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Holderness deep water wave climate data set and extreme wave height

D J T Carter

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1 Introduction

This note describes the derivation of a 'data set' synthesised to represent the wave climate at the buoy N3 off Holderness (near 53.83°N 0.15°E) and considers the extreme (100-year return) value there. The data set consists of 163 records of significant wave height, zero-upcross wave period and dominant wave direction, derived from data recorded from the September 1992 to December 1997. The wave height and period values are based on TOPEX data (from the nearest position to N3 in the GAPS data), the wave directions are based on wind directions measured at Leman. See Figure 1.

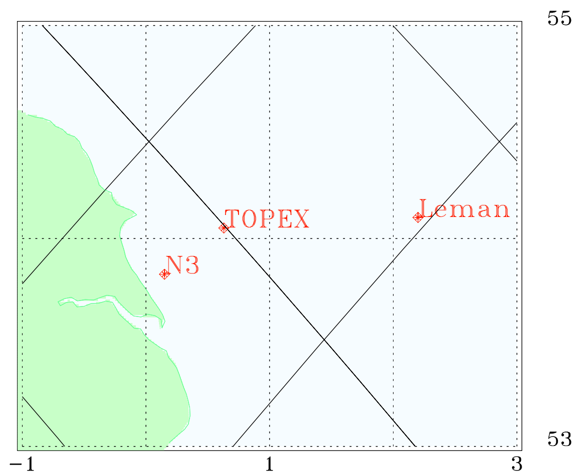

Figure 1: TOPEX tracks and locations referred to in this Report.

2 Wave heights and periods

Significant wave height (H_s) and wave period (T_z) have been extracted from the GAPS data from TOPEX Track 120 at the nearest location to N3: 54.05°N 0.63°E, which is 34.6 km from N3. Data were calibrated as described in previous reports, and, as well as checking the GAPS quality control flags of each record, an along-track comparison of H_s values was carried out - but this resulted in no values being removed at this location.

Estimates of T_z in the GAPS data were derived from altimeter H_s and σ^0 values. See JERICHO Technical Report (JTR) *Analysis of altimeter wave period estimates in the North Sea*, 15 June 1999 for a comparison of these periods and buoy data.

The relationship between H_s values along TOPEX Track 120 and at N3 was examined in JTR *TOPEX & N3 Wave Heights*, 9 June 1999, which showed that it depended on the direction of travel of the waves (measured at N3). It was found that for waves from 340° – 160° there was no significant difference between H_s at Track 120 and at N3; but for waves from 160° – 340° (i.e. from offshore) the relationship was:

$$H_s(N_3) = 0.386\,H_s(TOPEX) + 0.392 \tag{1}$$

Clearly this linear fit cannot hold at very low TOPEX H_s values, which would imply higher waves at N3 than in the open sea. So Equation 1 was applied only if $H_s > 0.638$ m [The intersection of Equation 1 and $H_s(N_3) = H_s(TOPEX)$]. If $H_s(TOPEX) < 0.638$ m or the direction was from 340° – 160° then $H_s(N_3)$ was assumed to be the same as the TOPEX value.

If the same H_s value was used for the N3 data set, then the TOPEX T_z value was also used, unchanged. However, when the H_s value was adjusted by equation 1 then the T_z value was adjusted as follows.

Carter (1982) gives the following relationships for fetch-limited waves:

$$H_s = 0.0163\,X^{0.5}U \qquad \text{and} \qquad T_z = 0.439\,X^{0.3}U^{0.4}$$

where X is fetch (km) and U is wind speed at 10 m (m/s); and for fully-developed seas:

$$H_s = 0.0248\,U^2 \qquad \text{and} \qquad T_z = 0.566\,U$$

From these equations, we get the ratio of fetch-limited to fully developed H_s as

$$R(H_s) = 0.6573X^{0.5}/U$$

and the ratio of periods as

$$R(T_z) = 0.7756X^{0.3}/U^{0.6} = 0.7756(X^{0.5}/U)^{0.6}$$

Therefore:

$$R(T_z) = 0.9977\,R(H_s)^{0.6}$$

or, approximately

$$R(T_z) \approx 1.0\,R(H_s)^{0.6} \tag{2}$$

Equation 2 has been used to estimate the wave period at N3 from the TOPEX value whenever the H_s value was adjusted. There is no reason for the waves at the TOPEX wave location to be fully developed, although with offshore waves they would be more nearly fully-developed than at

N3. As a check on Equation 2, the 13 pairs of records of H_s and T_z measured at N3 at the same time at at the TOPEX location were analysed; for each pair the two H_s values and the TOPEX T_z value were used to estimate the T_z value at N3, and this compared with the measured value at N3. The linear regression of estimated T_z on measured T_z had an intercept of 0.21 (not significantly different from 0) and a slope of 0.996 (not significantly different from 1); the correlation coefficient was 0.88 whilst that between the measured T_z at N3 and TOPEX was 0.35. From this small sample, Equation 2 gave estimates at N3 with a significant reduction in variance over simply using the TOPEX values.

3 Wave direction

JTR *Wind directions at Leman & Wave directions at Buoy N3*, 26 August 1999, reported on average little difference between wind direction measured at Leman and wave direction measured at N3. So wave directions at N3 associated with estimates of H_s and T_z from TOPEX data were taken to be the wind direction at Leman recorded within 1 hour of the TOPEX pass.

4 Distribution of H_s along Track 120 and at N3

4.1 Track 120

Figure 2 shows the cumulative distribution of H_s from TOPEX data for 1992-1997, with a probability scale such that a Fisher-Tippett Type 1 (FT-1) distribution would be a straight line. The location and scale shown in the Figure were estimated from the 163 data values by maximum likelihood. Apart from the highest value, of 5.9 m, the data appear to be well-described by the FT-1. (The second highest value of 4.4 m is also rather 'low' but values from the upper tail would be expected to show greater variability than those from the bulk of the data.) The 'top' of the plotted probability scale corresponds to the 100-year return value (for 3-hourly data), and is 7.8 m, with s.e. of 0.4 m.

The highest value of 5.90 m was recorded on 19 February 1996, together with a wave period estimate of 8.55 s and wind speed of 15.54 m/s; the wind at Leman was 45 kts (23 m/s) from 010°.

The second highest $H_s = 4.39$ m was on 15 February 1994, with 7.77 s and 12.6 m/s, and Leman wind of 140°/29 kts (15 m/s) - but it had been about $34 - 39$ kts from 110° for much of the previous 12 hours.

This analysis did not include 1998 because of lack of Leman data. Figure 3 shows the cumulative distribution for the TOPEX location for all years, up to December 1998 - a total of 205 records. There was a third value of $H_s > 4$ m – 4.17 m on 12 April 1998, with 7.76 s and 11.5 m/s. The fitted FT-1 is very similar to that for 1992-97; the 100-year return value is higher, at 8.0 m but not significantly so.

Analyses of data from locations along Track 120 about 30 km either side of that analysed above gave similar results, with $H_s > 4$ m on the same 3 occasions (1992-1998) [except at one location the 12 April 1998 event data was flagged as bad] with 100-year return values of 8.0 m and s.e. of 0.4 m. The maximum H_s recorded was 6.19 m 30 km SE of 54.05°N 0.63°E on 19 February 1996. This consistency along about 60 km of track gives a measure of confidence in the reality of these

high waves and in the estimates of extremes.

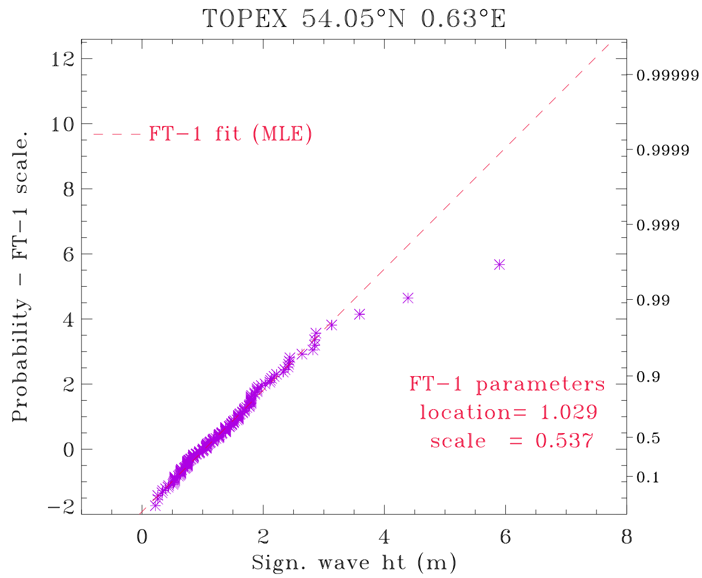

Figure 2: Cumulative probability distribution of H_s data from TOPEX, 1992-1997.

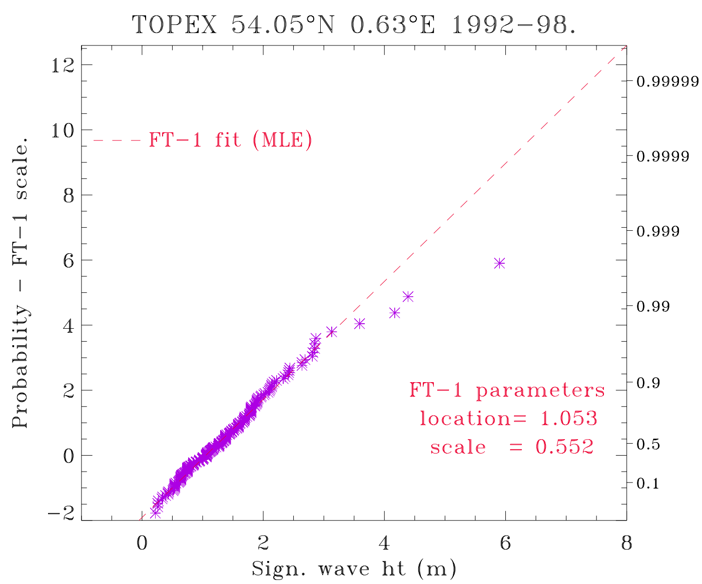

Figure 3: Cumulative probability distribution of H_s data from TOPEX, 1992-1998.

4.2 N3

Turning now to the distribution of H_s derived from the synthesized data set at N3. Figure 4 shows the cumulative distribution. The FT-1 no longer seems to be a good fit. Figure 5 shows the results of fitting a Generalised Extreme Value (GEV) distribution and the FT-1 fitted by the method of moments - the discrepancy between the two FT-1 fits is an indication that the data are not from FT-1. The 3-parameter GEV fit is statistically a highly significant improvement over the 2-parameter FT-1, and suggests a 100-year return value of 18.1 m. However, it may be a better fit, but it still appear not to be correct. The data seem to be compounded from two distributions, which considering their origin does not seem unreasonable.

Since all very high waves come from an onshore direction, and for these there is no evidence of change in height between TOPEX and N3, the best estimate of extreme wave height at N3 is the value estimated from the TOPEX data (a few high waves at TOPEX might come from offshore, so this could provide a slight over-estimate.)

A range of return values at N3 are shown in Table 1, calculated from the fit to TOPEX data from 1992-1998 with location and scale parameters as given in Figure 3. The table also includes a range of T_z values associated with these wave heights which have been calculated assuming a significant steepness of $\frac{1}{12}$ to $\frac{1}{16}$ where significant steepness (ss) is given by:

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

Nyr	1	10	50	100	200	1000
H_s m	5.46	6.73	7.62	8.00	8.38	9.25
s.e.(H_s)	0.26	0.32	0.37	0.39	0.41	0.46
T_z from	6.48	7.19	7.65	7.84	8.02	8.43
to (s)	7.48	8.30	8.83	9.06	9.27	9.73

Table 1: Estimates of extreme wave heights and their periods at N3

The direction from which these waves are coming cannot be precisely determined; but they almost certainly would be from 340 - 140, and the few measurements available suggest that the highest waves would be from the North.

Looking again at Figures 2 and 3, suggests that the 2 or 3 highest H_s values might themselves be from a different distribution than the bulk of data. However, the GEV does not give a significantly better fit to these data than the FT-1, so there is no firm evidence for such a worrying suggestion.

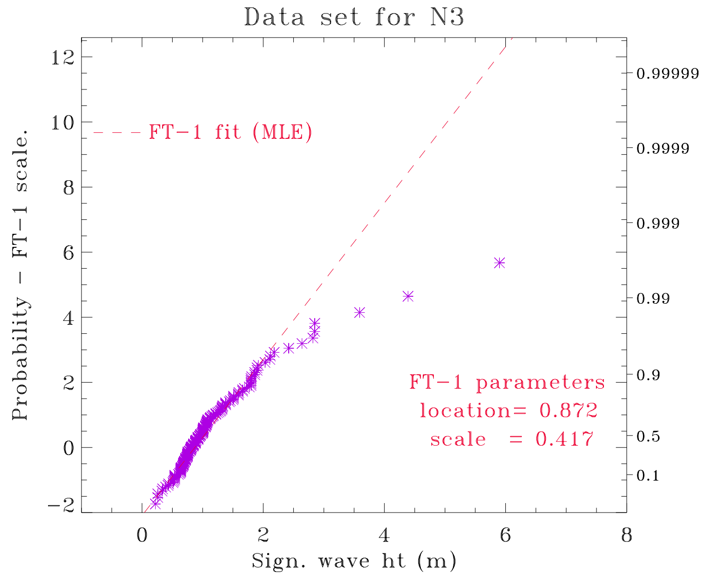

Figure 4: Cumulative probability distribution of estimated H_s at N3, 1992-1997.

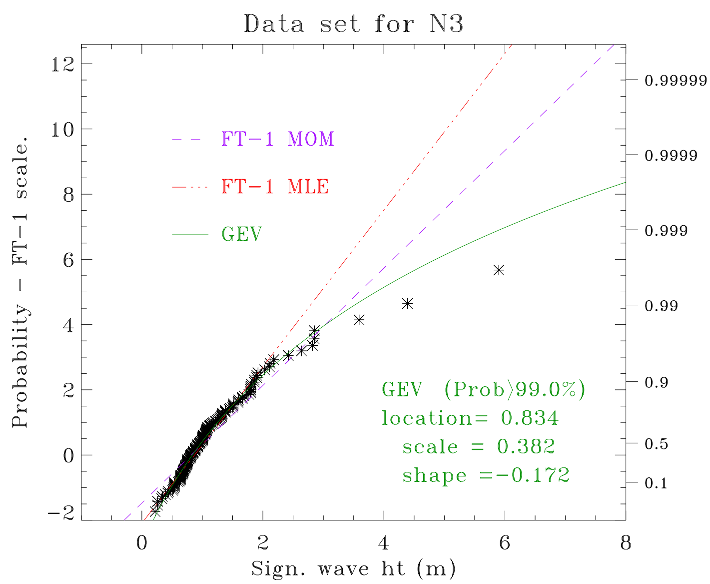

Figure 5: Cumulative probability distribution of estimated H_s at N3, 1992-1997, with fitted GEV distribution.

5 Conclusions

This report had two purposes

- To detail the derivation of the wave climate data set for N3
- To estimate extreme values of H_s at N3.

The former has been achieved, but based on less than 6 years of data, from late September 1992 to December 1997 - and with only 1 winter of data at the site of N3 for comparison. So the resulting data set only attempts to describe the wave climate at N3 during the 1990's, and contains no allowance for possible long-term (decadel) climate change.

The 100-year return value at N3 is estimated – from the 1992-1998 TOPEX data – to be 8.0 m with a standard error of 0.4 m (assuming that the water depth at N3 does not limit the wave height). Other values are given in Table 1. The rather large s.e. is a result of estimating the return value from so few data (205 values) - and both the return value and the s.e. have been derived assuming that data along the TOPEX Track are from an FT-1 distribution.

References

Carter, D. J. T. 1982.
Prediction of wave height and period for a constant wind velocity using the JONSWAP results. *Ocean Engng.*, **9**:17–33.