SCG/SCOPAC Storm Analysis Study Update 2024: Nearshore Waves

Front cover photo: view from Hengistbury Head (M. Wadey)

SCG/SCOPAC Storm Analysis Study Update 2024: Nearshore Waves

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Executive Summary

This report presents an updated analysis of coastal wave trends along the Southern Coastal Group and SCOPAC frontage. This obviously has significant implications for Flood and Coastal Erosion Risk Management (FCERM). Using data from nine nearshore wave buoys, collected between mid-2003 and mid-2024, the study extends analysis from the SCOPAC Storm Analysis (2020) study, examining changes in key wave parameters such as wave height, period, direction, and bimodal seas (where both wind-driven and swell waves are present).

Key Findings:

1. **Statistically Significant Trends**: Although small in magnitude, several statistically significant upward trends were identified for wind and swell wave periods. The trends are particularly robust for sites facing east (e.g., Sandown Bay and Weymouth). No significant trends were found in wave height, except at Hayling Island where wave heights increased by 0.2 meters over 21 years.
2. **Wave Direction Shifts**: Directional trends, such as a 4-degree northerly trend at Sandown Bay and a 2-degree southerly trend at Milford, were detected. Changes in wave direction can significantly affect sediment transport patterns and, in turn, the stability of beaches and shorelines.
3. **Extreme Winter Storm Seasons**: Extreme wave events have become more frequent over the last decade, with the winters of 2013/14 and 2023/24 standing out as the most intense storm seasons in the past two decades, with 2015/16, 2019/20 and 2006/7 also significant.
4. **Bimodal Seas**: The presence of bimodal seas, where both wind-driven and swell waves are present, showed a statistically significant upward trend for Chesil and Milford and appears more common after 2014. These conditions are known to cause greater beach erosion and more severe impacts on coastal defences.

Key recommendations resulting from this report (see Section 4.3 for further recommendations):

- **Regular Wave Trend Monitoring**: Conduct trend analysis updates every five years to track changes in wave height, period, and direction, while also investigating links to broader climate indices such as the North Atlantic Oscillation (NAO) and West Europe Pressure Anomaly (WEPA).
- **Enhance Data Integration**: Compare local nearshore data with offshore observations (e.g., from Met Office and CEFAS wave buoys) and explore the use of modelled data to identify cyclical patterns and extreme events, providing a more comprehensive understanding of regional wave behaviour.
- **Assess Impact on Coastal Defences**: Evaluate how wave trends affect wave run-up and overtopping rates across various coastal defence structures, using sensitivity tests to inform future design, appraisal, and funding considerations.

1. Introduction

The first "SCOPAC Storm Analysis Study" was undertaken, following the stormy winter of 2013/14. It provided an assessment of observed wave and sea level data across the English south coast between St Marys and Dover, including trends and comparison of extreme events and years (SCOPAC, 2020).

This report is an update to SCOPAC (2020), focusing on wave observations from the same nearshore Datawell Directional Waverider MkIII buoys from the National Network of Regional Monitoring Programmes (NNRCMP).

The time elapsed since the previous study allows for extension to, and reconsideration of the wave data and to look for more robust trends. For example, the previous wave time series applied for Hayling Island in SCOPAC (2020) was from 10th July 2003 to 31st Dec 2019 (16.5 years). This analysis adds over 4 years of observations that are quality controlled by the Channel Coastal Observatory. Note this study assesses wave data in isolation, while the SCOPAC (2020) study also included sea water levels – however we envisage that future updates will include sea level.

The 9 buoys analysed, from east to west, are Rustington, Bracklesham, Hayling Island, Sandown Bay, Milford, Boscombe, Chesil, Weymouth, West Bay (Table 1.1, Figure 1.1). Outputs include (1) Trend analyses of wave height, period, direction and bimodal seas, and (2) Event analysis (storm counts, swell duration and winter averages for wave parameters). The next section outlines the data and methods.

Table 1.1: List of the 9 nearshore sites assessed including mean spring tidal range (MSTR), the 0.25-year return probability 'storm threshold,' the water depth under the buoy, and the deployment date.

Ref.	Site	MSTR (m)	Storm H_s (m)	Water Depth (mCD)	Data Start*
1	Rustington	6.1	3.37	9.9	2003
2	Bracklesham	4.6	3.19	10.4	2008
3	Hayling Island	4.6	2.78	10.0	2003
4	Sandown Bay	3.3	2.48	10.7	2003
5	Milford	2.0	2.78	10.0	1997
6	Boscombe	1.5	2.61	10.4	2003
7	Weymouth	2.0	2.11	10.6	2006
8	Chesil	3.1	4.18	12.0	2007
9	West Bay	3.5	4.08	10.0	2007

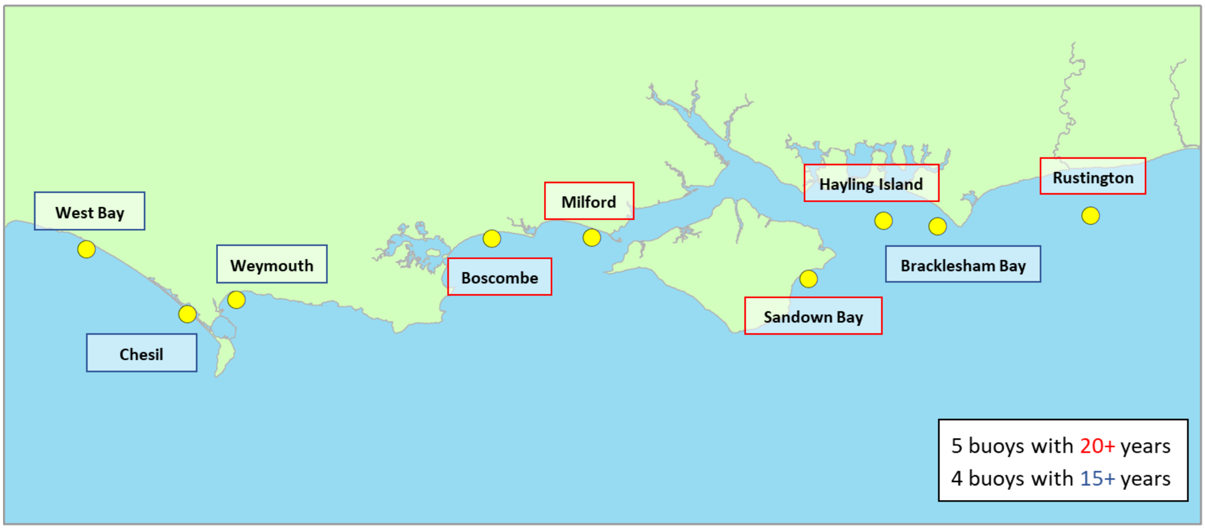

Figure 1.1: Map of wave buoys in this analysis (refer to Table 1.1)

2. Data and methods

All data were provided by the Southeast and Southwest Regional Coastal Monitoring Programmes and are free to download https://coastalmonitoring.org/realtimedata/#waves and a description of the wave parameters can be found at:
https://coastalmonitoring.org/ccoresources/waveparameterhandbook/

All wave buoys are consistent across the time series data, having been the same type/model (across time and across the region), which is beneficial for a robust trend analysis. More method detail relating to the data preparation is provided in **Appendix A**. The following analysis was carried out:

Part 1: wave trends (results in Section 3.1)

These were assessed using 90th, 95th and 99.5th percentiles for height, period (covering wind & swell), direction and bimodality. For each wave buoy, 11 wave parameters were assessed against these 3 different percentiles (referred to hereon as exceedances). This provides opportunity to find statistically significant (SS) trends in the parameters that were tested. Results are summarised in Section 3.1 and a fuller set of results figures are available in **Appendix B**.

Table 2.1: Wave parameters used in the trend analyses

Wave Height				
Significant wave height	H_s | H_{m0}	Significant wave height, derived from the spectrum	Spectral	QC
Significant wave height	$H_{1/3}$	Mean height of the highest 1/3rd of waves in the record	Statistical	No QC
Wind wave period				
Zero-crossing period	T_z | Tm_{02}	The mean period, estimated from the spectrum	Spectral	QC
Mean wave period	T_{av}	Mean period of the waves in the record	Statistical	No QC
Mean period	T_{m01}	The period associated with the mean frequency of the spectrum	Spectral	No QC
Swell wave period				
Peak period	T_p	The period of the most energetic waves in the spectrum	Spectral	QC
Calculated peak period	T_{pc}	Peak period, estimated from the moments of the spectrum	Spectral	No QC
Energy period	T_e	The period of an energy equivalent regular wave. Alternative for Tp for swell-monitoring	Spectral	No QC
Wave direction				
Peak wave direction	Dir	Direction associated with most energetic waves in the spectrum	Spectral	QC
Peak wave direction above a wave height threshold	Dir_thresh	Direction associated with most energetic waves in the spectrum, with data selected by Hs > 0.5m.	Spectral	QC
Bimodal Seas				
Occurrence of a bimodal sea state	-	A binary parameter indicating the presence of both wind-sea and swell, characterised by two peak frequencies in the spectrum.	Spectral	No QC

Trends assessment was based on annual exceedances by storm season[1] (not calendar year). This approach, rather than averaging across the entire distribution, is more robust because it emphasises the tails of the distribution, conditions regarded as most critical for coastal processes. Statistical significance is evaluated using the t-statistic, with data points based on an annual recovery under 80% excluded from the trend analysis. Results are summarised Section 3.1. Data included was from the start of each wave buoy deployment (refer to Table 1.1) until the end of May 2024.

[1] It is winter seasons or storm seasons that are the basis for analyses in this report, e.g. 1st July 200X to 30th June 200X+1)

There are changes to approaches taken in this study compared to SCOPAC (2020). Aside from the additional data lengths, aspects of the wave climate (wave height, wave period) are represented by multiple parameters, derived via different statistical methods (statistical and spectral). This approach to seeking robust trend analysis of the wave climate across the SCOPAC region we refer to as a "multi-parameter analysis" (MPA) of wave data measured by wave buoys. Table 2.1 provides an overview of the parameters used and their characteristics.

For each aspect of the wave climate, annual trends above the three exceedance thresholds were derived for multiple wave parameters. As much as possible, both parameters derived from statistical analysis of the heave data (refer to NNRCMP, 2022 and Appendix A) and parameters derived from the wave spectrum were included for each aspect to eliminate spectral processing errors. A combination of parameters that are quality controlled by CCO and non-quality-controlled parameters were included where possible, to remove trends that may have been introduced due to a particular QC process.

<u>Part 2: Wave Events (results in Section 3.2)</u>

In addition to the above, where trends for a whole data set were assessed, events were defined using a 16-hour peak separation or "storm window" (c.f. Dhoop and Mason, 2018; SCOPAC, 2020). It is recommended in future research, different peak separations are reviewed and tested, as this could change the event counts. Figure 2.1 demonstrates a set of time series data for wave heights and peaks in relation to a threshold. Parameters included the following, with results summarised in Section 3.2 and a fuller set available in **Appendix C**. Data is summarised for storm (winter) seasons.

- Storm event counts for each winter season used the Channel Coastal Observatory 0.25-year probability "Storm event threshold" and annual return period (based on peak H_S).

- We calculated the overall average H_S, H_{MAX}, T_P and T_{MAX} per winter season.

- Swell hours – this was mentioned for the Boscombe wave buoy in the SCOPAC (2020) report, given that in Feb/March 2014 prolonged swell waves, caused extensive damages to the beaches at Bournemouth. Thresholds to count swell hours were based on experience/judgement, a formal exceedance method was not applied. It is acknowledged a range of methods and thresholds for defining swell events could be assessed in future research. The "lower" swell hours count is defined as H_s above 1m combined simultaneously with peak period (T_p) above 18 seconds, whereas a larger swell was counted as $H_s \geq 2$m and $T_p \geq 19$s.

- Bimodal seas – the trend analysis in Part 1 is more detailed in terms of utilising spectral data. In this section we undertake a simpler summary of monthly bimodal seas percentage for each site and provide averages for each winter season.

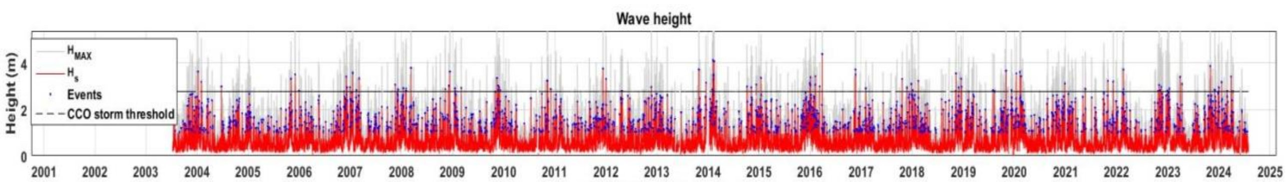

Figure 2.1: Example of time series data used to extract peaks (this example is for the Hayling Island wave buoy). The grey lines are the data for H_{MAX}, the red lines H_S, and the blue dots the "peaks" (we selected a 16-hour separation window). The 0.25-year "storm threshold" is shown the horizontal line – blue dots above that are counted as "storm events".

3. Results

3.1 Trend Analysis of Wave Parameters

A snapshot of the trend analysis is shown in Table 3.1, which summarises where there are 60 (of the total 293 tested) cases of statistical significance (SS). This is also illustrated in Figure 3.2 where a regional map is provided, for normalised (Figure 3.2a) and actual (Figure 3.2b) counts of SS counts in the analysis. This figure shows a 4-cell box summarising the results for each of the 9 sites, showing in the upper left corner SS wave height trend (as noted below, only found at Hayling), wind waves (blue), swell (purple) and direction (green). Stars are show for SS bimodal results (as noted below, 3 sites were analysed).

Some of the key observations are:

- One SS trend was found for wave height: at Hayling Island exceedance of the 90th percentile of H_{m0} has increased by +0.2m across 21 years (approx. +1cm per year) (Figure 3.1a). Mostly, wave height changes were not determined to be statistically significant across the region.

- Generally, the least instances of SS (zero) for all parameters was Bracklesham, the shortest data set (since 2008).

- The most SS detections were for wave period; notable at Sandown Bay (17 instances) and Weymouth (16 instances), the most eastward facing sites.

- The average spectral wave period (Tm_{01} and Tm_{02}) parameters detected the most SS trend occurrences across all percentile thresholds – most notably the sites near the Isle of Wight for T_{m02} (Hayling, Sandown and Milford) and Weymouth. A notable result is the 3.2s increase in peak period (T_p), across the measured time series, at the 90th percentile in Sandown Bay.

- For bimodal seas, three wave buoys were analysed. SS trends of increasing occurrence were determined at Milford (90th percentile) and Chesil (90th and 95th percentile), although not for Hayling despite an upward trend.

- SS directional trends were only found at 2 sites: at Sandown Bay a 4-degree northerly shift; and at Milford, using a threshold based directional analysis, there was a 2-degree southerly (Figure 3.1b).

- The above refers to positive trends. However, two SS negative trends were found, both at West Bay for T_e (wave energy period) where for the 90th and 95th percentile level these were respectively -0.39s and -0.57s from 2007 to 2024.

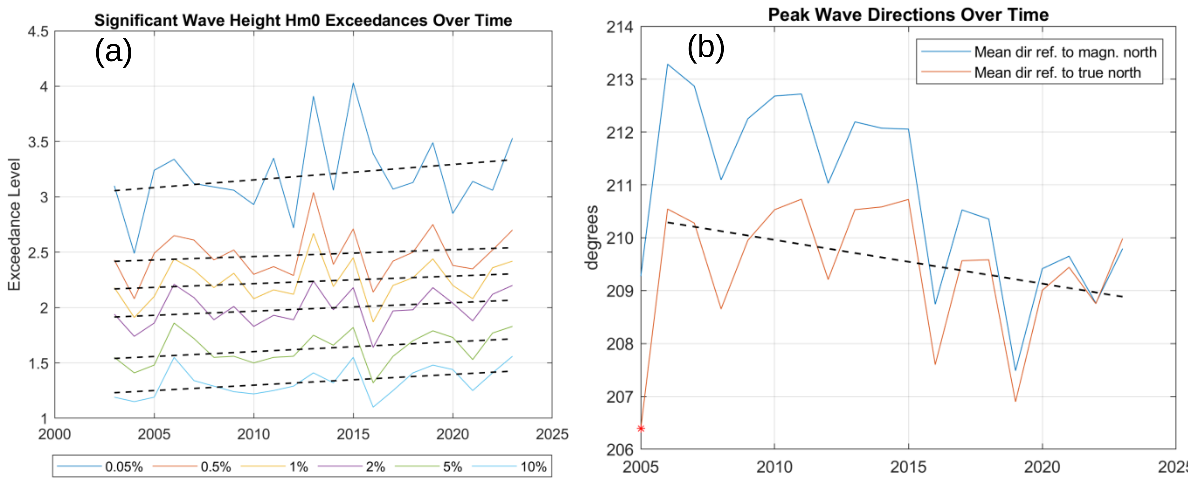

Figure 3.1 example plots of some of the statistically significant trends: (a) wave height at Hayling, (b) direction at Milford.

Table 3.1: Summary of the wave data trend results. The number in the 2nd column is the total number of parameters across the exceedance thresholds tested, that showed a statistically significant (SS) trend. The colour coding refers to the number of SS trends found at the site; red highlighting the highest counts, followed by orange and green. In each cell are the values found for the trend across the data set.

Site	No SS trends	Exceedance Level (perc)	Wave Height (m)		Wind Waves (m)			Swell Waves (s)			Bim (%)	Direction (deg)	
			Hm0	$H_{1/3}$	Tm_{02}	Tm_{01}	T_{av}	T_p	T_{pc}	T_e		Dir	Thres
Rustington	10	90				0.35		0.83	1.17	0.59			
		95				0.38		0.92	1.63	0.69			
		99.5				0.61			2.31				
Bracklesham	0	90											
		95											
		99.5											
Hayling	9	90	0.2		0.31	0.51			1.23	0.9			
		95			0.45	0.69			1.21	0.86			
		99.5											
Sandown Bay	14	90			0.17	0.2		3.2	1.44	0.5			
		95			0.23	0.34	0.16		1.78	0.63		4	
		99.5			0.49	0.76				1.12			
Milford	6	90			0.29	0.35					17		
		95			0.44								-2
		99.5			0.64								
Boscombe	3	90						1.06	1.37				
		95						0.81					
		99.5						-					
Weymouth	16	90			0.19	0.25	0.22	1.57	1.36	0.54			
		95			0.24	0.45	0.31	2.33	1.7	0.76			
		99.5			0.55	0.78	0.6			1.2			
Chesil	2	90									14		
		95									15		
		99.5											
West Bay	2	90								-0.39			
		95								-0.57			
		99.5											
No. SS trends per wave parameter			1	0	11	12	4	7	10	10	3	1	1

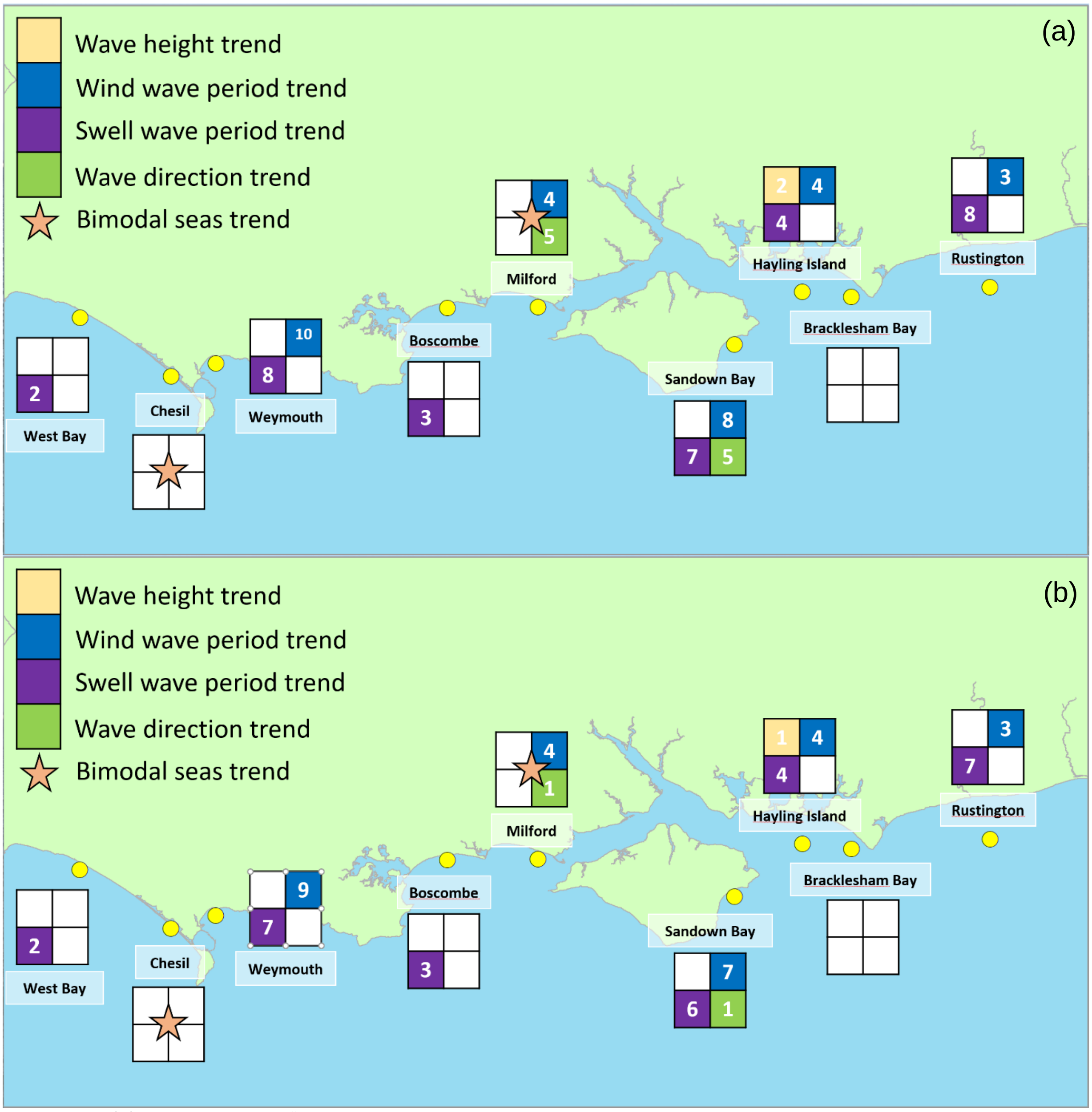

Figure 3.2 (a) top shows the “normalised” counts of statistically significant trends for each site according to the multi-parameter analysis (MPA), and (b) is the actual count. The normalised count is simply a slightly different way of summarising how strong the trends appeared for each element of wave climate, accounting for the fact that we considered a different number of wave parameters for different aspects of wave climate, i.e. 2 for wave height but 3 for wave periods.

3.2 Wave Events – storm seasons ranked and averaged

This section summarises the results for events, in terms of peaks and averages to compare annual storm seasons to one another. This is for each of the 9 sites in **Appendix C** with a regional overview at the end of this section.

An example for Hayling Island is given, in Figure 3.3 and Table 3.2 and a summary for all wave buoys in Table 3.3. Winter 2013/14 contained the most extreme events (of 0.25 year, 1 in 1 year and 1 in 5-year probability); for this example and the other sites in the region. For example, at Hayling there were 9 storms, 5 of which exceeded the annual return period threshold (and including a cluster of 2 above the 1 in 5-year event threshold). At Hayling, in 2020/21 there were over 119 hours of the swell waves counted by the lesser category (black dashed line in Figure 3.3), whilst 2006/7 stands out for the more extreme category (Figure 3.3b) with 18.5 hours of heavy swell that winter.

Table 3.2: Annual winter season peaks and averages for the Hayling Island wave buoy, the orange highlighted cells show the highest winter season value in the data set. For example 2013/14 saw the highest wave power event and largest count of storms including annual return period events.

Season		Event maxima			Winter annual averages				Counts of storms		Hours of swell		Bimodality (from monthly data)
Yr	Winter	H_S(m)	H_{MAX}(m)	PWR (kW/m)	H_S (m)	H_{MAX} (m)	T_P (s)	T_Z (s)	CCO 0.25 yr.	1 in 1yr	Cat1: H_S ≥1m & Tp≥18s	Cat 2: H_S ≥2m & Tp≥19s	
1	2003/4	3.64	5.88	58	0.63	0.96	7.57	3.65	3	1	33	0	-
2	2004/5	2.67	4.35	45	0.62	0.95	7.37	3.61	0	0	31.5	0	2%
3	2005/6	3.53	5.6	99	0.62	0.94	7.43	3.60	3	1	51	0	4%
4	2006/7	3.58	6.28	70	0.75	1.14	8.09	3.80	7	2	93	18.5	7%
5	2007/8	3.79	6.12	80	0.68	1.03	7.56	3.63	7	1	41	0.5	6%
6	2008/9	3.64	6.37	57	0.66	1.01	7.98	3.81	6	1	83.5	3.5	4%
7	2009/10	3.36	5.67	58	0.65	1.00	7.80	3.68	6	0	38	0.5	5%
8	2010/11	3.25	5.84	59	0.64	0.97	7.72	3.66	3	0	89	4.5	4%
9	2011/12	3.77	5.88	63	0.67	1.02	7.67	3.66	4	1	62.5	0	3%
10	2012/13	2.97	5.48	56	0.68	1.04	7.84	3.72	1	0	36.5	1.5	5%
11	2013/14	4.13	6.43	155	0.68	1.04	7.86	3.75	9	5	89.5	15.5	5%
12	2014/15	3.37	5.26	58	0.68	1.03	8.04	3.72	4	0	29	0	5%
13	2015/16	4.4	6.77	86	0.77	1.17	8.07	3.82	7	2	41	5.5	9%
14	2016/17	3.73	5.83	80	0.62	0.94	8.01	3.79	3	2	22	2.5	3%
15	2017/18	3.32	5.73	108	0.68	1.03	8.12	3.82	5	0	48.5	4.5	4%
16	2018/19	3.56	5.61	82	0.66	1.01	8.27	3.75	6	1	95.5	6	7%
17	2019/20	3.67	5.81	94	0.75	1.16	8.29	3.86	6	4	95	2.5	7%
18	2020/21	3.13	4.7	63	0.70	1.07	7.80	3.75	2	0	119	3.5	6%
19	2021/22	3.73	6.07	79	0.64	0.98	7.85	3.70	4	1	90	0	4%
20	2022/23	3.41	5.51	86	0.68	1.04	8.06	3.73	8	1	35	4	6%
21	2023/24	3.87	6.33	65	0.76	1.17	7.99	3.84	7	2	109.5	2	6%

Table 3.3 summarises for the 9 nearshore wave buoys how regionally 2013/14 was the most extreme winter for wave events, followed by 2023/24. After 2013/14, the other extreme years (in terms of temporally clustered wave events, as counted by the number of 1 in 1 year probability storms classified by H_s) are 2023/24 regionally, followed by 2015/16 and 2019/20. Winter 2013/14 was also most extreme when considering hours of swell and bimodal sea conditions.

Generally, the later decade is more extreme in terms of nearshore wave conditions. We recommend that future work explores a more sophisticated analysis of rankings, averaging and extremes to determine how seasons could be ranked highest in terms of wave activity and storms relevant to FCERM.

The exception pre-2014 seems to have been a large amount of swell and storms in 2006/7, notable for Rustington, Hayling and Milford. There were also high T_p and T_z averages in the westernmost open coast sites (Chesil and West Bay) in 2009/10.

The most recent winter in this analysis 2023/24 at 5 out of the 9 sites, stands out in terms of wave height averages (H_s and H_{max}). At Rustington, the recent 2023/24 winter also saw the highest average H_s, H_{max}, T_p and T_z in the 20 years of data. The most bimodal winters appear to have occurred either in 2013/14 or since – with Chesil experiencing its most bimodal seas (as recorded with the monthly data) in the recent 2023/24 winter (Table 3.4b).

Table 3.3: Summary for each season the storm event count and swell data summed for the nine wave buoys across the region. Red cells indicate the highest value, and the top five are also shaded.

Storm year	No. of with data	No. of storms (0.25yr+)	No. of storms (1 in 1 yr+)	Swell cat 1 (hrs)	Swell cat 2 (hrs)
1996/7	1	7	1		
1997/98	1	5	0		
1998/99	1	6	0		
1999/00	1	2	0		
2000/1	1	8	3		
2001/2	1	7	1		
2002/3	1	6	2		
2003/4	5	21	5	245	0
2004/5	5	4	0	168	0
2005/6	5	18	7	443	45
2006/7	8	43	7	1,069	100
2007/8	8	40	6	554	27
2008/9	9	27	3	853	33
2009/10	9	36	4	719	12
2010/11	9	24	1	1,074	40
2011/12	9	38	9	696	5
2012/13	9	20	0	561	9
2013/14	9	108	48	1,821	211
2014/15	9	31	4	581	5
2015/16	9	62	15	1,028	86
2016/17	9	16	10	567	32
2017/18	9	44	5	800	33
2018/19	9	45	8	1,173	32
2019/20	9	49	15	1,291	61
2020/21	9	34	6	1,378	101
2021/22	9	22	8	1,002	24
2022/23	9	54	9	678	40
2023/24	9	51	17	1,344	24

The months with the highest occurrence of bimodal seas remain, as reported in SCOPAC (2020), are December 2015 and February 2014. The most extreme monthly value across the data set was 38% in December 2015 at Hayling Island. Intriguing about monthly bimodality is that although periods such as December 2015 seemed quite innocuous in terms of wave height events there seems a link to beach drawdown and seawall failures which could be in the future be investigated further.

Table 3.4a. Top 5 most bimodal months when data is averaged across the 9 sites

Rank	Month	Bimodality	Stand out site & value
1	Dec-15	24%	Hayling Island (38%)
2	Feb-14	23%	Chesil (34%)
3	Feb-20	19%	Bracklesham (30%)
4	Jan-14	17%	Bracklesham & Chesil (25%)
5	Feb-21	17%	West Bay (25%)

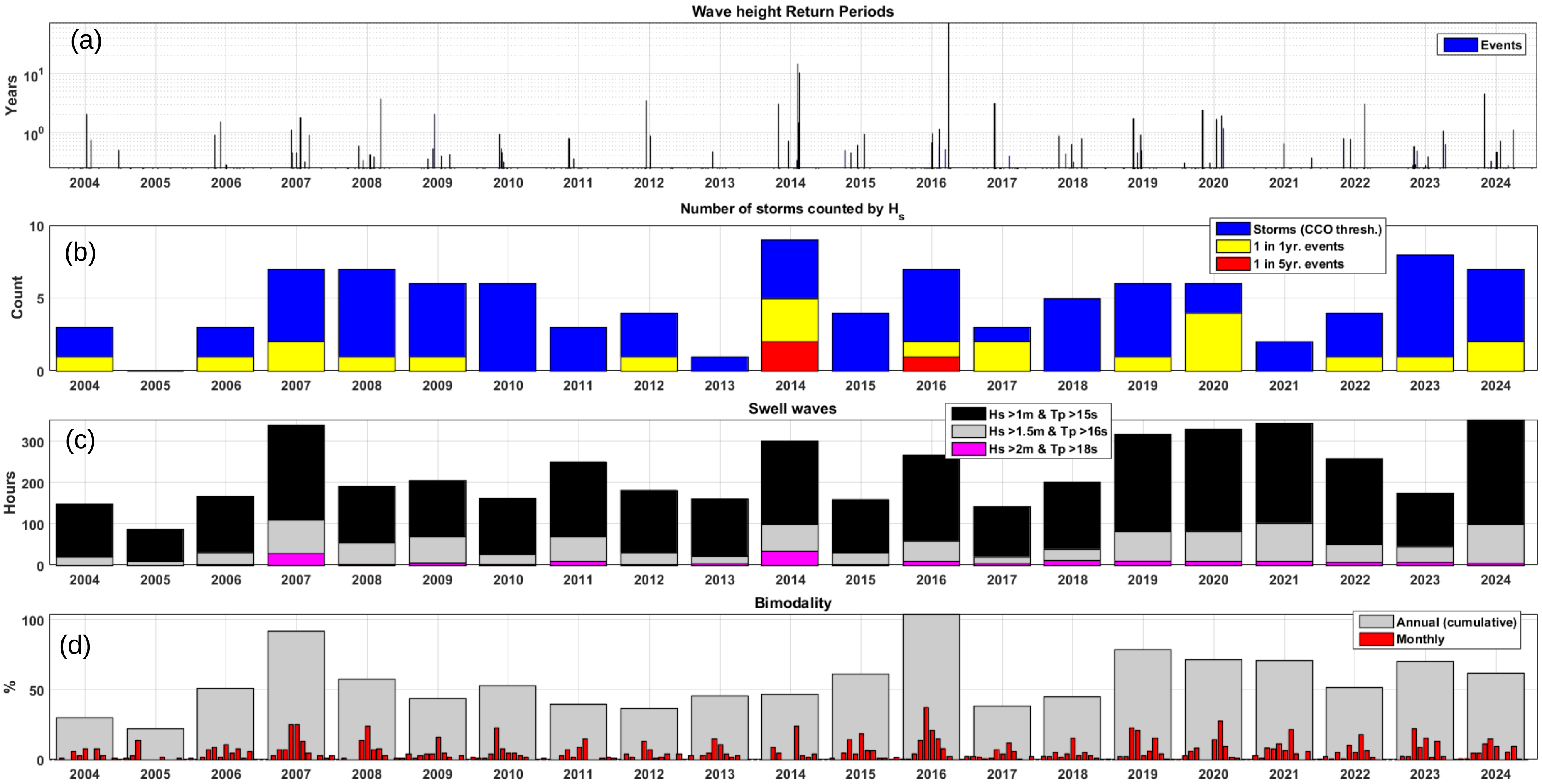

Figure 3.3 wave time series height at Hayling (a) showing event return periods according to Hs, (b) and bar plot counts of exceedance events, (c) winter swell hour, (d) bimodal seas.

Table 3.4b summarises the bimodal activity across the winter seasons. As already noted, this is a parameter of high FCERM interest. Again 2013/14 stands out, although regionally it is tied with 2015/16 and 2019/20 at 6% averaged monthly bimodality. Since the earliest point at which all wave buoys together provide data (2009/10 onwards) it is 2013/14 and since, that the highest bimodal monthly averages are observed. It is evident that 2006/7 was relatively extreme in this regard and would likely rank in the top 5 extreme winters since 2003. The highest seasonal bimodal averages are at Bracklesham (10% in 2019/20) and Chesil (9% in Winters 2013/14, 2015/16, 2019/20 and 2023/24).

Table 3.4b. Summary of winter season (yearly) bimodality, using monthly data for each site. The shaded red cells indicate the higher bimodal season for each buoy.

Season	Rustington	Bracklesham Bay	Hayling Island	Sandown Bay	Milford	Boscombe	Weymouth	Chesil	West Bay	Average
03/04										
04/05	3%		2%	0%		1%				2%
05/06	3%		4%	0%		1%				2%
06/07	6%		7%	1%	6%	3%				5%
07/08	4%		6%	0%	5%	1%	1%	4%	3%	3%
08/09	3%		4%	0%	2%	1%	1%	4%	3%	2%
09/10	4%	5%	5%	0%	4%	2%	0%	6%	5%	3%
10/11	3%	4%	4%	0%	3%	2%	0%	5%	3%	3%
11/12	2%	4%	3%	0%	3%	2%	0%	6%	4%	3%
12/13	4%	4%	5%	0%	3%	2%	0%	5%	5%	3%
13/14	6%	8%	5%	2%	7%	5%	2%	9%	8%	6%
14/15	4%	4%	5%	0%	4%	2%	0%	6%	6%	3%
15/16	8%	8%	9%	1%	8%	3%	1%	9%	8%	6%
16/17	4%	3%	3%	0%	3%	1%	0%	6%	4%	3%
17/18	4%	3%	4%	1%	3%	1%	1%	6%	4%	3%
18/19	6%	6%	7%	1%	6%	2%	1%	7%	6%	5%
19/20	7%	10%	7%	1%	8%	3%	1%	9%	7%	6%
20/21	5%	6%	6%	1%	6%	3%	1%	7%	6%	5%
21/22	5%	3%	4%	1%	3%	1%	0%	6%	5%	3%
22/23	6%	6%	6%	0%	6%	2%	1%	8%	6%	5%
23/24	6%	7%	6%	1%	7%	3%	1%	9%	7%	5%
Average>	**5%**	**5%**	**5%**	**1%**	**5%**	**2%**	**1%**	**7%**	**5%**	

4. Discussion and conclusions

4.1 Main findings

The trends and data in this report are an update to the SCOPAC (2020) Storm Analysis project focusing on wave parameter observations at the nearshore wave buoy sites. As noted below and in Table 3.1, there are some highlights from the additional 4 years of data. The methods and data understanding are always under development by the CCO and in this update provide indications of statistically significant wave trends worth further analysis as time goes on.

At Hayling Island, at the 90th percentile, was an upward statistically significant (SS) trend in significant wave height. We advise caution given that this is only two decades of data. No other SS trends in wave heights are yet found. Wave periods for the various parameters yielded far more SS across the eastern and central region, notably at the east facing sites (Weymouth and Sandown). It could be investigated in future work and emerging data if this can be linked to any cyclical nature to extreme swells, with some signals of an approximately half decade cycle. Perhaps for energy period (T_e) this could be correlated with larger scale climate indices.

This study assessed buoy measurements of direction with reference to magnetic north, and an effort to correct to geographic 'true' north. For example, at Hayling the magnetic declination at the site appears to have been changing by 0.14° east per year. The correction that was applied to the data was acceptable, but a more sophisticated approach could be explored to examine future trends. There are "signals" of southerly shifts with the only SS detection determined at Milford. The opposing (northerly) SS trend at Sandown should be revisited when more data is available.

The wave data indicates a recent higher prevalence of bimodal and swell conditions regionally, notable since 2014.

4.2 Comments on future wave climate (literature)

This study is unique in being a regional nearshore assessment of observed data sets. It will naturally be asked about its broader context in relation to large-scale ocean and coastal changes, and climate change. We emphasise that whilst the trends may indicate wave climate changes, the coastal system is complex with interactions between depth zones, shorelines and other processes.

Reading of the literature indicates conflicting projections where we can provide some comments regarding UK storm waves and future projections. Over recent decades, the UK and surrounding areas are believed to have experienced an increase in cyclone frequency (Priestley et al. 2020), along with a northward shift in storm tracks since the 1990s (Seneviratne et al. 2021). Mean wave heights across the North Atlantic are thought to have decreased, though extreme wave events may have increased slightly (Erikson et al. 2022). Studies specific to the UK present conflicting trends depending on the time periods studied, with findings varying across different analyses (Wolf & Woolf 2006, Ribel & Young 2019, Castelle et al. 2018, Fox-Kempter et al. 2021).

Looking into the future, natural variability in storm systems is expected to dominate storminess around the UK in the coming decades (Horsburgh et al. 2021). A range of global wave scenarios have been modelled including for high-emission climate change where projected trends in mean wave conditions are complex and uncertain (c.f. Morim et al. 2021). Some regions, including the English Channel, may experience increases in extreme wave events by the end of the century (Palmer et al. 2018; D'Agostini et al. 2022). Conflicting model projections, particularly regarding extreme waves, underscore the challenges in long-term forecasting (Bricheno et al. 2023). The current state of the field highlights the need for more refined regional studies to better understand localised impacts, especially given the variability in wave climate projections across different models.

Although this study assesses waves alone, any changes in wave generation may reflect changes in atmospheric conditions (e.g. storm tracks, wind patterns) independent of tidal effects. Waves shape beaches, erosion and sediment transport throughout the tidal cycle and understanding wave trends is essential for predicting long-term morphological changes to the coastline, which affects the stability and resilience of coastal defences, including beaches (affecting how future waves and tides interact with the coast). Wave data plays a role in the improvement and the calibration of predictive models for coastal flooding and erosion, designing coastal defences, planning maintenance, reinforcement, and adaptation of defences with implications to lifespan and functionality.

4.3 Future research suggestions

Recommendations for future research for wave analysis relevant to coastal systems include:

- To continue similar trend analysis of nearshore buoys with approx. 5-yearly updates. Ideally this would also consider extending the analysis spatially, to the entire wave buoy network.
- Consider *observed offshore* data trends and extremes (e.g. Met Office and CEFAS wave buoys) and correlate and compare with the *nearshore* data. This could link to a separate/related study using Met Office *hindcast* or other *modelled* data to determine if longer term trends or cyclical patterns can be evidenced in wave height, period, direction.
- Investigate links/correlation in wave data to climate indices (e.g. NAO, WEPA).

Recommendations more generally relating to future storm analysis research:

- This study assessed wave data in isolation. A further update on "still" water level (i.e. tide, surge, mean sea level) would be useful, and in response to feedback received during the project and SCOPAC (2020), to include as many gauges as possible (e.g. EA and CCO devices), whilst also to clarify/explain in detail methods and issues around tide gauge levelling and accuracy.
- Assess the effects of any emergent wave trends, perhaps using a range of sensitivity tests around the statistical significance (also peaks detection and storm definition), upon wave run up and overtopping rate. Ideally this would be applied for a range of sea level and storm scenarios across a selection of coastal defence types (e.g. vertical seawall, beach, etc). This adds potential for practical considering around FCERM, such as in scheme funding and design.
- Early on in this project were preliminary investigations of recorded wind speeds (mean, median and mode) and directions at Swanage Pier, Lymington and Sandown Pier. These did not fit within the eventual scope of the analysis but indicated signals of cyclical trends. This could be investigated in future work using regional data points including those from the CCO network and Solentmet Support Group.
- There is growing interest in combining the analysis of wind and rainfall data with waves and sea level, especially given that rainfall patterns are linked with landslips and landslide reactivation.

Findings and implications from this study were highlighted by SCG/SCOPAC as considerations for national research into wave extremes. Suggestions for further discussion include, relevant in FCERM design and risk assessment, the continued recognition and research into the impact of swell and bimodal waves. There is interest in where this work fits into the validation of overtopping discharges by field and physical modelling (e.g. WIREWALL); as well as modelling tools that can incorporate some of the practical impacts relating to swell and bimodal waves (previous examples have included SHINGLE-B and X Beach-G), with practitioners seeking "industry standard" overtopping tools for mixed sand and shingle beaches backed by a seawall. Questions asked during this research have been whether the State of The Nation (SoN) data set can integrate such trends and/or include extreme swell and bimodal waves. This may link to updates of design guidance and national flood and coastal erosion risk assessments and mapping (i.e. presently NAFRA and NCERM).

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APPENDIX A – FURTHER METHOD DETAIL FOR TREND ANALYSIS

Data Preparation

Wave data from the West Bay and Chesil wave buoys was provided by Southwest Costal Monitoring. Data from the buoys deployed at Weymouth, Boscombe, Milford, Sandown Bay, Hayling Island, Bracklesham, and Rustington was provided by the Southeast Regional Coastal Monitoring Programme. The quality-controlled data files, non-quality controlled and half hourly spectral files were used for the analysis.

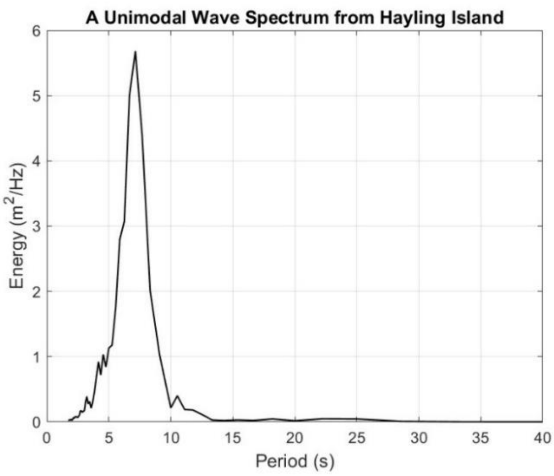
First, QC flags were assigned to H_s, T_z, T_p, and Dir by the CCO (c.f. Mason & Dhoop 2023); for the non-QC'd parameters, $H_{1/3}$, T_{av}, T_{m01}, T_pc, and T_e, an automated procedure was put in place: first, if data was flagged as 'buoy adrift' ("CCO flag 7") or H_s & T_z fail ("CCO Flag 1"), all parameters were failed. Next, a rate-of-change test was performed (using the criteria provided in Table 2). Finally, an out-of-range test is performed (using the minima in Table 2) and a maximum that was customised for each site. A final check on the data was performed by producing box plots for all parameters, for each year of data to scan for suspect trends or outliers.

Table A1: Parameters and tests for wave data not QC'd by CCO.

Parameter	Out of range		Rate-of-change over 30 min
	Minimum	Maximum	
$H_{1/3}$	0 m	User-defined	0.5 m
T_{av} & T_{m01}	1.6 s		2 s
T_{pc}	1.6 s		3 s
T_e			3 s

The binary bimodal seas parameter was derived directly from the time series of half hourly spectral files for each site. Spectra were considered bimodal if they fulfilled all of the following conditions (Mason et al. 2008; see Figure A1):

1) The minimum total energy of the wave spectrum is equivalent to Hs = 0.5 m
2) The peak energy in the smaller peak is at least one-third that of the larger peak
3) The peak energy in the smaller peak is at least 0.4 m^2 Hz^{-1} (equivalent of Hs ~0.2 m at 10 s)
4) The energy at the trough is less than half of the smaller peak



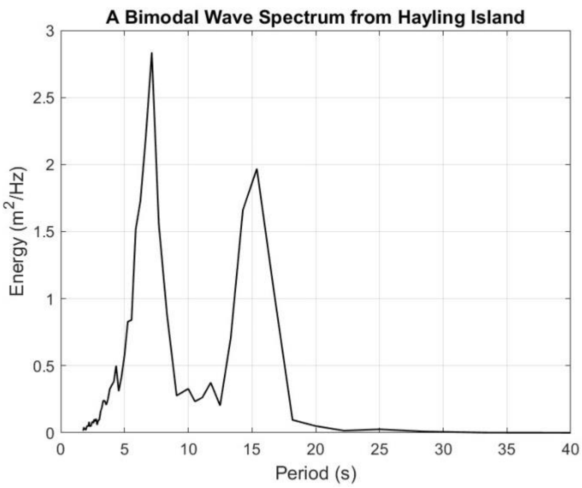


Figure A1: An example of a unimodal spectrum from Hayling Island (left) where the energy is located in the wind wave periods, and an example of a bimodal spectrum from Hayling Island (right) where there is a significant amount of energy in both the wind wave and swell wave components of the spectrum.

An automated procedure was used to quality control the spectra. First, the standard wave parameters were calculated for each spectrum. Out of range tests for H_s, T_p, T_z and Dir, and rate of change tests for Hs and Tz, matching those outlined in Mason & Dhoop (2023) were applied. Where a spectrum failed one of these tests, it was flagged and excluded from the analysis. The number of spectra categorised as bimodal were counted across each day to create a time series of the hours of bimodal seas occurring per day.

Data quality of the final dataset was evaluated by calculating the annual recovery rate for each parameter after data that failed QC tests had been removed. For each parameter, each year (i.e. storm season) that had a recovery of less than 80% was flagged.

Trend Analysis Using Annual Exceedances

Measured wave data is understood to typically conform to a Rayleigh distribution (e.g. Holthuijsen 2007: 64-5), characterized by a rapidly decaying left tail and a slowly decaying heavy right tail, indicating positive-skewed phenomena with a higher likelihood of extreme values (Figure A2). The non-normality of the Rayleigh distribution presents challenges when relying on traditional metrics such as the mean for trend analysis. Averaging in the presence of extreme values can lead to a distorted representation of the data, as these events disproportionately influence the mean. In Figure A2, the mean (0.67 m) has clearly been pulled towards the higher values by the extremes and does not accurately represent the central tendency in the data. At the same time, this mean provides little information about the largest waves in the data.

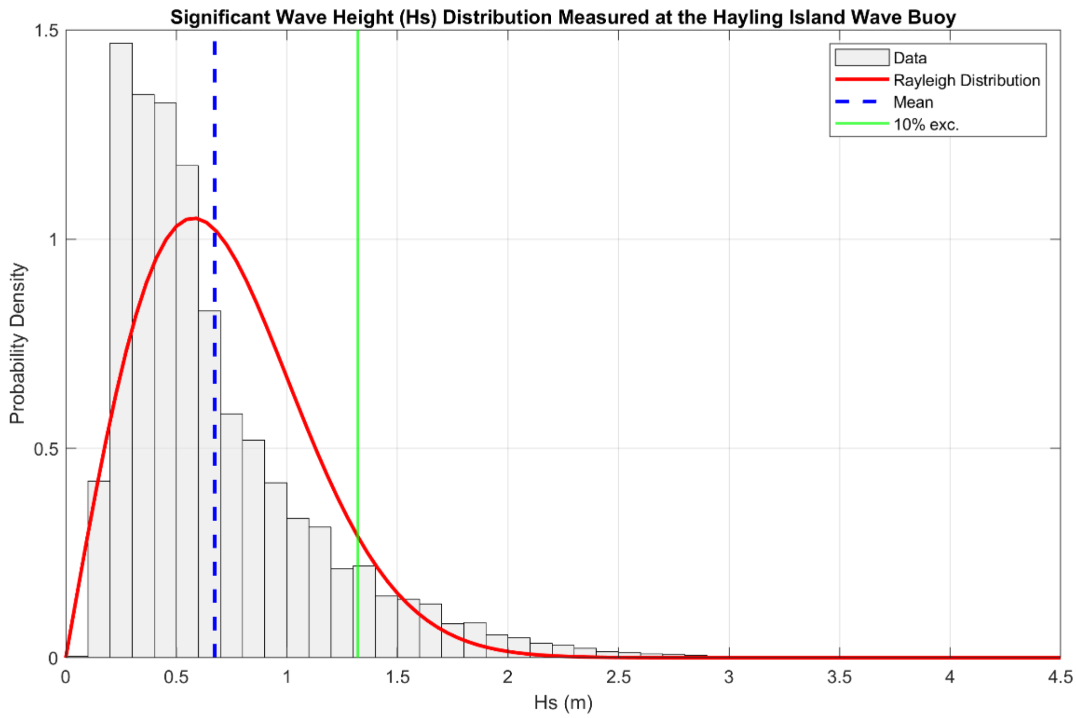


Figure A2: Illustration of the distribution of measured wave heights.

It was determined in this analysis that the mode (e.g. demonstrated by a value of 0.31 m in Figure A2) would better represent the central tendency, but a trend analysis focusing solely on such small wave heights ignores the practical significance of extreme (higher) waves relevant to coastal management practice. It is these extreme wave values that pose challenges, including the transport of larger volumes of beach material and higher overtopping rates of defences.

Analysing trends of annual exceedances offers a more robust approach. Instead of averaging across the entire distribution, this approach hones in on the tails, emphasizing conditions most critical for coastal processes. In the example shown in Figure A2, the 10% exceedance value is indicated in green (1.32 m). Exceedances analysis gives due consideration to extreme values without allowing them to disproportionately influence the overall trend assessment (Figure A2). This method provides a nuanced understanding of the data, facilitating the identification of trends driven by conditions practically relevant in coastal engineering and management.

For all parameters, the 10%, 5%, 2%, 1%, 0.5%, and 0.05% exceedances were calculated for each storm season covered by the time series. A storm season is defined as starting on the 1st July and ending the 30th June the following year. Line plots were produced to show the trends in the exceedances and a linear trend was fitted to the data. The statistical significance of the trend was evaluated using the t-statistic of the two-sided hypothesis test. If the p-value is greater than 0.05, the trend is not significant at the 5% significance level. However, if recovery for a storm season year is under 80%, a visual indicator is added to the plot and the data point is excluded from the trend analysis.

Finally, all plots showing trends in absolute numbers were normalised for comparison across the SCOPAC region by calculating the z-score at all exceedance levels. If the trend is statistically significant, the trend line is plotted in red.

Trend Analysis of Wave Direction

The wave direction is reported following the nautical convention, meaning that the direction is where the waves come from, measured clockwise from “magnetic north” (the direction a compass needle points toward as it aligns with the earth’s magnetic field). However, this could lead to misleading results, because the magnetic North Pole changes over time, in response to changes in the earth’s magnetic field.

This perpetual shift needs to be corrected for, to allow any inferences made about wave trends. The non-transient ‘geographic’ or ‘true’ north should be sought in the analysis. This was done by adding the magnetic declination for 1st January of each year, at the position of a buoy, to the annual storm season average wave directions. All declinations were sourced from NOAAs ‘Magnetic Declination Estimated Value’ online tool[2], using model IGRF (1590-2024).

The wave directions referenced to both magnetic and true north are provided in a line plot to visualise the correction that has been applied to the data. However, a linear trend line is only fitted to the data corrected for true north. Statistical significance is again evaluated using the t-statistic with data points based on an annual recovery under 80% excluded from the trend analysis.

[2] See https://ngdc.noaa.gov/geomag/calculators/magcalc.shtml

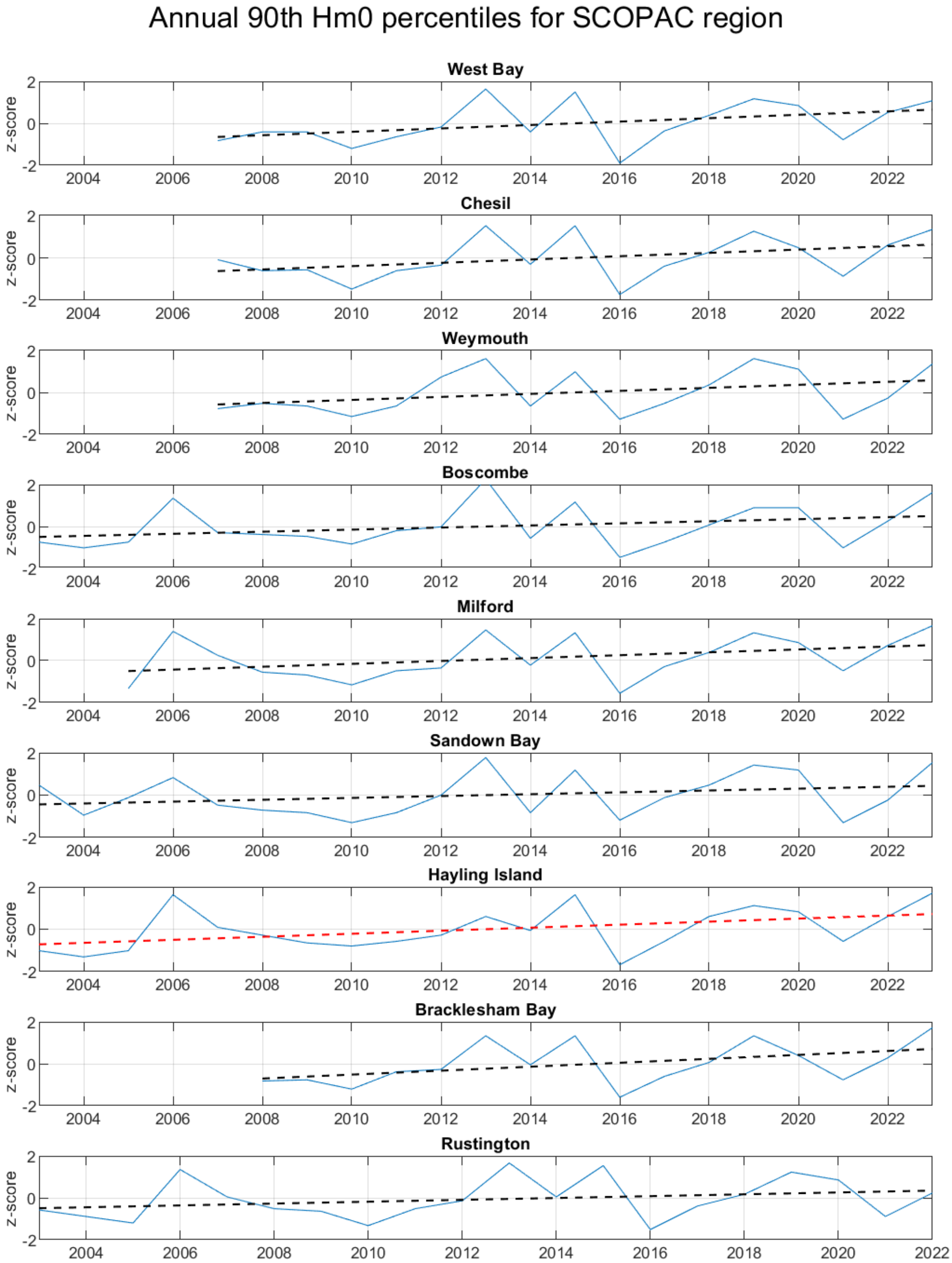
APPENDIX B – RESULTS FIGURES: TREND ANALYSIS

This section contains figures for the CCO wave trends analysis:

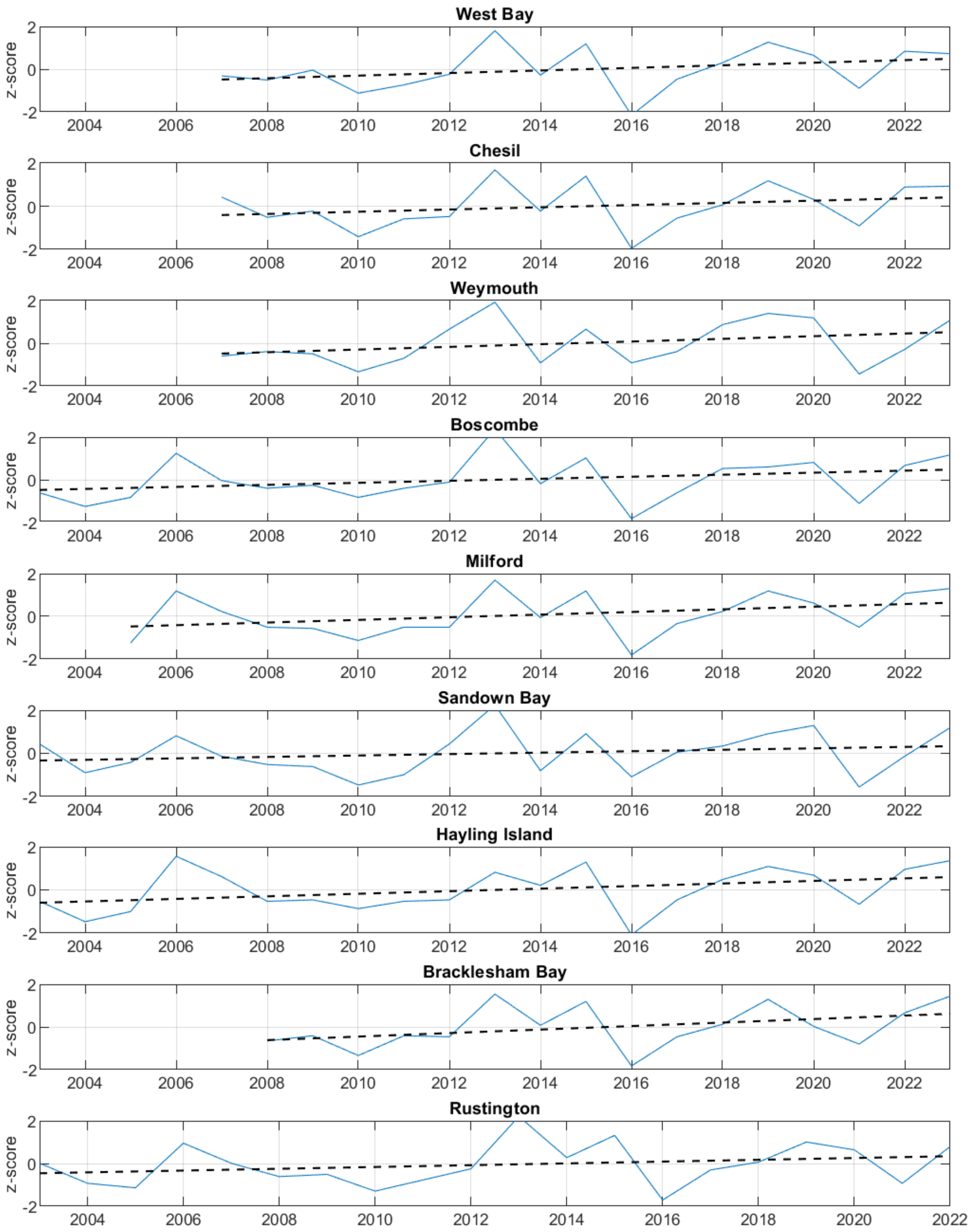
1. Wave height
2. Wave period
3. Wave direction
4. Bimodal

The dotted lines in the figures below show the trend. Storm seasons with less than 80% data recovery rate are not included in the trend. Red dotted lines denote significant trends, while black dotted lines denote that the trend is not significant.

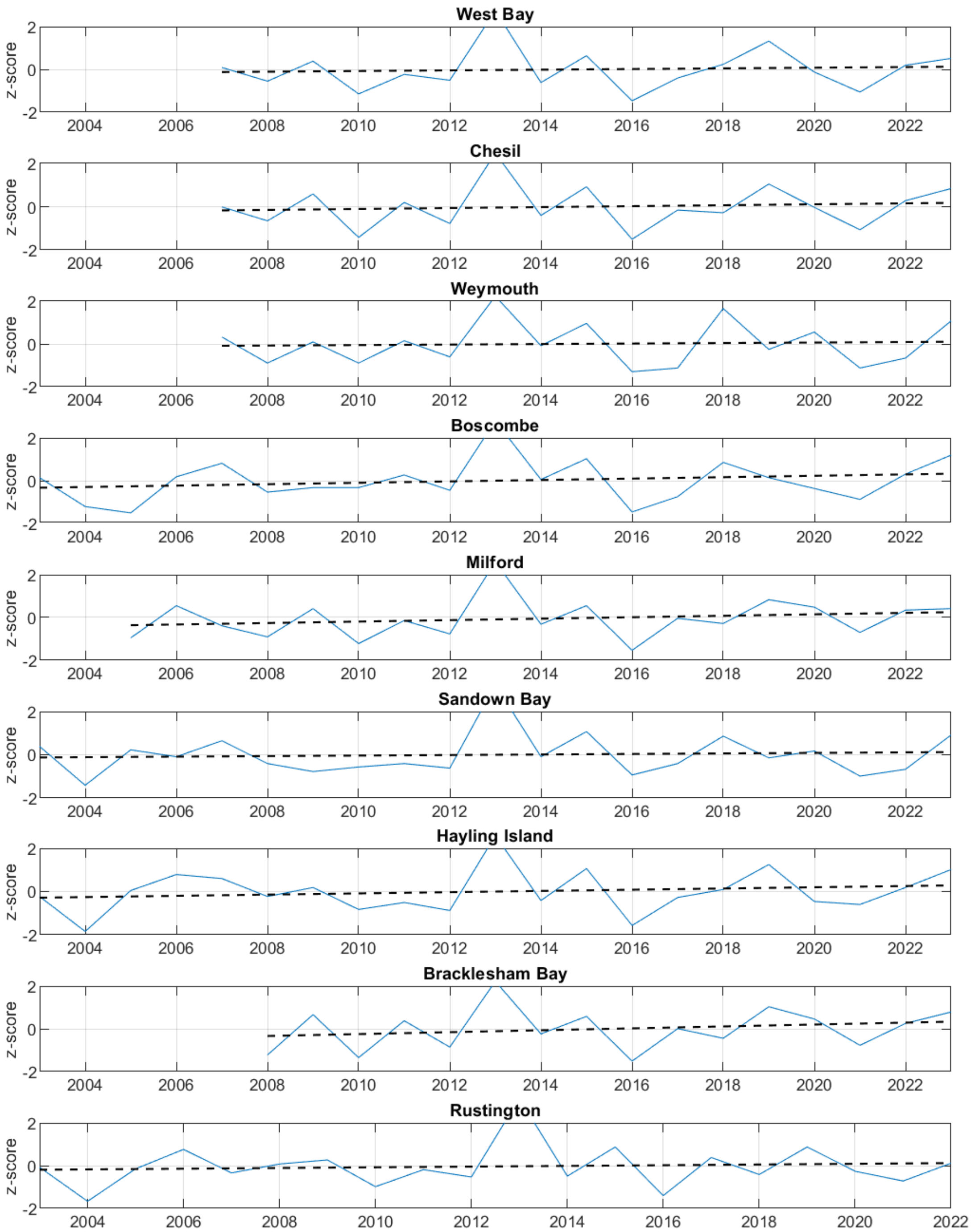
Part 1a - Wave Height H_{m0}

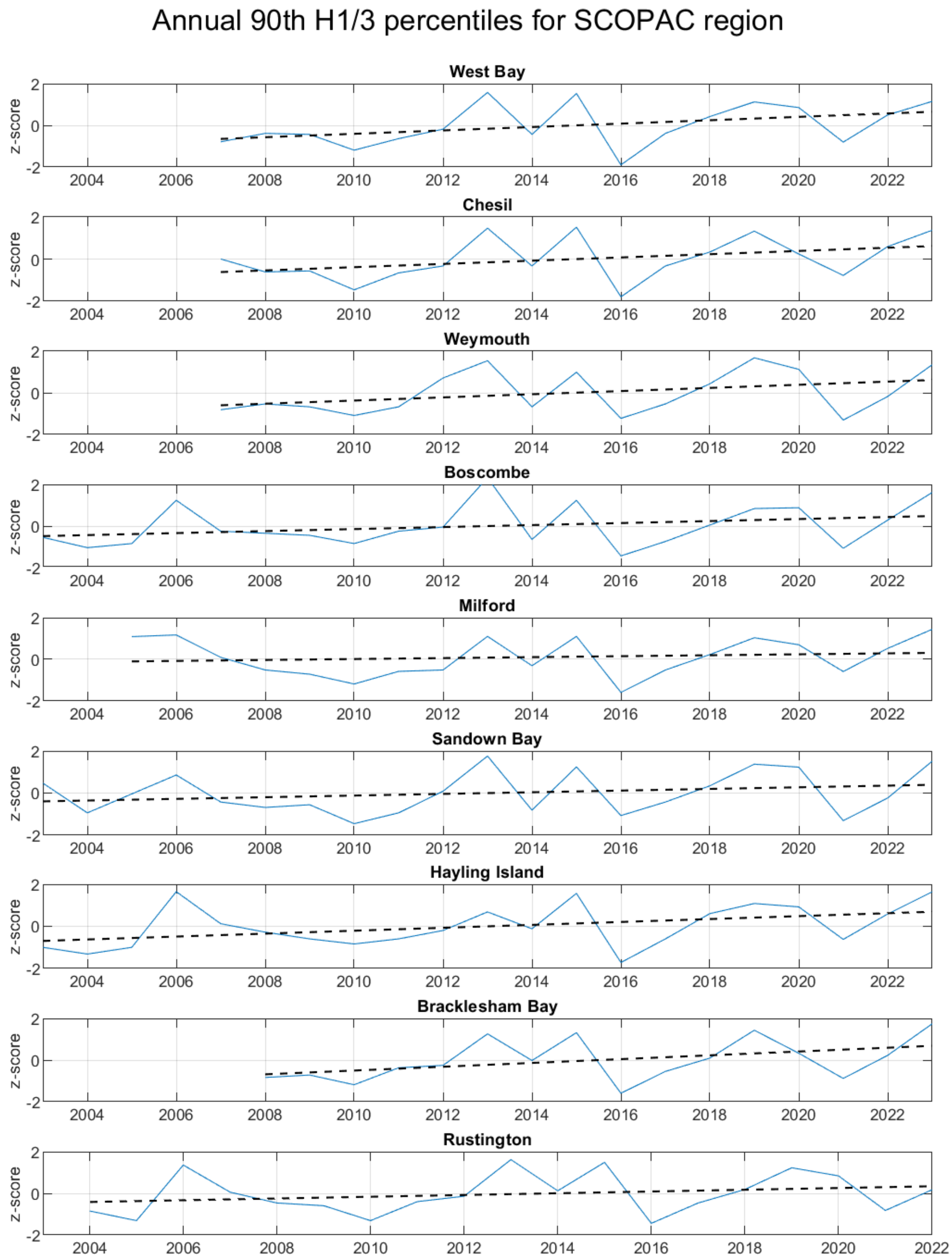


Annual 95th Hm0 percentiles for SCOPAC region



Annual 99.5th Hm0 percentiles for SCOPAC region





Annual 90th H1/3 percentiles for SCOPAC region
West Bay
Chesil
Weymouth
Boscombe
Milford
Sandown Bay
Hayling Island
Bracklesham Bay
Rustington
z-score
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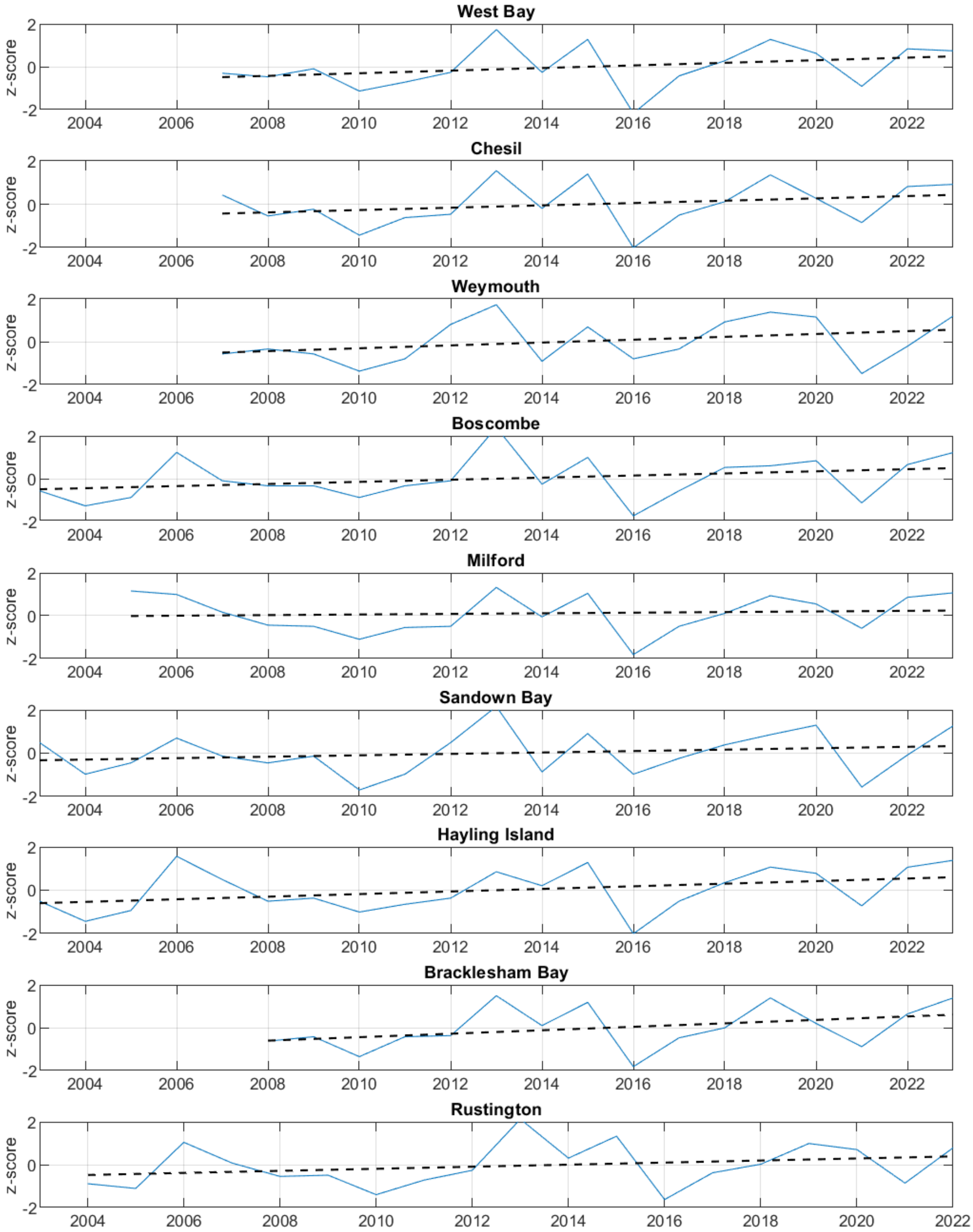
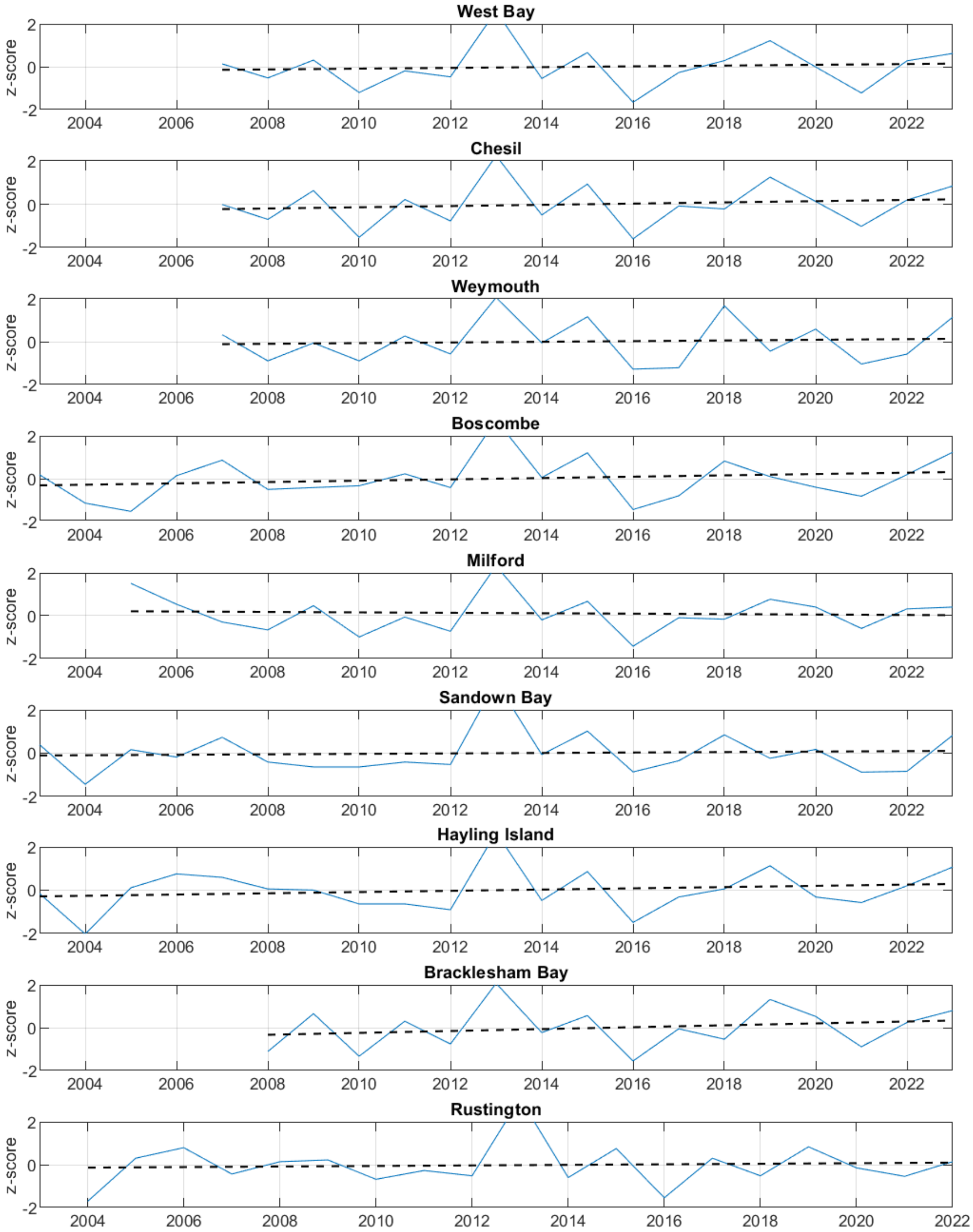
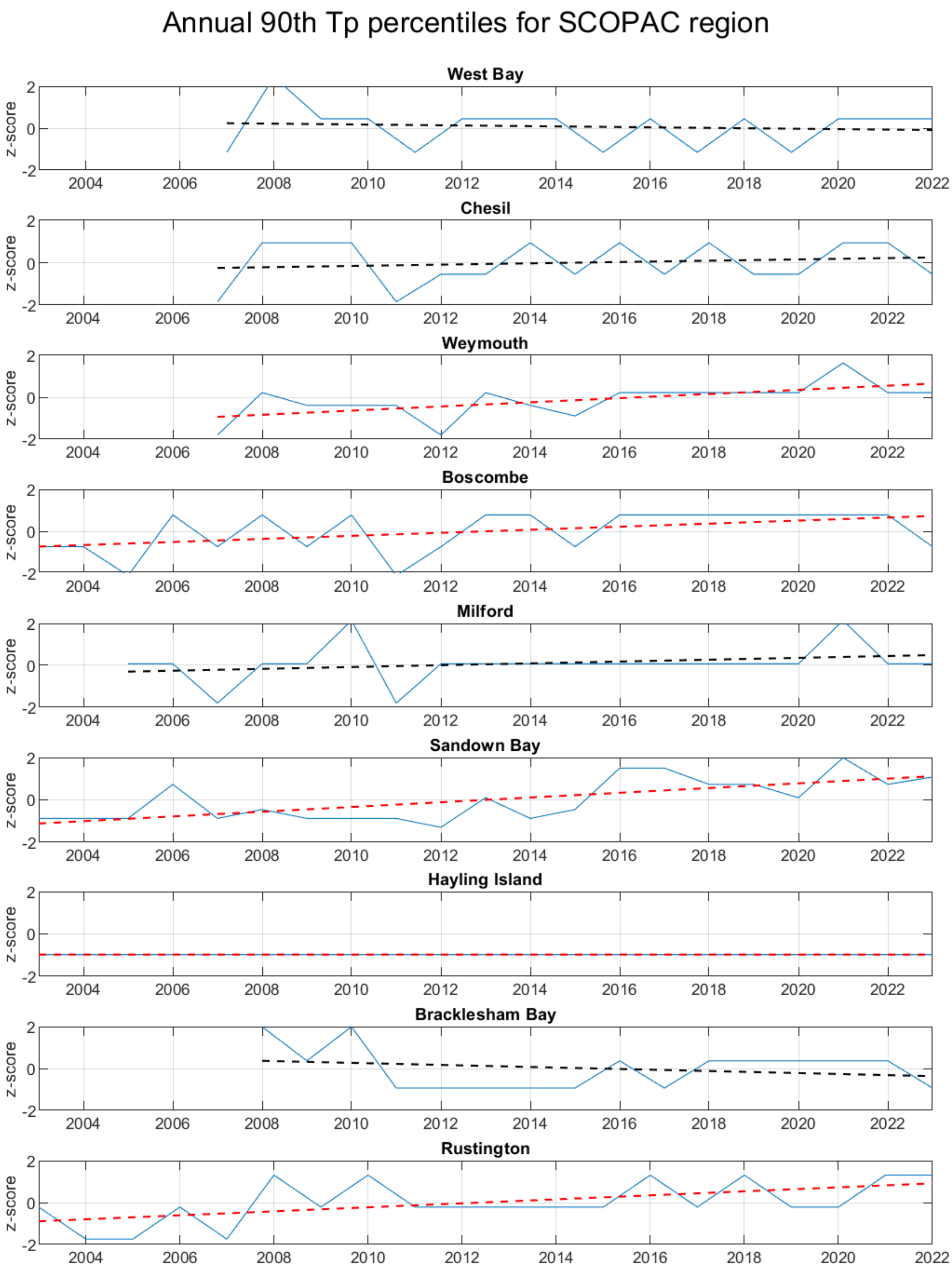
Annual 95th H1/3 percentiles for SCOPAC region

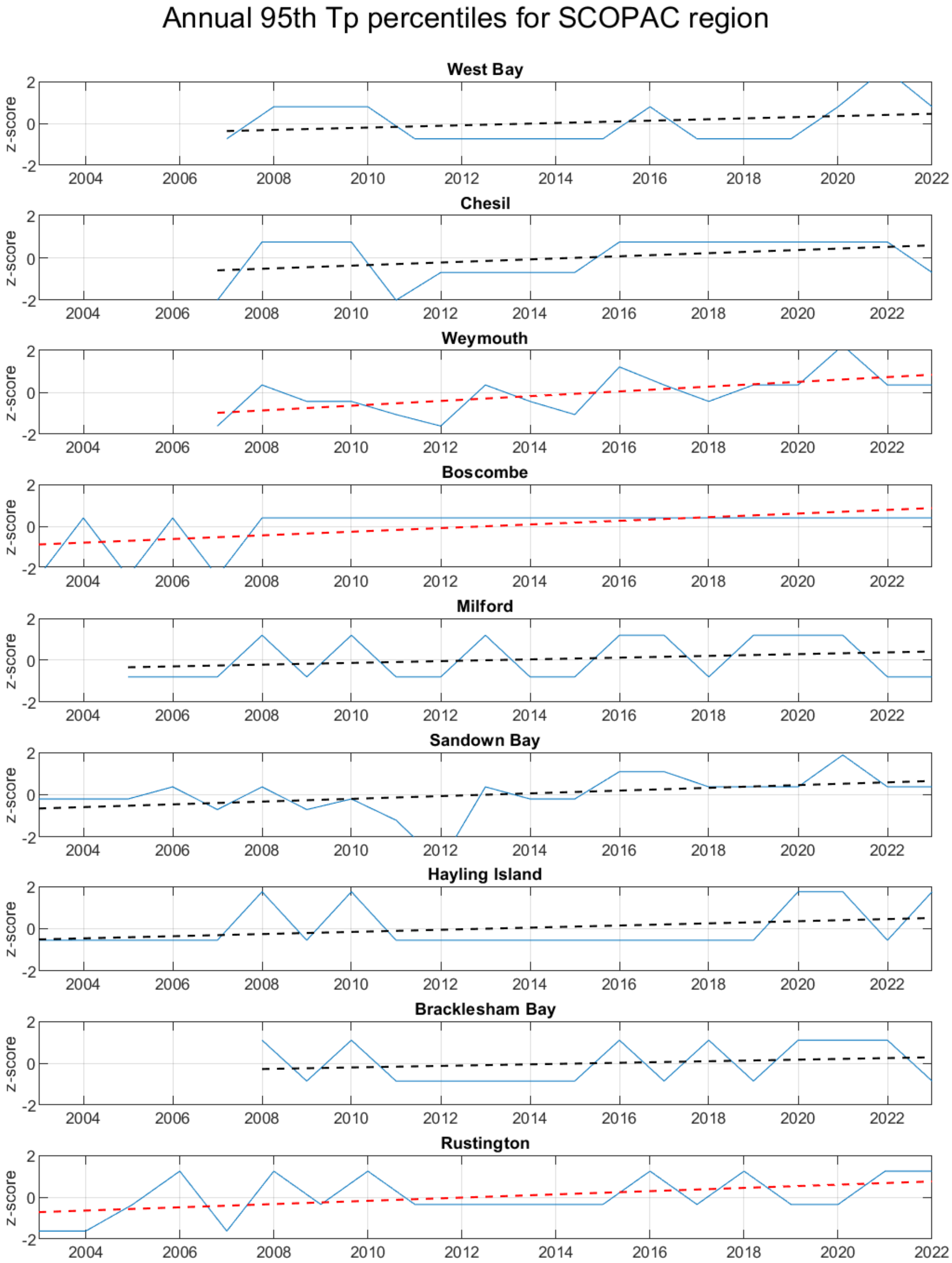


Annual 99.5th H1/3 percentiles for SCOPAC region



Part 2a - Peak Wave Period Tp




Annual 95th Tp percentiles for SCOPAC region
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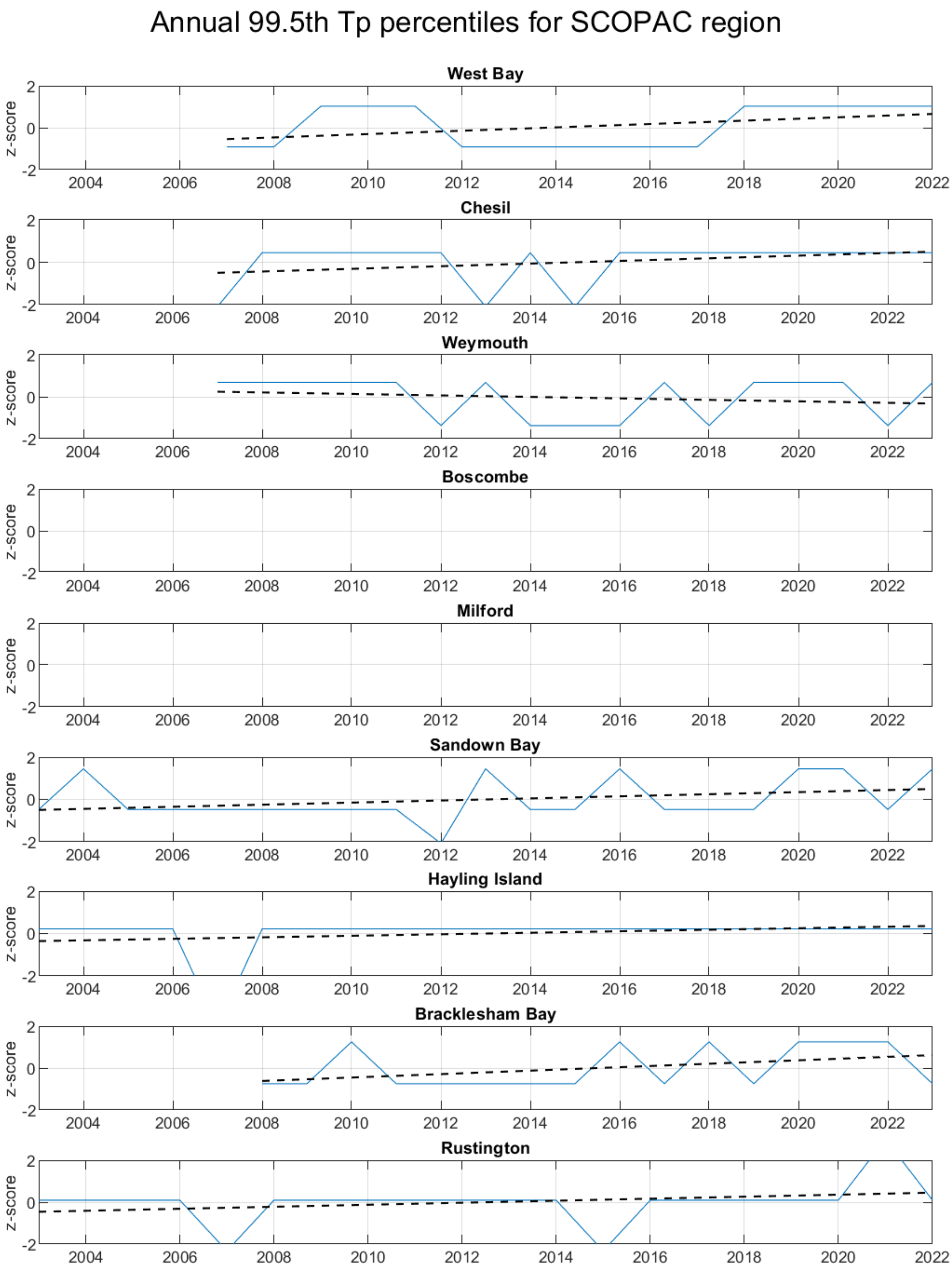
Annual 99.5th Tp percentiles for SCOPAC region
West Bay
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Weymouth
Boscombe
Milford
Sandown Bay
Hayling Island
Bracklesham Bay
Rustington
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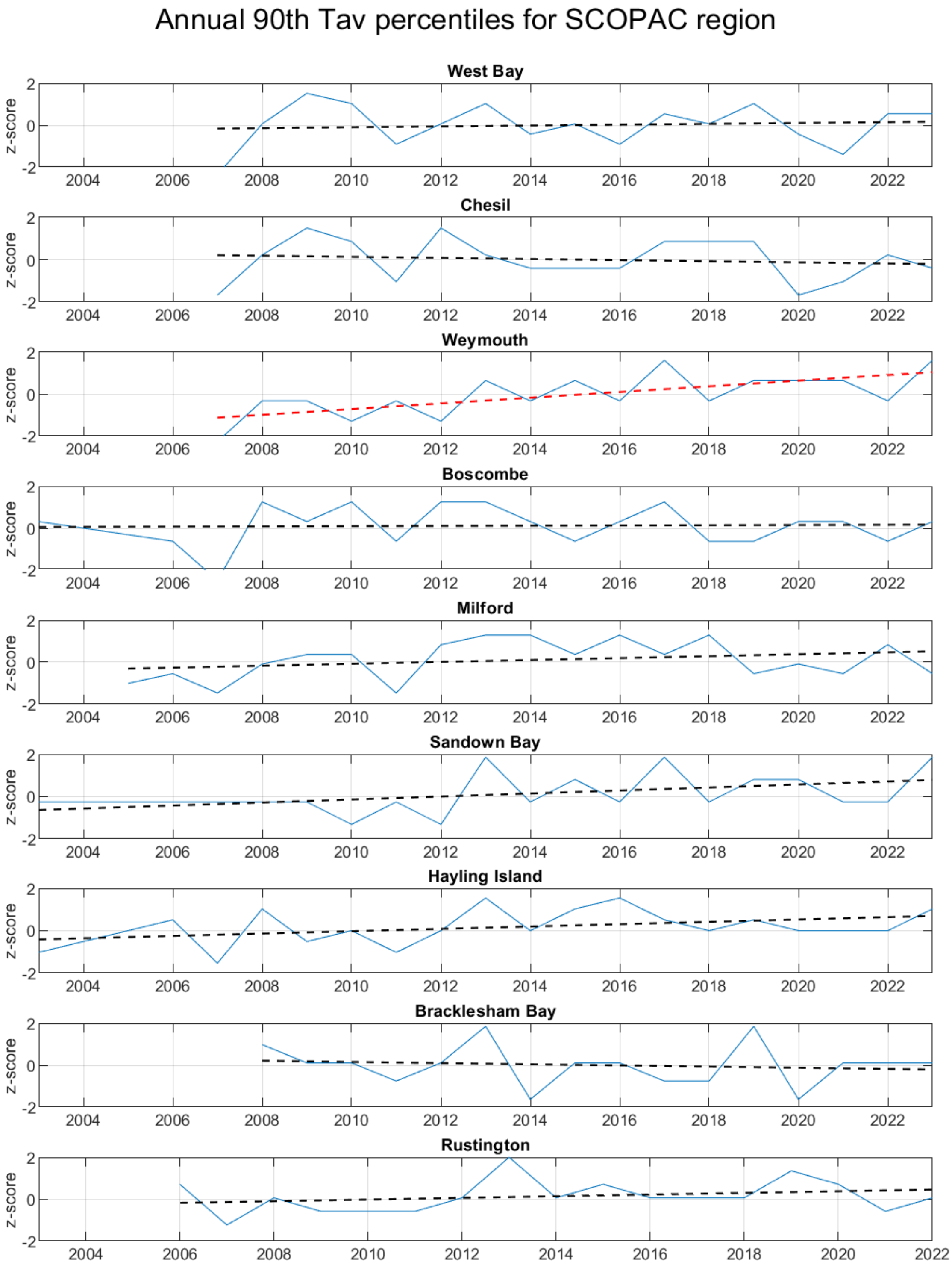
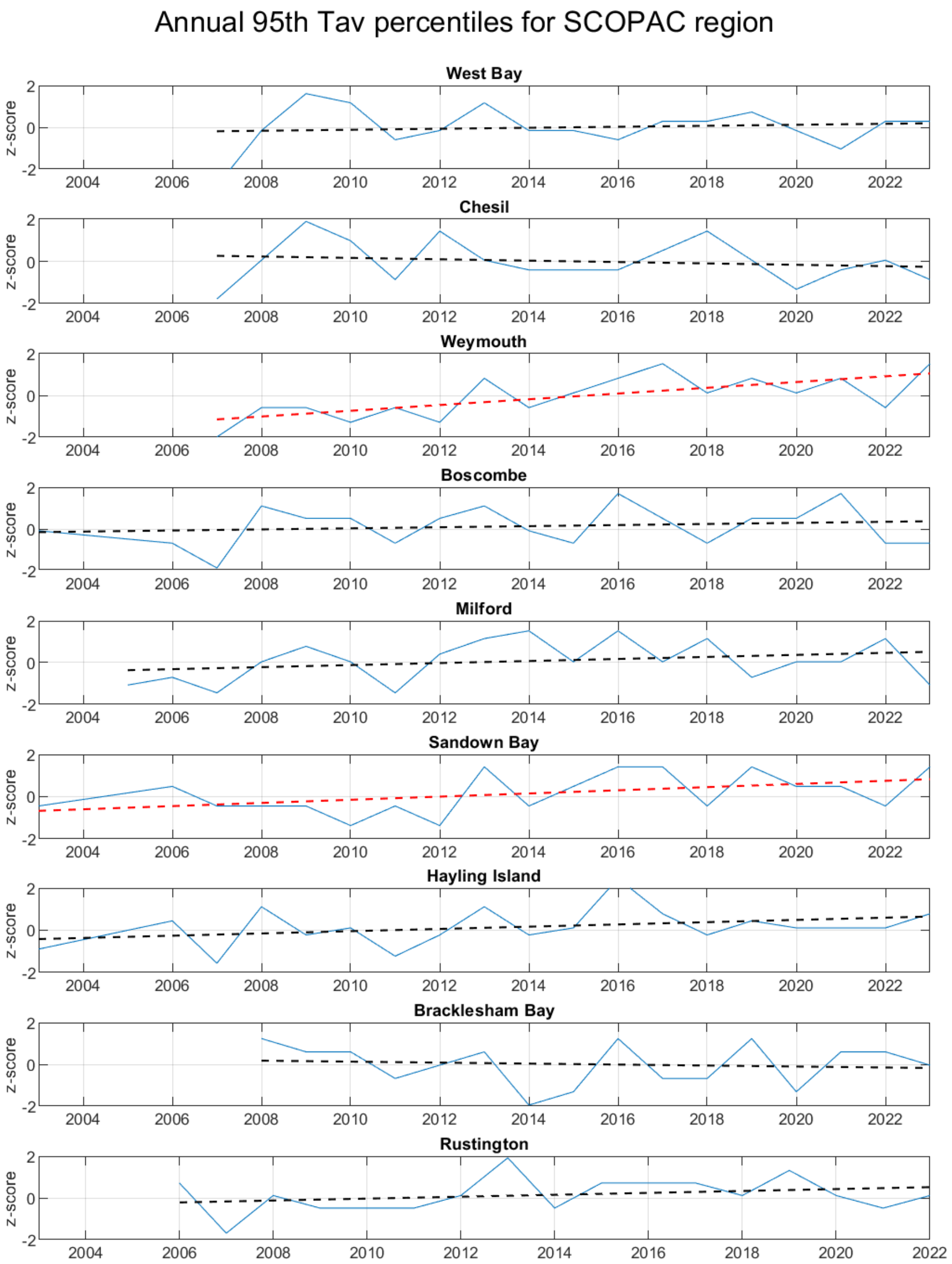
Part 2b - Wave Period Tav





Annual 95th Tav percentiles for SCOPAC region
West Bay
Chesil
Weymouth
Boscombe
Milford
Sandown Bay
Hayling Island
Bracklesham Bay
Rustington
z-score
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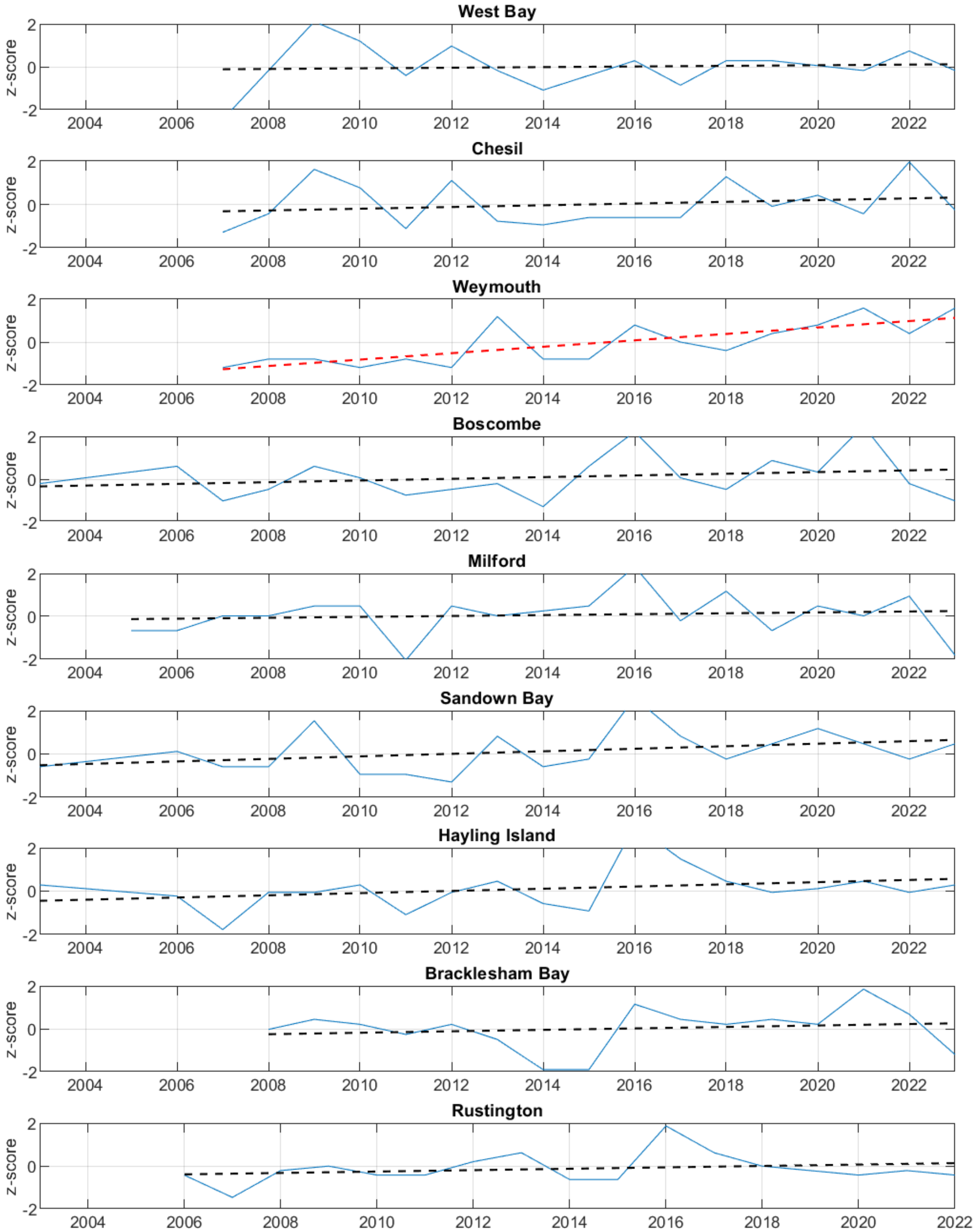
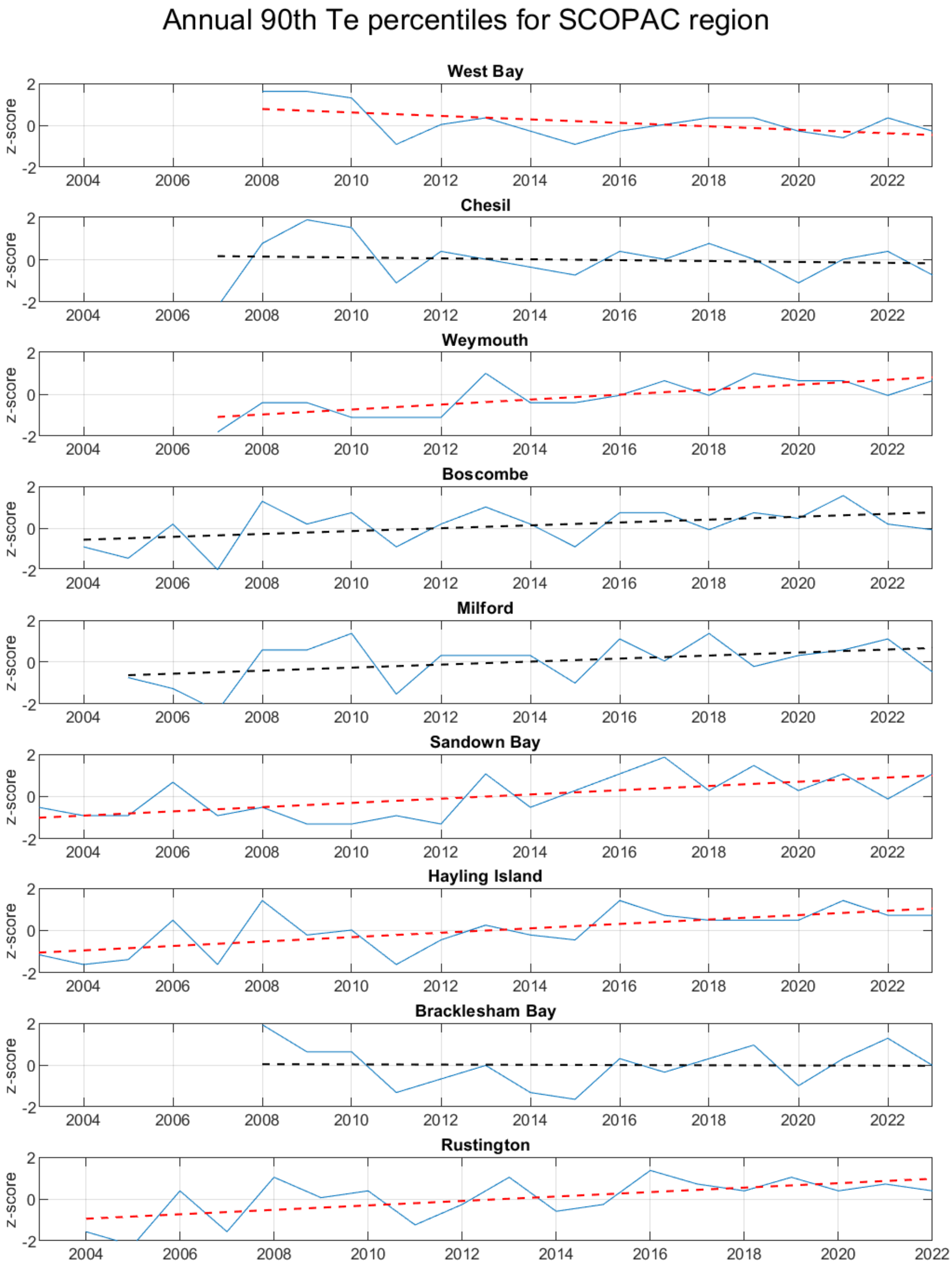
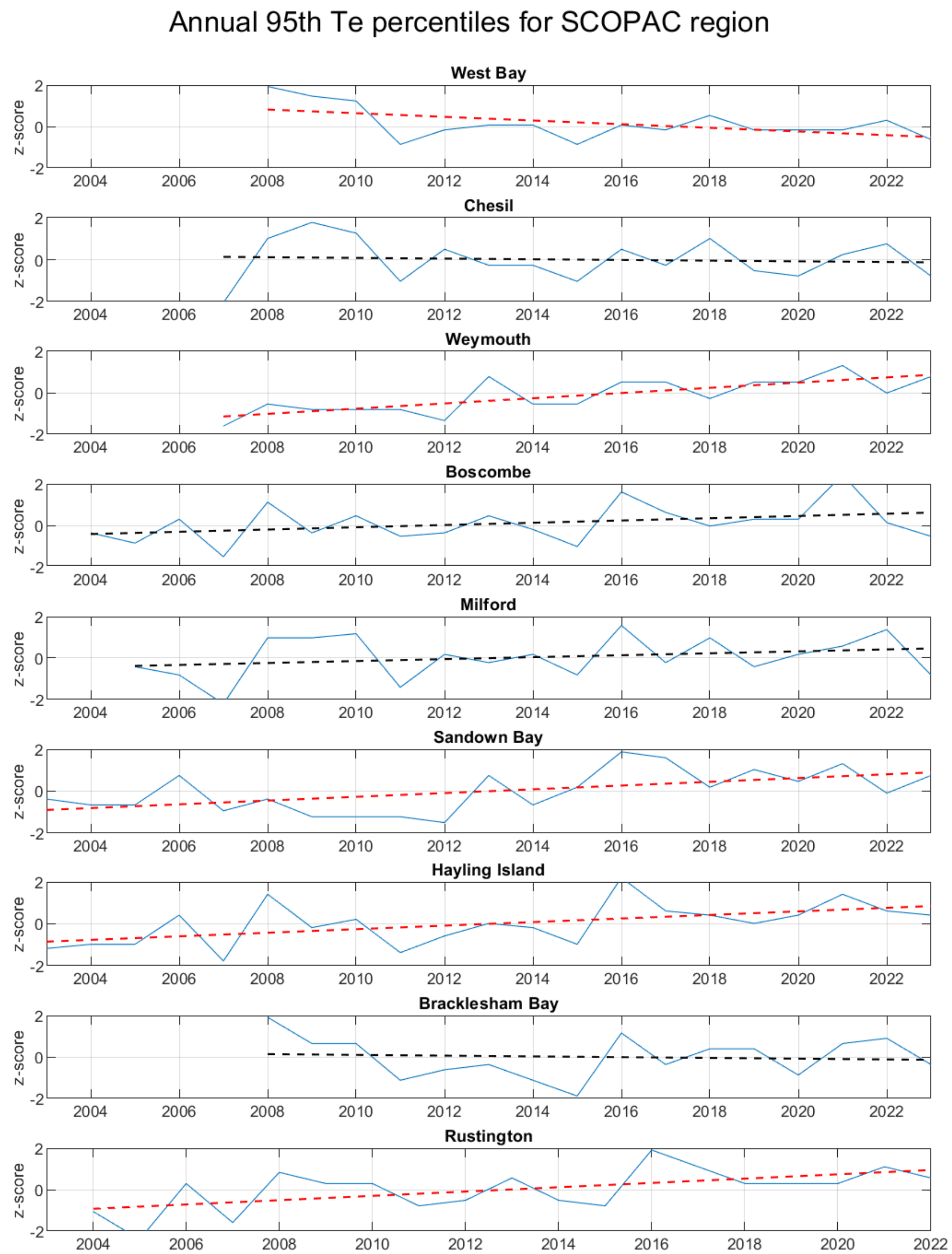
Annual 99.5th Tav percentiles for SCOPAC region



Part 2c - Energy Wave Period Te





Annual 95th Te percentiles for SCOPAC region
West Bay
Chesil
Weymouth
Boscombe
Milford
Sandown Bay
Hayling Island
Bracklesham Bay
Rustington
z-score
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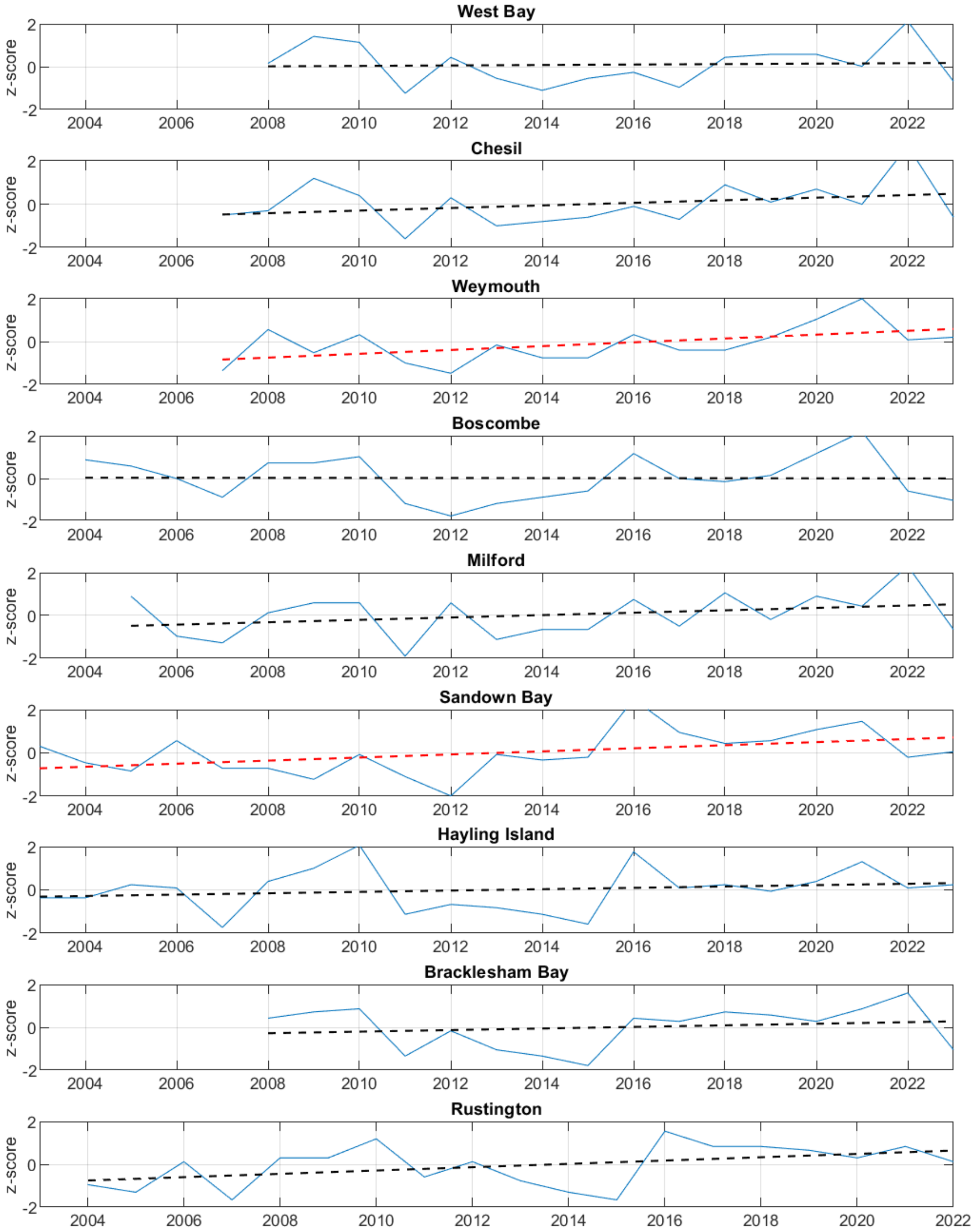
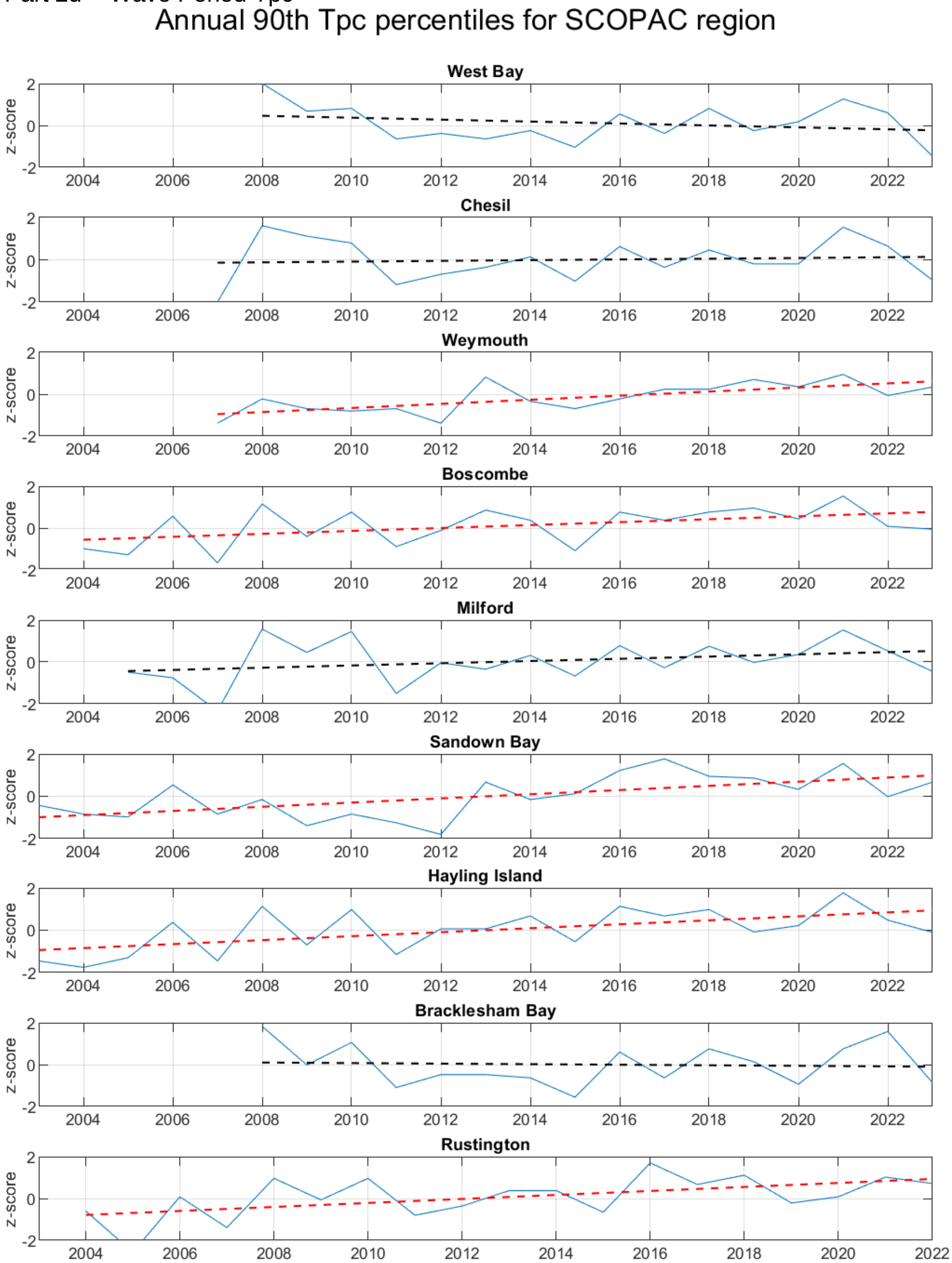
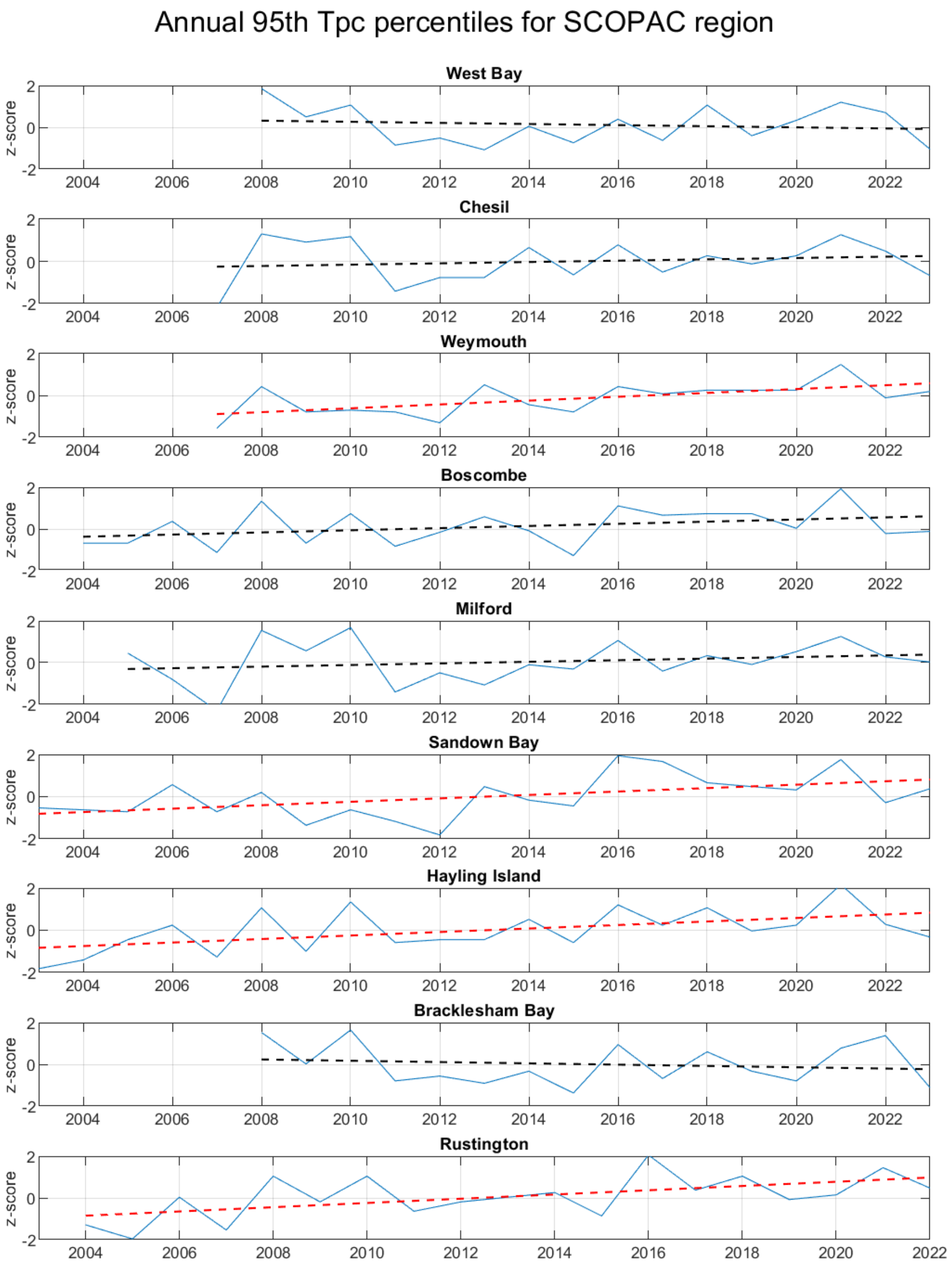
Annual 99.5th Te percentiles for SCOPAC region



Part 2d - Wave Period Tpc




Annual 95th Tpc percentiles for SCOPAC region
West Bay
Chesil
Weymouth
Boscombe
Milford
Sandown Bay
Hayling Island
Bracklesham Bay
Rustington
z-score
2004
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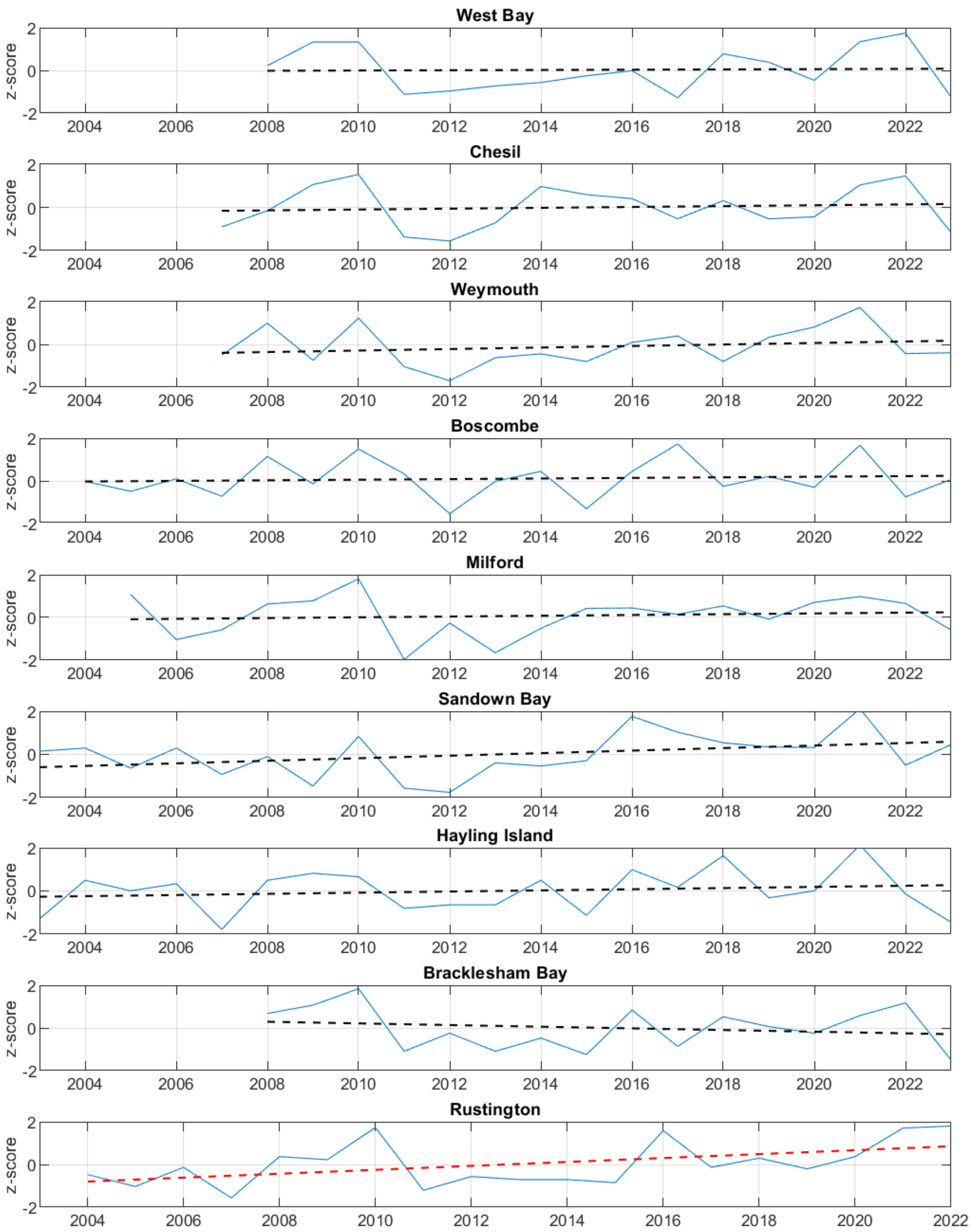
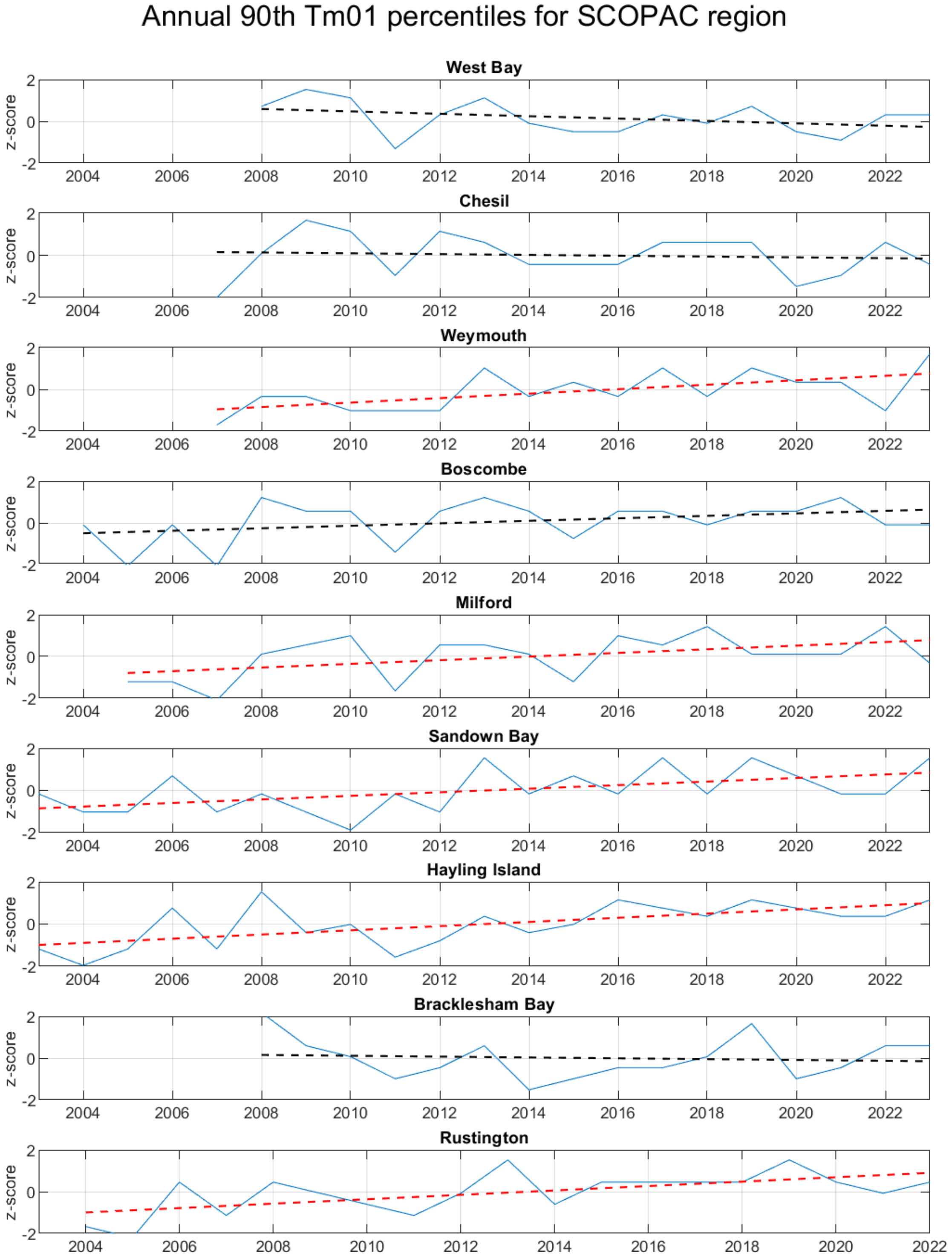
2022

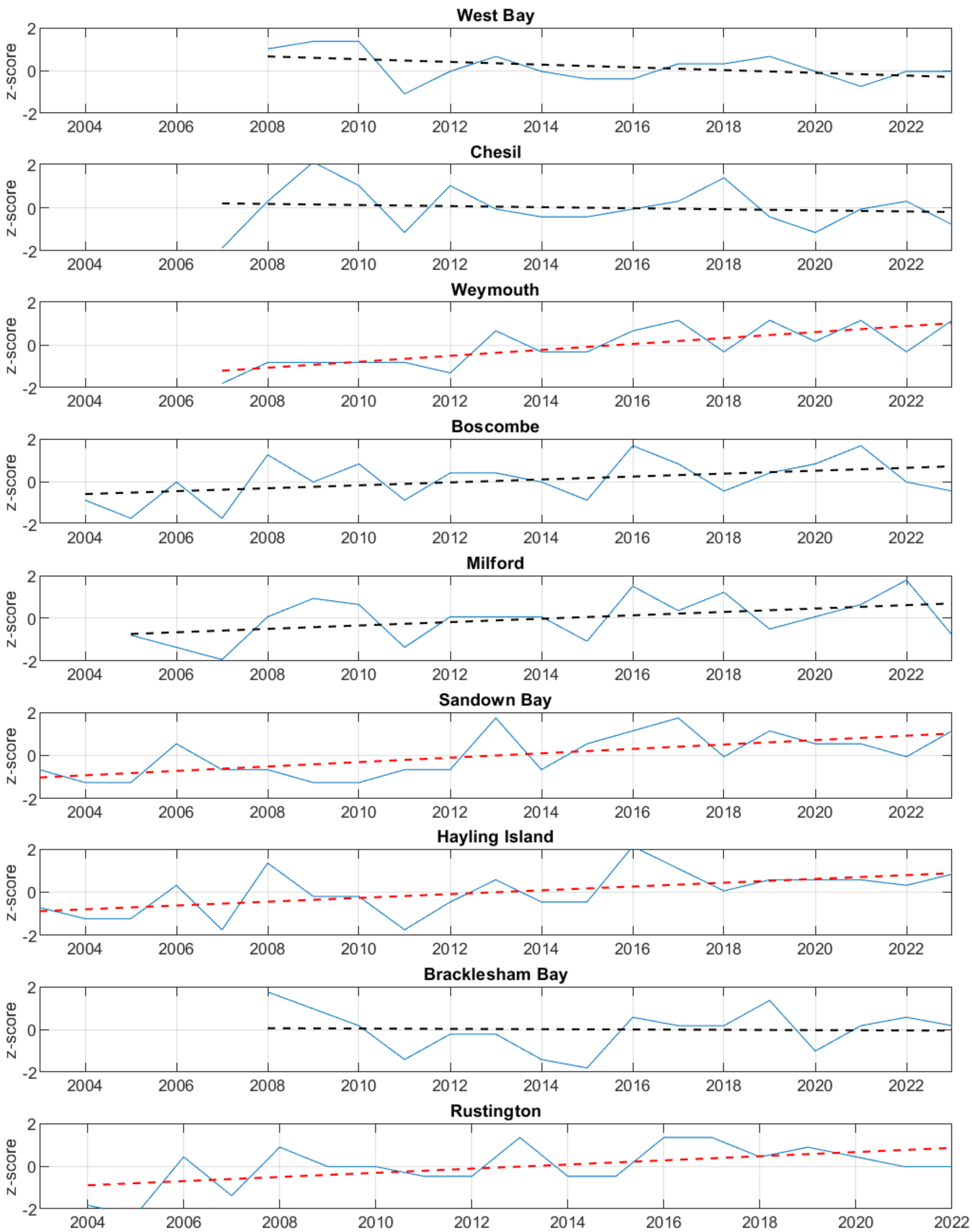
Annual 99.5th Tpc percentiles for SCOPAC region

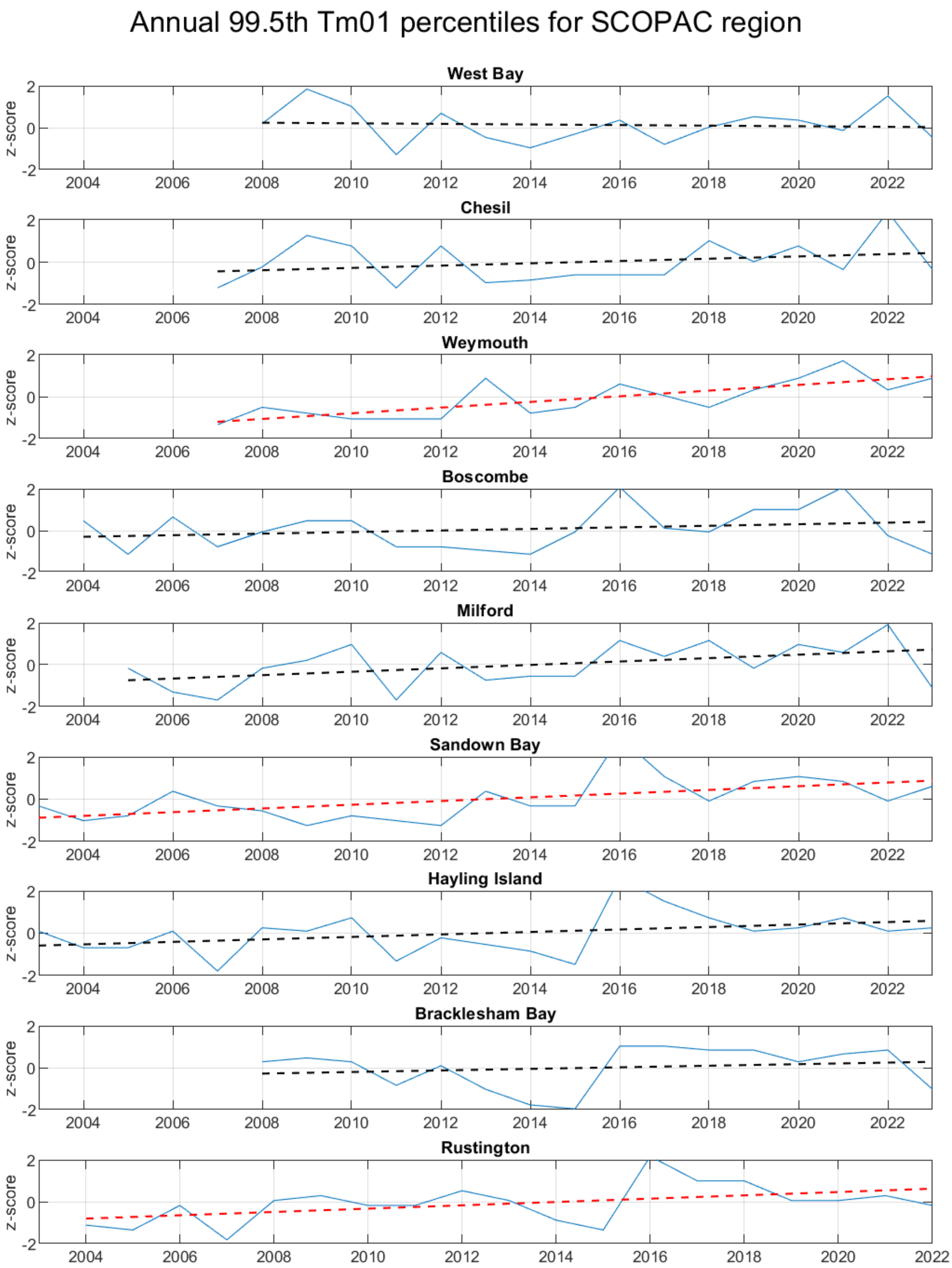


Part 2e - Wave Period Tm01



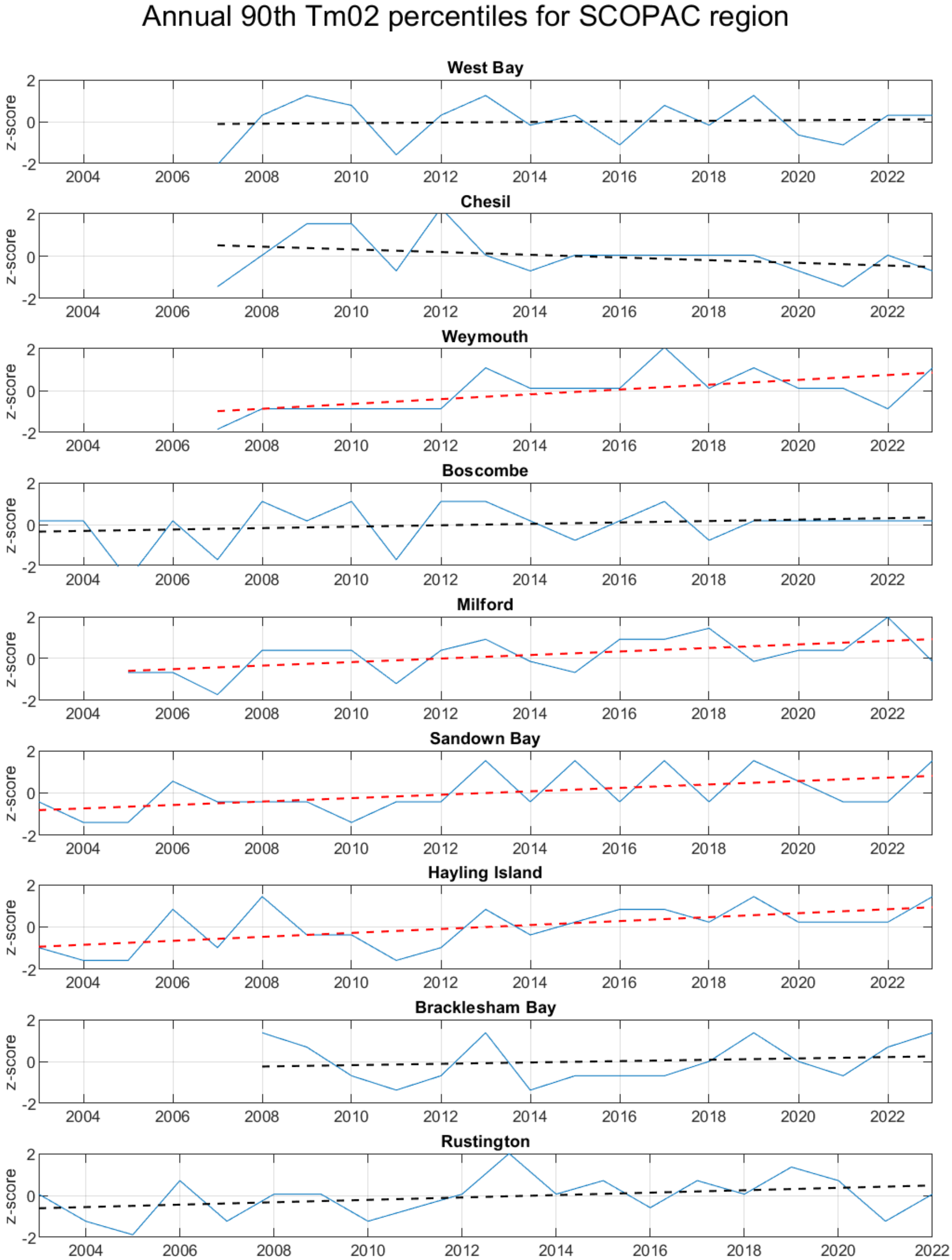
Annual 95th Tm01 percentiles for SCOPAC region



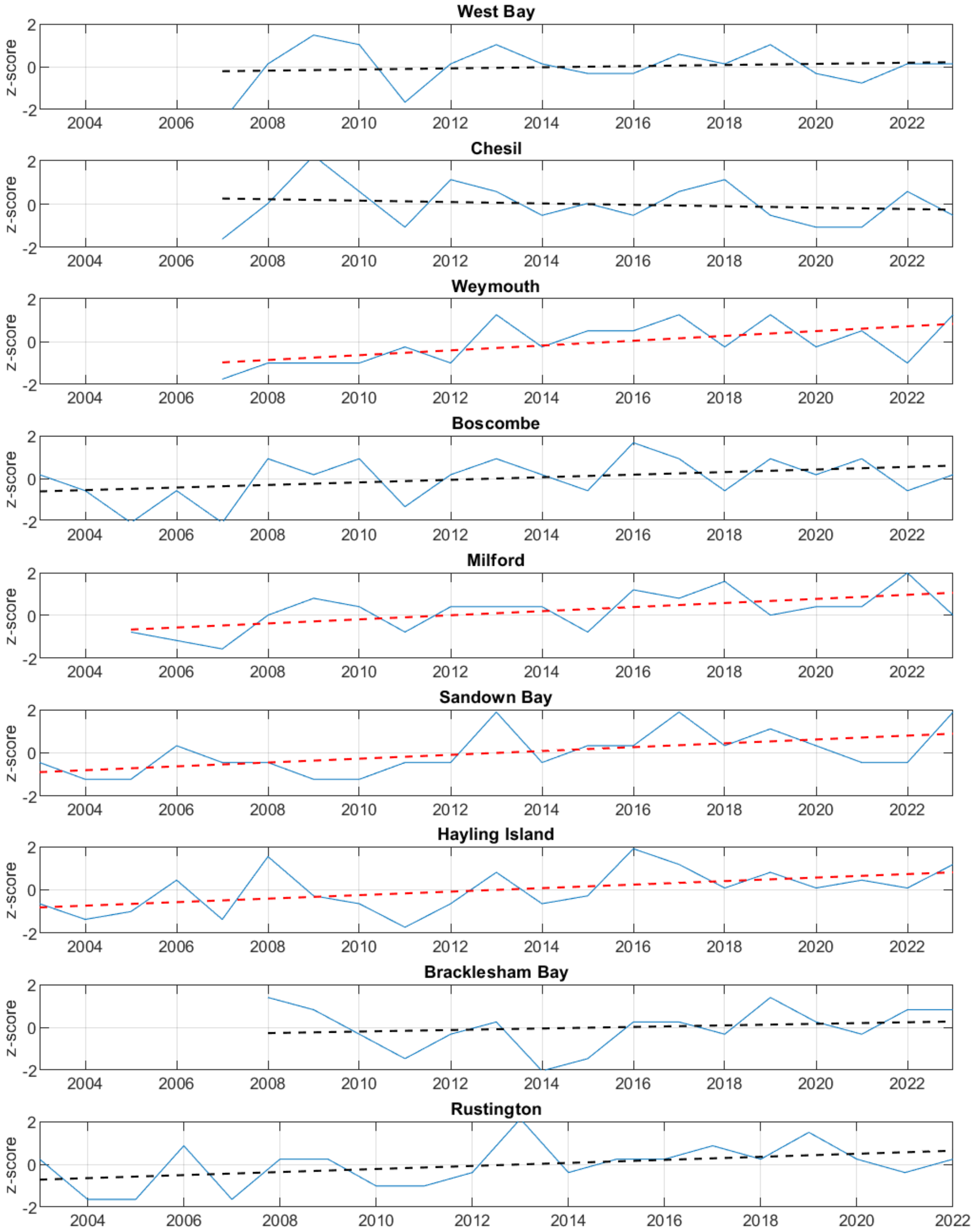


Annual 99.5th Tm01 percentiles for SCOPAC region
West Bay
Chesil
Weymouth
Boscombe
Milford
Sandown Bay
Hayling Island
Bracklesham Bay
Rustington
z-score
2
0
-2
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

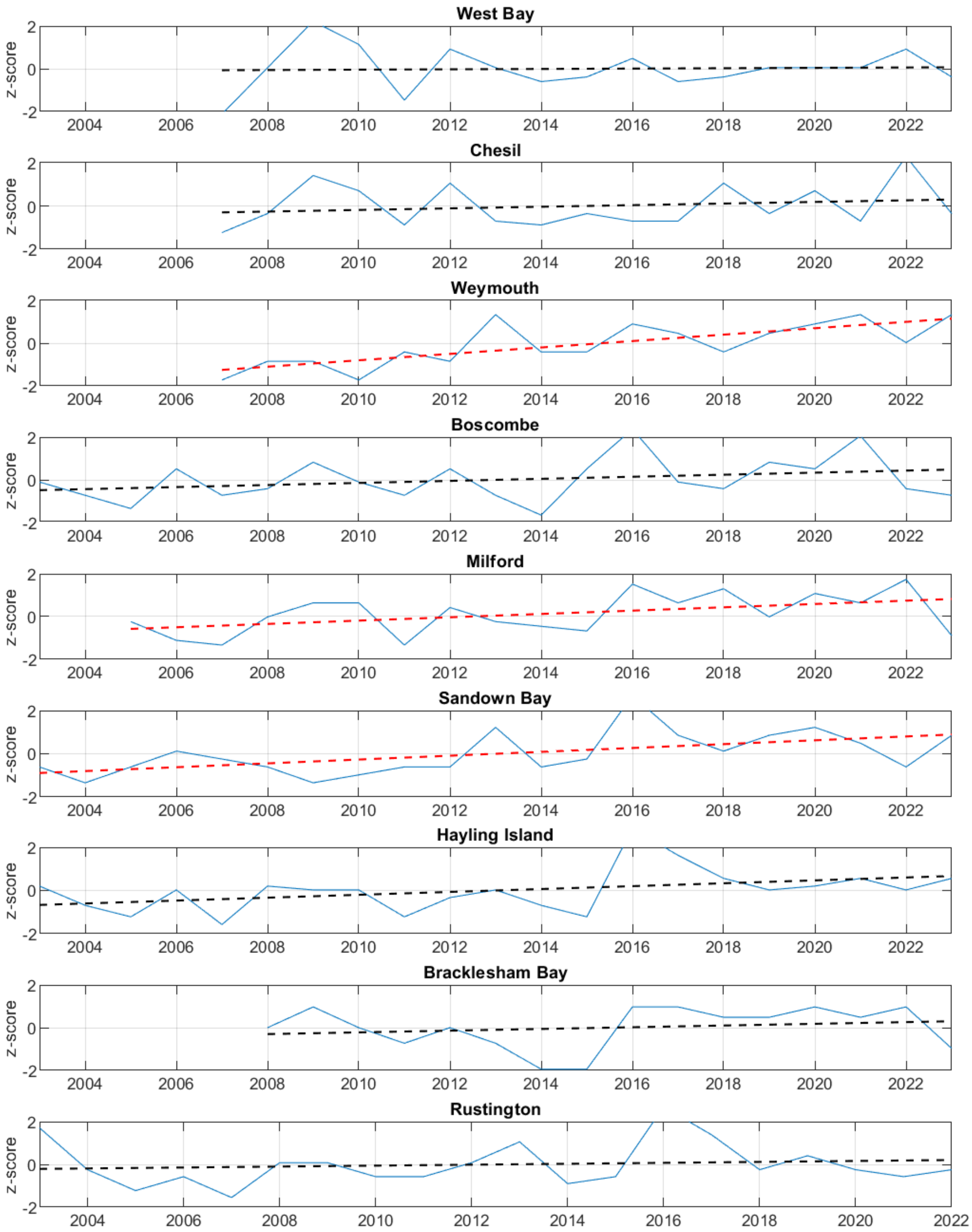
Part 2f - Wave Period Tm02



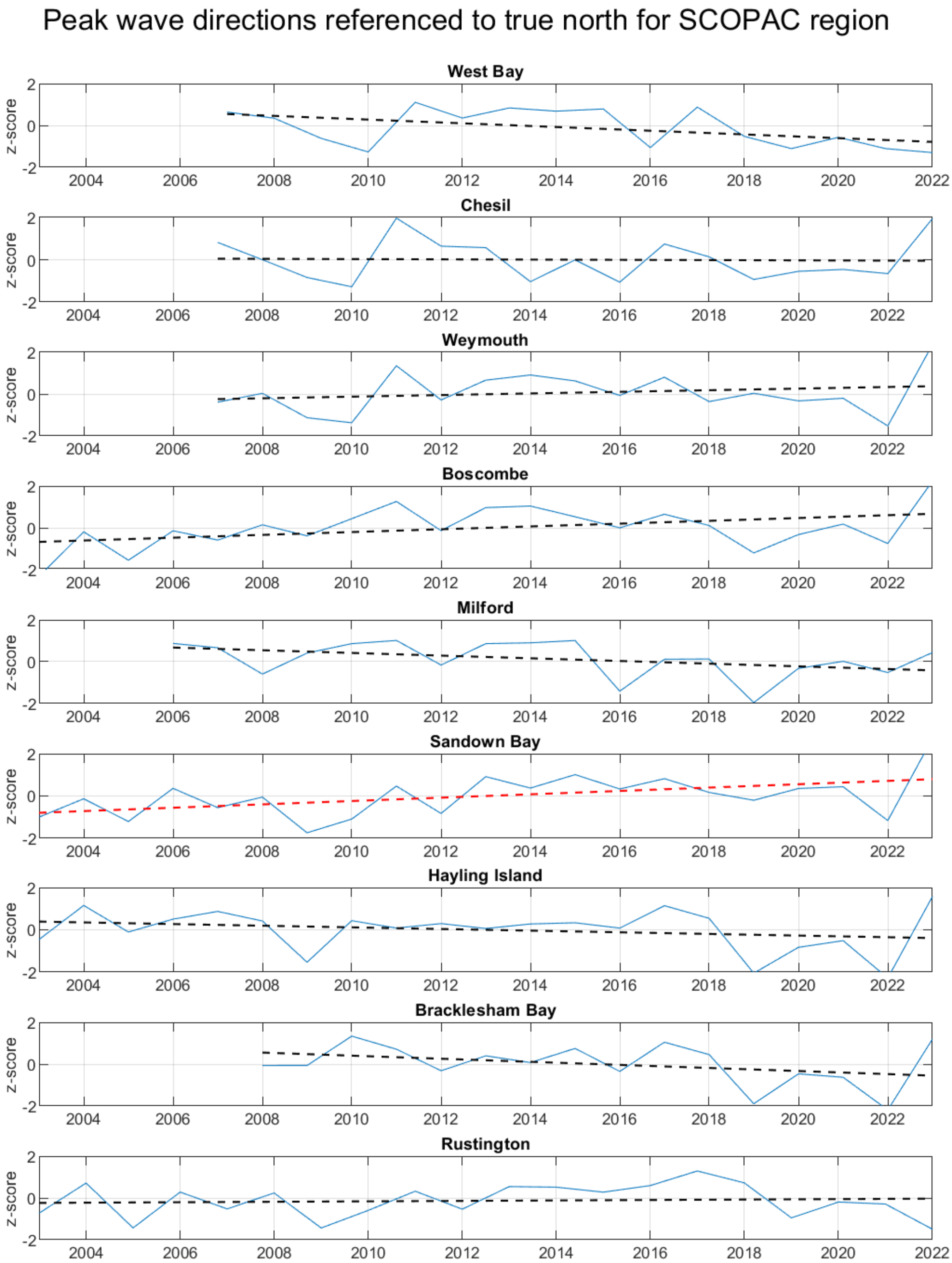
Annual 95th Tm02 percentiles for SCOPAC region



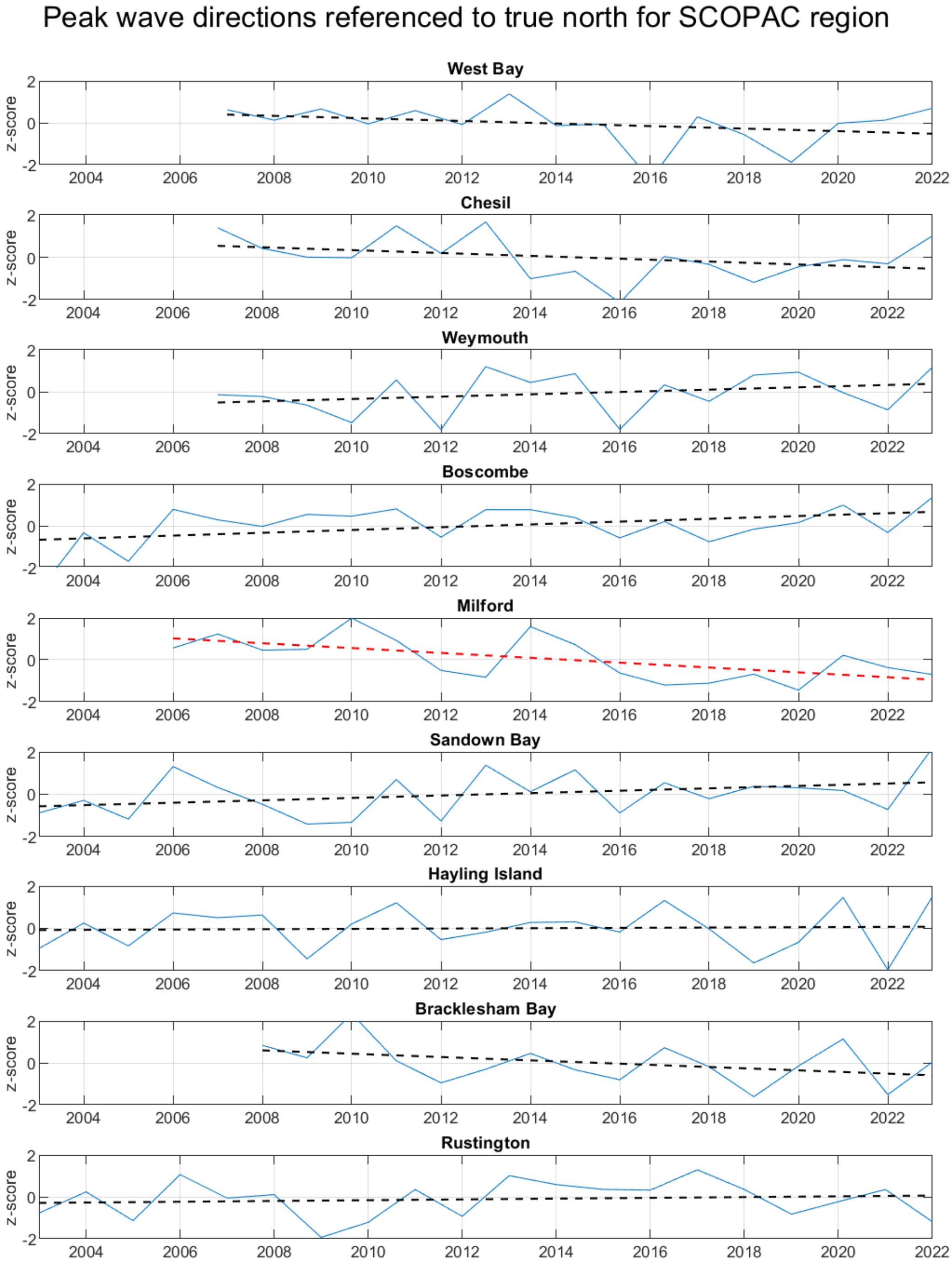
Annual 99.5th Tm02 percentiles for SCOPAC region

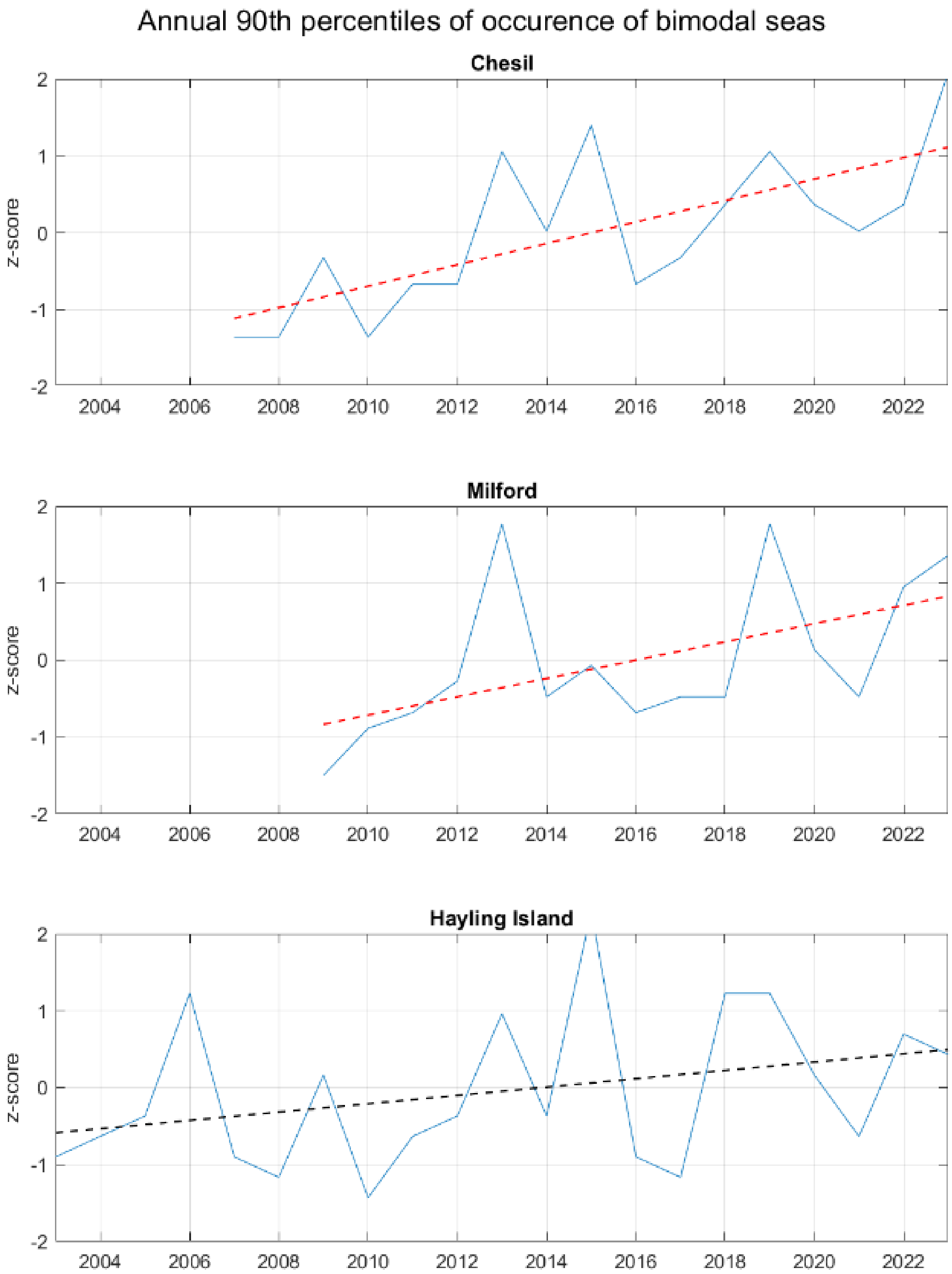


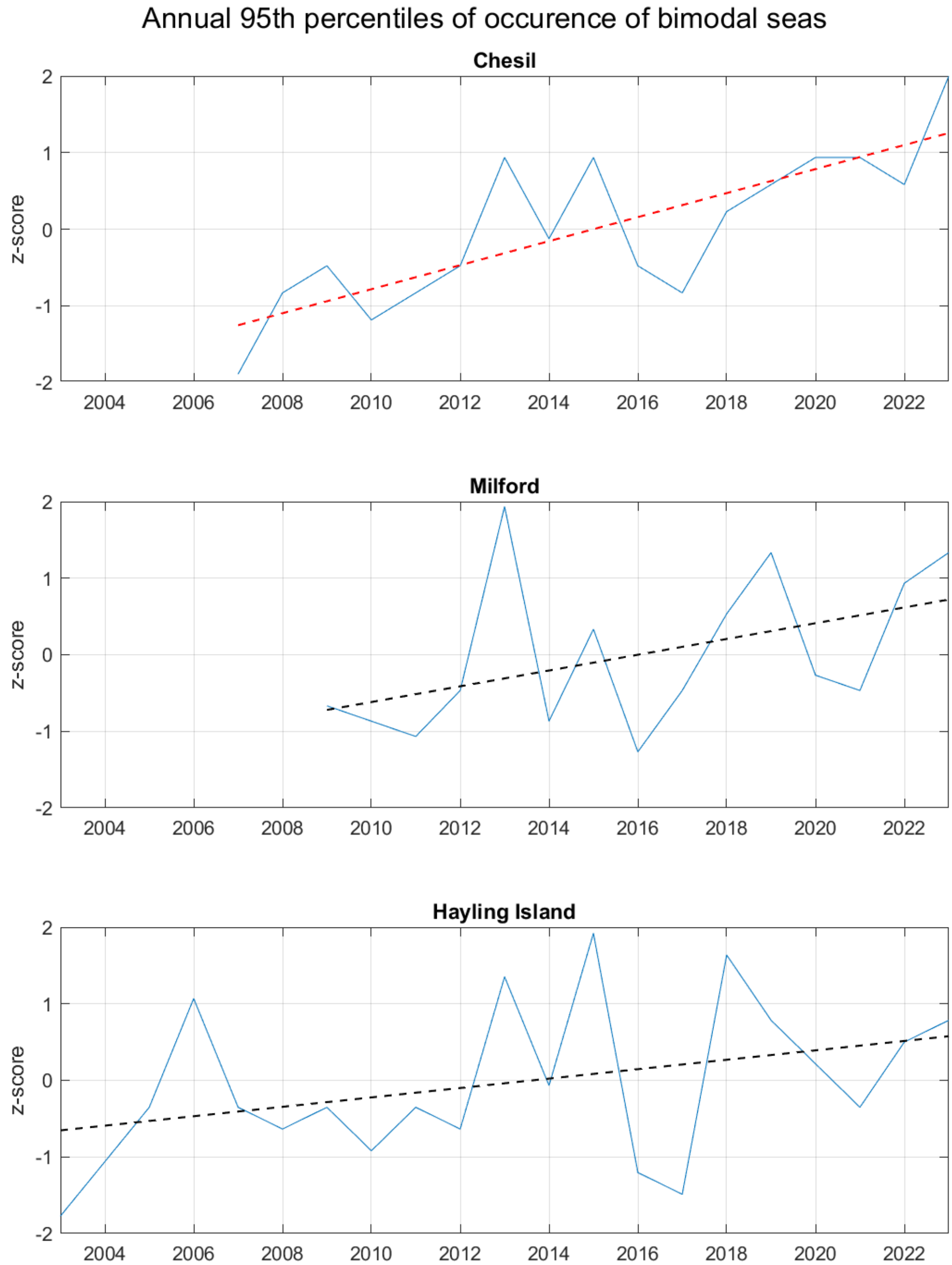
Part 3a - Direction (non threshold approach)



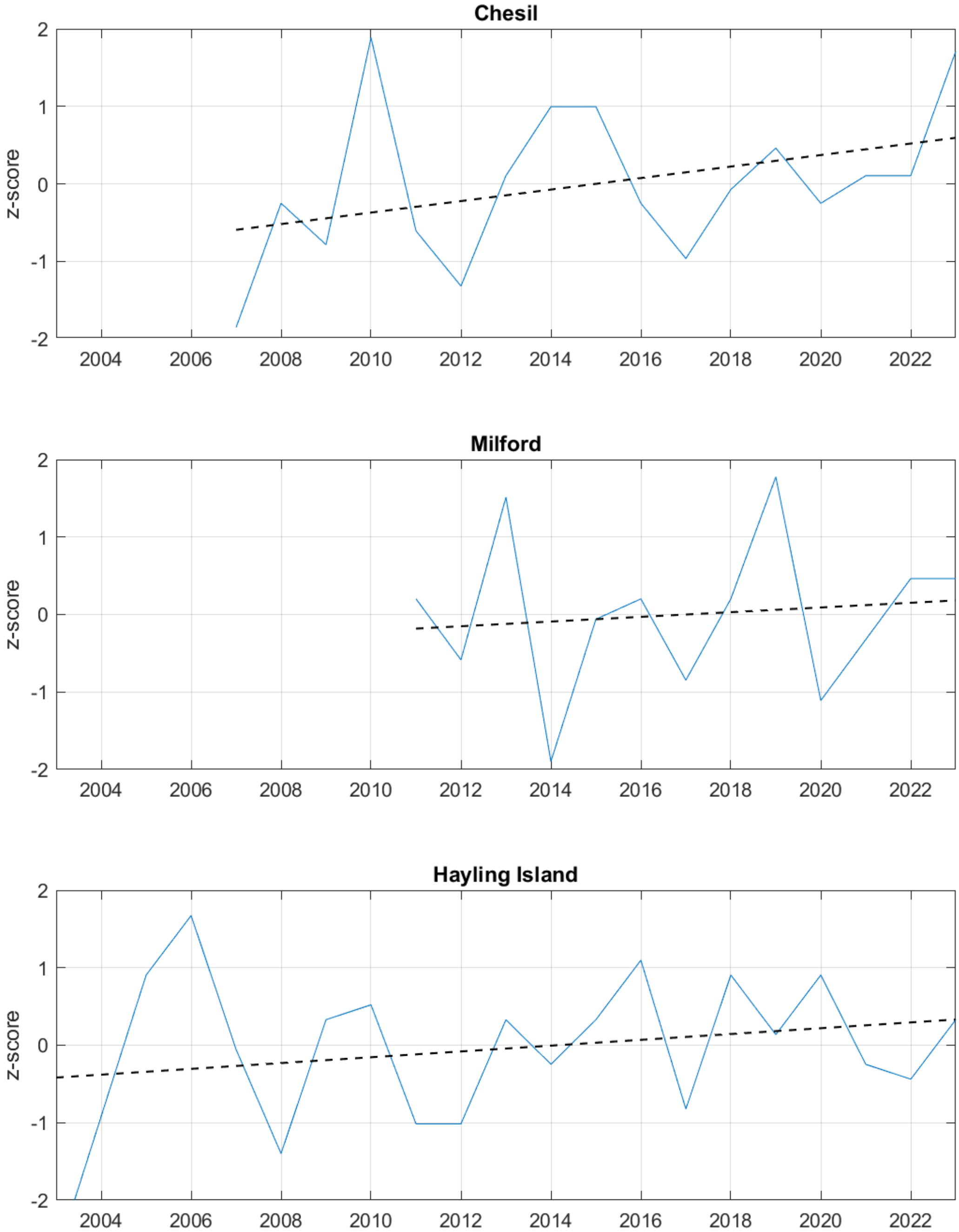
Part 3b - Direction (threshold approach: peak wave direction where Hs > 0.5m)


Peak wave directions referenced to true north for SCOPAC region
West Bay
Chesil
Weymouth
Boscombe
Milford
Sandown Bay
Hayling Island
Bracklesham Bay
Rustington
z-score
2
0
-2
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022


Annual 90th percentiles of occurence of bimodal seas
Chesil
Milford
Hayling Island
z-score
2
1
0
-1
-2
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

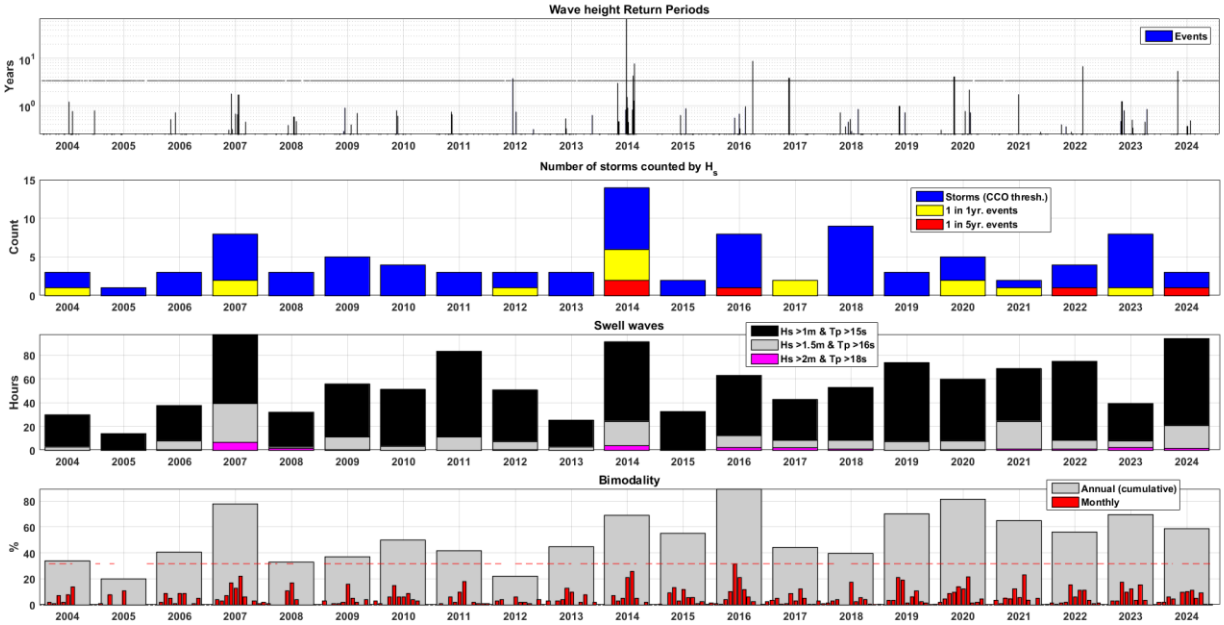

Annual 95th percentiles of occurence of bimodal seas
Chesil
Milford
Hayling Island
z-score
2
1
0
-1
-2
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

Annual 99.5th percentiles of occurence of bimodal seas



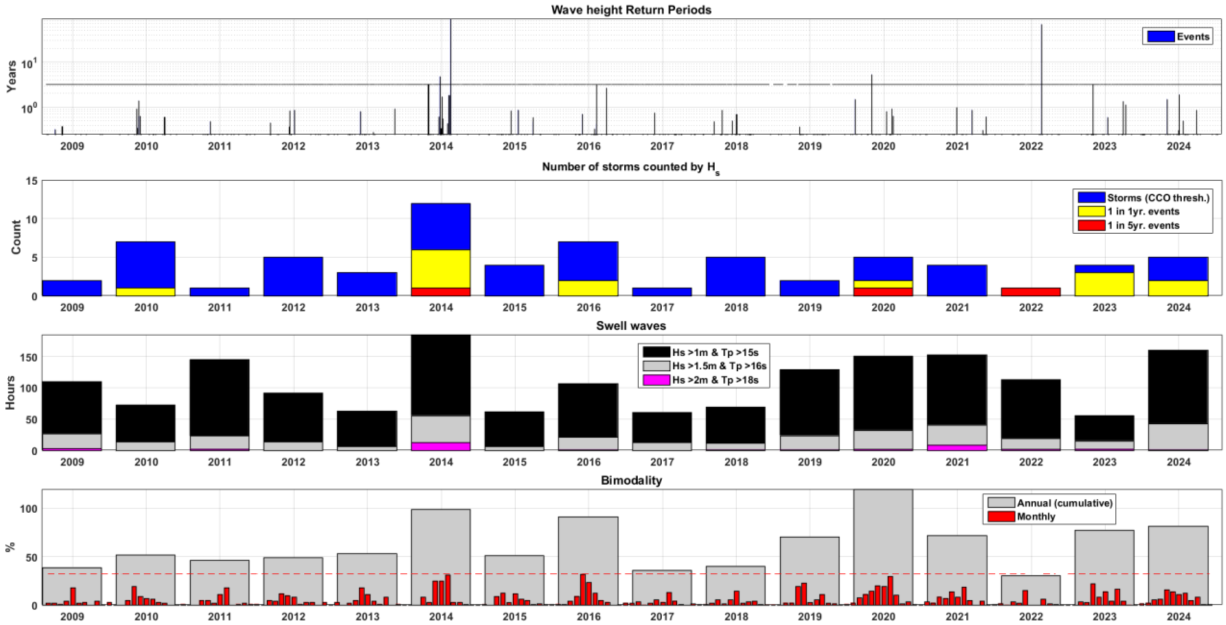
APPENDIX C – RESULTS FIGURES & TABLES: WINTER SEASON EVENTS

Rustington



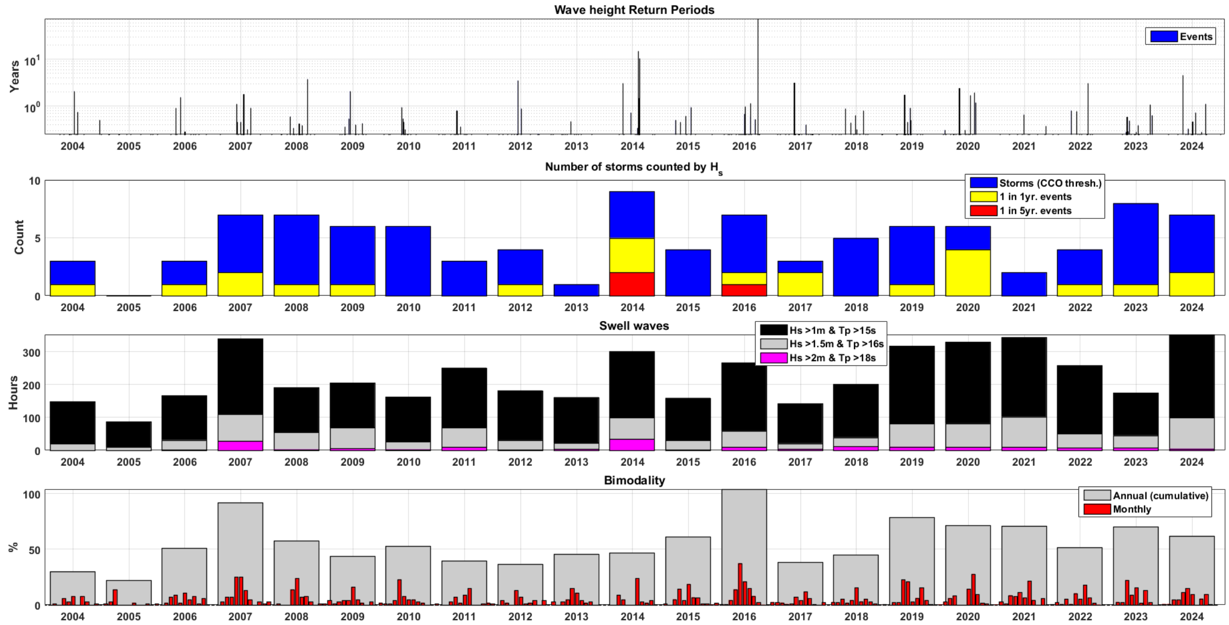
Winter season	averages				Storm Counts		Swell hours		Bimodality
	HS (m)	HMAX(m)	TP(s)	TZ(s)	0.25yr	1 in 1yr	Hs>=1m, TP>=18s	Hs>=2m, TP>=20s	
03/04	0.81	1.22	6.45	3.76	3	1	11.5	0	n/a
04/05	0.76	1.17	6.37	3.72	1	0	7	0	2%
05/06	0.75	1.15	6.30	3.65	3	0	16	0	2%
06/07	0.89	1.37	6.88	3.85	8	2	36	3.5	5%
07/08	0.80	1.23	6.36	3.70	4	0	13.5	1.5	3%
08/09	0.80	1.23	6.86	3.82	5	0	22.5	0	2%
09/10	0.79	1.21	6.76	3.75	4	0	14.5	0	3%
10/11	0.76	1.17	6.65	3.70	3	0	35.5	0	3%
11/12	0.81	1.25	6.58	3.78	3	1	14.5	0.5	3%
12/13	0.85	1.31	6.68	3.81	3	0	5.5	0	3%
13/14	0.90	1.37	6.82	3.88	14	6	32.5	2	6%
14/15	0.82	1.26	6.73	3.77	2	0	3	0	3%
15/16	0.94	1.44	6.75	3.89	8	1	8.5	0	6%
16/17	0.76	1.17	6.91	3.76	2	2	11	0.5	3%
17/18	0.83	1.26	6.87	3.85	9	0	11.5	1	3%
18/19	0.78	1.21	6.99	3.77	3	1	26.5	0	5%
19/20	0.93	1.44	6.84	3.93	5	2	16	0	6%
20/21	0.85	1.32	6.67	3.81	2	1	24	0.5	5%
21/22	0.76	1.18	6.75	3.70	4	1	26.5	0	3%
22/23	0.82	1.26	6.89	3.75	8	1	11	1.5	5%
23/24	1.00	1.55	7.06	4.03	4	1	33.5	0	5%

Bracklesham



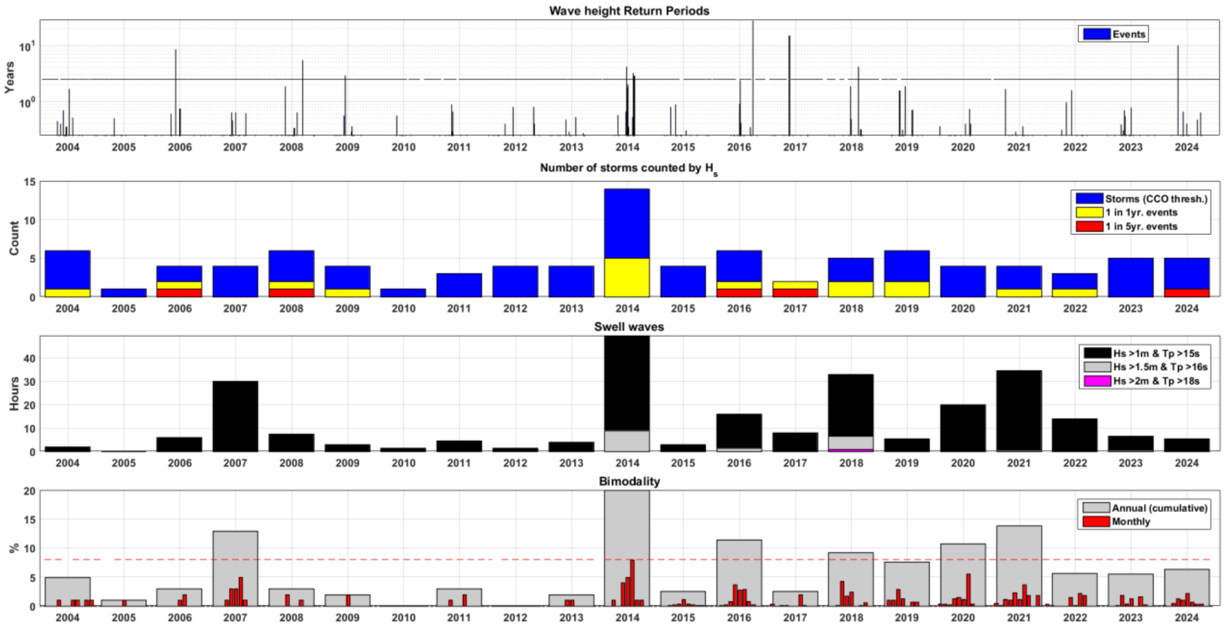
Winter	averages				Storm Counts		Swell hours		Bimodality
	HS (m)	HMAX(m)	TP(s)	TZ(s)	0.25yr	1 in 1yr	Hs>=1m, TP>=18s	Hs>=2m, TP>=20s	
09/10	0.71	1.08	7.78	3.98	7	1	14	0	5%
10/11	0.67	1.03	7.69	3.93	1	0	49.5	1.5	4%
11/12	0.76	1.17	7.59	4.00	5	0	21	0	4%
12/13	0.76	1.16	7.52	4.01	3	0	9.5	0	4%
13/14	0.82	1.25	7.52	4.03	12	6	49	4.5	8%
14/15	0.75	1.15	7.29	3.91	4	0	5	0	4%
15/16	0.86	1.31	7.44	4.03	7	2	9.5	0	8%
16/17	0.66	1.02	7.51	3.93	1	0	10	0	3%
17/18	0.74	1.12	7.50	4.01	5	0	18	0	3%
18/19	0.71	1.09	7.83	4.00	2	0	48	1	6%
19/20	0.87	1.33	7.86	4.15	5	2	51	0.5	10%
20/21	0.76	1.16	7.55	4.00	4	0	56	2.5	6%
21/22	0.68	1.03	7.54	3.90	1	1	36.5	0	3%
22/23	0.73	1.11	7.89	4.01	4	3	10	0.5	6%
23/24	0.88	1.36	7.50	4.08	5	2	40	0	7%

Hayling Island



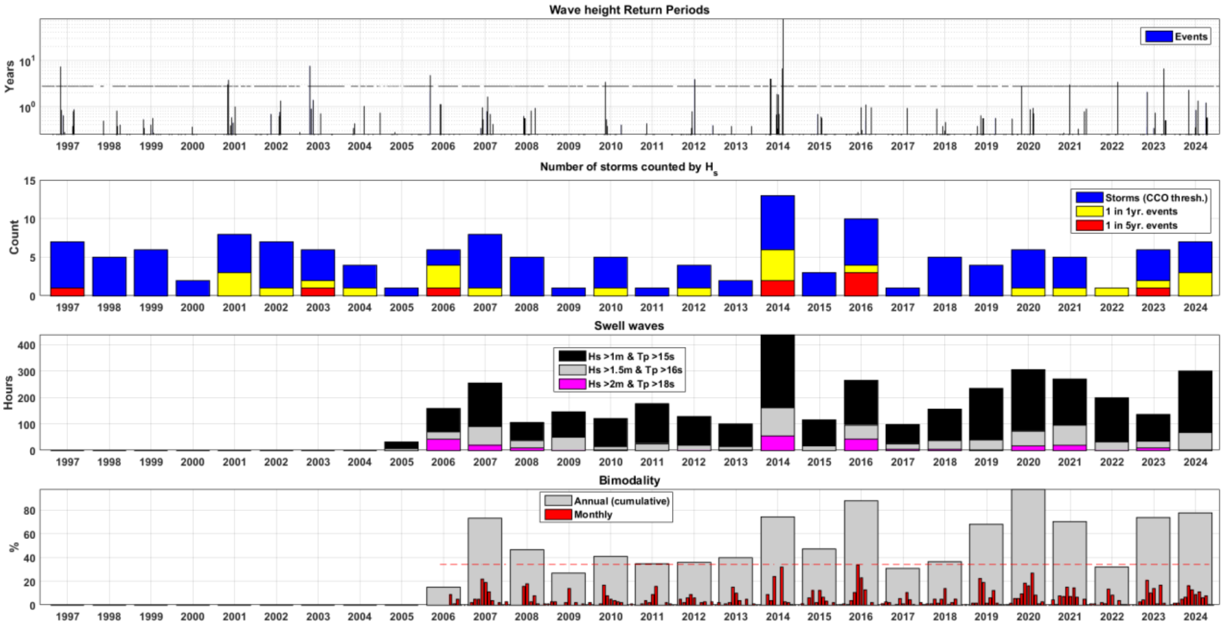
Winter	averages				Storm Counts		Swell hours		Bimodality
	HS (m)	HMAX(m)	TP(s)	TZ(s)	0.25yr	1 in 1yr	Hs>=1m, TP>=18s	Hs>=2m, TP>=20s	
03/04	0.63	0.96	7.57	3.65	3	1	33	0	
04/05	0.62	0.95	7.37	3.61	0	0	31.5	0	2%
05/06	0.62	0.94	7.43	3.60	3	1	51	0	4%
06/07	0.75	1.14	8.09	3.80	7	2	93	18.5	7%
07/08	0.68	1.03	7.56	3.63	7	1	41	0.5	6%
08/09	0.66	1.01	7.98	3.81	6	1	83.5	3.5	4%
09/10	0.65	1.00	7.80	3.68	6	0	38	0.5	5%
10/11	0.64	0.97	7.72	3.66	3	0	89	4.5	4%
11/12	0.67	1.02	7.67	3.66	4	1	62.5	0	3%
12/13	0.68	1.04	7.84	3.72	1	0	36.5	1.5	5%
13/14	0.68	1.04	7.86	3.75	9	5	89.5	15.5	5%
14/15	0.68	1.03	8.04	3.72	4	0	29	0	5%
15/16	0.77	1.17	8.07	3.82	7	2	41	5.5	9%
16/17	0.62	0.94	8.01	3.79	3	2	22	2.5	3%
17/18	0.68	1.03	8.12	3.82	5	0	48.5	4.5	4%
18/19	0.66	1.01	8.27	3.75	6	1	95.5	6	7%
19/20	0.75	1.16	8.29	3.86	6	4	95	2.5	7%
20/21	0.70	1.07	7.80	3.75	2	0	119	3.5	6%
21/22	0.64	0.98	7.85	3.70	4	1	90	0	4%
22/23	0.68	1.04	8.06	3.73	8	1	35	4	6%
23/24	0.76	1.17	7.99	3.84	7	2	109.5	2	6%

Sandown Bay



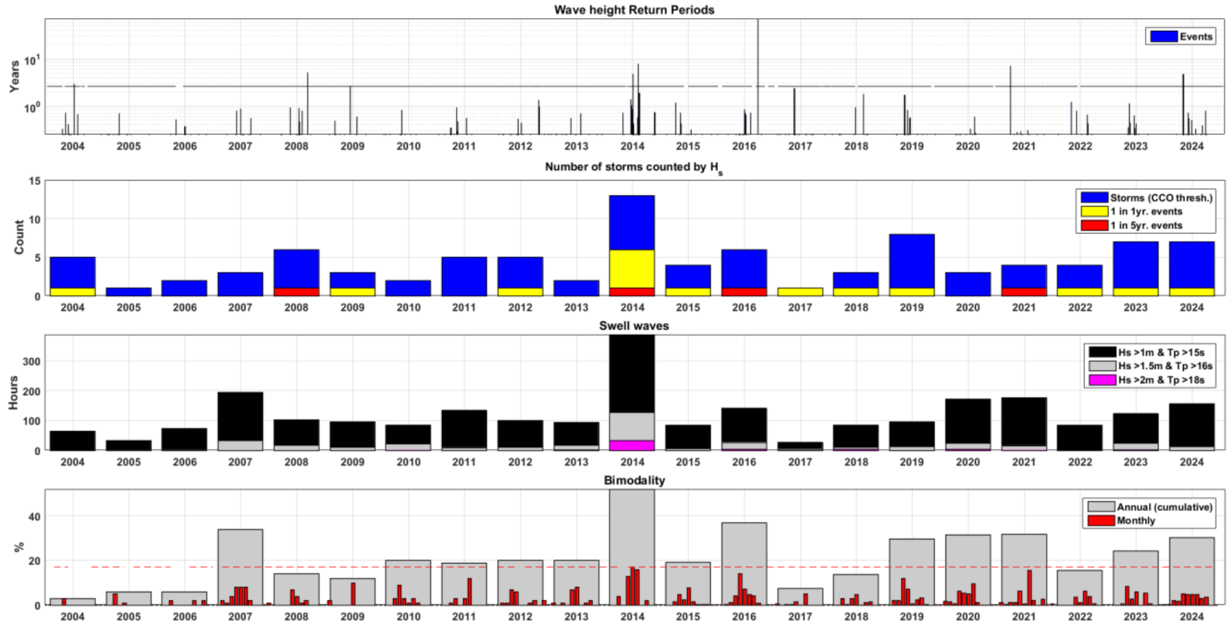
Winter	averages				Storm Counts		Swell hours		Bimodality
	HS (m)	HMAX(m)	TP(s)	TZ(s)	0.25yr	1 in 1yr	Hs>=1m, TP>=18s	Hs>=2m, TP>=20s	
03/04	0.51	0.79	5.88	3.66	6	1	0.5	0	
04/05	0.48	0.75	5.90	3.64	1	0	0	0	0%
05/06	0.49	0.77	5.81	3.62	4	2	6	0	0%
06/07	0.54	0.84	6.13	3.71	4	0	22	0	1%
07/08	0.50	0.78	5.80	3.65	6	2	6.5	0	0%
08/09	0.48	0.75	6.07	3.70	4	1	2.5	0	0%
09/10	0.49	0.77	5.70	3.66	1	0	1	0	0%
10/11	0.47	0.73	5.80	3.66	3	0	4.5	0	0%
11/12	0.49	0.76	5.73	3.65	4	0	1.5	0	0%
12/13	0.53	0.84	5.74	3.71	4	0	4	0	0%
13/14	0.55	0.85	6.08	3.71	14	5	42	0	2%
14/15	0.50	0.77	5.83	3.66	4	0	2.5	0	0%
15/16	0.58	0.89	6.00	3.71	6	2	11.5	0	1%
16/17	0.48	0.75	6.18	3.65	2	2	5	0	0%
17/18	0.51	0.78	6.38	3.74	5	2	23.5	1	1%
18/19	0.50	0.77	6.03	3.64	6	2	3	0	1%
19/20	0.57	0.89	6.13	3.71	4	0	16.5	0	1%
20/21	0.53	0.83	6.01	3.69	4	1	28.5	0	1%
21/22	0.47	0.73	6.20	3.60	3	1	12	0	1%
22/23	0.50	0.79	5.84	3.61	5	0	6	0	0%
23/24	0.54	0.84	6.06	3.68	5	1	5	0	1%

Milford



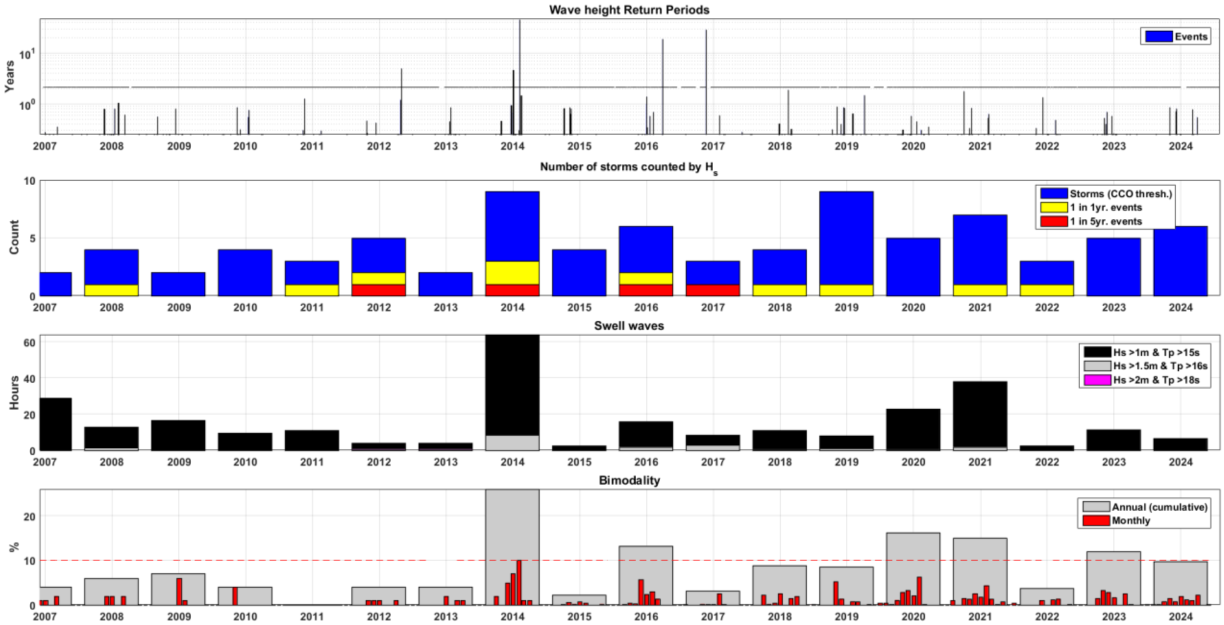
Winter	averages				Storm Counts		Swell hours		Bimodality
	HS (m)	HMAX(m)	TP(s)	TZ(s)	0.25yr	1 in 1yr	Hs>=1m, TP>=18s	Hs>=2m, TP>=20s	
97/98	0.54	1.01	n/a	4.00	5	0	n/a	n/a	n/a
98/99	0.68	1.25	n/a	4.13	6	0	n/a	n/a	n/a
99/00	0.48	0.88	n/a	3.41	2	0	n/a	n/a	n/a
00/01	0.50	0.91	n/a	3.79	8	3	n/a	n/a	n/a
01/02	0.57	1.04	n/a	3.69	7	1	n/a	n/a	n/a
02/03	0.66	1.22	n/a	4.40	6	2	n/a	n/a	n/a
03/04	0.59	1.09	n/a	4.24	4	1	n/a	n/a	n/a
04/05	0.56	0.95	8.12	4.16	1	0	23	0	n/a
05/06	0.55	0.97	7.97	4.00	6	4	99	42	6%
06/07	0.71	1.08	8.48	4.15	8	1	85	12	5%
07/08	0.63	0.97	7.97	4.06	5	0	42	3.5	2%
08/09	0.61	0.96	8.41	4.17	1	0	63	0.5	4%
09/10	0.60	0.93	8.59	4.18	5	1	28.5	0.5	3%
10/11	0.58	0.89	8.53	4.18	1	0	67.5	0	3%
11/12	0.66	1.01	8.08	4.12	4	1	42.5	0.5	3%
12/13	0.65	0.99	8.41	4.22	2	0	26	1	7%
13/14	0.72	1.08	8.47	4.22	13	6	157.5	30.5	4%
14/15	0.64	0.98	8.32	4.17	3	0	27.5	0	8%
15/16	0.77	1.16	8.55	4.24	10	4	90	38	3%
16/17	0.57	0.86	8.38	4.17	1	0	28.5	1	3%
17/18	0.65	1.00	8.40	4.23	5	0	39.5	0.5	6%
18/19	0.63	0.96	8.80	4.28	4	0	71	0.5	8%
19/20	0.74	1.12	8.47	4.23	6	1	114	3.5	6%
20/21	0.68	1.03	8.51	4.22	5	1	111.5	12	3%
21/22	0.60	0.92	8.49	4.15	1	1	82	0	6%
22/23	0.65	0.99	8.75	4.31	6	2	29	3.5	7%
23/24	0.78	1.20	8.31	4.22	7	3	83.5	0.5	5%

Boscombe



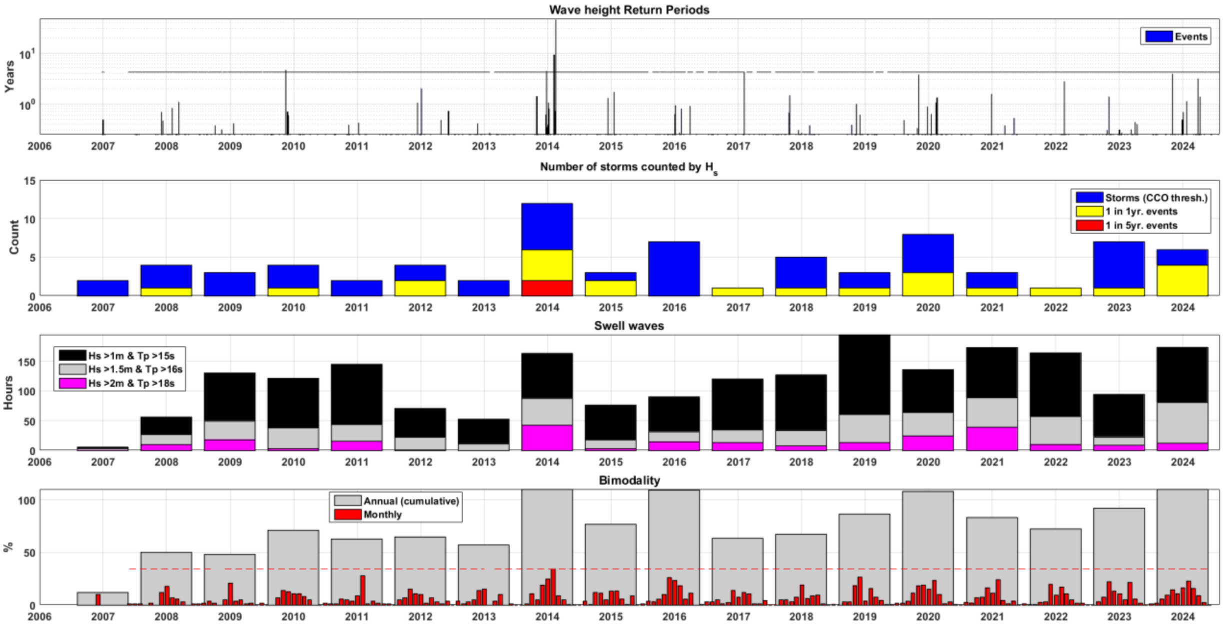
Winter	averages				Storm Counts		Swell hours		Bimodality
	HS (m)	HMAX(m)	TP(s)	TZ(s)	0.25yr	1 in 1yr	Hs>=1m, TP>=18s	Hs>=2m, TP>=20s	
03/04	0.51	0.79	7.02	3.88	5	1	17.5	0	
04/05	0.51	0.78	7.14	3.89	1	0	20.5	0	1%
05/06	0.50	0.77	6.81	3.80	2	0	43	0	1%
06/07	0.59	0.91	7.49	3.94	3	0	100	0	3%
07/08	0.53	0.81	6.98	3.84	6	1	56	0	1%
08/09	0.52	0.80	7.44	3.97	3	1	55	0	1%
09/10	0.53	0.81	7.33	3.98	2	0	35.5	1	2%
10/11	0.51	0.79	7.52	3.99	5	0	69.5	0	2%
11/12	0.55	0.84	7.15	3.87	5	1	61	0	2%
12/13	0.57	0.88	7.43	4.02	2	0	42	0	2%
13/14	0.61	0.94	7.55	3.94	13	6	212	16.5	5%
14/15	0.54	0.82	7.42	3.91	4	1	40.5	0	2%
15/16	0.61	0.94	7.18	3.94	6	1	44.5	0	3%
16/17	0.50	0.76	7.26	3.89	1	1	17.5	0	1%
17/18	0.52	0.80	7.49	3.99	3	1	46	2	1%
18/19	0.53	0.81	7.38	3.86	8	1	40.5	0	2%
19/20	0.61	0.94	7.62	3.94	3	0	82.5	2.5	3%
20/21	0.54	0.84	7.30	3.93	4	1	93	1	3%
21/22	0.48	0.75	7.46	3.87	4	1	41.5	0	1%
22/23	0.55	0.85	7.41	3.92	7	1	54.5	3	2%
23/24	0.61	0.93	7.11	3.86	7	1	67	0	3%

Weymouth



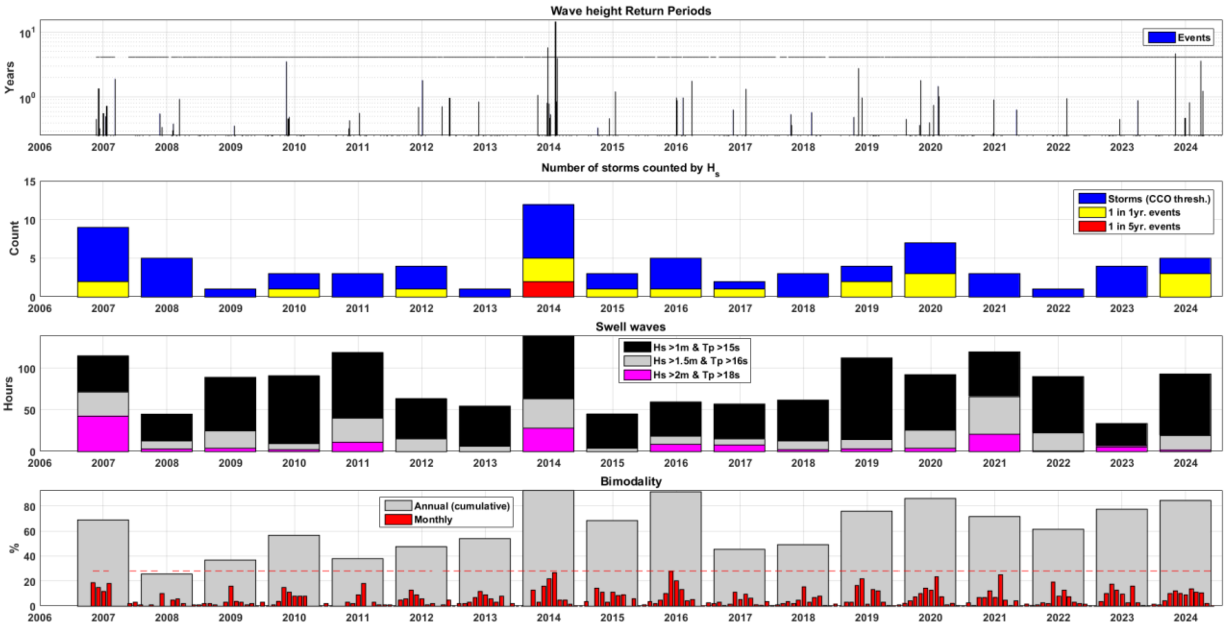
Winter	averages				Storm Counts		Swell hours		Bimodality
	HS (m)	HMAX(m)	TP(s)	TZ(s)	0.25yr	1 in 1yr	Hs>=1m, TP>=18s	Hs>=2m, TP>=20s	
06/07	0.49	0.75	7.36	3.88	2	0	24	0	0%
07/08	0.45	0.70	6.08	3.71	4	1	11	0	1%
08/09	0.45	0.70	6.61	3.82	2	0	13.5	0	1%
09/10	0.46	0.72	6.51	3.84	4	0	3	0	0%
10/11	0.45	0.69	6.34	3.79	3	1	8.5	0	0%
11/12	0.46	0.71	6.33	3.76	5	2	4	0.5	0%
12/13	0.51	0.80	6.19	3.83	2	0	4	0.5	0%
13/14	0.50	0.78	6.68	3.89	9	3	47.5	0	2%
14/15	0.46	0.71	6.37	3.79	4	0	2.5	0	0%
15/16	0.52	0.81	6.39	3.84	6	2	11	0	1%
16/17	0.44	0.68	6.49	3.78	3	1	7	0	0%
17/18	0.45	0.69	6.66	3.89	4	1	7.5	0	1%
18/19	0.46	0.72	6.56	3.78	9	1	4.5	0	1%
19/20	0.54	0.83	6.73	3.80	5	0	20.5	0	1%
20/21	0.48	0.74	6.64	3.83	7	1	31	0	1%
21/22	0.43	0.66	6.77	3.76	3	1	2.5	0	0%
22/23	0.47	0.73	6.50	3.75	5	0	6.5	0	1%
23/24	0.50	0.77	6.40	3.77	6	0	2	0	1%

Chesil



Winter	averages				Storm Counts		Swell hours		Bimodality
	HS (m)	HMAX(m)	TP(s)	TZ(s)	0.25yr	1 in 1yr	Hs>=1m, TP>=18s	Hs>=2m, TP>=20s	
06/07	1.12	1.77	16.74	4.91	2	0	3.5	0.5	n/a
07/08	0.94	1.43	7.85	4.57	4	1	36.5	3.5	4%
08/09	0.93	1.42	8.42	4.74	3	0	68.5	6.5	4%
09/10	0.93	1.41	8.88	4.89	4	1	48	0	6%
10/11	0.86	1.33	8.32	4.74	2	0	65.5	12.5	5%
11/12	0.98	1.50	8.08	4.66	4	2	31.5	1	6%
12/13	0.99	1.51	8.35	4.88	2	0	18.5	0	5%
13/14	1.09	1.63	8.39	4.73	12	6	68.5	25.5	9%
14/15	0.95	1.45	8.16	4.65	3	2	27.5	1.5	6%
15/16	1.13	1.70	8.30	4.82	7	0	28.5	4	9%
16/17	0.85	1.31	8.33	4.66	1	1	35.5	4	6%
17/18	0.97	1.49	8.24	4.72	5	1	43.5	4	6%
18/19	0.93	1.42	8.55	4.73	3	1	106.5	10	7%
19/20	1.11	1.68	8.42	4.83	8	3	62.5	16	9%
20/21	0.97	1.49	8.36	4.69	3	1	95.5	27.5	7%
21/22	0.87	1.35	8.51	4.61	1	1	101	1.5	6%
22/23	0.97	1.50	8.69	4.82	7	1	22	6.5	8%
23/24	1.14	1.77	8.01	4.74	6	4	61.5	3.5	9%

West Bay



Winter	averages				Storm Counts		Swell hours		Bimodality
	HS (m)	HMAX(m)	TP(s)	TZ(s)	0.25yr	1 in 1yr	Hs>=1m, TP>=18s	Hs>=2m, TP>=20s	
06/07	1.33	1.99	9.30	4.97	9	2	60	26	
07/08	0.78	1.19	7.72	4.23	5	0	23.5	2.5	3%
08/09	0.83	1.27	8.36	4.44	1	0	38	1	3%
09/10	0.83	1.26	8.77	4.64	3	1	33	0	5%
10/11	0.78	1.20	8.21	4.49	3	0	59.5	10	3%
11/12	0.86	1.31	7.93	4.35	4	1	27	0	4%
12/13	0.89	1.36	8.21	4.53	1	0	9.5	0	5%
13/14	0.97	1.45	8.38	4.55	12	5	46.5	19.5	8%
14/15	0.84	1.27	8.13	4.43	3	1	15	0	6%
15/16	1.00	1.52	8.19	4.56	5	1	16.5	3.5	8%
16/17	0.74	1.14	8.14	4.34	2	1	21.5	3	4%
17/18	0.87	1.33	8.10	4.50	3	0	19	1.5	4%
18/19	0.85	1.29	8.39	4.43	4	2	59	3.5	6%
19/20	1.00	1.51	8.29	4.57	7	3	25	2	7%
20/21	0.88	1.34	8.30	4.48	3	0	68.5	18	6%
21/22	0.77	1.18	8.37	4.37	1	0	49	0	5%
22/23	0.87	1.33	8.79	4.56	4	0	7.5	5	6%
23/24	0.99	1.54	7.91	4.48	5	3	38	1	7%

ADDENDUM – Webinar version of Figure 3.2a explanatory note

In Section 3 of this report, we provide a map summary figure of the study region, where for each wave buoy site, a box indicates the number of significant trends found for the respective wave parameters in our trend analysis (i.e. representing wave height, wind period, swell period and direction). This is both as normalised (Figure 3.2a) and actual (Figure 3.2b) values of these results.

We note that two versions of the normalised results figure were presented during the course of the project.

- The version in the main report (Figure 3.2a) is consistent with the chosen method, based upon testing wave data and assessing trends against the 3 exceedance thresholds: 10%, 5%, and 0.5%.

- A similar normalised version of this results figure was presented in the Webinar (10th December 2024) and reflects the same principles albeit an earlier iteration using 5 exceedance thresholds: 10%, 5%, 1%, 0.5% and 0.05%.

The differences between the Webinar version and Figure 3.2a do not affect the conclusions of the study and are provided here for completeness.

Figure presented in webinar showing “normalised” counts of statistically significant trends for each site, according to the multi-parameter analysis (MPA), using 5 exceedance thresholds: 10%, 5%, 1%, 0.5% and 0.05%.