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Was 2008 a typical year in Liverpool Bay?

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ABSTRACT

Metocean observations in Liverpool Bay over the year 2008 are compared with those over a longer period to determine whether 2008 is a "typical" year. Histograms are produced for each parameter for both 2008 and the long-term, and their shapes examined to see whether the general patterns, and also extremes, seen in the long-term are captured in 2008. This, in turn, will establish whether 2008 is a suitable annual cycle to study. The 2008 data collected will later be correlated to stratification events in Liverpool Bay with the aim of trying to determine the processes controlling stratification.

KEYWORDS

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1. Introduction

Metocean observations in Liverpool Bay over the year 2008 are compared with those over a longer period to determine whether 2008 is a "typical" year. Histograms are produced for each parameter for both 2008 and the long-term, and their shapes examined to see whether the general patterns, and also extremes, seen in the long-term are captured in 2008. This, in turn, will establish whether 2008 is a suitable annual cycle to study. The 2008 data collected will later be correlated to stratification events in Liverpool Bay with the aim of trying to determine the processes controlling stratification.

2. Methods

Most of the data is provided by the National Oceanography Centre's Coastal Observatory (COBS), which was a 10-year observational programme in Liverpool Bay that provides data with which a model can be validated against (Howarth and Palmer, 2011). The river flow data, however, is obtained from the Environment Agency's gauging stations provided by the Centre for Ecology and Hydrology's National River Flow Archive; and the tide data is provided by the National Tidal and Sea Level Facility and distributed by the British Oceanographic Data Centre. The data source for each of the parameters considered and the matlab scripts used to extract the required time series are shown in Table 1. Each script reads in the data, extracts the required parameter(s), isolates the 2008 time series (which is saved for use in later investigations) plots histograms and climatology roses (where appropriate), and calculates statistics including the mean and 10% exceedance level.

The mean is defined as $\bar{x} = \frac{\sum_1^n x_n}{n}$ and the 10% exceedance = 90th percentile, i.e., the value that 10% of the data are above.

NB The mean is calculated using "nanmean" in matlab so that any missing data points are excluded. For barometric pressure, the less than 10% exceedance is also calculated to give the value that 10% of the data are below. This captures the passage of extreme low pressure systems, representative of storm events, in addition to calm high pressure systems.

Table 1: The metocean parameters examined, along with their data source and the matlab script used to extract their time series.

Matlab script	Data source	Variable
Hilbre_dist.m	COBS: Hilbre Island weather station	Barometric pressure (mb)
		Precipitation (mm/10mins)
		Atmospheric temperature (°C)
wind_dist.m		Wind speed (m/s)
		Wind direction (deg)
wave_dist.m	CEFAS WaveNet: Liverpool Bay buoy	Wave height (m)
		Wave peak period (s)
		Wave direction (deg)
river_dist.m	CEH NRFA: Manley Hall (Dee) and Ashton Weir (Mersey) stations	River Dee discharge (m/s)
		River Mersey discharge (m/s)
tide_dist.m	NTSLF: Liverpool (Gladstone Dock) tide gauge	Tidal surge (m)
		Total tidal elevation (m)

3. Results

3.1 Hilbre Met Station Data

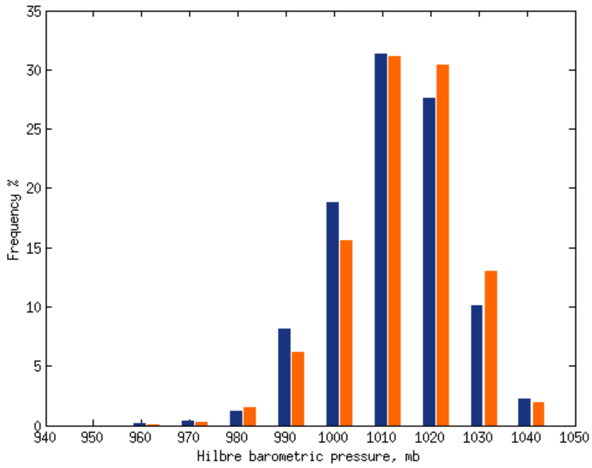

Figure 1: Histogram of barometric pressure in 2008 (blue) and over 2005-2012 (orange). Bin width: 10 mb.

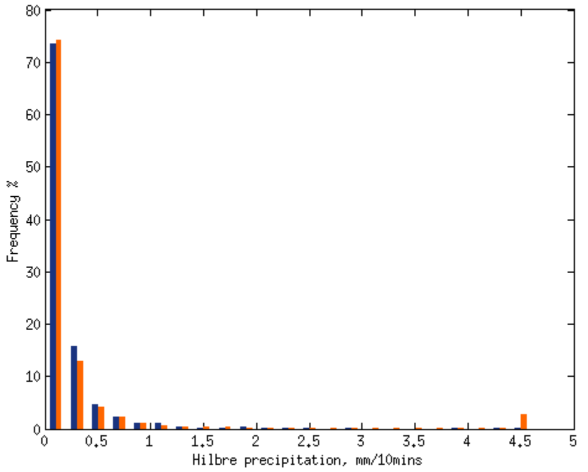

Figure 2: Histogram of precipitation in 2008 (blue) and over 2005-2012 (orange). Bin width: 0.5 mm/10mins.

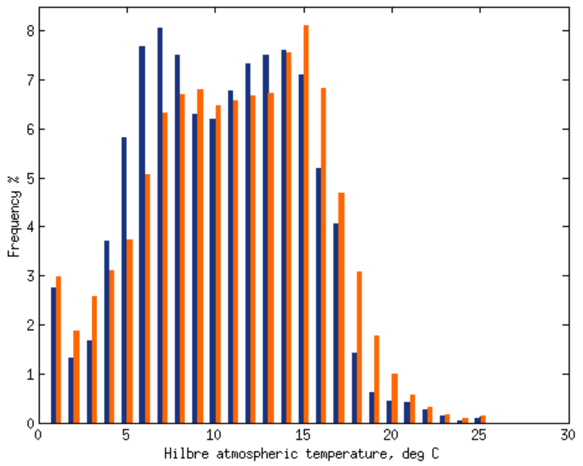

Figure 3: Histogram of atmospheric temperature in 2008 (blue) and over 2005-2012 (orange). Bin width: 1°C.

Barometric Pressure

The histogram (Fig. 1) shows a very similar distribution shape for 2008 to that of the longer period 2005-2012. However, in 2008 there are more occurrences of the lower pressure values around 990-1000mb, and less occurrences of the higher 1020-1040mb values. The typical value (1010 mb) is similar.

Table 2 shows all statistical values, except for the min value, for 2008 are lower than those for the long-term data. The minimum value is equivalent for both periods. These results suggest 2008 could have been more stormy than average.

Precipitation

Only precipitation events have been considered here so all zero data were removed. Any values above 64mm/10mins were discounted as being erroneous in accordance with Met Office recorded extremes[1]. The distributions are closely matched with the exception of the larger bar at 4.5 for 2005-2012 (Fig. 2). This suggests extreme precipitation events (with a return period greater than 1 in 1 year) have not occurred in 2008, while more frequent low rainfall events did occur.

The 10% exceedance and mean are both lower in 2008 than the long-term (Table 3). The large difference in means is a result of 2008 not capturing the more extreme events that occur over the long-term. The median is the same in both cases and is lower than the mean, supporting the histograms in that the vast majority of values are very low, with just a few much larger events.

Atmospheric Temperature

The overall shape of the distributions is very similar (Fig. 3), although 2008 shows slight peaks either side of the mean (10.24: Table 3). 2008 was also cooler in comparison to the long-term with a larger proportion of 4-8°C and 11-13°C values, and a lower proportion of the higher temperatures, 15°C onwards. The extreme values are similar.

Table 3 supports this with a slightly lower mean, median and 10% exceedance for 2008.

TABLE 2: Minimum, less than 10% exceedance, mean, median, 10% exceedance and maximum values for barometric pressure (mb) in 2008 and over 2005-2012.

		Min	<10% exceedance	Mean	Median	10% exceedance	Max
barometric pressure	2008	957.75	996.06	1012.30	1013.30	1027.50	1043.70
	2005-2012	957.75	997.99	1013.80	1014.80	1028.40	1044.20

TABLE 3: Mean, median and 10% exceedance values for precipitation (mm/10mins), atmospheric temperature (°C), wind speed (m/s) and direction (°) in 2008 and over 2005-2012.

		Time period	Mean	Median	10% exceedance
Hilbre met station data: Hilbre_dist.m	precipitation	2008	0.24	0.10	0.50
		2005-2012	0.67	0.10	0.60
	atmospheric temperature	2008	10.24	10.31	15.99
		2005-2012	10.92	11.16	16.83
	wind speed	2008	7.61	7.17	12.97
		2005-2012	7.05	6.63	12.30
	wind direction	2008	199.56	216.96	N/A
		2005-2012	198.41	215.48	N/A

Wind speed and direction

The shapes of the two histograms for wind speed are very closely-matched (Fig. 4(a)) with the 2008 bars being slightly lower than those of the long-term up to 6m/s and slightly higher from 8m/s onwards. Table 3 shows that the mean, median and 10% exceedance are both slightly higher in 2008 compared with the long-term. This is in contrast to the other parameters, which have all shown reduced values in 2008 thus far, suggesting that 2008 was a windier, but cooler and dryer year, which could be related to a change in storm track position for this year.

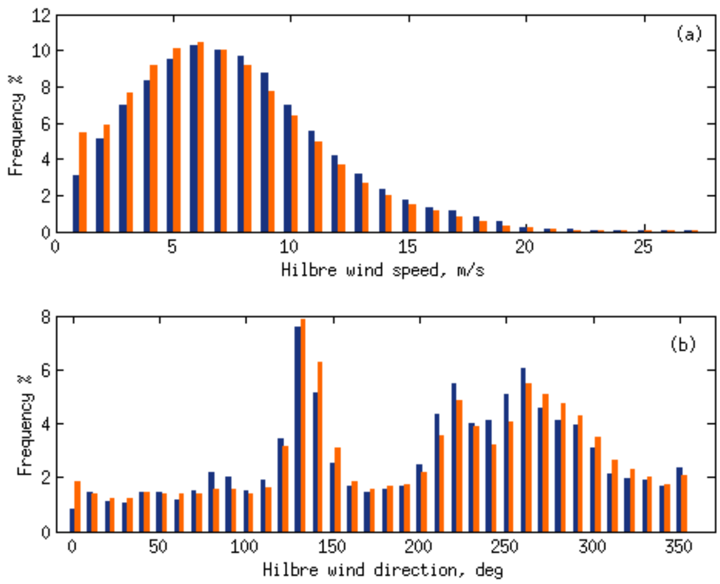

Figure 4: Histograms of (a) wind speed and (b) wind direction in 2008 (blue) and over 2005-2012 (orange). Bin width: (a) 1m/s; (b) 10°.

The histograms for wind direction (Fig. 4(b)) have the same general shape, but show some variability between bar heights for the two time periods, particularly at the peaks around 130-145° and 205-305°. The wind roses in Figure 5 again show the frequency differences in direction. We can see in both that there is dominance from 130-140°, the south-easterly contribution due to the funnelling effect of the Dee estuary, but a more collective dominance from 205-305°, near-westerly winds. In 2008, slightly less south-easterly winds were seen, and slightly more near-westerly. The mean wind direction is slightly larger in 2008 at 199.56° compared with 198.41° in the long-term, and the median is larger at 216.96° compared with 215.48°, supporting the visible increase in near-westerly winds.

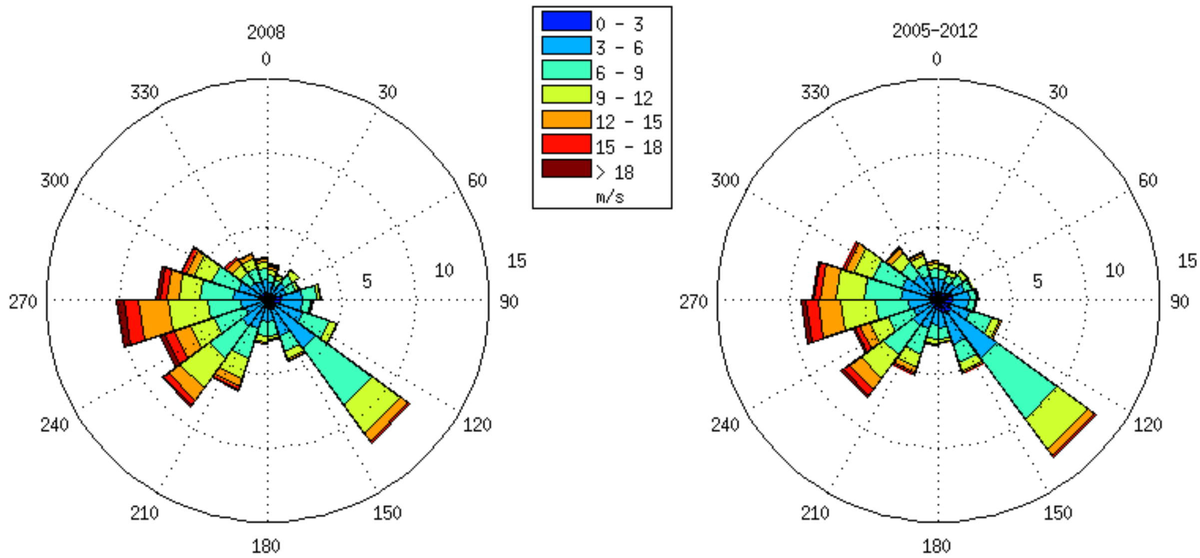

Figure 5: Wind roses for 2008 (left) and 2005-2012 (right). The bars display wind direction "from" (°) and the colour scale represents wind speed (m/s).

3.2 WaveNet Data

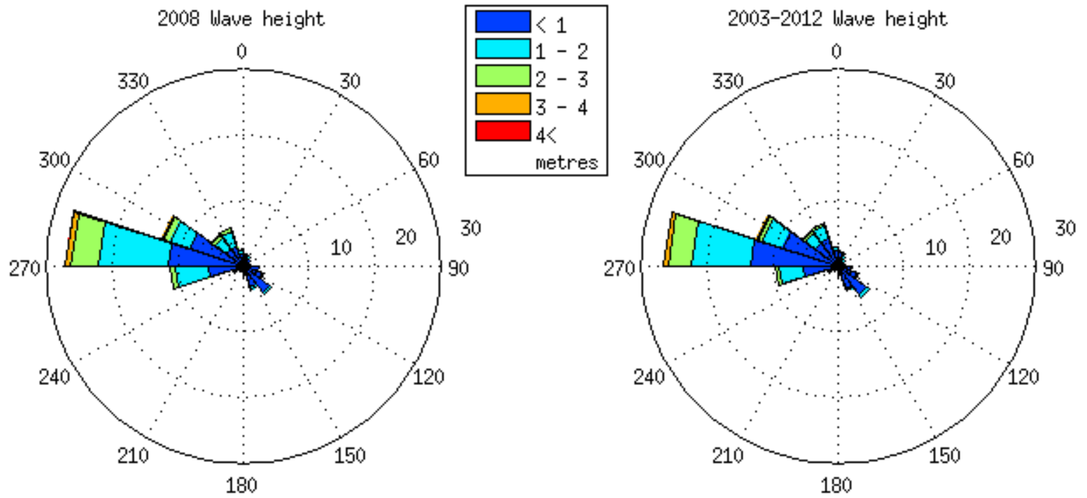

Figure 6: Wave roses for 2008 (left) and 2003-2012 (right). The bars display wave direction "from" (°) and the colour scale represents wave height (m).

Both wave roses (Fig. 6) and histograms (Fig. 8(a)) for wave height show 2008 to be typical of the longer time period. The 10% exceedance value, median and mean are both slightly higher for 2008 than the long-term (Table 4) due to the slightly higher initial frequency in the long-term. It is likely that this is related to the slight increase in near-westerly winds seen in the previous section as this direction is associated with the longest fetch for local wave generation.

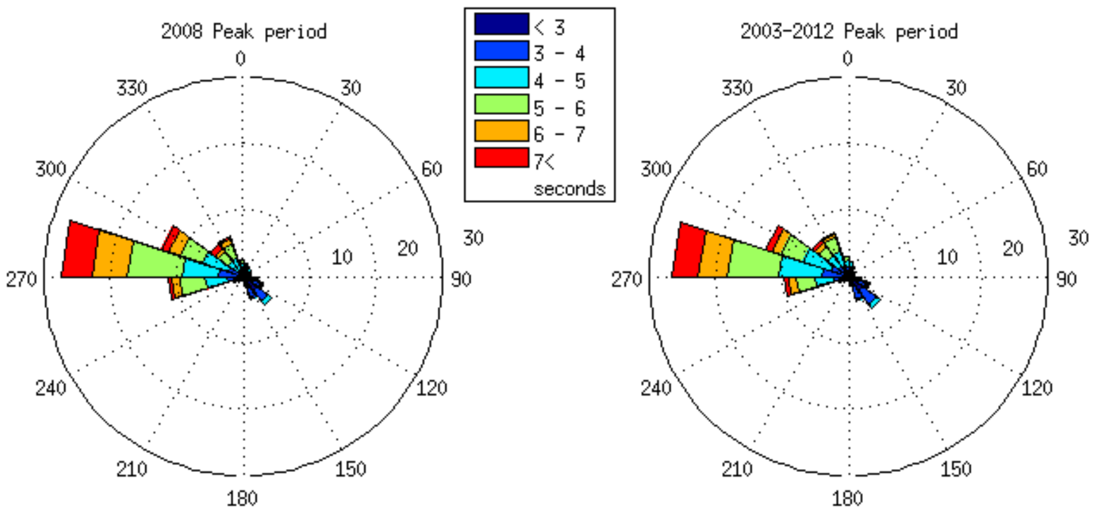

Figure 7: Wave roses for 2008 (left) and 2003-2012 (right). The bars display wave direction "from" (°) and the colour scale represents peak period (s).

Again, the roses for wave peak period are very similar (Fig. 7), as are the histograms (Fig. 8(b)), although they do show 2008 to have more peak periods between 5 and 7s than the longer-term and fewer occurrences of peak periods between 2.5 and 4.5s. This is again related to the occurrence of more westerly winds, as the longer fetch allows a more developed wind-sea within Liverpool Bay. The 10% exceedance value for 2008 is identical to that of the long-term with a very slightly higher mean of 4.7s compared with the long-term 4.58s, and a similar increase of 0.02s in the median value (Table 4). There are some large maximum values seen in Table 4. Following Wolf et al. (2011), peak wave periods of 20s and above were discarded. These long peak periods mean more powerful waves, which have an increased impact on sediment transport, erosion and over-washing, etc.

Table 4: Mean, median and 10% exceedance and maximum values for wave height (m) and peak period (s) in 2008 and over 2003-2012.

	Time period	Mean	Median	10% exceedance	Max
Wave height	2008	0.99	0.79	1.97	5.25
	2003-2012	0.90	0.71	1.80	5.37
Peak period	2008	4.70	4.55	6.67	16.67
	2003-2012	4.58	4.35	6.67	18.18

In terms of wave direction, again the shape of the histograms is closely matched, although 2008 shows a higher frequency of waves coming from 275-285° (Fig. 8(c)). This direction is associated with the longest fetch in Liverpool Bay and is the dominant wave direction. The mean directions are closely matched at 241.21° for 2008 and 242.55° for the long-term, as are the medians at 276° for 2008 and 277° for the long-term.

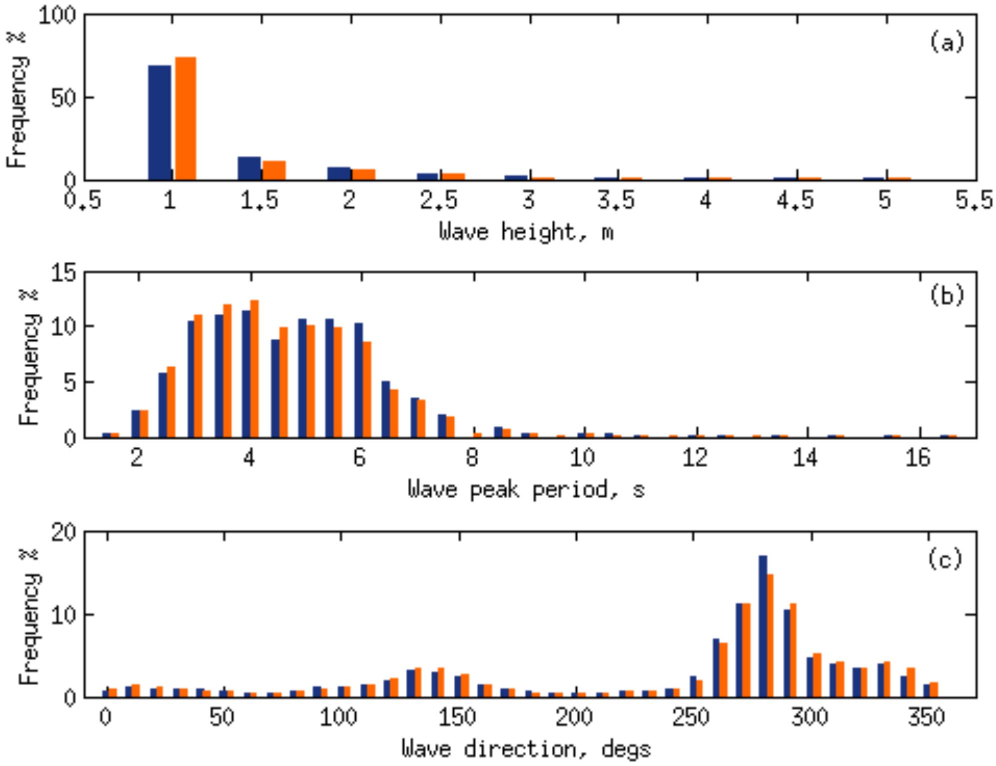

Figure 8: Histograms of wave (a) height, (b) peak period, and (c) direction in 2008 (blue) and over 2003-2012 (orange). Bin width: (a) 0.5m; (b) 0.5s; (c) 10°.

3.3 Tide Data

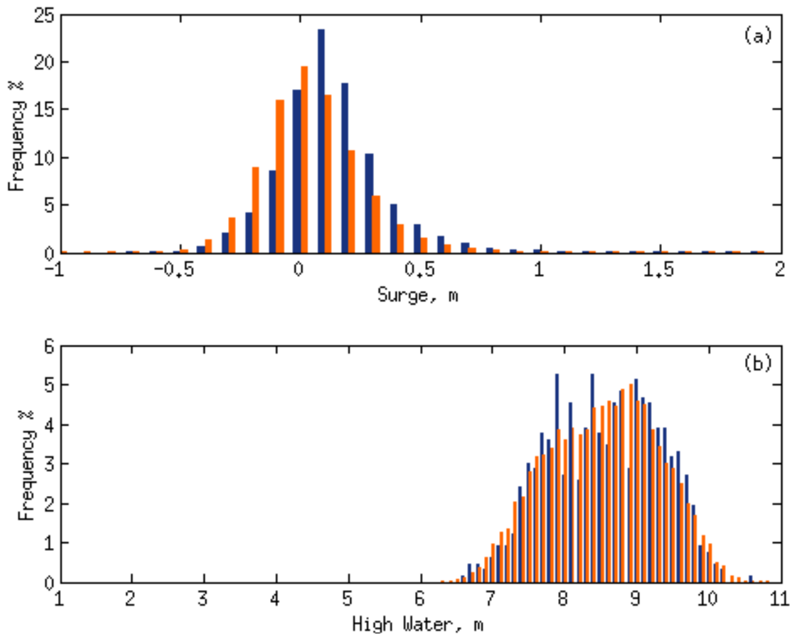

Figure 9: Histograms of (a) surge (m) and (b) total high water elevation (m) in 2008 (blue) and over 1991-2011 (orange). Bin width: 0.1m.

The histograms for surge and total high water display some variability between 2008 and the longer-term record (Fig. 9), particularly in terms of high water (HW) where the long-term forms a "smoother" inverse parabola than the single year, peaking at 9m compared with the multiple peaks of 2008 between 7.8 and 9m. These differences could be attributed to the sporadic occurrence of storm events and the inability of one year to capture the events seen over a longer period. Table 5, however, shows a difference of only 0.03m for HW in both mean and 10% exceedance levels, and 0.04m in median difference. The 2008 distribution is consistent with the NTSLF's predicted HW spring tide2 of 9.86m in Apr 2008 and 9.83m in Oct 2008 as the low frequency, higher values seen in Fig 9(b) are just above 10m and these include surge. Also, the mean HW according to the NTSLF is 9.39m and the histograms do peak just above 9m. The highest astronomical tide predicted for Liverpool between 2008 and 2026 according to the NTSLF is 10.37m, and the maximum HW level seen in this data set is 10.82m so storms do not increase the HW level much beyond the tidal extreme values. This is again due to the sporadic nature of storms and their timing in relation to the phase of the tide, creating variable changes in water level. The likelihood of the peak surge occurring at spring HW is low so the likelihood of HW exceeding the maximum spring HW by much is low.

The general shapes of the surge histograms are comparable, though 2008 experienced a higher frequency of positive surges and fewer negative surges than the longer term (Fig. 9(a)). The peak for 2008 is thus at 0.1m compared to 0m for the long-term, and 2008 also has higher 10% exceedance, median and mean values, but does not experience the largest surge (2.26m) seen over the whole time period (Table 5). Brown et al states that extreme surges can reach 2.3m, which is consistent with these results.

Table 5: Mean, median, 10% exceedance and maximum values for tidal surge and total high water elevation (m) in 2008 and over 1991-2011.

	Time period	Mean	Median	10% exceedance	Max
Surge	2008	0.13	0.12	0.39	1.94
	1991-2011	0.04	0.02	0.30	2.26
Total HW elevation	2008	8.56	8.60	9.56	10.56
	1991-2011	8.53	8.56	9.53	10.82

3.4 River Data

We can see that the 2008 histogram of the River Dee discharge is noticeably different to the long-term pattern; in 2008 the discharge shows two peaks, around 10 and 50m^3/s, whereas the long-term peaks around 5m^3/s then steadily decreases (Fig. 10(b)). This reduced accuracy is echoed in the Table 6 values, where there are much greater differences than seen for the other parameters (the mean flow rate for 2008 is 9.68m^3/s quicker than the long-term, the 10% exceedance value is 10.67m^3/s quicker and the median is 14.7m^3/s quicker). Figure 10(a) supports this in that much of the 2008 runoff is above the long-term mean.

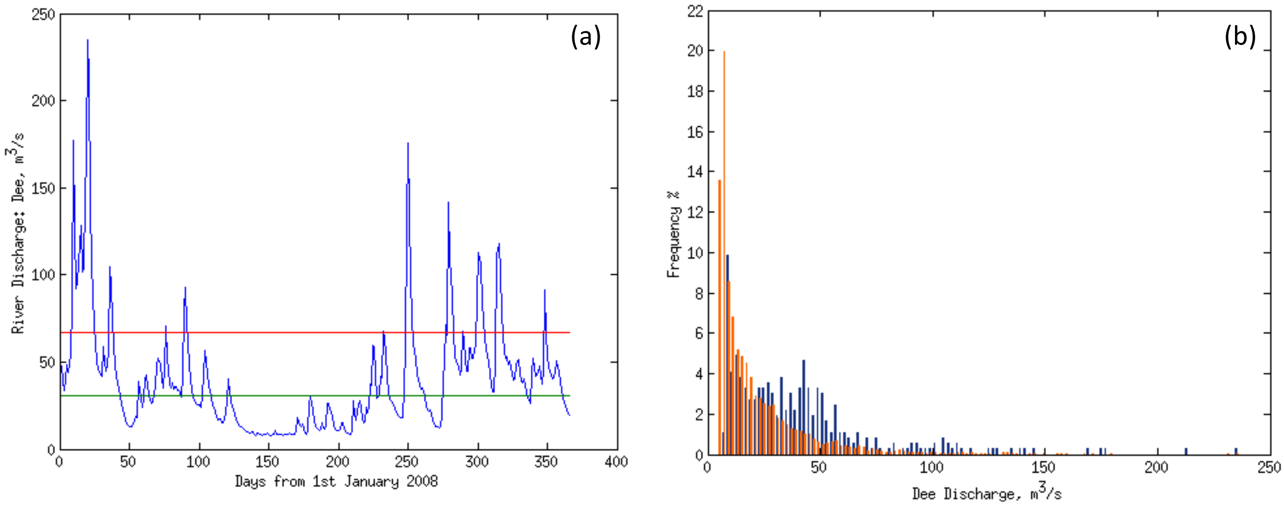

FIGURE 10: (a) River Dee discharge in 2008 (blue), 2001-2011 mean (green) and 2001-2011 10% exceedance value (red); and (b) histogram of River Dee discharge in 2008 (blue) and over 2001-2011 (orange). Bin width: 2m^3/s.

The River Mersey discharge 2008 histogram is more representative of the longer-term conditions; the shape matches, but the early peak is lower than that of the long-term (Fig. 11(b)). Figure 11(a) shows that, in contrast to the Dee discharge, much of the runoff is around the long-term mean value but there are four large peaks that raise this mean still from 13.59 to 18.39m3/s in 2008. The 10% exceedance and median values are also raised, though to a lesser extent (Table 6). Although both of these values have increased, it is to a lesser extent than the Dee. This could be due to the catchment areas being influenced by different storms and/or human activity, or to the gauging stations being at different locations within the catchments.

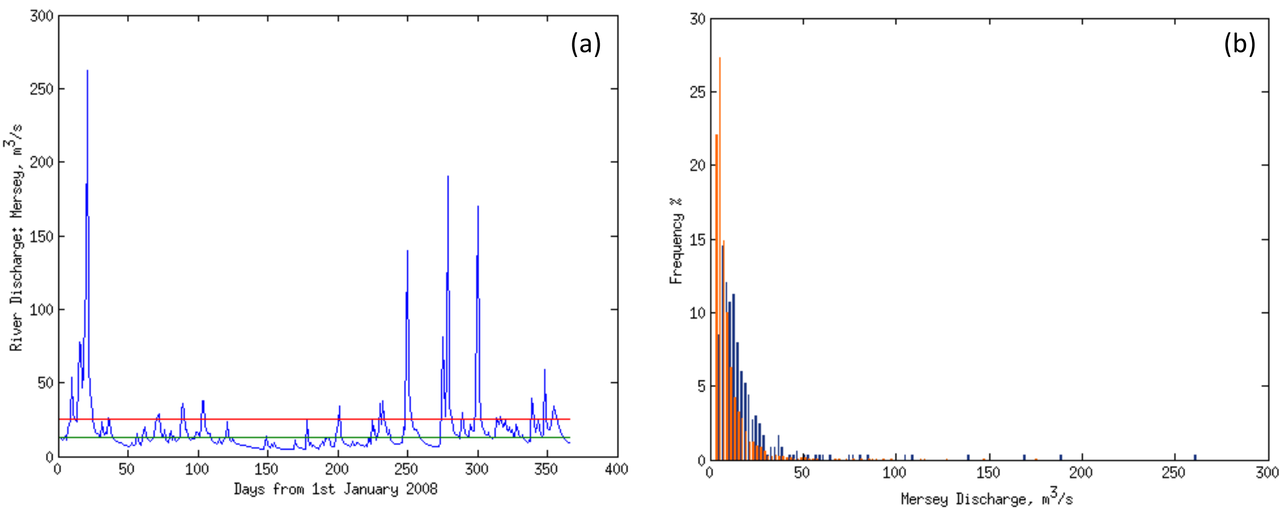

FIGURE 11: (a) River Mersey discharge in 2008 (blue), 2001-2011 mean (green) and 2001-2011 10% exceedance value (red); and (b) histogram of River Mersey discharge in 2008 (blue) and over 2001-2011 (orange). Bin width: 2m^3/s.

There are many factors influencing river discharge, hence rivers experience a large range of flow rates. The differences in the statistical values between 2008 and the long-term shown in Table 6 are therefore large in comparison to the differences seen previously in this report, but are still insignificant when compared with the range (min to max) in discharge values. Table 6 indicates that in 2008 there were a few high-discharge events that have a low frequency over the long-term. This is especially true for the Mersey where the maximum of 2008 is also the maximum over the whole period. As both rivers share low flow periods around day 150 and high flow periods at the start and during the autumn of the year, these can be used for comparison in later numerical studies.

TABLE 6: Minimum, mean, median, 10% exceedance and maximum values for rivers Dee and Mersey discharge (m/s) in 2008 and over the decade 2001-2011.

River	Time period	Min	Mean	Median	10% exceedance	Max
Dee	2008	7.85	40.23	33.40	77.43	235.00
	2001-2011	7.23	30.55	18.70	66.76	369.00
Mersey	2008	4.72	18.39	12.80	29.69	262.00
	2001-2011	3.68	13.59	9.09	26.00	262.00

3.5 Time Series

Figures 10(a) and 11(a) show high river discharge in January and Autumn, and many of the other parameters examined suggest that 2008 was perhaps a more stormy year, so the 2008 time series were plotted to examine seasonality and to highlight periods of calm and storm events (Figs. 12 and 13).

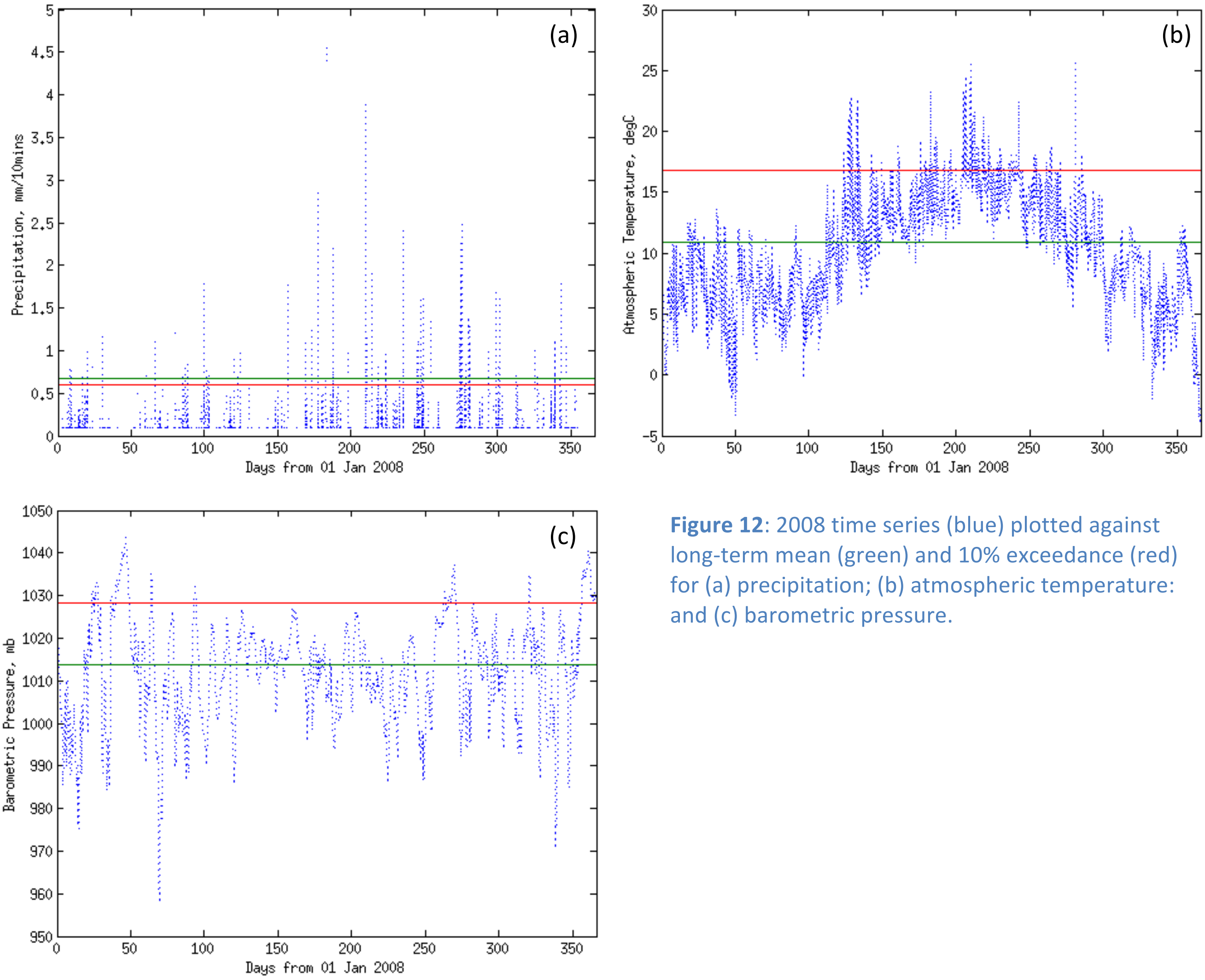

Figure 12: 2008 time series (blue) plotted against long-term mean (green) and 10% exceedance (red) for (a) precipitation; (b) atmospheric temperature: and (c) barometric pressure.

Figure 12(a) shows that the second half of the year was wetter than the first half; late summer into autumn was a particularly wet period within 2008. This could have contributed to the large river discharges seen in the autumn, but there was comparatively little precipitation at the start of the year, where river discharge was at its highest. It must be remembered that the precipitation observations are at the mouth of the Dee and not over the catchment so may not be correlated. Also, the majority of rain events do fall below the long-term mean, but there are some large sporadic precipitation events. This is indicative of the long-term in that the mean (green line) is above the 10% exceedance value (red line) so the rare but extreme precipitation events that occurred over the longer period have skewed the mean. Figure 14 shows the long-term precipitation time series and quite clearly shows some very large precipitation events occurring at the beginning of the first year. These values are influencing the high mean and are not necessarily accurate; they could be a result of miss-measurements particularly during windy periods or simply errors during the initial set-up of instruments period.

Figure 12(b) shows the seasonality in atmospheric temperature with a cooler winter and warmer summer. The temperatures are at their lowest at day 50, and also at the very end of the year. This coincides with there being no precipitation, a drop in all of the parameters shown in Figure 13 and high pressure. This could represent a clear, dry frosty morning.

We can see that the barometric pressure throughout 2008 was predominantly lower than in the long-term with much of the data falling around and below the mean and only rising above the 10% exceedance value in seven instances (Fig. 12(c)). This again suggests 2008 was a stormier year than average. The period of low pressure at the beginning of the year coincides with the highest river discharges, large surges and wave heights, and fast winds, but low precipitation. This could be due to any associated precipitation not falling, or not being captured, at Hilbre.

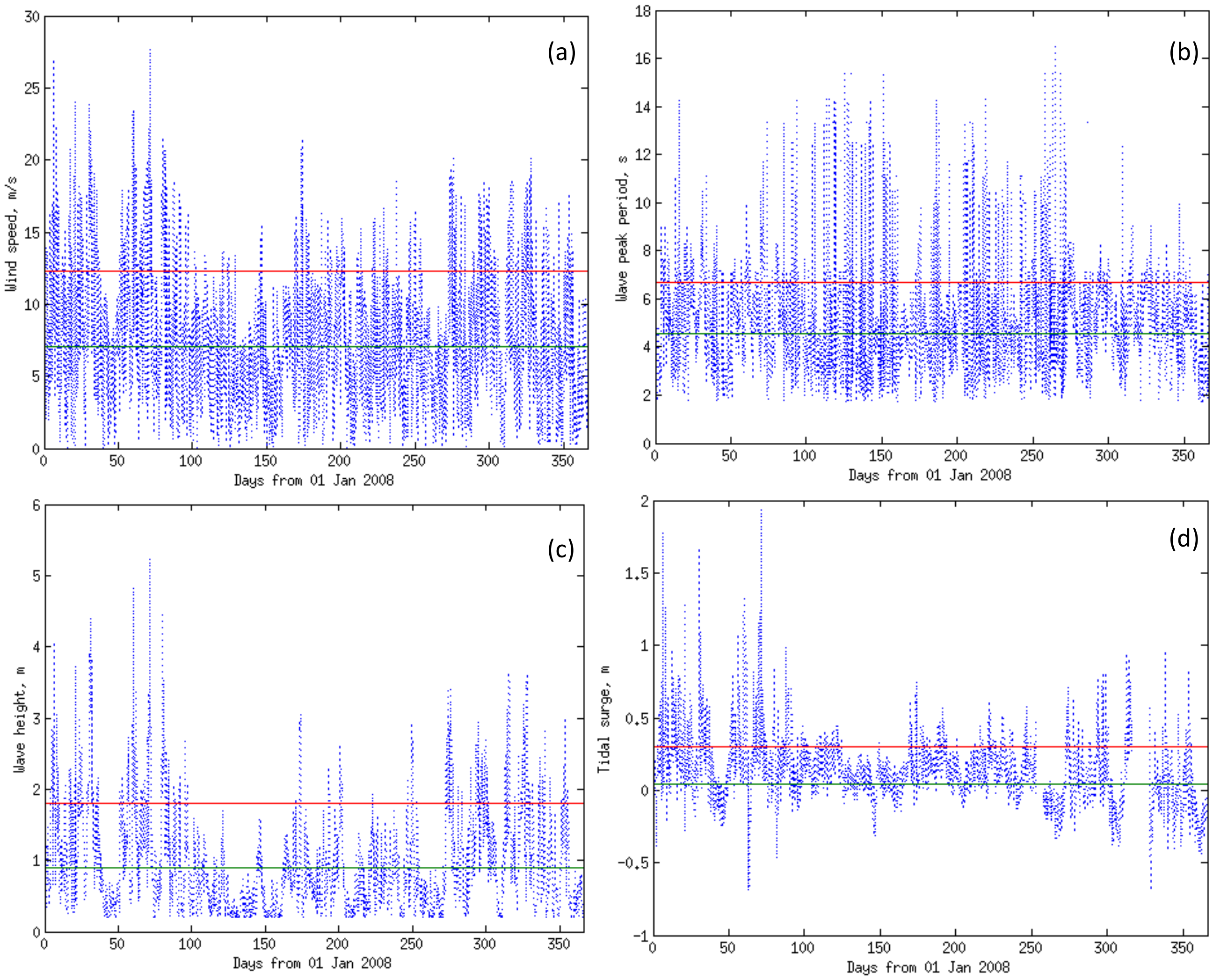

Figure 13: 2008 time series (blue) plotted against long-term mean (green) and 10% exceedance (red) for (a) wind speed; (b) wave peak period; (c) wave height; and (d) tidal surge.

Figure 13 supports the hypothesis that 2008 was windier with higher waves and large tidal surges. The four parameters shown all experienced values well above the mean and also display a large proportion of values above the 10% exceedance threshold. We can see that the instances of fast winds, around day 75 for example, are accompanied by large waves with shorter periods and also large tidal surges, suggesting locally generated waves under storm conditions. During periods of slower winds, around day 130 for example, there are also small waves of a long period and low tidal surge, suggesting that the waves have been generated externally in the Eastern Irish Sea and have propagated into Liverpool Bay.

4. Further Investigations: Precipitation

Due to the high, probably erroneous, precipitation rates seen at the beginning of 2005 (Fig.14), the data was capped again at 5mm/10mins, which is just above the 2008 maximum of 4.6mm/10mins, and histograms for 2008 and the long-term re-produced (Fig. 15).

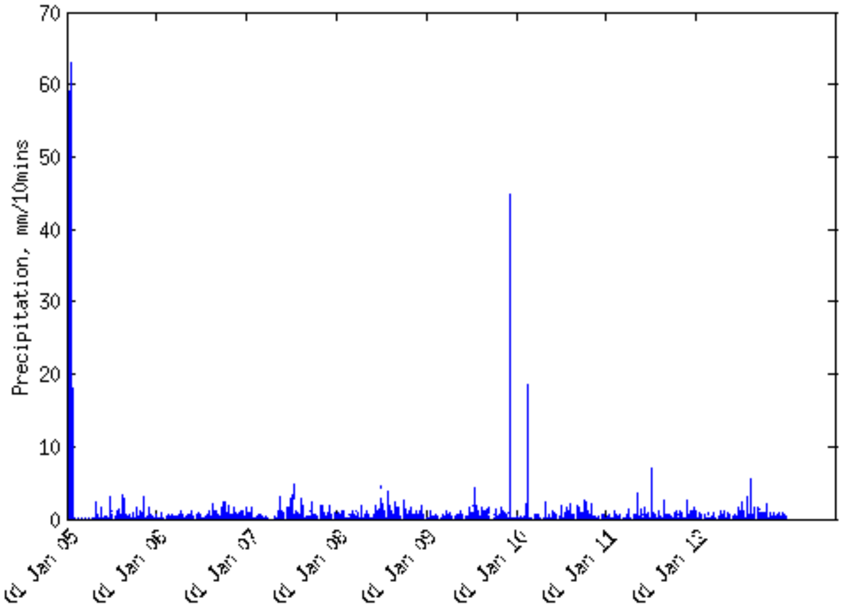

Figure 14: Precipitation rate (mm/10mins) over 2005-2012.

When compared with Figure 2, we can see the orange bar, representing the long-term data, at 4.5mm/10mins has gone and the orange bar at 0.1mm/10mins has increased. Table 7 shows a reduction of 0.47mm/10mins in the mean average with this capping of the data, bringing it much closer to the mean seen in 2008. The 10% exceedance value has also decreased to the same level of 2008.

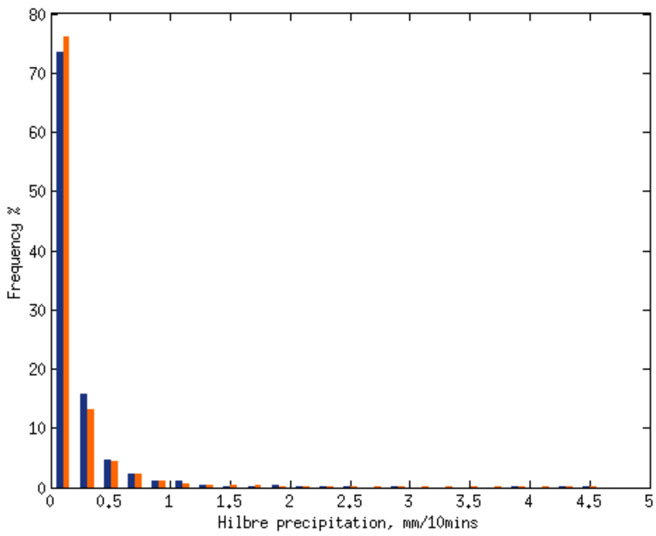

Figure 15: Histogram of precipitation (capped at 5mm/10mins) in 2008 (blue) and over 2005-2012 (orange). Bin width: 0.5 mm/10mins.

Table 7: Mean, median and 10% exceedance values for 2008 and over 2005-2012 for precipitation when capped at 5mm/10mins. The values in red show a reduction from the previous values.

	Time period	Mean	Median	10% exceedance
Precipitation (<5mm/10mins)	2008	0.24	0.10	0.50
	2005-2012	0.26	0.10	0.50

4. Discussion and Conclusions

Compared with a longer time period consisting of multiple annual cycles, in 2008 Liverpool Bay experienced a higher frequency of:

- lower pressures;
- lower precipitation;
- cooler atmospheric temperatures;
- slightly faster winds;
- slightly longer wave peak periods;
- greater tidal surges; and
- high river discharges.

We can also see that there was a particularly wet autumn. This suggests 2008 experienced more cyclones, in particular in autumn, causing stormier conditions. Although extreme precipitation events are less frequent the more consistent low precipitation events maintain a high frequency of high-flow river events.

The differences in the statistical values between 2008 and the longer time frames sampled for the listed parameters is negligible for our purposes, but highlights that the complex interaction between weather systems over the land and sea cause mixed responses in the metocean parameters studied.

The time-series plots produced now enable periods of contrasting conditions to be compared for future numerical study. Three possible such periods identified are:

1. before day 50 - stormy and high river flow;
2. ~day 150 - calm, with low river flow; and
3. ~day 260 - calm, with high river flow.

Overall, 2008 does suitably replicate the general properties of the collective long-term conditions, bearing in mind that the long-term is displaying data from many years and no two years are identical in terms of their climatology so some diversion from the average is to be expected, whichever year is used as a comparison.

The matlab scripts and extracted 2008 data can be found at:

/projectsa/iCoast/Mersey_CEFAS/IRS2008/2008_typical_year/

5. References

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