JERICHO TECH. REPORT 16

TOPEX & N3 Wave Heights

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1 Introduction

This note describes a comparison of significant wave heights, H_s, measured by TOPEX with data from the buoy N3 off Holderness (near 53.83°N 0.15°E – see Figure 1). Comparisons were obtained using all (omni-directional) data and by direction as determined by the buoy. The results

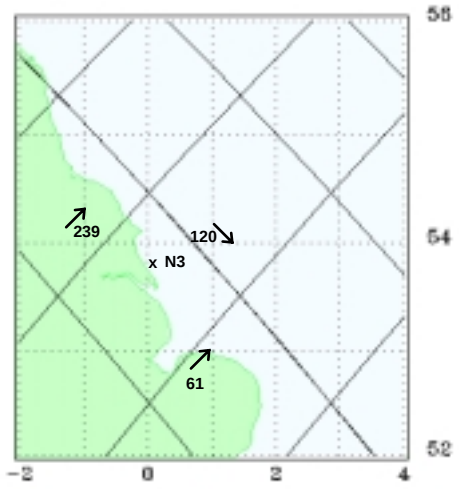

Figure 1: Location of buoy N3 and TOPEX tracks, including Tracks number 061, 120 & 239.

are rather unsatisfactory partly because of problems with the TOPEX data close to the coast where the altimeter is coming off the land (discussed below) and partly because of the small amount of data. N3 records are from 14 October 1994 to 28 February 1995, a total of 138 days, so at most one could expect 14 TOPEX passes along Track 120. To increase the number of data pairs for comparison, I used data from TOPEX cross-overs, of Tracks 061 and 120 near 53.51°N, 1.44°E, and Tracks 120 and 239 near 54.45°N, 0.05°E.

The TOPEX data, from October 1992 to December 1997, were taken from the 'GAPS' (interpolated) data provided by the Southampton Oceanography Centre. These data were quality-checked

and calibrated.

2 TOPEX wave heights

TOPEX Track 120 (see Figure 1) gives data for estimating the wave climate in open waters off Holderness, but changes in wave climate towards the coast and up to N3 can only come from Tracks 61 and 239, particularly the latter. So we start by investigating mean conditions along these 3 tracks. Immediately a problem arises because of the lack of near-shore data from Tracks 61 and 239. Removing all values in the GAPS data set flagged as unsatisfactory, and calculating means etc, gives results shown in Figures 2 and 3. These figures also show the results after removing 'outliers' outside 2 standard deviations about regression lines fitted against longitude for each pass. The pass along Track 239 on 2 October 1992 had 3 out of 16 values removed by these procedures, but there were still 3 remaining H_s values above 8 m with wind speed around 3 m/s, so the entire pass was removed.

		ALL DATA				Outliers Lost				Nb lost
lat.	long.	N	mean	s.d.	100-yr	N	mean	s.d.	100-yr	
53.09	0.81	16	1.78	1.28	13.81	5	1.09	1.52	15.34	11
53.13	0.86	52	1.13	0.65	7.25	36	1.09	0.73	7.91	16
53.17	0.92	83	1.23	0.78	8.51	64	1.07	0.74	8.02	19
53.21	0.98	106	1.20	0.73	8.00	85	1.10	0.71	7.76	21
53.25	1.03	122	1.17	0.85	9.13	110	1.09	0.70	7.67	12
53.29	1.09	164	1.40	1.02	10.96	125	1.09	0.71	7.69	39
53.33	1.14	188	1.27	0.80	8.80	170	1.21	0.75	8.19	18
53.37	1.20	193	1.23	0.76	8.38	191	1.22	0.76	8.32	2
53.41	1.26	198	1.26	0.77	8.42	197	1.26	0.76	8.42	1
53.45	1.31	205	1.27	0.79	8.63	203	1.28	0.79	8.63	2
53.49	1.37	207	1.32	0.82	8.97	200	1.31	0.82	8.98	7
53.52	1.43	201	1.35	0.83	9.14	200	1.35	0.83	9.15	1
53.56	1.48	201	1.37	0.83	9.11	198	1.36	0.83	9.13	3
53.60	1.54	200	1.40	0.89	9.73	197	1.38	0.83	9.11	3
53.64	1.60	198	1.40	0.79	8.83	195	1.41	0.80	8.85	3
53.68	1.65	200	1.44	0.84	9.28	197	1.43	0.84	9.25	3
53.72	1.71	206	1.45	0.90	9.90	204	1.45	0.90	9.90	2
53.76	1.77	206	1.45	0.91	9.99	204	1.45	0.91	10.00	2
53.80	1.83	205	1.48	0.92	10.12	203	1.48	0.93	10.15	2
53.84	1.88	208	1.46	0.92	10.07	208	1.46	0.92	10.07	0
53.87	1.94	207	1.47	0.93	10.17	206	1.47	0.93	10.19	1
53.91	2.00	206	1.48	0.94	10.28	202	1.44	0.87	9.55	4

Figure 2: Results from analysis of GAPS data along TOPEX Track 61.

The tabulated 100-year return values were calculated using the method of moments, from the mean and standard deviations, and assuming an interval of 3 hour.

The first location with any data along Track 239, as the altimeter comes off the land around 0.3°W, is at a longitude of 0.09°W, and not until 0.15°E is there a good data return. Track 061 is similar: no data until longitude 0.81°E and not consistently good until 1.20°E. For both tracks, the distance from the coast to consistently good data is about 50 km.

		ALL DATA				Outliers Lost				Nb lost
lat.	long.	N	mean	s.d.	100-yr	N	mean	s.d.	100-yr	
54.40	-0.09	160	1.63	1.02	11.14	113	1.59	0.96	10.54	47
54.44	-0.03	180	1.65	1.14	12.28	163	1.55	0.96	10.50	17
54.48	0.03	189	1.58	0.98	10.71	179	1.56	0.97	10.63	10
54.52	0.09	196	1.55	0.96	10.50	192	1.56	0.96	10.54	4
54.55	0.15	201	1.60	1.20	12.80	194	1.52	0.97	10.61	7
54.59	0.20	205	1.59	1.05	11.41	199	1.54	0.97	10.63	6
54.63	0.26	205	1.57	0.96	10.59	197	1.56	0.96	10.57	8
54.67	0.33	208	1.65	1.18	12.65	198	1.59	0.98	10.78	10
54.71	0.39	206	1.70	1.30	13.85	203	1.62	0.99	10.93	3
54.74	0.45	205	1.65	1.03	11.27	196	1.65	1.01	11.10	9
54.78	0.51	208	1.66	1.02	11.18	201	1.66	1.02	11.24	7
54.82	0.57	205	1.68	1.03	11.33	198	1.68	1.03	11.34	7
54.86	0.63	204	1.71	1.04	11.48	202	1.71	1.05	11.49	2
54.90	0.69	206	1.70	0.97	10.74	205	1.70	0.97	10.75	1
54.93	0.75	206	1.71	0.97	10.82	203	1.71	0.97	10.84	3
54.97	0.81	202	1.74	1.05	11.54	197	1.75	1.05	11.56	5

Figure 3: Results from analysis of GAPS data along TOPEX Track 239.

Figure 4 shows similar results along Track 120. The means and standard deviations - and consequently the 100-year return values appear to be lower along this track than along those coming off the land - more outliers are removed from Track 120 but this has little effect upon the standard deviation.

The highest H_s values recorded by TOPEX were 7.4 m on Track 239 on 16 September 1994, with wind speed of 15 m/s; 6.5–6.9 m along Track 61 on 21 February 1993 (with wind speeds of about 15 m/s); and 6.3 m on Track 120 on 19 February 1996, with wind speed of 16 m/s.

3 Omni-directional results

Comparisons of TOPEX data from each of these cross-overs with values from N3, obtained within 15 minutes of the TOPEX measurements are shown in Figure 5, in which the red line is the principal component fit and the magenta, dot-dashed, line is that through the origin and the centre of gravity.

The number of data values and correlation coefficients are:

Tracks	N	ρ
061/120	27	0.72
120/239	25	0.78

Table 1: Number (N) and correlation coefficient (ρ) from comparisons between buoy N3 H_s and TOPEX H_s.

Figure 6 shows a comparison of the combined data sets, with a correlation coefficient of 0.74.

		ALL DATA				Outliers Lost				Nb lost
lat.	long.	N	mean	s.d.	100-yr	N	mean	s.d.	100-yr	
54.43	0.05	205	1.40	0.80	8.85	188	1.39	0.80	8.84	17
54.40	0.11	205	1.39	0.80	8.91	200	1.38	0.81	8.93	5
54.36	0.16	206	1.38	0.80	8.83	202	1.38	0.80	8.90	4
54.32	0.22	211	1.41	0.80	8.93	205	1.41	0.81	9.00	6
54.28	0.28	212	1.41	0.79	8.79	209	1.41	0.79	8.83	3
54.24	0.34	206	1.40	0.76	8.53	198	1.40	0.77	8.60	8
54.20	0.40	205	1.39	0.77	8.64	198	1.41	0.78	8.67	7
54.17	0.46	207	1.36	0.77	8.56	204	1.36	0.76	8.44	3
54.13	0.52	206	1.36	0.78	8.66	202	1.37	0.78	8.64	4
54.09	0.58	208	1.38	0.77	8.63	201	1.38	0.78	8.65	7
54.05	0.63	206	1.37	0.76	8.52	202	1.39	0.76	8.52	4
54.01	0.69	208	1.38	0.78	8.69	202	1.38	0.78	8.70	6
53.97	0.75	209	1.37	0.79	8.78	206	1.37	0.79	8.79	3
53.93	0.81	207	1.37	0.80	8.82	203	1.37	0.80	8.86	4
53.90	0.87	208	1.38	0.80	8.87	205	1.38	0.80	8.90	3
53.86	0.92	201	1.40	0.79	8.77	198	1.40	0.79	8.82	3
53.82	0.98	202	1.38	0.76	8.54	196	1.38	0.77	8.57	6
53.78	1.04	200	1.37	0.77	8.56	195	1.38	0.77	8.61	5
53.74	1.10	203	1.36	0.76	8.51	198	1.37	0.77	8.56	5
53.70	1.15	203	1.36	0.75	8.34	198	1.37	0.75	8.37	5
53.66	1.21	200	1.34	0.72	8.12	196	1.35	0.72	8.13	4
53.62	1.27	196	1.37	0.71	8.06	190	1.37	0.72	8.10	6
53.59	1.33	199	1.37	0.71	8.05	188	1.38	0.73	8.18	11
53.55	1.38	201	1.34	0.70	7.91	198	1.34	0.69	7.84	3
53.51	1.44	202	1.32	0.69	7.79	193	1.33	0.69	7.80	9
53.47	1.50	199	1.30	0.68	7.67	185	1.31	0.70	7.83	14
53.43	1.55	200	1.31	0.70	7.81	185	1.32	0.71	7.98	15
53.39	1.61	204	1.31	0.72	8.07	195	1.32	0.73	8.11	9
53.35	1.66	203	1.31	0.70	7.82	200	1.30	0.70	7.86	3
53.31	1.72	210	1.30	0.71	7.97	207	1.30	0.72	8.01	3
53.27	1.78	208	1.32	0.77	8.54	198	1.31	0.74	8.20	10
53.23	1.83	209	1.31	0.75	8.38	194	1.30	0.74	8.26	15
53.19	1.89	200	1.30	0.72	8.01	190	1.26	0.69	7.73	10
53.15	1.94	205	1.27	0.69	7.70	193	1.26	0.69	7.76	12
53.12	2.00	199	1.28	0.68	7.62	188	1.27	0.68	7.67	11
53.08	2.06	198	1.25	0.64	7.24	180	1.26	0.60	6.87	18
53.04	2.11	198	1.24	0.66	7.44	191	1.22	0.62	6.99	7
53.00	2.17	198	1.25	0.68	7.64	187	1.27	0.69	7.74	11
52.96	2.22	201	1.24	0.71	7.84	196	1.26	0.71	7.87	5
52.92	2.28	201	1.27	0.71	7.95	197	1.27	0.71	7.96	4
52.88	2.33	205	1.27	0.72	8.00	199	1.27	0.72	8.03	6
52.84	2.39	201	1.29	0.73	8.16	185	1.30	0.74	8.24	16
52.80	2.44	204	1.29	0.74	8.26	187	1.26	0.74	8.18	17
52.76	2.50	203	1.31	0.73	8.15	180	1.27	0.72	8.04	23

Figure 4: Results from analysis of GAPS data along TOPEX Track 120.

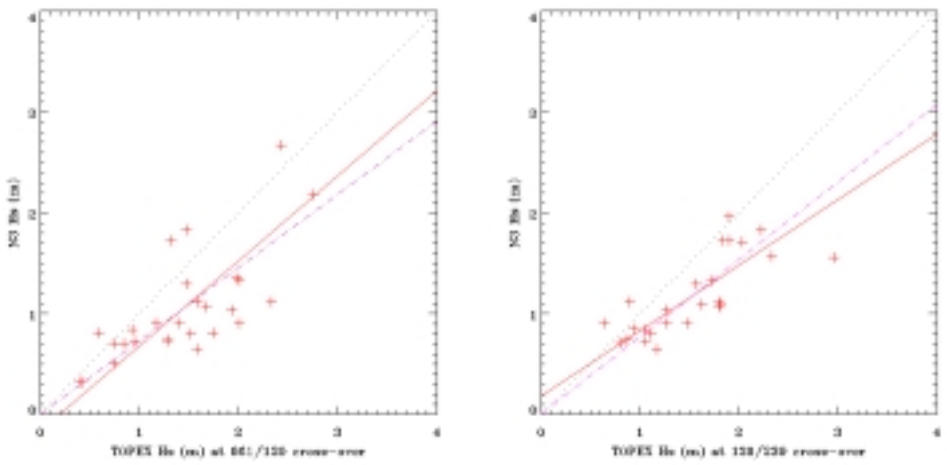

Figure 5: Comparison of N3 H_s values with those from TOPEX at cross-overs.

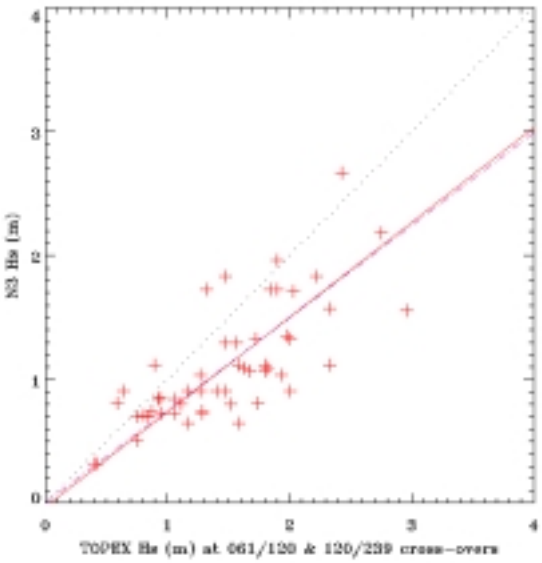

Figure 6: Comparison of N3 H_s values with those from TOPEX at cross-overs.

These cross-over positions are not the nearest TOPEX data to N3. This is around 54.05°N 0.63°E. But the correlation between the cross-over points and that location is high, as seen in Figure 7, which show regressions of H_s from 211 passes along Track 120 of TOPEX. The correlation between the nearest point to N3 and the 120/239 cross-over is 0.94; that between the nearest point to N3 and the, more distant, 061/120 cross-over is 0.91. (Removing the annual cycle reduces these values to 0.93 and 0.90.). The mean H_s values at the cross-overs are not significantly different from the mean at 54.05°N 0.63°E.

These results suggest that a reasonable 'rule of thumb' is that H_s at N3 is 0.75 of that at the TOPEX track further offshore. However, the lack of any high H_s values from these comparisons suggests that this result might not apply to high waves. Very high waves must be propagating towards the shore, and in these circumstances little change in height from the TOPEX track to N3 is to be expected.

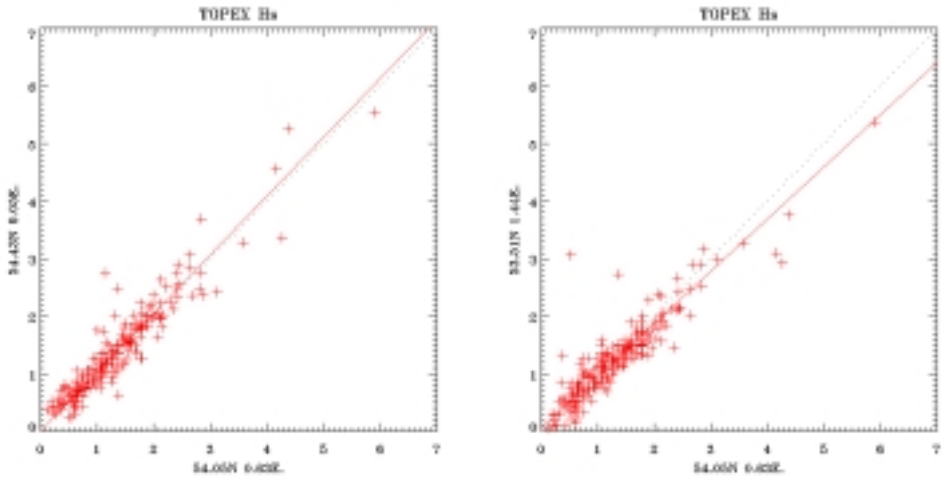

Figure 7: TOPEX H_s values:comparison of values nearest to N3 with those from cross-overs.

The highest H_s recorded at N3 was around 5 m on 1/2 January 1995 (when there was no TOPEX pass). The highest recorded TOPEX data along this portion of Track 120 during 1992-1997 was 6 m on 19 February 1996, when there was no data from N3 (nor from N2).

4 Analysis by Direction

The wave direction data from N3 enables us to investigate the relationship between H_s at N3 and from TOPEX as a function of direction. Taking the same data as in Figure 6 - but removing 'outliers' from the TOPEX transects, and plotting values colour coded for direction, gives Figure 8. (This has 49 values from both directions, 3 less than Figure 6.) The green line is the principal component fit to data with wave direction from 160°-340°; the magenta line that with direction from 340°-160°. The equations are

340° – 160°: $\quad H_s(N_3) = 1.083\, H_s(TOPEX) - 0.393$

(not significantly different from the 45° line), and

160° – 340°: $\quad H_s(N_3) = 0.386\, H_s(TOPEX) + 0.392$

This result, albeit from < 50 data pairs, supports the obvious hypothesis that waves from N-E have the same H_s at N3 as along the TOPEX Track 120; waves from other directions are generally lower H_s at N3, with the shorter fetch, than along the TOPEX track. However, in very light offshore winds the wave height at N3 and along the TOPEX tracks would be equal (except for any differences in swell) so the fitted line would not apply to very low H_s. The wind sea can be modelled using for example the results from JONSWAP given by Carter (1982). Assuming N3 has a fetch for winds from 160° to 340° of 15 km and the TOPEX data a fetch of 60 km, then the JONSWAP results give the same H_s at N3 and for TOPEX until a value of 0.16 m is reached, while above 0.32 m at N3 with 0.64 m at TOPEX, the N3 value is 0.50 that at TOPEX (with a curve; $H_sN3 = 0.40\sqrt{H_sTOPEX}$ in between). Figure 9 shows the combined data sets from Figure 8 with this theoretical line added.

If the interest is only in high waves, such as the 100-year return value, then this suggests that the distribution of H_s at N3 could be taken as that from TOPEX Track 120 - but what is 'high'? The highest measured TOPEX H_s, of 3 m, was with an offshore wave direction at N3, so 'high' is clearly > 3 m. In general it would seem more satisfactory to use estimates of wind direction

from West Sole or Leman as an indicator of which regression to use to get from the TOPEX H_s to that at N3. Unfortunately data available from West Sole only extend to 1988. Leman at 53.1°N 2.2°E is rather far south of Holderness; it should give a reasonable indication whether the wind is 'offshore' or 'onshore' although further investigation is needed - but it would at least provide a useful check of the percentage of occurences of the two wind directions.

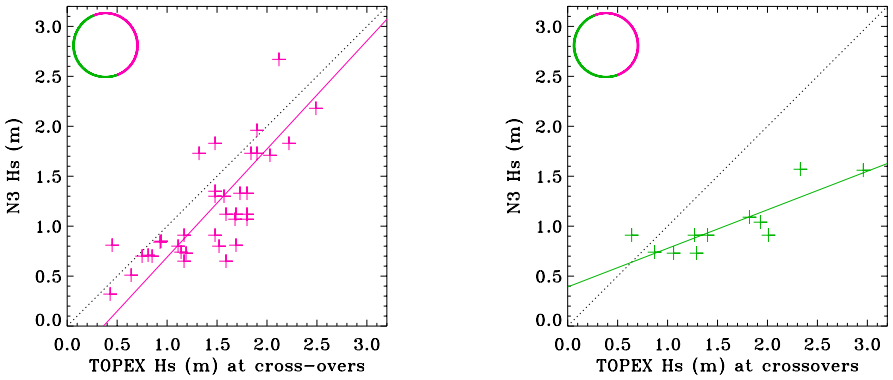

Figure 8: Comparison of values nearest in time at N3 and TOPEX cross-over locations by direction at N3.

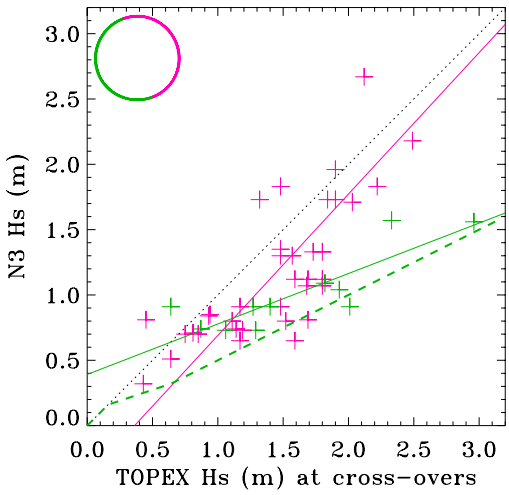

Figure 9: Comparison of values nearest in time at N3 and TOPEX cross-over locations by direction at N3. The dashed line is the theoretical line for offshore winds from the JONSWAP results.

5 Conclusion

The TOPEX data (along Track 120) provide an estimate of the wave climate well offshore of Holderness during the period 1992-97 (and now available to 1998). However, estimating the climate at the buoy N3 (in deep water) is difficult because the only TOPEX tracks any where near are such that the satellite is travelling off the land, and analysis of the data along these two tracks (61 and 239) reveal that the altimeter does not provide reliable estimates of H_s until the nadir is about 50 km from the coast.

Comparisons from the altimeter data and N3 indicate that the relationship depends upon the wind direction; with onshore winds, H_s at N3 and along TOPEX Track 120 are about the same, but with offshore winds H_s at N3 are about half those at Track 120. These results are roughly consistent with fetch limited sea states.

Extreme wave heights at N3 are to be expected with onshore winds, suggesting that for these extremes the estimate at Track 120 should be used - from Figure 4 a value for the 100-year return value of about $8 - 9$ m.

It is expected that the general wave climate at N3 can be determined from the TOPEX data together with the wind directions recorded at Leman, but this needs to be confirmed.

References

[1] 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.