Lyme Bay near-shore wave modelling: specification of boundary conditions

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INTRODUCTION The purpose of this note is to examine the boundary condition requirements for running a nearshore wave transformation model for Lyme Bay, with specific application to the SWAN model, but also with relevance to the STORMS model. The data sets available for model validation have been examined and seven events have been identified for which offshore (TOPEX altimeter) and inshore (bottom pressure) wave observations are available, where the wave heights exceeded 3m at least at the offshore locations.

1. Waves were recorded by the pressure recorder at West Bexington (WB), in about 10m water, from December 1987 to May 1995 (with gaps) (ref. Carter?). Maximum waves recorded during this time were at 09:56 8$^{th}$ December 1994, with significant wave height, Hs=5.13m and mean period, Tz=7.99s. A comparison of the WB data with TOPEX tracks 061 and 146 (September 1992 - August 1998) and Channel Light Vessel (UKMO data, referred to hereafter as CLV, January 1992 - May 1997) for the whole of December 1994 is shown in Figure 1. Wind speed and direction at CLV at 0900 8$^{th}$ December was 43 knots (22m/s) from 210°. Hs = 6.5m. N.B. CLV periods appear to be nonsense. West Bexington periods (Tz) appear in quite good agreement with TOPEX values.

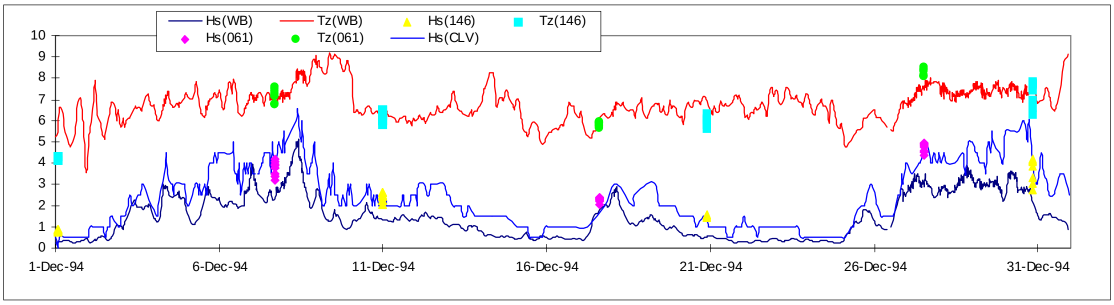


Figure 1: TOPEX (tracks 061 and 146), Channel Light Vessel and West Bexington data for December 1994

2. For TOPEX track 061 there is a reduction of wave height along-track, as the satellite approaches the coast (ref. Carter). This track closes the coast at the eastern-most end of the SWAN model grid and ends just offshore of the southern boundary of the model. The 9 highest wave cases are plotted in Figure 2, where the along-track point number increases towards the shore.

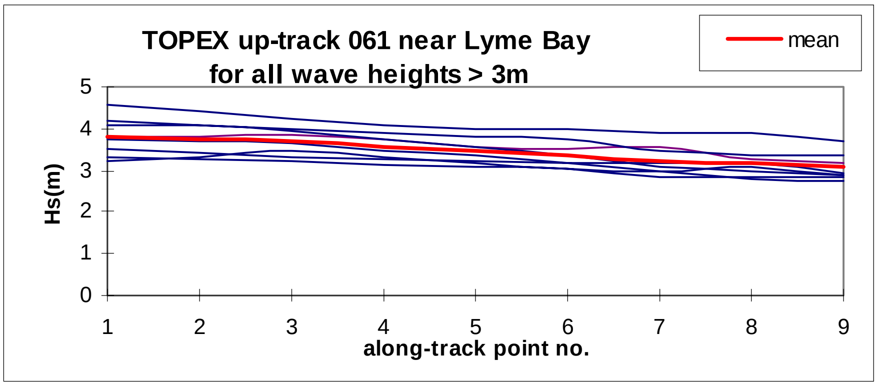


Figure 2: TOPEX wave data

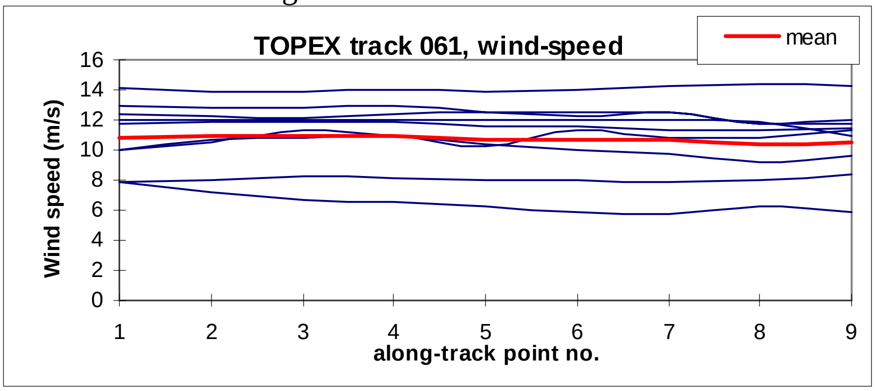


Figure 3: TOPEX wind data

These significant wave heights are reduced by a ratio of 0.81 on average. The associated wind speeds do not show such a consistent trend. Possible explanations include shoaling, fetch-limited growth and sheltering or a combination.

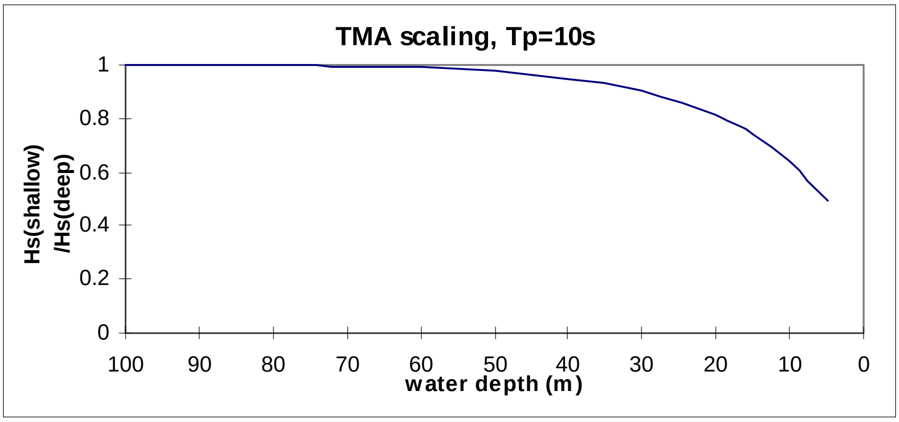


Figure 4: TMA scaling of wave height in 'shallow' water

(i) TMA scaling (see figure 4): Water depths are too deep along the TOPEX track for TMA scaling to make much difference i.e. Hs reduction cannot be purely shoaling, although Tucker (1994a) finds that the TMA spectrum is a good fit to the growth phase of waves in this vicinity. The depths are estimated to shoal from 70m to about 40m along the track plotted in figure 2. The predicted reduction in wave height would be 0.95 for these water depths - much less than observed.

(ii) Fetch-limited growth in shallow water is a possible explanation (e.g. Hurdle and Stive, 1989, see Table 1). To test also whether a wind-sea or combined sea/swell situation was likely, the parametric fetch-limited growth law was applied to the wind-speed and estimated fetch at the outer end of the TOPEX track (estimated depth 70m). The wind speed estimated from the TOPEX altimeter gives a better prediction of the local Hs than the CLV wind. Hurdle and Stive (1989) performs better than Shore Protection Manual (1984). Using a fetch of 200km seems to optimise agreement. No direct observation of wind direction is possible from the TOPEX data. Again the ratio of 0.96 is obtained for the difference in depth from 70m to 40m, assuming the fetch remains the same, whereas the observed average reduction for all 15 cases was 0.83. The assumption of constant fetch is probably unjustified. Most wind directions have limited fetch in the English Channel. Note that fetch from directions ~ 215-230°T would be almost unlimited, from the North Atlantic, whereas other directions have quite short fetch. In Lyme Bay directions 090-300°T are off the land. Possibly there is some sheltering if winds are from SE or E due to Portland Bill, so that the fetch may be reduced substantially nearer the coast.

| Date | Ws (TP10) | Hurdle & Stive (1989) h=70m Hs | Hurdle & Stive (1989) h=70m Tz =0.777Tp | Observed data (TOPEX) Hs (TP10) | Observed data (TOPEX) Tz (TP10) | Hs % error | Tz % error |
|---|---|---|---|---|---|---|---|
| 25 Oct 92 | 14.19 | 4.75 | 7.61 | 4.57 | 7.66 | 3.96% | -0.69% |
| 3 Dec 92 | 9.98 | 3.02 | 6.42 | 3.76 | 7.55 | -19.55% | -14.96% |
| 12 Jan 93 | 11.99 | 3.85 | 7.04 | 3.45 | 6.84 | 11.52% | 2.91% |
| 11 Apr 93 | 7.14 | 1.80 | 5.20 | 3.23 | 7.46 | -44.13% | -30.30% |
| 15 Dec 93 | 12.91 | 4.22 | 7.29 | 4.11 | 7.42 | 2.78% | -1.79% |
| 4 Jan 94 | 7.83 | 2.11 | 5.56 | 3.52 | 7.7 | -39.95% | -27.85% |
| 3 Feb 94 | 9.94 | 3.01 | 6.41 | 3.22 | 6.9 | -6.58% | -7.15% |
| 23 Feb 94 | 6.41 | 1.47 | 4.76 | 3.28 | 7.71 | -55.21% | -38.23% |
| 7 Dec 94 | 12.34 | 3.99 | 7.14 | 4.17 | 7.59 | -4.30% | -5.99% |
| 27 Dec 94 | 12.02 | 3.86 | 7.05 | 4.86 | 8.42 | -20.58% | -16.30% |
| 16 Jan 95 | 11.17 | 3.51 | 6.80 | 2.94 | 6.38 | 19.47% | 6.60% |
| 26 Jan 95 | 7.83 | 2.11 | 5.56 | 3.32 | 7.42 | -36.33% | -25.13% |
| 8 Jan 96 | 11.76 | 3.75 | 6.97 | 3.78 | 7.26 | -0.70% | -3.94% |
| 31 Oct 96 | 9.98 | 3.02 | 6.42 | 3.16 | 6.83 | -4.28% | -6.00% |
| 17 Feb 97 | 12.59 | 4.09 | 7.20 | 4.11 | 7.48 | -0.41% | -3.71% |
| Mean error | | | | | | -12.95% | -11.50% |

Table 1: Fetch-limited growth laws applied to TOPEX 061 data, where Hs>3m, assuming fetch = 200km

From Table 1, it may be seen that many events are quite well-predicted by the fetch-limited growth model, whereas others substantially underestimate wave height and period. These may be due to underestimating the wind-speed or fetch or the presence of a large swell component. Examination of the wind direction at CLV does not show any correlation between goodness of fit and long or short fetch conditions. However the time history of the wind was not examined.

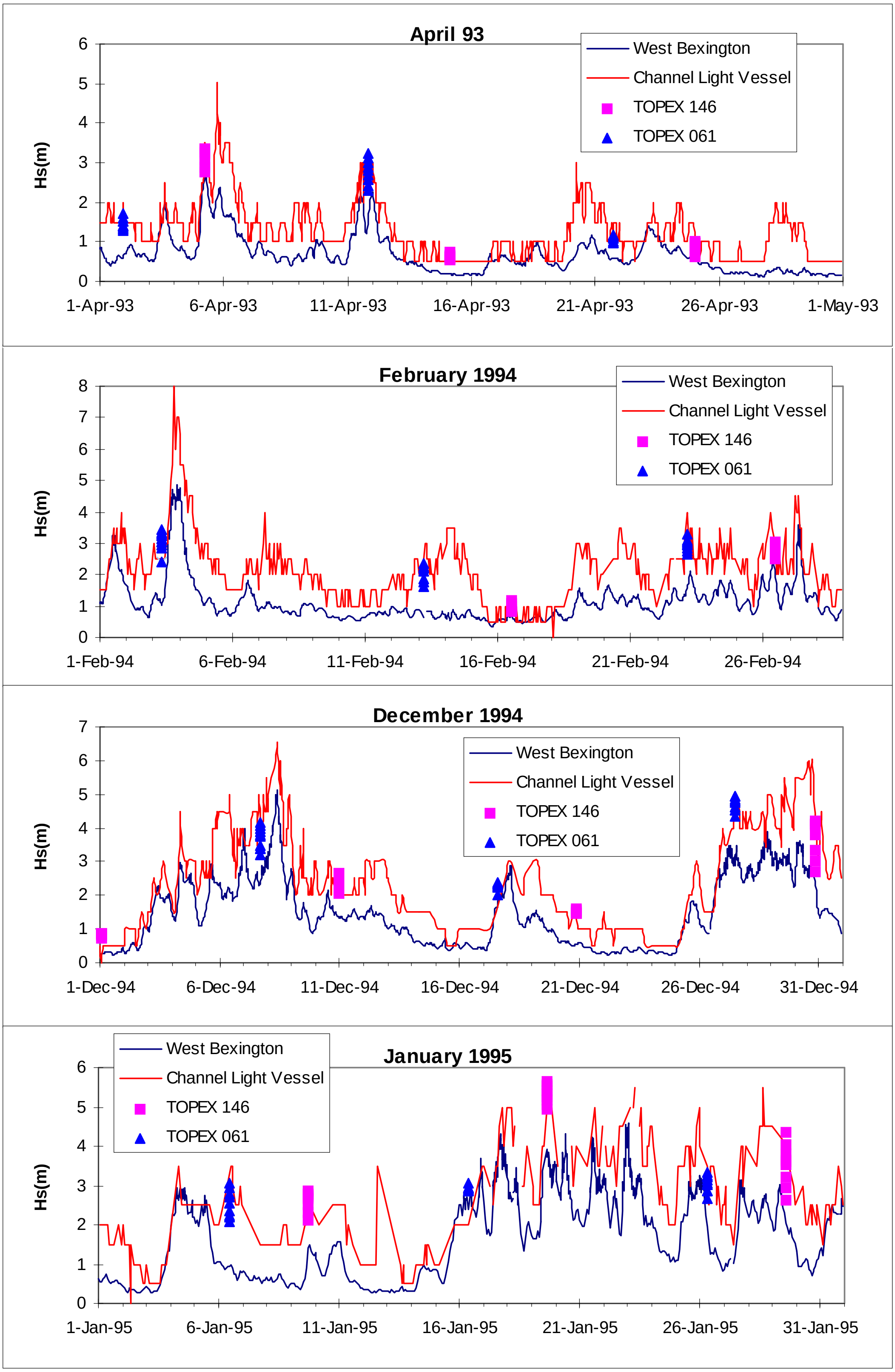


Figure 6: Comparison of significant wave height from TOPEX, CLV and West Bexington

To conclude, the observed reduction in wave height along the TOPEX track cannot be explained by the TMA (self-similarity) scaling alone, since the water is still quite deep (~40m) at nearest approach to coast. Therefore it seems more likely that the reduction is caused by a combination of shallow water fetch-limited wave growth and some sheltering, reducing the effective fetch as the coast is approached, i.e. by active wind effects rather than purely shoaling.

3. Comparison of TOPEX, CLV and WB waves for all TOPEX 061 data > 3m (15 occurrences). At 7 of these times there were also data at West Bexington. The dates are 11 April 1993, 3 and 23 February 1994, 7 and 27 December 1994 and 16 and 26 January 1995. The data for the months identified with these high wave events are plotted in Figure 6.

There is an overall agreement between the wave heights observed by TOPEX and CLV, with the track 061 data being lower than track 146 and generally less than the CLV data. The West Bexington wave heights are substantially lower than the TOPEX and CLV wave heights.

4. SWAN runs for coincident West Bexington and TOPEX data

There were 7 incidences of waves, with Hs>3m, recorded on the TOPEX 061 line and with simultaneous data at West Bexington. These events were simulated with the Lyme Bay SWAN model.

| | **Observed data (WB)** | | **Topex** | **CLV** | **Model** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Date** | **Hs (m)** | **Tz (s)** | **Ws (m/s)** | **Dp (°)** | **Tp (s)** | **Hs (m)** | **Tz (s)** | **Tp (s)** | **Hs (m)** | **Tz (s)** |
| **11 April 1993** | 1.45 | 7.11 | 5 | 190 | 8 | 1.98 | 5.2 | 10 | 2.11 | 6.14 |
| **3 February 1994** | 1.05 | 6.4 | 10 | 180 | 8 | 2.09 | 4.8 | 10 | 2.30 | 5.13 |
| **23 February 1994** | 1.63 | 8.33 | 6 | 150 | 8 | 1.64 | 4.7 | 10 | 1.70 | 5.40 |
| **7 December 1994** | 2.35 | 6.97 | 11 | 230 | 8 | 2.7 | 5.2 | 10 | 2.87 | 5.74 |
| **27 December 1994** | 3.04 | 7.58 | 11 | 230 | 10 | 3.5 | 6.7 | 12 | 3.67 | 7.51 |
| **16 January 1995** | 2.4 | 6.56 | 10 | 170 | 8 | 2.32 | 4.9 | 10 | 2.38 | 5.39 |
| **26 January 1995** | 2.23 | 7.37 | 8 | 300 | 8 | 1.22 | 3.8 | 10 | 1.22 | 4.01 |

Table 2: Results from SWAN runs

The model needs at least the following information: wind speed and direction, boundary wave height, peak period and direction. The TOPEX altimeter can supply wave height, an estimate of mean period and wind speed. The wind and wave direction are the most difficult parameters, the nearest measurements are at Channel Light

Vessel, some distance away. Tidal levels were estimated from Portsmouth so that this should not be a major factor in any errors in the model results. With only a wave height and period, the form of the input spectrum has to be estimated. Usually a JONSWAP spectrum is used, but this will not account for shoaling and combined sea/swell conditions. Tp=Tz/0.777 was chosen, (approximately constant for JONSWAP and OK for TMA in 30m water depth). Dp=Wd was also selected i.e. peak wave direction = wind direction at CLV (this is not very likely).

Most of the runs overestimate Hs, the exception being the 26 January 1995 which is substantially underestimated. Generally there is not enough dissipation between the open boundary and WB. This is despite changing from the default SWAN bottom friction option to the Madsen option (as optimised for Holderness). SWAN usually predicts much smaller Tz values than observed at West Bexington. The West Bexington periods, derived from a pressure gauge, may tend to be overestimated. In all but 2 of the 7 cases Tz(WB) > Tz at the open boundary, which is contrary to expectation for shoaling waves. Input wave direction is very important and difficult to determine. It is unlikely to be the same as wind direction at CLV. Specification of the input peak period is problematic. Increasing the peak period (see Table 1) does increase Tz at WB but also increases Hs which is already too large.

Changing the input wave direction (which is an unknown quantity), for the 2 events with largest discrepancies in wave height, can improve the agreement (see Table 2), but in the first instance this also reduces the wave period substantially, because effectively no waves are propagating into the model and the locally generated waves are very short, so this seems unrealistic. The last event is improved by allowing waves to enter the model whereas the wind direction is from the land.

| | **Observed data (WB)** | | **Topex** | **CLV** | **Model** | | |
|---|---|---|---|---|---|---|---|
| **Date** | **Hs (m)** | **Tz (s)** | **Ws (m/s)** | **Wd (°)** | **Dp (s)** | **Hs (m)** | **Tz (s)** |
| **3 February 1994** | 1.05 | 6.4 | 10 | 180 | 90 | 0.95 | 2.5 |
| **26 January 1995** | 2.23 | 7.37 | 8 | 300 | 240 | 2.09 | 5.1 |

Table 3: Runs with modified input wave direction

Note that the events of 11 April 1993, 23 February 1994, 27 December 1994 and 26 January 1995 were identified in section 2 as possibly being swell-dominated. This may explain the longer periods observed and the contribution of incoming waves in the last event.

5. SWAN results: longshore gradient of Hs

Several runs of the SWAN model were carried out to examine the longshore variation of Hs. Output from a line parallel to the open boundary, 5km inside the boundary, have been plotted. A range of wind-speeds, wind direction and corresponding input wave heights and directions were used.

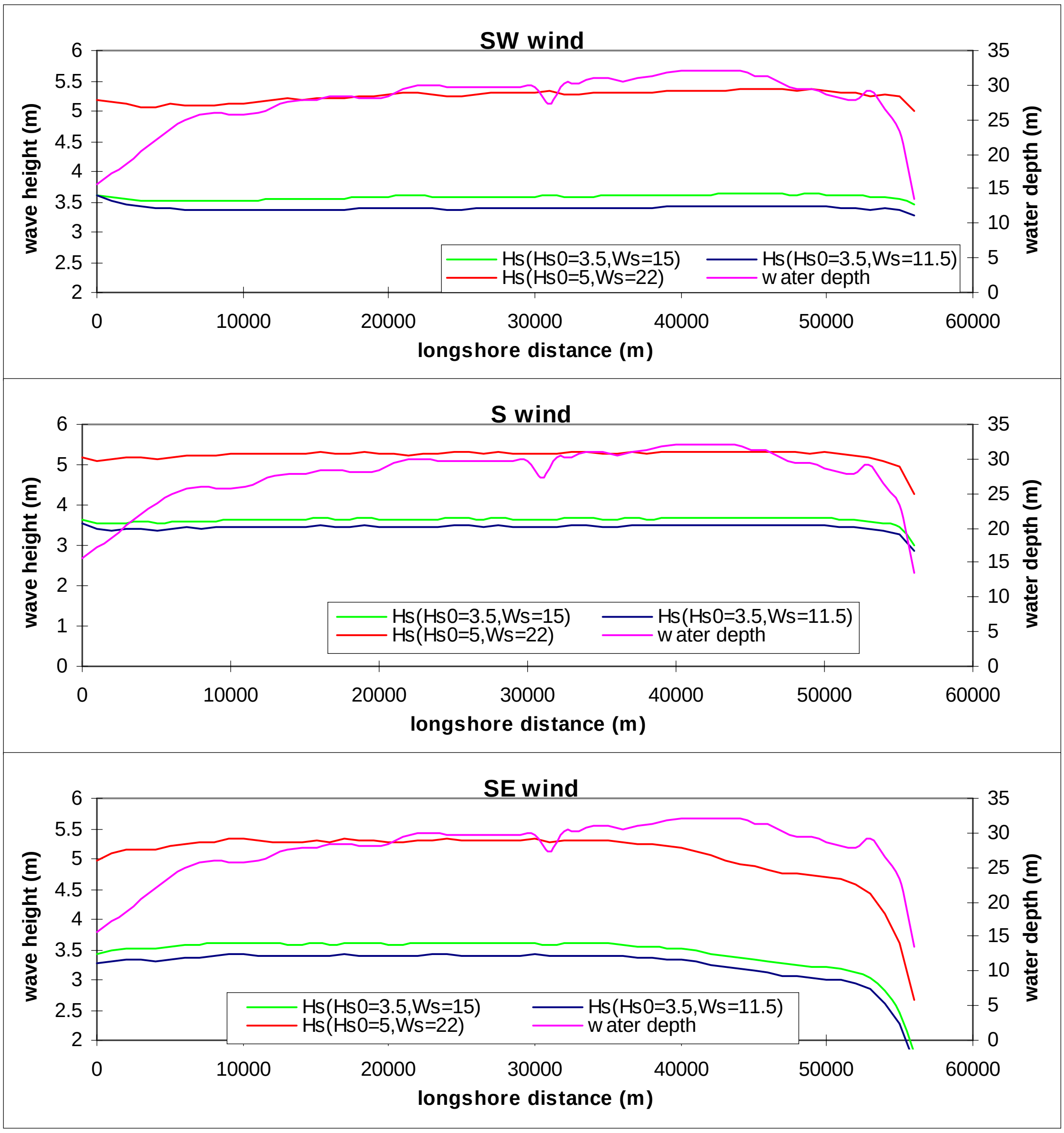


Figure 5: Longshore variation of wave height for different approach directions in Lyme Bay SWAN model

These results confirm the sheltering effect for wave directions from south and south-east. The wave height can be substantially reduced at the eastern end of the open boundary if the wind has an easterly component. On the other hand it is probably not necessary the adjust the boundary values themselves since the model adjusts the wave heights rapidly within 5km of the boundary.

<u>Conclusions</u> The only way to define the required input parameters more accurately is to nest the near-shore models in a coarser grid model of a much larger area e.g. the UKMO operational wave model. This would provide incoming wave direction and swell components which are difficult to identify in the TOPEX data. The optimal way to use the TOPEX data would then be in a data assimilation scheme which corrected the boundary conditions in a physically consistent way. Lyme Bay is likely to be the most difficult type of area to model since there are many land masses surrounding it in the English Channel which make it prone to local effects of fetch-limited growth, mixed sea and swell and sheltering.

For the JERICHO project the recommendation is to use the values from the inner end of TOPEX track 061 for the boundary significant wave height, with the associated Tz (converted to Tp for SWAN) and wind speed. The difference between Hs for TMA or JONSWAP spectrum at the outer boundary (30m water depth) is less than 5% so little would be gained by using a TMA spectrum. The ratio of Tz/Tp=0.777 is a reasonable approximation. Wind direction may possibly be equated with that at Channel Light Vessel but the most difficult parameter to specify is the incoming wave direction, particularly if there is a combined sea and swell. If the wave condition is wind-dominated, as is likely for extreme storm-generated waves the wind direction may be reasonable. The largest waves are likely to come from the SW (215-240°T) since this is the direction of unlimited fetch. However we should remember the event of February 1979 when extreme swell waves devastated Chesil Beach in locally calm weather (Draper and Bownass, 1983).

References

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