UNIVERSITY OF KWAZULU-NATAL

REVIEWING PRECAUTIONARY THRESHOLDS AT SEAPORT PRECINCTS ON ACCOUNT OF INTENSE COASTAL WEATHER CONDITIONS IN KWAZULU-NATAL

By

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A dissertation submitted in partial fulfillment of the requirements for the degree of MASTER OF COMMERCE IN MARITIME STUDIES

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01March 2021

DECLARATION

This research has not been previously accepted for any degree and is not being currently considered for any other degree at any other university.
I declare that this Dissertation contains my own work except where specifically acknowledged

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Signed………………………………………..

Date…………………………………………..

ACKNOWLEDGEMENTS

My first gratitude goes to the Most High sovereign God who has been merciful to me throughout this journey. I thank the Lord Jesus Christ for keeping me healthy and safe to be able to finalise this work without any challenges.

I would also like to thank Professor Trevor Jones for warming up to the idea of a meteorologist venturing into maritime commerce space, through his visionary leadership he was able to determine where meteorology and international trade converge. I have been able to benefit from Prof Jones years of experience and his outstanding academic leadership in the field of maritime commerce and researching, I am forever grateful.

Lastly I thank everyone who have availed their time and resources when I knocked on their doors in order to tap into the knowledge and expertise, I wish you success in your own endeavours.

ABSTRACT

The prevalence of port damages as a result of severe weather occurrences along the coastal areas of KwaZulu-Natal has highlighted possible future impacts that climate change is likely to induce on the port setup. This then raises concerns in terms of the readiness of ports to take precautionary measures that would protect lives as well as the infrastructure. This study seeks to influence a review in the manner in which meteorological forecast and warnings issued to marine services are communicated and utilised among harbour authorities. The study also seeks to explore the potential of improving the enforcement of the existing port regulation and guidelines in order to improve safety in the advent of climate change. In order to identify the climate variables contributing directly to any severe weather driven incidence a proper analysis of weather patterns dominant during occurrence is an initial step. The study determines the relevant climate variables responsible for the two incidents at the two commercial ports of focus accordingly. The study relies heavily on reported account of events from various platforms however this limitation is supplemented through sourcing opinions from a range of experts relevant to the study during interviews. One of the incidents happened on 19 August 2013 when the MV Smart, a fully-laden Capesized dry-bulk carrier, ran aground while on exit from Richards Bay harbour. Another incident occurred on 10 October 2017 when five vessels that were berthed in various areas of the Durban port broke their moorings and were blown across the harbour by the very strong winds during thegreat storm. As an incident reconstruction exercise the study superimposes the peak levels reached by the climate variables with the magnitude of damages at the time of peak. The marine weather forecast & warnings issued twice daily for marine services predicts the possible extreme levels of climate variables, hence the study verifies the effectiveness of this forecast in informing precautionary measures. Port operations have available an enabling regulation in the form of the National Ports Act (12/2005) as well as the IMO guidelines as material to ensure precautionary measures are taken in advance to severe weather occurrences at the port. The research contends that proper utilisation and elevated enforcement of this available regulatory material has become even more vital in the advent of climate change phenomenon. The study recommends that in order to inform proper decision making inside the harbour, real time observed weather conditions and climate variables including the wind forcing be regularly updated. There is also a need for the Transnet National Ports Authority (TNPA) to conduct climate change vulnerability studies specifically relating to the harbours, preferably reviewable after a 5 to 10 years period.

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LIST OF ABBREVIATIONS

AIS:	Automatic Identification System
BRM:	Bridge Resource Management
EIA:	Environmental Impact Assessment
CD:	Chart Datum
CMTP:	Comprehensive Maritime Transport Policy
CSAs:	Control Self Assessments
CSIR:	Council for Scientific and Industrial Research
DCT:	Durban Container Terminal
DEFRA:	Department for Environment, Food and Rural Affairs
DOF:	Degrees of Freedom
DWT:	Deadweight tonnage
GPS:	Global Positioning System
GMT:	Greenwich Mean Time
IHO:	International Hydrographic Organization
IMCO:	Inter-Governmental Maritime Consultative Organization
IMO:	International Maritime Organisation
IPCC:	Intergovernmental Panel on Climate Change
LOA:	Length overall
M/V:	Merchant Vessel
NOAA:	National Oceanic and Atmospheric Administration
OOW:	Officer on Watch
SAST:	South African Standard Time
SAWS:	South African Weather Service
SAMSA:	South African Maritime Safety Authority

SLR: Sea level rise

SOLAS: Safety of Life at Sea

TNPA: Transnet National Ports Authority

TPT: Transnet Port Terminals

UK: United Kingdom

UKC: Under-keel clearance

USACE: United States Army Corps of Engineers

USCCSP: United States Climate Change Science Program

UTC: Universal Time Coordinated

VTS: Vessel Traffic Service

WMO: World Meteorological Organization

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CHAPTER 1

INTRODUCTION

The purpose of this chapter is to provide an introduction to the dissertation. It sets out the background and context of the study; it identifies the principal issues to be dealt with in relation to the central research theme of the manner in which ports may modify precautionary thresholds in response to climate changes; it details the aim and the objectives of the study and it introduces the research questions that seek to attain the study objectives. Further, it sets out the rationale of the study and identifies those who stand to benefit from it, within the boundaries and limitations of the proposed research. Finally, it outlines the dissertation organization and structure that will follow in the main body of the work.

1.1 Background of the study

In the past decade coastlines have observed enormous damages owing to extraordinary storms (Coumou and Rahmstorf, 2012). Becker et al. (2013) note that climate change-driven coastal storm events are associated with increasing sea levels, strong winds and storm surges. Asariotis and Benamara (2012) in agreement also identify sea-level rise, strong winds and storm surges as responsible in producing climate-related impacts that leave seaports highly vulnerable. Seaports as a result are exposed to extensive challenges (Asariotis and Benamara, 2012; Oh and Reuveny, 2010) by virtue of their coastal location due to climate change-associated extreme weather occurrences.

The Intergovernmental Panel on Climate Change Report (IPCC:2007) asserts that climate change and sea level rise are expected to expose coasts to increasing risks and coastal erosion (Adger et al., 2007: 6). The coastline of South Africa is made up of a proportion of metropolitan areas, numerous towns and smaller settlements (Huq et. al., 2007). Sea storms and moderate to strong wave action is a common feature to this 3,650 km South African coastline (Griffiths, 2010). However the frequency and intensity of storms are expected to increase as a result of climate change occurrence; this will lead to storm surges, coastal erosion, sea-level rise and extreme weather events which will leave the South African coastline highly vulnerable (National Climate Change Response White Paper, 2011: 23).

The pathway of these storms is around the south-eastern part of the continent and this is where the five of the six major commercial ports of South African coastline are located, which are Richards Bay, Durban, East London, Port Elizabeth and Ngqura (Rossouw and Theron, 2012) . The east coast of Southern Africa falls under the Safety of Life At Sea Area (SOLAS) referred toas the METAREA VII[1], which is the second largest SOLAS worldwide[2]. Weather and climate forecasting for METAREA VII is the responsibility of South Africa under the auspices of the South African Weather Service (SAWS). The World Meteorological Organisation (WMO) which is the United Nations wing responsible for weather, climate and water systems and which has an authoritative voice to its Member States and Territories, is the one that delineates World Ocean into geographical sea regions (Kopacz, 2004). Observation networks and forecasting services in the meteorological ocean environment have been developed, maintained and expanded in fulfillment of the WMO vision (Asrar, 2012).

KwaZulu-Natal hosts two of the major sea transport hubs – the ports of Richards Bay and Durban - which fall under a section referred to as Durban east area 14 in METAREA VII. These are the busiest commercial ports in Africa and the Southern Hemisphere (Altman, 2002). According to Jones (1990), Richards Bay is busy owing to the richness and diversity of its facilities as well as volumes of cargo it handles and Durban serves as the linchpin of the subcontinent's seaborne commerce based on the value of the commodities that goes through. Seaports end up faced with a risk of closure as a result of the climate-related impacts and a potential of destructiveness, as Haveman and Shatz (2006) assert, this may result in operational delays that can cause major financial losses.

Recently observed incidents at the KwaZulu-Natal ports highlight eminent risks posed by unpredictable extreme weather and sea state conditions, which are likely driven by climate change occurrence. The resultant impacts to the maritime industry are potentially enormous, with the associated infrastructure damages, damage to vessels and port operation disruptions in turn affecting international trade activities as well as economic development facilitated through the ports (Becker et al., 2013).

1.2 Problem statement

The importance of this study relates to the reality of climate change occurrence and the recently

[1] METAREA means a geographical sea area established for the purpose of coordinating the broadcast of marine meteorological information. The term METAREA followed by a roman numeral may be used to identify a particular sea area. The delimitation of such areas is not related to and shall not prejudice the delimitation of any boundaries between States

[2] International Convention for the Safety of Life at Sea, 1974

observed associated extreme weather conditions that have left damages at the ports of KwaZulu- Natal. According to a newspaper report by Rawlins (2013), on 19 August 2013 a coal ship the ***MVSmart*** broke its hull while stuck on a sandbank outside the Richards Bay, after trying to exit port in heavy swells and high winds. On 10 October 2017 it was reported that gale force winds blew sideways a 348 metres length overall (LOA) ***MSC Ines*** Container Ship at the Durban harbour, lodging it between two breakwater walls of the harbor entrance. On that same day four other vessels broke away from their moorings due to gale force winds and some were pushed onto the sandbanks, or struck other moored vessels (Evans, 2017). Further reports indicate that cargo handling equipment, ship to shore cranes, buildings and infrastructure in and around the port were also damaged (Africa News Agency, 2017).

Operations at the seaports generate substantial business activity and hence this makes them crucial centres of economic activity (Goss, 1990). As a result of this the maritime safety measures are of paramount importance for the World Meteorological Organisation (WMO). In order to achieve this, a Manual on Maritime Safety Information is prepared for International Hydrographic Organization (IHO) Member States and South Africa has been an active member since 1951. At the country level there are policies and legislations aimed at ensuring maritime transport safety in general and under bad weather conditions with regards to port operations and vessel navigation. The recent incidents which are of focus for this research have introduced a trend of impacts within the port precinct affecting port infrastructure as well as navigating and berthing vessels.

Such impacts are driven by climate variables which are reported in the set of meteorological forecasts/warnings documentation issued twice daily for use by the concerned parties in the maritime operations. On both days of incidents of interest meteorological forecasts/warnings were issued. The level of damages that were still observed on both occasions therefore raises questions regarding forecasts/warnings relevance and usefulness, especially in the advent of climate change. Further, the intensity levels of climate variables should inform decision making regarding the activation of the precautionary thresholds that guide vessels navigation in and out of the port precinct as well as cessation (and subsequent resumption) of port operations. Consequently, the interest of this study relates to the relevance and usefulness of the existing precautionary thresholds for port operations in their current form with the advent of climate change during severe weather conditions and the associated extremely unstable sea state conditions.

1.3 Aim of the study

This study seeks to review precautionary thresholds at seaport precincts on account of intense coastal weather and sea state conditions in the principal commercial harbours in KwaZulu-Natal.

1.4 Objectives of the study

The principal objectives of this research dissertation are:

- To influence a review in the manner in which meteorological forecasts and warnings issued to marine services are communicated among harbour authorities.
- To assess the manner in which issued meteorological forecasts and warnings influence extra precautionary measures required to decide continuation of marine operations (including navigating and berthing vessels).
- To explore the potential of improving the enforcement of the existing guidelines applicable in anticipation of extreme weather and sea state conditions, in the advent of climate change.

1.5 Research questions

These objectives will be explored by subjecting the following research questions to rigorous interrogation:

- How do port layouts/features affect different climate variables associated with aparticular weather pattern?
- How do extreme levels of climate variables influence the sea state?
- How effective are the mechanisms of communicating meteorological forecast andwarnings issued to marine services among authorities at the harbour?
- How best can the issued meteorological forecast and warnings influence extra precautionary measures at port precinct?
- How best to enforce the existing guidelines applicable at the harbour in anticipation of extreme weather and sea state conditions, in the advent of climate change?

1.6 Rationale of the study

The research aims to provide some insights into the manner in which ports authorities and vessel owners take precautionary measures during severe weather conditions and associated extremely unstable sea state conditions. Recent incidents may suggest a need to review the manner in which meteorological forecasts and warnings are put into use at the seaport precinct in relation to the existing minimum thresholds that determine decisions to halt port operations and vessel movements. The prevalence of the climate change phenomenon in recent years is also a motivation for this study.

Subsequently, the study aims to bring into sharper focus the need for more effective and port precinct-specific meteorological forecasts and warnings, and that these are disseminated more timeously, in order to avert or minimise damages during extreme weather occurrences. Extending forecasts and warnings to be port precinct specific should assist in taking necessary precautions and hence protect port property (infrastructure), clients' property (both afloat and ashore), as well as port employees' and seafarer lives. The study therefore should benefit both Port Authority structures and the broad family of port users.

1.7 Study delimitations and scope

The focus of the study will be on the KwaZulu-Natal coastal area but specifically looking at the two principal commercial harbours of Richards Bay and Durban. The study will look generally at the effect and influence of various climatic variables on sea stateand conditions in relation to climate change occurrence. The study will take interest on the climate variables with a potential to affect port operations within the harbour and around its vicinity. Specifically, the interest of the study is on 19 August 2013 and 10 October 2017 incidents, in relation to the role the relevant climate variables played in respect of loss of or damage to vessels, damage to port infrastructure and superstructure, and disruptions of vessel movements.

1.8 Outline of the dissertation

Chapter Two reviews existing studies generally on the conditions that are of concern for coastal areas and specifically to the maritime industry e.g. swells structure, wave climate as well as windcomponent. The impact of such conditions on port operations, port infrastructure and vessel navigation as well as safety measures provided by the existing South African enabling legislationas well as international guidelines during extreme weather conditions forms part of this chapter'sreview. Chapter Three sets out the methodology applied in this study. To determine the research paradigmof the study, the chapter explores the mixed methods research approach. The chapter looks at the applicability of both quantitative and qualitative methods in a research. Then data collection and data analysis approaches are detailed.

Chapter Four contrasts the literature reviewed to the analysis outcomes (inclusive of the opinions sources from various experts through interviews) based on the actual occurrences on the days of interest. The influence of weather patterns and intensity of associated climate variables to the seastate behaviour and the impacts observed on port operations, infrastructure as well as on the vessels are also analysed. The usefulness of meteorological forecasts and warnings issued during severe weather and unstable sea state conditions to the end users in the maritime sector is alsoanalysed in relation to the incidents of focus.

Chapter Five provides summary of the study (including the study limitations) conclusions and recommendations based on the research and discussionsin this dissertation. It further details direction for future research in relation to improved port operations as well as policy implications in the face of climate change phenomenon.

CHAPTER 2

LITERATURE REVIEW

This chapter begins with assessing literature around sea level rise and associated impacts. This covers observed coastal trends, historical extreme storm events and the associated sea level rise threatening coastlines in general. Then it looks at sea wave characteristics and the associated weather systems. This includes the wave height and the manner at which it changes as waves approach the coastline, wave characteristics behaviour under changing seasonality and weather patterns as well as the observed historical impacts to the coastline, particularly the KwaZulu-Natal coast. Received literature dealing with wind component and weather systems are then explored, looking at the role of the wind speed in generating wave height, and determining the state of the sea as well as the associated weather system responsible for driving such wind conditions.

Then the assessment of climate variables and associated impacts on port physical infrastructure and operation follows. The chapter proceeds to look at the parameters at which such climate variables have a potential to threaten port infrastructure and operations. Sensitivity and exposure of a range of onshore as well within-port precinct infrastructure are discussed, mainly under the effect of extreme weather conditions. Then the identified climate variables and associated impacts on maritime navigation are interrogated. Discussion also covers entrance channel practices, wave predictions utilization as well as factors influencing vessel transit through the channel.

The main scope of literature review is subdivided into two parts; the theoretical framework part which provides the principal conceptual underpinnings of the study. Then follows the empirical literature part which first sought to determine the main influential marine climate variables and then proceeds to interrogate their interdependencies. The review concludes by looking at the existing South African maritime enabling regulation as well as International Maritime Organisation (IMO) safety guidelines and requirements for operations.

2.1 Climate change vulnerability and impacts associated with extreme events over KwaZulu-Natal

The degree of susceptibility of systems like geophysical, biological and socio-economic to adverse impacts of climate change as well the incapability of such systems to cope is defined as vulnerability to climate change (Parry et al. 2007). It then follows that vulnerability assessment is defined through a process for assessing, measuring, and/or characterising the disturbance of a natural or human system as a result of exposure, sensitivity and its adaptive capacity (Nelitz, M, Boardley, S, and Smith, R 2013).

Sectors that are threatened by climate change occurrence in KwaZulu-Natal include water resources, food security, human health, infrastructure (urban, rural and coastal), ecosystem services and biodiversity (Montmasson-Clair, G and Zwane, M 2016). Biophysical sensitivity and low adaptive capacity are cited as responsible for high vulnerability in the province of KwaZulu-Natal (Shezi, N and Ngcoya, M 2016).

In 2017 alone the Province of KwaZulu-Natal has been at the receiving end of some of the climate change driven occurrences. There has been a prolonged drought that the Province is still recovering from, which affected mainly water resources and agricultural production. Heavy rains accompanied by flash flooding affected different parts of the province causing enormous damages on human settlements due to outbursts of drainage systems in other parts, affecting operations at the industrial zones in other areas and leaving destructions in certain developments and infrastructure.

Most of the infrastructures and the developments affected under these severe weather conditions had undergone environmental assessments before getting authorized. Such occurrences therefore highlight a need for existing developments as well as those yet to be built to now take into consideration climate change impacts. A Synergistic approach going forward between government and developers will require climate change adaptation plans for the existing developments and assessment of climate change impacts for the current environmental assessment proposals.

2.2 Climate Change driven sea level rise risks patterns and trends to coastline

The 2007 Intergovernmental Panel on Climate Change (IPCC) report highlights that “coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea level rise” and that “the effect will be exacerbated by increasing human-induced pressures on coastal areas” (Adger et al., 2007). Consequently, as Asariotis et al. (2017) assert, ports location in coastal zones, low-lying areas and deltas make them susceptible to climate change induced impacts and open to associated risks. In agreement, Becker, Inoue, Fischer & Schwegler (2012) identify ports location along the coastal areas as a reason for their susceptibility to climate hazards mainly driven by climate variables like sea level rise, storm surges, extreme wind and waves, and flooding. This very location, as they continue, makes it very vital to work to minimize their vulnerability to natural hazards, in the heart of estuarine environment.

There is consensus among the scholars that natural coastline adjacent to ports will, due to extreme storm events combined with sea level rise, be exposed to an ever-increasing threat (Rossouw and Theron, 2009). Asariotis et al. (2017) agree, predicting serious broader implications that may be brought about by climate change impacts on ports in the form of rising sea levels, floods, storm surges and strong winds, extending to their land-based access points. Both Nicholls et al. (2007) & Rahmstorf (2007) agree with the projections of meteorological instability and changes in storm frequency and intensity. Vermeer & Rahmstorf (2009) project 1.9 m sea level rise by 2100 globally. Further indications are that sea level rise will be experienced by 70% of the coastlines worldwide based on the available scientific evidence (Holgate and Woodworth, 2004). Consequently, according to Lin et al. (2012) this is a recipe for increased wave damage and storm surge impacts on many regions. In the low-lying port infrastructure, devastating impacts induced by sea level rise are already evident (Schaeffer et al., 2012). Bender et al. (2010) believe these can be further exacerbated by intensifying tropical storms. As a result, transportation networks are under threat of being disrupted from extreme events like coastal inundation/erosion, wind hazards and inland floods (USCCSP 2008). Hallegatte et al. (2011) predict catastrophic disasters and business losses in some regions where local mean sea level rise will likely exceed global mean.

2.3 Impact to port operations and infrastructure due to sea level rise

Asariotis et al. (2017) warn that infrastructure and coastal activities are susceptible to significant hazards posed by extreme coastal sea levels. Such vulnerability posed by greater sea level rise on transport coastal infrastructure, as Esteban et al. (2015) point out, is felt in regions and seaports where high rates of mean sea level rise are combined with extreme storm surges/waves.

A storm surge is an abnormal rise of the sea levels with severe impact on coastal infrastructure and it occur as a result of extreme weather effects like extra tropical storms (Hallegate et al., 2013). Seaports infrastructure damages and failure, major operational disruptions as well as services interruptions are also possible with high wind events (Asariotis et al., 2017). Projections indicate that such extreme winds may be catastrophic when they occur in the future (Schaeffer et al., 2012). Port superstructures, underground utilities, vaults, wharves etc. are all highly threatened under the occurrence of rising mean and extreme sea levels in cases where protective infrastructure like the breakwaters is no longer effective (Asariotis et al., 2017). Such threat, as Becker et al. (2012) underscore, owes to the fact that port infrastructure design considers climate of the present time and storm events with centennial return periods and therefore is affected by climate change. Asariotis and Benamara (2012) point to structural designs lifetime limits leading to ports infrastructure being affected considerably due to climate change occurrence. Becker et al. (2012) assert that breakwaters have a lifespan that can extend to 60 years and further up to 100 years, whilst the berthing facilities are resilient up to 30 and 45 years. Becker et al. (2012) further mention that the cargo handling equipment has a resilient capacity to remain properly functional for a period of 15 up to 20 years.

Seaport operations are also potentially affected as a result of climate change-driven severe coastal storms (Asariotis et al., 2017). Adverse wave conditions, Rossouw and Theron (2012) contend, lead to penetration of long period waves generated by swell waves propagating in groups and this as a result make it difficult for large freight vessels to berth or navigate safely. Stenek et al. (2011) agree, based on the Muelles del Bosque (Cartagena, Colombia) study, findings of which show that climate variability and change has a potential to cause: (i) shipping traffic changes (in terms of patterns and levels); (ii) port operations disruptions due to increased flooding and lead to damages in stored goods; (iii) port access channels difficult to navigate; and

(iv) high economic losses to business. The climate variables, wind, waves and currents are responsible for such harbour disruptions (Asariotis et al., 2017). Wind has a potential to affect crane operations, waves may lead to agitation inside port domains and currents have a potential to affect manoeuvrability and leading to possible spills (Asariotis et al., 2017). According to Camus et al. (2019), harbour operations and infrastructure are conditioned by wave climate, extreme water levels or increase in mean sea level. Access of larger ships to the harbour may be hindered under future climatic conditions owing to sea level rises or storm surges (Conte and Lionello, 2013). Also, the reduction in dock freeboards under mean sea level variations have a potential to affect port operations like berthing prudent Under-keel clearance (UKC) thresholds as well as cargo loading and unloading (Sánchez-Arcilla, Sierra, Brown, Casas-Prat, Nicholls, Lionello,and Conte, 2016). Structural safety and functionality become affected by wind velocities and directions as well as climate modification and this leads to enhanced overtopping (Sánchez- Arcilla et al., 2016). Such modification, Sánchez-Arcilla et al. (2016) further expand, may also disturb those operations that can be performed under certain wind component thresholds e.g. loading/unloading, ship berthing, or crane operations. The state of safety levels and port operations are determined by the pressure exerted by wind and wave features on port structures (Schelfn and Östergaard, 1995).

2.4 Theoretical framework

Koeste and Rietveld (2009) highlight the most worrying consequences of climate change occurrence for coastal areas as being the increase in frequency and intensity of storm surges and flooding incidences induced by rise in sea levels. Subsequently as Cartwright (2011) asserts, novel coastal dynamics as well as amplification in historic coastal zone variability driven by climate change can thus be expected. Smith et al. (2010) acknowledge that there are drivers of coastal erosion which vary in time and space, which are of large magnitude and require attention in the advent of global climate change. Rossouw and Theron (2009) predict an accelerated rate ofstorminess and thus erosion owing to sea level rise (SLR). Furthermore, as Rossouw and Theron(2009) expand, negative impacts from the severe wave and wind climate on the coast and maritime activities can be anticipated owing to such accelerated storms. Corbella and Stretch (2012) point to a possibility of a combination of factors that leads to coastal storm damage among which are high waves, long duration storms, sea levels etc.

2.4.1 Sea level rise and associated impacts

Sea-level rise is a consequence of climate change that has impacts on coastal development (Hugo, 2013). Furthermore, the SLR (due to climate change), as Theron et al. (2010) assert, is among the most significant drivers that affect the still-water level at the shoreline and also bring extreme inshore sea water levels in the Southern African context. Hughes (1992) underscores sediment type and coastal platform as determinants of the effects of sea level rise to a particular coastline. Consequently, as Hughes (1992) further elaborates, the anticipated effects include increase in storm damage affecting coastal development and infrastructure, loss of land through erosion and flooding of low-lying parts of the coastline. Theron et al. (2010) infer that coastal erosion and flooding have occurred in high numbers along the KwaZulu-Natal coastline since 2005 due to extreme storms. Park & Suh (2012) define a localised event of flooding of coastal areas as a result of an uplifted water body coming into contact with the coast owing to atmospheric conditions as a storm surge. A storm surge is a wave with height exceeding 3.5 m threshold (Corbella & Stretch, 2013). Flooding potential on coastal infrastructure is high as a result of storm surges under scenarios of sea level rise (Hallegatte, Ranger, Mestre, Dumas, Corfee-Morlot, Herweijer and Wood, 2011). Vast flooding potential is possible for the coastal infrastructure due to se level rise associated with storm surges (Klemas, 2014).

2.4.2 Sea waves characteristics and weather systems

Holthuijsen (2007) points to two climate change-related coastal storm driven impacts that affect the near shore, which includes an increased wave height and changing offshore wave angles. The assessment of Mather and Stretch (2012) concurs, pointing to significant weather events that affect the southeastern coastline of Southern Africa on regular basis causing large wave events inthe process. In South Africa a largest recorded wave event that left severe coastal damage was experienced along the KwaZulu-Natal coastline on the east coast in March 2007 (Corbella and Stretch, 2012). Riddle (2015) estimates a storm surge of 8 m occurred on that day in 2007 during an abnormally high tide. In comparison to the 2007 event, Smith et al. (2013) declares the 2011 swells relatively low although they caused erosion due to their long duration (mid-May to November) but significant wave heights ranged between 2 m and 4.5 m. It appears, as Riddle

(2015) asserts that weather seasonality in accordance with the KwaZulu-Natal regional position also plays a role. During winter the weather systems have ability to produce large swells as compared to when it is summer (Riddle, 2015). Rossouw and Theron (2009) concur, acknowledging occurrence of seasonal variable wave intensity and direction around the South African coast. Consequently, Riddle (2015) believes potential of coastline erosion is best understood through understanding the wave characteristics. Corbella and Stretch (2012) define the character of the waves generated by tropical cyclones, cold fronts or cut-off lows off the KwaZulu- Natal coast as storm waves. However, on the contrary, according to Kruger et al. (2010) betweenyears 1962 and 2005 along the coast of Durban only seven cyclones out of the many that affectedthis coast were responsible for extreme waves and hence the authors conclude it is rare that tropical cyclones be the source of extreme waves in Durban. Instead, as Corbella and Stretch (2012) assert, largest wave events, such as the ones observed in the year 2007 on the KwaZulu- Natal coast, are associated with cut-off lows systems. Such systems have a potential to generate long wave periods further offshore which are mainly south-easterly.

2.4.3 Wind component and weather systems

MacHutchon (2006) remarks that the action of wind can generate sea waves which he terms 'a special type' formed on the air-water interface. Kruger et al. (2010) enhance this argument, charging that the nature of observed sea state and assessed wave height is determined by the wind speed. This means an increase in wind speed leads to build up of sea surface ripples into exceptionally high waves.

Generally, the wind strength along the coast is mainly determined by the dominant type of weather system at that particular time. Notably, in South Africa only one type of strong wind producing weather system is capable to induce extreme gusts along the coast and the adjacent interior regions and that is the extratropical cyclone (Kruger et al., 2010). This cyclone is the primary system capable of causing annual maximum gusts for the east coast of South Africa and its adjacent interior, whilst other systems are deemed secondary (Kruger et al., 2010). Two secondary systems are prevalent during winter in producing strong winds and gusts, one being high pressure systems ridging behind cold fronts and another being strong cold fronts that extend to the southern half of South Africa (Kruger et al., 2010). A large portion of the South African coast during the winter season records gale force winds on frequent basis and the KwaZulu-Natalcoast in particular experiences gale force winds as a result of the presence of a constantly strong Atlantic high pressure system that tends to move eastwards (Kruger et al., 2010).

2.5 Empirical literature

Sánchez-Arcilla (2016) identifies climate variables considered as the main marine variables to bethe mean sea level as well as those which make up storm features (i.e. peak wind speed, significant wave height, directions and associated surges). Sánchez-Arcilla (2016) further states that it is the very variables which make up storm features that end up affecting a harbour's infrastructure design, construction and maintenance. According to a study by RMIT University (2013) long-term performance effects that impact port infrastructure may come through a myriadof climate variables, like sea level rise, water table, temperature, rainfall/runoff, wave, wind, salinity and humidity. Koetse and Rietveld (2009) point to direct and indirect effects of sea level rise to the port infrastructure driven by storm surges on flooding incidences. McEvoy et al. (2013) concur that sea levels rise is not the only climate change-driven variable that affects port operations. There is also wind, wave and flooding that equally pose risk to port infrastructure and operations and the level of risk from these variables is determined by the intensity and frequency of storms and sea levels rise (Jacob et al., 2000).

Leviäkangas and Michaelides (2014) define climate variables intensity as high (or low) thresholds of certain weather parameters that exceed pre-existing (or measured) maximum values. These are harmful to any part of transport systems, which could be operations, infrastructures, cargo and more, driven by extreme events which are generally rare occurrences (Stamos et al., 2015). Mutumbo (2017) believes interaction of multiple climate variables producesuch events with extreme intensity and multiple effects. The interdependencies between these variables have become a point of interest when assessing port risk factors (Mutumbo, 2017). Pittock's (2009) illustration of wave action increase, generated by multiplier of effect of an increasing gust wind, shows that this in turn contributes to multiplying damage effects.

Sánchez-Arcilla et al. (2016) also highlight that the impact on port engineering and exploitation may be induced by several additional climatic factors. To clarify this point further, these authors point to structural safety, functionality and port operations susceptibility to climate modification of wind velocities and directions. This implies that port operations like loading, unloading, ship berthing or crane operations require adherence to certain thresholds to be performed without problems (Sánchez-Arcilla et al., 2016).

2.5.1 Climate variables and associated impacts on port physical infrastructure and operations

RMIT University (2013) lists six physical assets vulnerable to the effect of climate change as including berthing structures, protection barriers, port superstructure, channels and harbours, androad and rail networks. Kong's (2013) assessments determine that the berth structures (being structures built to provide a vertical support for ships to berth, moor, load and unload cargoes) suffer impact from wave action variation which then affects structural design (piers, wharves, jetties, bulkheads and docks). Similarly, breakwater armour is mainly affected by larger waves which have a potential to induce structural failure due to increased wave overtopping. In line with the interdependencies between these variable, Mutumbo (2017) underscores that the orientation of berths and channels, designs of mooring and fendering systems, operational depthsat berths, basins as well as approach channels all get affected by a combined influence of wind and wave action.

The United Kingdom Department for Environment, Food and Rural Affairs (Ramsbottom et al., 2012), conducted a climate risk assessment on infrastructure for nine ports in the United Kingdom from a number of climate variables. Looking at both qualitative and quantitative weather variables, the DEFRA study identified thresholds at which climate extremes pose risk to infrastructure at each port (Scott et al., 2013). However, the identification of relevant climate variables in this study was done with the assistance of the stakeholders and hence they are of importance for the UK ports set up. The impediment to this therefore, as McEvoy et al. (2013) assert, is that precise definition for many thresholds which affect operations are based on local knowledge and experience. Hence, these authors caution to be noted that determination of thresholds for different port operations are based on different formal and informal rules per particular port.

Once the climate variables of interests were identified in the DEFRA study, the vulnerability assessment posed by each variable on core operational assets was conducted looking specifically at their exposure and sensitivity to the identified extreme weather impacts. Scott et al., (2013) assessments of each relevant climate variable, shows that flash floods and storm surges impacts on shore cranes as well as yard cranes are significant, whilst with high speed winds impacts are significant to shore cranes yet moderate to yard cranes.

Port operations, large vessels and ship routing are also affected as a result of change in wave climate (Scott et al., 2013). Further, analysis by Hawkes et al. (2010) shows that wave height determines offshore loading and unloading operations; however, acceptability of wave height is not the sole determinant and there are cases where a maximum wave period maybe the criterion for operation regardless of an acceptable wave height.

In one of the circulars on the Gard Loss Prevention Circulars (Gard, 2013) which contain actual occurrences of impacts as a result of climate variables in the maritime sector, damage to fixed objects when manoeuvring in confine waters is discussed. Loss Prevention Circular No. 06-09 looks at increased cases of contact damages by vessels, mostly within port as a result of the cumulative effect of wind, sea, current and tidal conditions. According to Gard (2013), in confined waters the vessel can experience difficulty manoeuvring in a controlled fashion and endup making contact with fixed objects including berths, docks, locks and shore side equipment such as cranes.

In another circular on the Gard Loss Prevention Circulars (Gard, 2013) which contain actual occurrences of impacts as a result of climate variables in the maritime sector, moored vessels breaking out from their berths is discussed. Loss Prevention Circular No. 13-08 looks at increased incidents of moored vessels breaking out of their berths. According to Gard (2013), themajority of incidents occurred during periods of severe weather accompanied by very strong winds (as a climate variable) which acted on vessels.

2.5.2 Climate variables and associated impacts on maritime navigation

According to Mojafi (2014) vessels moving in and out of port are likely to be affected by high tides, winds and waves. The analysis of Hawkes et al. (2010) concurs, highlighting that higher waves are produced at the behest of increasing wind speeds and this combination has a potential to have direct effects on navigation. This may lead, Hawkes et al. (2010) continue, to delayed departure time for ships at terminals and consequences of such may include increased berthing times which in turn may require larger areas for waiting vessels to be anchored hence the standard of service of port is affected.

2.5.3 Navigation entrance channel practice

According to Demirbilek and Sargent (1999) harbours and ports have entrance channels as their initial point of entry, consequently various environmental and or transit conditions are influencedby various factors. Luettich, Westerlink, and Scheffner (1992) identify water levels and currents (tidal) as some of these factors. Effects of winds, waves, tides, currents, visibility, and navigationaids are factors that ensure safe operation within a channel (Demirbilek and Sargent, 1999). Operation of channels also needs to consider other factors like the density and type of traffic (whether it is one- or two-way traffic), ship speed, turning basins, and tug assistance (Grayet al. 2003). However, factors like waves, ship speed and resultant vessel motion effects in the navigable channel are less understood (Demirbilek and Sargent, 1999).

2.5.3.1 Wave prediction for channels

Demirbilek and Sargent (1999) remark that entrance channels design and operations make use of wave information; this is because wave climate at the channel site informs the establishment of appropriate navigational aids and the design vessel hydrodynamics and maneuvering characteristics, size and orientation of the channel (Da Conceição, 2018). Similarly, prediction of vessel motions and maneuvering characteristics for navigation channels, ports and harbours also relies on the wave information (Gray et al., 2003).

2.5.3.2 Factors influencing vessel transit

United States Army Corps of Engineers (USACE) assessments indicate that vessel transits in channels are affected by major operational factors that include wind, wave, and current conditions; visibility (day, night, fog, and haze), water level (including possible use of tidal advantage for additional water depth), traffic conditions (one- or two-way, cross traffic), speed restrictions, tug assistance and pilots, underkeel clearance, and ice (USACE 1984, 1995, 1999). Further, Demirbilek and Sargent (1999) point out that the depth requirements (which are largely restricted at low water) for vessels, may be reduced by tides and or water level fluctuations that enter into entrance channel design. Thus port access where channel usage is limited to high tide can be affected adversely (Busath, 1993). For instance, abrupt change of prevailing wind speed, surface currents, vessel speed, and position relative to channel banks may induce challenges to maneuvering (Infrastructure, 2013). Similarly, the mouth entrance channels may be unstable due to crosscurrents, winds, waves, and channel shoaling (Burchartch and Hughes, Part IV).

2.6 Maritime safety guidelines, requirements and legislation

South Africa is also a signatory to international standards on port operations and management under the International Maritime Organisation (IMO) and hence should adhere to these guidelines. The list of Treaties and Protocols ratified by South Africa under the IMO include;

- International Convention for the prevention of pollution from ships
- Protocol to the International Convention for the prevention of pollution from ships
- International Convention on Maritime Search and Rescue
- International Convention for safe containers
- London Dumping Convention
- International Convention on Tonnage Measurement of ships
- International Convention on standards of training and watchkeeping of seafarers
- International Convention on Civil liability for oil pollution damage
- Convention on the International regulations for preventing collisions at sea
- International Convention for the Safety of Life at Sea

- International Convention on Load Lines
- Convention on the International Maritime Satellite Organisation
- Torremolinos International Convention for the Safety of Fisshing Vessels
- International Convention on Standards of Training, Certification and Watchkeeping for Fishing Vessel Personnel
- International Convention on Oil Pollution Preparedness, Response and Co-operation
- International Convention on the Control of Harmful Anti-fouling Systems on Ships
- International Convention for the Control and Management of Ship's Ballast Water and Sediments
- Convention for the Suppression of Unlawful Acts Against the Safety of Maritime Navigation and its Protocol for the Suppression of Unlawful Acts Against the Safety of Fixed Platforms Located on the Continental Shelf (SUA Treaties)

  [Source: http://www.dirco.gov.za/foreign/Multilateral/inter/imo.htm]

The South African maritime legislation is better placed to influence investments that can help ports adapt to emerging environmental conditions; however, this body of legislation has yet to reform and take into consideration the issue of climate change. At the centre is the National Ports Act 12 of 2005, which sets the establishment of the National Ports Authority and provides for the port rules in terms of vessel navigation control, movement and berthing within the port. Together with the act, South African ports should follow the Inter-Governmental Maritime Consultative Organization (IMCO) which provides for basic principles and operational guidance relating to navigational watch-keeping. Also available are the IMO Standard Maritime Communications Phrases which serves to assist in guiding with the ship conduct and navigation safety as well as ensuring that communication across marine operations and specifically at the harbours is in a standardized language. In addition, there are Bridge Resource Management (BRM) principles that were adopted by the IMO in 2003 which put an emphasis on the proper exchange of information that is essential to a safe transit among the bridge team.

Issues of weather and safe navigation at sea are well covered by the National Ports Act (12/2005), and safe navigation of the ship and complying with the regulations under different circumstances including weather conditions are also covered under IMO Standard Maritime Communications Phrases. However, there is no acknowledgement of the reality of extreme weather conditions likely to be exacerbated by the occurrence of climate change and the effects on port operations in these documents. The Comprehensive Maritime Transport Policy (CMTP) for South Africa of 2017 does acknowledge climate change as responsible for current and future impacts to the maritime industry under CMTP Policy Statements (23) of desired outcomes however there is no specific section that is looking in detail on the subject of climate change. Even under the sub-section of environment and energy there is nothing that relates to issues of climate change or extreme weather conditions for that matter.

2.7 Chapter summary

Literature analysis shows that out of the three climate variables of relevance to this study, which are sea level rise, wind and wave, the mean sea level rise only affects the infrastructure whilst wind and wave affects both infrastructure and vessel navigation. The driving weather patterns seem to be synonymous for all three variables and in most cases these are associated with patterns of a cyclonic nature. Literature also shows that impact on infrastructure by these variables has a potential to affect operations and services depending on the level of their intensityand the level of damage. Further highlighted by the literature review is a lack of consideration of climate change-driven extreme weather conditions by the policies and legislations (old and new) in the country. Although issues of environmental sustainability and maritime safety highlight the need to be vigilant to weather changes, however recognizing climate change as a phenomenon already affecting the marine sector and that which has a potential to affect the sector severely in the future, is evidently absent. The next chapter will discuss the research methodology and research approach in terms of various research instruments employed by the study as well as datacollection and analysis.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter first discusses the term research in the context of methodology and design. Research methodology reflects how an inquiry into the study proceeds; this relates to a particular approach which covers analysis of the assumptions made as well as the principles and procedures in the inquiry (Schwardt, 2007). On the other hand, the research design aims to ensure that the research delivers outcomes that are credible, as MacMillan and Schumacher (2001) assert. In order to provide relevant answers to the research questions, the research design provides a plan for selecting subjects, research sites, and data collection procedures (MacMillan and Schumacher, 2001).

This chapter further looks at the paradigm and the research types before proceeding to the approach best suited for this type of research study, discussing in detail the components of the research approach adopted. Then the chapter explores the data collection techniques, which involve gathering existing facts and information relating to the study. Then the data analysis approach follows, which mainly establishes an evidential basis to support this research argument. Ethical considerations adhered to in the research are also covered before concluding on the chapter.

3.1 Research Methodology/Paradigm

This study seeks to review precautionary thresholds at seaport precincts on account of intense coastal weather and sea state conditions in the principal commercial harbours in KwaZulu-Natal. The assumption made here is that seaport precautionary thresholds are developed informed by the weather variables or climate variables thresholds.

The research focus is on the KwaZulu-Natal coastal area but specifically looking at the two commercial harbours, Richards Bay harbour and Durban harbour, both managed by the Transnet National Ports Authority (TNPA). Part of the required information relates to the time of occurrence of the two major events that form the focus of this research – the loss of the bulk carrier ***MV Smart*** in Richards Bay in August 2013, and various casualties of the great storm in Durban in October 2017. The envisaged approaches of data gathering will entail sourcing publicly available data from relevant platforms as well as conducting open-ended interviews withexperts involved in the aspects of maritime industry operations. The interest is on the time at which the grounding and subsequent loss of the vessel occurred and the issuance of the warning for the Richards Bay port: whilst for the

Durban port interest is on the time at which damages to the infrastructure were observed, and the time of dislocation of the vessels inside the port as well as issuance of the warnings.

Clearly this study focuses mainly on the ‘what’ and ‘how’ of the research problem and accordingto Creswell (2003) it follows a broad paradigm of pragmatism, as it is not committed to any one system of philosophy. This then sets the research problem at the centre and subsequently the research question(s) becomes central and thus dictates that data collection and analysis methods follow no other alternative paradigm in order to provide insights to the research problem (Creswell, 2003: 11). A pragmatic approach therefore involves determining for the research problem the best suited method; however, there are no limitations, it can be quantitative or qualitative research aligned methods, techniques and procedures (Johnson, Onwuegbuzie and Turner, 2007).

3.2 Research Approach

According to Chetty (2016) what determine research approach are mainly the study topic and the research problem. It thus, projects, as Chetty explains further, steps for data collection, analysis and interpretation as part of research concept plans and procedure. Sukamolson (2007) highlights methods of information gathering, objectives for the research and the application of the research study as the main determinants of research classification into threecategories. However, since different researchers have different criteria of classifying research, research types are therefore not limited to three. Pettigrew’s (1990) analysis classifies research as historical, present or futuristic depending on thetime differences between that of occurrence of the event being investigated and that when the data are collected for investigation.

This research is a historic research as it investigates past occurrence of August 2013 and October2017. Data collection methods for investigation involves visiting sites to observe and interact (interview) with participants who possess better understanding of real-life operations at the environment under study as well as documents review on issues leading to the occurrences understudy. Bryman (2006) accentuates that out of a number of different research methods that conduct participant observations, case studies, interviews and more, as part of research approach activities, the qualitative research consists a combination of most of such activities in its approach. This study therefore is more inclined to a qualitative research method with most of the above mentioned activities constituting its research strategy.

3.2.1 Qualitative Research

Qualitative research involves interaction with people or target audience as well as association with the situation or culture of the area under study (Weinreich, 2009). Hoepfl (1997) asserts that the type of research results produced when the qualitative paradigm is applied, are bound to differ greatly across different researchers due to the fact that the instrument of data collection is asole choice of that researcher and thus not common. The researcher method of collecting data may include unstructured interviews (open-ended), direct and participant observations, as well as document analysis and overview for the qualitative research (Voss, 2010).

(i) Basis for the Use of a Qualitative Methodology

Hoepfl (1997) in his assessment points out a number of considerations necessary to assist decision by a researcher opting for the qualitative approach. The first consideration involves ascertaining existence of a phenomenon of which very little is known, but which the research aims to better understand (Strauss and Corbin, 1990). The second consideration revolves around things already known yet on which the researcher aims to provide new perspectives (Hoepfl, 1997). The third consideration is that which involves situations impossible to interpret (Hoepfl, 1997).

(ii) Features of Qualitative Research

One of its features according to Patton (1990) is that data collection needs to be initiated first before it can be appropriate to finalise research strategies; this is so as to allow the researcher to observe and interpret meanings in context. Two other features involve upfront specification of the strategies in the proposal of data collection plans and the primary questions to be explored bythe research (Hoepfl, 1997). Sample size limitations as Patton (1990) asserts do not follow any specific criteria and the information type together with the purpose of inquiry determines the design of the qualitative study (Lewis, 2015). Eisner (1991) underscores the non-reliance on statistical test of the qualitative studies as a way to justify results but broadly utilizing multiple forms of evidence whilst the study's usefulness and credibility is left at the discretion of the researcher as well as the reader.

(iii) The Role of the Researcher in Qualitative Inquiry

Lincoln and Guba (1985) advise of the considerations that need to be taken by the researcher before conducting a qualitative study. The first advice is about "the researcher taking thenaturalist paradigm approach as part of the research.” Secondly, “the collection and interpretation of data requires the researcher to possess or hone appropriate skills.”

3.3. Data Collection Techniques

This study follows a qualitative research approach and according to Bogdan and Biklen (1982), other data techniques like document analysis, and observation can form part of a collaborative data collection strategy with qualitative interviews being the primary strategy. For the purpose ofthis study a collaborative strategy is necessary. Therefore in addition to site interviews, the observation of the sites at which the events occurred as well as the infrastructures in question forms part of the strategy. Documentation analysis that guides operations and the decision making during the occurrence of severe weather is also of particular interest for the study.

3.3.1 Interviews

There are three types of interviews that Jennings (2005) has highlighted and these include conversational interviews (mostly informal), semi-structured interviews (open and allow for new ideas during the interview), and open-ended interviews (more standardized and have no pre- determined limit). The open ended-ended type of questions is associated with the qualitative interviewing (Patton, 1990).

A mixture of these three types of interviews as detailed above is conducted in this study and this, according to Qu and Dumay (2011), allows for variations. Such an approach assists in achieving one of the research objectives, which is to explore the potential revision of the existing thresholds used to decide halt of port operations and cessation of vessels movement at the port precinct during extreme weather conditions.

Consequently, by appointment sessions to conduct in-depth varied interviews with experts involved in the aspects of maritime industry operations for both incidents were planned and conducted. In the case of the vessel lost while exiting Richards Bay port, the focus of interviews is on the behavior and handling of different vessels of different sizes as entering or leaving the port entrance waters under heavy weather and unstable sea state conditions; on general precautionary measures practised for a vessel navigating such conditions; as well as details on process followed on that particular day. Similarly, the focus of interviews for the Durban case is on the thresholds that inform operations cessation on account of inclement weather and the impact of extreme climate variables on physical infrastructure at the port precinct, as well as monitoring and ensuring stability of anchoring vessels of different sizes within the port precinct.

3.3.2 Documents reviews (analysis)

Hoepfl (1994) believes the analysis of documents such as newspaper accounts, official records, published data, diaries and reports provides a qualitative research with an invaluable source of information. In order to supplement data gained through interviews, Hoepfl (1994) utilised newspaper reports, university policy documents as well as self-evaluation data in her study of closure of technology teacher education programmes.

Similarly, this research has an objective to review the manner in which meteorological forecasts and warnings are put into use at the seaports (specifically within the specified port limits) and thus in addition to interviews, the study has conducted document analysis. One aspect involves working on published data used in literature review in order to identify relevant climate variablesthat may have played a role in both occurrences. In order to get a picture of the weather systems and patterns that prevailed on the two days of interest, assessment of newspaper accounts, synoptic weather charts as well as numerical weather models forms part of the study. Analysis ofthese documents should also further provide details of weather conditions on the days preceding the events as well as during the days of the events at each port. Lastly, the study has interrogated existing port regulation(s) as well as the international guidelines for port operations in order to assess the stipulated requirements for adherence during bad weather and unstable sea conditions at the harbour.

3.3.3 Observations

This is an instrument applied in order to be able to describe what is observed as well as its meaning, which can include the settings, activities and people as part of observational data make up (Hoepfl, 1994). Patton (1990) describes this instrument as a way to assist the researcher to uncover what might have been ignored or what could have been deliberately hidden and as a result lead to clearer and deeper understanding of events of interest as they occurred.

During the interview sessions, the observational data to be gathered serves to respond to one other objective of the research, which is assessing the manner in which seaports take extra precautionary measures during climate change driven occurrences. General harbour settings as well as activities undertaken during the occurrence of the events of study interest should assist to verify the usefulness of meteorological forecast and warnings issued. This relates to windconditions and sea waves, (or the current) strength especially for conditions inside port limits. Based on the verifications outcomes the study can possibly determine whether with climate change occurrence the forecast meteorological conditions are suitably applicable for the seaport precinct, specifically for conditions at the port entrance/exit and inside the port. The study would also aim to determine whether the existing thresholds used to decide halt of port operations and cessation of vessels movement at the port precinct are still relevant as well as whether general existing port safety regulations, standards, good practices remain relevant.

3.4 Data analysis

Activities that form part of qualitative data analysis as defined by Bogdan and Biklen (1982: 145) include deciding what you will tell others, discovering what is important and what has to belearned as well as searching for patterns and all this follows once data has been organized, broken into manageable units and synthesized. The researcher deals with raw data and therefore needs to skillfully place this data into logical and meaningful categories such that it is creatively examined in a holistic manner to ensure proper communication of the interpretations to others (Hoepfl, 1997). Burnard et al., (2008) identified two approaches to analyzing qualitative data. These are deductive and inductive approaches, which are the most fundamental out of a variety of different ways. In a deductive approach, interview transcripts analysis is approached from an angle of having probable responses expected out of participants (Burnard et al., 2008). Conversely, the inductive approach uses the actual data in order to build the structure of analysis without any preconceived expectations of probable responses from participants (Burnard et al., 2008). This study will therefore embark on an inductive approach in deriving the structure of analysis based on the themes below;

3.4.1 Analysis of general weather patterns along KwaZulu-Natal coast

The study performs trend analysis of weather systems (the driving climate variables) and sea conditions (wave behaviour) in order to determine general weather patterns along the KwaZulu- Natal coast during different seasons. This specifically looks at the weather systems, the wind component as well as the sea wave characteristics that prevailed in the Durban harbour area on 10 October 2017. Similarly, for 19 August 2013 the study looks at the weather systems, wind strength and sea wave levels that prevailed in the Richards Bay port area. It further looks at the detailed accounts from the literature and media reports.

3.4.2 Analysis of maximum intensity levels reached by the climate variables

In order to determine intensity of the climate variables posing risk to the port infrastructure and operations as well as on navigating vessel, analysis of a list of climate variables with potential to affect port infrastructure long-term performance and the vessel resilience is performed. As a way to reconcile information gathered from interviews and document reviews the study analysis first considers the recorded maximum levels reached by the climate variables on both days of interest from climatic records. Then comparison is drawn between the times at which climate variables reached extreme levels against the time at which actual incidents occurred. At the Richards Bay port, the time of extreme climate variables was compared with the time at which the exiting vessel was wrecked just outside breakwaters. In the Durban port case, the time of extreme climate variables was compared with the time at which infrastructure damages happened as well as the time at which berthing vessels were blown out of positions by a strong wind.

3.4.3 Impact analysis of maximum intensity levels of climate variables on port physical infrastructure and vessels within the port precinct

Elements of physical port infrastructure of relevance for this study's attention include berthing structures, protection barriers, port superstructure, cargo handling equipment, ship to shore cranes, buildings and channels. Analysis comprises comparison of the impact level on affected vessels and port infrastructure within port precinct during the 10 October 2017 severe storm at the Durban harbour with the maximum intensity of relevant climate variable(s) directly responsible. Also compared is the level of damage to a navigating vessel on 19 August 2013 at Richards Bay harbour with maximum intensity and behavior of climate variables directly responsible.

Then based on the already determined intensity of relevant climate variables together with the information from the open-ended interviews with relevant experts, analysis interrogates: 1) the navigating vessel resilience under severe weather and sea state conditions at Richards Bay harbour in relation to the 19 August 2013 conditions; and 2) the resilience of berthed vessels under severe weather and sea state conditions in Durban harbour in relation to the 10 October 2017 conditions.

3.4.4 Analysis of meteorological forecast issued for general sea condition and its relevance for port precinct boundaries.

As a standard practice, predictions of the wind strength and sea wave levels are issued in advance by the Weather Office as part of general marine weather forecast and warnings covering the broader coastal areas. The study sets out to determine and analyse the relevance of such predictions for the conditions within port precinct boundaries. The study analysis therefore compares the actual recorded (or reported) sea wave levels and stability during the 19 August 2013 occurrence at the Richards Bay sea port precinct against the predicted levels. Similarly, it compares the actual wind strength and the sea state recorded (or reported) at the Durban sea port precinct on 10 October 2017 against those predicted. The study further looks at the manner in which meteorological forecasts and warnings are communicated from the shore-side Vessel Traffic Service (VTS) to the on-board bridge team as well as among the bridge team. The study assesses the level of adherence to existing regulation(s) as well as the international guidelines and their effectiveness.

3.4.5 Analysis of the existing minimum thresholds that warrant halt of port operations and cessation of vessels movement within port precincts

Generally, minimum thresholds should be guided by standard operating procedures (international practice) to guide decision criteria that warrant port operations halt as well as cessation of vessel navigation in and out of the harbour during severe weather occurrence. The extreme levels reached by climate variables and weather parameters with a potential to lead to physical port infrastructure failure and operations disruptions or damage to vessel in navigation (based on engineering and physics) should inform the minimum threshold. The study therefore analyses theconditions that trigger the application of minimum thresholds. This is informed by the earlier analysis of maximum infrastructure performance levels and its point of break as well as the resilience capacity of a vessel (based on engineering and physics) navigating under maximum intensity levels of climate variables. Analysis further assesses any shifts (to higher than stipulated) in minimum thresholds requirement for both precincts. In order to achieve this, comparison of the extreme events in question against previously recorded extreme events at comparable levels of climate variables is conducted. The margins of shift should provide a yardstick to assess the relevance of standard operating procedures as well as the currently stipulated minimum thresholds in relation to global climatic changes.

3.5 Ethical considerations

This study adheres to the University of KwaZulu-Natal research policy which guides on whether the research is ethical and conforms to a code of conduct that guides students and staff around the ethics of research. The study therefore considers ethical matters relating to the storage of data collected, confidentiality, authorship and publication mainly relating to proper citation of people who are the source of information to the research. The planned collaborative data collection strategy which includes in-depth open-ended interviews with experienced individuals involved in aspects of the maritime industry operations and undertaking site observations, took place once ethical clearance (Appendix 3) approval for the study had been granted by the Ethics Committee.

3.6 Chapter Summary

This chapter, guided by the objectives of the study categorised the research approach as pragmatic and a method that would provide depth and meaning in responding to research questions to be qualitative. The research content (informed by publicly available information and responses from interviewed participants) for which this chapter provides a framework will be incorporated as part of research analysis. The research strategy then places a duty on the researcher to categorise collected raw data into logical and meaningful information before exploring and interpreting such information to provide a descriptive account of the study. Consequently, this chapter has outlined a thematic content analysis process to be followed by the study; this involves transcripts analysis, themes identification as well as associating themes with previous case studies from the literature. The outcomes of the analysis will then be presented in Chapter 4.

CHAPTER 4

RESULTS: PRESENTATION ANALYSIS AND DISCUSSION

The main objective of this chapter is to outline detailed discussion of the sequence of two recent major weather-related events at the two KwaZulu-Natal commercial harbours and to present analysis outcomes. The chapter first discusses and provides analysis of the Richards Bay harbourincident, which occurred on 19 August 2013. On this day, the fully-laden 151,000 dwt bulk carrier ***MV Smart*** ran aground on a sandbar off the port entrance while attempting leave port in heavy swells. The chapter then proceeds to a discussion and analysis of the Durban harbour incident, which occurred on 10 October 2017 during a heavy storm. On this day five vessels that were berthed in various areas of the port broke their moorings and were blown across the harbourin an uncontrolled fashion by the very strong winds. During this incident, the ***MSC Ines***, the ***SM New York***, the ***Bow Triumph*** as well as the SA Shipyard floating dock with the new harbour tug had to be re-floated. The 330-metre long container vessel ***MSC Ines*** ran aground across the harbour mouth, temporarily blocking the port entrance. Two other vessels, ***MSC Susanna*** and ***Maritime Newanda***, broke moorings and had to be held by harbour tugs to prevent them also running aground.

The chapter presents outcomes for each incident. It begins with a review of ports layout observations and assessments which are complemented by the relevant interviews in order to locate each incident. The discussion and analysis of reported and recorded conditions together with relevant interviews then follows. Permission by the Transnet National Port Authority (TNPA) was not granted for the researcher to conduct in-person observations as well as face-to- face interviews at both sites of incidents occurrence. As a result, perceptions, insights and opinions elicited through open-ended interviews with experienced individuals involved in the aspects of the maritime industry operations have been incorporated. These are featured as part of the port layout observations and assessments as well as discussion and analysis of reported and recorded conditions. The interviewed participants are specialists possessing understanding in different aspects of the maritime industry operations. These areas of specialist understanding were as follows:

- Respondent 1 possessed a specialist understanding of port precinct layout;
- Respondent 2 possessed a broad general understanding of sea state conditions;
- Respondent 3 possessed a familiarity with port operations and standards;
- Respondent 4 possessed an understanding of Durban harbour near-shore water dynamics;
- Respondent 5 possessed a specialist understanding of wave hydrodynamics and vessel behavior; and
- Respondent 6 was familiar with general and marine meteorological conditions.

The details of specific areas of specialisation within the maritime industry and operations for each interviewed participant are provided in Appendix 1.

The presentation of results reflects an inductive data analysis approach applied in accordance with the methodology of the study. Sites layout observations and assessments are based on the existing Google map pictures and images sourced from various specialist studies. Opinions from interviews with personnel familiar with the sites of focus provide confirmation of the current layout and conditions of the two harbours of Durban and Richards Bay. For each harbour, assessments illustrate positions of incident occurrence. In the Richards Bay case the one vessel affected, the ***MV Smart*** ran agroundonto a sand bar off the port entrance shortly after setting sail. In the Durban case, the five vessels that were affected broke from moorings at their respective berth and had to be re-secured before (or in some cases after) running aground. The container vessel ***MS Ines*** vessel ran aground across the port entrance blocking access and had to be re-floated by five tugs before she was safely secured alongside a berth. AIS tracking plots that could be sourced for some vessels leading up to and during the time of accident occurrence are also presented. Further, opinions from interviews conducted with personnel operating in the respective port precincts are also presented.

Documented conditions discussion and analysis first presents weather systems and associated conditions that prevailed a day prior to and on the actual day of respective incident occurrences at both harbours. This entails a thorough review of weather systems that prevailed during both incidents, making use of the sea level synoptic charts and recorded real-time data. Then the analysis of the wind component (5 minutes data) as influenced by the relevant weather systems follows. This is followed by the assessment of sea state conditions for 19 August 2013 and 10 October 2017 respectively, in the Durban East deep waters territory between 00:00 and 12:00 SAST as well as the wind conditions that prevailed at the port entrance and inside the port. Detailed account of events on the days of interest, the damages and impact on operations at the two harbours as reported in various platforms follows. This is followed by the analysis of the influence of sea state conditions on the stability of vessels, supplemented with opinions from interviews to ascertain the vessels' response and manoeuvring behaviour under such prevailing sea state conditions. Finally, discussion of coastal marine weather pre-warnings issued on both days is then presented, supplemented with opinions from interviews to provide insight in termsof the procedure followed as well as time and frequency of issuance of such warnings.

4.1 Positions of the harbours of interest and relevant features.

The areas of interest for this study fall under a large area called METAREA VII (Figure 4.1.1), as prescribed by the Safety of Life at Sea (SOLAS). This area is managed by the South African Weather Service (SAWS) as directed by SOLAS in terms of providing coastal and ocean weatherforecasts as well as warnings for both deepsea and near-shore zones.

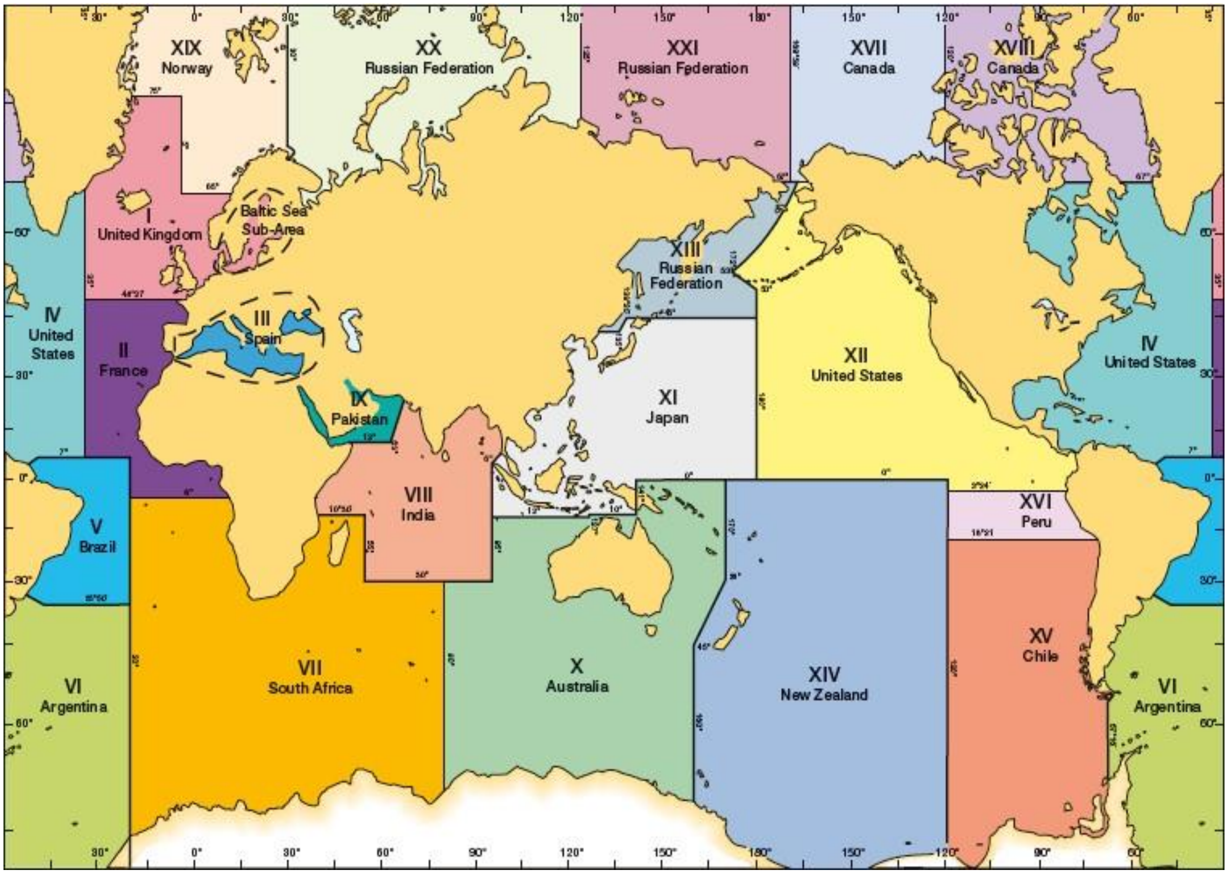

Figure 4.1.1: METAREAs for coordinating and promulgating meteorological warnings and forecasts (Source: WMO Manual on Maritime Safety Information)

METAREAs are sub-divisions of the NAVAREAs into Sub-Areas in which countries have coordinated systems for the promulgation of maritime safety information. METAREA VII overseen by South Africa has Sub-Areas which include Richards Bay and Durban harbours. These are the two commercial ports in the KwaZulu-Natal province within the Sub-Area 14 which is the Durban East area of METAREA VII (Figure 4.1.2).

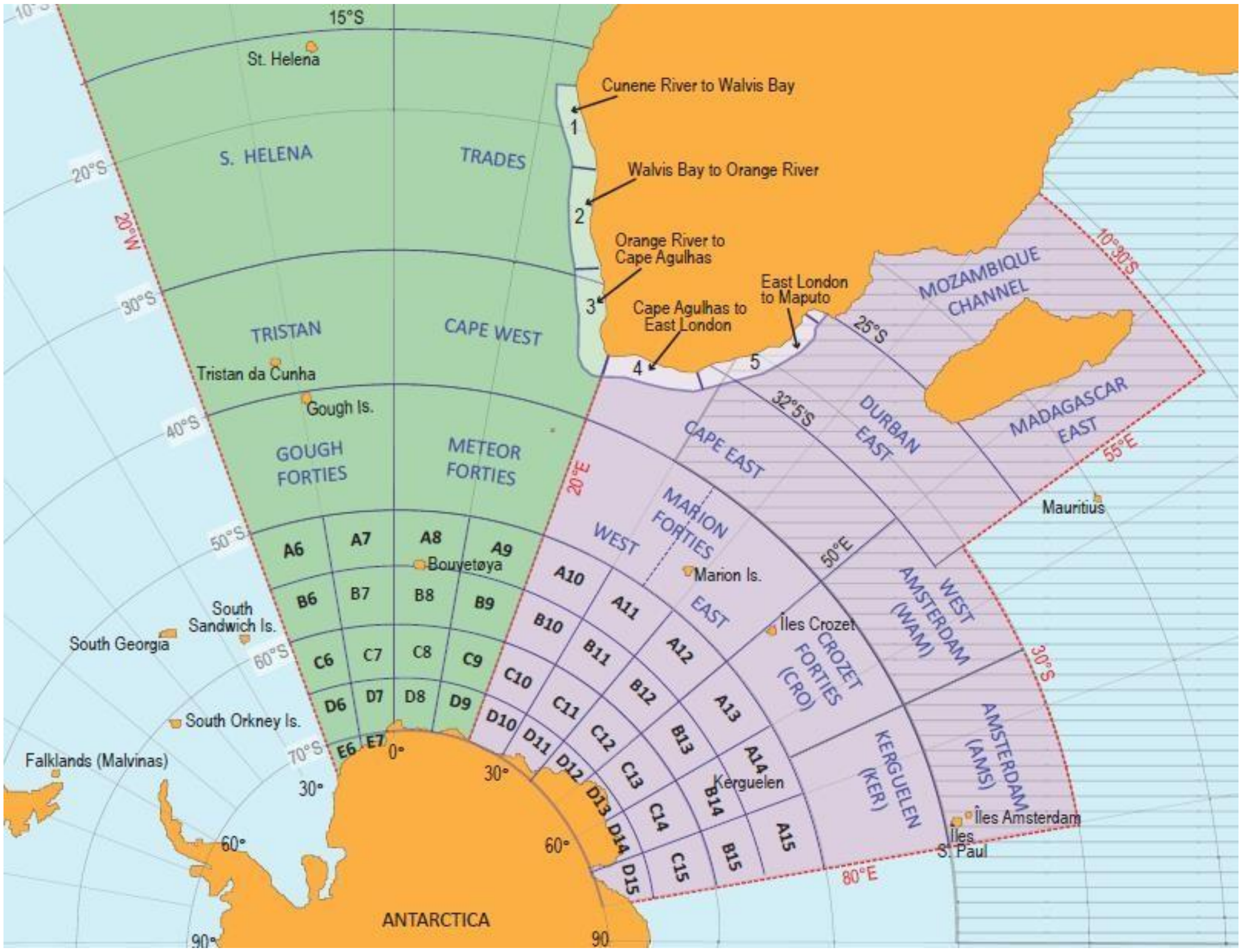

Figure 4.1.2: METAREA VII South Africa SafetyNET Forecasts (Source: WMO No 9 - Weather Reporting -- Volume D - Information for Shipping)

4.2 Richards Bay harbour incident – Layout Observations & Assessments (with the relevant interviews)

According to available report records, on 19 August 2013 the ***MV Smart***, a fully-laden Capesized dry-bulk carrier, ran aground while on exit from Richards Bay harbour. As reported in various platforms, shortly after setting sail from the Richards Bay Coal Terminal the 151,279 DWT bulk carrier ran onto a sand bar. The vessel was reported to have broken into half between 13:00 and 14:30 SAST off the Richards Bay port entrance.

4.2.1 The Richards Bay harbour layout

Richards Bay port is located 28˚ 48’S, 32˚ 02’E of METAREA VII. Layout depiction of differentparts of the port is shown in Figure 4.2.1 including the port entrance channel which is of interest to this study. The entrance channel is maintained to a depth -23.9 m CD offshore of the breakwaters, -21.9 m CD just inshore of the breakwaters and -19.4 m CD along most of the entrance channel (Figure 4.2.2). Respondent 1 confirms that dredging has to maintain channel depth slightly below or slightly above 20 m. This is in order to allow the possibility of handling larger ships, up to 20 m draught (about 250 000 DWT). Further, Respondent 1 highlights that Richards Bay port is mainly an export port for coal; as a result, large bulk carriers normally enterthe port light (about 10 to 12 m draught) and leave loaded (up to 17.1 m draught). Therefore, portlayout has to make provision for such activities.

Figure 4.2.1: Richards Bay Port key characteristics (Source: Port of Richards Bay Capacity Expansion EIA, Joint WSP/CSIR Report CSIR/NRE/ECO/ER/2015/Draft)

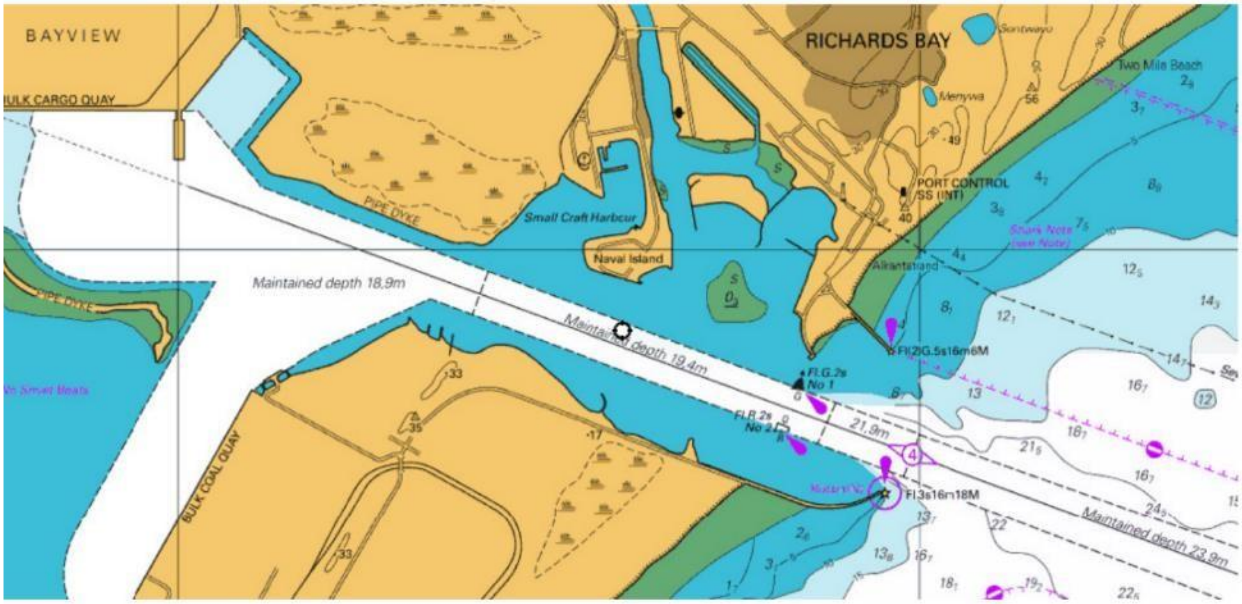

Figure 4.2.2: Richards Bay Harbour (Marine Chart: ZA_4174_0) [Source: GPS NAUTICAL CHARTS]

4.2.2 The Richards Bay port precinct characteristics of the tidal flow

Areas of pronounced tidal currents in Figure 4.2.3 depict conventionally north-easterly tidal flowalong the Mudflats. The port entrance channel is conventionally subject to south-easterly tidal currents. Respondent 2 confirms that the tidal flow depicted on Figure 4.2.3 can be taken as a conventional pattern followed by the currents at this port. Respondent 2 further notes that although this analysis is based on model data (and hence does not depict concise flow), it does, however, provide a best estimate for the port. Respondent 2 also highlights that the predominant wind direction at this harbour for a particular time of the day during a certain season is known, but further cautioned that there may be changes on year to year in terms of wind mean velocity.

Figure 4.2.3: Schematic representation of the major hydrodynamic processes for Richards bay harbour (CSIR Dredging and Dredge Spoil Disposal Modelling Specialist Study)

4.3 Richards Bay harbour incident – Analysis and discussion of documented conditions data (with relevant interviews)

The correlation between weather systems that prevailed on 19 August 2013 and the climatic variables to influence the sea state conditions as recorded contributed to the incident occurrence. The magnitude of impact is determined by the position and movement of the vessel under such a sea state in relation to the intensity of the climate variables.

4.3.1 Weather systems that prevailed over Richards Bay on 18 & 19 August 2013

On 18 August, a day before the incident, an Atlantic high coming from the west extended a ridgeto the east coastal areas, pushing behind a cold front that was situated further south-east of the coastal waters (Figure 4.3.1).

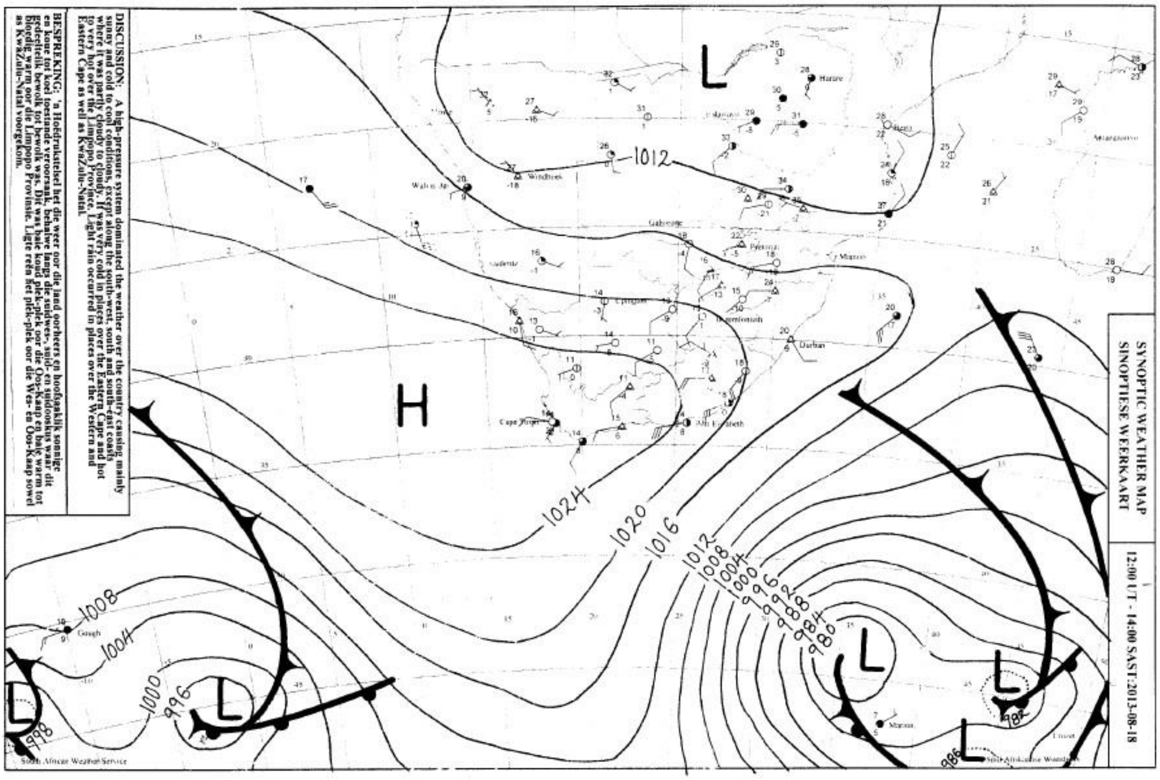

Figure 4.3.1: Sea level synoptic chart for Southern Africa for 18 August 2013 at 12:00 - 14:00 SAST (South African Weather Service)

On the 19th a bulging high pressure system dominated the west coast as well as the south and the east coast. The high had broken into an Atlantic high situated in the west coast and an Indian Ocean high dominating the southern as well as the eastern coastal areas. The Indian Ocean high pressure system remained fairly strong at 1024 kPa while moving eastwards. Kruger et al (2010), identified the implications of an Atlantic high pressure system that remains strong as it moves eastwards extending a ridge to the eastern parts, especially during winter, as being the associated strong winds with a potential of spreading to the entire KwaZulu-Natal coast. It is therefore expected that the anticyclonic flow associated with this system (Figure 4.3.2) produced strong southerly to south-easterly onshore flow wind along the east coast of the Durban East area. It canalso be noted that such strong southerly to south-easterly winds would be blowing against the conventional tidal current (Figure 4.2.3) at the port entrance. According to Respondent 2, when the tide sets against the wind the waves become considerably steeper and the sea state become considerably rougher.

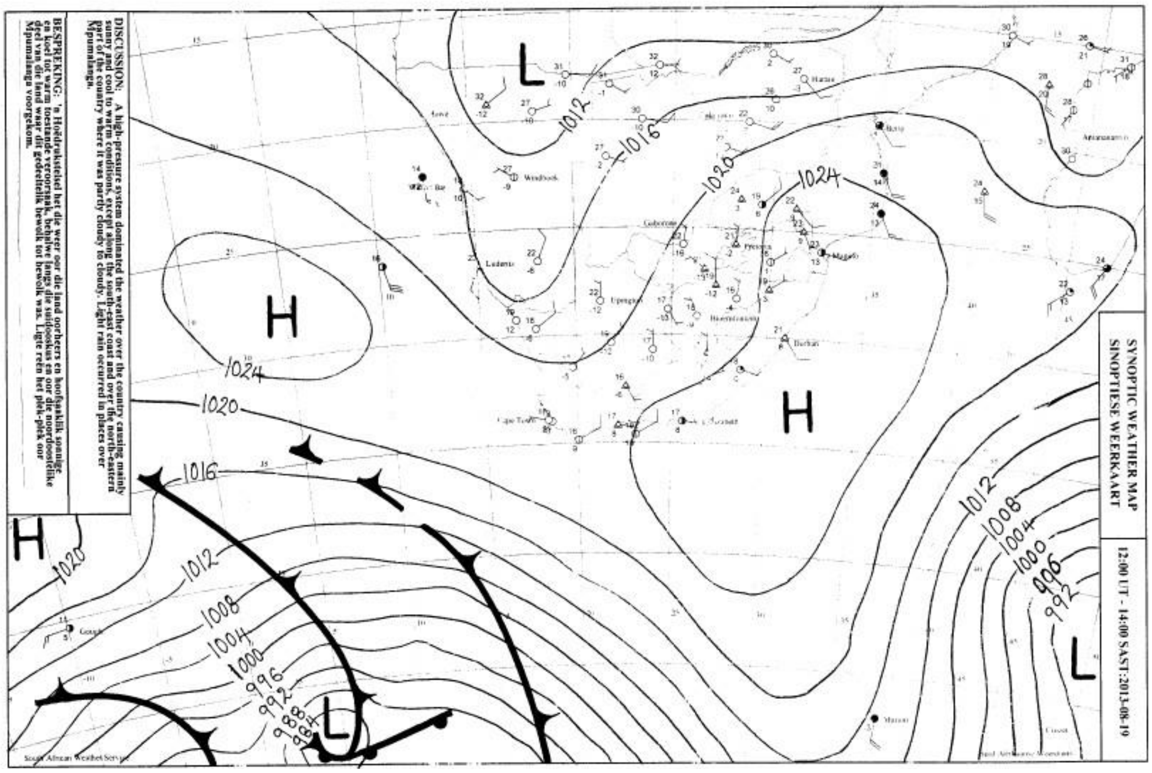

Figure 4.3.2: Sea level synoptic chart for Southern Africa for 19 August 2013 at 12:00 - 14:00 SAST (South African Weather Service)

4.3.2 Wind conditions that prevailed at the port entrance vicinity few minutes before incident occurrence

The time of initiation of vessel navigation and time of incident occurrence as depicted on the vessel navigation track (Figure 4.3.3) was between 11h11 and 12h23 GMT or 13h11 and 14h23 SAST. The time series five minute climatic data (Table 4.3.1) for Richards Bay shows gusty winds between 13h11 and 14h23 SAST. A wind gust of over 8.0 m/s dominates for most of the period with an apparent gust of 9.4 m/s showing around 14h05 SAST which subsequently drops to 8 m/s and below afterwards. Wind direction varies from a south-westerly, southerly to south- easterly direction during this period with the wind speed between 5.3 and 6.4 m/s (10.30 and 12.44 knots). Respondent 2 notes that the wind is mainly responsible for generating the surface waves at sea and that the size that the waves grow into increases with wind strength. Machutchon

(2006) explanation of this wind and wave dependence states that waves of many lengths will exist at the same time in a short crested field as a result of a gusty wind that is stronger than the critical wind speed.

Climate Number	Station Name	Date and Time	Wind Speed	Wind Direction	Gust	Temp	Hum	Pressure	Rain
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:00:00 PM	5.80	184.80	8.70	21.00	42.00	1,023.10	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:05:00 PM	6.40	178.10	8.50	20.90	40.50	1,023.10	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:10:00 PM	6.10	180.20	7.90	20.80	42.30	1,023.10	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:15:00 PM	6.00	179.10	7.70	20.80	40.70	1,023.00	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:20:00 PM	5.50	181.80	7.60	20.90	41.70	1,023.30	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:25:00 PM	6.20	177.80	8.20	20.80	42.40	1,023.10	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:30:00 PM	6.20	178.70	8.60	20.60	44.10	1,023.30	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:35:00 PM	5.60	191.00	8.10	21.10	41.90	1,023.10	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:40:00 PM	5.40	176.30	7.40	21.00	43.70	1,023.10	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:45:00 PM	5.80	182.50	7.70	20.60	45.00	1,023.00	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:50:00 PM	5.70	182.60	8.20	20.70	44.80	1,023.00	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 1:55:00 PM	5.90	176.60	8.60	20.50	44.20	1,023.00	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 2:00:00 PM	6.10	176.70	8.90	20.40	42.50	1,023.00	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 2:05:00 PM	6.20	176.30	**9.40**	20.30	45.00	1,023.00	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 2:10:00 PM	6.00	173.00	7.80	20.50	44.40	1,023.00	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 2:15:00 PM	5.70	180.10	7.60	20.40	45.90	1,023.00	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 2:20:00 PM	5.30	179.90	7.50	20.30	47.20	1,023.00	0.00
0305134 6	RICHARDS BAY AIRPORT	8/19/2013 2:25:00 PM	5.90	174.60	8.00	20.40	46.00	1,023.00	0.00

Table 4.3.1: Richards Bay time series five minute climatic data (South African Weather Service)

4.3.3 Sea state at the Durban East territory between 00:00 and 12:00 SAST

The wind and wave data comes from the weather observations reported by moving ships situated deep sea of the Durban East territory between 00:00 and 12:00 SAST on 19 August 2013. These provide an idea of the sea state on this particular day in the hours and minutes immediately before the incident. A south-westerly wind direction persisted between 00:00 and 12:00 SAST onthe Durban East region. A strong breeze with a mean speed of 24 knots prevailed for most part ofthis period, which is associated with large waves and extensive white foam crest. At 00:00 according to a vessel underway and situated at 31˚ 08’S, 29˚ 08’E within Durban East, the swell direction in the area came from a south-westerly direction, but changing to be from north-east 6 hours later at 06:00 (according to a ship situated 26˚ 90’S, 43˚ 02’E). The swell direction returned to a south-westerly direction at 12:00 SAST (according to a ship situated 26˚ 40’S, 45˚

03'E). The records of ships moving over the Durban East territory also reported swell height between 2 m and 3 m as well as the wave height that persistently remained at 3 m for the 12 hours period. The Durban East territory deep sea water was therefore dominated by rough sea conditions (Table 4.3.2) and large long period waves driven by a south-easterly/southerly wind.

Douglas Sea Scale Degree	**Height (m)**	**Description**
0	No wave	Calm (Glassy)
1	0 – 0.1	Calm (Rippled)
2	0.1 – 0.5	Smooth
3	0.5 – 1.25	Slight
4	1.25 – 2.5	Moderate
5	2.5 - 4	Rough
6	4 - 6	Very Rough
7	6 – 9	High
8	9 - 14	Very High
9	14 +	Phenomenal

Table 4.3.2: Douglas Sea Scale (from World Meteorological Organization)

4.3.4 Account of events, damages and impact on operations based on reports

The MV Smart vessel navigation route as depicted by Figure 4.3.3 was initiated along the Mudflats where the tidal flow is north-easterly. The vessel then took a north-easterly direction towards Echwebeni Natural heritage site, before taking a south-easterly course towards the narrow port entrance channel which is conventionally subject to south-easterly tidal currents. An offshore swell estimated to be above 4 meters is confirmed by Respondent 3 based on the first-hand information regarding monitoring daily ship operations and vessel movements in and out of the harbour. This corresponds with the assertions from an observer who happened to be nearby on a charter yacht, estimating swell offshore to have been about 4.8 m to 5.2 m and the period between the swells to be about 18 seconds.[3] As the MV Smart vessel exited the entrance channel it was therefore moving south-eastwards from a -19.4 m CD to a -21.9 m CD water depth (Figure 4.2.2). The MV Smart vessel with a 17.4 m draught thereafter ran aground on a sandbar offshore the breakwaters where water depth is maintained at -23.9 m CD (Figure 4.2.2) during a swell wave height above 4 m and 18 seconds period.

[3] https://m.news24.com/Multimedia/South-Africa/Ship-sinks-in-Richards-Bay-20130820/comments

According to Respondent 3, heavy winds and swells have a potential to affect marine services as well as port authority services and depending on the vessel category these can prevent the safe movement of vessels in and out of the port. The Port Control has a duty in line with standard procedure to closely monitor weather conditions and to advise the affected stakeholders when it is regarded unsafe to move vessels, added Respondent 3.

According to The Port Rules published in terms of National Ports Act 12 of 2005, for a commercial port it is mandatory for all vessels within harbour confines to adhere to compulsory pilotage. This means as the ***MV Smart*** was leaving the harbour on the day of the incident a pilot with specialized knowledge of the port's specific conditions was provided by the Authority in order to navigate the vessel out of the harbour. Port Rules further detail the responsibilities of a pilot in addition to navigating the vessel as determining the vessel's movements and to determine and control the movement of the tugs assisting the vessel under pilotage.

Respondent 3 highlights that the master is expected to assist the pilot during the phase of navigation and that the master remains in command of the vessel. As a result, continues Respondent 3, considerable information has to be exchanged between the pilot and the master within a short space of time. This exchange of information is guided by the IMO Code of Nautical Procedures and Practices, which requires an exchange of information regarding navigation procedures, local conditions and ship's characteristics between the master and the pilot.

According to Respondent 3 the master provides the pilot with navigation particulars of the ship, such as the draft, air draft and manoeuvring characteristics. The master is also entrusted with the duties of ensuring adequate navigational watch as guided by the IMCO RESOLUTION A.285(VII1) adopted on 20 November 1973. The master has a representative (under the master's general direction) known as the officer on watch (OOW). The OOW is a deck officer assigned with the duties of watch keeping and navigation on a ship's bridge. A list of the OOW duties is reflected on the IMCO resolutions and the OOW has a responsibility to communicate any unusual activity or any changes to the Master. The OOW is expected to check and monitor ship's draft and be aware of the Under Keel Clearance at all times as well as to inform the master ofany weather warnings and messages, to highlight those that relate largely to this study. The weather warnings issued on the day of the incident should be part of the information the OOW communicates to the pilot through the master.

Figure 4.3.3: The track of M/V Smart which resulted in grounding. After 1 hour and 12 minutes after setting sail [Source: SeaNews International Shipping Magazine]

4.3.5 Wave hydrodynamics and vessel behavior under unstable sea state conditions at the port entrance vicinity

As confirmed by Respondent 2 aligning with Respondent 1's assertions, the Richards Bay harbour entrance channel is maintained to a depth -23.9 m CD offshore of the breakwaters, -21.9 m CD just inshore of the breakwaters and -19.4 m CD along most of the entrance channel. This then means that the vessel moved south-eastwards, from a position characterised by water depth of roughly -19.4 m CD along the entrance channel, towards a depth of -21.9 m CD just inshore of the breakwaters where it broke its hull. At sea, wind is responsible for generating the majority of surface waves and those waves that travel outside their area of generation are known as swell (Lapworth, 2011). On this day such swell waves were driven by an intense southerly wind of 5,3 to 5,9 m/s gusting 8 m/s as detailed by the 5 minute data above.

According to Respondent 5 the wave steepness will continue to increase as the water depth decreases, hence wave height increases as the depths become shallow. On this day a swell moving towards the port entrance coming from sea would increase in height as it moves from a water depth of -23.9 m CD offshore of the breakwaters to a shallow water depth of -21.9 m CD just inshore of the breakwaters.

There are various forces that were acting on a vessel moving against a steep wave just inshore of the breakwaters and such dynamic forces exerted stresses on the ship structure. The rigid body motion of a ship can produce six degrees of freedom (DOF) movements due to wave-induced motion (Figure 4.3.4). The motions can either be translational or rotational and on the horizontal or vertical planes.[4]

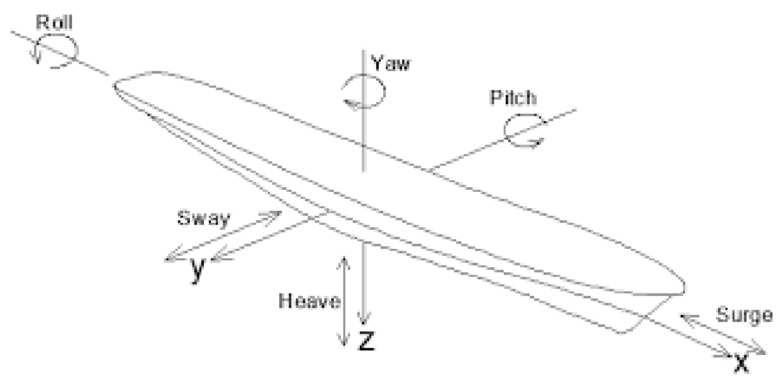

Figure 4.3.4: Ship Motion and Stresses - Three of the DOFs [**Source**: Mohammud_ Hanif Dewan/ship-motion-and-stresses]

[4] The International Journal on Advances in ICT for Emerging Regions 2010 03 (02):34 – 47

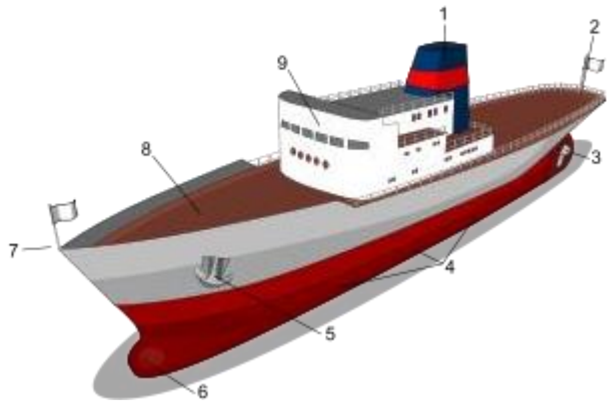

Figure 4.3.5: Main parts of ship. **1**: Funnel; **2**: Stern; **3**: Propeller and Rudder; **4**: Portside (the right side is known as starboard); **5**: Anchor; **6**: Bulbous bow; **7**: Bow; **8**: Deck; **9**: Superstructure [**Source**: Parts of a Ship – Image Courtesy of A12 at Lod Schema.png]

4.3.6 Marine weather predictions/warnings issued on 19 August 2013 for Richards Bay

The weather bulletin issued for coastal waters up to 50 nautical miles seaward on 19 August 2013 at 10:00 SAST (08:00 UTC) valid for the next 24 hours between 12:00 SAST on the 19th to12:00 SAST on the 20th included the following warnings;

- A gale warning issued for Durban East with wind (in knots) expected to be NW 15 to 25 in the extreme north-east at first, otherwise W to SW 20 to 30, reaching 35 in the south, becoming N to NE 15 to 25 in the extreme west the following day and spreading eastwards.
- The Sea State predictions of a south westerly swell at 5.5 to 6.5 m, reaching 8.5 to 9.5 m.

At the time of incident just after 14:00 SAST the marine weather predictions/warnings issued at 10:00 SAST were already applicable and should have formed part of information shared betweenthe OOW, pilot and the master.

4.3.7 Analysis and findings for the Richards Bay harbour incident

On this particular day the dominant surface weather system was a strong Atlantic high pressure moving eastwards and in line with Kruger et al. (2010) analysis of “Strong wind climatic zonesin South Africa” the KwaZulu-Natal coast experienced extremely strong winds as a result of the presence of this system. Also evident in this case is the argument advanced by Mutumbo (2017), of the interdependencies between the climate variables in posing such risks at the port.

Proportionality of the wind speed with the wave height produced the sea state observed on the particular day and confirmed the findings of Kruger et al. (2010). In this particular case we may not know the exact speed of the vessel at the time of her exit from Richards Bay, but the observation of Respondent 1 underscores that the vessel speed has to always be slower when entering or exiting a port entrance channel. This is done, continues Respondent 1, in order to adhere to the thresholds of speed at which vessels can enter or leave the harbour. Respondent 1 further note that since the vessel was in shallow waters just off-shore the breakwaters, she may have experienced significant changes in manoeuvring characteristics. This includes, continues Respondent 1, loss of rudder effect, changes in transverse thrust or most noticeably a reduction in vessel speed accompanied by a change in trim.

It therefore follows that when the ***MV Smart*** was exiting the harbour, at a reduced speed it moved against a strong direct south-easterly wind component. Consequently, the vessel may have lost the course with its speed drastically reduced and as a result dynamic forces may have been at play due to a combined effect of the ship's motion and that of strong wind as well assteep swell wave. This is in line with the analysis of Hawkes et al. (2010), which states that challenges to vessel maneuvering may come as a result of abrupt wind change (which was the case on this particular day as observed at 12:05 SAST in Table 4.3.1). One observer on a charter yacht at the harbour mouth during incident occurrence confirmed the sequence of events leading to the incident. As recorded in one of the newspapers[5], the observer believes that the swells which were of pronounced nature may have lifted the vessel's bow and thus increased power as aresult set the rudder to starboard to compensate. In such a case, Respondent 5 explains that the vessel may have rolled a bit lessening draft further to port. Consequently, the rudder must have touched first and stopped responding, continues Respondent 5. Then propeller must have touchednext, stalling the main engine, concludes Respondent 5. See Figure 4.3.5 for main parts of ship.

4.4 Durban harbour incident – Layout Observations & Assessments (with the relevant interviews)

On 10 October 2017 around 11:03 SAST, as detailed on the South African Maritime Authority (SAMSA) official statement, five vessels, together with a floating dock, were affected inside

[5] https://www.news24.com/News24/Ship-buckles-off-Richards-Bay-20130819

the Durban harbour due to strong winds associated with a severe weather storm. Two of these vessels (the ***MSC Susanna*** and ***Maritime Newanda***) according to reports, broke their moorings and had to be held by harbour tugs to prevent them from running aground. The other three vessels (the ***MSC Ines***, ***SM New York***, ***Bow Triumph***) were pushed into sandbanks, ran aground and as a result had to be re-floated, and returned to safe mooring berths.

4.4.1 Durban harbour coordinates and water depth

Durban port is situated at 29°52'S, 31°01'E of METAREA VII. The harbour entrance channel (the port's approach channel) is 19 m deep in the outer entrance shallowing to 16.5 m draught in the inner channel (within the harbour). The maximum depth from the Chart Datum is 13 m with awidth of 122 m for the port's entrance channel (Figure. 4.4.1).

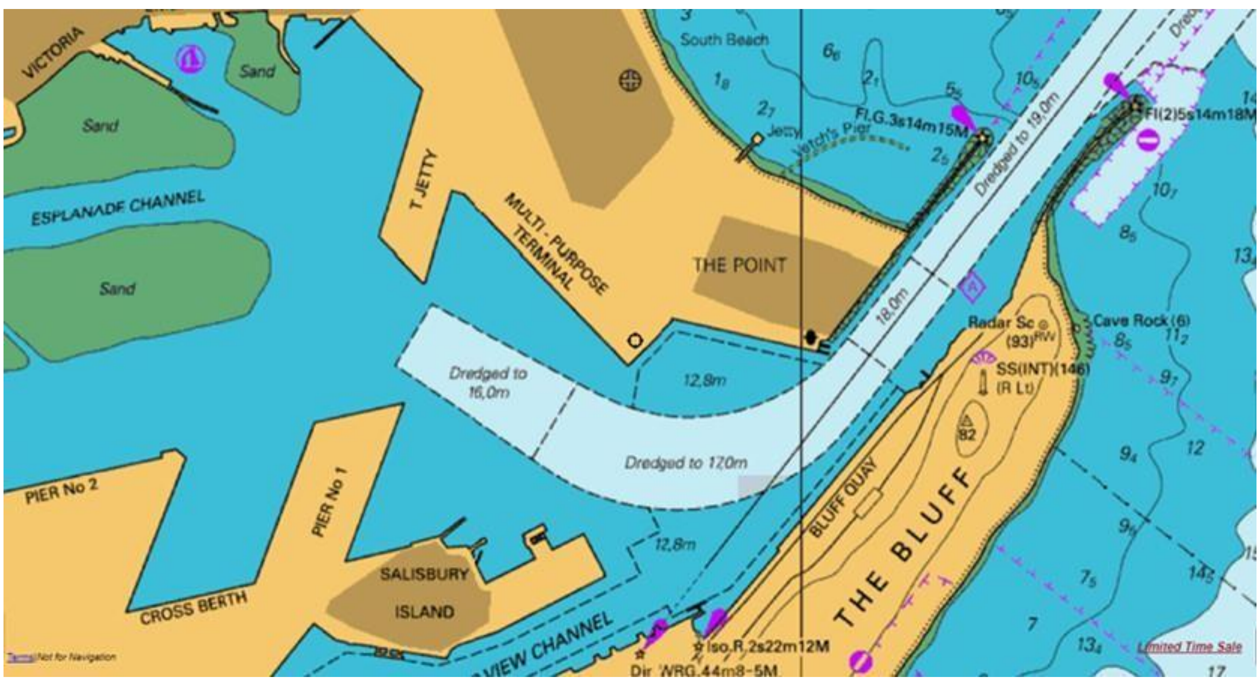

Figure 4.4.1: Durban Harbour (Marine Chart: ZA_0643_0) [GPS NAUTICAL CHARTS]

4.4.2 The Durban harbour interior layout characteristics and vessel positions

Figure 4.4.2 provides a labeled layout of the Durban harbour interior landmarks, terminals and boundaries whilst Figure 4.4.3 is an aerial view of the harbour depicting the berth positions.

According to the recorded data on the Durban daily ship movements for 10 October 2017[6], records show the ***MSC Susanna*** positioned at berth 108 at Durban Container Terminal and ***Maritime Newanda*** at berth 5 at Maydon Wharf. Records show the ***MSC Ines*** and ***SM New York*** vessels positioned at berths 203 and 204 respectively at the Container Terminal. Records further show the ***Bow Triumph*** positioned at berth 4 in Island View. These are specific berth areas within the harbour, where vessels were positioned prior being blown out of place by the strong wind.

Figure 4.4.2: Durban harbour interior layout and boundaries (Source: CruiseMapper, 2018)

[6] https://africaports.co.za/2017/10/10/durban-daily-ship-movements-10-october-2017/

Figure 4.4.3: Port of Durban berth positions – aerial view (Source: TNPA National Ports Plan, 2015)

4.5 Durban harbour incident – Document analysis (with relevant interviews)

On the 10 October 2017 a considerable storm struck the port of Durban. Visibility was brought to almost nil in the mid-morning as the storm broke. Recorded rain which fell across the southern part of the city of Durban including the port amounted to between 100 and 200 mm, as the accompanying winds gusted to a measured 91 knots.[7] According to the TNPA report, the disruptions due to storm driven extreme weather conditions of this day led to damages on cargo-handling equipment, buildings and quay walls within the port precinct. TNPA reported that some cranes were derailed by strong winds. Storm disruptions extended to marine services, terminal and rail operations within the Port of Durban and surrounding areas, according to the reports. Storm related damages extended to several premises, parts of the quayside were damaged as well as the Transnet School of Excellence situated

[7] https://www.vesseltracker.com/en/Ships/Msc-Susanna-9290543.html

near Durban Container Terminal on Pier 3 which was flooded. At the DCT Pier 1 and Pier 2 terminals TPT owned cargo handling equipment suffered damage. Damages were also reported at the Bulk, Break-bulk and Car Durban Terminals and these serve as key cargo handling infrastructure of the Durban port. Impact extended to several containers which were reported washed into the bay and port infrastructure damaged includes a total of three rubber tyre gantries and eight Ship-to-Shore cranes.[8]

4.5.1 Weather systems that prevailed over Durban harbour on 09 & 10 October 2017

On 9 October 2017 an Atlantic high pressure system extended its ridge to the southern and south-eastern coastal areas. At the same time a surface trough dominated over the eastern and north-eastern parts (Figure 4.5.1). As a result of both systems the south-eastern coastal areas were dominated by a confluence flow of southerly and south-easterly winds.

On 10 October 2017, the Atlantic high pressure system remained dominant, extending its ridge tothe whole eastern coastal areas with the surface trough having shifted to the northern parts of the country (Figure 4.5.2). As a result, the south-eastern coastal areas were largely dominated by southerly to south-westerly winds. According to Respondent 6, there is a definite relationship between the orientation and spacing of the isobars and the direction and speed of the wind. In both Figure 4.5.1 and Figure 4.5.2 between the ridging surface high and the surface trough there is a tight pressure gradient. The more the isobars are crowded together the tighter the pressure gradient and the stronger the wind, concludes Respondent 6.

[8] https://www.vesseltracker.com/en/Ships/Msc-Susanna-9290543.html

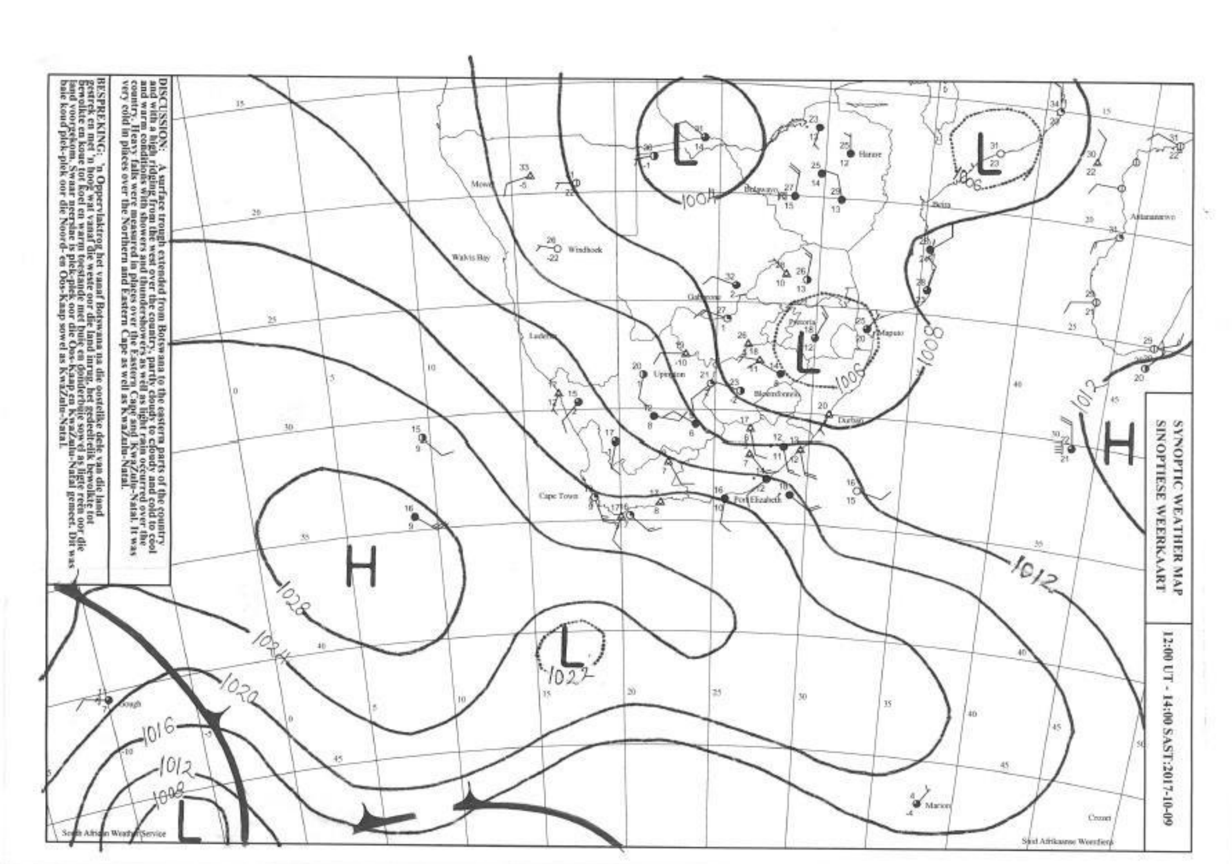

Figure 4.5.1: Sea level synoptic chart for Southern Africa for 09 October 2017 at 14:00 SAST (South African Weather Service)

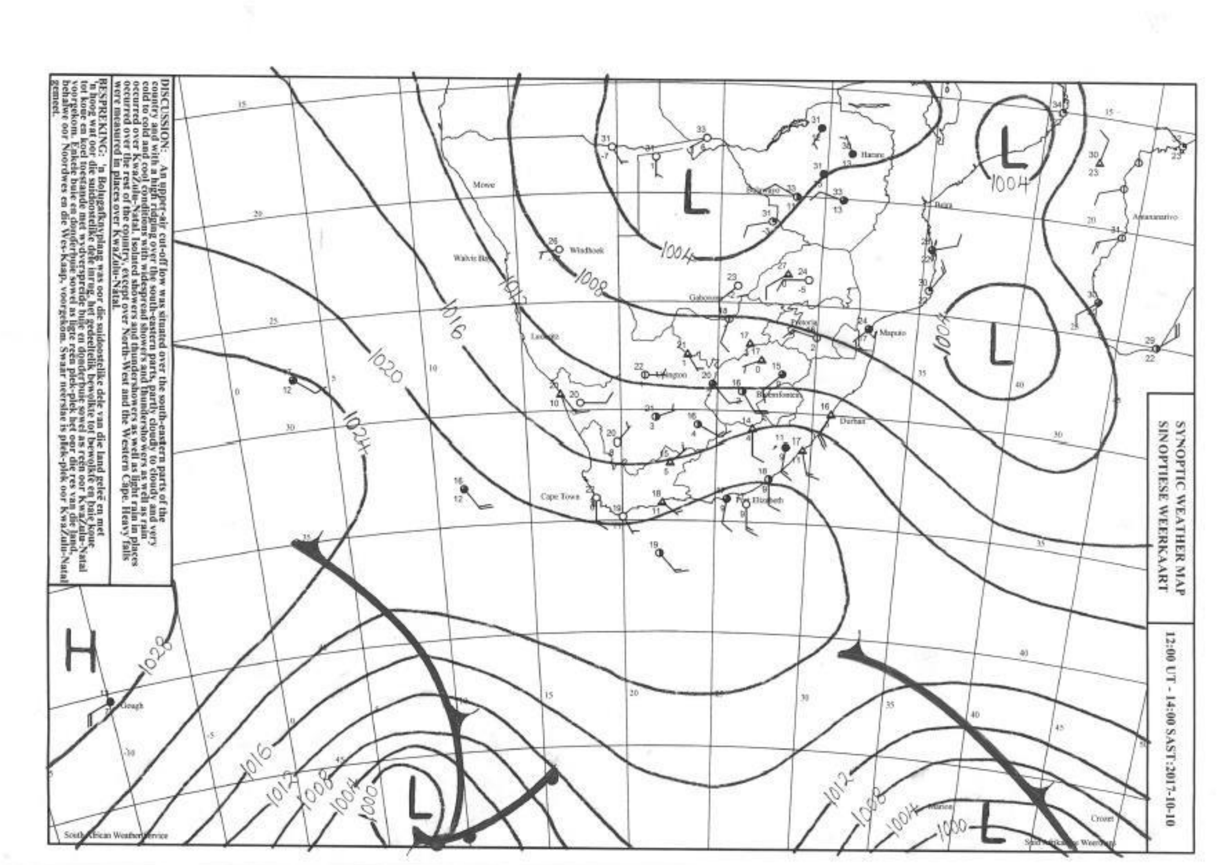

Figure 4.5.2: Sea level synoptic chart for Southern Africa for 10 October 2017 at 12:00 UT - 14:00 SAST (South African Weather Service)

4.5.2 Prevailing wind conditions prior to the incident at port precinct

According to Table 4.5.1 on 10 October 2017 a south-westerly wind component dominated between 11:00 to 17:40 SAST, becoming south-south-easterly at times during this period. Gale force wind was the order of the day with the wind speed perpetually increasing from 8.2 to 20.8 m/s (29.52 to 74.88 km/h) between 11:00 and 11:25 SAST. At this same period the wind gust was also picking up, increasing from 14.10 to 34.70 m/s (50.76 to 124.92 km/h). A wind speed drop was recorded as from 11:30 SAST up to 11:50 SAST however maintaining gale force nature, picking up again as from 11:55 until 12:20 SAST. Another sharp rise in wind speed was observed between 13:20 and 13:35 SAST ranging between 16.2 and 15.6 m/s (58.32 and 56.16 km/h), with a gust ranging between 24.5 and 28.00 m/s (88.2 and 100.8 km/h).

According to Respondent 3, a normal practice at the harbour involves the deployment of additional mooring lines in anticipation of high winds, taking into consideration the vessel's characteristics, type, size, trading pattern and the prevailing weather conditions. Respondent 3 further explained that the Master is expected to conduct appropriate risk assessments. Respondent 5, on the other hand, highlighted the wind loads exerted onto vessel's superstructure and hull above the waterline as one of the factors that need to be taken into consideration in relation to moored vessels and the mooring system.

Clim. No	Station Name	Date and Time	Speed	Wind direction	Gust	Temp	Hum	Pressure	Rain
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:00:00 AM	8.20	263.00	14.10	17.20	52.40	1,005.20	0.80
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:05:00 AM	9.10	248.10	15.40	16.90	53.10	1,005.10	2.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:10:00 AM	10.80	243.80	17.90	16.70	53.70	1,005.30	1.80
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:15:00 AM	11.10	252.00	17.70	16.20	54.90	1,004.60	3.60
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:20:00 AM	13.20	260.00	29.90	16.20	56.10	1,002.90	7.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:25:00 AM	20.80	241.90	34.70	16.10	59.50	1,002.90	5.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:30:00 AM	18.00	258.00	30.00	15.20	60.50	1,004.60	8.80
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:35:00 AM	17.60	267.90	29.70	14.70	43.60	1,004.60	9.80
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:40:00 AM	14.90	276.10	27.80	14.20	36.90	1,004.80	7.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:45:00 AM	13.50	269.50	25.80	14.30	35.10	1,004.60	7.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:50:00 AM	13.90	253.80	24.40	15.20	36.00	1,005.10	2.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 9:55:00 AM	18.20	247.30	28.10	15.70	33.40	1,004.70	4.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:00:00 AM	17.40	240.70	26.40	15.40	32.30	1,006.70	6.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:05:00 AM	11.50	223.50	19.70	15.40	34.00	1,007.60	4.20

0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:10:00 AM	11.80	229.30	17.90	15.30	35.40	1,009.10	1.80
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:15:00 AM	8.60	235.00	15.50	15.10	37.60	1,009.00	1.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:20:00 AM	8.50	266.10	12.70	14.90	39.10	1,008.10	1.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:25:00 AM	3.80	268.50	8.00	14.80	39.80	1,008.10	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:30:00 AM	8.00	216.20	19.80	16.40	40.10	1,009.00	0.80
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:35:00 AM	10.10	217.70	18.70	17.00	39.60	1,008.50	1.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:40:00 AM	10.10	211.90	20.80	16.80	40.00	1,008.00	2.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:45:00 AM	9.50	211.80	18.90	16.70	40.10	1,008.00	1.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:50:00 AM	13.70	206.70	23.30	16.70	40.80	1,008.50	0.60
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 10:55:00 AM	12.40	208.70	19.70	16.70	41.30	1,008.50	0.80
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:00:00 AM	12.80	203.30	19.10	16.70	41.50	1,008.00	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:05:00 AM	14.40	199.90	22.90	16.50	41.70	1,007.40	0.60
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:10:00 AM	13.00	201.20	25.20	16.70	41.70	1,007.80	0.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:15:00 AM	13.80	198.90	22.30	16.90	41.10	1,008.40	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:20:00 AM	16.20	202.20	24.50	16.90	39.50	1,008.00	0.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:25:00 AM	16.90	200.50	27.40	16.70	38.90	1,008.00	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:30:00 AM	15.00	200.50	23.80	16.80	38.50	1,007.80	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:35:00 AM	15.60	198.10	28.00	16.70	38.10	1,008.90	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:40:00 AM	12.80	202.80	21.70	16.70	38.40	1,009.50	0.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:45:00 AM	13.20	203.00	21.80	16.60	38.40	1,009.60	0.20

0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:50:00 AM	13.70	201.40	22.10	16.50	38.00	1,009.20	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 11:55:00 AM	9.70	205.50	18.00	16.70	38.90	1,009.70	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:00:00 PM	11.70	204.90	19.90	16.70	41.10	1,010.00	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:05:00 PM	12.10	205.20	19.50	16.80	42.00	1,010.30	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:10:00 PM	11.50	209.80	20.90	16.50	42.70	1,010.20	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:15:00 PM	10.80	203.60	17.90	16.50	43.30	1,010.00	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:20:00 PM	9.80	213.00	20.20	16.50	44.20	1,010.70	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:25:00 PM	12.10	209.70	19.60	16.50	44.00	1,011.00	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:30:00 PM	11.50	208.00	19.50	16.30	43.80	1,011.20	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:35:00 PM	10.60	210.50	17.90	16.30	43.00	1,011.20	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:40:00 PM	12.60	198.80	22.80	16.70	41.80	1,011.90	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:45:00 PM	14.00	196.40	21.70	16.20	39.20	1,011.50	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:50:00 PM	11.40	195.30	19.40	16.40	38.50	1,011.20	0.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 12:55:00 PM	10.60	208.30	21.40	16.40	38.00	1,011.30	0.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:00:00 PM	12.00	210.30	19.40	16.50	37.80	1,011.80	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:05:00 PM	10.90	210.60	16.80	16.70	38.80	1,011.80	0.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:10:00 PM	9.90	209.60	15.60	16.90	42.30	1,011.50	0.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:15:00 PM	8.10	210.10	13.30	17.00	41.70	1,011.30	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:20:00 PM	9.20	207.80	15.50	17.20	41.40	1,011.70	0.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:25:00 PM	9.10	215.90	18.30	16.70	42.70	1,012.10	0.20

0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:30:00 PM	8.50	219.40	14.10	16.40	42.80	1,012.30	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:35:00 PM	7.50	216.80	14.40	16.20	44.90	1,011.80	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:40:00 PM	11.50	207.60	21.70	16.30	44.30	1,012.30	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:45:00 PM	10.30	208.40	17.60	15.80	42.40	1,012.60	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:50:00 PM	9.10	208.90	14.80	16.10	46.00	1,013.10	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 1:55:00 PM	9.90	214.10	16.50	16.20	46.50	1,012.60	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:00:00 PM	9.90	212.10	21.10	16.30	46.80	1,012.60	0.60
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:05:00 PM	11.10	206.00	18.10	15.70	46.20	1,012.80	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:10:00 PM	7.70	205.90	11.90	16.10	47.90	1,013.40	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:15:00 PM	9.50	206.70	16.40	15.80	46.50	1,013.40	0.60
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:20:00 PM	8.70	200.80	15.60	16.10	47.00	1,013.40	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:25:00 PM	10.50	197.00	16.20	16.30	44.00	1,012.50	0.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:30:00 PM	9.30	202.80	13.60	16.30	43.40	1,013.00	0.00
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:35:00 PM	10.10	199.40	18.30	15.90	40.90	1,013.50	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:40:00 PM	8.80	197.00	15.10	16.20	44.80	1,013.50	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:45:00 PM	10.40	194.50	16.90	16.00	44.50	1,013.30	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:50:00 PM	9.20	199.40	15.60	15.90	46.00	1,013.10	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 2:55:00 PM	8.90	200.80	17.10	15.80	47.60	1,013.40	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 3:00:00 PM	10.20	196.30	17.80	16.00	48.30	1,014.00	0.20
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 3:05:00 PM	10.40	199.20	18.20	15.80	48.30	1,014.10	0.40

0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 3:10:00 PM	9.90	200.50	17.20	15.80	49.70	1,013.50	0.60
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 3:15:00 PM	9.20	205.70	16.20	15.60	52.10	1,013.40	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 3:20:00 PM	11.10	200.20	19.10	15.60	52.00	1,014.10	0.60
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 3:25:00 PM	9.00	204.10	14.90	15.40	53.40	1,014.10	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 3:30:00 PM	8.00	210.30	13.70	15.40	54.40	1,013.90	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 3:35:00 PM	7.70	214.20	15.10	15.60	55.30	1,013.70	0.40
0240837B7	DURBAN SOUTH MEREBANK	10/10/2017 3:40:00 PM	8.60	201.70	17.50	15.70	55.20	1,014.00	0.40

Table 4.5.1 Durban South Merebank weather station five minute data (Source: South African Weather Service)

4.5.3 Observed vessel positions, movements and recorded time of events inside the port

Available infographic display of vessel movements within port on 10 October 2017 (Genscape Vesseltracker AIS data), does show disruptions in progress as at 11:02 SAST. Two of the vessels already appear blown out of their initial recorded positions between 11h02 and 11h17 SAST. Disruptions of other vessels followed and this continued until just after 17:40 SAST.

The ***MSC Ines*** was one of the first vessels seen already away from the initial mooring position at container terminal, with uncontrolled movement towards the Point berths, then across the harbour towards Bluff and then finally towards the port entrance. Figure 4.5.3 show these vessel movement tracks towards the harbour entrance. The AIS data visuals show the vessel blown sideways from its initial berth at 203, making contact with a second vessel moored at D-berth at the Point, and then making heavy contact with the quaywall at the Bluff, before grounding acrossthe harbour mouth, completely blocking the port entrance at around 11:41 SAST. The vessel wasthen freed successfully by tugs around 14:22 SAST, and was moved to a secure initial alongside mooring at the Coal Terminal.

The ***MSC Susanna*** was the second vessel already away from the initial recorded berthing position (berth 108 at Durban Container Terminal). The vessel can be seen blown sideways out of control across the City Terminal waters (making contact with two berthed vessels in the process) and then towards the Coal Terminal between 11:02 and 13:03 SAST (Figure 4.5.4). Thevessel was then secured by harbour tugs to prevent it from running aground and finally towed to her mooring at T-Jetty at around 13:37 SAST.

The chemical tanker ***Bow Triumph*** that had maintained an initial recorded berthing position at berth 4 in Island View, finally broke its moorings at around 14:20 SAST. The vessel can be seen blown side to side across the Island View Channel and slowly drifting westwards until it ran aground on the sandbank adjacent to the Island View Terminal. The vessel was re-floated at 16h30 SAST according to reports, and was finally allocated a berth overnight for damage inspection.

The ***SM New York*** vessel can also be observed as at 11:02 SAST already away from the recorded initial position of mooring (berth 204 at the Container Terminal). According to reports the vessel broke from its moorings and drifted away from container terminal, but dropped anchorand grounded with minimal damage on the central sandbank between the Esplanade and MaydonChannels and the north wall of the Container Terminal. The info-graphics depict the vessel aground on this sandbank most of the period until at about 15:24 SAST when harbour tugs attendto it. The vessel was re-floated successfully and was secured alongside a berth at the T-Jetty.

The vessel ***Maritime Newanda*** vessel according to reports also broke loose from moorings as a result of strong winds and was held by tugs back to its berthing position. The vessel can be seen already at its original recorded berthing position at Maydon Wharf at about 17:37 SAST, confirming that it was successfully secured before running aground.

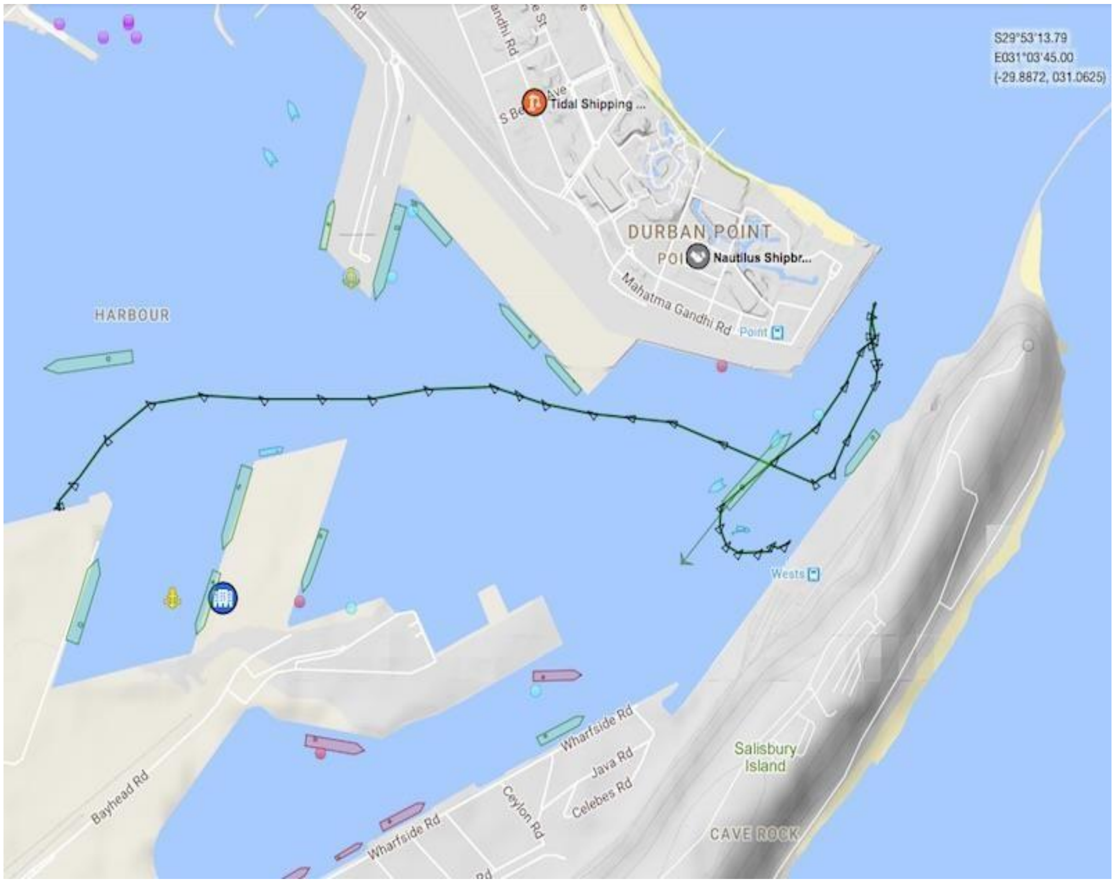

Figure 4.5.3: MSC INES navigation tracks to point of grounding and eventual towage to place of safety (Genscape Inc.: Genscape Vesseltracker AIS data)

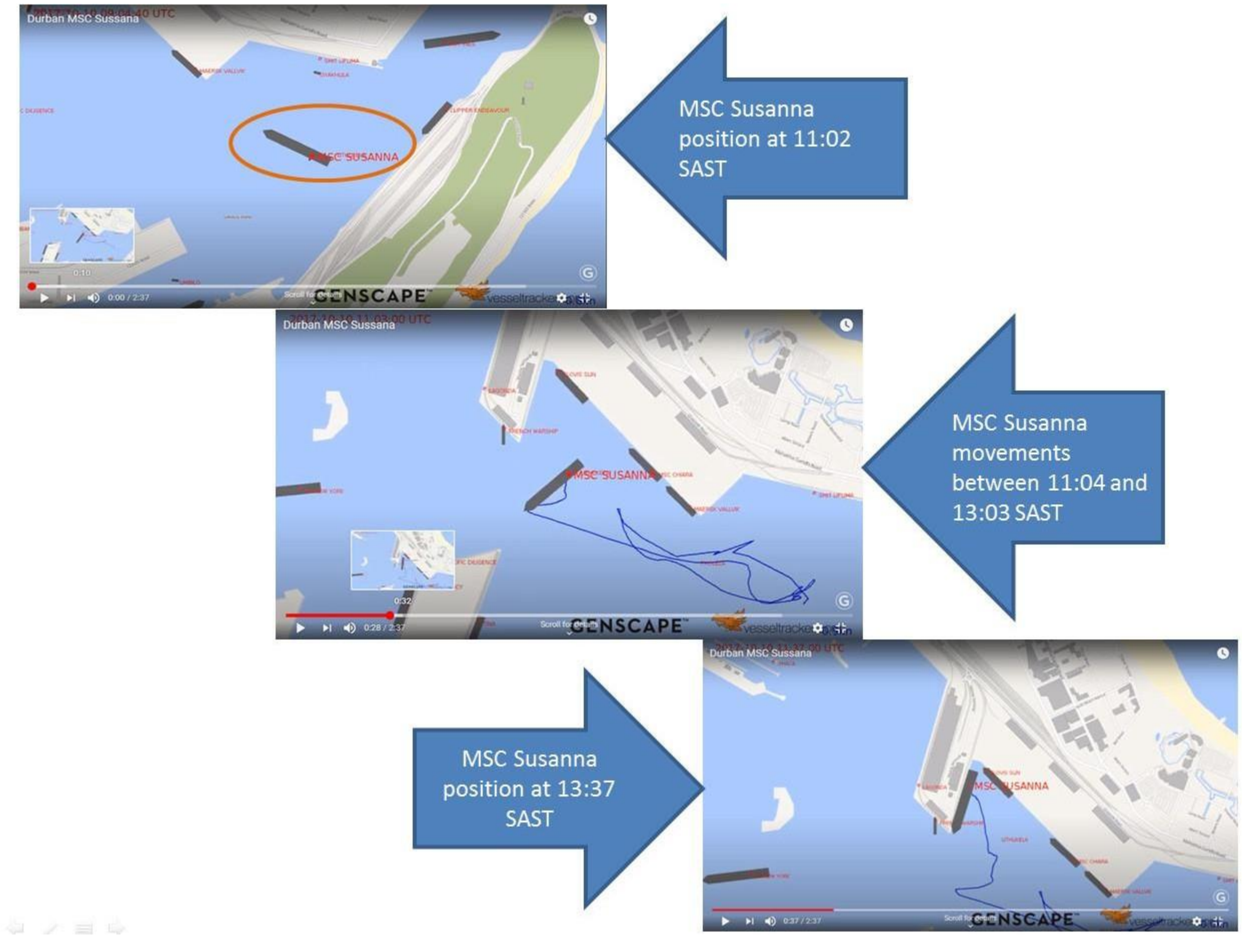

Figure 4.5.4: MSC SUSANNA movements out of control inside the harbour until remooring (Genscape Inc.: Genscape Vesseltracker AIS data)

4.5.4 Predicted weather conditions over Durban on 10 October for pre-warnings

The South African Weather Service (SAWS) issue marine weather forecasts twice in a day (one at 08h00 UTC and another at 13h00 UTC, i.e. 10:00 and 15:00 SAST), which cover a range of other atmospheric variables contributing to sea level variations. These forecasts are known as weather bulletin for coastal waters which extend up to 50 nautical miles seaward. Each of the marine forecasts issued twice a day are valid for a 24-hour period and incorporate sea state warnings.

The weather bulletin issued on 9 October 2017 at 10h00 SAST valid from 091200 to 101200 SAST included the following warnings; Sea State predictions of very rough seas with wave heights between 4.0 to 5.5m expected between Durban and Maputo. Wind prediction of a gale force wind S to SE 35 to 40KT expected between Durban and Maputo. On 10 October 2017 weather bulletin issued for coastal waters at 10h00 SAST valid from 101200 to 111200 SAST included the following warnings: Very rough seas with wave heights between 4.0 to 5.5m expected between Durban and Maputo, Sea State predictions of 3.0 to 4.0m, reaching 5.0 to 6.5mbetween Durban and Maputo, mainly south-easterly swell. Wind predictions of southerly to south-westerly 20 to 30, reaching 35 to 40 knots Durban and Maputo in the first period.

Tidal predictions according to the NOAA 2017 Tide Tables on October 10, 2017 expected low water at 0006 UT (0206 SAST) to be 1.0ft (0.30 m) reaching high levels at 0616 UT (0816 SAST) to a height of 6.0ft (1.83 m). Then at 1216 UT (1416 SAST) water levels were predicted to drop to 1.3ft (0.39 m) and picking up at 1835 UT (2035 SAST) to 5.9ft (1.79 m).

The NOAA Tide Tables provide what is known as astronomical tides (NOAA Tides Book 2017).As Respondent 6 elaborates, this means these are tide predictions which take into consideration only fundamental factors like the Moon proximity and the Sun's mass in the formation of tides. However, sea levels variations are also provoked by other atmospheric phenomena like wind, rain and atmospheric pressure, continues Respondent 6.

4.5.5 Analysis and findings for the Durban harbour incident

In reference to Tide Tables, vessels were blown out of moorings at the turn of the tide period (from flood to ebb tide, i.e. period between 08:16 and 14:16 SAST) and as the low tide set-in a number of affected vessels were already out of their original berthing positions. Based on Respondent 2 observations and experience, it is during the last half of the flood and the first half of the ebb tide when the fall of the tide from high water to low water takes place; and likewisethe rise of the tide from low water to high water takes place during the last half of the ebb and the first half of the flood. Since each tide period is predicted to last for a six-hour period it meansthe ebb may run for up to three hours after the water level has started to rise, and the flood may run for three hours after the water has started to fall. As Respondent 3 highlights, the period that the tidal velocity changes direction is known as the slack tide. The slack tide that occurs time after the high water is called high water slack and the one that occurs time after low water is called low water slack, according to Respondent 3. It therefore follows that on the day of the incident vessels were affected during the six-hour high water slack tide period.

According to Respondent 5, waves are highest during the ebb tide (i.e. when water is flowing outof the bay). When this is the case, continues Respondent 5, hazardous wave conditions will extend all the way across the bay entrance. However at flood tide (i.e. when water is entering the bay), according to Respondent 5, the wave height decreases more. This means that at flood tide, hazardous wave conditions are minimal, concludes Respondent 5. The impact of wave conditionson the vessels on this day is therefore not a possibility. This therefore rules out the applicability of assessments advanced by Kruger et al. (2010) for this incident. According to Kruger et al. (2010), the wind speed is proportional to wave height, and his assessments enhance the argumentthat increase in wind speed leads to build up of sea surface ripples into exceptionally high waves.Clearly the stronger wind at the time of vessel's breaking from moorings at high tide led to minimal wave influence and contribution. To affirm this, Respondent 3 asserts that the wave conditions in the access channel are normally much less than the deep sea wave (swell) conditions and even smaller at the ship berths. This means a reduction of the wave heights from the port entrance channel and ultimately at berths.

The notion of less hazardous waves also rules out the applicability of Rossouw and Theron's (2012) assessment, which identifies adverse wave conditions as leading to penetration of long period waves generated by swell waves propagating in groups into the port precinct. The non- existence of long period waves at the time of incidence, as Respondent 5 explains, rules out their effect inside the port precinct which is more harmful to ships at moorings than short waves. The long waves, according to Respondent 5 have very small wave amplitudes yet have relative long periods and can cause strong horizontal water movement next to berthing quays.

The prevailing gale force wind which remained gusty throughout the period at high-water slack tide appear to be responsible for breaking mooring ropes, then blowing some of these unmoored vessels side to side within the port waters and further leading some to run aground on nearby sandbanks. This is aligned to the findings of Asariotis et al. (2017), which identifies high wind events as having the potential to cause major operational disruptions as well as service interruptions at seaports. Rahmstorf (2012) affirms these findings and predicts futuristic catastrophic nature of extreme winds for ports. Respondent 4's observations on the day of incident also points to the strong wind effect near shore as responsible for the impact on the Royal Yacht Club boats. This is confirmed by various reporting platforms, showing how Yacht club boats were removed from moorings lines at berth. A number of factors may lead to mooringropes breakage during a very strong wind according to Respondent 2. The load applied to the mooring ropes may exceed their strength, highlights Responded 2, especially if the ropes are of reduced strength due to fatigue degradation and/or age degradation. Other factors include the useof multiple mooring ropes (of different diameters), as well as mooring of the ship with ropes made slack, concludes Respondent 2.

4.6 Chapter summary

The purpose of this chapter has been to provide a summary of the research findings according to each research objective of this study. The findings can be summarised as follows: prevailing weather systems especially at surface level determine the dominant weather variables along the coast. Meteorological forecasts and warnings communicate the intensity of such variables and hence possible impacts to the adjacent coastal infrastructure including the harbours. On both incidents of focus to this study the marine weather forecasts with associated warnings were issued by the responsible entity. Port operators as well as vessel operators and agents are amongst the network that receive these forecasts and associated warnings well in advance in order to make informed decisions. Although the forecast is not specific for the port precinct conditions, an understanding of near-shore prevailing sea state conditions provides an idea of possible effects of such state conditions for the port precinct.

Owing to their location along the coast, ports are obviously susceptible to novel coastal dynamics exacerbated by climate change occurrence. There is consequently an apparent need to relook at the effectiveness of meteorological forecasts and warnings for the marine sector at the behest of climate change occurrence. This in terms of the frequency of forecast and warnings updates issued based on frequently changing intensity of variables as well as the extension of the forecasting scope to also cover the conditions inside the harbour (like the state of water stability and other conditions not covered).

Climate change occurrence presents a need to revise the existing thresholds used to decide halt toport operations and cessation of vessel movement to align with changing frequency and intensity of climate variables that affect coastal conditions. Long period wave action is one dominant variable that played a major influence on Richards Bay incident, hence revision of thresholds needs to incorporate the effect of variables such as this one on water stability at port precinct. In the Durban case extreme strong wind, a looming feature driving the impact on a number of moored vessels on the day of incident, highlights the necessity of effective utilization of issued meteorological warnings to activate required prior risk assessment procedures within the port. The incident also occurred during a high water slack period; a research on the implication(s) of climate change occurrence on water stability within the port during the slack tide remains a fertile ground for future studies. Further, the scope of meteorological predictions and warnings ispresented with an opportunity to expand to consider the effect of the slack tide for marine fraternity clients.

It therefore follows that further research is demanded by the occurrence of climate change from the quality of meteorological predictions issued to seaport managers in order to activate precautionary measures. This relates to further researching and identification of atmospheric phenomena that are likely to induce new effects to the infrastructure, operations and vessel movements. The next chapter presents the conclusions and recommendations of this study.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter aims to draw together the analysis of weather data, perspectives of port practitionersand contributions from relevant literature that were undertaken in this study, to provide a set of summary research conclusions that are responsive to research questions posed, as well as to provide recommendations and suggestions for future research relevant to this topic.

5.1 Summary of the study

The reality of climate change occurrence has manifested itself through recent events observed at the two major KwaZulu-Natal commercial ports of Richards Bay and Durban, which have experienced extreme weather conditions that have left noticeable damages to vessels and port facilities. The two most notable of these events, which have formed the particular focus of this study were (i) the grounding of the 151,000 dwt bulk carrier ***MV Smart*** off the Richards Bay port entrance while on exit in heavy swells on the 19th of August 2013 and (ii) five moored vessels breaking out from their berths in the port of Durban during a period of adverse weather with high wind acting on the vessels on 10 October 2017.

At the Richards Bay harbour, on 19 August 2013; the ship ***MV Smart*** grounded on a sandbank at the side of the channel just outside the breakwaters. This was a culmination of ship’s engine put on full speed ahead proceeding to exit and then deviating slightly to starboard while still in the channel. This was followed by loss of speed for the ship and it started to turn to port as control tokeep the course in the channel was lost. As the ship was traversing a narrow channel with little clearance underneath the ability to manoeuvre was considerably reduced, basically the ship’s under-keel clearance was reduced to below half the ship’s draught. The ship loss of control is attributed to a landward moving heavy swell acting against the ship which led to the increased ship draught. The ship ultimately broke in two outside the channel.

At the Durban harbour on 10 October 2017 during adverse weather conditions, persistently gusting winds were recorded throughout the day. Five vessels that were alongside berths in various positions of the harbour; the ***MSC Ines***, the ***SM New York***, the **Bow Triumph**, the ***MSC Susanna*** and the ***Maritime Newanda*** broke moorings on account of wind loads exerted on their superstructures.

The persistently gusting winds then caused all five of these vessels to break theirmooring lines, and to blow off their respective berths in an uncontrolled manner. The port entrance was temporarily blocked by the container vessel ***MSC Ines***, which ran aground across the harbour mouth. Owing to adverse weather conditions, the affected vessels' superstructures and hull were subjected to persistently strong to gale-force south-southwesterly winds andconsequently the total load applied to the mooring ropes may have exceeded their strength. These events highlight the imminent risks posed by extreme weather and associated unstable sea state conditions likely driven by climate change occurrence. This has necessitated a relook at how the existing national port regulations as well as the international standards and guidelines are applied in order to take extra precautionary measures.

The study employed an inductive data analysis approach to verify the utilisation of the marine weather forecasts & warnings issued, predicting the intensity of climate variables and sea state conditions in and around port precincts. The verifications included assessing the manner in which meteorological forecasts and warnings do inform extra precautionary measures applied in anticipation of extreme weather conditions.

The study relied largely on publicly available data from different relevant data sources, such as weather data in the public domain from the South African Weather Services. To supplement these data, and in the absence of access to formal data sources from the port authorities, interviews were also conducted with different experts in order to gather diverse opinion to confirm a range of issues that will meet the objectives of the study.

The objectives of the study were:

- To influence a review in the manner in which meteorological forecasts and warnings issued to marine services are communicated among harbour authorities and port users.

- To assess the manner in which issued meteorological forecasts and warnings influence extra precautionary measures required to decide continuation of marine operations (including navigating and berthing vessels).
- To explore the potential of improving the enforcement of the existing guidelines applicable in anticipation of extreme weather and sea state conditions, in the advent of climate change.

The research has mainly confirmed the findings of Stenek et al. (2011), which were largely informed by the Muelles del Bosque (Cartagena, Colombia) study, that climate variability and change have a potential to cause: (i) shipping traffic changes (in terms of patterns and levels); (ii)port operations disruptions due to increased flooding and potential consequential damages to stored goods; (iii) potential navigational challenges in port approach channels, fairways and internal channels; and (iv) high economic losses to business. In line with the findings of Asariotiset al. (2017), which point to two climatic variables - wind and waves - as responsible principally for harbour disruption, these are the two variables that have received the greatest attention in the events of focus in this study.

5.2 Key Findings and Conclusions

This study had four specific research questions. A summary of the findings are presented below:

5.2.1 How do port layouts/features affect different climate variables associated with a particular weather pattern?

The dominant weather pattern at sea surface level in both cases of interest was a high pressure system ridging from the south west of the country. A ridging high pressure due to its anticyclone nature is associated with mainly south-southwesterly to south-easterly wind flow along the Durban-East coastal region. In the assessment presented by Theron et al. (2010), Hunter (1998) highlights that an intense migratory high propagating along the southern and eastern coastal areas, is among synoptic situations that can lead to a more intense development of the basic weather cycle, associated with gale force south-southwesterly winds and heavy swell conditions.

In both cases a dominant surface high pressure system migrating from the west induced persistently gusting wind throughout the period. As depicted on the bathymetry charts, entrance channels for both KwaZulu-Natal harbours are of shallow water nature. This therefore implies that any swell waves that were synoptically induced by the south-southwesterly to south-easterly strong wind drove heavy swell waves landwards into shallower waters at both harbour entrances.

For the Richards Bay case, in the Durban east territory deep seas on 19 August 2013 a number of moving ships between 00:00 and 12:00 SAST reported swell waves as high as 3 m driven by the dominant strong south-southwesterly winds. At the time the bulk carrier ***MV Smart*** initiated her planned departure from the port between 13:11 and 14:23 SAST, the Durban East deep sea state was dominated by rough sea conditions. As a result, south-south-westerly winds driven large long waves were propagating landwards and across the channel entrance. These heavy swell waves which were induced across the harbour entrance that is characterised by shallow waters therefore acted against the direction of movement of the ***MV Smart*** in her normal course on exit from the port.

As for the Durban case, on 10 October 2017 steadfastly south-south-westerly wind of gale force prevailed for most of the day. At the time when the five vessels together with a floating dock were affected inside the harbour, at around 11:03 SAST the wind velocity increased. CSIR (2011) asserts that the nature of flow in the entrance channel is influenced by large-scale wind- driven flows. Also small modifications to surface flows and wind waves in the port do occur due to such immediate wind influences (CSIR, 2011). The influence of wind-induced waves inside the harbour seem, however, to have been insignificant on the day of the incident, with their effectmainly limited to the entrance channel's shallow waters. However, the increasing wind velocity exerted a wind load directly on the infrastructure and berthing vessels inside the harbour, with the most specific impact on vessels berthed beam-on to the south-southwesterly wind. Consequently, the wind impact was particularly severe on vessels moored at berths 108 and 203- 205 in Durban Container Terminal, and at Island View.

5.2.2 How do extreme levels of climate variables influence the sea state?

Through the analysis of synoptic weather systems dominant per each incident, the study has identified the climate variables which featured prominently in each of the two incidents. Influence on the sea state condition and behaviour occurred at the times when climate variables (wind speed and the long waves in the Richards Bay incident) and wind velocity itself in the Durban incident were at extreme levels.

In the Port of Richards Bay long-period waves propagating from deep sea landwards towards the harbour, and driven by the strong south-southwesterly to south-easterly wind, are the climate variables which influenced the occurrence. On the day of the stranding of the ***MV Smart***, a heavyswell moving towards the port entrance coming from deep sea would increase in height as it moved from deep waters offshore of the breakwaters to a shallow water depth just inshore of the breakwaters. The analysis has shown that the wave steepness increases as the water depth decreases, which means the wave height increases as the water depth become shallower. The sea state was therefore that of a steeper wave height at shallow waters off the breakwaters of the Richards Bay entrance channel.

In the Port of Durban on the day of the "Great Storm" of 10 October 2017, as the prevailing strong wind remained gusty throughout the period the wind force was responsible for breaking mooring ropes. These unmoored vessels were further blown in an uncontrolled fashion inside theport and caused some to run aground on nearby sandbanks, to make contact with moored vessels,and to inflict damage on quaywalls and other port structures. The effect of wave being insignificant at berth in the absence of long wave influence, as mentioned before, rules out any violent vessel behaviour at the moorings in response to waves of varying periods and heights. The wind velocity that acted against the infrastructure and berthed vessels also acted against the water surface. It would therefore be expected that the sustained high wind would have significanteffect when acting against the tide. However, in this case the sea state outside and inside the harbour was considerably calmer since it was during a slack tide. Therefore, the sea state was that of less stressed water and with little or no movement either way.

5.2.3 How effective are the mechanisms of communicating meteorological forecast and warnings issued to marine services among authorities at the harbour?

The IMO Standard Maritime Communications Phrases serves to assist in guiding with the ship's conduct and navigation safety as well as ensuring that communication across marine operations and specifically at the harbours is in a standardised language. Part A of the Standard Maritime Communications Phrases focuses on the Safety Communications and sub-section AI/3 looks at the communication of Meteorological and hydrological conditions. Sub-sub section AI/3.1 is concerned with communicating winds, storms,tropical storms as well as sea state.

Further, The National Ports Act (12/2005) provides for the port rules in terms of vessel navigation control, movement and berthing within the port. In terms of information exchange, generally the Act makes provisions for circulation of relevant information by the bridge team on the vessels in the area of concern, under Chapter 2, Part B Section 10(b). In regards to look-out for any weather conditions that are detrimental to safe navigation, Chapter 2, Part H Section 56
(1) (j) requires that as soon as the master of a vessel which is within port limits becomes awareof such conditions, these are to be reported to the Harbour Master. Chapter 2, Part D Section 28
(1) (a) & (b) covers processes for ensuring of safety and security of the vessel at moorings within a port by the Harbour Master.

In order to facilitate the communication requirements aimed to ensure safe navigation as well as availability of essential information in time, Bridge Resource Management (BRM) principles as well as Vessel Traffic Service (VTS) become useful. The BRM mainly caters for on-board navigation decision-making involving master-pilot information exchange as well as bridge team briefing. The VTS is a shore-side service aimed to provide support to the bridge team, among these being the information service. The range of information includes physical changes in the navigational area, meteorological and hydrological conditions as well as manoeuvrability limitation of vessels. In both days of interest the daily weather bulletins were issued twice, one at 10h00 SAST and another at 15h00 SAST as required by IMO resolution A.1051(27).

In the Richards Bay harbour case on 19 August 2013, the effectiveness of the shore-side meteorological information going to the bridge team on-board to assist with decision making entailed keeping watch on the expected variant gale force wind with velocity of up to 35knots as well as a south-westerly 5.5 to 9.5 m swell. Theswell prediction according to expert's opinion should have assisted the planning of the voyage and anticipating ship's draught (increase) due to ship's movements caused by the kind of swell. The information regarding manoeuvrability limitations as communicated from the shore-side to the on-board bridge team, to be effective should have highlighted 1) narrow channel with little under keel clearance,and 2) confined and shallow water. This would assist with speed limitation decisions for the master according to the expert‘s opinion.

In the Durban harbour case on 10 October 2017, the effectiveness of the shore-side meteorological information goingto the master to assist with decision making relied on keeping watch on the predicted south to south-east gale force wind with velocity of up to 40knots. According to expert's opinion risk assessments should be undertaken with consideration of vessel characteristics and the predicted/prevailing weather conditions. Based on the knowledge of predicted wind conditions as received from the shore-side VTS the Master was empowered to make timely decisions. The expert's opinion highlighted that precautionary measures under such conditions would include amongst other things 1) ensuring that the vessels were appropriately ballasted for this kind of wind velocity and 2) arranging for the deployment of additional (storm) moorings. Continuous monitoring of prevailing wind conditions should have also assisted masters of vessels in the areas to determine if conditions were worsening to warrant necessary precautions.

It is therefore clear that adherence to the IMO Standard Maritime Communications Phrases, The National Ports Act (12/2005) and Bridge Resource Management (BRM) principles is required to ensure effective communication of meteorological forecast and warnings issued twice daily.

5.2.4. How best can the issued meteorological forecast and warnings influence extra precautionary measures at port precinct?

The Inter-Governmental Maritime Consultative Organization (IMCO) provides recommendations on basic principles and operational guidance relating to navigational watch- keeping. The document provides guidance in terms of watch arrangements; this is in terms of the composition of the watch, including the requirement for look-out(s). The first precautionary measure required therefore relates to the reduction of human errors in relation to information exchange among the bridge team.

Under the navigation guide the IMCO document highlights among other points that (i) the intended voyage shall be planned in advance taking into consideration all pertinent information and any course laid down shall be checked, and that; (ii) on taking over the watch the ship's estimated or true position, intended track, course and speed shall be confirmed; any navigational hazard expected to be encountered during the watch shall be noted.

Consequently, a number of Part A sub-sub-sections of The IMO Standard Maritime Communications Phrases read together assist to satisfy (ii) above. Under Part A section AI/6.2, sub-sub-sections .1.5 Hydrographic information, .1.7 Meteorological warnings, .1.8 Meteorological information, .3.3 Arrival, berthing, departure, and .3.5 Avoiding dangerous situations, providing safe situations read together cater for mechanism to prepare for precautionary measures.

Further, the National Ports Act (12/2005) under Chapter 2, Part C Section 26 (1), (2) & (3) requires as a precautionary measure provision of a mooring plan to the Harbour Master, who should assess its adequacy. In the Richards Bay harbour case, proper communication may have broken down between port control, the shipmaster and the pilot regarding the change of vessel speed. This points to lack of planning according to the issued meteorological forecast and warnings or real-time observed weather and sea state conditions, in this case swell height.

In the Durban harbour case, there was failure to prepare vessel moorings for adverse weather conditions with high winds (or wind force) acting on the vessels in accordance with forecast wind velocity. This also points to lack of planning according to the issued meteorological forecast and warnings or real-time observed weather conditions, in this case wind velocity.

In both cases, in light of the communicated meteorological forecast and warnings, strict adherence to requirements of the National Ports Act (12/2005) read together with relevant sections, sub-sections and sub-sub-sections of the IMO Standard Maritime Communications Phrases, would allow for advanced precautionary measures planning for any eventuality due to severe weather or sea state conditions at the harbour.

5.2.5 How best to enforce the existing guidelines applicable at the harbour in anticipation of extreme weather and sea state conditions, in the advent of climate change?

In port operations there are rules and regulations in place already taking into cognisance the possibility of the impacts of several unexpected incidences including those brought by the occurrence of severe weather. Specific to the incidents of focus in this study are regulations that guide in terms of (1) information exchange regarding vessel navigation control and movement aswell as weather conditions and sea state within port limits and (2) the requirements for vessel at moorings within the port.

There are international practices and principles as stipulated in the IMO treaties, which must be observed by member countries, supporting national regulations. In the advent of climate change where unpredictable severe weather conditions have become prevalent, the importance of information service support offered by the VTS on the shore-side to the on-board bridge team fornavigation decisions or the shipmaster(s) for risk assessment inside the harbour has become vital.Part B of the IMO Standard Communication Phrases which guide on the on-board communication phrases if adhered to would ensure to enforce proper briefing (i) on vessel position, movement and draft, (ii) on meteorological conditions (as and when received), (iii) on standing orders and bridge organization and (iv) on special navigational events.

Specific for the two cases of this study, sub-sub-section B1/1.1 Briefing on position, movement and draft read together with sub-sub-section B1/1.5 Briefing on meteorological conditions both of Part B, provide a proper guideline to enforce continuous monitoring when confronted with highly unpredictable weather conditions.

Generally compliance with laws, chart, schemes and directives with regards to vessel movement is covered under *Part H Section 48* of National Ports Act (12/2005): Ports Rules. The master of a vessel has a responsibility while within the approaches to a port or within port limits to;

(a) comply with all applicable international and South African legislation with respect to *vessel* movement, including the Merchant Shipping (Collision and Distress Signals) Regulations 2005 and the Convention on International Regulations for the Prevention of Collisions at Sea 1972;

(b) move in accordance with the *chart* of the *port* or the Traffic Separation Scheme applicable to the *port;* and

(c) adhere to the instructions of the *VTS* or port control with regard to designated anchorage areas that the *Harbour Master* may have determined.

Further, *section 52(1)* under *Part H* of National Ports Act (12/2005): Ports Rules put the responsibility on the Harbour Master to determine the order of the marine services including mooring of ships in the port. *Section 52(2)* requires that such determination is carried out taking into consideration issues of safety and the protection of the environment among others.

This is also confirmed by section 74(3) of the Act which requires the Harbour Master in relation to movement of vessels within port limits to according to section 74(3)(i) to promote safety of navigation in the port and section 74(3)(ii) regulate movement or mooring and unmooring of a vessel in the port.

5.3 Recommendations

The enabling regulation in the form of the Ports Act together with the international guidelines for IMO member countries are available to utilise and for enforcement during marine operations. Highly unpredictable meteorological conditions presented by climate change makes it more vital to adhere to these regulations and guidelines to ensure advance precautionary measures for port operations.

There seems to be reliance on the meteorological forecast and warnings which are issued twice daily in-line with the IMO resolution A.1051(27) for port operations; however, continuous updating of meteorological real-time observations is required in the IMO Standard Communication Phrases under Part B sub-sub-section 1.1.5.

Hourly update of real time observed weather conditions from the South African Weather Service received and shared by the VTS to the Bridge Team and shipmasters as part of information service is therefore recommended. This can be very useful especially to plan for the anticipated severe weather conditions presented by the occurrence of climate change and allow taking precautionary measures in advance.

Both incidences of focus for this study present a need to determine wind load or force on the vessels as well as the infrastructure inside the port. It is therefore recommended that with the use of the available five-minute wind change data, the wind load and forces acting on vessels and infrastructure inside the harbour be calculated, be continuously monitored by the VTS and be shared with relevant parties as part of information service support package.

In order to ensure compliance with the National Ports Act, No 12 of 2005 (Ports Act), TNPA has developed a Compliance Risk Management Plan, as well as a Critical Control Framework and Control Self Assessments (CSAs) for the Ports. The Compliance Risk Management Plan has a strategic focus area on sustainability aimed to pursue best practice on environmental risk management. Climate change is one of the initiatives proposed in the plan with the vulnerability assessment as one of the programmes that were envisaged in 2010 and implementation of the climate change strategy for Transnet had been earmarked as far back as 2011. This Transnet climate change strategy is not accessible in any public platform.

It is therefore recommended in light of the incidents of 2013 and 2017 in Richards bay and Durban harbours, respectively, together with many others of similar nature, that 1) Transnet expedite the process of conducting climate change vulnerability assessments for ports and 2) Theclimate change strategy that was developed in 2010/2011 should be reviewed in the light of the climate variability over the years.

5.4 Suggestions for future further research

There is a room for future research on the thresholds that can be applicable inside ports. Historical trend analysis to associate recorded climate variables intensities with various sea waterbehaviours patterns inside the harbour can provide such a threshold setting. Such thresholds existmainly for offshore and deep sea waters in the form of the Beaufort Wind Force Scale and Douglas Sea Scale. The Beaufort Wind Force Scale provides thresholds which associate wind speed and wave height intensity to the sea state conditions, while the Douglas Scale provides thresholds which associate the wind generated waves and swells intensity to the sea stateconditions. Climate change policy for the country does incorporate responses towards coastal infrastructure protection however there is a gap in terms of climate change responses specifically aimed for the port infrastructure. Research on how climate change issues can be mainstreamed into the already existing port management and operations regulation becomes vital as a result.

5.5 Concluding Statement

The research has highlighted the critical aspects of marine operations that will require more attention as climate change continues to bring adverse weather conditions, which ultimately affect port infrastructure and disrupt marine services. These interconnected aspects involves - communication of extreme weather conditions (predicted and observed) in order to activate timeous implementation of extra precautionary measures through a proper enforcement of the enabling regulation(s) and adherence to international guidelines on the part of all marine operators. It is also encouraging to notice the efforts that the maritime sector is already undertaking in realigning the guidelines and regulations as a response to climate change occurrence. Although some of these efforts are currently country specific however the nature of operation for the maritime industry nevertheless allows for peer-to-peer learning and the sharing of lessons learned among countries. In a sector mainly driven by international trade, it is possible to have country specific practices ultimately developing into internationally accepted standards of approach as guided by the relevant international agencies.

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