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WEST COAST

Preliminary Assessment of the Marine Environmental Conditions for Liquefied Natural Gas (LNG) Shipment and Transfer Operations for Areas along the West Coast of South Africa

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LIST OF ACRONYMS

CD	Chart Datum
CSIR	Council of Scientific and Industrial Research
DED&T	Department of Economic Development and Tourism
FSRU	Floating Storage and Regasification Unit
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MBM	Multi Buoy Mooring
MCA	Multi Criteria Analysis
MW	Mega Watts
NOAA	National Oceanic Atmospheric Administration
NCEP	National Centre for Environmental Prediction
PLEM	Pipe Line End Manifold
SPM	Single Point Mooring
SWAN	Simulating Waves Nearshore
TNPA	Transnet National Port Authority

1 INTRODUCTION

The CSIR was commissioned by the Department of Economic Development and Tourism (DED&T) of the Western Cape Government to conduct an assessment of the marine environmental conditions for the siting of an offshore LNG (Liquefied Natural Gas) receiving terminal along the West Coast of South Africa.

1.1 Background

The Western Cape government currently imports in excess of 2 000 MW per annum in electricity from the national ESKOM grid. However, constraints in supply coupled by the Western Cape government's regional development plans have seen the Western Cape government emphasise the role of electricity generation. To meet its projected economic development objectives, the Western Cape government has identified, amongst other things, independent electricity generation as one of the many measures to stimulate economic growth.

The DED&T has conducted pre-feasibility studies into the feasibility of a LNG import operation along the West Coast (Visagie, 2013). This study identified the project as potentially viable and that such an operation would add value to the regional and national economies, and will reduce the dependence on the national electricity grid operated by ESKOM, which has supply constraints. The study also highlighted the market potential for this alternative source of energy, not just for gas-fired power generation, but also for use as a fuel source for domestic, transportation and industrial sectors in the Western Cape.

The study further identified the Cape West Coast region (Saldanha Bay – Cape Town Corridor) as a potential siting area, which is the area of interest for this study. This report addresses the Saldanha Bay – Cape Town Corridor offshore area, along the coast. The area within Saldanha Bay is covered in CSIR report (2014a).

1.2 Objectives of the study

The objective of this study is to provide a technical basis for the assertions made in the pre-feasibility study in relation to the suitability of the potential site locations. The present report focuses on two potential locations for the import of LNG along the West Coast of South Africa.

1.3 Project Approach and Limitations

Marine environmental conditions are critical for the design and operability of an LNG import facility. Therefore, the CSIR conducted a preliminary assessment of the local marine environmental conditions along the West Coast, based on the following approach:

- Collate and review all relevant and available information on marine environmental conditions
- Derive the short wave (swell) climate in the area of the proposed LNG terminals using a numerical wave model setup for the West Coast
- High level statistical analysis of marine environmental conditions
- Relate wind, current and wave information to vessel operability criteria

In conducting the assessment, the CSIR relied on data in its possession and other publicly available data. No field investigations or detailed numerical modelling of the ship motion or ocean currents have been conducted to support the conclusions in the report.

2 METHODOLOGY

The potential sites for the LNG receiving terminal along the West Coast have to fulfil three basic maritime requirements for the water area of the LNG receiving terminal in terms of this project, viz.:

(i) Navigability
- Required water depth (without dredging)
- Acceptable current, wave and wind climate

(ii) Manoeuvrability
- Adequate turning (tactical) basin length and depth
- Availability and power of tugs (wave condition for efficiency)

(iii) Operability
- Required water depth (for vessel and LNG receiving terminal)
- Berthing, mooring and de-berthing operation (un-mooring and sailing)
- Downtime persistency (the number and duration of operation windows based on waves, wind and currents)

A qualitative matrix is provided to compare potential site locations and the proposed operations for the LNG receiving terminal in Section 10. The **GREEN** – **ORANGE** – **RED** system will be used to assess the fulfilment of the basic requirements where GREEN is RARE impact, ORANGE is POSSIBLE impact and RED is ALMOST CERTAIN impact. The degree of suitability for the various elements of the basic requirements is shown in Section 10.

It should be noted that this approach is not a ranking of the two potential locations and their operations, as a ranking of an option is a combination of various elements, inter alia capital, operational and maintenance costs, which in this project have not been quantified, but which should be in the scope for future work.

3 SITE SELECTION

3.1 Proposed Locations

Two locations have been selected as possible sites for an offshore LNG receiving terminal along the West Coast i.e. within St Helena Bay and the area between Dassen and Robben Islands. The criteria by which the sites were selected will be discussed in Section 4. The selected sites are shown in *Figure 3-1* and circled yellow. The terminal can be located at any marine location within the indicated ellipses.

Figure 3-1: Selected sites along the West Coast

The site between Dassen and Robben Island was chosen due to its proximity to the ESKOM Ankerlig Power Plant at Atlantis. At this location, gas will be directly supplied to the plant via a high pressure transmission pipeline. Although further away from Atlantis, St Helena Bay would provide more shelter against South-westerly storms.

Among the criteria followed in selecting these locations, adherence to the exclusion zones as stipulated by the maritime gas industry was considered. This exclusion zone refers to areas that for safety and operational reasons require certain distances from LNG vessels or terminals. It should be noted that the criteria followed are applied to the present conceptual stage and that further research might be required at detailed design stages of the project. The exclusion zones and distances are therefore mentioned below:

- At least 1 600 m from any residential area
- At least 500 m from other port operations infrastructure
- At least 300 m from moored LNG vessels to passing ships

Jetty mooring is not feasible for the exposed offshore locations under review. Offshore alternative mooring systems are turret or Single Point Mooring (SPM) buoy systems. Based on the Golar-Bluewater report (2011), it should be noted that the terminals for the proposed environment will be considered at depths of 30 m and 50 m.

3.2 Proposed LNG Import terminals

For the two proposed location, LNG vessel will operate as per the Golar-Bluewater concept specification (2011). The Floating Storage and Regasification Unit (FSRU) will be permanently moored to the sea bed at a water depth of 50 m by means of turret (as *Figure 3-2*) or demountable buoy systems. The internal turret will be placed in the bow, below the main deck. Two operations could be envisaged at this location depending on the metocean conditions, viz. tandem and side-by-side offloading (see *Figure 3-3*).

Cryogenic transfer hoses will be used to transfer LNG from the import tanker to the FSRU. From the FSRU, the re-gasified gas will flow to the swivel system in the turret or buoy and continue through the import risers and pipeline end manifold (PLEM) at the sea bottom, with some 80 bar delivery pressure.

Figure 3-2: Turret Moored FSRU

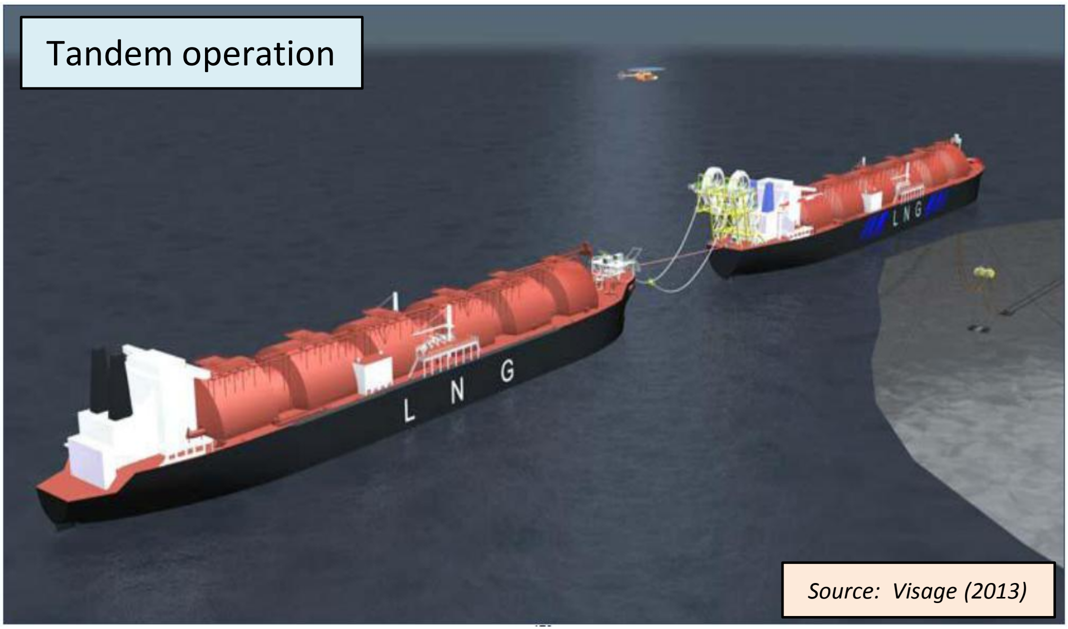


Figure 3-3: Tandem and Side-by-side operations

3.3 Summary of operations

The summary of the options and operations described above is given in *Table 3-1* below. It is worth noting that from this section forward, the proposed locations and operations will be referred to by the option numbers given in the first column of *Table 3-1*.

Table 3-1: LNG Import terminal options

Options numbers	Area	Mooring System used	Type of offloading operation
1	Location 1 (St Helena Bay)	Turret/ demountable buoy System	Side by Side
2	Location 1 (St Helena Bay)	Turret/ demountable buoy System	Tandem
3	Location 2 (Between Dassen and Robben Island)	Turret/ demountable buoy System	Side by Side
4	Location 2 (Between Dassen and Robben Island)	Turret/demountable buoy System	Tandem

Two scenarios were considered for the St Helena Bay options. The scenarios includes locating the proposed terminal at the extreme points within the bay, i.e. one Scenario is locating the terminal close to Stompneuspunt in the South-west and the other locating it closer to Elands Bay, in the North-east.

4 ENVIRONMENTAL CONDITIONS

This section gives a brief overview of the preliminary data gathering and analysis relevant for the study.

The following conventions and terminology are used in this report:

- H_{m0} is the significant wave height, determined from the zeroth moment of the wave energy spectrum. It is approximately equal to the average of the highest one-third of the waves in a given sea state.
- T_p is the peak wave period, defined as the wave period corresponding to the maximum wave energy density in the wave energy spectrum.
- Mean wave direction (MWD) is defined as the mean direction calculated from the full two-dimensional wave spectrum by weighting the energy at each frequency.
- Current direction is the direction to which the current is going, measured clockwise from true north.
- Wave/wind direction is the direction from which the wave/wind is coming, measured clockwise from true north.
- Swell is defined as waves with peak wave periods greater than 8 s.

All levels will be stated relative to Chart Datum (CD), which in South Africa is presently equal to Lowest Astronomical Tide (LAT). The reference coordinate system to be used will be UTM Zone 28S WGS84.

4.1 Bathymetry

Water depth estimates are required for the assessment of the navigation and mooring of vessels.

The bathymetry of the West Coast as presented in this report was obtained from the South African Navy Hydrographic Office series of Admiralty Charts, which were supplemented with marine survey data conducted by the CSIR. Figure *4-1* shows the depths in St Helena Bay in the vicinity of the points of interest, while the area between Dassen Island and Robben Island is shown in Figure 4-2.

St Helena Bay has a gently sloping bottom. The distance of the -30 m depth contour from the shoreline ranges from at least 1 km to 7 km offshore, decreasing towards Elands Bay at the northern end of St Helena Bay. The seabed continues to slope gently with the -50 m contour being at a distance of 7 km to 16 km offshore.

The area between Robben and Dassen Island also has a gently sloping bottom. The isobaths of -30 m ranges from 2 km to around 6 km from shore.

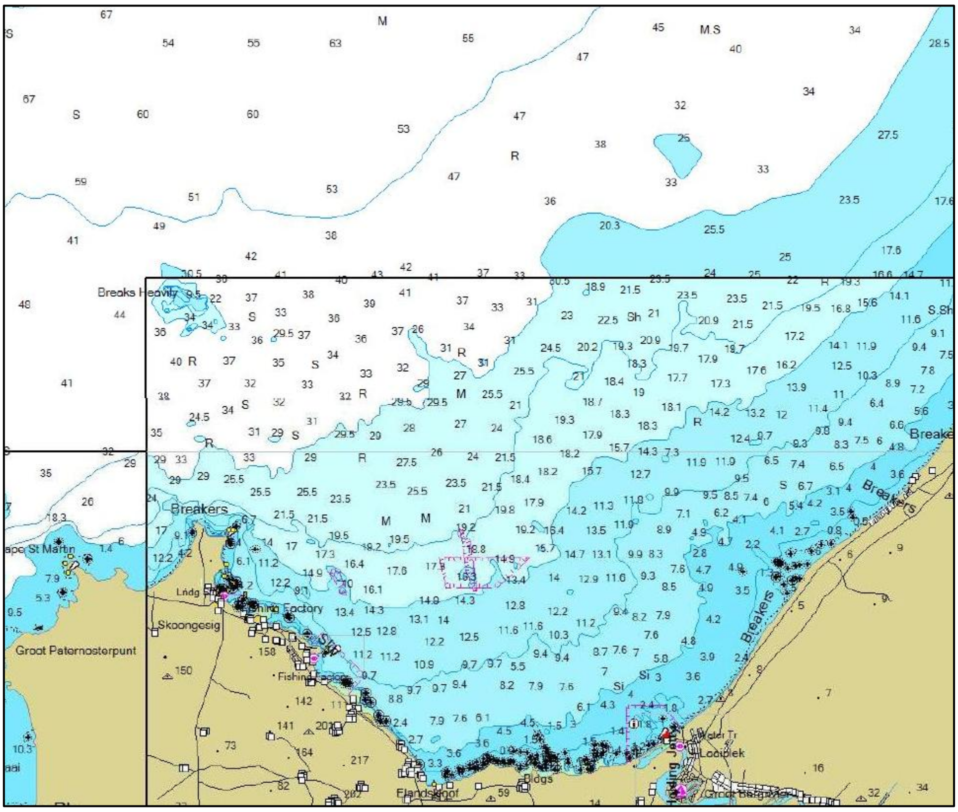


Figure 4-1: St Helena Bay bathymetry

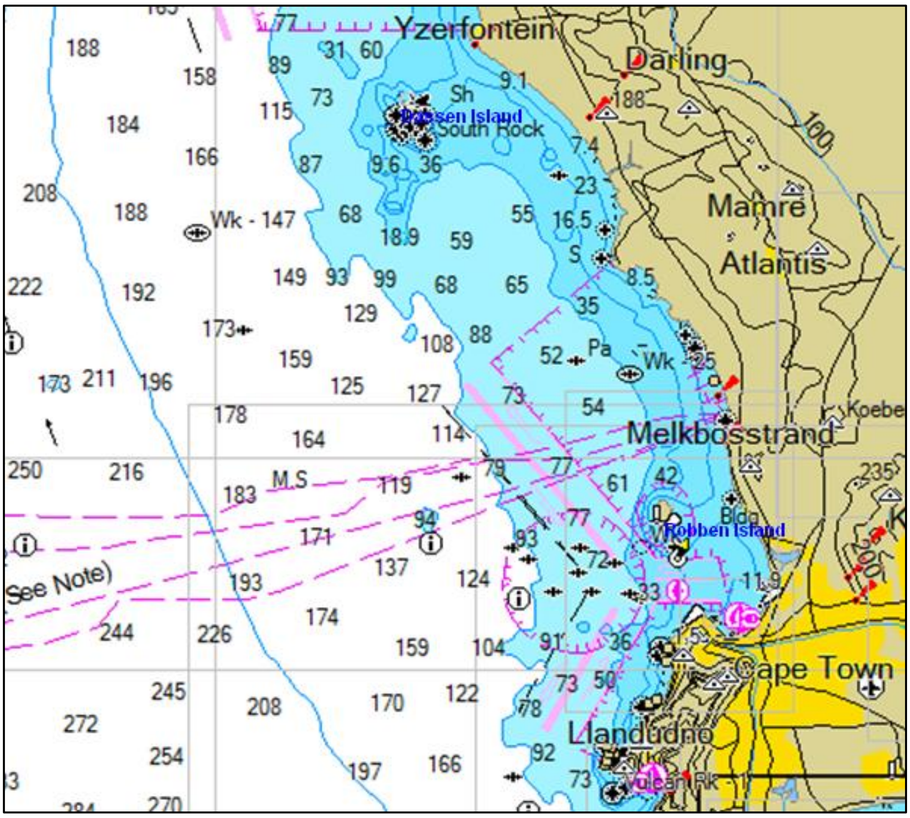


Figure 4-2: Bathymetry of the area between Dassen and Robben Island

5 METOCEAN CONDITIONS

5.1 Meteorological conditions

The meteorological conditions are important for navigation and mooring purposes.

5.1.1 Atmospheric conditions

The climate along the West Coast does not vary significantly from the Saldanha Bay climate as presented in CSIR (2014a). The climate is mild to cool and is strongly influenced by the cold Benguela Current that moves up the West Coast of southern Africa. Temperatures are mostly less than 20°C and rarely exceed 30°C (CSIR, 2006). The area has a semi-arid Mediterranean climate with an average annual rainfall of about 200 mm. Most of the rainfall occurs in winter with summers generally being dry. Coastal fogs caused by the interaction between cold marine air (the result of the Benguela Current) and the warmer land mass are common, particularly in autumn. A summary of the general parameters are given in *Table 5-1*.

Table 5-1: General atmospheric conditions in Saldanha Bay (CSIR, 2006)

Atmospheric Conditions	Value
Minimum ambient temperature	1°C [July]
Maximum ambient temperature	37°C [November]
Minimum relative humidity	15%
Maximum relative humidity	100%
Average annual relative humidity	70% [at 14:00] to 80% [at 08:00]
Average air pressure	1 013 mB
Highest daily rainfall	20 mm [estimated]
Highest monthly rainfall	60 mm [estimated]
Mean annual rainfall	220 mm
Rain days per annum	50 days [estimated]
Annual 90-percentile rainfall	300 days [estimated]
Wettest month	July/August
Fog days per annum	80 to 111 days (mostly mornings)

5.1.2 Wind climate

Wind effects on LNG tankers are enhanced due to their high lateral windage area, which will consequently affect the pilotage, berthing, manoeuvring, and offloading. *Figure 5-1* shows the locations, for which the CSIR used to extract the wind and wave data for the West Coast.

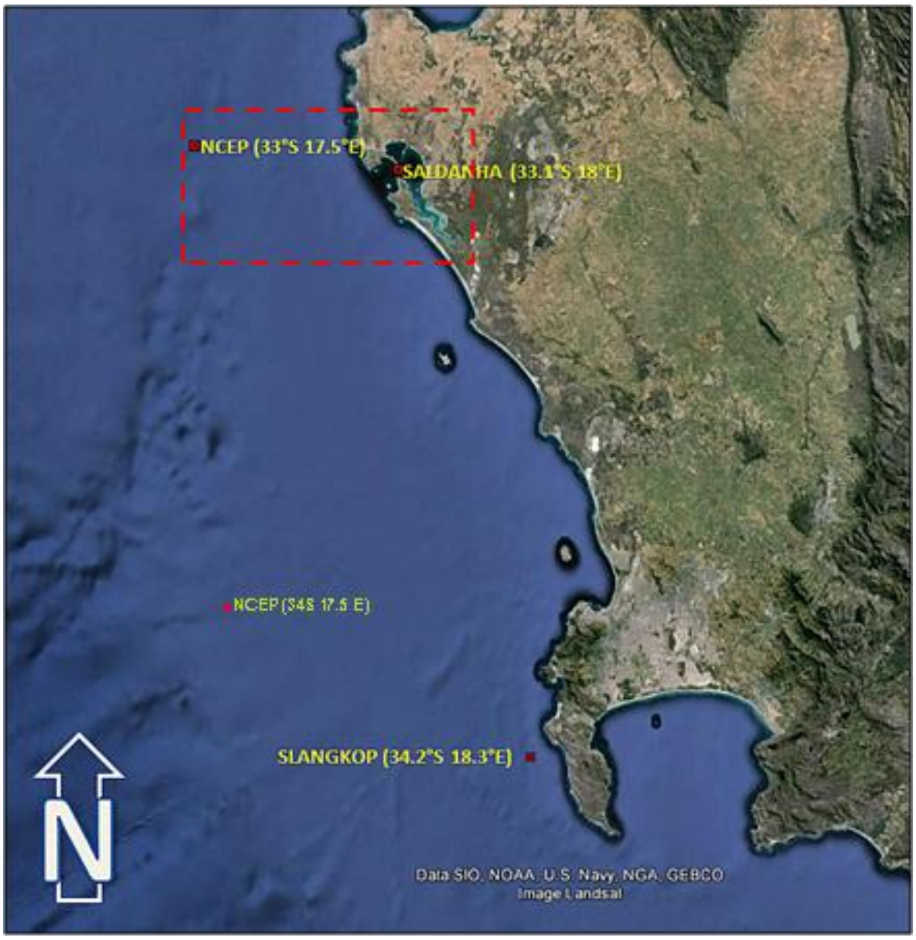


Figure 5-1: Wind and wave stations along the West Coast

The Offshore hindcast data were extracted from the NOAA WAVEWATCH III Global Ocean Wave Model with a grid resolution of 1.0° N-S x 1.25°E-W. The hindcast data contain fourteen years (February 1997 to December 2013) of three-hourly wave and wind parameters, viz. the significant wave height (H_{m0}), peak wave period (T_p), mean wave direction at peak period (D_p), wind speed, wind direction and wind velocity components. This wind data represents the hourly average speed, at 10 m above sea level.

The offshore wind climate used for St Helena Bay is based on the NOAA/NCEP hindcast data. The grid-point is located approximately 35 km offshore of Saldanha Bay (*Figure 5-2*). The wind rose which represents the annual joint occurrence distribution of the wind speed and direction for this NCEP point is presented in *Figure 5-2*. The annual and seasonal wind roses are presented in Appendix A.

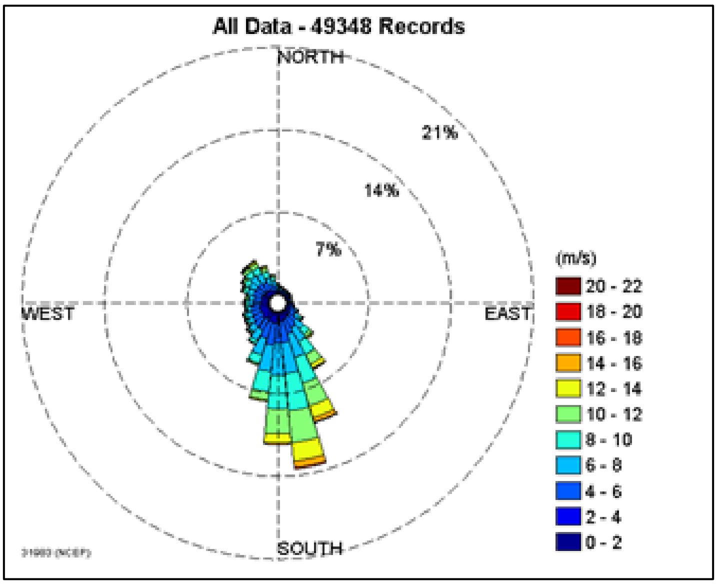


Figure 5-2: Offshore wind rose from NCEP (33°S, 17.5°E) – offshore St Helena Bay

The offshore wind climate representing the Cape South-West Coast was also based on the NCEP data set. The grid-point is located approximately 75 km offshore of Cape Town (*Figure 5-1*). The annual wind rose is presented in *Figure 5-3*. The complete set of wind roses is presented in Appendix A.

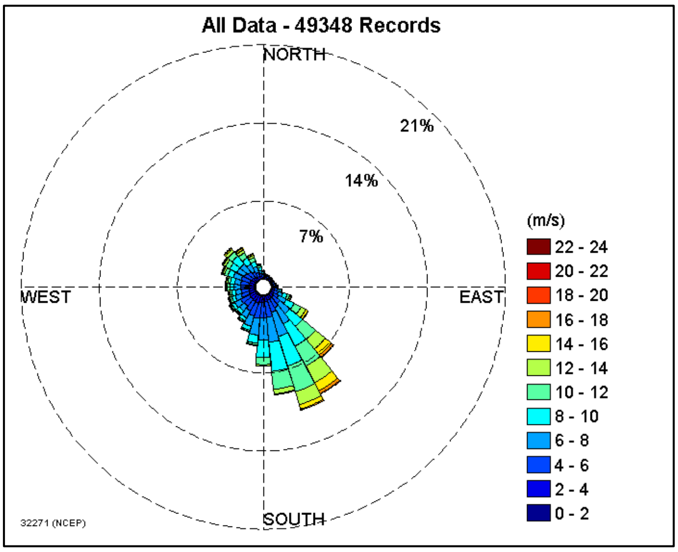


Figure 5-3: Offshore wind rose from NCEP (34°S, 17.5°E) – offshore Cape Town

The winds along the west coast of the Western Cape show significant southerly winds and distinct northerly wind. There are significant components in the north-westerly wind (during the spring and winter months), which can be attributed to the passage of cold front systems during this period. The winds along the coast of the Western Cape have a diurnal component due to strong effects of the land and sea breezes (Van Ballegooyen & Taljaard, 2012).

5.2 Oceanographic conditions

Oceanographic conditions are important for the navigation and manoeuvring within the vicinity of the LNG receiving terminal.

5.2.1 Water levels

Water depth estimates are required for the assessment of the navigation and mooring of ships.

The tides along the coast of South Africa are similar to those in Saldanha Bay. The tidal signal is semi-diurnal (with period of 12 hours 25 minutes) i.e. two high tides and two low tides occur per day, with diurnal inequalities. The mean tidal range during neap tides is 0.57 m and the mean tidal range for the spring tides is 1.51 m.

5.2.2 Wave data

Wave effects on LNG tankers are critical in the offloading operations. *Figure 5-1* shows the locations, for which the CSIR used to extract the wave climate for the West Coast.

a) Slangkop Directional Waverider Buoy

The CSIR maintains a deep-water directional Waverider buoy for Transnet Port Authority (TNPA) along the West Coast. This buoy was originally located approximately 13 km west, offshore of Kommetjie from 1978 to 1993. In 1994 the buoy was moved to its current position in the vicinity of Cape Point. However, directional wave data are only available from 2004 and these were used for this study.

b) NOAA/NCEP Offshore hindcast data [February 1997 to December 2013]

Offshore hindcast data was extracted from the NOAA WAVEWATCH III Global Ocean Wave Model at location 33° S, 17.5° E with a grid resolution of 1.0°N-S x 1.25°E-W. The hindcast data contains fourteen years (February 1997 to December 2010) of three-hourly wave and wind parameters, viz. the significant wave height (H_{m0}), peak wave period (T_p), mean wave direction at peak period (D_p), wind speed, wind direction and wind velocity components.

5.2.3 Wave climate

Most of the swell energy in the Atlantic basin along the West Coast of South Africa is generated from extra-tropical storms between latitudes 40° and 70°. However, secondary low pressure systems in the Atlantic do generate local short-crested waves.

The offshore wave climate along south of the West Coast is based on the Slangkop directional Waverider. The reason for using the Slangkop Waverider is that at depths of 50 m, the wave conditions along the West Coast of the Western Cape should be fairly uniform. This has been verified for Saldanha Bay for other studies (CSIR, 2013). The wave rose presenting the joint occurrence distribution of H_{mo} and direction is given in *Figure 5-4*.The annual and seasonal wave roses are presented in Appendix B.

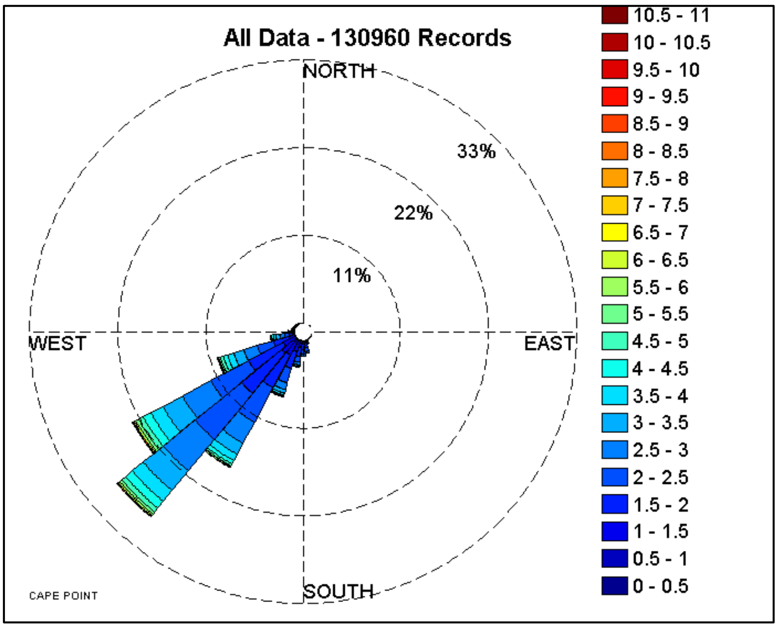


Figure 5-4: Slangkop wave rose for Hmo and direction

The waves along the Cape west coast approach from a predominantly South-westerly direction varying between South-south-west and West-south-west. This reflects the generation field of the low pressure systems passing the area from west to easterly directions.

5.3 Current Conditions

The primary ocean current on the West Coast, the Benguela Current, is formed by the prevailing south easterly trade winds, forcing cold, nutrient rich water up the African coastline from the South Atlantic. Current velocities vary between 0.1 m/s to 0.3 m/s along the coast (CSIR, 2006). Inshore of the Benguela Current, the Benguela Upwelling System is instigated by local South-easterly winds, which invoke moderate currents along the coastline, up to velocities of 0.5 m/s. *Figure 5-1* shows the typical current regime in St Helena Bay.

Very little current data are available for the Cape South-West Coast. Therefore, if further LNG studies are envisaged for this region, a current monitoring programme or exercise is recommended. This will entail the deployment of at least one instrument capable of recording ocean current data at various depths through the water column.

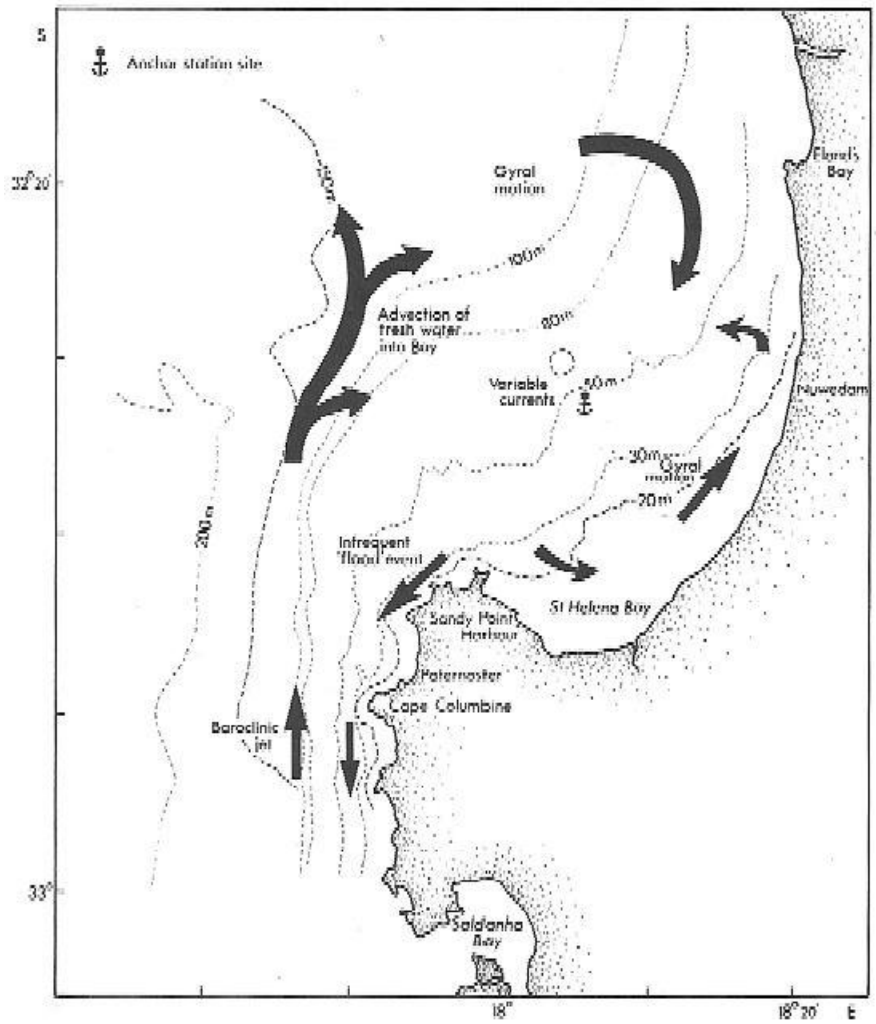


Figure 5-1: Schematic of wind driven currents in St Helena Bay under NW wind conditions (CSIR, 2006)

6 NUMERICAL WAVE MODELLING

6.1 Overview

The data measured by the CSIR's Slangkop Waverider buoy off Kommetjie represents the wave conditions along the Cape South-West Coast. However, the measured data are not representative of the wave climate in St Helena Bay since the waves propagating into the bay are subjected to processes such as wave refraction and diffraction thereby reducing in height. Thus, the area behind the Stompneus Point headland is protected against the offshore waves approaching from the dominant South-Westerly direction.

The wave climate in the sheltered area has been derived from a wave refraction study using the numerical wave model SWAN. This section provides an overview of the numerical modelling exercise set up for this study.

6.2 Model approach

The wave generation and refraction model SWAN (Simulating Waves Nearshore) was applied (Booy, et al, 1999). This model has been widely employed on engineering projects worldwide and has been applied and successfully validated against measured data at several local sites. SWAN is run within the DELFT3D suite of numerical models, as applied by the CSIR.

The SWAN model is based on the discrete spectral action balance equation and is fully spectral in all directions and frequency, implying that short-crested random wave fields propagating simultaneously from widely different sources can be accommodated. Thus, the model is driven by boundary conditions of winds and waves.

The seabed topography was described in SWAN by numerical representation of the bathymetry. The information used to describe the bathymetric layout in the SWAN model, was derived from a number of survey data sets, e.g. digitising the bathymetric SAN charts of the South African Hydrographical office (SANHO). More detail on the model setup is presented in Appendix C.

For the purposes of this model study, the wind and wave conditions were defined by the approximate 15 years of numerical forecast offshore data set. This data set is based on the daily forecasts from the National Centre for Environmental Prediction (NCEP), a sub-division of the USA based NOAA group. The location of the grid-point used is shown in *Figure 6-1* and *5-1*.

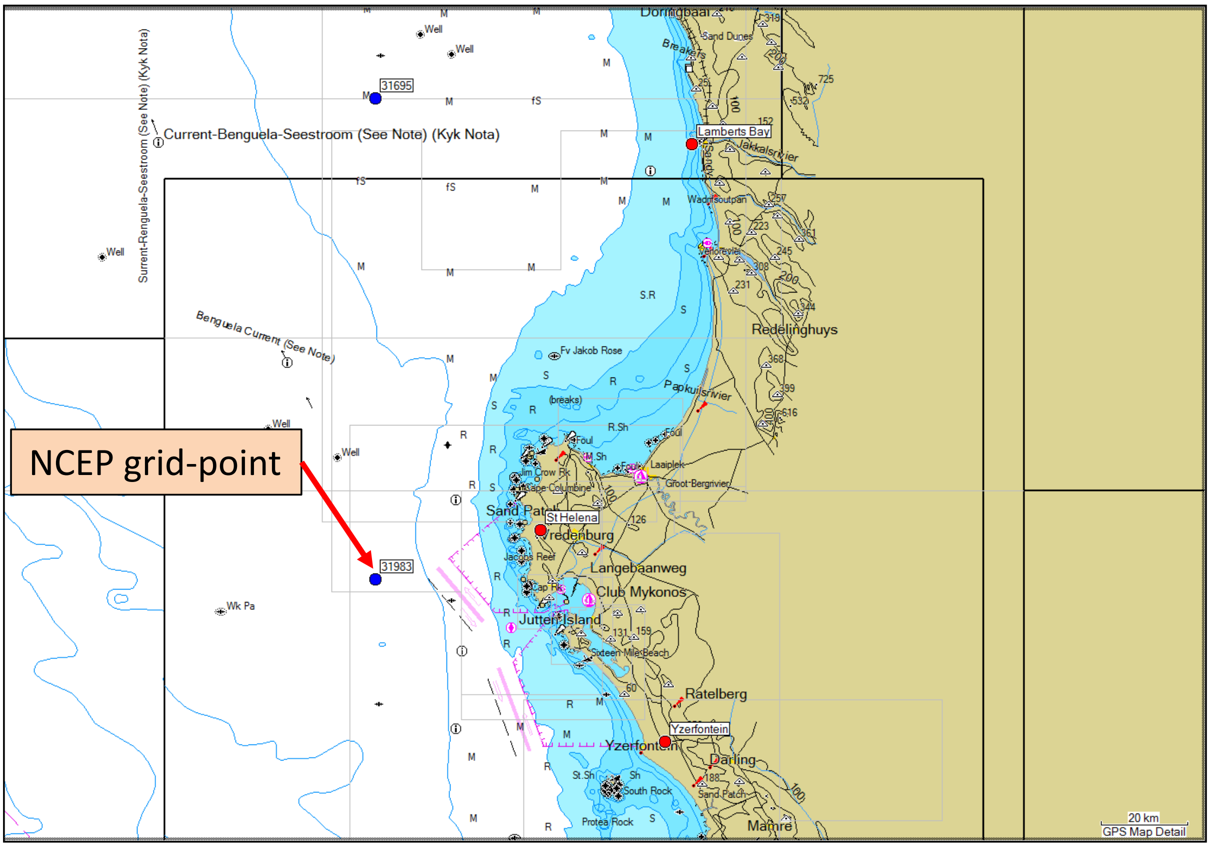


Figure 6-1: Location of NCEP grid-point used for the SWAN modelling study

The procedure for deriving the wave climate at the relevant output locations can be described as follows:

(i) Simulate a range of wind and wave conditions, based on the NCEP data. Thus, obtain wave parameters at all the output locations for the corresponding input wind and wave conditions.

(ii) Using the input wave conditions and corresponding output or resultant wave parameters, create a matrix of transformation coefficients.

(iii) Use the matrix to convert the approximate 15 year offshore NCEP data set to wave height, period and direction time-series at all the relevant output locations.

(iv) To verify the conversion process, the simulated wave height time-series were compared to the corresponding data as measured by the CSIR Waverider. Examples of the comparison are presented in Appendix C.

(v) Wave roses for the results are shown in Appendix D and were used for the downtime analysis. The output locations of the SWAN model used in this study are shown in *Figure 6-2*.

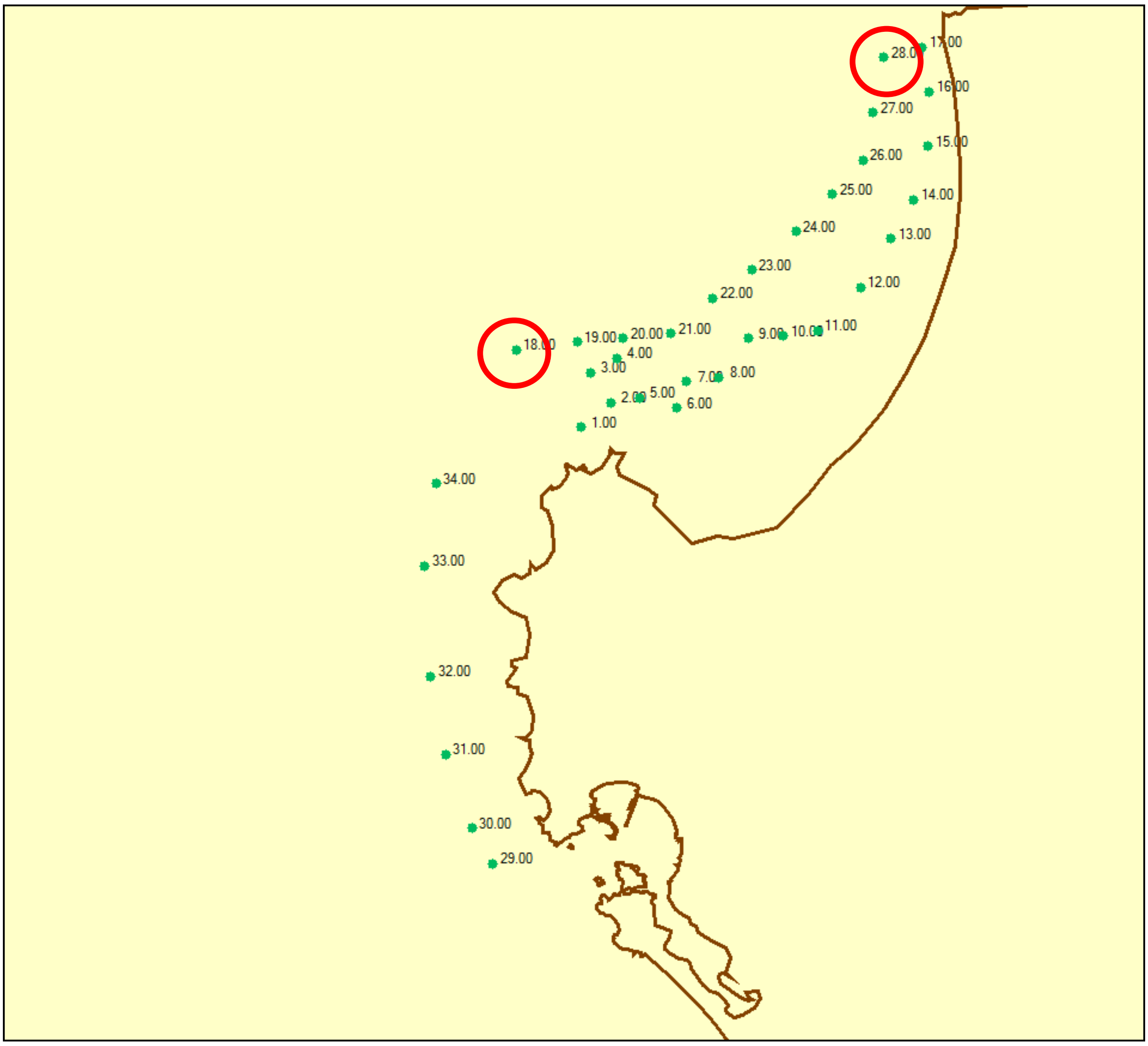


Figure 6-2: Output Locations for SWAN model

7 DESIGN VESSEL AND FSRU DIMENSIONS

This assessment is based on what is termed the "design vessel". The LNG receiving terminal is required to accommodate LNG vessels up to 145 000 m^3. The client indicated that an FSRU of capacity 138 000 m^3 is to be used for the study.

The dimensions of the 145 000 m^3 LNG vessel and FSRU are summarised in *Table 7-1*.

Table 7-1: Design Vessel and FSRU dimensions

Parameter	**Design Vessel**	**FSRU**
Capacity (m^3)	145 000	138 000
Deadweight (t)	75 500	-
LOA (m)	295	304.9
B (moulded)	48	43.5
D (moulded)	26.7	25.0
Draught (moulded)	11.5	11.5

8 OPERATIONAL REQUIREMENTS

The operational requirements for the LNG operations were obtained from the following references:

- **SIGTTO** – Society of International Gas Tanker and Terminal Operators Ltd:
    - Site Selection and Design for LNG Ports and Jetties (1997);
    - LNG Operations in Port Areas (2003)

- **OCIMF** – Oil Companies International Marine Forum:
    - Prediction of Wind and Current Loads on VLCCs (Very Large Crude Carriers);

- **PIANC** – Permanent International Association of Navigation Congresses:
    - Harbour approach channels - design guidelines (2014)
    - Crude oil and gas tankers (2012)
    - Dangerous Cargoes in Ports (2000)
    - Criteria for movements of moored ship in harbours, a practical guide (1995)
    - Dangerous Goods in Ports (1985)

Unloading operations will be undertaken using the individual ship pumping systems to supply the required discharge pressure to pump the liquid products to the FSRU. Therefore, no pumping is necessary from the Energy Centre during unloading. It is standard industry practice that the unloading operations will be supervised by Energy Centre staff connected by telephone / radio with key staff located within the facility control.

The limiting criteria for manoeuvring for the FLNG operations states that for a single point moored vessel, the limiting wave height is 5.5 m for approach, unloading and departure (Golar report, 2011). The limiting wind speed is 17 m/s for all operations (O' Connor, 2014). The allowance for high wind speeds accounts for the vessel’s ability to weathervane and to align to the prevailing wind direction.

9 DOWNTIME ANALYSIS

The downtime computation focused on the vessel approach, berthing and departure time lost resulting from environmental conditions. The analysis combined the time lost due to wind, waves and current conditions. The resulting downtimes from these conditions were superimposed (i.e. not just added) to obtain the total downtime. The downtime computation was based on the available windows for unloading during a period of 13 years. The computational method was evaluated by checking the resulting downtime to the exceedance graphs.

The downtime computation referenced the available literature and criteria as listed in Section 8. The resulting downtime remains an estimate and could in reality vary significantly when factoring the approach manoeuvre, the local traffic, etc. The time required for vessel manoeuvring during approach and departure was set to two hours and one hour respectively. The downtime for unloading is dependent on the type of loading system used.

It is assumed that the loading arms used for the side by side unloading comprise 16" cryogenic hoses, two of which are used to transfer the LNG. The tandem unloading will use 16" cryogenic hoses with an unloading time of 27 hours. These durations are schematically illustrated below.

Operation	Required time (Hours)		
Approach	2		
Berth\unloading		27	
Departure			1

Based on the downtime analysis of the winds and waves combined, the percentage operability at the different locations could be derived. The results are presented in *Table 9-1*. Two location scenarios were evaluated in St Helena Bay, i.e. points 18 and 28 as shown on Figure 6-2.

Table 9-1: Annual and seasonal operability summary

Area/Location	Type of Mooring	Season	Operability (%)
Between Robben and Dassen Island (see Figure 3-1)	Side by side	Yearly	54
		Autumn	50
		Winter	36
		Spring	43
		Summer	58
	Tandem		
		Yearly	94
		Autumn	93
		Winter	89
		Spring	93
		Summer	96
St Helena Bay (Point 18) (see Figure 6-2)	Side by side	Yearly	55
		Autumn	62
		Winter	40
		Spring	50
		Summer	60
	Tandem		
		Yearly	98
		Autumn	98
		Winter	97
		Spring	99
		Summer	99
St Helena Bay (point 28) (see Figure 6-2)	Side by side	Yearly	75
		Autumn	85
		Winter	66
		Spring	80
		Summer	88
	Tandem		
		Yearly	99
		Autumn	99
		Winter	98
		Spring	99
		Summer	99

The downtime was found to be the highest in winter and lowest in summer. Seasonal operability between Dassen and Robben Island was found to be (assuming tandem offloading):

- 89% In winter
- 93% in Autumn and Spring
- 96% in Summer

Similarly, the downtime in St Helena Bay was found to be the highest in winter. Furthermore, it was found that the downtime decreased the closer one gets to Elands Bay, at the northern extreme of St Helena Bay. This could be attributed to the increase in sheltering from the more southerly waves by Stompneus Point. Seasonal operability within St Helena is 99.9% in summer and 99.5 % in winter when solely looking at the wave conditions.

A more simplistic approach could also be used to estimate the downtime resulting from wave conditions by using the wave height exceedance graphs. The exceedance graphs provide in Figure 9-1 shows the percentage of time a wave height is exceeded for the two locations, green representing St Helena Bay and blue representing the area between Robben and Dassen Island. Based on *Figure 9-1*, it can be estimated that the effect of waves along would contribute less than 0.1 percent downtime within St Helena Bay when using the wave limit of 5.5 m.

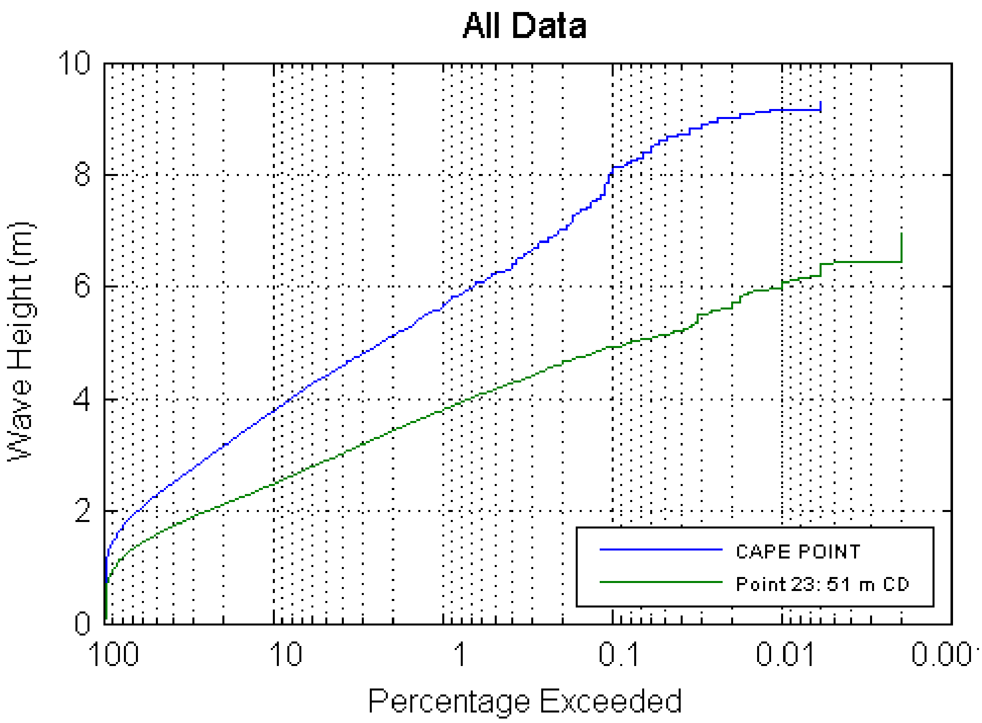


Figure 9-1: Wave height exceedance graph for St Helena Bay and the area between Dassen and Robben Island

10 MULTI-CRITERIA ANALYSIS

This section provides a discussion and rating of the proposed terminal locations based on system integrity, operational efficiency and longevity.

In addition to determining the percentage operability of the various options, a Multi-Criteria Analysis (MCA) was conducted to assist in highlighting the more favourable options. The MCA, as applied in this study, was based on a similar approach followed by the CSIR in a Vulnerability Assessment study for the Mozambican coast (Theron & Barwell, 2012).

The MCA involved the derivation of a qualitative matrix that provided an additional means of comparing the four options to each other.

The first step was to identify various elements and activities that could be impacted by the Metocean drivers, i.e. winds, short waves (swell), currents and the general weather conditions (e.g. fog, rain). For this study the combination of elements and activities is defined as components. These are categorised into three types, namely (1) those that relate to the safety of humans and shipping within the operational area (system integrity), (2) those that influence the operational efficiency and business of the LNG operation and (3) those elements that affect the long-term economic and environmental sustainability of the operation (longevity).

The list of elements within each of the categories is provided in *Table 10-1*. Note that this list is by no means considered a complete list. It could be expanded in future with relative ease if so required.

Table 10-1: List of elements used for assessment and associated weightings for Metocean drivers

			Weightings to determine relative risk of the various components			
No	**Elements to be impacted**	**Type of impact**	**Wind**	**Short waves**	**Currents**	**Weather**
1	Mooring structures & arrangements: Turret mooring	System intergrity	0.5	1	0.5	0
2	Ship navigability		1	0.5	0.25	1
3	Ship manoevrability		1.5	1	0.75	1
4	Small vessel traffic		0.5	1	0.25	1
5	Piping: submerged pipe/PLEM		0.5	0.5	0.5	0
6	Coupling and uncoupling vessels	Operational Efficiency	1.5	2	1	0.25
7	Transfer/offloading of LNG from ship to FSRU		1	1	0.5	0.25
8	Turret: maintenance	Longevity	0.5	1	1	0

The second step is to describe and score the specific vulnerability (in terms of a likely qualitative description) of each component for a range from Very Low (Vulnerability score of 1) to Very High (score of 5) – see *Table 10-2*. The scoring criteria can also be further developed if needed.

Table 10-2: Scoring table: Vulnerability Criteria

Vulnerability criteria	Vulnerability Classification & Score				
	VL	L	M	H	VH
	1	2	3	4	5
Likelihood that wind would impact on operations	Rare	Unlikely	Possible	Likely	Almost certain
Likelihood that wave would impact on operations	Rare	Unlikely	Possible	Likely	Almost certain
Likelihood that long wave would impact on operations	Rare	Unlikely	Possible	Likely	Almost certain
Likelihood that current would impact on operations	Rare	Unlikely	Possible	Likely	Almost certain
Impact of Weather: Rainfall, fog, visibility, lightning	Rare	Unlikely	Possible	Likely	Almost certain

The third step comprised defining the relative weighting of each of the identified components in the context of the identified Metocean drivers. The relative weightings as defined by the CSIR team and used in this study so far are also shown in *Table 10-1*. This is a subjective exercise based on an understanding and local knowledge and needs to be tested, verified and validated in time. Note that these values can also be refined in future with input and insight gained from the potential workshops focussing on this study. This assessment could form a key component of the next phase of the study.

The fourth step is to assess and score the actual vulnerability of each component to the identified Metocean drivers, i.e. score the elements in *Table 10-1* using *Table 10-2*. This exercise was conducted for each of the four LNG options. The vulnerability score for each of the components as well as an overall score for each of the option was then calculated (Step Five).

Based on the scoring exercise, an index for each Metocean driver is obtained for each of the four options. The summary of the results of this assessment is presented in Table 10- 3. The higher the rating value or score, the higher the impact of the metocean driver on the particular option. In general, the wind, current and weather will have similar effects or impacts on the four options. However, the summary indicates that the impact of swell is higher for side by side offloading and for operations between Dassen and Robben Islands. This is also graphically illustrated in Figure 10-1.

Based on the summary, it appears options 1 and 2 (in St Helena Bay) score generally lower than the rest, indicating that these two options should be considered for further evaluation.

The GREEN – ORANGE – RED system used assesses the fulfilment of the basic requirements where GREEN is RARE impact, ORANGE is POSSIBLE impact and RED is ALMOST certain impact.

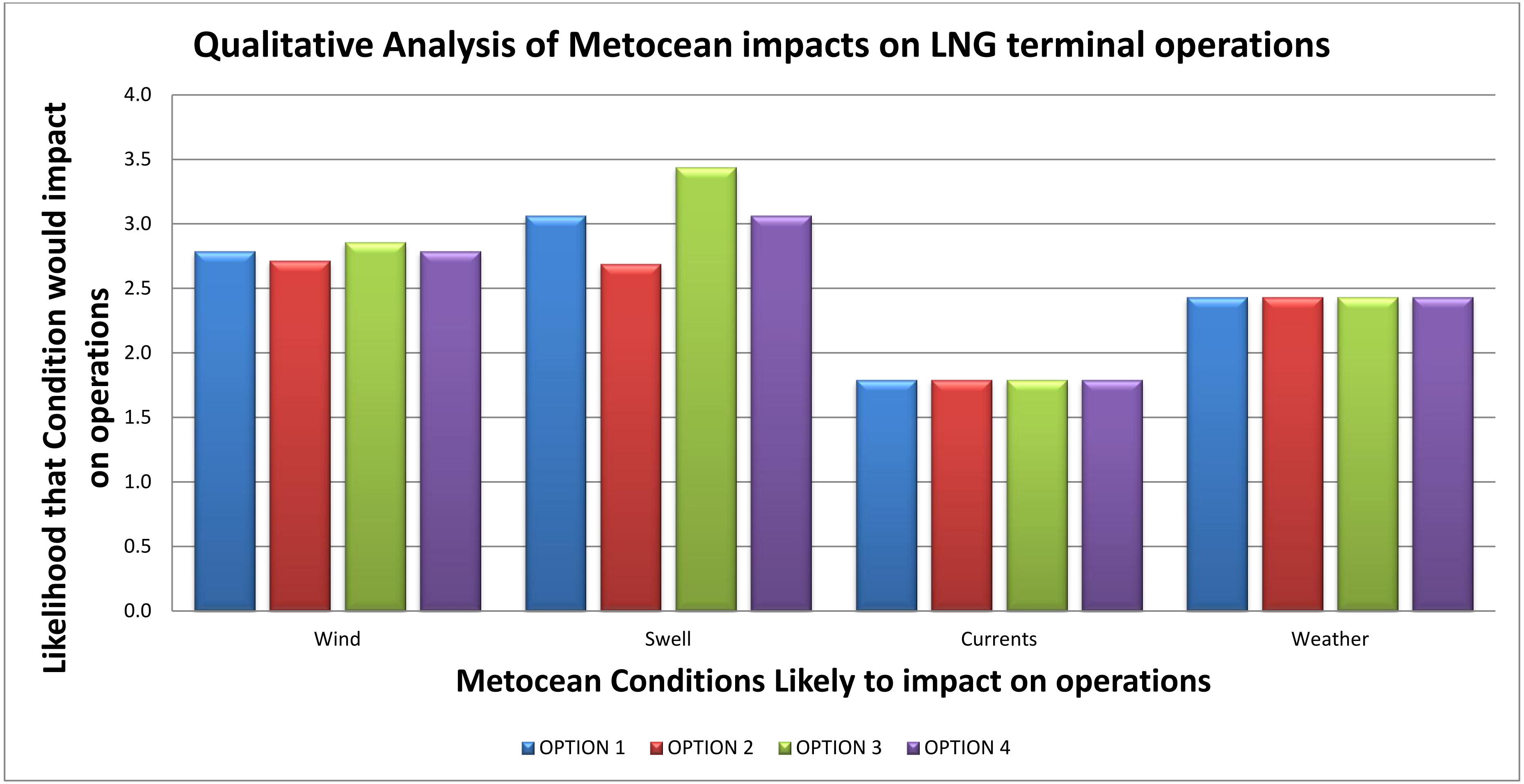
Table 10-3: Vulnerability rating for 4 options across the selected Metocean drivers

Option	Location	Type of Operation (Offloading)	Wind	Short Waves	Currents	Weather
1	St Helena Bay	Side by side	2.8	3.1	1.8	2.4
2	St Helena Bay	Tandem	2.7	2.7	1.8	2.4
3	Between Robben and Dassen Islands	Side by side	2.9	3.4	1.8	2.4
4	Between Robben and Dassen Islands	Tandem	2.8	3.1	1.8	2.4

Table 10-4: Vulnerability coding for 4 options across the selected Metocean drivers

	Likelihood that condition will impact port operations			
	Wind	Swell	Currents	Weather
OPTION 1	Possible	Likely	Unlikely	Possible
OPTION 2	Possible	Possible	Unlikely	Possible
OPTION 3	Possible	Likely	Unlikely	Possible
OPTION 4	Possible	Likely	Unlikely	Possible

Figure 10-1: Vulnerability rating for 4 options across the selected Metocean drivers



11 CONCLUSIONS AND RECOMMENDATIONS

The CSIR conducted an assessment of the marine environmental conditions for the siting of an offshore LNG (Liquefied Natural Gas) receiving terminal along the West Coast of South Africa. The study focussed on two potential areas along the Cape South-West Coast, namely the region between Dassen Island and Robben Island as well as St Helena Bay. The approach followed in this study focused on deriving the operability of LNG offloading options as impacted by the marine environmental conditions. These conditions included the winds, waves and limited current information.

Both locations have adequate operability, sufficient depth and ensure that the LNG terminal will be separated from other port and maritime operations. It appears that for the used (limited) criteria, St Helena Bay has advantages for offshore LNG import compared to the open West Coast.

The limiting criteria used for the downtime are based on the proposed Golar-Bluewater (2011) FSRU which have a higher envelope of operation for up to 5.5 m wave heights. Caution need to be taken when using the results as the criteria used might not be applicable for other FSRU's.

This report should be read in conjunction with the environmental impact report: *'Environmental Screening Study for a proposed LNG terminal at Saldanha and associated pipeline infrastructures to Atlantis and Cape Town, Western Cape, South Africa (CSIR, 2014b).* The selection of the appropriate site should be based on the outcome of both this and the environmental report, as well as on design and financial considerations.

Based on the results of this study, the following recommendations are made:

(i) Since little ocean current data are available, a measurement programme should be undertaken if the open coast option for a LNG facility is chosen for further study. The data will be vital in assessing the current regime in the area of interest.

(ii) Conduct a proper ship motion study whereby the forces on the mooring lines of the FSRU and LNG transport vessels can be assessed.

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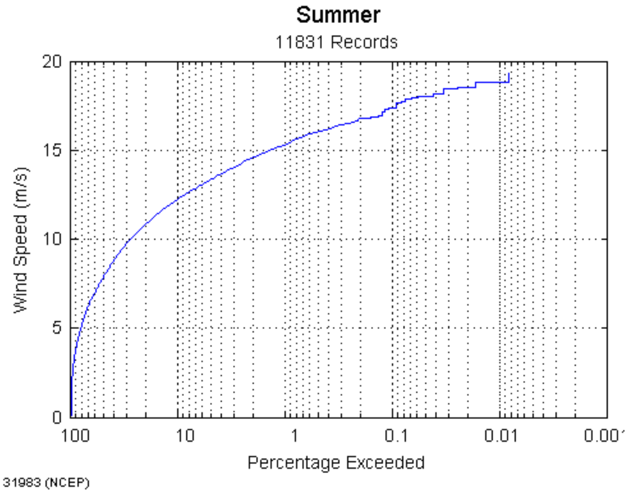
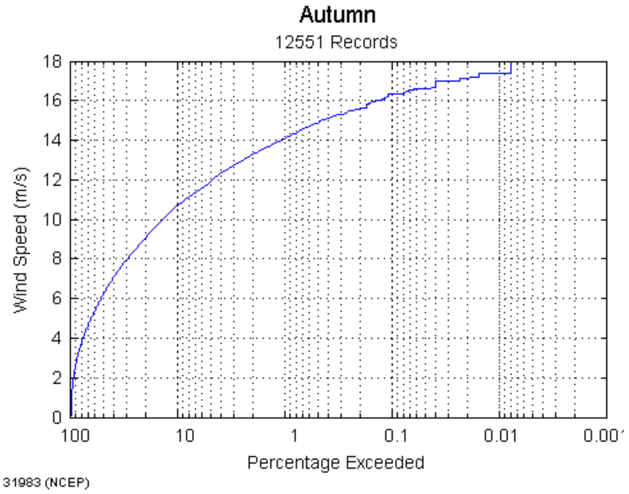
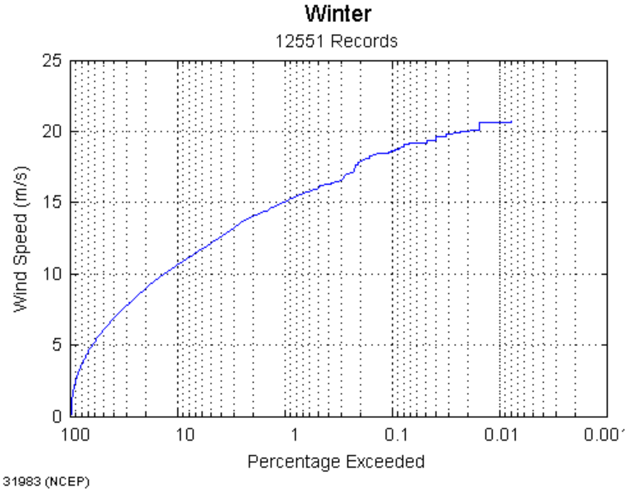
APPENDIX A: WIND STATISTICS

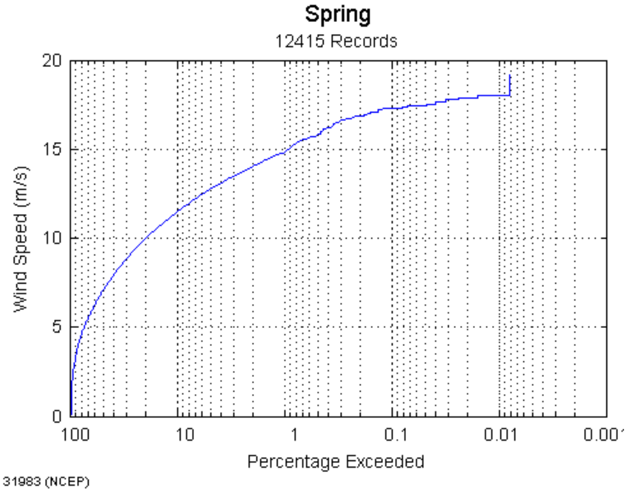
This appendix provides information on the offshore wind climates as based on the NCEP numerical data. The following information is provided:

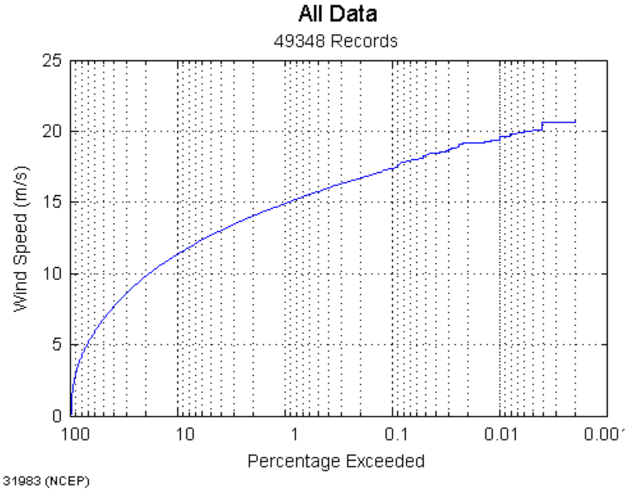
(i) Percentage exceedance of wind speed: NCEP grid point off St Helena – Figure A1 (annual and seasonal)
(ii) Joint occurrence distribution of wind speed and direction (wind rose): NCEP grid point off St Helena – Figure A2
(iii) Percentage exceedance of wind speed: NCEP grid point off Cape Town – Figure A3 (annual and seasonal)
(iv) Joint occurrence distribution of wind speed and direction (wind rose): NCEP grid point off Cape Town – Figure A4





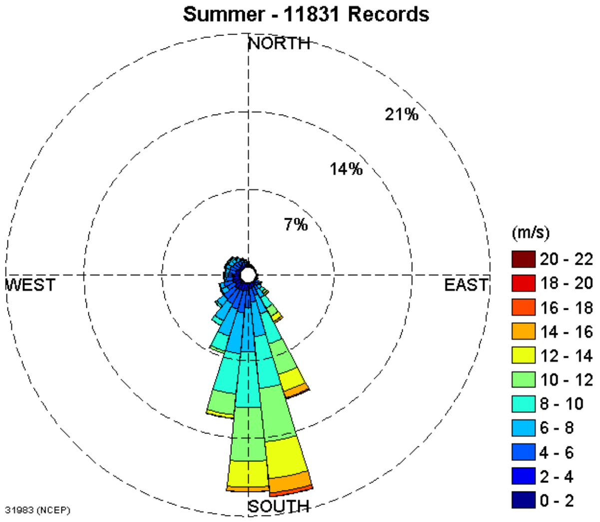


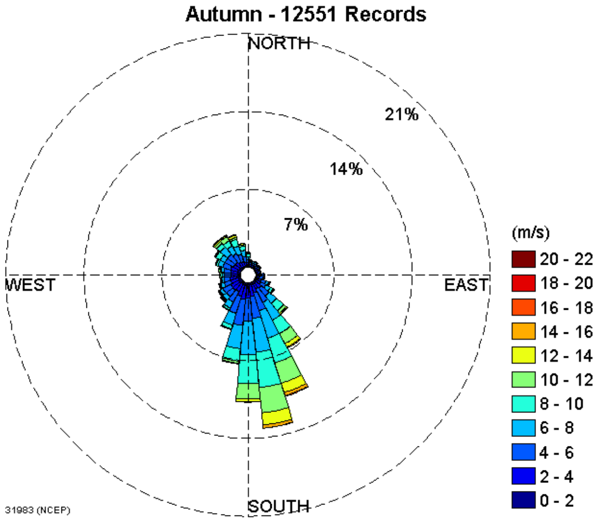


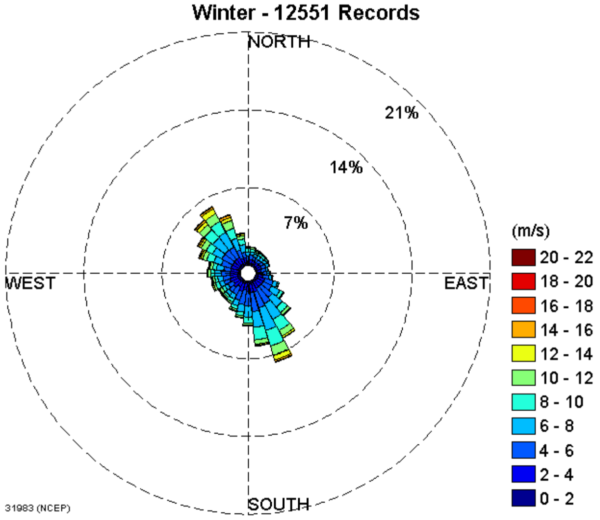


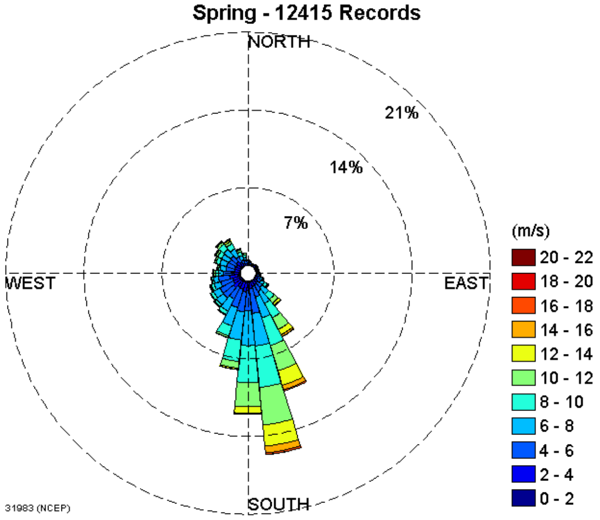
Wind Speed Exceeded (m/s)					
	1.0%	5%	10%	25%	50%
All Data	14.94	12.65	11.37	9.19	6.77
Summer	15.29	13.34	12.24	10.26	7.87
Autumn	14.10	11.88	10.71	8.48	6.22
Winter	15.06	12.10	10.66	8.34	6.01
Spring	14.84	12.75	11.51	9.38	7.08

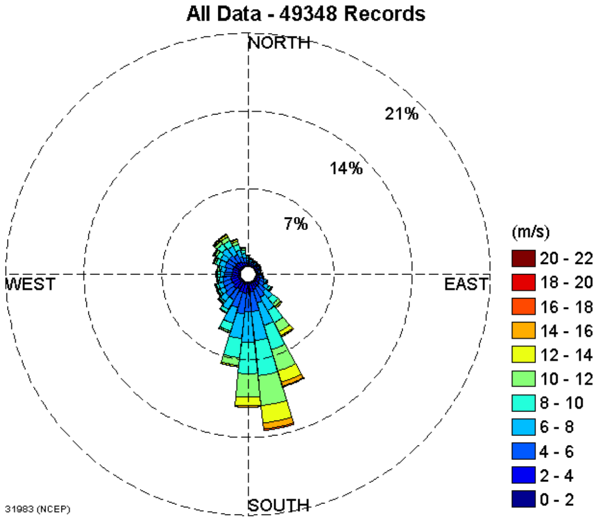
CSIR | St Helena (NCEP) Wind Speed Exceedance 1997-01-30 to 2013-12-01 | Figure A1





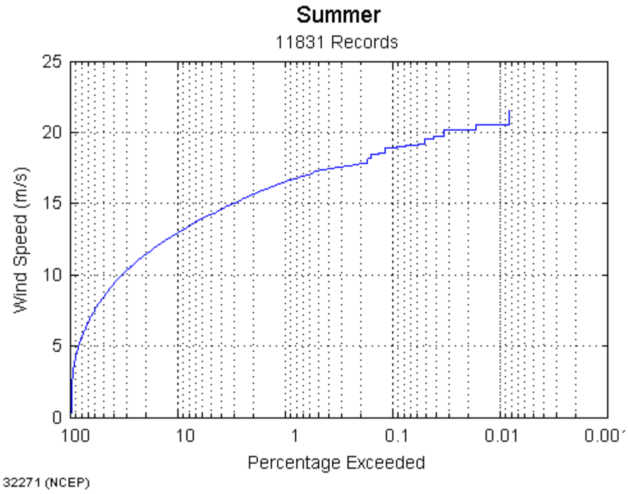


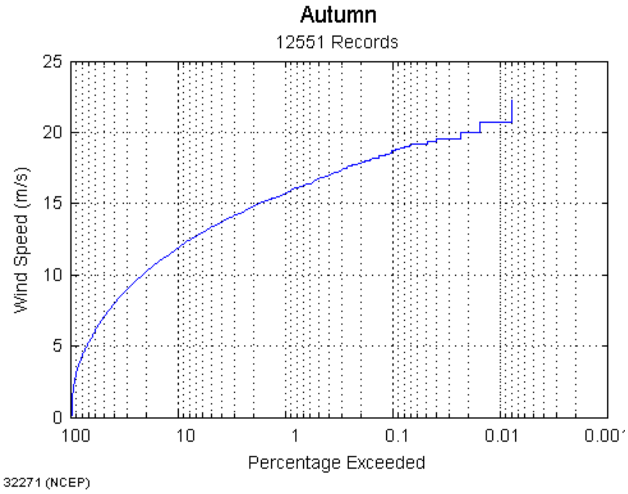


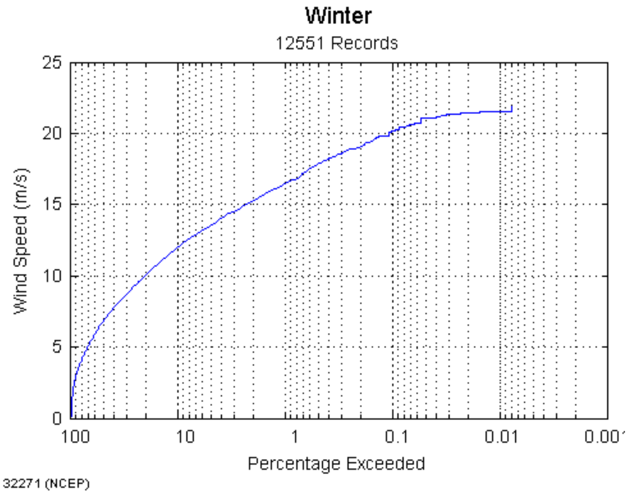


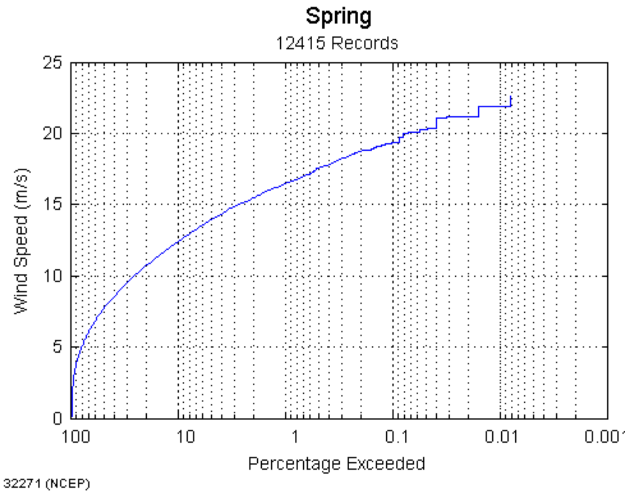
Period	1997-01-30 to 2013-12-01
Station	31983 (NCEP)
Position	33.00000 S, 17.50000 E
Instrument Type	WaveWatch III
Records	49348

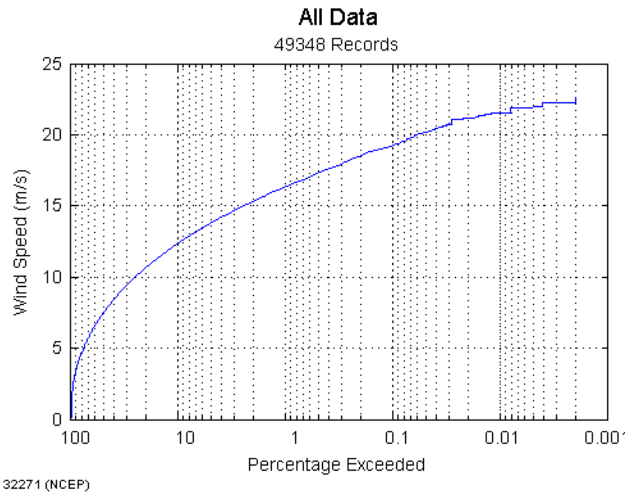
CSIR	St Helena (NCEP) Wind speed vs direction 1997-01-30 to 2013-12-01	Figure A2









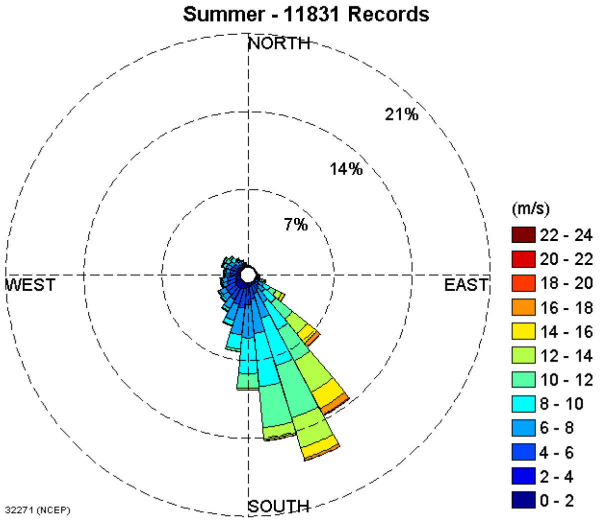


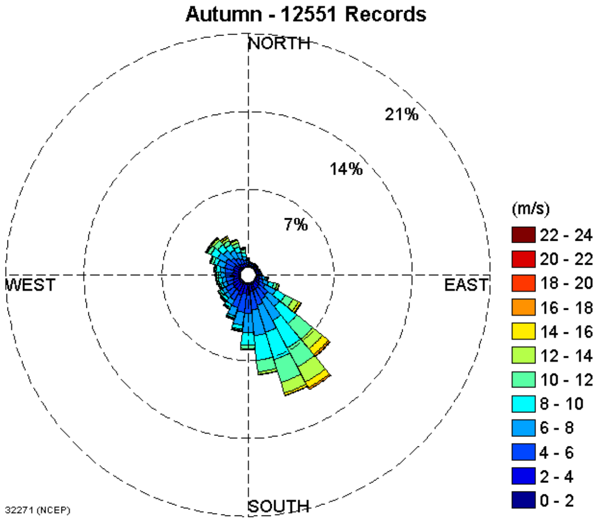
Wind Speed Exceeded (m/s)					
	1.0%	5%	10%	25%	50%
All Data	16.34	13.77	12.40	9.98	7.49
Summer	16.54	14.22	12.94	10.84	8.41
Autumn	15.73	13.35	11.90	9.55	7.02
Winter	16.49	13.51	12.02	9.36	6.81
Spring	16.49	13.91	12.43	10.08	7.71

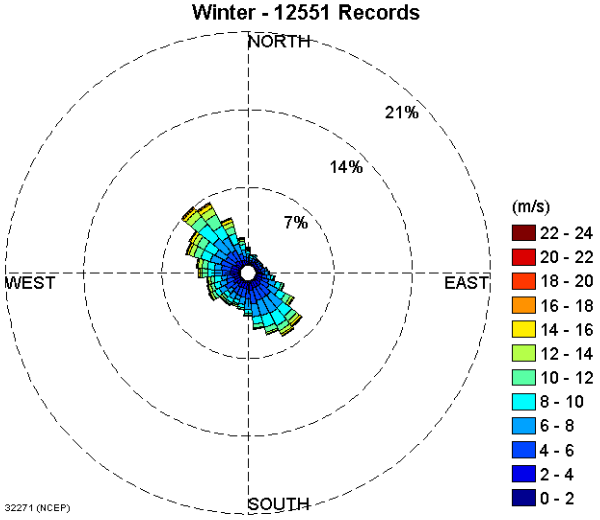
CSIR

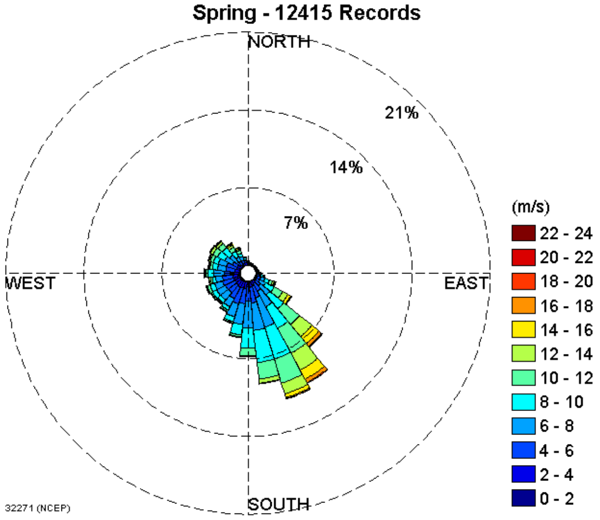
Off Cape Town (NCEP)
Wind Speed Exceedance
1997-01-30 to 2013-12-01

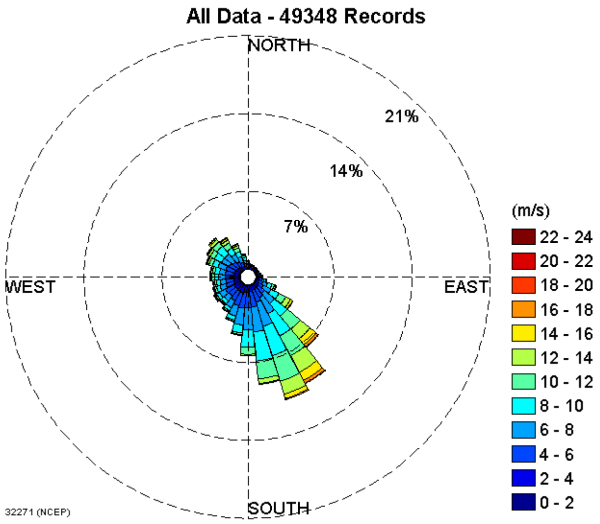
Figure A3









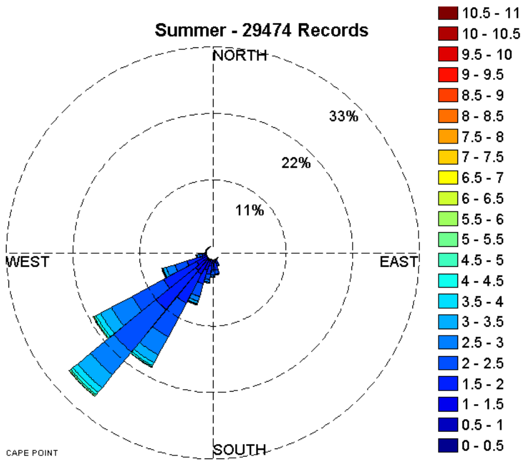


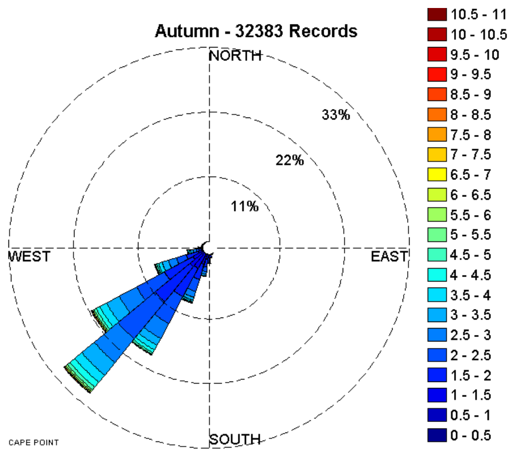
Period	1997-01-30 to 2013-12-01
Station	32271 (NCEP)
Position	34.00000 S, 17.50000 E
Instrument Type	WaveWatch III
Records	49348

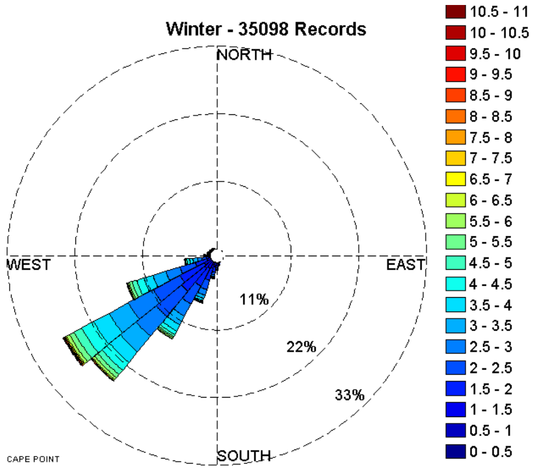
CSIR	Off Cape Town (NCEP) Wind speed vs direction 1997-01-30 to 2013-12-01	Figure A4

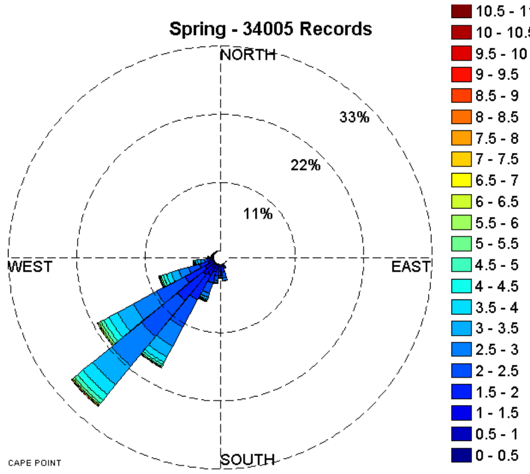
APPENDIX B: WAVE ROSES - SLANGKOP BUOY

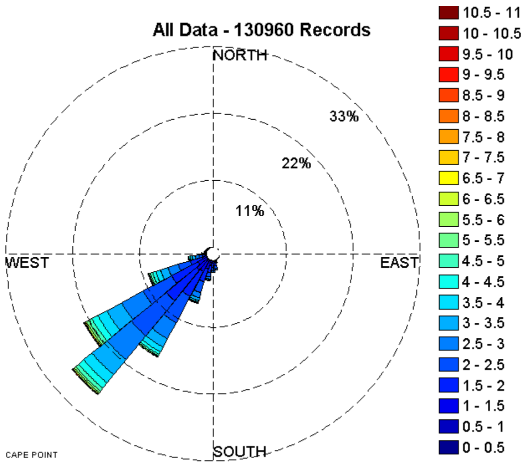
This appendix provides information on the offshore wave climate as based on the the Slangkop wave buoy data. The joint occurrence distribution of wave height and direction is presented as annual and seasonal wave roses in Figure B1











Period	2004-01-01 to 2014-01-31
Station	Slangkop
Position	34.204 S, 18.28667 E
Instrument Depth	0 m
Water Depth	70 m
Instrument Type	Directional Waverider
Records	130960

CSIR	Slangkop Wave Height (Hmo) vs Wave Direction 2004-01-01 to 2014-01-31	Figure B1

APPENDIX C: NUMERICAL WAVE MODELLING: SWAN

The SWAN model comprised two computational grids – a coarse and fine grid (see Figures C1a and C1b). Details of the grid setup are given in Table C1.

Table C1: Numerical Parameters used in Delft 3D-WAVE (SWAN)

Grid	Resolution	Offshore extent	Length
Coarse	1000 x 1000 m	65 km	120 km
Fine	300 x 300 m	25 km	100 km

The settings of the main model parameters are summarised in Table C2. Example outputs of the model are presented in Figure C2. The plot shows the wave height contours and the wave vectors for a 2 m significant wave height and 12 s conditions approaching from South-south westerly, Westerly and North-north-westerly directions. The output locations of the modelling are shown in Figure C3. Note that a number of output locations were selected. These cover the areas of interest as well as potential future areas for further investigations.

Table C2: Numerical parameters used in Delft3D-WAVE (SWAN).

Parameter	**Value/Description**
Wave spectral shape	JONSWAP
Spectral peak enhancement factor	2
Width of the energy distribution	25
Bottom friction coefficient	Madsen (0.05)
Spectral direction resolution	72 sectors
Frequency range	Varying: ranged from 2.5 to 0.025 Hz

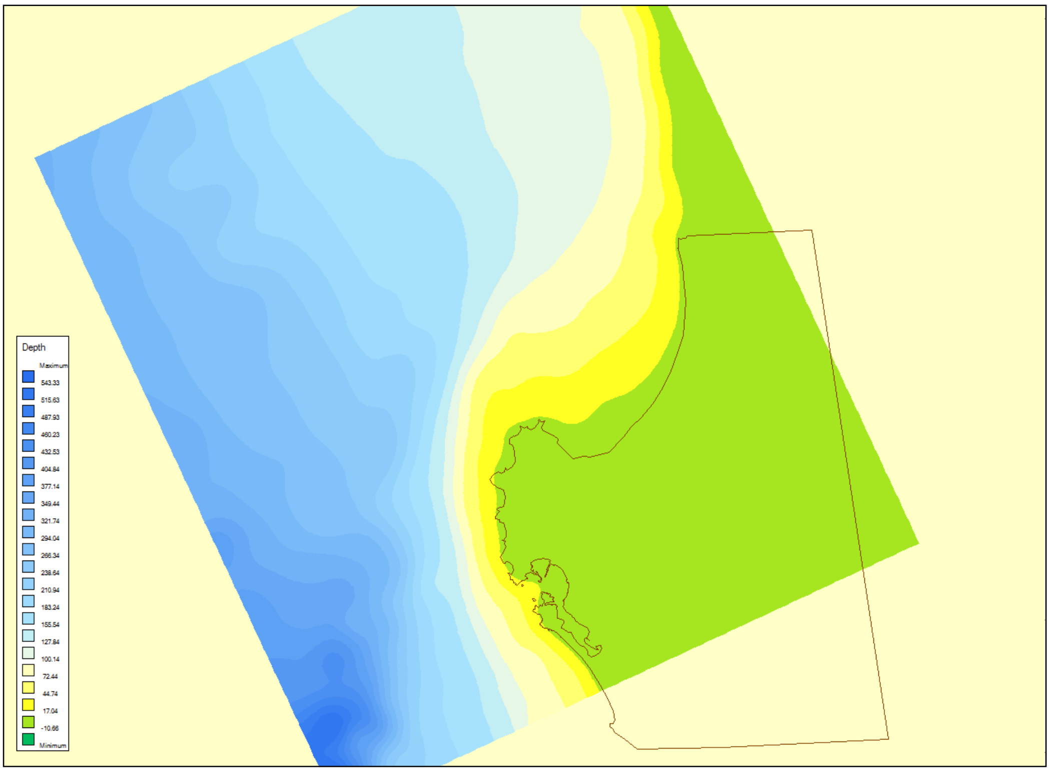


Figure C1a: Coarse Computational grid

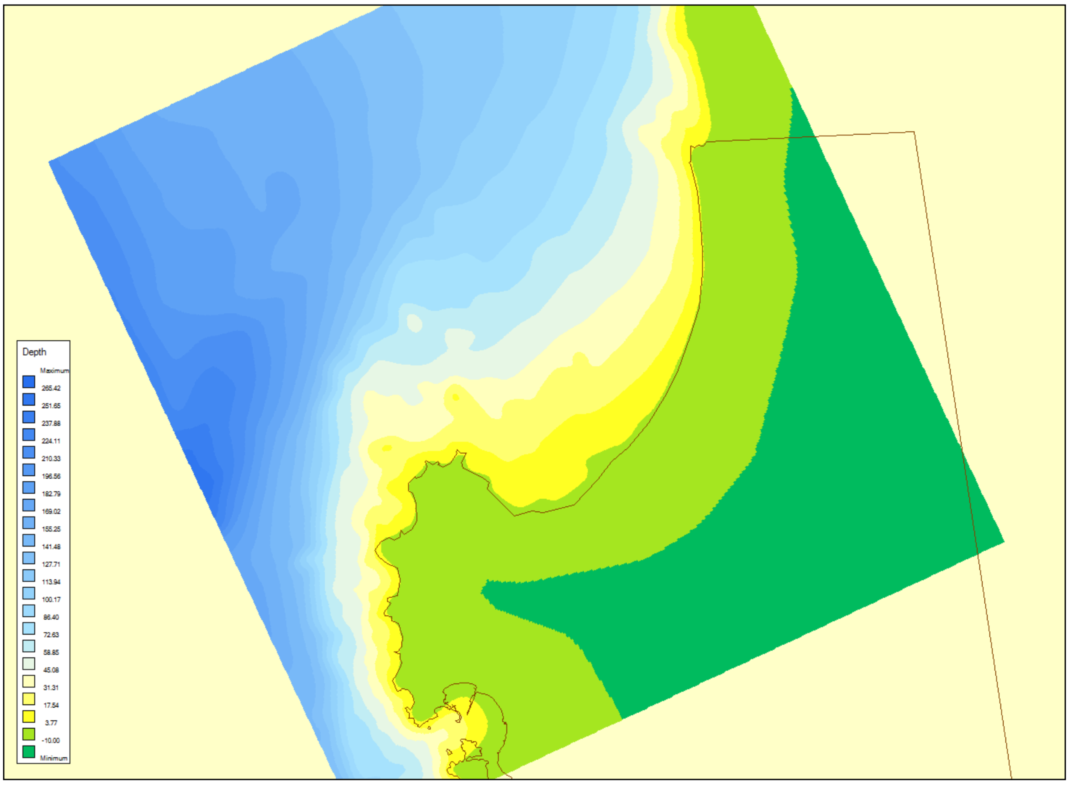


Figure C1b: Fine Computational Grid

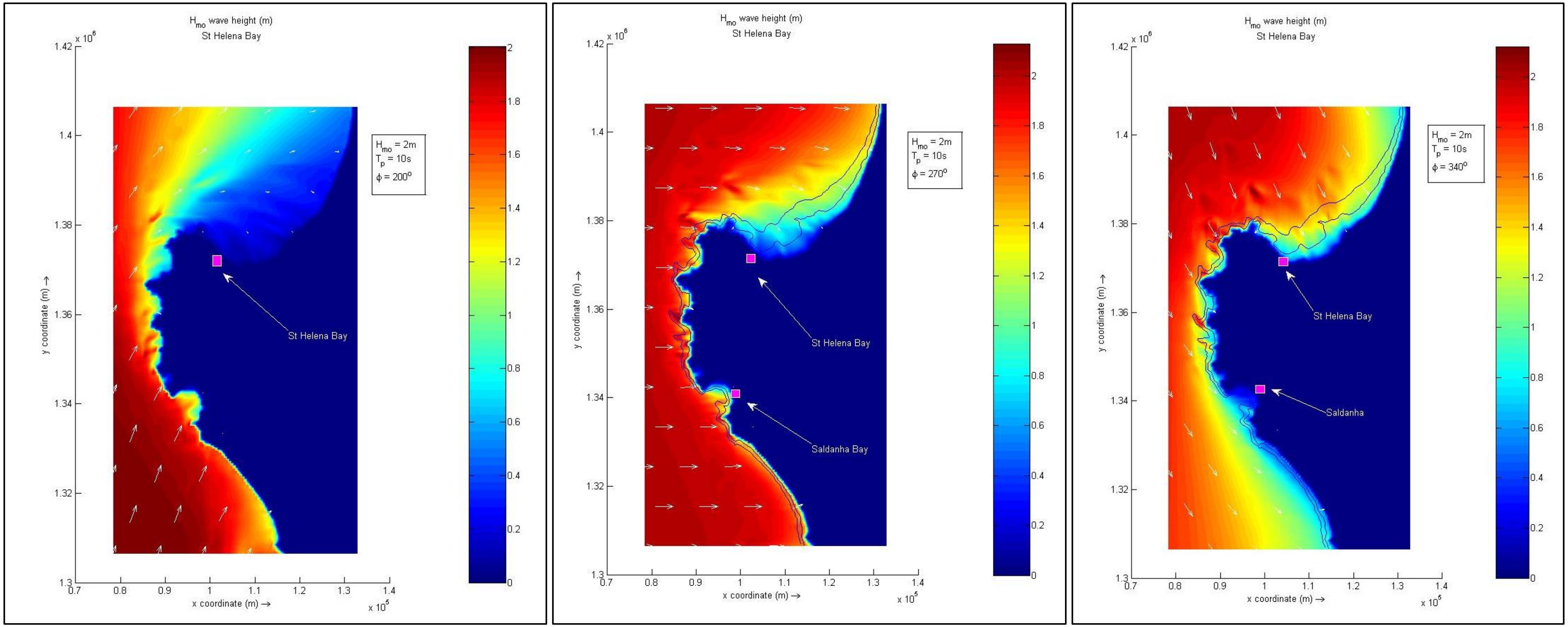


Figure C2: Waves Vector Plots for SSW, W, NNW directions

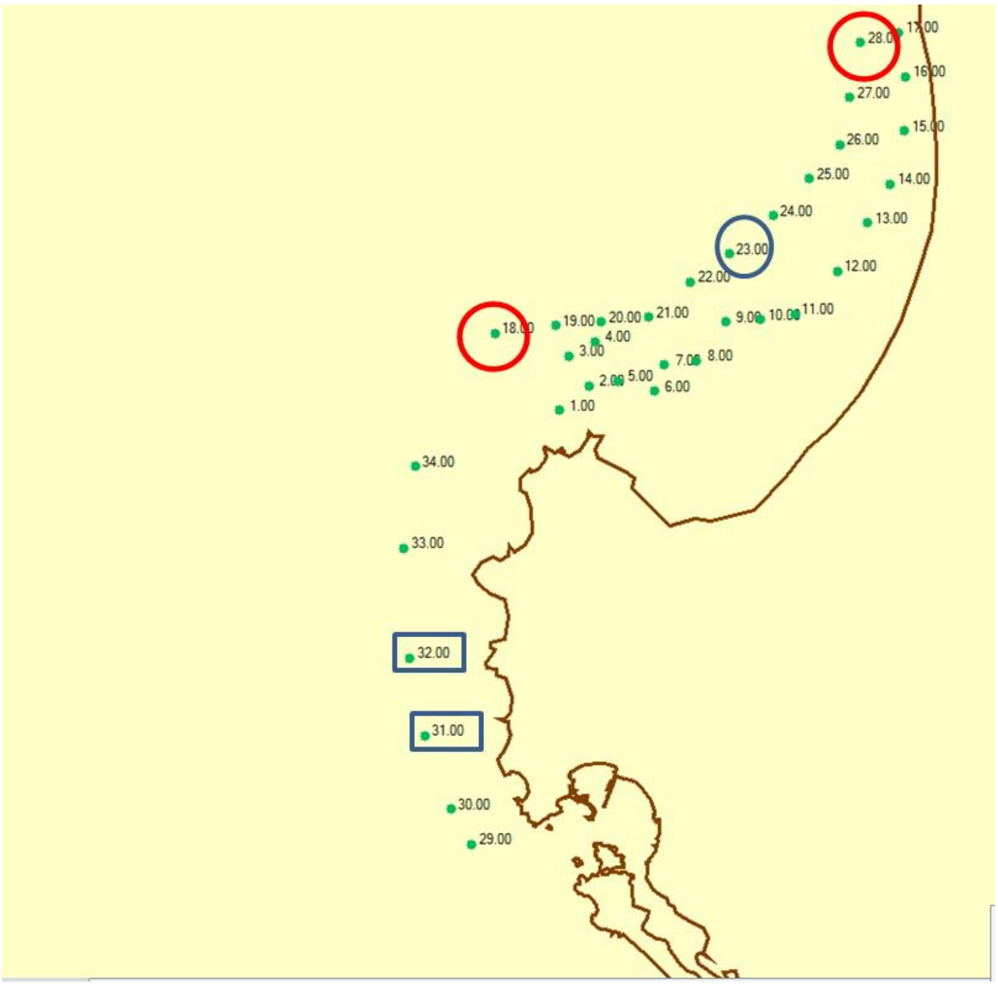


Figure C3: Output Locations for SWAN model

In order to verify the model setup, the model output was compared to corresponding data from the Slangkop wave buoy. Since the Slangkop wave data is considered to be representative of the wave climate off the South-West Coast, for a water depth of about 70 m, the output of the SWAN modelling could be compared with the measured data. Output locations were taken at approximately the same water depth as that of the Waverider buoy. These locations are presented in Figure C4. Note that output locations 29 to 34 represented the 70 m water depth contour.

Since the Slangkop wave data are considered to be representative of the wave climate off the South-West Coast, for a water depth of about 70 m, the output of the SWAN modelling could be compared with the measured data. Output locations were taken at approximately the same water depth as that of the Waverider buoy.

The two time-series plots of wave height for locations 31 and 32, covering the period December 2011 to November 2013, are presented in Figures C5a and C5b. As shown the simulated data follow the measured data well.

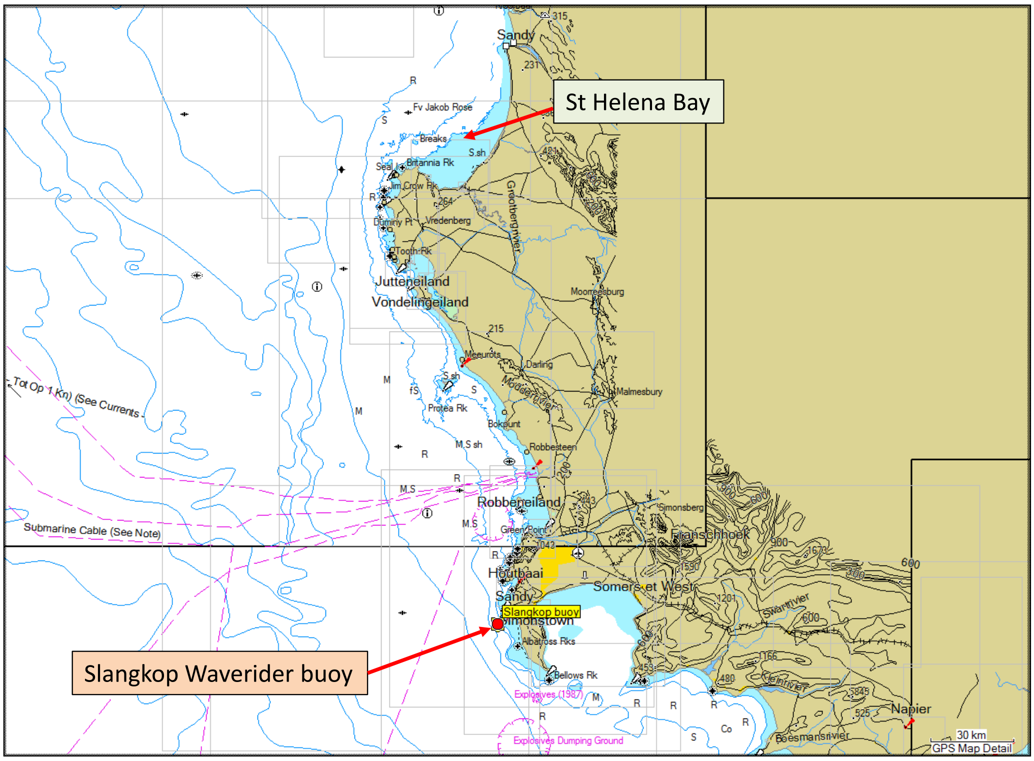


Figure C4: Output Locations for SWAN model

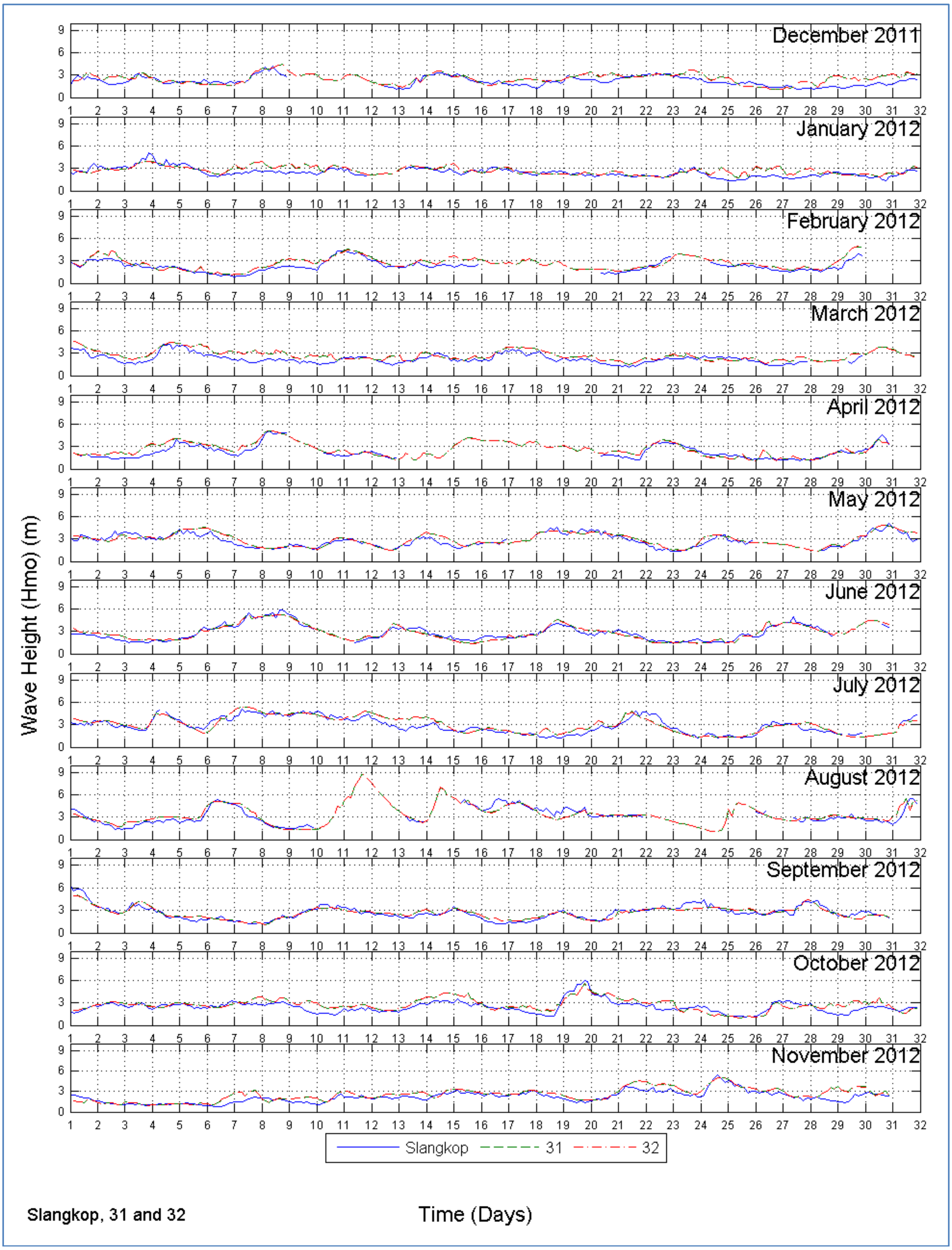


Figure C5a: Wave height of SWAN Simulation and Measured Slangkop Buoy – December 2011 to November 2012

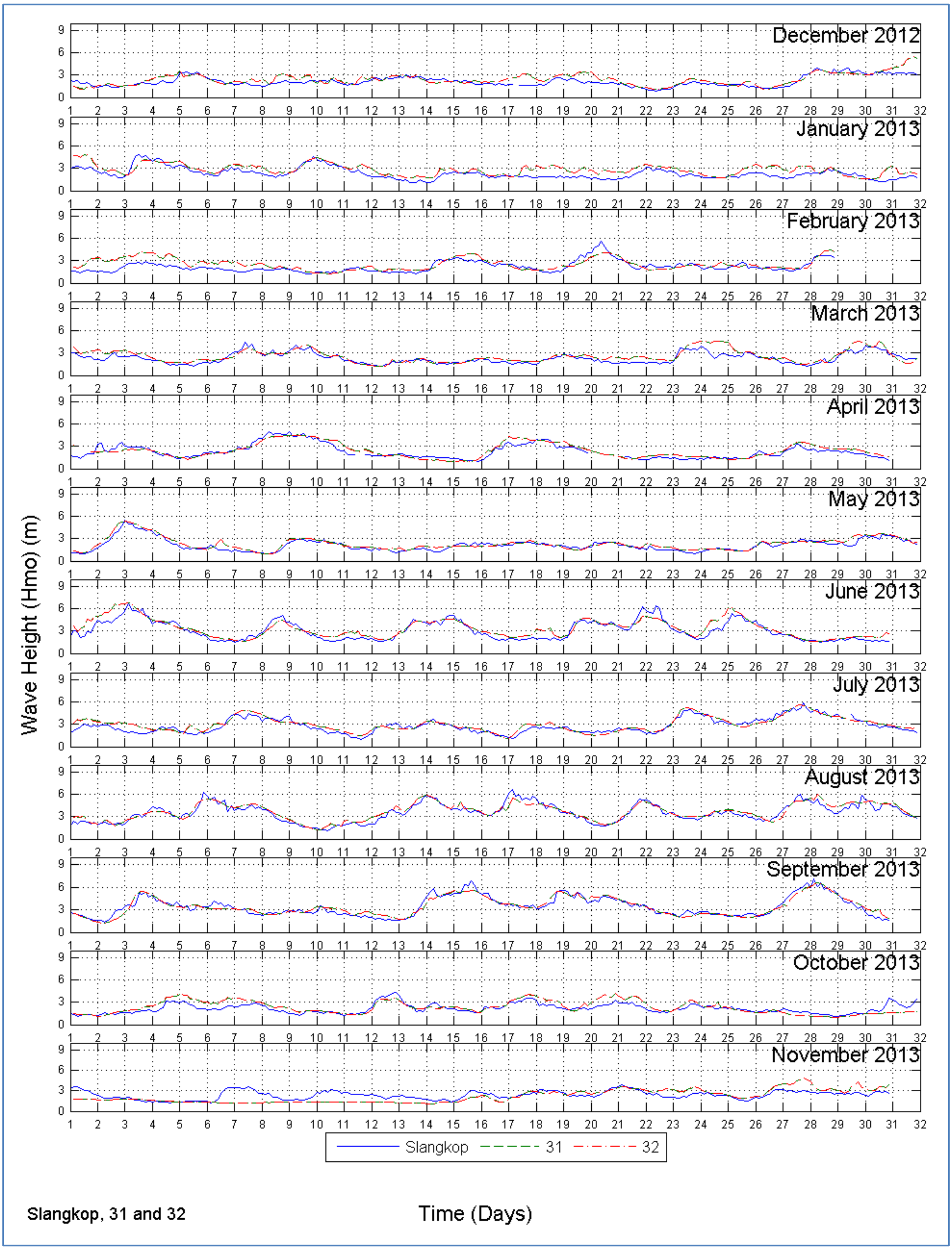
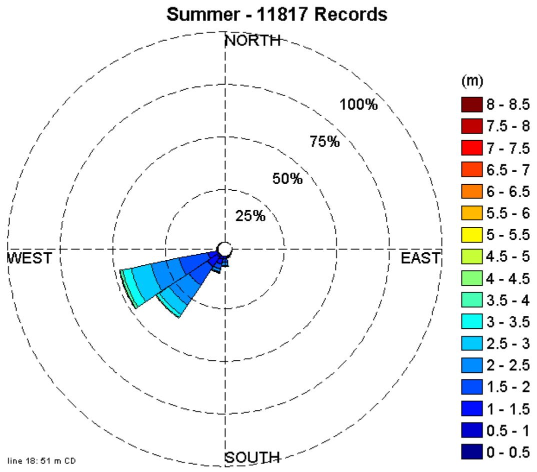


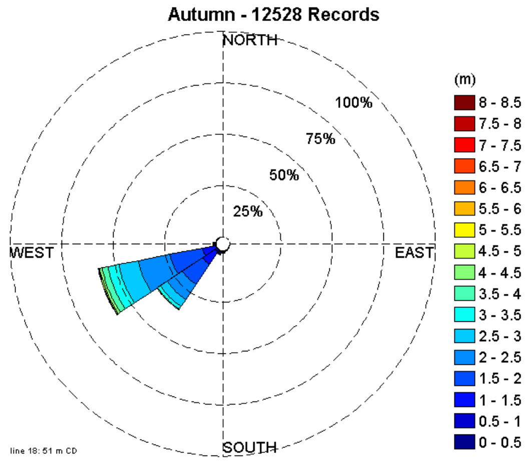
Figure C5b: Wave height of SWAN Simulation and Measured Slangkop Buoy – December 2012 to November 2013

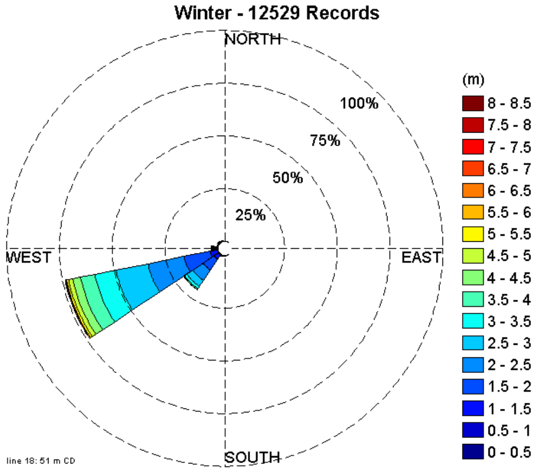
APPENDIX D: SWAN OUTPUT – WAVE STATISTICS

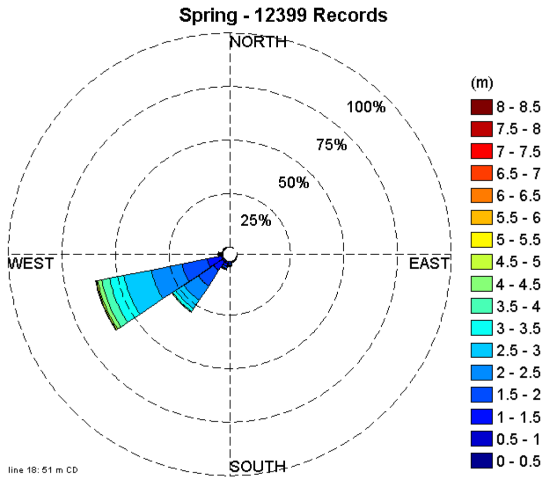
This appendix provides information on the wave climates as based on the selected output locations of the SWAN model. The following information is provided:

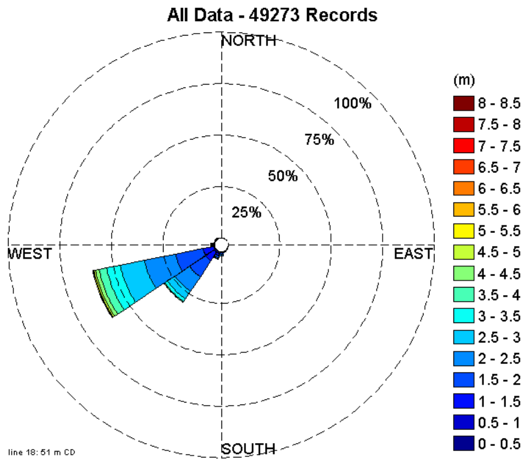
(i) Joint occurrence distribution of wave height and direction (wave roses): location point 18– Figure D1
(ii) Joint occurrence distribution of wave height and direction (wave roses): location point 23– Figure D2
(iii) Percentage exceedance of wave height for Slangkop and location 23 – Figure D3
(iv) Percentage exceedance of wave height for Location 18, 23 & 28 – Figure D4







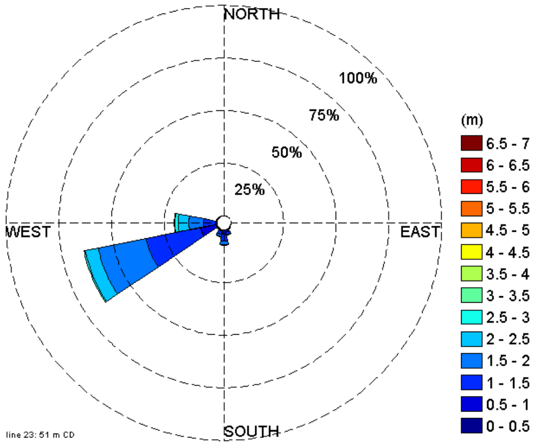




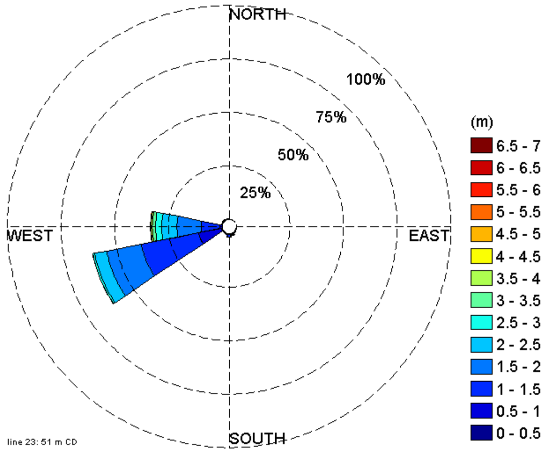
Station	Point 18

CSIR	Wave Roses: Output location 18	Figure D1

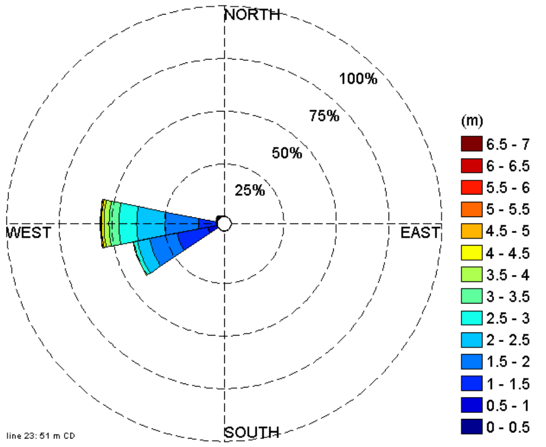
Summer - 11817 Records



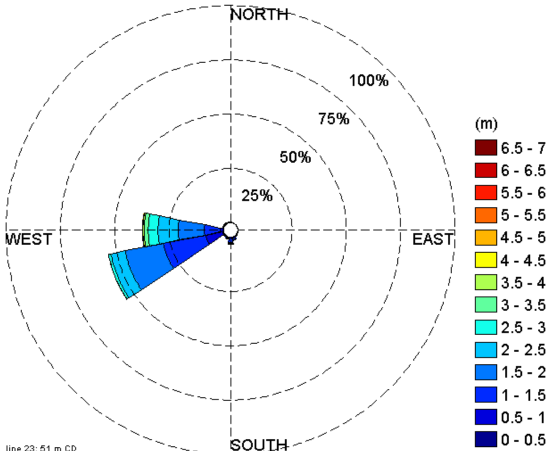
Autumn - 12528 Records



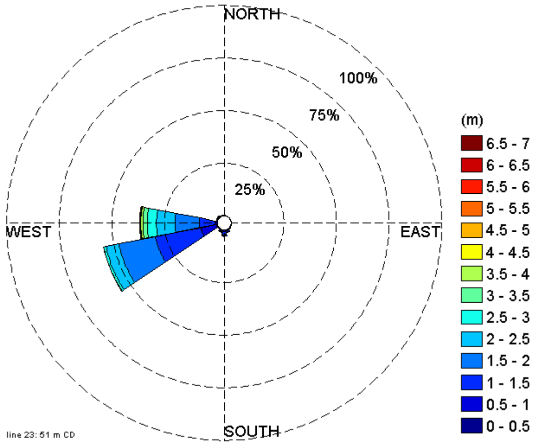
Winter - 12529 Records



Spring - 12399 Records

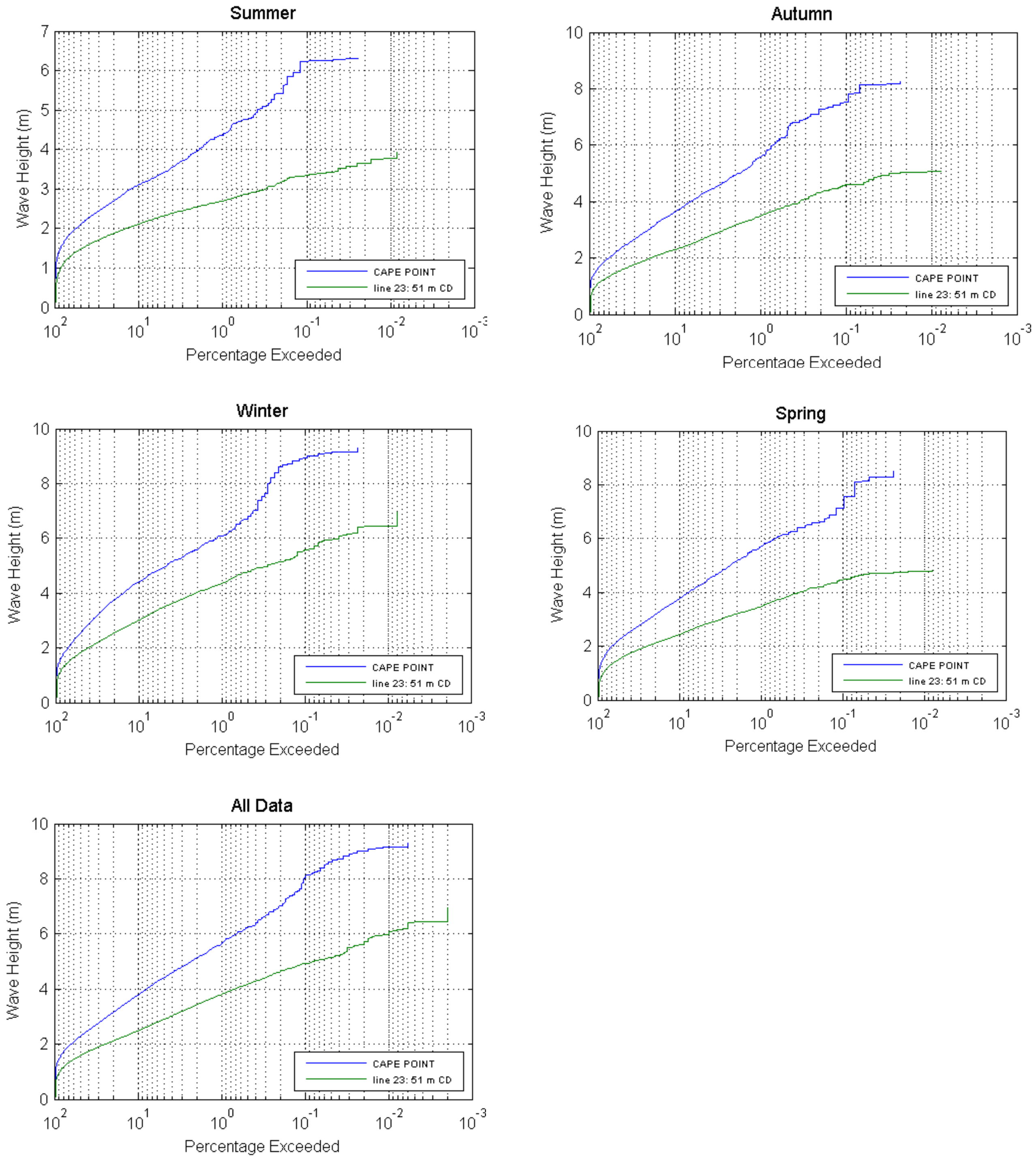


All Data - 49273 Records



Station	Point 23

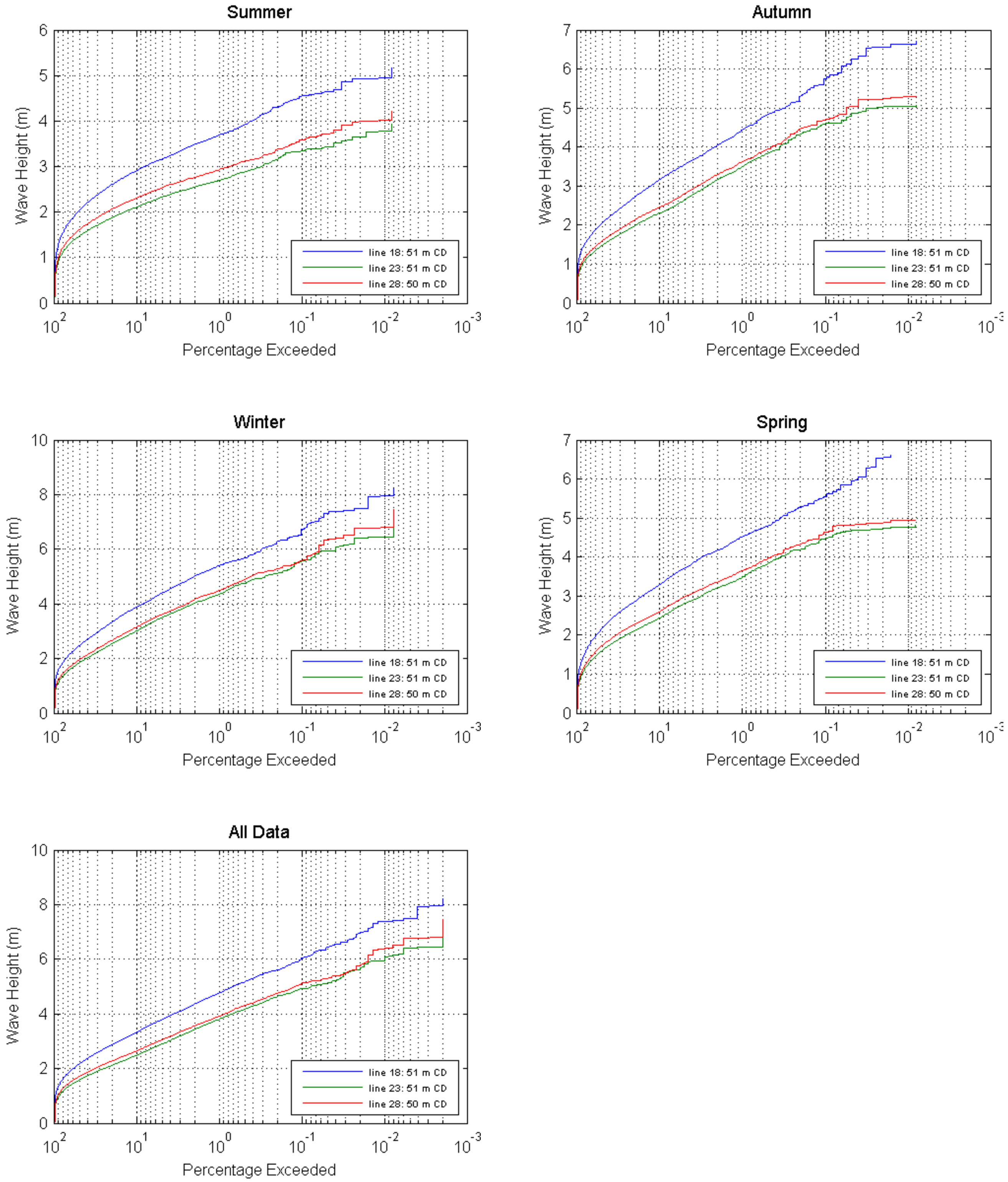
CSIR	Wave Roses: Output location 23	Figure D2



CSIR

Wave Height Exceedance for
Slangkop (Cape Point) & Locations 23

Figure
D3



CSIR	Wave Height Exceedance for Locations 18, 23 & 28	Figure D4

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