A Guide to Sea State at Calshot (draft version 2)

Peter K Taylor, April 2019

1. Introduction

1.1 Purpose of this Note

Estimating Sea State by observation from Calshot Tower is not easy. It is difficult to determine wave height when looking down from above. Furthermore the various areas of water visible from the Tower are sheltered to a greater or lesser extent. This note describes the development of a diagram to be used in the NCI Calshot Tower observation room as a guide to the most likely sea state for a given wind direction and speed. It is suggested that such a diagram will minimise cases where the sea state is underestimated in the hourly weather reports.

1.2 Rationale

The length of the stretch of water over which the wind has blown to generate waves is the "fetch". Compared to other NCI stations the location of Calshot is unusual in that, for almost all directions from the Tower, the fetch is relatively short, being limited by either by the mainland coast or by the Isle of Wight. That implies that for most wind conditions the sea state near the station will be limited by the geographical fetch and not by for how long the wind has been blowing. Because at Calshot the fetch in any direction is known, it is possible to calculate mathematically what the height of the waves will be for a given wind direction and speed.

It must be emphasised this calculation would not be possible for other NCI stations, for example Hengistbury Head, because there the wave heights will depend strongly on the length of time for which the wind has been blowing and also on what the wind conditions are further to windward. the effective fetch will not be geographically limited and therefore will be vary variable.

In the note, Section 2 will describe the development of a spreadsheet to investigate the variability of sea state near to Calshot. The spreadsheet has been used to determine what sea state is likely to occur for a given wind, and also on how much the actual sea state might vary from the predicted value. Based on these results, Section 3 will then describe the construction of a diagram for use in Calshot Tower as a guide to Sea State estimation.

2. A Spreadsheet to predict Sea State at Calshot

2.1 How the results will be presented

The results from the spreadsheet will be presented in the form of a "Sea State diagram". An example is shown in Figure 1 (overleaf). The top, horizontal scale shows the wind direction in terms of compass point and bearing in degrees. For information, the value of the fetch used is also shown (nm). The left hand, vertical scale shows the wind speed in kts, m/s, and Beaufort Force. For each combination of wind direction and wind speed the calculated sea state is indicated by the colouring.

2.2 The Method Used in the Spreadsheet

2.2.1 Introduction

Two locations were chosen for wave estimation; the positions of the Calshot *Light Float* and of the *Reach Buoy*. The *Light Float* is exposed to the waves in the Solent and will usually exhibit the rougher sea state. The *Reach Buoy* represents the area likely to be used by watchkeepers when assessing the sea state. Compared to the *Light Float,* this position is usually more sheltered. The exception is for NW winds blowing down Southampton Water when conditions at *Reach* may be rougher than at the *Light Float*.

Wind			N		NE		E			SE		S		SW		W			NW		N
kts	m/s	degs:	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360
		nm:	2.1	1.7	1.7	2.0	3.2	112.4	112.4	8.7	5.2	3.2	5.6	10.4	10.4	1.7	1.2	2.0	7.6	3.4	2.1
0	0.0	BF = 0	caG	caG	caG	caG	caG	caG	caG	caG	caG	caG	caG	caG	caG	caG	caG	caG	caG	caG	caG
1	0.5	1	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR
2	1.0		caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR
3	1.5		caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR
4	2.1	2	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR	caR
5	2.6		caR	caR	caR	caR	smo	smo	smo	smo	smo	smo	smo	smo	smo	caR	caR	caR	smo	smo	caR
6	3.1		caR	caR	caR	caR	smo	smo	smo	smo	smo	smo	smo	smo	smo	caR	caR	caR	smo	smo	caR
7	3.6	3	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	caR	smo	smo	smo	smo
8	4.1		smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	caR	smo	smo	smo	smo
9	4.6		smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo
10	5.1		smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo
11	5.7	4	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo
12	6.2		smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo
13	6.7		smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo
14	7.2		smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo
15	7.7		smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo
16	8.2		smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo	smo
17	8.7	5	smo	smo	smo	smo	smo	slt	slt	slt	smo	smo	smo	slt	slt	smo	smo	smo	slt	smo	smo
18	9.3		smo	smo	smo	smo	smo	slt	slt	slt	smo	smo	smo	slt	slt	smo	smo	smo	slt	smo	smo
19	9.8		smo	smo	smo	smo	smo	slt	slt	slt	smo	smo	slt	slt	slt	smo	smo	smo	slt	smo	smo
20	10.3		smo	smo	smo	smo	smo	slt	slt	slt	slt	smo	slt	slt	slt	smo	smo	smo	slt	smo	smo
21	10.8		smo	smo	smo	smo	smo	slt	slt	slt	slt	smo	slt	slt	slt	smo	smo	smo	slt	smo	smo
22	11.3	6	smo	smo	smo	smo	smo	slt	slt	slt	slt	smo	slt	slt	slt	smo	smo	smo	slt	smo	smo
23	11.8		smo	smo	smo	smo	smo	slt	slt	slt	slt	smo	slt	slt	slt	smo	smo	smo	slt	smo	smo
24	12.3		smo	smo	smo	smo	smo	slt	slt	slt	slt	smo	slt	slt	slt	smo	smo	smo	slt	slt	smo
25	12.9		smo	smo	smo	smo	slt	slt	slt	slt	slt	slt	slt	slt	slt	smo	smo	smo	slt	slt	smo
26	13.4		smo	smo	smo	smo	slt	slt	slt	slt	slt	slt	slt	slt	slt	smo	smo	smo	slt	slt	smo
27	13.9		smo	smo	smo	smo	slt	slt	slt	slt	slt	slt	slt	slt	slt	smo	smo	smo	slt	slt	smo
28	14.4	7	smo	smo	smo	smo	slt	slt	slt	slt	slt	slt	slt	slt	slt	smo	smo	smo	slt	slt	smo
29	14.9		smo	smo	smo	smo	slt	slt	slt	slt	slt	slt	slt	slt	slt	smo	smo	smo	slt	slt	smo
30	15.4		smo	smo	smo	smo	slt	slt	slt	slt	slt	slt	slt	slt	slt	smo	smo	smo	slt	slt	smo
31	15.9		slt	smo	smo	smo	slt	slt	slt	slt	slt	slt	slt	slt	slt	smo	smo	slt	slt	slt	slt
32	16.5		slt	smo	smo	slt	slt	slt	slt	slt	slt	slt	slt	slt	slt	smo	smo	slt	slt	slt	slt
33	17.0		slt	smo	smo	slt	slt	slt	slt	slt	slt	slt	slt	slt	slt	smo	smo	slt	slt	slt	slt
34	17.5	8	slt	slt	slt	slt	slt	mod	mod	slt	slt	slt	slt	mod	mod	slt	smo	slt	slt	slt	slt
35	18.0		slt	slt	slt	slt	slt	mod	mod	slt	slt	slt	slt	mod	mod	slt	smo	slt	slt	slt	slt
36	18.5		slt	slt	slt	slt	slt	mod	mod	slt	slt	slt	slt	mod	mod	slt	smo	slt	slt	slt	slt
37	19.0		slt	slt	slt	slt	slt	mod	mod	slt	slt	slt	slt	mod	mod	slt	smo	slt	slt	slt	slt
38	19.5		slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	slt	mod	mod	slt	smo	slt	slt	slt	slt
39	20.1		slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	slt	mod	mod	slt	smo	slt	slt	slt	slt
40	20.6		slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	slt	mod	mod	slt	smo	slt	mod	slt	slt
41	21.1	9	slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	slt	mod	mod	slt	slt	slt	mod	slt	slt
42	21.6		slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	slt	mod	mod	slt	slt	slt	mod	slt	slt
43	22.1		slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	slt	mod	mod	slt	slt	slt	mod	slt	slt
44	22.6		slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	slt	mod	mod	slt	slt	slt	mod	slt	slt
45	23.2		slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	slt	mod	mod	slt	slt	slt	mod	slt	slt
46	23.7		slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	slt	mod	mod	slt	slt	slt	mod	slt	slt
47	24.2		slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	mod	mod	mod	slt	slt	slt	mod	slt	slt
48	24.7	10	slt	slt	slt	slt	slt	mod	mod	mod	slt	slt	mod	mod	mod	slt	slt	slt	mod	slt	slt
49	25.2		slt	slt	slt	slt	slt	mod	mod	mod	mod	slt	mod	mod	mod	slt	slt	slt	mod	slt	slt
50	25.7		slt	slt	slt	slt	slt	mod	mod	mod	mod	slt	mod	mod	mod	slt	slt	slt	mod	slt	slt
51	26.2		slt	slt	slt	slt	slt	mod	mod	mod	mod	slt	mod	mod	mod	slt	slt	slt	mod	slt	slt
52	26.8		slt	slt	slt	slt	slt	mod	mod	mod	mod	slt	mod	mod	mod	slt	slt	slt	mod	slt	slt
53	27.3		slt	slt	slt	slt	slt	mod	mod	mod	mod	slt	mod	mod	mod	slt	slt	slt	mod	slt	slt
54	27.8		slt	slt	slt	slt	slt	mod	mod	mod	mod	slt	mod	mod	mod	slt	slt	slt	mod	slt	slt
55	28.3		slt	slt	slt	slt	slt	mod	mod	mod	mod	slt	mod	mod	mod	slt	slt	slt	mod	slt	slt

Figure 1. Typical example of a sea state diagram produced by the spreadsheet. In this example the colours indicate: "Calm(glassy)" in yellow, "Calm(rippled)" in orange, "Smooth" in brown, "Slight" in green, "Moderate" in blue.

At each location the distance to land has been read from a chart along bearings at 5 degree intervals. The charted high water mark was used to define the shore line. The fetch would be shorter at low tide but the change in the calculated wave heights would mostly be very small except for some very short fetches. However in those cases the possible variation in sea states would itself be small. The wind has been assumed to be constant along the fetch. Since most fetches to Calshot are short, less than 5 nm, this assumption will normally be reasonable.

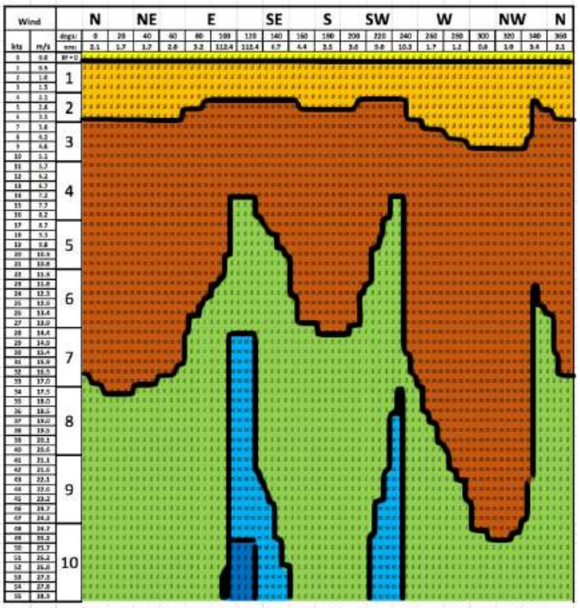
It has been assumed that, at every point along the fetch, the water is deep enough that the waves do not "feel the bottom". The water depth required for this to be true gets greater as the waves get larger and their wavelength increases. For example, it will be shown (section ??) that very rough waves predicted for severe gales from the SE would not in reality reach the Calshot region because of the presence of the Bramble Bank. However for typical conditions the assumption of "deep water" will be shown to be valid.

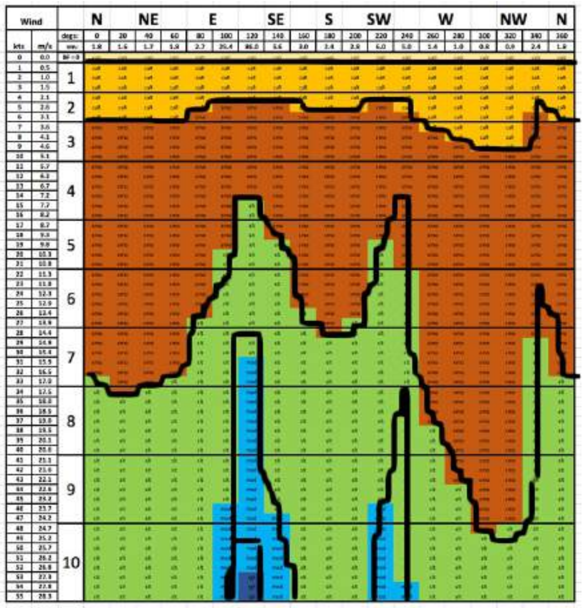
The sea state calculations[1] have been performed for every 5° bearing. A small angular step was used in order to account for those directions where the fetch varies rapidly with bearing. A 5° step was considered adequately small because predicted wave height only varies with the square root of the fetch.

However, wind observations at Calshot are not reported to 5° resolution, rather they are reported using compass points. Thus, for ease of use, the results have been subsampled into intervals of 20°. The method of sub-sampling will next be considered.

2.2.2 Method of sub-sampling

The spreadsheet allows two methods to sub-sample the calculated values; a "box-car" average over ±10°, or using the roughest sea state calculated within a ±10° range of the chosen bearing. Figure 2 shows examples of a sea state diagram constructed using the original 5° resolution, using an averaged value, and using the maximum wave height within the range.





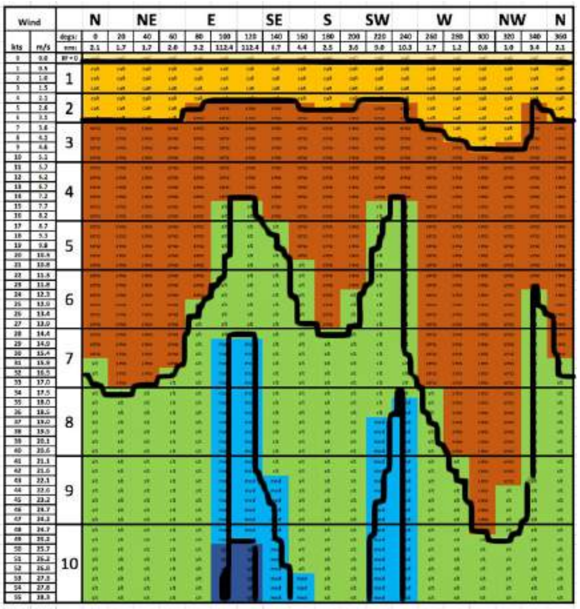


Figure 2. Example comparison of sub-sampling methods to calculate sea state:

(top left) the calculated 5° values, the black lines indicate the sea state transitions and have been superimposed on the other plots;

(top right) averaging over ±10°;

(left) using the maximum in the ±10° range.

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[1] see Section 4 for a description of the equations used.

Examination of Figure 2 suggests that taking the average value best represents the calculated transition between "Smooth" and "slight" sea states. However there is a problem with this method. The rougher values of sea state predicted for the longer fetches which occur along restricted ranges of bearings are not represented. Using the maximum value within a range preserved these "Moderate" sea state predictions. This was also considered more realistic since waves do not travel directly down wind, rather they tend to fan out from a source. Therefore in the following discussion, the 20° values used have been obtained by using the roughest sea state within the interval chosen.

2.3. Spreadsheet results

<u>2.3.1 Effect of Position</u>

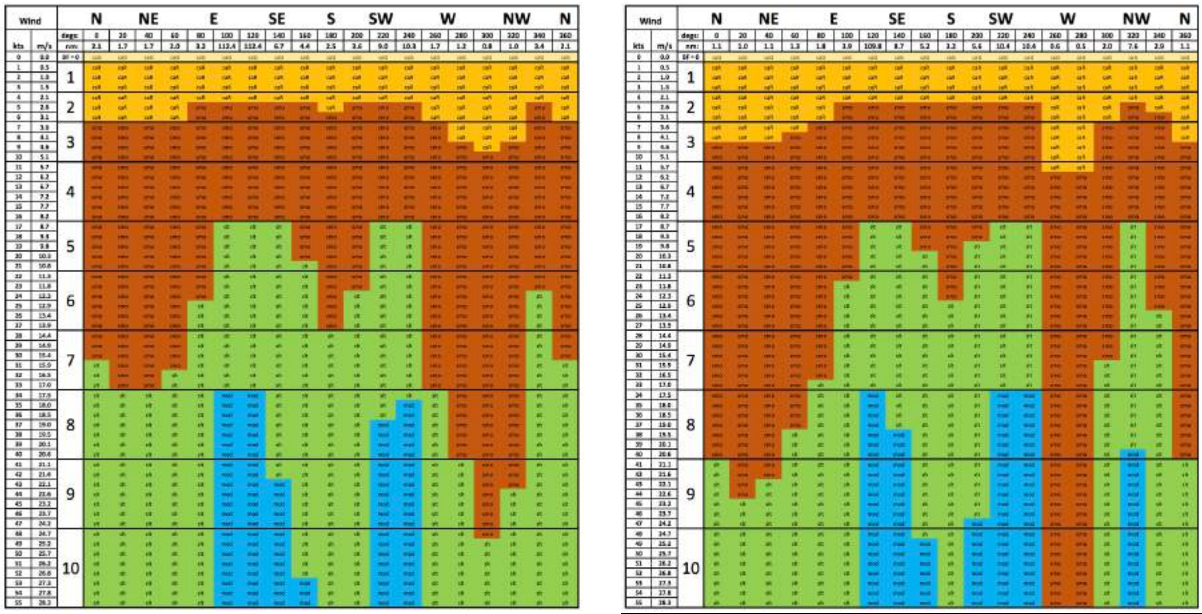


Figure 3. Comparison of sea state for: (left) Calshot Light Float and (right) Reach Buoy

The calculated sea state after "3 hours" duration wind at Calshot Light Float and Reach Buoy is shown in Figure 3. Overall the patterns look very similar. "Calm(glassy)" only occurs when there is no wind, "Calm(rippled) occurs for all force 1 and some force 2 winds. For almost all force 4 winds the sea state is "Smooth". At both positions, "Moderate" sea states are calculated for winds from the ESE and SW by W corresponding from winds from the East Solent and the West Solent respectively.

At Reach Buoy, the more sheltered location results in a "Smooth" sea state continuing to be calculated for force 8 winds from the N and NE and also for even the strongest winds from the W.

The major difference at Reach from the Light Float results is that, for force 9 winds from the NW, "Moderate" sea state is predicted. This is due to the direct fetch down Southampton Water from Totton. Figure 4 shows a case (10th March 2019) when force 8 to 9 NW winds produced such a sea state. Life-rings (visible on SP) are either 24" or 30" in diameter so the waves beyond SP would need a trough to crest distance of 2 life-ring diameters to be classed as "Moderate" - which indeed looks likely.

Figure 4. Sea state approaching Moderate near Hook Buoy with a force 8 gusting 9 wind from the NW.

2.3.2 Are the waves Fetch or Duration limited?

For a given fetch, if the wind has not been blowing long enough to fully develop the waves, the sea state will be "duration limited" and different equations are used to calculate the resulting sea state. Thus for duration limited waves, the sea state, both actual and calculated, will depend on the length of time the wind has been blowing, which is usually ill defined. The calculated sea state will also be less accurate because the equations assume that there was no wind or waves at time = 0 after which a constant wind started to blow and the waves develop from a flat calm sea. In reality this does not happen!

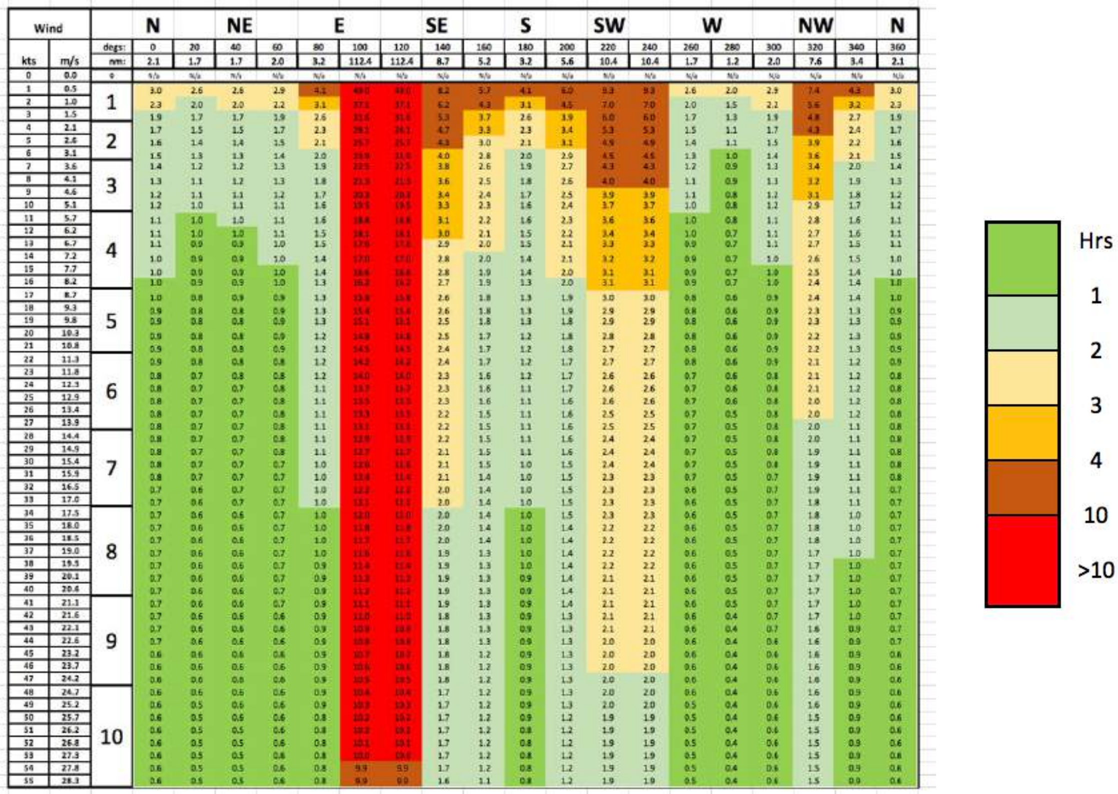


Figure 5. Time in hour for waves (developing from flat calm) to become fetch limited.

Fortunately, at Calshot the waves are more often limited by fetch rather than by duration. This is illustrated by Figure 5 which shows the minimum time for which a given wind must have been blowing in order for the waves to be fetch limited. After 2 hours the whole of the dark and light green region is fetch limited. After 4 hours every part of the diagram, except light winds from the SW and NW, and all winds from the ESE, are fetch limited.

The time periods indicated in Figure 5 will be over estimated since they assume that no waves were present at the start of the period. In reality a wave field usually exists, and the time needed to adjust to a new wind speed and direction is significantly shorter than that needed to generate a sea from calm.

Because the fetch is open to the ESE (stretching as far as France) waves from that one restricted sector are always duration limited. Fortunately winds of strengths greater than force 6 from that sector are rare (UKHO 2017) and if stronger winds were to occur, the waves reaching Calshot would limited by breaking in the shallow water of the East Knoll to Bramble Bank area.

It is the fact that, for most conditions, the sea state at Calshot will be limited by the geographical fetch, that allows the calculation of a diagram showing sea state as a function of wind direction and speed. Because this is a fundamental requirement, Figure 6 (below) illustrates the progression from duration limited to fetch limited and how the predicted sea state develops.

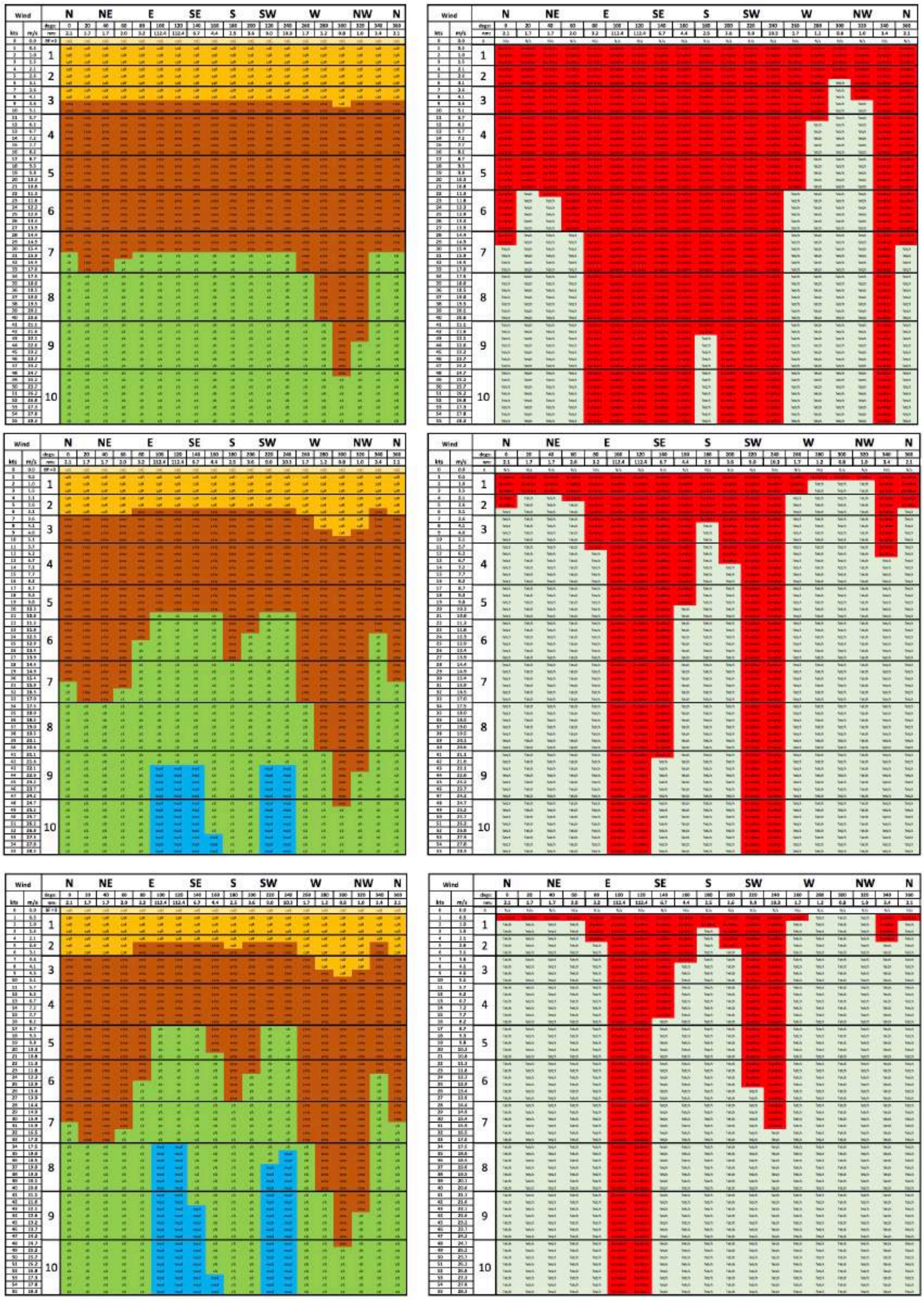


Figure 6a. Left column: Calculated Sea State at the Light float for "duration" (top) 1 hour, (middle) 2 hours, (bottom) 3 hours. Right column: red areas indicate combinations of wind and fetch for which the sea state is duration limited.

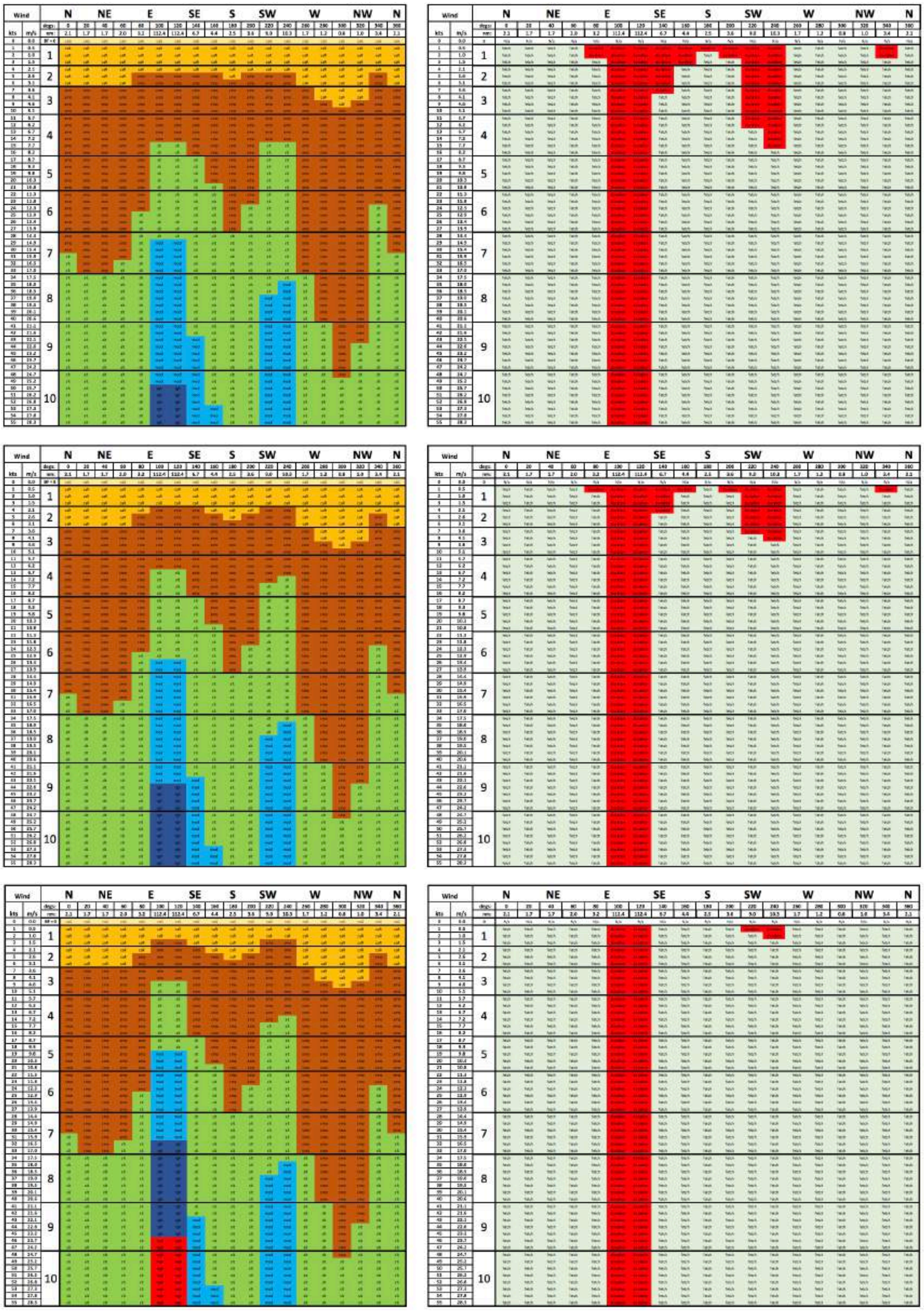


Figure 6b. Left column: Calculated Sea State at the Light float for "duration" (top) 4 hours, (middle) 5 hours, (bottom) 6 hours. Right column: red areas indicate combinations of wind and fetch for which the sea state is duration limited.

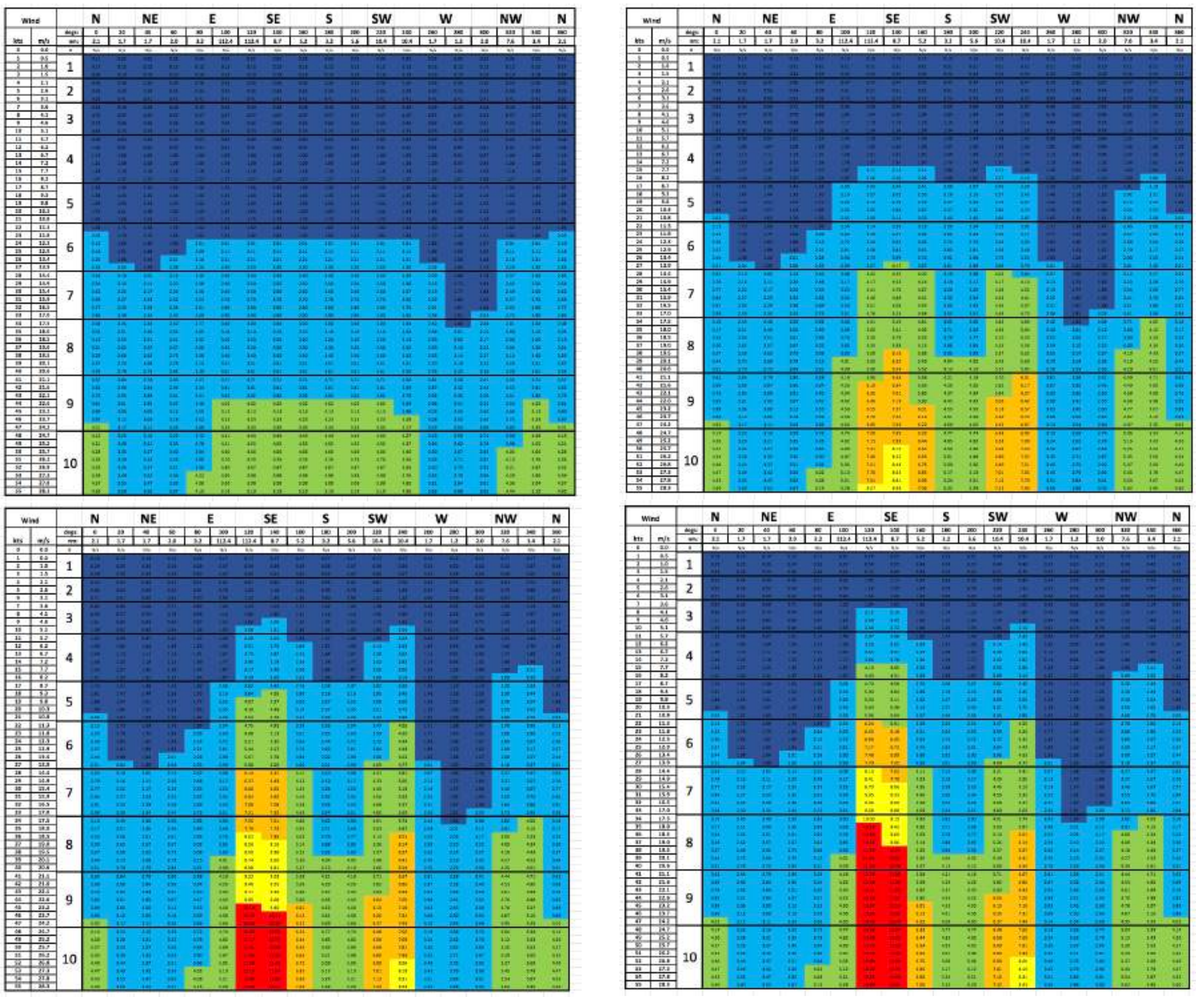
Figure 6 (above) shows the calculated sea state for durations of 1 to 6 hours (left hand column) and also the combinations of wind and fetch for which the sea state is duration limited (right hand column, red areas).

First examining Figure 6a; at 1 hour of wind following a flat calm (top plot), the sea state is still mostly duration limited (red area). Very light winds struggle to generate waves from a calm surface, so even after 2 hours (middle plot) the sea state is still duration limited for the lightest winds at all fetches . The sea state is also fetch limited for the longer fetch directions, that is winds from the ESE and from the SW. After 3 hours (bottom plot) it is only the longest fetch directions where the sea state continues to be duration limited.

For wind durations greater than 3 hours (Figure 6b) the wave conditions are fetch limited for all but the lightest winds or the longest fetches.

<u>2.3.3 Effect of depth</u>

The wavelength of the waves is the distance from one wave crest to the next. Waves are considered to start being modified by "feeling" the sea bed when the depth is around half the wavelength of the dominant waves. However it is only at a depth of about one quarter of the wave length that these shallow water effects start to become very significant.



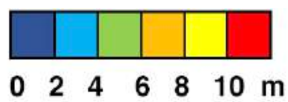


Figure 7. Depth at which the waves begin to be significantly modified for durations of (top left to bottom right): 1, 2, 4, and 6 hours.

Figure 7 (above) shows the quarter wavelength value for the dominant ("spectral peak") waves after periods of 1, 2, 4, and 6 hours. For comparison, the Thorn Channel and the shipping channel in Southampton Water have a maintained depth of over 13m, and most of the Solent is deeper than that. Thus, because the fetch is limited, most waves reaching Calshot have not grown to a size where they are limited by the water depth; they behave as "deep water waves" as has been assumed in the calculations.

The major exception to there being adequate depth for wave propagation is the area from Bramble Bank and East Knoll northwest towards the Hill Head and Lee on Solent coast where depths are less than 5m (all depths quoted are relative to Chart Datum but high tide would add, at most, 5m).

Due to the effectively unlimited fetch to the ESE very rough sea states are predicted at Calshot for gale and storm force winds from that direction (e.g. see Figure 6b). Such winds rarely, if ever, occur. The climatology for Lee on Solent (UKHO, 2017) suggests the occurrence frequency of force 7 easterlies to be around 1% to 2% with stronger winds not registering.

If gale force ESE winds did occur, the waves generated would experience significant shallow water effects at depths of 10m or more. Thus, significant wave breaking would occur over the Bramble Bank and East Knoll and prevent the roughest seas reaching Calshot. For that reason it seems likely that, even though the area is exposed to long fetches to the ESE, the roughest sea state which might occur at Calshot is "Moderate" .

3. Construction of the Sea State Guide

The spreadsheet described in Section 2, is useful for exploring the wave climate at Calshot. However for operational use a single, hard copy Sea State diagram is required. This has been constructed as follows:

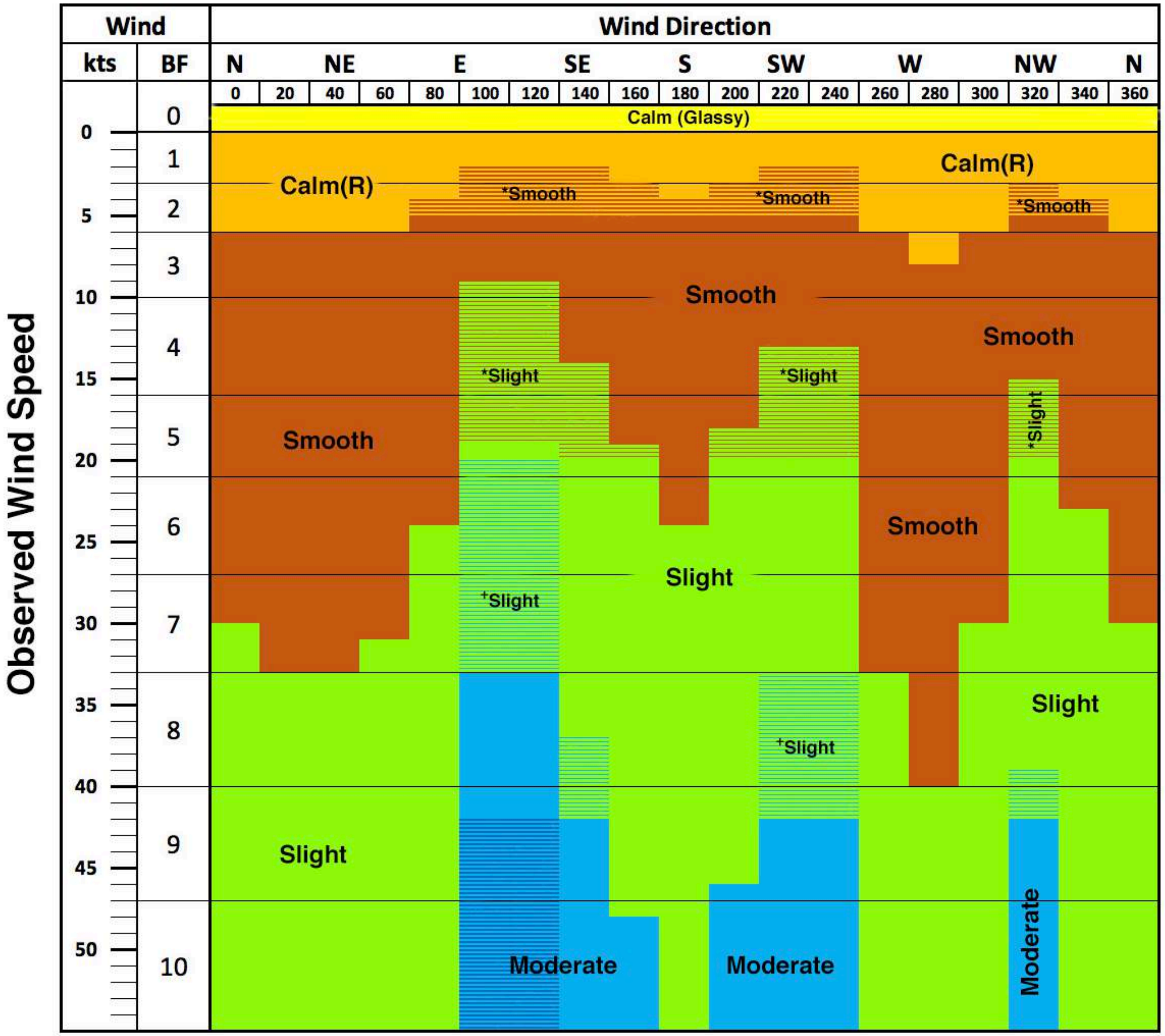
The spreadsheet has been used to calculate sea state diagrams using durations of 2, 4, and 8 hours. For each diagram the sea state selected for a given wind direction and speed is that calculated for Calshot Light Float or the Reach Buoy, whichever is the rougher. This ensures that, for safety reasons, the roughest sea state occurring in the Calshot area will be what is reported.

The three diagrams for the different duration periods have been combined using the following rules:

- the sea state is the same for all three durations: that sea state is used;
- the sea states differ between the durations: the diagram is shaded between the two appropriate colours but the rougher sea state is recommended if it is "Smooth" or "Slight".
- the sea states differ between "Slight" and "Moderate": the diagram is shaded between the two appropriate colours but "Slight" is recommended because of duration limitation of "Moderate" sea states.
- some durations indicate sea states rougher than "moderate": diagram shaded darker but "moderate" recommended because of depth limitations for the roughest sea states..

The resulting Sea State diagram and the accompanying key is shown in Figure 8 (next page).

Sea State at Calshot



Key	
	Calm (Glassy) no wind or waves
	Calm (Rippled) less than 10cm (4")
	***Smooth** - might be **Calm(rippled)** if waves still developing
	Smooth 10cm - 0.5m (4" - 1'8")
	***Slight** - might be **Smooth** if waves still developing
	Slight 0.5m - 1.25m (1'8" - 4')
	+Slight - might be **Moderate** if it's been windy for some time
	Moderate above 1.25m (above 4')
	Moderate - Very Rough over **Bramble** (very rare conditions)

4. Appendix: Equations used

The principles of wave forecasting are described, for example, in WMO (1998). For this study the equations used are those derived empirically by Carter (1982) from the JONSWAP spectra. JONSWAP was an experiment conducted in the North Sea in which wave spectra were measured for fetch and duration limited conditions with off-shore winds and relatively short fetches; thus conditions equivalent in nature to those experienced at Calshot.

For fetch limited conditions:

$$H_s = 0.0163X^{0.5}U_{10n} \qquad T_p = 0.566X^{0.3}U_{10n}^{0.4}$$

and for duration limited seas:

$$H_s = 0.0146D^{5/7}U_{10n}^{9/7} \qquad T_p = 0.540D^{3/7}U_{10n}^{4/7}$$

The seas are considered fetch limited if:

$$D > 0.0167X^{0.7}U_{10n}^{-0.4}$$

As noted by Taylor and Yelland (2001), this condition matches H_s but not L_p between fetch and duration conditions. However, any discontinuity introduced is not significant for our purposes.

For determining the depth at which the waves depart from deep water values, L_p has been determined from the deep water dispersion relationship:

$$L_p = gT_p^2/2\pi$$

The symbols used are:

D = duration in hours

g = acceleration due to gravity

H_s = significant wave height (m)

L_p = wavelength at the energy spectrum peak

T_p = wave period at the energy spectrum peak

U_{10n} = 10m neutral wind speed (m/s) (observed wind speed used)

X = fetch in km

5. References

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

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Footnote - About the Author

Peter Taylor is a retired scientist from the National Oceanography Centre in Southampton where he headed a research division on Ocean Circulation and Climate and a research team on Marine Meteorology, specifically the interactions between the atmosphere and ocean, and the accuracy of marine meteorological observations. He is now a Watchkeeper at NCI Calshot Tower.