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Numerical Investigation into Wave Transformation around King Island

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Abstract

Increased global energy demand and the threat of climate change have persuaded governments to focus their resources on finding methods of renewable energy. In recent times ocean waves have been considered the most exploitable and predictable means of renewable energy source. However, before any site can be considered for a wave energy device, the wave characteristics around the area must be studied. This has caused increased investigation into the renewable power availability in the near shore region.

This paper presents a numerical study into the wave transformation around King Island, Tasmania using the simulation software package Simulating WAves Nearshore (SWAN). The research was conducted for three dominate wave directions with the most frequent wave heights and periods based on the bathymetric data from Geoscience Australia and the hydrodynamic conditions from BMT Fluid Mechanics. The numerical results demonstrated the wave transformation patterns in the near shore region around King Island. Diffraction was most noticeable on the eastern side for the three simulated wave directions while wave shoaling and refraction effects occurred along the West coast when the waves were dominantly from the West and South-West directions.

By evaluating the obtained wave transformation information from SWAN simulation results, two potential locations where wave energy converters can be installed are identified and discussed. The Southern tip of King Island was observed to be feasible for a point absorber type wave energy device which would allow for the greatest power generation for any given wave height despite the changing direction, while the Eastern side was observed to be suitable for attenuator type wave energy devices in rays to harness wave energy.

Introduction

With increasing global energy demand and concerns about anthropogenic climate change, world governments are under increasing pressure to find alternative forms of energy [1,2]. Cornett [3] states this research has sparked renewed interest in marine renewable energy in many countries, in which Europe is leading the way. Marine renewable energy consists of current, osmotic, ocean thermal and tidal but the most consistent and exploitable form of marine power is wave power [3]. Pecher [4] states that ocean waves provide a sustainable, power-dense, predictable and widely available source of energy that could provide about 10 % of worlds energy needs. Hemer and Griffin [5] estimate that ~1300 TWh/yr of wave energy is available between Geraldton, WA and the southern tip of Tasmania, approximately five times the energy requirement for Australia. This has led to the development of new methods to harness wave power and hence an increase in locations at which wave energy is economically viable. Many of these locations are in the near shore region.

In the recent years there has been increased interest in the installation of wave energy converters in the near shore regions around Australia. The Commonwealth Scientific and Industrial Research Organization (CSIRO) have recently conducted studies to estimate the possible wave power around Australia. The Ocean Renewable Energy (2015-2050) Report [6] illustrated the national wave energy potential distribution, and from which the near shore region of King Island, located between mainland Australia and Tasmania in the Bass Strait, has large potential energy resources, as highlighted in Figure 1.

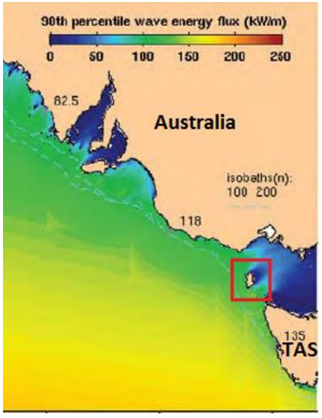

Figure 1. King Island potential energy resources [6]

The main objective of this study was to conduct numerical modelling of wave transformation around King Island and, identify suitable wave energy converting devices for different near shore locations. For this purpose, a wave transformation model [7], SWAN, was used to replicate the hydrodynamic conditions due to its ability to accurately model wave transformation in the near shore region. The wave data input was determined from BMT Global Wave Statistics [8].

Numerical Modelling Methodology

This study applied the SWAN model to King Island off the North West tip of Tasmania in order to assess the wave transformation and possible wave energy convertor locations. The model domain included the near shore region of the island, to a water depth of 50m. The model was conducted using multiple user inputs from various sources. The modelling process is shown in Figure 2

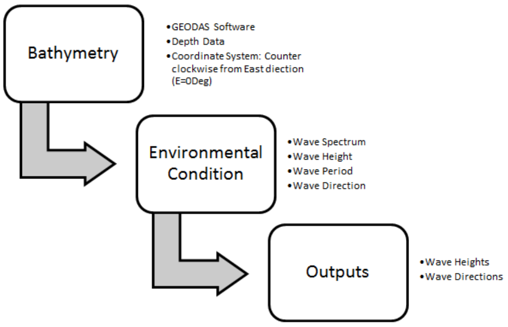

Figure 2. Processes for developing the SWAN wave model

Bathymetry Input Data

The main input parameter of the computational domain is the bathymetric data. The bathymetry data was collated using Geophysical Data Management System (GEODAS) software, in particular the coastline extractor and the Hydro-Plot. This software outputs the bathymetric data into a three column matrix in the form of longitude, latitude and depth. The bathymetric grid determines which global coordinate system is used during the modelling. There are two choices of coordinate systems offered by SWAN: spherical or Cartesian, the latter was used in this research.

Environmental Condition

The boundary conditions employed in the model determine the operation mode for the SWAN software. There are multiple inputs required when setting up the boundary conditions, including: wave spectrum and wave parameters. The first condition to be set was the wave spectrum. The options available in SWAN include; JONSWAP, PM and Gaussian spectrums. The wave spectral model used in this study was the JONSWAP wave spectrum, which accounts for bottom friction in the analysis. The input wave parameters included the wave height, period and incoming direction.

Case Study: King Island

There are two main reasons to choose King Island, Tasmania for this case study. The first being is the large potential energy observed close to shore referring to [3,6]. These two reports showed the potential wave energy around the west coast of Tasmania and King Island was up to 125KW/m. The southwest coast of Tasmania was also identified as having high wave energy potential; however, it was excluded due to the complexity of transporting the energy to the consumers. The second reason was the existing infrastructure from the King Island Renewable Energy Integration Project. This project was started by Hydro Tasmania and includes onsite storage for renewable energy and a subsea cable tied into the Melbourne power grid on mainland Australia.

Bathymetric Setup

In this study, SWAN cycle Version III 40.91AB was used for the wave simulations. The simulations were carried out in third generation mode using the Cartesian coordinate system.

The SWAN model was set up to cover the bathymetry area consisting of the region between $143^{o}40'$ E to $144^{o}36'$ E and $39^{o}33'$ S to $40^{o}16'$ S. The spatial resolution of the bathymetry data source was $0.0025^{o} \times 0.0025^{o}$ (250m × 250m), which can be seen in Figure 3. The bathymetric grid consists of 320 points of longitude and 320 points of latitude.

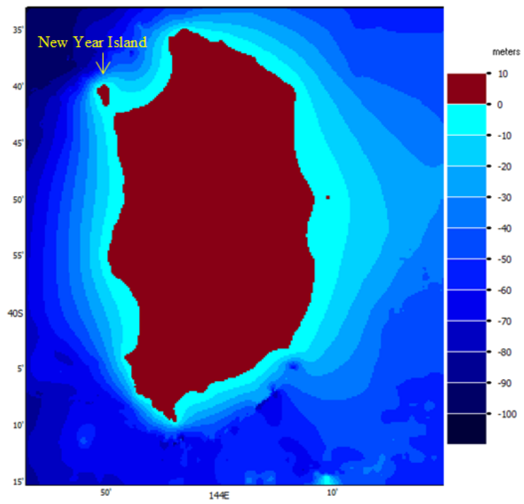

Figure 3. King island bathymetry

Input Offshore Wave Conditions

In order to accurately derive the wave transformation around King Island, the hydrodynamic conditions must be studied. This was achieved through an analysis of the significant wave heights and wave periods from the BMT Global Wave Statistics database [8]. The SWAN model was run using the most frequent wave scenarios. A total number of twelve scenarios were run as indicated in Table 1.

Case	Wave Direction	Significant Wave Height (m)	Period (s)	
			A	B
1	West	2	7.5	8.5
2	West	3	8.5	9.5
3	South West	2	7.5	8.5
4	South West	3	8.5	9.5
5	South	2	7.5	8.5
6	South	3	8.5	9.5

Table 1. SWAN simulation input wave parameters

Results

Wave transformations around King Island were determined by observing the wave directional changes and the wave height changes that occur as the waves approach the island. The bending of wave direction and increase in wave height due to the varying of water depth when waves passing the island are commonly referred as wave refraction and shoaling.

Wave Height Changes

The westerly wave direction was observed to be the most frequent wave direction. Figure 4 shows the impact of the near shore bathymetry of King Island on the westerly incoming waves at 2m and 3m wave height. It can be seen that both wave heights are significantly reduced from diffraction around the King Island and the New Year and Christmas Islands (Figure 3).

Figure 4 also shows the slight shoaling along the west coast in a water depth of less than 10m. This is more evident in the 3m wave model due to the increased incoming wave height. There is some shoaling evident in the 2m model in approximately 7-8m of water compared to the shoaling of the 3m wave height in 8-10m of water.

The south westerly wave direction was observed to be the second most consistent wave direction from the BMT hydrodynamic data. The results from this modelling can be seen in Figure 5, where the wave height was observed as the wave train passed the islands near shore region. The south westerly wave direction shows a decrease in wave height as it enters the 30m isobaths along the west coast. As the wave approached the shoreline it starts to shoal in 8m for the 2m wave height and 9m in the 3m model. The shoaling was evident along the whole west coast with the northern parts of the bays observing the highest wave heights.

The diffracted wave height was observed to have different effects for the different wave heights. The smallest diffracted wave height for the 2m wave model (Figure 5A) was observed at the north eastern tip, whereas the 3m wave model (Figure 5B) showed a minimal wave height on the east coast.

The southerly wave direction was recorded as the third most frequent wave direction observed and the results can be seen in Figure 6. This figure shows the effect of shoaling and diffraction on the southerly wave train. It can be seen from Figure 6A that the greatest effect on wave height due to diffraction is on the western side of the northern tip and a smaller amount halfway up the eastern coast. The 3m wave condition, Figure 6B, also showed a significant reduction in wave height near the Northern tip but showed greater area of reduced wave height along the eastern coast. Shoaling can be seen on both wave models predominately on the middle headland on the western coast. There is a small amount of shoaling on the eastern coast of both models.

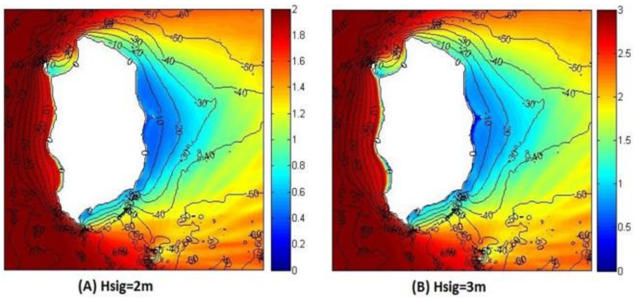

Figure 4. Changes in wave height during the westerly wave direction (A) Input wave height of 2m, (B) Input wave height of 3m

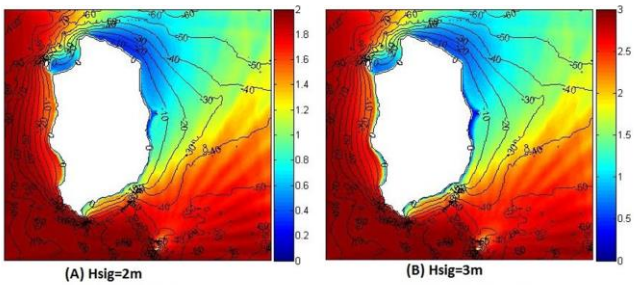

Figure 5. Changes in wave height during the south westerly wave direction (A) Input wave height of 2m, (B) Input wave height of 3m

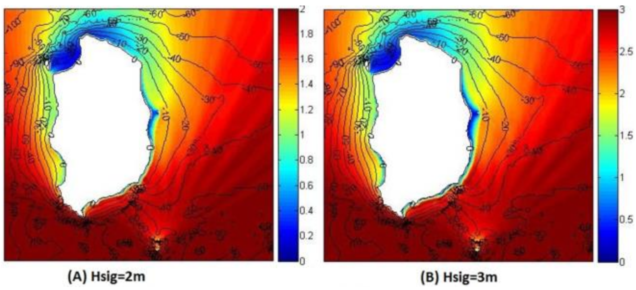

Figure 6. Changes in wave height during the southerly wave direction (A) Input wave height of 2m, (B) Input wave height of 3m

Wave Directional Changes

Figure 7 shows the change in direction of the westerly wave train as it passes King Island. The major wave direction change occurs on the lee side of the island. The wave direction on the eastside has changed from the 0 degree (westerly) wave direction to a resulting wave direction of 225 degrees (north easterly) for the top half of the island and 150 degrees (south easterly) wave direction for the bottom half of the island. It is also noted that refraction occurs around in the bays located on the west coast. The northern bay near New Year and Christmas islands has the most noticeable refraction.

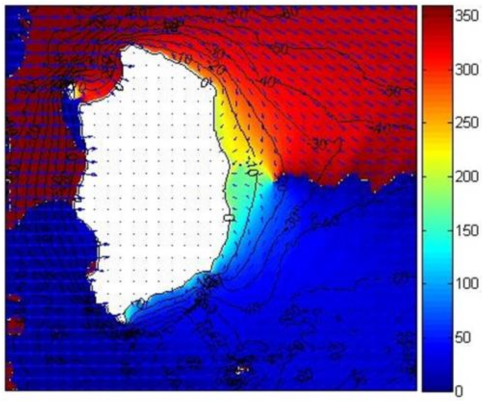

Figure 7. Changes in wave direction during the westerly wave (scale is wave direction in degrees, where 0 degree is west)

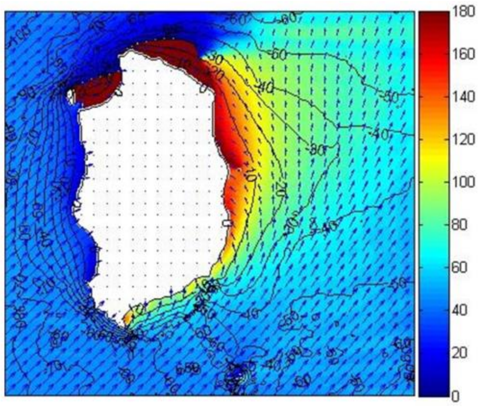

Figure 8. Changes in wave direction during the south westerly wave

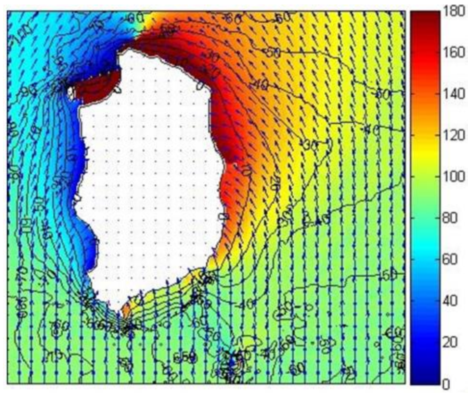

Figure 9. Changes in wave direction during the southerly wave

The south westerly wave direction showed the minimum amount of wave direction change; this can be observed in Figure 8. The south westerly wave affects the majority of King Island with the west and southern coastal areas affected heavily by this wave direction. The eastern side of the island has the greatest effect from diffraction as the wave changes from a south westerly direction to a south easterly. The northern coastline of the island is subject to two different directional waves which cause a resultant westerly directional wave on the western side and an easterly direction on the eastern side.

Figure 9 demonstrates the effect of propagation through the near shore region has on the southerly wave direction due to diffraction. The greatest amount of diffraction is seen on the eastern side of the island, where the wave direction changes from southerly direct to easterly. Along the western coast the apparent wave direction is a south westerly direction.

Discussion

The effects of wave transformation were evident in all the wave directional models presented. The major effects seen in the modelling were diffraction and shoaling, which were evident in each model.

Strong diffraction effects on both of wave height and wave direction are demonstrated. There were two different locations at which the wave height was significantly reduced. The first location was halfway up the eastern side of the island and the second location was located at the northern end of the island. These locations were also the locations of the greatest diffracted wave direction changes. This can be seen by comparing the wave direction with the wave height.

Shoaling was the next greatest effect to the wave height in the near shore region. This effect was most seen along the westerly coastline. This was due to the larger distance between the changing depth and the main wave directions. The depth changes along the west coast were over a greater distance to that than that on southern area. This allowed for the bottom topography to impact the wave for a longer period of time. As there would be shoaling present on the southern tip of the island, the bottom topography changes from a depth of 60m to 1m over a distance of 100m. This sudden depth change makes it difficult to accurately model the effects of shoaling.

From the results there are different locations at which a wave energy device may be installed. The first location possible location would be a device that requires a constant wave direction installed along the east coast of the island. The ideal wave energy converter for the eastern coast would be an attenuator energy device. These devices require a semi consistent wave direction to allow for the maximum energy production, an example of this is the Pelamis wave energy device [5].

The other location is the southern tip and surrounding area. This location allows for the maximum wave heights at the three most frequent wave directions but the angle of the wave can change up to 90 degrees. The advised energy device to be installed on the southern tip of the island is a surface or sub surface point absorber. Although its efficiency is not as great as attenuator energy devices, the point absorber does not require a consistent wave direction as it is small and generates energy from a pressure differential created by the heave motion of the device [9]. This device will allow for high power generation for any given wave height despite the changing direction which was seen on the southern tip of the island.

Conclusions

Understanding the wave transformation in the near shore region is vital for ocean engineering. Fewer investigations into near shore wave modelling exist compared to the modelling of deep water waves. From the lack of knowledge about potential wave energy in the near shore region, most of the renewable energy devices have been designed for deep water applications. CSIRO investigated the potential wave energy around Australia, from which it was observed that King Island could be a potential site for different suitable wave energy converting devices. Therefore, it is necessary to model and understand the wave transformation around the island.

The models were run using the SWAN modelling program in the third generation mode. The environmental data was retrieved from BMT [8] with the bathymetry information from Geoscience Australia. The models were run for a total number of twelve cases with difference wave heights, period and incoming angle. The following conclusions can be drawn:

- The numerical modelling results from SWAN can provide detailed wave information for potential wave energy converting device development and design. The accuracy of predicted waves is dependent on the bathymetric and offshore wave data.
- The wave transformation results clearly demonstrated the wave diffraction patterns in the near shore region around King Island. Diffraction was most noticeable on the eastern side for the three wave direction investigated in this study.
- The wave shoaling and refraction effects are most noticeable mainly along the west coast when the waves are dominantly from the west and south-west directions.
- The southern tip of King Island had the highest wave heights due to wave transformation, making it a suitable location for point-absorber type wave energy devices.
- The eastern side demonstrates a fairly constant wave direction pattern which would be more suitable for attenuator type wave energy devices.

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