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Examining storms, sediment supply, and coastal change within the historical record

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Examining storms, sediment supply, and coastal change within the historical record

Abstract

Beaches that receive more sediment than can be removed by storm erosion will not recede as the sea level rises from future global warming. This research examines the interplay between sediment supply and the frequency and magnitude of storms within the historical record at Bengello Beach, Moruya, New South Wales. During a series of large storms in May-June 1974, Bengello Beach lost approximately 50% of its sand volume and evidence of this erosion is preserved by a 40+ year beach profile campaign that recorded subsequent sediment accumulation. This historical beach-profile history can be contextualised with the barrier's stratigraphic record captured by the progradation in the past 7,000 years allowing inferences to be made of larger scale changes. The three main objectives of this study are: 1) Examine the links between river flooding, coastal storms and beach changes during large storm events 2) Determine if the Moruya River is delivering sediment to the beach and 3) Analyse the frequency and magnitude of river flooding, coastal storms and beach changes from the historical record and beyond. This methodological approach will focus on analysing pre-existing datasets including: a 40+ year beach profile dataset, a 34- and 46-year wave buoy dataset from Batemans Bay and Port Kembla, peak discharge from the Moruya River and estuarine hydrodynamic models. While it is common to observe intense rain and river flooding in association with coastal storms, preliminary results from the analyses indicate that no strong correlation exist between the occurrence of high river discharge and high significant wave height. However, estuarine hydrodynamic models indicate that sediment reaching the river mouth during floods appears to coincide with increased coastal accretion. Furthermore, within the wave rider buoy records, differences in the quantity, peak significant wave height, duration and period of moderate to extreme storms were noticed on the seasonal scale in addition to an increasing occurrence of severe events (Hsig 5-6m) which have appeared throughout the record since 2000. In response to the observed trends in storm wave 3 characteristics, the effect of various climatic influences can be inferred. The implications of this study will highlight the sensitivity of coastal barriers to storm erosion and changing storm frequency relationships seen throughout the early 21st century.

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Examining storms, sediment supply, and coastal change within the historical record

Travis Adam Anderson

Supervisors:
Dr Amy Dougherty and Associate Professor Tim Cohen

This thesis is presented as part of the requirement for the conferral of the degree:
Earth and Environmental Science (Honours)

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October 2020

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Beaches that receive more sediment than can be removed by storm erosion will not recede as the sea level rises from future global warming. This research examines the interplay between sediment supply and the frequency and magnitude of storms within the historical record at Bengello Beach, Moruya, New South Wales. During a series of large storms in May-June 1974, Bengello Beach lost approximately 50% of its sand volume and evidence of this erosion is preserved by a 40+ year beach profile campaign that recorded subsequent sediment accumulation. This historical beach-profile history can be contextualised with the barrier's stratigraphic record captured by the progradation in the past 7,000 years allowing inferences to be made of larger scale changes. The three main objectives of this study are: 1) Examine the links between river flooding, coastal storms and beach changes during large storm events 2) Determine if the Moruya River is delivering sediment to the beach and 3) Analyse the frequency and magnitude of river flooding, coastal storms and beach changes from the historical record and beyond. This methodological approach will focus on analysing pre-existing datasets including: a 40+ year beach profile dataset, a 34- and 46-year wave buoy dataset from Batemans Bay and Port Kembla, peak discharge from the Moruya River and estuarine hydrodynamic models. While it is common to observe intense rain and river flooding in association with coastal storms, preliminary results from the analyses indicate that no strong correlation exist between the occurrence of high river discharge and high significant wave height. However, estuarine hydrodynamic models indicate that sediment reaching the river mouth during floods appears to coincide with increased coastal accretion. Furthermore, within the wave rider buoy records, differences in the quantity, peak significant wave height, duration and period of moderate to extreme storms were noticed on the seasonal scale in addition to an increasing occurrence of severe events (Hsig 5-6m) which have appeared throughout the record since 2000. In response to the observed trends in storm wave

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Certification

I, Travis Adam Anderson declare that this thesis submitted in fulfilment of the requirements for the conferral of the degree Earth and Environmental Science (Honours), from the University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualifications at any other academic institution.

[redacted]

Travis Adam Anderson
7th of October 2020

List of Names or Abbreviations

- RCP- Representative Concentration Pathways
- Hsig- Significant Wave Height
- SST- Sea Surface Temperature
- SP- Surface Pressure
- DPIE- Department of Planning, Industry and Environment
- MHL- Manly Hydraulics Laboratory
- XRD- X- Ray Diffraction
- SEM- Scanning Electron Microscope
- LPIII- Log Pearson III
- GEV- Generalised Extreme Value
- GPD- Generalised Pareto Distribution
- STR- Sub Tropical Ridge
- IOD- Indian Ocean Dipole
- ENSO- El Nino Southern Oscillation
- SOI- Sothern Oscillation Index
- IPO- Interdecadal Pacific Oscillation
- PDO- Pacific Decadal Oscillation

Table of Contents

List of Figures

List of Tables and Equations

Chapter 1

1. Introduction

1.1. Background

The Australian coastline consists of a multitude of beaches that have undergone and will continue to undergo volumetric changes in response to coastal storms. The temporal characteristics of coastal waves and extreme events have been previously examined by Shand et al. (2010; 2011). These studies have detailed the seasonal variations examined within wave characteristics along the wave rider buoy network of the Australian East Coast as well as the average recurrence intervals of extreme events within these records. Bengello Beach is uniquely suited to examine the volumetric changes these wave characteristics may cause on the beach face due to it having the longest record recor of profile change in Australia, if not the world Mclean et al. (2010). Bengello Beach is also known to have built seaward (Prograded) over the Holocene as extensive work has been carried out on the coastal barrier and series of dune ridges that spans ~2km to the mainland (Oliver et al., 2015; 2020). Therefore, despite sea level rise, if Bengello Beach continues to receive ample sediment supply as it has for the past 7,000 years and its accommodation space remains sufficient, volumetric changes could be potentially offset.

For the past 6,000-7,000 years, the sea level around Australia has experienced slight fluctuations but is generally considered to be relatively stable (Dougherty et al., 2019a). Due to the impacts of climate change, most notably the thermal expansion of ocean water and the melting of ice sheets, glaciers and ice caps, the volume of sea water contained in ocean basins will increase thus leading to sea level rise (Mimura., 2013). In order to predict sea level rise, the IPCC fifth assessment report used a process-based model in conjunction with four representative concentration pathways (RCP) that are based on varying degrees of continued greenhouse gas emissions. As seen in Figure 1, the IPCC predicts a global mean sea level rise by 2100 ranging from an average of 40cm in RCP2.6 to 62.5cm in RCP8.5 (Church et al., 2013).

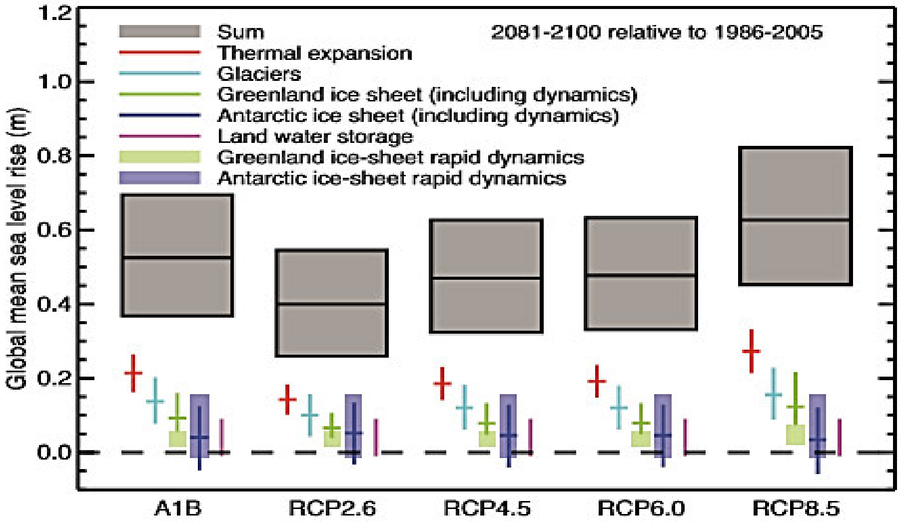


Figure 1: Five scenarios of global mean sea level rise for 2081-2100. A1B is a balanced emphasis on all energy sources while RCP2.6 to RCP8.5 represent the lowest greenhouse gas emission scenario to the highest. Sourced from Church et al., 2013, pp1180.

In addition to sea level rise, the frequency and severity of storms will also be affected by climate change. At a localised scale, warmer temperatures will cause an increase in the activity of small scale convective systems along the coast, leading to more intense winds and rain, as well as an intensification of east coast lows and extreme wave conditions (Department of Climate Change., 2009). At a larger scale, sea level rise will elevate the platform for storm surges, tides, and waves. This elevation will subsequently escalate the impacts of extreme events as well as compound otherwise minor events to ultimately cause increased damage to coastal infrastructure. (Bruyère et al., 2019; Leonard et al., 2014; Oppenheimer et al., 2019; Tonmoy and El-zein., 2018). Furthermore, sea level rise will affect the recurrence interval of extreme coastal events with Oppenheimer et al. (2019) theorising storms that occur once every hundred years during current climatic conditions could potentially occur annually. With climate change having such a potentially adverse effect on coastal processes, it is important to determine how coasts will respond in the future.

1.2. Project Rationale

Initially, the idea of the project was to ground truth the interplay between sediment supply and storms beyond the historical record at Bengello Beach. This would have been conducted by first examining the morphology and stratigraphy of the Bengello Beach prograded barrier through the use of Light Detection and Ranging (LiDAR) and a Ground Penetrating Radar (GPR) for storm scarps and subsequently ground-truthing them with coring as recommended by Dougherty et al. (2019b). Sediment collected from the cores would then be compared to beach surface samples and river point bars through the use of XRD and SEM as recommended by Carvalho et al. (2019) in order to ascertain the degree of fluvial contribution to the beach in comparison to the past. However, due to the constraints set on fieldwork as a result of the COVID 19 outbreak, many of the proposed field-based data analyses proved to be unviable and thus the focus of the thesis shifted to the analysis of pre-existing data sets. The lack of fieldwork subsequently changed following an ease of restrictions and a series of large storms in July. During this fieldwork, samples were collected from 4 point bars along the Moruya River and the eroded Bengello Beach face.

As an alternative to conducting a stratigraphic and morphologic examination of Bengello Beach for storm scarps and inferring a centennial to millennial scale history, the wave characteristics recorded by wave rider buoys were examined as it would allow the temporal trends of storms to be examined. While the sediment supply element of the project has been maintained, as cored samples from various areas across the barrier are stored at UOW, it was further augmented via the examination of high discharge events along the Moruya River. In addition to these analyses, volumetric change at Bengello Beach was examined to note coastal changes associated with fluvial delivery and storm erosion.

While Shand et al. (2010; 2011) has previously examined wave characteristics and the occurrence of extreme events, further analysis of wave rider buoy data is required to explore different parameters. By examining the seasonal, yearly, and decadal trends in storm occurrence, severity, duration and period, an understanding of how storms will increasingly influence beaches will be ascertained Furthermore, due to the occurrence of the extreme flooding and wave events in July 2020, the influence of an extreme event on the average recurrence intervals of storms can be examined. Due to the occurrence of climatically induced sea level rise and increased storm severity and frequency, the need for these results is further heightened as it will aid the planning and prevention of damage due to these events. In addition to storm examination, the volumetric change and sediment supply at Bengello Beach are to be examined as it will allow a better understanding of whether coastal erosion will be offset by sediment supply and potentially provide information on whether other prograded barriers could resist the effects of coastal erosion.

1.3. Aims and Objectives

Three aims exist for this project and in order to accomplish these, several objectives are outlined:

1) Examine the links between river flooding, coastal storms and beach changes during large storm events. As part of this objective the following has been undertaken:
    a) Conduct an analysis on the wave rider buoy data and determine when storms occur.
    b) Examine the volumetric change at Bengello Beach
    c) Plot the discharge data, storm data and volumetric data to compare trends.
2) Determine if the Moruya River is delivering sediment to the beach. As part of this objective the following has been undertaken:

    a) Conduct a magnitude-frequency analysis on discharge to verify how often the threshold for scouring throughout the entire lower Moruya River estuary has occurred.
    b) Compare sediment taken from Moruya river point bars (fluvial in origin), to samples taken from the back barrier, the 1974/78 scarp and modern beach face with XRD and SEM to examine fluvial to marine contribution.
3) Analyse the frequency and magnitude of coastal storms, river flooding and beach changes from the historical record and beyond.
    a) Enter the storm data, discharge data and volumetric data into a magnitude frequency analysis program (Flike) to determine the recurrence interval of events that have occurred as well as the potential recurrence interval of events in the future

Through the completion of these objectives, the project seeks to understand the temporal trends exhibited by storms as it will it allow preparations to be enacted to combat the impacts of storms.

1.4 Outline and Scope

This thesis is separated into the following chapters. Chapter one introduces previous work conducted on wave characteristics, extreme value analyses and volumetric analyses which provide the foundations of this project as well as the rationale, aims and objectives. Chapter two investigates climatic influences on Australia, previous storms and the associated impacts, the formation of different barriers, the effect sediment supply has on coastal variation, how to detect the origin of sediment and the data and distributions required for a magnitude frequency analysis. Chapter three details the regional setting of the main study site (Bengello Beach) and includes the reasoning for, and locations of additional study sites. Chapter four details the methods used to examine and collect data in this study including; the selection of storms from waverider buoy data, the combination of river discharge records, the digitisation of volumetric graphs, the creation of magnitude frequency curves with an appropriate distribution, the collection of sediment samples via coring and sediment analysis through the use of XRD and SEM. Chapter five presents the results for the temporal analysis of storms, if the Moruya River is delivering sediment to Bengello Beach and the links between river flooding, coastal storms and beach changes during storm events. Chapter six is a discussion of these results and an explanation for why they occur, methodological limitations and recommendations for future coastal management. Finally, Chapter seven will conclude the thesis, surmising the main points for the project.

Chapter 2

2. Literature Review

2.1. Australian climatic influences

Australia's climate is affected by a series of climatic influences that have varying levels of impact on different regions throughout various temporal scales (ie weeks to decades). Some of the most notable climatic influences to affect Australia are the El Nino Southern Oscillation (ENSO), the Southern Annular Mode (SAM), the Pacific Decadal Oscillation (PDO), the Interdecadal Pacific Oscillation (IPO), the Indian Ocean Dipole (IOD) and the Sub Tropical Ridge (STR) and the location of origin for most of these forces can be seen can be seen in Figure 2.

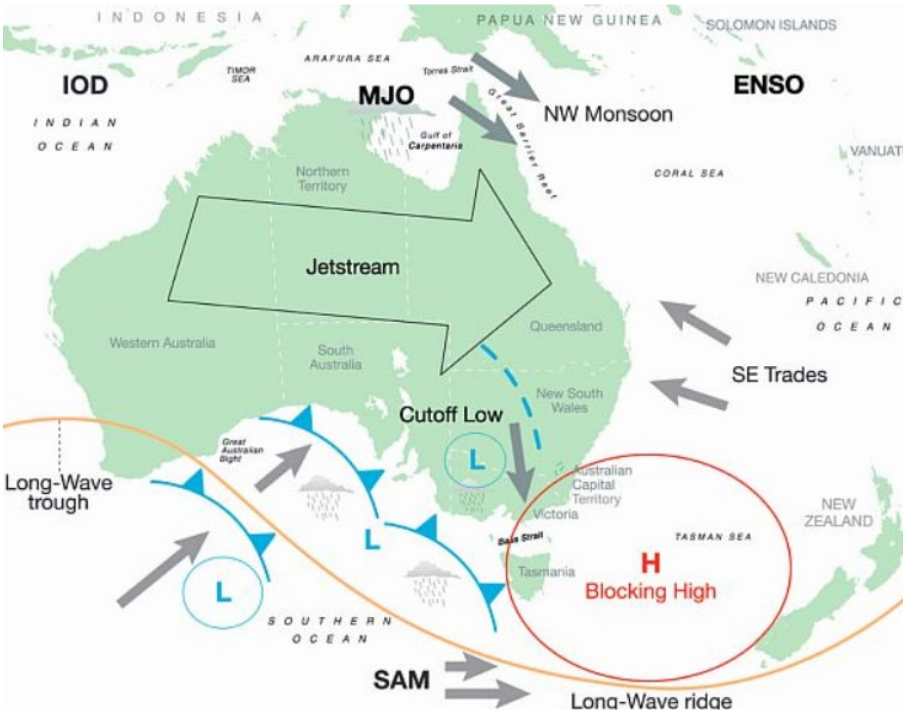


Figure 2: The location of origin of various climatic influences affecting Australia. Not shown are the IPO, PDO and STR. (Sourced from Risbey et al., 2008)

2.1.1. Australian climatic influences from the Pacific Ocean

In the Pacific Ocean, the dominant climatic influences are ENSO, PDO and IPO. The stages in ENSO, termed EL Nino, La Nina and ENSO neutral, are determined by variations in the Southern Oscillation Index (SOI) which is defined by the sea level pressure difference between the Indonesian low and South Pacific Subtropical High (Suppiah, 2004). El Nino events are associated with higher sea surface temperatures (SST) in the central and eastern Pacific Ocean with higher than average surface pressure (SP) around the north east of Australia and lower than average pressure in the central Pacific (Suppiah, 2004). Contrasting to El Nino, La Nina events are associated with a higher SST in the western Pacific Ocean with lower than average SP around the north east of Australia and higher than average SP in the central Pacific (Bureau of Meteorology n.da; Suppiah, 2004). ENSO events typically persist for periods of 6-18 months (Mantua and Hare, 2002).

While the PDO and IPO are similar to ENSO in the sense they influence the SP and SST of the Pacific Ocean, they differ in spatial and temporal influence. Both the PDO and IPO occur on an interdecadal temporal scale with the IPO being noted as a Pacific wide manifestation of the PDO (Mantua and Hare, 2002; Pui et al., 2011).

2.1.2. Australian climatic influences from the Indian Ocean

In the Indian Ocean, the dominant climate influence is the Indian Ocean Dipole and it is determined by the difference between SST and SP of the west and east Indian Ocean (Bureau of Meteorology n.db). During a positive IOD, SST around Indonesia are cooler than average causing an increase in SP in the region while during a negative IOD, SST around Indonesia are warmer than average causing a decrease in SP in the region (Bureau of Meteorology n.db). The IOD is also noted as having an interplay with ENSO with positive a IOD reinforcing an El Nino event while a negative IOD reinforces a La Nina event (Bureau of Meteorology n.db). IOD events typically persist on a monthly to seasonal scale (Bureau of

Meteorology n.db).

2.1.3. Australian climatic influences from the Southern Ocean

In the Southern Ocean, the Southern Annular Mode influences the north south movement of strong westerly winds that are prominent in the mid to high latitudes of the southern hemisphere (Bureau of Meteorology, n.dc). During a positive SAM, a higher SP and temperature is present in the mid latitudes while during a negative SAM a higher SP and temperature is present in the high latitudes (Lim et al., 2016). SAM events typically persist on a weekly to monthly scale (Bureau of Meteorology n.dc).

2.1.4. Other Australian climatic influences

The Sub Tropical Ridge influences the intensity of the cold fronts that impact Australia through its positioning and intensity (Bureau of Meteorology, n.dd; Timbal and Drosdowsky, 2013). While the STR is a continuous climatic influence, its positioning can deviate in accordance with the temperature and subsequently alter its influence on cold fronts. During warmer periods of the year, the STR is positioned further south of the Australian continent thus decreasing the intensity of cold fronts that affect southern Australia while during colder periods, the STR is positioned over central Australia thus allowing cold fronts to affect southern Australia to a greater extent (Bureau of Meteorology, n.dd). Changes in the intensity of the STR are also noted as influencing the Australian climate with past periods of rainfall deficiency coinciding with periods of an intensified STR (Timbal and Drosdowsky, 2013).

2.1.5. Impact of climate change on Australian climatic influences

Anthropogenic climate change impacts the occurrence and severity of the climatic influences that effect Australia. Extreme ENSO events are forecast to occur more frequently (Muis et al., 2018), the SAM has been found to occur in a positive trend (Wang and Cai, 2013), the STR has also been found to have an increased intensity (Bureau of Meteorology, 2017a) and the back to back occurrence of positive IOD events have been identified and are forecast to happen more frequently (Cai et al., 2009). Due to these variations to Australia's climatic influences, climate change will likely increase the effect storms play on coastal erosion.

2.1.6 Framework for minimising the effects of storms on infrastructure

In order to mitigate the effects of climate change and subsequently lessen its influence on sea level rise, storms and extreme events, emission reductions are undertaken by the global community in the form of UN led legal agreements. In 1997 the Kyoto Protocol was formed with the intention of legally binding a countries leadership to emission reduction targets and as of 2020 there are 192 parties to the Kyoto protocol (United Nations, n.d.). In 2015 the Paris agreement was formed with the intention of intensifying and accelerating the actions needed to limit the temperature rise in this century to less than 2 degrees Celsius above pre industrial levels and as of 2020 186 countries have ratified this (United Nations, n.d.).

Differing to the global concerted effort to reduce emissions, the mitigation of the impacts of sea level rise, storms and extreme coastal events are undertaken at a more localised scale and these methods are classified as protection, accommodation and retreat (Bray et al., 1997). Accommodation focuses on the continued use of vulnerable areas by adjusting the infrastructure with alterations, such as the increased elevation of buildings, and altering the usage of land, such as setting it aside for coastal inundation. Due to the flexibility of accommodation, it can be easily combined with protection and retreat methods for appropriate risk mitigation and cost effectiveness (Bray et al., 1997).

Protection encourages the defence of vulnerable areas by committing to their further development with structures such as sea walls and groynes, and soft engineering practices such as beach nourishment. While protection proves advantageous in the sense that assets are protected, this advantage could become nominal when the cost of perpetually improving defences becomes economically unviable or if the pace of environmental change is too great to keep up with (Bray et al., 1997).

Retreat focuses on the abandonment of a vulnerable area by relocating the inhabitants and prohibiting future development. While the economic costs of the abandoned land can potentially be high, it may be mitigated via a gradual retreat and economically viable if the coast is underdeveloped (Bray et al., 1997).

With thirteen percent of the combined population of Australia and New Zealand living in the Low Elevation Coastal Zone, an area contiguous to the coast that is less than 10m above sea level (Mcgranahan et al., 2007), the potential impacts of sea level rise as well as the augmentation of storms and extreme events are severe. Against this backdrop of sea level rise, storms will be the drivers of coastal change however not all beaches will respond uniformly. Insight into when storms, floods and beach change occur in the past can provide insight on when and where severe erosion will likely occur, informing prioritization of management strategies to mitigate impacts.

2.2. Storms

2.2.1. Seventies storms

From the 25th- 26th of May and the 8th-14th of June 1974, two separate, closely spaced storm events occurred which caused substantial damage along the NSW coastline (Doyle et al., 2019; Lord and Kulmar, 2000). The effects of these events, in combination with the impacts of the events occurring on the 18th –20th March, 31st May–2nd June, 15th –16th June, and 18th –21st June 1978 have left erosion scarps still visible at many locations along the coast (Doyle et al., 2019; Lord and Kulmar, 2000). As a result of these events, most notably the 1974 storms, it was realised that a lack of data existed for the scope and frequency of severe coastal storms events. Subsequently, a network of seven waverider buoys and six tide gauge recorders were established with the locations shown in Figure 3 (Lord and Kulmar, 2000).

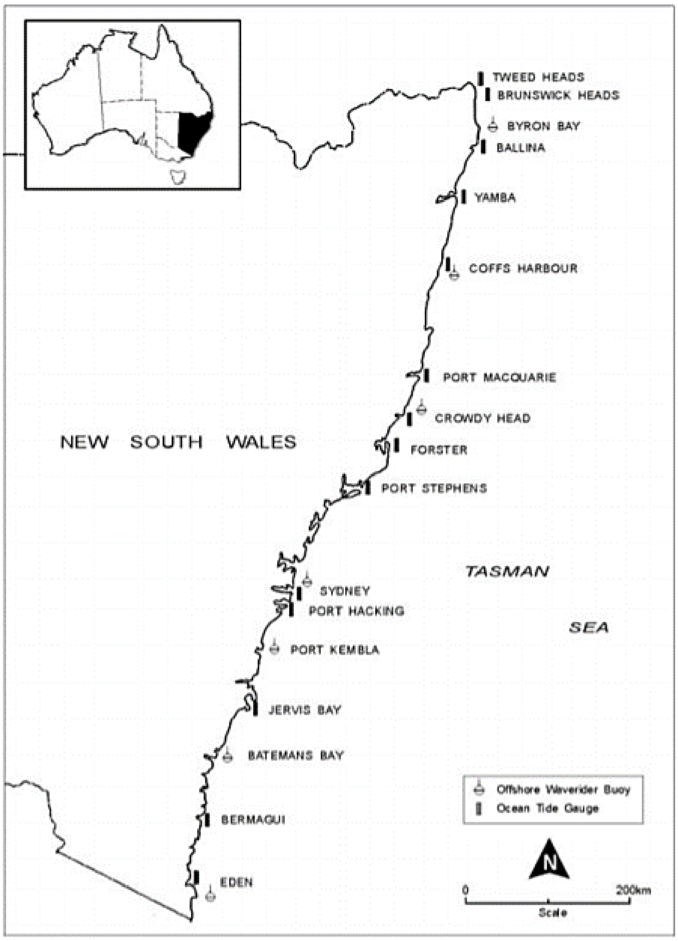


Figure 3:The location of the waverider buoys and ocean water level stations maintained by the Manly Hydraulics Laboratory in NSW. Sourced from Lord and Kulmar, 2000.

2.2.2. Defining a storm event

Glatz et al. (2017) defined a storm event as an event where the significant wave height, the mean wave height of the highest third of the waves in a record, exceeds 3m for at least 1 hour. For events exceeding 1 hour in duration, Glatz et al. (2017) determined the significant wave height by calculating the maximum value exceeded by *n* consecutive records during an event of *n* duration. While events with a significant wave of less than 3m were not included in the analysis, it is recognised that during some storm events, the significant wave height may drop below this threshold before once more exceeding it. In this situation, if less than 24 hours has elapsed before regaining a significant wave height greater than 3m and if the storm was clearly part of an individual weather system, the separate episodes were considered as a single event (Glatz et al., 2017).

2.2.3. A history of storm erosion

In order to extend the magnitude and frequency of storms beyond the instrumental record, storm scarps in combination with the heavy mineral deposits over topping their erosion surface, can be used (Dougherty et al., 2004, Goslin and Clemmenson, 2017). While this data can be recorded within the relict ridges of a prograded barrier, they can be erased in a receding, stationary, or a prograded barrier (if the storm is large enough) by subsequent high energy events (Dougherty, 2014). As seen in Figure 4a, a large storm will leave behind an erosive signature such as a dune scarp and these will typically have a concentration of coarse-grained sediment and heavy minerals (Dougherty, 2014). As seen in Figure 4b, the sediment transported offshore during the storm is reworked back onto the shore by lower energy swell waves and it subsequently buries the storm scarp (Dougherty, 2014). This volumetric change has been documented over time at Bengello Beach by the collection of a series of beach profiles that measure differences in topography using survey equipment or remote sensing techniques (Mclean et al., 2010). Longer-term records of beach behaviour are preserved in barriers that maintain a positive sediment budget (Dougherty et al., 2004). After an erosional event, normal progradation resumes and beach ridges inland become isolated from active nearshore processes, thus preserving a succession of storm scarps within the barrier stratigraphy (Figure 4c: Goslin and Clemmenson, 2017).

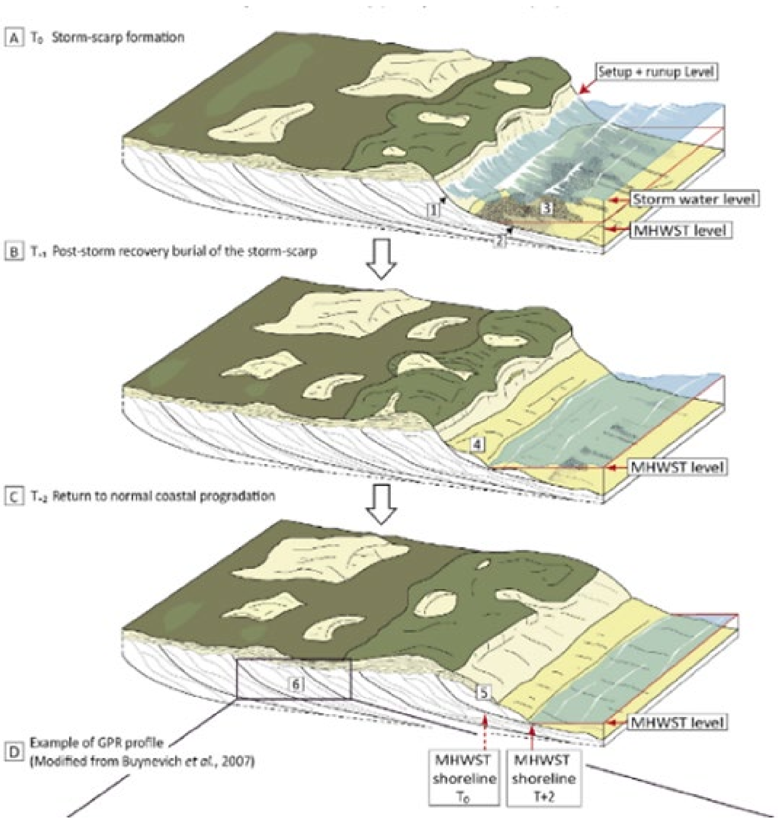


Figure 4: A diagram detailing storm scarp formation (A), post-storm recovery & storm scarp burial (B) and return to progradation (C). Sourced from Goslin and Clemmensen, 2017 pp 89

2.2.4. Previous storm studies

Previous studies of coastal storms along the NSW coastline have demonstrated spatial and temporal trends across the record. As outlined in Shand et al. (2010), on a seasonal basis, the significant wave height is found to have substantial variation along the coast. In the north, larger waves occur during the autumn with lower waves occurring during the spring and summer while in the south, wave heights are a lot more consistent. Similar to the trends in significant wave height, the mean peak wave direction in Shand et al. (2010) was also found to have spatial and temporal differences. Mean peak wave direction is found to occur with a more easterly direction at the northern buoys or during summer and from a more southerly direction at the southern buoys or during winter. While the mean peak wave period in Shand et al. (2010) is found to exhibit similar seasonal variations to the other wave characteristics, with autumn and winter having increased periods and spring and summer having reduced periods, the spatial trend does not hold with periods remaining relatively consistent across the coast.

In order to determine the likelihood of large, low probability wave events occurring, an average recurrence interval (ARI) is calculated by fitting a theoretical distribution to the historical wave data (Shand et al., 2011). With the addition of several major storms to the record between 2010 and 2017, the importance of regularly updating the extreme value analysis is evident with these severe events defining the tail of the data distribution (Glatz et al., 2017). It is noted in Glatz et al. (2017) that the extreme significant wave heights and the respective recurrence intervals that were previously determined by WRL (2010) have now increased due to the occurrence of these additional severe events, with the increase most substantial at Eden.

2.3. Barriers

A coastal barrier is a wave built accumulation of sediment occurring on an elongated coastal ridge that is above the high tide level and it is split into the three zones of beach, barrier interior and landward margin (Bird, 2005; Fitzgerald and Buynevich, 2009). While barriers typically consist of feldspar- quartz sand derived from granite or reworked sandstone, lithological variations exist over different landscapes. In locations influenced by glacial shaping or fast flowing rivers a mix of gravel may be present while black sand may be present in locations featuring a prominence of volcanic rocks (Bird, 2005; Fitzgerald and Buynevich, 2009; Szilo and Bialik, 2018). Depending on factors such as rate of sediment supply, rate of sea level rise, wave and tidal energy, climate and topography, barriers will either be stationary, receding or prograding (Fitzgerald and Buynevich, 2009). Stationary barriers will occur when sea level rises at a moderate pace while simultaneously having a modest sediment supply (Otvos, 2012). Receding barriers will occur when sea level rise, long term erosion or a negative sediment supply to be driven landwards over the coastal lagoon (Carter and Woodroffe, 1994 p159; Jones et al., 1997). Prograded barriers occur typically during a time of a time of stable or decreasing sea levels that have a positive sediment budget and sizeable accommodation space available (Oliver et al., 2016; 2017; Otvos, 2012).

2.3.1. Prograded barriers

Prograded barriers are coastal landforms composed of a series of relict ridges that form along coastlines with positive sediment budgets and a sizeable accommodation space (Oliver et al., 2016; 2017). The time required for each individual ridge to form can range between an average rate of 30-150 years and this is dependent on factors such as the ridge dimensions, the nearshore bottom gradient and the rate at which the ridge is supplied with sand (Otvos, 2000). After a new beach ridge is formed via progradation, beach ridges immediately inland of these positions become isolated from active nearshore processes and subsequently preserve their past shoreline position and shape thus creating a history of storm erosion and changes in sea level (Dougherty., et al 2019; Tamura, 2012).

2.4. Sediment supply

The sediment that forms most of Australia's present-day sandy coastlines at least partially originated from the continental shelf. Following the last glacial period, the sediment was transported up the shelf before accumulating on the present-day coast during the relatively stable sea level of the past 6,500 years (Roy et al., 1994). Variations in sediment supply can affect beach ridge size and spacing as decreases can cause larger, widely spaced ridges and increases can cause smaller, closely spaced ridges (Rae, 2011). When examining the barriers on the South East Australian coast, sediment supply is an important aspect to examine as supply imbalances, along with having enough accommodation space, will affect whether a barrier is stationary, receding or prograding (Dillenburg et al., 2006; Fitzgerald and Buynevich, 2009).

2.4.1. Effect of sediment supply on progradation

Variations in sediment supply exert a notable impact on the movement of coastlines as they can influence whether it will prograde or recede. When coastlines maintain a negative sediment budget, as seen when storms cause erosion of sediment to outpace accumulation, they will recede landward. Contrasting to this, when coastlines maintain a positive sediment budget, as seen when fluvial transport allows accumulation of sediment to outpace erosion, they will prograde seawards (Rosati, 2005). Furthermore, in settings where sediment supply is high enough, progradation can outpace sea level rise allowing barriers to be more resilient to erosion in a future of global warming (Fruergaard et al., 2015). An example of this occurrence can be seen in Dillenburg et al. (2006) examination of the Curumim barrier in Brazil where progradation occurred while the sea level was rising near the end of the Postglacial Marine Transgression.

2.4.2. Tracing sediment supply

The two dominant types of sediment lithologies found along the New South Wales coastline are marine sediments and fluvial sediments (Carvalho et al., 2019). Marine sediments are found to consist of rounded, well sorted quartz sands with less than 10% lithic and feldspar grains and the potential for shell fragments and heavy minerals (Carvalho et al., 2019). Contrasting to this, fluvial sediments are found to consist of more angular sand grains that are richer in lithics and feldspars (Carvalho et al., 2019).

In order to trace the origin of sediments from their area of deposition, a physical or chemical aspect of the mineralogy is chosen and compared between potential source materials (O’Brien, 2001). A notable method of sediment tracing is X-Ray Diffraction (XRD) which uses an X-ray beam to measure the distance between atoms and subsequently identify mineral concentrations (Sisinggih et al., 2006). An XRD was used both by Carvalho et al. (2019) to determine the origin of sediment in the Shoalhaven prograded barrier and Porritt (2018) to determine the origin of sediment for the Gilbert River Delta. In addition to the XRD analysis, a Scanning Electron Microscope (SEM) analysis can be used to examine a samples roundness and make inferences to the amount of time it has been in the transportation cycle (Carvalho et al., 2019; Nelson, 2018).

2.5 Magnitude frequency analysis

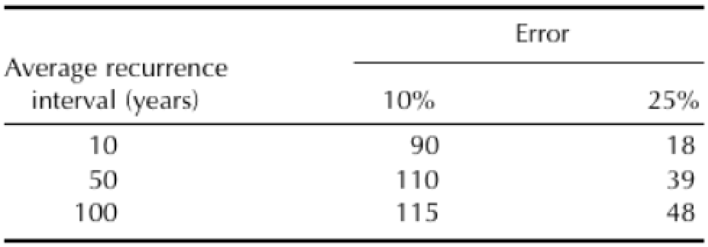
A magnitude frequency analysis is a method of assigning the probability of occurrence to an event of any size (Gordon et al., 2004). The probability of an event occurring is typically expressed as a 1-in-*n*- year chance and it would subsequently be expected to occur on average once every *n* years. The average length of time between any two events of the same severity are termed the average recurrence interval (ARI) and the probability of occurrence can be expressed using the formula in Equation 1 with P representing probability and T representing the ARI (Gordon et al., 2004).

1)

$$P = \frac{1}{T}$$

In order to estimate the recurrence interval of any given event, it is noted by Gordon et al. (2004) that an increasingly large data set is required to obtain greater accuracy. As seen in Table 1, for an event with a recurrence interval of 10 years, 90 years of data is required to achieve an error margin of 10% and for recurrence intervals of 50 years or greater, over 100 years of data is required. Contrasting to this, for recurrence intervals of 10 years, only 18 years of data is required to achieve an error margin of 25% and for recurrence intervals of 50 years or greater, over 39 years of data is required.

Table 1: The amount of data (years) required to obtain a recurrence interval to a 10% and 25% error margin (Sourced from Gordon et al 2004)



Average recurrence interval (years)	Error	
	10%	25%
10	90	18
50	110	39
100	115	48

2.5.1 Data series

An extreme wave analysis can be conducted by using an annual maximum series or a peak over threshold method (Glatz et al., 2017). The annual maximum series utilises the largest significant wave height value that occurred for each year of the record while the points over threshold method consists of utilising all values above a specific threshold (Glatz et al., 2017, UNESCO, 2005**).** When choosing which data series to use, it is worth noting that both have shortfalls. While the annual maximum series will fail to consider the second largest event in a year, even if it exceeds other annual maximums, the points over threshold values may be influenced by the recession curves of previous events (UNESCO, 2005). In the report by UNESCO (2005) it was ultimately determined that at recurrence intervals of greater than 10 years, annual maximum and points over threshold data series yielded similar or comparable prediction event magnitudes.

2.5.2. Distributions

In order to determine the significant wave height of a specific average recurrence interval, a theoretical distribution is typically applied to the historical storm wave data (Shand, 2011) and this can be done through the extreme value analysis package Flike (TUFLOW, 2015). Five different distributions are available for use in Flike and they are the Log Pearson III (LPIII), Log Normal, Generalised Extreme Value (GEV), Gumbel and Generalised Pareto distributions (GPD) (Paul et al., 2016).

The LPIII distribution utilises three parameters- standard deviation (shape), scale and location and it is typically used for examining flood data due to only having a lower limit and no upper limit (Gordon et al., 2004; Limpert et al., 2001; Phien and Hira, 1983). The Log Normal distribution utilises two parameters, standard deviation (shape) and scale (Limpert et al., 2001) and it is often used for examining flood peak and low flow data. The GEV distribution can be used to model the smallest or largest values among a large data set and depending if the data tail is decreasing exponentially, decreasing as a polynomial or if its finite will determine if it’s a type I, II or III respectively (Mathsworks, 2020). The Gumbel distribution is part of the generalised extreme value sub family and it has been previously applied to the annual maximum significant wave heights in Glatz et al. (2017) & Katalinic and Parunov (2020). The GPD is used to model independent values above a specified threshold and as a result it has been previously applied in points over threshold analyses of extreme wave events (Kiriliouk et al., 2017; Zhou et al., 2016).

Chapter 3

3. Study Site

3.1. Bengello Beach

Bengello Beach is located on the South Coast of New South Wales, Australia, and is approximately 7km north east of the township of Moruya with its location seen in Figure 5. It is a dissipative, crescent shaped beach compartment with an easterly aspect, and it is surrounded by Broulee Island to the North and Moruya River to its south (Mclean et al., 2010). The is made up of very well to well sorted fine to medium grained quartzose-feldspathic sands (~125µm- 500µm) that consist of subtle differences across the nearshore, beach and the 5-8m dune ridges that back onto the active beach (Mclean et al., 2010). Bengello Beach fronts a barrier that has been prograding for close to the past 7,000 years and it consists of approximately 60 relict foredunes, which are visible in the lidar in Figure 6 and they have been formed on average every 110 years (Oliver et al., 2015).

Figure 5: An overview of the study sites used. The blue circles represent areas where a volumetric profile exists, and the yellow circles represent an area where a wave rider buoy is present

Figure 6: LiDAR at Bengello Beach demonstrating the presence of dune ridges

Bengello Beach has been the subject of various scientific studies detailing the beach morpho dynamics for the past 50 years (Mclean et al., 2010). Since January 1972, a volumetric study of Bengello Beach has been conducted where four profiles have been frequently surveyed at the centre of the beach. This has been done at fortnightly intervals from 1972- 1976, monthly intervals from 1976-1989- and six-week intervals from1989-2010 (Mclean et al., 2010). Between 2013 and 2014, Oliver et al. (2015) collected a series of OSL samples across the barrier allowing the construction of a chronological record.

3.1.1. Moruya River

The Moruya river gauges at Riverview and Wamban have been used to denote the discharge occurring throughout the river over time and subsequently infer fluvial sediment delivery to Bengello Beach. The location of the river gauges can be seen in Figure 7**.**

Figure 7: The location of the river gauges on the Moruya River at Wamban and Riverview

3.1.2 Sediment supply from the Moruya River to Bengello Beach

Variations in the erosion and accretion within the Moruya River have been examined in the model analysis of sediment bed change in the Moruya river's lower estuary in AMOG consulting (2003). As can be seen in Figure 8a, under once in one-year flood conditions, flow velocity only exceeded the threshold for scouring near the entrance of the river. This means that the severity and area of erosion, as shown by the dark blue regions, and sedimentation, as shown by the black regions, are limited to that area. For all floods with a recurrence interval greater than once every two years, the velocity exceeded the threshold for scouring throughout the entire river with an increasingly larger area being impacted more severely as the recurrence intervals increased. As can be seen when comparing Figure 8a to Figure 8b and Figure 8c, which display the one in five and a one in fifty-year flood conditions respectively, this is evident. When examining the bed change in relation to increasing flood conditions, it is also noted that as the recurrence interval increases, an increasing degree of sedimentation is occurring to the north of the jetty, which is highlighted by the red circle. Due to the position of this sediment, it is thus likely being delivered to the beach via longshore drift.

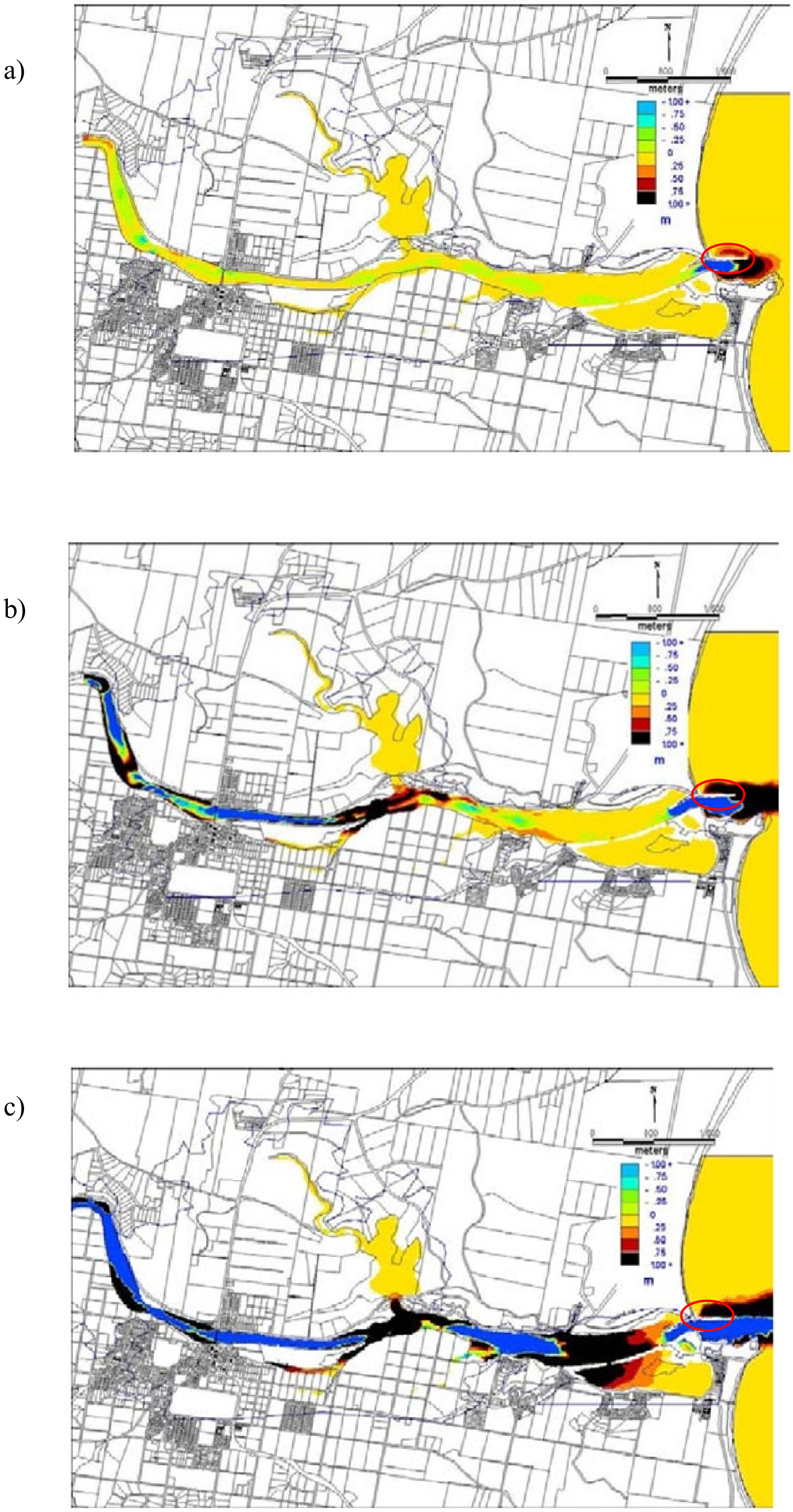
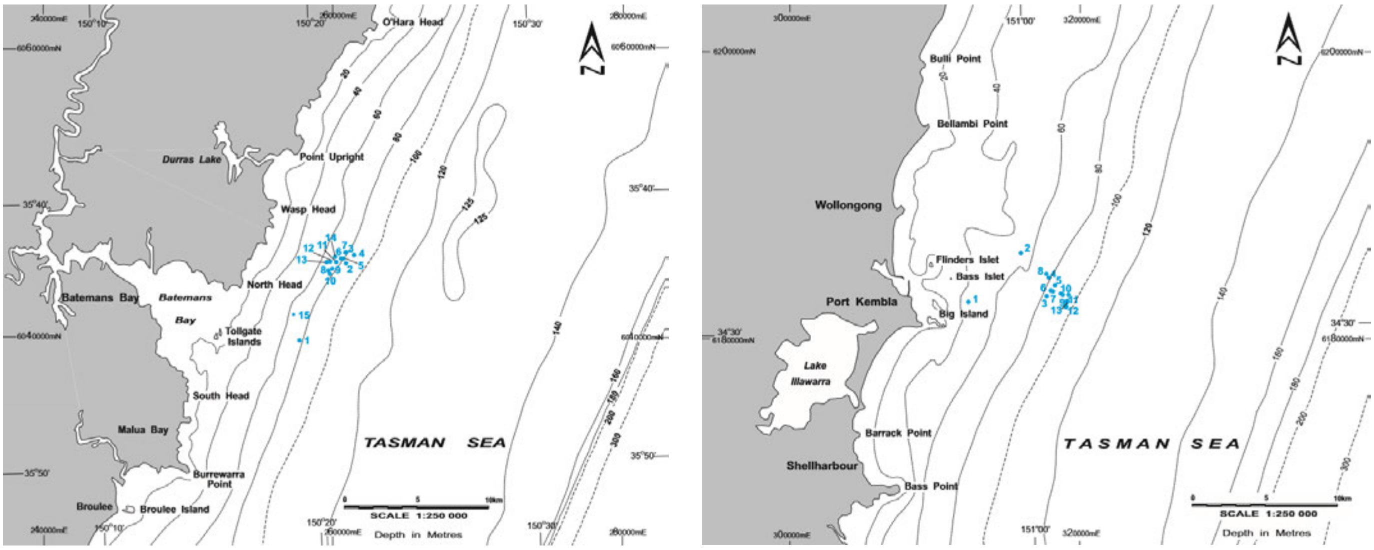


Figure 8: a) The modelled bed change occurring during a 1 in 1-year flood event in the Moruya rivers lower estuary. b) The modelled bed change occurring during a 1 in 5-year flood event in the Moruya rivers lower estuary. c) The modelled bed change occurring during a 1 in 50-year flood event in the Moruya rivers lower estuary. As evident by the area north of the Jetty (red circle) an increasing amount of sediment is potentially reaching the beach. Sourced from AMOG Consulting 2003

3.2. Additional study sites

A wave rider buoy at Batemans Bay was used to examine the wave characteristics at Bengello Beach due to its proximity to the site (27km north-east). In addition to this, a wave rider buoy at Port Kembla was used due to the length of the record, it records the characteristics of the 1974 and 1978 storm events. The locations of both buoys are seen in Figure 9a and 9b.



a)

b)

Figure 9: a) The various locations of the Batemans Bay Waverider Buoy. b) The Various locations of the Port Kembla Waverider Buoy

The volumetric data set from the central profile of Narrabeen Beach has been utilised as due to its similar active duration to the volumetric profiling at Bengello Beach and lack fluvial contribution to sediment, it will prove useful in determining fluvial contribution. The location of Narrabeen- Collaroy beach relative to Bengello Beach is seen in Figure 5**.**

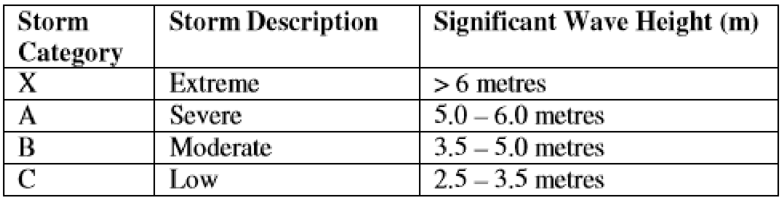
Chapter 4

4. Methods

4.1. Selection of storms

In order to conduct a selection of storm events, significant wave height (Hsig), which is the mean wave height of the largest 33% of waves (Glatz et al., 2017), was examined from wave rider buoys off the coast of Batemans Bay and Port Kembla. The waverider buoy data found at Batemans Bay covered the period from 27/5/1986 16:00 until 1/8/20 0:00 and the waverider buoy data found at Port Kembla covered the period from 7/2/1974 12:00 until 1/8/20 0:00. A storm event in this analysis is defined as an event where the Hsig exceeds 3.5m for at least one hour. Initially the storm classification threshold was set at 2.86m, which is twice the average Hsig over the entire Batemans Bay record. The threshold was then increased to 3m as used in the storm selection methodology of Glatz et al. (2017). The threshold was then further increased to 3.5m Hsig based on the classification of a moderate storm as seen in Table 2.

Table 2: Storm Severity Classification (NSW Government cited in Watson et al 2007)



Storm Category	Storm Description	Significant Wave Height (m)
X	Extreme	> 6 metres
A	Severe	5.0 – 6.0 metres
B	Moderate	3.5 – 5.0 metres
C	Low	2.5 – 3.5 metres

While events classified as low severity (2.5 m < Hsig < 3.5 m) were not included in the analysis, it is recognised that during events with a longer duration, the Hsig may drop below 3.5m for a period of time before once more exceeding this threshold. In this instance, if the Hsig drops beneath 3.5m for longer than 24 hours or drops below 2.5m during that same period before once more exceeding 3.5m, the data will be considered as multiple storm events as seen in Figure 10a and b. Contrasting to this, if the Hsig drops beneath 3.5m for shorter than 24 hours and stays above 2.5m during that same period before exceeding 3.5m, the data will be considered a single storm event as seen in Figure 10c and d.

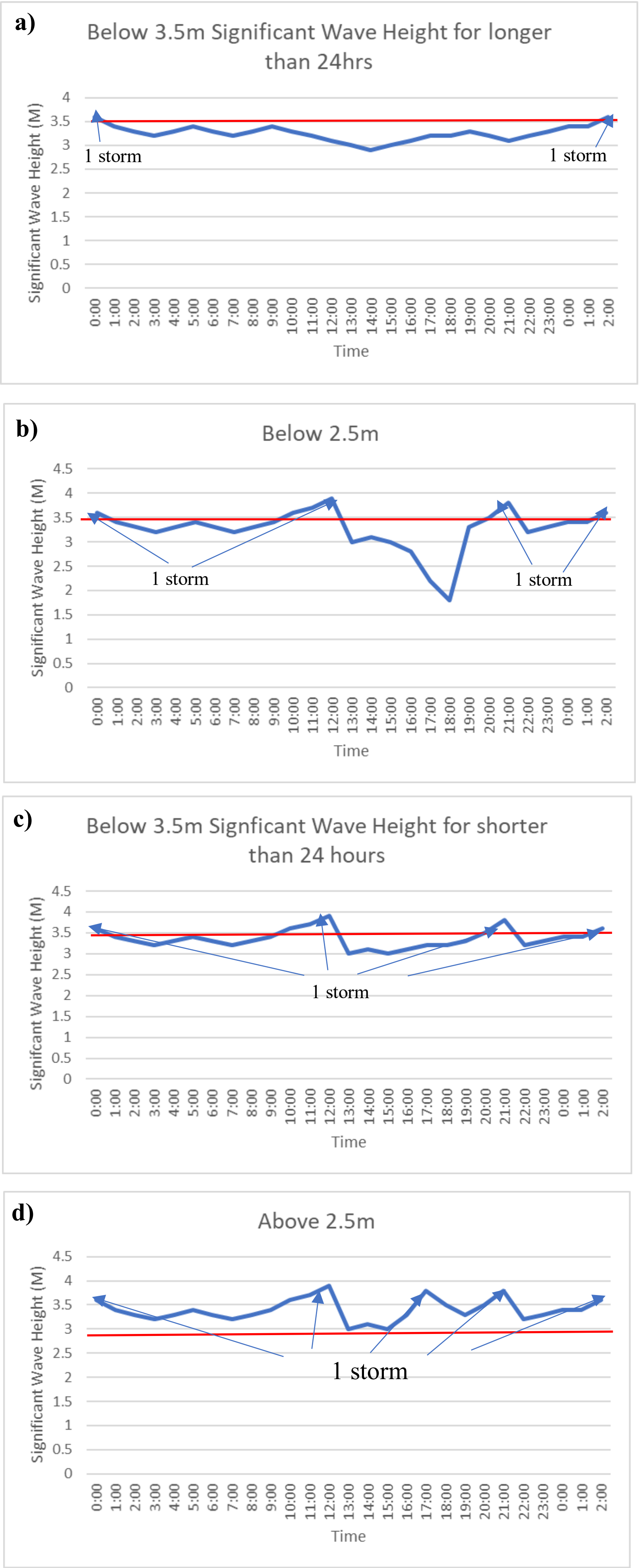


Figure 10: a) Both instances of Hsig exceeding 3.5m are separated by 24 hours where Hsig is less than 3.5m and thus they are classified as separate storms. b) The instances of Hsig exceeding 3.5m are separated by a Hsig less than 2.5m and thus they are classified as separate storms. c) Hsig does not drop below 3.5m for longer than 24 hours and thus all instances of exceedance are classified as the same storm. d) Hsig does not drop below 2.5m and thus all instances of exceedance are classified as the same storm.

The peak significant wave height, duration, wave period, wave direction, storm severity and season of occurrence for each of these storms were then graphed within Microsoft Excel in an effort to find any trends at a seasonal, yearly and decadal scale. This data has also been included in Appendix 2 and 3 with peak significant wave height, wave period and wave direction being noted to 2 decimal places.

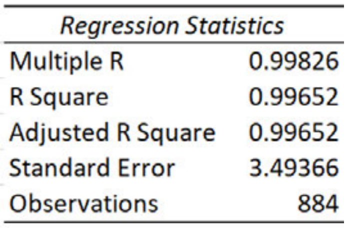
4.2. Defining storm clusters

A storm cluster is defined in this thesis as an event where 3 or more storms with a severity of moderate or greater occur within a period of 30 days.

4.3. Identification of flood events

When identifying flood events along the Moruya River, the datasets utilised were the discharge values at Wamban from 24/09/1959 until 11/07/2013 and Riverview from 8/2/2011 until the 1/8/2020. In order to combine the two discharge records, a linear regression in Microsoft Excel was first used to demonstrate the strength of the relationship between the 2 stations. In Table 3 it can be seen that both the Multiple R and R Square values are close to 1 thus indicating a strong positive relationship and a goodness of fit on the regression line.

Table 3: Regression statistics for the linear regression between the Moruya River discharge at the Wamban and Riverview stations. Due to the proximity of the Multiple R and R square values to 1, the regressed values are found to have a good fit and a strong relationship. Sourced from Cheusheva 2019.



Regression Statistics	
Multiple R	0.99826
R Square	0.99652
Adjusted R Square	0.99652
Standard Error	3.49366
Observations	884

The discharge data for Riverview from 12/07/2013 until 1/8/2020 was then entered into the equation of the regression line, seen in Figure 11, and as a result, an approximate discharge at Wamban during this period was created.

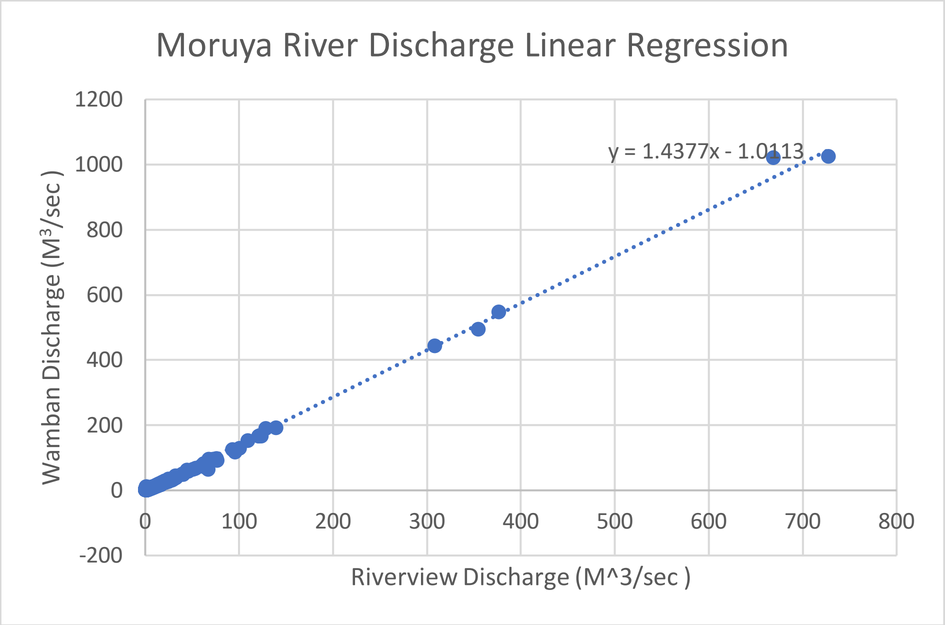


Figure 11: A linear regression graph for the Moruya River discharge between Riverview and Wamban. The equation displayed on the line has been used to convert the Riverview discharge data to an approximate value as if it was taken at Wamban.

4.4. Volumetric analysis

4.4.1. Photogrammetry

Photogrammetry is the process of extracting high resolution spatial data from aerial photography in order to depict changes within an environment throughout time and the subsequent rate that they occur (Hanslow et al., 2015); and is commonly used to retroactively extract topographic profiles to determine beach change. Since the 1940's, the aerial photography for this process has been gathered via planes, satellite imagery and Unmanned Aerial Vehicles (UAV) (Nikolakopoulos et al., 2019). By examining the changing relative spatial position of various points within the photographs over time, photogrammetry can be used to denote coastal recession, riverbank erosion, variations in high tide mark, changing vegetation area and variations in the location of the top and bottom of the back beach escarpment (Hanslow et al., 2015). Furthermore, by using a mosaic of photos, three dimensional coordinates are able to be obtained for points of interest via the lines of sight from each camera and this subsequently allows volume variations to be determined for coasts and riverbanks. (Hanslow et al., 2015; Sajinkumar and Oommen, 2018).

4.4.2. Light Detection and Ranging (LiDAR)

Light Detection and Ranging (LiDAR) is conducted by emitting a laser pulse from an aircraft mounted laser range finder towards the ground and measuring the time before it returns to the sensor (Dougherty et al., 2019b; Omasa et al., 2007). By determining the time between the emission and return of the pulse and by subsequently combining this data with GPS, an area of tens to hundreds of kilometres in extent can be remotely mapped at a 1 m or less horizontal resolution and 0.1-0.15m vertical resolution (Dougherty et al., 2019b; Omasa et al., 2007). Following this data collection, LiDAR can be used to create a digital terrain model that displays subtle changes in dune topography such as the presence of beach- foredune ridges (Dougherty et al., 2019b). When LiDAR data is viewed in conjecture with satellite imagery, a more complete data set can be obtained that will allow a morphological examination that avoids natural and anthropogenic altered areas and instead isolates the areas of the barrier impacted by storms (Dougherty et al., 2019b). Topographic transects can be drawn from LiDAR digital elevation models to extract beach profile data and determine volumetric changes. Existing LiDAR was sourced from Geoscience Australia.

4.4.3. Digitisation

The analysis of volumetric data utilises graphs found in Mclean et al. (2010) and Turner et al. (2016) that display the volume of Bengello Beach from January 1972 until October 2010 (Figure 12a) and for comparison the volume of central Narrabeen Beach from 24/04/1976 until 31/07/2020 (Figure 12b), respectively. With the values on the graphs being reliant on a visual examination, both graphs were subsequently digitised using the program PlotDigitizer and this allowed an approximate value of each point to be determined. The digitised data was then transferred into Microsoft Excel where the dates previously in decimal form were changed to the DD/MM/YYYY format and volumetric change between points were noted.

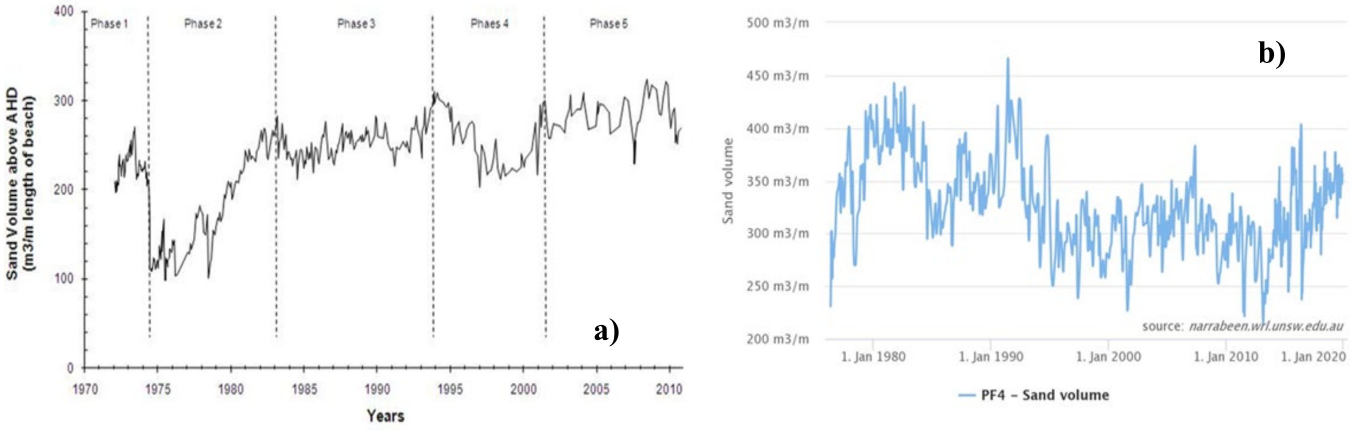


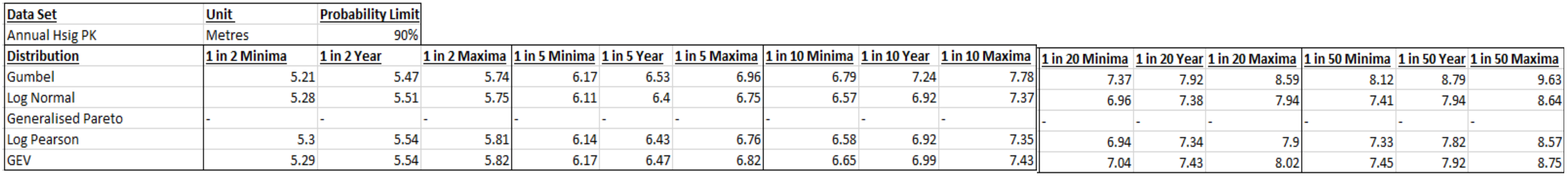
Figure 12: a) Volumetric Record of Bengello Beach (Mclean et al 2010). B) Volumetric Record of Narrabeen Beach at its central profile (Turner et al 2016).

4.5. Recurrence interval

The Gumbel distribution was chosen to be used for the significant wave height analysis as recommended by Katalinić and Parunov (2020). The Gumbel distribution was also applied to the annual maximum erosion and accretion data as it was reasoned that as waves were responsible for sediment movement, the same recurrence interval model would be applicable. Ultimately the LPIII model was chosen as it is the government standard in Australia (Gordon et al., 2004) and it was found to be the best performer by Paul et al. (2016) when conducting a flood frequency analysis. For Further discussion and validation of these distributions, see Appendix A1.8.

Table 4:a) The recurrence interval for the 5 distributions of the annual maximum significant wave height at Port Kembla. b) The recurrence interval for the 5 distributions of the annual maximum river discharge at Moruya.

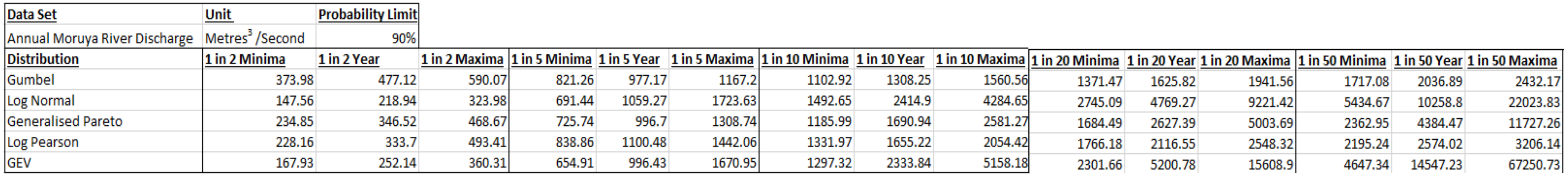
a)



Data Set	**Unit**	**Probability Limit**
Annual Hsig PK	Metres	90%

Distribution	**1 in 2 Minima**	**1 in 2 Year**	**1 in 2 Maxima**	**1 in 5 Minima**	**1 in 5 Year**	**1 in 5 Maxima**	**1 in 10 Minima**	**1 in 10 Year**	**1 in 10 Maxima**	**1 in 20 Minima**	**1 in 20 Year**	**1 in 20 Maxima**	**1 in 50 Minima**	**1 in 50 Year**	**1 in 50 Maxima**
Gumbel	5.21	5.47	5.74	6.17	6.53	6.96	6.79	7.24	7.78	7.37	7.92	8.59	8.12	8.79	9.63
Log Normal	5.28	5.51	5.75	6.11	6.4	6.75	6.57	6.92	7.37	6.96	7.38	7.94	7.41	7.94	8.64
Generalised Pareto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Log Pearson	5.3	5.54	5.81	6.14	6.43	6.76	6.58	6.92	7.35	6.94	7.34	7.9	7.33	7.82	8.57
GEV	5.29	5.54	5.82	6.17	6.47	6.82	6.65	6.99	7.43	7.04	7.43	8.02	7.45	7.92	8.75

b)



Data Set	**Unit**	**Probability Limit**
Annual Moruya River Discharge	Metres^3 /Second	90%

Distribution	**1 in 2 Minima**	**1 in 2 Year**	**1 in 2 Maxima**	**1 in 5 Minima**	**1 in 5 Year**	**1 in 5 Maxima**	**1 in 10 Minima**	**1 in 10 Year**	**1 in 10 Maxima**	**1 in 20 Minima**	**1 in 20 Year**	**1 in 20 Maxima**	**1 in 50 Minima**	**1 in 50 Year**	**1 in 50 Maxima**
Gumbel	373.98	477.12	590.07	821.26	977.17	1167.2	1102.92	1308.25	1560.56	1371.47	1625.82	1941.56	1717.08	2036.89	2432.17
Log Normal	147.56	218.94	323.98	691.44	1059.27	1723.63	1492.65	2414.9	4284.65	2745.09	4769.27	9221.42	5434.67	10258.8	22023.83
Generalised Pareto	234.85	346.52	468.67	725.74	996.7	1308.74	1185.99	1690.94	2581.27	1684.49	2627.39	5003.69	2362.95	4384.47	11727.26
Log Pearson	228.16	333.7	493.41	838.86	1100.48	1442.06	1331.97	1655.22	2054.42	1766.18	2116.55	2548.32	2195.24	2574.02	3206.14
GEV	167.93	252.14	360.31	654.91	996.43	1670.95	1297.32	2333.84	5158.18	2301.66	5200.78	15608.9	4647.34	14547.23	67250.73

Chapter 5

5. Results

This section will highlight the results of this study and it is structured in terms of storm wave characteristics, Moruya River discharge and volumetric change. Sub sections of these broader topics divide the data according to previous temporal differences (seasonal, yearly, and decadal), spatial differences and predicting the frequency and magnitude of future events Initially, storm wave characteristics from both Batemans Bay and Port Kembla were going to be included in the results however due to the similarity in the observed trends at both sites, the occurrence, severity, duration, period and direction from Port Kembla were deemed superfluous to the thesis results and are instead included in Appendix A1.1, A1.2, A1.3 and A1.9. It must be noted however that the Port Kembla wave characteristics from 1974- 1986 are included in the Figure 25- 27 in order to supplement the Batemans Bay record and capture the large erosive events of the mid to late 70s. In order to prove the strength of relationship between the wave characteristics and validate its use, the significant wave height from both Batemans Bay and Port Kembla were compared in a linear regression with a Multiple R value of 0.8 and an R Square value of 0.65 (Appendix 7). The inaccuracies in the regression between Port Kembla and Batemans Bay are deemed acceptable as they are attributed to the reduced wave climate at Batemans Bay resulting from the coastal orientation (Shand et al., 2011).

Unlike the wave characteristics from Port Kembla, the volumetric data at Narrabeen will prove useful in this examination as it will allow the effect of variations in beach recovery on volumetric change to be examined. The magnitude and frequency of the volumetric change however is deemed inconsequential as it is not a focus of the study and is thus included in the Appendix 10.

5.1. Storm wave characteristics

When examining the occurrence of storm events on a seasonal scale, a minimum threshold of 3.5m has been used. As seen on the seasonal scale in Figure 13, at Batemans Bay, there were 84 storms in winter, 57 in autumn, 52 in spring and 43 in summer. Due to this difference in storm occurrence, subsequent examinations will be presented using a percentage rather than the number of occurrence as it will allow the seasons to be compared more accurately.

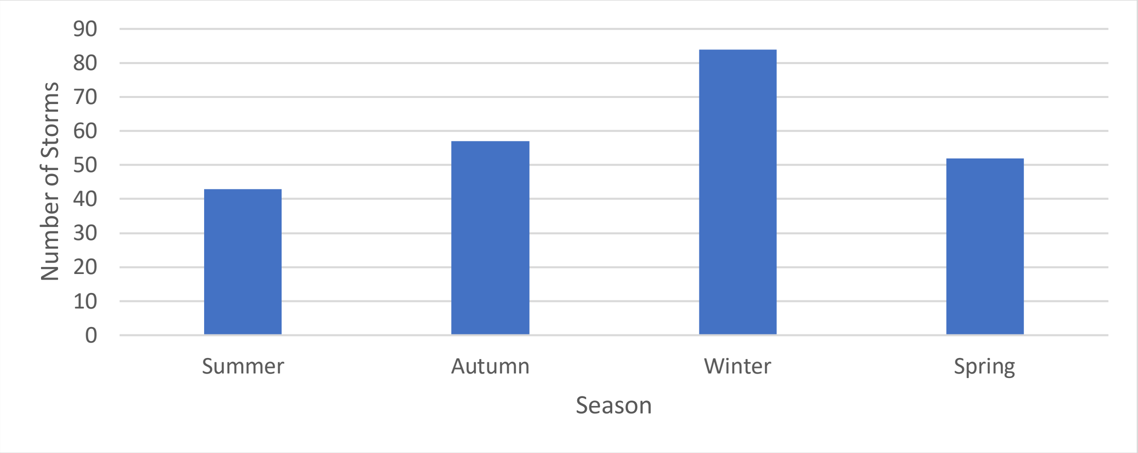


Figure 13: The seasonal distribution of storms at Batemans Bay with a Hsig greater than 3.5m (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Of the storms noted to occur over the threshold of Hsig 3.5m at Batemans Bay in Figure 13, the distribution between moderate (Hsig 3.5-5m), severe (Hsig 5-6m) and extreme severity (6m+) can be seen in Figure 14. As seen in Figure 14, winter had the most severe and extreme storms (19%), followed by spring (15%), then autumn (7%), and summer (5%).

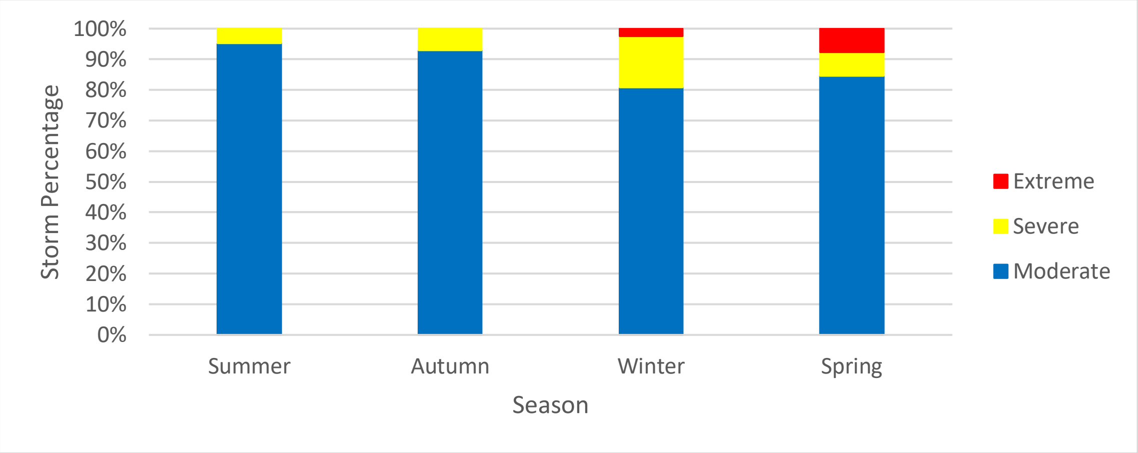


Figure 14: Percentage of storms of each severity in a season at Batemans Bay with a Hsig greater than 3.5m. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Variations in the durations of storms exceeding 3.5m Hsig are noted on the seasonal scale. As seen in Figure 15 , at Batemans Bay, 34% of the storms occurring during winter, 21% of the storms occurring during autumn, 19% of the storms occurring during spring and 9% of the storms occurring during summer had a duration longer than 24 hours.

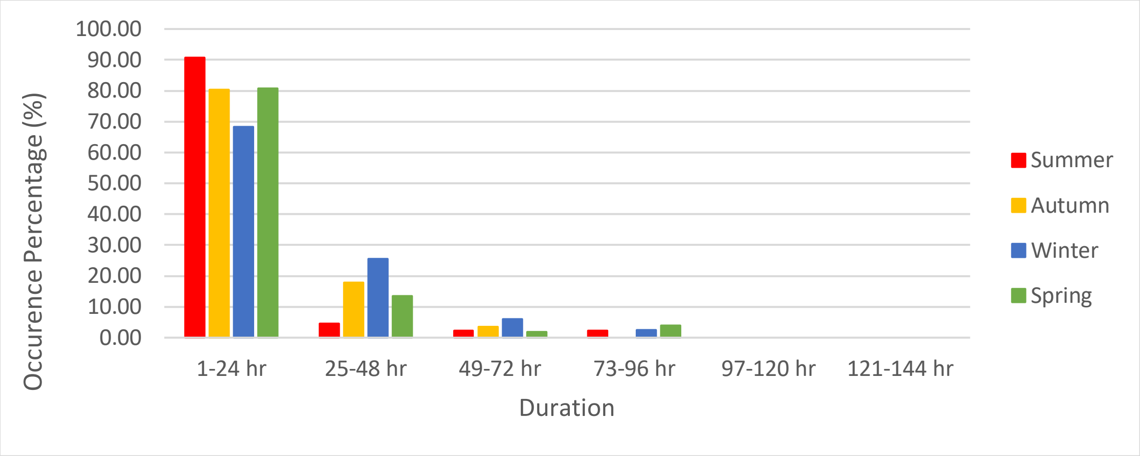


Figure 15:Percentage of seasonal storm durations at Batemans Bay with a Hsig greater than 3.5m. . (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Variations in the wave direction of storms exceeding 3.5m Hsig are noted on the seasonal scale. As seen in Figure 16, of the wave data at Batemans Bay including wave directions, the highest percentage of winter (61%), spring (45%) and autumn (45%) storm waves occurred from the south south east (146.25- 168.75 degrees) while the highest percentage of summer (50%) storm waves occurred from the south (168.75- 191.25).

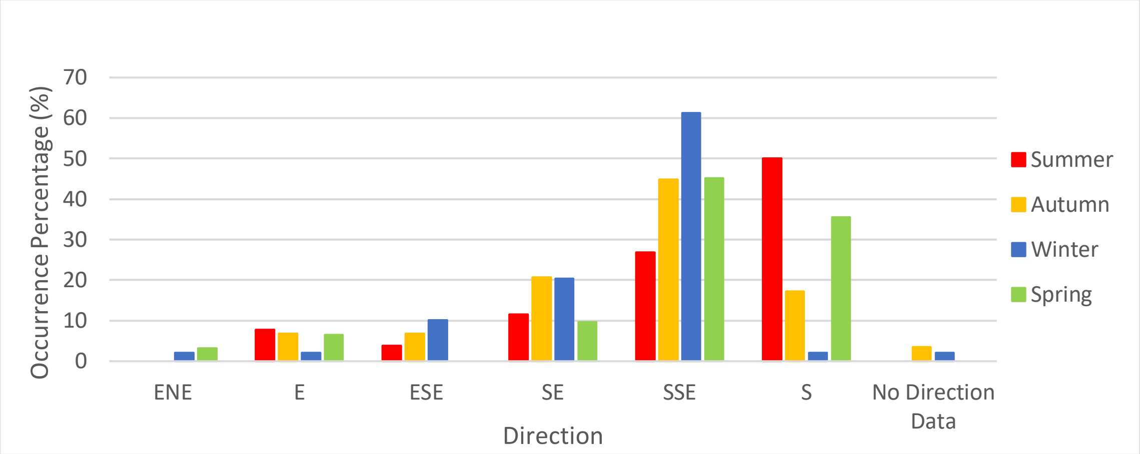


Figure 16: Percentage of seasonal storm wave directions at Batemans Bay with a Hsig greater than 3.5m.. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

When examining the occurrence of severe and extreme storms at Batemans Bay on a yearly to decadal scale, differences are found based on the temporal scale and event severity. While no trends are noticeable in the occurrence of severe and extreme storms on a yearly basis, as seen in Figure 17a and b, when the occurrence of severe storms are taken on a decadal basis, it is evident that occurrence is increasing throughout time as seen in Figure 18a. However, contrasting to the decadal trend observed with severe storms, no consistent increase is observed with extreme storms as seen in Figure 18b.

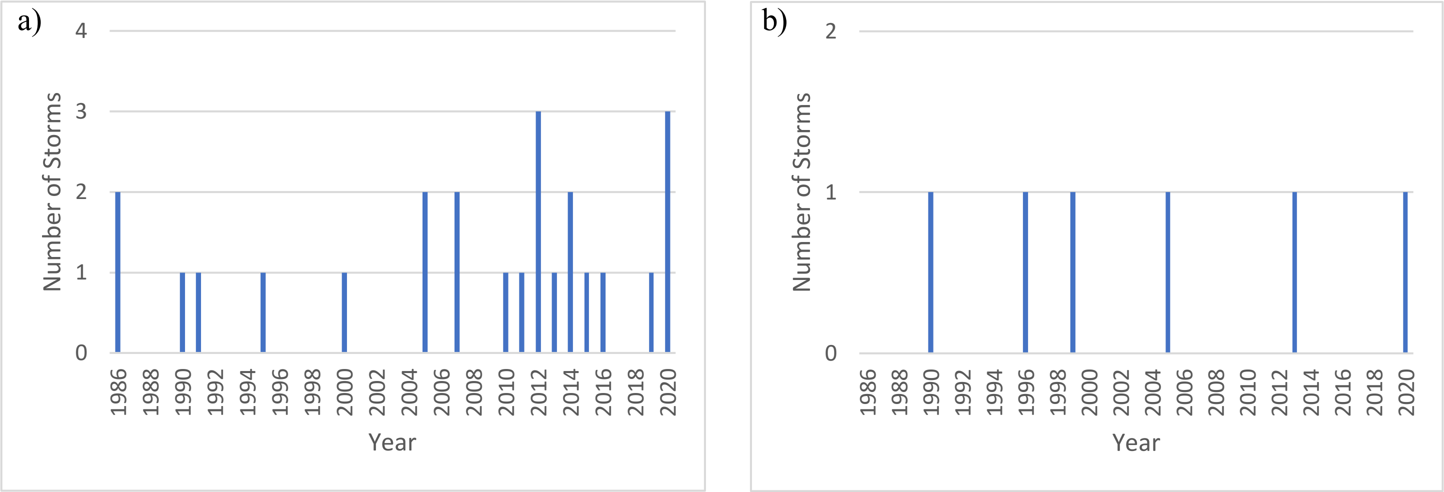


Figure 17: a) Yearly occurrence of severe storm events (5-6m) at Batemans Bay. b) Yearly occurrence of extreme storms (6m+) at Batemans Bay. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

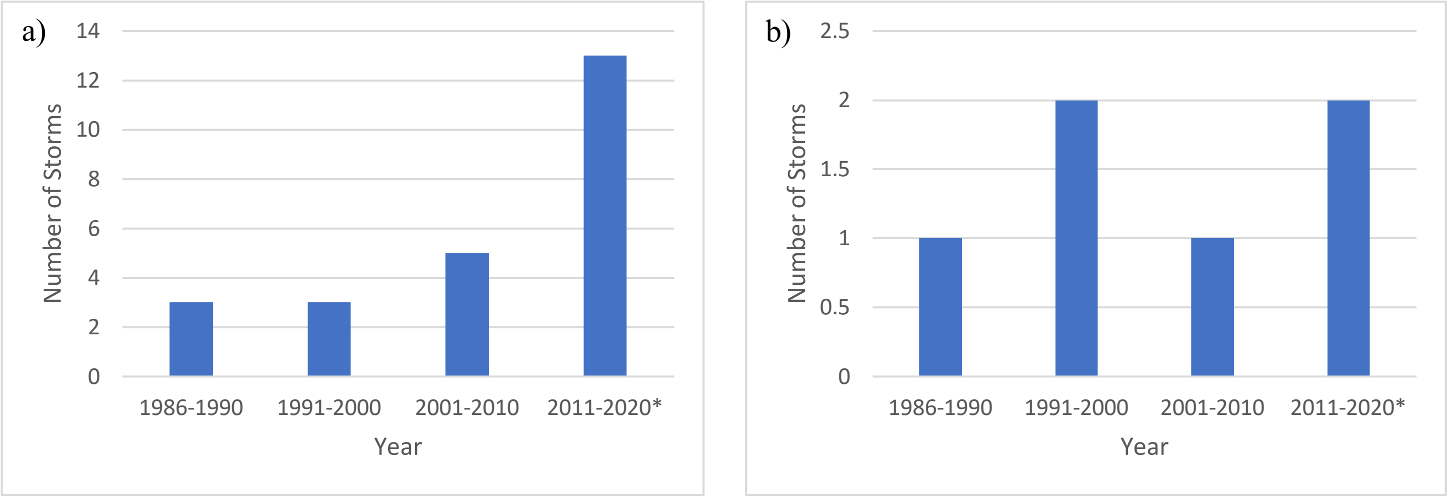


Figure 18: a) Decadal occurrence of severe storms (5-6m) at Batemans Bay. b) Decadal occurrence of extreme storms (6m+) at Batemans Bay. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Variations in the occurrence of severe and extreme events as a percentage of the total yearly storms exceeding 3.5m Hsig are noted on the interannual scale. As evident by Figure 19, at Batemans Bay, it was found that a higher percentage (>30%) of events were greater than moderate severity every 7-10 years during 1986, 1996, 2005, 2012, 2019, and 2020.

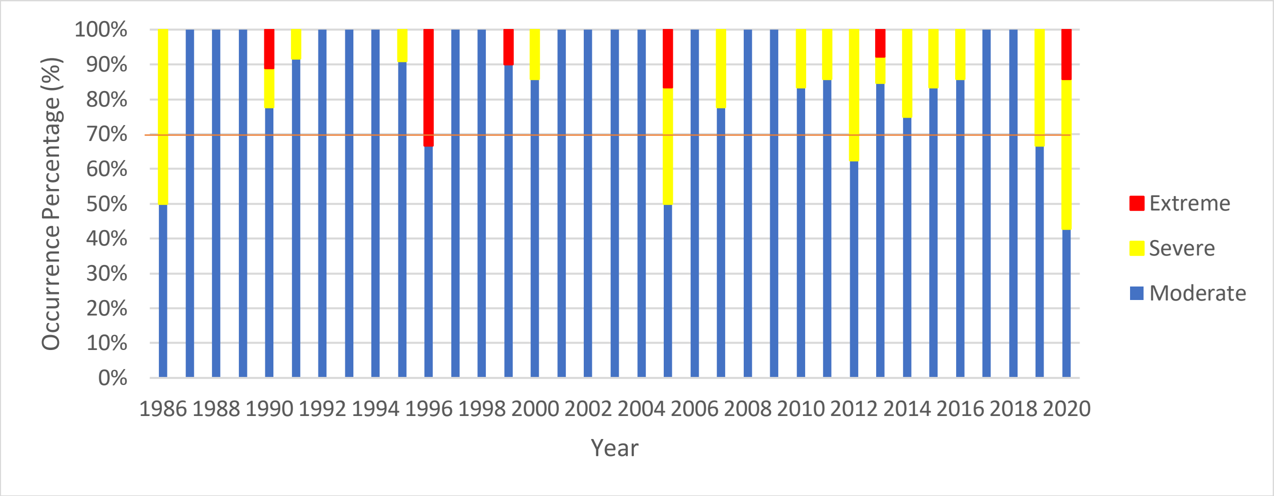


Figure 19: Yearly percentage of severe and extreme storms against total storm occurrence at Batemans Bay with a Hsig greater than 3.5m.. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Variations in the durations of storms exceeding 3.5m Hsig are noted on the interannual scale. When examining the duration of storm events as a percentage of the various storm durations present during the year, it was found that long duration events (> 72 hours) occurred at different intervals between sites. As evident by Figure 20, at Batemans Bay, every 5-10 years (1986, 1991, 2001, 2011) an event with a duration longer than 72 hours occurred.

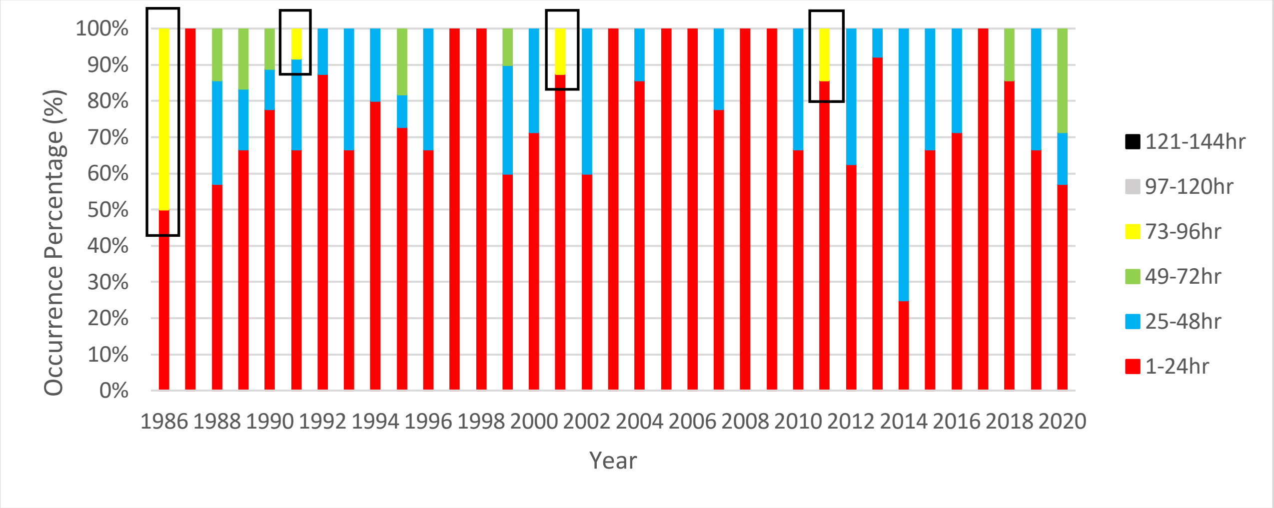


Figure 20: Percentage of storm durations occurring yearly at Batemans Bay with a Hsig greater than 3.5m.. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Contrary to the yearly and decadal trends observed in occurrence, severity and duration; wave direction and period demonstrate no apparent trends and are thus included in Appendix 4 and 5 rather than the results.

When examining the storm clustering that occurs at Batemans Bay, differences are observed based on the temporal scale. While on the yearly scale no apparent trend exists (seen in Appendix A1.3) storm clustering on the decadal scale appears to experience a gradual increase before plateauing as seen in Figure 21.

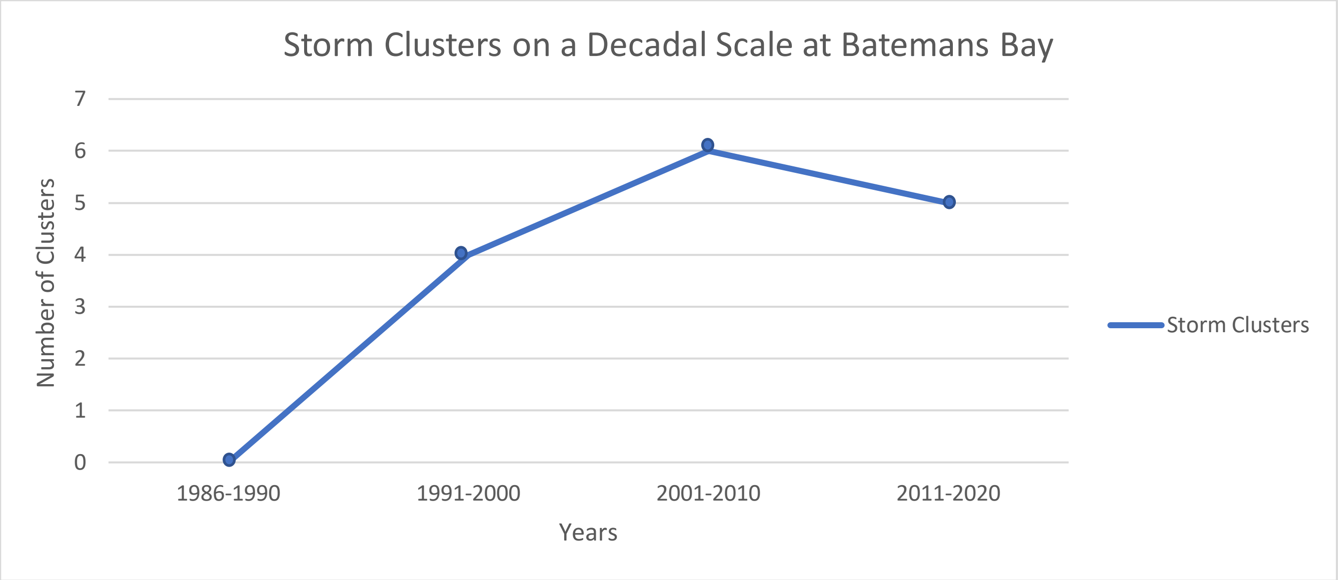


Figure 21: Storm clusters on a decadal scale at Batemans Bay with a Hsig greater than 3.5m.. It must be noted that the reduced clustering from 1986-1990 may be due to the fact that a whole decade of data was not collected (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

The magnitude and frequency analysis for the significant wave heights at Batemans Bay predict how often future storm events of varying severity may occur. In order to determine the recurrence interval of these events, the annual maximum has been entered into a magnitude frequency curve. The largest Hsig reached during the recorded period at Batemans Bay was 7.19m in 1996 and this event has a recurrence interval of 59 years.

Due to the occurrence of a series of large storms along the east coast of Australia during July 2020, after the initial period of examination, the effect an extreme event has on magnitude frequency analysis can be explored. At Batemans Bay, during this period, an extreme storm event was recorded, and it is only the 6th such occurrence over the wave rider buoy record to occur. As a result, the severity of events associated with each recurrence interval have increased and the associated magnitude frequency curve can be seen in Figure 22. The 1 in 2, 1 in 5, 1 in 10, 1 in 20, 1 in 50 and 1 in 100 year-recurrence intervals associated with the magnitude frequency analyses of storms at Batemans Bay before and after the July event can be seen in Table 6.

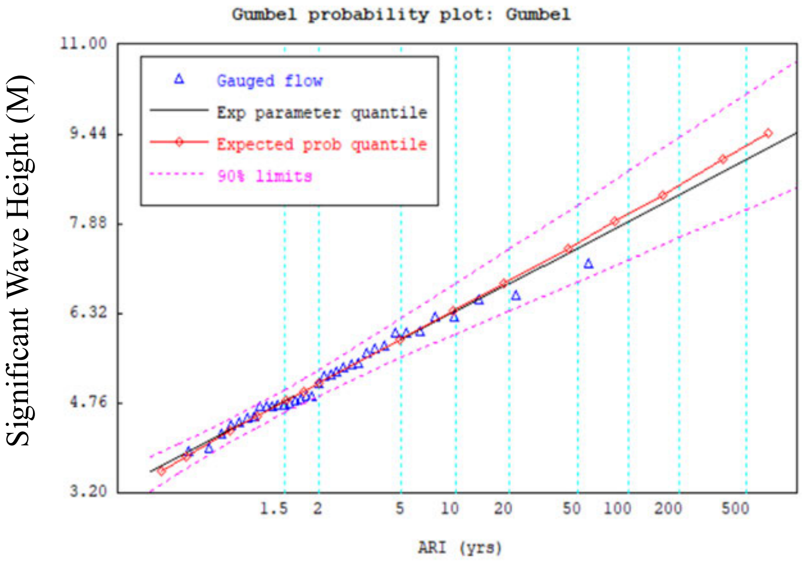


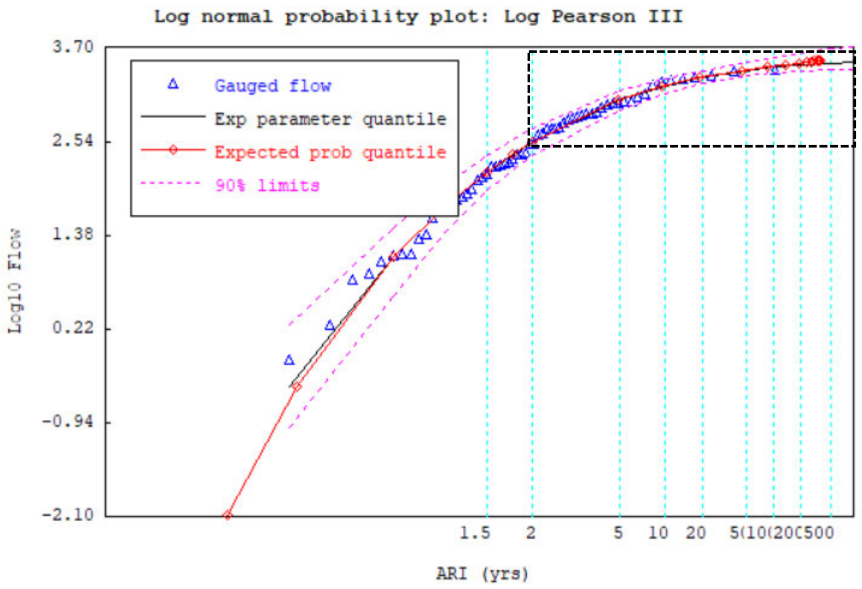
Figure 22: Magnitude- frequency curve displaying the recurrence interval of significant wave height events at Batemans Bay with a Hsig greater than 3.5m.. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Table 5: Variations in the Average Recurrence Intervals of the significant wave height events greater than 3.5m between Batemans Bay and Batemans Bay post July 2020 storms. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Location	**1 in 2 Year ARI**	**1 in 5 Year ARI**	**1 in 10 Year ARI**	**1 in 20 Year ARI**	**1 in 50 Year ARI**	**1 in 100 Year ARI**
Batemans Bay	5.07m	5.79m	6.27m	6.73m	7.33m	7.78m
Batemans Bay including July 2020	5.10m	5.85m	6.35m	6.83m	7.45m	7.91m

5.2. Moruya River discharge

The magnitude and frequency analysis for the river discharge on the Moruya River can predict how often future flood events of varying severity may occur. In order to determine the recurrence interval of Moruya River discharge events, the annual maximum have been entered into a magnitude frequency curve and the results can be seen in Figure 23. By using the 1 in 2 year flood value from the magnitude frequency curve of 333m^3/s as a threshold for the occurrence of severe discharge events, the yearly to decadal trends in flood occurrence can be determined and this is seen in Figure 24.



All discharges >333m^3/s

Figure 23: Annual Maximum Discharge Recurrence interval for Moruya River (M^3/sec) (Discharge data used in this analysis is provided by the Bureau of Meteorology)

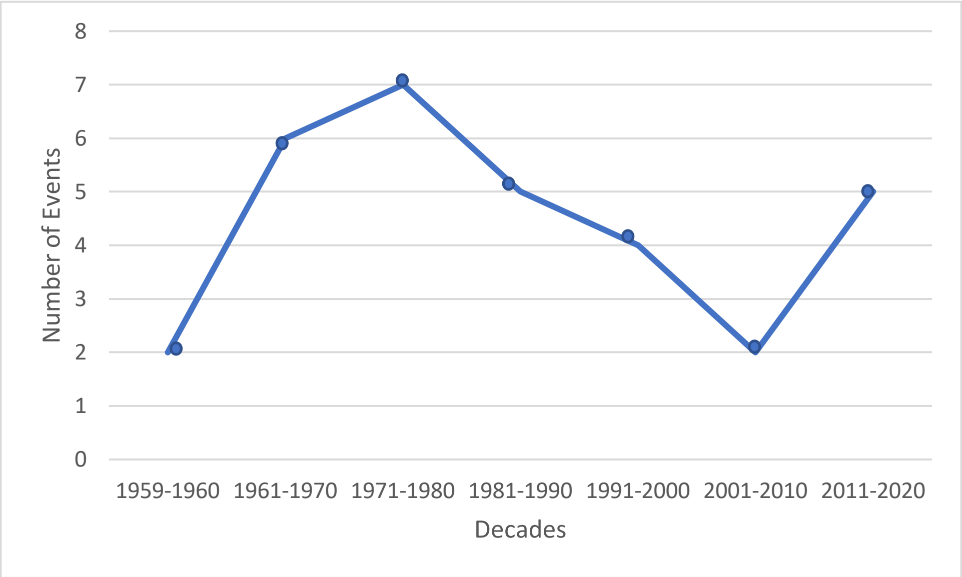


Figure 24: Decadal distribution of Moruya River discharge events exceeding a 1 in 2 year recurrence interval. It must be noted that the reduced number of discharge events from 1959-1960 may be due to the fact that a whole decade of data was not collected (Discharge data used in this analysis is provided by the Bureau of Meteorology)

In order to examine the co-occurrence of flooding and coastal storms, high river discharge events and Hsig events greater than 3.5m have been plotted against each other. As seen in Figure 25, the high river discharge events along the Moruya River are from 1974-2020 have while the significant wave heights are across the combined records of Batemans Bay and Port Kembla during the same period. In addition to this, 1 in 20, 1 in 50 and 1 in 100-year recurrence intervals for discharge and significant wave heights as well as the 1 in 2 year recurrence interval for discharge have been plotted to conceptualise the severity of events that occur during the record. Ultimately, it does not appear that a strong correlation exists between flooding and storms as seen by a series of linear regressions, linear regressions without missing data and lagged regressions between river height and significant wave height in Appendix 7. It should be noted however, that when examining Figure 25, all large floods seem to occur coincident with coastal storms with the exception of 1975 however this is likely due to the missing data during this period. When examining the recurrence intervals for these events in Figure 25, it appears that more severe discharge events are occurring less often while more severe significant wave height events occur more often.

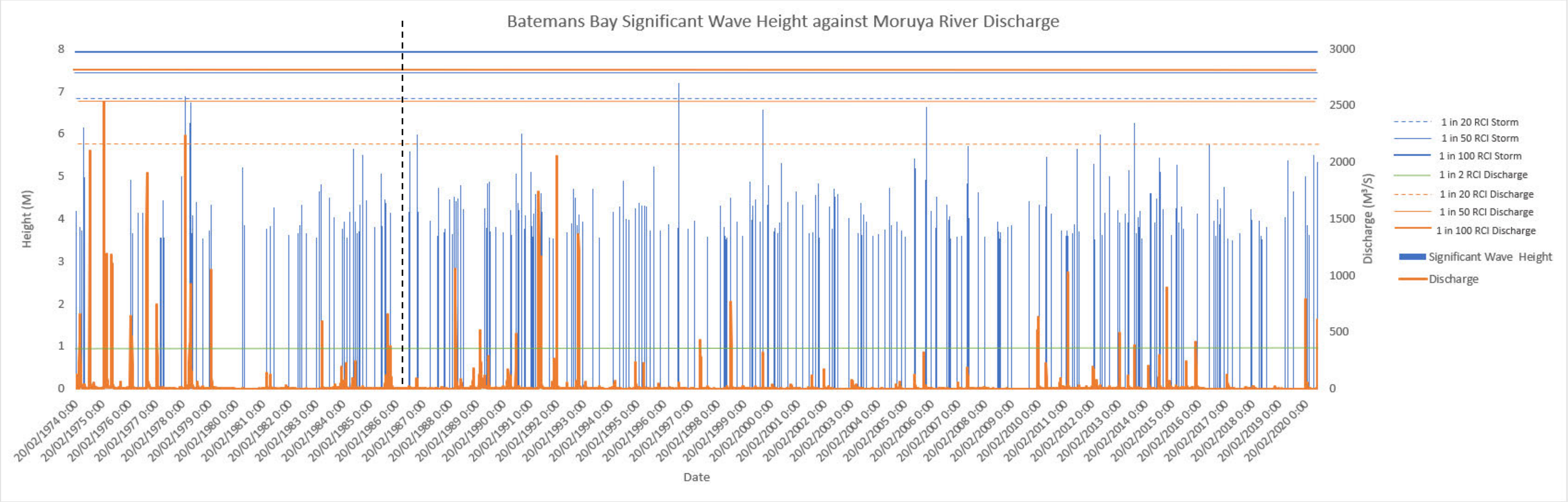


Figure 25: Storm significant wave height (blue) plotted against river discharge (orange). To the right of the vertical dashed line is data from Batemans Bay to the left of the vertical dashed black line is wave data from Port Kembla which has been included to extend the record of Batemans Bay. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL. Discharge data used in this analysis is provided by the Bureau of Meteorology)

5.3. Influences on volumetric change

There are multiple influences on volumetric change at Bengello Beach. When comparing the volumetric record from Bengello Beach to storm wave characteristics and Moruya River discharge, the clustering of severe Hsig events, the duration of storms and the occurrence of high river discharge are found to occur with the largest volumetric changes (Figure 26a-c).

The impact of post-storm beach recovery and fluvial sediment supply on beach volume have been compared by examining the volumetric record of Bengello Beach and Narrabeen Beach. This comparison is able to occur as Bengello Beach likely receives sediment from the nearby Moruya River during flooding while Narrabeen Beach is a non-river fed beach. Furthermore, due to the length of the two volumetric records, this analysis is uniquely poised to examine these processes at a larger time scale.

As can be seen at Bengello Beach in Figure 27a, following periods of high discharge, the volume experiences an increase beyond previously stable levels. In addition to this, Bengello demonstrates an overall increasing volume as evident by the positive inclination of the trendline. Contrasting to this, while Narrabeen's volume in Figure 27b demonstrates minor increases that are associated with post-storm beach recovery, it is found to experience an overall loss of sediment.

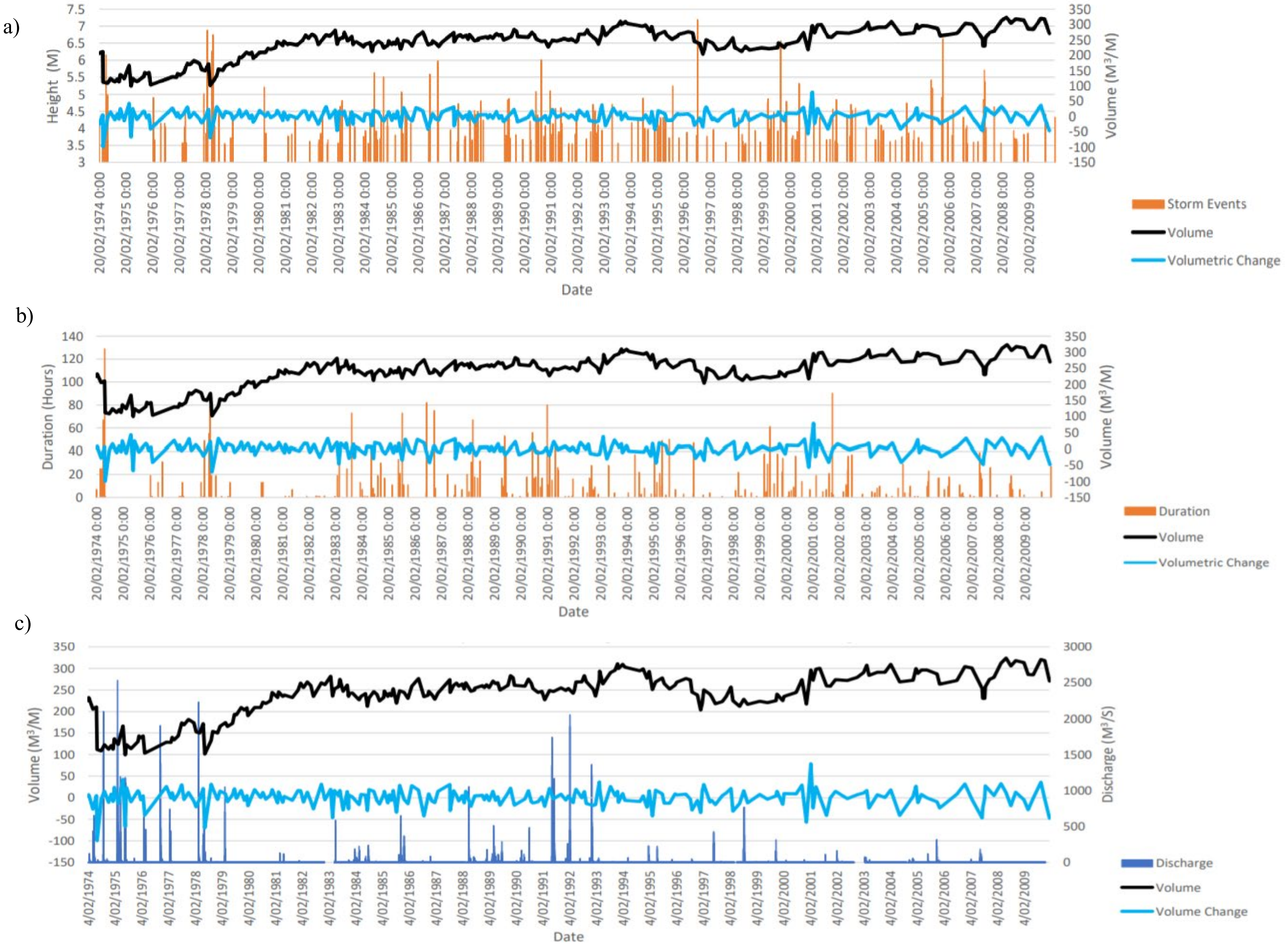


Figure 26: *a) Peak Hsig of storm events exceeding 3.5m Hsig vs volumetric change at Bengello Beach. b) Duration of storm events exceeding 3.5m Hsig versus volumetric change. c) Moruya River discharge Versus volumetric change. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL. Discharge data used in this analysis is provided by the Bureau of Meteorology)*

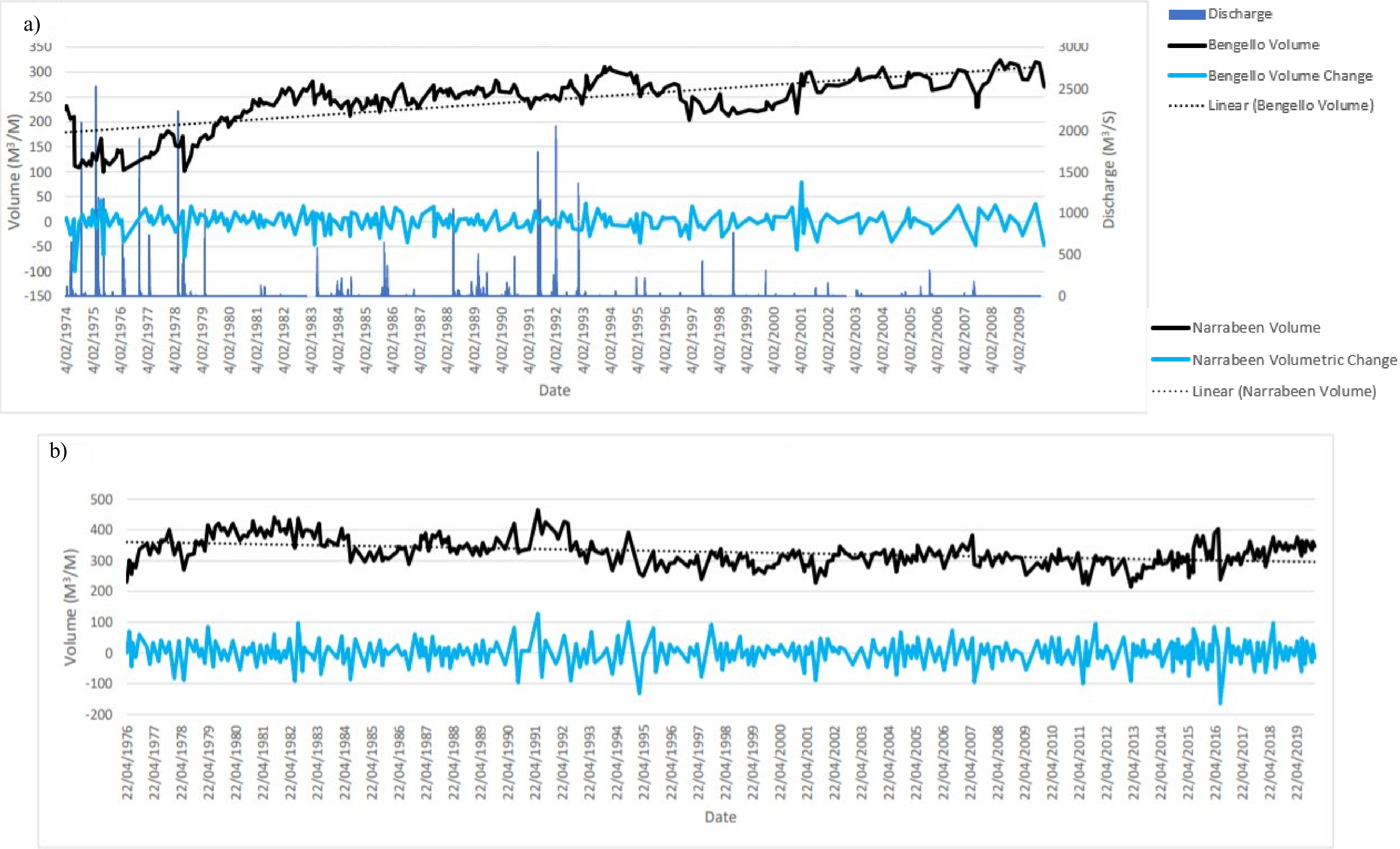


Figure 27: a) Moruya River discharge plotted against the volume and volumetric change at Bengello Beach. (Data is sourced from Mclean et al 2010) b) Volume and volumetric change at Narrabeen Collaroy Beach (Data is sourced from Turner et al 2016)

The magnitude and frequency analysis for the volumetric changes at Bengello Beach can predict how often erosion and accretion events of difference severity may occur. The recurrence intervals for erosive and accretive events at Bengello Beach have been determined regardless of storm size by applying a magnitude frequency analysis on the volumetric change data seen in Figure 26 and Figure 27a. The magnitude frequency analysis of erosion is displayed in Figure 28a and the largest events were found to initiate erosion of 99.16m^3/m and 70.16m^3/m of sediment, have a recurrence interval of 65 and 25 years and occur in 1974 and 1978 respectively. Other notable erosive events occurred in 1973, 1975, 2000 and 2007 and they affected 55.88 m^3/m, 66.97 m^3/m, 56.94 m^3/m and 47.01 m^3/m of sediment respectively. Contrasting to the scale of the erosion events, the largest accretive events, as seen in Figure 28b only affected 78.81 m^3/m and 42.98 m^3/m of sediment, have a recurrence interval of 64 and 2 years and occur in 2001 and 1975 respectively. Other notable accretive events occurred in 1993 and 2009 and they effected 36.90 m^3/m and 35.84 m^3/m of sediment, respectively. The 1 in 2, 1 in 5, 1 in 10, 1 in 20, 1 in 50 and 1 in 100-year recurrence intervals associated with the volumetric magnitude frequency analyses at Bengello Beach can be seen in Table 6.

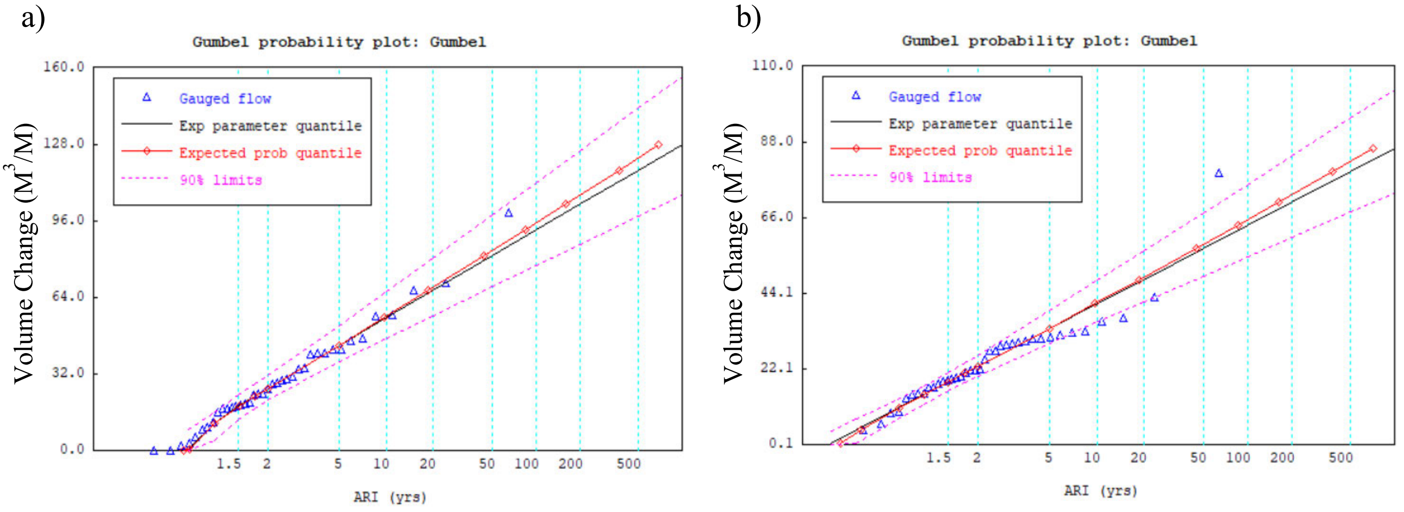
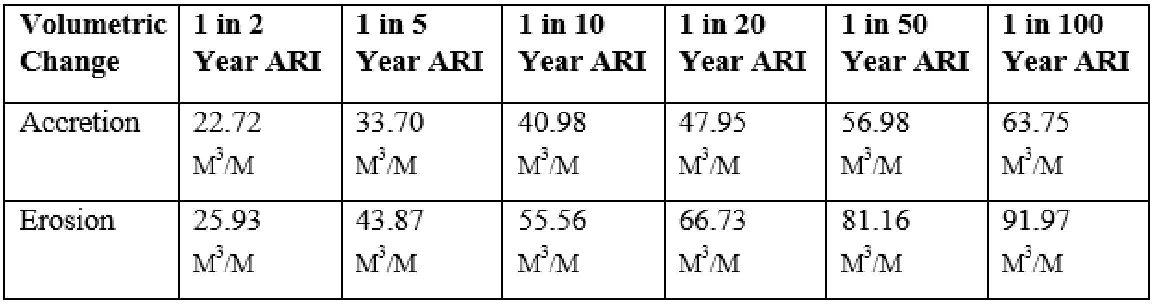


Figure 28: b) Magnitude- frequency curve displaying the recurrence interval of erosive events at Bengello Beach. b) Magnitude- frequency curve displaying the recurrence interval of accretive events at Bengello Beach. (Data is sourced from Mclean et al 2010)

Table 6: Variations in the accretion and erosion Average Recurrence Intervals at Bengello Beach from 1974-2010. (Data is Sourced from Mclean et al 2010)



Volumetric Change	**1 in 2 Year ARI**	**1 in 5 Year ARI**	**1 in 10 Year ARI**	**1 in 20 Year ARI**	**1 in 50 Year ARI**	**1 in 100 Year ARI**
Accretion	22.72 M^3/M	33.70 M^3/M	40.98 M^3/M	47.95 M^3/M	56.98 M^3/M	63.75 M^3/M
Erosion	25.93 M^3/M	43.87 M^3/M	55.56 M^3/M	66.73 M^3/M	81.16 M^3/M	91.97 M^3/M

While the Recurrence Intervals of erosive and accretive events occurring at Narrabeen Collaroy have been determined, due to the nearby Sydney waverider buoy not being examined, volumetric trends are included in the Appendix 10 rather than the results as they would not be attributed to any specific occurrence

Chapter 6

6. Discussion

This section will discuss the results as well as implications of this study and it is structured in terms of: the influence of climate, drivers of beach change, the way past events inform future forecasts, the limitations of waverider data resolution and future work. These sections will address the aims of the thesis and ultimately increase our understanding of storms as well as how the coast will respond to such events.

6.1. Influence of climate

Winter storms are found to influence coastal variation to an extent greater than any other season. As seen in Figures 13-15, winter storms are found to occur the most often above a 3.5m Hsig, be the most severe, and have the longest durations. This prominence means that storm damage will most likely occur in winter as a result of the increased energy as well as the increased chance of an event coinciding with high tide thus allowing a larger storm base (Lord and Kulmar 2000). Seasonal variations in wave direction (Figure 16) will also exert a notable impact on coastal erosion as beaches of different orientations will potentially be impacted more or less severely by storms.

When examining the cause of this seasonal variation, climate is found to have a notable influence. During the Australian autumn and winter, a strong correlation is found to exist between a positive Southern Annular Mode (SAM) and wave heights in the Southern Ocean with increases in wave height and an increased prominence of southerly waves occurring (Hemer et al., 2010; 2011). It must be noted however that additional factors besides climate influence the seasonal distributions of storms. As seen in Figure 29 from Shand et al. (2010), during the Australian autumn and winter, an increased occurrence of southern secondary lows is noted. This increase is attributed to warm sea surface temperature anomalies and enhanced convection in the Indian Ocean, high latitude blocking of the Tasman Sea and warm sea surface temperature anomalies in the western Pacific (Browning and Goodwin, 2013).

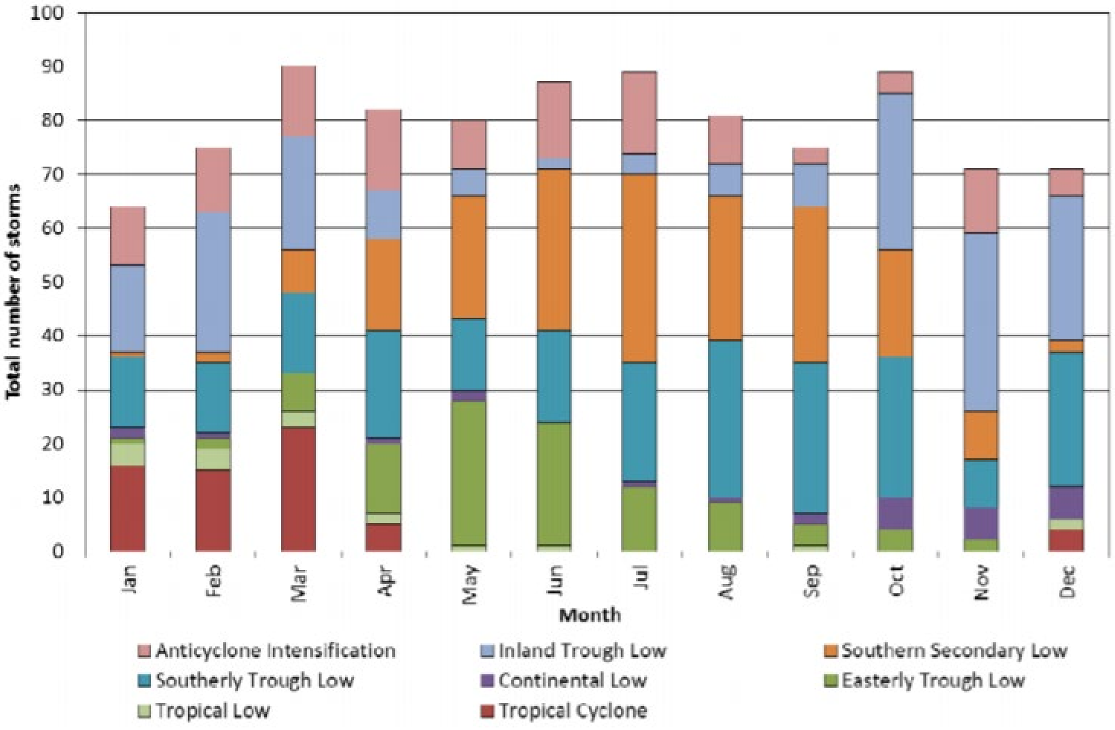


Figure 29: Total number of storms observed along the NSW Coast for each month (Sourced from Shand et al 2010)

On an interannual scale, the storm trends observed in Figure 19 and 20 are likely a caused by the climatic influences effecting Australia such as the SOI and SAM. Variations in the SOI are found to impact storm severity and frequency. During a positive SOI (La Nina), storms were found to occur more often and have a higher severity than during periods of negative SOI (El Nino) (Harley et al., 2010; Shand et al., 2010; You and Lord, 2008). If the SAM is positive during a La Nina phase, its effects on the wave climate can be reinforced whereas if its negative during an El Nino phase, its effects on the wave climate can be reduced (Mortlock and Goodwin, 2016). In addition to storm severity and frequency, SOI is found to also effect wave direction. During a La Nina and El Nino Southern Oscillation (ENSO) neutral phase, waves are unidirectional in nature and they predominantly occur from the south east whereas during an El Nino, waves are bidirectional in nature and they can occur from the south east and east. (Mortlock and Goodwin, 2016).

Interdecadal variations in the storm trends observed in the Figure 19 and 20 are similarly are theorised to be impacted by the climatic influences effecting Australia such as the IPO. Like the SOI, variations in the IPO effect storm frequency and severity with storminess increasing during a negative IPO (Helman and Tomlinson, 2018). It must be noted however that waverider buoy data only spans a positive phase of the IPO and thus any trends observed in storm frequency and severity will be bias towards one half of the story (Shand et al., 2010).

The increased occurrence of severe storms on a decadal scale (Figure 18a) is likely a result of moderate events increasing in severity in response to climate change. Changes on a local scale such as warmer air temperatures, will cause an increase in the activity of small scale convective systems along the coast, leading to more intense winds and rain, as well as an intensification of east coast lows and extreme wave conditions (Department of Climate Change, 2009). It is theorised that extreme storms do not experience a similar increasing trend (Figure 18b) as a relatively low number of severe storms have occurred that could be augmented by climate change and subsequently increase in severity to extreme classification. If the occurrence of severe storms continues in an increasing trend this may change. The yearly to decadal trends in the percentage of storm severity and storm duration means that events of an increased severity and duration occur on a cycle and thus we can predict periods of increased risk based on these trends.

Climate has also been found to influence storm clustering. While only a minor trend was evident in the examination of storm clustering at Batemans Bay on the decadal scale in Figure 21, variations in the occurrence of storm clusters have been previously found to result from changes in climatic influencers. Variations of storm clustering at New Zealand have been examined by Godoi et al. (2017) and it was found that during El Nino and El Nino like conditions, seen during a positive Indian Ocean Dipole (IOD) and a positive Pacific Decadal

Oscillation (PDO), an increase in storm clusters would occur on the southwestern coast. Conversely, during La Nina and La Nina like conditions, increases in storm clustering were experienced on the north coast. In addition to these factors, it was found that a positive SAM also increased the clustering of storms (Godoi et al., 2017).

The decadal variations in discharge exceeding 1 in 2-year events on the Moruya River, as documented in figure 24, are likely influenced by decadal SST anomalies such as the IPO (Pui et al., 2010) as well as inter-annual variability (e.g. ENSO and IOD; Bureau of Meteorology, 2016; Risbey et al., 2009). These 20th and 21st century trends may also be caused by anthropogenic warming and its impact on the climate as well as the position and intensity of major climatological phenomena such as the Sub Tropical Ridge (STR) (Timbal and Drosdowsky, 2013).

Traditionally ENSO has been viewed as the principal influence on Australian rainfall variability, with La Nina phases coinciding with increased rainfall and El Nino phases coinciding with decreased rainfall (Bureau of Meteorology, 2016; Risbey et al., 2009). Variations in the IOD are found to further accentuate the effects of variations in ENSO phases with a negative IOD increasing the rainfall during a La Nina period while a positive IOD increases the dryness during an El Nino period (Risbey et al., 2009). Like the IOD, the IPO is found to also influence the magnitude of ENSO, in particular La Nina events, with a negative IPO being associated with increased rainfall (Pui et al., 2010). In addition to the climate influencers, the increased greenhouse gases associated with climate change are found to also likely influence rainfall associated with the ENSO cycle by causing rainfall belts to shift from their normal positions (Bureau of Meteorology, 2017b).

While the southward shift in the positioning of the STR has been previously examined as a possible explanation of southeast Australia rainfall variability, the intensification of the STR is noted as a more important factor (Timbal and Drosdowsky, 2013). The culmination of the

STR intensification in 1997-2009 is seen in the decline in discharge events exceeding a 1 in 2-year recurrence interval in Figure 24.

The co-occurrence of storms and high river discharge events or lack thereof are also influenced by climate. The co-occurrence of storm and high river discharge events that are observed in the Figure 25 are likely due to both phenomena resulting from wind and low-pressure systems (Zheng et al 2013). However, while a co-occurrence is noted between these events, an inverse relationship is also noted with severe river discharge events (exceeding 1 in 20 ARI) decreasing in frequency throughout time while severe storm events (exceeding 1 in 20 ARI) increase in frequency throughout time. This inverse relationship could be attributed to climate change as it is noted to cause both an intensification of extreme wave conditions and a displacement of rainfall belts from their normal positions (Bureau of Meteorology, 2017; Department of Climate Change, 2009).

6.2. Drivers of beach change

Multiple factors influence volumetric change at Bengello Beach. The factors observed in Figure 26a-c that appear to most impact volumetric change are storm clustering, storm duration and river discharge; however, the influence of other factors cannot be disregarded. In addition to wave direction influencing which beaches will be most impacted by storms, due to variations in orientation, waves occurring from a non-modal direction will cause increased erosion due to beach morphology not being equilibrated to the wave energy (Mortlock et al., 2017). Furthermore, a correlation was exhibited between increased severity and direction at Batemans Bay with an increase in wave severity from moderate to severe coinciding with a more easterly wave origin (Appendix 6). Variations in tide and water level (ie storm surge) can similarly exert influence on the severity of volumetric changes as it can increase the base of extreme coastal events (Lord and Kulmar, 2000; Tonmoy and El-zein, 2018). Furthermore, variations in post-storm recovery are found to also influence volumetric change as it will determine if a beach has experienced complete recovery, partial recovery, excess recovery or no recovery before the next erosive event (Karunarathna et al 2014; Phillips, 2018).When viewing volumetric changes in respect to coastal forcing, it is thus necessary that a multivariate approach is undertaken.

As a sedimentological analysis has not been undertaken to prove that the Moruya river is a sediment source to Bengello Beach, its contribution remains contentious. In a study by Oliver et al. (2020), while Bengello Beach is acknowledged as the most likely recipient of sediment from the Moruya River, it is believed that the sediment promoting steady progradation instead originates from adjacent shorefaces to the south such as Pedros Beach. Contrasting to this, modelling of the Moruya Rivers lower estuary in the report by AMOG (2003) (Figure 8) infer its contribution to sediment supply at Bengello Beach. In the report, sediment from the river is noted as reaching the beach via longshore drift during flood events with an increased likelihood of this occurring during floods greater than or equal to events with a 1 in 2-year recurrence interval. Preliminary sedimentological analysis on barrier sands seems to support the modelling that the river is contributing to coast (Appendix A1.11).

The influence of Moruya River flooding on sediment supply to Bengello Beach is further seen when examining post storm beach recovery. As seen when the various versions of beach recovery as outlined in Philips 2018 (Figure 30) are compared to the volumetric trends seen at Bengello Beach and Narrabeen Beach (Figure 31), differences in the beaches ability to recover post-storm are evident. While Bengello demonstrates excess recovery and a subsequent volumetric increase around high discharge events in Figure 31a (likely due to additional sediment sources such as the nearby river), Narrabeen only experiences partial recovery and a subsequent volumetric decline as seen by Figure 31b.

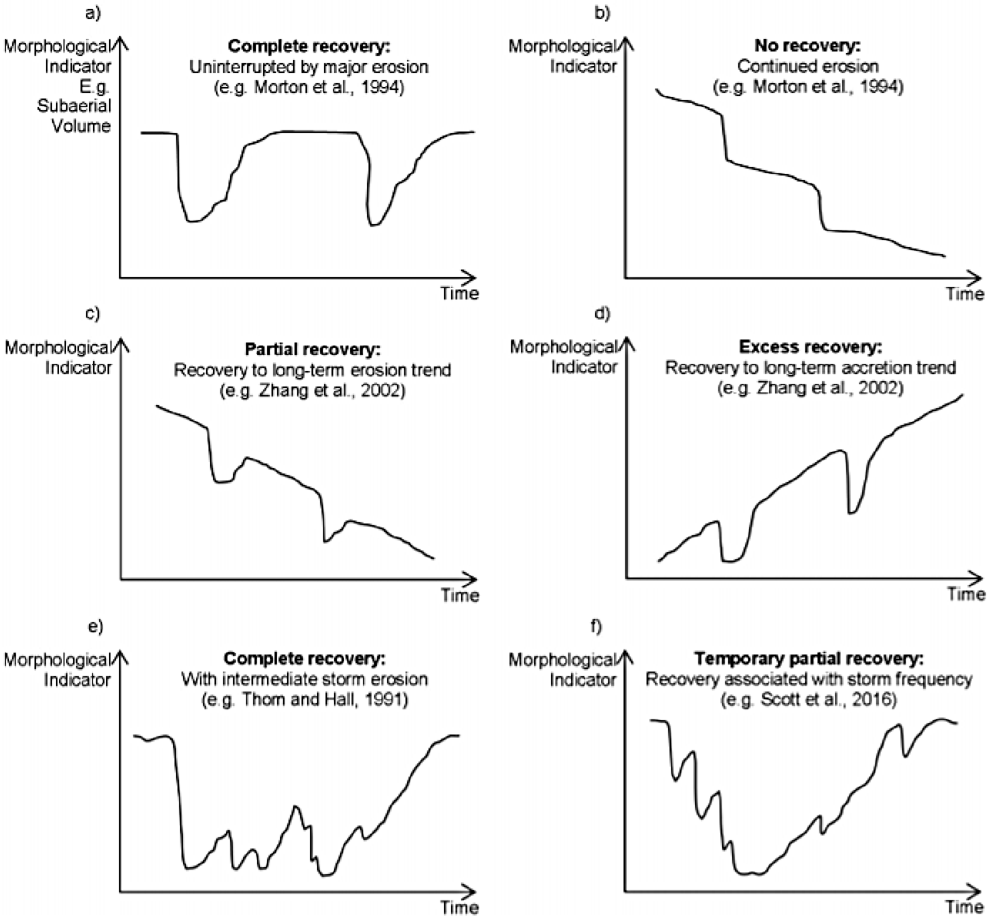


Figure 30: Variations in beach recovery (Sourced from Philips 2018)

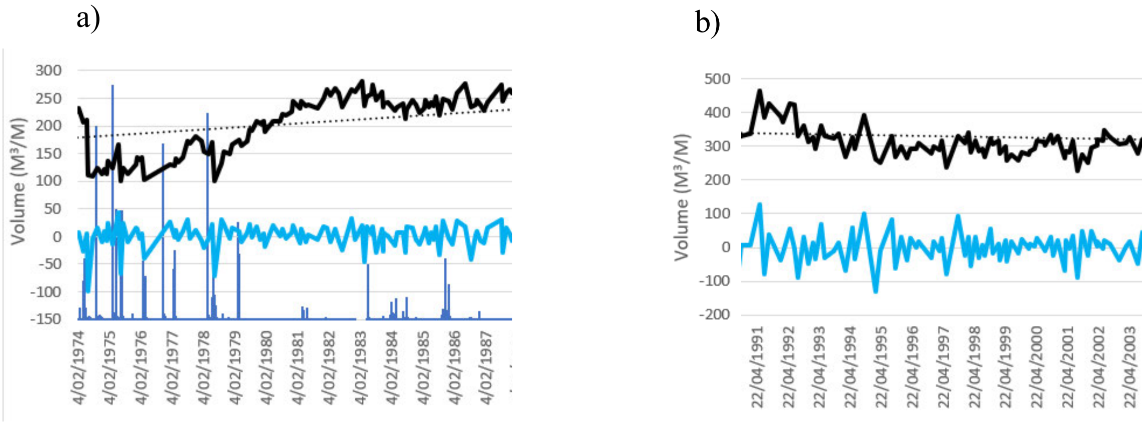


Figure 31: a) Excess beach recovery observed in the volumetric profile of Bengello Beach. b) Partial beach recovery observed in the volumetric profile at Narrabeen Beach. (Volumetric data sourced from Mclean et al 2010 and Turner et al 2016)

6.3. Past events inform future forecasts

Regularly updating storm magnitude frequency analyses will become a necessary process when forecasting future events. After the occurrence of a single storm in July, albeit one of extreme classification, the significant wave height associated with each recurrence interval subsequently increased (Table 5). With the severity of storms likely to continue to increase as a result of climate change (Figure 18a), regular updates of the average recurrence intervals are necessary as they are influenced the most by the top 5-10 events within the record (Glatz et al., 2017).

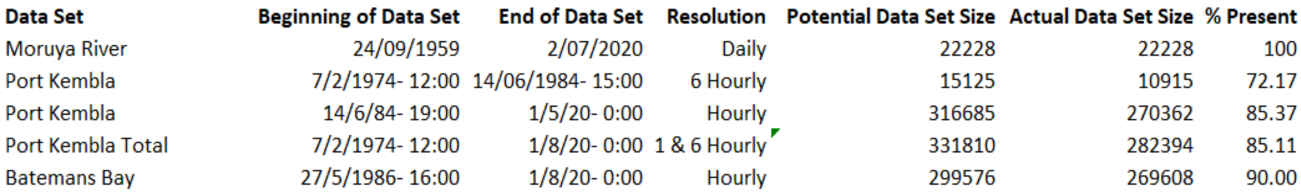
By using a magnitude frequency analysis on volumetric change, the causes of erosion and accretion can be examined and subsequently used to predict the severity of events in the future. The severity of the 1974 erosive event in Figure 28a is attributed to the co-occurrence of high tide and a storm surge causing the highest recorded water level (Lord and Kulmar, 2000) thus raising the base and by extension, the severity of the storm (Tonmoy and El-zein, 2018). In addition to these factors, substantial erosion is also attributed to the clustering of storm events with 1974, 1978 and 2007 being such examples. Other notable erosive events such as 1973, 1975 and 2000 lack comprehensive wave data to allow a comparison to be made.

The size of the 1975 accretionary event in Figure 28b is attributed to multiple flood events occurring, most notably a 1 in 30-year flood as well as post-storm beach recovery following the inferred occurrence of a storm (an erosive spike occurs in Figure 12a). In addition to the occurrence of flooding, the lack of storm occurrence as seen during 1993, 2009 and the second half of 1975 are believed to also effect accretion as the erosion associated with the storms aren't interrupting it thus allowing ample sediment build up. While the 2001 event in Figure 28b is the highest accretionary event noted, it is viewed as an outlier as there is no known reason for the magnitude of the observed volume increase.

6.4. Limitations of waverider data resolution

The significant limitation of this study is the gaps within the waverider buoy data sets. As can be seen in Table 7, Port Kembla is missing nearly 15% of its total data set and due to the length and variations in resolution, this equates to approximately 8.2 years of data missing from its record. Similar to Port Kembla, as can be seen in Table 7, Batemans Bay is missing 10% of its total set and this equates to approximately 3.6 years of data missing from its record. An additional limitation regarding the waverider buoy data sets is the lack of directional data present within the early records as its not recorded at Batemans Bay until 23/02/2001 10:00 and it is not recorded consistently at Port Kembla until 20/06/2012 10:00.

Table 7: The Percentage of data present within the river and waverider data sets



Data Set	Beginning of Data Set	End of Data Set	Resolution	Potential Data Set Size	Actual Data Set Size	% Present
Moruya River	24/09/1959	2/07/2020	Daily	22228	22228	100
Port Kembla	7/2/1974- 12:00	14/06/1984- 15:00	6 Hourly	15125	10915	72.17
Port Kembla	14/6/84- 19:00	1/5/20- 0:00	Hourly	316685	270362	85.37
Port Kembla Total	7/2/1974- 12:00	1/8/20- 0:00	1 & 6 Hourly	331810	282394	85.11
Batemans Bay	27/5/1986- 16:00	1/8/20- 0:00	Hourly	299576	269608	90.00

6.5. Future work

Future work that could be conducted to augment the findings of this thesis are as follows:

- Conduct a GPR analysis along the barrier at Bengello Beach and subsequently ground truth and storm scarps in order to establish a storm record on the centennial to millennial scale.
- Analyse the sediment found at Bengello Beach and the surrounding back barrier in order to determine its provenance. This was one of the original objectives but due to Covid it was believed that this would be unattainable. However, more than halfway through the thesis, travel restrictions lightened and at the same time a series of large storms occurred prompting a field excursion to Moruya. During this excursion, sediment samples from 4 Moruya River point bars and the Bengello Beach face were collected for the sedimentary analysis. A preliminary analysis using a microscope

identified the existence of heavy minerals and feldspar in similar concentrations to samples that have been previously collected from the beach ridges in the rear of the barrier. Due to the collection of the samples late in the thesis, analysis further analysis such as grain size, XRD and SEM will be used in the future to verify the sediments origin. Details regarding the collection of the sediment samples and methods of examination are included in Appendix A1.11.

- Examine the waverider buoy data from additional sites along the east Australian coastline in order to ensure trends determined at Batemans Bay and Port Kembla were not site specific.
- Calculate the erosive potential of the storms recorded in the appendix of this thesis by using the significant wave height, storm duration and period in combination with the sediment grain size and beach slope of the studied sites as done in Mendoza and Jiménez (2006). With the long volumetric record present at Bengello Beach, this could potentially allow beach recovery and rates of deposition during fair-weather to be determined.

Chapter 7

7. Conclusion

The Australian coastline consists of a multitude of beaches that have undergone and will continue to undergo volumetric changes in response to coastal storms. This is becoming an increasingly important issue to examine in the face of climatically driven sea level rise and increased storm severity as coastal infrastructure could potentially be influenced to a larger extent depending if the beach is prograding or receding. By studying wave rider buoy data, river discharge data and volumetric data this study attempted to ascertain the historical trends within these data sets, determine the links between these data sets and to determine the provenance of the sediment reaching Bengello Beach. The conclusions for this study are:

- Storms are most likely to occur at an increased severity when winter, a positive SOI (La Nina), a positive SAM, a negative IPO and a positive PDO all co-occur. Conversely, storms are least likely to occur at an increased severity when summer, a negative SOI (El Nino), a negative SAM, a positive IPO and a negative PDO all co-occur.
    - Coastal erosion will most likely occur during periods of increased storm severity (as outlined above) however it may be offset by periods of decreased storm erosion as well as a weaker STR as it could cause an increase in flooding and by extension, an increase in sediment delivery to the coast.
- Coastal storms and high river discharge events were found to co- occur however their severity experienced an inverse relationship that is likely a result of climate change.
- A multivariate approach that takes into account max significant wave height, storm duration, storm wave period, storm wave direction, river discharge, variations in post-storm recovery and variations in tide and water level is required when examining the volumetric changes at Bengello Beach

- Bengello Beach is experiencing an overall increase in volume with notable increases coinciding with high river discharge events from the Moruya River.
- Storm magnitude frequency analyses need to be conducted regularly as due to the increasing occurrence of severe events, recurrence intervals will likely continue to decrease

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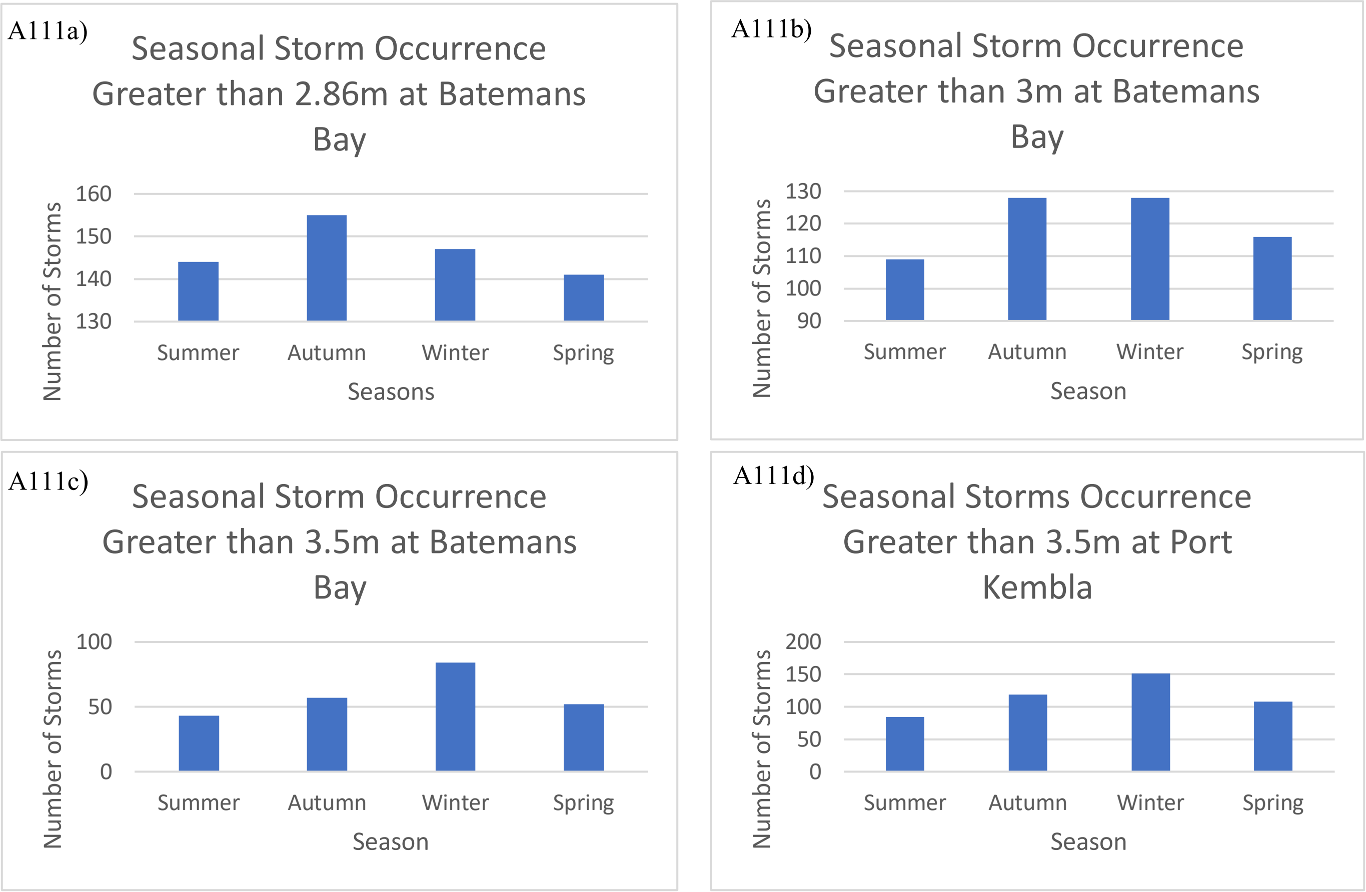
Appendix

Appendix 1: Extended results

A1.1. Seasonal storm distribution

A1.1.1. Occurrence and severity

When examining the occurrence of storm events on a seasonal scale, a variety of thresholds have been enacted. While initial thresholds used to define a storm of Hsig 2.86m and Hsig 3m noted minor differences (A111a and A111b), the difference in occurrence began to increase upon the thresholds rise to Hsig 3.5m. As seen in A111c at Batemans Bay, there were 84 storms in winter, 57 in autumn, 52 in spring and 43 in summer. As seen in A111d, at Port Kembla, there were 151 storms in winter, 119 in autumn, 108 in spring and 84 in summer.



A111: a) The seasonal distribution of storms at Batemans Bay with a Hsig greater than 2.86m. b) The seasonal distribution of storms at Batemans Bay with a Hsig greater than 3m. c) The seasonal distribution of storms at Batemans Bay with a Hsig greater than 3.5m. d) The seasonal distribution of storms at Port Kembla with a Hsig greater than 3.5m. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Of the storms noted to occur over the threshold of Hsig 3.5m at Batemans Bay and Port Kembla in Figure A111c and d, the distribution between moderate (Hsig 3.5-5m), severe (Hsig 5-6m) and extreme severity (6m+) can be seen in Figure A111e and f. As seen in Figure A111e, at Batemans Bay, 19% of the storms occurring during winter, 15% of the storms occurring during spring, 7% of the storms occurring during autumn and 5% of the storms occurring during summer were above moderate severity. As seen in Figure A111f, at Port Kembla, 22% of the storms occurring during winter, 18% of the storms occurring during autumn, 10% of the storms occurring during spring and 6% of the storms occurring during summer were above moderate severity.

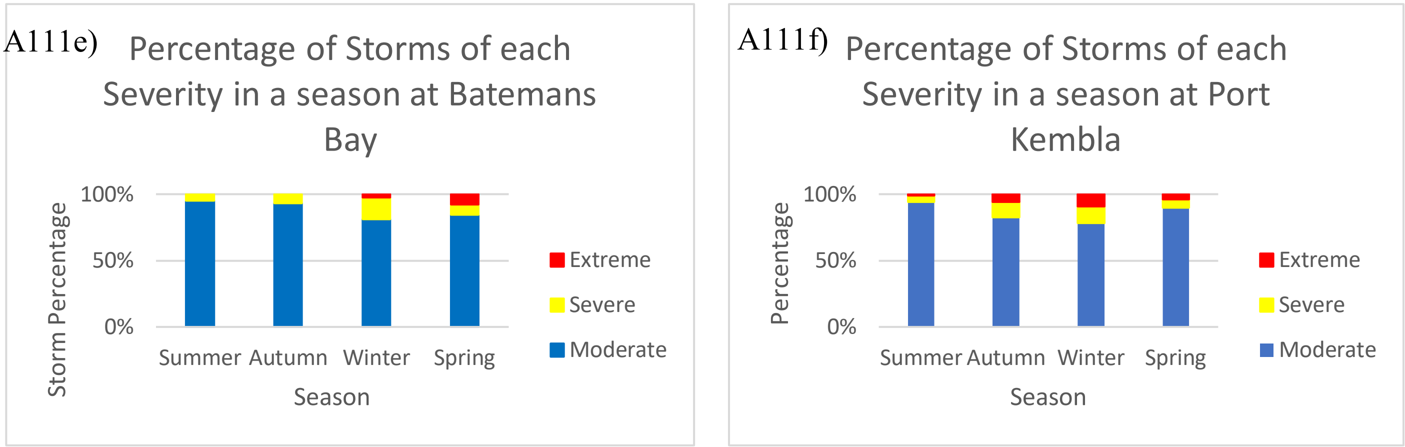
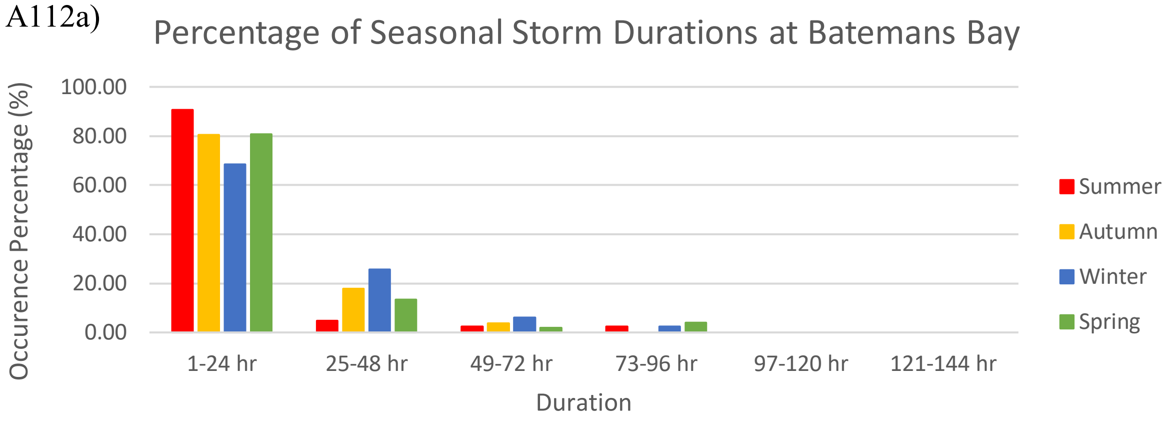


Figure A111: e) Percentage of storms of each severity in a season at Batemans Bay. f) Percentage of storms of each severity in a season at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

A1.1.2. Duration

When examining the duration of storms exceeding 3.5m Hsig, variations are noted on the seasonal scale. As seen in Figure A112a, at Batemans Bay, 34% of the storms occurring during winter, 21% of the storms occurring during autumn, 19% of the storms occurring during spring and 9% of the storms occurring during summer had a duration longer than 24 hours. As seen in Figure A112b, at Port Kembla, 32% of the storms occurring during winter, 24% of the storms occurring during autumn, 20% of the storms occurring during spring and 12% of the storms occurring during summer had a duration longer than 24 hours.

A112a)



A112b)

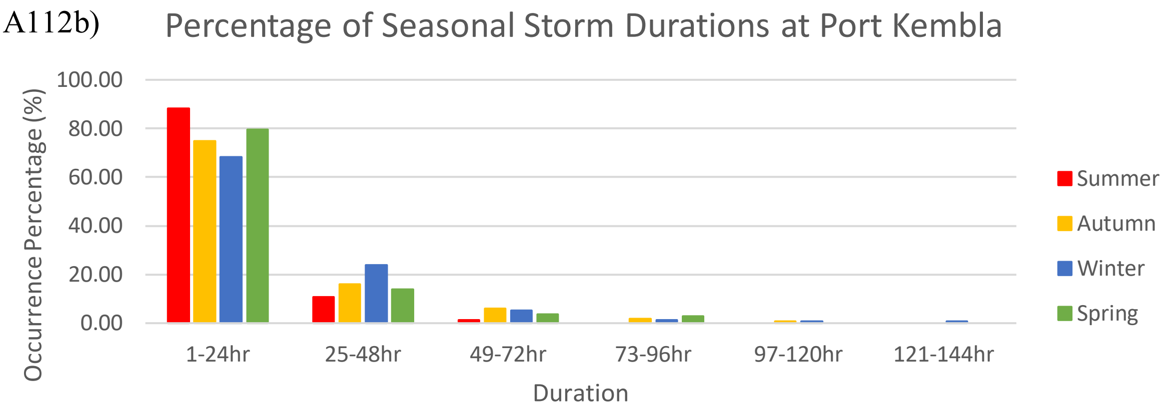
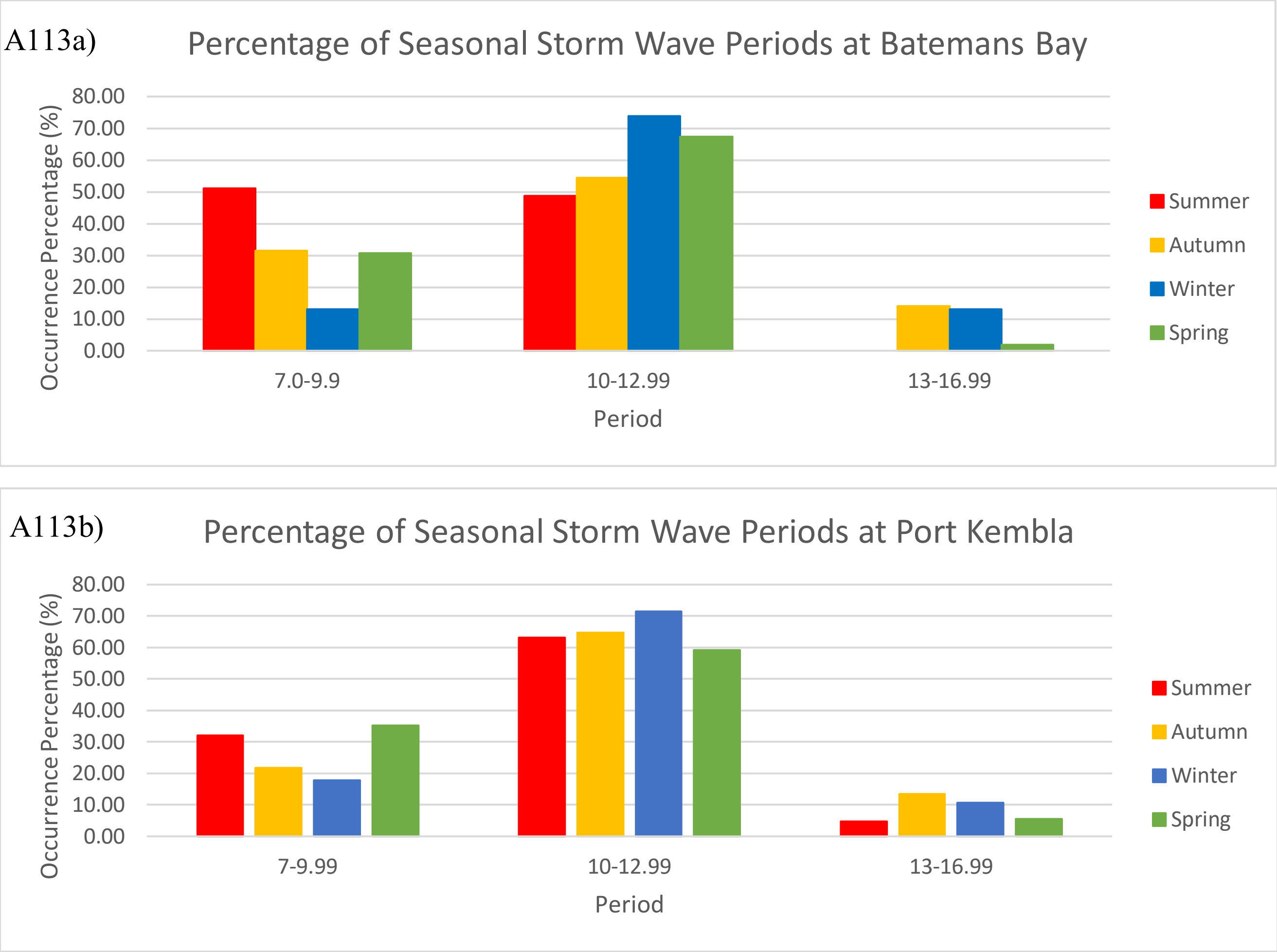


Figure A112: A) Percentage of seasonal storm durations at Batemans Bay. B) Percentage of seasonal storm durations at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

A1.1.3. Wave period

When examining the wave period of storms exceeding 3.5m Hsig, variations are noted on the seasonal scale. As seen in Figure A113a, at Batemans Bay, 87% of the storms occurring during winter, 69% of the storms occurring during spring, 68% of the storms occurring during autumn, and 49% of the storms occurring during summer had wave periods of 10 seconds or greater. As seen in Figure A113b, at Port Kembla, 82% of the storms occurring during winter, 78% of the storms occurring during autumn, 65% of the storms occurring during spring, and 68% of the storms occurring during summer had wave periods of 10 seconds or greater.


A113a)

Percentage of Seasonal Storm Wave Periods at Batemans Bay

A113b)

Percentage of Seasonal Storm Wave Periods at Port Kembla

Figure A113:a) Percentage of seasonal storm wave periods at Batemans Bay. b) Percentage of seasonal storm wave periods at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

A1.1.4. Wave direction

When examining the wave direction of storms exceeding 3.5m Hsig, variations are noted on the seasonal scale. As seen in Figure A114a, of the wave data at Batemans Bay including wave directions, the highest percentage of winter (61%), spring (45%) and autumn (45%) storm waves occurred from the south south east (146.25- 168.75 degrees) while the highest percentage of summer (50%) storm waves occurred from the south (168.75- 191.25). As seen in Figure A114b, of the wave data at Port Kembla including wave directions, the highest percentage of winter (59%) and autumn (55%) storm waves occurred from the south south east while the highest percentage of spring (50%) and summer (47%) storm waves occurred from the south.

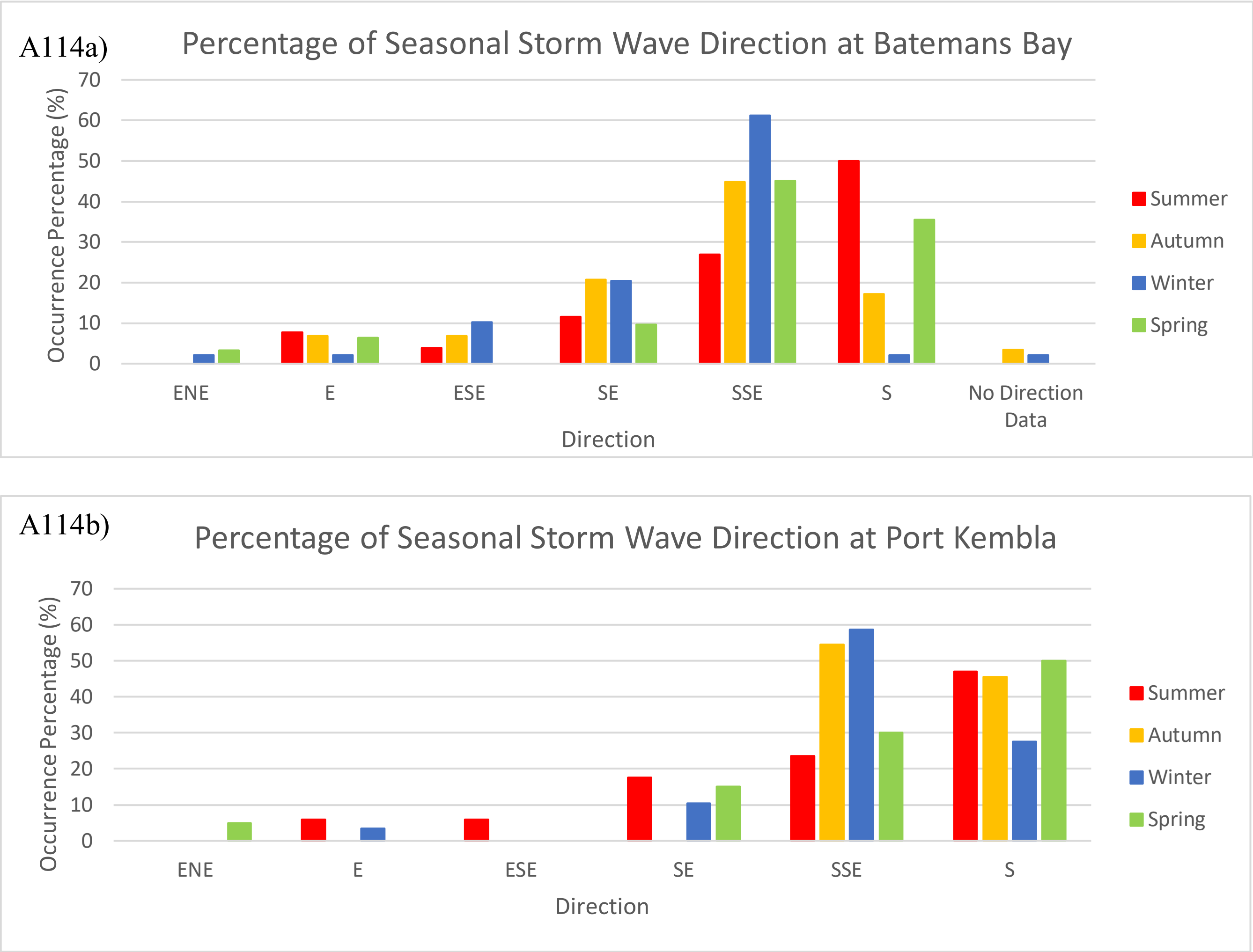


Figure A114:a) Percentage of seasonal storm wave directions at Batemans Bay. b) Percentage of seasonal storm wave directions at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

A1.2. Yearly to decadal storm distribution

A1.2.1. Severe and extreme storm occurrence

When examining the occurrence of severe and extreme storms at Batemans Bay and Port Kembla on a yearly to decadal scale, differences are found based on the temporal scale and event severity. While no trends are noticeable in the occurrence of severe and extreme storms on a yearly basis, as seen in Figure A121a-d, when the occurrence of severe storms are taken on a decadal basis, at both sites it is evident that occurrence is increasing throughout time as seen in Figure A121e and f. However, contrasting to the decadal trend observed with severe storms, no consistent increase is observed with extreme storms as seen in Figure A121 g and h.

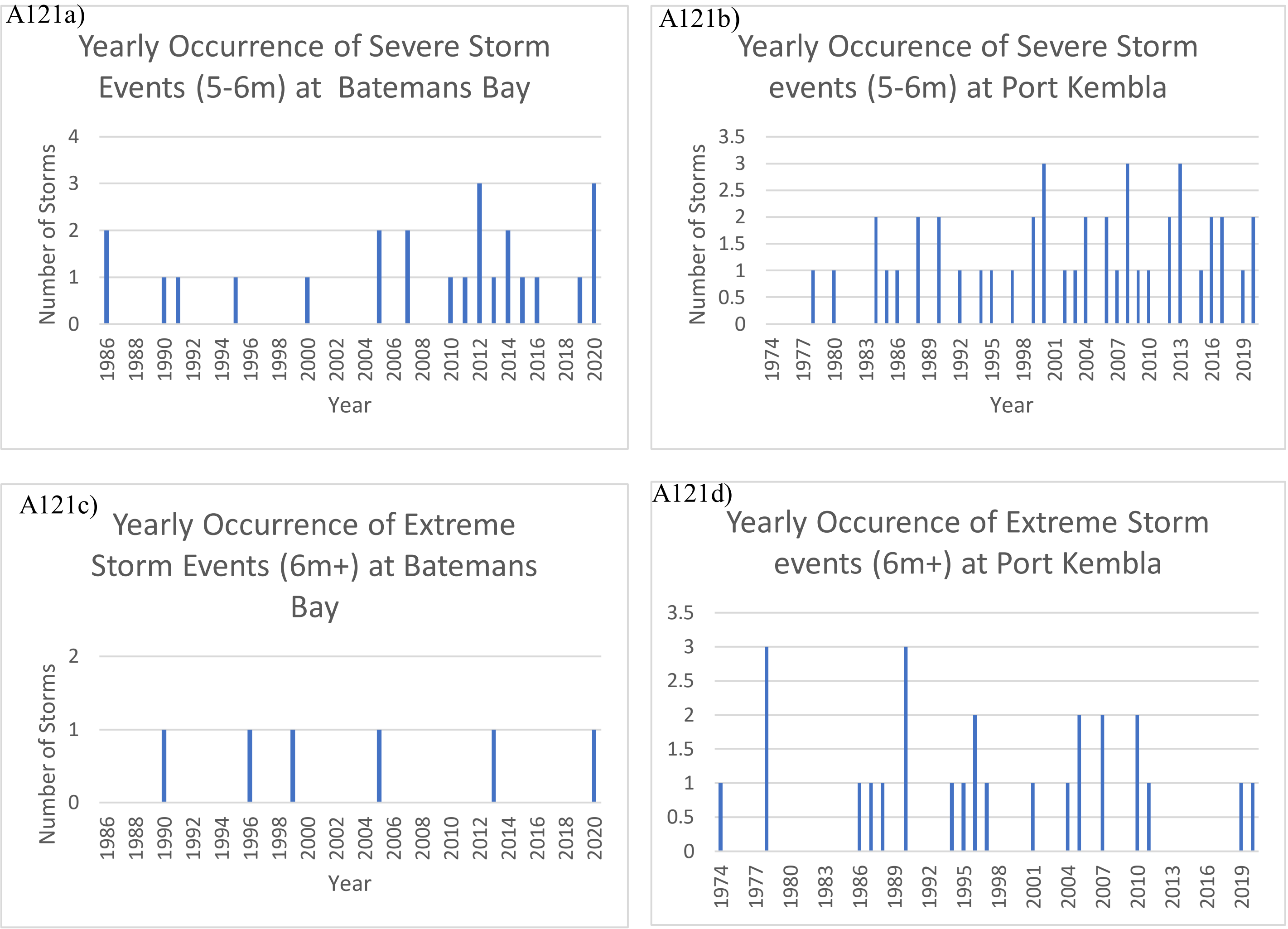


Figure A121:a) Yearly occurrence of severe storm events (5-6m) at Batemans Bay. b) Yearly occurrence of severe storm events (5-6m) at Port Kembla. c) Yearly occurrence of extreme storms (6m+) at Batemans Bay. d) Yearly occurrence of extreme storm events (6m+) at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

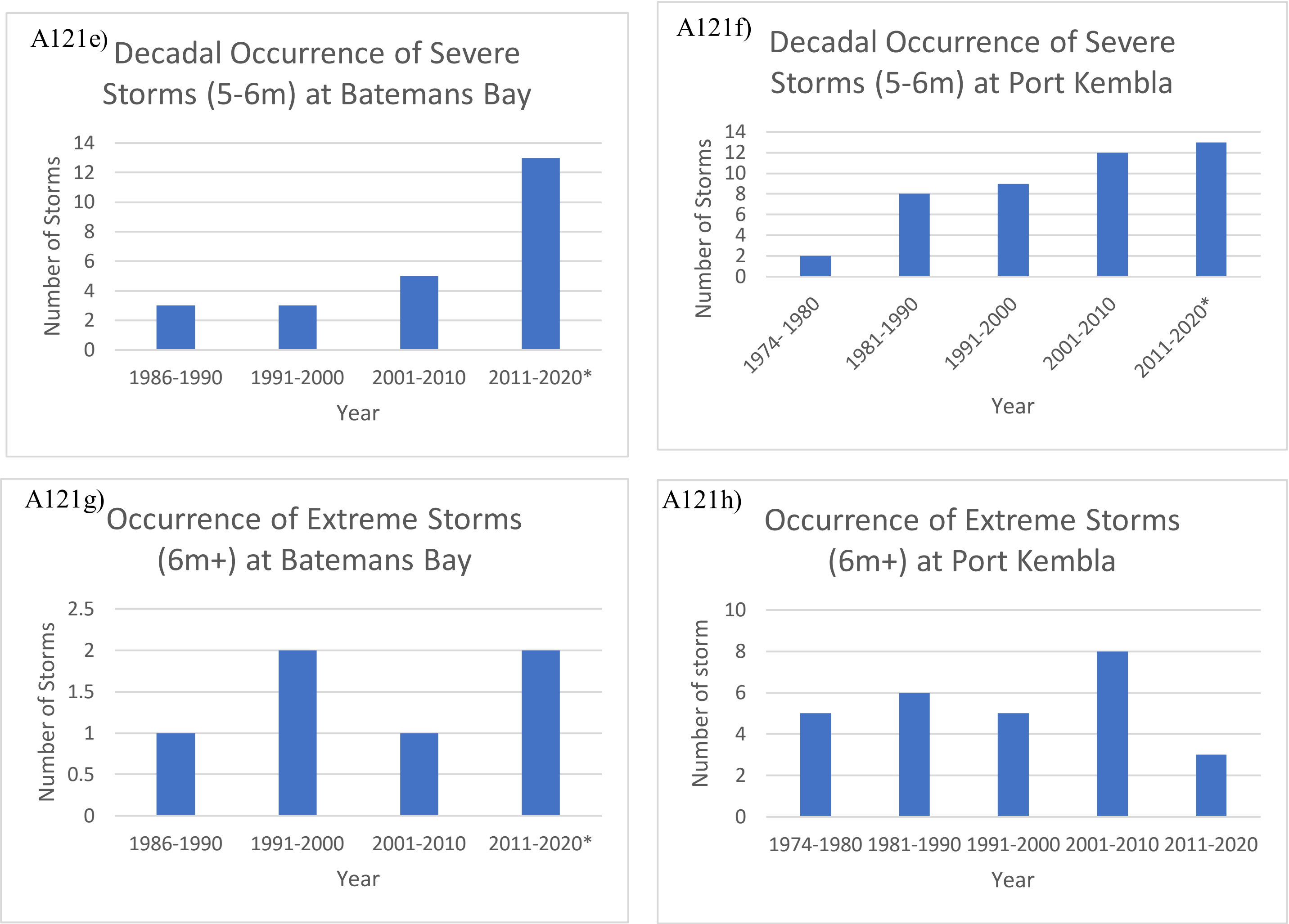
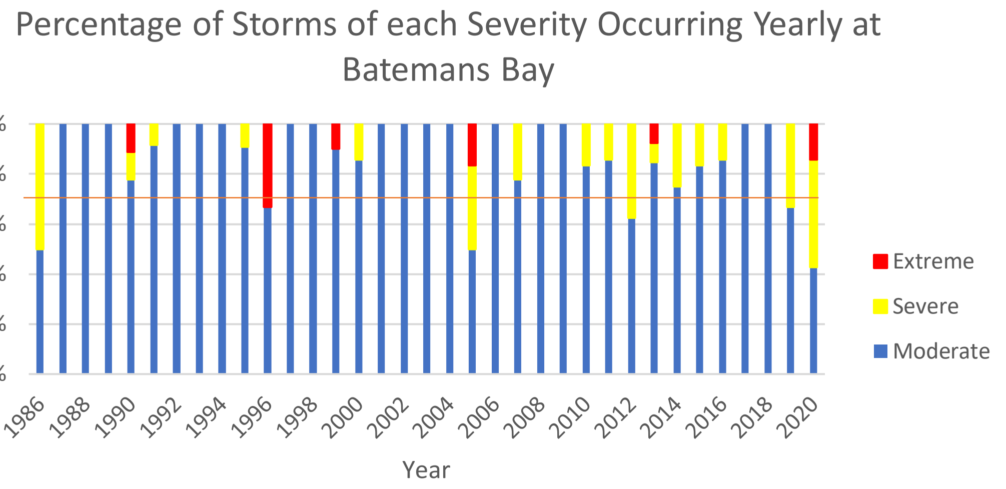


Figure A121: e) Decadal occurrence of severe storms (5-6m) at Batemans Bay. f) Decadal occurrence of Severe Storms (5-6m) at Port Kembla. g) Decadal occurrence of extreme storms (6m+) at Batemans Bay. h) Decadal occurrence of extreme Storms (6m+) at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

A1.2.2. Percentage of storm severity

When examining the occurrence of severe and extreme events as a percentage of the total yearly storm occurrence, it was found that a higher percentage (>30%) of events were more severe at different intervals between sites. As evident by Figure A122a, at Batemans Bay, every 7-10 years (1986, 1996, 2005, 2012, 2019, 2020) a higher percentage of events were of severe and extreme severity. As evident by Figure A122b, at Port Kembla, every 7-13 years (1978, 1980, 1990, 2000, 2007, 2020) a higher percentage of events were of severe and extreme severity.

A122a)



A122b)

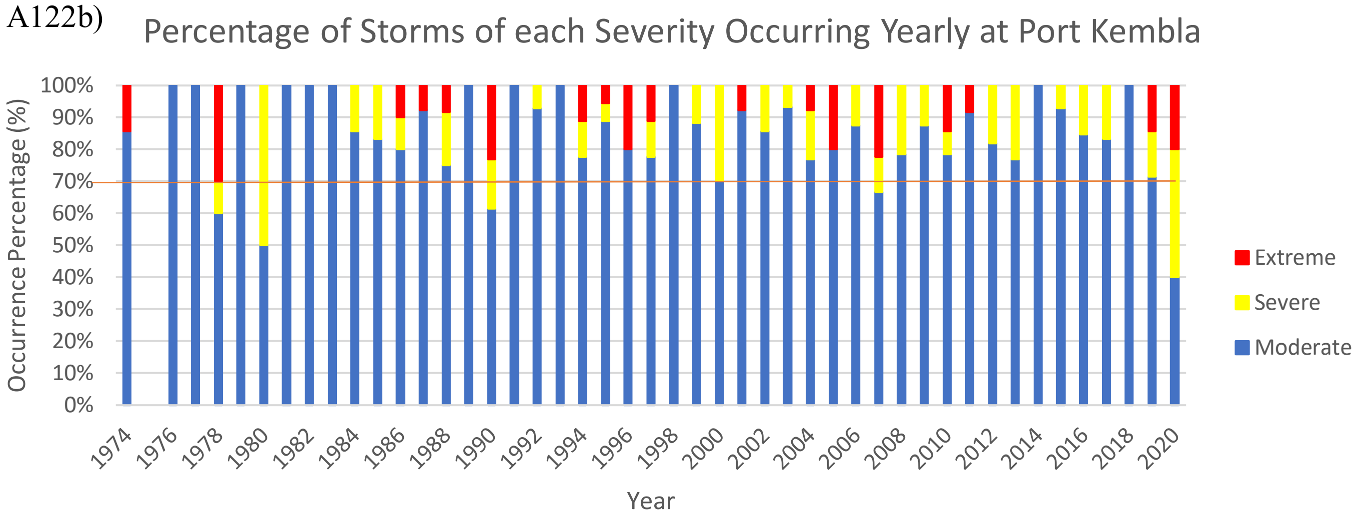
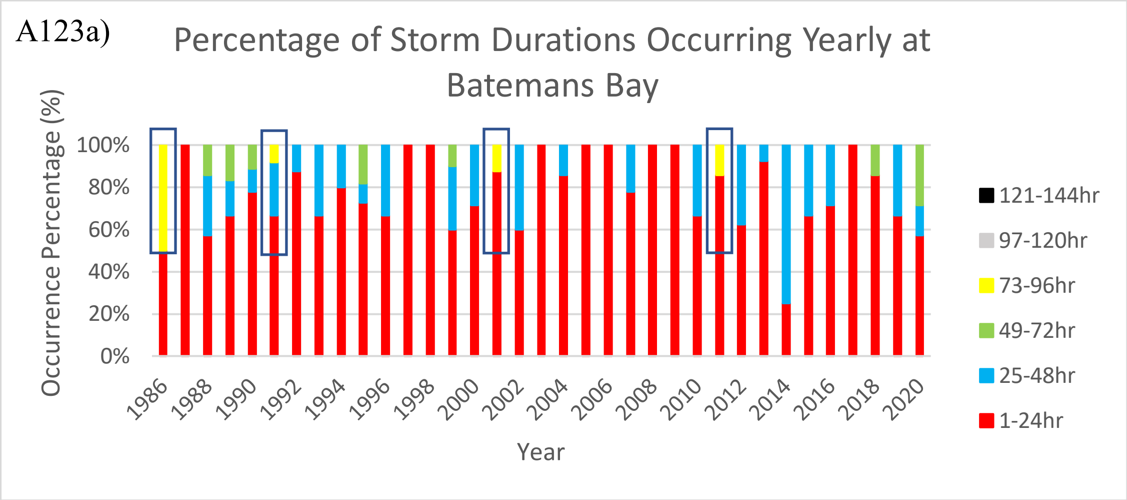


Figure A122: a) Yearly percentage of severe and extreme storms against total storm occurrence at Batemans Bay. b) Yearly percentage of severe and extreme storms against total storm occurrence at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

A1.2.3. Storm duration

When examining the duration of storm events as a percentage of the various storm durations present during the year, it was found that long duration events (> 72 hours) occurred at different intervals between sites. As evident by Figure A123a, at Batemans Bay, every 5-10 years (1986, 1991, 2001, 2011) an event with a duration longer than 72 hours occurred. As evident by Figure A123b, at Port Kembla, every 4-10 years (1974, 1978, 1984, 1985, 1986, 1987, 1994, 1995, 1999, 2001, 2011, 2020) an event with a duration longer than 72 hours occurred.



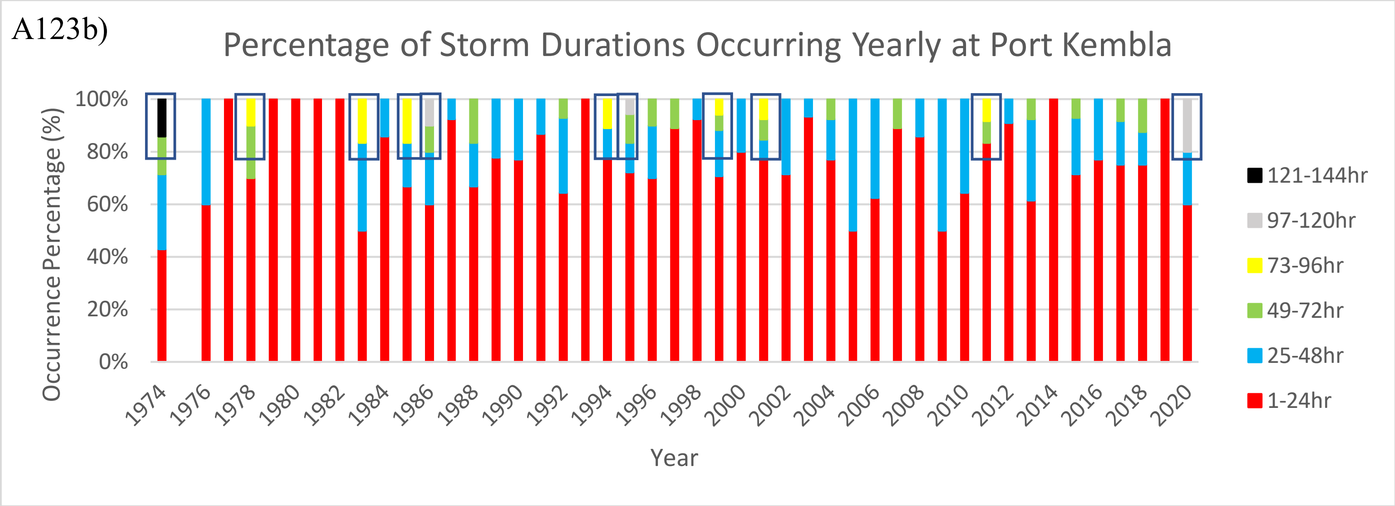


Figure A123: a) Percentage of storm durations occurring yearly at Batemans Bay. b) Percentage of storm durations occurring yearly at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

A1.3. Storm clusters

When examining the storm clustering that occurs at Batemans Bay and Port Kembla, minor differences are observed based on the temporal and spatial scale. While on the yearly scale no apparent trend exists, as seen in Figure A130a-b, storm clustering on the decadal scale appears to experience a gradual increase before plateauing at different periods across the two sites as seen in Figure A130c-d.

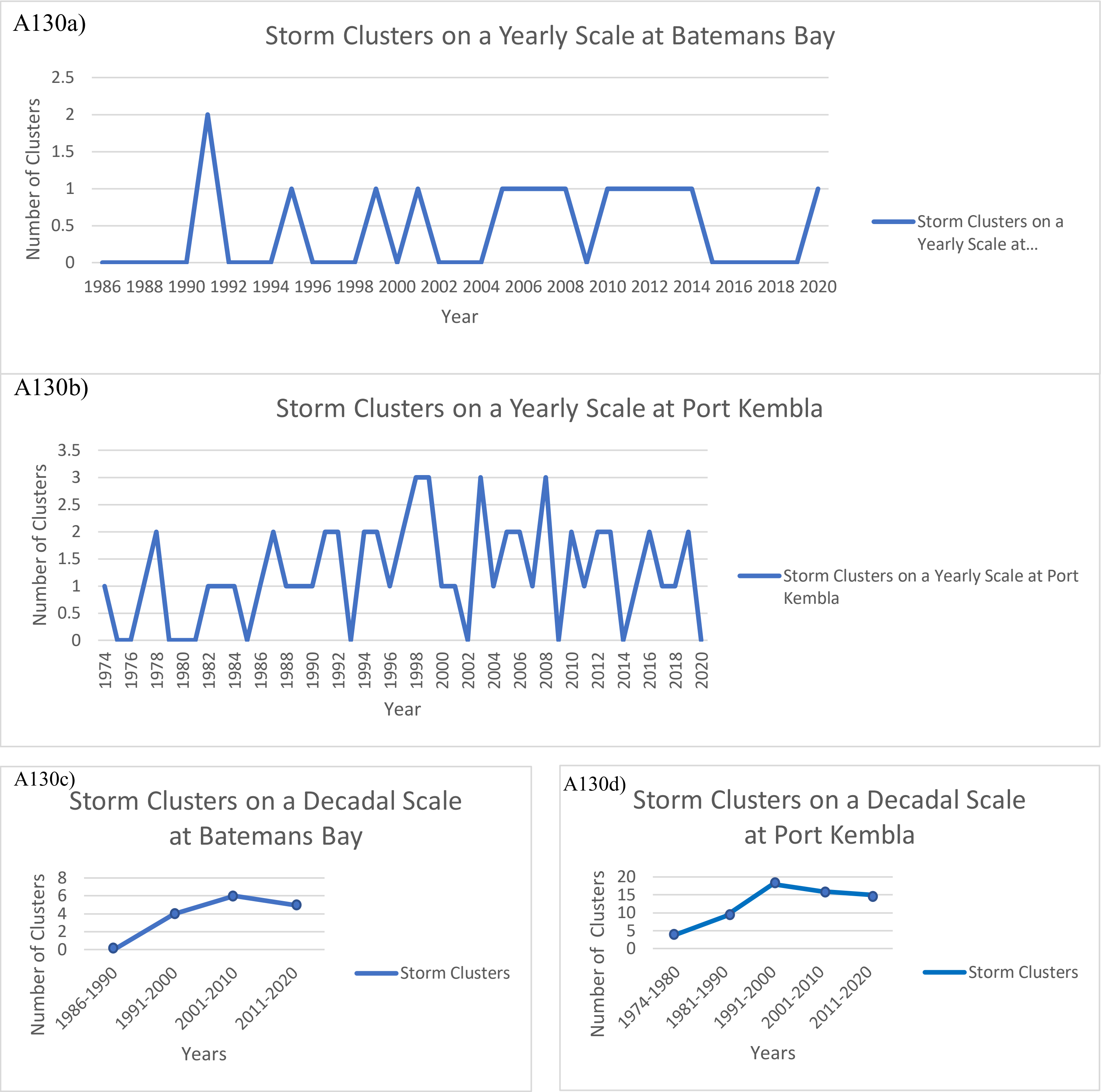
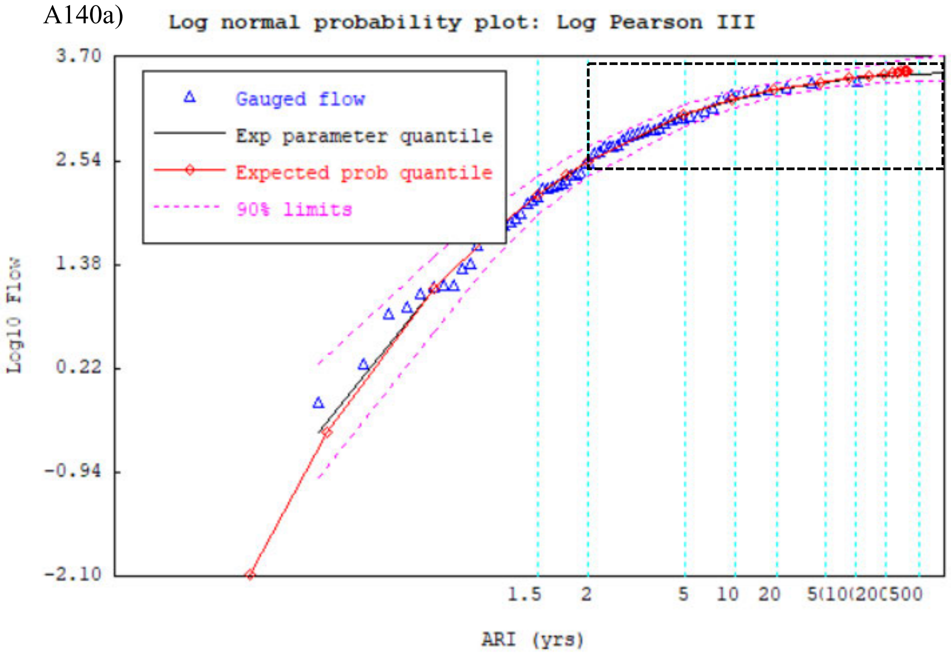


Figure A130: a) Storm clusters on a yearly scale at Batemans Bay. b) Storm clusters on a yearly scale at Port Kembla. c) Storm clusters on a decadal scale at Batemans Bay. d) Storm clusters on a decadal scale at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

A1.4. Moruya River discharge

In order to determine the recurrence interval of Moruya River discharge events, the annual maximum has been entered into a magnitude frequency curve and the results can be seen in Figure A140a. By using the 1 in 2 year flood value from the magnitude frequency curve of 333m^3/s as a threshold for the occurrence of severe discharge events, the yearly to decadal trends in flood occurrence can be determined and this is seen in Figure A140b.

A140a)



Greater than 333m^3/s

Figure A140a: Annual Maximum Discharge Recurrence interval for Moruya River (M^3/sec) (Discharge data used in this analysis is provided by the Bureau of Meteorology)

A140b)

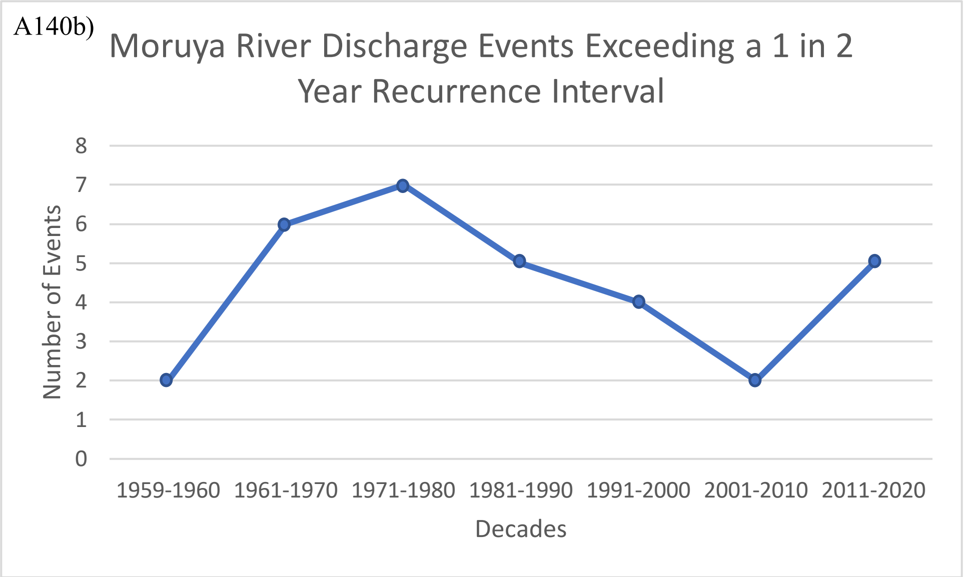


Figure A140b: Decadal distribution of Moruya River discharge events exceeding a 1 in 2 year recurrence interval. (Discharge data used in this analysis is provided by the Bureau of Meteorology)

A1.5. Co-occurrence of storms and high discharge events

High river discharge events along the Moruya River from 1974-2020 have been charted against high significant wave heights across the combined records of Batemans Bay and Port Kembla during the same period in Figure A150. In addition to this, 1 in 20, 1 in 50 and 1 in 100-year recurrence intervals for discharge and significant wave heights as well as the 1 in 2 year recurrence interval for discharge have been charted to conceptualise the severity of events that occur during the record. While it doesn't appear that a strong correlation exists between flooding and storms in Figure A150, it should be noted that all floods occurred coincident with coastal storms with the exception of 1975 however this is likely due to the missing data during this period. When examining the recurrence intervals for these events, it appears that more severe discharge events are occurring less often while more severe significant wave height events occur more often.

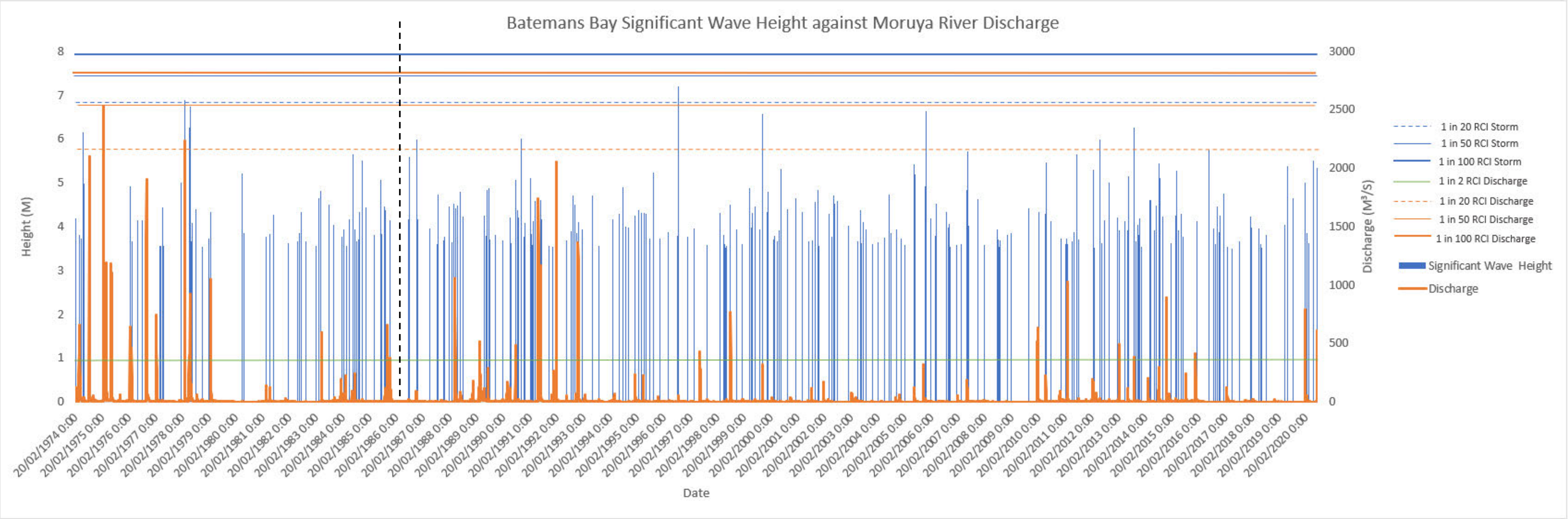
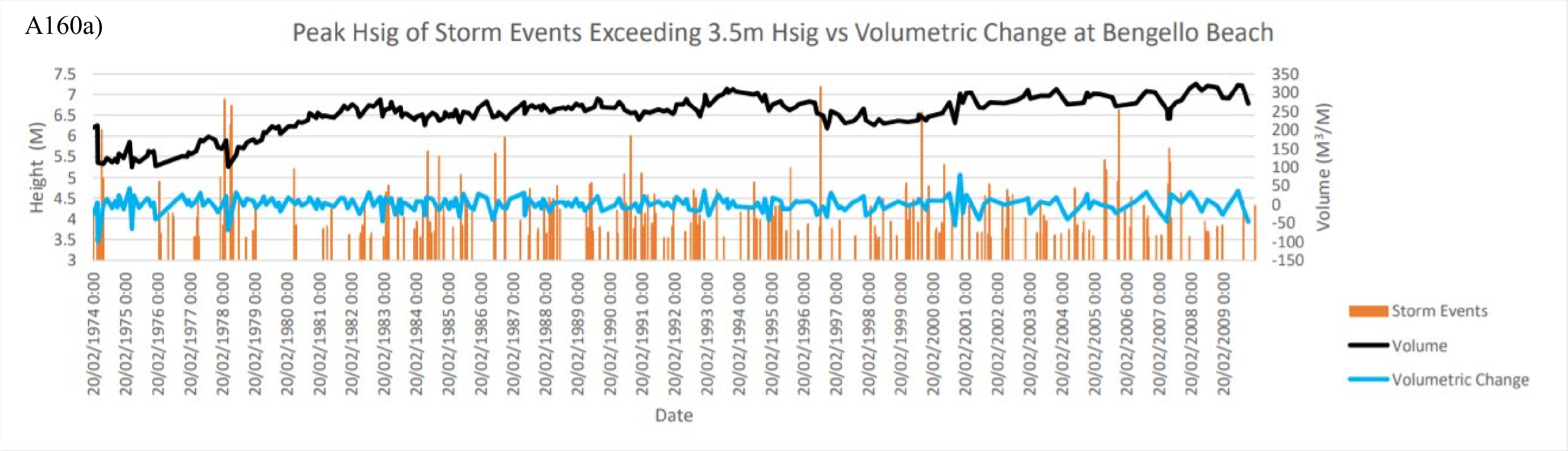


Figure A150: Storm significant wave height (blue) plotted against river discharge (orange). To the left of the vertical dashed black line is wave data from Port Kembla which has been included to extend the record and to the right of the dashed line is data from Batemans Bay. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL. Discharge data used in this analysis is provided by the Bureau of Meteorology)

A1.6. Influences on volumetric change at Bengello Beach

When examining the influences on the volumetric record at Bengello Beach, the significant wave height, duration, wave period and direction from the combined wave records of Batemans Bay and Port Kembla, as well as Moruya River discharge are plotted against the volumetric record of Bengello Beach and these can be seen in Figure A160a-e. While each aspect will impact the volume to varying extents, the proximity of more severe events (clustering) as seen by the proximity of orange lines in Figure A160a, the duration of storm events as seen in Figure A160b and the occurrence of high river discharge events as seen in Figure A160e, were found to coincide with the largest changes in volume.

A160a)


Peak Hsig of Storm Events Exceeding 3.5m Hsig vs Volumetric Change at Bengello Beach
Height (M)
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
Volume (M³/M)
350
300
250
200
150
100
50
0
-50
-100
-150
20/02/1974 0:00
20/02/1975 0:00
20/02/1976 0:00
20/02/1977 0:00
20/02/1978 0:00
20/02/1979 0:00
20/02/1980 0:00
20/02/1981 0:00
20/02/1982 0:00
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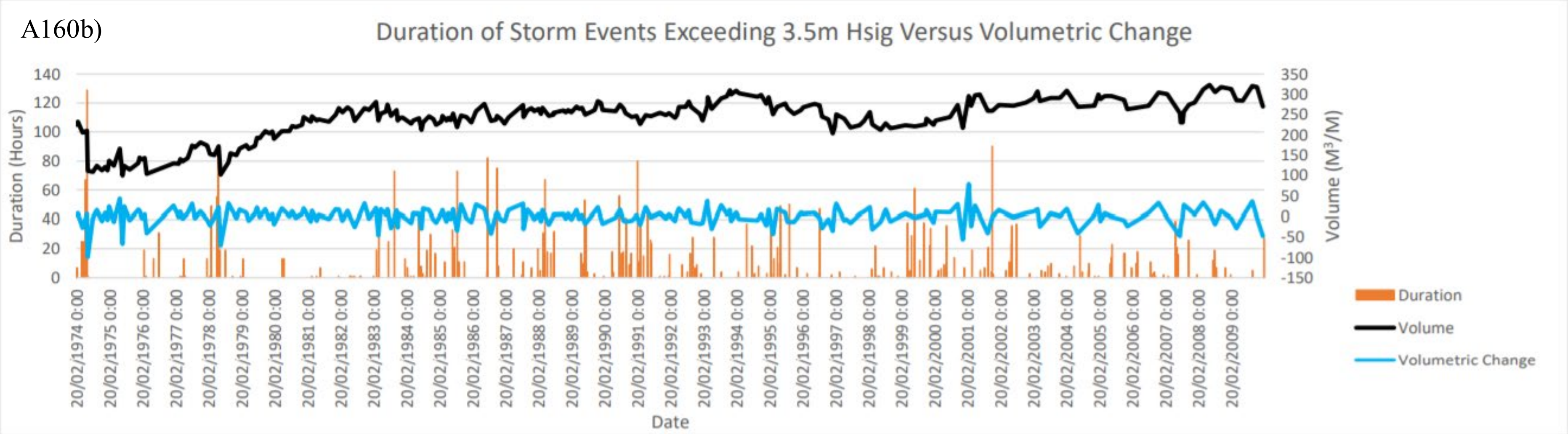
20/02/2000 0:00
20/02/2001 0:00
20/02/2002 0:00
20/02/2003 0:00
20/02/2004 0:00
20/02/2005 0:00
20/02/2006 0:00
20/02/2007 0:00
20/02/2008 0:00
20/02/2009 0:00
Date
Storm Events
Volume
Volumetric Change

A160b)


Duration of Storm Events Exceeding 3.5m Hsig Versus Volumetric Change
Duration (Hours)
140
120
100
80
60
40
20
0
Volume (M³/M)
350
300
250
200
150
100
50
0
-50
-100
-150
20/02/1974 0:00
20/02/1975 0:00
20/02/1976 0:00
20/02/1977 0:00
20/02/1978 0:00
20/02/1979 0:00
20/02/1980 0:00
20/02/1981 0:00
20/02/1982 0:00
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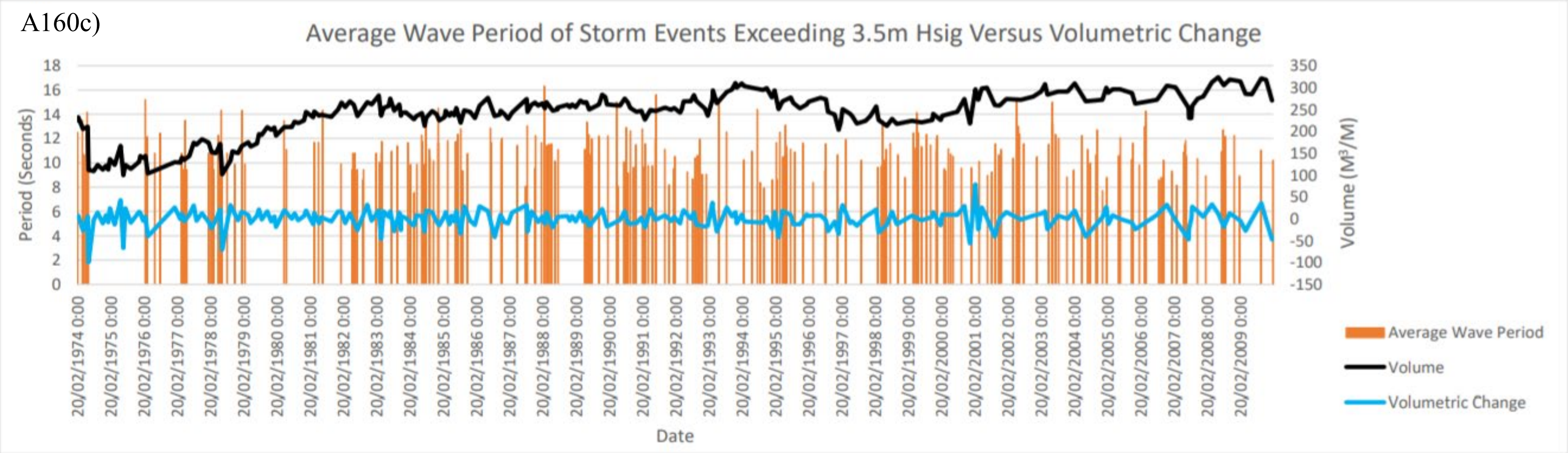
20/02/2003 0:00
20/02/2004 0:00
20/02/2005 0:00
20/02/2006 0:00
20/02/2007 0:00
20/02/2008 0:00
20/02/2009 0:00
Date
Duration
Volume
Volumetric Change

A160c)


Average Wave Period of Storm Events Exceeding 3.5m Hsig Versus Volumetric Change
Period (Seconds)
18
16
14
12
10
8
6
4
2
0
Volume (M³/M)
350
300
250
200
150
100
50
0
-50
-100
-150
20/02/1974 0:00
20/02/1975 0:00
20/02/1976 0:00
20/02/1977 0:00
20/02/1978 0:00
20/02/1979 0:00
20/02/1980 0:00
20/02/1981 0:00
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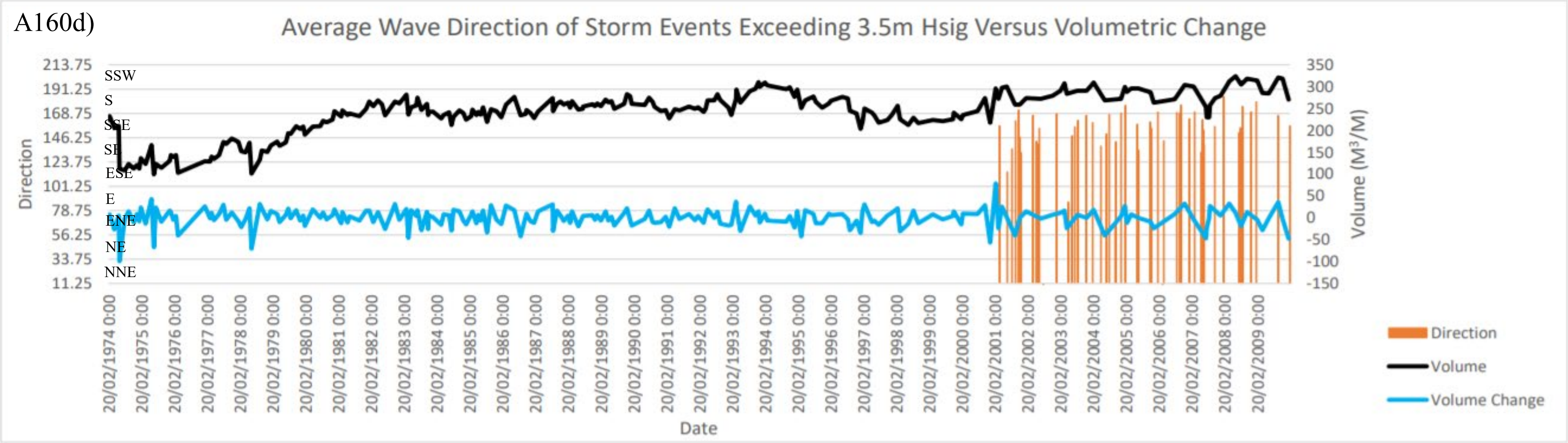
20/02/2002 0:00
20/02/2003 0:00
20/02/2004 0:00
20/02/2005 0:00
20/02/2006 0:00
20/02/2007 0:00
20/02/2008 0:00
20/02/2009 0:00
Date
Average Wave Period
Volume
Volumetric Change

A160d)



A160e)

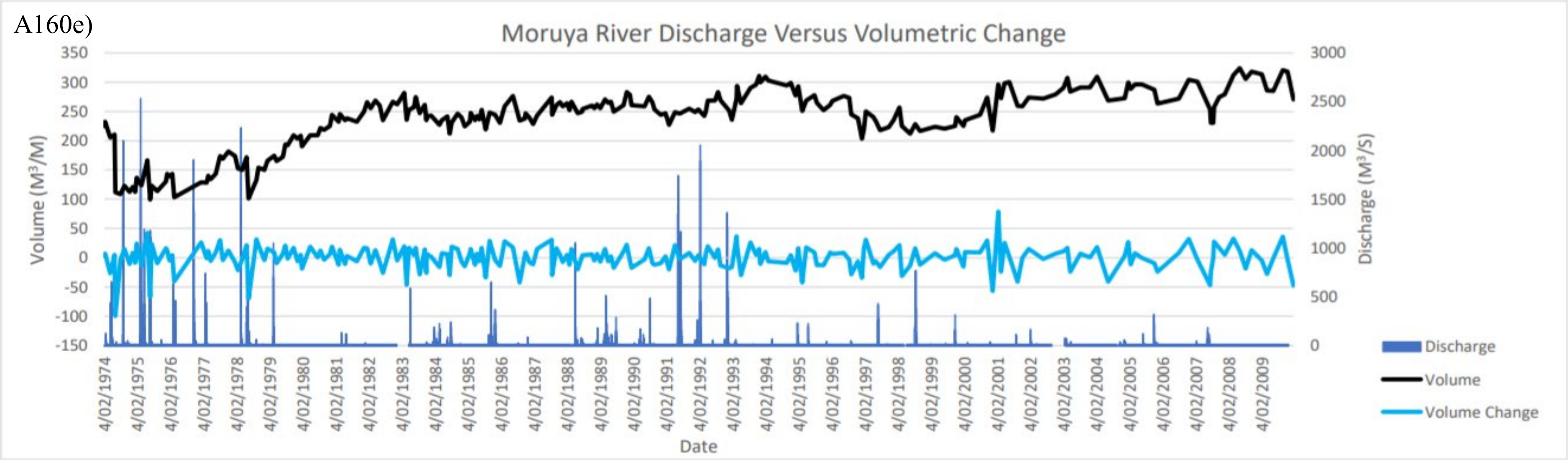


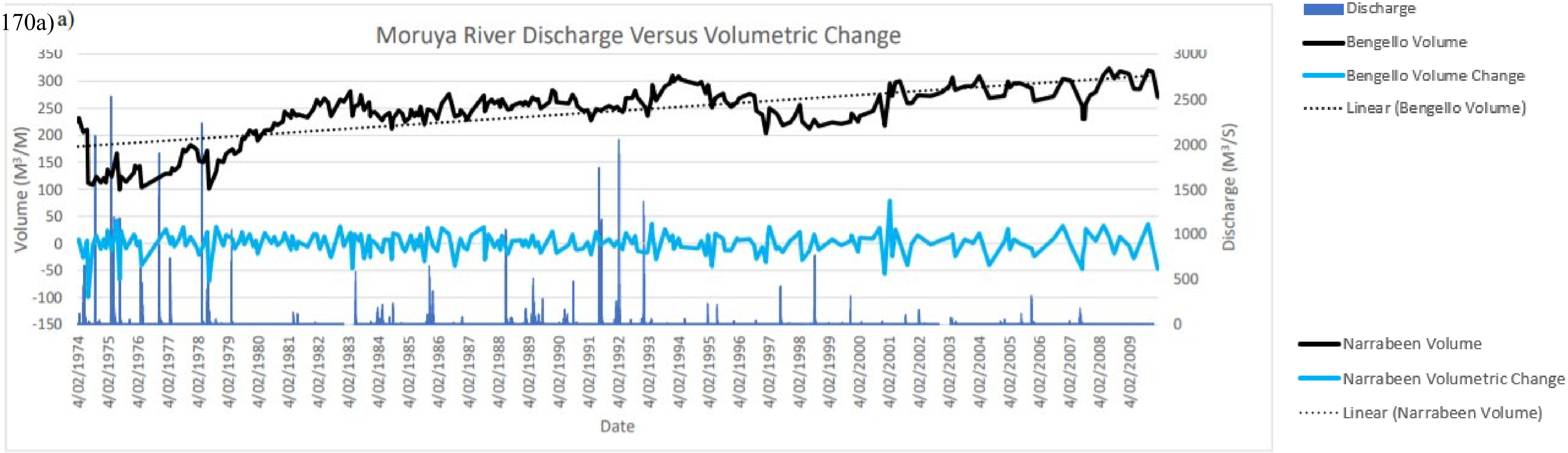
Figure A160: *a) Peak Hsig of storm events exceeding 3.5m Hsig vs volumetric change at Bengello Beach. b) Duration of storm events exceeding 3.5m Hsig versus volumetric change. c) Average wave period of storm events Exceeding 3.5m Hsig versus volumetric change. d) Average wave direction of storm events exceeding 3.5m Hsig versus volumetric change. e) Moruya River discharge Versus volumetric change. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL. Discharge data used in this analysis is provided by the Bureau of Meteorology)*

A1.7. Bengello Beach volumetric changes and the effect of Moruya River Discharge vs Narrabeen Beach volumetric changes

The impact of post-storm beach recovery and fluvial sediment supply on beach volume have been compared by examining the volumetric data of Bengello Beach at Moruya, a site that likely receives sediment from the river during flooding, and Narrabeen Beach, a non-river fed beach. As can be seen at Bengello Beach in Figure A170a, following periods of high discharge, the volume experiences an increase beyond previously stable levels. In addition to this, Bengello demonstrates an overall increasing volume as evident by the positive inclination of the trendline. Contrasting to this, while Narrabeen's volume in Figure A170b demonstrates minor increases that are associated with post-storm beach recovery, it is found to experience an overall loss of sediment.

28

A170a)



A170 b)

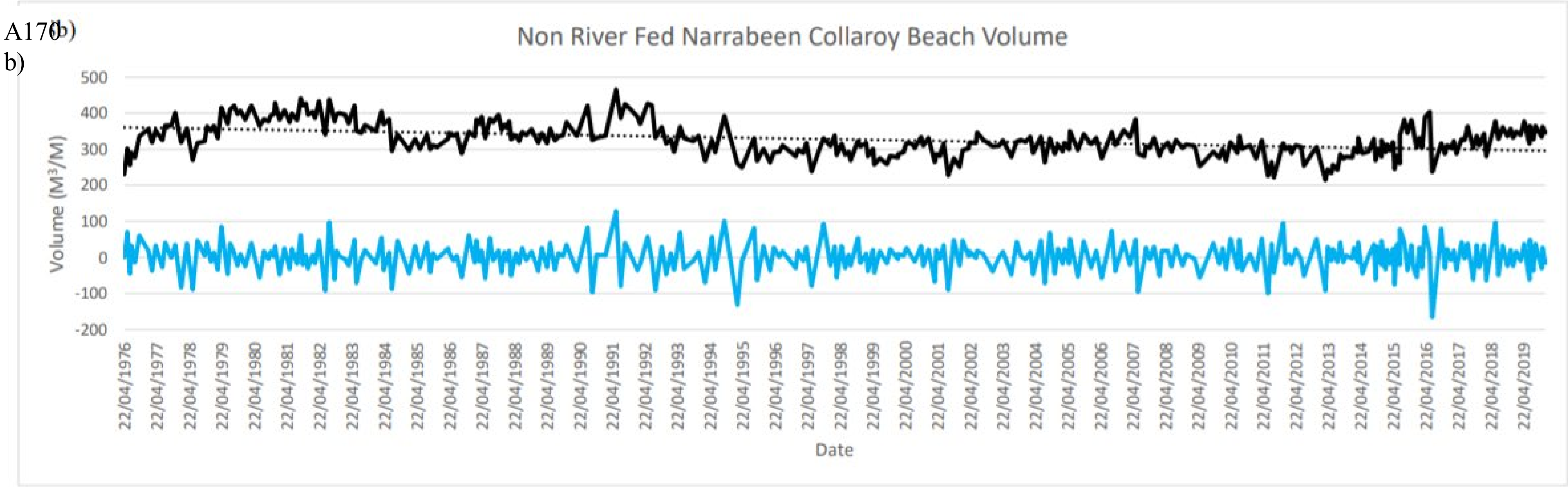


Figure A170: a) Moruya River discharge plotted against the volume and volumetric change at Bengello Beach. (Data is sourced from Mclean et al 2010) b) Volume and volumetric change at Narrabeen Collaroy Beach (Data is sourced from Turner et al 2016)

A1.8. Magnitude frequency distribution validation

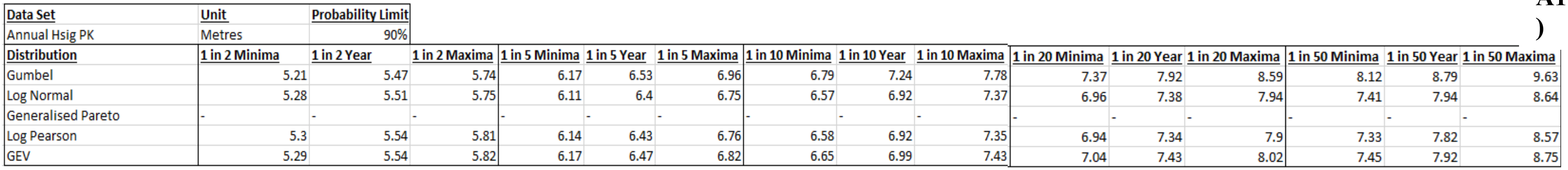
Recurrence intervals were created by entering the significant wave height, river discharge and volumetric change data into Flike, an extreme value analysis package that utilises historical records to calculate the recurrence intervals of flood events (TUFLOW, 2015). In order to obtain the most accurate recurrence interval for each data set, a table of values were created which compared the 1 in 2, 1 in 5, 1 in 10, 1 in 20 and 1 in 50 year recurrence intervals for the Gumbel, Log Normal, GPD, LPIII and GEV analysis distributions. The position of each data point was plotted in the distribution using the Cunnane plotting position formula to ensure it was done without bias (Cunnane, 1978).

As can be seen in Table A180a, the annual maximum analysis of the significant wave height data at Port Kembla displays differences between the distributions minima and maxima of <1m until a 1 in 50-year recurrence interval. Due to this relatively small discrepancy (~12.5% of average value), multiple models could be considered for use. Ultimately, the Gumbel distribution was chosen to be used for this analysis as recommended by Katalinić and Parunov (2020). The Gumbel distribution was also applied to the annual maximum erosion and accretion data as it was reasoned that as waves were responsible for sediment movement, the same recurrence interval model would be applicable.

As can be seen in Table A180b, the annual maximum analysis of the Moruya River discharge data displays differences between the distributions minima and maxima of between 130m^3/s and 260m^3/s respectively at a recurrence interval of 1 in 2 years and between 3700m^3/s and 65000m^3/s respectively at a recurrence interval of 1 in 50 years. Due to the substantial difference between the distributions, the 50-year recurrence intervals for each distribution were viewed in comparison to the observed values on the Moruya River to find the most accurate fit. By conducting this examination, both the Gumbel and LPIII distributions were found to be applicable. Ultimately the LPIII model was chosen as it is the government standard in Australia (Gordon et al., 2004) and it was found to be the best performer by Paul et al. (2016) when conducting a flood frequency analysis.

Table A180:a) The recurrence interval for the 5 distributions of the annual maximum significant wave height at Port Kembla. b) The recurrence interval for the 5 distributions of the annual maximum river discharge at Moruya.

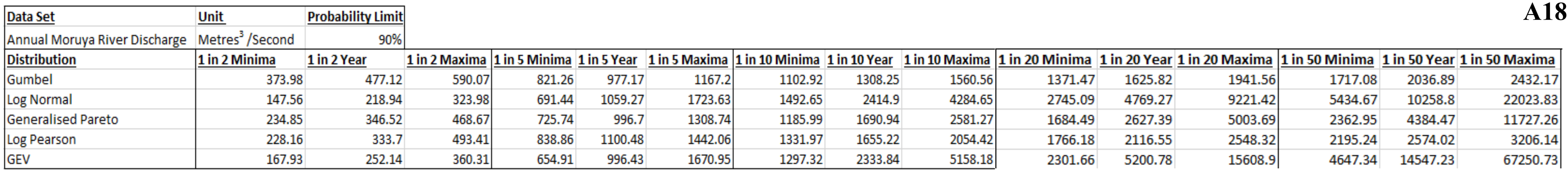
A180a)



Data Set	Unit	Probability Limit
Annual Hsig PK	Metres	90%

Distribution	1 in 2 Minima	1 in 2 Year	1 in 2 Maxima	1 in 5 Minima	1 in 5 Year	1 in 5 Maxima	1 in 10 Minima	1 in 10 Year	1 in 10 Maxima	1 in 20 Minima	1 in 20 Year	1 in 20 Maxima	1 in 50 Minima	1 in 50 Year	1 in 50 Maxima
Gumbel	5.21	5.47	5.74	6.17	6.53	6.96	6.79	7.24	7.78	7.37	7.92	8.59	8.12	8.79	9.63
Log Normal	5.28	5.51	5.75	6.11	6.4	6.75	6.57	6.92	7.37	6.96	7.38	7.94	7.41	7.94	8.64
Generalised Pareto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Log Pearson	5.3	5.54	5.81	6.14	6.43	6.76	6.58	6.92	7.35	6.94	7.34	7.9	7.33	7.82	8.57
GEV	5.29	5.54	5.82	6.17	6.47	6.82	6.65	6.99	7.43	7.04	7.43	8.02	7.45	7.92	8.75

A180b)



Data Set	Unit	Probability Limit
Annual Moruya River Discharge	Metres^3 /Second	90%

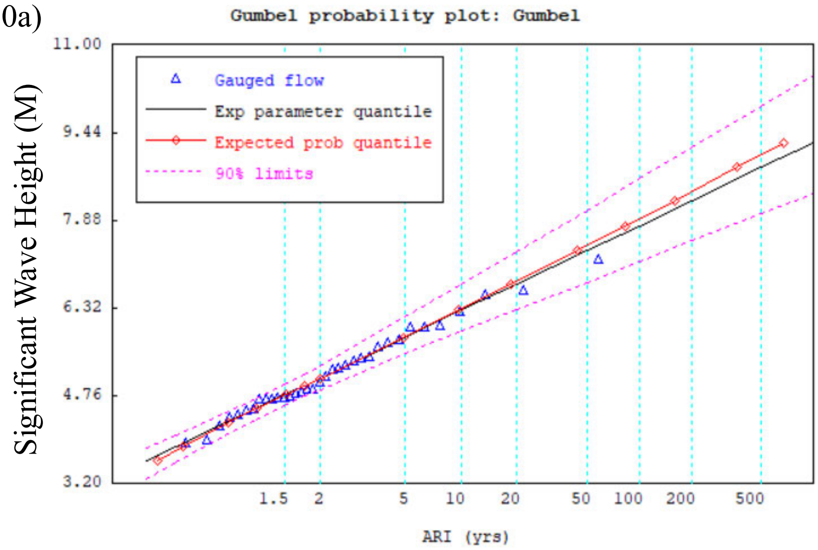
Distribution	1 in 2 Minima	1 in 2 Year	1 in 2 Maxima	1 in 5 Minima	1 in 5 Year	1 in 5 Maxima	1 in 10 Minima	1 in 10 Year	1 in 10 Maxima	1 in 20 Minima	1 in 20 Year	1 in 20 Maxima	1 in 50 Minima	1 in 50 Year	1 in 50 Maxima
Gumbel	373.98	477.12	590.07	821.26	977.17	1167.2	1102.92	1308.25	1560.56	1371.47	1625.82	1941.56	1717.08	2036.89	2432.17
Log Normal	147.56	218.94	323.98	691.44	1059.27	1723.63	1492.65	2414.9	4284.65	2745.09	4769.27	9221.42	5434.67	10258.8	22023.83
Generalised Pareto	234.85	346.52	468.67	725.74	996.7	1308.74	1185.99	1690.94	2581.27	1684.49	2627.39	5003.69	2362.95	4384.47	11727.26
Log Pearson	228.16	333.7	493.41	838.86	1100.48	1442.06	1331.97	1655.22	2054.42	1766.18	2116.55	2548.32	2195.24	2574.02	3206.14
GEV	167.93	252.14	360.31	654.91	996.43	1670.95	1297.32	2333.84	5158.18	2301.66	5200.78	15608.9	4647.34	14547.23	67250.73

A1.9. Storm magnitude frequency analysis

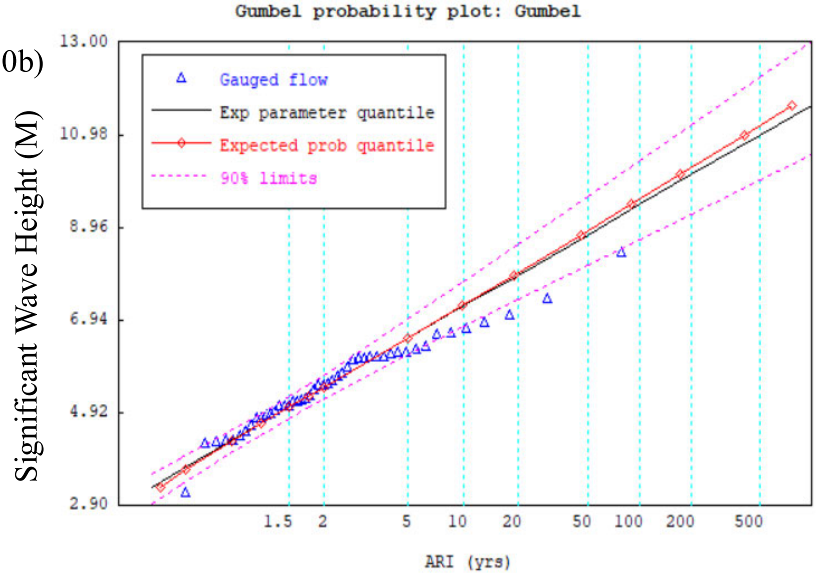
The magnitude and frequency analysis for the significant wave heights at Batemans Bay and Port Kembla, shown in Figure A190a and b respectively, demonstrate the potential range of significant wave height events (storms) that may be encountered at a larger time scale. The largest Hsig reached during the recorded period at Batemans Bay was 7.19m in 1996 and this event has a recurrence interval of 58.67 years while the largest Hsig reached during the recorded period at Port Kembla was 8.43m in 1997 and this event has a recurrence interval of 78.67 years.

Due to the occurrence of a series of large storms along the east coast of Australia during July 2020, after the initial period of examination, the effect an extreme event has on a magnitude frequency analysis can be explored. At Batemans Bay, during this period, an extreme storm event was recorded, and it is only the 6th such occurrence over the wave rider buoy record to occur. As a result, the severity of events associated with each recurrence interval have increased and the magnitude frequency curve can be seen in Figure A190c. Contrasting to Batemans Bay, the impact of the July Storms on the magnitude frequency analysis at Port Kembla cannot be determined due to the lack of data present from June 19th- August 1st as the wave rider buoy was knocked out during this time. The 1 in 2, 1 in 5, 1 in 10, 1 in 20, 1 in 50 and 1 in 100-year recurrence intervals associated with the magnitude frequency analyses of Figure A190a-c can be seen in Table A190.

A190a)



A190b)



A190c)

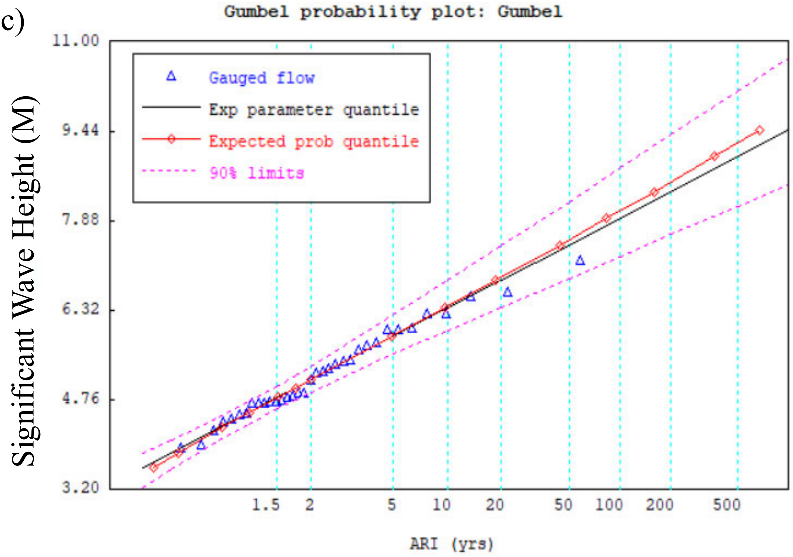
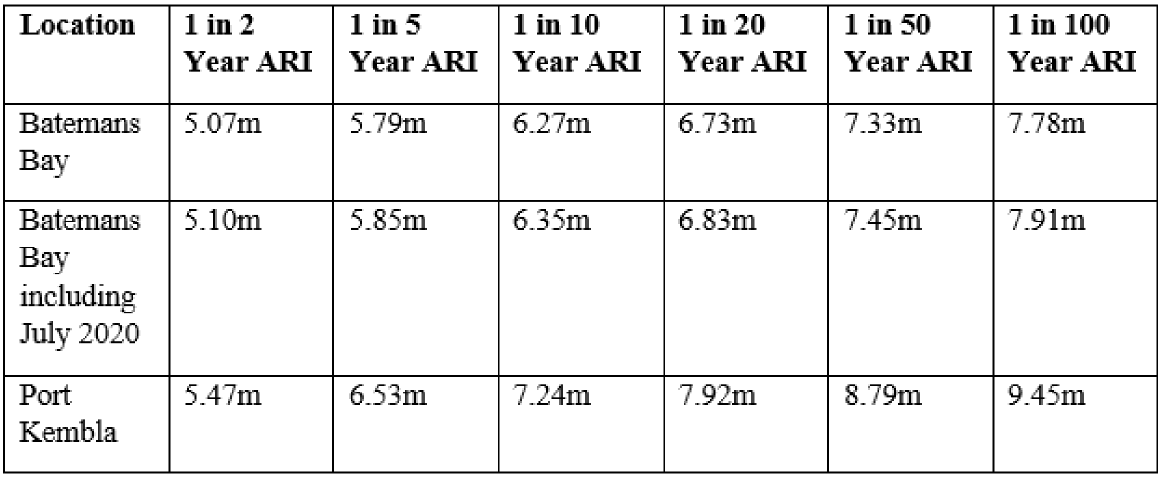


Figure A190: a) Magnitude- frequency curve displaying the recurrence interval of significant wave height events at Batemans Bay. b) Magnitude- frequency curve displaying the recurrence interval of significant wave height events at Port Kembla. c) Magnitude-frequency curve displaying the recurrence interval of significant wave height events at Batemans Bay including the July 2020 storms. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

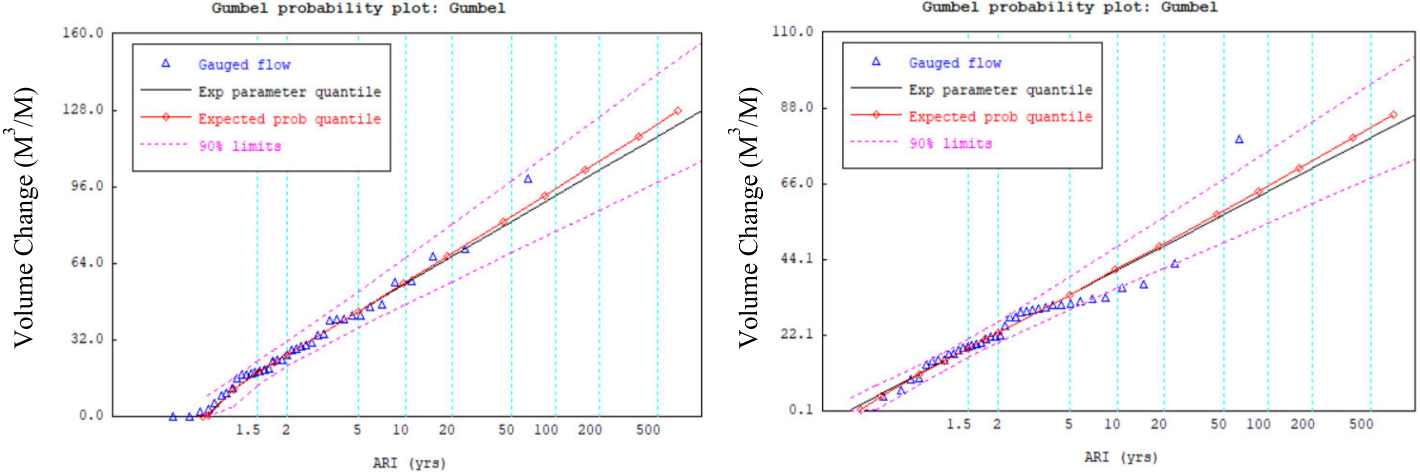
Table A190: Variations in the Significant Wave Height Average Recurrence Intervals at Batemans Bay, Port Kembla and Batemans Bay including the July 2020 storms. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)



Location	**1 in 2 Year ARI**	**1 in 5 Year ARI**	**1 in 10 Year ARI**	**1 in 20 Year ARI**	**1 in 50 Year ARI**	**1 in 100 Year ARI**
Batemans Bay	5.07m	5.79m	6.27m	6.73m	7.33m	7.78m
Batemans Bay including July 2020	5.10m	5.85m	6.35m	6.83m	7.45m	7.91m
Port Kembla	5.47m	6.53m	7.24m	7.92m	8.79m	9.45m

A1.10. Volumetric change magnitude frequency analysis

The recurrence intervals for erosive and accretive events at Bengello Beach have been determined regardless of storms size by applying a magnitude frequency analysis on the volumetric change data seen in Figure A1100a. The magnitude frequency analysis of erosion is displayed in Figure A1100a and the largest events were found to effect 99.16m^3/m and 70.16m^3/m of sediment, have a recurrence interval of 65.33 and 24.50 years and occur in 1974 and 1978 respectively. Other notable erosive events occurred in 1973, 1975, 2000 and 2007 and they effected 55.88 m^3/m, 66.97 m^3/m, 56.94 m^3/m and 47.01 m^3/m of sediment respectively. Contrasting to the scale of the erosion events, the largest accretive events, as seen in Figure A1100b only effected 78.81 m^3/m and 42.98 m^3/m of sediment, have a recurrence interval of 63.67 and 23.87 years and occur in 2001 and 1975 respectively. Other notable accretive events occurred in 1993 and 2009 and they effected 36.90 m^3/m and 35.84 m^3/m of sediment respectively. The 1 in 2, 1 in 5, 1 in 10, 1 in 20, 1 in 50 and 1 in 100-year recurrence intervals associated with the volumetric magnitude frequency analyses at Bengello Beach can be seen in Table A1100.

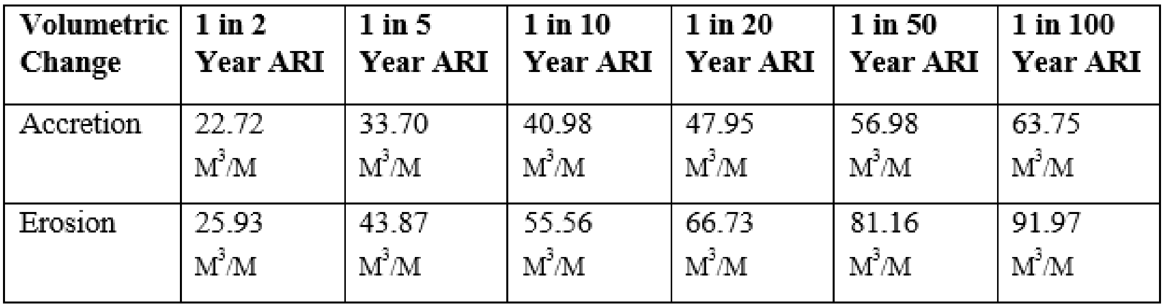


A1100a)

A1100b)

Figure A1100: a): Magnitude- frequency curve displaying the recurrence interval of erosive events at Bengello Beach. b) Magnitude- frequency curve displaying the recurrence interval of accretive events at Bengello Beach. (Data is sourced from Mclean et al 2010)

Table A1100: Variations in the accretion and erosion Average Recurrence Intervals at Bengello Beach from 1974-2010. (Data is Sourced from Mclean et al 2010)



Volumetric Change	**1 in 2 Year ARI**	**1 in 5 Year ARI**	**1 in 10 Year ARI**	**1 in 20 Year ARI**	**1 in 50 Year ARI**	**1 in 100 Year ARI**
Accretion	22.72 M^3/M	33.70 M^3/M	40.98 M^3/M	47.95 M^3/M	56.98 M^3/M	63.75 M^3/M
Erosion	25.93 M^3/M	43.87 M^3/M	55.56 M^3/M	66.73 M^3/M	81.16 M^3/M	91.97 M^3/M

A1.11. Sediment analysis

A1.11.1. Sediment sampling

During 2016 and 2019**,** sediment samples were collected from the Bengello Beach backbarrier and 1974/78 storm scarp by Mcbride et al. (n.d) and the 2019 EESC320 capstone respectively. During 2020 sediment samples were collected from 4-point bars along the Moruya River, the February 2020 storm scarp and a beach surface sample following the July 2020 storms. The locations these samples were taken from can be seen in Figure A1111. While grab samples were predominantly collected for this study, in order to obtain older samples from events such as the 1970s scarp, a hand auger was used. A hand auger consists of a bit and a series of extensions attached to a T- shaped handle that when rotated, allows the bit to advance to a deeper depth. Hand augers are used in shallow- depth subaerial deposits in environments such as sand dunes, fluvial terraces, sandy soil and loess. They are viewed as a cost effective and efficient method of sampling sediment at remote sites as they only require a single person to operate (Nelson et al., 2019).

Figure A1111: Locations the sediment were sampled from for the thesis: The red circle represents the location of the back barrier sample. The white circles represent the 74/78 scarp and the beach surface sample. The Yellow circles represent the locations of the point bar river samples.

A1.11.2 Sedimentological analysis

Due to time constraints, a sedimentological analysis using a mastersizer, SEM and XRD was unable to be undertaken to prove the origin of sediment at Bengello Beach. It must be noted however that a preliminary examination has been undertaken using a microscope and feldspar and lithics, evidence of fluvial contribution, have been identified.

In order to conduct a grain size analysis of the samples collected, laser diffraction from a Malvern Mastersizer will be utilised (Zular et al., 2013). Laser diffractometers are capable of detecting particles ranging in size from ~0.1 to 2000 µm equivalent spherical diameter by utilising Mie theory (Horwell, 2007). For Mie theory to work, four aspects are assumed: the particles being measured are spherical in shape, the suspension is dilute, the optical properties of the particles and medium are known, and the particles are homogenous (Malvern 2010).

X-Ray Diffraction (XRD) utilises the distinctive scattering patterns of X rays when they bombard a sample to denote its mineralogical composition (Jenkins and Snyder, 1996). In order to note the different minerals present within a sample, Braggs law is used to obtain the distance between atoms within the sample (d-spacing) and by comparing this to the d-spacing of known minerals, an unknown mineral can be determined. Furthermore, the richness of minerals within the sample can be determined by examining the ratio of peak intensity of different order reflections (Sisinggih et al., 2006). X-Ray Diffraction will be used in this study to examine the changing feldspar to quartz ratio in the collected samples as it will allow variations in fluvial contribution to be noted as done in Carvalho et al. (2019).

A Scanning Electron Microscope (SEM) is a machine capable of examining specimens within a sub-nanometre resolution. A SEM functions by emitting a focused electron beam through a vacuum and scanning a square area of the sample. When these electrons strike the surface of the sample, various photons and charged particles get emitted and collected thus allowing an image to be formed and displayed on a monitor (Stokes, 2008). Similar to Carvalho et al.

(2019), a SEM will be used to conduct a qualitive analysis of the roundness and sphericity of grains. This analysis will subsequently be utilized to allow an inference into the grains time within the transportation cycle (Nelson, 2018).

Appendix 2: Port Kembla storm data

1974 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.18	20/2/74 18:00	20/2/74 12:00	20/2/74 18:00	12.49	-	Summer	Mod
3.81	14/4/74 18:00	13/4/74 18:00	14/4/74 18:00	13.50	-	Autumn	Mod
3.72	3/5/74 18:00	2/5/74 18:00	3/5/74 18:00	10.66	-	Autumn	Mod
6.15	26/5/74 0:00	25/5/74 6:00	28/5/74 0:00	12.37	-	Autumn	Ext
3.60	5/6/74 12:00	5/6/74 12:00	5/6/74 12:00	14.17	-	Winter	Mod
4.99	13/6/74 12:00	9/6/74 12:00	14/6/74 18:00	12.66	-	Winter	Mod
3.58	16/6/74 0:00	16/6/74 0:00	16/6/74 0:00	10.12	-	Winter	Mod
No data is present after 2/8/74 6:00							

1975 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
No data is present until 3/7/75 18:00 and no waves reach a Hsig greater than or equal to 3.5m							

1976 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.91	5/03/76 15:00	5/3/76 3:00	5/3/76 21:00	15.19	-	Autumn	Mod
3.66	26/3/76	26/3/76	26/3/76	12.15	-	Autumn	Mod

	21:00	21:00	21:00				
4.14	17/6/76 15:00	17/6/76 15:00	18/6/76 3:00	10.80	-	Winter	Mod
4.14	12/8/76 9:00	11/8/76 9:00	12/8/76 15:00	12.38	-	Winter	Mod
4.04	15/8/76 15:00	14/8/76 9:00	15/8/76 15:00	12.42	-	Winter	Mod
No data is present until 4/2/76 15:00							

1977 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
3.56	8/4/77 15:00	8/4/77 15:00	8/4/77 15:00	10.80	-	Autumn	Mod
3.56	29/4/77 9:00	29/4/77 9:00	29/4/77 9:00	9.45	-	Autumn	Mod
4.04	15/5/77 21:00	15/5/77 21:00	16/5/77 9:00	9.45	-	Autumn	Mod
4.43	19/5/77 9:00	19/5/77 9:00	19/5/77 9:00	13.50	-	Autumn	Mod
3.56	4/6/77 3:00	4/6/77 3:00	4/6/77 3:00	9.45	-	Winter	Mod
No data is present until 22/3/77 15:00 and from 14/6/77 15:00 – 28/9/77 15:00							

1978 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
5.01	29/1/78 9:00	28/1/78 21:00	29/1/78 9:00	10.80	-	Summer	Sev
3.85	1/3/78 3:00	1/3/78 3:00	1/3/78 3:00	10.80	-	Autumn	Mod
6.88	19/3/78 15:00	18/3/78 21:00	20/3/78 21:00	11.05	-	Autumn	Ext
3.95	24/3/78 3:00	24/3/78 3:00	24/3/78 3:00	9.45	-	Autumn	Mod
6.26	20/5/78 21:00	20/5/78 21:00	23/5/78 3:00	12.29	-	Autumn	Ext
6.74	2/6/78 3:00	31/5/78 21:00	4/6/78 3:00	11.58	-	Winter	Ext

3.67	17/6/78 9:00	17/6/78 9:00	17/6/78 9:00	14.32	-	Winter	Mod
4.08	25/6/78 21:00	25/6/78 15:00	26/6/78 9:00	10.92	-	Winter	Mod
4.40	23/8/78 15:00	23/8/78 3:00	23/8/78 21:00	10.80	-	Winter	Mod
3.54	11/11/78 21:00	11/11/78 21:00	11/11/78 21:00	9.89	-	Spring	Mod

1979 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.72	5/2/79 15:00	5/2/79 15:00	5/2/79 15:00	14.32	-	Summer	Mod
4.34	4/3/79 15:00	4/3/79 9:00	4/3/79 21:00	9.89	-	Autumn	Mod

1980 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
5.21	10/5/80 3:00	9/5/80 21:00	10/5/80 9:00	13.45	-	Autumn	Sev
3.85	3/6/80 3:00	3/6/80 3:00	3/6/80 15:00	11.10	-	Winter	Mod
No data until 12/2/80 15:00							

1981 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.77	5/4/81 3:00	5/4/81 3:00	5/4/81 3:00	11.70	-	Autumn	Mod
3.83	24/5/81 3:00	24/5/81 3:00	24/5/81 3:00	11.70	-	Autumn	Mod
4.26	10/7/81	10/7/81	10/7/81	14.32	-	Winter	Mod

	3:00	3:00	9:00				

1982 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.62	26/1/82 21:00	26/1/82 21:00	26/1/82 21:00	9.89	-	Summer	Mod
3.66	1/6/82 3:00	1/6/82 3:00	1/6/82 3:00	9.45	-	Winter	Mod
3.56	3/6/82 15:00	3/6/82 15:00	3/6/82 15:00	10.80	-	Winter	Mod
3.85	25/6/82 9:00	25/6/82 9:00	25/6/82 9:00	10.80	-	Winter	Mod
4.33	20/7/82 3:00	20/7/82 3:00	20/7/82 3:00	9.45	-	Winter	Mod
3.54	21/9/82 9:00	21/9/82 9:00	21/9/82 9:00	8.57	-	Spring	Mod
3.66	30/9/82 9:00	30/9/82 9:00	30/9/82 9:00	9.45	-	Spring	Mod

1983 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.56	17/2/83 21:00	17/2/83 21:00	17/2/83 21:00	10.80	-	Summer	Mod
4.65	21/3/83 21:00	21/3/83 9:00	22/3/83 3:00	10.05	-	Autumn	Mod
3.56	13/4/83 3:00	13/4/83 3:00	13/4/83 3:00	10.80	-	Autumn	Mod
4.82	17/4/83 21:00	16/4/83 21:00	18/4/83 15:00	11.76	-	Autumn	Mod
4.50	3/8/83 15:00	3/8/83 3:00	4/8/83 3:00	10.95	-	Winter	Mod
4.04	5/10/83 15:00	4/10/83 21:00	7/10/83 21:00	11.40	-	Spring	Mod

1984 High significant Wave Height Events at Port Kembla (Resolution: 6hrs until 14/6/1984 19:00, Resolution of remainder of the year: 1hr)							
Highest	**Date**	**Date and**	**Date and**	**Average**	**Average**	**Season of**	**Storm**

Significant Wave Height	and time of Highest Hsig	time of first occurrence above 3.5m Hsig	time of last occurrence above 3.5m Hsig	Wave Period of occurrence above 3.5m Hsig	Wave direction of occurrence above 3.5m Hsig	Occurrence	Severity
3.77	31/1/84 15:00	31/1/84 15:00	1/2/84 3:00	11.67	-	Summer	Mod
3.78	28/2/84 21:00	28/2/84 21:00	29/2/84 3:00	9.87	-	Summer	Mod
3.94	1/3/84 21:00	1/3/84 21:00	1/3/84 21:00	8.55	-	Autumn	Mod
3.56	8/4/84 15:00	8/4/84 15:00	8/4/84 15:00	7.54	-	Autumn	Mod
4.17	7/5/84 15:00	7/5/84 15:00	7/5/84 15:00	9.87	-	Autumn	Mod
4.78	30/6/84 13:00	30/6/84 2:00	30/6/84 21:00	12.28	-	Winter	Mod
5.64	4/7/84 18:00	4/7/84 15:00	6/7/84 9:00	11.75	-	Winter	Sev
3.93	27/7/84 23:00	27/7/84 22:00	28/7/84 5:00	9.88	-	Winter	Mod
3.66	15/8/84 12:00	15/8/84 12:00	15/8/84 14:00	13.07	-	Winter	Mod
3.70	20/9/84 13:00	20/9/84 13:00	20/9/84 13:00	11.10	-	Spring	Mod
4.34	29/9/84 18:00	29/9/84 13:00	30/9/84 7:00	10.35	-	Spring	Mod
5.50	7/11/84 9:00	6/11/84 18:00	7/11/84 23:00	10.15	-	Spring	Sev
4.05	28/12/84 9:00	27/12/84 20:00	28/12/84 10:00	11.64	-	Summer	Mod
4.43	31/12/84 13:00	31/12/84 6:00	31/12/84 22:00	14.49	-	Summer	Mod

1985 High significant Wave Height Events at Port Kembla (Resolution: 1hr)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
3.80	14/4/85 12:00	14/4/85 8:00	14/4/85 18:00	11.81	-	Autumn	Mod
5.07	10/7/85 14:00	10/7/85 1:00	11/7/85 9:00	11.75	-	Winter	Sev

3.84	1/8/85 13:00	1/8/85 2:00	1/8/85 22:00	12.37	-	Winter	Mod
4.47	3/9/85 17:00	2/9/85 12:00	5/9/85 12:00	12.78	-	Spring	Mod
4.38	20/9/85 21:00	20/9/85 18:00	21/9/85 4:00	9.35	-	Spring	Mod
4.15	18/11/85 23:00	18/11/85 18:00	19/11/85 4:00	10.77	-	Spring	Mod
Missing data from 25/4/85 6:00- 12/6/85 10:00, 22/9/85 7:00-30/10/85 7:00							

1986 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
3.82	18/1/86 10:00	18/1/86 9:00	18/1/86 17:00	10.30	-	Summer	Mod
3.95	24/1/86 0:00	23/1/86 21:00	24/1/86 3:00	9.50	-	Summer	Mod
5.18	6/4/86 0:00	5/4/86 22:00	6/4/86 3:00	10.38	-	Autumn	Sev
3.71	21/5/86 3:00	21/5/86 1:00	21/5/86 3:00	12.63	-	Autumn	Mod
4.39	26/7/86 1:00	26/7/86 0:00	26/7/86 9:00	12.61	-	Winter	Mod
6.78	6/8/86 3:00	5/8/86 7:00	9/8/86 7:00	11.49	-	Winter	Ext
3.89	11/8/86 7:00	10/8/86 17:00	11/8/86 18:00	13.66	-	Winter	Mod
3.67	15/9/86 18:00	14/9/86 19:00	15/9/86 20:00	10.58	-	Spring	Mod
4.93	21/11/86 13:00	19/11/86 17:00	22/11/86 2:00	12.19	-	Spring	Mod
3.59	29/11/86 21:00	29/11/86 21:00	29/11/86 21:00	12.20	-	Spring	Mod

1987 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
3.57	9/4/87 3:00	9/4/1987 3:00	9/4/1987 3:00	8.80	-	Autumn	Mod

4.05	18/5/87 13:00	18/5/87 9:00	18/5/87 16:00	11.38	-	Autumn	Mod
3.76	13/7/87 4:00	12/7/87 23:00	13/7/87 5:00	11.00	-	Winter	Mod
6.08	3/8/87 16:00	3/8/87 12:00	4/8/87 7:00	11.49	-	Winter	Ext
3.81	20/8/87 0:00	19/8/87 21:00	20/8/87 2:00	9.27	-	Winter	Mod
3.92	1/9/87 13:00	1/9/87 12:00	2/9/87 6:00	12.37	-	Spring	Mod
4.05	30/9/87 19:00	30/9/87 18:00	30/9/87 22:00	8.96	-	Spring	Mod
3.83	5/10/87 7:00	5/10/87 7:00	5/10/87 9:00	9.50	-	Spring	Mod
4.28	20/10/87 18:00	20/10/87 9:00	21/10/87 13:00	8.96	-	Spring	Mod
3.76	26/10/87 2:00	25/10/87 23:00	26/10/87 2:00	8.28	-	Spring	Mod
5.16	12/11/87 8:00	11/11/87 19:00	12/11/87 18:00	9.08	-	Spring	Mod
3.56	4/12/87 4:00	3/12/87 19:00	4/12/87 4:00	10.49	-	Summer	Mod
3.68	22/12/87 20:00	22/12/87 20:00	22/12/87 21:00	10.65	-	Summer	Mod

1988 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.08	1/2/88 0:00	31/1/88 21:00	1/2/88 4:00	8.66	-	Summer	Mod
5.39	9/2/88 19:00	9/2/88 4:00	10/2/88 9:00	12.53	-	Summer	Mod
3.84	12/3/88 2:00	12/3/88 1:00	12/3/88 2:00	9.15	-	Autumn	Mod
4.62	9/4/88 3:00	9/4/88 1:00	10/4/88 5:00	11.49	-	Autumn	Mod
6.14	30/4/88 18:00	29/4/88 1:00	1/5/88 18:00	11.43	-	Autumn	Ext
5.478	25/5/88 5:00	25/5/88 1:00	25/5/88 23:00	12.08	-	Autumn	Sev
4.69	6/7/88 11:00	6/7/88 11:00	6/7/88 11:00	10.14	-	Winter	Mod
5.03	8/8/88 13:00	8/8/88 8:00	10/8/88 12:00	11.99	-	Winter	Sev

3.71	24/8/88 6:00	24/8/88 6:00	24/8/88 8:00	9.27	-	Winter	Mod
4.24	13/9/88 6:00	13/9/88 4:00	13/9/88 12:00	9.43	-	Spring	Mod
3.54	16/9/88 10:00	16/9/88 10:00	16/9/88 10:00	10.20	-	Spring	Mod
3.73	5/11/88 23:00	5/11/88 22:00	5/11/88 23:00	10.20	-	Spring	Mod

1989 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.88	20/2/89 14:00	20/2/89 11:00	20/2/89 17:00	9.00	-	Summer	Mod
3.66	21/2/89 20:00	21/2/89 20:00	21/2/89 23:00	13.50	-	Summer	Mod
3.52	15/3/89 0:00	15/3/89 0:00	15/3/89 0:00	7.70	-	Autumn	Mod
3.72	27/4/89 12:00	27/4/89 10:00	27/4/89 12:00	11.83	-	Autumn	Mod
4.16	1/6/89 11:00	31/5/89 22:00	1/6/89 14:00	11.32	-	Winter	Mod
3.83	12/7/89 0:00	11/7/89 13:00	12/7/89 21:00	12.15	-	Winter	Mod
4.89	25/7/89 10:00	25/7/89 0:00	26/7/89 23:00	11.38	-	Winter	Mod
4.45	12/8/89 10:00	11/8/89 12:00	12/8/89 22:00	11.44	-	Winter	Mod
4.05	26/9/89 20:00	26/9/89 14:00	26/9/89 21:00	9.68	-	Spring	Mod

1990 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.33	11/2/90 10:00	11/2/90 1:00	12/2/90 6:00	9.33	-	Summer	Mod
4.80	7/3/90 11:00	6/3/90 23:00	7/3/90 22:00	10.62	-	Autumn	Mod
5.61	27/4/90	27/4/90	27/4/90	11.86	-	Autumn	Sev

	12:00	2:00	23:00				
3.61	18/5/90 8:00	18/5/90 8:00	18/5/90 9:00	8.85	-	Autumn	Mod
3.75	29/5/90 20:00	29/5/90 15:00	29/5/90 20:00	11.65	-	Autumn	Mod
6.11	1/8/90 23:00	1/8/90 8:00	2/8/90 5:00	9.85	-	Winter	Ext
6.65	26/8/90 18:00	26/8/90 1:00	27/8/90 23:00	12.98	-	Winter	Ext
5.16	14/9/90 23:00	14/9/90 17:00	15/9/90 8:00	9.96	-	Spring	Sev
6.47	13/10/90 2:00	12/10/90 12:00	14/10/90 4:00	12.68	-	Spring	Ext
4.29	22/10/90 16:00	22/10/90 14:00	23/10/90 0:00	10.14	-	Spring	Mod
4.57	24/10/90 9:00	24/10/90 2:00	24/10/90 21:00	11.02	-	Spring	Mod
4.00	18/11/90 18:00	18/11/90 17:00	18/11/90 23:00	10.87	-	Spring	Mod
4.05	11/12/90 15:00	11/12/90 13:00	11/12/90 19:00	11.29	-	Summer	Mod

1991 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
4.27	16/2/91 21:00	16/2/91 17:00	17/2/91 3:00	10.74	-	Summer	Mod
3.99	1/3/91 23:00	1/3/91 15:00	2/3/91 1:00	9.56	-	Autumn	Mod
3.86	23/3/91 14:00	23/3/91 14:00	23/3/91 22:00	11.83	-	Autumn	Mod
3.54	22/4/91 4:00	22/4/91 4:00	22/4/91 4:00	11.10	-	Autumn	Mod
3.70	23/4/91 1:00	23/4/91 1:00	23/4/91 2:00	12.20	-	Autumn	Mod
3.57	27/4/91 12:00	27/4/91 12:00	27/4/91 13:00	9.85	-	Autumn	Mod
4.08	10/6/91 1:00	9/6/91 15:00	10/6/91 23:00	9.66	-	Winter	Mod
3.99	12/6/91 5:00	12/6/91 3:00	12/6/91 6:00	8.68	-	Winter	Mod
4.64	11/7/91 18:00	11/7/91 3:00	12/7/91 2:00	11.84	-	Winter	Mod
4.21	15/7/91 13:00	15/7/91 5:00	15/7/91 20:00	10.21	-	Winter	Mod

4.50	23/7/91 17:00	23/7/91 1:00	24/7/91 6:00	15.45	-	Winter	Mod
3.90	12/9/91 16:00	12/9/91 13:00	12/9/91 22:00	9.28	-	Spring	Mod
3.53	27/10/91 19:00	27/10/91 19:00	27/10/91 19:00	11.1	-	Spring	Mod
3.85	12/12/91 3:00	11/12/91 22:00	12/12/91 6:00	8.83	-	Summer	Mod
3.79	13/12/91 18:00	13/12/91 17:00	13/12/91 19:00	8.70	-	Summer	Mod

1992 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.89	10/2/92 4:00	9/2/92 14:00	10/2/92 18:00	9.12	-	Summer	Mod
3.94	14/2/92 21:00	14/2/92 17:00	15/2/92 3:00	9.95	-	Summer	Mod
3.59	16/3/92 11:00	16/3/92 11:00	16/3/92 11:00	11.10	-	Autumn	Mod
3.53	19/3/92 19:00	19/3/92 19:00	20/3/92 0:00	13.28	-	Autumn	Mod
4.82	8/4/92 3:00	8/4/92 0:00	8/4/92 9:00	10.48	-	Autumn	Mod
3.73	23/5/92 2:00	22/5/92 22:00	23/5/92 2:00	10.16	-	Autumn	Mod
3.85	28/6/92 15:00	27/6/92 21:00	28/6/92 17:00	9.81	-	Winter	Mod
3.56	10/7/92 8:00	10/7/92 8:00	10/7/92 8:00	10.20	-	Winter	Mod
3.84	21/7/92 1:00	21/7/92 0:00	21/7/92 2:00	9.27	-	Winter	Mod
4.60	25/8/92 13:00	24/8/92 16:00	25/8/92 22:00	10.17	-	Winter	Mod
5.17	20/10/92 20:00	20/10/92 17:00	22/10/92* 23:00	11.33	-	Spring	Sev
4.26	13/11/92 6:00	12/11/92 9:00	13/11/92 13:00	10.39	-	Spring	Mod
3.60	30/11/92 20:00	30/11/92 20:00	30/11/92 21:00	9.15	-	Spring	Mod
3.70	1/12/92	1/12/92	2/12/92	11.54	-	Summer	Mod

	21:00	19:00	2:00				
*Gap in data from 22/10/92 until 25/10/92 19:00- Storm may go for longer than stated							

1993 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
4.51	30/3/93 19:00	30/3/93 16:00	31/3/93 6:00	11.77	-	Autumn	Mod
4.44	4/5/93 10:00	4/5/93 9:00	4/5/93 12:00	10.88	-	Autumn	Mod
4.28	13/6/93 23:00	13/6/93 13:00	13/6/93 23:00	14.52	-	Winter	Mod
3.92	4/9/93 0:00	3/9/93 20:00	4/9/93 3:00	10.93	-	Spring	Mod
4.12	5/10/93 0:00	4/10/93 22:00	5/10/93 2:00	10.28	-	Spring	Mod
3.77	23/11/93 9:00	23/11/93 6:00	23/11/93 9:00	11.10	-	Spring	Mod

1994 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
4.81	28/2/94 9:00	28/2/94 7:00	28/2/94 19:00	10.56	-	Summer	Mod
6.24	13/3/94 23:00	12/3/94 2:00	15/3/94 4:00	12.53	-	Autumn	Ext
5.13	13/4/94 19:00	13/4/94 9:00	14/4/94 22:00	10.12	-	Autumn	Sev
4.58	10/6/94 19:00	10/6/94 17:00	11/6/94 0:00	13.01	-	Winter	Mod
3.58	7/9/94 0:00	7/9/94 0:00	7/9/94 0:00	10.20	-	Winter	Mod
3.63	25/9/94 23:00	25/9/94 22:00	26/9/94 6:00	12.51	-	Spring	Mod
3.56	12/10/94 0:00	12/10/94 0:00	12/10/94 11:00	10.93	-	Spring	Mod
4.49	20/10/94 21:00	20/10/94 20:00	21/10/94 10:00	9.50	-	Spring	Mod
3.52	29/12/94	29/12/94	29/12/94	10.20	-	Summer	Mod

	8:00	8:00	8:00				

1995 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
4.01	20/1/95 22:00	20/1/95 17:00	20/1/95 23:00	9.50	-	Summer	Mod
4.66	21/1/95 13:00	21/1/95 10:00	21/1/95 23:00	10.11	-	Summer	Mod
3.94	24/1/95 3:00	23/1/95 19:00	24/1/95 5:00	13.85	-	Summer	Mod
3.69	31/1/95 10:00	31/1/95 10:00	31/1/95 11:00	9.15	-	Summer	Mod
3.72	17/2/95 11:00	17/2/95 11:00	17/2/95 15:00	8.46	-	Summer	Mod
5.33	4/3/95 20:00	1/3/95 14:00	5/3/95 17:00	10.62	-	Autumn	Sev
3.83	7/3/95 19:00	7/3/95 18:00	7/3/95 19:00	15.10	-	Autumn	Mod
3.68	31/3/95 18:00	31/3/95 18:00	31/3/95 19:00	9.50	-	Autumn	Mod
3.75	11/4/95 12:00	11/4/95 6:00	11/4/95 13:00	13.44	-	Autumn	Mod
3.68	5/5/95 10:00	5/5/95 10:00	5/5/95 11:00	9.85	-	Autumn	Mod
4.28	18/5/95 6:00	17/5/95 21:00	19/5/95 3:00	9.25	-	Autumn	Mod
4.38	16/6/95 14:00	16/6/95 10:00	16/6/95 20:00	9.85	-	Winter	Mod
4.64	18/6/95 17:00	17/6/95 17:00	19/6/95 23:00	10.94	-	Winter	Mod
4.82	21/6/95 12:00	21/6/95 9:00	22/6/95 6:00	10.22	-	Winter	Mod
4.23	5/9/95 23:00	5/9/95 21:00	5/9/95 23:00	9.13	-	Spring	Mod
6.65	25/9/95 19:00	25/9/95 6:00	27/9/95 4:00	11.14	-	Spring	Ext
4.19	24/10/95 4:00	24/10/95 1:00	24/10/95 8:00	10.11	-	Spring	Mod
4.11	21/12/95 20:00	21/12/95 15:00	22/12/95 2:00	11.87	-	Summer	Mod

1996 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest	Date	Date and	Date and	Average	Average	Season of	Storm

Significant Wave Height (m)	and time of Highest Hsig	time of first occurrence above 3.5m Hsig	time of last occurrence above 3.5m Hsig	Wave Period of occurrence above 3.5m Hsig	Wave direction of occurrence above 3.5m Hsig	Occurrence	Severity
3.52	12/2/96 22:00	12/2/96 22:00	12/2/96 22:00	10.20	-	Summer	Mod
4.14	13/5/96 17:00	13/5/96 14:00	13/5/96 19:00	9.74	-	Autumn	Mod
3.62	9/7/96 8:00	8/7/96 14:00	9/7/96 8:00	11.13	-	Winter	Mod
4.09	16/7/96 13:00	15/7/96 7:00	16/7/96 21:00	11.24	-	Winter	Mod
4.33	29/7/96 1:00	28/7/96 16:00	29/7/96 3:00	11.041	-	Winter	Mod
4.69	19/8/96 13:00	19/8/96 11:00	20/8/96 2:00	10.48	-	Winter	Mod
7.41	31/8/96 10:00	30/8/96 23:00	2/9/96 0:00	11.35	-	Winter	Ext
3.91	6/11/96 14:00	6/11/96 6:00	6/11/96 20:00	9.84	-	Spring	Mod
6.09	19/11/96 6:00	18/11/96 22:00	20/11/96 4:00	12.75	-	Spring	Ext

1997 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.06	8/1/96 12:00	8/1/96 12:00	8/1/96 15:00	11.10	-	Summer	Mod
4.26	7/4/97 8:00	7/4/97 7:00	7/4/97 13:00	10.34	-	Autumn	Mod
8.43	11/5/97 2:00	9/5/97 13:00	12/5/97 5:00	11.65	-	Autumn	Ext
5.16	26/6/97 20:00	26/6/97 15:00	27/6/97 12:00	10.64	-	Winter	Sev
3.72	30/6/97 5:00	30/6/97 4:00	30/6/97 11:00	12.55	-	Winter	Mod
3.60	22/7/97 20:00	22/7/97 20:00	22/7/97 20:00	11.10	-	Winter	Mod
3.73	25/9/97 1:00	25/9/97 1:00	25/9/97 2:00	9.50	-	Spring	Mod
3.64	4/10/97 0:00	4/10/97 0:00	4/10/97 1:00	10.30	-	Spring	Mod

4.05	7/10/97 18:00	7/10/97 16:00	7/10/97 23:00	9.31	-	Spring	Mod
4.26	10/12/97 0:00	9/12/97 23:00	10/12/97 7:00	9.73	-	Summer	Mod

1998 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.53	16/2/98 23:00	16/2/98 23:00	17/2/98 2:00	11.10	-	Summer	Mod
3.85	23/2/98 10:00	23/2/98 10:00	23/2/98 12:00	10.20	-	Summer	Mod
4.99	19/5/98 3:00	18/5/98 20:00	19/5/98 16:00	10.18	-	Autumn	Mod
4.22	8/6/98 21:00	8/6/98 13:00	9/6/98 13:00	11.11	-	Winter	Mod
3.71	17/6/98 6:00	17/6/98 6:00	17/6/98 6:00	9.50	-	Winter	Mod
3.57	26/6/98 14:00	26/6/98 14:00	26/6/98 14:00	12.20	-	Winter	Mod
3.61	10/7/98 22:00	10/7/98 21:00	10/7/98 22:00	12.85	-	Winter	Mod
3.71	15/7/98 9:00	15/7/98 5:00	15/7/98 13:00	9.34	-	Winter	Mod
3.70	6/8/98 23:00	6/8/98 23:00	6/8/98 23:00*	8.20	-	Winter	Mod
4.21	17/8/98 19:00	17/8/98 9:00	17/8/98 23:00	8.95	-	Winter	Mod
3.52	20/10/98 7:00	20/10/98 7:00	20/10/98 7:00	9.50	-	Spring	Mod
4.07	1/11/98 11:00	31/10/98 21:00	1/11/98 12:00	9.64	-	Spring	Mod
3.56	18/11/98 21:00	18/11/98 21:00	18/11/98 21:00	8.80	-	Spring	Mod

*Gap in data from 6/8/98 23:00 until 9/8/98 17:00- Storm may go for longer than stated

1999 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**

4.50	5/2/99 20:00	5/2/99 12:00	6/2/99 4:00	12.67	-	Summer	Mod
3.71	26/2/99 4:00	25/2/99 11:00	26/2/99 7:00	11.77	-	Summer	Mod
3.75	23/3/99 2:00	23/3/99 2:00	23/3/99 3:00	9.15	-	Autumn	Mod
4.47	7/4/99 1:00	6/4/99 23:00	7/4/99 3:00	10.82	-	Autumn	Mod
4.75	23/4/99 18:00	21/4/99 17:00	24/4/99 20:00*	11.74	-	Autumn	Mod
4.60	28/4/99 21:00	28/4/99 15:00	29/4/99 15:00	11.61	-	Autumn	Mod
4.05	25/5/99 4:00	25/5/99 1:00	25/5/99 14:00	14.87	-	Autumn	Mod
4.38	12/6/99 10:00	12/6/99 5:00	12/6/99 21:00	12.89	-	Winter	Mod
5.09	14/7/99 12:00	14/7/99 1:00	16/7/99 12:00	11.77	-	Winter	Sev
3.57	1/8/99 6:00	1/8/99 6:00	1/8/99 6:00	10.20	-	Winter	Mod
4.09	21/8/99 3:00	21/8/99 2:00	21/8/99 5:00	9.68	-	Winter	Mod
3.56	11/9/99 3:00	11/9/99 3:00	11/9/99 3:00	9.50	-	Spring	Mod
4.01	12/9/99 14:00	12/9/99 13:00	13/9/99 7:00	12.16	-	Spring	Mod
5.09	24/10/99 8:00	24/10/99 2:00	25/10/99 13:00	10.14	-	Spring	Sev
4.40	10/11/99 22:00	10/11/99 11:00	11/11/99 20:00	12.24	-	Spring	Mod
3.53	12/12/99 6:00	12/12/99 6:00	12/12/99 6:00	10.20	-	Summer	Mod
3.92	19/12/99 18:00	19/12/99 17:00	20/12/99 0:00	11.98	-	Summer	Mod

*Could potentially be two separate storms as a gap in data exists between 21/4/99 23:00 and 23/4/99 12:00

2000 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.29	6/1/00 0:00	5/1/00 20:00	6/1/00 5:00	12.26	-	Summer	Mod
3.52	28/1/00 22:00	28/1/00 22:00	28/1/00 22:00	9.50	-	Summer	Mod

5.78	6/4/00 2:00	5/4/00 21:00	6/4/00 12:00	10.79	-	Autumn	Sev
4.28	6/5/00 18:00	6/5/00 13:00	6/5/00 23:00	11.42	-	Autumn	Mod
4.34	31/5/00 6:00	31/5/00 3:00	31/5/00 12:00	13.40	-	Autumn	Mod
5.65	2/6/00 13:00	1/6/00 5:00	2/6/00 21:00	12.80	-	Winter	Sev
5.78	30/6/00 14:00	30/6/00 6:00	1/7/00 19:00	11.11	-	Winter	Sev
3.78	16/8/00 18:00	16/8/00 18:00	17/8/00 12:00	9.94	-	Winter	Mod
4.67	26/9/00 19:00	26/9/00 18:00	27/9/00 0:00	10.36	-	Spring	Mod
3.62	11/10/00 8:00	11/10/00 5:00	11/10/00 8:00	10.98	-	Spring	Mod

2001 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.14	16/1/01 1:00	15/1/01 23:00	16/1/01 2:00	10.88	-	Summer	Mod
4.13	28/3/01 11:00	28/3/01 9:00	28/3/01 12:00	10.88	-	Autumn	Mod
3.99	12/4/01 15:00	11/4/01 22:00	12/4/01 19:00	10.15	-	Autumn	Mod
4.12	7/5/01 18:00	7/5/01 6:00	8/5/01 10:00	9.65	-	Autumn	Mod
3.58	18/5/01 16:00	18/5/01 14:00	18/5/01 16:00	7.87	-	Autumn	Mod
3.68	29/5/01 13:00	29/5/01 7:00	29/5/01 13:00	8.81	-	Autumn	Mod
4.53	16/6/01 5:00	15/6/01 19:00	16/6/01 14:00	12.48	-	Winter	Mod
6.30	28/7/01 19:00	27/7/01 19:00	29/7/01 21:00	11.62	-	Winter	Ext
3.53	1/8/01 23:00	1/8/01 23:00	1/8/01 23:00	10.20	-	Winter	Mod
3.90	29/8/01 22:00	29/8/01 20:00	30/8/01 13:00	10.14	-	Winter	Mod
4.85	8/10/01 19:00	8/10/01 8:00	9/10/01 3:00	11.78	-	Spring	Mod
4.92	19/11/01 16:00	18/11/01 19:00	22/11/01 10:00	10.27	-	Spring	Mod

4.19	4/12/01 22:00	4/12/01 22:00	5/12/01 6:00	11.00	-	Summer	Mod

2002 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.05	30/3/02 6:00	30/3/02 4:00	30/3/02 14:00	10.45	-	Autumn	Mod
3.76	22/4/02 1:00	21/4/02 21:00	22/4/02 2:00	10.63	-	Autumn	Mod
3.65	29/5/02 11:00	28/5/02 23:00	29/5/02 15:00	15.05	-	Autumn	Mod
4.23	18/6/02 21:00	18/6/02 0:00	19/6/02 9:00	12.28	-	Winter	Mod
5.16	29/6/02 9:00	29/6/02 2:00	29/6/02 21:00	12.74	-	Winter	Sev
4.57	15/8/02 23:00	14/8/02 20:00	16/8/02 15:00	12.16	-	Winter	Mod
3.61	23/8/02 12:00	23/8/02 12:00	24/8/02 0:00	10.14	-	Winter	Mod

2003 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.67	8/1/03 21:00	8/1/03 21:00	8/1/03 22:00	10.65	-	Summer	Mod
3.54	10/4/03 0:00	10/4/03 0:00	10/4/03 0:00	12.20	-	Autumn	Mod
3.78	16/4/03 3:00	16/4/03 3:00	16/4/03 4:00	11.10	-	Autumn	Mod
4.23	18/4/03 23:00	18/4/03 8:00	19/4/03 9:00	11.60	-	Autumn	Mod
3.61	4/5/03 22:00	4/5/03 22:00*	4/5/03 22:00	10.20	-	Autumn	Mod
3.80	17/5/03 11:00	17/5/03 9:00	17/5/03 16:00	11.93	-	Autumn	Mod
4.55	27/6/03 15:00	27/6/03 11:00	27/6/03 23:00	13.77	-	Winter	Mod
3.85	31/7/03	31/7/03	31/7/03	13.50	-	Winter	Mod

	8:00	8:00	8:00				
4.18	10/8/03 12:00	10/8/03 4:00	10/8/03 14:00	11.24	-	Winter	Mod
4.00	14/8/03 19:00	14/8/03 18:00	15/8/03 4:00	11.42	-	Winter	Mod
5.44	4/9/03 2:00	3/9/03 20:00	4/9/03 17:00	13.39	-	Spring	Sev
4.31	3/10/03 5:00	3/10/03 4:00	3/10/03 10:00	10.46	-	Spring	Mod
3.67	12/10/03 20:00	12/10/03 14:00	13/10/03 6:00	11.33	-	Spring	Mod
4.16	27/10/03 10:00	27/10/03 7:00	27/10/03 14:00	12.20	-	Spring	Mod
3.88	2/11/03 20:00	2/11/03 17:00	2/11/03 22:00	10.50	-	Spring	Mod
*Gap in data from 21/4/03 15:00 until 4/5/03 21:00- Storm may go for longer than stated							

2004 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
5.10	27/2/04 7:00	25/2/04 19:00	27/2/04 20:00	11.59	-	Summer	Sev
3.74	1/3/04 1:00	29/2/04 22:00	1/3/04 2:00	11.32	-	Autumn	Mod
4.25	12/5/04 8:00	12/5/04 5:00	13/5/04 0:00	11.90	-	Autumn	Mod
3.55	10/7/04 5:00	10/7/04 5:00	10/7/04 5:00	12.20	-	Winter	Mod
5.84	18/7/04 9:00	18/7/04 1:00	19/7/04 19:00	11.15	-	Winter	Sev
4.64	15/8/04 15:00	15/8/04 6:00	16/8/04 12:00	10.67	-	Winter	Mod
4.42	2/10/04 4:00	1/10/04 22:00	2/10/04 15:00	10.66	-	Spring	Mod
4.42	21/10/04 7:00	21/10/04 4:00	21/10/04 18:00	11.77	-	Spring	Mod
6.20	28/10/04 13:00	28/10/04 9:00	29/10/04 6:00	14.20	-	Spring	Ext
3.93	15/12/04 2:00	15/12/04 1:00	15/12/04 4:00	10.25	-	Summer	Mod
3.64	20/12/04 11:00	20/12/04 11:00	20/12/04 11:00	10.20	-	Summer	Mod
3.51	27/12/04 21:00	27/12/04 21:00	27/12/04 21:00	9.50	-	Summer	Mod

4.47	29/12/04 2:00	28/12/04 21:00	29/12/04* 8:00	12.23	-	Summer	Mod
*Gap in data from 29/12/04 10:00 until 12/1/05 11:00- Storm may go for longer than stated							

2005 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
6.10	23/3/05 3:00	22/3/05 16:00	24/3/05 4:00	11.04	-	Autumn	Ext
4.02	26/3/05 0:00	25/3/05 22:00	26/3/05 0:00	11.17	-	Autumn	Mod
3.83	4/4/05 6:00	4/4/05 6:00	4/4/05 7:00	9.50	-	Autumn	Mod
3.77	17/5/05 16:00	17/5/05 13:00	19/5/05 1:00	11.71	-	Autumn	Mod
3.68	29/5/05 22:00	29/5/05 9:00	30/5/05 6:00	14.01	-	Autumn	Mod
3.59	31/5/05 19:00	31/5/05 19:00	31/5/05 19:00	12.20	-	Autumn	Mod
4.51	24/6/05 16:00	24/6/05 3:00	25/6/05 4:00	10.88	-	Winter	Mod
4.43	30/6/05 19:00	30/6/05 15:00	1/7/05 2:00	9.89	-	Winter	Mod
6.11	10/7/05 15:00	10/7/05 8:00	11/7/05 18:00	12.19	-	Winter	Ext
4.25	28/11/05 15:00	27/11/05 17:00	28/11/05 19:00	9.99	-	Spring	Mod

2006 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.70	7/2/06 5:00	7/2/06 2:00	7/2/06 11:00	10.78	-	Summer	Mod
5.23	9/4/06 9:00	8/4/06 5:00	10/4/06 4:00	15.04	-	Autumn	Sev
3.91	16/4/06 17:00	16/4/06 10:00	16/4/06 22:00	14.13	-	Autumn	Mod
4.37	3/6/06 13:00	2/6/06 22:00	4/6/06 7:00	11.45	-	Winter	Mod

5.13	11/6/06 17:00	11/6/06 10:00	12/6/06 5:00	12.19	-	Winter	Sev
3.63	8/7/06 18:00	8/7/06 16:00	8/7/06 20:00	16.42	-	Winter	Mod
4.60	14/7/06 4:00	13/7/06 11:00	14/7/06 14:00	13.54	-	Winter	Mod
4.49	18/7/06 21:00	18/7/06 5:00	19/7/06 14:00	10.61	-	Winter	Mod
4.64	7/9/06 17:00	7/9/06 4:00	8/9/06 5:00	9.89	-	Spring	Mod
4.14	10/9/06 1:00	9/9/06 18:00	10/9/06 20:00	9.99	-	Spring	Mod
3.99	8/10/06 20:00	8/10/06 17:00	8/10/06 22:00	11.09	-	Spring	Mod
4.04	21/10/06 2:00	21/10/06 1:00	21/10/06 5:00	9.88	-	Spring	Mod
3.87	28/10/06 18:00	28/10/06 11:00	29/10/06 3:00	10.53	-	Spring	Mod
3.76	5/11/06 15:00	5/11/06 10:00	5/11/06 16:00	8.62	-	Spring	Mod
3.61	16/11/06 13:00	16/11/06 13:00	16/11/06 17:00	9.02	-	Spring	Mod
4.35	29/11/06 15:00	29/11/06 14:00	29/11/06 19:00	10.05	-	Spring	Mod

2007 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.86	25/3/07 0:00	24/3/07 22:00	25/3/07 5:00	9.15	-	Autumn	Mod
6.13	9/6/07 14:00	8/6/07 1:00	10/6/07 19:00	10.48	-	Winter	Ext
5.01	16/6/07 9:00	16/6/07 6:00	17/6/07 2:00	9.58	-	Winter	Sev
6.15	20/6/07 7:00	20/6/07 2:00	20/6/07 20:00	11.54	-	Winter	Ext
4.94	29/6/07 0:00	28/6/07 17:00	29/6/07 6:00	12.12	-	Winter	Mod
4.03	6/7/07 11:00	6/7/07 9:00	6/7/07 14:00	12.70	-	Winter	Mod
4.69	9/7/07 19:00	9/7/07 9:00	10/7/07 7:00	10.75	-	Winter	Mod
3.64	17/10/07 3:00	17/10/07 3:00	17/10/07 4:00	11.16	-	Spring	Mod

4.76	5/11/07 12:00	5/11/07 2:00	6/11/07 1:00	11.15	-	Spring	Mod
*Gap in data from 28/12/06 22:00 until 30/1/07 10:00							

2008 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.76	5/1/08 9:00	5/1/08 5:00	5/1/08 10:00	12.23	-	Summer	Mod
4.05	8/2/08 0:00	7/2/08 21:00	8/2/08 5:00	10.58	-	Summer	Mod
4.19	28/2/08 23:00	28/2/08 22:00	29/2/08 2:00	9.52	-	Summer	Mod
4.19	1/3/08 2:00	29/2/08 23:00	1/3/08 5:00	10.92	-	Autumn	Mod
5.91	22/7/08 18:00	22/7/08 7:00	24/7/08 2:00	14.10	-	Winter	Sev
4.32	29/7/08 2:00	28/7/08 17:00	29/7/08 13:00	10.45	-	Winter	Mod
3.72	8/8/08 9:00	8/8/08 9:00	8/8/08 11:00	9.54	-	Winter	Mod
4.53	17/8/08 13:00	16/8/08 21:00	17/8/08 21:00	12.51	-	Winter	Mod
5.09	23/8/08 5:00	23/8/08 2:00	23/8/08 17:00	10.28	-	Winter	Sev
4.67	6/9/08 20:00	6/9/08 4:00	7/9/08 3:00	11.29	-	Spring	Mod
4.04	8/9/08 23:00	8/9/08 22:00	9/9/08 4:00	10.07	-	Spring	Mod
3.83	10/9/08 16:00	10/9/08 9:00	10/9/08 19:00	13.29	-	Spring	Mod
5.62	15/12/08 9:00	14/12/08 23:00	15/12/08 20:00	12.45	-	Summer	Sev
3.52	19/12/08 20:00	19/12/08 20:00	19/12/08 20:00	10.27	-	Summer	Mod

2009 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**

3.56	11/2/09 3:00	11/2/09 1:00	11/2/09 3:00	9.50	-	Summer	Mod
3.57	18/2/09 7:00	18/2/09 7:00	18/2/09 7:00	9.50	-	Summer	Mod
3.97	31/3/09 15:00	31/3/09 10:00	2/4/09 1:00	11.62	-	Autumn	Mod
3.85	19/4/09 18:00	19/4/09 18:00	19/4/09 23:00	12.05	-	Autumn	Mod
4.33	22/5/09 21:00	22/5/09 3:00	23/5/09 15:00	11.13	-	Autumn	Mod
5.30	8/10/09 18:00	7/10/09 23:00	9/10/09 4:00	12.34	-	Spring	Sev
4.00	17/11/09 9:00	17/11/09 9:00	17/11/09 16:00	12.65	-	Spring	Mod
4.04	30/11/09 20:00	30/11/09 17:00	1/12/09 17:00	11.57	-	Spring	Mod

2010 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.93	16/2/10 0:00	16/2/10 0:00	17/2/10 0:00	10.72	-	Summer	Mod
3.75	1/3/10 3:00	1/3/10 3:00	1/3/10 3:00	10.27	-	Autumn	Mod
4.61	15/5/10 0:00	14/5/10 10:00	15/5/10 21:00	12.37	-	Autumn	Mod
4.19	26/5/10 15:00	26/5/10 11:00	27/5/10 0:00	9.75	-	Autumn	Mod
5.32	31/5/10 11:00	30/5/10 14:00	31/5/10 20:00	11.98	-	Autumn	Sev
3.51	4/6/10 20:00	4/6/10 20:00	4/6/10 20:00	10.27	-	Winter	Mod
3.89	7/6/10 0:00	6/6/10 14:00	7/6/10 5:00	9.85	-	Winter	Mod
6.37	3/8/10 2:00	2/8/10 21:00	3/8/10 16:00	11.63	-	Winter	Ext
6.20	13/8/10 10:00	12/8/10 21:00	14/8/10 1:00	12.20	-	Winter	Ext
3.63	4/9/10 20:00	4/9/10 20:00	4/9/10 20:00	10.27	-	Spring	Mod
3.89	17/9/10 22:00	17/9/10 13:00	19/9/10 5:00	13.99	-	Spring	Mod

3.63	21/9/10 22:00	21/9/10 22:00	21/9/10 23:00	11.70	-	Spring	Mod
3.93	16/10/10 20:00	16/10/10 20:00	16/10/10 22:00	11.52	-	Spring	Mod
3.82	2/11/10 8:00	2/11/10 4:00	2/11/10 18:00	9.53	-	Spring	Mod
*Gap in data from 7/6/10 16:00 until 13/7/10 10:00							

2011 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.75	6/2/11 18:00	6/2/11 18:00	6/2/11 18:00	11.16	-	Summer	Mod
3.79	22/2/11 1:00	22/2/11 0:00	22/2/11 4:00	10.29	-	Summer	Mod
3.68	2/3/11 5:00	2/3/11 5:00	2/3/11 6:00	12.23	-	Autumn	Mod
3.56	26/3/11 12:00	26/3/11 12:00	26/3/11 12:00	12.23	-	Autumn	Mod
3.55	4/4/11 18:00	4/4/11 18:00	4/4/11 18:00	13.52	-	Autumn	Mod
4.31	1/6/11 16:00	31/5/11 9:00	2/6/11 11:00	11.04	-	Autumn	Mod
3.51	14/6/11 23:00	14/6/11 23:00	14/6/11 23:00	9.50	-	Winter	Mod
6.13	20/7/11 4:00	19/7/11 23:00	23/7/11 10:00	11.90	-	Winter	Ext
3.71	19/8/11 20:00	19/8/11 19:00	19/8/11 20:00	10.27	-	Winter	Mod
3.60	1/12/11 3:00	1/12/11 3:00	1/12/11 5:00	9.28	-	Summer	Mod
4.12	4/12/11 21:00	4/12/11 17:00	4/12/11 23:00	9.83	-	Summer	Mod
4.02	14/12/11 11:00	14/12/11 0:00	14/12/11 17:00	10.18	-	Summer	Mod
*Gap in data from 31/8/11 0:00 until 12/10/11 10:00							

2012 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)							
Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above**	**Season of Occurrence**	**Storm Severity**

					3.5m Hsig		
3.59	12/1/12 1:00	12/1/12 1:00	12/1/12 1:00	10.27	-	Summer	Mod
3.62	2/3/12 7:00	2/3/12 7:00	2/3/12 8:00	9.89	-	Autumn	Mod
5.26	8/3/12 7:00	7/3/12 23:00	8/3/12 21:00	11.56	-	Autumn	Sev
3.60	4/7/12 7:00	4/7/12 4:00	4/7/12 7:00	11.45	162.50 (SSE)	Winter	Mod
4.44	30/7/12 18:00	30/7/12 14:00	31/7/12 3:00	10.65	174.62 (S)	Winter	Mod
3.95	1/8/12 4:00	1/8/12 2:00	1/8/12 17:00	14.55	140.87 (SE)	Winter	Mod
5.73	11/8/12 21:00	11/8/12 00:00	12/8/12 19:00	11.45	159.38 (SSE)	Winter	Sev
4.35	7/10/12 14:00	7/10/12 10:00	8/10/12 1:00	12.71	163.31 (SSE)	Spring	Mod
4.13	12/10/12 7:00	12/10/12 7:00	12/10/12 7:00*	11.45	172.00 (S)	Spring	Mod
3.71	22/10/12 12:00	22/10/12 12:00	22/10/12 22:00	10.31	177.83 (S)	Spring	Mod
3.66	28/10/12 3:00	28/10/12 3:00	28/10/12 3:00	11.45	165.00 (SSE)	Spring	Mod
*Gap in data from 14/5/12 23:00 until 20/6/12 10:00, Gap in data from 12/10/12 7:00 until 12/10/12 22:00- Storm may go longer than stated							

2013 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
4.26	29/1/13 4:00	28/1/13 17:00	29/1/13 20:00	11.53	93.30 (E)	Summer	Mod
5.58	19/4/13 15:00	19/4/13 11:00	20/4/13 15:00	12.14	-	Autumn	Sev
5.21	2/6/13 17:00	2/6/13 11:00	3/6/13 10:00	10.72	-	Winter	Sev
4.26	16/6/13 7:00	15/6/13 6:00	17/6/13 11:00	11.86	-	Winter	Mod
4.26	19/6/13 14:00	18/6/13 21:00	19/6/13 23:00	11.34	-	Winter	Mod
4.84	25/6/13 22:00	24/6/13 21:00	26/6/13 19:00	10.56	-	Winter	Mod
4.32	24/7/13 8:00	24/7/13 2:00	24/7/13 14:00	11.60	-	Winter	Mod
5.03	17/9/13	16/9/13	17/9/13	9.267	73.08	Spring	Sev

	1:00	22:00	9:00		(E)		
4.01	14/10/13 5:00	14/10/13 4:00	14/10/13 6:00	10.68	171.67 (S)	Spring	Mod
4.12	29/10/13 16:00	29/10/13 14:00	29/10/13 20:00	9.33	177.14 (S)	Spring	Mod
3.95	3/11/13 23:00	3/11/13 21:00	4/11/13 19:00	10.61	169.52 (S)	Spring	Mod
4.64	11/11/13 20:00	11/11/13 11:00	12/11/13 4:00	9.87	128.94 (SE)	Spring	Mod
3.55	25/11/13 17:00	25/11/13 17:00	25/11/13 17:00	8.17	170.00 (S)	Spring	Mod

2014 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.78	25/1/14 14:00	25/1/14 11:00	25/1/14 14:00	11.01	173.75 (S)	Summer	MOd
4.12	15/6/14 21:00	15/6/14 21:00*	16/6/14 2:00	12.67	166.80 (SSE)	Winter	Mod
4.29	12/12/14 5:00	11/12/14 16:00	12/12/14 15:00	9.95	141.79 (SE)	Summer	Mod

*Gap in data from 9/4/14 8:00 until 4/6/14 13:00, Gap from 15/6/14 14:00- 15/6/14 21:00- Storm could have started earlier

2015 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
5.07	30/1/15 11:00	29/1/15 22:00	31/1/15 2:00	12.34	153.31 (SSE)	Summer	Sev
4.42	6/3/15 0:00	6/3/15 0:00*	6/3/15 2:00	12.93	179.50 (S)	Autumn	Mod
3.74	7/3/15 16:00	7/3/15 7:00	7/3/15 16:00*	12.76	175.50 (S)	Autumn	Mod
3.75	10/4/15 5:00	10/4/15 5:00*	10/4/15 5:00	12.14	156.00 (SSE)	Autumn	Mod
4.04	17/7/15 14:00	17/7/15 9:00	18/7/15 13:00	10.22	168.52 (SSE)	Winter	Mod
4.44	25/8/15 5:00	25/8/15 0:00	25/8/15 8:00*	8.84	152.00 (SSE)	Winter	Mod

4.08	25/8/15 23:00	25/8/15 19:00	26/8/15 8:00	10.68	140.07 (SE)	Winter	Mod
3.72	28/8/15 17:00	28/8/15 17:00	28/8/15 17:00	11.45	172.00 (S)	Winter	Mod
4.51	30/8/15 11:00	30/8/15 9:00	1/9/15 3:00	12.47	168.23 (SSE)	Winter	Mod
3.54	10/9/15 3:00	10/9/15 3:00	10/9/15 3:00	10.83	148.00 (SSE)	Spring	Mod
4.68	22/9/15 21:00	22/9/15 19:00	24/9/15 23:00	10.79	166.71 (SSE)	Spring	Mod
3.79	7/10/15 11:00	7/10/15 11:00	7/10/15 12:00	9.34	179.50 (S)	Spring	Mod
4.04	22/10/15 20:00	22/10/15 17:00	22/10/15 21:00	9.33	181.60 (S)	Spring	Mod
3.58	12/12/15 7:00	12/12/15 7:00	12/12/15 7:00	11.14	172.50 (S)	Summer	Mod

*Gap from 5/3/15 0:00- 6/3/15 0:00- Storm could have started earlier, Gap from 7/3/15 16:00- 8/3/15 0:00- Storm could have finished later, Gap from 8/4/15 3:00- 10/4/15 5:00- Storm could have started earlier, Gap from 25/8/15 8:00- 25/8/15 12:00- Storm could have finished later

2016 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
3.57	7/1/16 14:00	7/1/16 13:00	7/1/16 18:00	10.21	151.67 (SSE)	Summer	Mod
4.18	14/1/16 21:00	14/1/16 20:00	14/1/16 23:00	9.71	184.25 (S)	Summer	Mod
3.87	4/2/16 18:00	4/2/16 16:00	4/2/16 22:00	9.08	174.43 (S)	Summer	Mod
4.43	20/3/16 4:00	19/3/16 18:00	20/3/16 20:00	13.94	165.31 (SSE)	Autumn	Mod
3.84	23/4/16 6:00	23/4/16 4:00	23/4/16 11:00	9.03	175.63 (S)	Autumn	Mod
5.13	25/5/16 10:00	25/5/16 6:00	25/5/16 21:00	13.91	157.38 (SSE)	Autumn	Sev
5.54	5/6/16 22:00	5/6/16 17:00*	6/6/16 17:00	14.14	91.75 (E)	Winter	Sev
4.18	12/6/16 1:00	12/6/16 1:00	12/6/16 2:00	10.83	161.50 (SSE)	Winter	Mod
3.52	25/6/16 13:00	25/6/16 13:00	25/6/16 13:00	10.83	156.00 (SSE)	Winter	Mod
4.25	7/7/16 4:00	6/7/16 23:00	7/7/16 21:00	10.76	163.73 (SSE)	Winter	Mod
4.43	4/8/16	2/8/16	4/8/16	10.23	167.86	Winter	Mod

	3:00	18:00	13:00		(SSE)		
4.74	24/10/16 20:00	24/10/16 11:00	25/10/16 9:00	13.39	144.70 (SE)	Spring	Mod
4.12	15/11/16 0:00	14/11/16 19:00	15/11/16 2:00	10.80	175.00 (S)	Spring	Mod
*Gap from 4/6/16 9:00- 5/6/16 17:00- Storm could have started earlier							

2017 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.51	18/1/17 22:00	18/1/17 22:00	18/1/17 22:00	10.27	183.00 (S)	Summer	Mod
4.66	6/3/17 12:00	5/3/17 15:00	7/3/17 22:00	10.10	158.73 (SSE)	Autumn	Mod
5.48	11/4/17 11:00	11/4/17 5:00	12/4/17 2:00	12.14	177.10 (S)	Autumn	Sev
4.46	27/4/17 16:00	27/4/17 2:00	28/4/17 2:00	11.35	165.32 (SSE)	Autumn	Mod
3.75	7/6/17 3:00	7/6/17 1:00	7/6/17 4:00	9.23	181.00 (S)	Winter	Mod
3.87	1/7/17 4:00	30/6/17 22:00	1/7/17 6:00	11.85	171.78 (S)	Winter	Mod
5.52	20/8/17 3:00	19/8/17 16:00	20/8/17 16:00	12.86	151.17 (SSE)	Winter	Sev
4.29	28/8/17 8:00	28/8/17 6:00	28/8/17 14:00	12.10	171.00 (S)	Winter	Mod
4.10	30/8/17 23:00	30/8/17 23:00	1/9/17 1:00	10.81	164.96 (SSE)	Winter	Mod
4.40	10/9/17 9:00	9/9/17 22:00	10/9/17 21:00	13.54	158.46 (SSE)	Spring	Mod
3.66	2/11/17 0:00	2/11/17 0:00	2/11/17 0:00	10.83	147.00 (SSE)	Spring	Mod
3.52	6/12/17 3:00	6/12/17 3:00	6/12/17 3:00	10.83	142.00 (SE)	Summer	Mod

2018 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.31	14/1/18	14/1/18	14/1/18	9.45	182.00	Summer	Mod

	14:00	11:00	17:00		(S)		
4.66	16/1/18 7:00	15/1/18 21:00	17/1/18 4:00	11.5	154.50 (SSE)	Summer	Mod
4.16	31/1/18 23:00	31/1/18 19:00	1/2/18 1:00	10.70	174.57 (S)	Summer	Mod
3.64	20/2/18 5:00	20/2/18 5:00	20/2/18 5:00	9.32	158.00 (SSE)	Summer	Mod
3.58	26/2/18 8:00	26/2/18 8:00	26/2/18 8:00	8.90	140.00 (SE)	Summer	Mod
4.74	1/6/18 5:00	31/5/18 19:00	3/6/18 9:00	10.91	163.35 (SSE)	Winter	Mod
3.76	19/6/18 12:00	19/6/18 12:00	19/6/18 12:00	11.57	169.00 (S)	Winter	Mod
4.83	29/8/18 18:00	29/8/18 11:00	30/8/18 6:00	14.06	145.80 (SE)	Winter	Mod

2019 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.76	1/6/19 10:00	1/6/19 10:00	1/6/19 10:00	11.45	152.00 (SSE)	Winter	Mod
7.05	4/6/19 12:00	4/6/19 12:00*	5/6/19 8:00	11.66	159.86 (SSE)	Winter	Ext
3. 62	6/6/19 23:00	6/6/19 19:00	6/6/19 23:00	11.22	163.00 (SSE)	Winter	Mod
5.14	22/8/19 13:00	22/8/19 12:00	23/8/19 5:00	12.00	173.67 (S)	Winter	Sev
3.63	29/8/19 11:00	30/8/19 0:00	30/8/19 1:00	8.06	172.62 (S)	Winter	Mod
4.34	9/9/19 19:00	9/9/19 17:00	9/9/19 19:00	9.84	173.00 (S)	Spring	Mod
3.67	17/9/19 21:00	17/9/19 19:00	17/9/19 22:00	9.90	130.25 (SE)	Spring	Mod

*Gap from 4/6/19 5:00- 4/6/19 12:00- Storm could have started earlier

2020 High significant Wave Height Events at Port Kembla (Resolution: 6hrs)

Highest Significant Wave Height (m)	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.28	3/2/20	3/2/20	4/2/20	11.16	169.88	Summer	Mod

	23:00	21:00	4:00		(S)		
6.24	9/2/20 15:00	9/2/20 2:00	10/2/20 7:00	10.79	108.35 (ESE)	Summer	Ext
3.75	14/3/20 9:00	14/3/20 9:00	14/3/20 9:00	9.95	178.67 (S)	Autumn	Mod
5.908	23/5/20 2:00	22/5/20 2:00	26/5/20 12:00	12.04	162.38 (SSE)	Autumn	Sev
5.021	4/6/20 3:00	3/6/20 19:00	4/6/20 13:00	12.57	160.58 (SSE)	Winter	Sev
Missing Data 19/6/2020 1:00 until 1/8/2020 0:00							

Appendix 3: Batemans Bay storm data

1986 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.16	25/7/86 22:00	25/7/86 21:00	26/7/86 0:00	12.85	-	Winter	Mod
5.59	6/8/86 7:00	5/8/86 20:00	9/8/86 5:00	11.63	-	Winter	Sev
5.98	19/11/86 4:00	18/11/86 20:00	21/11/86 22:00	11.77	-	Spring	Sev
4.18	29/11/86 17:00	29/11/86 15:00	29/11/86 22:00	12.00	-	Spring	Mod
Missing Data 1/1/1986 0:00 until 27/5/1986 16:00							

1987 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.96	18/5/87 10:00	18/5/87 6:00	19/5/87 1:00	11.45	-	Autumn	Mod
3.61	19/8/87 18:00	19/8/87 17:00	19/8/87 18:00	8.05	-	Winter	Mod
4.72	2/9/87 6:00	2/9/87 2:00	2/9/87 12:00	13.05	-	Spring	Mod
3.68	24/11/87 20:00	24/11/87 20:00	24/11/87 20:00	9.50	-	Spring	Mod
3.77	3/12/87 2:00	2/12/87 20:00	3/12/87 2:00	12.23	-	Summer	Mod

1988 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.45	9/2/88 12:00	9/2/88 5:00	10/2/88 0:00	11.66	-	Summer	Mod

3.65	7/3/88 14:00	7/3/88 10:00	7/3/88 14:00	16.30	-	Autumn	Mod
4.52	9/4/88 1:00	8/4/88 21:00	10/4/88 3:00	11.44	-	Autumn	Mod
4.42	29/4/88 9:00	29/4/88 0:00	1/5/88 18:00	11.53	-	Autumn	Mod
4.49	25/5/88 2:00	24/5/88 22:00	25/5/88 15:00	11.55	-	Autumn	Mod
4.80	6/7/88 18:00	6/7/88 6:00	6/7/88 22:00	10.14	-	Winter	Mod
4.23	8/8/88 16:00	8/8/88 11:00	9/8/88 18:00	11.08	-	Winter	Mod

1989 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.25	1/6/89 1:00	31/5/89 20:00	1/6/89 12:00	11.12	-	Winter	Mod
3.79	23/6/89 22:00	23/6/89 18:00	24/6/89 3:00	13.37	-	Winter	Mod
4.80	11/7/89 9:00	11/7/89 7:00	13/7/89 11:00	12.29	-	Winter	Mod
4.88	25/7/89 3:00	24/7/89 11:00	26/7/89 2:00	10.63	-	Winter	Mod
3.71	12/8/89 11:00	12/8/89 9:00	12/8/89 12:00	11.98	-	Winter	Mod
3.81	28/10/89 21:00	28/10/89 21:00	28/10/89 23:00	12.20	-	Spring	Mod

1990 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.68	5/2/990 19:00	5/2/990 19:00	5/2/990 19:00	12.20	-	Summer	Mod
4.20	15/5/90 13:00	15/5/90 6:00	15/5/90 23:00	14.98	-	Autumn	Mod
3.63	24/5/90 8:00	24/5/90 6:00	24/5/90 9:00	8.10	-	Autumn	Mod
5.07	2/8/90	1/8/90	3/8/90	10.08	-	Winter	Sev

	12:00	11:00	18:00				
4.39	26/8/90 18:00	26/8/90 13:00	27/8/90 5:00	12.90	-	Winter	Mod
4.22	14/9/90 5:00	14/9/90 0:00	14/9/90 17:00	9.14	-	Spring	Mod
6.01	13/10/90 1:00	12/10/90 10:00	14/10/90 2:00	12.62	-	Spring	Ext
3.77	18/11/90 18:00	18/11/90 16:00	19/11/90 0:00	9.63	-	Spring	Mod
4.08	11/12/90 18:00	11/12/90 11:00	12/12/90 3:00	11.50	-	Summer	Mod

1991 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
5.10	18/2/91 18:00	16/2/91 16:00	19/2/91 23:00	12.78	-	Summer	Sev
3.82	1/3/91 19:00	1/3/91 10:00	1/3/91 20:00	9.63	-	Autumn	Mod
3.58	11/3/91 22:00	11/3/91 22:00	11/3/91 22:00	7.30	-	Autumn	Mod
4.13	23/3/91 14:00	23/3/91 10:00	24/3/91 23:00	11.55	-	Autumn	Mod
4.58	27/4/91 5:00	27/4/91 0:00	27/4/91 14:00	9.77	-	Autumn	Mod
3.82	8/6/91 19:00	8/6/91 18:00	10/6/91 16:00	9.75	-	Winter	Mod
3.90	12/6/91 11:00	12/6/91 10:00	12/6/91 13:00	9.33	-	Winter	Mod
4.60	11/7/91 12:00	11/7/91 2:00	12/7/91 3:00	11.93	-	Winter	Mod
4.16	17/7/91 16:00	17/7/91 1:00	18/7/91 0:00	12.02	-	Winter	Mod
4.13	23/7/91 17:00	23/7/91 17:00	23/7/91 20:00	15.60	-	Winter	Mod
3.55	27/10/91 21:00	27/10/91 21:00	27/10/91 21:00	11.10	-	Spring	Mod
3.54	14/12/91 1:00	14/12/91 1:00	14/12/91 1:00	8.20	-	Summer	Mod

1992 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave	**Date and time of**	**Date and time of first**	**Date and time of last occurrence**	**Average Wave Period of**	**Average Wave direction**	**Season of Occurrence**	**Storm Severity**

Height	Highest Hsig	occurrence above 3.5m Hsig	above 3.5m Hsig	occurrence above 3.5m Hsig	of occurrence above 3.5m Hsig		
3.83	28/1/92 15:00	28/1/92 15:00	28/1/92 15:00	9.50	-	Summer	Mod
4.51	10/2/92 12:00	10/2/92 10:00	11/2/92 1:00	10.55	-	Summer	Mod
3.69	28/6/92 6:00	27/6/92 22:00	28/6/92 6:00	9.24	-	Winter	Mod
3.90	24/8/92 15:00	24/8/92 14:00	24/8/92 17:00	8.68	-	Winter	Mod
4.70	25/9/92 19:00	25/9/92 18:00	26/9/92 10:00	10.39	-	Spring	Mod
4.51	21/10/92 14:00	21/10/92 3:00	22/10/92 6:00	10.65	-	Spring	Mod
3.86	13/11/92 21:00	13/11/92 19:00	14/11/92 1:00	11.94	-	Spring	Mod
4.10	5/12/92 11:00	5/12/92 10:00	5/12/92 18:00*	9.04	-	Summer	Mod

*Gap in data from 5/12/92 18:00 until 16/12/92 12:00- Storm may go for longer than stated

1993 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
3.95	25/1/93 11:00	25/1/93 10:00	25/1/93 12:00	9.07	-	Summer	Mod
4.70	14/6/93 6:00	13/6/93 20:00	14/6/93 23:00	15.33	-	Winter	Mod
3.56	4/9/93 0:00	4/9/93 0:00	4/9/93 3:00	12.53	-	Spring	Mod

1994 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
4.16	12/3/94 1:00	12/3/94 0:00	12/3/94 3:00	10.25	-	Autumn	Mod
4.29	10/6/94 17:00	9/6/94 13:00	11/6/94 1:00	10.97	-	Winter	Mod

4.89	9/8/94 16:00	9/8/94 9:00	10/8/94 6:00	14.38	-	Winter	Mod
4.00	6/9/94 19:00	6/9/94 18:00	6/9/94 20:00	8.40	-	Spring	Mod
3.98	20/10/94 19:00	20/10/94 14:00	20/10/94 21:00	7.93	-	Spring	Mod

1995 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.26	21/1/95 16:00	21/1/95 16:00	21/1/95 18:00	8.60	-	Summer	Mod
4.37	5/3/95 3:00	4/3/95 1:00	5/3/95 14:00	11.66	-	Autumn	Mod
4.08	12/3/95 18:00	12/3/95 18:00	12/3/95 20:00	8.60	-	Autumn	Mod
4.31	11/4/95 6:00	11/4/95 1:00	11/4/95 13:00	12.52	-	Autumn	Mod
4.31	19/5/95 0:00	18/5/95 11:00	19/5/95 7:00	10.50	-	Autumn	Mod
3.98	12/6/95 23:00	12/6/95 22:00	13/6/95 7:00	13.11	-	Winter	Mod
3.89	17/6/95 21:00	17/6/95 19:00	19/6/95 19:00	10.56	-	Winter	Mod
4.29	21/6/95 14:00	21/6/95 10:00	21/6/95 20:00	11.35	-	Winter	Mod
3.72	9/8/95 2:00	9/8/95 2:00	9/8/95 3:00	11.10	-	Winter	Mod
5.24	25/9/95 22:00	25/9/95 5:00	27/9/95 6:00	10.90	-	Spring	Sev
3.72	21/12/95 19:00	21/12/95 13:00	21/12/95 19:00	11.63	-	Summer	Mod

1996 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.88	12/4/96 5:00	12/4/96 5:00	12/4/96 7:00	8.40	-	Autumn	Mod
3.79	19/8/96	19/8/96	19/8/96	9.35	-	Winter	Mod

	13:00	11:00	13:00				
7.19	31/8/96 20:00	31/8/96 7:00	2/9/96 5:00	11.57	-	Winter	Ext

1997 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
3.77	8/1/97 12:00	8/1/97 11:00	8/1/97 12:00	10.65	-	Summer	Mod
3.97	7/4/97 22:00	7/4/97 20:00	7/4/97 23:00	11.93	-	Autumn	Mod
3.58	24/9/97 22:00	24/9/97 22:00	24/9/97 22:00	10.20	-	Spring	Mod

1998 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
4.31	24/3/98 12:00	24/3/98 9:00	24/3/98 14:00	9.63	-	Autumn	Mod
3.82	6/5/98 13:00	5/5/98 20:00	6/5/98 17:00	9.74	-	Autumn	Mod
3.61	19/5/98 19:00	19/5/98 19:00	19/5/98 19:00	13.50	-	Autumn	Mod
3.51	8/6/98 18:00	8/6/98 18:00	8/6/98 18:00	10.20	-	Winter	Mod
3.56	23/6/98 19:00	23/6/98 19:00	23/6/98 19:00	11.10	-	Winter	Mod
4.49	8/8/98 23:00	8/8/98 17:00	8/8/98 23:00	11.60	-	Winter	Mod
3.94	1/11/98 21:00	1/11/98 19:00	1/11/98 22:00	10.65	-	Spring	Mod

1999 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above	Season of Occurrence	Storm Severity

					3.5m Hsig		
3.59	14/1/99 1:00	14/1/99 1:00	14/1/99 1:00	8.80	-	Summer	Mod
4.76	23/4/99 23:00	23/4/99 18:00	23/4/99 23:00*	12.45	-	Autumn	Mod
4.87	29/4/99 4:00	28/4/99 11:00	30/4/99 0:00	11.20	-	Autumn	Mod
3.98	25/5/99 17:00	25/5/99 13:00	25/5/99 17:00	14.14	-	Autumn	Mod
4.31	12/6/99 9:00	12/6/99 3:00	13/6/99 7:00	12.45	-	Winter	Mod
4.47	15/7/99 12:00	14/7/99 4:00	16/7/99 16:00	11.35	-	Winter	Mod
3.93	12/9/99 12:00	12/9/99 12:00	12/9/99 23:00	12.33	-	Spring	Mod
6.57	24/10/99 17:00	24/10/99 7:00	25/10/99 20:00	11.47	-	Spring	Ext
3.82	29/12/99 18:00	29/12/99 15:00	30/12/99 0:00	12.02	-	Summer	Mod
4.33	31/12/99 14:00	31/12/99 8:00	1/1/00 5:00	11.00	-	Summer	Mod
*Gap in data from 23/4/99 23:00 until 25/4/99 10:00- Storm may go for longer than stated							

2000 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.79	6/1/00 7:00	5/1/00 18:00	7/1/00 3:00	12.24	-	Summer	Mod
3.70	23/3/00 14:00	23/3/00 14:00	23/3/00 14:00	9.50	-	Autumn	Mod
3.78	5/4/00 23:00	5/4/00 23:00	6/4/00 3:00	9.36	-	Autumn	Mod
3.66	6/5/00 20:00	6/5/00 16:00	6/5/00 21:00	11.13	-	Autumn	Mod
3.91	2/6/00 13:00	2/6/00 8:00	2/6/00 16:00	10.73	-	Winter	Mod
5.31	30/6/00 18:00	30/6/00 2:00	1/7/00 13:00	10.55	-	Winter	Sev
4.40	26/9/00 16:00	26/9/00 13:00	27/9/00 2:00	9.56	-	Spring	Mod

2001 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant	**Date and**	**Date and time of**	**Date and time of last**	**Average Wave**	**Average Wave**	**Season of Occurrence**	**Storm Severity**

Wave Height	**time of Highest Hsig**	**first occurrence above 3.5m Hsig**	**occurrence above 3.5m Hsig**	**Period of occurrence above 3.5m Hsig**	**direction of occurrence above 3.5m Hsig**		
4.66	15/1/01 22:00	15/1/01 19:00	16/1/01 1:00	9.60	-	Summer	Mod
4.33	12/4/01 12:00	11/4/01 22:00	12/4/01 16:00	10.12	157.18 (SSE)	Autumn	Mod
3.67	10/7/01 5:00	10/7/01 4:00	10/7/01 8:00	8.96	114.40 (ESE)	Winter	Mod
3.68	29/8/01 20:00	29/8/01 14:00	29/8/01 20:00	9.26	136.00 (SE)	Winter	Mod
4.56	8/10/01 18:00	8/10/01 5:00	9/10/01 1:00	11.56	161.90 (SSE)	Spring	Mod
3.63	13/11/01 20:00	13/11/01 20:00	13/11/01 23:00	10.65	172.00 (S)	Spring	Mod
4.84	21/11/01 14:00	18/11/01 15:00	22/11/01 8:00	10.51	146.74 (SSE)	Spring	Mod
3.56	5/12/01 20:00	5/12/01 20:00	5/12/01 21:00	11.10	132.50 (SE)	Summer	Mod

2002 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.28	21/4/02 19:00	21/4/02 18:00	21/4/02 22:00	10.38	167.00 (SSE)	Autumn	Mod
3.77	29/5/02 9:00	28/5/02 23:00	29/5/02 9:00	15.19	143.00 (SE)	Autumn	Mod
4.70	18/6/02 16:00	18/6/02 1:00	19/6/02 0:00	13.01	139.96 (SE)	Winter	Mod
4.52	29/6/02 15:00	29/6/02 0:00	30/6/02 11:00	12.37	154.58 (SSE)	Winter	Mod
4.59	15/8/02 22:00	14/8/02 18:00	16/8/02 6:00	11.58	-	Winter	Mod

2003 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**

4.03	8/1/03 17:00	8/1/03 17:00	8/1/03 19:00	10.50	168.33 (SSE)	Summer	Mod
3.66	17/5/03 14:00	17/5/03 12:00	17/5/03 16:00	11.54	86.60 (E)	Autumn	Mod
4.38	27/6/03 18:00	27/6/03 17:00	27/6/03 18:00	15.00	80.00 (E)	Winter	Mod
3.63	30/6/03 23:00	30/6/03 23:00	1/7/03 2:00	13.18	148.00 (SSE)	Winter	Mod
4.09	31/7/03 0:00	30/7/03 20:00	1/8/03 3:00	12.34	156.34 (SSE)	Winter	Mod
3.94	3/9/03 20:00	3/9/03 17:00	4/9/03 2:00	12.00	162.30 (SSE)	Spring	Mod
3.61	5/12/03 17:00	5/12/03 17:00	5/12/03 19:00	8.83	167.00 (SSE)	Summer	Mod

2004 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.64	16/2/04 9:00	16/2/04 9:00	16/2/04 9:00	9.40	160.00 (SSE)	Summer	Mod
3.76	15/5/04 2:00	14/5/04 19:00	15/5/04 2:00	12.25	138.25 (SE)	Autumn	Mod
4.74	18/7/04 8:00	17/7/04 23:00	19/7/04 3:00	11.10	149.61 (SSE)	Winter	Mod
3.86	15/8/04 5:00	15/8/04 4:00	15/8/04 7:00	9.95	167.50 (SSE)	Winter	Mod
3.65	21/10/04 14:00	21/10/04 13:00	21/10/04 16:00	10.65	67.75 (ENE)	Spring	Mod
3.94	29/10/04 4:00	29/10/04 1:00	29/10/04 10:00	12.72	142.50 (SE)	Spring	Mod
3.74	27/12/04 16:00	27/12/04 16:00	27/12/04 16:00	7.70	169.00 (S)	Summer	Mod

2005 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.58	12/2/05 23:00	12/2/05 23:00	12/2/05 23:00	8.80	176.00 (S)	Summer	Mod
5.42	23/6/05	23/6/05	24/6/05	10.61	158.80	Winter	Sev

	22:00	19:00	4:00		(SSE)		
4.74	1/7/05 0:00	30/6/05 16:00	1/7/05 5:00	9.59	56.29 (ENE)	Winter	Mod
5.18	10/7/05 21:00	10/7/05 10:00	11/7/05 8:00	12.07	134.64 (SE)	Winter	Sev
4.92	15/11/05 20:00	15/11/05 17:00	16/11/05 9:00	10.28	160.65 (SSE)	Spring	Mod
6.63	28/11/05 19:00	28/11/05 9:00	29/11/05 1:00	11.64	155.00 (SSE)	Spring	Ext

2006 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.19	7/2/06 3:00	6/2/06 23:00	7/2/06 5:00	9.81	169.57 (S)	Summer	Mod
3.80	3/4/06 17:00	3/4/06 13:00	3/4/06 22:00	12.98	-	Autumn	Mod
4.53	16/4/06 20:00	16/4/06 8:00	17/4/06 1:00	14.25	143.33 (SE)	Autumn	Mod
4.32	7/9/06 14:00	7/9/06 10:00	7/9/06 20:00	8.60	169.45 (S)	Spring	Mod
3.98	8/10/06 14:00	8/10/06 14:00	8/10/06 16:00	8.80	169.00 (S)	Spring	Mod
4.07	21/10/06 0:00	20/10/06 22:00	21/10/06 1:00	8.13	176.50 (S)	Spring	Mod
3.54	28/10/06 7:00	28/10/06 7:00	28/10/06 7:00	10.20	166.00 (SSE)	Spring	Mod

2007 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.59	27/1/07 13:00	27/1/07 12:00	27/1/07 13:00	9.32	163.50 (SSE)	Summer	Mod
3.61	24/3/07 17:00	24/3/07 17:00	24/3/07 17:00	8.17	170.00 (S)	Autumn	Mod
4.84	9/6/07 12:00	9/6/07 0:00	10/6/07 14:00	10.89	132.82 (SE)	Winter	Mod
3.82	16/6/07 8:00	16/6/07 5:00	16/6/07 15:00	10.38	110.00 (ESE)	Winter	Mod

5.70	20/6/07 5:00	19/6/07 23:00	20/6/07 19:00	11.49	144.81 (SE)	Winter	Sev
3.64	21/6/07 19:00	21/6/07 19:00	21/6/07 19:00	10.83	163.00 (SSE)	Winter	Mod
5.37	28/6/07 18:00	28/6/07 8:00	29/6/07 4:00	11.82	153.57 (SSE)	Winter	Sev
4.03	9/7/07 6:00	9/7/07 5:00	9/7/07 20:00	10.54	139.81 (SE)	Winter	Mod
4.62	5/11/07 7:00	4/11/07 20:00	5/11/07 21:00	10.34	156.65 (SSE)	Spring	Mod

2008 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.57	7/2/08 21:00	7/2/08 21:00	7/2/08 22:00	8.92	184.50 (S)	Summer	Mod
3.94	29/7/08 0:00	28/7/08 19:00	29/7/08 6:00	10.91	150.67 (SSE)	Winter	Mod
3.70	16/8/08 18:00	16/8/08 18:00	17/8/08 12:00	12.73	155.39 (SSE)	Winter	Mod
3.53	23/8/08 0:00	23/8/08 0:00	23/8/08 0:00	9.77	152.00 (SSE)	Winter	Mod
3.60	6/9/08 21:00	6/9/08 16:00	6/9/08 22:00	12.17	82.00 (E)	Spring	Mod
3.69	8/9/08 19:00	8/9/08 19:00	8/9/08 19:00	8.52	175.00 (S)	Spring	Mod
3.82	15/12/08 2:00	15/12/08 0:00	15/12/08 6:00	12.25	170.14 (S)	Summer	Mod

2009 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.85	10/2/09 21:00	10/2/09 21:00	10/2/09 22:00	8.92	179.50 (S)	Summer	Mod
4.42	8/10/09 8:00	7/10/09 19:00	8/10/09 23:00	11.06	167.03 (SSE)	Spring	Mod

2010 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest	**Date**	**Date and**	**Date and**	**Average**	**Average**	**Season of**	**Storm**

Significant Wave Height	and time of Highest Hsig	time of first occurrence above 3.5m Hsig	time of last occurrence above 3.5m Hsig	Wave Period of occurrence above 3.5m Hsig	Wave direction of occurrence above 3.5m Hsig	Occurrence	Severity
4.33	16/2/10 2:00	15/2/10 11:00	16/2/10 13:00	10.22	157.23 (SSE)	Summer	Mod
3.86	15/5/10 1:00	14/5/10 23:00	15/5/10 4:00	13.71	135.50 (SE)	Autumn	Mod
4.29	26/5/10 6:00	26/5/10 5:00	26/5/10 11:00	8.86	117.00 (ESE)	Autumn	Mod
5.46	30/5/10 20:00	30/5/10 7:00	31/5/10 15:00	11.34	118.19 (ESE)	Autumn	Sev
4.12	3/8/10 6:00	2/8/10 21:00	3/8/10 11:00	10.96	159.22 (SSE)	Winter	Mod
3.73	27/12/10 18:00	27/12/10 18:00	27/12/10 18:00	8.52	183.00 (S)	Summer	Mod

2011 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.60	21/2/11 23:00	21/2/11 23:00	21/2/11 23:00	9.32	179.00 (S)	Summer	Mod
3.72	1/3/11 21:00	1/3/11 20:00	1/3/11 21:00	8.01	181.50 (S)	Autumn	Mod
3.61	22/3/11 9:00	22/3/11 9:00	22/3/11 15:00	10.59	93.00 (E)	Autumn	Mod
3.67	25/5/11 2:00	25/5/11 0:00	25/5/11 6:00	10.37	168.00 (SSE)	Autumn	Mod
3.87	10/6/11 18:00	10/6/11 18:00	10/6/11 18:00	10.88	157.50 (SSE)	Winter	Mod
5.64	22/7/11 4:00	20/7/11 3:00	23/7/11 20:00	11.86	128.39 (SE)	Winter	Sev
3.71	19/8/11 19:00	19/8/11 17:00	19/8/11 21:00	10.28	108.20 (ESE)	Winter	Mod

2012 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above**	**Season of Occurrence**	**Storm Severity**

					3.5m Hsig		
3.79	1/3/12 20:00	1/3/12 20:00	2/3/12 2:00	8.76	156.33 (SSE)	Autumn	Mod
5.29	8/3/12 3:00	7/3/12 19:00	8/3/12 22:00	11.44	139.89 (SE)	Autumn	Sev
3.53	22/3/12 0:00	22/3/12 0:00	22/3/12 0:00	8.52	186.00 (S)	Autumn	Mod
5.98	6/6/12 0:00	5/6/12 18:00	6/6/12 22:00	12.19	146.29 (SSE)	Winter	Sev
3.61	4/7/12 4:00	4/7/12 4:00	4/7/12 4:00	10.27	152.00 (SSE)	Winter	Mod
4.00	1/8/12 8:00	1/8/12 2:00	1/8/12 19:00	14.29	135.59 (SE)	Winter	Mod
4.15	10/8/12 13:00	10/8/12 12:00	12/8/12 6:00	10.82	154.46 (SSE)	Winter	Mod
5.01	12/10/12 1:00	11/10/12 18:00	12/10/12 13:00	10.10	154.00 (SSE)	Spring	Sev

2013 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.20	29/1/13 12:00	29/1/13 3:00	29/1/13 21:00	12.34	88.53 (E)	Summer	Mod
3.912	23/2/13 18:00	23/2/13 8:00	24/2/13 0:00	11.33	101.00 (E)	Summer	Mod
4.13	4/5/13 17:00	4/5/13 13:00	4/5/13 19:00	9.10	188.14 (S)	Autumn	Mod
3.91	15/6/13 13:00	15/6/13 2:00	15/6/13 14:00	10.60	168.54 (SSE)	Winter	Mod
5.15	25/6/13 8:00	24/6/13 17:00	26/6/13 2:00	10.22	123.26 (ESE)	Winter	Sev
6.26	17/9/13 5:00	17/9/13 0:00	17/9/13 6:00	9.62	82.14 (E)	Spring	Ext
3.66	13/10/13 19:00	13/10/13 19:00	13/10/13 19:00	7.28	185.00 (S)	Spring	Mod
4.05	29/10/13 11:00	29/10/13 10:00	29/10/13 16:00	9.04	182.00 (S)	Spring	Mod
3.81	3/11/13 16:00	3/11/13 16:00	3/11/13 19:00	9.91	167.75 (SSE)	Spring	Mod
3.80	9/11/13 20:00	9/11/13 19:00	9/11/13 21:00	9.18	172.33 (S)	Spring	Mod
3.72	12/11/13 2:00	12/11/13 0:00	12/11/13 2:00	8.65	124.67 (SE)	Spring	Mod
4.18	25/11/13	25/11/13	25/11/13	11.15	171.67	Spring	Mod

	17:00	13:00	21:00		(S)		
3.53	29/12/13 7:00	29/12/13 7:00	29/12/13 7:00	7.85	178.00 (S)	Summer	Mod

2014 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
4.60	12/4/14 16:00	12/4/14 0:00	13/4/14 17:00	11.84	135.50 (SE)	Autumn	Mod
4.61	4/5/14 23:00	4/5/14 11:00	5/5/14 12:00	14.10	160.42 (SSE)	Autumn	Mod
3.91	15/6/14 12:00	15/6/14 11:00	15/6/14 14:00	10.83	173.75 (S)	Winter	Mod
4.47	19/7/14 14:00	18/7/14 19:00	20/7/14 7:00	12.14	159.03 (SSE)	Winter	Mod
5.43	18/8/14 19:00	17/8/14 22:00	19/8/14 19:00	10.75	129.13 (SE)	Winter	Sev
3.74	30/8/14 2:00	29/8/14 22:00	30/8/14 10:00	11.68	112.50 (ESE)	Winter	Mod
5.11	3/9/14 1:00	2/9/14 21:00	4/9/14 6:00	11.47	145.89 (SE)	Spring	Sev
4.24	14/10/14 9:00	14/10/14 8:00	15/10/14 16:00	11.02	148.20 (SSE)	Spring	Mod

2015 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
3.63	30/1/15 1:00	30/1/15 1:00	30/1/15 9:00	11.86	137.22 (SE)	Summer	Mod
4.24	9/4/15 9:00	8/4/15 16:00	9/4/15 21:00	11.88	154.71 (SSE)	Autumn	Mod
5.27	21/4/15 22:00	20/4/15 20:00	22/4/15 12:00	10.09	148.71 (SSE)	Autumn	Sev
3.92	14/5/15 23:00	14/5/15 18:00	15/5/15 11:00	12.86	156.41 (SSE)	Autumn	Mod
4.29	18/6/15 11:00	18/6/15 9:00	18/6/15 15:00	10.82	162.43 (SSE)	Winter	Mod
3.77	18/7/15 9:00	18/7/15 9:00	18/7/15 9:00	10.83	158.00 (SSE)	Winter	Mod

2016 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
4.12	14/1/16 20:00	14/1/16 17:00	14/1/16 21:00	8.91	175.40 (S)	Summer	Mod
5.75	7/7/16 2:00	6/6/16 18:00	7/7/16 23:00	10.93	160.28 (SSE)	Winter	Sev
3.96	3/9/16 23:00	3/9/16 23:00	4/9/16 2:00	11.62	160.50 (SSE)	Spring	Mod
3.61	23/9/16 8:00	23/9/16 8:00	23/9/16 9:00	10.02	172.00 (S)	Spring	Mod
4.45	24/10/16 14:00	23/10/16 7:00	24/10/16 21:00	12.44	160.54 (SSE)	Spring	Mod
3.88	14/11/16 21:00	14/11/16 18:00	14/11/16 22:00	10.09	180.00 (S)	Spring	Mod
4.25	24/11/16 14:00	24/11/16 13:00	25/11/16 1:00	12.04	157.54 (SSE)	Spring	Mod

2017 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave Height	Date and time of Highest Hsig	Date and time of first occurrence above 3.5m Hsig	Date and time of last occurrence above 3.5m Hsig	Average Wave Period of occurrence above 3.5m Hsig	Average Wave direction of occurrence above 3.5m Hsig	Season of Occurrence	Storm Severity
4.76	18/1/17 21:00	18/1/17 16:00	19/1/17 0:00	10.36	162.78 (SSE)	Summer	Mod
4.13	20/1/17 22:00	20/1/17 21:00	21/1/17 9:00	10.90	159.46 (SSE)	Summer	Mod
3.54	7/3/17 0:00	6/3/17 16:00	7/3/17 1:00	9.98	161.40 (SSE)	Autumn	Mod
3.50	8/5/17 21:00	8/5/17 21:00	8/5/17 21:00	12.93	163.00 (SSE)	Autumn	Mod
3.66	19/8/17 17:00	19/8/17 16:00	19/8/17 17:00	10.54	160.50 (SSE)	Winter	Mod
3.64	28/8/17 5:00	28/8/17 0:00	28/8/17 5:00	10.19	168.17 (SSE)	Winter	Mod

2018 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)

Highest Significant Wave	Date and time of	Date and time of first	Date and time of last occurrence	Average Wave Period of	Average Wave direction	Season of Occurrence	Storm Severity

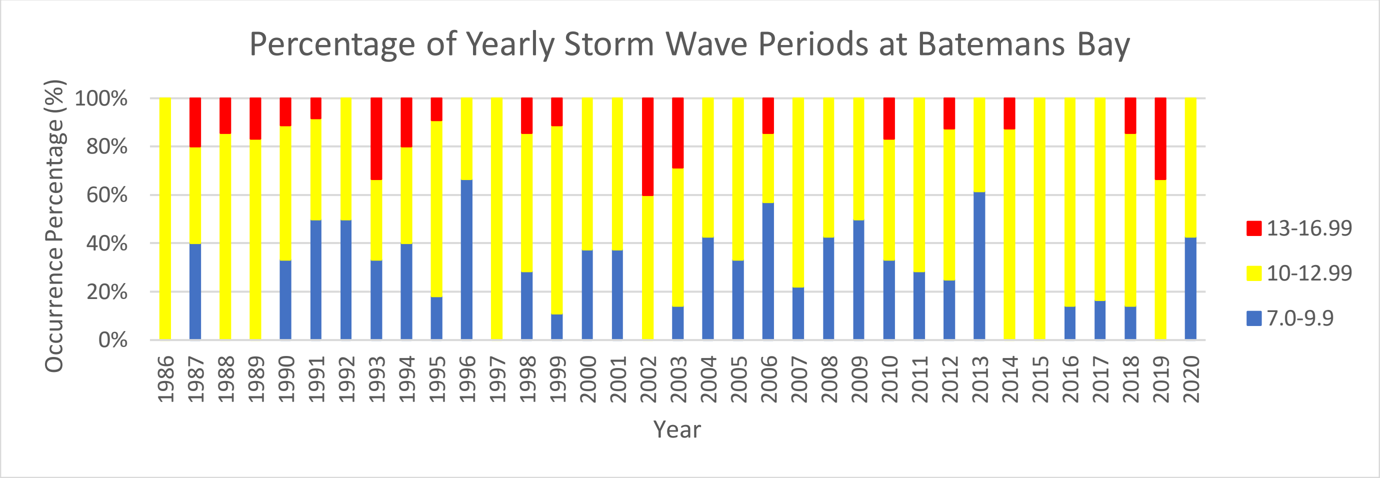
Height	**Highest Hsig**	**occurrence above 3.5m Hsig**	**above 3.5m Hsig**	**occurrence above 3.5m Hsig**	**of occurrence above 3.5m Hsig**		
4.22	17/1/18 19:00	16/1/18 4:00	18/1/18 11:00	11.80	137.66 (SE)	Summer	Mod
3.97	31/1/18 19:00	31/1/18 16:00	31/1/18 21:00	8.30	187.50 (S)	Summer	Mod
3.96	13/5/18 0:00	12/5/18 8:00	13/5/18 3:00	11.78	164.60 (SSE)	Autumn	Mod
3.59	2/6/18 22:00	2/6/18 7:00	2/6/18 22:00	11.25	150.26 (SSE)	Winter	Mod
3.52	19/6/18 7:00	19/6/18 7:00	19/6/18 7:00	11.45	149.00 (SSE)	Winter	Mod
3.81	20/8/18 6:00	19/8/18 23:00	20/8/18 10:00	11.78	168.42 (SSE)	Winter	Mod
3.50	29/8/18 17:00	29/8/18 17:00	29/8/18 17:00	14.85	147.00 (SSE)	Winter	Mod

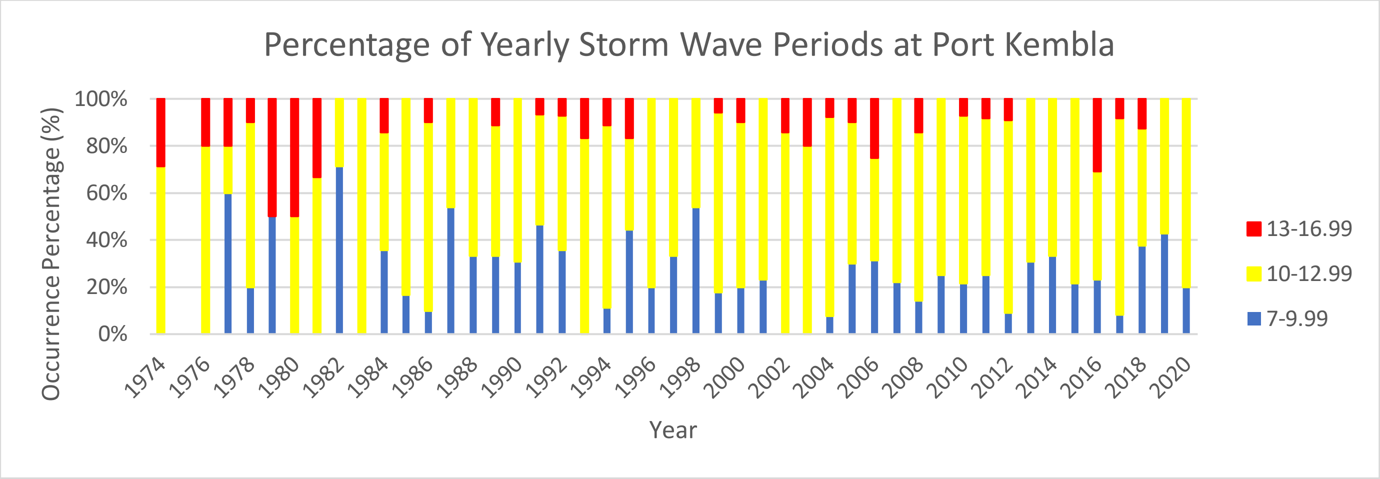
2019 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
4.03	7/5/19 1:00	6/5/19 22:00	7/5/19 5:00	11.80	157.88 (SSE)	Autumn	Mod
5.38	4/6/19 16:00	4/6/19 1:00	5/6/19 8:00	11.41	153.66 (SSE)	Winter	Sev
4.66	22/8/19 19:00	22/8/19 9:00	23/8/19 5:00	13.07	158.50 (SSE)	Winter	Mod

2020 High significant Wave Height Events at Batemans Bay (Resolution: 1hr)							
Highest Significant Wave Height	**Date and time of Highest Hsig**	**Date and time of first occurrence above 3.5m Hsig**	**Date and time of last occurrence above 3.5m Hsig**	**Average Wave Period of occurrence above 3.5m Hsig**	**Average Wave direction of occurrence above 3.5m Hsig**	**Season of Occurrence**	**Storm Severity**
3.75	3/2/20 18:00	3/2/20 18:00	3/2/20 20:00	8.91	178.67 (S)	Summer	Mod
5.00	9/2/20 22:00	9/2/20 6:00	9/2/20 14:00	10.48	107.38 (ESE)	Summer	Sev
3.86	26/2/20 19:00	26/2/20 18:00	26/2/20 20:00	9.52	178.33 (S)	Summer	Mod
3.63	22/3/20	22/3/20	22/3/20	8.52	179.00	Autumn	Mod

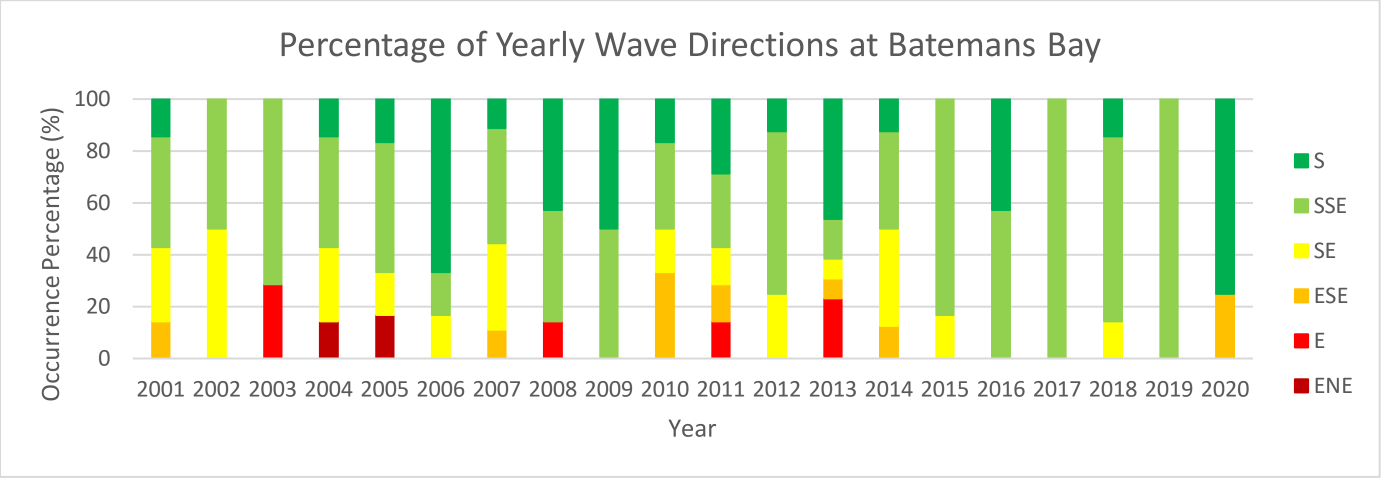
	21:00	21:00	21:00		(S)		
5.503	23/5/20 1:00	22/5/20 15:00	25/5/20 14:00	11.00	153.90 (SSE)	Autumn	Sev
5.332	15/7/20 2:00	14/7/20 5:00	16/7/20 21:00	12.00	135.25 (SE)	Winter	Sev
6.253	27/7/20 20:00	27/7/20 4:00	28/7/20 21:00	10.27	158.88 (SSE)	Winter	Ext

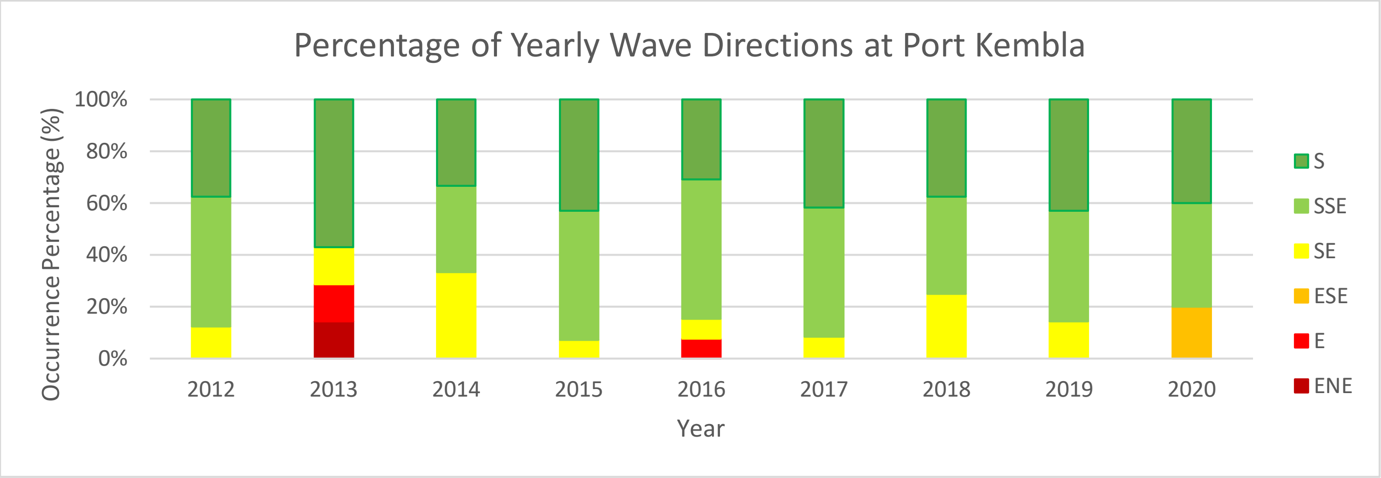
Appendix 4: Yearly/Decadal wave period trends



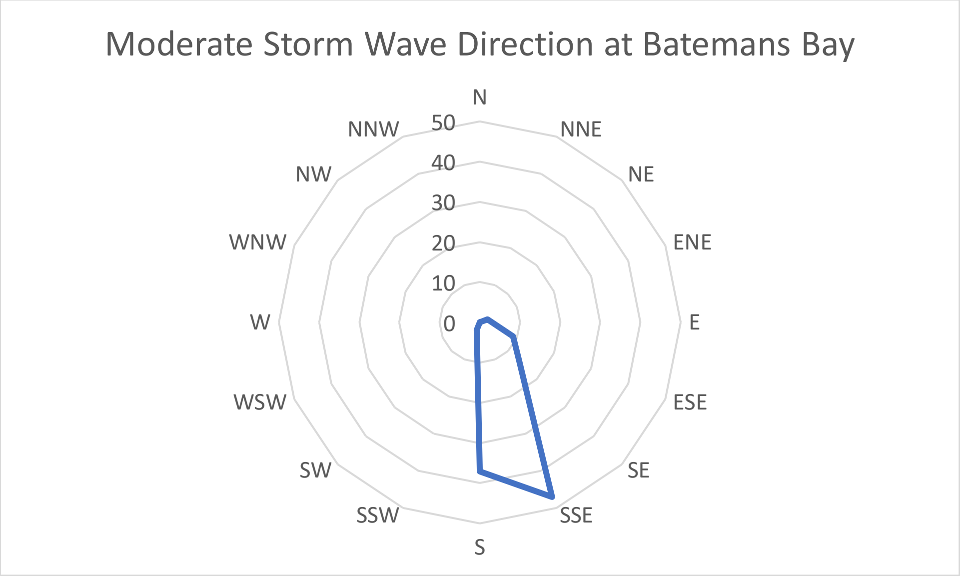


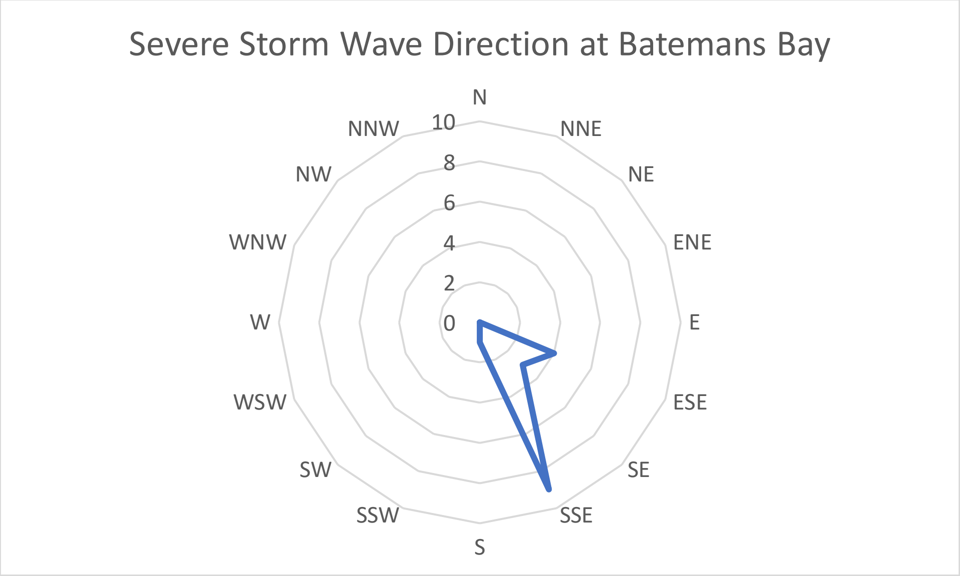
Appendix 5: Yearly/Decadal wave direction trends

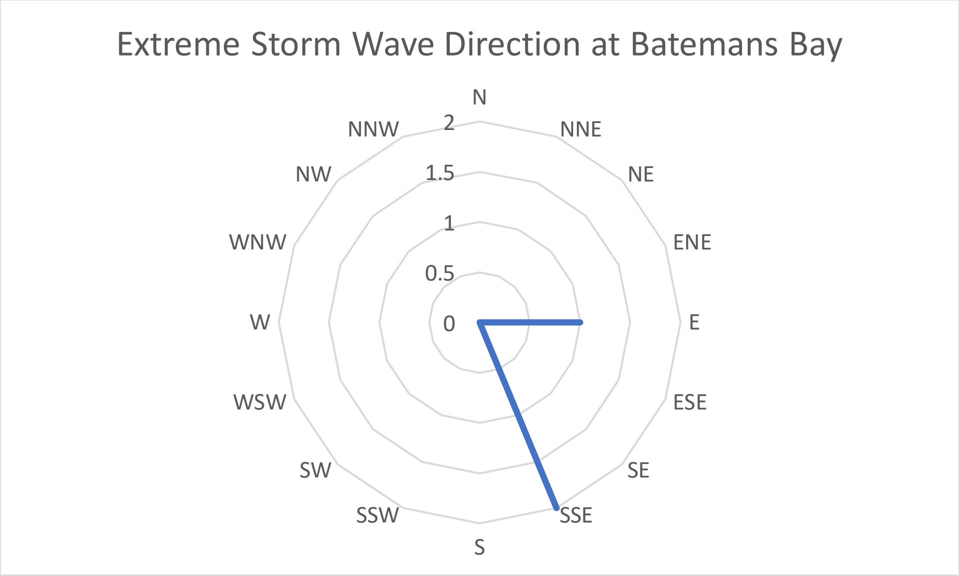




Appendix 6: Batemans Bay wave direction against severity





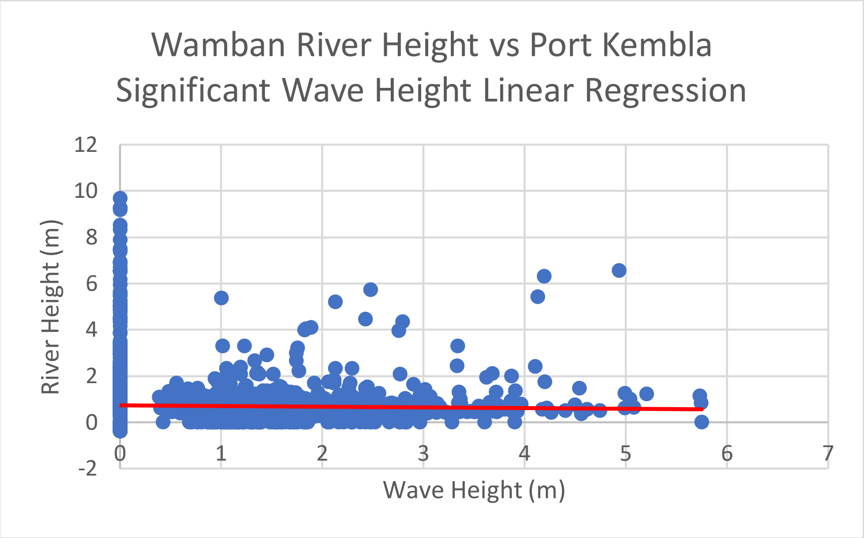


Appendix 7: Regression analyses

Port Kembla Vs Wamban

1974- 1988

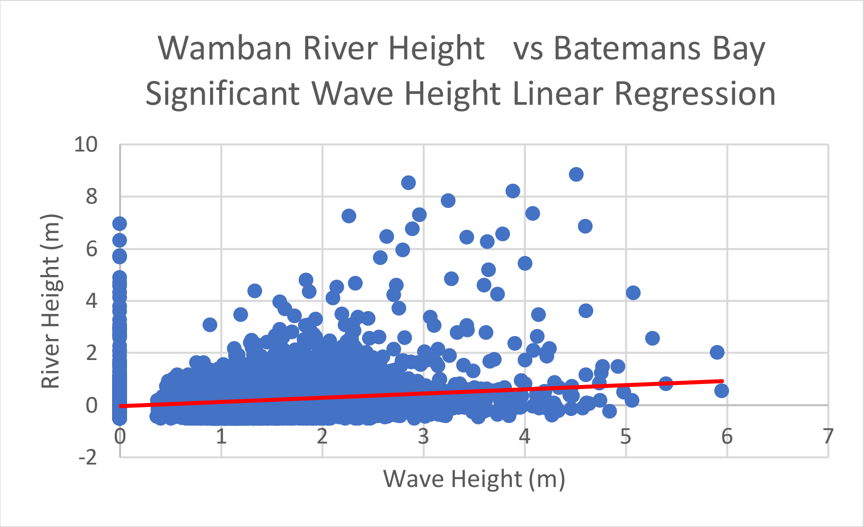
Regression Statistics	
Multiple R	0.0371
R Square	0.00138
Adjusted R Square	0.00119
Standard Error	0.67741
Observations	5478



Batemans Bay Vs Wamban

1986-2013

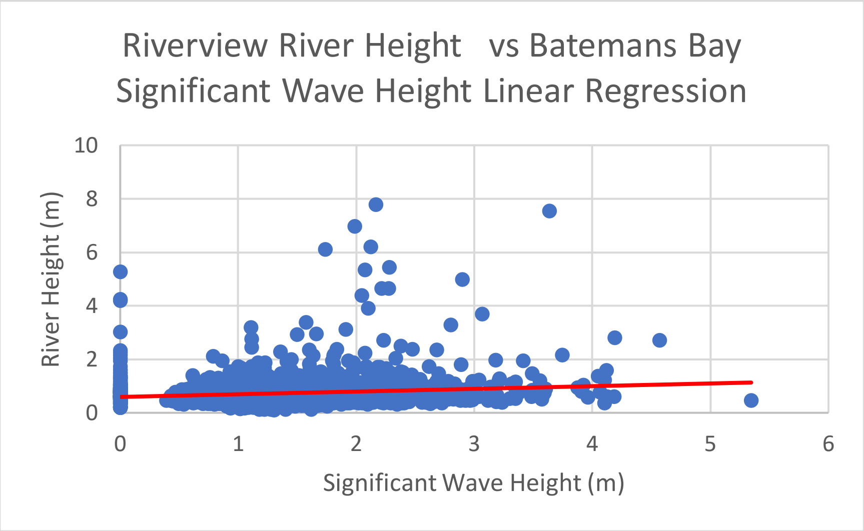
Regression Statistics	
Multiple R	0.19995
R Square	0.03998
Adjusted R Square	0.03988
Standard Error	0.56734
Observations	9872



Batemans Bay Vs Riverview

2013-2020

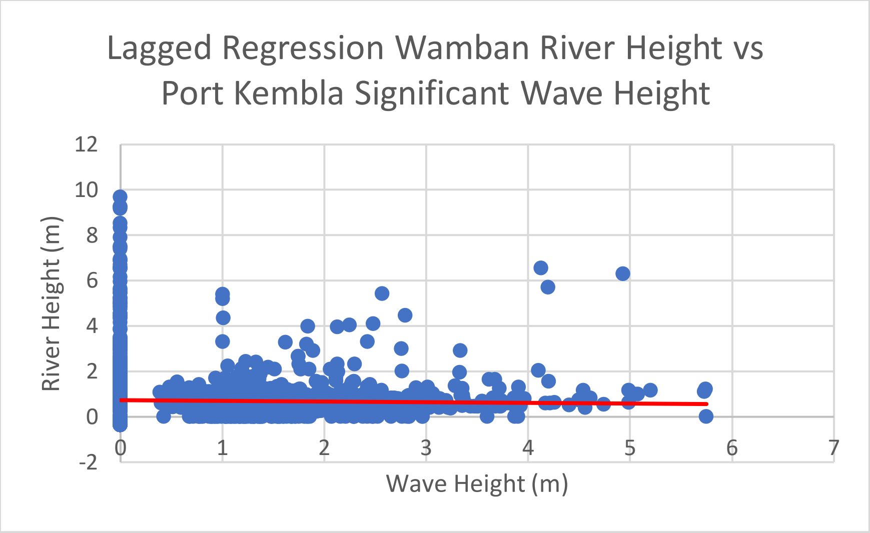
Regression Statistics	
Multiple R	0.14217
R Square	0.02021
Adjusted R Square	0.01982
Standard Error	0.50628
Observations	2463



Port Kembla Vs Wamban

1974- 1988

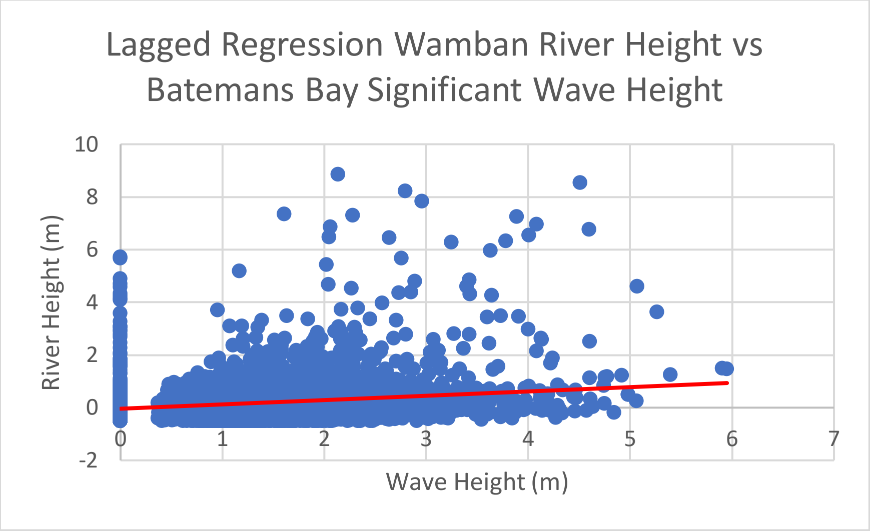
Regression Statistics	
Multiple R	0.03696
R Square	0.00137
Adjusted R Square	0.00118
Standard Error	0.67741
Observations	5477



Batemans Bay Vs Wamban

1986-2013

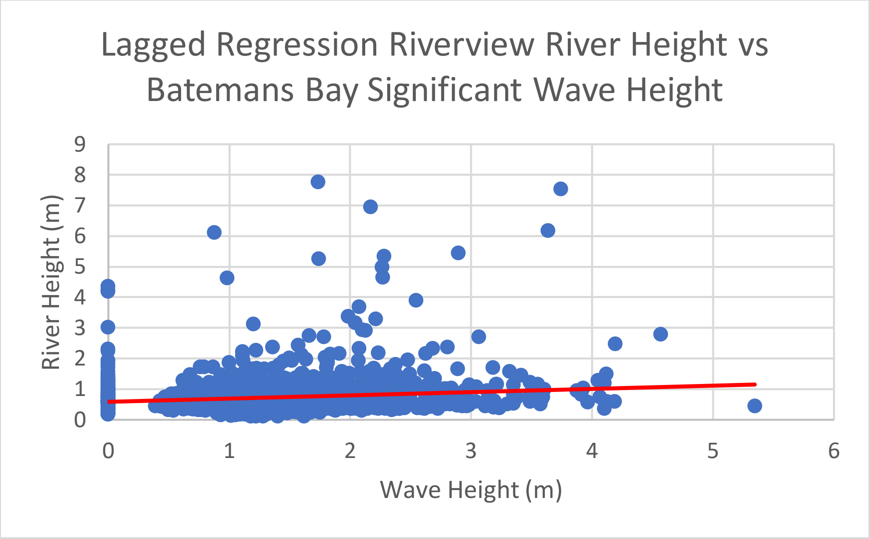
Regression Statistics	
Multiple R	0.20303
R Square	0.04122
Adjusted R Square	0.04112
Standard Error	0.567
Observations	9871

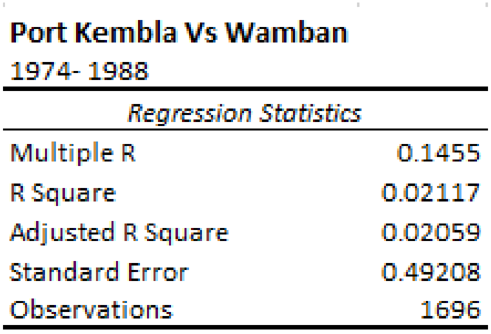


Batemans Bay Vs Wamban

1986-2013

Regression Statistics	
Multiple R	0.20303
R Square	0.04122
Adjusted R Square	0.04112
Standard Error	0.567
Observations	9871

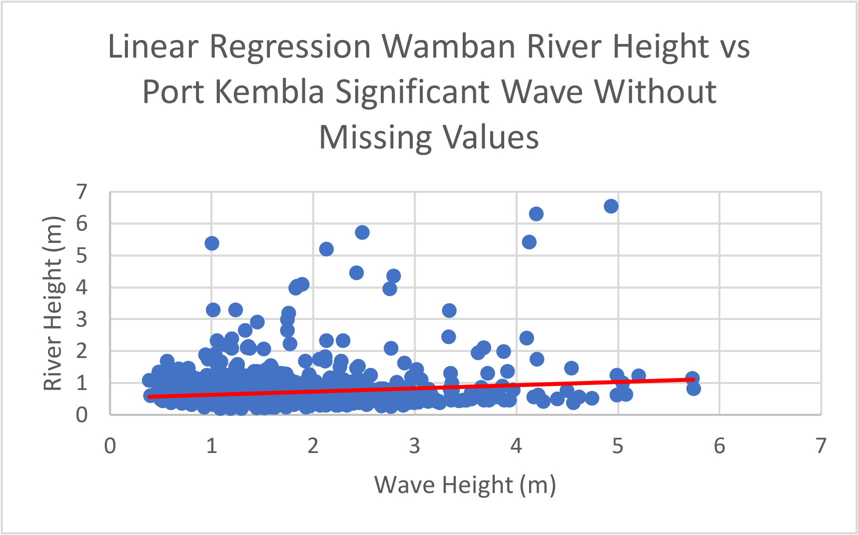


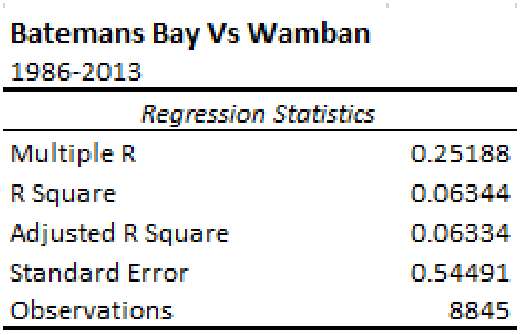


Port Kembla Vs Wamban

1974- 1988

Regression Statistics	
Multiple R	0.1455
R Square	0.02117
Adjusted R Square	0.02059
Standard Error	0.49208
Observations	1696

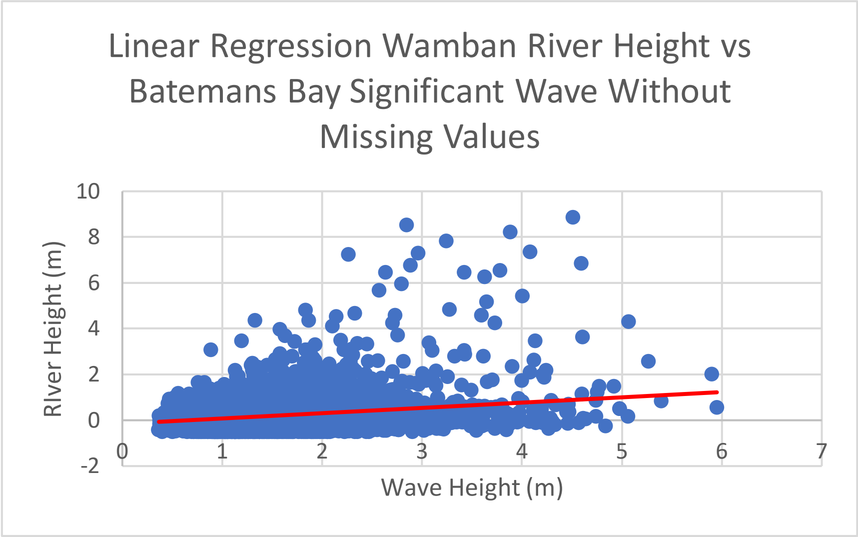


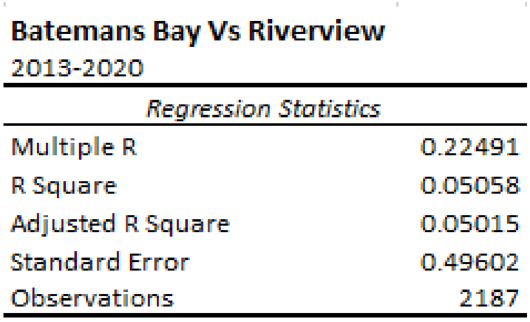


Batemans Bay Vs Wamban

1986-2013

Regression Statistics	
Multiple R	0.25188
R Square	0.06344
Adjusted R Square	0.06334
Standard Error	0.54491
Observations	8845

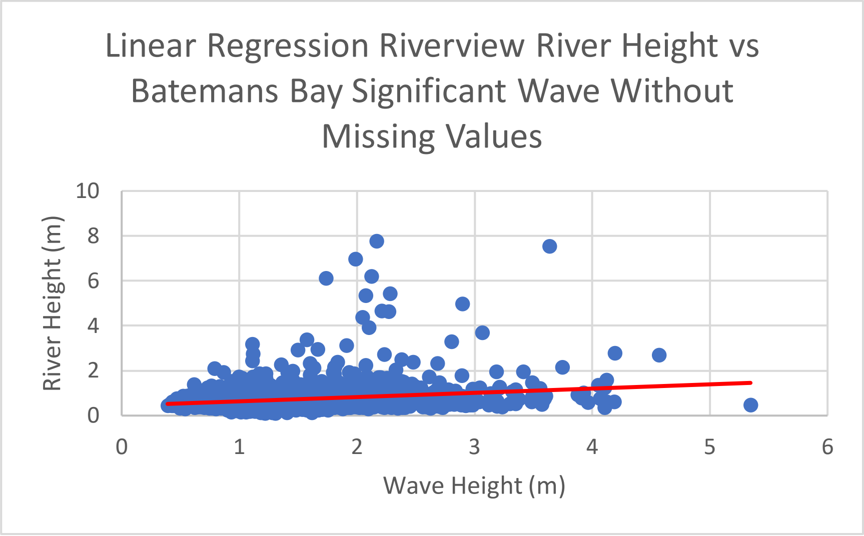




Batemans Bay Vs Riverview

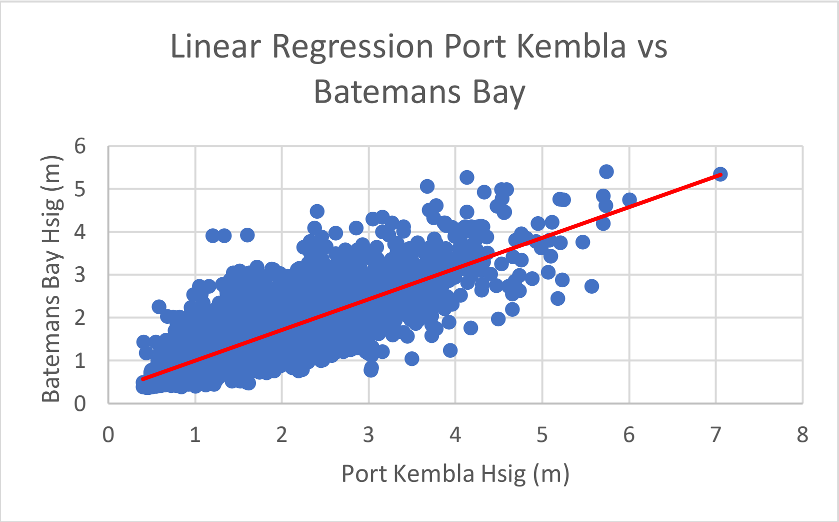
2013-2020

Regression Statistics	
Multiple R	0.22491
R Square	0.05058
Adjusted R Square	0.05015
Standard Error	0.49602
Observations	2187



Batemans Bay Vs Port Kembla
1986-2020

Regression Statistics	
Multiple R	0.805875018
R Square	0.649434545
Adjusted R Square	0.649397698
Standard Error	0.354086587
Observations	9516



Appendix 8: Digitised Bengello Beach volume

Date	Approximate date	Volume	Volume Change
1972.042	15/01/1972	208.95976	0
1972.145	21/02/1972	197.72209	-11.23767
1972.165	29/02/1972	210.78207	13.05998
1972.323	27/04/1972	206.22627	-4.5558
1972.364	12/05/1972	239.02809	32.80182
1972.515	6/07/1972	215.94533	-23.08276
1972.638	20/08/1972	234.32042	18.37509
1972.727	22/09/1972	214.42673	-19.89369
1972.796	17/10/1972	239.17995	24.75322
1972.933	6/12/1972	232.49811	-6.68184
1972.96	16/12/1972	242.36902	9.87091
1973.001	1/01/1973	247.07669	4.70767
1973.097	4/02/1973	238.2688	-8.80789
1973.166	1/03/1973	254.82156	16.55276
1973.261	5/04/1973	239.63553	-15.18603
1973.419	1/06/1973	269.552	29.91647
1973.549	19/07/1973	213.66742	-55.88458
1973.693	9/09/1973	217.6158	3.94838
1973.755	2/10/1973	233.10555	15.48975
1973.94	8/12/1973	220.95673	-12.14882
1974.097	4/02/1974	224.75322	3.79649
1974.125	14/02/1974	232.19438	7.44116
1974.269	8/04/1974	205.46696	-26.72742
1974.406	28/05/1974	210.78207	5.31511
1974.426	4/06/1974	111.61731	-99.16476
1974.591	3/08/1974	108.58011	-3.0372
1974.707	15/09/1974	123.310555	14.730445
1974.865	11/11/1974	112.52847	-10.782085
1974.954	14/12/1974	121.032646	8.504176
1975.029	10/01/1975	112.680336	-8.35231
1975.077	28/01/1975	136.67426	23.993924
1975.221	21/03/1975	123.46242	-13.21184
1975.399	25/05/1975	166.43887	42.97645
1975.481	24/06/1975	99.46849	-66.97038
1975.536	14/07/1975	123.310555	23.842065
1975.701	12/09/1975	114.04707	-9.263485
1975.961	16/12/1975	130.44798	16.40091
1975.995	29/12/1975	143.50797	13.05999
1976.071	25/01/1976	139.10402	-4.40395
1976.153	24/02/1976	143.35611	4.25209
1976.215	18/03/1976	103.11314	-40.24297
1977.03	10/01/1977	129.23311	26.11997
1977.187	9/03/1977	128.17009	-1.06302
1977.235	26/03/1977	139.86333	11.69324

1977.311	23/04/1977	134.39636	-5.46697
1977.468	19/06/1977	143.20425	8.80789
1977.599	6/08/1977	173.42445	30.2202
1977.681	5/09/1977	169.32422	-4.10023
1977.845	4/11/1977	181.62491	12.30069
1978.051	18/01/1978	173.57631	-8.0486
1978.133	17/02/1978	152.46773	-21.10858
1978.27	8/04/1978	149.88611	-2.58162
1978.393	23/05/1978	171.45027	21.56416
1978.455	15/06/1978	101.29081	-70.15946
1978.702	13/09/1978	132.57404	31.28323
1978.763	5/10/1978	154.1382	21.56416
1978.935	7/12/1978	150.18982	-3.94838
1979.037	13/01/1979	165.83144	15.64162
1979.236	27/03/1979	174.63933	8.80789
1979.311	23/04/1979	165.07213	-9.5672
1979.497	30/06/1979	172.36143	7.2893
1979.565	25/07/1979	193.47	21.10857
1979.64	21/08/1979	192.10327	-1.36673
1979.819	25/10/1979	209.26347	17.1602
1979.935	7/12/1979	203.34093	-5.92254
1980.031	11/01/1980	208.65604	5.31511
1980.072	26/01/1980	189.82536	-18.83068
1980.319	25/04/1980	209.11162	19.28626
1980.545	17/07/1980	209.41534	0.30372
1980.634	18/08/1980	222.01974	12.6044
1980.737	25/09/1980	218.67882	-3.34092
1980.922	2/12/1980	224.90509	6.22627
1980.976	22/12/1980	244.03949	19.1344
1981.189	9/03/1981	232.04253	-11.99696
1981.223	22/03/1981	245.55809	13.51556
1981.374	16/05/1981	235.23158	-10.32651
1981.435	7/06/1981	238.42065	3.18907
1981.737	25/09/1981	232.34624	-6.07441
1981.943	10/12/1981	249.3546	17.00836
1982.045	16/01/1982	265.60364	16.24904
1982.155	25/02/1982	255.429	-10.17464
1982.299	19/04/1982	268.33713	12.90813
1982.422	3/06/1982	260.1367	-8.20043
1982.525	10/07/1982	234.62415	-25.51255
1982.826	28/10/1982	266.36295	31.7388
1982.957	15/12/1982	261.65527	-4.70768
1983.169	2/03/1983	281.54898	19.89371
1983.237	27/03/1983	235.68716	-45.86182
1983.313	24/04/1983	252.84738	17.16022
1983.47	20/06/1983	257.55505	4.70767
1983.512	5/07/1983	274.71527	17.16022
1983.628	17/08/1983	246.62111	-28.09416

1983.792	16/10/1983	261.04782	14.42671
1983.834	31/10/1983	235.07973	-25.96809
1983.847	5/11/1983	241.306	6.22627
1983.977	22/12/1983	242.97646	1.67046
1984.231	24/03/1984	227.183	-15.79346
1984.299	18/04/1984	234.92787	7.74487
1984.471	20/06/1984	241.45786	6.52999
1984.546	17/07/1984	211.99696	-29.4609
1984.601	6/08/1984	230.82764	18.83068
1984.779	11/10/1984	245.8618	15.03416
1984.902	25/11/1984	239.33182	-6.52998
1984.992	27/12/1984	224.44951	-14.88231
1985.149	23/02/1985	232.34624	7.89673
1985.176	5/03/1985	247.22855	14.88231
1985.3	19/04/1985	235.07973	-12.14882
1985.362	11/05/1985	242.06529	6.98556
1985.437	8/06/1985	236.14275	-5.92254
1985.505	3/07/1985	252.99924	16.85649
1985.629	17/08/1985	219.28625	-33.71299
1985.745	28/09/1985	248.29156	29.00531
1985.916	30/11/1985	244.19135	-4.10021
1986.06	22/01/1986	230.06834	-14.12301
1986.204	15/03/1986	258.61807	28.54973
1986.458	16/06/1986	276.23386	17.61579
1986.656	27/08/1986	234.16856	-42.0653
1986.807	21/10/1986	237.66135	3.49279
1986.835	31/10/1986	246.92484	9.26349
1986.951	13/12/1986	239.17995	-7.74489
1987.061	22/01/1987	228.09415	-11.0858
1987.184	8/03/1987	242.8246	14.73045
1987.622	15/08/1987	273.65225	30.82765
1987.643	22/08/1987	243.88762	-29.76463
1987.766	6/10/1987	260.4404	16.55278
1987.876	15/11/1987	265.7555	5.3151
1987.965	18/12/1987	258.61807	-7.13743
1988.095	3/02/1988	263.7813	5.16323
1988.164	28/02/1988	252.08807	-11.69323
1988.219	20/03/1988	266.8185	14.73043
1988.41	29/05/1988	247.07669	-19.74181
1988.548	18/07/1988	249.65831	2.58162
1988.554	20/07/1988	254.21413	4.55582
1988.849	5/11/1988	260.1367	5.92257
1988.918	30/11/1988	255.429	-4.7077
1988.993	28/12/1988	261.65527	6.22627
1989.096	3/02/1989	255.12529	-6.52998
1989.24	28/03/1989	270.3113	15.18601
1989.329	29/04/1989	264.38876	-5.92254
1989.418	1/06/1989	266.8185	2.42974

1989.507	3/07/1989	249.50645	-17.31205
1989.801	19/10/1989	260.89597	11.38952
1989.897	23/11/1989	283.06757	22.1716
1989.993	28/12/1989	278.3599	-4.70767
1990.034	12/01/1990	260.89597	-17.46393
1990.432	6/06/1990	258.31436	-2.58161
1990.569	26/07/1990	274.86713	16.55277
1990.672	2/09/1990	265.29993	-9.5672
1990.733	24/09/1990	253.60669	-11.69324
1990.925	3/12/1990	244.19135	-9.41534
1991.069	25/01/1991	246.77296	2.58161
1991.179	6/03/1991	226.87927	-19.89369
1991.35	7/05/1991	248.44344	21.56417
1991.501	1/07/1991	246.01367	-2.42977
1991.781	12/10/1991	254.36598	8.35231
1991.96	16/12/1991	248.89902	-5.46696
1992.056	20/01/1992	253.15111	4.25209
1992.234	25/03/1992	242.06529	-11.08582
1992.289	14/04/1992	249.20273	7.13744
1992.35	7/05/1992	268.64084	19.43811
1992.556	21/07/1992	268.64084	0
1992.652	25/08/1992	282.76385	14.12301
1992.727	22/09/1992	269.2483	-13.51555
1992.987	26/12/1992	251.48064	-17.76766
1993.07	25/01/1993	235.53531	-15.94533
1993.213	18/03/1993	272.43735	36.90204
1993.227	23/03/1993	293.39407	20.95672
1993.344	5/05/1993	263.7813	-29.61277
1993.638	20/08/1993	290.05316	26.27186
1993.803	19/10/1993	295.36826	5.3151
1993.892	25/11/1993	310.40244	15.03418
1993.94	8/12/1993	299.62036	-10.78208
1994.091	2/02/1994	309.18756	9.5672
1994.173	3/03/1994	302.96127	-6.22629
1994.741	27/09/1994	294.15338	-8.80789
1994.851	6/11/1994	298.7092	4.55582
1995.002	1/01/1995	276.8413	-21.8679
1995.077	28/01/1995	292.9385	16.0972
1995.207	16/03/1995	250.72134	-42.21716
1995.324	28/04/1995	268.64084	17.9195
1995.577	29/07/1995	277.44876	8.80792
1995.646	23/08/1995	264.84433	-12.60443
1995.845	4/11/1995	252.08807	-12.75626
1996.05	18/01/1996	261.50342	9.41535
1996.112	9/02/1996	267.88156	6.37814
1996.461	16/06/1996	276.23386	8.3523
1996.626	15/08/1996	272.89294	-3.34092
1996.687	7/09/1996	244.49507	-28.39787

1996.886	19/11/1996	238.2688	-6.22627
1997.009	3/01/1997	203.64465	-34.62415
1997.071	25/01/1997	219.28625	15.6416
1997.126	14/02/1997	250.26576	30.97951
1997.359	10/05/1997	240.09111	-10.17465
1997.427	4/06/1997	233.86484	-6.22627
1997.557	22/07/1997	217.91951	-15.94533
1997.825	27/10/1997	223.38649	5.46698
1997.962	17/12/1997	234.776	11.38951
1998.14	20/02/1998	256.34018	21.56418
1998.208	17/03/1998	225.36067	-30.97951
1998.462	17/06/1998	212.14882	-13.21185
1998.619	14/08/1998	228.54973	16.40091
1998.763	5/10/1998	216.40091	-12.14882
1999.216	19/03/1999	223.99393	7.59302
1999.51	5/07/1999	220.653	-3.34093
1999.832	30/10/1999	225.36067	4.70767
1999.86	9/11/1999	240.24298	14.88231
2000.079	28/01/2000	225.2088	-15.03418
2000.134	17/02/2000	235.23158	10.02278
2000.579	29/07/2000	244.3432	9.11162
2000.798	18/10/2000	273.65225	29.30905
2000.963	17/12/2000	217.16022	-56.49203
2001.134	17/02/2001	295.9757	78.81548
2001.209	17/03/2001	272.2855	-23.6902
2001.326	28/04/2001	298.10175	25.81625
2001.47	20/06/2001	299.92407	1.82232
2001.716	18/09/2001	259.22552	-40.69855
2001.86	9/11/2001	258.92178	-0.30374
2002.052	19/01/2002	273.95596	15.03418
2002.497	30/06/2002	271.98178	-1.97418
2002.867	12/11/2002	279.1192	7.13742
2003.107	8/02/2003	290.35687	11.23767
2003.224	22/03/2003	307.21338	16.85651
2003.299	19/04/2003	283.3713	-23.84208
2003.621	14/08/2003	290.66058	7.28928
2003.902	25/11/2003	290.96432	0.30374
2004.114	10/02/2004	309.33942	18.3751
2004.45	12/06/2004	268.64084	-40.69858
2004.95	12/12/2004	272.13364	3.4928
2005.067	24/01/2005	299.31662	27.18298
2005.128	15/02/2005	288.07898	-11.23764
2005.259	4/04/2005	295.9757	7.89672
2005.471	20/06/2005	295.82385	-0.15185
2005.848	5/11/2005	286.71222	-9.11163
2005.944	10/12/2005	263.02203	-23.69019
2006.588	2/08/2006	271.67807	8.65604
2006.889	20/11/2006	304.17615	32.49808

2007.157	26/02/2007	300.68338	-3.49277
2007.54	16/07/2007	253.60669	-47.07669
2007.561	23/07/2007	230.06834	-23.53835
2007.629	17/08/2007	230.2202	0.15186
2007.657	27/08/2007	257.55505	27.33485
2007.814	24/10/2007	274.25967	16.70462
2007.986	25/12/2007	279.1192	4.85953
2008.246	30/03/2008	312.0729	32.9537
2008.438	8/06/2008	323.6143	11.5414
2008.609	9/08/2008	305.0873	-18.527
2008.787	14/10/2008	317.8436	12.7563
2009.102	6/02/2009	313.43964	-4.40396
2009.26	4/04/2009	285.49734	-27.9423
2009.452	13/06/2009	284.73804	-0.7593
2009.74	26/09/2009	320.57706	35.83902
2009.877	15/11/2009	317.6917	-2.88536
2010.055	20/01/2010	270.3113	-47.3804

Appendix 9: Digitised Narrabeen Beach volume

Date	Approximate date	Volume	Volume Change
1976.31	22/04/1976	231.1114	0
1976.397	24/05/1976	301.8901	70.77872
1976.484	25/06/1976	257.1135	-44.77655
1976.528	11/07/1976	290.8918	33.77822
1976.631	18/08/1976	276.5598	-14.33197
1976.775	9/10/1976	337.3392	60.77945
1977.052	18/01/1977	355.4538	18.1146
1977.158	26/02/1977	319.1219	-36.33191
1977.266	7/04/1977	352.901	33.77908
1977.483	25/06/1977	325.2372	-27.66385
1977.563	24/07/1977	366.4603	41.22315
1977.749	30/09/1977	365.5738	-0.88654
1977.867	12/11/1977	401.353	35.77921
1978.06	21/01/1978	318.9112	-82.44181
1978.224	22/03/1978	358.1354	39.22422
1978.408	28/05/1978	269.9157	-88.21964
1978.562	24/07/1978	317.1398	47.22406
1978.785	13/10/1978	322.1426	5.0028
1978.856	8/11/1978	363.5879	41.44526
1978.978	22/12/1978	351.5895	-11.99841
1979.06	21/01/1979	365.4793	13.88989
1979.184	8/03/1979	331.2588	-34.22054
1979.297	18/04/1979	415.9267	84.6679
1979.487	26/06/1979	370.707	-45.21973
1979.568	26/07/1979	409.7079	39.00095
1979.687	7/09/1979	421.265	11.55703
1979.783	12/10/1979	398.044	-23.22095
1979.884	18/11/1979	407.0453	9.0013
1980.026	9/01/1980	381.3805	-25.66484
1980.208	16/03/1980	421.6049	40.22446
1980.474	21/06/1980	365.2751	-56.32982
1980.602	7/08/1980	382.7211	17.44603
1980.742	27/09/1980	377.9452	-4.77597
1980.806	21/10/1980	394.8348	16.88964
1980.908	26/11/1980	397.2806	2.44575
1980.951	13/12/1980	429.3921	32.11157
1981.077	28/01/1981	382.2827	-47.10942
1981.232	25/03/1981	407.5069	25.22417
1981.384	20/05/1981	374.7311	-32.77577
1981.466	19/06/1981	398.5099	23.77876
1981.625	16/08/1981	381.0675	-17.44239
1981.731	23/09/1981	441.9576	60.89011
1981.799	18/10/1981	421.514	-20.44354
1981.891	21/11/1981	427.1819	5.66781
1981.95	12/12/1981	395.8494	-31.33248

1982.098	4/02/1982	402.9623	7.11297
1982.174	4/03/1982	386.9633	-15.99902
1982.3	19/04/1982	433.4093	46.44595
1982.485	26/06/1982	341.1896	-92.21967
1982.615	12/08/1982	438.3022	97.11255
1982.769	7/10/1982	377.8598	-60.44232
1982.833	31/10/1982	396.6384	18.77854
1982.926	3/12/1982	400.4173	3.77893
1983.112	9/02/1983	394.9753	-5.44205
1983.198	13/03/1983	372.1986	-22.77665
1983.389	21/05/1983	421.4232	49.22456
1983.451	13/06/1983	351.2019	-70.22129
1983.6	6/08/1983	345.7593	-5.44253
1983.71	16/09/1983	367.094	21.33468
1984.046	16/01/1984	350.0984	-16.99566
1984.218	19/03/1984	404.9893	54.89094
1984.277	10/04/1984	369.2123	-35.77696
1984.452	13/06/1984	382.7701	13.55776
1984.535	13/07/1984	294.8825	-87.88762
1984.707	14/09/1984	340.9957	46.11319
1985.065	23/01/1985	296.3337	-44.66202
1985.248	31/03/1985	328.3359	32.00225
1985.39	22/05/1985	299.6711	-28.6648
1985.609	10/08/1985	341.0071	41.33604
1985.715	17/09/1985	299.5642	-41.44299
1985.798	18/10/1985	311.2318	11.66769
1985.919	1/12/1985	305.5667	-5.66514
1986.261	5/04/1986	330.4599	24.8932
1986.288	15/04/1986	346.0158	15.55585
1986.428	5/06/1986	337.7954	-8.2204
1986.53	12/07/1986	343.2411	5.44571
1986.683	6/09/1986	288.2432	-54.9979
1986.901	24/11/1986	349.5791	61.33594
1987.088	1/02/1987	335.4704	-14.1087
1987.131	16/02/1987	381.9153	46.44488
1987.225	23/03/1987	370.5832	-11.33212
1987.297	18/04/1987	389.3618	18.77866
1987.405	27/05/1987	331.2522	-58.10959
1987.558	22/07/1987	384.4763	53.22403
1987.652	25/08/1987	375.4775	-8.99878
1987.808	21/10/1987	395.2572	19.77972
1987.905	26/11/1987	353.2585	-41.99866
1987.997	29/12/1987	368.2597	15.00113
1988.063	23/01/1988	359.2605	-8.99914
1988.135	18/02/1988	377.7058	18.44531
1988.205	15/03/1988	327.9291	-49.77676
1988.353	8/05/1988	339.2643	11.33517
1988.447	11/06/1988	321.5989	-17.6654

1988.538	15/07/1988	347.8221	26.22329
1988.669	1/09/1988	339.9349	-7.8872
1988.826	28/10/1988	356.1591	16.22418
1989.033	12/01/1989	318.1619	-37.99725
1989.143	21/02/1989	344.2743	26.11243
1989.303	20/04/1989	316.832	-27.44233
1989.402	26/05/1989	358.0553	41.22336
1989.544	17/07/1989	323.835	-34.22031
1989.664	30/08/1989	335.6143	11.77928
1989.794	16/10/1989	339.3937	3.7794
1989.903	25/11/1989	374.9506	35.55686
1990.222	22/03/1990	337.6214	-37.32919
1990.549	19/07/1990	420.9587	83.33731
1990.698	11/09/1990	324.9608	-95.99788
1990.818	25/10/1990	331.7401	6.77928
1991.106	7/02/1991	337.4104	5.67032
1991.42	2/06/1991	465.7474	128.337
1991.566	25/07/1991	386.0828	-79.6646
1991.702	16/09/1991	425.64	39.55718
1992.087	31/01/1992	389.5338	-36.10614
1992.172	3/03/1992	370.8683	-18.66552
1992.39	21/05/1992	427.3154	56.44708
1992.53	12/07/1992	422.3172	-4.9982
1992.641	21/08/1992	331.8744	-90.44284
1992.833	31/10/1992	361.6545	29.78014
1992.968	19/12/1992	315.1008	-46.5537
1993.115	10/02/1993	327.436	12.33517
1993.211	18/03/1993	293.3262	-34.1098
1993.4	25/05/1993	363.2173	69.89113
1993.515	6/07/1993	331.5522	-31.66515
1993.795	17/10/1993	322.2224	-9.32975
1993.961	16/12/1993	337.6689	15.4465
1994.162	28/02/1994	268.3383	-69.33058
1994.38	18/05/1994	325.6743	57.33598
1994.476	22/06/1994	291.6756	-33.9987
1994.756	2/10/1994	392.1234	100.44775
1995.158	26/02/1995	260.1288	-131.99457
1995.298	18/04/1995	250.2417	-9.88708
1995.672	2/09/1995	331.4685	81.22678
1995.762	5/10/1995	268.4698	-62.99868
1995.954	14/12/1995	300.6944	32.22457
1996.171	2/03/1996	263.9194	-36.77494
1996.28	11/04/1996	291.2541	27.33467
1996.448	12/06/1996	292.9229	1.66878
1996.539	15/07/1996	310.5907	17.66779
1996.942	10/12/1996	280.2625	-30.32813
1997.014	5/01/1997	299.2634	19.00086
1997.183	7/03/1997	289.1545	-10.10895

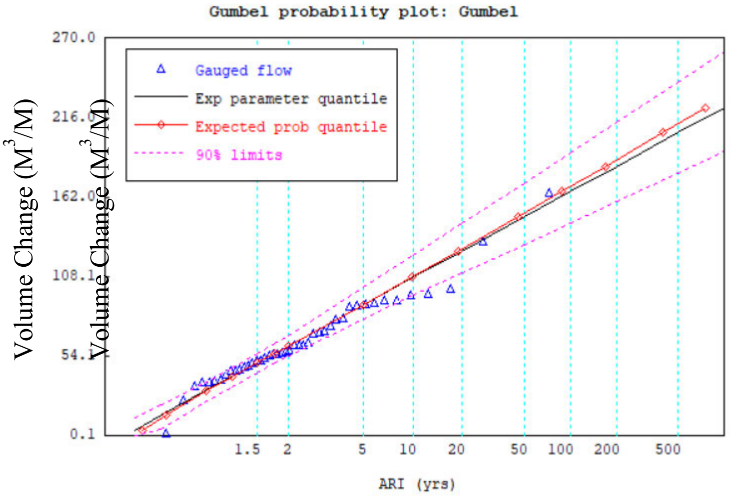
1997.282	12/04/1997	317.9334	28.77899
1997.438	8/06/1997	238.9356	-78.99783
1997.802	19/10/1997	331.4956	92.55996
1998.009	3/01/1998	308.6094	-22.88619
1998.145	21/02/1998	339.3888	30.77942
1998.215	19/03/1998	283.9454	-55.44343
1998.352	8/05/1998	315.5026	31.55723
1998.466	19/06/1998	285.393	-30.10956
1998.577	29/07/1998	292.2833	6.89026
1998.644	23/08/1998	269.3953	-22.88798
1998.863	10/11/1998	322.9535	53.5582
1998.929	5/12/1998	307.2878	-15.66577
1999.114	10/02/1999	317.4012	10.11343
1999.164	28/02/1999	279.8463	-37.55484
1999.33	30/04/1999	300.1817	20.33539
1999.362	12/05/1999	258.0711	-42.11059
1999.537	14/07/1999	275.1845	17.11331
1999.752	1/10/1999	258.6317	-16.5528
1999.852	6/11/1999	281.5218	22.89011
2000.095	3/02/2000	276.8582	-4.66356
2000.103	6/02/2000	286.5249	9.66673
2000.27	7/04/2000	291.1937	4.6688
2000.351	7/05/2000	317.1947	26.00097
2000.547	18/07/2000	314.1972	-2.9975
2000.613	11/08/2000	302.5314	-11.6658
2000.805	20/10/2000	334.8671	32.3357
2000.873	14/11/2000	310.0902	-24.77686
2001.029	10/01/2001	331.8699	21.77969
2001.221	21/03/2001	264.6503	-67.2196
2001.266	7/04/2001	285.6509	21.00052
2001.387	21/05/2001	281.4302	-4.22067
2001.495	29/06/2001	316.3204	34.89019
2001.633	19/08/2001	226.989	-89.33137
2001.806	21/10/2001	274.5466	47.55763
2001.985	25/12/2001	251.1045	-23.44211
2002.083	30/01/2002	297.7723	46.66778
2002.268	7/04/2002	301.9969	4.2246
2002.286	14/04/2002	319.2193	17.2224
2002.481	24/06/2002	317.1107	-2.10864
2002.703	13/09/2002	327.3357	10.22504
2002.86	9/07/2002	346.4488	19.11306
2003.003	1/01/2003	307.784	-38.66476
2003.216	19/03/2003	309.7867	2.0027
2003.326	28/04/2003	326.0103	16.22358
2003.582	31/07/2003	278.1248	-47.88552
2003.745	28/09/2003	321.6823	43.55754
2003.866	12/11/2003	326.906	5.22374
2004.006	2/01/2004	320.3523	-6.55374

2004.163	28/02/2004	335.6876	15.33526
2004.25	31/03/2004	288.911	-46.77656
2004.488	26/06/2004	335.1362	46.22517
2004.606	8/08/2004	263.8045	-71.33167
2004.767	6/10/2004	331.4731	67.66855
2004.911	28/11/2004	287.2528	-44.2203
2005.011	4/01/2005	311.6984	24.44568
2005.161	27/02/2005	294.367	-17.3314
2005.215	19/03/2005	317.4788	23.11177
2005.356	9/05/2005	299.5917	-17.88706
2005.38	18/05/2005	350.4808	50.88906
2005.626	16/08/2005	297.373	-53.10784
2005.808	21/10/2005	342.0418	44.66884
2006.024	8/01/2006	313.7113	-28.3305
2006.19	10/03/2006	332.4912	18.77985
2006.363	12/05/2006	274.9379	-57.55322
2006.663	29/08/2006	348.4971	73.5592
2006.769	7/10/2006	310.3875	-38.10968
2007.025	9/01/2007	354.1684	43.78092
2007.222	22/03/2007	333.7265	-20.44187
2007.395	24/05/2007	382.7286	49.00208
2007.468	19/06/2007	287.5075	-95.22108
2007.664	30/08/2007	280.7322	-6.77526
2007.717	18/09/2007	308.7329	28.00061
2007.839	2/11/2007	303.29	-5.4429
2007.957	15/12/2007	332.6247	29.33478
2008.129	16/02/2008	281.5159	-51.1088
2008.211	17/03/2008	299.5169	18.00101
2008.386	20/05/2008	318.1858	18.66882
2008.5	1/07/2008	293.1873	-24.99846
2008.637	20/08/2008	326.8556	33.6683
2008.843	3/11/2008	303.1916	-23.66398
2008.954	14/12/2008	312.7486	9.55695
2009.215	19/03/2009	308.5297	-4.21891
2009.368	14/05/2009	253.0873	-55.44235
2009.793	16/10/2009	292.5371	39.44974
2009.971	20/12/2009	275.4283	-17.1088
2010.071	25/01/2010	300.3184	24.89011
2010.176	5/03/2010	267.8753	-32.44302
2010.311	23/04/2010	319.4325	51.55712
2010.518	8/07/2010	289.4352	-29.99728
2010.579	30/07/2010	338.1025	48.66732
2010.675	3/09/2010	301.1038	-36.99868
2010.916	30/11/2010	310.4402	9.33638
2011.106	7/02/2011	274.1093	-36.33086
2011.278	11/04/2011	326.0003	51.89096
2011.463	17/06/2011	226.114	-99.88627
2011.581	31/07/2011	264.1154	38.00139

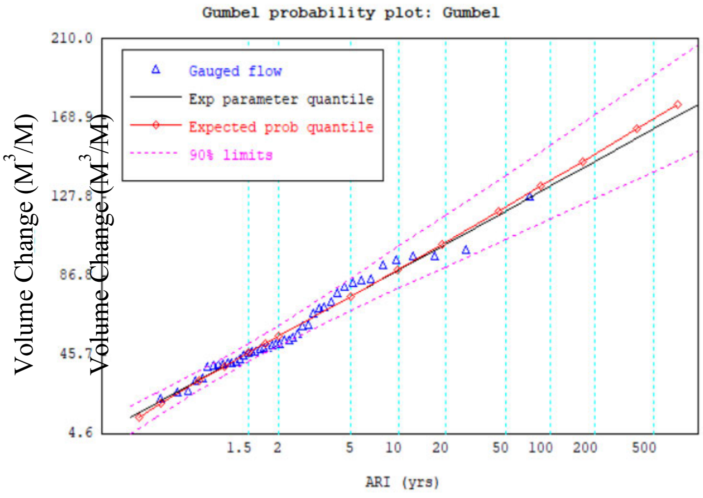
2011.65	25/08/2011	221.672	-42.44345
2011.939	8/12/2011	316.7865	95.11456
2012.006	2/01/2012	299.2318	-17.55469
2012.116	11/02/2012	307.2333	8.00141
2012.192	10/03/2012	288.7898	-18.44342
2012.33	29/04/2012	311.3471	22.55722
2012.488	26/06/2012	306.0158	-5.3313
2012.567	25/07/2012	254.7947	-51.22109
2012.953	14/12/2012	306.4661	51.67147
2013.231	25/03/2013	214.4699	-91.99627
2013.303	20/04/2013	244.2485	29.77863
2013.416	31/05/2013	234.1388	-10.10965
2013.46	16/06/2013	256.9171	22.77826
2013.601	7/08/2013	243.5856	-13.3315
2013.69	8/09/2013	285.8089	42.22327
2013.784	13/10/2013	273.2546	-12.55432
2013.867	12/11/2013	279.3667	6.11215
2014.044	16/01/2014	276.7023	-2.66443
2014.107	8/02/2014	303.0364	26.33408
2014.22	21/03/2014	290.0378	-12.99855
2014.234	26/03/2014	332.4823	42.44453
2014.369	14/05/2014	288.1508	-44.33151
2014.563	24/07/2014	293.82	5.66913
2014.727	22/09/2014	330.4886	36.66867
2014.779	11/10/2014	269.045	-61.44364
2014.823	27/10/2014	300.3788	31.3338
2014.955	14/12/2014	279.6028	-20.77603
2014.96	16/12/2014	325.0472	45.4444
2015.075	27/01/2015	292.0487	-32.99847
2015.129	16/02/2015	312.6049	20.55622
2015.214	19/03/2015	295.606	-16.99888
2015.314	24/04/2015	319.7183	24.1123
2015.367	13/05/2015	245.1636	-74.55468
2015.439	9/06/2015	281.4978	36.33413
2015.524	10/07/2015	260.9434	-20.55441
2015.527	11/07/2015	339.0543	78.11096
2015.653	26/08/2015	381.6114	42.55708
2015.749	30/09/2015	346.1682	-35.44316
2015.876	15/11/2015	380.8365	34.66822
2015.934	6/12/2015	359.0595	-21.77701
2016.041	15/01/2016	303.7276	-55.33185
2016.122	13/02/2016	331.8397	28.1121
2016.209	16/03/2016	303.5075	-28.3322
2016.294	16/04/2016	388.9529	85.44535
2016.441	9/06/2016	403.1769	14.22405
2016.512	5/07/2016	237.956	-165.22092
2016.793	16/10/2016	316.9594	79.0034
2016.908	27/11/2016	286.7387	-30.2207

2016.98	23/12/2016	310.2951	23.55642
2017.083	30/01/2017	303.1853	-7.1098
2017.174	4/03/2017	322.742	19.55667
2017.261	5/04/2017	286.8543	-35.88769
2017.415	1/06/2017	328.6339	41.77962
2017.499	1/07/2017	325.4128	-3.22112
2017.607	10/08/2017	364.4141	39.00128
2017.771	9/10/2017	302.9718	-61.44223
2017.879	17/11/2017	337.862	34.8902
2017.956	16/12/2017	309.9742	-27.88785
2018.102	6/02/2018	343.976	34.00177
2018.182	7/03/2018	280.3105	-63.66549
2018.462	18/06/2018	377.4249	97.11444
2018.55	20/07/2018	328.7595	-48.66544
2018.677	4/09/2018	361.4277	32.66821
2018.828	30/10/2018	336.6519	-24.77581
2018.929	6/12/2018	357.4309	20.77902
2019.005	1/01/2019	332.6541	-24.77674
2019.106	7/02/2019	348.8776	16.22346
2019.228	24/03/2019	339.657	-9.22065
2019.345	6/05/2019	377.2139	37.55695
2019.5	2/07/2019	315.3271	-61.88678
2019.514	7/07/2019	364.5494	49.22228
2019.629	18/08/2019	328.2176	-36.33178
2019.681	6/09/2019	365.5515	37.33392
2019.833	19/11/2019	334.3313	-31.22021
2019.905	27/11/2019	362.2211	27.88974
2019.99	28/12/2019	347.3333	-14.88779

Appendix 10: Narrabeen Collaroy volumetric change magnitude frequency analysis



Magnitude- frequency curve
displaying the recurrence
interval of erosive events



Magnitude- frequency curve
displaying the recurrence
interval of erosive events

Volumetric Change	**1 in 2 Year ARI**	**1 in 5 Year ARI**	**1 in 10 Year ARI**	**1 in 20 Year ARI**	**1 in 50 Year ARI**	**1 in 100 Year ARI**
Accretion	55.37 M^3/M	76.20 M^3/M	90 M^3/M	103.23 M^3/M	120.35 M^3/M	133.19 M^3/M
Erosion	60.76 M^3/M	88.80 M^3/M	107.36 M^3/M	125.16 M^3/M	148.20 M^3/M	165.47 M^3/M

Variations in the accretion and erosion Average Recurrence Intervals at Bengello Beach from 1974-2010.

Appendix 11: Recurrence intervals with a 90% probability limits

Annual Maximum Moruya River Discharge (Log Pearson III)

Recurrence interval yrs	Exp parameter quantile	Monte Carlo 90% quantile probability limits	
1.001	0.01	0.00	0.14
1.010	0.32	0.03	1.86
1.100	12.78	4.15	28.90
1.250	52.93	25.72	95.43
1.500	141.98	86.46	224.26
1.750	238.57	156.18	360.99
2.000	333.70	228.16	493.41
5.000	1100.48	838.86	1442.06
10.000	1655.22	1331.97	2054.42
20.000	2116.55	1766.18	2548.32
50.000	2574.02	2195.24	3206.14
100.000	2821.67	2407.90	3702.42
200.000	3003.61	2550.43	4159.95
500.000	3169.68	2646.52	4707.89
1000.000	3254.96	2681.23	5011.04

Annual Maximum Batemans Bay Significant Wave Height (Gumbel)

Recurrence interval yrs	Exp parameter quantile	Monte Carlo 90% quantile probability limits	
1.001	3.60	3.27	3.84
1.010	3.85	3.57	4.06
1.100	4.27	4.06	4.45
1.250	4.53	4.33	4.70
1.500	4.77	4.58	4.96
1.750	4.94	4.75	5.14
2.000	5.07	4.87	5.29
5.000	5.79	5.50	6.15
10.000	6.27	5.91	6.74
20.000	6.73	6.29	7.31
50.000	7.33	6.77	8.05
100.000	7.78	7.14	8.61
200.000	8.22	7.50	9.16
500.000	8.81	7.98	9.90
1000.000	9.25	8.34	10.45

Annual Maximum Batemans Bay Significant Wave Height- Including July Values (Gumbel)

Recurrence interval yrs	Exp parameter quantile	Monte Carlo 90% quantile probability limits	
1.001	3.57	3.23	3.82
1.010	3.84	3.55	4.06
1.100	4.27	4.05	4.46
1.250	4.54	4.34	4.72
1.500	4.79	4.60	4.99
1.750	4.97	4.77	5.18
2.000	5.10	4.89	5.33
5.000	5.85	5.55	6.23
10.000	6.35	5.97	6.84
20.000	6.83	6.36	7.43
50.000	7.45	6.87	8.20
100.000	7.91	7.25	8.78
200.000	8.38	7.63	9.36
500.000	8.99	8.12	10.12
1000.000	9.45	8.50	10.69

Annual Maximum Port Kembla Significant Wave Height (Gumbel)

Recurrence interval yrs	Exp parameter quantile	Monte Carlo 90% quantile probability limits	
1.001	3.30	2.93	3.59
1.010	3.68	3.36	3.94
1.100	4.30	4.04	4.52
1.250	4.67	4.44	4.89
1.500	5.03	4.79	5.27
1.750	5.28	5.03	5.53
2.000	5.47	5.21	5.74
5.000	6.53	6.17	6.96
10.000	7.24	6.79	7.78
20.000	7.92	7.37	8.59
50.000	8.79	8.12	9.63
100.000	9.45	8.68	10.41
200.000	10.10	9.24	11.19
500.000	10.97	9.98	12.22
1000.000	11.62	10.53	12.99

```
Annual Maximum Bengello Beach Erosion (Gumbel)

 Recurrence   Exp parameter    Monte Carlo 90% quantile
   interval      quantile          probability limits
     yrs
 ------------------------------------------------------
      1.001        0.00        0.00        0.00
      1.010        0.00        0.00        0.00
      1.100        0.74       -4.83        8.86
      1.250       11.36        4.02       16.20
      1.500       18.29       13.03       23.05
      1.750       22.65       17.69       27.67
      2.000       25.93       20.95       31.31
      5.000       43.87       37.17       52.18
     10.000       55.56       46.97       66.50
     20.000       66.73       56.33       80.31
     50.000       81.16       68.30       98.19
    100.000       91.97       77.25      111.62
    200.000      102.73       86.17      124.99
    500.000      116.93       97.80      142.81
   1000.000      127.66      106.57      156.11
```

```
Annual Maximum Bengello Beach Accretion (Gumbel)

 Recurrence   Exp parameter    Monte Carlo 90% quantile
   interval      quantile          probability limits
     yrs
 ------------------------------------------------------
      1.001        0.44       -4.30        3.89
      1.010        4.35        0.34        7.35
      1.100       10.69        7.59       13.24
      1.250       14.56       11.76       17.05
      1.500       18.26       15.52       20.95
      1.750       20.77       17.98       23.68
      2.000       22.72       19.81       25.88
      5.000       33.70       29.52       38.81
     10.000       40.98       35.74       47.64
     20.000       47.95       41.54       56.12
     50.000       56.98       48.97       67.23
    100.000       63.75       54.61       75.52
    200.000       70.49       60.21       83.81
    500.000       79.38       67.55       94.79
   1000.000       86.10       73.06      102.99
```

Annual Maximum Narrabeen Beach Erosion (Gumbel)

```
 Recurrence   Exp parameter    Monte Carlo 90% quantile
   interval      quantile          probability limits
     yrs
 ------------------------------------------------------

     1.001          3.90       -6.75        11.89
     1.010         13.88        4.77        20.84
     1.100         30.07       22.94        36.09
     1.250         39.93       33.42        45.86
     1.500         49.37       42.87        55.76
     1.750         55.80       49.13        62.66
     2.000         60.76       53.83        68.16
     5.000         88.80       78.97       100.60
    10.000        107.36       95.17       122.43
    20.000        125.16      110.35       143.86
    50.000        148.20      129.70       171.35
   100.000        165.47      144.39       192.11
   200.000        182.67      158.99       212.71
   500.000        205.37      178.18       239.99
  1000.000        222.53      192.67       260.59
```

Annual Maximum Narrabeen Beach Accretion (Gumbel)

```
 Recurrence   Exp parameter    Monte Carlo 90% quantile
   interval      quantile          probability limits
     yrs
 ------------------------------------------------------
     1.001         13.11        4.63        19.42
     1.010         20.53       13.29        25.96
     1.100         32.56       27.09        37.06
     1.250         39.89       34.98        44.29
     1.500         46.91       42.08        51.64
     1.750         51.68       46.75        56.81
     2.000         55.37       50.23        60.98
     5.000         76.20       68.71        85.37
    10.000         90.00       80.45       102.05
    20.000        103.23       91.41       118.08
    50.000        120.35      105.69       138.94
   100.000        133.19      116.39       154.62
   200.000        145.97      127.03       170.22
   500.000        162.84      140.95       190.78
  1000.000        175.59      151.48       206.42
```

Appendix 12: Draft paper for NSW Coastal Conference

28TH ANNUAL
NSW Coastal Conference

EXAMINING STORMS WITHIN THE HISTORICAL RECORD

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Abstract

Storms will drive erosion of beaches during the forecast increase in sea level because of global warming over the remainder of the century. To best understand how storms may behave in the future, it is important to understand trends in past storms. This research examines the interplay between the frequency and magnitude of storms within the historical record by compiling and examining records of wave data from two different sites along the New South Wales Coast. The main objectives of this study are to present and provide a cursory storm analysis of an extensive dataset complied from a 34- and 46-year wave buoy dataset from Batemans Bay and Port Kembla. Within the wave rider buoy records, differences in the quantity, peak significant wave height, duration and period of moderate to extreme storms were noticed on the seasonal scale in addition to an increasing occurrence of severe events (Hsig 5-6m) which have appeared throughout the record since 2000. The implications of this study will highlight trends in storm events and changing storm frequency relationships seen throughout the early 21st century.

Introduction

The Australian coastline consists of a multitude of beaches that have undergone and will continue to undergo volumetric changes in response to coastal storms. The temporal characteristics of coastal waves and extreme events have been previously examined by Shand et al. (2010; 2011). These studies have detailed the seasonal variations examined within wave characteristics along the wave rider buoy network of the Australian East Coast as well as the average recurrence intervals of extreme events within these records. While Shand et al. (2010; 2011) has previously examined wave characteristics and the occurrence of extreme events, further analysis of wave rider buoy data is required to explore different parameters. By examining the seasonal, yearly, and decadal trends in storm occurrence, severity, duration and period, an understanding of how storms will increasingly influence beaches will be ascertained. Due to the occurrence of climatically induced sea level rise and increased storm severity and frequency, the need for these results is further heightened as it will aid the planning and prevention of damage due to these events.

The impacts of climate change (most notably the thermal expansion of ocean water and the melting of ice sheets, glaciers and ice caps) the volume of sea water contained in ocean basins will increase thus leading to sea level rise (Mimura., 2013). As seen in Figure 1, the IPCC predicts a global mean sea level rise by 2100 ranging from an average of 40cm in RCP2.6 to 62.5cm in RCP8.5 (Church et al., 2013). Furthermore, sea level rise will affect the recurrence interval of extreme coastal events with Oppenheimer et al. (2019) claiming storms that occur once every hundred years during current climatic conditions could potentially occur annually (Oppenheimer et al., 2019). This increase alone will enable storm waves to erode further inland, exacerbating landward retreat along some coasts.

In addition to sea level rise, the frequency and severity of storms will also be affected by climate change. At a localised scale, warmer temperatures will cause an increase in the activity of small scale convective systems along the coast, leading to more intense winds and rain, as well as an intensification of east coast lows and extreme wave conditions (Department of Climate Change., 2009). At a larger scale, sea level rise will elevate the platform for storm surges, tides, and waves. This elevation will subsequently escalate the impacts of extreme events as well as compound otherwise minor events to ultimately cause increased damage to coastal infrastructure. (Bruyère et al., 2019; Leonard et al., 2014; Oppenheimer et al., 2019; Tonmoy and El-zein., 2018). With climate change having such a potentially adverse effect on coastal processes, it is important to understand how storms have occurred in the past in order to best determine how they may change in the future. This is particularly important to inform best practice management plans that mitigate their impacts due to global warming.

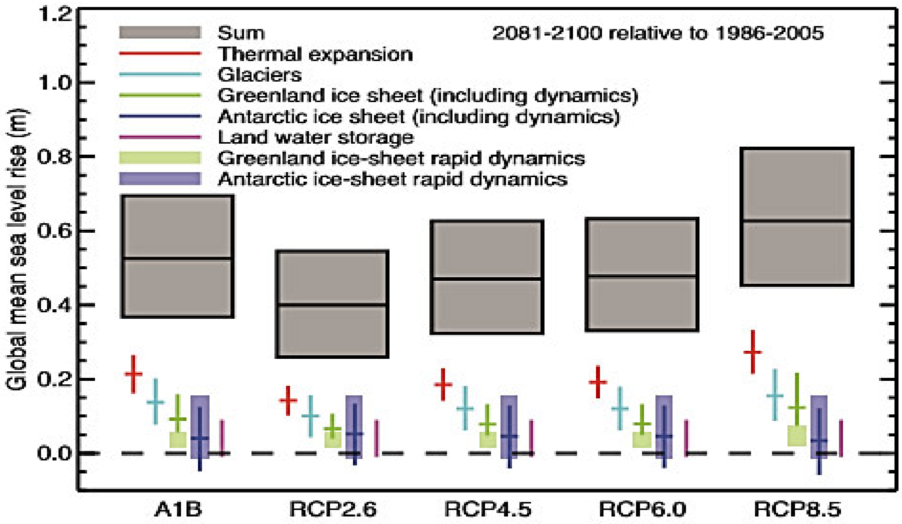


Figure 1: Five scenarios of global mean sea level rise for 2081-2100. A1B is a balanced emphasis on all energy sources while RCP2.6 to RCP8.5 represent the lowest greenhouse gas emission scenario to the highest. Sourced from Church et al. (2013).

The aim of this paper is to present wave rider buoy data compiled from Port Kembla (1974-2020) and Batemans Bay (1986-2020) in order to extract and examine the preserved storm record:

a) Conduct an analysis on wave rider buoy data Port Kembla and Batemans Bay to determine storms characteristics.
b) Plot the storm data to compare trends.

Through the completion of these objectives, the project seeks to understand the temporal trends exhibited by storms as it will it allow preparations to be enacted to combat the impacts of these erosive events.

Background

Australian climatic influences

Australia’s climate is affected by a series of climatic influences that have varying levels of impact on different regions throughout various temporal scales (ie weeks to decades). Some of the most notable climatic influences to affect Australia are the El Nino Southern Oscillation (ENSO), the Southern Annular Mode (SAM), the Pacific Decadal Oscillation (PDO), the Interdecadal Pacific Oscillation (IPO), the Indian Ocean Dipole (IOD) and the Sub Tropical Ridge (STR) and the location of origin for most of these forces can be seen can be seen in Figure 2.

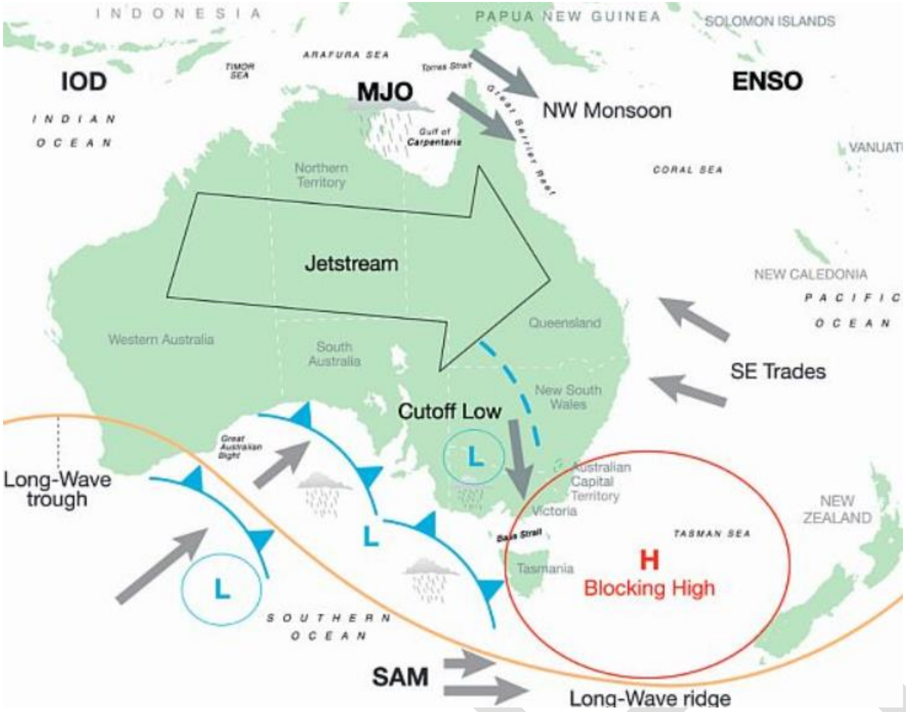


Figure 2: The location of origin of various climatic influences affecting Australia. Not shown are the IPO, PDO and STR. (Sourced from Risbey et al., 2008)

Australian climatic influences from the Pacific Ocean

In the Pacific Ocean, the dominant climatic influences are ENSO, PDO and IPO. The stages in ENSO, termed EL Nino, La Nina and ENSO neutral, are determined by variations in the Southern Oscillation Index (SOI) which is defined by the sea level pressure difference between the Indonesian low and South Pacific Subtropical High (Suppiah, 2004). El Nino events are associated with higher sea surface temperatures (SST) in the central and eastern Pacific Ocean with higher than average surface pressure (SP) around the north east of Australia and lower than average pressure in the central Pacific (Suppiah, 2004). Contrasting to El Nino, La Nina events are associated with a higher SST in the western Pacific Ocean with lower than average SP around the north east of Australia and higher than average SP in the central Pacific (Bureau of Meteorology n.da; Suppiah, 2004). ENSO events typically persist for periods of 6-18 months (Mantua and Hare, 2002).

While the PDO and IPO are similar to ENSO in the sense they influence the SP and SST of the Pacific Ocean, they differ in spatial and temporal influence. Both the PDO and IPO occur on an interdecadal temporal scale with the IPO being noted as a Pacific wide manifestation of the PDO (Mantua and Hare, 2002; Pui et al., 2011).

Australian climatic influences from the Indian Ocean

In the Indian Ocean, the dominant climate influence is the Indian Ocean Dipole and it is determined by the difference between SST and SP of the west and east Indian Ocean (Bureau of Meteorology n.db). During a positive IOD, SST around Indonesia are cooler than average causing an increase in SP in the region while during a negative IOD, SST around Indonesia are warmer than average causing a decrease in SP in the region (Bureau of Meteorology n.db). The IOD is also noted as having an interplay with ENSO with positive a IOD reinforcing an El Nino event while a negative IOD reinforces a La Nina event (Bureau of Meteorology n.db). IOD events typically persist on a monthly to seasonal scale (Bureau of Meteorology n.db).

Australian climatic influences from the Southern Ocean

In the Southern Ocean, the Southern Annular Mode influences the north south movement of strong westerly winds that are prominent in the mid to high latitudes of the southern hemisphere (Bureau of Meteorology, n.dc). During a positive SAM, a higher SP and temperature is present in the mid latitudes while during a negative SAM a higher SP and temperature is present in the high latitudes (Lim et al., 2016). SAM events typically persist on a weekly to monthly scale (Bureau of Meteorology n.dc).

Other Australian climatic influences

The Sub Tropical Ridge influences the intensity of the cold fronts that impact Australia through its positioning and intensity (Bureau of Meteorology, n.dd; Timbal and Drosdowsky, 2013). While the STR is a continuous climatic influence, its positioning can deviate in accordance with the temperature and subsequently alter its influence on cold fronts. During warmer periods of the year, the STR is positioned further south of the Australian continent thus decreasing the intensity of cold fronts that affect southern Australia while during colder periods, the STR is positioned over central Australia thus allowing cold fronts to affect southern Australia to a greater extent (Bureau of Meteorology, n.dd). Changes in the intensity of the STR are also noted as influencing the Australian climate with past periods of rainfall deficiency coinciding with periods of an intensified STR (Timbal and Drosdowsky, 2013).

Impact of climate change on Australian climatic influences

Anthropogenic climate change impacts the occurrence and severity of the climatic influences that effect Australia. Extreme ENSO events are forecast to occur more frequently (Muis et al., 2016), the SAM has been found to occur in a positive trend (Wang and Cai, 2013), the STR has also been found to have an increased intensity (Bureau of Meteorology, 2017a) and the back to back occurrence of positive IOD events have been identified and are forecast to happen more frequently (Cai et al., 2009). Due to these variations to Australia's climatic influences, climate change will likely increase the effect storms play on coastal erosion.

Storms

From the 25th- 26th of May and the 8th-14th of June 1974, two separate, closely spaced storm events occurred which caused substantial damage along the NSW coastline (Doyle et al., 2019; Lord and Kulmar, 2000). The effects of these events, in combination with the impacts of the events occurring on the 18th –20th March, 31st May–2nd June, 15th –16th June, and 18th –21st June 1978 have left erosion scarps still visible at many locations along the coast (Doyle et al., 2019; Lord and Kulmar, 2000). As a result of these events, most notably the 1974 storms, it was realised that a lack of data existed for the scope and frequency of severe coastal storms events. Subsequently, a network of seven waverider buoys and six tide gauge recorders were established with the locations shown in Figure 3 (Lord and Kulmar, 2000).

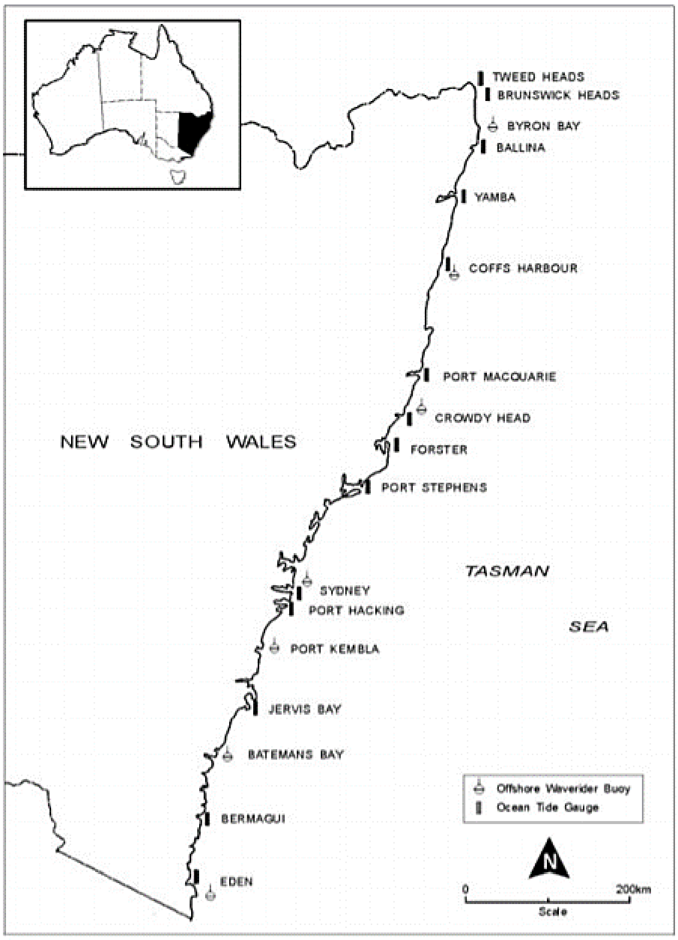


Figure 3:The location of the waverider buoys and ocean water level stations maintained by the Manly Hydraulics Laboratory in NSW. Sourced from Lord and Kulmar, 2000.

Defining a storm event

Glatz et al. (2017) defined a storm event as an event where the significant wave height, the mean wave height of the highest third of the waves in a record, exceeds 3m for at least 1 hour. For events exceeding 1 hour in duration, Glatz et al. (2017) determined the significant wave height by calculating the maximum value exceeded by n consecutive records during an event of n duration. While events with a significant wave of less than 3m were not included in the analysis, it is recognised that during some storm events, the significant wave height may drop below this threshold before once more exceeding it. In this situation, if less than 24 hours has elapsed before regaining a significant wave height greater than 3m and if the storm was clearly part of an individual weather system, the separate episodes were considered as a single event (Glatz et al., 2017).

Previous storm studies

Previous studies of coastal storms along the NSW coastline have demonstrated spatial and temporal trends across the record. As outlined in Shand et al. (2010), on a seasonal basis, the significant wave height is found to have substantial variation along the coast. In the north, larger waves occur during the autumn with lower waves occurring during the spring and summer while in the south, wave heights are a lot more consistent. Like the trends in significant wave height, the mean peak wave direction in Shand et al. (2010) was also found to have spatial and temporal differences. Mean peak wave direction is found to occur with a more easterly direction at the northern buoys or during summer and from a more southerly direction at the southern buoys or during winter. While the mean peak wave period in Shand et al. (2010) is found to exhibit similar seasonal variations to the other wave characteristics, with autumn and winter having increased periods and spring and summer having reduced periods, the spatial trend does not hold with periods remaining relatively consistent across the coast.

To determine the likelihood of large, low probability wave events occurring, an average recurrence interval (ARI) is calculated by fitting a theoretical distribution to the historical wave data (Shand et al., 2011). With the addition of several major storms to the record between 2010 and 2017, the importance of regularly updating the extreme value analysis is evident with these severe events defining the tail of the data distribution (Glatz et al., 2017). It is noted in Glatz et al. (2017) that the extreme significant wave heights and the respective recurrence intervals that were previously determined by WRL (2010) have now increased due to the occurrence of these additional severe events, with the increase most substantial at Eden.

Methods

Study Sites

A wave rider buoy at Batemans Bay was used to examine the wave characteristics. In addition to this, a wave rider buoy at Port Kembla was used due to the length of the record, it records the characteristics of the 1974 and 1978 storm events. The locations of both buoys are seen in Figure 4a and 9b.

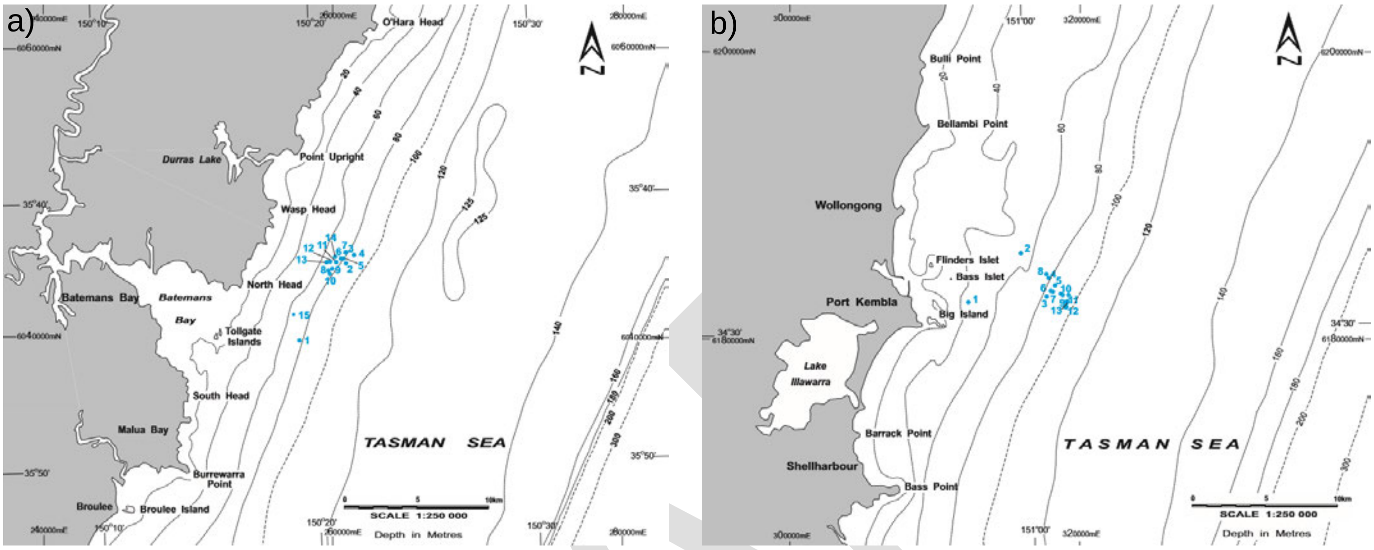
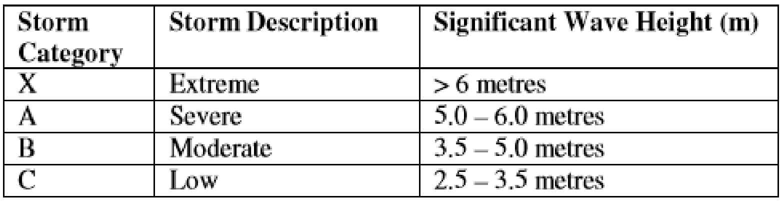


Figure 4: a) The various locations of the Batemans Bay Waverider Buoy. b) The Various locations of the Port Kembla Waverider Buoy

Selection of storms

In order to conduct a selection of storm events, significant wave height (Hsig), which is the mean wave height of the largest 33% of waves (Glatz et al., 2017), was examined from wave rider buoys off the coast of Batemans Bay and Port Kembla. The waverider buoy data found at Batemans Bay covered the period from 27/5/1986 16:00 until 1/8/20 0:00 and the waverider buoy data found at Port Kembla covered the period from 7/2/1974 12:00 until 1/8/20 0:00. A storm event in this analysis is defined as an event where the Hsig exceeds 3.5m for at least one hour. Initially the storm classification threshold was set at 2.86m, which is twice the average Hsig over the entire Batemans Bay record. The threshold was then increased to 3m as used in the storm selection methodology of Glatz et al. (2017). The threshold was then further increased to 3.5m Hsig based on the classification of a moderate storm as seen in Table 1.

Table 1: Storm Severity Classification (NSW)



Storm Category	Storm Description	Significant Wave Height (m)
X	Extreme	> 6 metres
A	Severe	5.0 – 6.0 metres
B	Moderate	3.5 – 5.0 metres
C	Low	2.5 – 3.5 metres

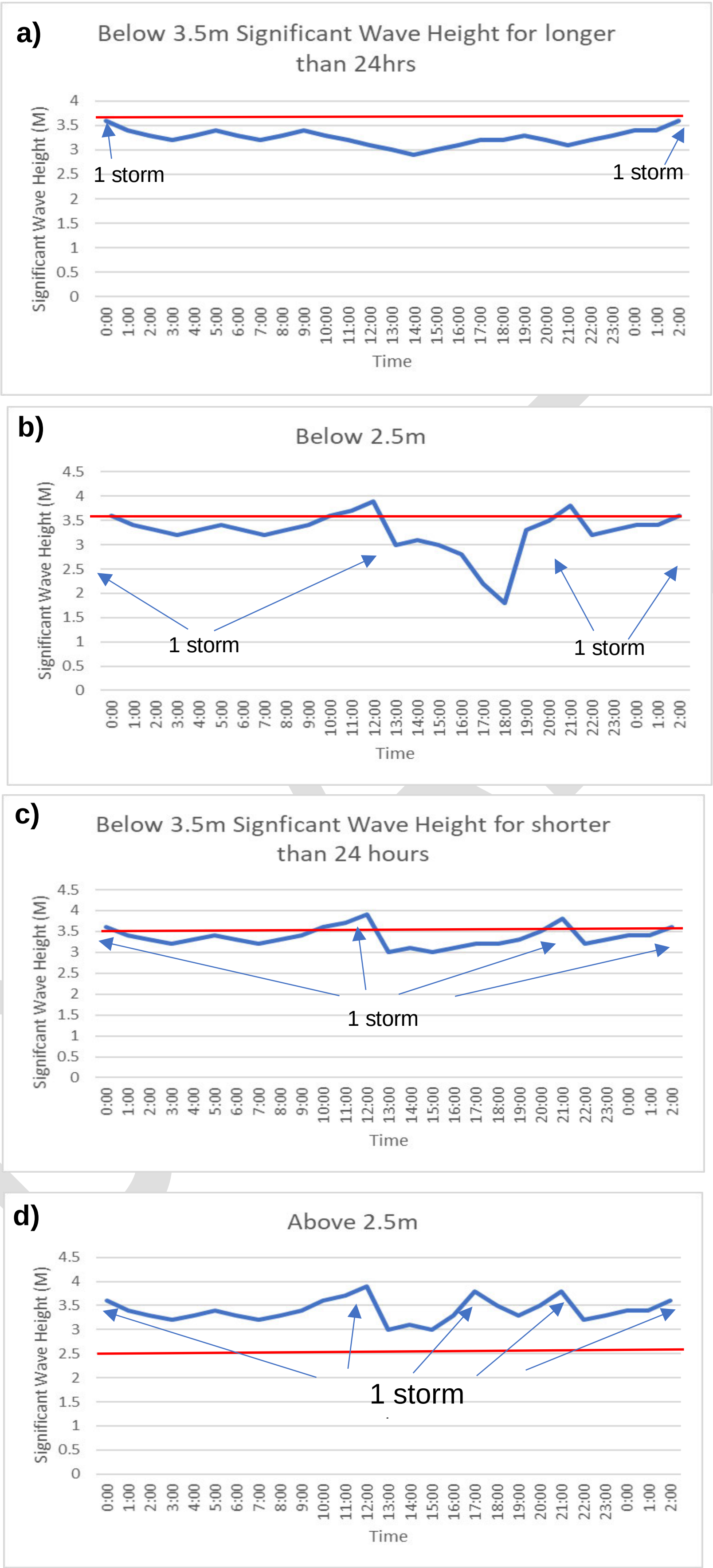


Figure 5: a) Both instances of Hsig exceeding 3.5m are separated by 24 hours where Hsig is less than 3.5m and thus they are classified as separate storms. b) The instances of Hsig exceeding 3.5m are separated by a Hsig less than 2.5m and thus they are classified as separate storms. c) Hsig does not drop below 3.5m for longer than 24 hours and thus all instances of exceedance are classified as the same storm. d) Hsig does not drop below 2.5m and thus all instances of exceedance are classified as the same storm.

While events classified as low severity (2.5 m < Hsig < 3.5 m) were not included in the analysis, it is recognised that during events with a longer duration, the Hsig may drop below 3.5m for a period of time before once more exceeding this threshold. In this instance, if the Hsig drops beneath 3.5m for longer than 24 hours or drops below 2.5m during that same period before once more exceeding 3.5m, the data will be considered as multiple storm events as seen in Figure 5a and b. Contrasting to this, if the Hsig drops beneath 3.5m for shorter than 24 hours and stays above 2.5m during that same period before exceeding 3.5m, the data will be considered a single storm event as seen in Figure 5c and d.

The peak significant wave height, duration, wave period, wave direction, storm severity and season of occurrence for each of these storms were then graphed within Microsoft Excel in an effort to find any trends at a seasonal, yearly and decadal scale. This data has also been included in Appendix 2 and 3 with peak significant wave height, wave period and wave direction being noted to 2 decimal places.

Defining storm clusters

A storm cluster is defined in this study as an event where 3 or more storms with a severity of moderate or greater occur within a period of 30 days.

Results

This section will highlight the results of this study including storm wave characteristics over seasonal, yearly and decadal timeframes. A complete compilation of the storm wave characteristics from both Batemans Bay and Port Kembla are instead included in Supplemental Information (Appendix 2-6). There is also additional analysis including examinations undertaken in order to further explore elements of the data and their accompanying figures are included in the Supplemental Information:

- **Yearly/Decadal Directional Wave Period Trends:** No trend was observed at Batemans Bay or Port Kembla (Appendix 4).
- **Yearly/Decadal Directional Wave Directional Trends:** No trend was observed at Batemans Bay or Port Kembla (Appendix 5).
- **Batemans Bay Wave Direction against Severity:** While moderate waves occurred predominantly from the south and south/south east, severe and extreme waves occurred predominantly from south/south east and more easterly aspects (Appendix 6).

Seasonal storm distribution

Occurrence and severity

When examining the occurrence of storm events on a seasonal scale, a variety of thresholds have been enacted. While initial thresholds used to define a storm of Hsig 2.86m and Hsig 3m noted minor differences Figure 6), the difference in occurrence began to increase upon the thresholds rise to Hsig 3.5m. As seen in Figure 6c at Batemans Bay, there were 84 storms in winter, 57 in autumn, 52 in spring and 43 in summer. As seen in Figure 6d, at Port Kembla, there were 151 storms in winter, 119 in autumn, 108 in spring and 84 in summer.

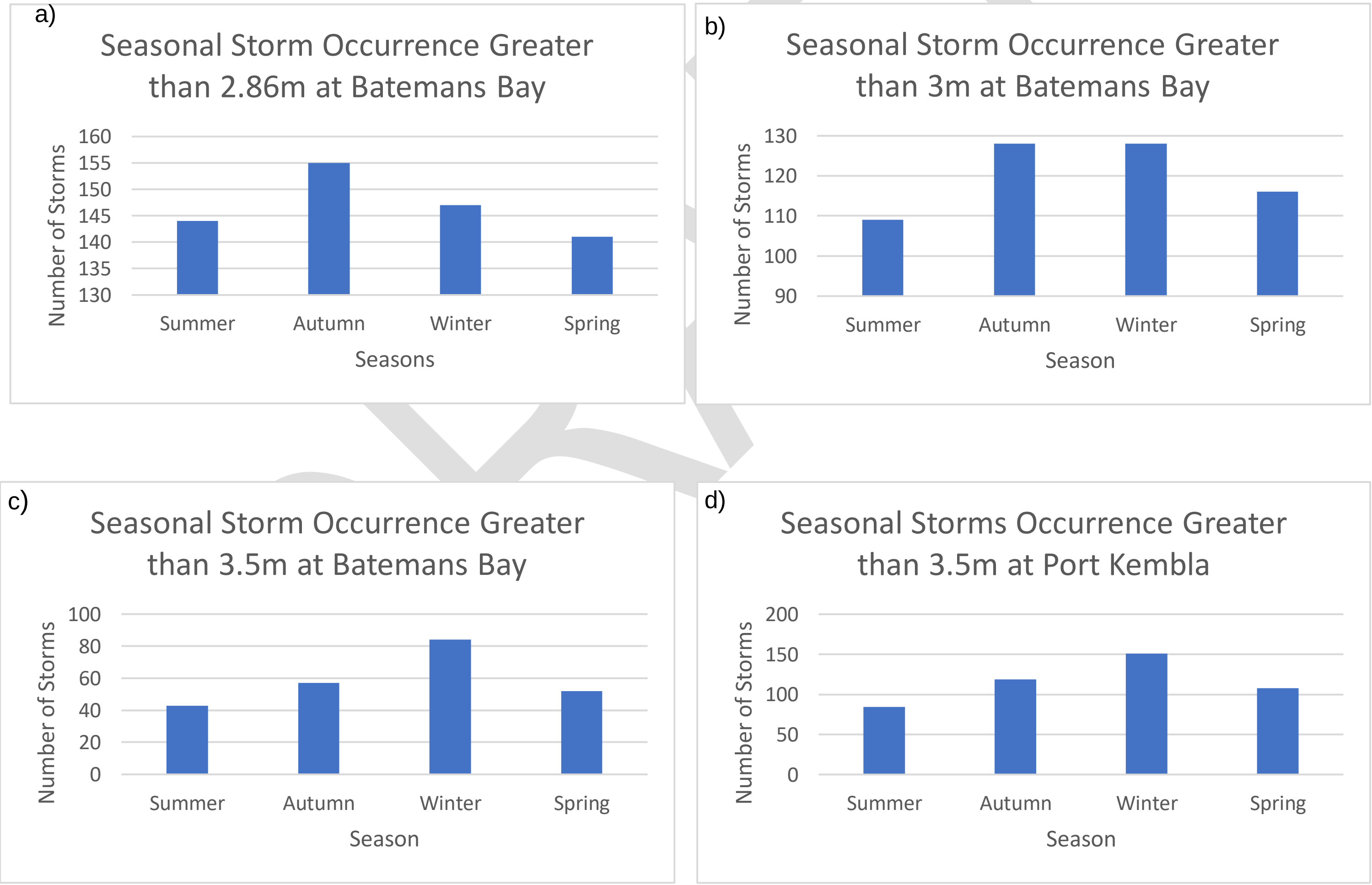


Figure 6: a) The seasonal distribution of storms at Batemans Bay with a Hsig greater than 2.86m. b) The seasonal distribution of storms at Batemans Bay with a Hsig greater than 3m. c) The seasonal distribution of storms at Batemans Bay with a Hsig greater than 3.5m. d) The seasonal distribution of storms at Port Kembla with a Hsig greater than 3.5m. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Of the storms noted to occur over the threshold of Hsig 3.5m at Batemans Bay and Port Kembla in Figure 6c and d, the distribution between moderate (Hsig 3.5-5m), severe (Hsig 5-6m) and extreme severity (6m+) can be seen in Figure 7a and b. As seen in Figure Figure 7a, at Batemans Bay, 19% of the storms occurring during winter, 15% of the storms occurring during spring, 7% of the storms occurring during autumn and 5% of the storms occurring during summer were above moderate severity. As seen in Figure 7b, at Port Kembla, 22% of the storms occurring during winter, 18% of the storms occurring during autumn, 10% of the storms occurring during spring and 6% of the storms occurring during summer were above moderate severity.

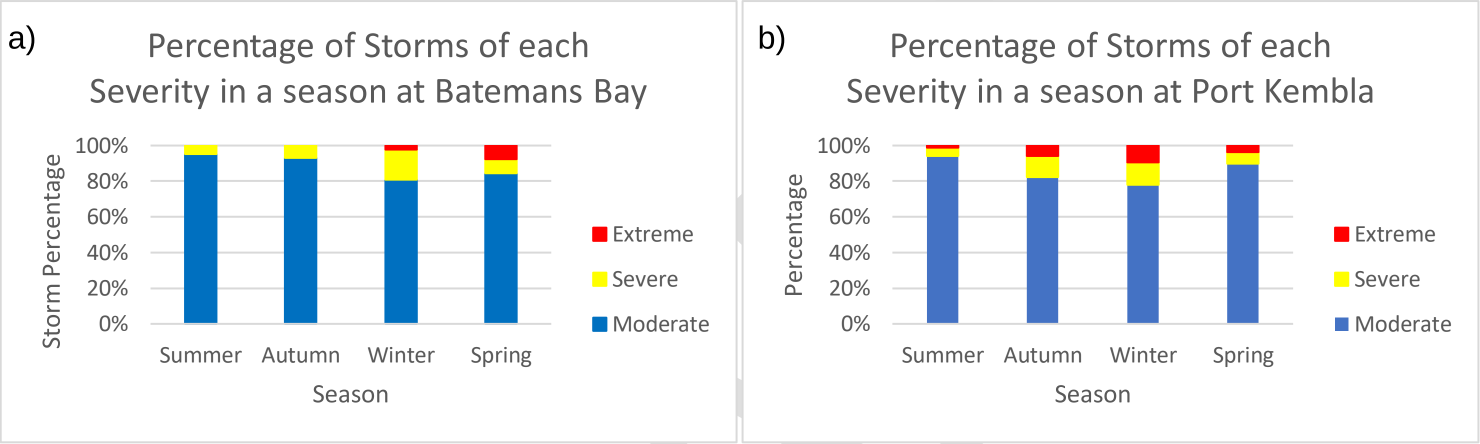


Figure 7: a) Percentage of storms of each severity in a season at Batemans Bay. b) Percentage of storms of each severity in a season at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Duration

When examining the duration of storms exceeding 3.5m Hsig, variations are noted on the seasonal scale. As seen in Figure 8a, at Batemans Bay, 34% of the storms occurring during winter, 21% of the storms occurring during autumn, 19% of the storms occurring during spring and 9% of the storms occurring during summer had a duration longer than 24 hours. As seen in Figure 8b, at Port Kembla, 32% of the storms occurring during winter, 24% of the storms occurring during autumn, 20% of the storms occurring during spring and 12% of the storms occurring during summer had a duration longer than 24 hours.

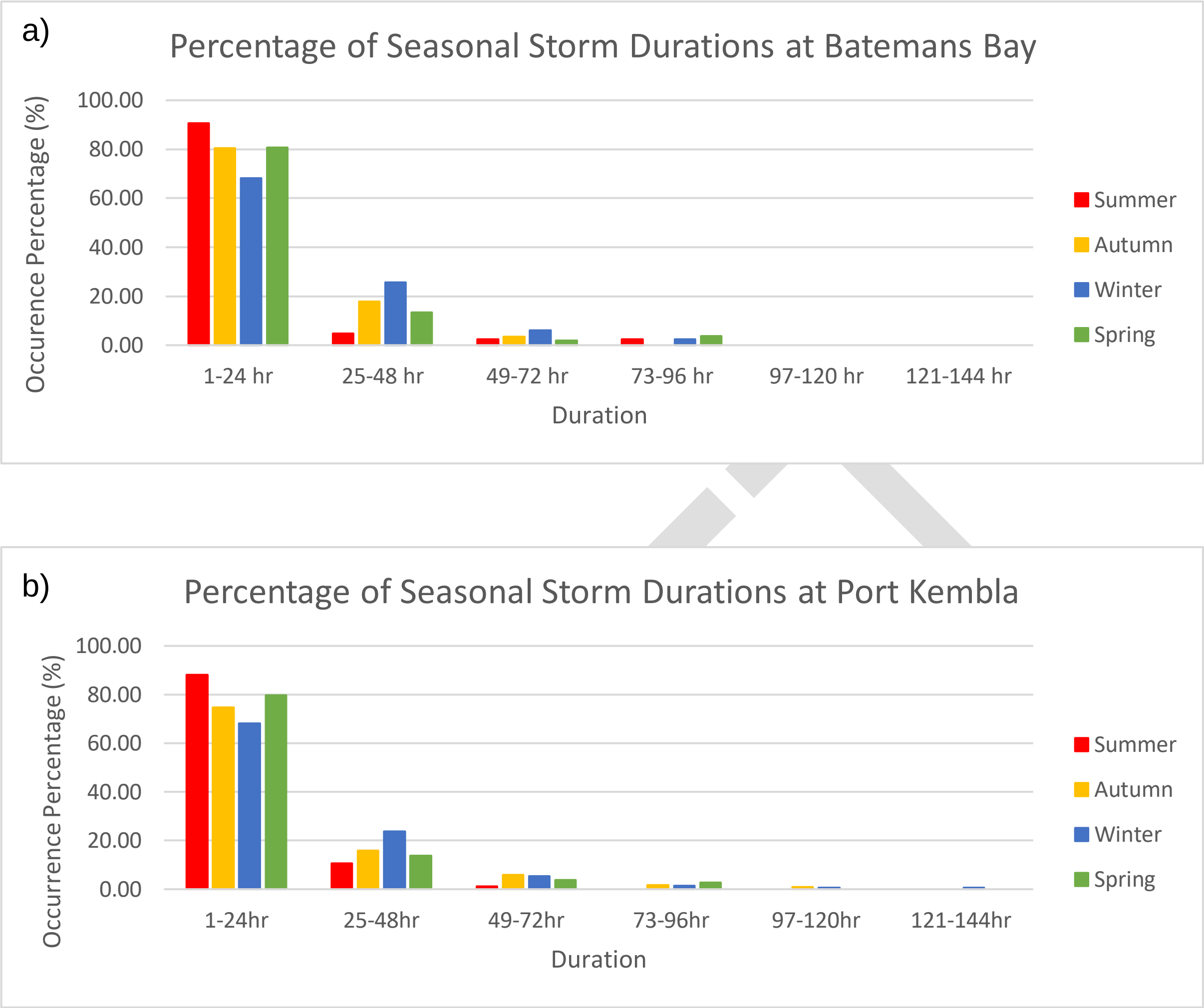


Figure 8: a) Percentage of seasonal storm durations at Batemans Bay. b) Percentage of seasonal storm durations at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Wave period

When examining the wave period of storms exceeding 3.5m Hsig, variations are noted on the seasonal scale. As seen in Figure 9a, at Batemans Bay, 87% of the storms occurring during winter, 69% of the storms occurring during spring, 68% of the storms occurring during autumn, and 49% of the storms occurring during summer had wave periods of 10 seconds or greater. As seen in Figure 9b, at Port Kembla, 82% of the storms occurring during winter, 78% of the storms occurring during autumn, 65% of the storms occurring during spring, and 68% of the storms occurring during summer had wave periods of 10 seconds or greater.

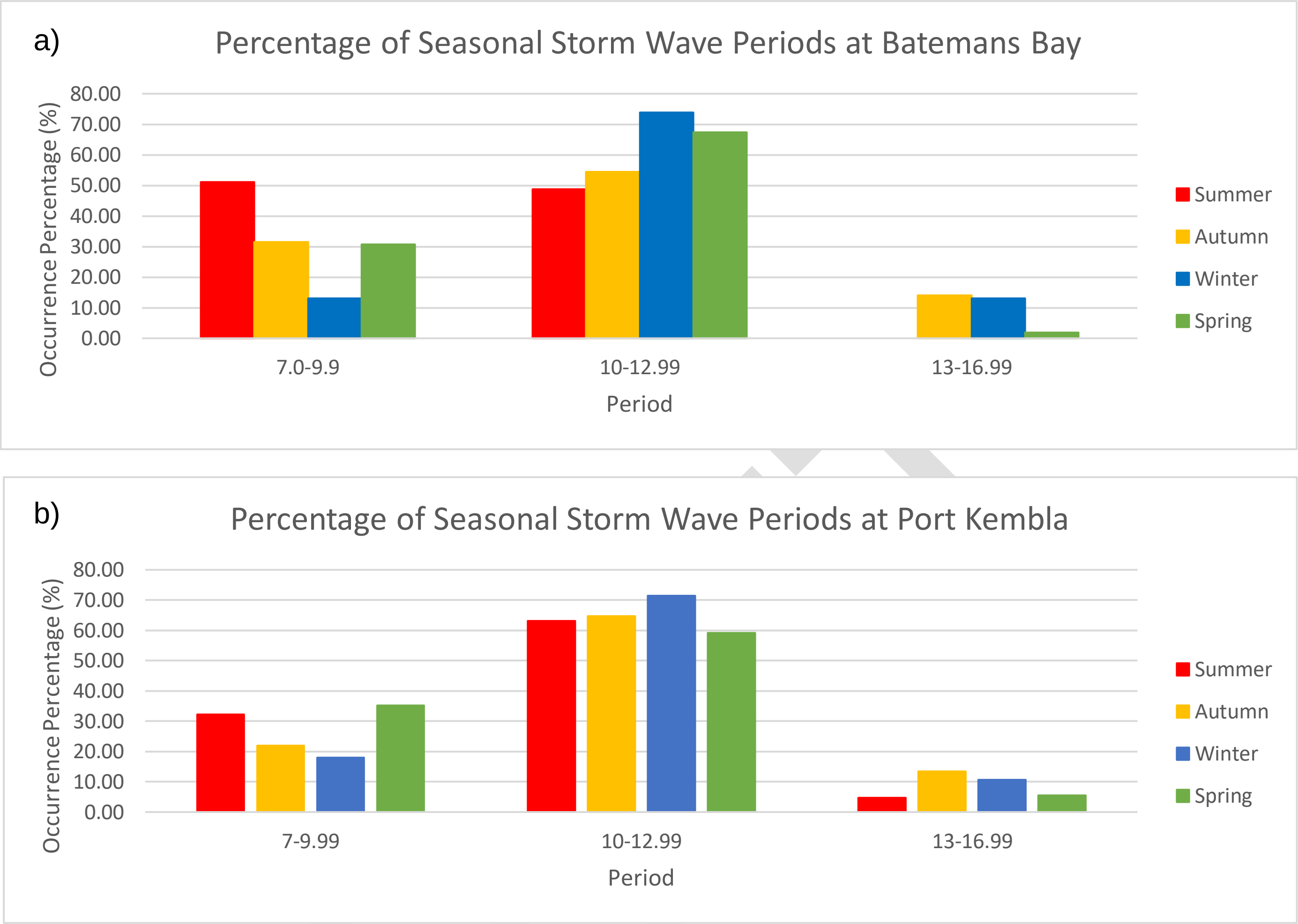


Figure 9: a) Percentage of seasonal storm wave periods at Batemans Bay. b) Percentage of seasonal storm wave periods at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Wave direction

When examining the wave direction of storms exceeding 3.5m Hsig, variations are noted on the seasonal scale. As seen in Figure 10a, of the wave data at Batemans Bay including wave directions, the highest percentage of winter (61%), spring (45%) and autumn (45%) storm waves occurred from the south south east (146.25- 168.75 degrees) while the highest percentage of summer (50%) storm waves occurred from the south (168.75- 191.25). As seen in Figure 10b, of the wave data at Port Kembla including wave directions, the highest percentage of winter (59%) and autumn (55%) storm waves occurred from the south south east while the highest percentage of spring (50%) and summer (47%) storm waves occurred from the south.

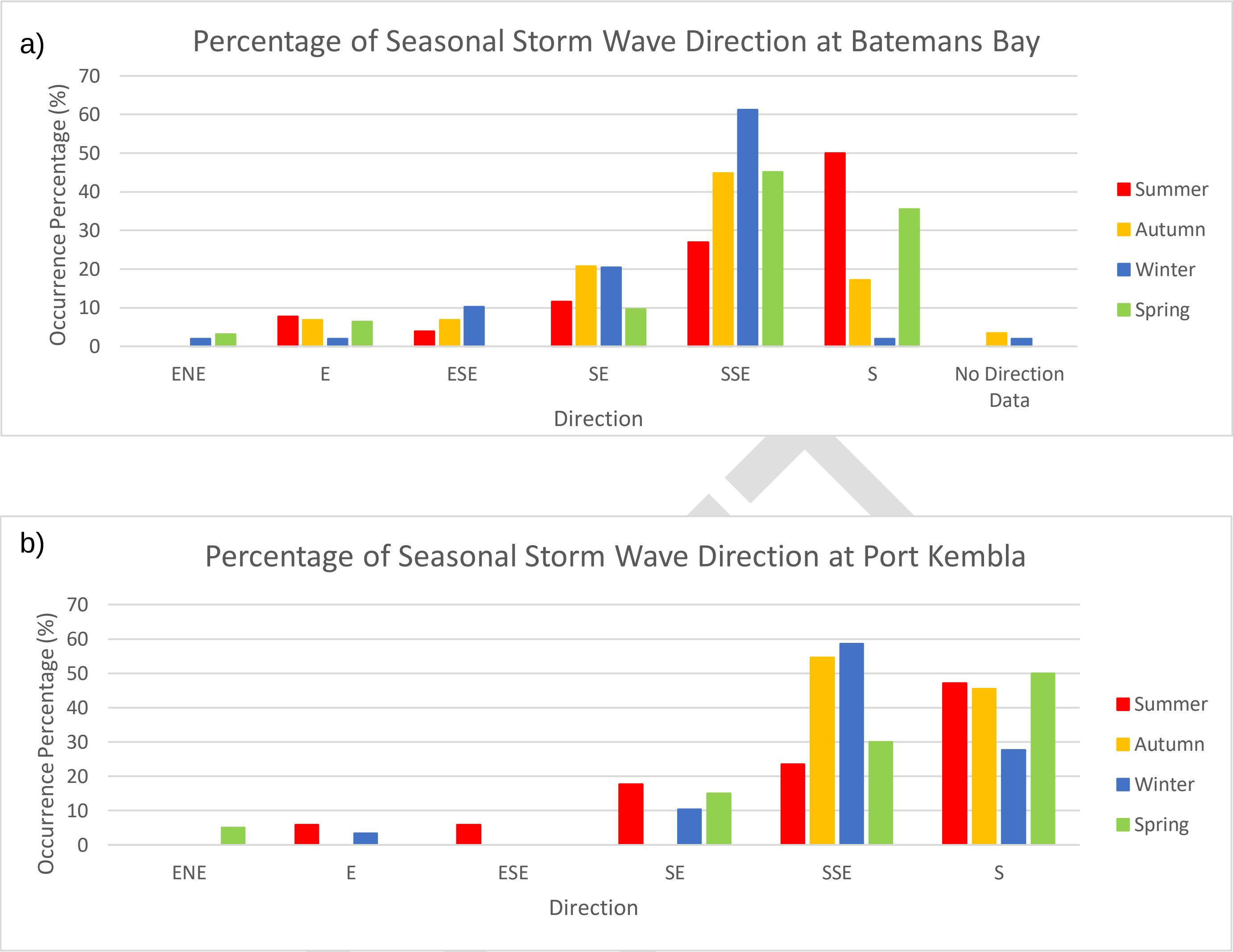


Figure 10: a) Percentage of seasonal storm wave directions at Batemans Bay. b) Percentage of seasonal storm wave directions at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Yearly to decadal storm distribution

Severe and extreme storm occurrence

When examining the occurrence of severe and extreme storms at Batemans Bay and Port Kembla on a yearly to decadal scale, differences are found based on the temporal scale and event severity. While no trends are noticeable in the occurrence of severe and extreme storms on a yearly basis, as seen in Figure 11, when the occurrence of severe storms are taken on a decadal basis, at both sites it is evident that occurrence is increasing throughout time. However, contrasting to the decadal trend observed with severe storms, no consistent increase is observed with extreme storms as seen in Figure 12.

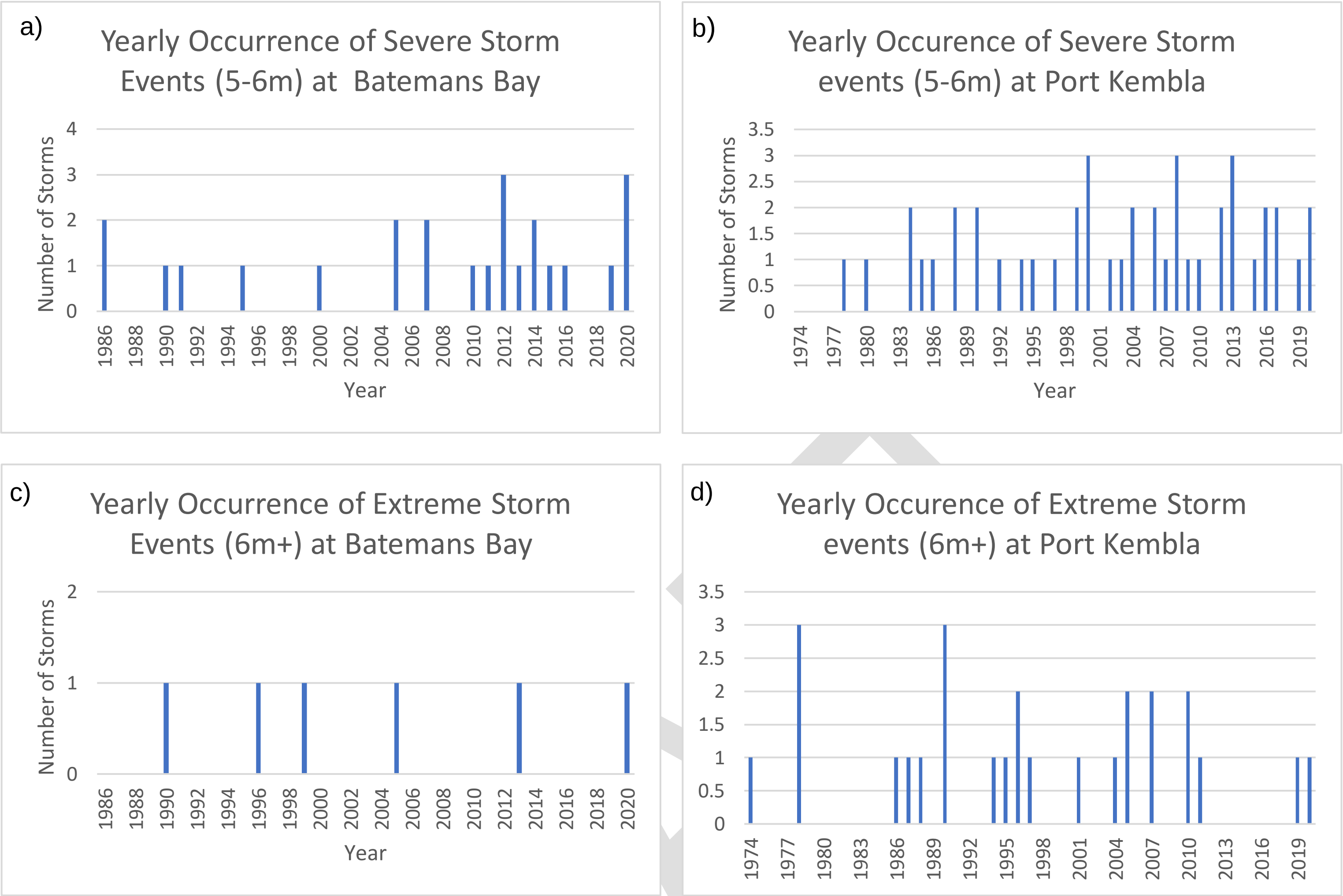


Figure 11: a) Yearly occurrence of severe storm events (5-6m) at Batemans Bay. b) Yearly occurrence of severe storm events (5-6m) at Port Kembla. c) Yearly occurrence of extreme storms (6m+) at Batemans Bay. d) Yearly occurrence of extreme storm events (6m+) at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

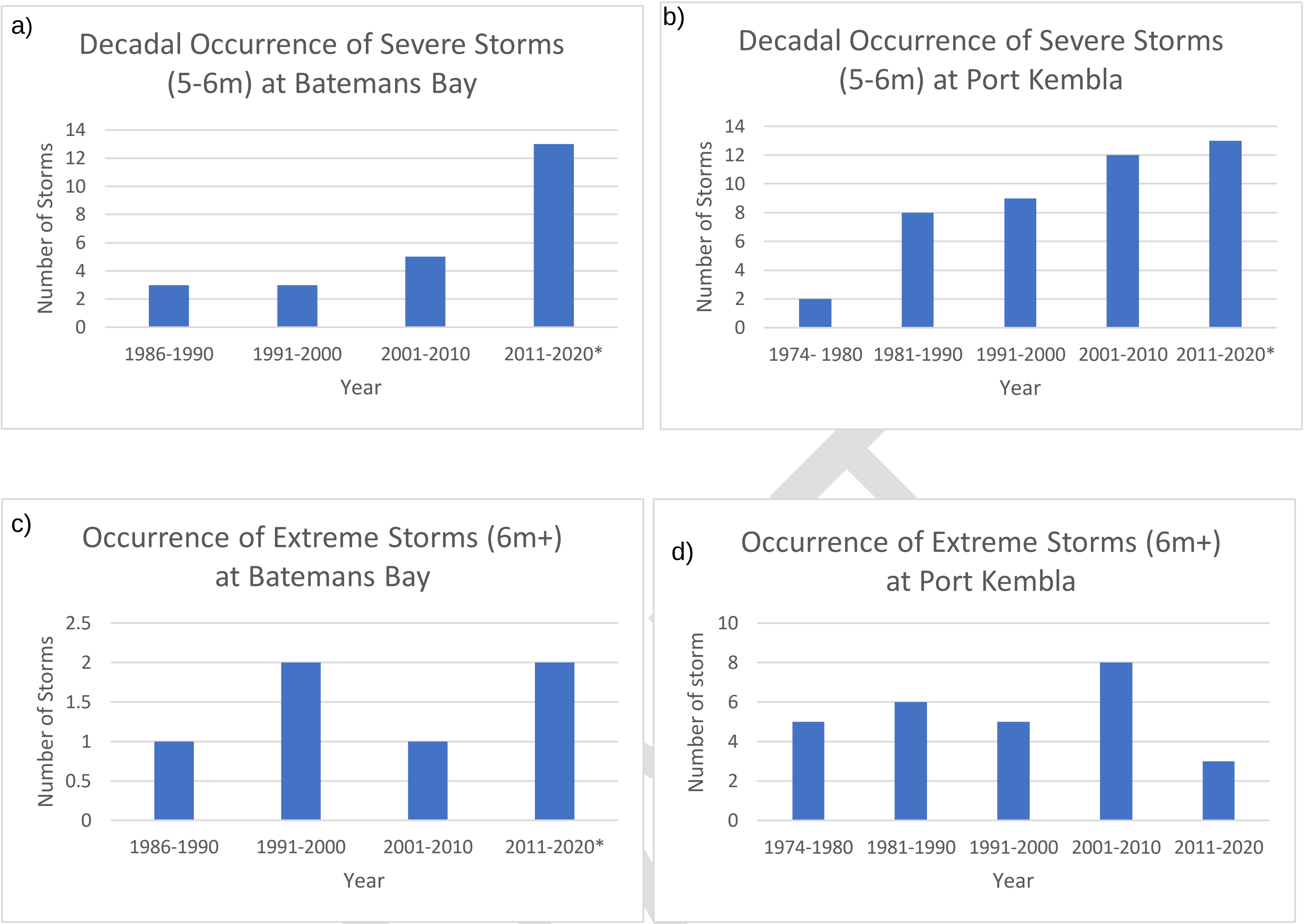


Figure 12 A121: a) Decadal occurrence of severe storms (5-6m) at Batemans Bay. b) Decadal occurrence of Severe Storms (5-6m) at Port Kembla. c) Decadal occurrence of extreme storms (6m+) at Batemans Bay. d) Decadal occurrence of extreme Storms (6m+) at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Percentage of storm severity

When examining the occurrence of severe and extreme events as a percentage of the total yearly storm occurrence, it was found that a higher percentage (>30%) of events were more severe at different intervals between sites. As evident by Figure 13a, at Batemans Bay, every 7-10 years (1986, 1996, 2005, 2012, 2019, 2020) a higher percentage of events were of severe and extreme severity. As evident by Figure 13b, at Port Kembla, every 7-13 years (1978, 1980, 1990, 2000, 2007, 2020) a higher percentage of events were of severe and extreme severity.

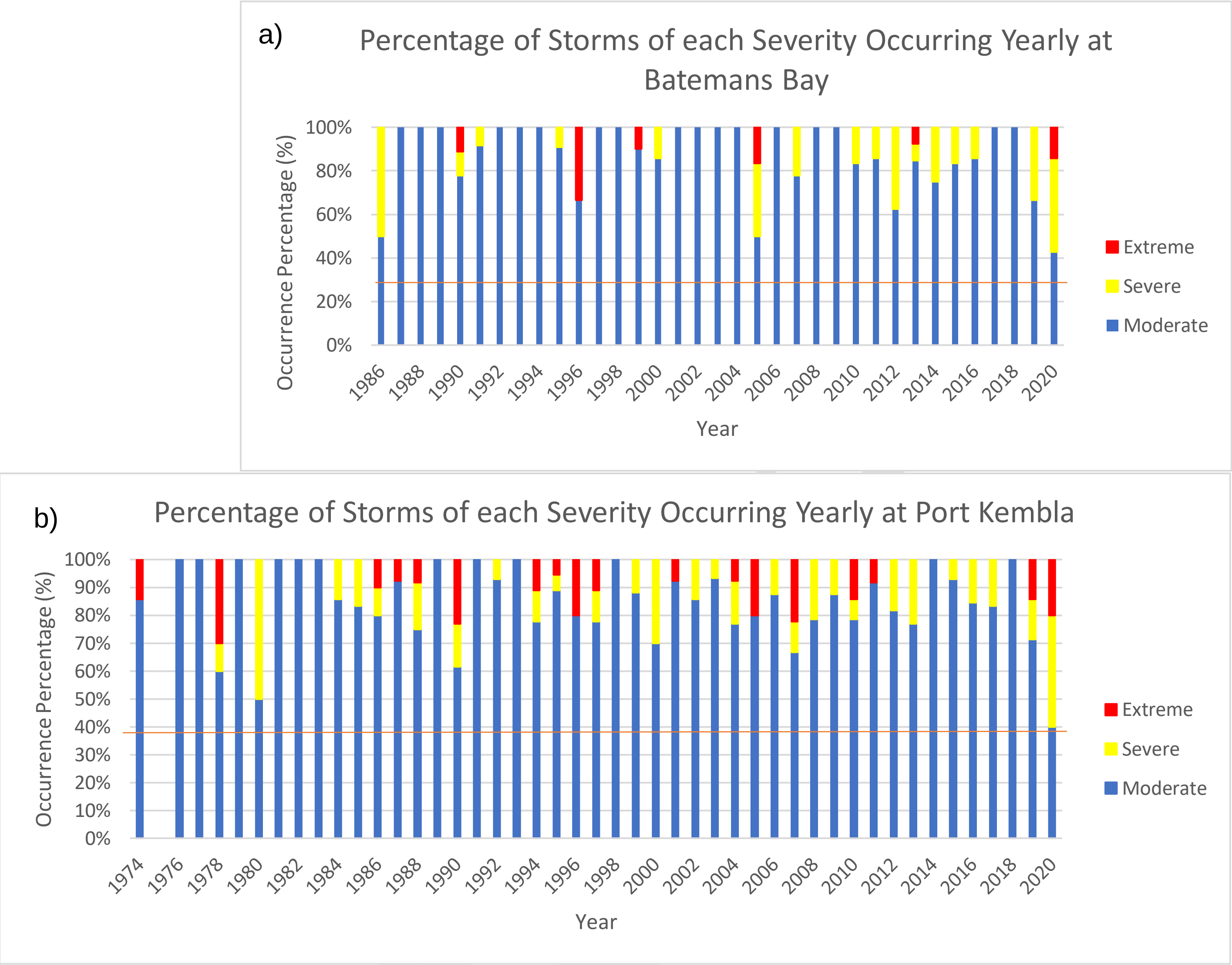


Figure 13: a) Yearly percentage of severe and extreme storms against total storm occurrence at Batemans Bay. b) Yearly percentage of severe and extreme storms against total storm occurrence at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Storm duration

When examining the duration of storm events as a percentage of the various storm durations present during the year, it was found that long duration events (> 72 hours) occurred at different intervals between sites Figure 14. At Batemans Bay, every 5-10 years (1986, 1991, 2001, 2011) an event with a duration longer than 72 hours occurred. As evident at Port Kembla, every 4-10 years (1974, 1978, 1984, 1985, 1986, 1987, 1994, 1995, 1999, 2001, 2011, 2020) an event with a duration longer than 72 hours occurred.

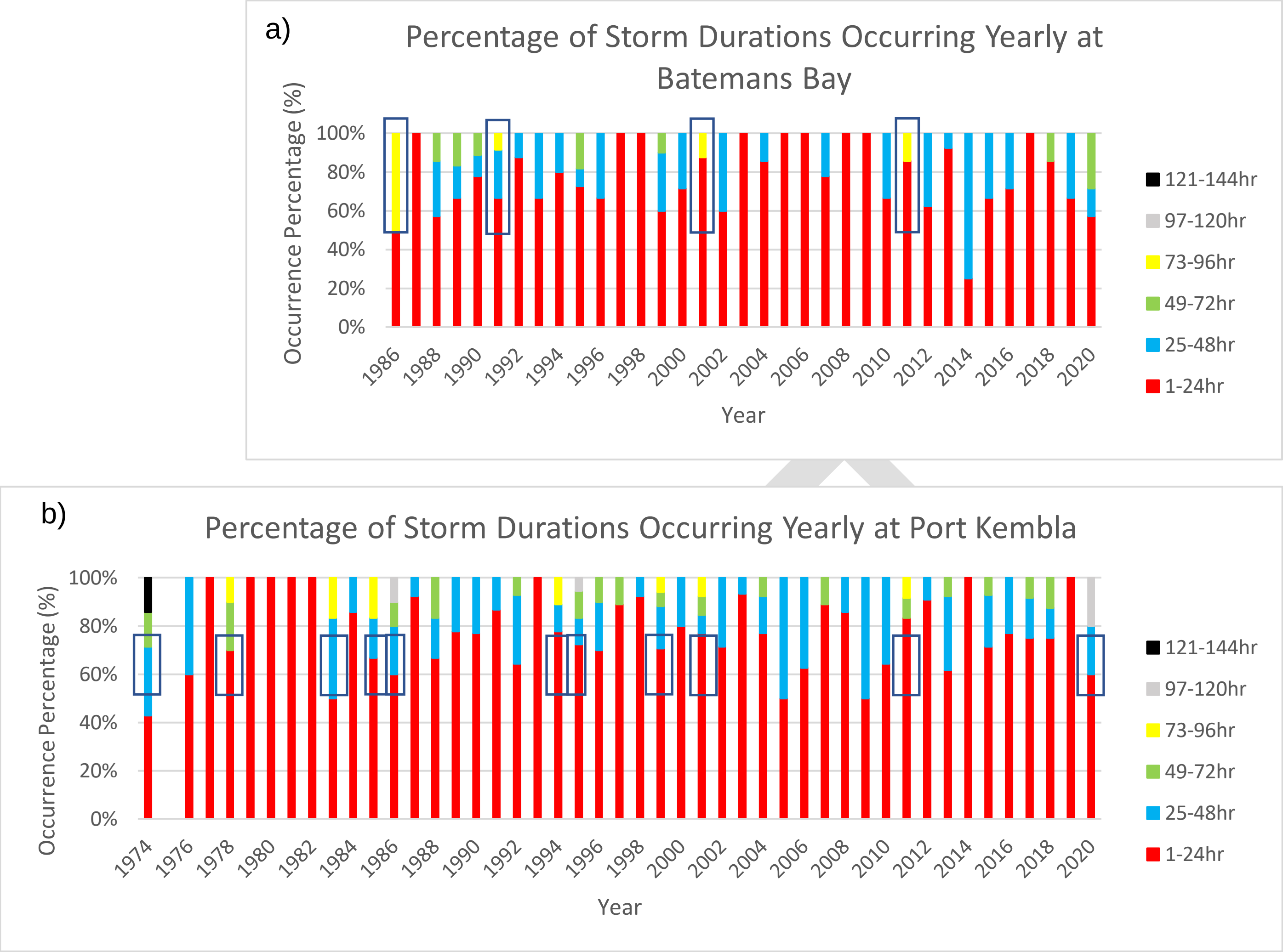


Figure 14: a) Percentage of storm durations occurring yearly at Batemans Bay. b) Percentage of storm durations occurring yearly at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Storm clusters

When examining the storm clustering that occurs at Batemans Bay and Port Kembla, minor differences are observed based on the temporal and spatial scale. While on the yearly scale no apparent trend exists, as seen in Figure 15a-b, storm clustering on the decadal scale appears to experience a gradual increase before plateauing at different periods across the two sites as seen in Figure 15c-d.

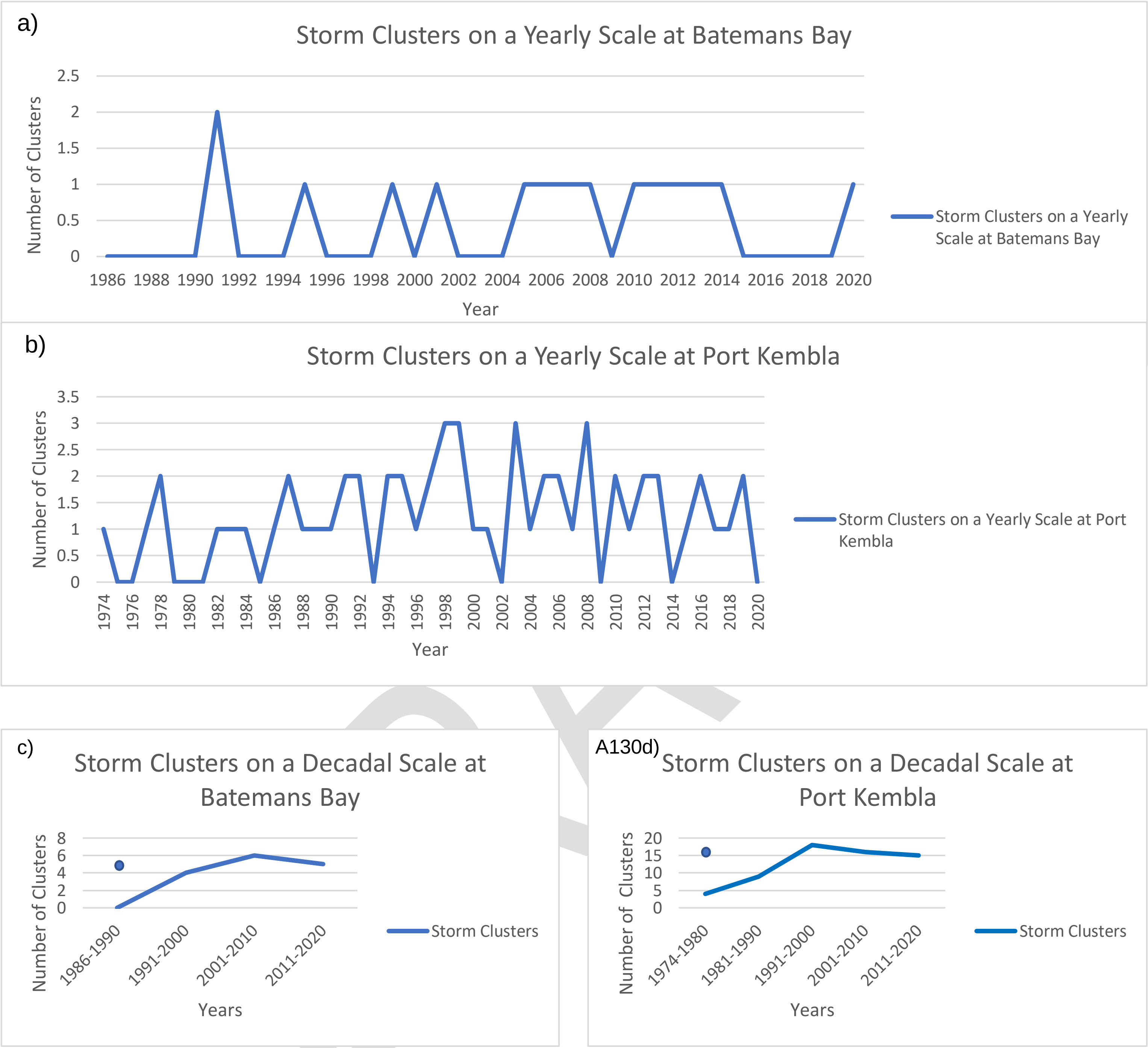


Figure 15: a) Storm clusters on a yearly scale at Batemans Bay. b) Storm clusters on a yearly scale at Port Kembla. c) Storm clusters on a decadal scale at Batemans Bay. d) Storm clusters on a decadal scale at Port Kembla. (Wave data used in this analysis is owned by DPIE and was collected and provided by the MHL)

Discussion

Storm wave characteristics

The seasonal distribution of storms on a local showed winter was the stormiest. At a localised spatial scale, the trends in seasonal storm wave distribution observed in section 5.1 are found to coincide with the total monthly number of storms observed along the NSW coast outlined in Shand et al. (2010). As seen in Figure 16, the winter months are found to be some of the most stormy months with August registering the lowest storm occurrence of ~80 while the summer months are found to be some of the least stormy with February registering the highest storm occurrence of ~75. As can be seen in Figure 16, majority of the storms occurring during winter were southern secondary lows, easterly trough lows and southerly trough lows while majority of the storms occurring during summer were tropical cyclones, southerly trough lows and inland trough lows. At a larger spatial scale, climatic influences were also found to affect the seasonality of wave characteristics. During the Australian autumn and winter, a strong correlation is found to exist between a positive Southern Annular Mode (SAM) and wave heights in the Southern Ocean with increases in wave height and an increased prominence of southerly waves occurring (Hemer et al., 2010; 2011).

Winter was also the season with the greatest occurrence, severity, duration and wave period. The seasonal differences in the occurrence and severity of storms mean that greater storm damage will likely occur during winter in comparison to any other season and the occurrence and severity of storms in autumn and spring may be site dependant. The seasonal differences in storm duration means that storms during winter will more likely impact the coast for a longer duration than any other season and have an increased chance of coinciding with high tide thus causing more damage (Lord and Kulmar 2000). The seasonal differences in the storm wave periods means that greater storm damage will likely occur during winter in comparison to any other season due to the higher likelihood of more energetic waves and that the wave period of storms in autumn and spring may be site dependant. In addition to these effects it is also noted that storms are more likely to occur close to the shore at Batemans Bay during summer and Port Kembla during Spring due to having a higher percentage of wave periods below 10 seconds (Hughes, 2016). The seasonal differences in the storm wave directions means that during each season, beaches of a different orientation will potentially be impacted more or less severely by storms.

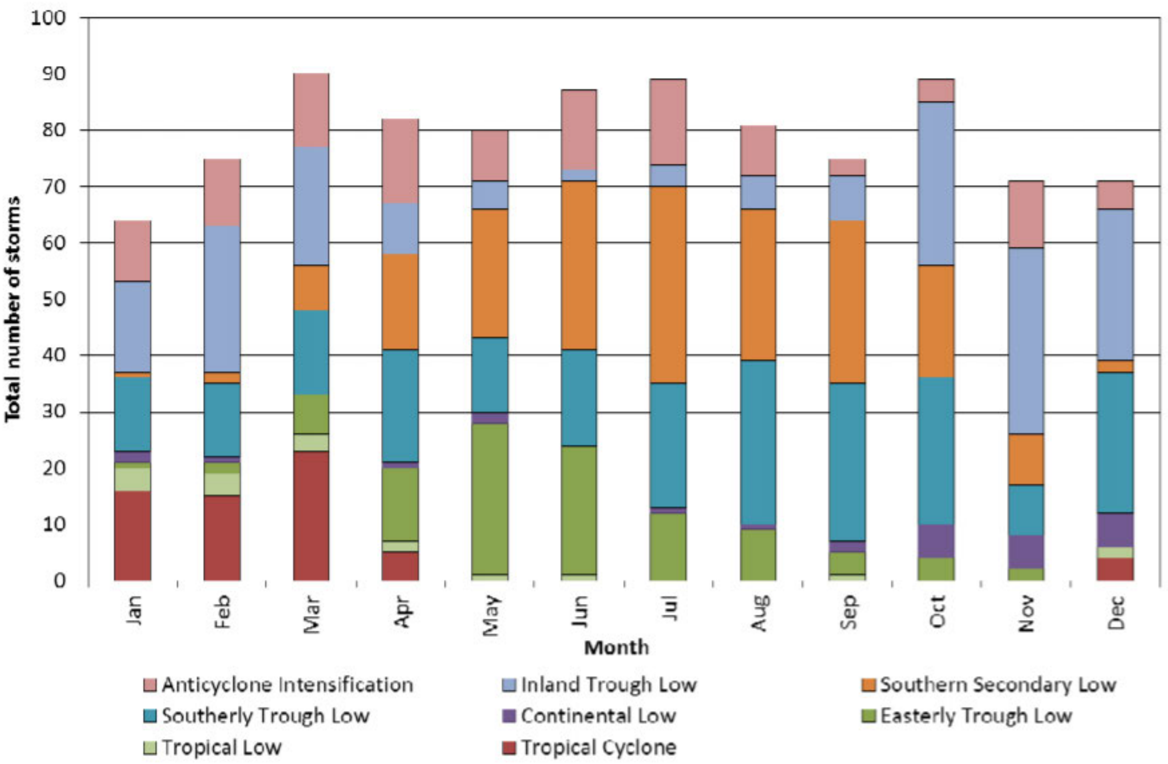


Figure 16: Total Number of Storms Observed along the NSW Coast for Each Month (Sourced from Shand et al 2010)

Yearly to Decadal Storm Distribution

On an interannual scale, the storm trends observed in section 5.2 are likely a caused by the climatic influences effecting Australia such as the SOI and SAM. Variations in the SOI are found to impact storm severity and frequency. During a positive SOI (La Nina), storms were found to occur more often and have a higher severity than during periods of negative SOI (El Nino) (Harley et al., 2010; Shand et al., 2010; You and Lord, 2008). If the SAM is positive during a La Nina phase, its effects on the wave climate can be reinforced whereas if its negative during an El Nino phase, its effects on the wave climate can be reduced (Mortlock and Goodwin, 2016). In addition to storm severity and frequency, SOI is found to also effect wave direction. During a La Nina and El Nino Southern Oscillation (ENSO) neutral phase, waves are unidirectional in nature and they predominantly occur from the south east whereas during an El Nino, waves are bidirectional in nature and they can occur from the south east and east. (Mortlock and Goodwin, 2016).

Interdecadal variations in the storm trends observed in the results are similarly are theorised to be impacted by the climatic influences effecting Australia such as the IPO. Like the SOI, variations in the IPO effect storm frequency and severity with storminess increasing during a negative IPO (Helman and Tomlinson, 2018). It must be noted however that waverider buoy data only spans the El Nino like phase of the IPO and thus any trends observed in storm frequency and severity will be bias towards one half of the story (Shand et al., 2010).

Severe and Extreme Storms

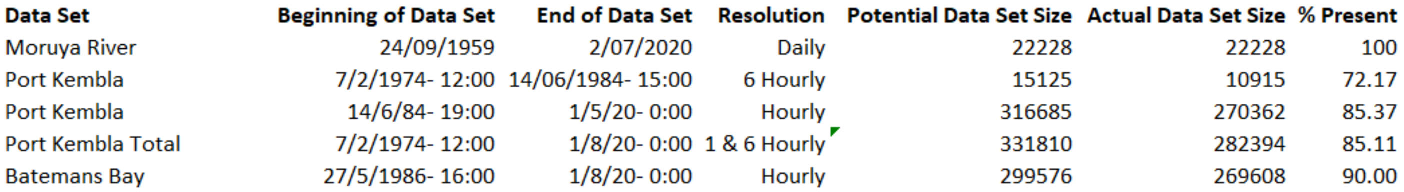
Severe storms are likely increasing in occurrence on a decadal scale due to moderate events increasing in severity in response to climate change. Changes on a local scale such as warmer temperatures, will cause an increase in the activity of small scale convective systems along the coast, leading to more intense winds and rain, as well as an intensification of east coast lows and extreme wave conditions (Department of Climate Change, 2009). It is theorised that extreme storms do not experience a similar increasing trend due to the relatively low number of severe storms that currently occur that could be augmented by climate change, however, if the occurrence of severe storms continue in an increasing trend this may change. The yearly to decadal trends in the percentage of storm severity means that severe events occur on a cycle and we can thus predict periods of increased risk based on these trends. The yearly to decadal trends in the storm duration means that longer events occur on a cycle and we can thus predict periods of increased risk based on these trends.

While only a minor trend was evident in the examination of storm clustering at Batemans Bay and Port Kembla ion the decadal scale, variations in the occurrence of storm clusters have been previously found to result from changes in climatic influencers. Variations of storm clustering at New Zealand have been examined by Godoi et al. (2017) and it was found that during El Nino and El Nino like conditions, seen during a positive Indian Ocean Dipole (IOD) and a positive Pacific Decadal Oscillation (PDO), an increase in storm clusters would occur on the southwestern coast. Conversely, during La Nina and La Nina like conditions, increases in storm clustering were experienced on the north coast. In addition to these factors, it was found that a positive SAM also increased the clustering of storms (Godoi et al., 2017).

Limitations of waverider data resolution

The significant limitation of this study is the gaps within the waverider buoy data sets. As can be seen in Table 2, Port Kembla is missing nearly 15% of its total data set and due to the length and variations in resolution, this equates to approximately 8.2 years of data missing from its record. Like Port Kembla, as can be seen in Table 2, Batemans Bay is missing 10% of its total set and this equates to approximately 3.6 years of data missing from its record. An additional limitation regarding the waverider buoy data sets is the lack of directional data present within the early records as its not recorded at Batemans Bay until 23/02/2001 10:00 and it is not recorded consistently at Port Kembla until 20/06/2012 10:00.

Table 2: The Percentage of data present within the river and waverider data sets



Data Set	Beginning of Data Set	End of Data Set	Resolution	Potential Data Set Size	Actual Data Set Size	% Present
Moruya River	24/09/1959	2/07/2020	Daily	22228	22228	100
Port Kembla	7/2/1974- 12:00	14/06/1984- 15:00	6 Hourly	15125	10915	72.17
Port Kembla	14/6/84- 19:00	1/5/20- 0:00	Hourly	316685	270362	85.37
Port Kembla Total	7/2/1974- 12:00	1/8/20- 0:00	1 & 6 Hourly	331810	282394	85.11
Batemans Bay	27/5/1986- 16:00	1/8/20- 0:00	Hourly	299576	269608	90.00

Framework for minimising the effects of storms on infrastructure

With thirteen percent of the combined population of Australia and New Zealand living in the Low Elevation Coastal Zone, an area contiguous to the coast that is less than 10m above sea level (Mcgranahan et al., 2007), the potential impacts of sea level rise as well as the augmentation of storms and extreme events are severe.

In order to mitigate the effects of climate change and subsequently lessen its influence on sea level rise, storms and extreme events, emission reductions are undertaken by the global community in the form of UN led legal agreements. In 1997 the Kyoto Protocol was formed with the intention of legally binding a countries leadership to emission reduction targets and as of 2020 there are 192 parties to the Kyoto protocol (United Nations, n.d.). In 2015 the Paris agreement was formed with the intention of intensifying and accelerating the actions needed to limit the temperature rise in this century to less than 2 degrees Celsius above pre industrial levels and as of 2020 186 countries have ratified this (United Nations, n.d.).

Differing to the global concerted effort to reduce emissions, the mitigation of the impacts of sea level rise, storms and extreme coastal events are undertaken at a more localised scale and these methods are classified as protection, accommodation and retreat (Bray et al., 1997). Accommodation focuses on the continued use of vulnerable areas by adjusting the infrastructure with alterations, such as the increased elevation of buildings, and altering the usage of land, such as setting it aside for coastal inundation. Due to the flexibility of accommodation, it can be easily combined with protection and retreat methods for appropriate risk mitigation and cost effectiveness (Bray et al., 1997).

Protection encourages the defence of vulnerable areas by committing to their further development with structures such as sea walls and groynes, and soft engineering practices such as beach nourishment. While protection proves advantageous in the sense that assets are protected, this advantage could become nominal when the cost of perpetually improving defences becomes economically unviable or if the pace of environmental change is too great to keep up with (Bray et al., 1997).

Retreat focuses on the abandonment of a vulnerable area by relocating the inhabitants and prohibiting future development. While the economic costs of the abandoned land can potentially be high, it may be mitigated via a gradual retreat and economically viable if the coast is underdeveloped (Bray et al., 1997).

Conclusion

The Australian coastline consists of a multitude of beaches that have undergone and will continue to undergo volumetric changes in response to coastal storms. This is becoming an increasingly important issue to examine in the face of climatically driven sea level rise and increased storm severity as coastal infrastructure could potentially be influenced to a larger extent depending sediment supply. By studying wave rider buoy data this study attempted to ascertain the historical trends. The conclusions for this study are:

- Storms are most likely to occur at an increased severity when winter, a positive SOI (La Nina), a positive SAM, a negative IPO and a positive PDO all co-occur. Conversely, storms are least likely to occur at an increased severity when summer, a negative SOI (El Nino), a negative SAM, a positive IPO and a negative PDO all co-occur.
- Coastal erosion will most likely occur during periods of increased storm severity (as outlined above) however it may be mitigated by a weaker STR as it would cause an increase in flooding and by extension, an increase in sediment delivery to the beach.

References

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