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AN INVESTIGATION OF THE WAVE ENERGY RESOURCE OFF THE SOUTH AFRICAN SOUTHWEST COAST

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ABSTRACT
In order to effectively harness the wave energy off the South African coast a comprehensive description of the wave energy resource is required. This paper presents the results of an investigation of the South African wave energy resource, focusing on the spatial distribution of wave energy on the southwest coast. The objective of the investigation was achieved through the analysis of measured- and modelled wave data.

KEY WORDS
Energy conversion; Wave power; Spatial distribution; Resource mapping.

1. Introduction

South Africa has committed to generate 10 000 GWh of renewable energy per annum by 2013. This paper aims to assist the Government in reaching its renewable energy goals by providing a description of the spatial distribution of wave power of the South African coastal region with the largest known wave power resource. From the outcome of the study sites suited for wave energy conversion can be identified (refer to [1, 2] for a description of the various types of wave energy converters (WEC's)).

Previous work on the South African wave power climate was conducted in the late seventies to early eighties [3]. A portion of this paper will focus on the revision of this work by presenting the results of the analysis of the additional 23 years of recorded wave data.

The study comprises of a literature review and wave data analyses of measured- and modelled hindcast wave data. In order to achieve the study's main objective, the aims of each subset of the study were achieved (see Fig. 1).

2. Literature Study

In the literature review of the study the global offshore wave power distribution was investigated by considering wave power distribution maps, such as those developed by Oceanor (http://www.oceanor.no/). It was found that South Africa has a substantial offshore wave power resource, compared to the rest of the world, of approximately 50 kW/meter wave crest averaged over a year.

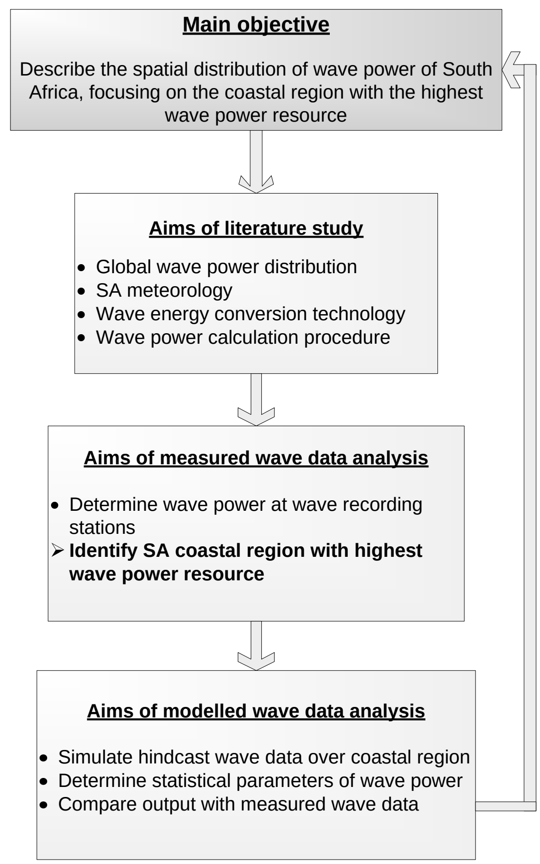

Figure 1. Main and Sub-objectives of the Study

The factors contributing to South African's abundant wave power resource were investigated by considering the wave generations conditions caused by local meteorology. In general, the wave conditions in South Africa are influenced by low pressure systems (generated in the South Atlantic Ocean) moving from west to east. Tropical cyclones in summer are also a source of wave generation on the east coast in particular.

During the literature review linear wave theory was investigated and wave parameters relevant to wave power were identified (refer to [4] for detailed description of linear wave theory and recorded wave data). Wave power is dependent on the wave height squared and the wave period. In order to determine wave power for a measured wave record a regular wave height and -period parameter is required containing the same wave energy density as the measured irregular wave record. The root-mean-square wave height (H_{RMS}, Eq.1) and the energy period (T_e, Eq. 2) linear parameters were found to have the equivalent energy density of the irregular wave records to be analyzed.

$$H_{RMS} = \frac{H_s}{\sqrt{2}} \quad (1)$$

where H_s is the significant wave height, a wave parameter commonly recorded at wave recording stations.

$$T_e = \frac{\sum \frac{E(f_i)}{f_i}}{\sum E(f)} \quad (2)$$

where: $\frac{E(f_i)}{f_i}$ = the ratio of the energy density to frequency interval f_i. $\sum E(f) = m_0$ = the total energy in the recorded wave spectrum. Wave power in deep water is calculated according to Eq. 3:

$$\overline{P} = \overline{E}C_{go} = \frac{\rho g H_{RMS}^2}{8}\frac{gT_e}{4\pi} = \frac{\rho g^2 H_{RMS}^2 T_e}{32\pi} \quad (3)$$

where g is the gravitation constant, d is the water depth, ρ is the density of sea water (1025 kg/m^3), C is the wave celerity, C_{go} is the group velocity and $\overline{E}$ is the energy density.

The literature review was concluded after an investigation into the current status of wave energy conversion technology. This gave a background of different types of wave energy converter units (either under development or in operation) which could be considered for wave energy conversion on the South African coastline. WEC units were categorised according to its basic principle of energy conversion. The three main categories and the associated devices considered include:

- Oscillating water column (OCEANLINX, LIMPET, SWEC)
- Reservoir storage (WAVEDRAGON)
- Relative motion (AQUABUOY, PELAMIS, ARCHIMEDES WAVE SWING)

The next section of the paper presents the results of the measured wave data analysis conducted to identify the South African coastal region with the greatest wave power resource.

3. Measured wave data analysis

Wave data of five recording stations along the South African coast were considered during the recorded wave data analysis of this study. The stations are representative of the various coastal regions of South Africa [7]. The distribution of the recording stations along the coast is presented in Fig. 2 below.

The wave data recorded at the Port Nolloth station represents the expected wave conditions on South Africa's west coast. During the recorded data analysis the wave conditions on the west coast were compared to that of the south west coast (wave data of Slangkop- and Cape Point recording station) to determine if there is a decrease in wave power as waves propagate north from the storm generation zone in the South Atlantic Ocean.

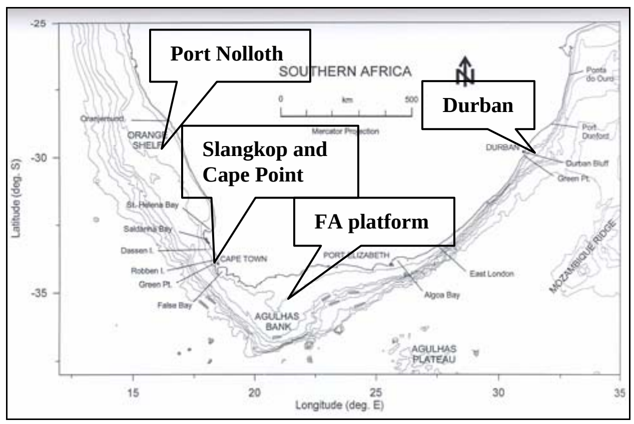

Figure 2. Distribution of Wave Recording Stations along the South African Coast

The wave data recorded at FA platform and Durban recording station represents the wave conditions on the south- and east coast respectively. Information relevant to all wave recording stations analysed is presented in Table 1 below.

For the purpose of comparison of wave power conditions at the different recording stations the degree of concurrent or overlapping recording periods, was investigated. The two wave parameters most relevant to wave power, i.e. wave height and –period (T_p, peak period), recorded at each recording station were analysed to give an initial indication of expected wave power conditions at the various recording stations. Cape Point, Slangkop and FA platform was found to have the greatest recorded values of wave height and –period. Refer to [4] for detailed analysis of wave parameters recorded at wave recording stations. Refer to Table 2 for average wave height and -period values at the wave recording stations.

Table 1
Relevant information of wave recording stations

Recording Station	Lat Long coordinates	Distance offshore (km)	Water depth (m)	Description of data	Recording period	% Coverage	Wave recorder
Port Nolloth	29° 46.8'S 16° 46'E	30	100	3 Hourly Hs and Tp	1987/04/08 to 1996/08/31	63%	Waverider
Slangkop	34° 7.6'S 18° 10.6'E	13	170	6 Hourly Hs and Tp	1978/10/03 to 1993/06/12	72%	Waverider
Cape point	34° 12.2'S 18° 17.2'E	7	70	3 Hourly Hs and Tp	2000/07/01 to 2006/06/30	92%	Waverider
FA platform	34° 58.2'S 22° 10.2'E	72.5	113	1 Hourly Hs, Tz and Hmax	1998/01/01 to 2003/12/31	97%	Radar
Durban	29° 59.2'S 30° 59.9'E	2.3	42	3 Hourly Hs and Tp	1992/08/11 to 2001/10/31	69%	Waverider

The variability of annual and seasonal wave power of each wave recording station was analysed in terms of basic statistical parameters. These parameters include: average wave power over the recording period, 90% probability of exceedance of wave power (represents the lowest expected wave power conditions) and 5% probability of exceedance of wave power (represent the recorded extreme wave power events).

The wave energy development index (WEDI), defined by Hagerman (2002) as the ratio of annual average wave power to the maximum recorded wave power, was determined for each recording station. Port Nolloth has the greatest WEDI which implies that the average annual wave power at Port Nolloth can be harnessed with the smallest capital cost for survivability compared to the other recording stations. Refer to Table 2 for WEDI values of the various recording stations.

Probability of exceedance and frequency of occurrence analyses were conducted seasonally and for the mean annual record at each recording station.

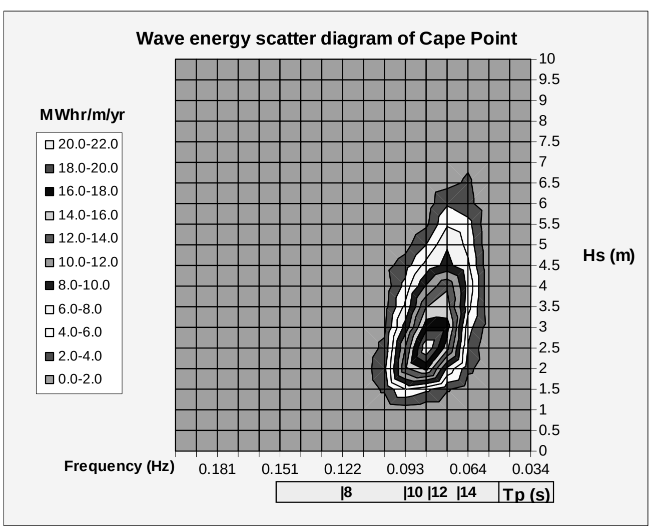

Figure 3. Wave Energy Scatter at Cape Point

A wave energy scatter analysis was conducted for the all the wave recording stations. During wave energy scatter analysis [5] the number of concurrent H_s and T_p records are determined. These occurrence values are then converted to an equivalent number of hours per year. The amount of power generated by each concurrent H_s and T_p value is determined. Lastly, the available mean annual wave energy (kWh/m) per year per H_s, T_p bin (pre-selected Hs and Tp ranges) is determined. An example wave energy scatter diagram is presented for the Cape Point station, which was found to have the greatest wave energy scatter. Refer to [4] for the detailed wave energy scatter analysis and the wave energy scatter diagrams of the other wave recording stations.

From the comparison of basic statistical parameters (see Table 2 below) of wave power and the probability of exceedance of wave power Cape Point, Slangkop and the FA platform were identified as the stations with the greatest wave power resource, followed by the Port Nolloth and Durban recording station. It can thus be concluded that the South African South West coast has the greatest wave power. The results of the investigation of the spatial distribution of wave power in this region are presented in the next section.

Table 2
Statistical Parameters of Wave Height (H_s), Wave Period (T_p) and Wave Power (P) at Wave Recording Stations

Wave recording station	Ave H_s (m)	Ave T_p (s)	Ave P (kW/m)	90% P	5% P	WEDI
Port Nolloth	2.1	12	26	7	73	9
Slangkop	2.5	12	39	10	110	5
Cape Point	2.5	12	39	9	114	4
FA platform	2.7	9	36	8	106	4
Durban	1.7	10	14	5	36	1

4. Modelled wave data analysis

The objective of the modelled wave data analysis is to provide a detailed description of the spatial distribution of wave power of the South African coastal region with the greatest wave power, i.e. south west coast. This objective is achieved through the numerical simulation of ocean wave propagation (using SWAN wave model) over the above mentioned coastal region. The SWAN wave model was employed during this study, because it is gives accurate results, is freely available and is relatively easy to use.

In order to simulate wave transformation from deep water (offshore) to near-shore, deep sea wave data is required as input into the numerical model. The hindcast wave data of the National Centre for Environmental Prediction (NCEP) was used for this purpose. The objective, methodology and desired output of the analysis are presented in Fig 5 below.

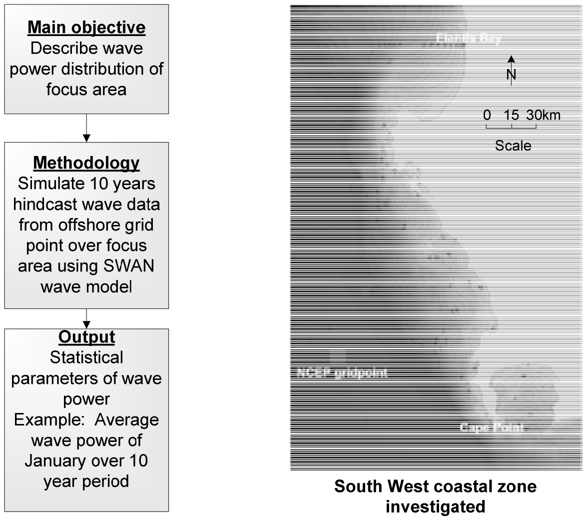

Figure 5. Presentation of Objective, Methodology, Output and Investigation Area

In order to time effectively simulate the entire ten year NCEP hindcast wave data record over the study area certain assumptions were required. The impact of these assumptions were investigated in the sensitivity analysis of the study and it was found that the analysis provided accurate estimates of wave power in the offshore and near shore area with marginal overestimation in the shallow water region.

From the modelled wave data analysis the mean monthly-, annual-, mean seasonal- and mean annual wave power distribution of the south west coastal zone was determined and presented in the form of wave power distribution maps. An example of a spatial distribution map of wave power is presented below in Fig. 6 for the mean annual average wave power of the focus area for a ten year period.

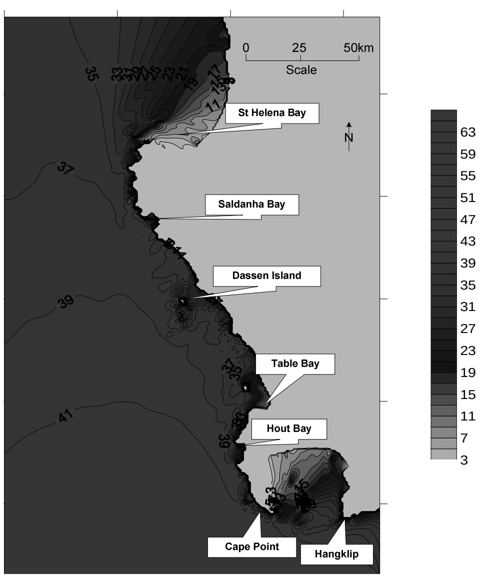

Figure 6. Mean Annual Average Wave Power Distribution (kW/m) of the South West Coastal Zone Based on 10 years of Hindcast Wave Data

The output from the modelled data analysis was compared to the measured wave data of Cape Point recording station. The results of the comparison are presented below in Fig. 7 which shows that the analysis provides accurate estimates of wave power of the focus area.

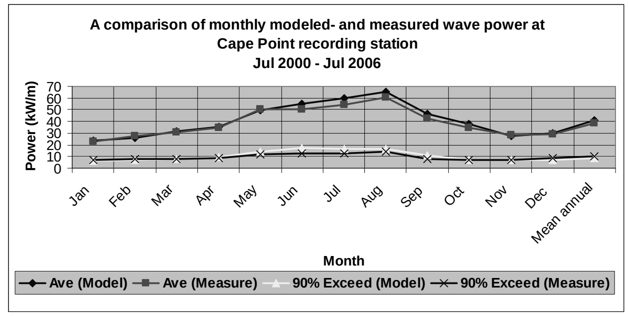

Figure 7. Monthly Measured and Modeled Wave Power

5. Conclusion

From the wave power analysis of measured wave data it was found that the Slangkop and Cape Point wave recording stations have the highest wave power resource with a mean annual average wave power of approximately 40kW/m (refer to Table 2). Based on this part of the study the south west coast was identified as the coastal zone exposed to the highest wave power and was therefore selected as the focus study area for which detailed spatial wave power distribution statistics were determined. From the modelled wave data analysis it was found that the average offshore wave power resource ranges from 35kW/m in the north to 41 kW/m in the south. Output from the modelled wave data analysis indicates wave power focal zones such as along the western coast of Cape Point and the southern coast of Dassen Island. It is recommended that further detailed numerical analysis be conducted after the identification of sites for potential wave farms in order to accurately estimate wave power conditions in shallow water locations.

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