Appendix D

Wave

Appendix D. Wave

D1. Calculation of Wave Power

The quantification of the power transmitted by a wave moving across the sea surface was calculated using methodology similar in format to that described in Tucker and Pitt (2001) and used in the Seapower South West study. Assuming a sinusoidal wave form and applying Pointing's theorem, wave power (P_w, per metre unit along the wave crest) is described by:

$$P_w = 0.125 \rho g H^2 c_g \tag{1}$$

where :

ρ = water density (kg/m^3);
g = acceleration due to gravity (m/s^2);
H = wave height for a monochromatic wave train (m);
c_g = wave group speed (m/s), the speed at which wave energy will propagate).

In order to calculate the wave power from the available model integrated parameters, further calculations are required to derive H and c_g. As H_s describes the height of the highest one-third of waves in a given sea-state, a more appropriate statistic is required to describe H for all waves. This statistic is the root mean square wave height (H_{rms}).

The three statistics can be related (following Abramowitz and Stegun, 1965) as follows:

$$H = H_{rms} = \frac{H_s}{1.416} \tag{2}$$

therefore, power is redefined as:

$$P_w = 0.0623 \rho g H_s^2 c_g \tag{3}$$

with c_g is defined as:

$$c_g = 0.5c\left(1 + \frac{2kh}{\sinh 2kh}\right) \tag{4}$$

where :

h = water depth (m);
k = wavenumber;
c = wave phase velocity $c = \frac{\sigma}{k}$ (5)

In Equation ( ) $\sigma = 2\pi / T$ for T the wave period (in seconds). Wave group speed can therefore be described as a function of water depth and wave period, but will require an iterative process for the relationship to be solved quantitatively. Within the calculations carried out in this project, a process of 20 iterations were used for each data point based on the model depth and an initial starting value for c of:

$$c = \frac{gT}{2\pi} \tag{6}$$

based on a deep water approximation and using an appropriate value of wave period T.

As previously stated (Section 4.2), the archived wave model statistic for wave period is zero-upcrossing period (T_z). This statistic is derived using the spectrum second moment and as a result may be sensitive to high-frequency low energy variations in the wave spectrum. A more generally accepted statistic for wave power calculations is the energy period (T_e) which represents lower frequencies better. This parameter is defined using:

$$T_e = \frac{m_{-1}}{m_0} \tag{7}$$

Whilst T_e is not directly computed by the wave model, an approximation can be made based on T_z. The approximation assumes that a standard JONSWAP spectrum is representative of the average wave conditions over time, in this case the NORSOK (1999) recommended design values for γ, σ_a and σ_b [2](2.0, 0.07 and 0.09 respectively) for the North Atlantic were applied. T_z and T_e were calculated based on the theoretical spectra for peak periods between 3 and 20 seconds and their ratio determined. The ratio was found to vary between 1.0 and 1.17, with the ratio for a T_z value of approximately 8 to 9 seconds equalling 1.14. This last value was chosen as representative of the best (most) power estimate based on annual mean T_z values for all cases, and hence T_e is universally determined across the UKCS using:

$$T_e \approx 1.14 T_z \tag{8}$$

To determine the sensitivity of the rescaled wave period parameters on the derived wave power, both T_z and T_e have been applied to the power calculations. The Atlas database identifies these wave power estimates as ‘Power1’ and ‘Power2’, respectively.

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[2] where γ = peak enhancement of the spectral peak of the wind sea; σ_a and σ_b = the narrowness of the peak

D2. Met Office Numerical Validation

The validation exercise was undertaken in two parts. Firstly the UK Waters Model and observation time-series data were compared. Secondly the UK Waters Model has been compared with a long time series (the European Wave Model) in order to ensure that the results given by the former is broadly representative of long term variations in wave climate. Both these validations are now discussed.

As with the wind data validation (Appendix C4) observation time-series data were selected from sites comprising the Met Office Marine Automatic Weather Station (MAWS) Network (Figure 17) in order to undertake the validation exercise.

These sites provide observations of both marine wind and wave parameters, specifically significant wave height and wave period. Locations were chosen to provide a spread of data around the UKCS and are summarized in Table D2.1.

Table D2.1 Met Office Marine Automatic Weather Station (MAWS) sites used in validation study

Station Name	WMO Number	Station Position		Station Type	Water Depth (Model* m)
		Latitude	Longitude		
K5	64045	59° 04’ N	11° 25’ W	Buoy	> 200.0
RARH	62106	57° 00’ N	09° 54’ W	Buoy	> 200.0
Aberporth	62301	52° 17’ N	04° 30’ W	Buoy	31.0
Turbot Bank	62303	51° 37’ N	05° 09’ W	Buoy	40.0
Seven Stones	62107	50° 04’ N	06° 04’ W	Lightship	73.0
Lyme Bay	62101	50° 37’ N	02° 44’ W	Buoy	33.0
Greenwich	62305	50° 25’ N	00° 00’ E	Lightship	54.0
K17	62026	55° 25’ N	01° 10’ E	Buoy	69.0
K16	62109	57° 00’ N	00° 00’ E	Buoy	84.0

The data distribution plus mean and standard deviation values generated over the annual cycle for significant wave height (H_s), and zero-upcrossing period (T_z) were used. In addition, RMS errors between model and observation data values were determined to provide some assessment of the model predictive performance. The zero-upcrossing period derived wave power statistic ‘Power 1’ was examined in terms of its distribution and mean and standard deviation. The RMS statistic was not derived for Power 1 since this is inherently biased toward errors in the highest wave power estimates and therefore does not compare well between sites.

UK Waters Model & Observations

Annual Statistics

Statistics comparing model data and available observations during the period 1st June 2000 to 31st May 2003 for wind, wave and wave power parameters are discussed below

Wave and Wave Power

For open sea sites (K5, RARH, Seven Stones, K17 and K16) there is a difference of less than 5% between model and observations values of mean H_s (Table D2.2). With the exception of Seven Stones, the lowest values of standard deviation errors (less than 5%) and RMS errors (less than 20% of the mean value) are also found for these sites. Nonetheless, the good performance of mean and standard deviation values at Seven Stones suggest that over the period of investigation these poor predictions balance out.

Table D2.2 Annual wave statistics for validation sites

Station Name	H_s Mean (m)			H_s Std. Dev. (m)			T_z Mean* (s)		H_s RMS Error (m)
	Model	MAWS	$\%^e$	Model	MAWS	$\%^e$	Model	MAWS	
K5	3.17	3.29	-4	1.66	1.64	1	8.22	8.87	0.33
RARH	3.05	3.19	-4	1.65	1.64	1	8.07	8.92	0.56
Aberporth	1.19	1.12	6	0.75	0.74	1	5.80	5.90	0.30
Turbot Bank	1.59	1.80	-12	1.09	1.11	-2	6.65	7.54	0.41
SevenStones	2.38	2.30	3	1.40	1.33	5	n/a	n/a	0.68
Lyme Bay	1.11	0.96	16	0.84	0.69	22	6.18	5.43	0.33
Greenwich	1.38	1.01	37	0.84	0.80	5	n/a	n/a	0.50
K17	1.84	1.79	3	0.96	0.97	-1	6.36	6.59	0.30
K16	2.01	1.99	1	1.07	1.07	0	6.75	6.86	0.36

T_z mean value weighted according to wave energy.

n/a data is not applicable since lightship based readings of period are biased toward low frequencies due to vessel response characteristics.

^{e} Error calculated as a percentage using (Model/MAWS - 1)*100 values. Negative values show an underprediction, positive values an overprediction

Incorrect representation of sheltering effects within the Bristol Channel, English Channel and Cardigan Bay may also be responsible for the poorer performance of the model wave data with respect to observations (in percentage terms) at the Aberporth, Turbot Bank, Lyme Bay and Greenwich stations. At these shallow water sites differences between model and reality may be compounded by wave refraction effects occurring at a bathymetric scale below that in the wave model grid. For Aberporth, Turbot Bank and Lyme Bay the error in mean H_s between model and observations ranges up to 15%, whilst Greenwich is the worst performer with an error in mean H_s of approximately 35%.

Generally the models slightly underpredict mean wave period at the MAWS sites. The exception to this is the Lyme Bay station where both the period and wave height is overpredicted. These statistics suggest that at Lyme Bay the model underestimates the role of friction and refraction in locally reducing wave heights at the wave buoy. These errors in both wave height and period are compounded in the wave power calculations and lead Lyme Bay to perform exceptionally badly in its prediction of P_1 mean and standard deviation. Otherwise, the tendency for the model data to slightly underpredict wave period will reduce model estimates of wave power with respect to those calculated using the observations (Table D2.3). This is the case for the K5, RARH and Turbot Bank sites where both mean and standard deviation P_1 values are underestimated by the model. At K16, K17 and Aberporth mean wave heights are overpredicted and the overall effect is to produce an overestimate of P_1 mean and standard deviation of less than 10% at these sites.

Table D2.3 Annual wave power statistics for validation sites

Station Name	P_1 Mean (kW/m)			P_1 Std. Deviation (kW/m)		
	Model	MAWS	% Error[e]	Model	MAWS	% Error[e]
K5	49.77	57.92	-14	70.52	79.29	-11
RARH	46.85	55.12	-15	69.62	76.65	-9
Aberporth	5.69	5.22	9	8.98	9.47	-5
Turbot Bank	12.24	17.06	-18	21.96	27.79	-11
Seven Stones	n/a	n/a	n/a	n/a	n/a	n/a
Lyme Bay	5.93	3.66	62	11.38	7.82	45
Greenwich	n/a	n/a	n/a	n/a	n/a	n/a
K17	13.31	13.07	2	17.64	18.33	-4
K16	16.92	16.84	0	23.47	23.94	-2

n/a data is not applicable since lightship based readings of period are biased toward low frequencies due to vessel response characteristics.

[e] Error calculated as a percentage using (Model/MAWS - 1)*100 values. Negative values show an underprediction, positive values an overprediction.

Data Distributions

Wave Height and Power

Distributions of modelled and observed significant wave height (H_s) and wave power (P_1) are shown in Figures D2.1 to D2.9. The annual statistics for these sites suggest a difference in model performance between the open sea stations (K5, RARH, Seven Stones, K17 and K16) and those stations closer to the coastline. For all the 'open seas' stations, a very good agreement is observed in the distribution of H_s. This agreement is maintained for wave power at the K17 and K16 wave buoys. K5 and RARH slightly underpredict the frequency of significant wave heights occurring in the range 3 to 5m, and when coupled with a general underestimate of wave period for these buoys in the model, there is a general underestimation of the power occurrence in the range 5 to 60kW/m.

For other sites no clear pattern in the behaviour of modelled versus observed H_s and P_1 distributions can be found. At Aberporth, where the poorest performance of the wind component also occurs (see following section), the frequency of H_s over 2m is overpredicted by the model, whilst the frequency of H_s under 1m is underpredicted. Nevertheless, the agreement in distribution of wave power over the climate period is reasonably good. This is due to differences in the distribution of period between model and observations which balance the spread of power forecasts. At Greenwich, similar differences in the distribution of modelled and observed H_s may be seen. At Turbot Bank, the period is generally underpredicted by the model leading to an underestimation (compared to the observation data) of the frequency of power values less than 20kW/m. This is despite a reasonable agreement between significant wave height distributions. The worst comparison of P_1 is Lyme Bay, where the model overpredicts both H_s frequencies for wave heights greater than 1.5m and wave period values. This leads to a large overprediction of the frequency of P_1 values in the range 2 to 60kW/m.

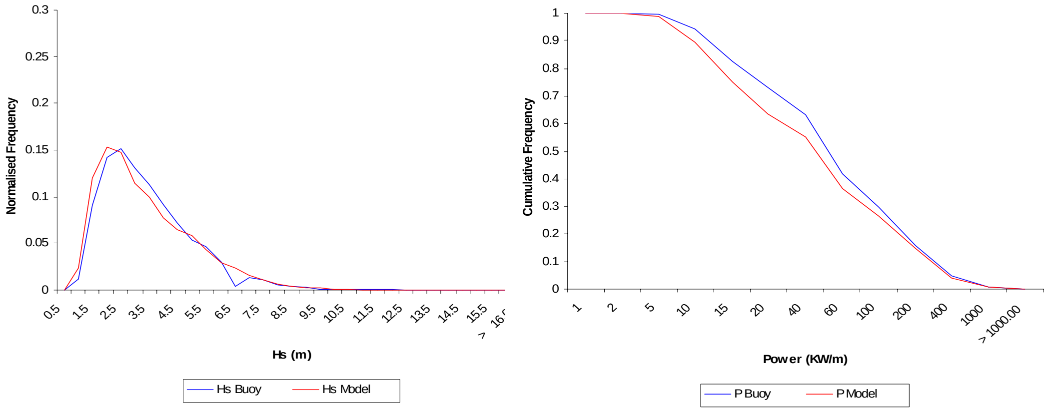

Figure D2.1 Modelled and observed significant wave height (H_s) and wave power (P_1) distributions at the K5 MAWS station

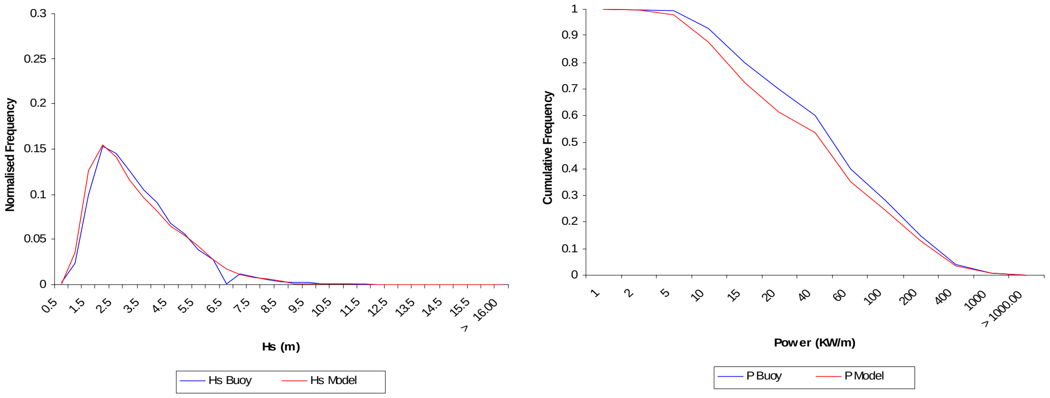

Figure D2.2 Modelled and observed significant wave height (H_s) and wave power (P_1) distributions at the RARH MAWS station

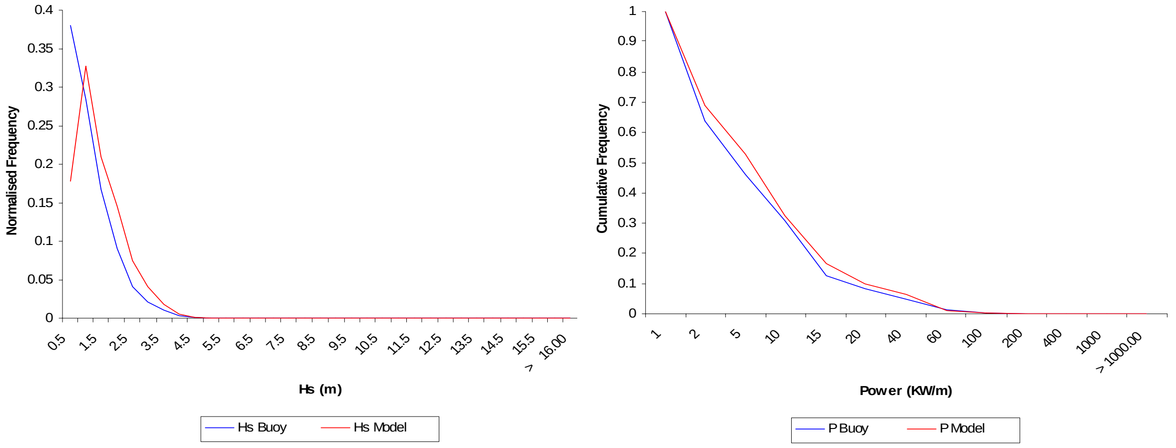

Figure D2.3 Modelled and observed significant wave height (H_S) and wave power (P_1) distributions at the Aberporth MAWS station

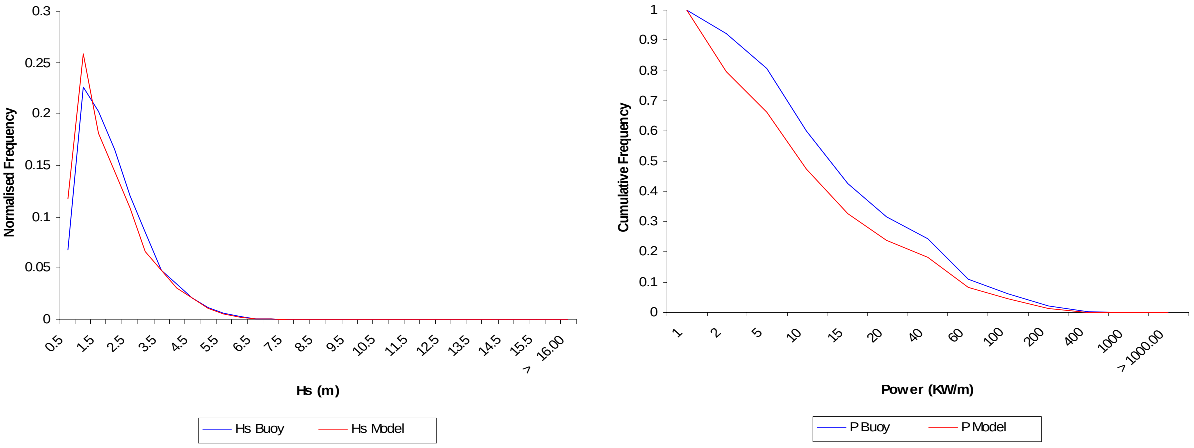

Figure D2.4 Modelled and observed significant wave height (H_S) and wave power (P_1) distributions at the Turbot Bank MAWS station

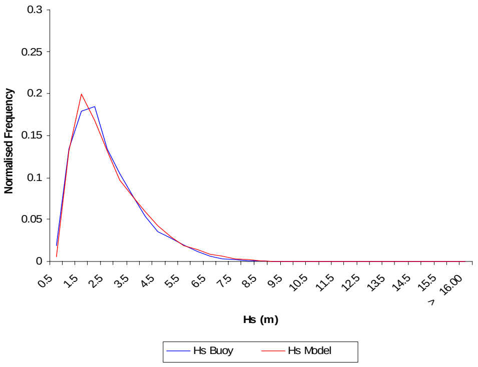

Figure D2.5 Modelled and observed significant wave height (H_S) distributions at the Seven Stones MAWS station

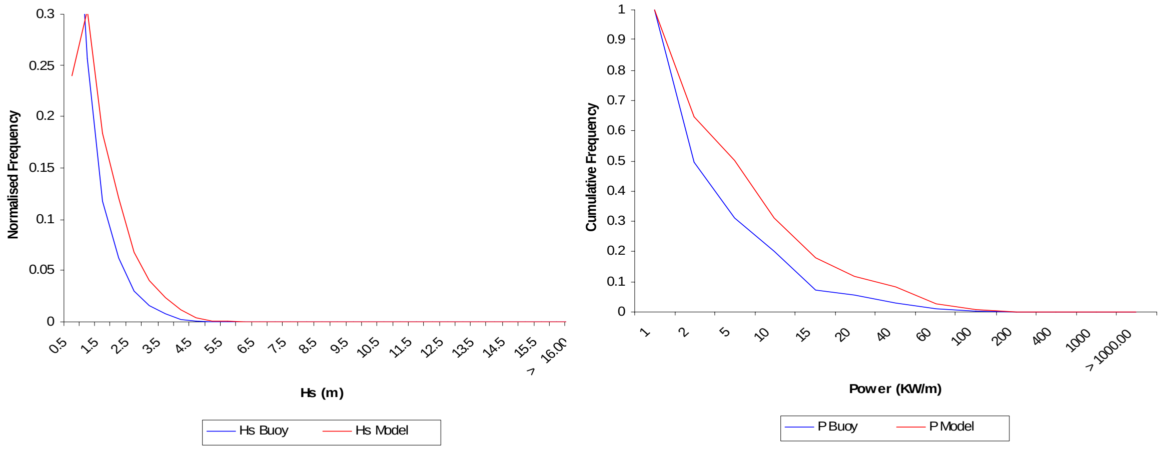

Figure D2.6 Modelled and observed significant wave height (H_S) and wave power (P_1) distributions at the Lyme Bay MAWS station

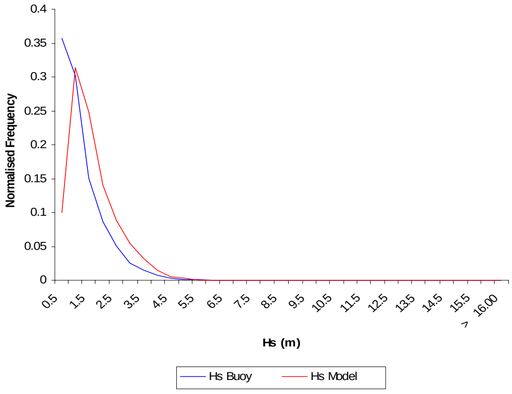

Figure D2.7 Modelled and observed significant wave height (H_S) distributions at the Greenwich MAWS station

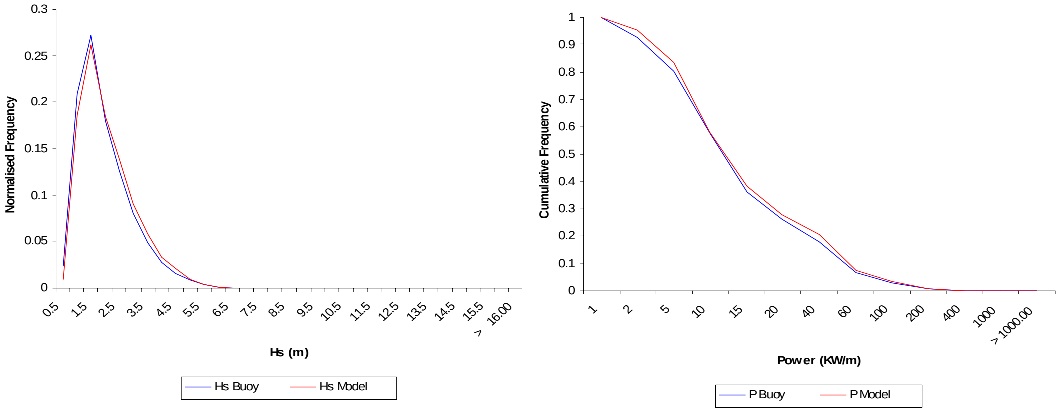

Figure D2.8 Modelled and observed significant wave height (H_S) and wave power (P_1) distributions at the K17 MAWS station

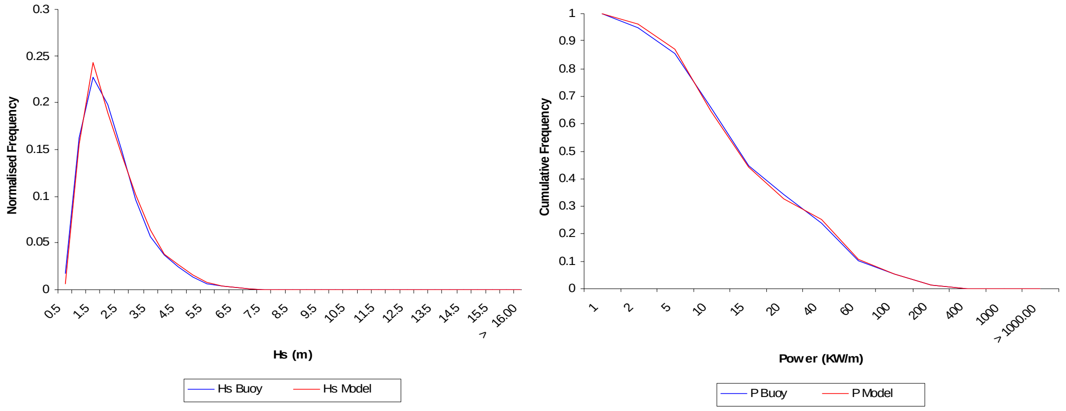

Figure D2.9 Modelled and observed significant wave height (H_s) and wave power (P_1) distributions at the K16 MAWS station

UK Waters Model and European Wave Model Comparisons

In general, both annual and seasonal wave height averages for the three data types fall within 15% of each other (Table D2.4), suggesting a reasonable agreement between the short and long term datasets for the averaged climatology.

Table D2.4 also indicates that broadly the best agreement between the data types occurs for the winter seasonal H_s averages, whilst agreements are worst for the summer season. The reason for this may be that the more frequent occurrence of storm events in the winter allows for a sufficiently broad population of wave heights to be included in the shorter time-series to provide a good representation of long term climate. Conversely in summer, the frequency of storm events is sparser and as a result the potential for differences between the shorter time-series and longer time-series in terms of wave height populations may be higher.

Differences in agreement between the three data types are also found along geographical lines, where the results can be roughly divided into 'open sea' sites (K5, RARH), 'partially sheltered' sites (Aberporth, Turbot Bank, Seven Stones, K17, K16) and 'sheltered' sites (Greenwich, Lyme Bay). At the open sea sites, H_s distributions are similar for all data types and seasonal H_s averages for the final three years of the time-series are in good agreement (Figures D2.10 and D2.11). In addition the spread of H_s averages over the shorter (last three years) time-series (UK Waters, observed) is approximately similar to that of the preceding 10 years (from the European model). Table D2.5 shows that for the open seas sites the highest H_s averages (winter season) for the UK Waters and MAWS data are within 10% of those from the longer term European wave model data.

Table D2.4 Comparison of annual and seasonal H_s averages from the long term European Wave Model archive and three-year time-series of UK Waters Wave Model and MAWS Network Observed data

Station Name	Data Type	H_s Mean (m)				
		Annual	Winter	Spring	Summer	Autumn
K5	European	3.22	4.51	3.08	1.98	3.32
	UK Waters	3.16	4.35	2.96	2.00	3.39
	MAWS	3.29	4.51	3.13	2.15	3.44
RARH	European	3.08	4.35	2.91	1.89	3.17
	UK Waters	3.05	4.16	2.82	2.03	3.28
	MAWS	3.19	4.33	3.09	2.06	3.31
Aberporth	European	1.05	1.48	0.95	0.67	1.10
	UK Waters	1.19	1.49	1.10	0.88	1.33
	MAWS	1.12	1.48	1.03	0.76	1.22
Turbot Bank	European	1.79	2.51	1.62	1.16	1.89
	UK Waters	1.59	2.18	1.55	1.05	1.94
	MAWS	1.80	2.37	1.74	1.24	1.78
Seven Stones	European	2.35	3.32	2.17	1.47	2.45
	UK Waters	2.38	3.22	2.27	1.48	2.53
	MAWS	2.30	3.10	2.26	1.44	2.35
Lyme Bay	European	1.30	1.84	1.20	0.81	1.37
	UK Waters	1.11	1.61	1.12	0.72	1.26
	MAWS	0.96	1.39	0.94	0.67	0.99
Greenwich	European	1.26	1.72	1.14	0.84	1.36
	UK Waters	1.38	1.82	1.29	0.92	1.52
	MAWS	1.01	1.39	0.90	0.58	1.18
K17	European	1.82	2.43	1.69	1.16	1.99
	UK Waters	1.85	2.31	1.64	1.34	2.14
	MAWS	1.79	2.31	1.56	1.29	2.01
K16	European	1.93	2.60	1.83	1.18	2.11
	UK Waters	2.01	2.52	1.80	1.39	2.30
	MAWS	1.99	2.57	1.74	1.36	2.25
▨	Data where errors between long-term and short term datasets are greater than 15% are highlighted.					

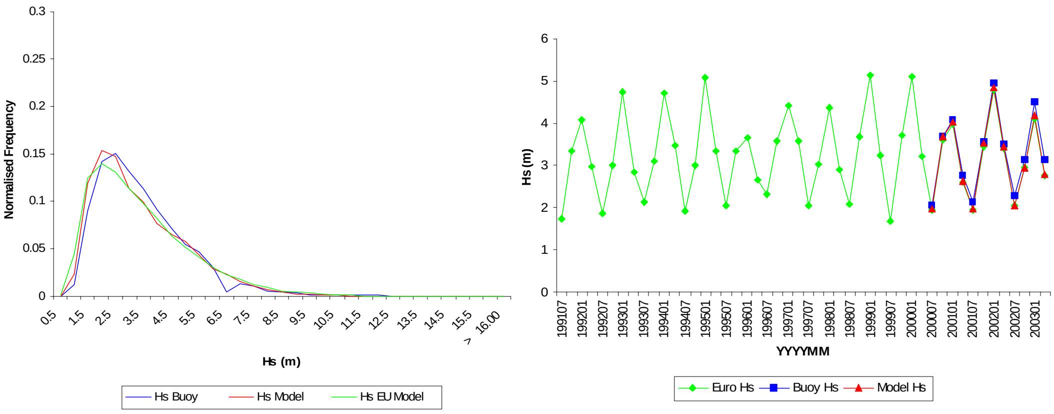

Figure D2.10 UK Waters wave model (Model), European wave model (EU Model/Euro) and observed significant wave height (H_S) distributions and seasonal H_S average time-series for the K5 MAWS station

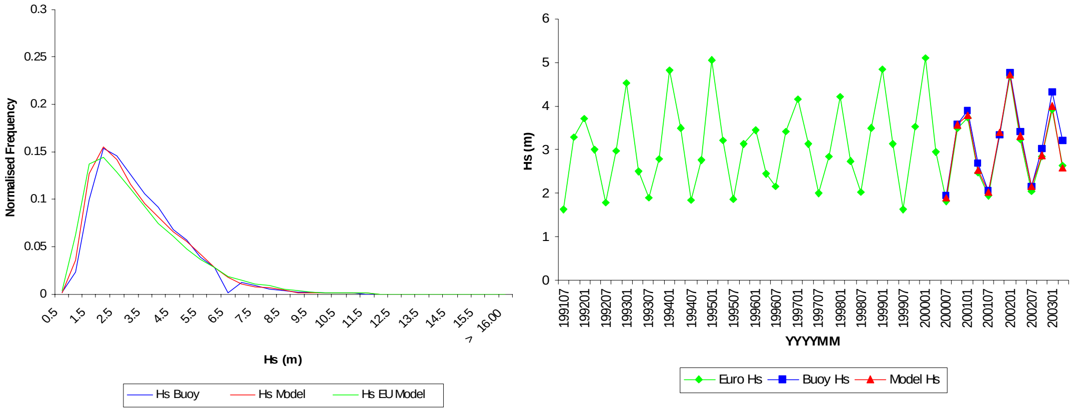

Figure D2.11 UK Waters wave model (Model), European wave model (EU Model/Euro) and observed significant wave height (H_S) distributions and seasonal H_S average time-series for the RARH MAWS station

Table D2.5 Comparison of maximum seasonal H_S averages from the long term European Wave Model archive and three-year time-series of UK Waters Wave Model and MAWS Network Observed data.

Station Name	Maximum Seasonal H_S Mean (m)		
	European	UK Waters	MAWS
K5	5.12	4.84	4.94
RARH	5.11	4.71	4.76
Aberporth	2.05	1.77	1.74
Turbot Bank	3.28	2.50	2.61
Seven Stones	4.21	3.50	3.27
Lyme Bay	2.53	1.73	1.40
Greenwich	2.34	2.02	1.58
K17	2.96	2.41	2.36
K16	3.08	2.57	2.65

At the partially sheltered sites (Figures D2.12 to D2.13), distributions of H_S are generally similar. However, agreement between seasonal H_S averages over the last three years is not as good as for the open water sites and maximum H_S average values from the shorter time-series (Table D2.6) only fall within 25% of the European data high. For the Aberporth, Seven Stones and Turbot Bank sites (western UKCS) this is due to some higher than normal conditions experienced in 1994 and 1995, whilst for K16 and K17 (North Sea) the maximum was observed in winter 2000. The change observed between open sea sites and partially sheltered sites is further exaggerated at the fully sheltered sites (Lyme Bay and Greenwich, Figures D2.14 and D2.15). In these cases, the two model H_S distributions remain similar, but both differ significantly from the wave buoy distribution. These differences are also shown in both the seasonal H_S average time-series agreement between the data types and differences in maximum H_S value (Table D2.5). In addition, the sheltered sites have the largest difference between 1994 and 1995 H_S maxima and the remaining seasonal H_S average time-series.

Again, the differences in agreement between data types at different locations are likely due to the number of storm events experienced at each site. For the UKCS, the source of storm waves will be from eastward tracking North Atlantic depressions, to which the open sea sites will be exposed almost all of the time. These locations therefore experience a wide range of sea conditions in the shortest possible time, such that short term wave parameter populations will quickly become similar to the populations from a longer term dataset. For more sheltered sites however, the exposure to storms will become far more dependent upon the actual storm track in order for waves to propagate to a given location. Partially sheltered areas such as the Southwest Approaches and North Sea will still be exposed to a wider range of conditions than those experienced in more sheltered areas such as the English Channel and Irish Sea. For these areas it may take somewhat longer therefore for the populations of wave parameters to approach a full climatology. In the examples shown here, sites in 'sheltered' southern locations (Aberporth, Turbot Bank, Seven Stones, Lyme Bay, Greenwich) experienced their highest winter H_S averages in 1994 and 1995. Although H_S averages were also high in 1994 and 1995 for the North Sea sites (K17 and K16) the highest H_S average actually occurred for winter 2000. In all these cases, the outlying values were not included in the Atlas estimate of wave climatology.

In terms of future changes in wave resource related to climate, no long term annual trends in either overall storminess (which would be indicated by a regular increase or decrease in annual H_S averages) or inter-seasonal variability (indicated by a regular increase or decrease in the difference between summer and winter H_S averages) are apparent in the seasonal H_S average time-series (Figures D2.10 to D2.18). This suggests that in the short term little change in wave resource aside from that induced by regular variations in North Atlantic storm tracks is likely for the UKCS. However, the sample of data presented is too small a sample to make any judgements regarding wave climate change beyond the next few years.

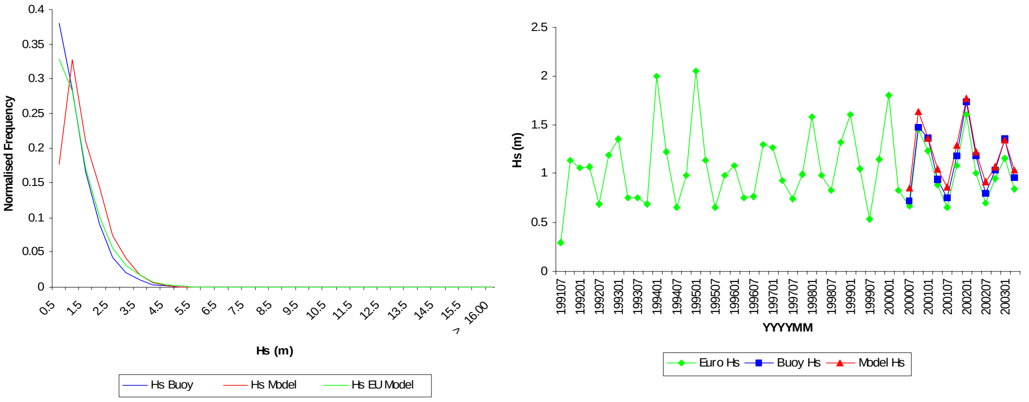

Figure D2.12 UK Waters wave model (Model), European wave model (EU Model/Euro) and observed significant wave height (H_S) distributions and seasonal H_S average time-series for the Aberporth MAWS station

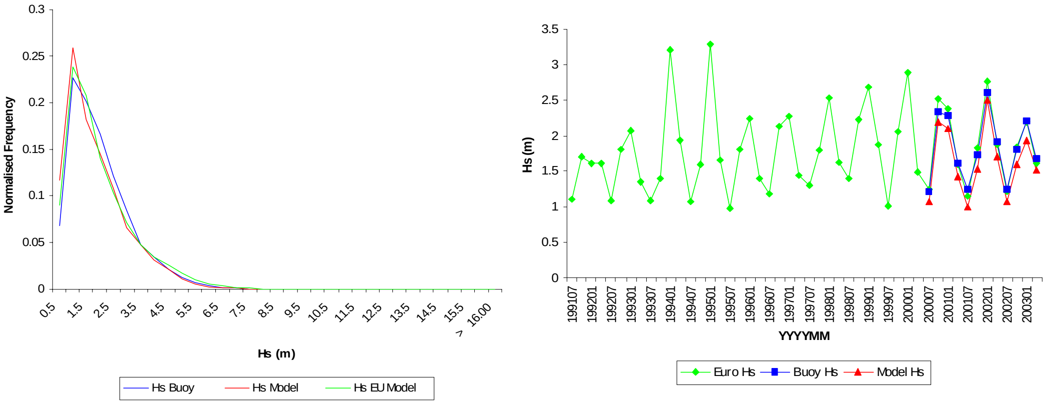

Figure D2.13 UK Waters wave model (Model), European wave model (EU Model/Euro) and observed significant wave height (H_S) distributions and seasonal H_S average time-series for the Turbot Bank MAWS station

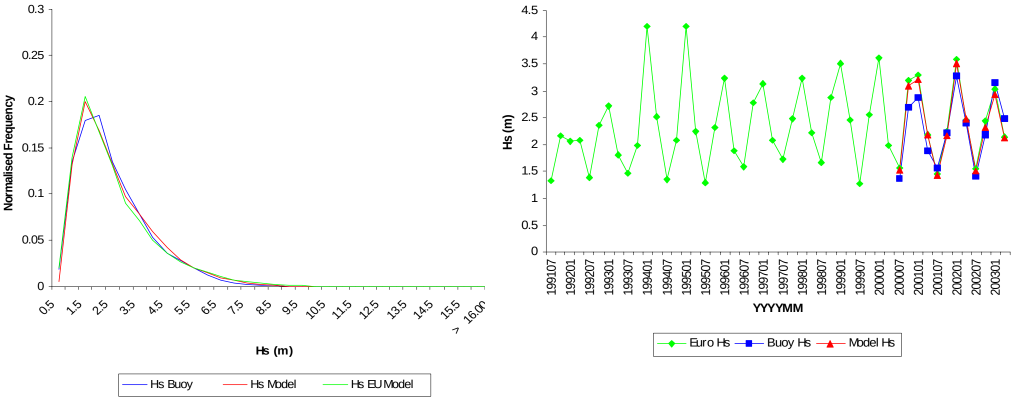

Figure D2.14 UK Waters wave model (Model), European wave model (EU Model/Euro) and observed significant wave height (H_S) distributions and seasonal H_S average time-series for the Seven Stones MAWS station

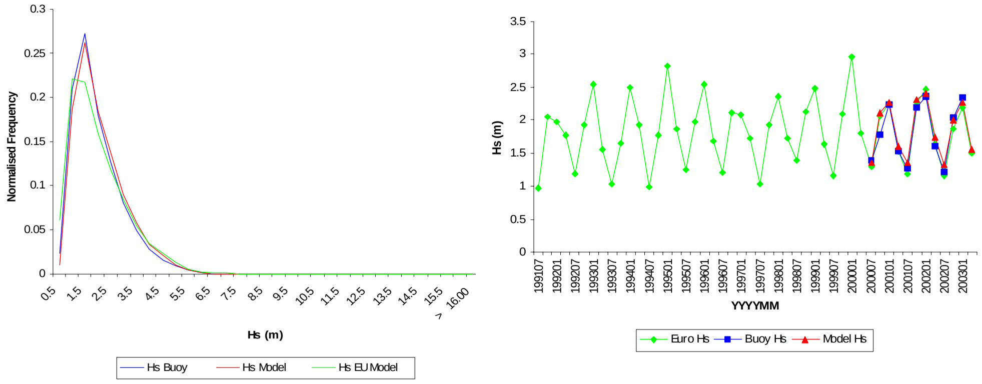

Figure D2.15 UK Waters wave model (Model), European wave model (EU Model/Euro) and observed significant wave height (H_S) distributions and seasonal H_S average time-series for the K17 MAWS station

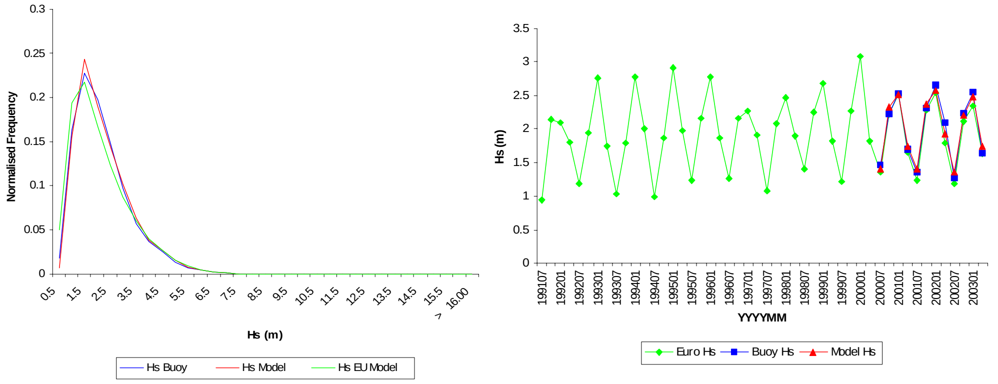

Figure D2.16 UK Waters wave model (Model), European wave model (EU Model/Euro) and observed significant wave height (H_S) distributions and seasonal H_S average time-series for the K16 MAWS station

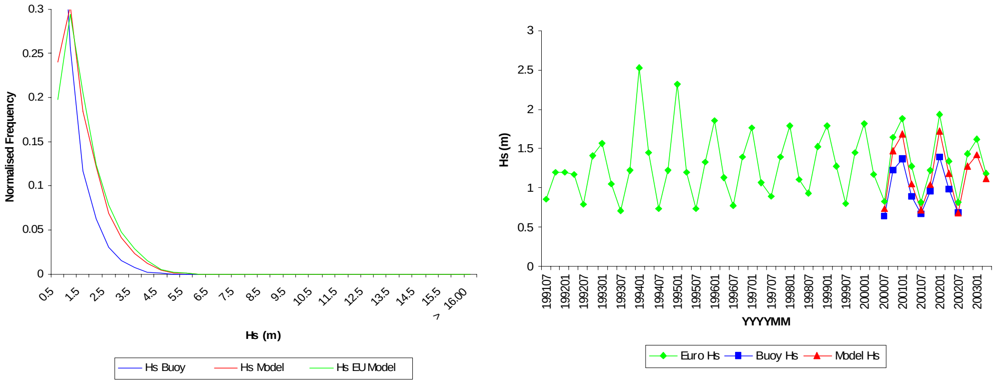

Figure D2.17 UK Waters wave model (Model), European wave model (EU Model/Euro) and observed significant wave height (H_S) distributions and seasonal H_S average time-series for the Lyme Bay MAWS station

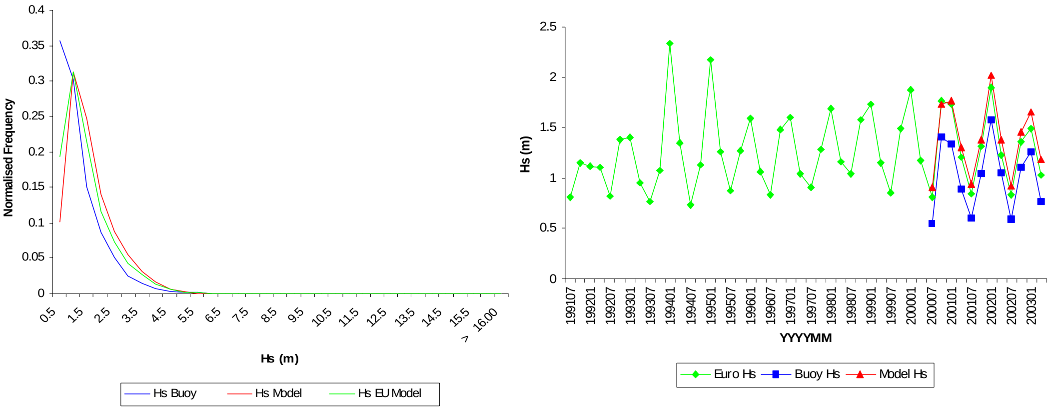

Figure D2.18 UK Waters wave model (Model), European wave model (EU Model/Euro) and observed significant wave height (H_S) distributions and seasonal H_S average time-series for the Greenwich MAWS station

Discussion of the Atlas Resource Validation

Met Office wave models use a well established second generation spectral scheme, which has been developed over the past 15 years to produce a robust and generally highly reliable source of wave prediction for offshore regions. The UK Waters model, from which the Atlas database is sourced is the most recent development in these models' evolution.

An important part of the modelling process is day-to-day validation of the model focusing on predictive capacity. For purposes of the Atlas database, this validation study has attempted to provide some insight into the behaviour of a UKCS wide model dataset as an indicator of climatology through some simple data comparisons carried out over a small selection of sites where reliable observed marine data is available. A more complete examination of the model data may well be possible through comparison with existing larger geographical datasets (e.g. from satellite observations) but in terms of time and cost falls outside of the remit of this project. Nevertheless results from this study, allied to some general 'health warnings' associated with the well established models from which the Atlas data was sourced, does allow a valid discussion of the results.

Results of the wave resource validation indicate that whilst modelled mean statistics are generally within 15% of the observations, the model data performs best at 'open sea' sites, i.e. away from the near coastal zone. In particular, very good results were achieved at the North Sea stations. The Atlantic stations, which are exposed to extremely energetic and long fetch storms, showed a slight tendency to underpredict the most energetic wave heights and periods. That the model performed best in open seas is not entirely surprising since closer to the coastline a number of physical processes become important that, although included in the model scheme, can be affected by changes in bathymetry occurring below the scale of the model grid. Specifically these include bottom friction, sheltering and refraction effects that may decrease (or possibly increase) the amount of swell energy reaching a site, and can have considerable local variations (for example in leeward or more open ends of bays). Again the recommendation is to treat the near coastal zone carefully, making full use of available bathymetric charts and local observations where possible in any decision making. Data from points further offshore in the Atlas should provide a robust guide as to the nature of wave energy incident to the near coastal zone.

Recent developments in use of, and operations occurring in, the near coastal zone have highlighted the need for improved modelling such areas. Model technology for near coastal areas is well established, ranging from fairly simple refraction models to spectral schemes such as SWAN. However, studies tend to be commissioned piecemeal for specific sites and as such provide a similarly sparse resource in geographic terms to long term observational data. With improvements in computer capacity however, improving the resolution of more regional or UKCS-wide models is a likely development in the foreseeable future.

It is also worth noting the swell component of the wave resource. For calculations of wave power made for the Atlas an assumption was made that the integrated parameters used in calculation represented a unimodal wave spectrum based on the JONSWAP experiment results (detailed in Appendix D1). This assumption ignores the regularly occurring scenario of a sea-state consisting of significant but distinct windsea and swell components. After a comparison of Atlas wave power statistics with a spectral study performed for a data point in the south west region (Seapower South West, Metoc 2004) it is suggested that the affect of this assumption may be to apply an extra underestimate of approximately 10% to the ‘Power 2’ wave power calculations performed for this Atlas. As a result it is worth noting the regions of the UKCS where sea-state is likely to regularly include an energetic swell component. Particularly these include the Atlantic coasts of the UK, of which the west and north coasts of Scotland and Ireland will regularly receive swell emanating from North Atlantic depressions. The south west of England (and to a lesser extent South Wales) is also a regular recipient of such swell energy, although Ireland will have a sheltering effect when depressions track too far north (particularly during the summer months). Far less regularly, swell generated from storms in FitzRoy and Biscay will track north toward south facing coasts of south west England. To allow a significant swell component to penetrate either the North Sea basin or English Channel requires an even rarer coincidence of swell energy and direction. Combined with frictional effects in these comparatively shallow waters, this means that incidence of significant swell energy in the far south-eastern regions of the UKCS is highly irregular.

North Atlantic Oscillation

Variability in the occurrence frequency and track of storms across the North Atlantic toward Europe is commonly termed as the ‘North Atlantic Oscillation’ (NAO). The NAO varies on both inter-annual and seasonal timescales, but usually discussion focuses on annual variations of the winter NAO, since this is when storms are most common. Two distinct patterns of NAO are most common, with either frequent strong storms tracking north-eastward and termed a 'high' NAO, or less frequent and weaker storms tracking directly east and into Mediterranean Europe ('low' NAO). These changes will impact wave heights on the UKCS in terms of maximum wave heights experienced, frequency of extreme conditions, and, in the case of more sheltered locations, the potential exposure to remotely generated swell waves.

NAO variability is presently described using indices based on the difference between sea level pressures measured near Iceland and the Azores/Iberian peninsula (e.g. Jones *et al*., 1997). Using such an index, high NAO periods are linked with a positive NAO index, and conversely low NAO periods with a negative index. Over the last 30 years, the NAO index has taken a positive value for the majority of winters, indicating that the most common storm track influencing waves on the UKCS is north-eastward. In terms of the more recent data used in this dataset, NAO index values have been generally weak, although in comparison with the European model dataset, strong positive NAO values occurred in winters 1994, 1995 and 2000, whilst a strong negative NAO index was observed in winter 1996. An element of this signal is apparent in the variability of seasonal H_s values shown in Figures D2.12 to D2.18.

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