Books produced by Kenn Batt at Coroner's Court, Wednesday 15/3/2000

Weather for Sailing by Ray Sanderson (Stanford Marine)

High Performance Sailing by Frank Bethwaite (Waterline)

Heavy Weather Sailing by K. Adlard Coles and Peter Bruce (McGraw Hill)

Deep Sea Sailing by Erroll Bruce (Stanley Paul)

Wind Waves Weather (NSW Waters) by Bureau of Meteorology (AGPS)

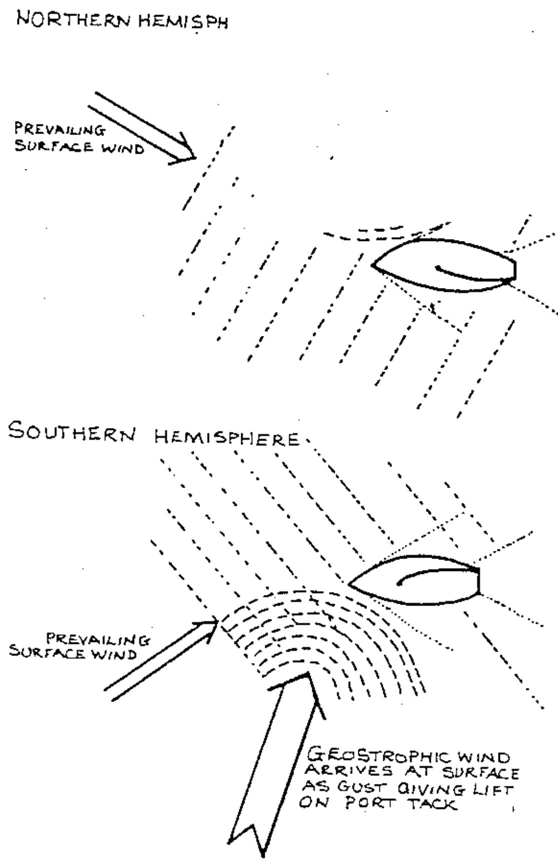
Offshore Yachting magazine Dec/Jan 1998 by CYCA (Jamieson Publishing)

Oceanography and Seamanship by William G. Van Dorn (Dodd, Mead)

RORC Manual of Weather at Sea by Dag Pike (David and Charles)

The Users Guide to the Australian Coast by Greg Laughlin

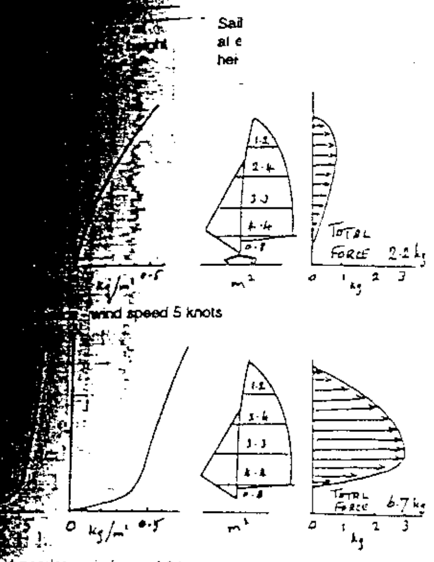
WIND
WEATHER FOR SAILING
BY
RAY
SANDERSON



23 Wind shifts caused by gusts. The wind veers in gusts in the Northern Hemisphere, and backs in the Southern.

also much more when the air is unstable, i.e. convection is uninhibited and cumulus clouds develop, than when it is stable with little or no vertical motion from the surface. Diagram 22 shows a wind trace (anemogram) typical of conditions over the sea. It can be seen that even in the 'steady' conditions shown, the wind direction frequently swings 15% or so either side of the mean, and that the wind speed also varies, often by about 15% and less frequently by about 40° from the mean. The gusts (peaks) tend to coincide with short-term veering and the lulls with backing.

HIGH PERFORMANCE SAILING BY FRANK BETHWAITE



the tops of the sails drive. In breeze, all areas of sail drive
between 5 and 6 knots (boat assumed stationary)

...ange of dynamics between 5 and 6 knots

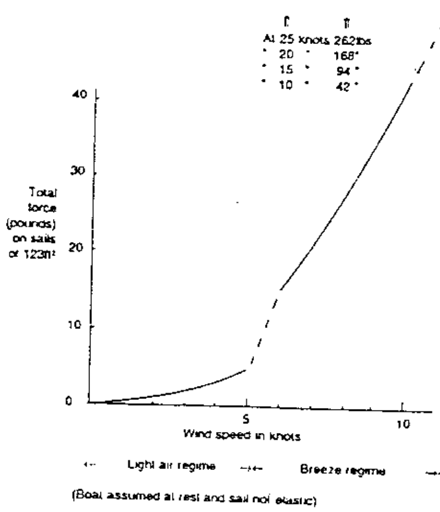


Fig 5.2 Change of sail force with wind speed

...of wind, the change from one to the other is abrupt, it is easy to sense and feel, and the boat needs ...ndled quite differently in light air compared with a breeze.

The shape of the breeze

...5.3 shows the speed traces of six lake breezes of speeds 6, 8, 10, 12.5, 15 and 20 knots. Note that each ...characterised by gusts and lulls (marked 'G' and 'L'). If you look at them, foreshortened, by tilting the ...ge away from you and looking at them upwards from the bottom of the page, you can see how each trace ...ems to be half gust, half lull, and very little in between.

Note particularly that, in addition to the obvious gusts and lulls, all the traces show, continuously, a second and much faster frequency. This is the fluctuation frequency. The notes below the traces of Fig. 5.3 tabulate the vital data about gusts and fluctuations at the six wind speeds.

The gust-lull sequence of these breezes normally sweeps a range of about 35-40% of the average windspeed. This is the difference between the average speed of the gust and the average speed of the lull. The periodic extremes are much greater. In Fig. 3.3 it is obvious that the extreme gusts are three to four times as strong as the extreme lulls. The average life of each gust is about 30 seconds, and the average life of each lull is similarly about 30 seconds. But, as a glance at Fig. 5.3 will make clear, gusts and lulls do not repeat regularly at any of the wind speeds.

Each trace of Fig. 5.3 shows, in addition to the more 'massive' gusts and lulls, a second, continuous, smaller, faster and more regular frequency. These typically sweep a speed range about one third of that of the gust-lull range, and they repeat about five times faster. These are the fluctuations. The combination of gusts and fluctuations together constitute the 'pattern' of every turbulent breeze. They fit together in a special way.

Diagrams which help in visualising this pattern are given in Figs 5.4 to 5.9.

Fig. 5.4 shows, first, how the average gust-lull pattern changes as the seconds tick away. Fig. 5.5 shows how the fluctuation pattern changes. Fig. 5.6, which is a combination of Figs 5.4 and 5.5, shows the average, continuous and everpresent wind speed pattern of every turbulent breeze. Note particularly that this very normal wind is in reality two separate winds, one a little stronger, and one a little lighter, which alternate continuously. It almost never blows at its mean speed at all. Further, the change from any speed to any other speed always occurs abruptly. This is why wind speed traces always look 'spiky'.

Figs 5.4, 5.5 and 5.6 show only the speed of the wind. Figs 5.7 and 5.8 show the direction as well.

Heavy weather Sailing
by Coles & Bruce

hole in the isobars was as empty as the chart analyst thought. If there had been a fleet of yachts in the area at the time, would they possibly have recorded a form of 'cyclonic pool' such as was identified during the Fastnet race? It is the sheer lack of dense observational network over the sea that must miss many odd nasties as they form over deep sea areas.

In both the case of the Fastnet yacht race and of the *Marques*, we have certain conditions which appear to be necessary for the local enhancement of the wind and the sea, which could apply to many other survival situations at sea. Other related research shows that very large capsizing waves are generated by intense depressions which have cold upper troughs associated with them. The coldness aloft is a necessary condition for the development of strong convection currents, but it does not seem that these necessarily should have to produce thunder. No obvious signs may appear to the mariner that such conditions actually exist. However, it is more likely that they would occur in summer or over warm seas than over cold seas in winter. Nevertheless very cold outflows from the polar regions could produce the same effects in winter, which they have been shown to do in both the North Atlantic and North Pacific.

The survival conditions appear to occur on the southern flank of the parent depression; in the cases of the 1965 Channel Race gale and the 1979 Fastnet gale the hurricane-force winds occurred some 200 miles to the south-east of the low centre. In fact the weather maps for these two survival situations bear an uncanny resemblance. Each has a minor area of not particularly deep low pressure some hundreds of miles ahead of the low centre, the signs of a mass of relatively cold air aloft over and to the north of the depression centre, and the already-mentioned immensely strong winds 200 miles to the south-east of the centre. I am envisaging that the cyclonic pools were able to draw in to themselves winds of 10–20 knots, or more in some cases. If such winds are added to the general windfield of say 40–45 knots then sustained corridors of wind with speeds of 50–70 knots could be produced in some places on the windward sides of the pools. On the leeward sides the inflow would be opposing the general wind and so here wind speeds as low as 25 knots might be reported – which indeed they were during the height of the Fastnet storm.

These conditions may be much more prevalent at sea than previously thought leading to locally enhanced wind speeds and attendant seas. For when winds are normal gale force or below then the frictional drag of the wind on the sea is such as to make the seas build up only over a period of time, which may be considerable. However, when winds get to near hurricane force, the frictional coupling betwe[en] wind and sea surface is so strong that great breaking waves are generated almost [at] once. These waves have very steep faces. The speed of their crests exceeds that of th[e] wave as a whole and so, just like shoreside breakers, they must curl over at the cre[st] and break.

Wind at sea and at coastal stations

As is well known, the wind increases with height in the extreme conditions discuss[ed] above, so not only the position but the height of any anemometer readings must [be] taken into account. The standard height for wind observations is 33 ft (10 metr[es]

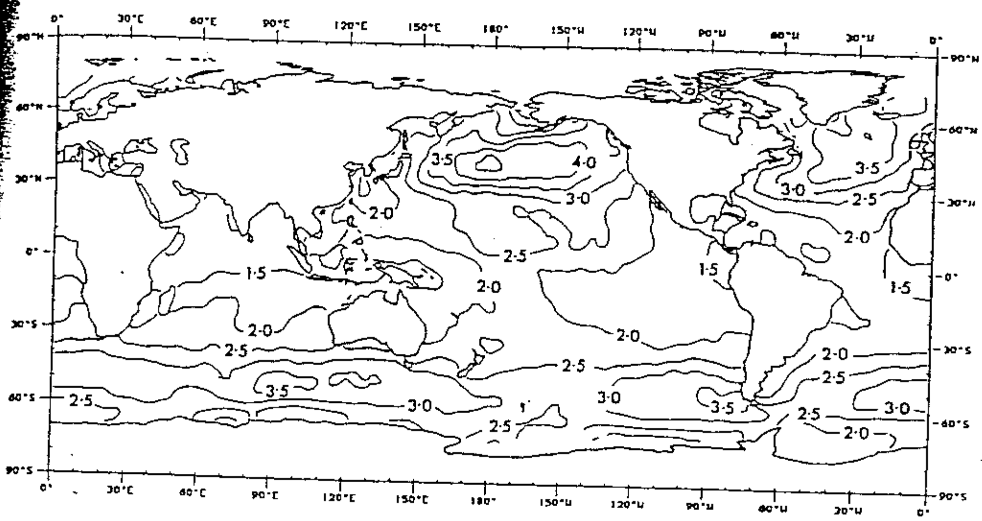


Fig 31.18. GEOSTAT global mean significant wave height for January to March 1987 contoured in metres.

average height. In fact, the most likely highest individual wave in three hours will be approximately 1.8 times H_S in height, so if H_S = 10 m, you are likely to encounter an 18 m wave during a three hour period.

It is important to remember that it was stated earlier that significant wave height is close to visually estimated mean wave height. It can be seen that it really is the high waves in the sea which heavily influence one's estimate, and that there is a large proportion of lower waves present, together with the higher waves which are relatively fewer in number.

Long-term wave statistics

Wave conditions are continually changing. As an illustration, Fig 31.15 shows measurements of significant wave height taken once every three hours from two particularly stormy months (January and February 1974), together with August 1979 and November 1986, at Seven Stones Light Vessel off Land's End, the south-western tip of the UK. The passing of severe storms can be seen in the rising and falling of the sea state; the average significant wave height over the whole of each month is 4.4 m (January 1974), 3.4 m (February 1974), 1.8 m (August 1979) and 4.1 m (November 1986), with individual measurements of significant wave height varying between about one and eleven m.

As well as varying within months with the passing of weather systems, the sea state varies from month to month throughout the year, from winter storms to relatively calm summers, with intermediate transitional conditions during spring and autumn. Fig 31.16, again from Seven Stones LV data, shows this annual cycle using the overall average value of significant wave height for each calendar month: the January value (month 1) is the average of all January values from all years, etc.

This timescale of climate variation is caused in the North Atlantic by i) the poleward summer migration of the mid-latitude atmospheric front between warm tropical and

WIND

Deep SEA
SAILING
BY
ERROLL BRUCE

caused by the … with the high lapse-rat… …like the stable conditi… … any time give an indic… …esence of turbulence a…

Disturba… …rt distance above it, bu… …g craft. In coastal waters it is often … …e seems to increase the wind strength, although in fact … wind is unchanged, but the turbulence is greater. In the open ocean a heavy sea will increase the turbulence of the air; this is particularly noticeable in the Gulf Stream whose current, sometimes running locally at 5 knots, often causes a confused sea; yet as soon as a yacht crosses out of the fast running waters of the Stream, not only does the sea at once become more placid but the wind feels more modest as well.

It is an utter fallacy to believe that open waters always enjoy steady winds.

Measurement of wind.

Wind strength is measured by the Beaufort scale, in which the various Forces represent mean wind velocity at a height of 33 feet above the sea. The correct Beaufort scale number does not show the force of the strongest gust, which will be an amount greater than the mean depending on the turbulence. In the typhoon mentioned in the last page the anemometer recording, during the height of the storm, showed that the mean wind speed was 110 knots, or Force 17 on the Beaufort scale, although two gusts exceeded 160 knots.

As a very general guide, in cyclonic winds above gale force the fiercest gusts will be about 40 per cent higher than the mean wind force. Conversely a yachtsman noting an actual wind velocity of 50 knots by the anemometer at his masthead should not record the wind as Force 10, which is a whole gale; it may well be only Force 7, which is not a gale at all. Very close to the surface of the sea the wind strength will be far less than the mean velocity of 33 feet, so the reading of a hand anemometer held by a man in the cockpit will give no true comparison with the Beaufort figure; on one occasion with a moderate wind in the open sea, sails were lowered and a hand anemometer held 16 feet up the mast recorded 35 per cent higher than another identical

WAVES

perhaps seventee

would be overtal ... nning

Apparent frequency ...				
Running at 6 knots	Close hauled (48 degrees to wind) at 4.5 knots	Period	Length	Speed
Seconds	Seconds	Seconds	Feet	Knots
8	3.2	4	82	12
8.2	4.1	5	125	15
8.5	5.1	6	184	18
9.8	Too rough	7	250	21
10.4		8	326	24
11.3		9	413	27
12.0		10	510	30
13.0		11	617	33
14.0		12	734	36

Table XIII*a*. Apparent and actual wave characteristics

Table XIII*b* shows the mean waves that might be expected in the open ocean after various winds have been blowing for certain times, starting from a calm sea. Nature ridicules averages, and the seaman is concerned with the extreme sea that may endanger his vessel; in practice it is likely that the highest wave will be forty per cent greater than the mean, or higher still when such factors as currents affect the movement of the water. With the stronger winds the wave height will usually be limited by fetch in the open sea; thus a Force 8 gale will only raise 17 feet high mean waves in twenty-four hours if the wind is blowing over the sea for 500 miles to windward; a Force 6 strong breeze needs a fetch of 200 miles to reach 8.5 feet in the same time.

Rough sea.

In a strong wind waves of different lengths, and therefore velocities, build up to form a rough sea. The fastest waves will move at the speed of the wind forming them, and possibly even faster, but these waves are low and have only a small influence on the sea. The predominant waves, which are the highest, will probably work up to about two-thirds of the wind speed, but the varying velocities of different wave systems

WIND WAVES WEATHER
NSW WATERS
APPS.

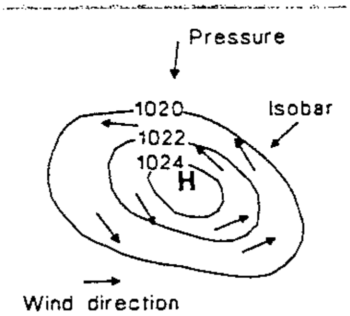
Wind is the movement of air. Wind speed is directly related to the pressure gradient. Hence when you see the isobars close together on a weather map, you can expect strong winds in that area. Near the surface of the earth wind blows at a slight angle across the isobars towards the lower pressure. This angle is greater over land than over water due to the greater friction over land.

In Australia, wind observations are averaged over ten minutes and units are either in knots (kn) for maritime and aviation purposes, or in kilometres per hour (km/h) for other purposes. One knot is equal to 1.85 km/h. Wind needs to be averaged over a short time interval because it consists of gusts of differing strengths and directions. Wind direction is the direction from which the wind blows, and is usually described in terms of the eight compass points N, NE, E, SE, S, SW, W, NW. Hence, a wind described as SW 15 knots is a wind blowing from the southwest with a ten-minute mean speed of 15 knots.

A wind gust is a sudden increase in the wind strength of very short duration (less than 20 seconds). The gustiness of the wind is increased by rough terrain (including buildings etc.), hence the wind flow over the land, or waterways close to land, will be gustier than over the smoother ocean.

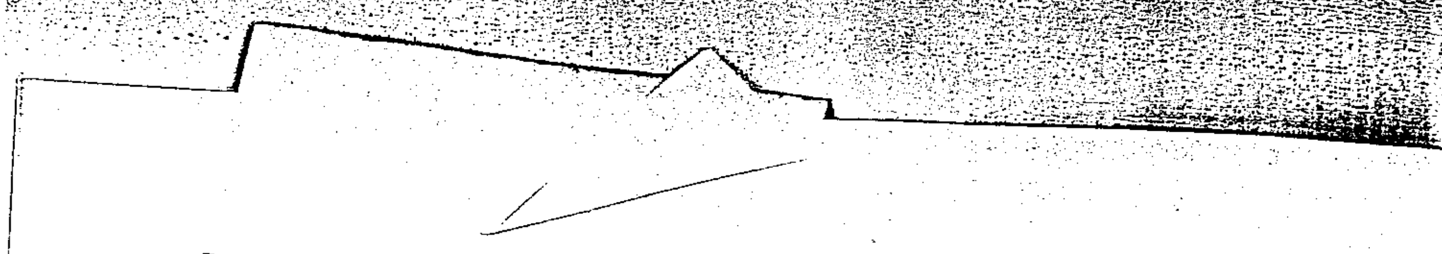
A squall consists of a sudden increase in the wind speed that lasts for several minutes before returning to near its former value. A squall may contain many gusts. The wind direction often changes in a squall.

High pressure systems (sometimes referred to as anticyclones) are regions where the air pressure is higher than the surroundings. They are denoted by the letter **H** on the weather map and have closed isobars around the centre. The isobars have progressively lower values away from the centre. Wind spirals in an anticlockwise direction out of highs in the southern hemisphere (clockwise in the northern hemisphere).



The air in a high is also gently descending and generally we find settled (or fine) weather with lighter winds. Near the coast this is not necessarily the case as the high may be directing moist onshore winds towards the coast with associated cloud and rain, and at other times local conditions can generate strong sea-breezes.

Low pressure systems (also known as depressions or cyclones) are regions where the air pressure is lower than the surroundings. The centre is usually denoted by the letter **L** on the weather map and is encircled by a number of closed isobars. These isobars have progressively higher values away from the centre.



Significant wave height is the average height of the highest one-third of the waves. It is about equal to the average height of the waves as estimated by an experienced observer.

Wind duration is the time over which the wind has been blowing.

Wind fetch is the distance upstream from the point of observation over which the wind blows with constant speed and direction.

Wind waves (local seas)

Wind waves are produced by the local prevailing wind. They travel in the direction of the prevailing wind, i.e. a northerly wind will produce southerly moving waves.

The height of wind waves depends on :

- the strength of the wind
- the time the wind has been blowing
- the fetch.

The higher the wind speed, and the longer the duration and fetch, the higher the wave and the longer the period. Wind waves are steeper than swell waves, with shorter periods and wavelengths. The sea appears more confused than for swell waves alone.

The tables at right show the significant wave height for various wind speeds, durations and fetches. For example, with a fetch of 40 nautical miles, a wind of 25 knots and a duration of about 6 hours, a significant wave height of 1.9 metres is expected. For longer fetches, a 40 knot wind blowing for 6 hours will give waves averaging 3.8 metres.

It is important to note that waves higher and lower than the average can occur. Generally, in open water, a wave of 1.86 times the significant wave height can be expected in every thousand waves. If the significant wave height is 3.8 metres, with a period of 7.7 seconds, then a wave of 7 metres can be expected every two hours or so.

Swell waves

Swell waves are wind-generated waves that have moved away from their area of formation. They may originate in the heavy seas created by a deep low pressure system offshore. As they move away, they become more rounded and regular in height and period and are often detected thousands of kilometres from their source area. As the swell travels, its height decreases and its period and wavelength increase, because short waves have too little energy to enable them to travel long distances against the action of friction. Swell waves are long waves in comparison with the wind waves and may have wavelengths from 30 to 500 times their wave height.

Offshore

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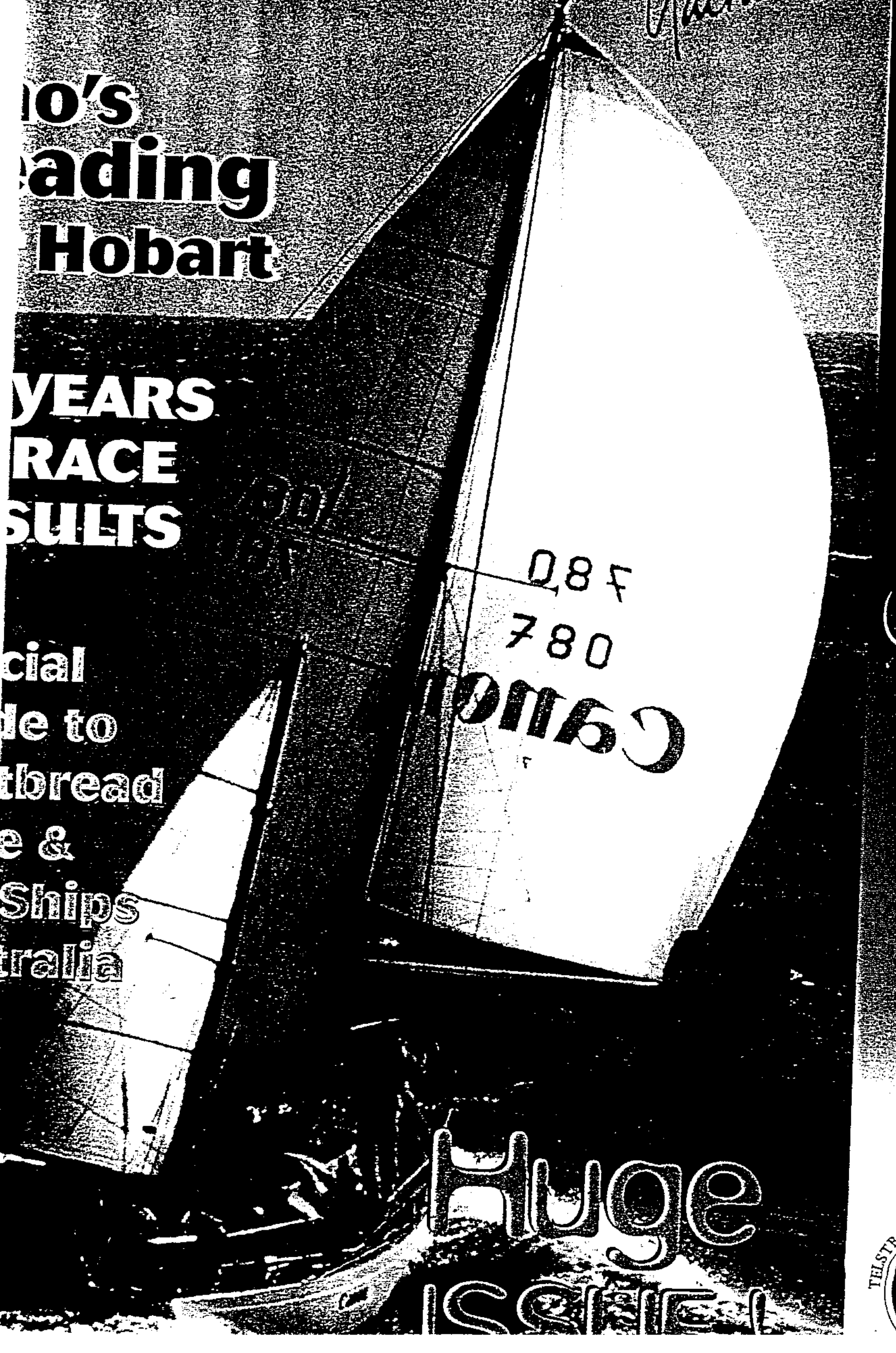
AZINE OF THE CRUISING YACHT CLUB OF AUSTRALIA

Yachting



Official Programme

TELSTRA SYDNEY TO HOBART

Weather Watch

To be or not to be...

A guide to weather prediction at sea with a Hobart race bias

Weather prediction is quite complex at the best of times as there are many variables to be taken into account.

It is made even more complicated at sea than compared to the land when one considers the relative lack of data available to the user.

One way of filling this void, is for YOU to perform regular, say at least every three hours, observations. These observations should include (write it down, our memory often forgets?)the following:

- wind direction and speed
- cloud type
- temperature (air and sea)
- barometric tendency and
- sea and swell conditions

By logging the above variables and noting any trends in conjunction with regular forecasts, you should be able to build up a picture of what is going on around you and in particular it is the observation of cloud, followed by the barometric tendency that will give you an indication of any impending significant changes.

It is these changes with which you are particularly concerned because you know what the weather is at the current time, and presumably comfortable with, but changes in both wind direction and speed for example, may affect your future strategy.

You should become very familiar with at least the 10 main cloud types, namely, cirrus,cirrostratus, cirrocumulus (high-level clouds), altocumulus, altostratus (middle-level clouds), nimbostratus, stratocumulus, stratus, cumulus and cumulonimbus (low-level clouds). A very good knowledge of what we call accessory clouds in the trade is also recommended. Some examples of accessory clouds are as follows, arcus clouds which are more commonly known as roll and shelf clouds, mammatus, lenticularis, and pileus just to name a few.

There are many good weather books and cloud charts around for you to buy or borrow that will help you here (check out Boat Books). When you are happy with this aspect (it takes time!!!!) then you can start to concentrate on cloud sequences or trends. It is the sequence or trend that is very important for forecasting. An example of a "must know" cloud trend (outside of the tropics) is that associated with the passage of a cold front.

It goes like this, 20 to 36 hours before the arrival of the cold front, we will generally observe high-level clouds, 6 to 12 hours before-hand middle-level cloud will be observed and marking the leading edge of the front at the surface will be our low-level clouds. Please remember that from the point of view of cloud and weather, each cold front will be different, and that some fronts are cloud-free.

The aneroid barometer is your main instrument at sea to sense significant changes. It is the tendency, rise or fall over a time interval, of the pressure that we are interested in and not the instantaneous value. For example, a pressure rise or fall of say 6 hectopascals (6 millibars) or more over a 3 hour period will tell us that either we have at least strong winds or greater now or they are just around the corner!! The greater the pressure change over the three hour period the stronger the winds. Note: On a moving yacht the pressure tendency as calculated by you from the barometer is not for a fixed point.

For example, a yacht planing at 20 kts in an easterly direction while an active cold front is moving in the same direction at 25kts. In this case the barometric tendency on the yacht may show only a small rate of pressure fall whereas a nearby island may show a large fall, thus indicating a vigorous system. In this case the yacht's barometric tendency may be providing slightly misleading information. The equivalent pressure tendency for a stationary point is equal to the following: (pressure tendency on yacht) - (yacht's velocity x pressure gradient)

We will now just concentrate on wind forecasting for a while. The basic weather forecast obtained via radio (write it down or better still record it) will give both wind speed and direction and essentially there is little cause to argue with what the forecaster is suggesting. Please note that wind directions and speeds mentioned in official forecasts (and observations) are for a height of 10 metres (33 feet) above the ocean or land surface and are 10 minute averages. Gusts are generally not mentioned at all in forecasts!! So be aware!.

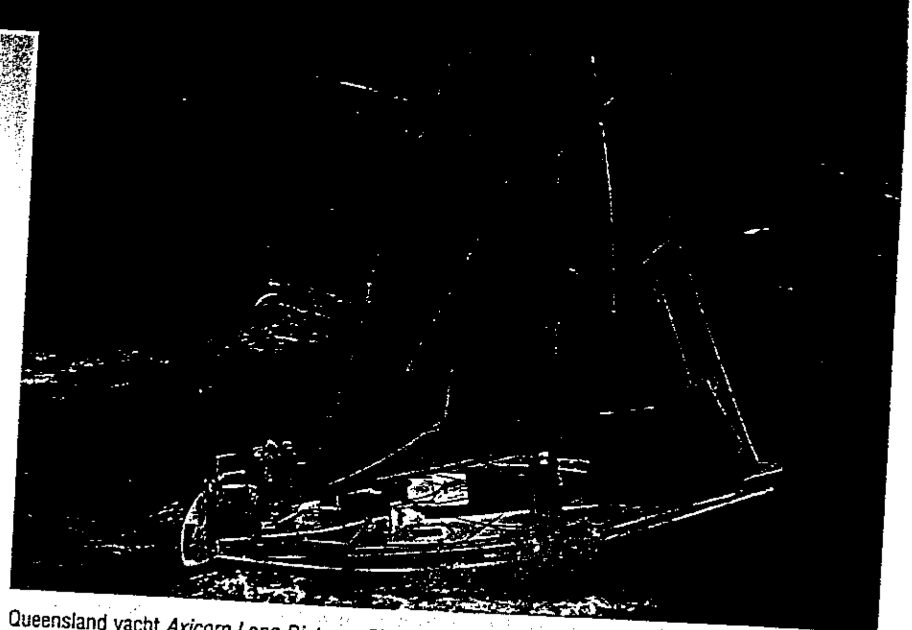
But we also need to know when a

cold front, for example, will be passing over us. You can obtain this information from the forecast but this will need to be fine-tuned by the Eye Ball Mark 1 Method, noting the cloud changes (as well as pressure changes) which herald the advance of the cold front and eventually its passage (as discussed above). But it has to be said that by the time you see the signs of the front the changes are probably imminent. Generally the stronger the front, the worse the wind/weather accompanying it. A weak front may pass through your area without any significant impact apart from a shift in the winds and a small drop in temperature).

Frontal forecasting is difficult especially during the warmer months as fronts can accelerate, slow down or disappear completely whilst making their passage along the NSW south coast. The mountains to the west can retard the passage of the front northward, particularly over and close to the mountains. Meanwhile, closer to the coast and further seawards, the front could be racing northwards at speeds around 30 to 40 knots.

The best example of this behaviour is the Southerly Buster. One sure way of forecasting the arrival of this event and other events, at least during the day, is to look to the south of your position and note the effect of the change on other boats. We can also hope that some low cloud is accompanying the change and note your barometric tendency (falling ahead, rising behind).

With a surface (or MSL = mean sea level) weather map (or analysis or anal) obtained from an onboard weatherfax, you are much more in control of the situation. The orientation and spacing of the isobars will give you a quick, broad picture of the wind situation as well as the position of the major weather feature(s). By comparing the current chart with the previous chart, you can estimate the approximate speed of the front (or any other weather system) and hence have a good idea of when the front, and hence a wind change, will arrive in your area (persistence forecasting).



Queensland yacht *Axicorp Long Distance Challenger* battling south soon after the start of the 1996 Telstra Sydney to Hobart Race. (Pic - Ian Mainsbridge)

A quick method to help you gauge the speed of the front and hence the approximate wind speed at the surface behind the change is to estimate the wind speed from the isobaric spacing just behind the front. This does unfortunately take some practice!! The average speed of a cold front and its associated low pressure system is approximately 25 knots over southern Australia. A high pressure system moves with an average speed of around 15 knots.

"Due to lack of observational data, experience suggests that over the oceans, alternating bands or areas of locally stronger and lighter winds can occur which the ocean or coastal waters forecasts tend to ignore at times."

One of the best tools available via onboard weatherfax is the surface prognosis (prog). This chart indicates either the human's or the computer's thoughts on where weather systems will be positioned at a particular time in the future. This product when used in conjunction with the methods outlined above, will help you more so, for example, establish the time of arrival of the cold front and hence the wind change over your area. Please remember that these charts are a good guide and not gospel!!

Having a weather chart as well as the transmitted weather forecast can give you a great deal of confidence in your ability to predict wind changes at sea. One problem however is the cost of a decent weatherfax. One solution is that most boats do not have a fax because of the costs involved. Don't despair! Coastal Waters and High Seas forecasts prepared by the Bureau of Meteorology are generally an excellent guide and all we need is the barometer, your weather knowledge and the Eye Ball Mark 1 Method to fine-tune the forecast. Good local knowledge gives you a big edge!!

After you predict the general windflow, the job does not stop there! One has to then take into account all the local variations which can affect your forecast.

These local variations are more likely to occur close to the coast (within 10 nm). However even in ocean waters (greater than 10 nm from the coast)variations can still occur. Due to lack of observational data, experience suggests that over the oceans, alternating bands or areas of locally stronger and lighter winds can occur which the ocean or coastal waters forecasts tend to ignore at times.

This is especially true of pure trade wind flow. Gusty winds will occur in the area around a cold front, but some evidence suggests that when we have a tight pressure gradient (isobars close together on a weather chart), the wind arranges itself in corridors of stronger wind interspersed with areas of lighter winds and these stronger winds can be 20 knots or more higher in speed than the average wind speed.

This situation is similar to waves at sea where we talk about average wave heights, but nonetheless there can be some waves at least twice that height.

So in trying to predict or fine-tune

Weather words of wisdom

Your homework begins (beside any reading and/or course-work) at least three weeks before the race commences with the religious collection of daily weather maps from say the Bureau of Meteorology's Weather by Fax service, dial 019 725210 for surface weather maps. You should check this service out further by dialling the main directory on freepoll 1800 630 100 for the main directory and freepoll 1800 061 440 for national services or the Bureau's home page on the World Wide Web **http://www.bom.gov.au** and getting into phase with the weather.

Know the frequency of frontal passages through Sydney, Bass Strait and Hobart (e.g. front through every two days in Hobart and Bass Strait and every three days in Sydney), how intense these frontal passages have been and the track of the front and its associated low pressure system. Information on the state of the East Australia Current can be obtained from the CSIRO home page at **http://www.dmr.csiro.au** also **http://anfl.pacit.tas.gov.au/shyr95/weather/csiro/latest_SST/latest_SST.html** and on a World Wide Web site at **http://www.rsmas.miami.edu/htbin/imagery/m:e aussiecurgac-0**

Another great site is the Telstra site at **http://syd-hob97.telstra.com/au**

During the race, listen to the special race forecasts (Radio relay vessel at sked times) and to any other weather (VIS, VIM, AM/FM commercial and ABC stations down the track and for those with mobile phones, the Bureau's Dial-It and 0055 services.

For those with an internet link during the race there is the Bureau's home page **http://www.bom.gov.au**, as well as one courtesy of the Tasmanian Government at **http://anfl.pacit.tas.gov.au/ shyr95/weather/**) and don't forget to monitor oceanographic conditions (your own observations) take down the details and fine-tune the game plan.

Coastal observations as read out in conjunction with coastal waters forecasts, for example, will give you some idea of what lies ahead or inshore of you. But please remember that these observing sites can be markedly affected by local effects, such as the topography around the site and the elevation of the site and most of the time will not be representative of conditions further offshore.

From a wind point of view the Derwent River generally shuts down after 2200 hr. So be prepared for some really light wind work between 2200 and 0700 hr on most occasions.

As far as basic race strategy is concerned, you cannot go past that offered by Tony Shaw in the ORCA Newsletter of November 1993. This excellent strategy was reproduced in last year's race issue.

At the end of the day, it is a feel (an emotional involvement) for the wind which no amount of weather forecasts and charts can generate, which will allow you to predict its behaviour and will take away some of the nasty surprises which seem to catch out yacht skippers who fail to realise the changes taking place.

Good, safe racing.

the wind direction and speed from a weather forecast, or a weather map or better still, both, you should always bear in mind that the wind could be stronger or lighter than the forecast suggests.

We also find that the wind is generally stronger over warm water and less in speed over colder water. If we have warm air over cold water, we have what is called a stable air-sea interface (sailing layer) and hence a marked wind shear situation.

This generally means more twist on port tack and less twist on starboard. With cold air over warm water, we have an unstable air-sea interface and hence a weak wind shear situation. This generally implies straighter leeches. This is one of the reasons why air and sea temperatures should be logged. Sea water temperature should be monitored from a current point-of-view along with GPS or traditional navigation procedures. GPS derived set and drift data should be averaged over a 30 minute period to be of any use.

Inshore the situation can be different again. Here not only can the funnelling/channelling effects around headlands, up and down river valleys and through straits have a significant effect on the strength of the wind, it can also have a marked effect on sea conditions, especially when wind opposes tide or current (remember the 1993 race).

High coastal cliffs/hills or mountains can create problems with both onshore and offshore winds. The rule is keep clear of coastlines by at least 10 times the height of the cliff/hill/mountain. Another rule is that offshore winds increase in speed and back (go left)in direction as they blow out over the water, onshore winds decrease in speed as they approach the land and the direction will veer (go right) a little.

If conditions allow, a sea breeze will setup and will be strongest within say, 5 nm of the coast and will be at its strongest during the mid to late afternoon. Some of the strongest seabreezes occur on the south coast of NSW. Sea breezes along the east Tasmanian Coast are northeasters and become southeasters along the south coast and in the Derwent (if you get there during daylight hours!

Under broad westerly flow, a big lee vortex is generally evident along the east Tasmanian coast. This means that light SE to NE winds will prevail from the coast (apart from sea breezes being strongest within 5 nm of the coast) out to approximately 50 nm. The upshot of all this is that a compromise will have to be struck regarding your position off the coast. A tricky one indeed??

"If conditions allow, a sea breeze will setup and will be strongest within say, 5 nm of the coast and will be at its strongest during the mid to late afternoon"

Reference: The RORC Manual of Weather at Sea by Dag Pike (David & Charles 1994)

Kenn Batt is available for meteorological advice and can be contacted on (02) 99180749 (after-hours) and (02)92961622 (work hours).

OCEANOGRAPHY & SEAMANSHIP
BY
W.G. VAN DORN

WEATHER INSTRUMENTATION

The basic weather measurements for shipboard forecasting are wind speed and direction, pressure, temperature, and humidity. Instrumentation is standard, and is described in most books on seamanship and navigation, but there are a few options worth discussing here, as well as some pointers on their employment and interpretation. Any of them may be obtained either as indicating or recording instruments. The former are much cheaper, and suffice for most ordinary purposes. But there is a certain advantage in being able to review at a glance the past few hours of a record to determine slow, average rates of change, which can be accomplished only with considerable effort and uncertainty by use of indicating instruments. As a first choice, most yachtsmen would elect a recording barograph, and secondly, a recording anemometer, but there is no particular necessity for recording temperature or humidity. Both of the latter can be obtained with a simple sling psychrometer, which can be whirled as often as desired.

The standard reference height for anemometers is 10 meters (33 feet) above the waterline. For a standard lapse rate, wind speed increases logarithmically with height above the sea, and any other mounting height can be corrected to standard height by using the curve of Fig. 28. In rough seas, a mast-mounted cup anemometer will read high by the amount of the average cross-wind velocity of the mast as a ship rolls or pitches. This error increases with mounting height, but on sailing craft a masthead mounting is still preferable to spreader mounting, where a larger error is introduced through distortion of the wind field by the sails. Masthead mounting also prevents possible fouling by flopping halyards, etc., and provides a better estimate of the average wind in heavy weather, when high seas significantly perturb the wind flow.

Gustiness is another factor that affects the determination of slow changes in the mean wind. Gustiness increases with increasing wind and sea state, and can amount to instantaneous readings that differ by as much as 50 per cent in speed and 10–15° in direction from the mean values, averaged over several minutes. Studies show that five-minute averages suffice to eliminate most gust effects under moderate weather conditions, but in heavy weather twenty-minute averages may be required. Indicating anemometers are not ordinarily capable of much longer than one-minute averages, but this period can sometimes be extended by special order from the manufacturer. Time-averaging with recording anemometers is readily accomplished by eye.

Mercury barometers are fast approaching extinction on shipboard, owing to their cost, fragility, and the number of corrections necessary to give a proper reading. Therefore these remarks concern only aneroid (bellows-actuated) pressure instruments, which are temperature-compensated and require no gravity correction. Recording barographs have no special mounting requirements, except to avoid exposure to extreme temperature changes and shock. These are best minimized by rubber-mounting in a central (midship) location, away from direct waves are further exaggerated by unequal growth rates. Hence, for all wind speeds above six knots—if not before—we can no longer follow the growth of representative, nearly identical waves, but must adjust our sights to deal with a statistical ensemble (directional spectrum) of waves, moving within, roughly, 50° of the wind direction. The ensemble contains waves of all heights and periods from a lower limit dictated by capillary dissipation to some upper limit determined by a balance between the rates at which energy is supplied by the wind and removed by dissipative processes—principally breaking.

GROWTH AND DECAY OF A WAVE SPECTRUM

In most standard references, you will find it stated that the growth of a wave spectrum is governed by three factors: the wind *speed* (assumed uniform in space); its *duration* (assumed uniform in time); and the distance (*fetch*) over which it blows (assumed to be finite). It should be recognized that these factors are only idealizations that are rarely realized in nature and still harder to appraise. Still, our present—and reasonably successful—techniques for describing and forecasting the state of the sea depend upon assigning numbers to them, and using statistical hydrodynamic models for spectral growth under the assumed conditions.

Wave Statistics: In a statistical model, we temporarily forget about individual waves, wave groups, and the fact that any wave system can be considered as the simple superimposition of a number of ideal, periodic wave trains, although we shall later recover these concepts in considering ocean swell after it leaves the area of wave generation. Instead, we think of sea state as a spectrum of wave energy that is constant, or slowly changing, within a given region. In any such region, we attempt to specify, on the average, the present and future probability that certain numbers of waves of any particular height, wavelength, period, and direction of motion will be present.

The statistical sea surface is represented as a quasi-random and ever-changing pattern of bumps and hollows that *never repeats itself*. Thus our previous wave properties require redefinition, since it is manifest that the distance (wavelength) or time interval (period) between any two adjacent bumps passing a fixed point of observation are unlikely to be the same as those between preceding or succeeding bumps. Yet it is bumps and hollows that we actually see, and any realistic model must be expressed in terms of quantities that we can observe and measure.

For our new definitions, consider a statistically long (20-minute) record of sea surface elevation at a fixed location in deep water (Fig. 72), where the wind speed, direction, duration, and fetch are presumed known, or can be estimated from meteorological reports. We first divide the record into N equal parts at intervals of, say $\frac{1}{2}$ second. In a 20-minute record, we will have $N = 2{,}400$ intervals. Next, for each interval we tabulate the vertical distance (surface elevation) between

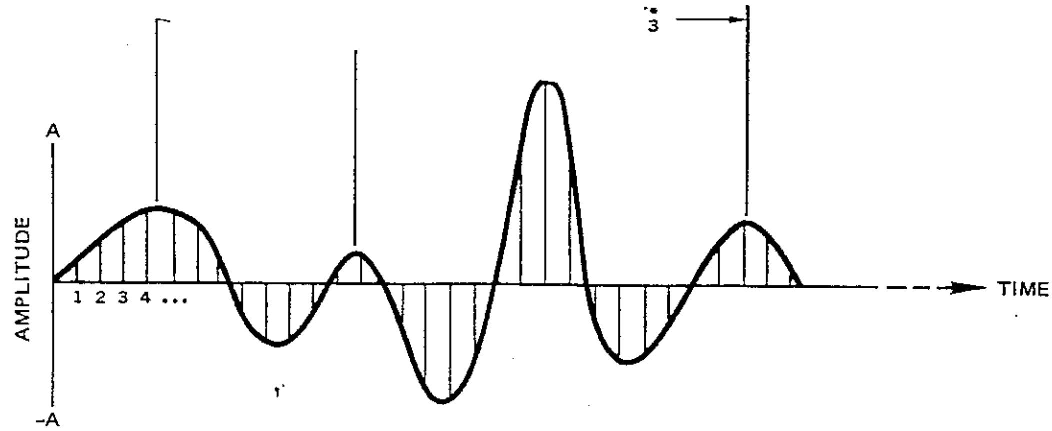


FIGURE 72 Deep-water wave-record sample, showing construction for statistical analysis.

the equilibrium (no wave) level and the wave profile, and label them A_1, $A_2 \ldots A_N$. We now define a number E as twice the average of the sum of the squares of the individual wave amplitudes:

$$E = \frac{2}{N}(A_1^2 + A_2^2 + \ldots A_N^2) \text{ ft.}^2$$

The number E* can be thought of as a measure of the average wave energy per unit surface area of the composite sea state during the time covered by our record. Analysis of many such records has shown that, within the generating area, wave heights are randomly distributed in space and time, and that if we can forecast E, we can estimate the probability of encountering waves of any height in a slowly changing sea state.

Certain properties of random waves let us say several things about their height distribution. The curve in Fig. 73 gives the percentage probability that all waves in a given sea state E will be higher than the heights (in feet) obtained by multiplying the appropriate numbers along the vertical scale by the square root of E. For example, the dashed lines indicate that 30 per cent of all waves will be higher than $2.2\sqrt{E}$ ft. This figure also lists four common height indices:

$H_f = 1.41\sqrt{E}$ = the most frequent probable wave height
$H_a = 1.77\sqrt{E}$ = the average height of all waves present
$H_3 = 2.83\sqrt{E}$ = the average of the highest one-third of all waves
$H_{10} = 3.60\sqrt{E}$ = the average of the highest one-tenth of all waves

The height index H_3 is often called the *significant* wave height, on the premise that mariners are chiefly interested in the larger waves present. From the distribution curve, the probability of encountering a significant wave is 15 per cent, roughly

*For the purposes of this book, we shall often use a more convenient wave parameter, $\sqrt{E}$ (ft.), which, for want of a better name, I shall refer to as the *sea state index*, or just *sea state*.

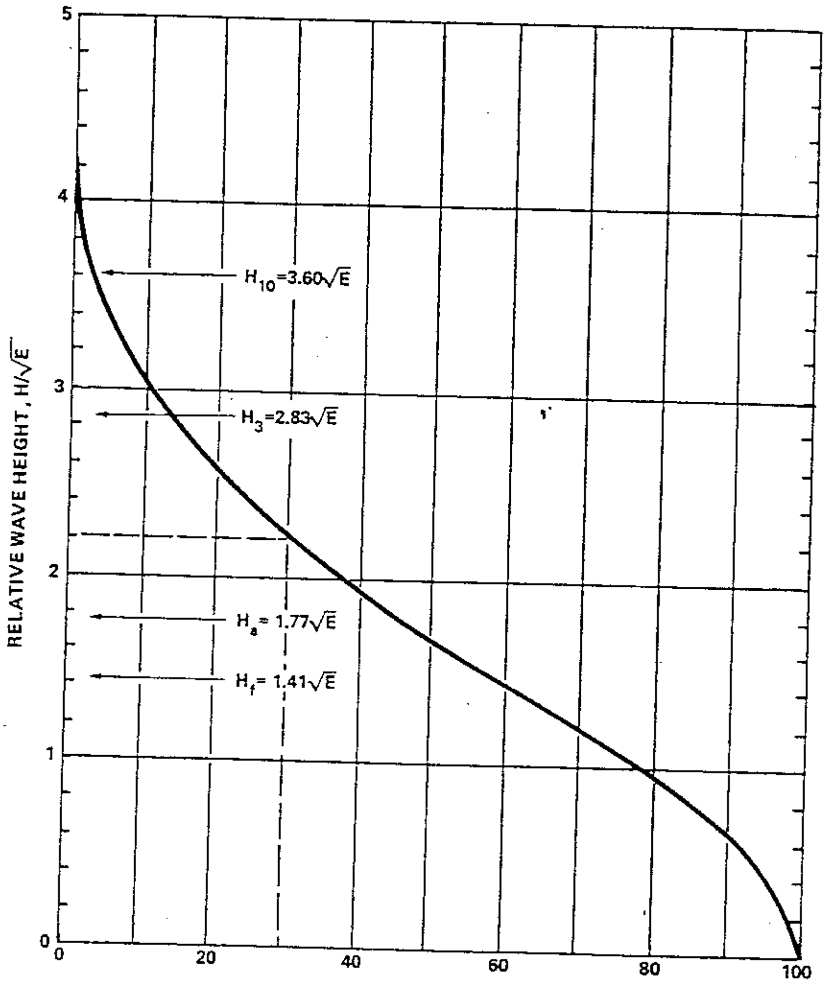
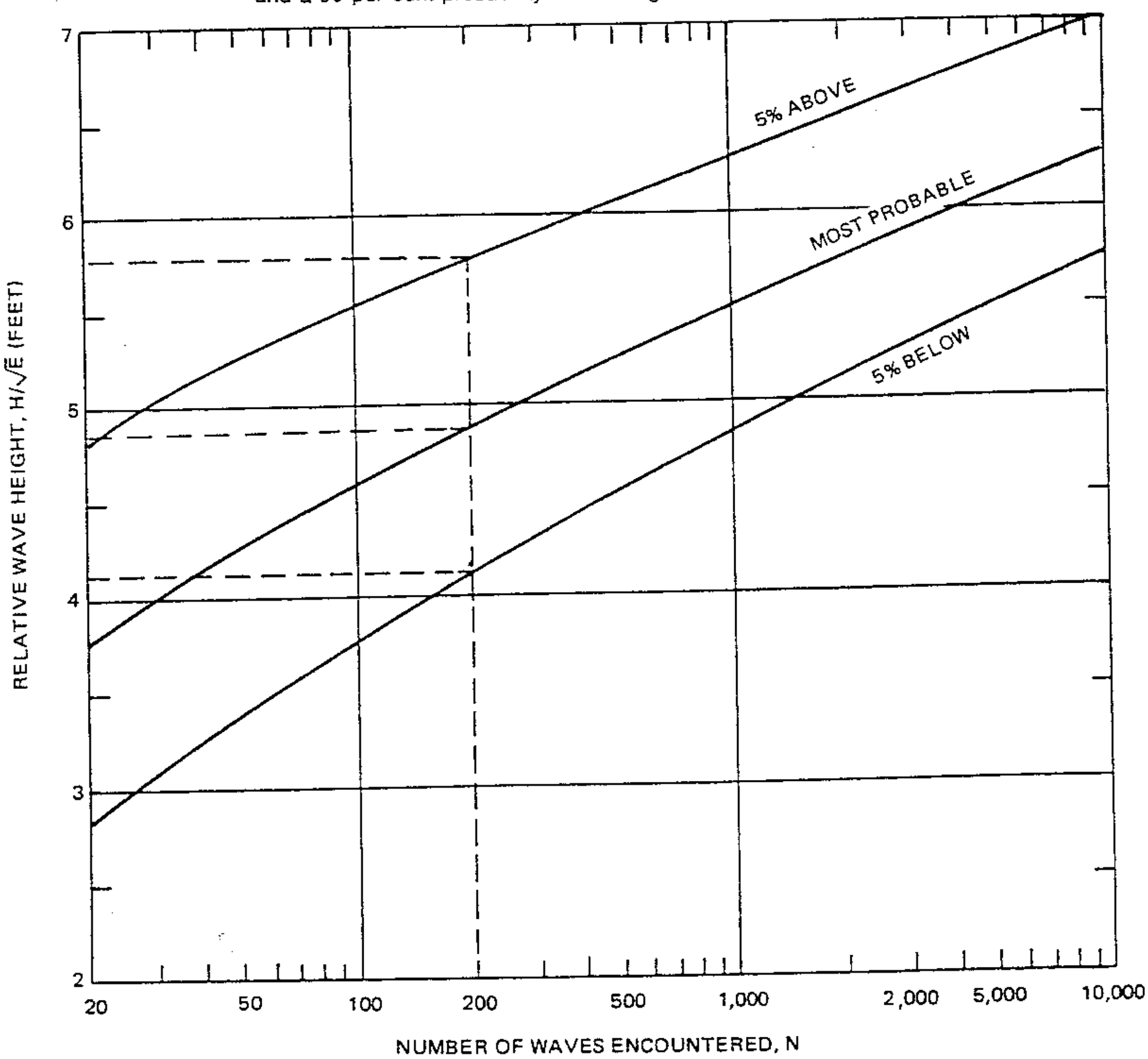


FIGURE 73 Wave-height distribution as a function of probability of occurrence in a random sea. Dashed example shows that, in a long record, 30 per cent of all waves will have heights greater than $2.2\sqrt{E}$.

in accord with the common saying, "Every seventh wave is highest." But, we are only dealing with statistics; one is as apt to encounter two such waves in succession as one in every thirty, etc. One must flip a coin an infinite number of times to have as many heads as tails.

The shape of the distribution curve is such that very high—or very low—waves are increasingly unlikely events, but both are of special interest. In heavy seas, a group of low waves may give you time to bring a ship about, shorten sail, or take an opportune navigation sight. A group of high waves may contain a giant, breaking, "rogue" wave that can poop a vessel, or pitch-pole her end for end. Because low waves are not dangerous, and because the probability of a succession of them cannot be calculated without specifying their number and size, we will say nothing more than that the chance is best following a succession of abnormally high waves. However, a single rogue wave can spell disaster, and its probability is easily estimated. Figure 74 gives the chance of encountering abnormally high waves, as a function of relative height and the total number (N) of waves encountered. At any sea state, E, the example (dashed lines) indicates that within any 200-wave sample there is a 5 per cent chance that one wave will exceed $H = 5.8\sqrt{E}$, an equal chance that it will be lower than $H = 4.1\sqrt{E}$, and a most probable value of about $4.8\sqrt{E}$. All three curves slope upward to the right,

FIGURE 74 Extreme wave probability increases with the number N of waves encountered. Example shows that there is a 5 per cent chance that the highest of 200 successive waves will exceed $H = 5.8\sqrt{E}$, the same chance that it will be lower than $H = 4.1\sqrt{E}$, and a 90 per cent probability of its being in between.



indicating that one runs the same percentage risk of encountering progressively higher waves, the more that have passed by. The length of time required to establish these probabilities depends upon the average wave period for any particular sea state, as defined below.*

Whereas the wave heights in a growing sea are randomly distributed, their periods and wavelengths are not. In Fig. 72 (p. 191), the time intervals between successive wave crests passing our recording station are labeled T_1^*, T_2^*, T_3^*, etc. In general, these intervals are all different, and bear no simple relation to the periods of the component ideal, periodic waves that happen to combine to produce the observed wave record. Yet, the theory of forecasting is based upon the statistics of observed waves and their relation to local wind conditions. Moreover, the forecasting curves, described below, assign a value of E to every ideal wave period present in a predicted spectrum, which, in turn, can be interpreted as the joint probability that waves of a certain height will occur at certain time intervals. Accordingly, we introduce new definitions for the observable wave "period" and "wavelength":

T^* = time interval between consecutive wave crests from an observed record
T_a^* = average of all of the above intervals from a given record
L^* = the distance between two adjacent crests, measured perpendicular to their direction of travel
L_a^* = the average of many consecutive measurements of L^*

The above quantities are purely statistical. For the purposes of this book, they are only used, in connection with the forecasting curves, to provide estimates of sea state and ship behavior. T^* and L^* do *not* obey the same relationship $L = CT = 5T^2$ given in Part IV for periodic progressive waves in deep water. However, their respective averages obey a similar law: $L_a^* = KT_a^{*2}$, where K is a constant that depends on the stage of sea state development. For practical purposes, K varies between the limits $2.6 < K < 3.4$ from an immature to a fully developed sea. A mean value, $K = 3.0$, will be at most 12 per cent in error at any sea state.

Since T_a^* is the average time interval between waves in a random sea, the total time required for N waves to pass a fixed observation point will be $NT_a^*/3{,}600$ hours. This relationship can be applied in using Fig. 74 to estimate the time-probability of extreme waves. Suppose that $T_a^* = 9$ seconds, a number easily obtained at sea by timing twenty to fifty waves. Then, for our previous example, $NT_a^*/3{,}600 = 200 \times 9/3{,}600 = \frac{1}{2}$ hour; e.g., we could expect the statistics cited to apply to any half-hour sample—provided that average conditions do not change over this interval. Fig. 74 applies best to slowly decaying swell, or to the short-term expectancy of ship motions. It can provide ball park estimates in fully developed or fetch-limited seas (see below), but will underestimate extreme-wave height in a rapidly growing sea.

However, as we shall see in Part VI, the speed of a moving vessel relative

*There is also a physical upper limit, not well established, due to breaking.

to the waves must be considered in determining the effective period of wave encounter, T_e, which would be used instead of T_a^* in estimating time probability. We will also show how similar probability estimates can be made of excessive—even catastrophic—ship motions, using the ship itself as an indicator of average conditions.

Sea State under Steady Winds: Ignoring wave energy that might be leaking into a given region from other sources, the wave spectrum described in Part IV provides all the information necessary to determine the sea state as a function of local wind conditions. Since wave energy is proportional to the square of wave amplitude A^2 (or height, H^2), an energy spectrum can be defined as a continuous curve that gives the appropriate value of A^2 for every wave period T within the ensemble of ideal, periodic waves that combine to form the sea state. As a hypothetical case, consider that a wind of constant speed $V > 6$ knots springs up over an infinite stretch of calm water bounded at its upwind end by a straight shoreline (Fig. 75a).* As described above, waves will be generated and continue to increase in amplitude and period until, locally, a steady state is attained, the nature of which depends upon the distance offshore (fetch), and whose time of establishment increases with distance. Ultimately, after a (somewhat poorly defined) time t_m, a condition defined as a *fully developed sea* (FDS) will be achieved at all distances beyond some minimum fetch F_m, and no further changes of sea state occur. Everywhere upwind of F_m, the average wave amplitude and range of periods present increase with fetch, from zero at the shoreline to their constant FDS values at—and beyond—F_m.

These changes with distance are qualitatively illustrated (Fig. 75b) by the spectral curves $S_1, S_2 \ldots S_m$, corresponding to successive offshore distances (fetches) $F_1, F_2 \ldots F_m$. The curves all arise from a common origin at the left, and initially follow the heavy curve for the fully developed spectrum S_m, but consecutively branch to the right, passing through successively higher energy maxima at successively longer periods $T_1, T_2 \ldots T_m$, after which they turn sharply downward and cut off along the period axis. The areas under the spectral energy curves give the total wave energy present in the local sea state at the respective fetches. Since the average energy density E of the actual sea state is, by definition, the same as that for the ideal wave spectrum, we can label these areas $E_1, E_2 \ldots E_m$. The total energy increases with offshore distance, but the fact that all the spectral curves are congruent toward the left shows that this energy increase is manifested by the progressive appearance of longer and higher waves. The rather abrupt cutoff of each spectrum near some maximum period indicates that there are few waves of longer period present at that particular fetch. The cutoff phenomenon is an observational fact of nature to which the forecasting theory has been adapted and, for fetches less than F_m, is attributed to the faster growth of small waves. The cutoff T_m at the minimum FDS fetch F_m—and the further observation that all

*The shoreline is not important; the upwind end of a fetch could as well be defined as the place where the wind starts to blow.

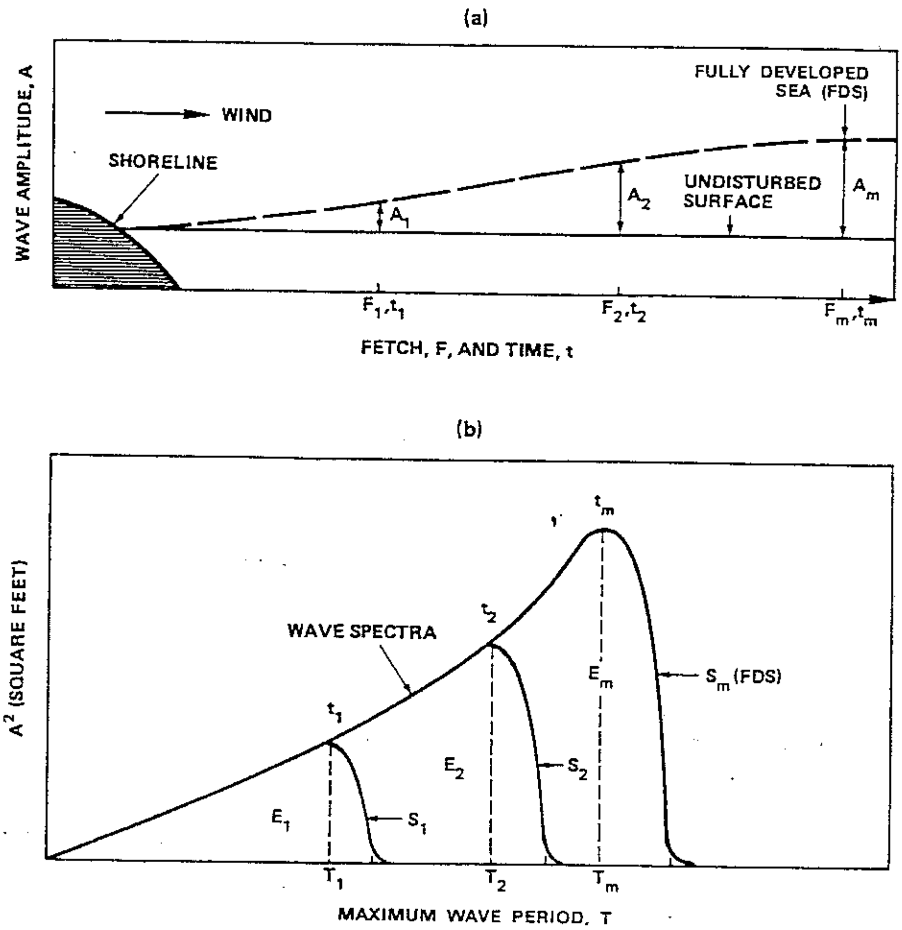


FIGURE 75 (a) Growth of wave amplitude as a function of fetch, *F*, and time, *t*, under a steady wind. An FDS state occurs beyond F_m after a time, t_m.
(b) Growth of a wave spectrum at corresponding fetches and times.

spectra are constant beyond F_m—is attributed to the fact that waves of this period travel as fast as the wind, and their subsequent growth is thereby arrested. However, careful studies indicate that there actually are some longer (but lower) waves present in the spectrum of a fully developed sea, but their contribution to the total wave energy present is negligible for all practical purposes.

Should the wind cease at any time $t < t_m$, or the available fetch be less than F_m (as, say, restricted by a lee shore), the equilibrium sea state is said to be *duration-limited* or *fetch-limited*, respectively. Waves will develop and grow offshore as before, but their growth will be arrested at some distance or time governed by whichever factor is limiting. If fetch-limited, the effect is merely to chop off the FDS wave spectrum at a period appropriate to the available fetch, beyond which a steady state will obtain. If duration-limited, the spectrum will be chopped off in the same way—but not necessarily at the same distance—at the moment the wind dies, and will begin to shrink again as the waves pass out of the area of generation, or are dissipated by viscosity or breaking.

To a reasonable approximation, the spectral curves of Fig. 75b can also be construed as giving the time history of sea state development at a fixed position. That is, curve S_1 is the spectrum for the equilibrium sea state prevailing at time t_1 at all points downwind of F_1, etc. Thus, with a steady wind of duration $t > t_m$, sea state growth at *any* distance $F > F_m$ will be defined by successive spectra S_1, $S_2 \ldots S_m$ at corresponding times $t_1, t_2 \ldots t_m$, as indicated. This important concept is the basis for our later discussion of sea state growth (see p. 206).

Properties of a Fully Developed Sea: Because it defines the upper limit of wave growth and the maximum range of wave periods to be expected in a steady wind field, the FDS spectrum S_m provides a convenient estimate of maximum sea conditions wherever the fetch is unlimited and the average wind can be forecast (as, for example, in the trade wind belts). This is because its relevant parameters are all simple functions of wind speed, V (knots):

$\sqrt{E_m} = 0.0068V^2$ feet = maximum sea state at fetches greater than F_m
$F_m = 3.65V^{4/3}$ miles = minimum fetch to establish an FDS*
$t_m = 6.43V^{1/3}$ hours = minimum wind duration to establish an FDS
$T_m = 0.38V$ seconds = period associated with highest waves in spectrum
$T_a^* = 0.29V$ seconds = average observable wave period
$L_a^* = 3.4T_a^{*2} = 0.28V^2$ feet = average wavelength in FDS spectrum.

While the theoretical FDS spectrum contains all ideal periods from zero to infinity, the waves near its ends are so small that, for practical purposes, only periods within the range $4 < T < T_m$ seconds need be considered.

The reader need not be concerned about evaluating the fractional powers of V in these equations; all of them (except L_a^*, which would not fit nicely on the same graph) are plotted for convenient reference in Fig. 76. For example, with a steady wind of 30 knots, the small arrows indicate the respective FDS values: $\sqrt{E_m} = 6.0$ feet, $F_m = 340$ miles, $t_m = 20$ hours, $T_m = 11.2$ seconds, and $T_a^* = 8.4$ seconds.

If the wind persisted for at least 20 hours, and the available fetch were at least 340 miles, we could use Figs. 73 and 74 to make the following maximal sea state forecast:

$H_f = 1.41 \times 6.0 = 8.5$ feet = most frequent (most probable) wave height
$H_a = 1.77 \times 6.0 = 11$ feet = average height of all waves
$H_3 = 2.83 \times 6.0 = 17$ feet = significant wave height
$H_{10} = 3.60 \times 6.0 = 22$ feet = average height of the highest 10 per cent of all waves

*If a background sea exists before the wind starts to blow, t_m may be considerably shorter (see p. 217).

From Fig. 73, we can also determine, say, that:

10 per cent of all waves will be higher than 3 × 6.0 = 18 feet
10 per cent will be lower than about 0.6 × 6.0 = 3.6 feet
90 per cent will be between 3.6 and 18 feet high

From Fig. 74, and with $T_a^* = 8.4$ sec., there will be a 5 per cent chance of encountering a single wave higher than 5.8 × 6.0 = 35 feet among every 200 waves that pass during an average interval of 200 × 8.4/3,600 = 0.47 hr. Conversely, within five hours, about 5 × 3,600/8.4 = 2,600 waves will pass, among which there will be a 5 per cent expectancy of a single wave higher than 6.6 × 6.0 = 40 feet, or nearly four times the average wave height! Thus we see that there is a small—but real—chance of encountering a really big wave every few hours, even in a moderate sea.

Figure 76 indicates how rapidly the various FDS wave parameters increase with wind speed. Given enough time and sea room, any wave height index (H_a, H_{10}, etc.) increases as V^2; i.e., they will all be 36 times higher at $V = 60$ knots than at 10 knots. But total wave energy increases as the fourth power of wind speed, and will be *1,300* times higher at 60 knots than at 10 knots! Comparative values for other parameters are given in Table 3, from which we can see that the minimum duration t_m to reach FDS conditions increases by only 80 per cent, while the minimum fetch required is about 11 times larger.

TABLE 3 Comparative FDS wave parameters at 10 and 60 knots

V (knots)	t_m (hrs.)	F_m (mi.)	T_m (sec.)	T_a^* (sec.)	L_a^* (ft.)
10	14	80	3.7	2.9	28
60	25	870	22	17	1,000

The spectacular growth of the FDS spectrum, even between wind speeds of 20 and 40 knots, is illustrated in Fig. 77. The spectrum for 10 knots would be invisible at this scale, and that for 50 knots 44 per cent larger than for 40 knots.

At this point, we digress from statistics for the moment to consider the physical appearance of the sea surface at various stages of development. Probably the most familiar description of sea state at successively higher wind speeds is given by the misnamed* Beaufort Scale of Wind Force (Table 4). The Beaufort Scale is concerned mainly with apparent wave height, and the relative prevalence of breakers, whitecaps, spray, and foam streaks. The test of its reliability is how consistently these features correlate with wind speed alone. Although we still have no quantitative data on the incidence of wave breaking in random storm seas, it should be evident from our previous discussion that only FDS conditions are reproducible functions of wind speed. With a limited fetch and high winds, the waves can be just as high (or higher) than in an FDS state at much lower wind speeds. But

*The Beaufort Scale increases roughly as $V^{2/3}$. Wind force, however measured, increases as the square of wind speed, as do all FDS wave height indices.

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isobars strive to ev creating bands of increased pressed. It is not easy to find evidence of these phenomena because they can only be determined by closely spaced comparative measurements which are not available over sea areas and which may not necessarily prove reliable when taken over land areas where the varying effects of friction and land shape can give a false impression. However experience at sea in open sea conditions away from the land does suggest that there can be considerable local variations in wind strength which generally occur in, or at least are particularly noticeable in, more extreme wind conditions. This suggests that there is a greater instability in the pattern of isobars in these conditions than the general weather maps might suggest and that these variations are often more than just gusts of wind. These gusts are a short-lived counterpart of the wide variations of wind strength and, to some extent, direction which can be expected in more extreme conditions.

Gusts are a feature of most strong wind situations and reflect the general instability of the wind, instability generated by the turbulence of the wind in contact with the sea. Everyone with a sailboat will be aware of these gusts which are generally short-lived, usually lasting for only a few minutes but often increasing the wind strength by up to two numbers on the Beaufort Scale. Squalls are a somewhat similar phenomenon but tend to be related more to temperature differences in the air and so to be more prolonged and generally more visible. Squalls are often associated with rain, and it can be the condensing of the water vapour contained in clouds which releases heat, which in turn provides the thermal energy which helps to generate the squall. Whilst not easily predictable in terms of location, squalls can be predictable in a more general way as a result of the prevailing meteorological conditions. We will look at them in more detail

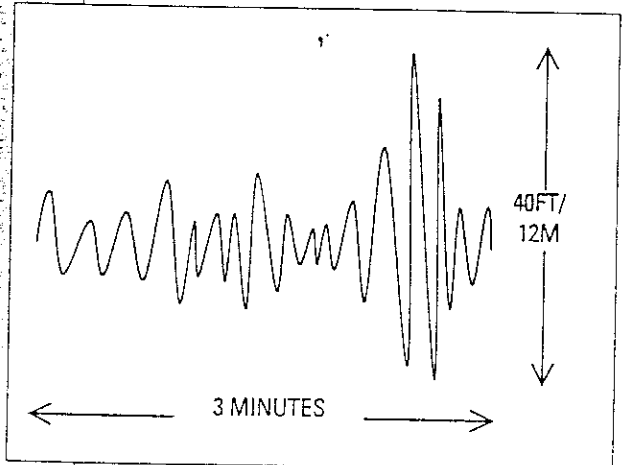
Wind speed range	Factor for maximum gust speed	Factor for mean gust speed	Factor for assessing yacht mean speed
Daytime			
Force 3-4	2.0	1.6	1.8
Force 5-6	1.8	1.5	1.25
Force 7-8	1.6	1.5	1.25
Night-time			
Force 3-4	1.9	1.5	1.5
Force 5-6	1.8	1.5	1.5
Force 7-8	1.7	1.5	1.5

This table provides a means of calculating the maximum winds which can be expected based on forecast values. The forecast value doesn't allow for gusts, whereas the table shows the wind speed can be double the forecast strength. Gusts tend to be less violent at night, hence the reduced correction factors.

crossing. There could be three or four, in which case trying to forecast wave height and conditions can become very difficult.

Significant Wave Height

From this you might think it was almost impossible to forecast wave height. However, there is almost invariably one predominant wave train which sets the pattern, and this is usually what the forecasters are talking about in their forecast of wave height – but even then, if you look at the recordings of wave conditions from wave recorders mounted on buoys or ships you will see a considerable variation of wave heights within a particular wave train. The forecasters try to make the expected sea conditions more comprehensible by using what they call the significant wave height as the basis of their forecast.



Typical trace from a wave recorder which shows how much larger waves can be found in a generally moderate wave train.

Significant wave height, as we mentioned briefly in Chapter 3, is defined as the average of the highest one-third of the waves passing a particular point. This height has been selected because it tends to agree reasonably well with the wave heights reported by experienced observers on board ships when they are trying to estimate the average height of the highest of the waves in a particular wave pattern. Forecasters use the significant wave height because it will conjure up a particular picture in the minds of experienced mariners and they will know what the forecaster has in mind. What the significant wave height does not tell you is the maximum height of waves which might be found in a wave pattern; yet it is this height which often exercises the minds of yachtsmen and there is considerable concern about the occurrence of 'freak' waves which are part of the folklore of going to sea. The term 'freak' tends to suggest that these more extreme waves are totally unexpected and unpredictable, but this is not quite true. One has only to look at the statistics from wave recorders to recognise that these higher than normal waves do exist and that they are definable.

Very Large Waves

There are various figures which relate to these so called 'freak' waves, and one commonly quoted value forecasts the highest wave which may pass a particular point over a ten minute period. Research suggests that this highest wave will be 1.6 times the significant wave height. If you take a three hour period then the highest wave experienced in that time could be twice the significant wave height. These statistics themselves can be quite frightening and, put another way, they suggest that one wave in every 23 will be twice the average height, one wave in 1,175 will be three times the average height, and one wave in every 300,000 will be four times the average height. Note here that the statistics are talking about the *average* wave height and not the significant wave height. Nonetheless, they give food for thought.

These statistics are certainly worth bearing in mind when you are at sea in rough weather because they emphasise the need always to keep something in hand rather than push your boat to the limits. However they do need to be put into perspective. Firstly, the average height of a wave train is lower than you might think. We tend to judge the sea solely by the larger waves we encounter, as it is these waves which have a greater impact, and we tend to forget or ignore the smaller waves. Waves of twice the average height would probably be included among the larger waves which registered in our minds when trying to estimate the height of waves at sea. This is why the significant wave height has been established as a yardstick because it gives a better indication of the larger waves normally encountered in an average sea.

Secondly, if you take a wave period of 10 seconds, which can be fairly average in rough seas, then this means that there are 6 waves a minute, 360 waves an hour, and 8,640 waves per 24 hours passing a given point. This means that the chance of meeting that one wave in 300,000 which is four times the average height, is fairly remote, particularly bearing in mind that these waves tend to be transient rather than travel as huge waves over long distances. However statistics are one thing and reality is another, and that wave four times higher than average could be just waiting around the corner as the next wave, rather than one perhaps 300,000 waves away. We talk about experiencing freak waves which come out of the blue, but 'rogue waves' might be a better term to use and the biggest problem faced by those experiencing these waves is perhaps not so much the actual height of the wave, but whether it is breaking or not. A very large wave appearing out of the blue on its own is not particularly dangerous if the gradient of the wave is still similar to that of the smaller waves. Where the risks occur is when this larger than normal wave is generated with a wave length similar to that of the smaller waves. Then of course the gradient steepens dramatically and suddenly this larger than normal wave is also a breaking wave, and this is when trouble can start. As these large waves tend to be generated from a combin-ation of existing wave peaks which are superimposed one on top of the other to create the extra height, then they can occur with a short wave length and a very steep gradient and that is when you can get into severe difficulties.

Out in the sea where the waves are not generally breaking except for the comparatively gentle action of 'white horses' and similar instability, the

The Users Guide to the Aus. Coast
By
Greg Laughlin

'rough' lake surrounded by hills ($\alpha > 0.3$), and the region has an annual average wind speed of 16 knots, we can expect the smooth lake to experience, annually, 15 gusts to 20 knots, 12 gusts to 40 knots, 4 gusts to 60 knots and 1 gust to 80 knots. In sharp contrast, at the rough lake we can expect 1400 gusts to 20 knots, 1100 gusts to 40 knots, 400 gusts to 60 knots, 60 gusts to 80 knots and 5 gusts to 100 knots. These figures are based on probability equations and should be used with great caution (think of the probability when playing Two-up or when trying to toss 3 heads in a row). But the numbers show a very sharp increase in the gustiness of the wind for a relatively modest increase in surface roughness. Although lakes are used in this example, the principle holds true for near off-shore winds in much the same way.

To take an example over a much shorter period — say, 5 minutes: if the wind speed at 100 metres above the surface is 40 knots, then one can expect the peak 1–3 second gust to be 56 knots. Closer to the ground, at 30 metres, the peak gust could be 60 knots and at 2 metres 70 knots. Of course, the rougher the ground, the greater this effect.

WIND AND BARRIERS

The behaviour of wind blowing around (and over) three-dimensional objects such as islands, headlands, ridges and even mountain ranges is important for users of the Australian coast, particularly those who either 'harness' the wind for motive power (for example, hang-gliders and sailors) or those who can be directly influenced by it (powerboaters and surfers).

As a rule, the stronger the wind, the stronger the effect of topography on it. Many sailors will have experienced fluky and gusty airflows close downwind of steep islands or near cliffs in an off-shore wind. In landlocked estuaries or where mountains come close to the shore, the steady wind that blows out at sea may be translated to an unpredictable horror, with strong and seemingly random shifts in direction and strength. This makes it important to know about the kind of local wind and turbulence effects you may encounter and the reasons behind them. As the patterns of wind flow around a topographic feature 100 metres high by 1 kilometre long are quite different from those around one of the same shape but ten times bigger, the subject is best dealt with by referring to small scale effects and large scale effects.

Effects at small scales

'Small scale' means landscape features no bigger than tens of metres in height and up to some hundreds of metres across. Together with the wind strength, this scale determines what wind patterns to expect. In the main, the winds described in the following scenarios are fresh breezes or, if the winds are light, it is daytime.

The small islet

Imagine sailing downwind towards a small steep islet that is roughly circular. Its height is h and diameter d. The islet is quite steep, so we can expect to see all the possible wind patterns demonstrated, especially separation or reversal of wind direction behind the islet — a phenomenon that occurs behind steep obstacles only. The breeze is fresh, around 20 knots and not too gusty. As we approach and round the islet we encounter three areas with quite different wind regimes. These are shown in Figure 3.6, where the wind's streamlines close to the water are shown as blue, those about halfway up the islet as green and those a small distance above the islet as yellow. The grey 'cloud', particularly noticeable downwind of the islet, is the area where most wind disturbance occurs.

Immediately upstream of the islet, in what we might call region A, the average wind speed reduces and turbulence or gustiness increases. The winds start to swerve to the right or left of the islet. Region A does not extend very far upwind (the upper limit is about equal to the height of the islet, h) — its extent being shown by where the three sets of streamlines start to become distorted upwind of the islet: this is well upwind of the grey region of maximum disturbance.

As we round the islet to the right or left (region B), the average wind speeds up and the turbulence levels, both in absolute terms and relative to the average wind, decrease. This effect also extends barely one islet height out from the shoreline and is most pronounced close in — the extent is shown by where the three sets of streamlines are no longer

General factors contro... wave height

The main factors affecting wave height are:

- wind speed — the higher the wind speed, the larger the waves
- wind duration — the longer the wind has been blowing, the higher the waves will become
- fetch — the longer the distance for which the wind has been acting (over water), the larger the waves will become
- water depth — the deeper the water, the larger the waves (excluding cases where deep water abruptly becomes shallow)
- the presence of ocean currents — an opposing current tends to reduce wavelength and to increase wave height; a current travelling in the same direction as the waves tends to increase wavelength and decrease wave height.

'Rogue', 'freak' or 'king' waves

The phenomenon of significant wave height (H_s) can help to explain what we call 'rogue', 'freak' or 'king' waves. On average, approximately 1 in 1000 waves reaches 1.85 times the significant wave height. Given that, at sea, a typical wave period might be 10 to 11 seconds (and correspond to an average wavelength of about 200 metres), then a 'rogue' wave will occur on average once every 3 hours (that is, 1000 waves with period 10 to 11 seconds will pass the observer in about 3 hours). All boaters should consider this carefully: if the waves are averaging 2 metres and the boat is handling them with little trouble, don't become complacent — sooner or later (usually in less than 3 hours!) a wave of 4 metres or larger will pass. The 'one-in-a-thousand' concept is useful not only for those at sea; experienced rock fishers will always tell you never to turn your back on the ocean. Unexpectedly large waves have washed many of their fellow anglers off the rocks.

> It is not a matter of *whether* a large wave will occur, but *when*! Frequently – and all too frequently in the media – one hears reports of 'rogue' or 'freak' waves. Such reports actually contribute to a belief that these large waves cannot be predicted and therefore accidents and fatalities are an act of God. Large waves *will* occur; what we are less sure of is precisely *when*.

...ry useful, it is important to bear ... e 1 to 1000 relation is a statistical generalisation, much the same as expecting an equal number of heads and tails in coin tossing (which will certainly happen in the long term, as all gamblers know).

All wave height graphics in this section refer to significant wave height, as do most forecasts and wave height reportings.

Wave heights in open water

Seas and swell

Most people who use coastal, sea and oceanic waters (that is, non-inland waters) use two terms to describe the state of the water at any given time. These are the *seas* and the *swell.*

Seas (or sea waves) are waves generated more or less locally by wind and still under the influence of this wind. Sea waves usually do not move very far away from the area in which they were generated.

Swell (or swell waves) are derived from sea waves that have travelled well away from the area where they were generated — which may be hundreds, if not thousands, of kilometres out to sea. They arrive as regular, organised 'sets'. The distance between successive swell waves is usually longer (that is, swells have longer wavelengths than seas) and have a smooth, rounded appearance. They can be formed by tides, coastal landslides, storms at sea, undersea earthquakes, and so on; but most commonly they are caused by wind sustained over a long period of time and over a long fetch (recalling that fetch is the distance the wind has travelled over water).

> Because seas are still under the influence of the wind that caused them, they generally travel in the same direction as the prevailing wind. Sea waves tend to be more irregular (choppy, disorganised) than swell waves.

As wind is always gusty, it is not hard to understand that it will push down harder on some parts of the water than others, causing distortions or ripples. These rapidly grow to the point where they are big enough to affect the flow of the wind. Once this happens, the wind will exert a stronger force on the windward side than the leeward side of the chop, causing it to grow rapidly in size (and produce what are called 'newly formed seas'). Provided that the wind continues to blow, waves will continue to grow so long as they receive more energy from the wind than they dissipate (usually by breaking). As will be shown in more detail later, wave height depends on sea surface roughness (the rougher the surface, the more 'grip' the wind has), wind speed (the stronger the wind, the larger the waves), wind duration (the longer the wind blows, the larger the waves will become) and fetch (the longer the fetch, the bigger the waves).

Newly formed seas are very chaotic and disorganised. The largest waves are formed by storms — often a series of storms — at sea. As the waves continue to grow, the windward wave surface becomes steeper and steeper until the wave height approaches about one-seventh of the wavelength. Once the steepness reaches 1:7, the wave usually breaks, forming whitecaps and spray. Waves merge, overtake each other, cancel each other out and generally interact randomly until, after a certain amount of time, the energy received approximately equals that lost; this is called a 'fully developed sea'. Both the time taken and the fetch required for a fully developed sea increases with increasing wind.

> Sea waves (seas) generally move more *slowly* than the wind that generated them due to 'slippage' between the wind and the waves it causes.

As the waves continue to develop they tend to fan out from the storm area, gradually forming lower, longer and more rounded swell waves. Since the waves have fanned out (this is called 'angular dispersion') their energy is dissipated over a greater area, hence the wave height is reduced. Swell waves lose little energy as they move and can thus travel vast distances.

> Swell waves (swell) generally move *faster* than the wind that generated them due to complex interactions (for example, 'leapfrogging') which take place over several days and hundreds to thousands of kilometres of ocean.

Figure 4.6 shows a model of the development of seas and swell in open ocean under the influence of a storm. This is shown in terms of both fetch (distance) and time, since waves take a finite time to travel such distances.

The transition of seas into swell does not happen over short distances or in short periods of time. We have already seen that seas tend to be higher and steeper than swell, but by how much? And how fast do seas and swell travel in relation to the wind that formed them? In order to answer these questions clearly, we need to look more closely at wave behaviour.

Initially, the wind starts to blow on calm water, forming ripples that quickly become chop. Chop tends to be fairly steep (5 per cent, or 1:20) and moves much more slowly than the wind causing it; a rule of thumb is that chop moves at about 20 per cent of the wind speed.

However, as the wind continues, the waves become not only bigger, but steeper as well; in a fully developed sea, where energy lost equals energy gained, the waves are very steep (10 per cent, or 1:10) and move at about 50 per cent of the wind speed. The wave height will depend on wind speed.

As the waves move well away from where they were generated, they become very much flatter (2 per cent, or 1:50) and may end up travelling as fast as, or faster than, the wind that generated them. When fully mature, swell wave velocity is proportional to wavelength. Despite the theoretical distinction between seas and swell, it is unlikely, after fifty or so hours of constant wind — particularly if it's strong, that there will be any real difference between a well-developed sea and a swell; some waves could have travelled 500 kilometres away from where they first formed.

Relationships between swell-wave velocity, wavelength and wave period

In mid-latitude waters, the following simple relationships apply to swell-wave velocity, periodicity and wavelength (where velocity is in metres per second, wavelength in metres, and periodicity, T, in seconds).

$$\text{swell wave velocity} = 1.25\sqrt{\text{wavelength}}$$

$$\text{swell wave velocity} = 1.56 \times \text{waveperiod}$$

$$\text{wavelength} = 1.56T^2$$

These equations are practical and useful for

21

"27."

From: 450301492@telstra.ves.net <450301492@telstra.ves.net>
To: peter_campbell@bigpond.com <peter_campbell@bigpond.com>
Date: Saturday, 26 December 1998 4:23
Subject: Message from Inmarsat-C mobile

This email was sent from Sword of Orion during the Telstra Sydney Hobart 1998 Race courtsey of Tetra.

Sword of Orion, the Reichel Pugh 44 is now climbing back thru the fleet, carrying a red flag after a collison on the start with Nokia.

It has just moved past Ninety Seven, the Farr 47 and is very gradually closing on Quest, the Nelson-Marek 46 as the IMS B fleet surfs toward Wollongong, in 2-3 knots of current and strengthening northerly sea breezes.

During the start line incident Sword of Orion sustained severe damage.

The damage to the three starboard staunchions has been repaired, however delamination occurred in a metre long section at the starboard stern quarter.

Of major concern however is the damage sustained by the mast. There is a compression crease about 2 metres above the deck.

Rob Kothe

Sword of Orion

"28"

RFD

YELLOW
ISSUED WITH NEW LIFERAFTS

IMPORTANT NOTICE

SECURING YOUR LIFERAFT TO THE DECK

IMPORTANT: If you use this kit or another system of your own design it is imperative that your liferaft be adequately secured. Continuous motion of your vessel at sea might gradually stretch and/or loosen the lashings. Check them periodically. Waves over the deck in adverse conditions can produce substantial forces. A knockdown or rollover could exert even more. Strong lashings can help prevent inadvertent loss of your liferaft.

a) Ensure the stainless steel pad eyes supplied in this kit are strongly fastened to the deck and that the deck itself is up to the task. RFD recommends "through fastening" with backing plates or washers under the deck. Use stainless steel nuts and bolts in preference to self-tappers.

b) This kit includes approximately 1 metre of 600 lb. breaking strain cord which can be used to attach pelican hook, snap shackle or other manual quick release device to the webbing lashings. RFD recommends multiple turns to join the release to the lashings for added strength. Shackles can facilitate.

c) Our kit is optional and is supplied as an aid to satisfactory installation. It is suitable for most vessels but might not suit all, e.g., boats with pronounced deck cambers, sloping surfaces, canvas or vinyl areas, etc.

d) RFD recommends that you regularly inspect your liferaft's lashings for tightness and for signs of UV degradation. Renew at first signs of wear, chaffing or other deterioration.

e) Suitable securing of your liferaft is solely your responsibility. RFD does not accept responsibility for any failure to adequately install and maintain your liferaft-to-deck system.

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RFD

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SUED EACH YEAR WITH
"REMINDER" NOTICES FOR WHEN
RAFTS ARE DUE FOR SERVICE

IMPORTANT NOTICE

NOW IS THE TIME TO CHECK THE CONDITION OF THE LASHINGS THAT SECURE YOUR LIFERAFT TO THE DECK.

Continuous motion of your vessel at sea might gradually stretch and/or loosen the lashings. Waves over the deck in adverse conditions can produce substantial forces. A knockdown or rollover could exert even more. Strong, secure lashings can help prevent inadvertent loss of your liferaft.

1) RFD recommends regular checking of your liferaft's lashings for tightness and for signs of UV or other degradation. Renew them at first signs of wear, chaffing or other deterioration.

2) Ensure strong attachment of quick release mechanism (usually pelican hook or snap shackle) to the webbing lashings. Use multiple turns of cord to attach one to the other - or shackle them together.

3) RFD does not install liferafts nor does it accept responsibility for any failure to adequately install or maintain your liferaft-to-deck securing system. Securing your liferaft is solely the responsibility of the owner/skipper of the vessel.

For friendly advice, please contact our offices listed below.

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