JERICHO TECH. REPORT 30

Wave Climate at St Gowan for JERICHO

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1 Introduction

This report describes the analysis of data from the Met. Office buoy at St Gowan, 51.5°N 4.9°W to obtain an input data set for the 'STORM' model and extreme wave heights for the 'SWAN' model. Results are compared to those from a similar analysis of wave heights from the WASA hindcast data set, and to results from the 'Guidance Notes' and from analysis of rather distant TOPEX data. Figure 1 shows locations referred to in this report.

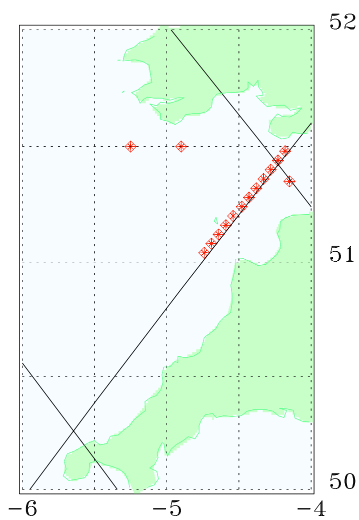

Figure 1: Location of the Met. Office buoy (51.5°N 4.9°W), WASA grid point (51.5°N 5.25°W), and of TOPEX GAPS data referenced in this report.

2 Met. O. buoy data

Data from the Met. Office buoy at St Gowan extends from September 1992 to December 1997, but the wave data for the first two years was unsatisfactory - either missing or of dubious quality. The data from September 1994 appeared generally good, although a few obvious 'outliers' had to be removed following an inspection of a plot of wave height against wind speed; also a series of records with wave height and wave period both set to 0 were removed. This left 27 127 records, at hourly intervals. To reduce the data to a more manageable size, data for noon were extracted, and then - in order to obtain roughly the same number of records for each season, only the noon values for December 1994 to December 1997 (inclusive) were used. This gave a total number of records of 1040, divided between the seasons as follows: DJF:271 MAM:238 JJA:272 SON:259.

The largest value of significant wave height (H_s) in this set was 8.5 m at 1200Z on 28 October 1996, with a wind speed of 32 knots (16.5 m/s). The largest in all the data was 10 m at 2000Z on 24 December 1997, with again 32 knots.

The records contain H_s to the nearest 0.5 m, wave period to the nearest 0.5 s, and wind velocity (nearest knot, and degrees). Note that, for example, wave code = 3 is taken to mean $H_s = 1.25 - 1.75$ m, although we were unable to clarify this, and it is not clear what wave code = 0 means.

3 Estimation of extreme waves

3.1 Wave height

Figure 2 shows the cumulative distribution of wave height from these 1040 records, plotted on FT-1 scale, so that if the H_s values were from an FT-1 distribution, then they would lie close to a straight line - which they clearly do not. Figure 3 shows the distribution of H_s from the 617 records with wind direction θ such that $300° \geq \theta > 120°$. This gives a much-improved straight line, with location and scale FT-1 parameters estimated by maximum likelihood, of 1.384 and 0.959 m respectively; giving a 100-year return value of 12.95 m (standard error = 0.38 m) with the wind in this direction (assumed to be for $100 \times 617/1040$ % of the time). Figure 4 shows the distribution of H_s with wind direction $\theta \leq 120°$ or $\theta > 300°$; again a reasonable fit to an FT-1 with location and scale parameters of 0.863 m and 0.522 m, and 100-year return value of 6.95 m.

The omni-directional extreme wave height should be obtained by compounding the two distributions shown in Figures 3 and 4, but the latter contributes such low waves, compared to those from Figure 3, that it can be ignored, and estimates taken only from the distribution fitted in Figures 3 - but allowing for the fraction of time with winds from between 120° and 300°.

Table 1 gives estimates of return values of H_s and standard errors, together with wave periods and directions obtained as described in Subsections 3.2 and 3.3.

Return period (yr)	1	10	50	100	200	1000
$H_s(m)$	8.54	10.74	12.29	12.95	13.62	15.13
s.e.(H_s)	0.24	0.31	0.36	0.38	0.40	0.45
$T_z(s) from$	9.9	11.1	11.9	12.2	12.5	13.2
to	10.5	11.7	12.6	12.9	13.2	13.9
Direction (°)	250	250	250	250	250	250

Table 1: Estimate of extreme wave parameters at 51.5°N 4.9°W.

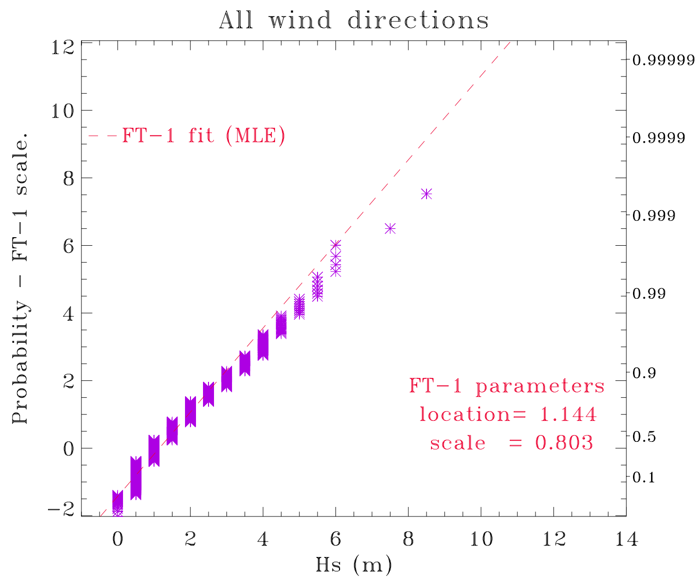

Figure 2: Cumulative Probability distribution of Hs from 1040 records from the Met. Office buoy, 51.5°N 4.9°W.

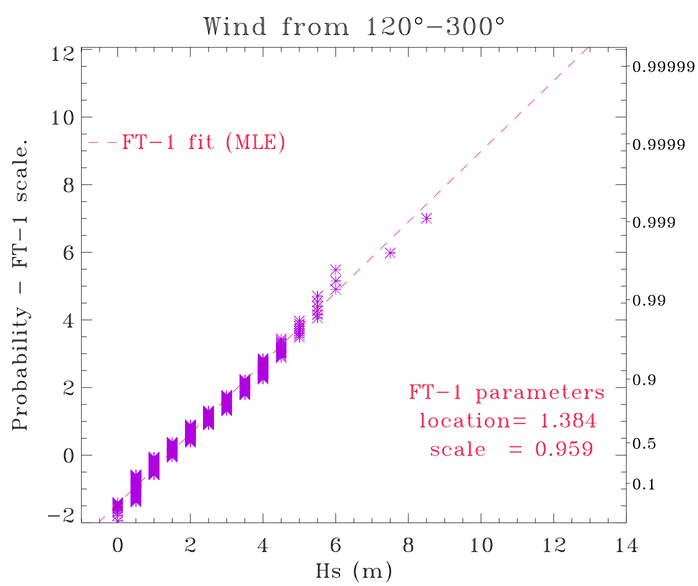

Figure 3: Cumulative Probability distribution of Hs from 617 records from the Met. Office buoy, 51.5°N 4.9°W., with wind from 120°-300°.

3.2 Wave period

For this relatively open site, the significant steepness of high waves is assumed to lie in the range 1/18 to 1/20, where significant steepness, ss is defined by

$$ss = \frac{2\pi\, H_s}{g\, T_z^2}$$

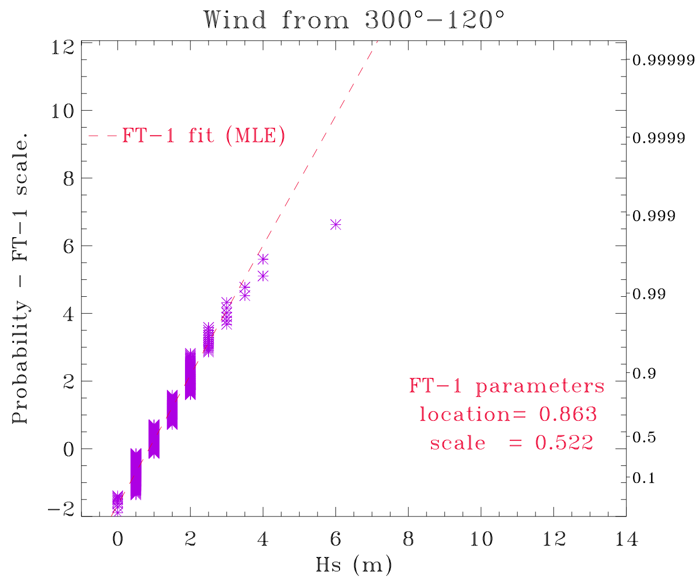

Figure 4: Cumulative Probability distribution of Hs from 423 records from the Met. Office buoy, 51.5°N 4.9°W. , with wind from 300°-120°.

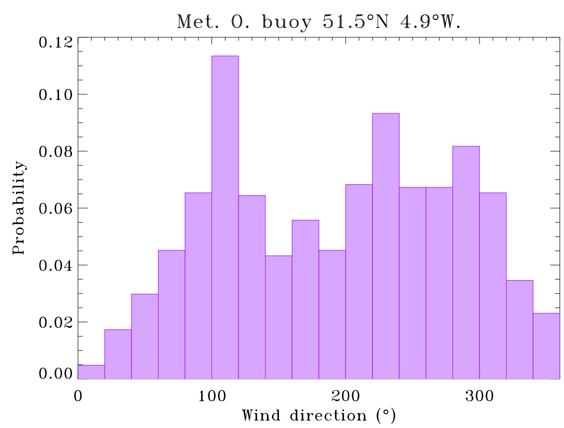

Figure 5: Distribution of wind direction from 1040 records from the Met. Office buoy.

where T_z is the mean upcross wave period and $g = 9.81\, ms^{-2}$, which gives, for $ss = 1/18$ and $ss = 1/20$, $T_z = 3.395\sqrt{(H_s)}$ and $T_z = 3.579\sqrt{(H_s)}$ respectively.

3.3 Wave direction

Figures 5, 6 and 7 show the distributions of wind direction measured by the Met. Office buoy throughout the year, and when significant wave height was > 3 m and > 4 m respectively. In general, the distribution is fairly uniform, except for a lack of winds from the North, and a 'spike' at 80° – 100° (perhaps topographically induced). As Figures 6 (with 101 out of the 1040 records) and 7 (with 35 records) show, as H_s increases, the wind direction, and presumably the wave direction, take on a narrower distribution, centred on 250°.

As a check on the use of wind direction for wave direction, an analysis of the WASA hindcast data

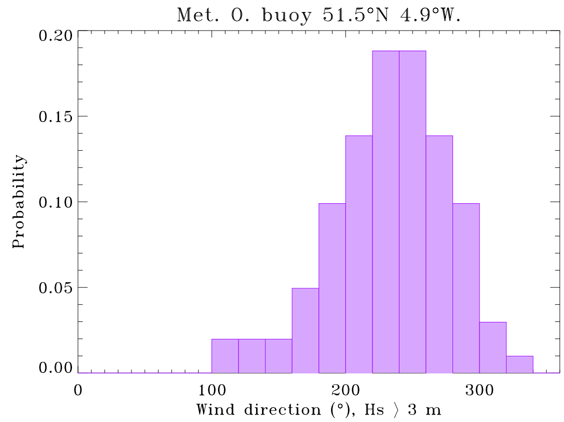

Figure 6: Distribution of wind direction from the Met. Office buoy with Hs > 3m.

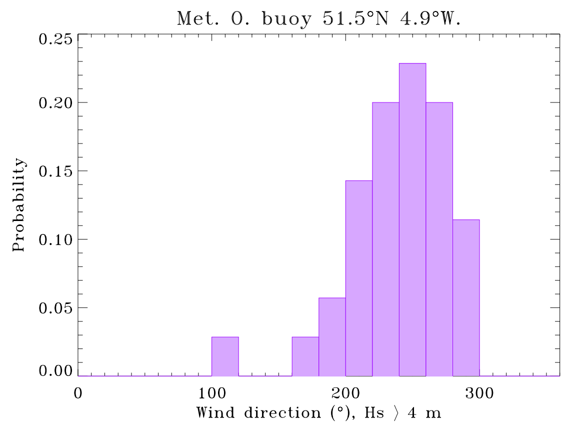

Figure 7: Distribution of wind direction from the Met. Office buoy, with Hs > 4m.

set at a nearby grid point - slightly to the west at 51.5°N 5.25°W - was carried out. Figures 8 and 9 show the distributions of wave and wind directions for the 305 records from 1990-1994 with $H_s > 6$ m (waves hindcast every 3 hr from winds changed every 6 hours). (The directions shown are those from which the wind and waves are coming.) Clearly there is a good correlation between the two directions - but the wave directions have a narrower distribution. The $H_s > 6$ m from 340°-360° occurred during a 24 hour period in December 1990, with winds of 21–24 m/s and wave heights of 8–9 m, both from about 345°–355°. The Met. Office buoy is not so exposed to this direction. The event with wind from 73° and wave from 95° - and height 6.7 m - was during September 1993; the E–NE wind rose from 15.4 m/s to 33.4 m/s within 6 hours, resulting in hindcast $H_s > 5$ m for more than 9 hours with direction backing from 125° to 070°.

4 Other estimates of extreme wave height

4.1 WASA hindcast

The WASA data set consists of 3-hourly hindcast estimates of wave parameters, including wave height and direction, derived from a 3rd generation wave model driven by 6-hourly winds. The data analysed here are these 3-hourly values from 1990–1994 at the wave model grid point 51.5°N

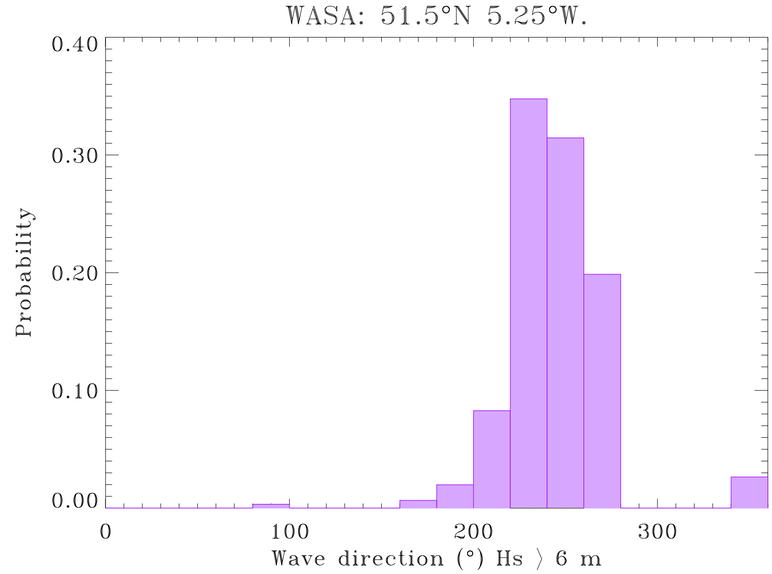

Figure 8: Distribution of wave direction from the WASA study, with Hs > 6m.

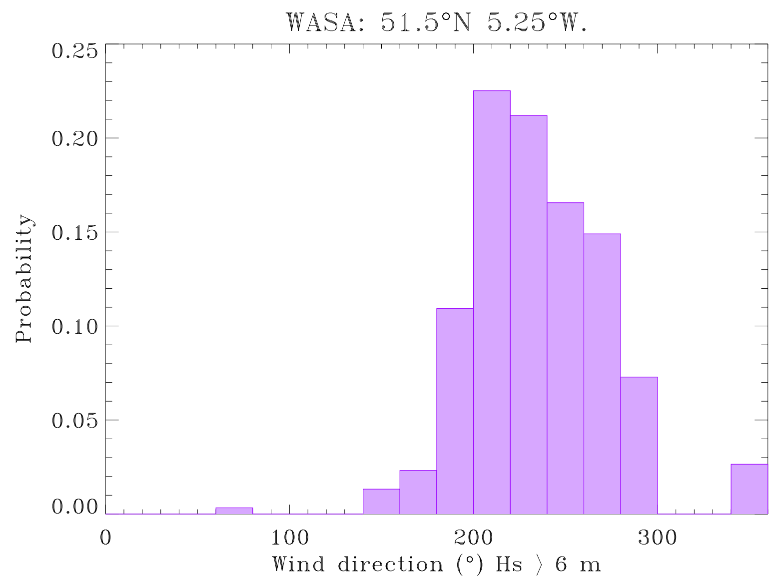

Figure 9: Distribution of wind direction from the WASA study, with Hs > 6m.

5.25°W (see Figure 1). Figures 10, 11 and 12 show the cumulative distributions of H_s with directions corresponding to those in Figures 2, 3 and 4, except that data were selected using wave direction instead of wind direction. None of these data sets appear to be from an FT-1 distribution, and it is not obvious how to extrapolate the plotted values to estimate the 100-year return value. Fitting an FT-1 censored at 5 m to the data from 120° to 300° gives the result shown in Figure 13, with a 100-year return value of 16.1 m (with a s.e., assuming 3-hourly values are independent, of 0.4 m). A similar analysis of the WASA data for 1954-59 gives almost identical results, with an estimated 100-year return value of 16.0 m.

A statistically sounder method of analysis is to use the asymptotic extreme value theory, although only ten years of data are inadequate to give a useful estimate of the 100-year return value. Analysing the ten annual maximum H_s values from the WASA data set at 51.5°N 5.25°W, which range from 8.0 m in 1956 to 11.8 m in 1994, and ignoring the effect of the within-year cycle upon the asymptotic theory, gives the result shown in Figure 14, with 100-year return value of 15.7 m and s.e. approximately of 1.7 m.

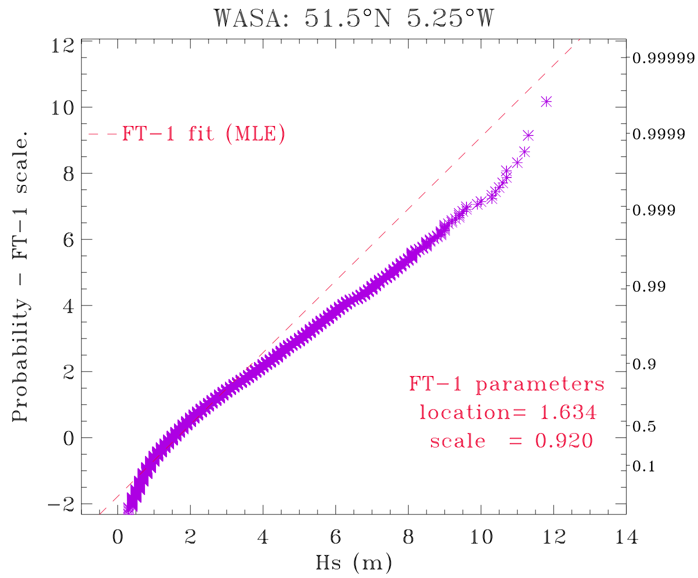

Figure 10: Cumulative probability distribution of Hs from the WASA data set 1990-1994.

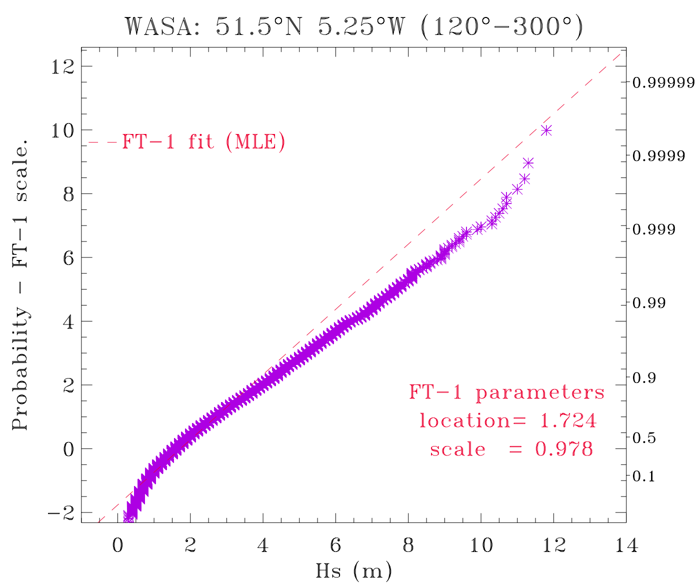

Figure 11: Cumulative Probability distribution of Hs from the WASA data set 1990-94, with waves from 120°-300°.

However one looks at the WASA data set, the suggestion is that the 100-year return value is greater than from the analysis of the Met. Office data. It is not possible to quantify how much of the

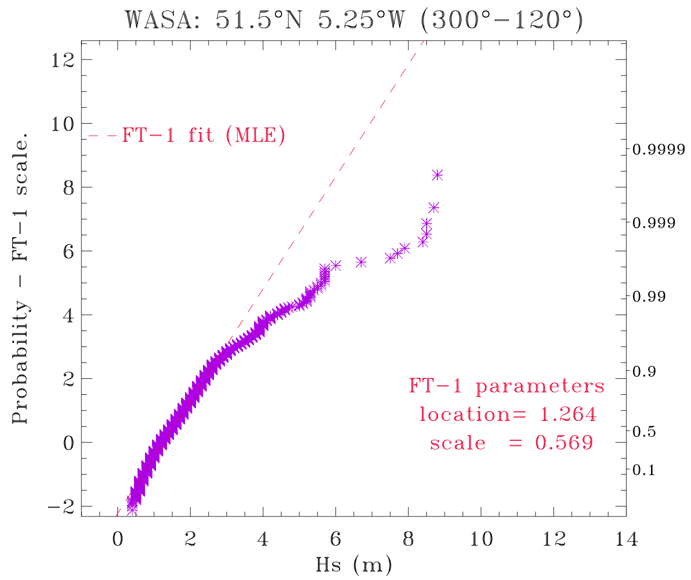

Figure 12: Cumulative probability distribution of Hs from the WASA data set 1990-1994, with waves from 300°-120°.

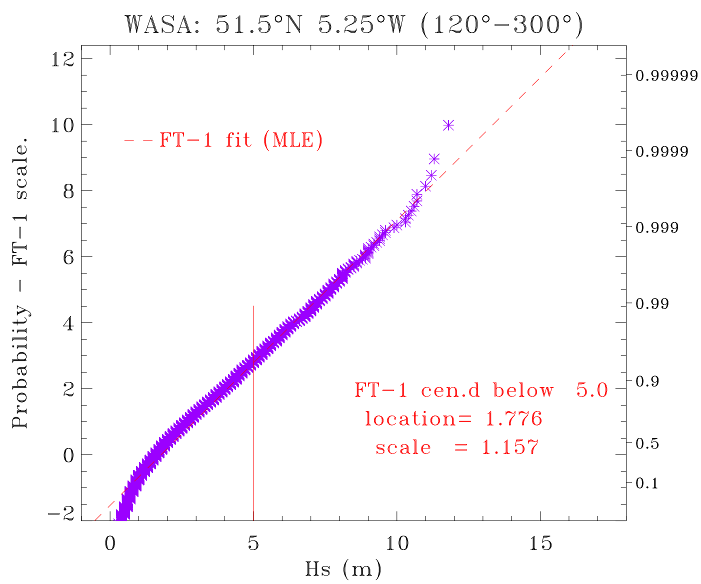

Figure 13: Cumulative probability distribution of Hs from the WASA data set 1990-1994, with waves from 120°-300°, showing FT-1 fit to data above 5 m.

difference is due to shortcomings in the data and in the hindcast model results and how much to the difference in exposure of the two sites.

4.2 'Guidance Notes'

The 'Guidance Notes' (4^{th} edition of *Offshore Installations: Guidance on Design, Construction & Certification*, published by the UK Dept. of Energy), gives indicative values for the 50-year return

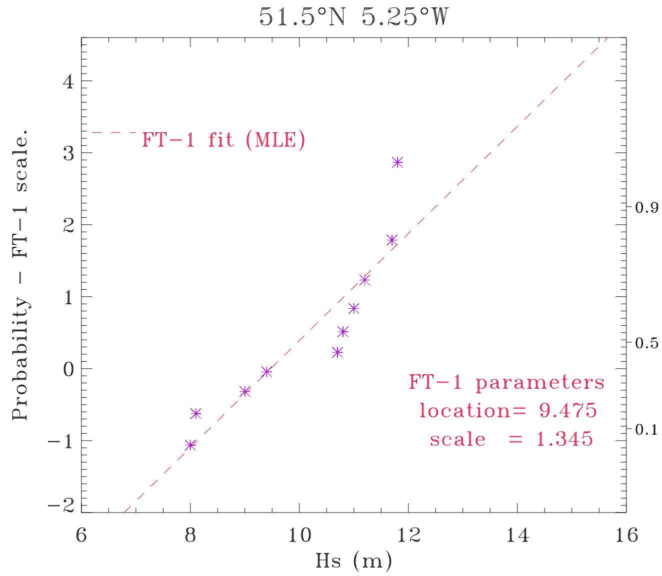

Figure 14: Cumulative probability distribution of annual maxima of Hs from the WASA data set 1954-59 & 1990-94.

value of H_s in waters around the UK. It includes an estimate from Shipborne Wave Recorder data obtained at the St Gowan Light Vessel at 51.5°N 5.0°W, about 7 km west of the Met. Office buoy, from 1975 to 1978. The 50-year value is 12.4 m, compared to that of 12.29 m given in Table 1 - well within the confidence interval. From the support document to the Guidance Notes, the 100-year return value was estimated from the SBWR data to be 13.1 m, compared to 12.95 m in Table 1.

4.3 TOPEX data

As seen in Figure 1, there are no TOPEX measurements close to St Gowan. The nearest are along Track 239 close to the Somerset coast. Records from Track 146 across the mouth of the Severn are severely affected by land, and only one location - to the south of Track 239 - has sufficient data for analysis, and the results suggest that there is still a problem with the measurements at this location -see Table 2.

At each of the 'GAPS' locations along Track 239, there are about 170 records which passed the quality checks (but fewer at 51.16°N 4.59°W close to Lundy Island). Figure 15 shows cumulative distributions from some of these locations. Table 2 gives the 100-year return values estimated from the censored FT-1 fit to data above 1 m.

Lat. (°N)	51.04	51.12	51.20	51.28	51.36	51.44	51.35
Long. (°W)	4.74	4.64	4.54	4.43	4.33	4.23	4.15
$H_s(m)$	12.1	12.1	10.0	9.7	10.3	10.2	12.1
s.e.(H_s)	0.7	0.8	0.7	0.6	0.7	0.7	0.9

Table 2: 100-year return values of Hs from TOPEX data

Note that these results were obtained using all TOPEX data from October 1992 to December 1998; omitting the October-December 1992 data, to obtain a more even distribution of observations throughout the year gave very small changes in 100-year return values – generally smaller by less than 0.2 m. The final column in this Table is the one location analysed from Track 146, with anomolously high return value at this easterly location. The 100-year return value at the westerly end of Track 239, of 12.1 m with s.e. of 0.7 m, is fairly close to that estimated at the Met. Office buoy (13.0 m), but within about 12 km, it drops to 10 m.

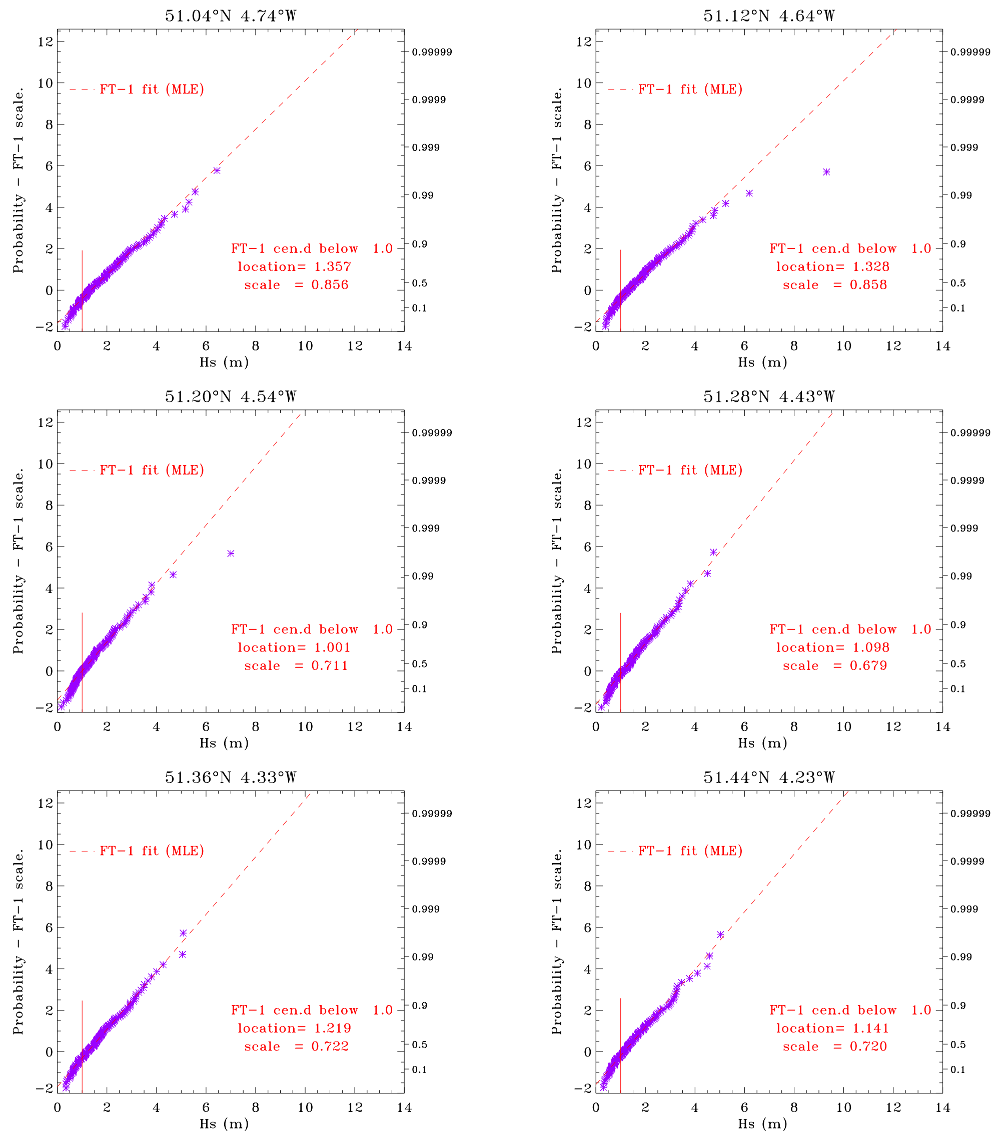

Figure 15: Cumulative Probability distribution of Hs from TOPEX Track 239.

The gradient along Track 239 is not strictly given by this analysis because some records at one location pass the quality control when records at other locations do not. There are 140 passes along the track which obtained 'good' data at all of 8 GAPS locations. The mean H_s and other statistics from these 140 passes are given in Table 3. This Table shows a significant change in mean H_s between 4.64W and 4.48W - a distance along the TOPEX Track of about 18 km, possibly due to Lundy and the shallow water around the island.

Lat. (°N)	Long. (°W)	mean H_s (m)	sd(H_s) (m)	se(mean H_s) (m)
51.04	4.74	1.928	1.112	0.094
51.08	4.69	1.910	1.081	0.091
51.12	4.64	1.903	1.061	0.090
51.24	4.48	1.484	0.803	0.068
51.28	4.43	1,565	0.834	0.071
51.32	4.38	1.651	0.879	0.074
51.36	4.33	1.691	0.908	0.077
51.40	4.28	1.663	0.923	0.078

Table 3: Mean values of Hs from TOPEX Track 239.

5 Conclusions

Estimates of wave conditions at St Gowan have been obtained from buoy data recorded by the Met. Office from September 1992 to December 1997, which gives wave period and wind direction as well as wave height.

Without this buoy, we would have had to use (a) Shipborne Wave Recorder data from 7 km to the west - without directional information, (b) hindcast data, such as the WASA data, or (c) satellite altimeter data from a TOPEX track about 50 km to the southeast. The SBWR data would seem to have been a useful substitute - with directional information inferred from the exposure to the southwest of the location. The WASA data, from a model grid point 24 km to the west, would not have been satisfactory, giving higher extreme waves, possibly due to the more exposed location, especially from the northwest. At a couple of locations analysed along the TOPEX track, the wave climate appears similar (slightly lower) to that at St Gowan, but there are considerable variation in extreme wave height along the track, and without the buoy data, there would have been no way of selecting the location with wave climate similar to that at St Gowan.

So without buoy or SBWR measurements within a few kilometre of the required location, reliable estimates of wave climate would not have been available. Perhaps results could have been obtained from a finer mesh wave model of the general area, capable of showing variations over 5 – 10 km distances.