JERICHO TECH. REPORT 25

# Waves and winds in Lyme Bay

D J T Carter

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## 1 Introduction

Wave height climate statistics in the English Channel and into Lyme Bay are provided by the conveniently located TOPEX Track 061. However, the altimeter does not give directional information. It is reasonable to assume that the larger waves in Lyme Bay are from the Southwest and that the direction of waves in the Bay are generally similar to the wind direction. This note examines these assumptions by comparing wind direction at the Met. Office buoy in Lyme Bay with the TOPEX wave heights, to see whether the larger waves are associated with Southwesterly winds. Locations are shown in Figure 1; mean wave heights along Track 061 are shown in Figure 2. It also investigates wave periods estimated from TOPEX, and compares wind speeds from TOPEX with those from the buoy.

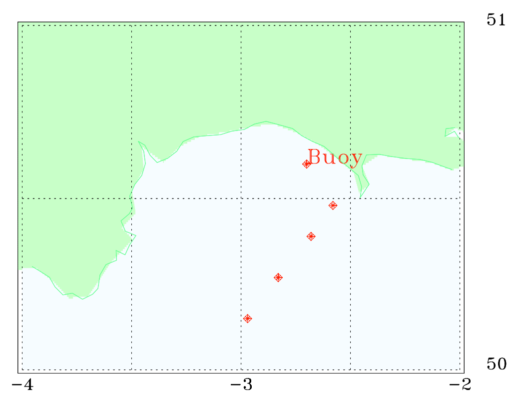


**Figure 1: Met. Office buoy and TOPEX locations along Track 061 referred to in this Report.**

## 2 Buoy and altimeter data

Previous JERICHO Technical Reports have discussed the TOPEX GAPS data set and the Lyme Bay buoy data. The buoy is at 50.6°N 2.7°W; and data have been recorded since 1988, initially

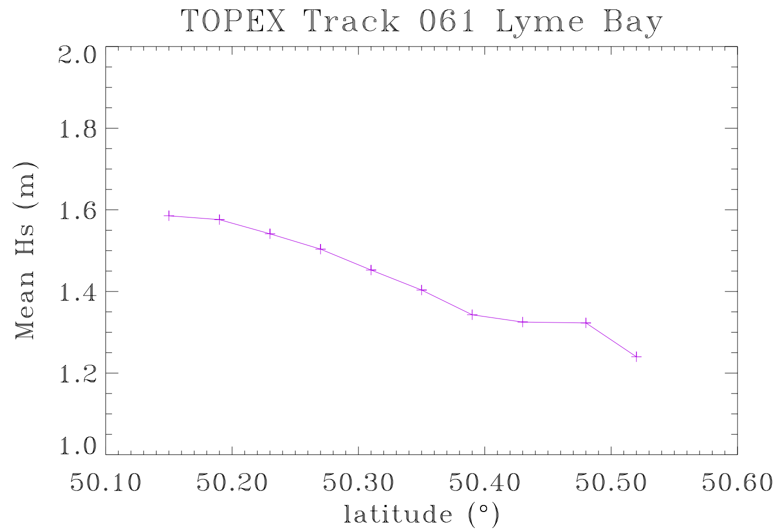


**Figure 2: Mean wave height from all passes of TOPEX into Lyme Bay.**

at 3-hourly intervals and hourly since 21 March 1994. Records include wind speed and direction, also wave heights and periods but the wave data are very poor with and few satisfactory wave data in the entire data set. Unfortunately there are also some rather large breaks in the wind records, with a gap from August 1994 to December 1996. Our records end in December 1997. There are TOPEX data, wave height, wind speed and estimates of wave period, at 10-day intervals, from September 1992.

## 3 Wave height and wind direction

Extracting significant wave height, $H_s$, from the altimeter data, and wind direction (from which it was coming), $\theta$, at the buoy up to 1 hour prior to the passage of TOPEX (3 hours before March 1994) gave about 75 pairs of $(H_s, \theta)$ values at 6 km intervals along the Track 061. (the wind direction before the wave measurement, and not the nearest in time was used because it was felt this should better reflect the wind sea direction at the time.) Figure 3 shows the distributions of $(H_s, \theta)$ at four locations along the TOPEX track, as it moves into Lyme Bay. In general at these locations the directional distribution appears quite uniform, but the higher waves are – roughly as expected – from between South and West, with the highest waves, of about 4 m, from the Southwest. Note that there appears to be a reduction in height of these high waves as the location moves shoreward - similar to the trend seen in Figure 2. The highest measured $H_s$ at 50.15° 2.97°W is 4.6 m, recorded on 25 October 1992, with a wind direction at the buoy of 230°, and wind speed of 28 kt (14.4 m/s); the highest at the other locations were from the same pass – see Table 3.

## 4 Wave period and wind direction

Figure 4 gives the distributions of $(T_z, \theta)$ at four locations along the TOPEX track, i.e. the upcross wave period estimated from the TOPEX altimeter. These distributions show that the longer-period waves are associated with winds (and presumably with waves) from the southwest quadrant. Because of the correlation between $H_s$ and $T_z$ from the altimeter – see Section 7 – this

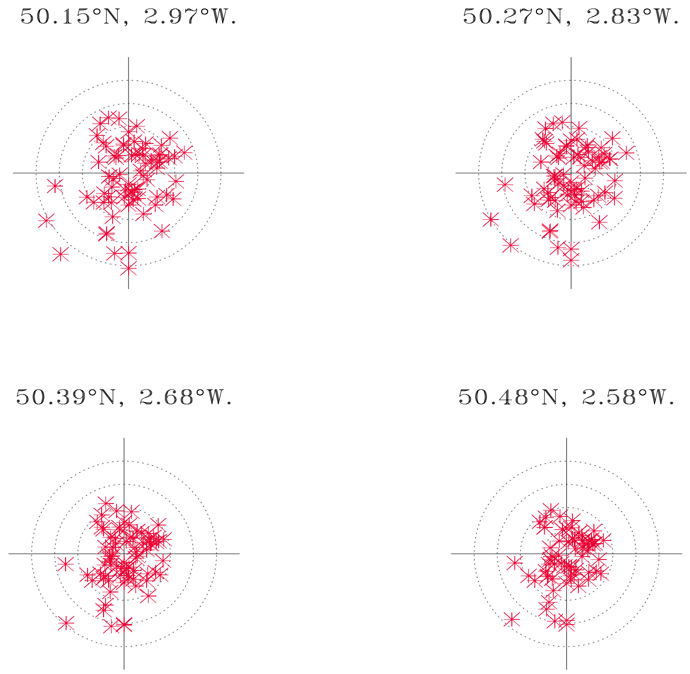


**Figure 3: Distribution of Hs (circles at 1 m intervals) and wind direction (+ve y-axis: North).**

could have been inferred from Section 3, but it is reassuring to see the evidence. The periods with winds from the Northeast are most limited.

# 5 Comparison of buoy and TOPEX winds

A comparison of wind speeds estimated from TOPEX at location 50.48°N 2.58°W with those from the buoy within the previous hour (3-hours for data before 21 March 1994) is shown in Figure 5. The correlation between the two data sets is 0.83; the principal component fit suggests that the buoy winds are about 6% less than the TOPEX values, although this is not statistically significant.

Comparisons with TOPEX locations at increasing distance from the buoy show a decrease in correlation, and an increase in slope - see Table 2. The change in slope, decreasing into Lyme Bay, is supported by the general reduction in mean wind speed from all TOPEX data along the track, as shown in Figure 6.

| Latitude (°N)<br>Longitude (°W) | 50.15<br>2.97 | 50.27<br>2.83 | 50.39<br>2.68 | 50.48<br>2.58 | Wind<br>Direction |
|---|---|---|---|---|---|
| 25 Oct. 1992 | 4.6 | 4.1 | 3.9 | 3.7 | 230° |
| 15 Dec. 1993 | 4.1 | 3.8 | 3.1 | 2.9 | 270° |
| 4 Jan. 1994 | 3.5 | 3.3 | 3.2 | 3.0 | 260° |
| 3 Feb. 1994 | 3.2 | 3.3 | 3.0 | 2.9 | 180° |
| 17 Feb. 1997 | 4.1 | 4.0 | – | – | 210° |

**Table 1: Examples of TOPEX Hs along Track 061.**

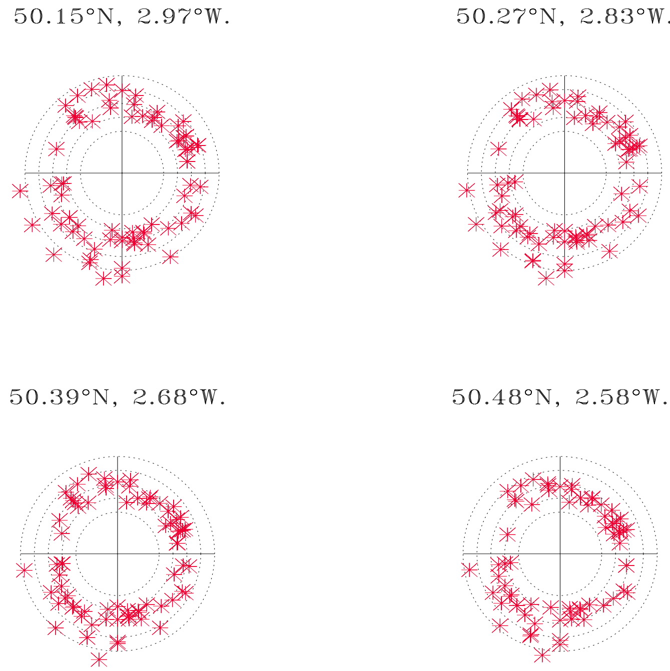


**Figure 4: Distribution of wave period (circles at 3, 4, 5, 6 & 7 s) and wind direction (+ve y-axis: North).**

| TOPEX Lat. °N | Long. °W | $\rho$. | intercept m | slope |
|---|---|---|---|---|
| 50.15 | 2.97 | 0.797 | 0.094 | 1.046 |
| 50.27 | 2.83 | 0.804 | -0.003 | 1.036 |
| 50.39 | 2.68 | 0.818 | 0.030 | 0.990 |
| 50.48 | 2.58 | 0.836 | 0.067 | 0.936 |

**Table 2: Correlation of wind speeds from TOPEX and buoy at 50.6°N 2.7°W, and intercept & slope of principal component fit (TOPEX on buoy).**

## 6 Extreme wave height

Extreme wave heights can be estimated from the TOPEX data by fitting them to an FT-1 distribution and extrapolating to the required probability. Figure 7 shows some results; the top of the probability scale corresponds to the 100-year return value, calculated for 3-hourly observations.

The FT-1 distribution appears to be a reasonable fit (except at very low wave heights – but TOPEX cannot accurately resolve such low waves, while the FT-1 distribution permits negative values). Figure 8 shows return values plotted against latitude along the TOPEX Track 061; values are tabulated in Table 3. The standard error of the 100-year return values are about 0.5 m, decreasing to about 0.3 m for the 1-year return value.

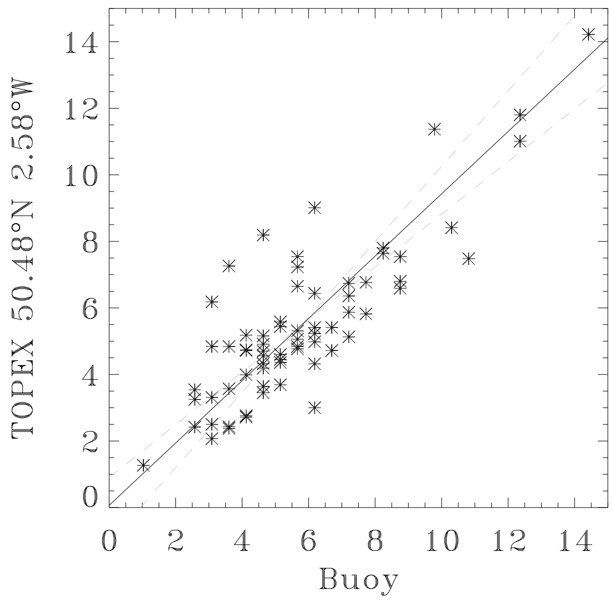


**Figure 5: Comparison of wind speed from the buoy and from TOPEX.**

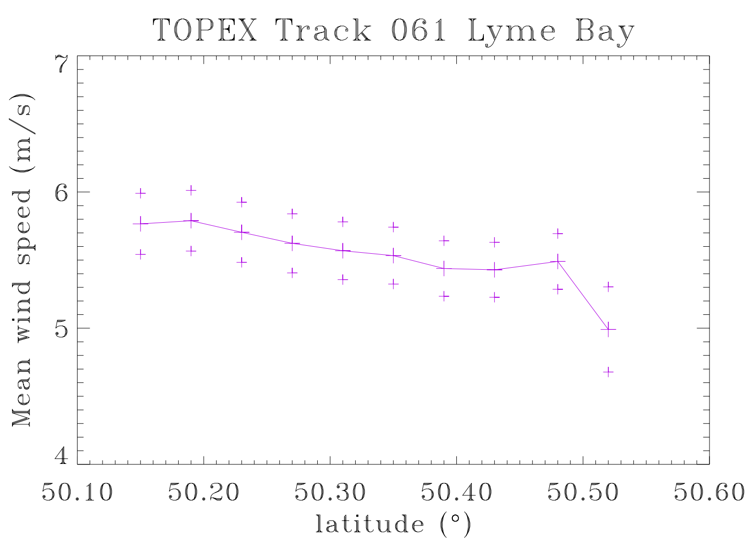


**Figure 6: Mean wind speed from all passes of TOPEX into Lyme Bay, with ±standard error.**

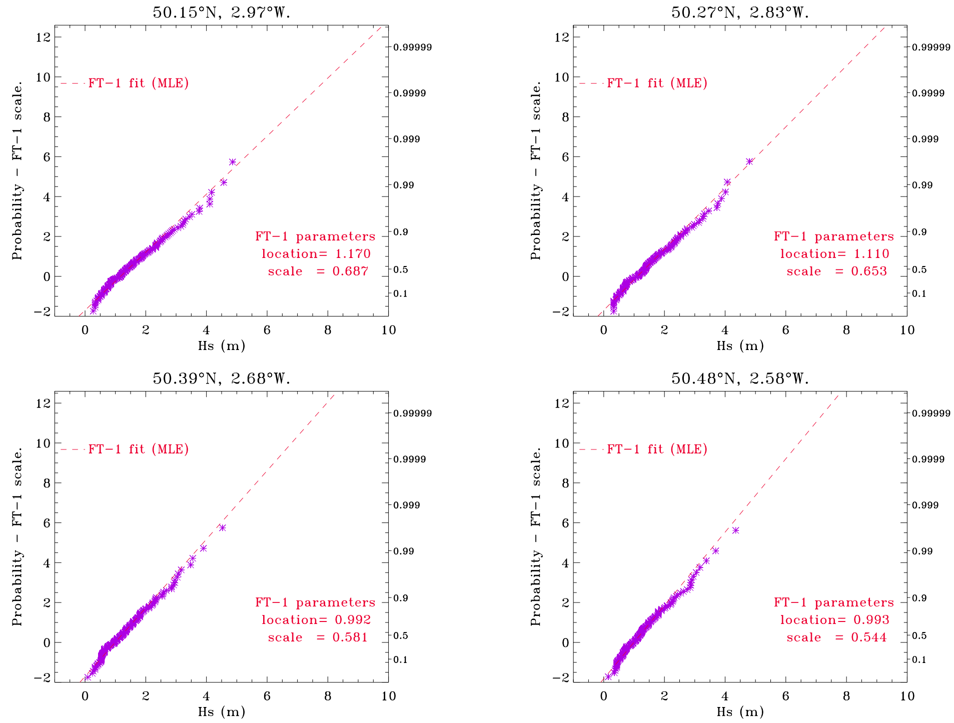


**Figure 7: Cumulative probability distributions of Hs and fitted FT-1 distributions.**

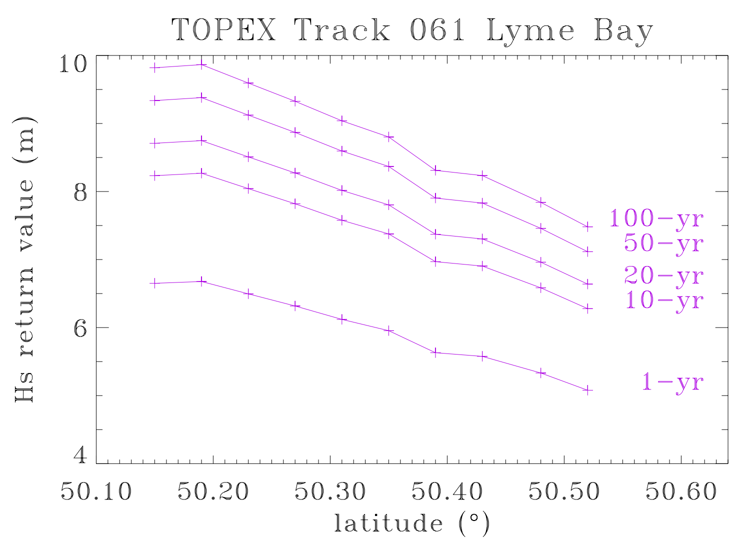


**Figure 8: Return values of significant wave height from all TOPEX passes into Lyme Bay.**

# 7 Wave height and period

The zero-upcross wave period is calculated from the altimeter estimates of $H_s$ and $\sigma^0$ by a complex numerical algorithm, but the results appear, from the TOPEX Lyme Bay data, to indicate a good

| Lat. °N | Long. °W | No. | $\alpha$ m | $\beta$ m | 100-yr return m | s.e.(100-yr return) m |
|---|---|---|---|---|---|---|
| 50.15 | 2.97 | 173 | 1.170 | 0.687 | 9.82 | 0.533 |
| 50.19 | 2.92 | 170 | 1.161 | 0.691 | 9.87 | 0.541 |
| 50.23 | 2.87 | 173 | 1.136 | 0.672 | 9.60 | 0.521 |
| 50.27 | 2.83 | 177 | 1.110 | 0.653 | 9.33 | 0.500 |
| 50.31 | 2.78 | 177 | 1.069 | 0.633 | 9.04 | 0.485 |
| 50.35 | 2.73 | 177 | 1.029 | 0.617 | 8.80 | 0.473 |
| 50.39 | 2.68 | 175 | 0.992 | 0.581 | 8.31 | 0.448 |
| 50.43 | 2.63 | 170 | 0.980 | 0.576 | 8.24 | 0.451 |
| 50.48 | 2.58 | 154 | 0.993 | 0.544 | 7.84 | 0.447 |
| 50.52 | 2.53 | 71 | 0.923 | 0.521 | 7.48 | 0.630 |

**Table 3: Maximum likelihood estimates of FT-1 fit to TOPEX Hs along Track 061. (No.: number of observations, $\alpha$ & $\beta$: location and scale parameters.)**

linear relationship between $H_s$ and $T_z^2$. This relationship is shown in Figure 9 at four locations along Track 061, using data when wind velocity was measured at the Met. Office buoy, so that the observations with southwesterly winds could be analysed separately. The results of the linear regressions of $T_z^2$ on $H_s$ are given in Table 4. The standard errors of the intercepts and slopes of all the data at each location are about 0.8 and 0.5 respectively, those with southwesterly winds are about 1.5 and 0.8; so the differences between any of these lines are not significant, but there is a suggestion of a difference between those from the southwest and the omni-directional fit, and of a trend with distance of the location from shore.

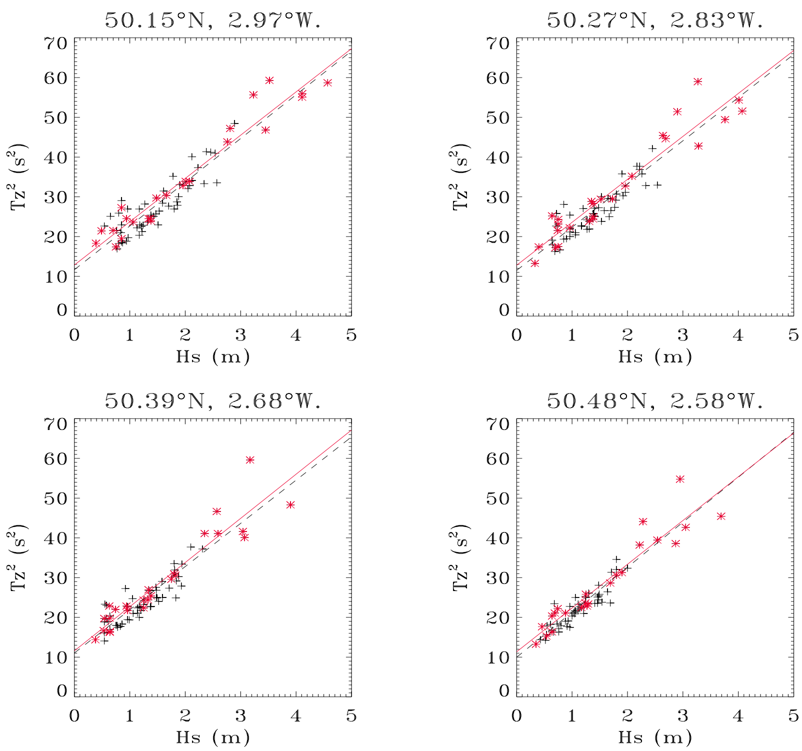


**Figure 9: Plot of Tz$^2$ oagainst Hs. * indicate data with buoy winds from between 180° and 270°, solid line is regression of these data, dashed line is regression of all Tz$^2$ on Hs.**

Figure 10 gives a similar plot of all TOPEX data at one location, 50.39°N 2.68°W, the solid line is the regression of $T_z^2$ on $H_s$ for southwesterly winds from Figure 9. The regression of $T_z^2$ on $H_s$ (the dashed line in Figure 10) has intercept and slope of 11.14 and 10.89, not significantly different from the values for the limited data set analysed in Figure 9 (11.04 and 10.87). Similar agreement was foumd at the other three locations analysed in Figure 9.

Taking an approximate value from all four locations for southwesterly winds, from Table 4, of intercept=12 and slope=11 gives an equation for $T_z$ of

$$T_z = \sqrt{(12 + 11\, H_s)} \quad (1)$$

However, this implies a significant steepness $(2\pi H_s/gT_z^2)$ as given in Table 5. These steepnesses seem rather too low, particularly at lower wave heights – the UK Guidance Notes on the Design of Offshore Structures suggests a significant steepness for design waves of about 1/16 – 1/20, with the possibility of steeper waves in coastal waters with fetches less than about 250 km. For extreme waves, it would seem sensible to consider the effect of waves with a range of periods from 1/16 to that given by Equation 1.

| TOPEX Lat. | Long. | All data | | | SW.ly winds | | |
|---|---|---|---|---|---|---|---|
| °N | °W | N | intercept | slope | N | intercept | slope |
| 50.15 | 2.97 | 74 | 11.66 | 11.00 | 24 | 12.84 | 10.89 |
| 50.27 | 2.83 | 74 | 11.49 | 10.87 | 26 | 12.78 | 10.81 |
| 50.39 | 2.68 | 76 | 11.04 | 10.87 | 25 | 11.57 | 11.11 |
| 50.48 | 2.58 | 68 | 9.97 | 11.32 | 23 | 11.34 | 11.00 |

**Table 4: Regression of Tz² on Hs.**

| | | | | | |
|---|---|---|---|---|---|
| $H_s(m)$ | 2 | 4 | 6 | 8 | 10 |
| $T_z(s)$ | 5.8 | 7.5 | 8.8 | 10.0 | 11.0 |
| Significant steepness | 1/27 | 1/22 | 1/20 | 1/20 | 1/19 |

**Table 5: Examples of Tz from Equation 1 and significant steepness.**

# 8 An extreme event

Extreme waves occurred in the English Channel on 13 February 1979, resulting in considerable damage and flooding to the area around Lyme Bay (Draper & Bownass, 1983). Damage was especially severe at Chiswell on the Isle of Portland, where waves over-topped Chesil Beach, the crest of which is about 12 m above high tide level, causing extensive flooding. At the time the wind was easterly at about 10 knots. The waves seem to have built up in the warm sector of a depression which moved across the Atlantic at the same speed as the wave energy propagated; the

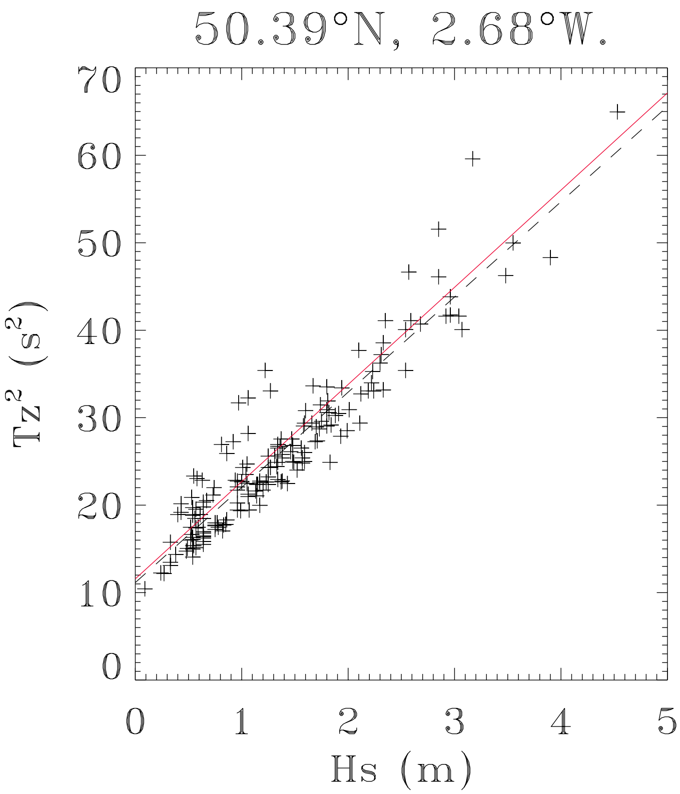


**Figure 10: Plot of $Tz^2$ oagainst Hs; dashed line is regression of all $Tz^2$ on Hs, solid line is regression with wind direction between 180° and 270° from Figure 9.**

depression slowed and filled in mid-Atlantic but the very high and very long swell waves travelled on eastwards. A buoy in the Southwest Approaches recorded $H_s$ and $T_z$ of 7 m and 18 s, while a Waverider off Sines, south of Lisbon, recorded 9.4 m and 20 s. The wave height decreased as the swell travelled up the English Channel, but 2 m was recorded at a sheltered location in Christchurch Bay. Damage appears to have been caused as much by the high period of the waves as by their height. Draper & Bownass (1983) report that refraction studies indicated that 20 s waves would focus in the middle of Lyme Bay and 18 s waves would focus on the Isle of Portland.

This seems to have been a very rare event, caused by a depression moving at just the right speed in the precise direction to propel swell waves up the English Channel; no similar event has been recorded, so it is impossible to estimate its return period. Moreover, because this event is so unusual it cannot be taken as a coming from the general distribution of wave height in the area, so estimates of extreme $H_s$ obtained by extrapolating into the upper tail of this distribution could not be expected to include it.

## 9 Conclusions

The report has investigated available data in Lyme Bay from the TOPEX altimeter and the Met. Office buoy, to see how both - very different - data sets might be used to determine the wave

climate in the Bay. It has been found that the wind data from the buoy and the wave height and period data from the altimeter give a coherent picture, assuming the waves in the Bay have the same direction as the wind.

Comparisons of wind speeds measured from buoy and altimeter show good agreement.

Extreme wave heights have been estimated from the TOPEX data (see Table 3); these waves would be expected from the Southwest quadrant. The mean and extreme wave heights decrease with locations moving into the Bay - as does the mean wind speed. This behaviour differs from that found off Holderness where there was no evidence of reduction in wave height as waves approached the shore. Whether the reduction is due to the sheltering effect of the promontary of Start Point (as suggested by the reduction in wind speed) or to refraction of the prevailing SWly waves has not been determined.

Analysis of TOPEX wave heights and estimated wave periods indicates that the zero-upcross period to be associated with a specific value of $H_s$ is given by Equation 1. However, this relationship gives a significant steepness which is rather too low compared to that recommended in the UK Guidance Notes, so for extreme $H_s$ values, a range of periods down from that from Equation 1 to that with a significant steepness of 1/16 (i.e. $T_z = 3.20\sqrt{H_s}$) should be considered.

The event of February 1978 (see Section 8) is a cause for concern, in that it appears to have produced highly dangerous conditions at the shore, but was such a rare event that it is not reflected in the data or analysis elsewhere in this note. The possibility of 18–20 second waves in Lyme Bay should be considered when designing coastal defences.

# References


Draper, L. and Bownass, T. M. 1983.
Wave devastation behind Chesil Beach.
*Weather*, **38**:346–352.