences between the observed SAR spectra and the estimated SAR spectra in the sheltered and non-sheltered regions agree well with each other. In the present case, it can be concluded that the observed SAR spectra can be regarded as a linear combination of the wind-wave SAR spectra and the swell SAR spectra.

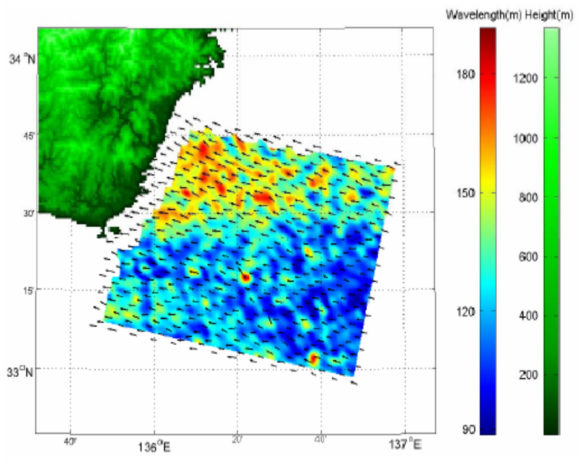

Fig.2 Wavelength (color) and propagation direction (arrow) of surface waves for each sub-image and land topography (green).

4. SAR-IMAGED SPIRAL EDDIES IN MUTSU BAY AND THEIR DYNAMIC AND KINEMATIC MODELS [3]

A pattern of slick streaks winding into a spiral, known as a spiral eddy (Fig.3), was identified in 5 images taken by the ERS-1/2 synthetic aperture radar (SAR) in Mutsu Bay (Japan); dynamic and kinematic models of these spiral eddies have been proposed. Common characteristics of the five spiral eddies are: 1) an eddy diameter of about 15 km; 2) their location in the western part of the bay; and 3) their cyclonic direction of rotation. Moreover, the wind conditions over the bay were common: prior to acquiring the images, a strong easterly wind continued blowing for more than one day. The wind field on the bay is known to be orographically steered and has strong wind stress vorticity, which generates cyclonic circulation (Fig.4).

The diameter and location of the circulation simulated with a numerical ocean model corresponded well to those of the identified spiral eddies (Fig.5). Based on these facts, we propose a dynamic model for the movement of a slick streak, and a kinematic model for the formation of a spiral eddy. We have assumed calm air, a microlayer and seawater with a cyclonic circulation in the dynamic model (Fig.6).

The balance of forces is established in the microlayer among the frictional force from the seawater, the frictional force from the calm air, the gravitational force, and the Coriolis force. As a result, the velocity vector of the microlayer deflects slightly towards the center of the cyclonic circulation. We have assumed a point source of the microlayer in the kinematic model. The shapes of a slick streak simulated with the models agree well with the identified patterns in the SAR images.

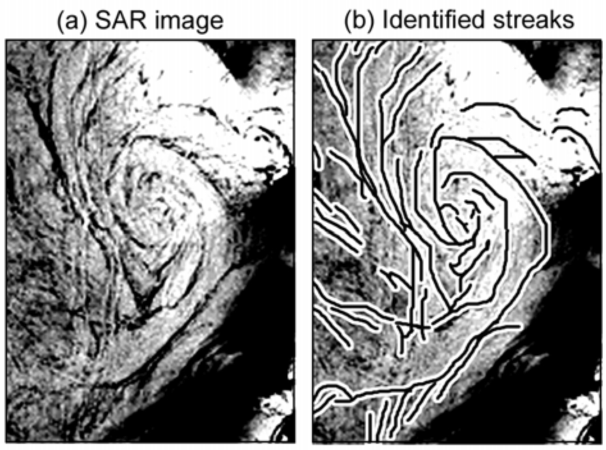

Fig.3 Enlarged image of spiral eddy in Fig. 3(a), (a) with and (b) without identified slick streaks.

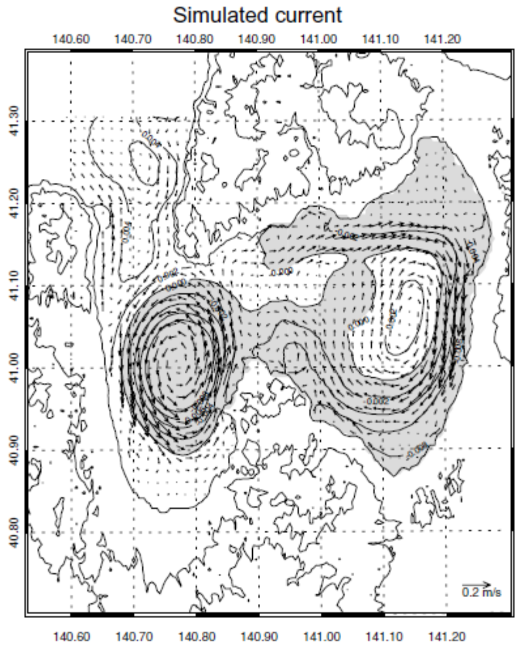

Fig.4 Vertically averaged current vectors (arrows in m s–1) and sea-surface elevation (contours in meters, negative elevation areas are hatched) on Day 5 simulated with three-dimensional numerical ocean model. The given boundary condition of the simulation for the five days is the OS-wind field derived from a SAR image.

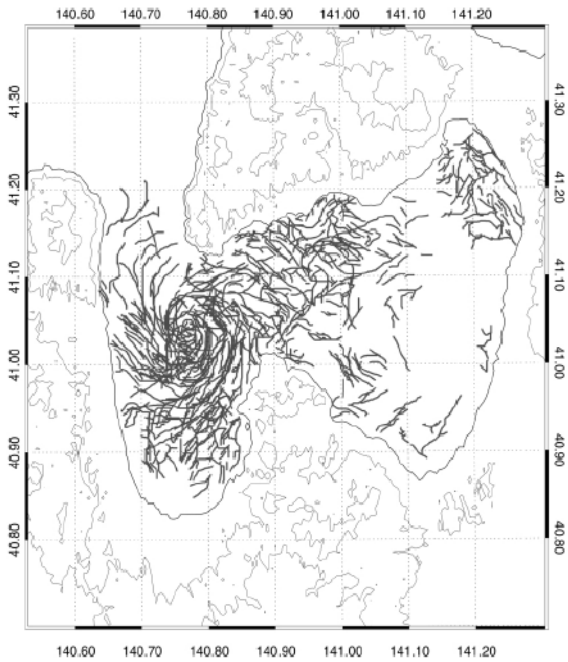

Fig.5 All slick streaks identified in five SAR images.

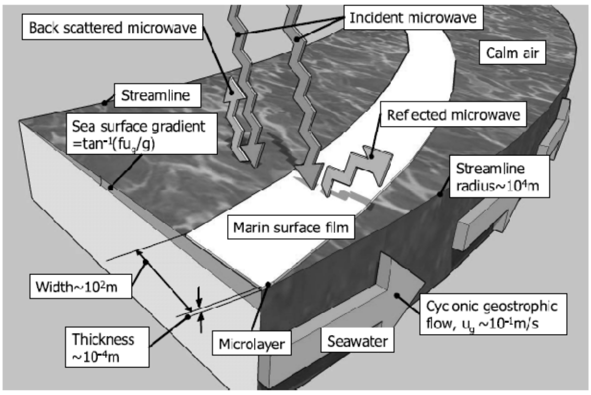

Fig.6 Schematics of the spiral eddy based on analysis of SAR images and sea surface wind observations.

5. RETRIEVAL OF SWELL PARAMETERS USING PALSAR ON BOARD ALOS [4]

We have developed retrieval methods for swell parameters such as wave height, wavelength, and wave propagation direction (wave direction, hereafter) from images of the Phased Array type L-band Synthetic Aperture Radar (PALSAR) on board the Advanced Land Observing Satellite (ALOS) taken over coastal seas around Japan. The retrieval methods for wavelength and wave direction use the PALSAR image spectrum. The SAR image spectrum has an inherent 180o direction ambiguity, which can be solved using the fact that the swells only propagate toward the coast.

Using the coupling swell spectra and the PALSAR image spectra, an empirical L-band modulation transfer function (MTF_{L-band}) was obtained for the wave height retrieval through linear regression analysis. A comparison between SAR-derived and in situ wave parameters showed close agreement. For the wavelength, the bias was 10.4 m, the root mean-square error (RMSE) was 18.3 m, and the correlation coefficient was 0.93. For the wave direction, the bias was 1.3o, the RMSE was 15.5o, and the correlation coefficient was 0.94. These results demonstrate that the L-band SAR imaging mechanism for swells is mostly linear. For the wave height, the bias was 0.08 m, the RMSE was 0.30 m, and the correlation coefficient was 0.80 (Fig. 7).

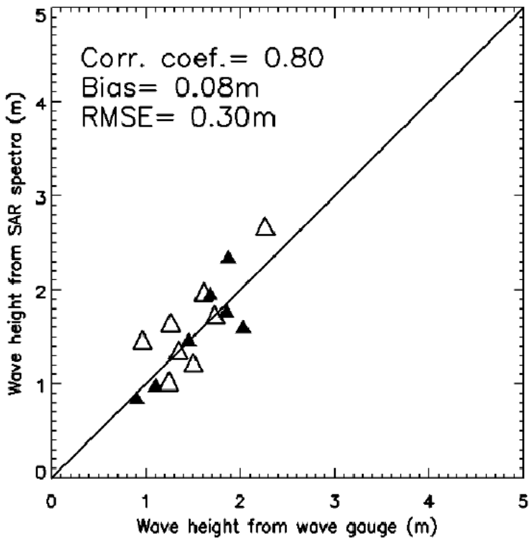

Fig.7 Validation of the significant wave heights retrieved from PALSAR. The black triangles were converted from the surface wave spectra used for the MTF derivation. The white triangles were the match-ups independent of the MTF regression analyses.

6. A CASE STUDY ON TRANSFORMATION OF SWELLS PROPAGATING INTO SENDAI BAY

Sendai Bay is located in the Tohoku Area of Japan (Fig.8). From a PALSAR scene (Fig.9) on 24 September 2006, a high-resolution two-dimensional map of swell wavelength and propagating direction is retrieved (Fig.10, 11) .

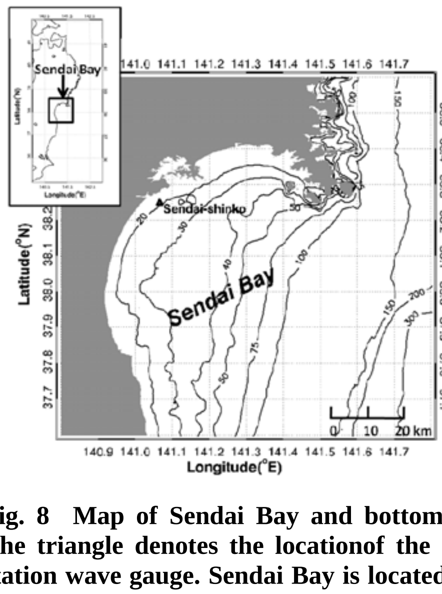

Fig. 8 Map of Sendai Bay and bottom topography. The triangle denotes the locationof the Sendaishinko station wave gauge. Sendai Bay is located on northern Honshu Island, Japan, facing the Pacific Ocean (upper-left panel).

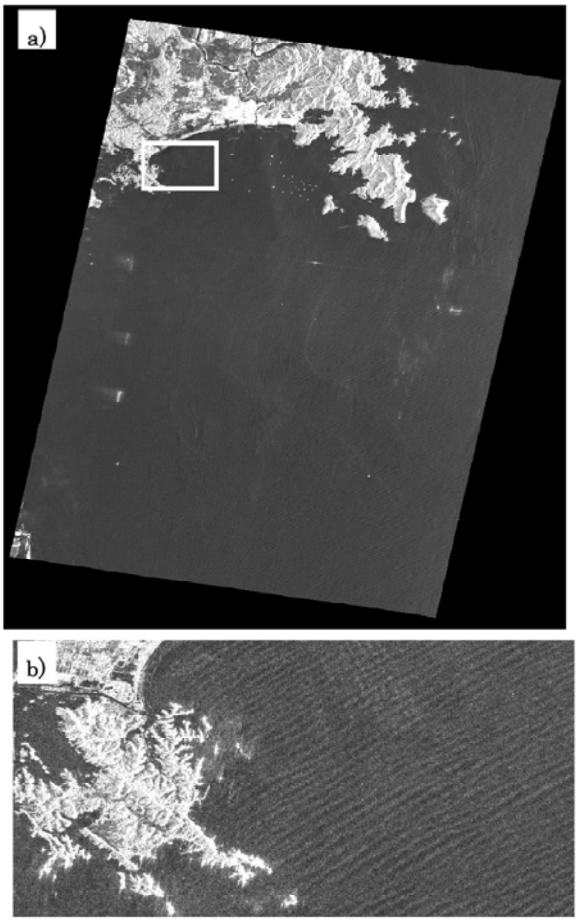

Fig.9 a) PALSAR image of Sendai Bay taken at 01:06 UTC on 24 September 2006. b) An enlarged/enhanced image of the white square in a).

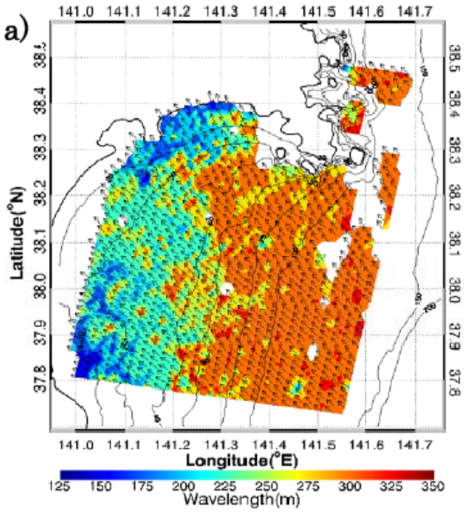

Fig. 10 Wavelength and direction map of Sendai Bay retrieved from the PALSAR image obtained at 01:06 UTC on 24 September 2006. Grid resolution is about 1.0×2.0 km. Colors indicate the wavelengths and arrows indicate the directions.

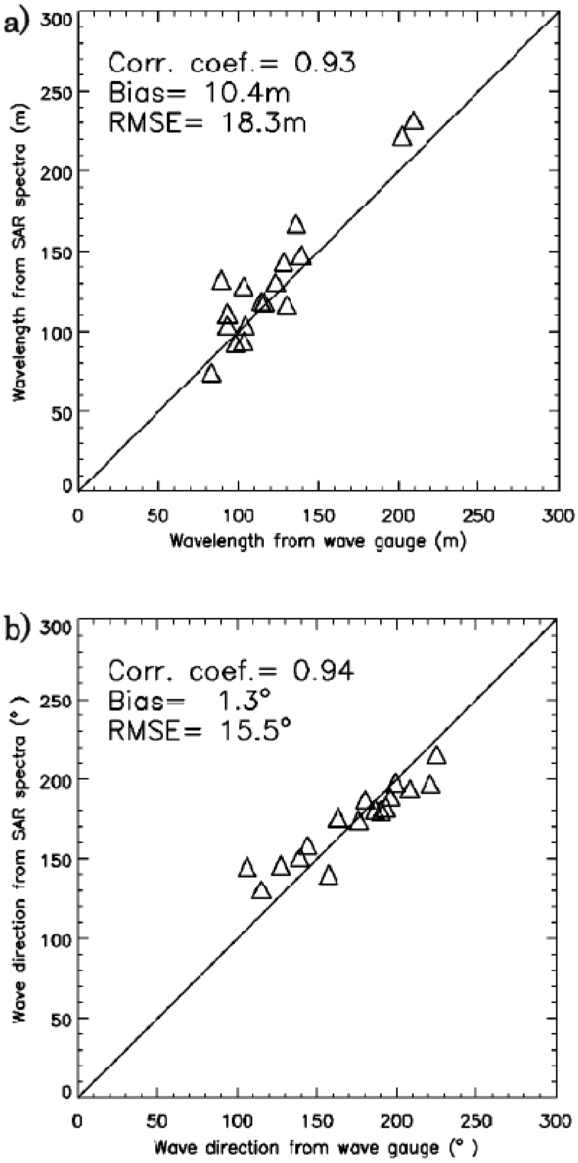

Fig.11 Validation results for a) the SAR-derived wavelength (SAR ・) and b) the SAR-derived wave direction (cited from Wei et al. (2010)). The Nationwide Ocean Wave Information Network for Ports and HArbourS (NOWPHAS) in situ parameters are used as the sea truth data.

Features of the wavelength map are investigated by comparing with a wavelength map calculated through the Infinitesimal Amplitude Surface Wave (IASW) theory with the in situ measurement of swell period (Fig.12). They correspond well with each other in most areas though large differences appear in the near-shore area (Area-I) and the complicated bottom topography area (Area-II). Since the spatial resolution of swell parameters is not enough to investigate the surface waves in Area-I, the wavelet transform (WT) along a swell ray is applied for the spatial resolution improvement. Using the WT wavelength map, it is shown that the large difference in Area-I disappears. For Area-II, the perturbation theory on surface waves propagating obliquely on gentle slope is introduced. The large wavelength difference in Area-II is well explained by the second order solution of the perturbation theory.

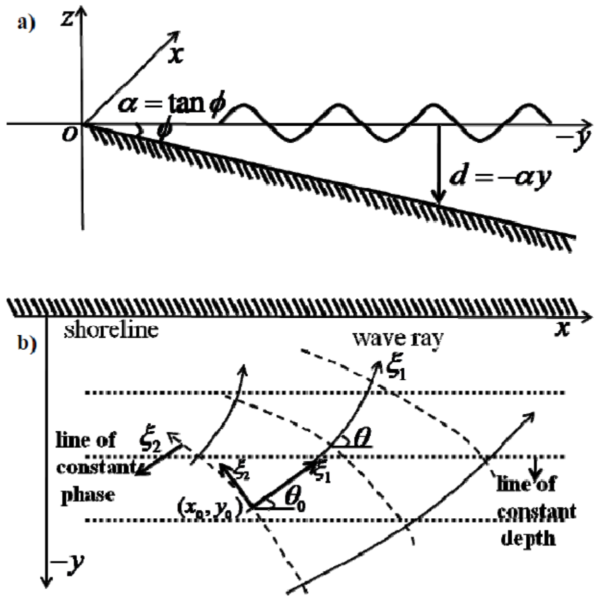

Fig. 12 Definition sketch of the wave refraction problem. a) Geometry of the propagating surface waves on a gentle bottom slope. b) Configuration of the wave ray coordinate system.

7. REFERENCES

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