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PORT OF SALDANHA

Preliminary Assessment of the Marine Environmental Conditions for Liquefied Natural Gas (LNG) Shipment and Transfer Operations for Areas within Saldanha Bay

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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 a LNG (Liquefied Natural Gas) receiving terminal inside the precinct of the Port of Saldanha.

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 (Visagie, 2013).

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 area within the port of Saldanha Bay. The areas along the West Coast and within St Helena Bay are 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 three potential locations for the import of LNG within Saldanha Bay.

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 within Saldanha Bay, based on the following approach:

- Collect 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 by setting up a numerical wave model for Saldanha Bay
- Derive the long-period wave climate in the area of the proposed LNG trestle jetty option using the CSIR's already numerical long-period wave model setup for Saldanha Bay
- Derive the current regime based on the CSIR's already numerical hydrodynamic model setup for Saldanha Bay
- High level statistical analysis of marine environmental conditions
- Relate wind 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 have been conducted to support the conclusions in the report.

2 METHODOLOGY

The potential sites for the LNG receiving terminal, within the precinct of the Port of Saldanha, have to fulfil three basic maritime requirements for the waterside area in terms of this project, viz.:

(i) Navigability
- Required access channel 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 (unmooring 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 three 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 Saldanha Bay

The three identified potential locations for the LNG receiving terminal are in Saldanha Bay within the port limits of the Port of Saldanha. The Port of Saldanha is about 100 km north of Cape Town, situated on the West Coast of South Africa in Saldanha Bay, which is a large embayment that covers an area of 95 km^2. In the south, Saldanha Bay leads into Langebaan Lagoon through a tidal inlet located near the town of Langebaan. Langebaan Lagoon forms part of the West Coast National Park and is Marine Protected Area (Ramsar Site). The Port of Saldanha effectively splits Saldanha Bay in two bays (called Small Bay and Big Bay) via a 2 km long causeway and a 1 km long jetty structure, which are both orientated in a south-south-westerly direction.

3.2 Proposed Locations

Three locations have been selected as possible sites for the LNG receiving terminal within the Bay. The criteria by which the sites were chosen 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 location within the indicated ellipses.

Figure 3-1: Selected Sites within Saldanha Bay (yellow) and initially proposed sites (blue)

It should be noted that in the initial terms of reference, the proposed sites included an area onshore in Small Bay, an area around Jutten Island and an area in Big Bay, North east of the jetty and east of the proposed Liquefied Petroleum Gas (LPG) terminal. It was determined that the first two of the proposed sites were not feasible based on the present Transnet development plan and the possibility of these areas encroaching in Protected areas.

It was determined that any LNG development within Small Bay will close Small Bay for other operations and future port development. It was then concluded that the option be eliminated and replaced with a more feasible site. No development would be allowed on Jutten Island as it is classified as Marine Protected Area.

As stipulated in the terms of reference, any elimination of potential sites needs to be followed by a proposal of new sites. A set of criteria was followed during the selection of the proposed sites which are discussed below.

- Site one, positioned onshore Big Bay, was chosen because of its proximity to a future port expansion area. The expansion area as seen in Appendix A was selected by Transnet as a potential site for energy importing facility.

- Site two retains the initial position proposed by the client in Big Bay north east of the jetty. The area was chosen such that the minimum available water depth equalled the draught plus safe underkeel clearance of the vessel. This would help in mitigating the extent of dredging required.

- Site three is located close to Salamander Bay. It is expected that the wave energy around this area will be low as a result of wave diffraction and refraction. Salamander Bay is at a distance from port operation and residential areas. Hence it is assumed to have a low probability of impacting on port operations. Its proximity to land could result in the option of an onshore jetty terminal.

Among the criteria, adherence to the exclusion zones according to limitations set by the maritime gas industry was accepted. An exclusion zone refers to an area around LNG vessels or terminals that for safety and operational reasons has to be excluded from marine activities by others and which are a safe distance to existing activities and infrastructure. 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 specified exclusion zones and distances are the following:

- At least 1 600 m from any residential area
- At least 500 m from other port operations and infrastructure
- At least 500 m from the LPG terminal
- At least 300 m between moored LNG vessels and passing ships

The extent of the exclusion zones in relation to the proposed terminal areas can be seen in Appendix B.

4 PROPOSED LNG IMPORT TERMINALS

There are three location options for the LNG receiving terminal within the Port of Saldanha precinct as indicated in Section 3. The marine siting requirements for these three options for the LNG receiving terminal are discussed below.

4.1 Location1: Trestle Jetty

At location 1, the LNG receiving terminal is envisaged to be a trestle jetty operation, which requires sufficient depth to safely moor and navigate the LNG vessels. The vessel will be moored to a jetty and offloaded (using cryogenic offloading arms) to storage tanks and regasification ashore. Thereafter, the gas will be transported through gas pipes to consumers. This onsite operation occupies a significant footprint of between 15 and 28 hectares and high construction costs. If located nearshore in shallow water, this option may require dredging.

4.2 Location 2 Option 1 and 2: FSRU with turret mooring system

At location 2, the LNG vessel will operate as per the Golar-Bluewater (2011) concept specification which uses a Floating Storage and Regasification Unit (FSRU). This FSRU will be permanently moored to the sea bed at a water depth of at least 30 m by means of a turret system, as can be seen in Figure 4-1. The turret system could be an internal turret or a dismountable buoy system. The turret will be placed in the bow, below the main deck. Two operation options could be envisaged at this location depending on the metocean conditions viz. option one being the tandem and options two as the side-by-side offloading.

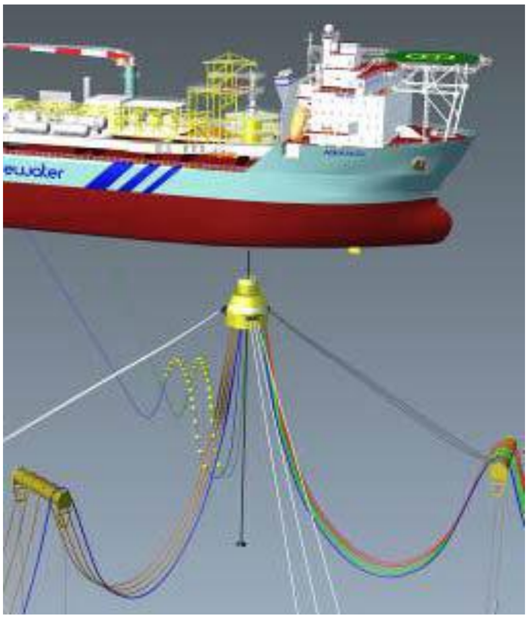


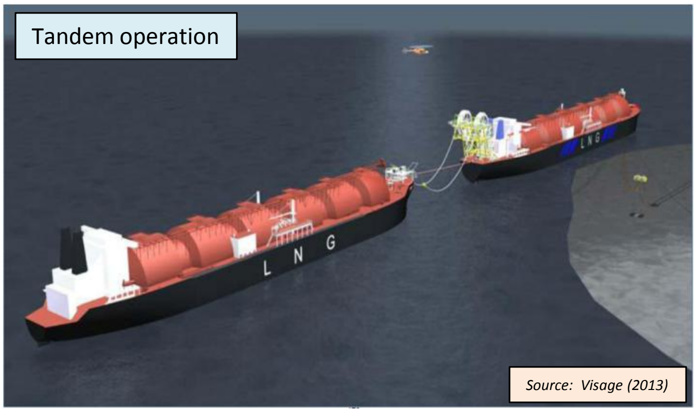
Figure 4-1: Demountable buoy moored FSRU

Cryogenic transfer hoses will be used to transfer LNG from the import tanker to the FSRU. At the FSRU, the LNG will be stored and gradually regasified. From the FSRU, the produced gas will flow to the swivel system in the turret and continue to the import risers and pipeline end manifold (PLEM) at the sea bottom, with some 80 bar delivery pressure. Due to the turret this system requires a water depth of at least 30 m, which is not available within Saldanha Bay. Localised dredging around the position of the turret would be required. It is expected that the terminal would then be placed at a position with a minimum water depth of more than the draught plus underkeel clearance of the vessel to mitigate the extent of dredging required.

4.3 Location 3: Trestle Jetty or FSRU operation

For location 3, three operations are envisioned, that is, a land based operation (Option 1) like the one in Section 4.1.1, a turret moored FSRU operation (Option 2 and 3) with tandem (*Figure 4-2*) or side by side offloading similar to those described in Section 4.1.2 and an FSRU on a trestle / floating jetty (Option 4).

For the last operation, the FSRU will be permanently moored to a floating jetty as depicted in Figure 4-3. This would eliminate the need to dredge and will restrain the FSRU from weathervaning. The LNG vessel will unload side by side to the FSRU through cryogenic pipes, as shown in Figure 4-3. Gas pipes will then be used to transport gas to customers.



Source: Visage (2013)

Figure 4-2: Tandem offloading operation

Figure 4-3: Side by side operating FSRU moored at a Jetty (Hoegh LNG website)

4.4 Summary of operations

The summary of the options and operations described above is given in *Table 4-1* 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 4-1*.

Table 4-1: LNG Import terminal options

Options numbers	Area	Mooring System used	Type of offloading operation
1	Location 1 (Big Bay)	Trestle jetty	Berthed Vessel
2	Location 2 (Big Bay)	Submersible Demountable buoy	Tandem
3	Location 2 (Big Bay)	Submersible Demountable buoy	Side by Side
4	Location 3 (Salamander Bay)	Floating Jetty	Side by side
5	Location 3 (Salamander Bay)	Floating Jetty	Either side of the jetty
6	Location 3 (Salamander Bay)	Submersible Demountable buoy	Tandem
7	Location 3 (Salamander Bay)	Submersible Demountable buoy	Side by side
8	Location 3 (Salamander Bay)	Trestle Jetty	Berthed Vessel

5 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 in this report as waves with peak wave periods greater than 8 s.

All levels will be stated relative to Chart Datum (CD). Chart Datum in South Africa is presently equal to Lowest Astronomical Tide (LAT), which in Saldanha Bay is presently 0.865 m below the national land levelling datum. The reference coordinate system to be used will be UTM Zone 28S WGS84.

5.1 Bathymetry

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

The bathymetry of the Port of Saldanha was obtained from the United Kingdom Hydrographic Office series of Admiralty Charts, which were supplemented with marine survey data conducted by the CSIR. *Figure 5-1* shows the depths in Saldanha Bay in the vicinity of the points of interest.

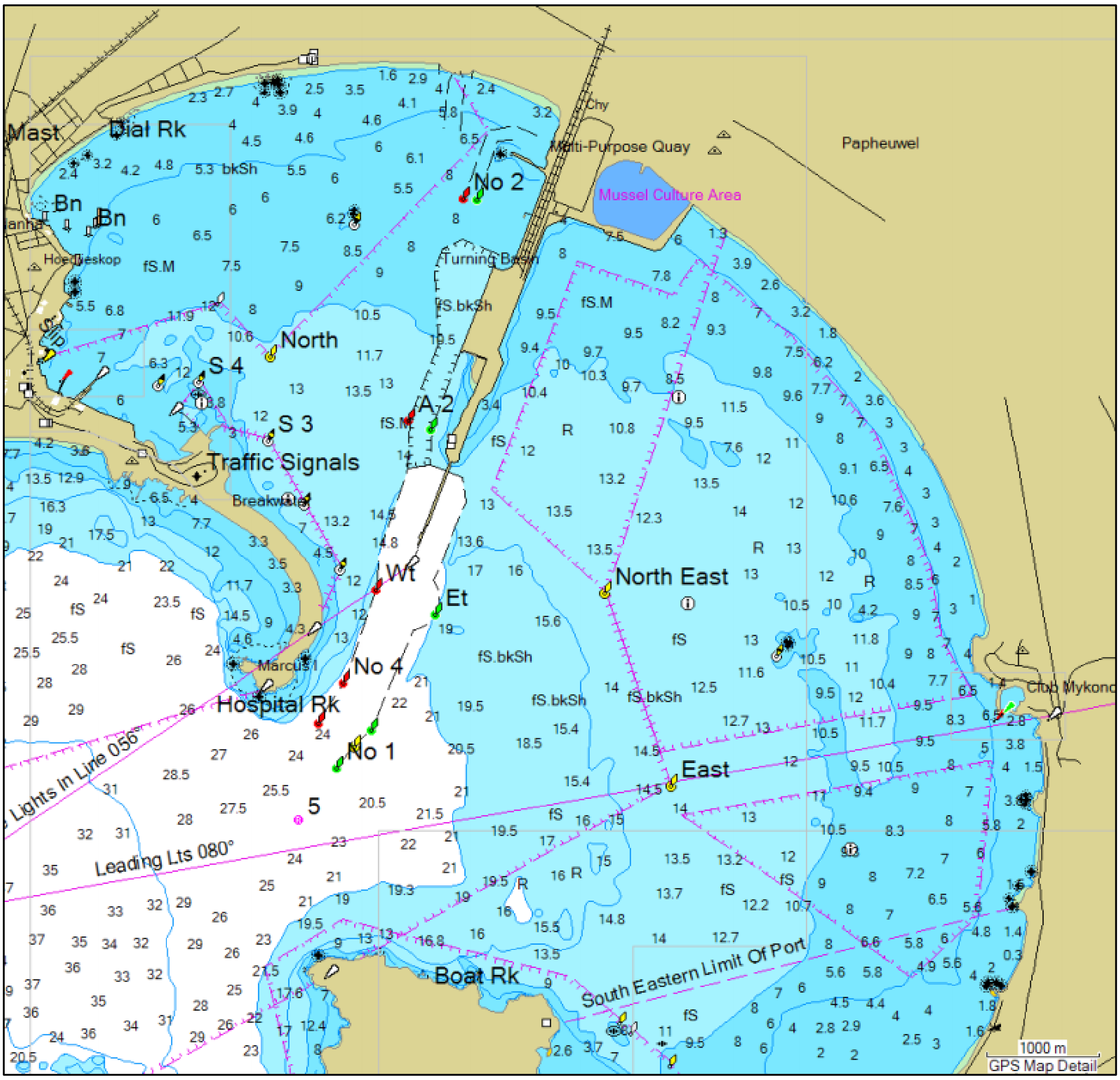


Figure 5-1: Saldanha Bay bathymetry

The narrow entrance into Small Bay leads into a relatively shallow bay, which has more than 50% of its sea bottom in waters less than 10 m depth. There is a gradual slope from the shoreline to the deepest areas of Small Bay. This bay is sheltered from the incoming wave energy. The wave energy penetrating into Small Bay is the result of refraction and diffraction (off Marcus Island) processes.

Big Bay, on the other hand, has more than 50% of its sea bed in waters between 10 m and 20 m depth. There is a steep slope from the shoreline to the deepest areas of Big Bay. This bay is more exposed than Small Bay, with most of the wave energy into Saldanha Bay being dissipated in this bay.

5.2 Meteorological Conditions

The meteorological conditions are important for navigation and mooring purposes.

5.2.1 Atmospheric conditions

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 (mainly mornings)

Saldanha Bay and Langebaan Lagoon are situated on the Cape West Coast, approximately 100 km north of Cape Town. The climate of this area 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, 1996). 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 fog caused by the interaction between cold marine air (the result of the Benguela Current) and the warmer land mass are common, particularly in autumn.

There is a strong seasonality in the winds over Saldanha Bay, reflecting the changes in the synoptic weather patterns prevailing at different times during the year. Southerly winds predominate in this region for most of the year, modulated by short periods of calm conditions or north-westerly winds which are associated with the propagation of coastal lows southwards along the west coast of southern Africa and weather fronts passing south of the subcontinent. Only in the mid-winter months do north to north-westerly winds predominate.

5.2.2 Wind data

Wind effects on LNG tankers are enhanced due to their high lateral windage area, which will consequently affect the pilotage, turning, berthing, manoeuvring, and offloading. Figure 5-2 shows the locations for which the CSIR used to extract the wind climate for Saldanha Bay.

Figure 5-2: Wind stations in the vicinity of the Port of Saldanha

a) Saldana Port Control

The CSIR maintains a wind station for Transnet at the Port of Saldanha, which is located at Port Control. This station contains a continuous wind dataset in excess of 10 years [January 2004 to date].

b) Air Force Base (AFB) Langebaanweg

The AFB Langebaanweg weather station contains a wind dataset in excess of 30 years [August 1973 to January 2014]. This wind station would only be used to verify any local effects.

c) South African Weather Service (SAWS) Station Langebaan

The Langebaan SAWS weather station contains a wind dataset in excess of 15 years [July 1997 to January 2014]. This wind station would only be used to verify any local effects.

d) NOAA/NCEP Offshore hindcast data

Offshore hindcast data were extracted from the NOAA WAVEWATCH III Global Ocean Wave Model with a grid resolution of 1.0^{o} N-S x 1.25° W-W. The hindcast data set contain 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. Hindcast data does not include cyclone generated waves, but this is not.relevant for Saldanha.

5.2.3 Offshore wind climate

The offshore wind climate used for this study is based on the NOAA/NCEP hindcast data (33°S, 17.5°E) – Figure 5 3.

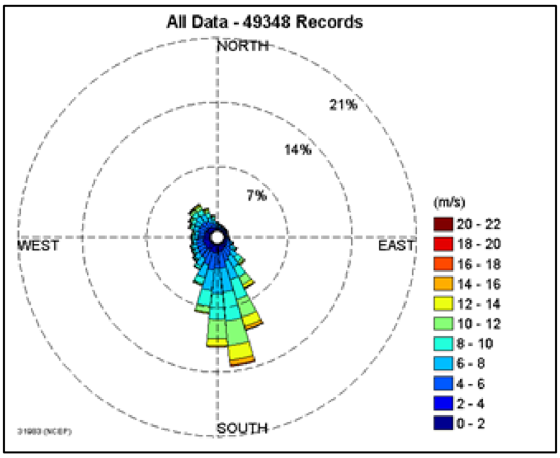


Figure 5-3: Offshore wind rose from NCEP (33°S, 17.5°E)-offshore St Helena Bay

The winds along the west coast of the Western Cape show significant southerly winds and distinct north wind. The strong south winds in Saldanha Bay are further enhanced by the "funnelling effects" of winds along the lagoon due to the topography. There are significant components in the north-westerly winds (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). Seasonal wind roses and exceedance graph are attached in Appendix C.

5.2.4 *Nearshore wind climate*

The nearshore wind climate is based on the Saldanha Port Control wind station. The Langebaan and AFB Langebaanweg data were used to verify the dominant local wind effects.

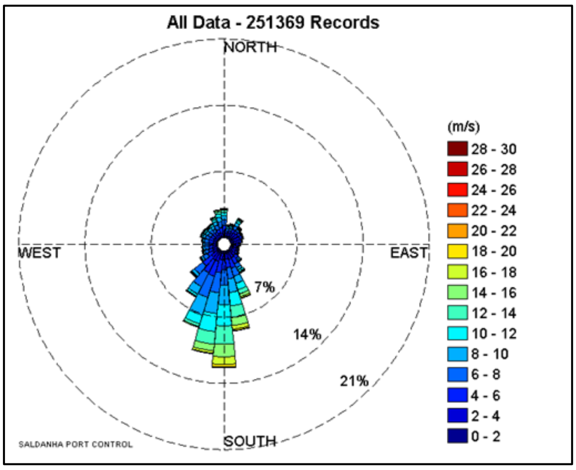


Figure 5-4: Nearshore wind rose from Saldanha Port Control

The nearshore wind roses show a distinct seasonal difference in the wind climate. The strong austral (southerly) winds are more pronounced during the spring and summer months, whilst the strong boreal (northerly) winds are more pronounced during the autumn and winter months. There are significant boreal wind components in the north-westerly sector (during the spring and winter months), which can be attributed to the passage of cold front systems during this period. The significant boreal wind components in the north-easterly (during the autumn and winter months) can be attributed to the dominant local effects (e.g. topography, land and sea breezes, length and season of the wind measurement, etc.) during this period.

The wind data from Port Control is recorded at one minute intervals for a period of 20 minutes, at the end of which the data is analysed and the minimum, average and maximum wind velocity recorded as the representation of the 20 minutes records. It is industry practise to convert the 20 minutes data to an hour averaged speed. The conversion was performed for Port Control data using the conversion factor described in the Coastal

Engineering Manual. The conversion factor was found to be 0.98 for Port Control, as calculated by O’ Connor (O' Connor, 2014).

Furthermore, the data recorded at Port Control represent wind speed at altitudes of about 50 m above sea level. This data tends to be an overestimation when dealing with marine wind effects at the standard 10 m elevation. The “1/7” rule is applied to convert the data to be representative of the speed at 10 m above sea level. The conversion factor was found to be 0.8 for Port Control (O' Connor, 2014).

The exceedance distribution for the nearshore wind climate based on the Saldanha Port Control wind dataset is shown in *Figure 5-5*. The wind speed in this figure is the 20-min average speed, converted to 10 m above sea level. Seasonal wind roses and exceedance graph are attached in Appendix C.

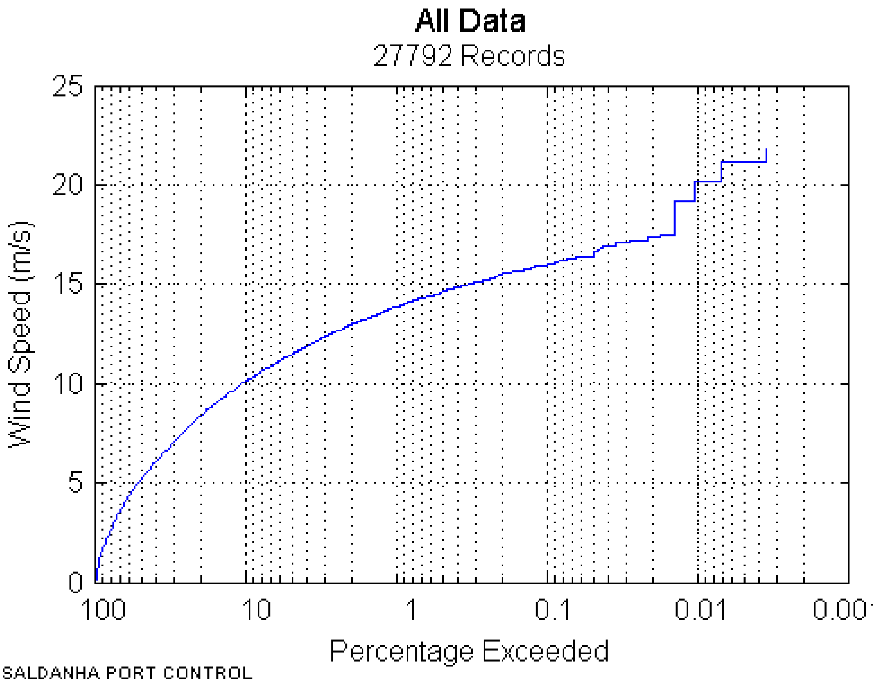


Figure 5-5: Annual wind speed exceedance at Saldanha Port Control

5.3 Oceanographic Conditions

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

5.3.1 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 (and in Saldanha Bay) are semi-diurnal (with a period of 12 hours 25 minutes), i.e. two high tides and two low tides occurring per day, with diurnal inequalities. The mean tidal range during neap tides is +0.57 m and the mean tidal range for spring tides is +1.51 m.

The tidal water levels for the Port of Saldanha, which are summarised in Table 5-2, were obtained from the Tide Tables, published by the South African Navy Hydrographic Office (SANHO).

Table 5-2: Tidal Levels in Saldanha Bay (SANHO, 2013)

Water Level	**Abbreviation**	**Water Level (m CD)**
Highest astronomical Tide	HAT	+2.03
Mean High Water Springs	MHWS	+1.75
Mean High Water Neaps	MHWN	+1.27
Mean Level	ML	+0.99
Mean Low Water Neaps	MLWN	+0.70
Mean Low Water Springs	MLWS	+0.24
Lowest Astronomical Tide	LAT	0.00

Measured water levels at the site will differ from the predicted astronomical tides due to changes in atmospheric pressure and wind effects (referred to as storm surge), which is called the meteo tide, as well as other factors including shelf waves and edge waves (collectively known as tidal residuals). Therefore, the design water levels for the LNG receiving terminal location should be determined as a combination of a defined astronomical tidal level, the additional meteo tide, a design tidal residual, as well as an allowance for long term sea level rise.

5.3.2 Wave data

Wave effects on LNG tankers are critical in the offloading operations. Figure 5-6 shows the locations, which the CSIR used to extract the wave climate for Saldanha bay.

a) Slangkop Waverider Buoy

The CSIR maintains a directional Waverider buoy for Transnet National 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. The available dataset for the two periods of the Waverider buoy covers a period in excess of 30 years.

b) Saldanha Waverider Buoy

The CSIR also maintains a non-directional Waverider buoy for TNPA, which is located approximately 2 km south west of the Port of Saldanha jetty from 2004 to 2014. The available dataset covers a period in excess of 10 years.

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

Offshore hindcast data was extracted from the NOAA WAVEWATCH III Global Ocean Wave Model with a grid resolution of 1.0° x 1.25°. The hindcast data contains fourteen years (February 1997 to December 2010) of three-hourly wave and wind parameters, viz. the significant wave height (Hm0), peak wave period (Tp), mean wave direction at peak period (Dp), wind speed, wind direction and wind velocity components.

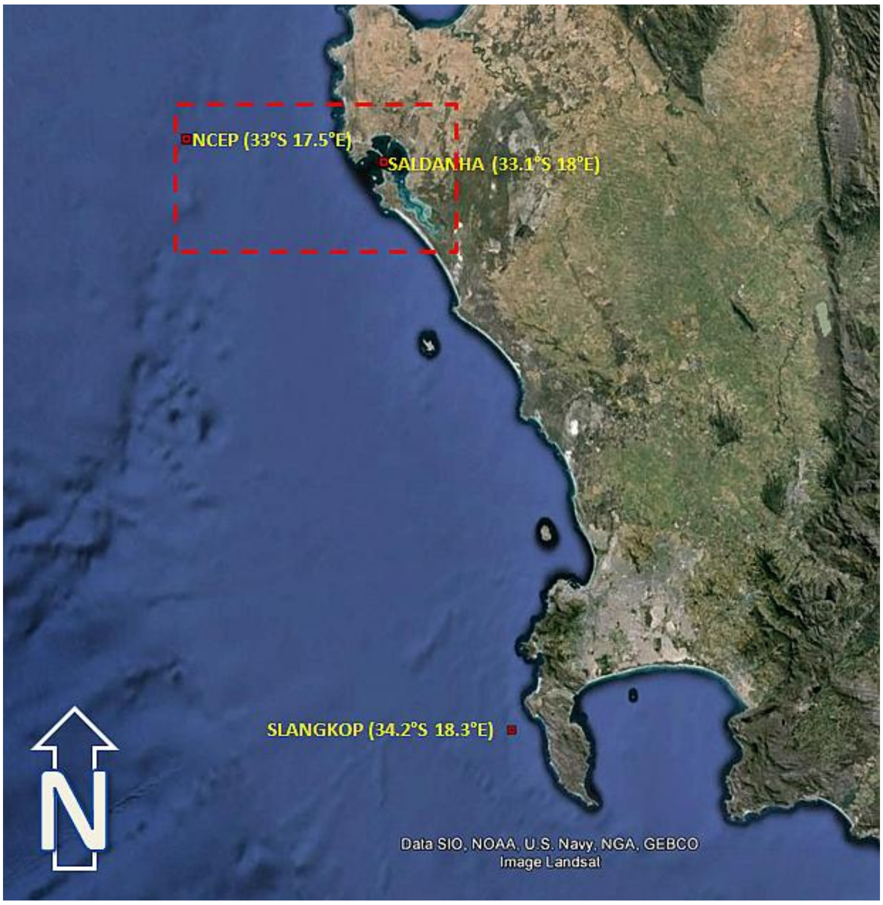


Figure 5-6: Wave stations used for Saldanha wave climate

5.3.3 Short period 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° south of the Equator. However, secondary low pressure systems in the Atlantic do generate local short-crested waves.

a) Offshore Wave Climate

The offshore wave climate is based on the Slangkop directional Waverider (34.2°S, 18.3°E). The reason for using the Slangkop Waverider data was that at depths of 70 m, the wave conditions along the west coast of the Western Cape should be the same. This has been verified for Saldanha Bay for other studies (CSIR, 2013). The waves along the west coast of the Western Cape show significant occurrence of waves from a south-westerly direction.

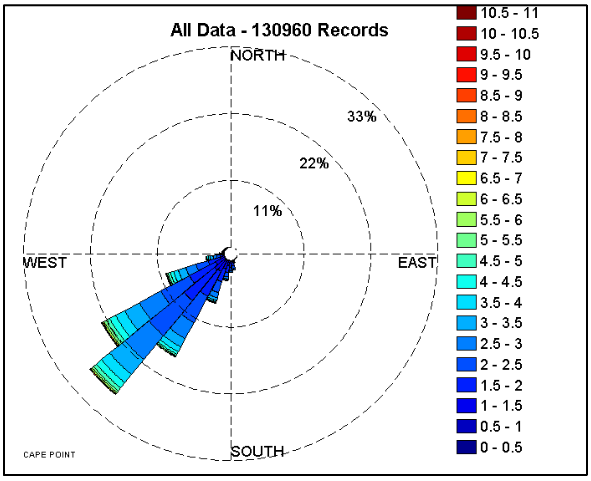


Figure 5-7: Slangkop Wave rose

b) Nearshore Wave Climate

The nearshore wave climate is based on the Saldanha one-directional Waverider buoy. The austral waves into Saldanha Bay approach from offshore from a south-westerly direction. It must be noted that this is also the orientation of the entrance into Saldanha Bay. These waves are refracted and diffracted into Big Bay and Small Bay. As the waves propagate into Small Bay, there is further reduction of the wave heights to H_{mo} of less than 0.5 m as they reach the beaches along Small Bay. However, as the waves propagate into Big Bay, there is less reduction of the wave heights with H_{mo} of more or less than 1 m, depending on the waves reaching the beaches along Big Bay.

5.3.4 Long period wave climate

Long-period waves or Long waves are almost invisible since they have wave lengths of several hundreds of metres and heights of only centimetres. They often occur jointly with strong swell action and are therefore hidden within the more visual swell waves. However, these long waves may have a significant impact, e.g. in the form of harbour basin oscillations and effecting moored vessels.

A number of ports in South Africa have experienced problems with moored vessels (Rossouw, 2013). These problems are manifested in the form of large vessel motions, (un)loading interruptions and breaking of mooring lines. For example, serious mooring problems were experienced in Duncan Dock of the Port of Cape Town, during the winter months of 1940 to 1942 (before Schoeman Dock was built). Causes to the problems were identified as basin resonance in Duncan Dock, which was initiated by long-period waves (Wilson, 1959 and 1965, and Joosting, 1957 and 1963). The long waves also referred to as infragravity waves, have periods in the range of 30 s to 500 s.

If the natural periods of the moored ships (usually the horizontal motions surge, sway and yaw) coincide with the oscillatory periods of basin resonance, large moored ship motions can be expected, as was the case in Duncan Dock. With later modification to the layout of the Port of Cape Town, and specifically the construction of Schoeman Dock in 1977, the mooring problems in the Port of Cape Town have almost disappeared. This can be attributed to “detuning” of the oscillatory water flow conditions (the “pumping mode”) at the entrance of Duncan Dock.

A second major South African port where serious mooring problems were experienced was the Port of Saldanha. Completed in 1976, the port was built for the export of iron ore and the import of oil, receiving bulk carriers and tankers of up to 300 000 DWT. The vessels are moored along an open jetty at the end of a causeway. Large motions were experienced by these vessels, but in this case no apparent basin oscillation could be identified as the cause of the mooring problems. During the 1980s the mooring problems were investigated by Wilson (1975) and the CSIR (Moes and Holroyd, 1982). It was concluded that in this port, the long waves were directly the cause of the mooring problems (Moes, 2003). No or little long-wave resonance was found in Small Bay and Big Bay but mainly in the vicinity of the jetty area. It thus appeared to be more a case of a focusing of reflected long-wave energy from the concave shores of the bay to the jetty area.

Of interest is the relationship found in Saldanha Bay. *Figure 5-8* presents the correlation between the short waves measured at caisson 25, and the long waves measured with a pressure sensor at the tip of the harbour jetty. Although some scatter was found, a lower envelope appeared to be present. The scatter can perhaps be explained by some long waves enter the bay as free long waves (i.e. not bound to the incoming swell). Furthermore, the data samples would also contain the reflected waves from the shore in the bay, resulting in a complex long wave pattern in the bay.

A reliable data set was obtained for the period May 2001 to November 2005 (Rossouw et al, 2013). The data indicated the median long wave height (HmoLW50%) is approximately 0.07 m, while the wave height, exceeded for 1 % of the time (HmoLW1%), is about 0.2 m.

It is also worth noting the impact of long waves was encountered in Mossel Bay and the Port of Ngqura (Rossouw et al, 2013).

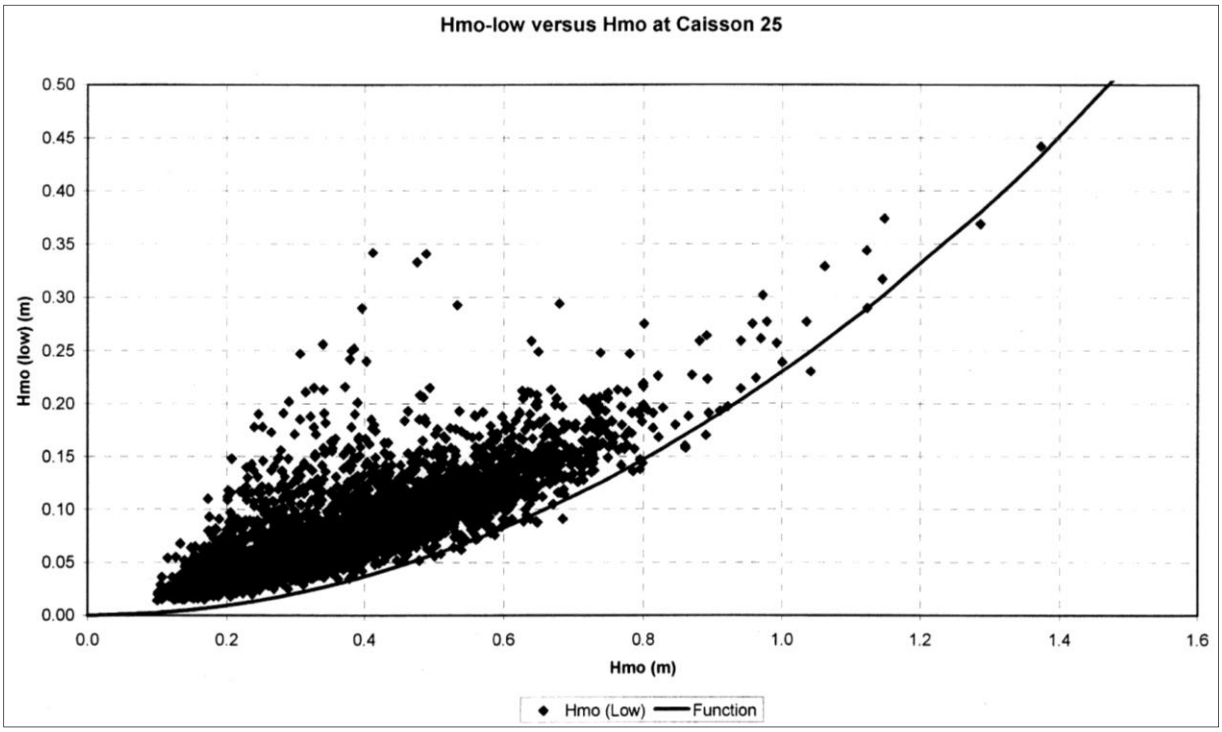


Figure 5-8: Long wave height at caisson 25 related to swell at caisson25

No long period wave modelling was done for this project. However, the CSIR has conducted various long period wave modelling studies in the bay for other proponents and as such has a good base for understanding the long period wave climate in the bay. The long wave conditions in Big Bay reach H_{m0} of 0.5 m with T_p ranging from 30 s – 100 s. The long period waves are bound in the short period wave group and are released due to wave refraction, diffraction, shoaling, breaking and reflection processes. The long waves propagate generally in the direction of the short period wave group. These long waves are critical for computing motions of vessels moored to fixed terminals. A depiction of the long wave distribution within the bay is shown in Figure 5-9: Significant long wave height inside the *Port for* a *condition of Hm0= 6.0 m, Tp = 17 s and Dir = 225o at Slangkop-Waverider buoy*

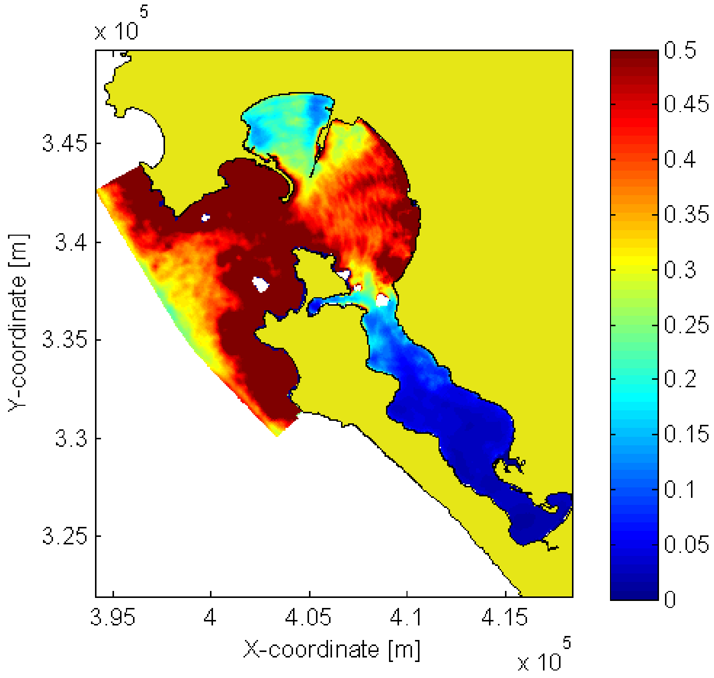


Figure 5-9: Significant long wave height inside the Port for a condition of H_{m0}= 6.0 m, T_p = 17 s and Dir = 225^o at Slangkop-Waverider buoy

Based on *Figure 5-9*, it can be inferred that the long wave experienced around Salamander Bay are of the same magnitude to those experienced at caisson 25 and nearshore Big Bay. An estimate of the magnitude of the long waves can be derived from the scatter graph shown on *Figure 5-8*, by using the following relationship:

$$Long\ Wave\ (Hm0) = 0.014 * (Square\ of\ the\ Saldanha\ waverider\ Hm0)$$

5.4 Currents Conditions

To simulate the complex flow-patterns within Saldanha Bay required that the three-dimensional processes typical of the hydrodynamics of Saldanha Bay be simulated with reasonable accuary. This was achieved by applying the numerical Delft3D modelling suite (Van Ballegooyen et al, 2007), the description of which is provided in Appendix D. The generated current data set represent a period of June 1999 to June 2000. The current roses for the three sites are presented in *Figure 5-11*, which illustrates the general direction of the flow patterns.

The current regime within Saldanha Bay is dominated by tidal water level variations and wind driven flows (Van Ballegooyen, et al., 2002). The former is predominant in Small Bay with the latter predominant in the rest of Saldanha Bay. Tidal forcing is stronger in areas surrounding the mouth of Saldanha Bay (Van Ballegooyen & Taljaard, 2012) and with increasing proximity to Langebaan Lagoon (Van Ballegooyen & Taljaard, 2012). Wave driven currents are dominant in the surf zone.

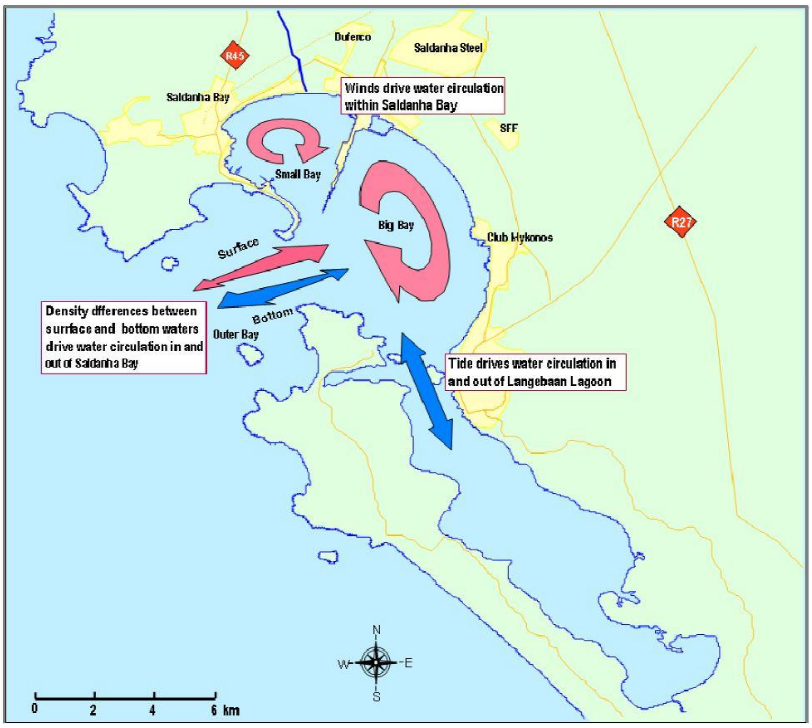


Figure 5-10: Schematic of wind driven and tidal currents in Saldanha Bay under NW wind conditions (Van Ballegooyen, et al., 2007)

The Saldanha Bay area is subject to very low current velocities. 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 shore (Van Ballegooyen, et al., 2007). Inshore of the Benguela Current proper, 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. Due to the disjointed geography of Saldanha Bay, particularly the outer islands, protruding headlands and narrow harbour mouth, the Benguela Current has little effect within the bay area.

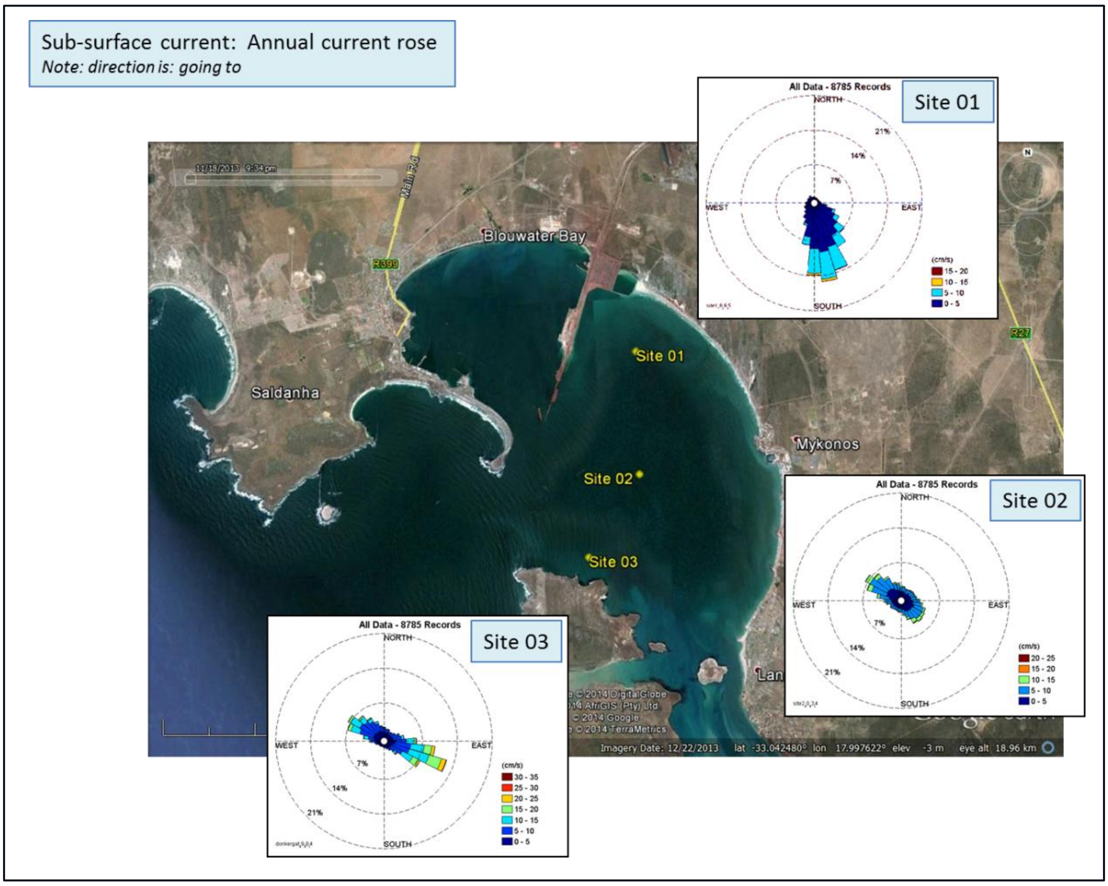


Figure 5-11: Subsurface current speed and direction for the proposed locations

The current velocity is the lowest in the Big Bay area of Location 1, exceeding magnitude of approximately 0.1 to 0.12 m/s for bottom and subsurface layers for only 1 % of the time. The velocity can be attributed to the shallow bathymetry at this location and the effect of tidal and wind driven circulation. Seasonal variation roses and exceedance graphs of the velocity are attached in Appendix D.

The current within the Big Bay area of Location 2 shows distinct North-westerly and South-easterly directions for both the subsurface layer, as seen is *Figure 5-11* above. Current speed is higher in summer with 0.15 m/s and 0.12 m/s speeds exceeded 1 % of the time for subsurface and bottom layer, respectively. Currents at this location are a combination of the tidal forcing and wind driven current.

The current speed is highest around Salamander Bay with a distinct South-easterly component and a slight easterly component. The velocity at this location is attributed to the tidal forcing in and out of Langebaan Lagoon and the density difference between the surface and bottom waters. The 1 % exceedance (on annual basis) at this location is 0.22 and 0.15 m/s for the subsurface and bottom layers, respectively.

6 NUMERICAL WAVE MODELLING

6.1 Overview

Waves propagating into Saldanha Bay are subjected to processes such as refraction and reflections which results in decreased wave heights and altered wave directions. The extent to which the alterations occur are further determined by the amount of sheltering from waves that a specific location experiences. Areas such as Salamander Bay are protected to some extent. Thus, the wave data collected with the CSIR's Waverider buoy in the main entrance to the bay are not representative of the wave climate in the rest of the bay.

Fortunately, the wave climate in the sheltered area could be derived using a numerical wave model. 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. 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 that 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 Figure 5-2.

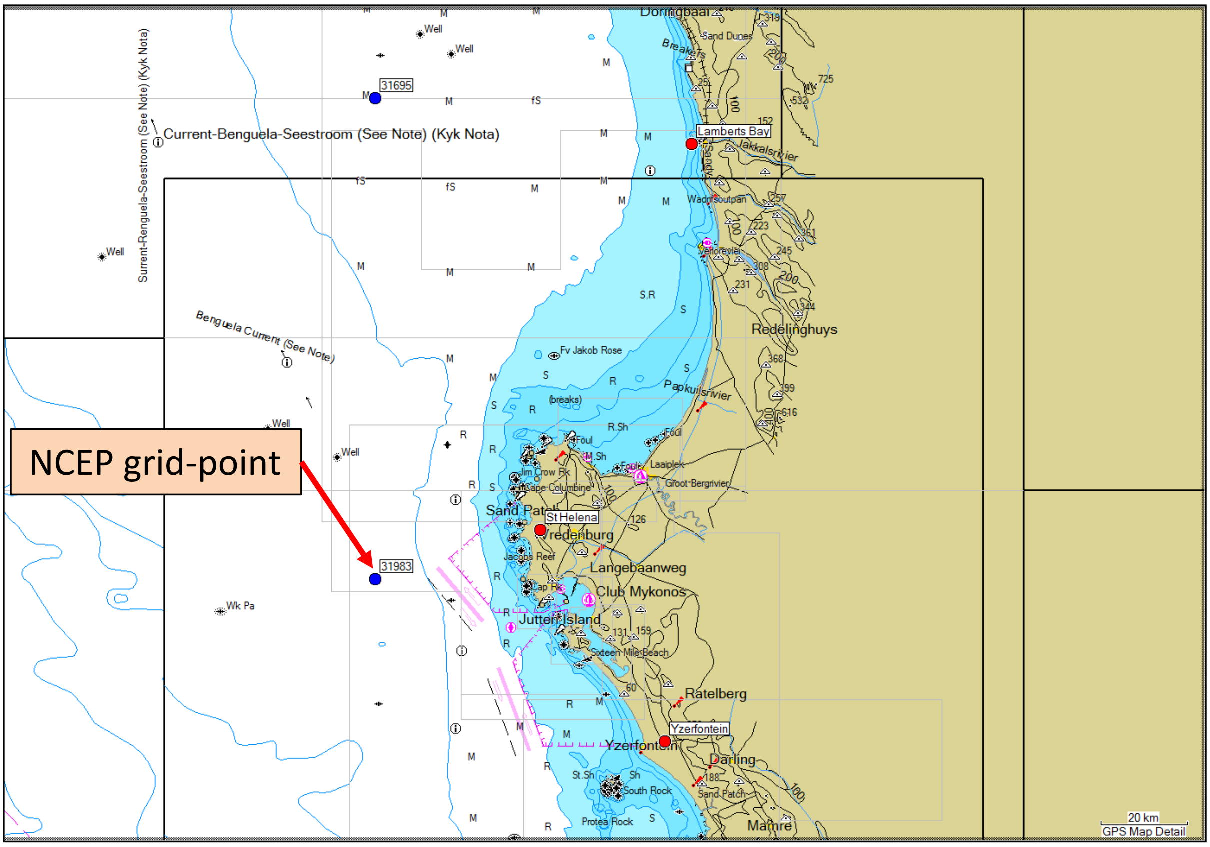


Figure 6-1: Location of NCEP grid-point used for SWAN modelling study

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 is shown in *Figure 6-2*. The annual wave roses for the three sites are shown in *Figure 6-3*. These roses indicate the general incoming wave direction of the waves entering the bay.

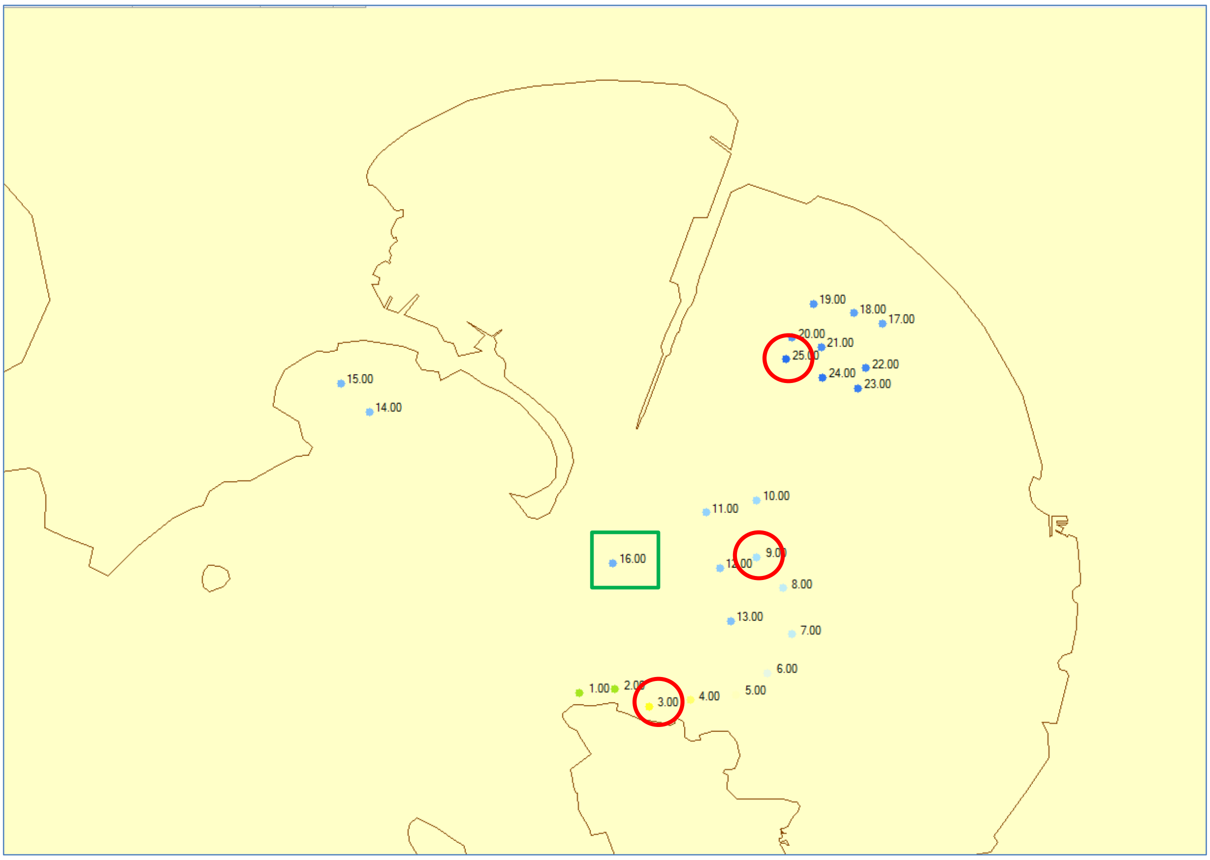


Figure 6-2: Output Locations for SWAN model

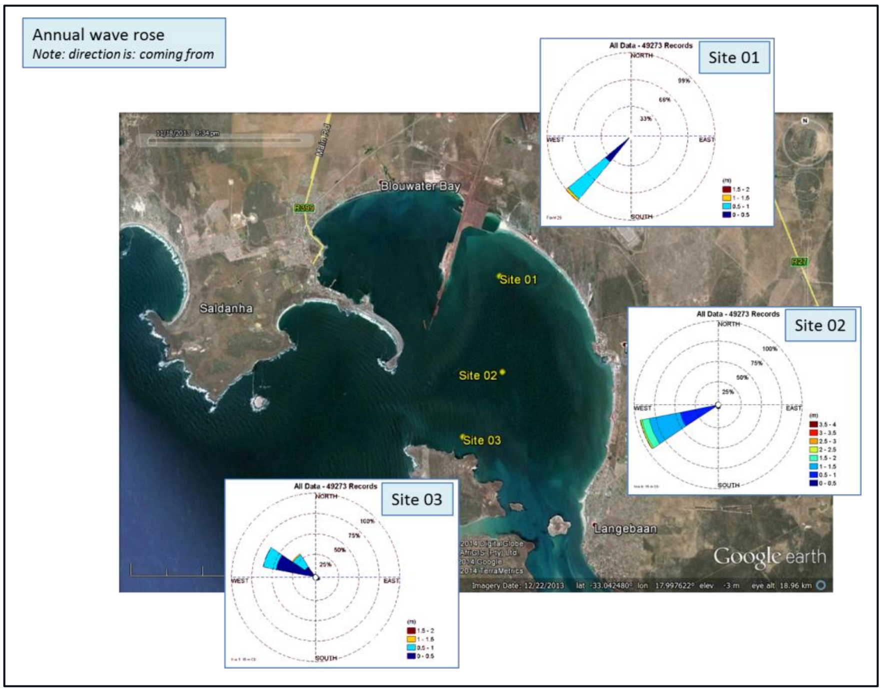


Figure 6-3: Annual wave roses for the three locations

7 LNG RECEIVING TERMINAL FUNCTIONAL REQUIREMENT

This section provides a brief overview of the functional requirements of the LNG receiving terminal limited only to the LNG vessel, FSRU, tugs and loading equipment criteria. The functional requirements will be superimposed in the downtime analysis of the LNG receiving terminal.

7.1 Spatial and Capacity Requirements

The design capacity for the LNG terminal storage will be 400 000 m^3 as per DED&T (2013). No terminal planning (turning circles, entrance channel, etc.) will be conducted as part of this study. This will be part of the detailed design stage of the project.

7.2 Design Vessel and FSRU Dimensions

No vessel mix was provided for the study, so the 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 design 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

7.3 Tug boats

The efficient and safe manoeuvring of vessels in confined water and in sheltered locations is determined in part by the use of tugs for assistance. The assistance is vital during the approach, berthing, unloading and departure operations. The amount and size / power of tug assistance required is dependent on the wind, waves and current conditions together with the type of terminal and offloading procedures followed. Other factors contributing to the selection of tugboat are the size and type of the design ship, the approach route, the exposure of the terminal and the bollard pull that each tugboat can mobilise. For example, quayside operations and side by side offloading would require more tugs than single point mooring and tandem offloading.

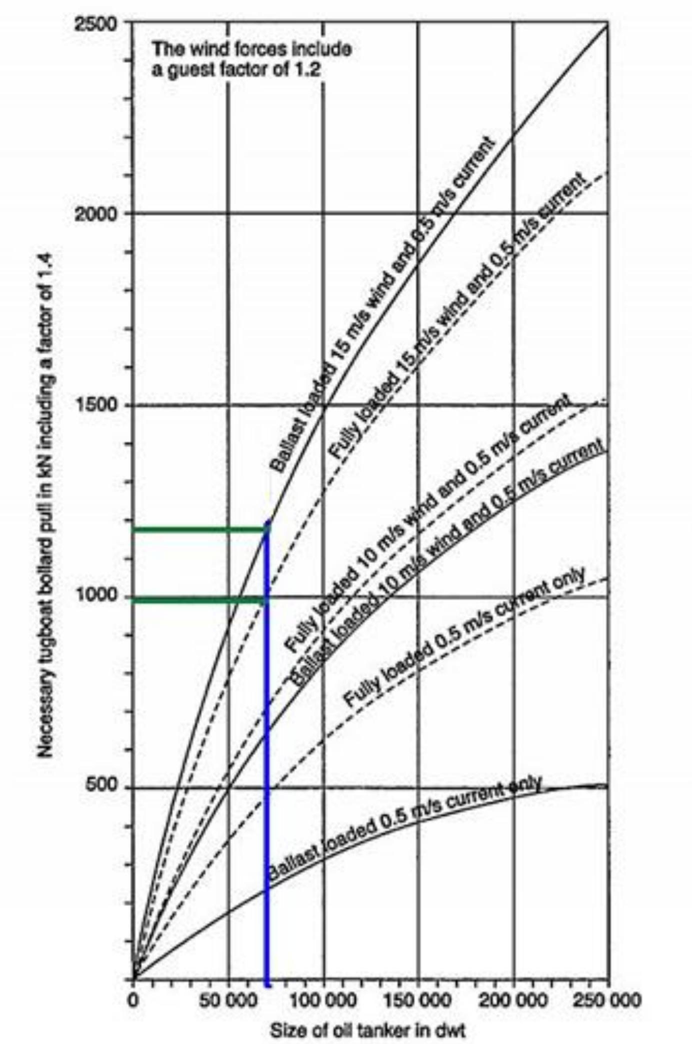


Figure 7-1: Necessary tugboat pull for crosswise wind and current acting on an oil tanker at deep water (Thoresen, 2003)

It is estimated, on the basis of Figure 7-1, that between one and three tugs with a total bollard pull of 1 000 kN will be required for operations, depending on the type of operation.

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) (1977);
  - Mooring Equipment Guidelines (2008);

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

Unloading operations will be undertaken using the individual ship pumping systems to supply the required discharge pressure to pump the liquid products to the floating LNG vessel or to onshore tanks. 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.

8.1 Summary of Limiting Criteria for Manoeuvring

The limiting criteria for manoeuvring for the abovementioned references is summarised in *Table 8-1* and *Table 8-2*.

Table 8-1: Required water depth (Oomen, 2002)

Water depth component	**Depth (m)**
Maximum draught of laden design	11.5
Minimum keel clearance (safety margin)	1.0
Allowance for siltation	1.0
Allowance for ship motions, turning and wind heel	1.5
Minimum water depth required	**15.0**

Table 8-2: Tug boats operation limits (Oomen, 2002)

Tug properties	**Limiting**
Normal tug boat assistance (hook up)	Hs<1.8-2.0m
Tug boats at lee-side of vessel (tug operations)	Hs<2.5m (when sailing)
Cross-currents	<0.5m/s

8.2 Summary of Limiting Criteria for Berthing and Departure

The limiting criteria for berthing and departure for the design vessel for a range of FLNG terminals are summarised in *Table 8-3*.

Table 8-3: Various LNG terminal limiting operational criteria (Ligteringen & Velsink, 2012)

Activity	**Jetty**	**MBM**	**SPM**
Mooring possible with wind up to 30 knots and head waves of:	H_{mo} : 1.0 - 2.0 m	H_{mo} : 1.0 m	H_{mo} : 2.0 - 2.5 m
Unloading possible with wind up to 40 knots and head waves of:	H_{mo} : 1.5 - 2.0 m	H_{mo} : 2.0 - 2.5 m	H_{mo} : 3.0 - 4.5 m
Ship has to leave berth with wind of 60 knots and waves higher than:	-	H_{mo} : 2.0 - 3.0 m	H_{mo} : 3.5 - 5.0 m
Assistance during Berthing limited by:	Mooring launches and tugs	Mooring launches and tugs	None
Assistance during departure limited by:	Mooring launches and tugs	Mooring launches and tugs	None

Table 8-4: Limiting Wind Condition (O' Connor, 2014)

Activity	**Terminal type**	**Wind speed**	**Source**
Boarding	Offshore	15-17 m/s	(TNPA,2013)
Tug connection	Entrance channel	15-17 m/s	(TNPA,2013)
Berth operation	Trestle jetty / Side by side offloading		
Offloading	Trestle jetty / Side by side offloading	15-17 m/s	(Thoresen,2010) (Cork &Ridha, 2008)
Disconnect arms	Trestle jetty / Side by side offloading	24-25 m/s	
Remain at berth	Tresttle jetty / Side by side offloading		

8.3 Limiting Criteria for (Un) loading and Mooring

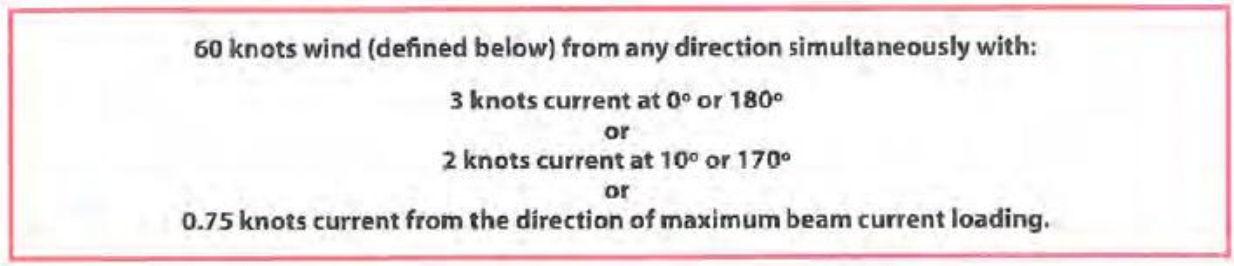
In PIANC, 2012, the following limiting conditions for the safe mooring of oil and gas tankers have been formulated as a guideline:

1. A wind speed limit of 12.5 m/s (25 knots) for berthing vessels with a projected wind area between 3 000 m^2 and 5 000 m^2. (with a 20% lower speed for vessels with a larger wind area and a 20% higher speed for vessels with smaller wind areas)
2. A wind speed limit of 15 m/s (30 knots) for cargo transfer operations.
3. A wind speed limit of 20 m/s (40 knots) to disconnect the loading arms.
4. A wind speed limit of 22 m/s (45 knots) for vessel mooring.

Vessels should be held at anchor if higher wind velocities are forecasted. If the vessel is already moored at the berth when such conditions occur, extraordinary risk mitigation measures, such as ballasting to reduce wind area, using additional mooring lines and using one or more standby tugs (to push the vessel against the berth), should be taken to reduce the risk of the vessel breaking out. In such circumstances, it is recommended that loading arms are disconnected before allowing the tug to push the vessel alongside the berth.

The above wind speeds should be the average over 60 s, with gust factor of 1.25 relative an average wind speed over 10 min. The representative height of the wind speed should be 10 m above sea level.

The OCIMF, in their Mooring Equipment Guidelines of 2008, have formulated the following combined environmental limits for safe mooring:



60 knots wind (defined below) from any direction simultaneously with:

3 knots current at 0° or 180°
or
2 knots current at 10° or 170°
or
0.75 knots current from the direction of maximum beam current loading.

The current speed limits hold for a minimum underkeel clearance of 10% of the vessel's draught. For a smaller underkeel clearance, the limiting current speed should be lower. The wave forces on the vessel should be calculated based on the maximum wave height Hmax, which may be calculated from the Rayleigh distribution of wave heights and the number of waves N over a typical time span (e.g. 3 hours) as follows:

$$Hmax = Hmo \sqrt{(0.5.\ln N)}$$

The maximum allowable motions of a gas tanker for efficient and safe (un)loading, according to PIANC, 1995, are:

Table 8-5: Limiting moored gas tanker motions (PIANC, 1995)

Motion	Limits
Surge	2.0 m
Sway	2.0 m
Yaw	2°
Pitch	2°
Roll	2°

8.4 Measures for Improved Mooring Conditions

There are a number of ways to improve mooring conditions in the case where long waves cause adverse conditions. It should be realized that changing the long-wave heights, periods or frequency range is almost impossible. Therefore, the local long-wave energy distribution over their frequency range has to be accepted as a given. It should also be realized that in case of (near) resonance conditions, the amplitude of the forcing is not very critical for its resonance effect. For example, if the amplitude of a long wave would be reduced by half, a moored ship resonating at this long-wave period would experience after some time almost the same extreme motions (limited by damping) as for the unreduced long-wave amplitude. A long-wave amplitude reduction would only be effective at some frequency-distance away from the resonant condition.

The remaining potential counter measures that can be applied in Saldanha Bay can be the following:

1. Shift the natural period of horizontal oscillation of the moored ship to a frequency range with lower long-wave energy by :

    - changing the mooring layout,
    - changing the stiffness (pretension) of the mooring lines (of course, all lines should at all times remain under tension and not be allowed to become slack),
    - reducing the re-bouncing effect of the fenders.

2. Reduce the long-wave amplitude, which could be realized by :

    - reducing the local swell amplitude and, thereby, the long wave amplitude of the bound long waves, by refraction and diffraction,
    - reflecting the breaking swell and the bound long waves back to the open sea/ocean,
    - damping/absorbing the bound and free long waves by shallow sand banks.

The emphasis in Saldanha Bay should be on optimizing the mooring line layout, by ascertaining that the loads in the mooring lines are evenly distributed over the available mooring lines.

9 DOWNTIME ANALYSIS

The downtime computation focused on the vessel approach, berthing and departure time lost resulting from environmental conditions. The analysis was done concurently for wind, waves and current conditions. The resulting downtimes from these conditions were superimposed to develop the total downtime.

The downtime computations are based on available literature and criteria (Golar-Bluewater, 2011; Ligteringen & Velsink, 2012 and O' Connor, 2014) and remain an estimate which could in reality vary significantly when factoring the shape of the approach / channel, traffic etc. Limiting wave heights for mooring gas tankers along the jetty operation followed the criteria set by H. Ligteringen and H. Velsink (2012). The approach and departure limits were set to the tug operation limits and water level (MLWN). The time required for vessel manoeuvring during approach and departure was set to an hour and two hours 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. Time required for unloading was calculated to be 18 hours, based on the design vessel capacity (145 000 m^3) and the unloading arms rates (4 000 m^3 per hour) for the jetty. The tandem and side by side unloading will use 16” cryogenic hoses with an unloading time of 27 hours.

Table 9-1: Total operation hours for the jetty terminal

Operation	Required time (Hours)		
Approach	2		
Berth\unloading		18	
Departure			1

Table 9-2: Total Operation hours for tandem and side by side unloading

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

Wind speed of 15 m/s was chosen as the limit for operations and the wave height limits used for the three locations are shown *Table 9-3* below.

Table 9-3: Limiting criteria used for downtime computation

Type of operation	Wave Limit	References
Trestle Jetty	1.5 m	(Ligteringen & Velsink, 2012)
FSRU side by side	2.5 m	(Golar-Bluewater, 2011)
FSRU Tandem	5.5 m	(Golar-Bluewater, 2011)

Following the downtime of waves and wind combined, it was found that operability at the different locations on annual and seasonally basis is stated in *Table 9-4* below:

Table 9-4: Seasonal and annual operability for different locations in Saldanha Bay

Area/Location	Type of operation	Season	Operability
Onshore Operation	Trestle Jetty	Yearly	96
		Autumn	95
		Winter	93
		Spring	96
		Summer	97
Big Bay	Side by side	Yearly	97
		Autumn	95
		Winter	95
		Spring	97
		Summer	96
	Tandem		
		Yearly	99
		Autumn	97
		Winter	97
		Spring	98
		Summer	99
Salamander Bay	Side by side	Yearly	97
		Autumn	96
		Winter	96
		Spring	98
		Summer	97
	Trestle Jetty		
		Yearly	97
		Autumn	96
		Winter	96
		Spring	98
		Summer	97
	Tandem Offloading		
		Yearly	98
		Autumn	97
		Winter	97
		Spring	99
		Summer	99

A more simplistic approach could be used to estimate the downtime resulting from wave conditions by using the wave height exceedance graphs. The exceedance graphs provided in Figure 9-1 shows the percentage of time a wave height is exceeded for the three locations, red representing nearshore Big Bay, green representing central Big Bay and blue representing Salamder Bay. Based on *Figure 9-1*, it can be estimated that the effect of waves along would contribute less than 0.01 percent downtime when using the wave limit of 2.5 m.

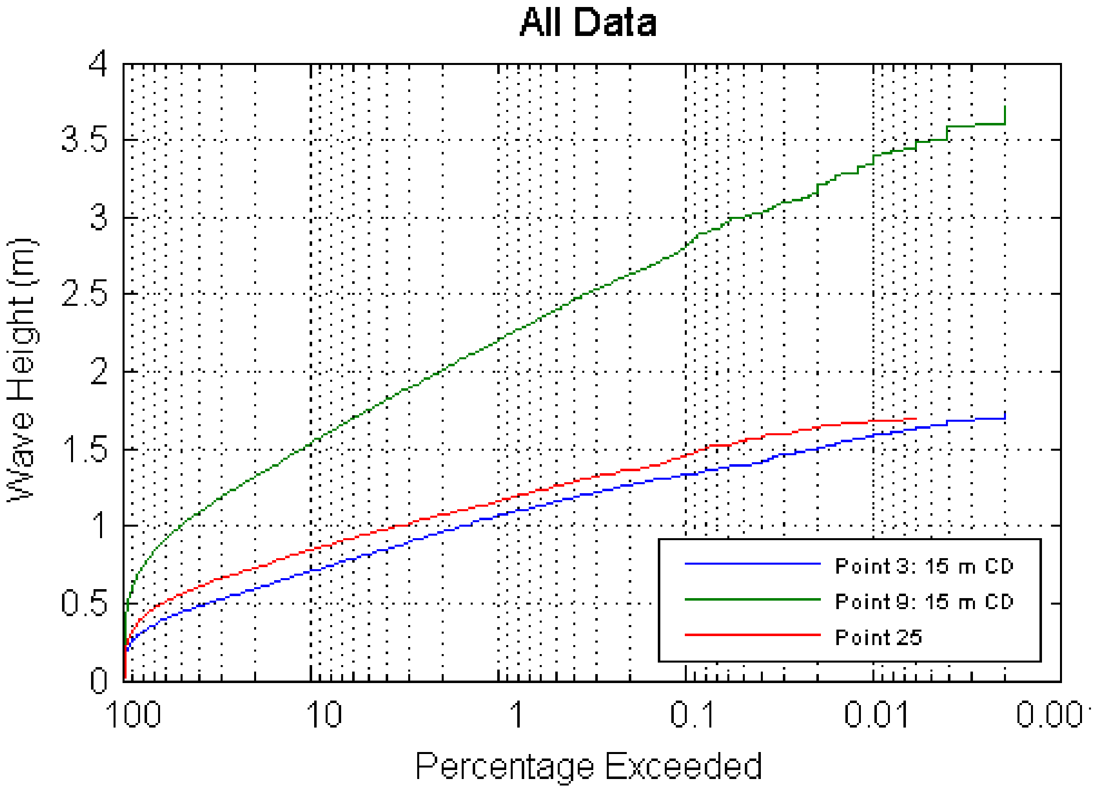


Figure 9-1: Wave height exceedance graph for the three proposed locations

10 MULTICRITERIA ANALYSIS

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

10.1 MCA Coding and Rating

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 8 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, waves, long-waves, 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

			Weights to determine relative risk of the various components				
No	**Type**	**Elements to be impacted**	**Wind**	**Waves**	**Long waves**	**Currents**	**Weather**
1	System integrity	Access ways to and within area (roads & railways)	0	0	0	0	0.25
2		Mooring structures & arrangements:					
2.1		Tresle jetty: (bollards, storm bollards, fenders) & mooring type [wrt ship safety]	1	0.5	2	0.25	0
2.2		Floating jetty	1.5	1	0.25	0.5	0
2.3		Submersable-demountable buoy [wrt ship safety]	0.5	1	0	0.5	0
3		Ship navigability in channel	1	0.5	0	0.25	1
4		Ship navigability / manoevrability inside port basin	1	0.5	0	0.25	1
5		Small vessel traffic	0.5	0.25	0	0.25	0.25
6		Pipes					
6.1		Piping: submerged pipe/PLEM	1	1	0	2	0
6.2		Piping: Connections/Valve system on Jetty	2	1	0	0	0
7	Operational efficiency	Coupling/Berthing vessels	1.5	1	1	0.5	0.5
8		Transfer/offloading of LNG from ship to shore: via jetty or SDB	1.5	1	1.5	0.5	0
9		Un-coupling/De-berthing vessels	1.5	1	1	0.5	0.5
10		Entering / Departure of vessel: Port vs Channel (with tug assistance)	1	0.5	0	0.25	1
11	Longevity	Jetty maintanance	0.25	0.75	0	0.5	0.25
12		Sub-demountable buoy: maintenance	0.5	1	0	0.5	0
13		Depth requirement for sub-demountable buoy/Turret buoy (Dredging)	0	1	0	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.

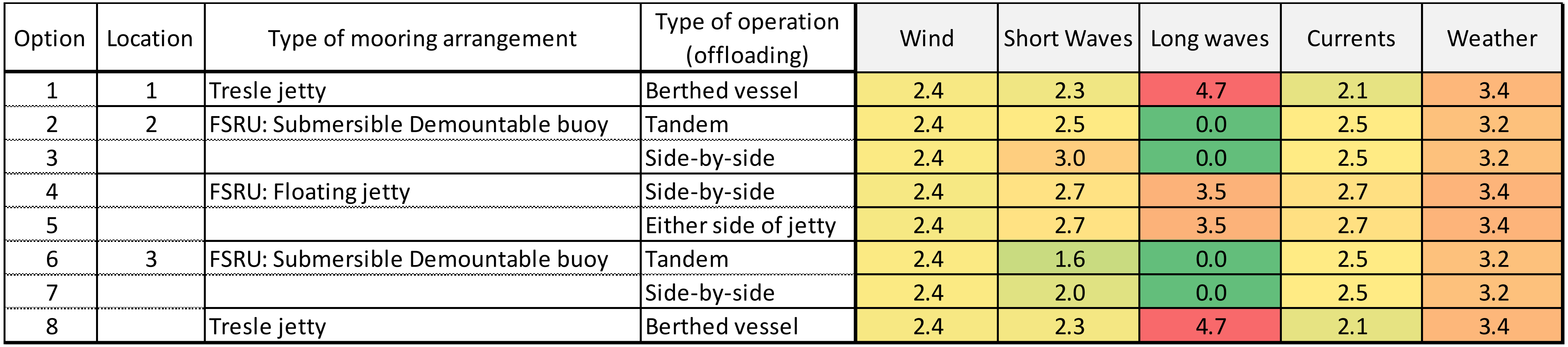
The fourth step is to assess and score the actual vulnerability of each component to the identified Metocean drivers, i.e. score the elements in *Table 10-1* using *Table 10-2*. This exercise was conducted for each of the 8 LNG options. The vulnerability score for each of the components as well as an 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 8 options. The summary of the results of this assessment is presented in Table 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 eight options. However, the summary indicates the trestle jetty options may be impacted by long waves. This is also graphically illustrated in Figure 1.

Based on the summary, it appears options 6 and 7 score generally lower than the rest, indicating 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 8 options across the selected Metocean drivers



Option	Location	Type of mooring arrangement	Type of operation (offloading)	Wind	Short Waves	Long waves	Currents	Weather
1	1	Tresle jetty	Berthed vessel	2.4	2.3	4.7	2.1	3.4
2	2	FSRU: Submersible Demountable buoy	Tandem	2.4	2.5	0.0	2.5	3.2
3			Side-by-side	2.4	3.0	0.0	2.5	3.2
4		FSRU: Floating jetty	Side-by-side	2.4	2.7	3.5	2.7	3.4
5			Either side of jetty	2.4	2.7	3.5	2.7	3.4
6	3	FSRU: Submersible Demountable buoy	Tandem	2.4	1.6	0.0	2.5	3.2
7			Side-by-side	2.4	2.0	0.0	2.5	3.2
8		Tresle jetty	Berthed vessel	2.4	2.3	4.7	2.1	3.4

Table 10-4: Vulnerability coding for 8 options across the selected Metocean drivers

	Likelihood that condition will impact port operations				
	Wind	Short Waves	Long waves	Currents	Weather
OPTION 1	POSSIBLE	POSSIBLE	ALMOST CERTAIN	POSSIBLE	LIKELY
OPTION 2	POSSIBLE	POSSIBLE	RARE	POSSIBLE	LIKELY
OPTION 3	POSSIBLE	POSSIBLE	RARE	POSSIBLE	LIKELY
OPTION 4	POSSIBLE	POSSIBLE	LIKELY	POSSIBLE	LIKELY
OPTION 5	POSSIBLE	POSSIBLE	LIKELY	POSSIBLE	LIKELY
OPTION 6	POSSIBLE	UNLIKELY	RARE	POSSIBLE	LIKELY
OPTION 7	POSSIBLE	UNLIKELY	RARE	POSSIBLE	LIKELY
OPTION 8	POSSIBLE	POSSIBLE	ALMOST CERTAIN	POSSIBLE	LIKELY

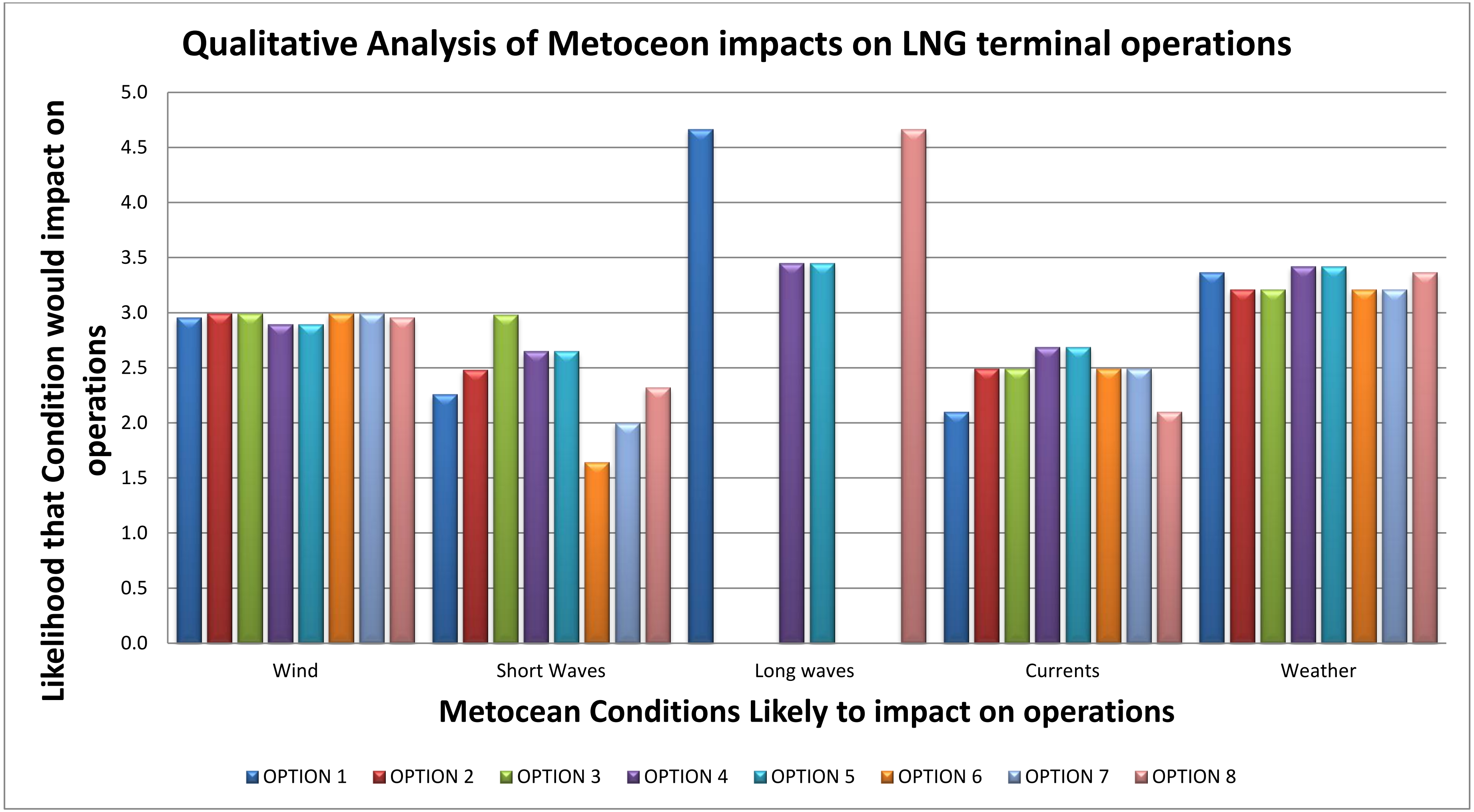


Figure 10-1: Vulnerability rating for 8 options across the selected Metocean drivers

10.2 Dredging

Dredging is the biggest component in deciding the cost effective terminal location and is referred to numerous times in the Multi-Criteria Analysis (MCA) rating. The preliminary dredging requirements are discussed below as relevant for each location.

The water depth nearshore is less than the draught of the design vessel and would therefore prevent navigability and manoeuvrability if dredging is not performed. The volume of dredging required could be decreased by extending the jetty further offshore. A water depth of 11.5 m could be reached by constructing a jetty that extends at least to 1.5 km from the shore. However, even at this depth dredging would still be required to allow for sufficient underkeel clearance. The volume of dredging might increase depending on the designer's chosen channel width and turning circle area. Onshore terminals are expected to have Land Area Requirements between 15 ha to 28 ha and could require land reclamation (O' Connor, 2014).

Water depths at Location two are more than the draught though not deep enough to allow for the required additional underkeel clearance of 3.5 m. Localised dredging would be required at the position of the turret to the depth of 30 m and around the vessel's weathervaning area to depths equal to the draught plus underkeel clearance. The use of an FSRU would not require land reclamation.

Location three near Salamander Bay will require minimal to no dredging depending on the chosen location within the proposed area. Salamander Bay is reasonably sheltered from waves.

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 within Saldanha Bay. The study focussed on three potential areas in the bay, namely in Big Bay (next to the TNPA causeway), more towards the centre of Big Bay and also closer to Salamander Bay, opposite Langebaan. 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, current and waves. The study included the computation of the percentage operability for the proposed locations and the report also outlined the metoceon conditions within the Saldanha Bay that could hamper the operation of the proposed LNG receiving terminals.

From the analysis performed it was found that the weather conditions within the Port of Saldanha Bay are suitable for LNG operations and for the use of floating terminals. The downtime analysis results indicate a loss in operational time of between 50 and three days per annum. The computed downtime did not account for time loss due to current conditions as a result of the lack of appropriate current measuring programmes within the Bay. However, the effect of adverse current conditions is not expected to be significant based on previous studies done on the current regime within the Bay.

It appears from both qualitative and downtime analysis, that Salamander Bay seems to be a more suitable site for the LNG import terminal when using an FSRU facility moored to a submersible demountable buoy. The results also highlighted the difference in operability of FSRU and land based facility. The use of an FSRU results in increased operability more so when the tandem offloading is used.

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.

This report should be read in conjunction with the environmental 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 detailed design and costing consideration.

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

- Since little ocean current and wave data are available, a measurement programme should be undertaken at the final selected site a LNG facility, if Saldanha Bay is chosen for further study. The data will be vital in assessing the current regime in the area of interest.
- The present hydrodynamic and wave models should be verified for the particular selected location in detail. This information will be vital for further design studies.
- A proper ship motion study should be undertaken whereby the forces on the mooring lines of the FSRU and LNG transport vessels can be assessed. Note that in conjunction with such a study, the long wave conditions must also be determined at the particular/proposed site.

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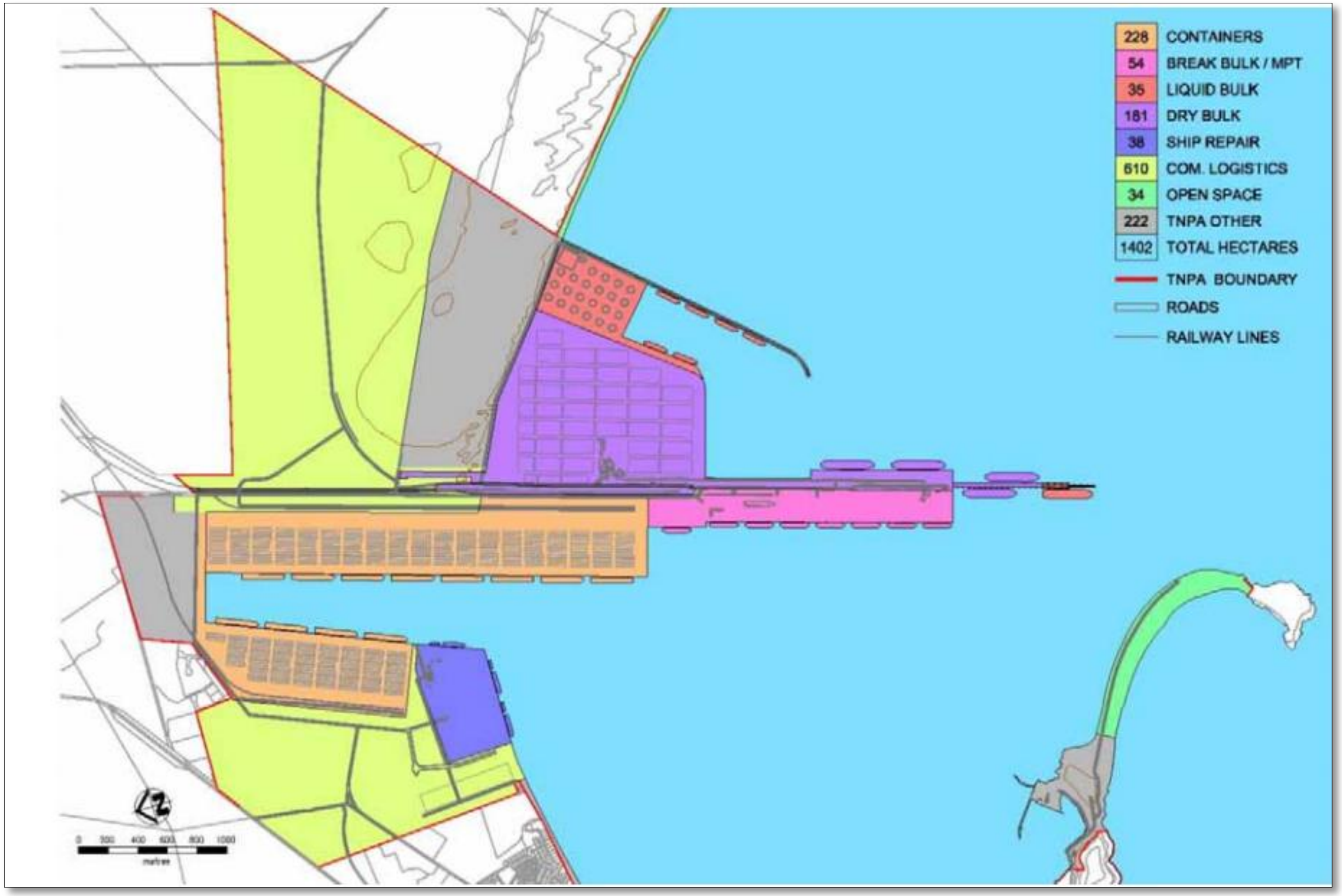
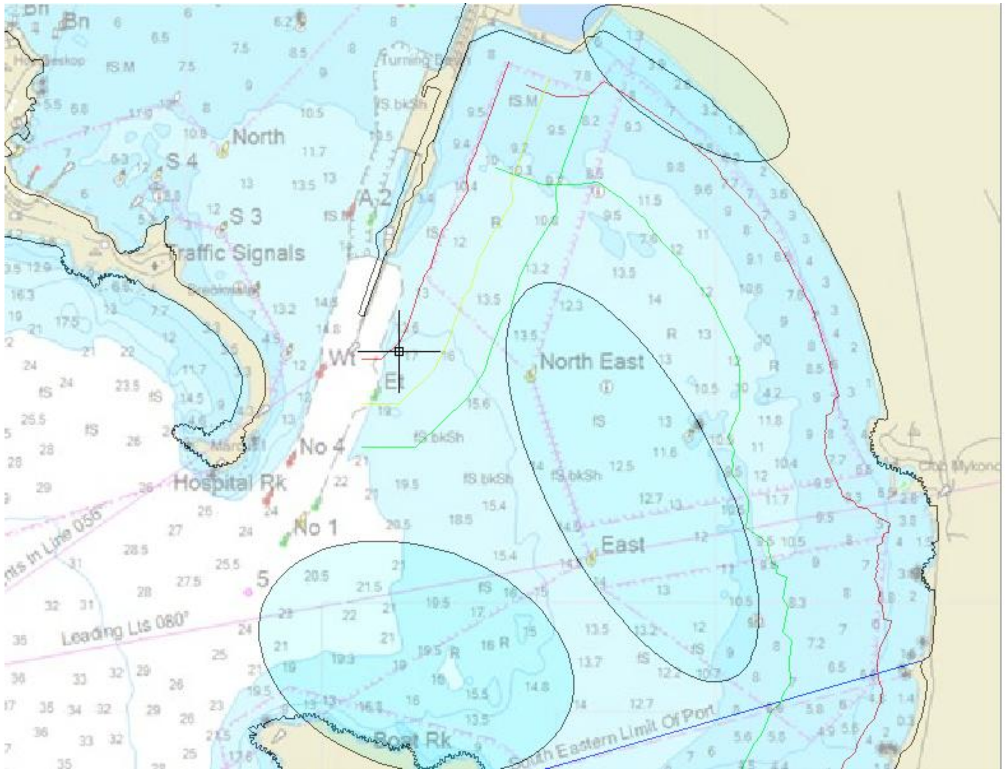
APPENDIX A: LAND USAGE AROUND SALDANHA BAY



APPENDIX B: PROPOSED TERMINAL LOCATIONS AND EXLUSION ZONES

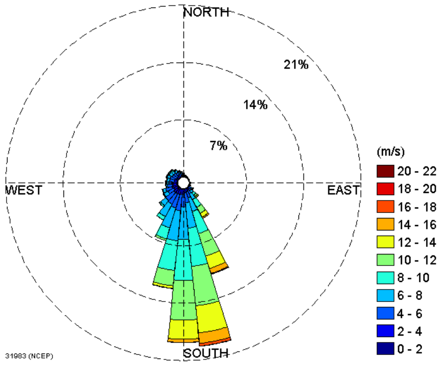
This appendix shows the proposed locations (circled) and their position relative to the exclusion zone. The red line represent the 500m exclusion from all port operations, the green line represents the 1 500 m exclusion from residential areas.



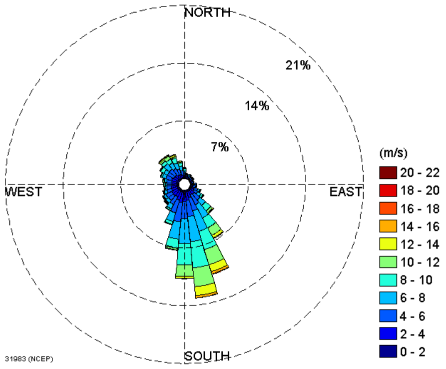
Saldanha bathymetry with proposed LNG locations and their exclusion zones

APPENDIX C: WIND SPEED ROSE AND EXCEEDANCE GRAPHS

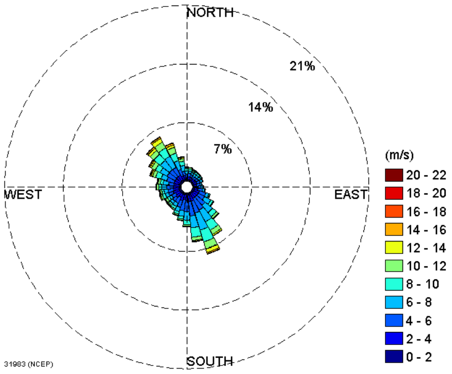
Summer - 11831 Records



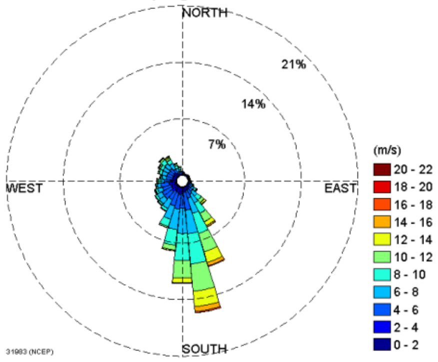
Autumn - 12551 Records



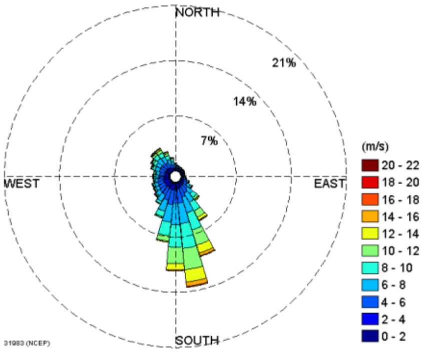
Winter - 12551 Records



Spring - 12415 Records



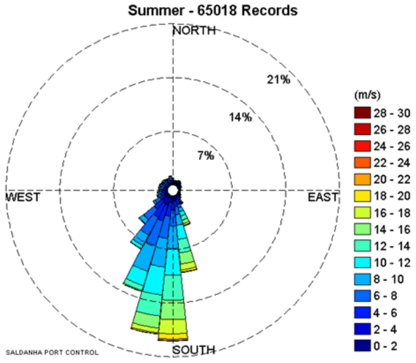
All Data - 49348 Records

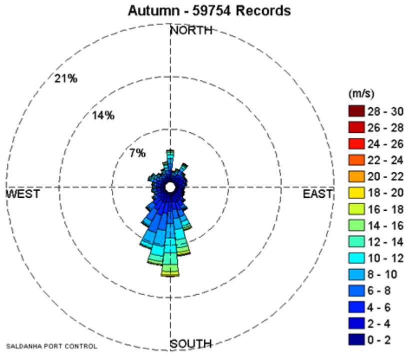


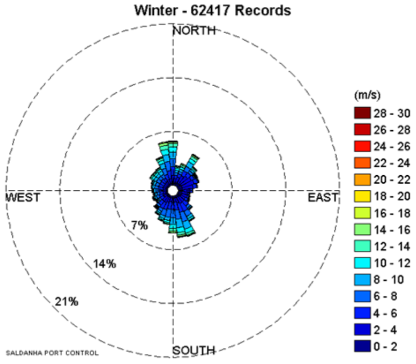
Period	1997-01-30 to 2013-12-01
Station	31983 (NCEP)
Position	33.00 S, 17.5E
Instrument Type	WaveWatch III
Records	49348

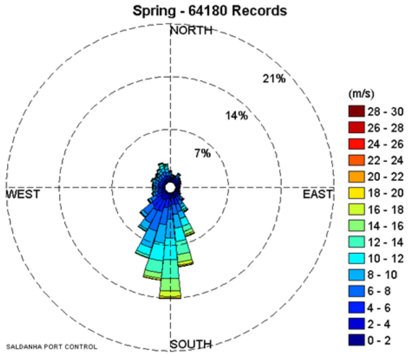
CAPE POINT
Wind Speed vs Wave Direction

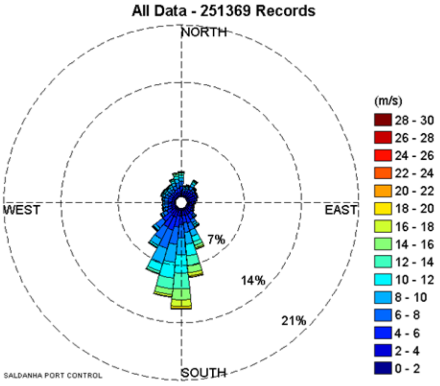
Figure C1







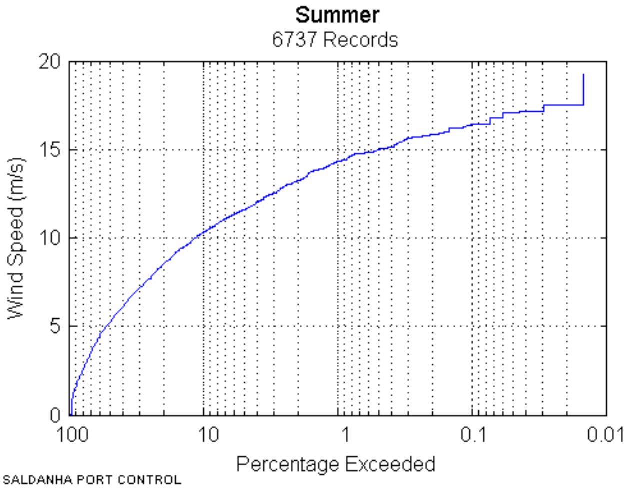


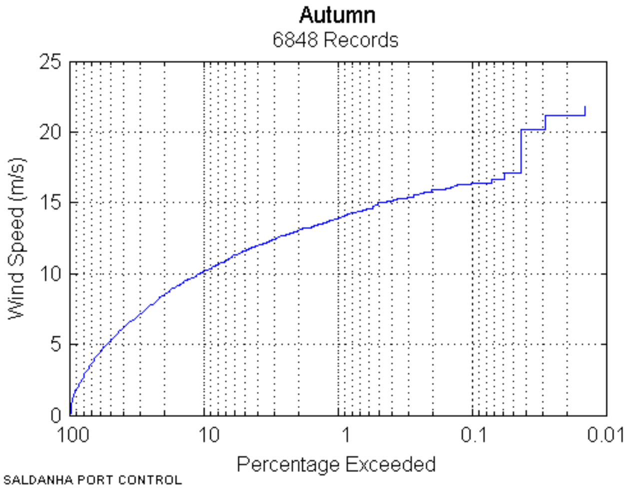


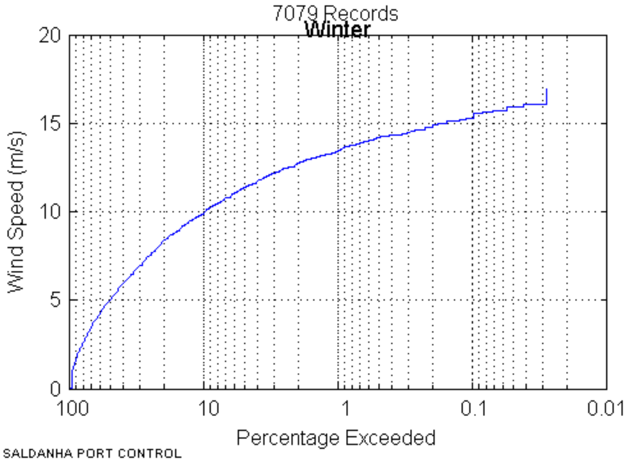
Station	Saldahna Port
Position	33.02 S, 17.96E
Height above surface	18 m
Records	251369

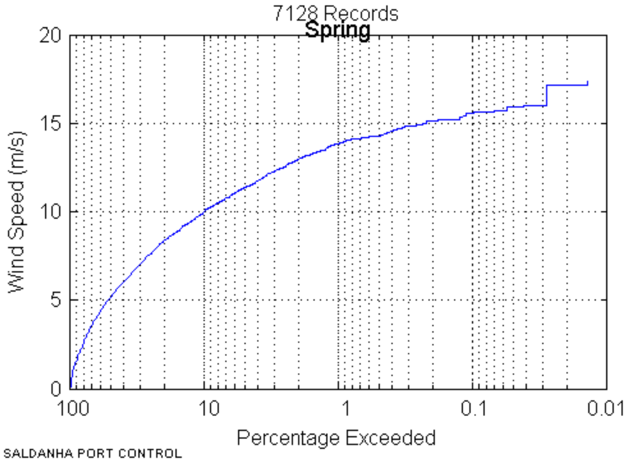
Saldanha Port Control
Wind Speed vs Wave Direction

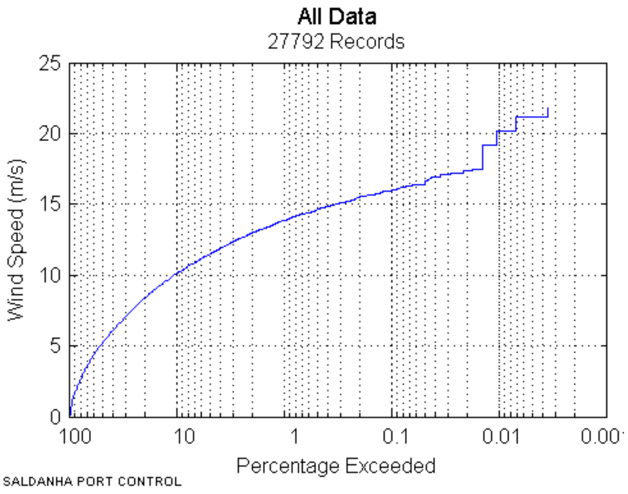
Figure C-2











Wind Speed Exceeded (m/s)					
	1.0%	5%	10%	25%	50%
All Data	13.88	11.53	10.12	7.69	5.18
Summer	14.35	11.61	10.35	7.77	5.26
Autumn	13.96	11.61	10.12	7.77	5.26
Winter	13.49	11.37	9.96	7.61	5.02
Spring	13.80	11.37	10.04	7.69	5.18

Wind Speed Exceedance

Figure C-3

APPENDIX D: HYDRODYNAMIC AND WATER QUALITY MODEL SET-UP AND CALIBRATION

To model the hydrodynamic, two modules were used, namely Delft3D-WAVE and Delft3D-FLOW. These modules are used in the so-called “online” mode which implies that the two modules operate interactively. The Delft3D-WAVE module uses a time series of waves and calculates a wave field every 2 hours and it uses the exact water levels from the Delft3D-FLOW module during these calculations. Every two hours Delft3D-WAVE passes the relevant wave information to Delft3D-FLOW. This information, together with wind and atmospheric data were used in DELFT3D-FLOW to simulate the hydrodynamics of the bay that include processes such as upwelling, wave- and wind-driven flows and turbulent mixing within the water column.

The models were set up and calibrated prior to generating a current field covering a period of one year. The locations of the instrumentation providing the calibration data are given in Figure B.1. Two modelling simulation periods were considered:

The first modelling exercise covered the period 20 October to 15 December 2006. This period coincided with a measurement campaign to ensure accurate calibration of the model. The focus of these calibrations was on the wave and wind-driven flows in Big Bay.

The second modelling period covered 1 July 1999 to 1 July 2000. During this period measurements were made of the water column stratification in Small Bay that also has been used to calibrate the model. These calibrations focussed on ensuring accurate simulation of the upwelling dynamics over the adjacent shelf and their influence on flows and water column mixing processes within the bay, the main focus being on Small Bay.

The general computational grid for DELFT3D-FLOW is shown in Figure D-2. A comparison of the modelled and predicted currents in the vicinity of the jetty (Figure D-1: position A) is presented in Figures D-3 and D-4. The U-component indicates the Easterly flow-component of the current while the V-component represents the Northerly flow-component of the current vector.

Following the elaborate calibration exercise as described in Van Ballegooyen et al (2007), it was concluded that the model can reliably simulate the overall tidal, wind- and wave-driven circulation as well as the water-column mixing processes. Therefore, the model was considered to be applicable for the purposes of deriving the current field over time in Saldanha Bay.

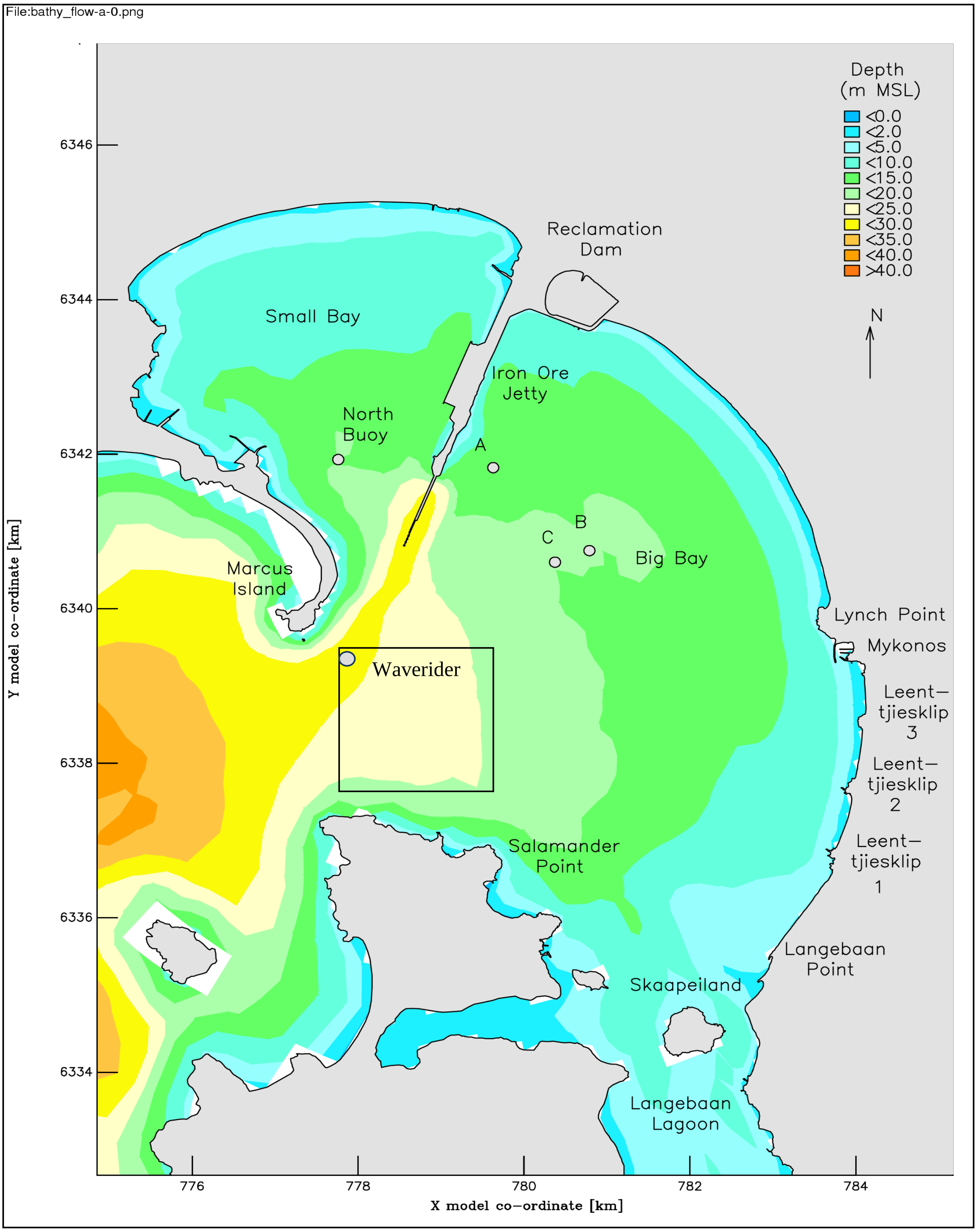


Figure D-1: Position of the instrumentation providing the data used to calibrate the model (Van Ballegooyen et al, 2007)

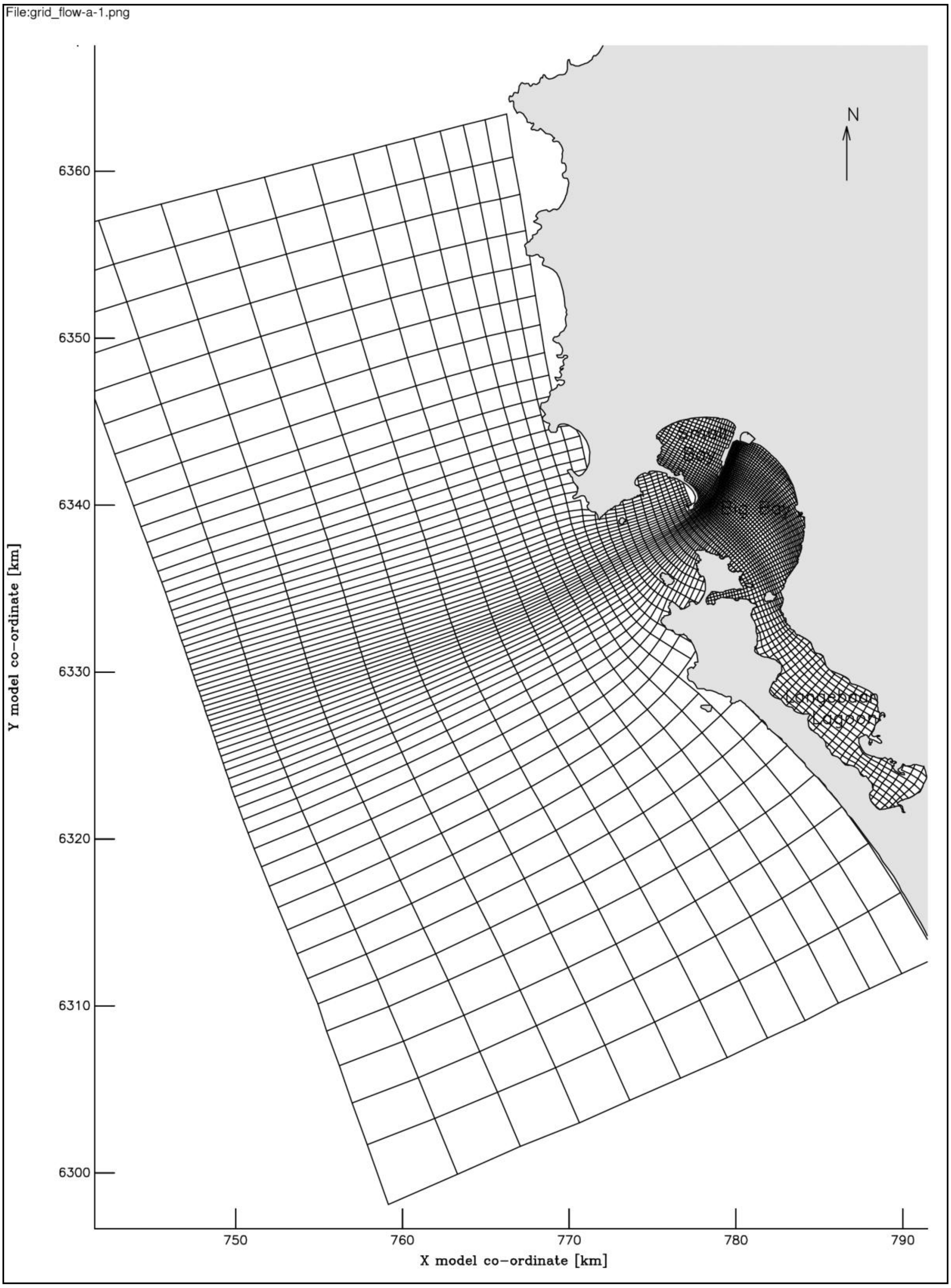


Figure D-2: The basic computational grid used in the hydrodynamic simulations (Van Ballegooyen et al, 2007)

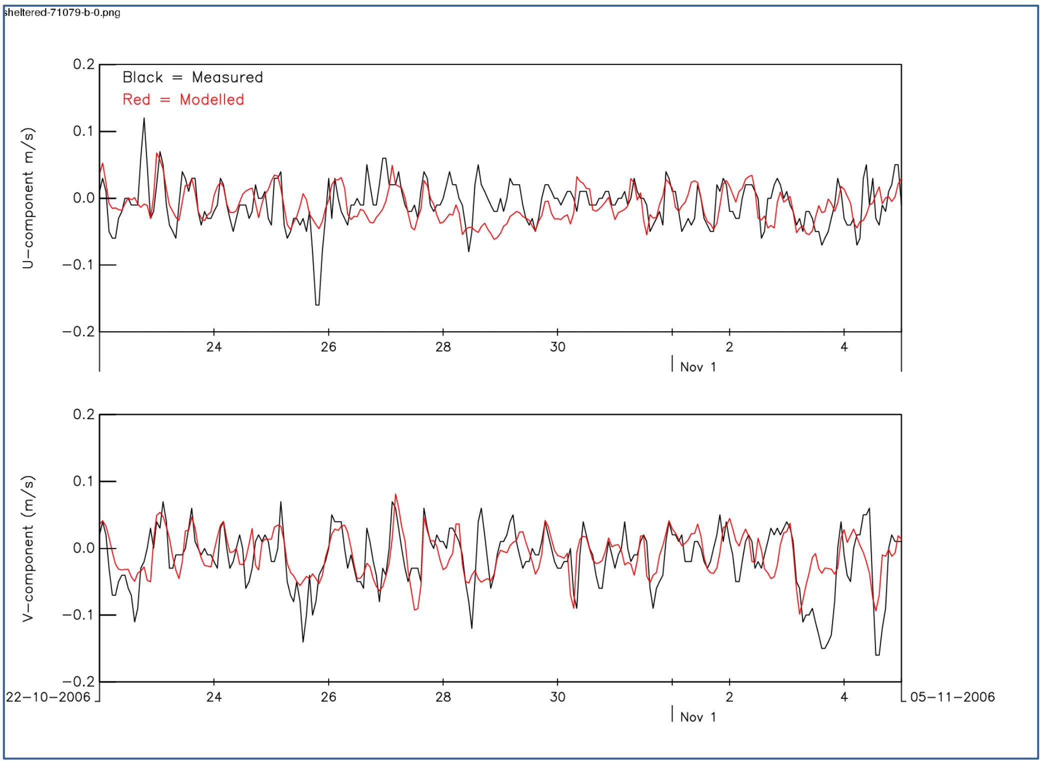
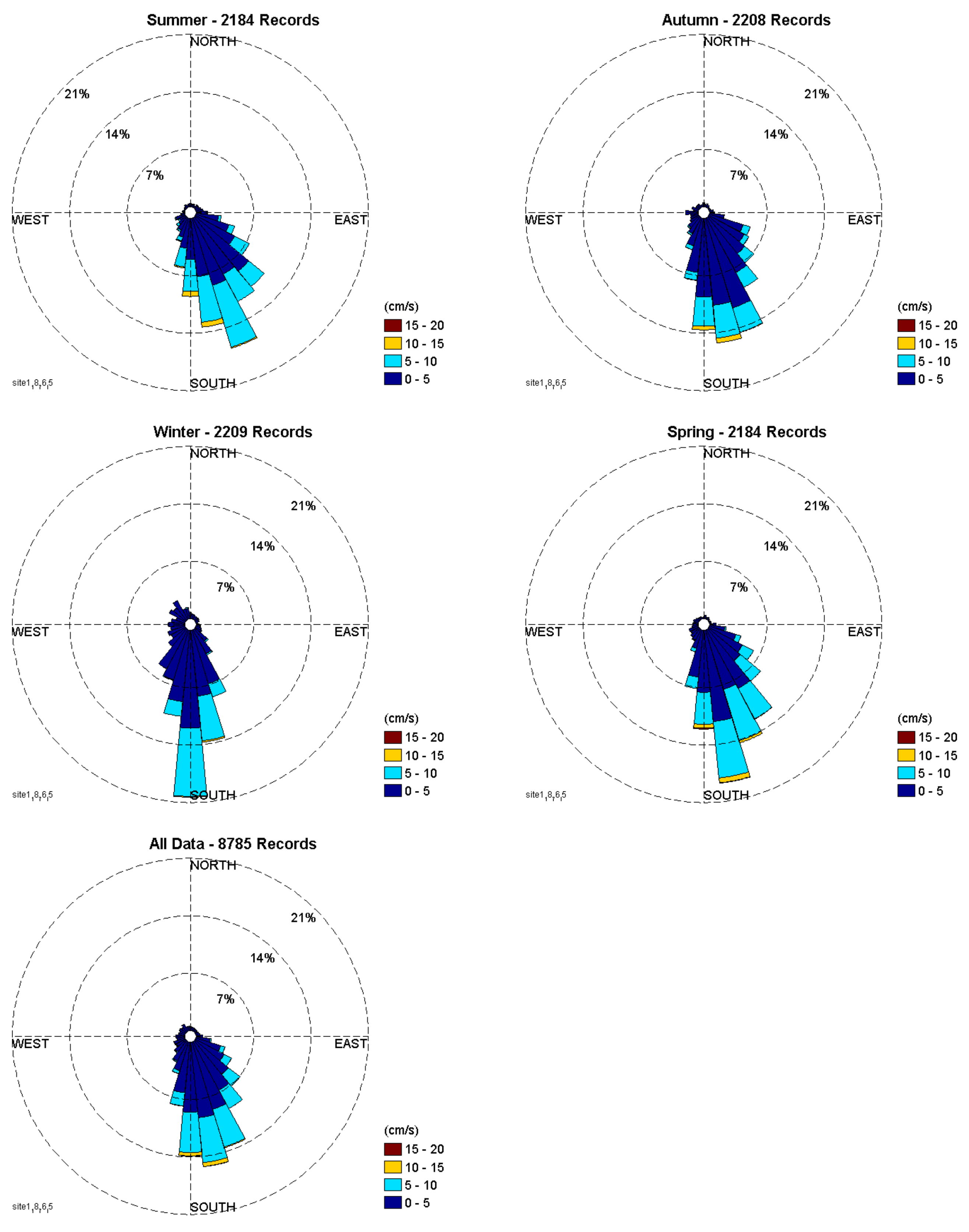
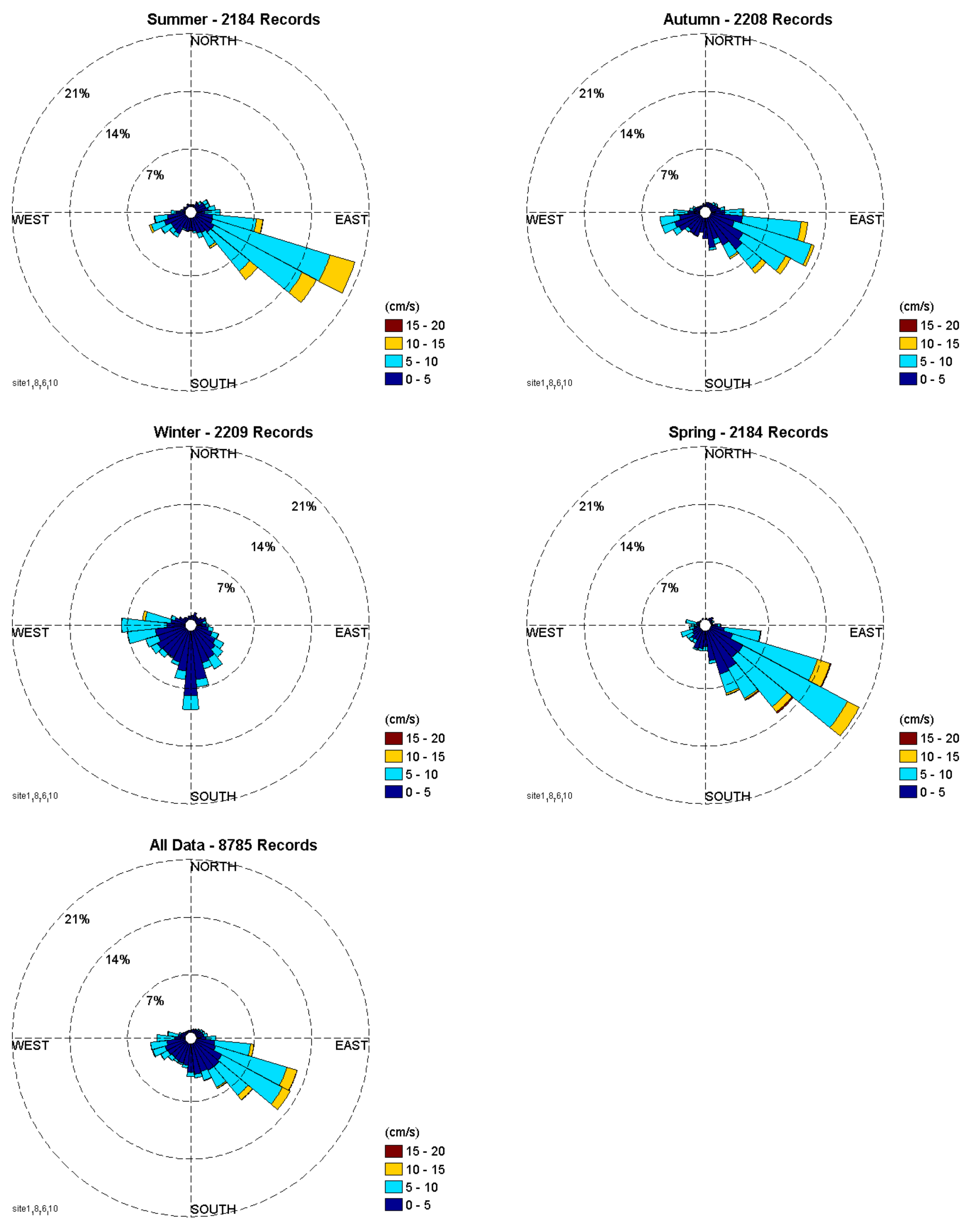


Figure D-3: Measured and modelled bottom currents at position A (see Figure B.1) from 22 October 2006 to 5 November 2006 (Van Ballegooyen et al, 2007)



Location 01 Subsurface current
Current Speed vs Current Direction
1999-07-01 to 2000-07-01

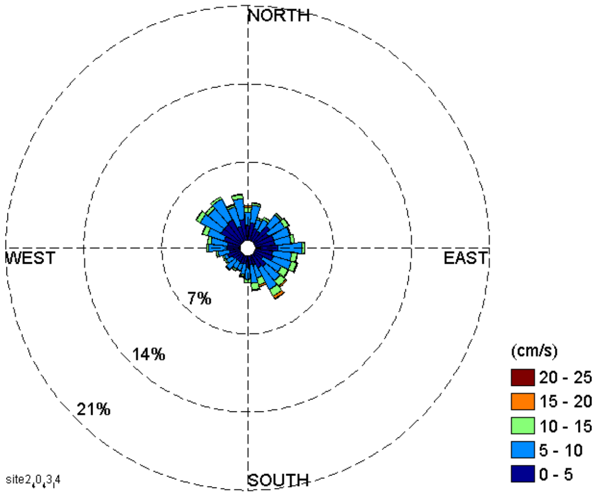
Figure D-4

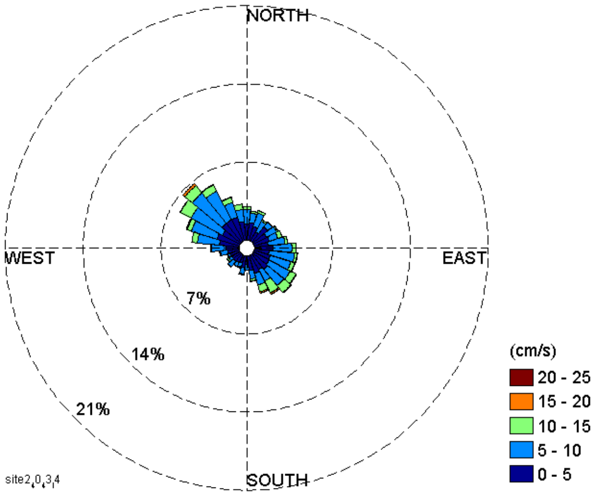


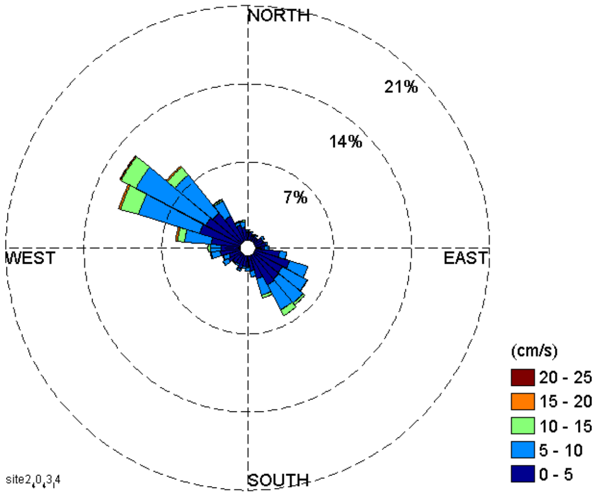
CSIR

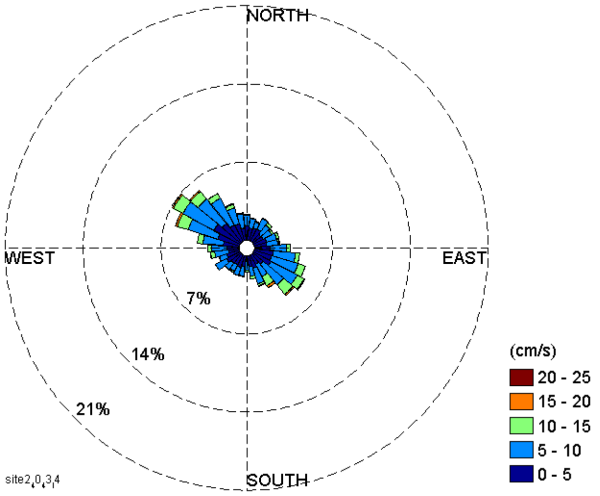
Location 01 Bottom current
Current Speed vs Current Direction
1999-07-01 to 2000-07-01

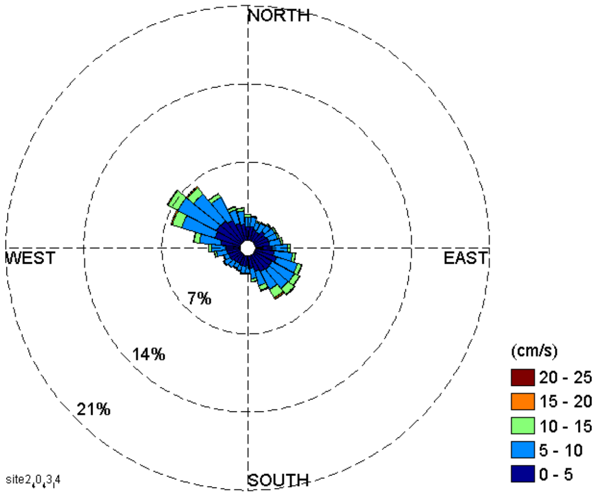
Figure D-5


Summer - 2184 Records


Autumn - 2208 Records

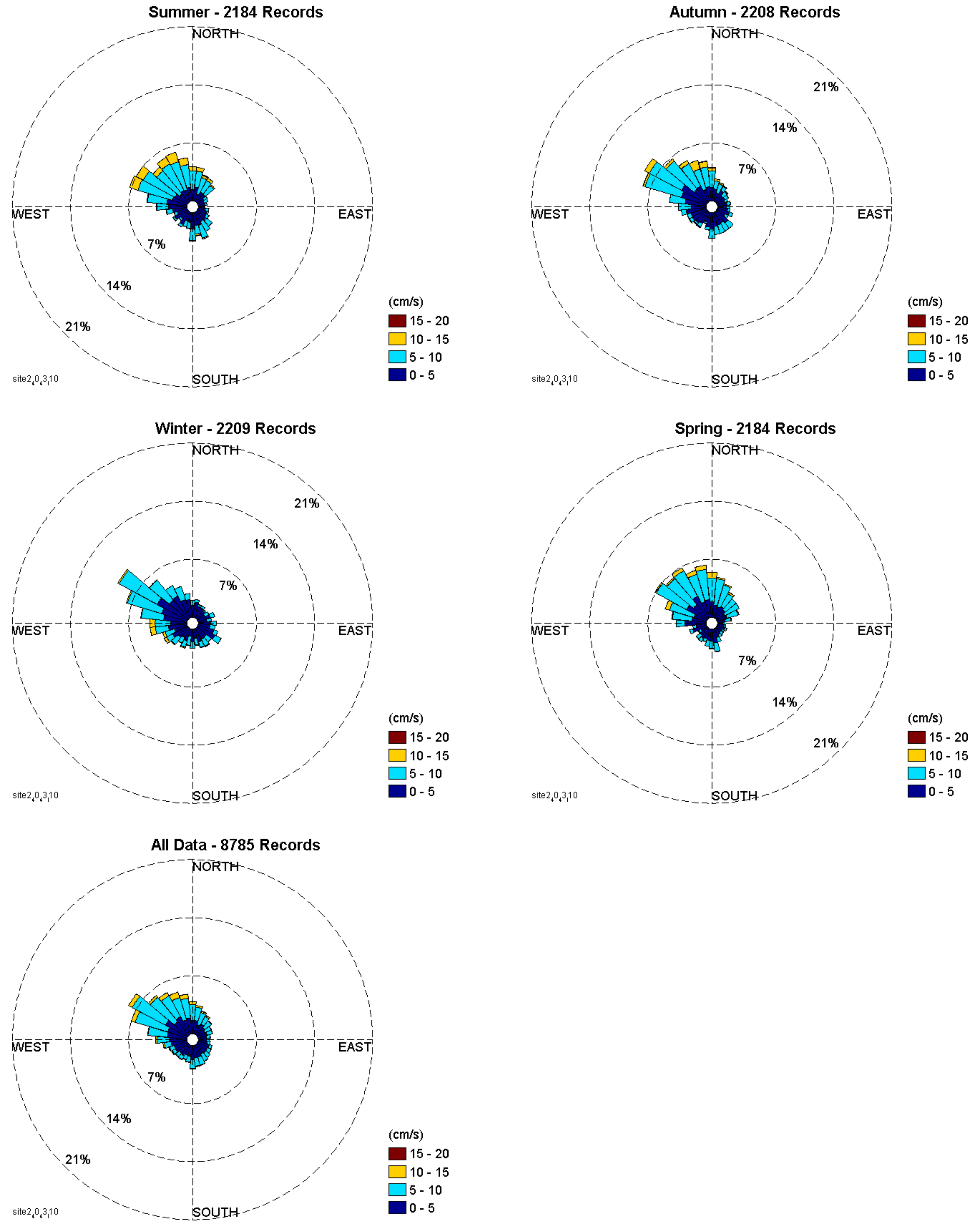

Winter - 2209 Records


Spring - 2184 Records


All Data - 8785 Records

Location 02 Subsurface current
Current Speed vs Current Direction
1999-07-01 to 2000-07-01

Figure D-6


Summer - 2184 Records

Autumn - 2208 Records

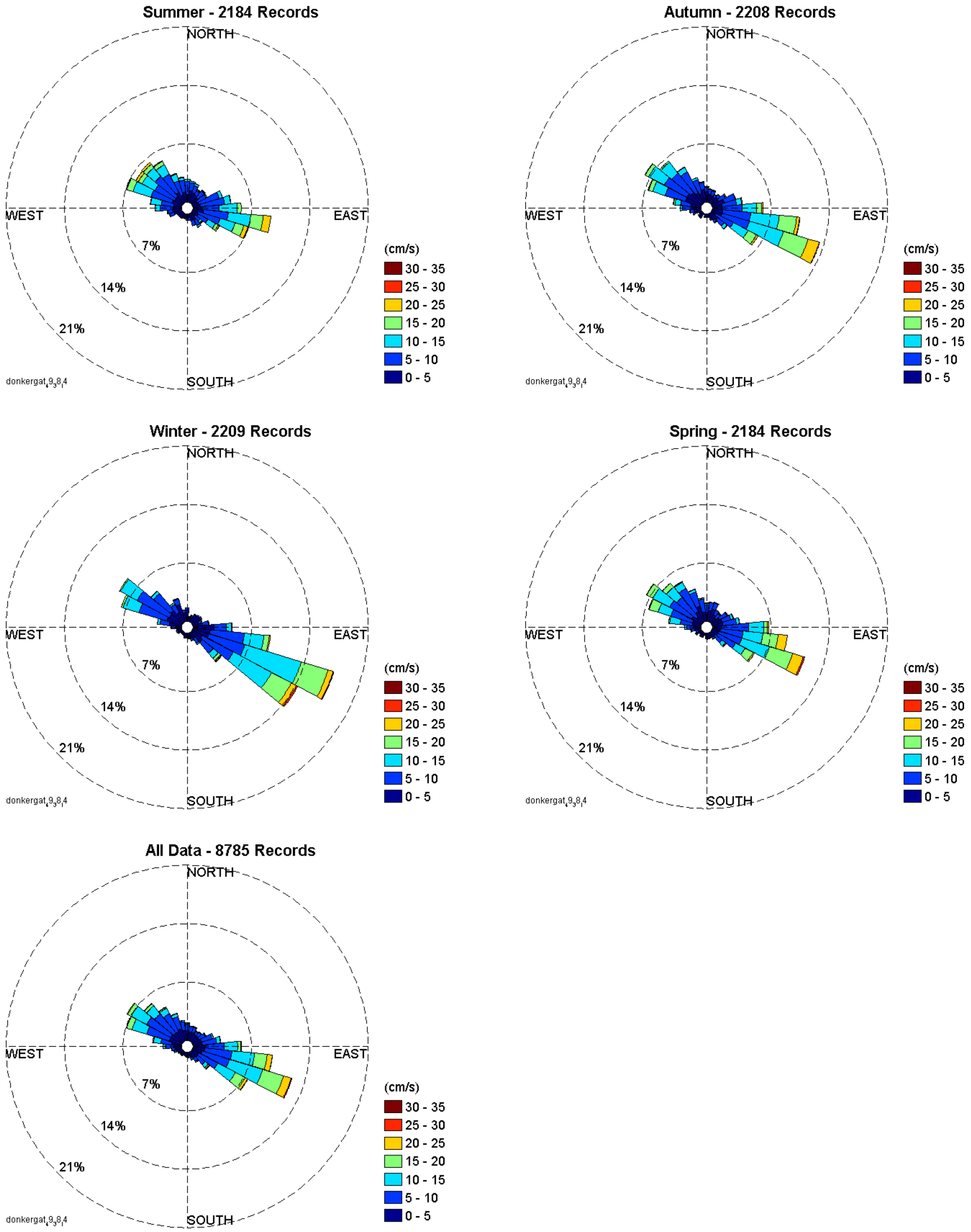
Winter - 2209 Records

Spring - 2184 Records

All Data - 8785 Records

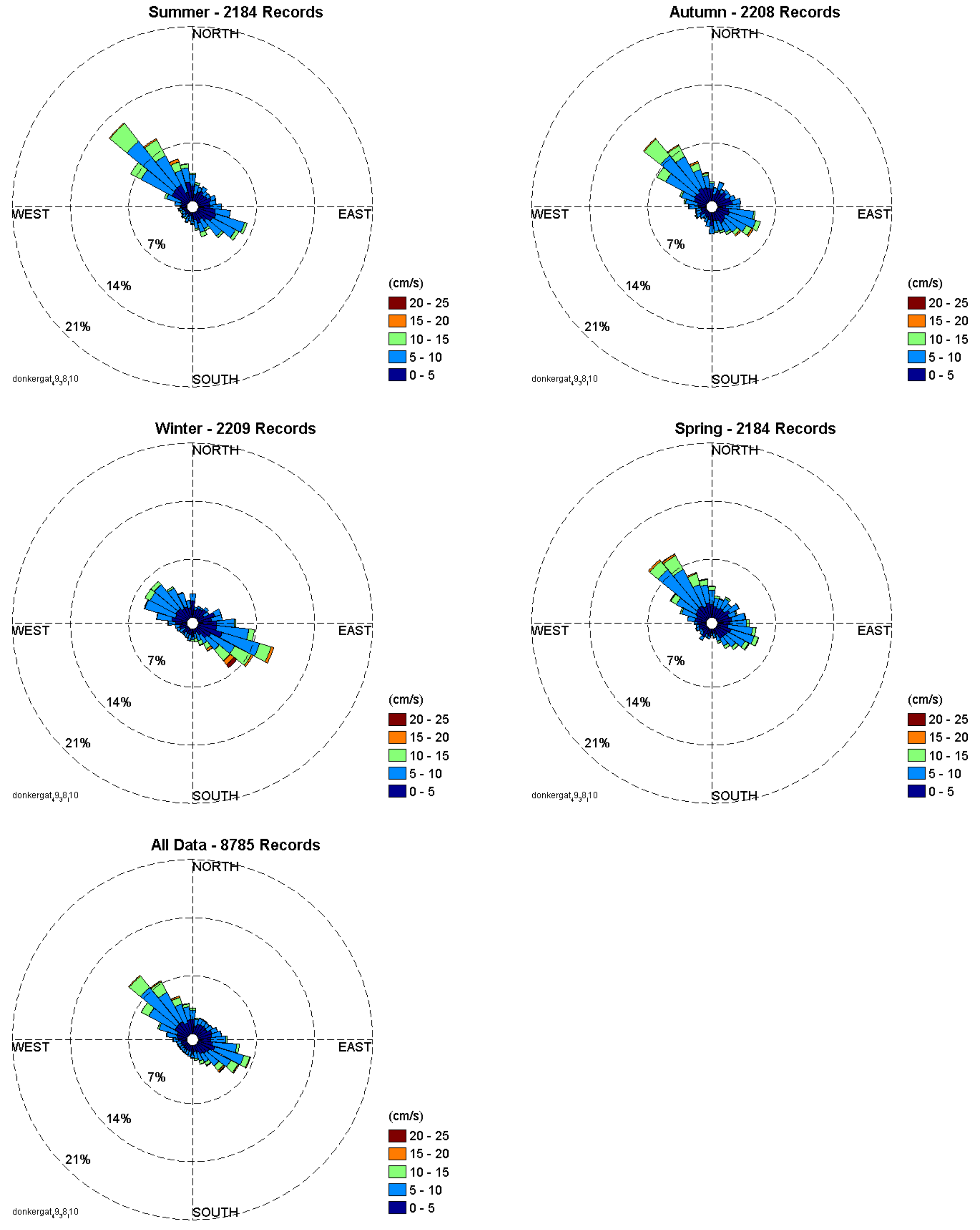
Location 02 Bottom Currents
Current Speed vs Current Direction
1999-07-01 to 2000-07-01

Figure D-7



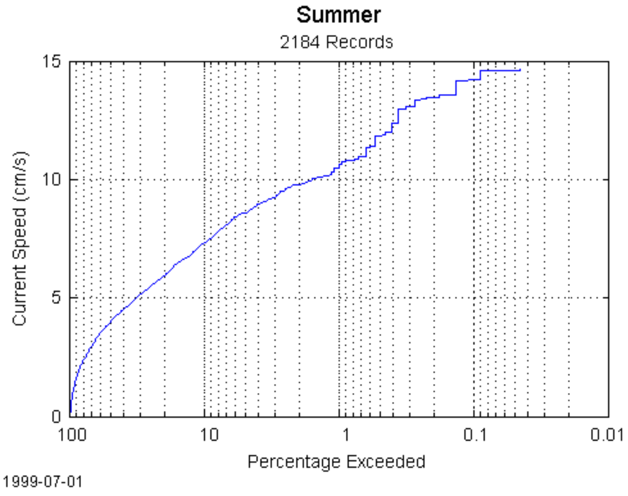
Location 03 Sub surface Current
Current Speed vs Current Direction
1999-07-01 to 2000-07-01

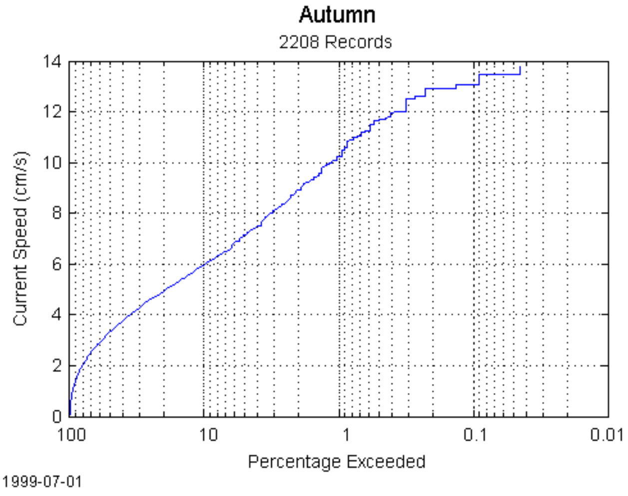
Figure D-8

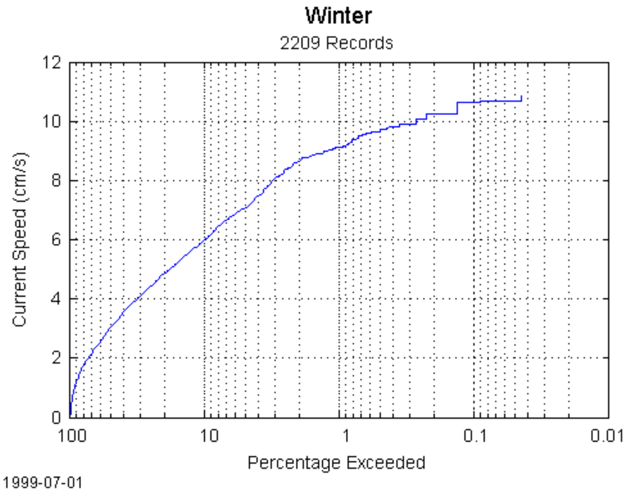


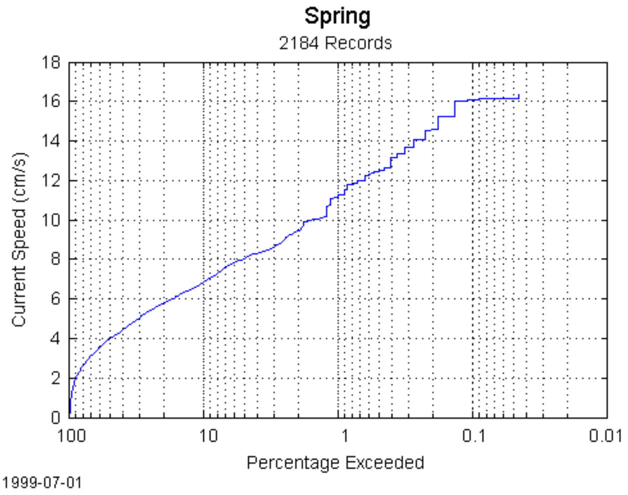
Location 03 Bottom Current
Current Speed vs Current Direction
1999-07-01 to 2000-07-01

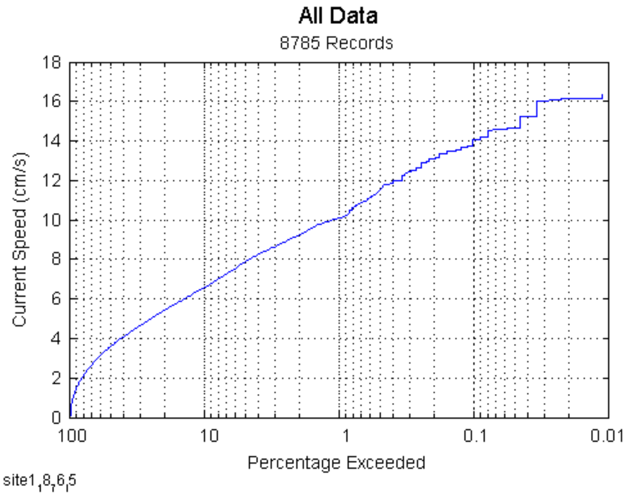
Figure D-9









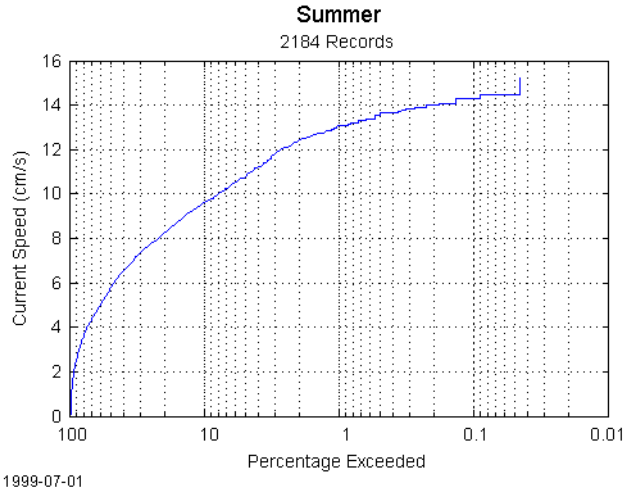


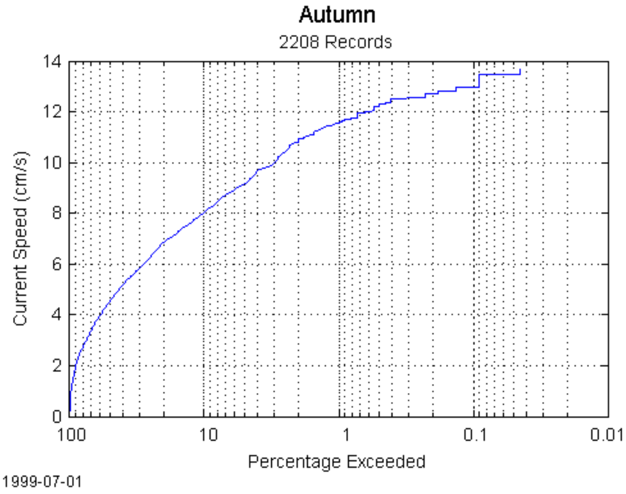
Current Speed Exceeded (cm/s)					
	1.0%	5%	10%	25%	50%
All Data	10.09	7.88	6.57	5.00	3.58
Summer	10.62	8.60	7.32	5.52	4.00
Autumn	10.22	7.13	5.95	4.60	3.34
Winter	9.12	7.06	6.01	4.43	3.02
Spring	11.26	8.01	6.83	5.41	3.99

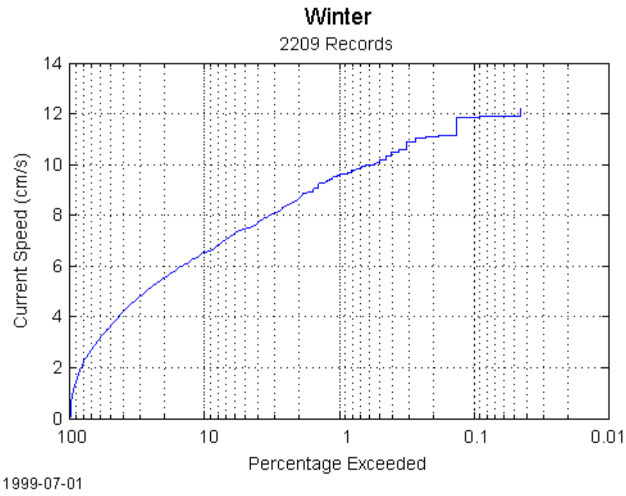
CSIR

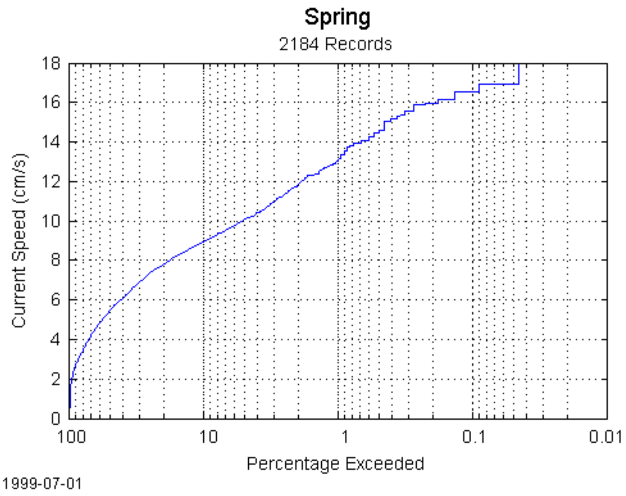
Location 01 Subsurface Currenrs
Current Speed Exceedance
1999-07-01 to 2000-07-01

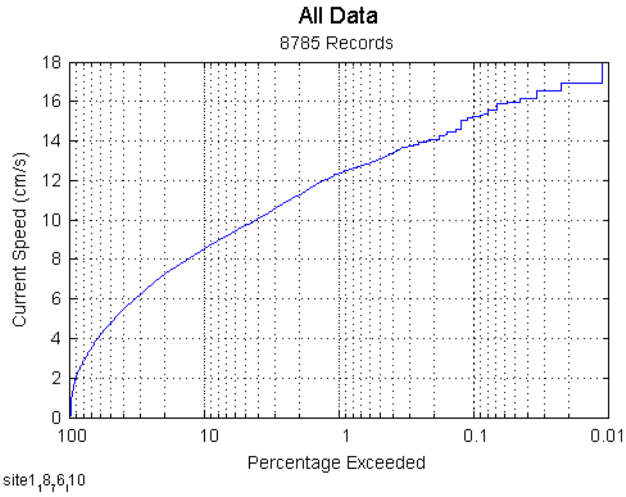
Figure D-10







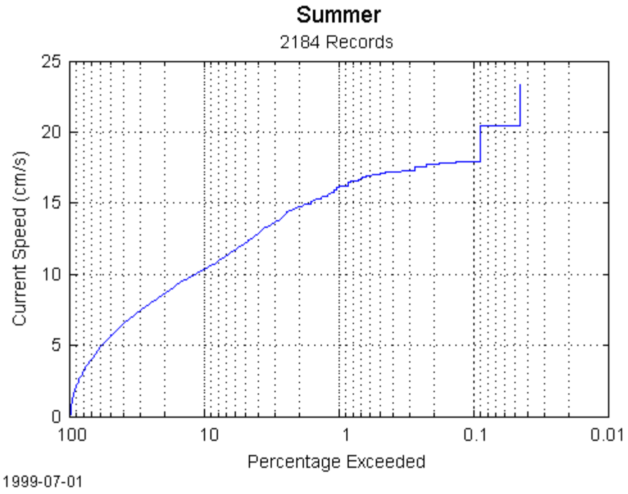


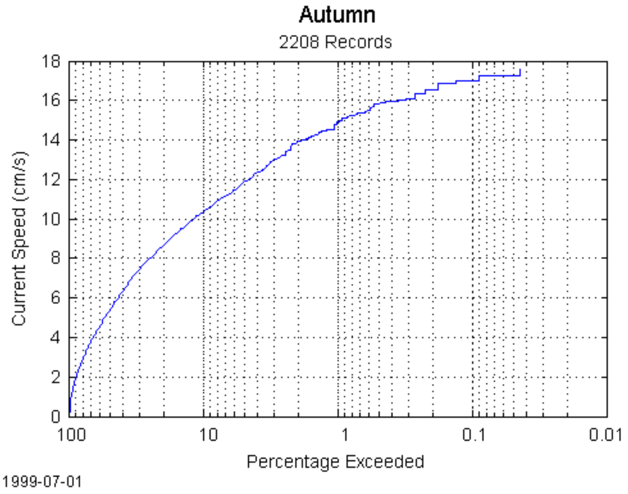


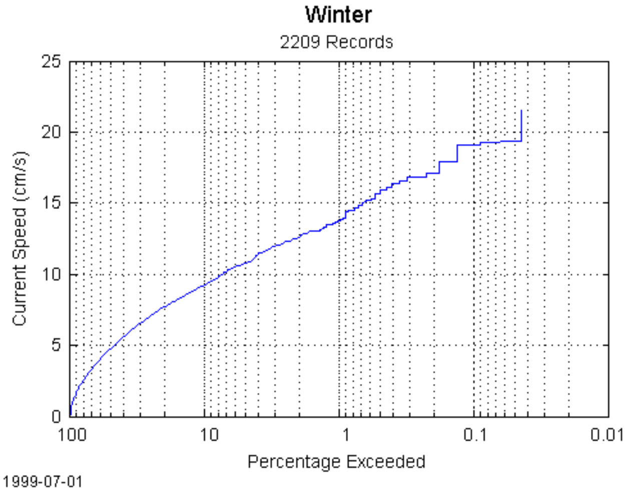
Current Speed Exceeded (cm/s)					
	1.0%	5%	10%	25%	50%
All Data	12.35	9.73	8.55	6.72	4.78
Summer	13.06	10.76	9.62	7.78	5.78
Autumn	11.56	9.13	8.01	6.28	4.54
Winter	9.57	7.48	6.53	5.15	3.68
Spring	13.12	10.06	8.95	7.37	5.44

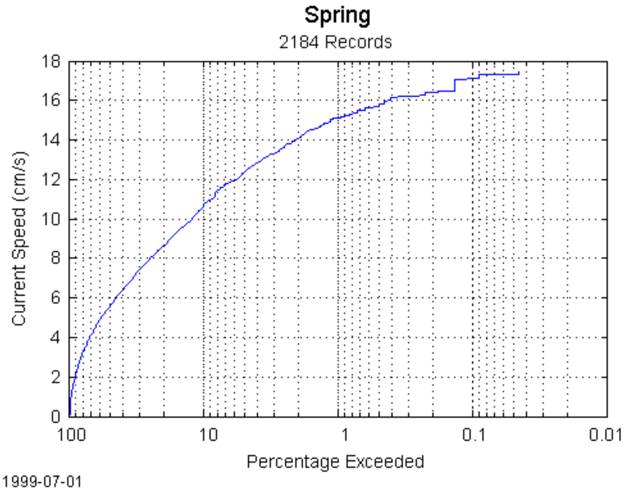
Location 01 Bottom Currents
Current Speed Exceedance
1999-07-01 to 2000-07-01

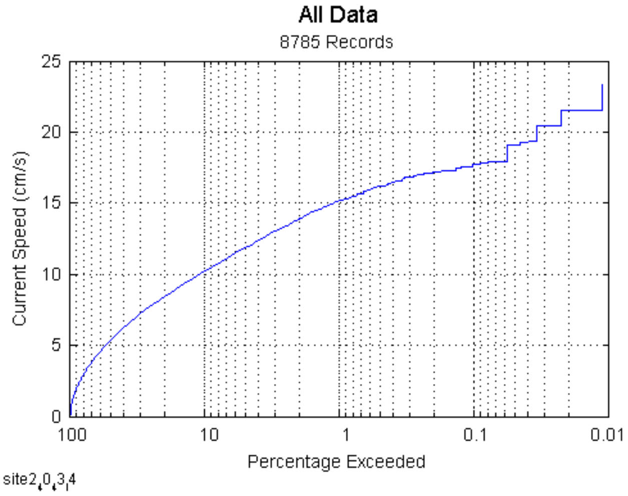
Figure D-11









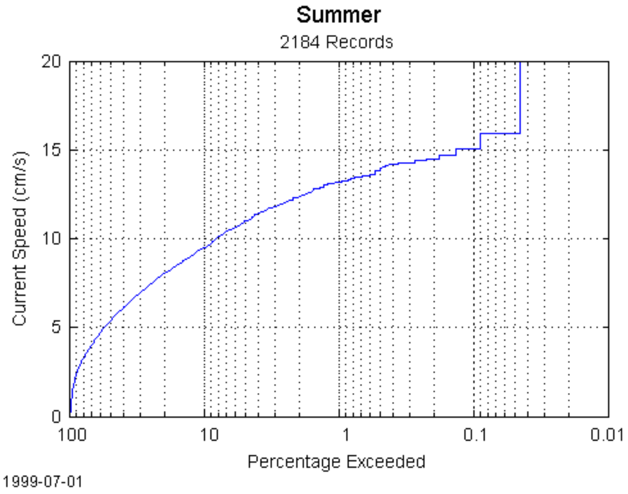


Current Speed Exceeded (cm/s)					
	1.0%	5%	10%	25%	50%
All Data	15.17	11.90	10.20	7.78	5.33
Summer	16.18	12.19	10.32	8.01	5.63
Autumn	14.90	11.90	10.36	8.01	5.40
Winter	13.72	10.77	9.25	7.10	4.75
Spring	15.13	12.38	10.76	8.02	5.57

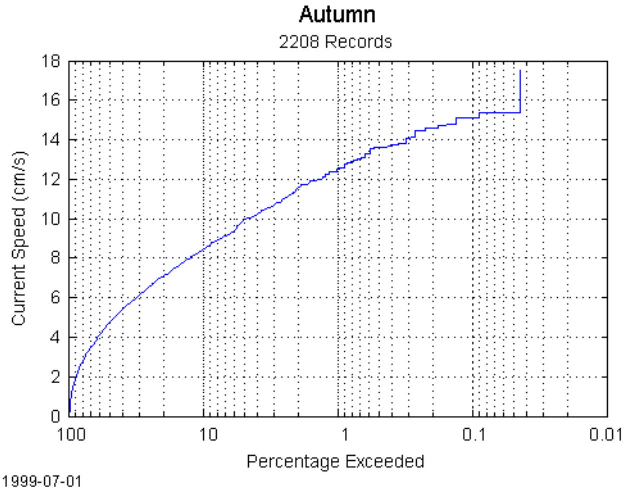
CSIR

Location 02 Subsurface Currents
Current Speed Exceedance
1999-07-01 to 2000-07-01

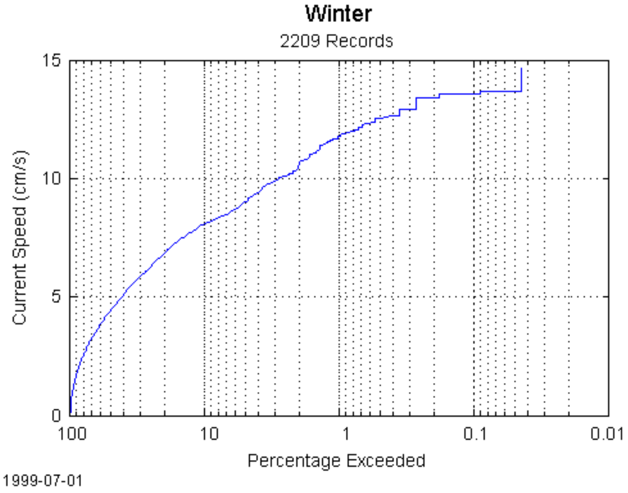
Figure D-12


Summer
2184 Records

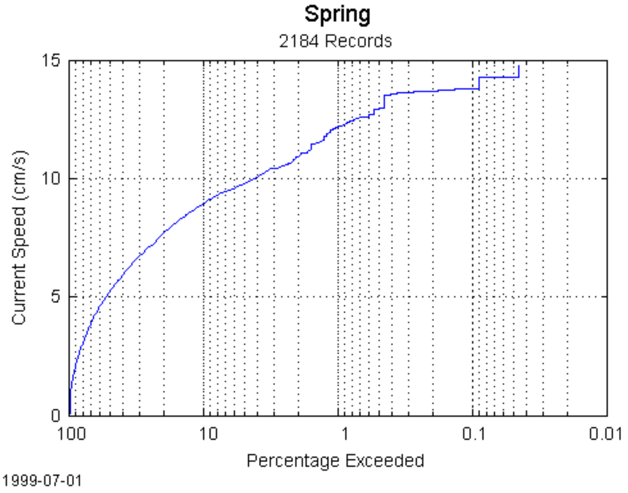
1999-07-01


Autumn
2208 Records

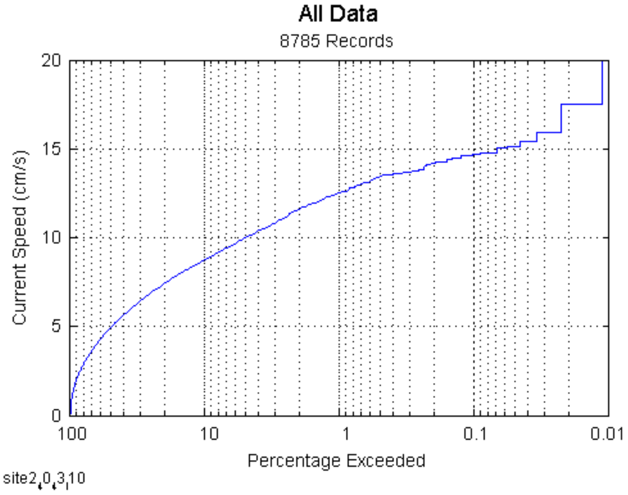
1999-07-01


Winter
2209 Records

1999-07-01


Spring
2184 Records

1999-07-01

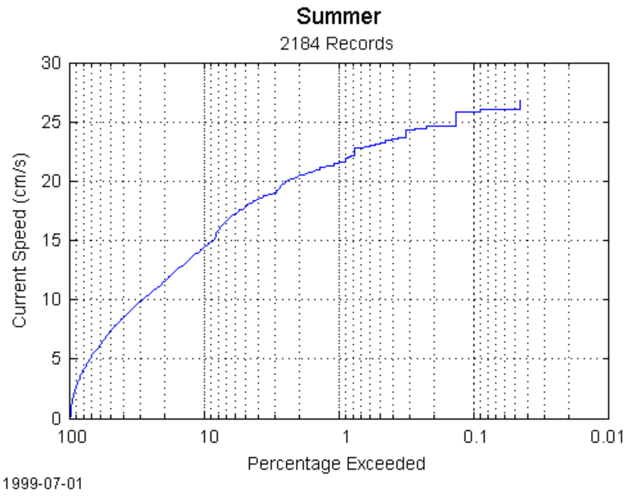

All Data
8785 Records

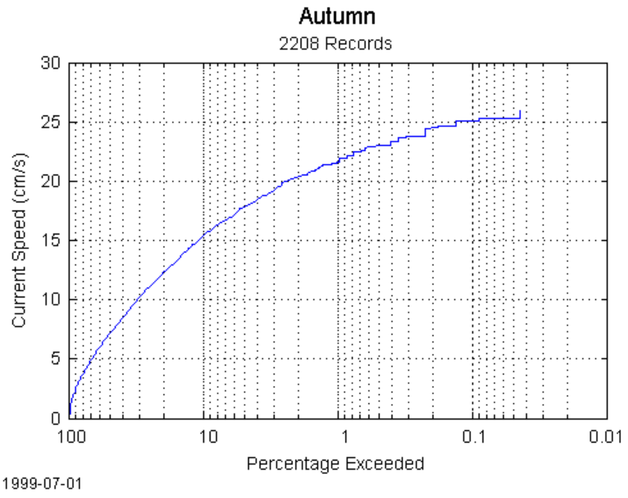
site2,0,3,10

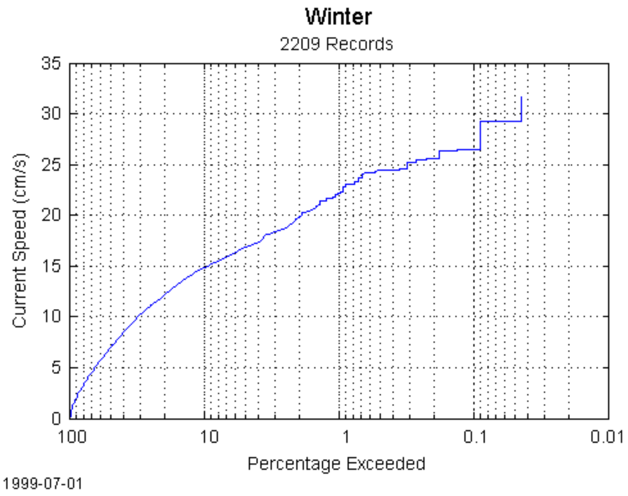
Current Speed Exceeded (cm/s)					
	1.0%	5%	10%	25%	50%
All Data	12.53	9.99	8.77	6.91	4.93
Summer	13.18	10.99	9.50	7.46	5.41
Autumn	12.51	9.93	8.46	6.58	4.73
Winter	11.77	9.01	8.09	6.29	4.44
Spring	12.19	9.80	8.92	7.13	5.26

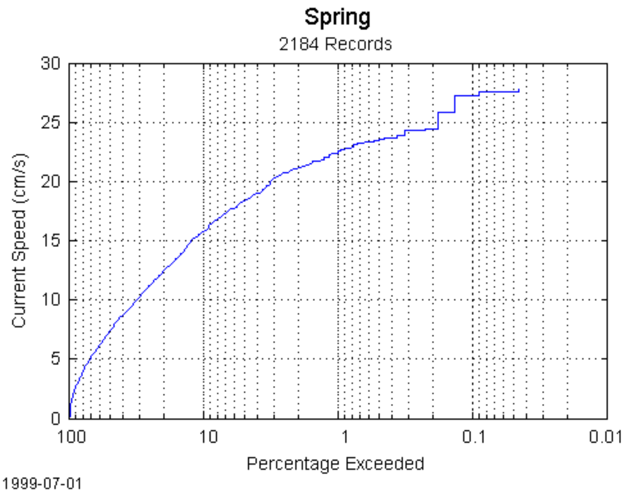
Location 02 Bottom currents
Current Speed Exceedance
1999-07-01 to 2000-07-01

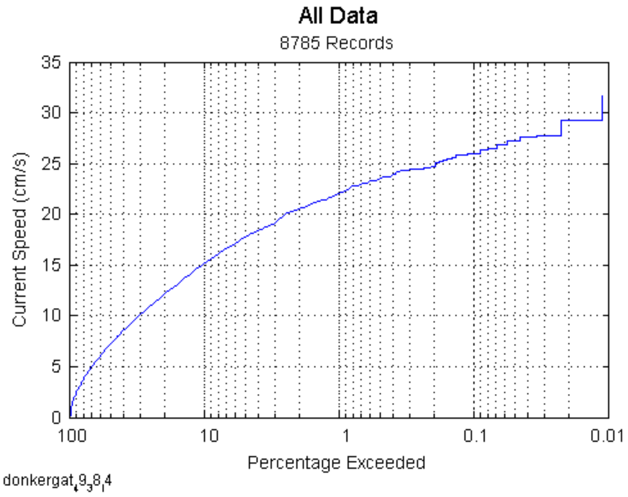
Figure D-13





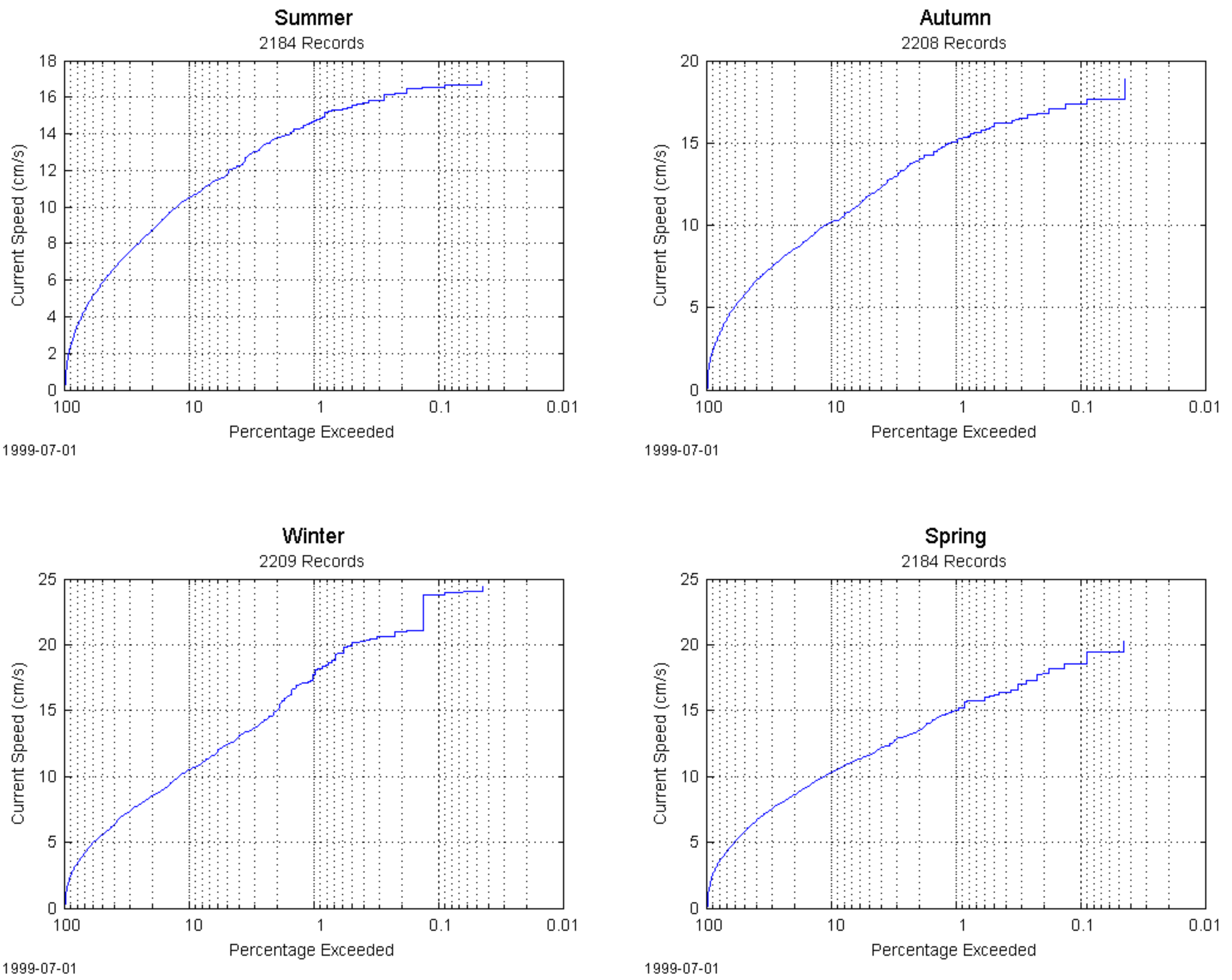


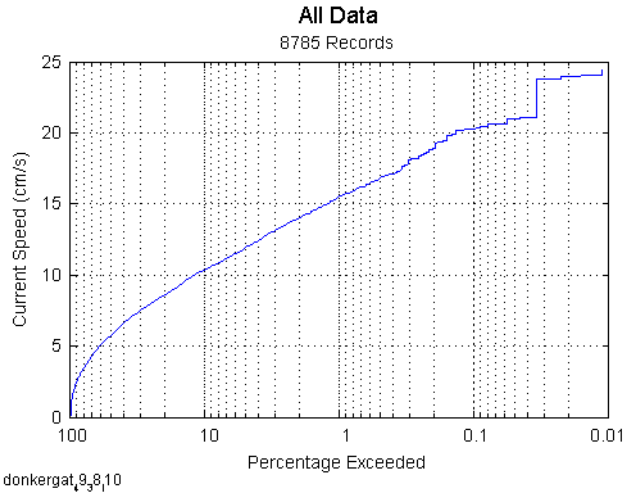




Current Speed Exceeded (cm/s)					
	1.0%	5%	10%	25%	50%
All Data	22.06	17.75	15.18	11.01	7.24
Summer	21.57	17.77	14.45	10.54	7.37
Autumn	21.56	17.78	15.45	11.13	7.16
Winter	22.20	16.84	14.83	11.14	7.01
Spring	22.57	18.38	15.78	11.26	7.40

CSIR	Location 03 Subsurface Current Current Speed Exceedance 1999-07-01 to 2000-07-01	Figure D-14





Current Speed Exceeded (cm/s)					
	1.0%	5%	10%	25%	50%
All Data	15.54	11.92	10.35	7.98	5.73
Summer	14.74	11.76	10.51	8.07	5.85
Autumn	15.06	11.82	10.21	7.98	5.77
Winter	17.76	12.45	10.54	7.86	5.56
Spring	15.06	11.62	10.29	8.02	5.79

Location 03 Bottom Currents
Current Speed Exceedance
1999-07-01 to 2000-07-01

Figure D-15

APPENDIX E: NUMERICAL WAVE MODELLING DATA

Overview

Waves propagating into Saldanha Bay are subjected to processes such as refraction and reflections which results in decreased wave heights and altered wave directions. The extent to which the alterations occur are further determined by the amount of sheltering from waves that a specific location experiences. Areas such as Salamander Bay are protected to some extent. Thus, the wave data collected with the CSIR's Waverider buoy in the main entrance to the bay are not representative of the wave climate in the rest of the bay.

Numerical modelling tools are available to the CSIR for derivation of wave heights and directions in the rest of the bay. This section provides an overview of a recent numerical modelling study for Saldanha Bay.

Model approach

The wave generation and refraction model SWAN (Simulating Waves Nearshore) was applied (Booij, 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 [e.g. (CSIR, 2006))]. 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. 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).

For the purposes of the 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 E-1.

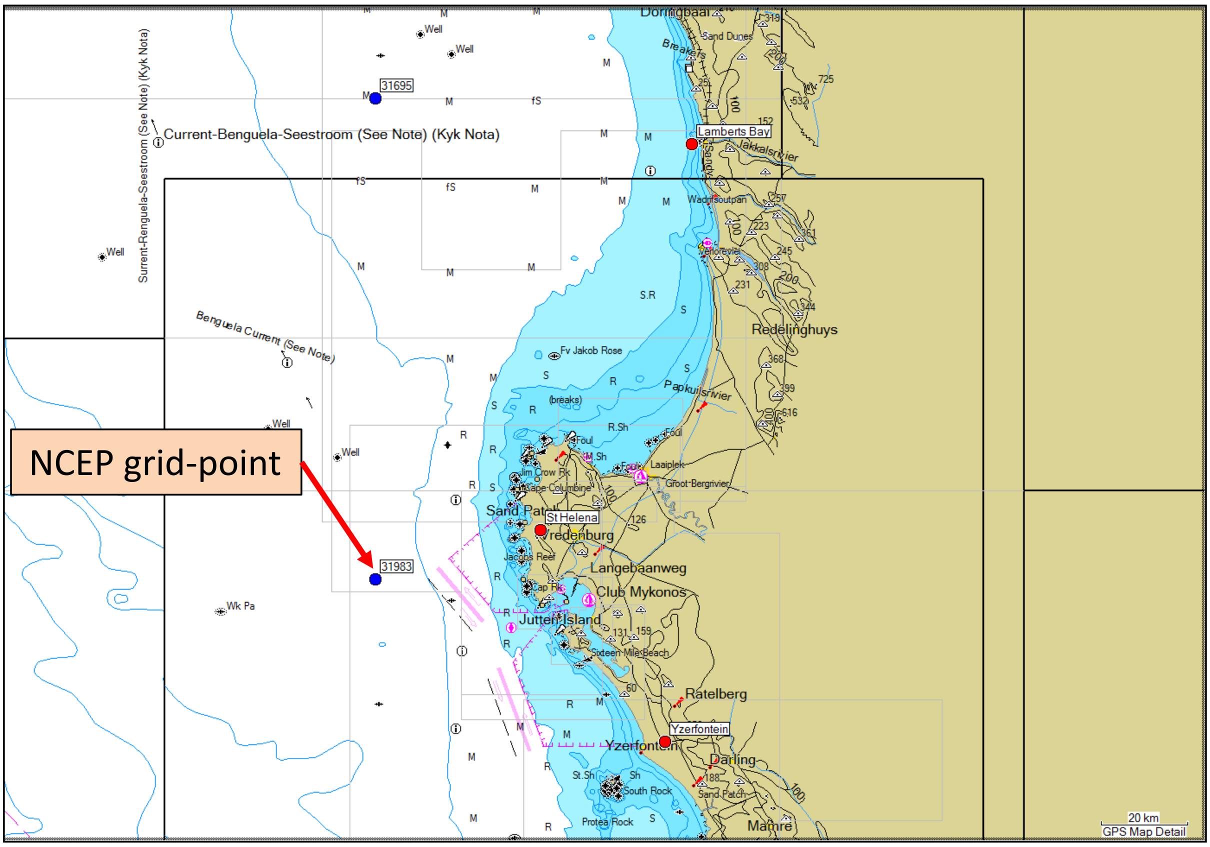


Figure E-1: Location of NCEP grid-point used for SWAN modelling study

The model comprised three computational grids – a coarse, medium and fine grid. The computational grids of the coarse and fine grids are shown in Figures E-2 and E-3. Details of the grid setup are given in Table E-1.

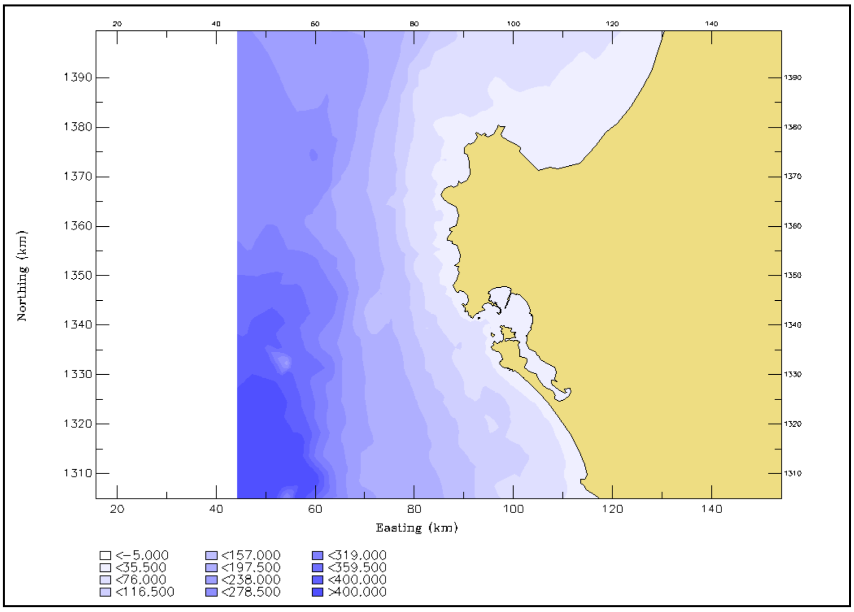


Figure E-2: Coarse Computational grid

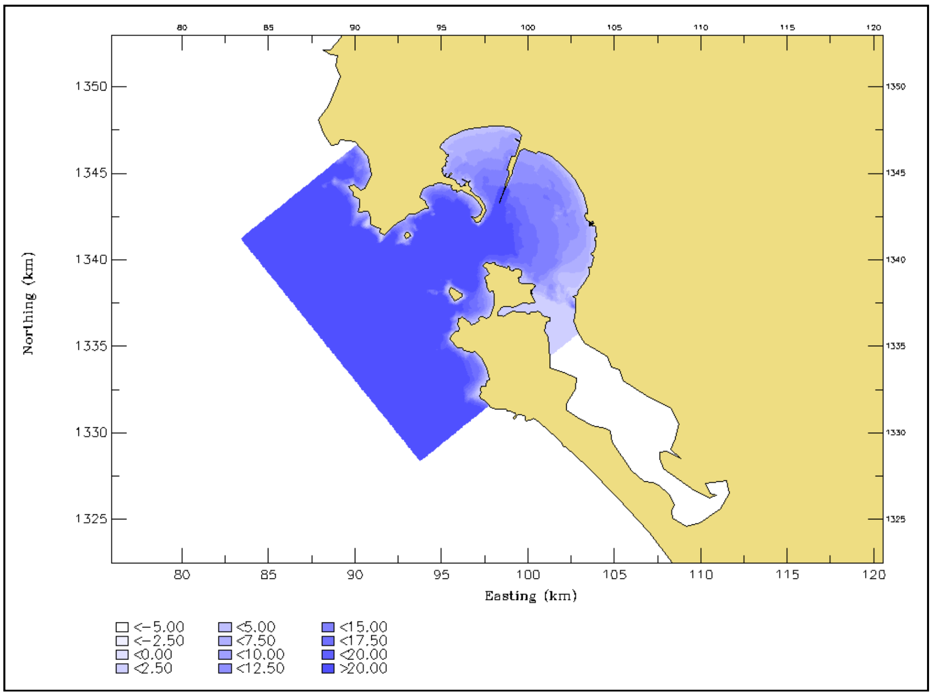


Figure E-3: Fine Computational Grid

Table E-1: Numerical Parameters used in Delft 3D-WAVE (SWAN)

Grid	Resolution	Offshore extent	Length
Coarse	1000 x 1000 m	48 km	120 km
Medium	500 x 500 m	15 km	100 km
Fine	100 x 100 m	17a km	16 km

The settings of the main model parameters are summarised in Table E-2. The model output, shows the wave height contours and the wave vectors for a 2 m significant wave height and 12 s condition approaching from South-south-westerly, Westerly and North-westerly directions (Figure E-4). The output locations of the modeling are shown in Figure E-4. Note that a number of output locations were selected (Figure E-5). These cover the areas of interest as well as potential future areas for further investigations.

Table E-2: 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

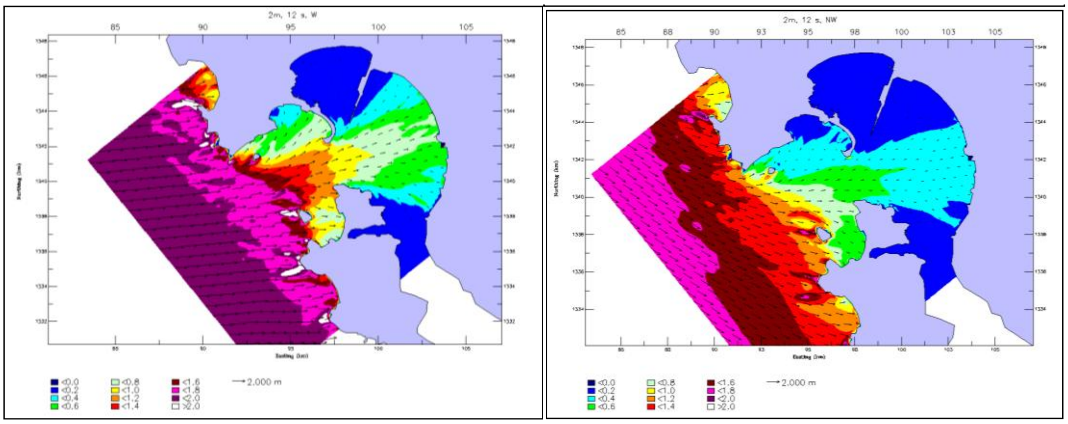


Figure E-4: waves Vector plots for W and NW

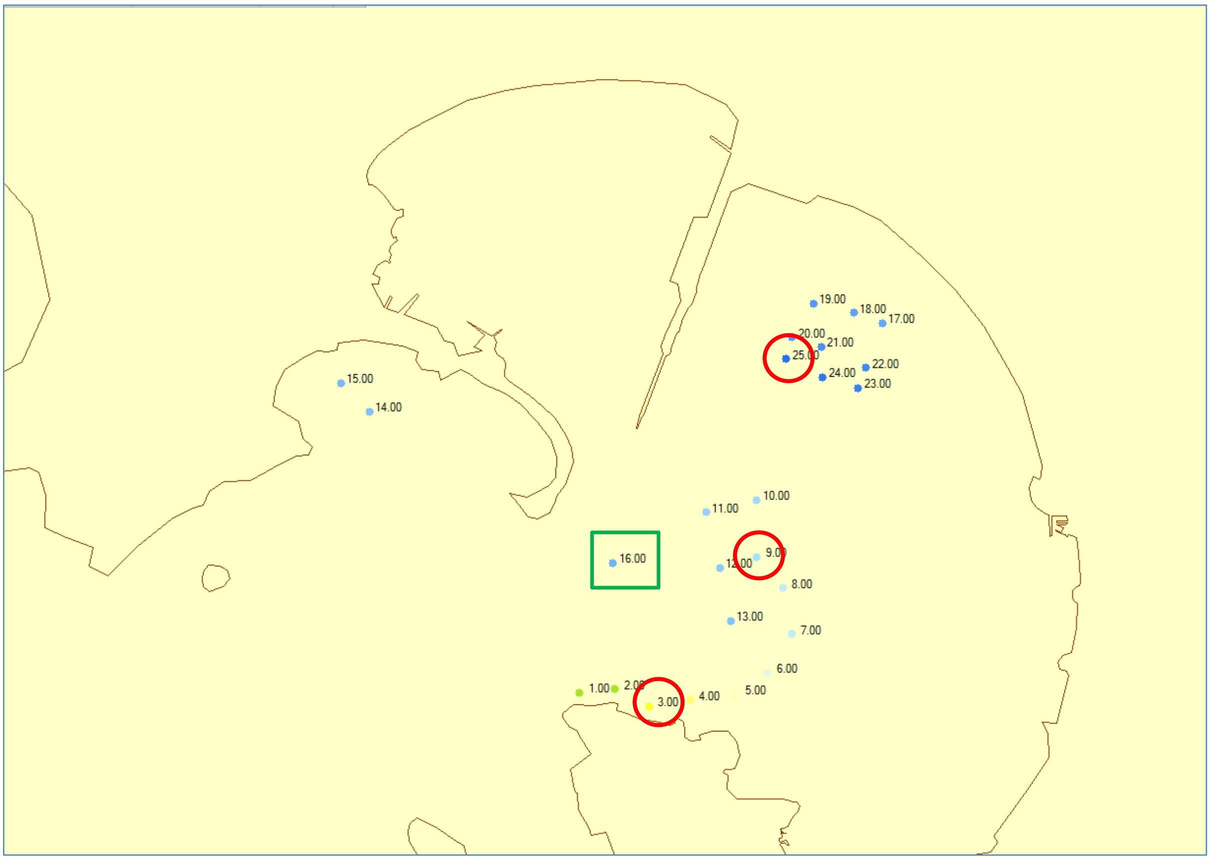


Figure E-5: Output Locations for Swan model

In order to verify the model setup, the model output was compared to corresponding data from the Saldanha wave buoy. Output location 16 (see Figure E-6 and E-7) is located at wave buoy. The two time-series plots, covering the period December 2011 to November 2013, are presented in Figure E-6. As shown the simulated data follow the measured data well.

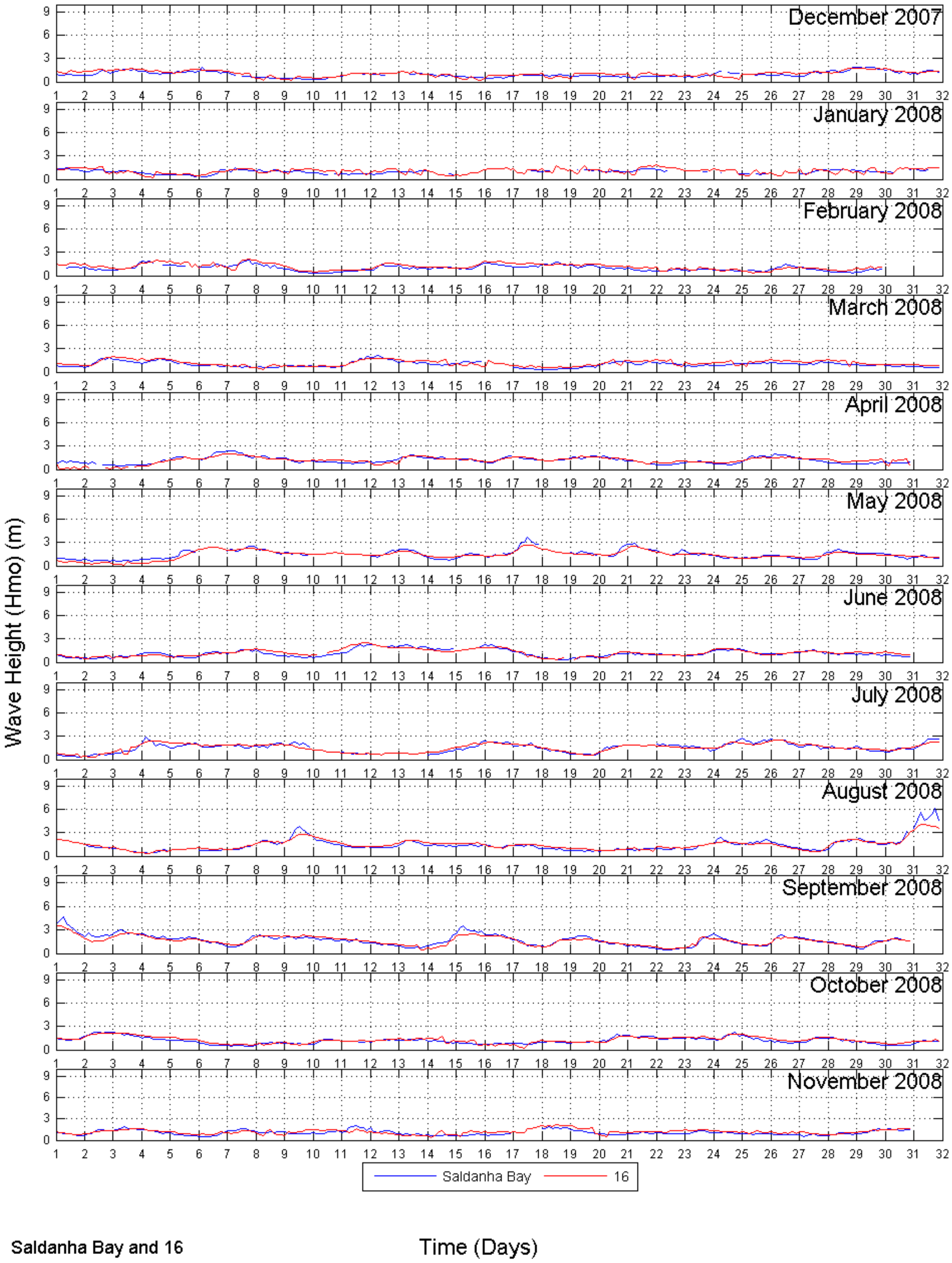


Figure E-6: Wave height of Swan Simulation and Measured Waverider Buoy

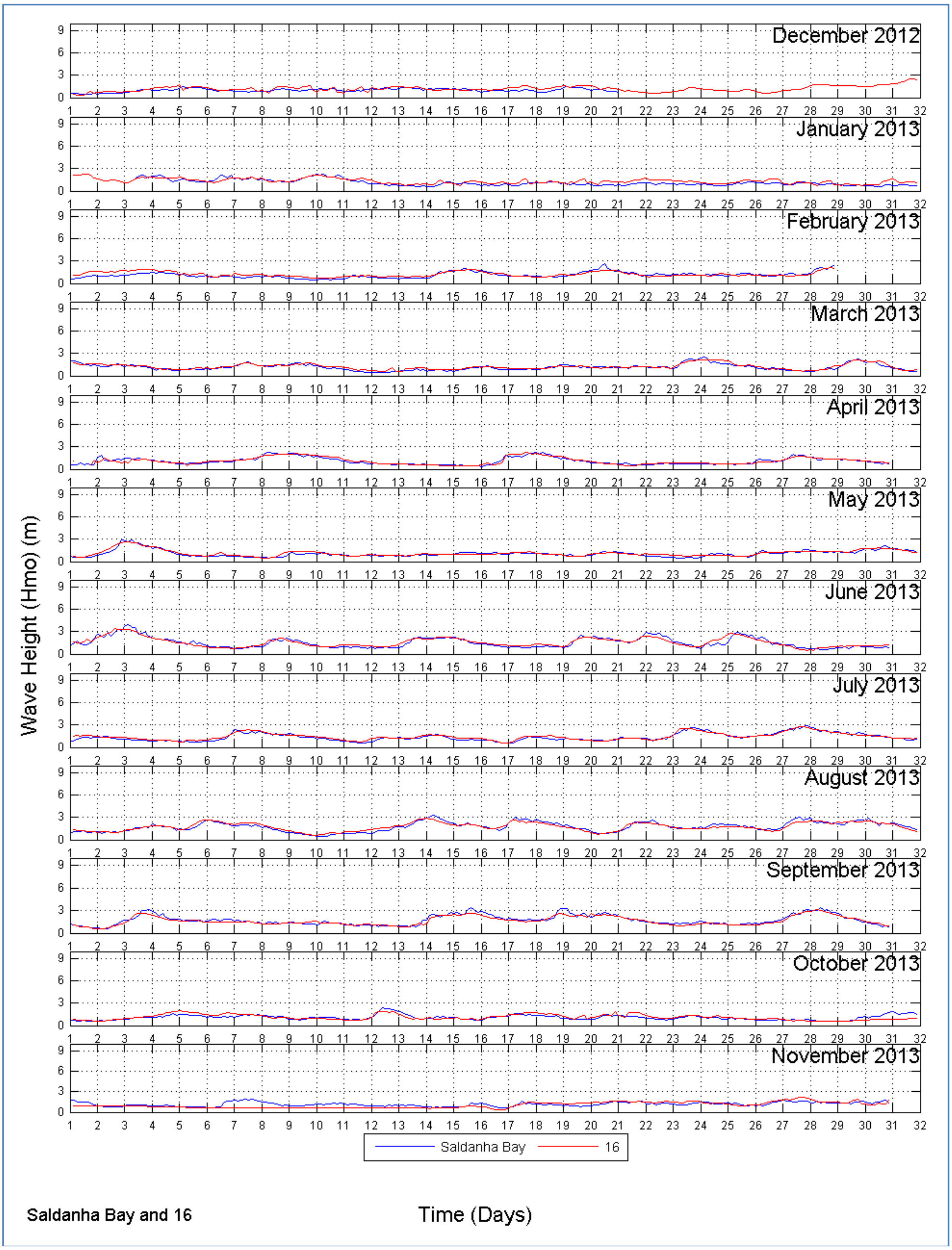


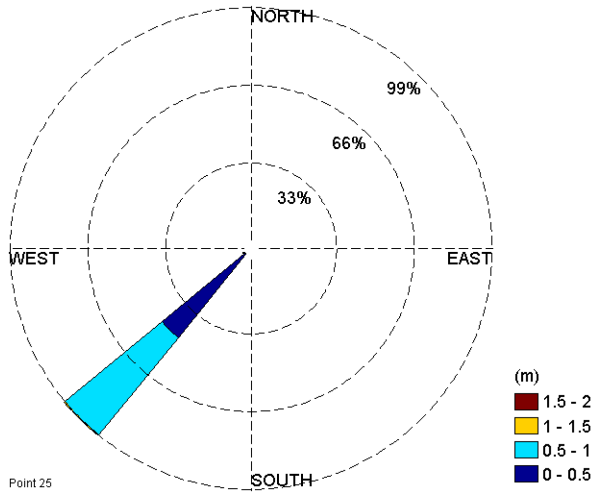
Figure E-7: Wave height of Swan Simulation and Measured Waverider Buoy

APPENDIX F: SWAN OUTPUT – WAVE STATISTICS

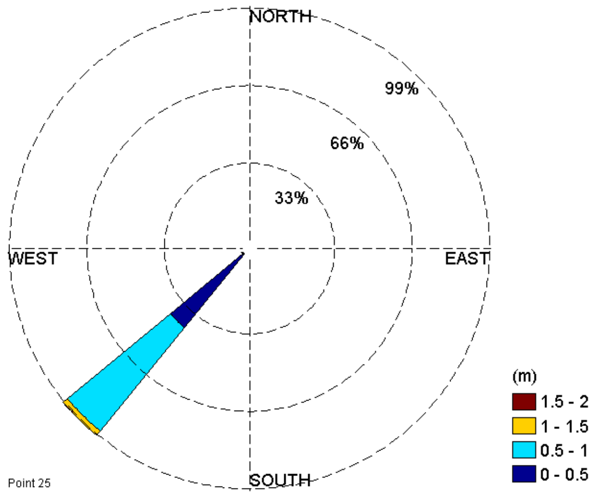
This appendix provides information on the wave climates as based on the selected output locations of the SWAN model. The following information is provided for Output locations 25 (Site 1), 9 (Site 2) and 3 (Site 3 – Salamander Bay):

(i) Joint occurrence distribution of wave height and direction (wave roses): location point 25 (Site 1) – Figure F1
(ii) Joint occurrence distribution of wave height and direction (wave roses): location point 9 (Site 2) – Figure F2
(iii) Joint occurrence distribution of wave height and direction (wave roses): location point 3 (Site 3) – Figure F3
(iv) Percentage exceedance of wave height for Location 25 – Figure F4
(v) Percentage exceedance of wave height for Location 9 – Figure F5
(vi) Percentage exceedance of wave height for Location 3 – Figure F6
(vii) Percentage exceedance of wave height for Location 3 – Figure F7

Summer - 11817 Records

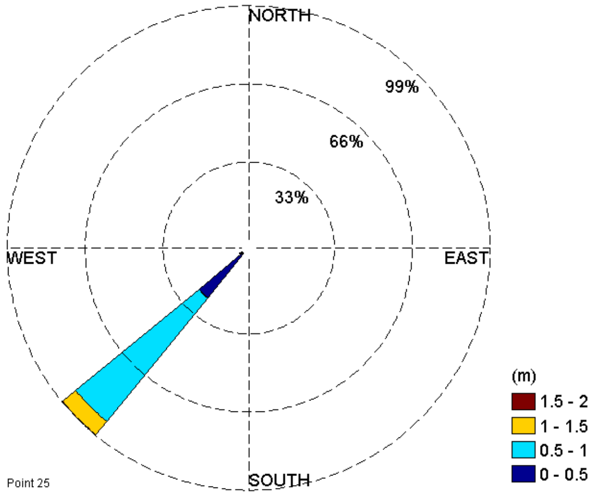


Autumn - 12528 Records

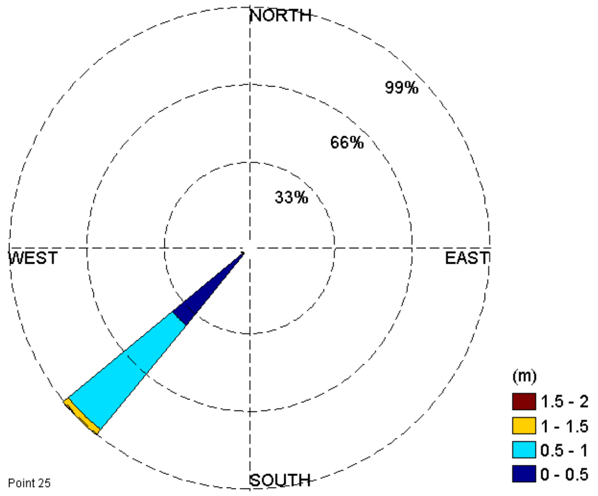


(viii)

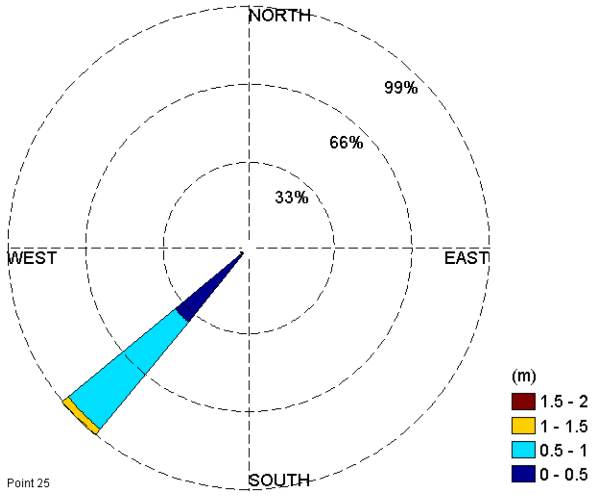
Winter - 12529 Records



Spring - 12399 Records



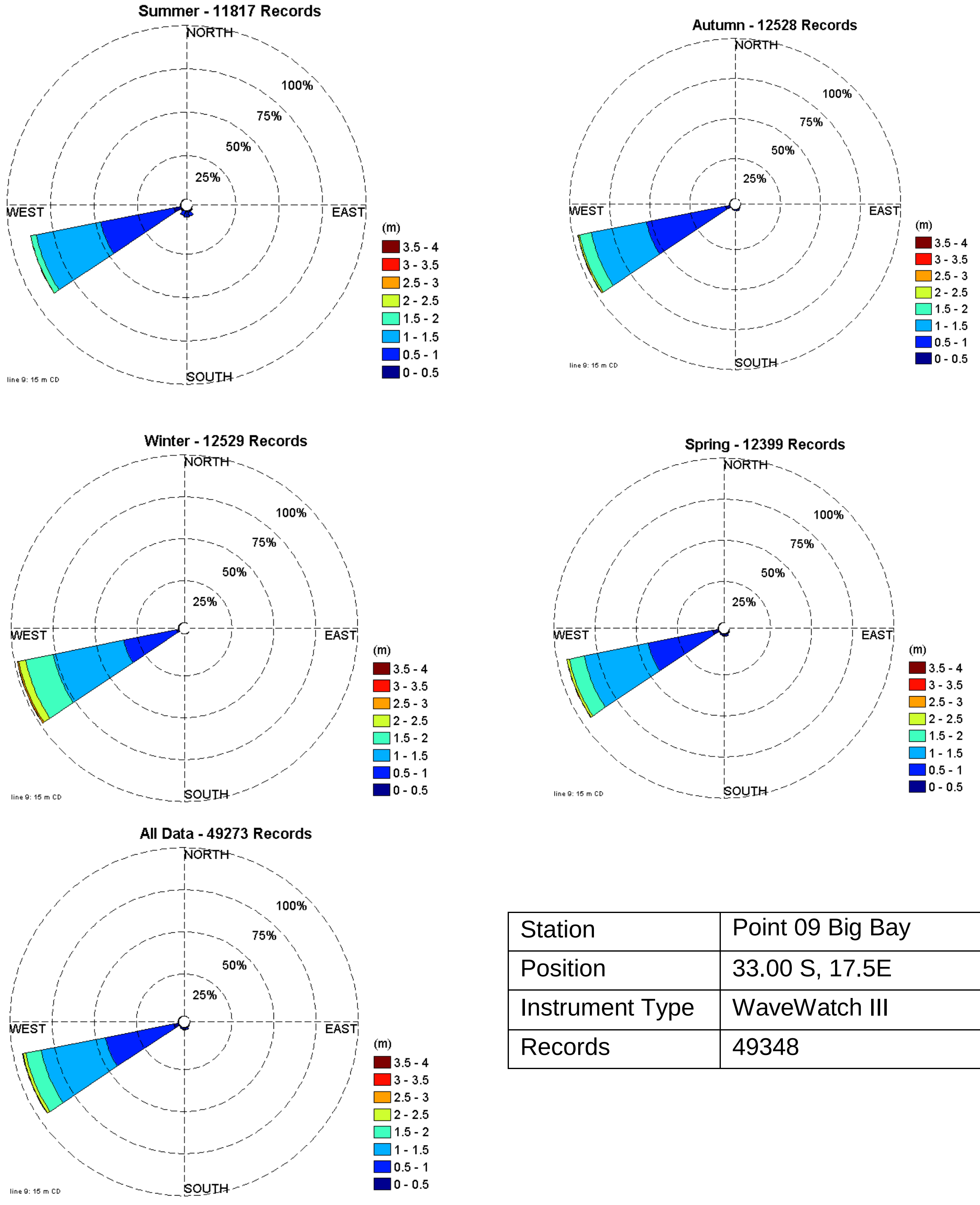
All Data - 49273 Records



Station	Point 25: 14 m CD
Position	1405390.00 S, 118826.00 E
Instrument Depth	0 m
Water Depth	51.0 m
Instrument Type	swan model data
Records	49273

Point 25: 14 m CD
Wave Height (Hmo) vs Wave Direction
Location 01

Figure F-1



Summer - 11817 Records

Autumn - 12528 Records

Winter - 12529 Records

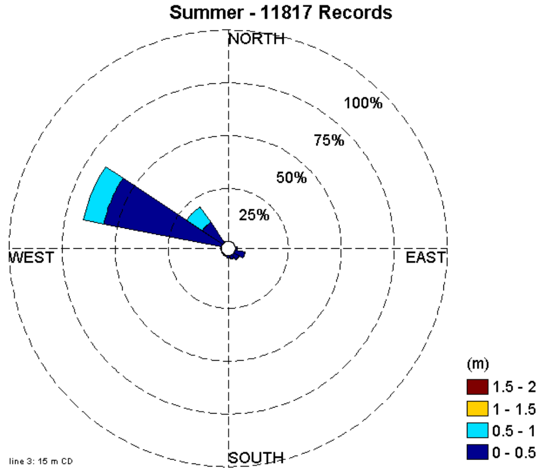
Spring - 12399 Records

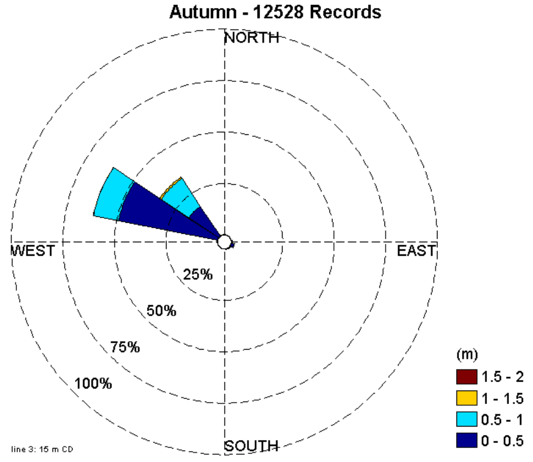
All Data - 49273 Records

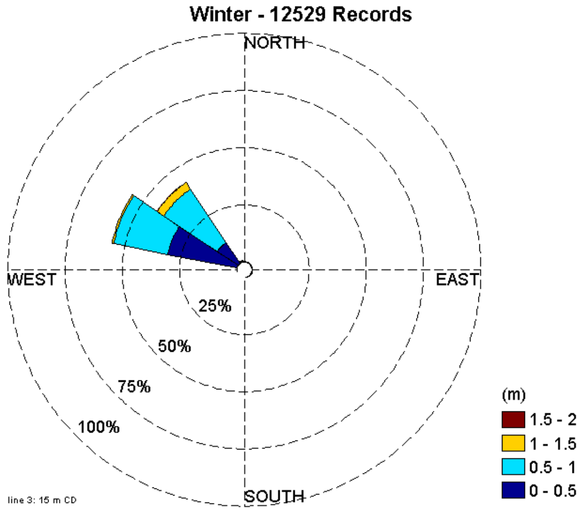
Station	Point 09 Big Bay
Position	33.00 S, 17.5E
Instrument Type	WaveWatch III
Records	49348

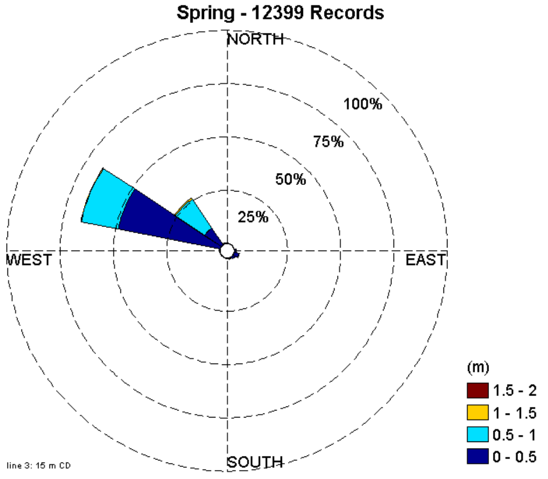
Point 09: 15 m CD
Wave Height (Hmo) vs Wave Direction
Location 02

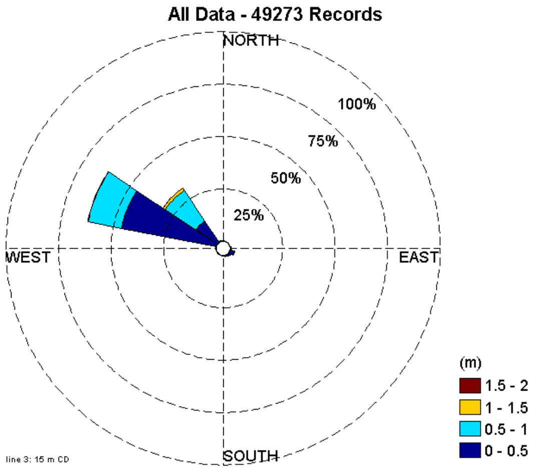
Figure F-2







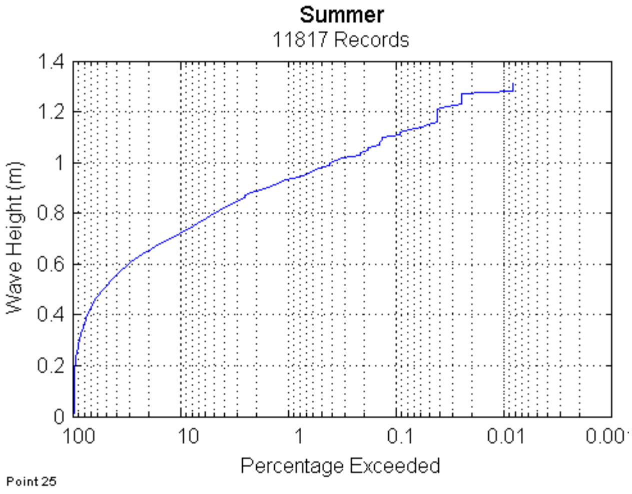


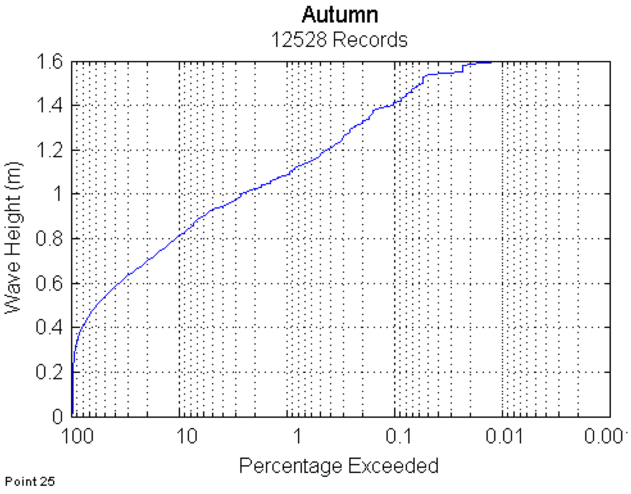


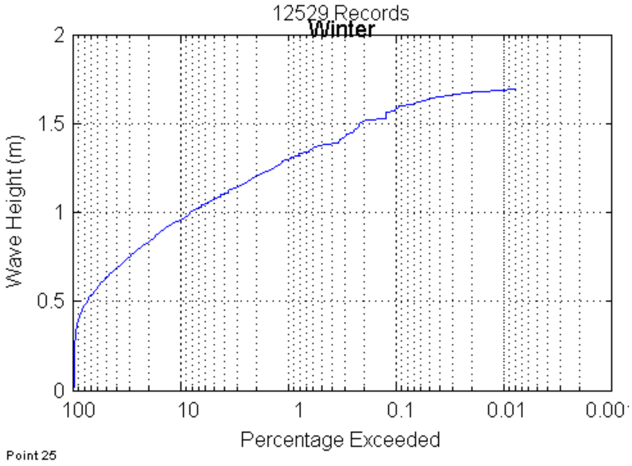
Station	Point 03 Salander Bay
Position	33.00 S, 17.5E
Instrument Type	WaveWatch III
Records	49348

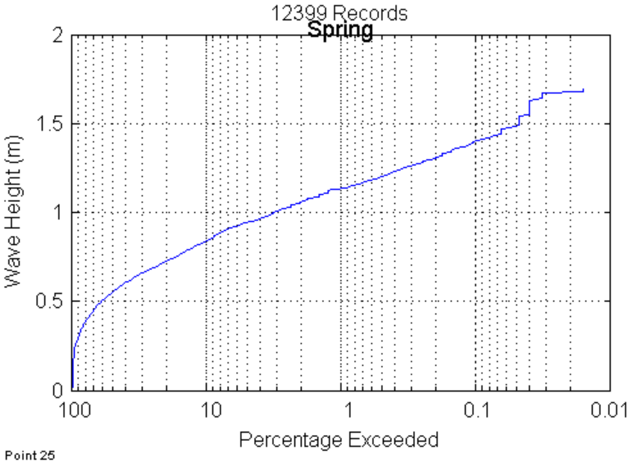
Point 03 : 16 m CD
Wind Speed vs Wave Direction
Location 03

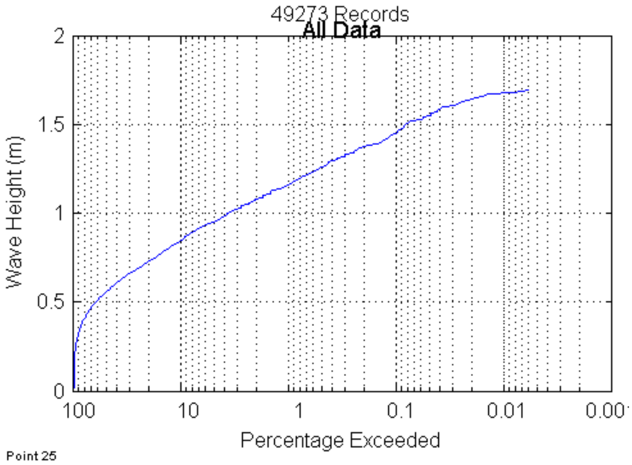
Figure F-3







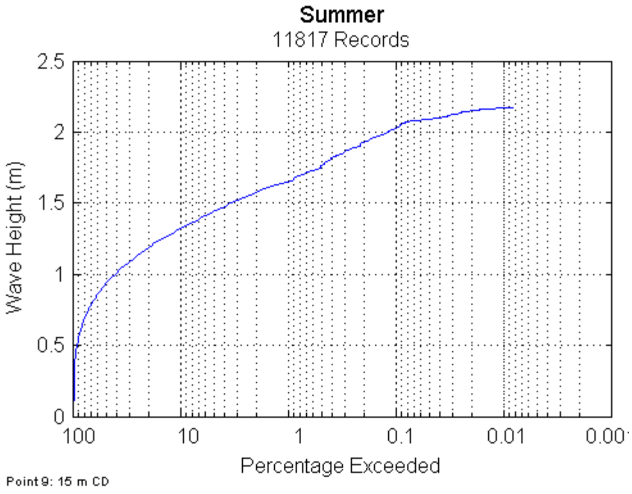


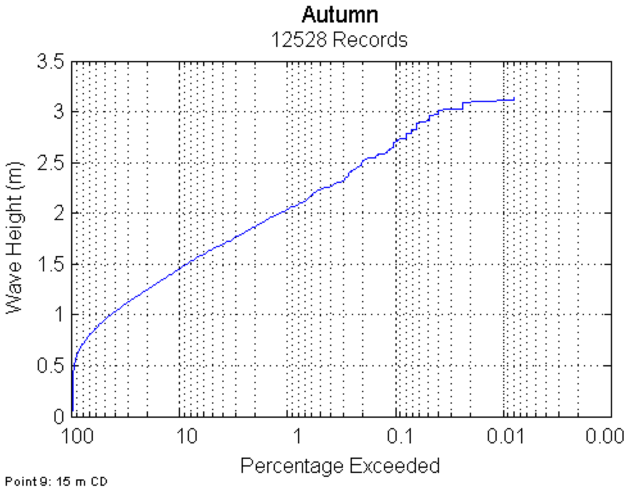


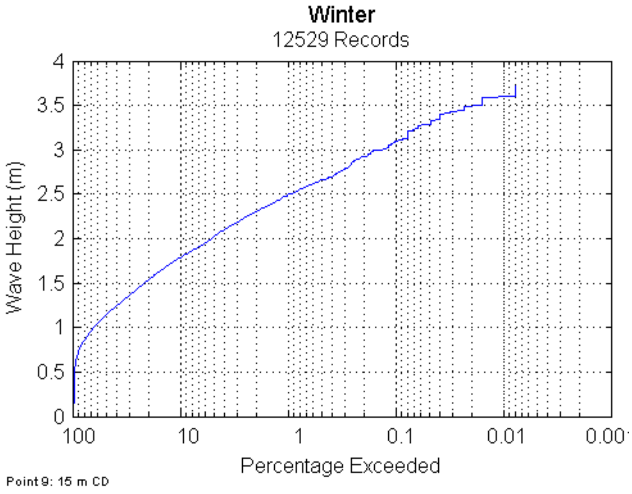
Wave Height Exceeded (m)					
	1.0%	5%	10%	25%	50%
All Data	1.16	0.95	0.84	0.69	0.55
Summer	0.93	0.79	0.72	0.62	0.51
Autumn	1.08	0.92	0.81	0.66	0.53
Winter	1.29	1.06	0.96	0.79	0.63
Spring	1.13	0.94	0.84	0.68	0.55

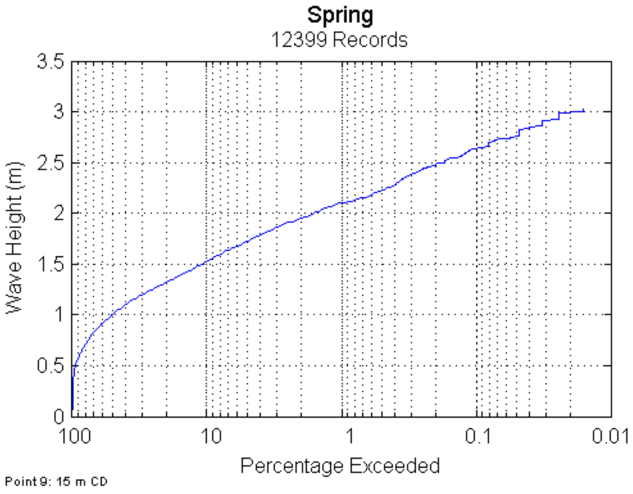
Point 25: 14 m CD
Wave Height Exceedance
Location 01

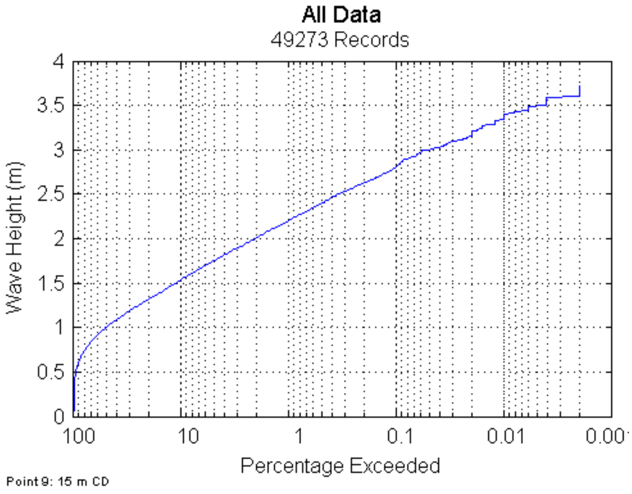
Figure F-4









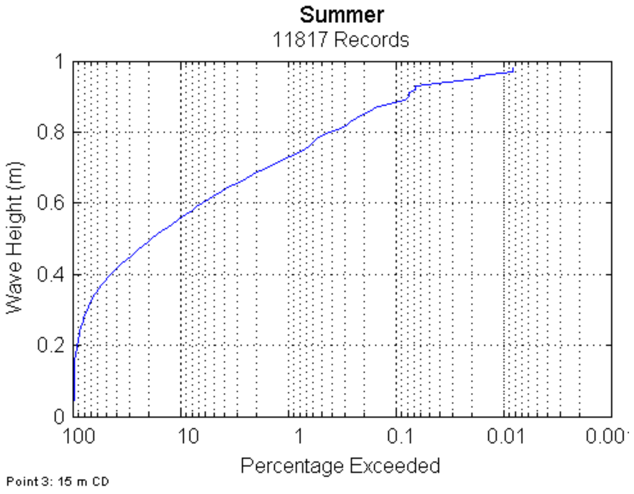


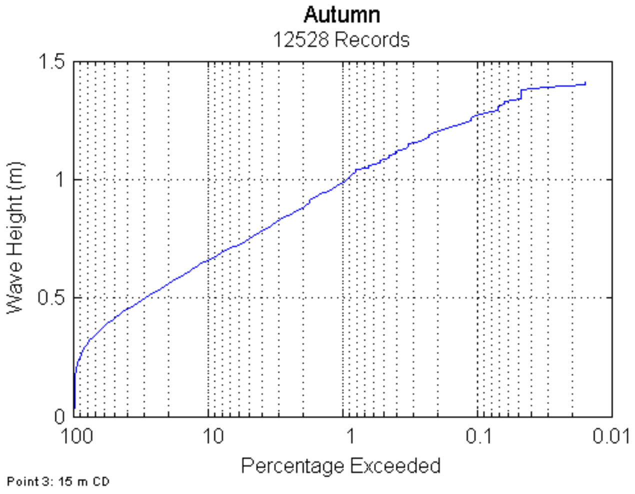
Wave Height Exceeded (m)					
	1.0%	5%	10%	25%	50%
All Data	2.20	1.75	1.54	1.25	1.00
Summer	1.65	1.44	1.32	1.13	0.93
Autumn	2.03	1.64	1.45	1.18	0.95
Winter	2.49	2.02	1.79	1.44	1.14
Spring	2.10	1.72	1.52	1.25	1.00

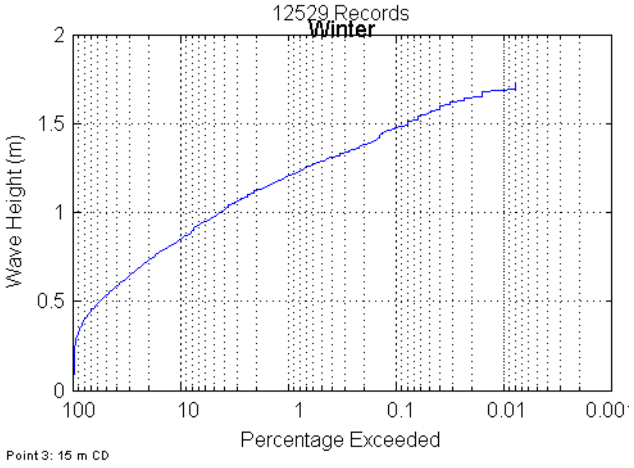
CSIR

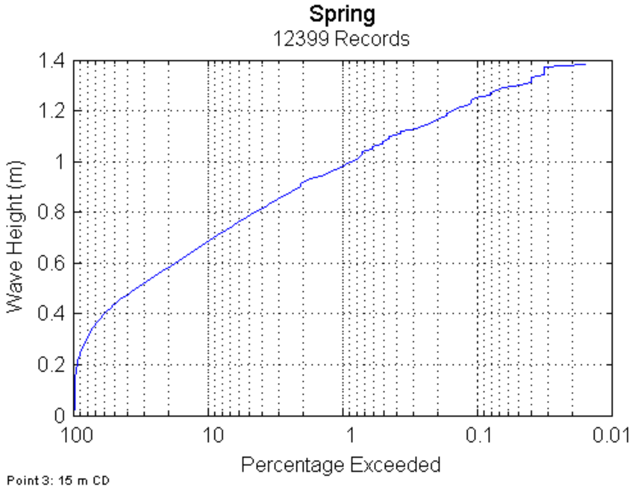
Point 9: 15 m CD
Wave Height Exceedance
Location 02

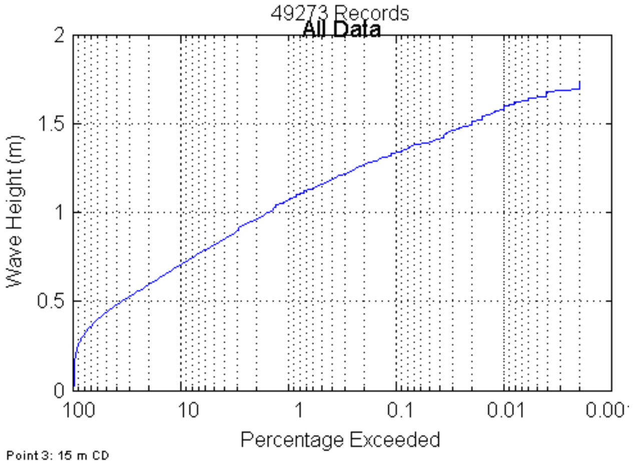
Figure F-5


Summer
11817 Records


Autumn
12528 Records


12529 Records
Winter

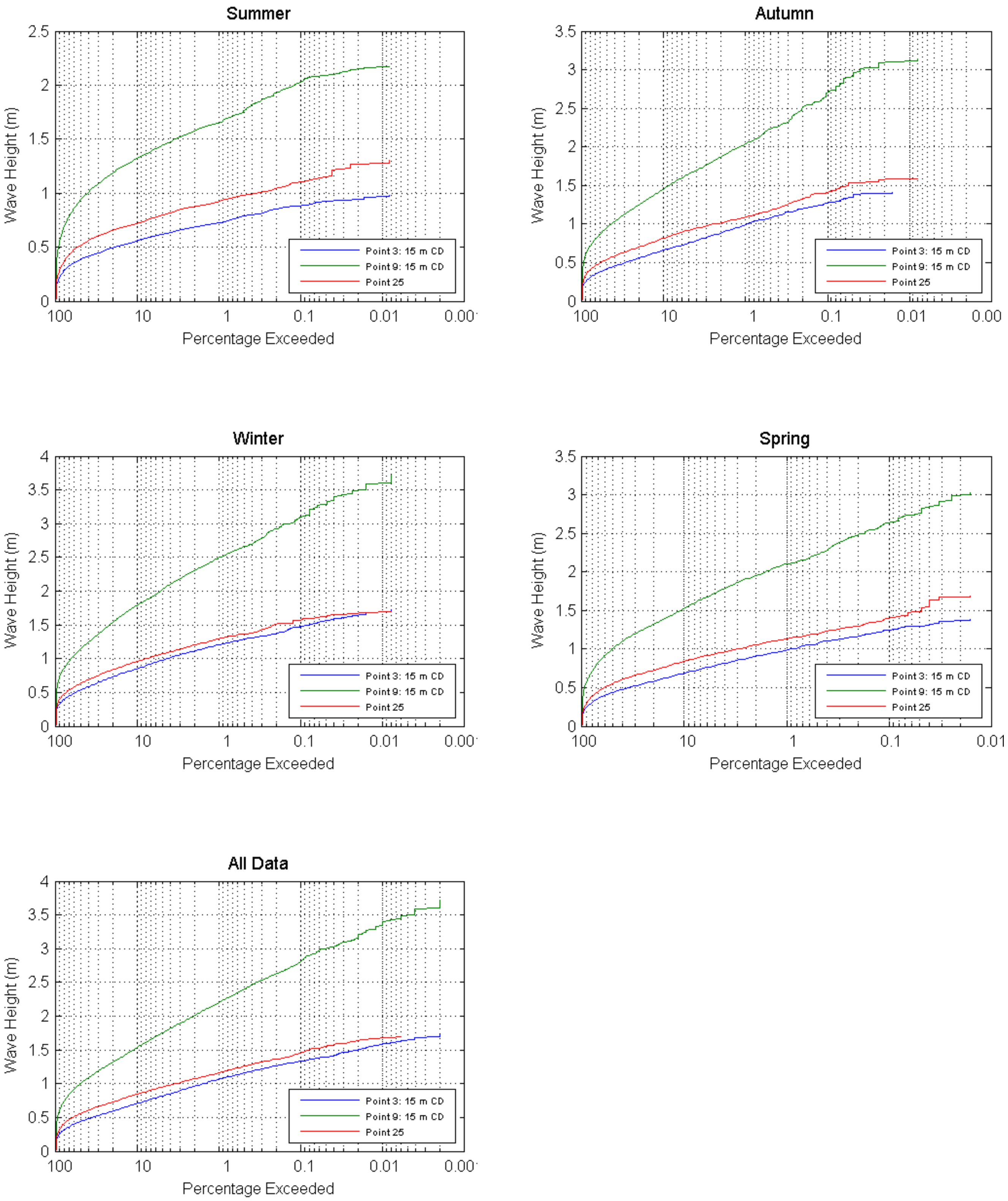

Spring
12399 Records


49273 Records
All Data

Wave Height Exceeded (m)					
	1.0%	5%	10%	25%	50%
All Data	1.06	0.81	0.70	0.55	0.43
Summer	0.72	0.62	0.55	0.47	0.38
Autumn	0.98	0.75	0.66	0.52	0.41
Winter	1.20	0.97	0.85	0.68	0.53
Spring	0.98	0.78	0.68	0.55	0.43

Point 3: 15 m CD
Wave Height Exceedance
Location 01

Figure F-6



Wave Height Exceedance
For the three locations

Figure F-7

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