Mid Latitude Cyclones

Mid latitude cyclones are part of the subpolar low pressure system that extends around the entire Southern Hemisphere in a belt centred on 40° to 60°S latitude, the so called 'Roaring Forties and Raging Fifties'. The northern side of this system forms the southern boundary of the subtropical high pressure system. Like the high it shifts with the seasons, moving closer to the southern Australian continent in winter and further south in summer. The lows or cyclones that are embedded in this belt are continually moving from west to east. On average, one passes south of Australia every three to four days with between 80 and 100 passing south of the continent each year. These cyclones are responsible for both the spiralling westerly wind streams and the persistent southerly waves that arrive on average 350 days a year along the southern Australian coast. While they tend to pass south of the state during summer, during winter they shift northwards and penetrate into the southwest and occasionally as far north as Shark Bay, as indicated by the winter rainfall pattern (Fig. 1.9a).

Local winds and sea breezes play a major role in the climate and coastal processes around much of the Western Australian coast. Figure 1.10 illustrates the summer and winter 9 am and 3 pm wind roses. During summer winds tend to be lighter and more variable in the morning, whereas in the afternoon the onshore sea breeze dominates all locations, though its direction ranges from southeast, to south to west around the coast. The sea breeze is particularly strong along the west coast (see Perth, Carnarvon, Port Hedland, Broome) and contributes to the local wind waves climate, as well as locally wind driven currents. In winter winds tend to be offshore in the morning and light onshore in the afternoon, indicating a weaker sea breeze.

Figure 1.9a shows the annual *rainfall* pattern, with the humid northwest and southwest receiving up to 800 mm, and the large arid central coastal zone and centre with rainfall less than 400 mm. The seasonality is also highlighted and clearly shows the summer maxima in the north associated with the northwest monsoons and occasional cyclones, which bring 400 mm as far south as Broome, and lesser amounts as far south as Shark Bay. In winter the reverse applies with the humid cold fronts bringing up to 800 mm to the southwest corner, and penetrating as far north as Shark Bay. The coast between Shark Bay and Eighty Mile beach and the interior however remain relatively dry with annual rainfall less than 400 mm.
The annual and seasonal temperature pattern is illustrated in Figure 1.9b. It highlights the latitudinal gradation in *temperature*, with annual means of 27°C in the north grading down to 18°C along the south coast. During summer high temperatures extend south with all of the state above a 20°C mean, while in winter cooler temperatures prevail, with only the northwest averaging over 20°C. There is a slight moderating in summer temperatures along the coast owing to the impact of the southerly sea breezes. Likewise in winter temperatures are slightly warmer along the coast adjacent to the warmer ocean waters, as the interior cools under the clear dry high pressure conditions.

Ocean Processes

Oceans occupy 71% of the world's surface. They therefore influence much of what happens on the remaining land surfaces. Nowhere is this more the case than at the coast and nowhere are coasts more dynamic than on sandy beach systems. The oceans are the immediate source of most of the energy that drives coastal systems. Approximately half the energy arriving at the world's coastlines is derived from waves; much of the rest arrives as tides, with the remainder contributed by other forms of ocean and regional currents. In addition to supplying physical energy to build and reshape the coast, the ocean also influences beaches through its temperature, salinity and the rich biosphere that it hosts.

There are eight types of ocean processes that impact the Western Australian coast, namely: wind and swell waves, tides, shelf waves, ocean currents, local wind driven currents, upwelling and downwelling, sea surface temperature and ocean biota (Table 1.5). Each of these and their impacts are discussed briefly below.

Ocean Waves

There are many forms of waves in the ocean ranging from small ripples to wind waves, swell, tidal waves, tsunamis and long waves, including standing and edge waves; the latter lesser known but very important for beaches. In this book, the term 'waves' refers to the wind waves and swell, while other forms of waves are referred to by their full name. The major waves and their impact on beaches are discussed in the following sections.

Wind Waves

Wind waves, or sea, are generated by wind blowing over the ocean. They are the waves that occur in what is called the area of wave generation; as such they are called '*sea*'. Five factors determine the size of wind waves:

- *Wind velocity* - wave height will increase exponentially as velocity increases;
- *Wind duration* - the longer the wind blows with a constant velocity and direction, the larger the waves will become until a fully arisen sea is reached; that is, the maximum size sea for a given velocity and duration;
- *Wind direction* will determine, together with the Coriolis force, the direction the waves will travel;
- *Fetch* - the area of sea or ocean surface is also important; the longer the stretch of water the wind can blow over, called the fetch, the larger the waves can become;
- *Water depth* is important, as shallow seas will cause wave friction and possibly breaking. This is not a problem in the deep ocean, which averages 4.2 km in depth, but is very relevant once waves start to cross the Western Australian continental shelf, which averages less than 100 m, and particularly as waves encounter the shallow rocks and reefs which dominate much of the coast resulting in smaller waves at the shore.

Swell

Wind waves become swell when they leave the area of wave generation, by either travelling out of the area where the wind is blowing or when the wind stops blowing. Wind waves and swell are also called free waves or progressive waves. This means that, once formed, they are free of their generating mechanism, the wind, and they can travel long distances without any additional forcing. They are also progressive, as they can move or progress unaided over great distances.

Once swell leaves the area of wave generation, the waves undergo a transformation that permits them to travel great distances with minimum loss of energy. Whereas in a sea the waves are highly variable in height, length and direction, in swell the waves decrease in height, increase in length and become more uniform and unidirectional. As the speed of a wave is proportional to its length, they also increase in speed (Fig. 1.11).

A quick and simple way to accurately calculate the speed of waves in deep water is to measure their period, that is, the time between two successive wave crests. The speed is equal to the wave period multiplied by 1.56 m. Therefore a 12 sec wave travels at 12 x 1.56 m/s, which equals 18.7 m/s or 67 km/hr. In contrast, a 5 sec wave in the gulfs travels at 28 km/hr, whereas a 14 sec wave travels at 79 km/hr. What this means is that the long ocean swell is travelling much faster than the short seas and that as sea and swell propagate across the ocean, the longest waves travel fastest and arrive first at the shore.

Swell also travels in what surfers call 'sets' or more correctly *wave groups*, that is, groups of higher waves followed by lower waves. These wave groups are a source of long, low waves (the length of the groups) that become very important in the surf zone, as discussed later.

Swell and seas will move across the ocean surface as *progressive waves*, through a process called orbital motion. This means the wave particles move in an orbital path as the wave crest and trough pass overhead. This is the reason the wave form moves, while the water, or a person or boat floating at sea, simply goes up and down, or more correctly around and around. However when waves enter water where the depth is less than 25% of their wave length (wave length equals wave period squared, multiplied by 1.56; for example, a 12 sec wave will be 12 x 12 sec x 1.56 = 225 m in length and a 5 second wave only 39 m long) they begin to transform into shallow water waves, a process that may ultimately end in wave breaking. Using the above calculations this will happen on the open coast when the long 12-14 sec swell reaches between 50 and 80 m depth, while in the northwest the short 3-5 sec seas will begin to feel bottom between 5 and 10 m.

Wave Shoaling

As waves move into shallow water and begin to interact with the seabed or 'feel bottom', four processes take place, affecting the wave speed, length, height, energy and ultimately the type of wave breaking (Fig. 1.12).

- *Wave speed* decreases with decreasing water depth.
- Variable water depth produces variable wave speed, causing the wave crest to travel at different speeds over variable seabed topography. At the coast this leads to *wave refraction*. This is a process that bends the wave crests, as that part of the wave moving faster in deeper water overtakes that part moving more slowly in shallower water.
- At the same time that the waves are refracting and slowing, they are interacting with the seabed, a process called *wave attenuation*. At the seafloor, some potential wave energy is transformed into kinetic energy as it interacts with the seabed, doing work such as moving sand. The loss of energy causes a decrease or attenuation in the overall wave energy and therefore lowers the height of the wave.
- Finally, as the water becomes increasingly shallow, the waves shoal, which causes them to slow further; and, decrease in length but increase in height, as the crest attempts to catch up to the trough. The speed and distance over which this takes place determine the type of *wave breaking*.

WAVE TYPES: sea and swell

Waves are generated by wind blowing over water surfaces. Large waves require very strong winds, blowing for many hours to days, over long stretches of deep ocean.

Sea waves occur in the area of wave generation, in close vicinity to the mid latitude cyclones, with sea breeze conditions around the coast and accompanying the northwest monsoon and Trade winds in the north.

Swells are sea waves that have travelled out of the area of wave generation. Swell dominates the southern Australian open coast, however much energy is lost along the west coast as they encounter shallow nearshore reefs.

Wave Breaking

Waves break basically because the wave trough reaches shallower water (such as the sand bar) ahead of the following crest. The trough therefore slows down, while the crest in deeper water is still travelling a little faster. Depending on the slope of the bar and the speed and distance over which this occurs, the crest will attempt to 'overtake' the trough by spilling or even plunging forward and thereby breaking (Fig. 1.13).

There are three basic types of breaking wave:

- *Surging breakers,* which occur when waves run up a steep slope without appearing to break. They transform from an unbroken wave to beach swash in the process of breaking. Such waves can be commonly observed on steeper beaches when waves are low, or after larger waves have broken offshore and reformed in the surf

OCEAN WAVE GENERATION, TRANSFORMATION AND BREAKING

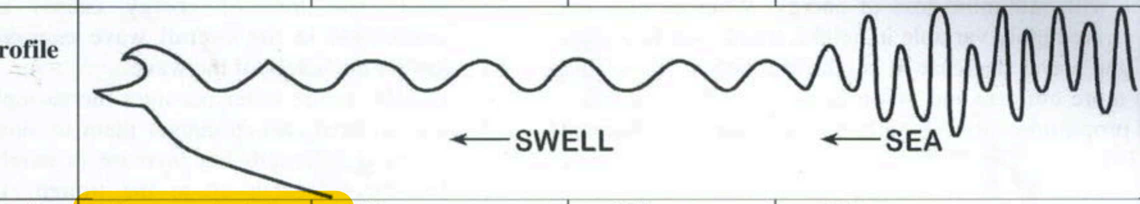
Wave Type	**Breaking**	**Shoaling**	**Swell**	**Sea**
Environment	Shallow water – surf zone	Inner continental shelf	Deep water >> 100m	Deep water >>100m Long fetch = sea/ocean surface Wind velocity↑waves↑ Wind duration↑waves↑ Wind direction = wave direction
Distance travelled	~100 m	1 to 100 km	100s to 1000s km	100s to 1000s km
Time required	Seconds	Minutes	Hours to days	Hours to days
Wave profile				
Water depth	1.5 x wave height	<100m	>>100m	>>100m
Wave character	Wave breaks Wave bore Swash	Higher Shorter Steeper Same speed	Regular Lower Longer Flatter Faster	Variable height High Short Steep Slow
Example:				
Height (m)	2.5 to 3	2 to 2.5	2 to 3	3 to 5
Period (sec)	12	12	12	6 to 8
Length (m)	0 to 50	50 to 220	220	50 to 100
Speed (km/h)	0 to 15	15 to 60	66	33 to 45
Distance travelled (km/day)			1600	800 to 1100

Figure 1.11 Waves begin life as 'sea' produced by winds blowing over the ocean or sea surface. If they leave the area of wave generation they transform into lower, longer, faster and more regular 'swell', which can travel for hundreds to thousands of kilometres. As all waves reach shallow water, they undergo a process called 'wave shoaling', which causes them to slow, shorten, steepen and finally break. This figure provides information on the characteristics of each type of wave. The Western Australian coast receives year round swell on all open southwest and south coasts, with shorter wind waves associated with strong sea breeze conditions, especially along the west coast, and the northern northwest summer monsoons.

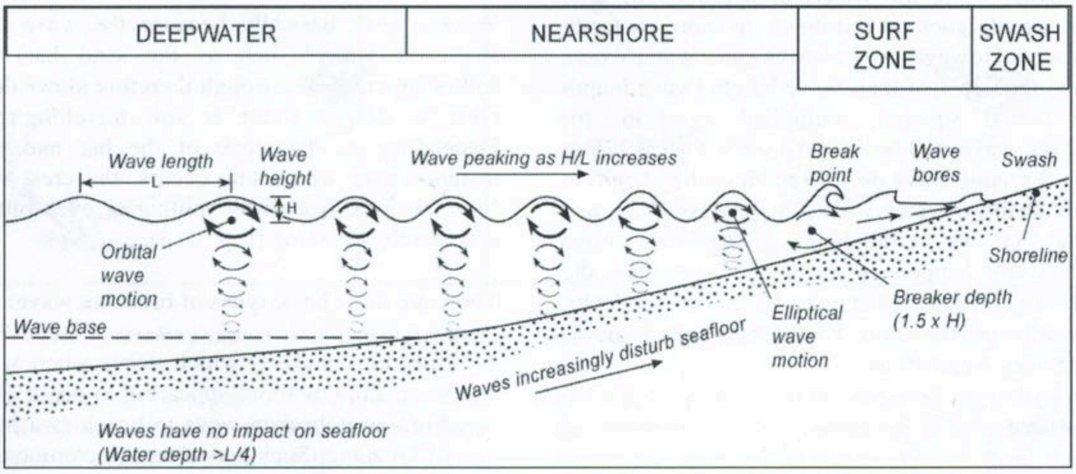


Figure. 1.12 As waves move into shallow coastal waters they shoal and in doing so slow, shorten, steepen and may increase in height. At the break point they break and move across the surf zone as wave bores (broken white water) and finally up the beach face as swash . Below the surface, the orbital wave currents are also interacting with the seabed, doing work by moving sand and ultimately building and forever changing the beach systems.

Figure 1.13 Long regular swell breaking at Sand Patch, South Coast.

zone. They then may reach the shore as a lower wave, which finally surges up the beach face as swash.

- *Plunging or dumping waves,* which surfers know as a tubing or curling wave, occur when shoaling takes place rapidly, such as when the waves hit a reef or a steep bar and/or are travelling fast. As the trough slows, the following crest continues racing ahead and as it runs into the stalling trough, its forward momentum causes it to both move upward, increasing in height, and throw forward, producing a curl or tube.

- *Spilling breakers* on the other hand occur when the seabed shoals gently and/or waves are moving slowly, resulting in the wave breaking over a wide zone. As the wave slows and steepens, only the top of the crest breaks and spills down the face of the wave. Whereas a plunging wave may rise and break in a distance of a few metres, spilling waves may break over tens or even hundreds of metres.

Broken Waves

As waves break they are transformed from a progressive wave to a mass of turbulent white water and foam called a *wave bore.* It is also called a *wave of translation*, as unlike the unbroken progressive wave, the water actually moves or translates shoreward. Surfers, assisted by gravity, surf on the steep part of the breaking wave. Once the wave is broken, boards, bodies and whatever can be propelled shoreward with the leading edge of the wave bore, while the turbulence in the wave bore is well known to anyone who has dived into or under the white water.

Surf Zone Processes

Ocean waves can originate thousands of kilometres from a beach and can travel as swell for days to reach their destination. However, on reaching the coast, they can undergo wave refraction, shoaling and breaking in a matter of minutes to seconds. Once broken and heading for shore, the wave has been transformed from a progressive wave containing potential energy to a wave bore or wave of translation with kinetic energy, which can do work in the surf zone.

There are four major forms of wave energy in the surf zone - broken waves, swash, surf zone currents and long waves (Table 1.6).

- *Broken waves* consist of wave bores and perhaps reformed or unbroken parts of waves. These move shoreward to finally reach the shoreline where the bore immediately collapses and becomes swash.
- *Swash* runs up and down the beach as uprush and stops, then end of the wave. Some soaks into the beach, while the remainder runs back down as backwash. Some of the backwash may reflect out to sea as a reflected wave, albeit a much smaller version of the original source.
- *Surf zone currents* are generated by broken and unbroken waves, wave bores and swash. They include orbital wave motions under unbroken or reformed waves; shoreward moving wave bores; the uprush and backwash of the swash across the beach face; the concentrated movement of the water along the beach as a longshore current; and where two converging longshore or rip feeder currents meet, their seaward moving rip currents.
- The third mechanism is a little more complex and relates to *long waves* produced by wave groups and, at times, other mechanisms. Long waves accompany sets of higher and lower waves. However, the long waves that accompany them are low (a few centimetres high), long (perhaps a few hundred metres) and invisible to the naked eye. As sets of higher and lower waves break, the accompanying long waves also go through a transformation. Like ocean waves they also become much shorter as they pile up in the surf zone, but, unlike ocean waves, they do not break, but instead increase in energy and height toward the shore. Their increase in energy is due to what is called 'red shifting', a shift in wave energy to the red or lower frequency part of the wave energy field. These waves become very important in the surf zone, as their dimensions ultimately determine the number and spacing of bars and rips.

As waves arrive and break every few seconds, the energy they release at the break point diminishes shoreward, as the wave bores decrease in height toward the beach. The energy released from these bores goes into driving the surf zone currents and into building the long waves. The long wave crest attains its maximum height at the shoreline. Here it is visible to the naked eye in what is called *wave set-up* and *set-down*. These are low frequency, long wave motions, with periods in the order of several times the breaking wave period (30 sec to a few minutes), that are manifest as a periodic rise (set-up) and fall (set-down) in the water level at the shoreline. If you sit and watch the swash, particularly during high waves, you will notice that every minute or two the water level and maximum swash level rises then rapidly falls.

Table 1.6 Wave motions in the surf zone

Wave form	Motion	Impact
Unbroken wave	orbital	stirs sea bed, builds ripples
Breaking wave	crest moves rapidly shoreward	wave collapses
Wave bore	all bore moves shoreward	shoreward moving turbulence
Swash	up-down beach face	controls beach face accretion & erosion
Surf zone currents	water flows shoreward, longshore and seaward (rips)	moves water and sediment in surf, builds bars, erodes troughs
Long waves	slow on-off shore	determines location of bars & rips

The height of wave set-up is a function of wave height and also increases with larger waves and on lower gradient beaches, to reach as much as one third to one half the height of the breaking waves. This means that if you have 1, 2, 5 and 10 m waves, the set-up could be as much as 0.3, 0.6, 1.5 and 3.0 m high, respectively. For this reason, wave set-up is a major hazard on low gradient, high energy Western Australian beaches, as occur along parts of the South East and South coasts.

Because the waves set up and set down in one place, the crest does not progress. They are therefore also referred to as a *standing wave*, one that stands in place with the crest simply moving up and down. These standing long waves are extremely important in the surf zone as they help determine the number and spacing of bars and rips.

Western Australian Wave Climate

While it is easy to see waves and to make an estimate of their height, period, length and direction, accurate measures of these statistics are more difficult. If we are, however, to properly design for and manage the coast we need to know just what types of waves are arriving at the shore. Traditionally, wave measurements have been made by observers on ships and at lighthouses visually estimating wave height, length and direction. This was the case in Western Australian lighthouses until they were automated in the 1970s. Since then the only wave measuring system has been operating off Perth.

The Datawell Waverider buoy is the present state-of-the-art on-site wave recording device. It operates using an accelerometer housed in a watertight buoy, about 50 cm in diameter. The buoy is chained to the sea floor, usually in about 80 m water depth. As the waves cause the buoy to rise and fall, the vertical displacement of the buoy is recorded by the accelerometer. This information is transmitted to a shore station and then by phone line to a central computer, where it is recorded. The first Australian Waverider buoy was installed off the Gold Coast in 1968. Today, Queensland and New South Wales have a network of Waverider buoys stretching from Weipa to Eden, the most extensive in the world.

There is just one permanent Waverider off Perth for the Western Australian coast. A number of buoys have been deployed temporarily at 40 sites, primarily near ports, between Esperance and Ningaloo. Data from these deployments is available from the Department of Infrastructure and Planning. In the Southern Ocean the Bureau of Meteorology maintains Waverider buoys off Cape Du Couedic in South Australia and Cape Sorell in Tasmania. The waves recorded at these sites are discussed later.

Wave climate refers to the seasonal variation in the source, size and direction of waves arriving at a location. Waves on the Western Australian coast originate from six possible sources - mid latitude cyclones and the large high pressure systems, and the more localised sea breeze systems in the south and west, and in the northwest from the offshore Trade winds and summer onshore westerly monsoonal winds, as well as infrequent tropical cyclones (Table 1.7)

Swell

Mid latitude cyclones produce year round swell that arrives right across the southern Australian coast (Fig. 1.14), with a slight summer minimum and late winter maximum. The swell is long (10-14 sec), moderate to high (2-3 m) and arrives predominantly from the west (20%) and southwest (60%), being more southerly in the north of the Bight region and more westerly along the South Coast. Swell height is also higher toward the south, decreasing toward the equator, as indicated in Figure 1.14.

Table 1.7 Wave sources and characteristics along the Western Australian coast

Source	Location	Direction	Season	Characteristics
Mid latitude cyclones	40-60°S	S-SW	year-round	moderate-high S-SW swell (see Fig. 1.14)
High pressures	centred on 30°S	westerly	Winter max in south	westerly seas on swell
Sea breeze	along entire coast	S-SW-south W-NW-north	summer max	short, low seas
Trade winds	central-northwest coast	E-SE	year round, winter max	short, seas to 3 m
Monsoonal winds	Kimberley region	W-NW	summer	short seas to 2 m
Tropical cyclones	northwest coast	W	summer	high seas to several metres

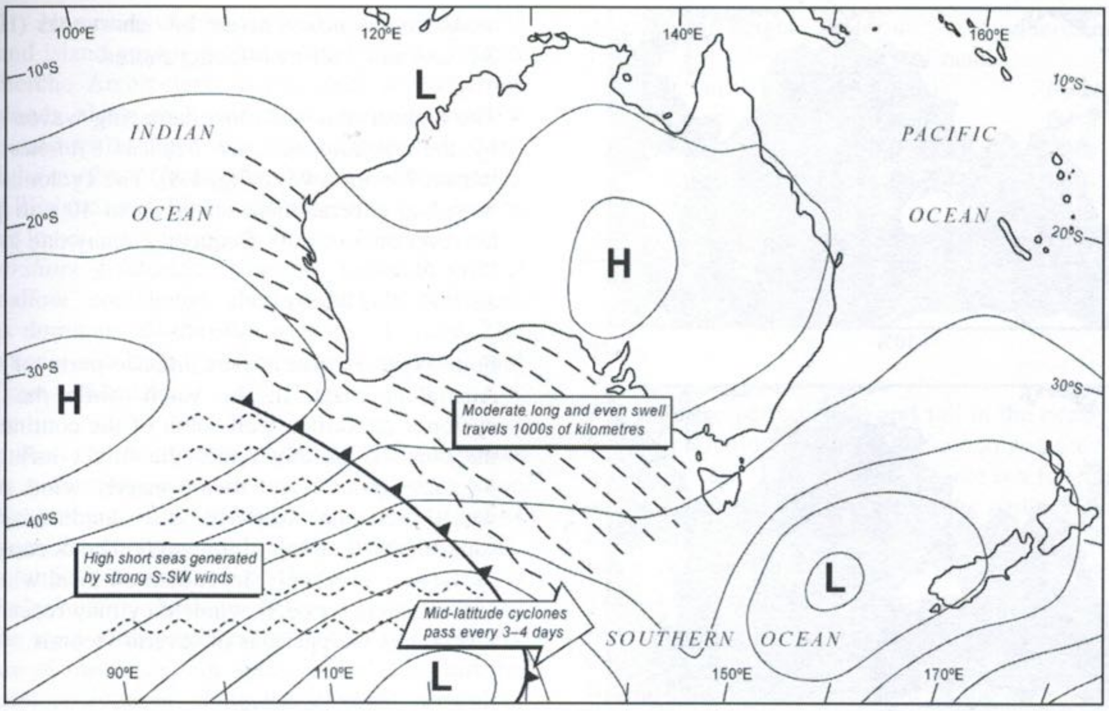


Figure 1.14 An example of a mid latitude cyclone and cold front passing south of Australia. As the cyclone traverses the Southern Ocean, its strong west to southwesterly winds, blowing over a long stretch of ocean, produce high seas. As the sea waves travel north of the cyclone, they become more regular, long crested high swell. In this summer example the cyclones are located well south of the continent and the swell can take one to two days to reach the south Western Australian coast. In winter the lows are closer to the coast and occasionally cross the coast, producing bigger seas and swell and accompanying strong westerly winds.

Figure 1.15 illustrates the global wave environment based on satellite altimetry. The figure clearly indicates that the world's highest average waves occur across the Southern Ocean, including south of Western Australia. In coastal waters the waves average 4-5 m for 10% of the year, 2-3 m for 50% and 1-2 m for 90%.

Figure 1.16 plots the monthly wave conditions for the three southern Australian wave recording sites. The table displays three variables: H_s the significant wave height which records the one-third highest waves; H_{max} the maximum wave height and records the 10% highest waves; and T_p the peak wave period, the time between each wave. Four characteristics are obvious. First, waves are high (>1.7 m) year round peaking during the winter months (>2.2 m) when the mid latitude cyclones move closer to Australia. Second, very high waves (3 to 5 m) occur year round. Third, wave period is long (>12 s) and also increases slightly during the winter months, due in part to the higher waves and also to the presence of shorter period summer sea breeze waves. Fourth, there is a progressive decrease in wave height between Cape Sorell at 42°S with a mean of 3 m, Cape Du Couedic at 36°S with 2.7 m and Perth at 32°S with 2.1 m. This decrease continues up the west coast.

In summary, the dominant source of swell waves affecting the southern half of the state, south of North West Cape, are the year-round mid latitude cyclones centred between 40 and 60°S. Waves arrive predominantly from the southwest and west. GEOSAT data (Fig. 1.13) indicates that the waves are rarely less than 0.5 m (<10%), that they average between 2 m and 3 m and reach 3 m 40% of the year, 4 m 15% and 5 m about 5% of the time. The waves are high year round, with a slight decrease in summer when the mid latitude cyclones are located further to the south and decrease slightly in intensity, with the lowest waves in January (1.5-2.5 m) and the highest in late winter (July-October, 2.5-3.5 m) and year-round average of 3 m at Cape Sorell, 2.7 m at Cape Du Couedic and 2.1 m at Perth. In total, the southern half of Western Australia, particularly the south coast, faces squarely into one of the world's highest energy deepwater wave environments. Waves reach the coastal zone as a moderate to high year-round swell with peak periods of 12-14 s.

Sea breeze flows onshore around the entire coast, particularly during the hotter summer months (Fig. 1.10). Their direction varies around the coast from more southerly in the southern half to more westerly in the northern half. In the southwest they are particularly strong. They average 25 km/hr and can reach over 50 km/hr generating short, steep southerly seas (Hb <1 m, T≈3-5s), usually from late morning to afternoon. These produce a distinctive summer wave climate with usually calmer conditions in the morning and strong sea breeze waves in the late morning to afternoon. In addition these winds are responsible for much of the coastal dune activity along the southwest coast.

In the northwest, two seasonal wind systems generate coastal seas. For most of the year the moderate to occasionally fresh easterly *Trade winds* blow predominantly offshore, producing low waves and calms along the coast. During summer the light to moderate *northwest*

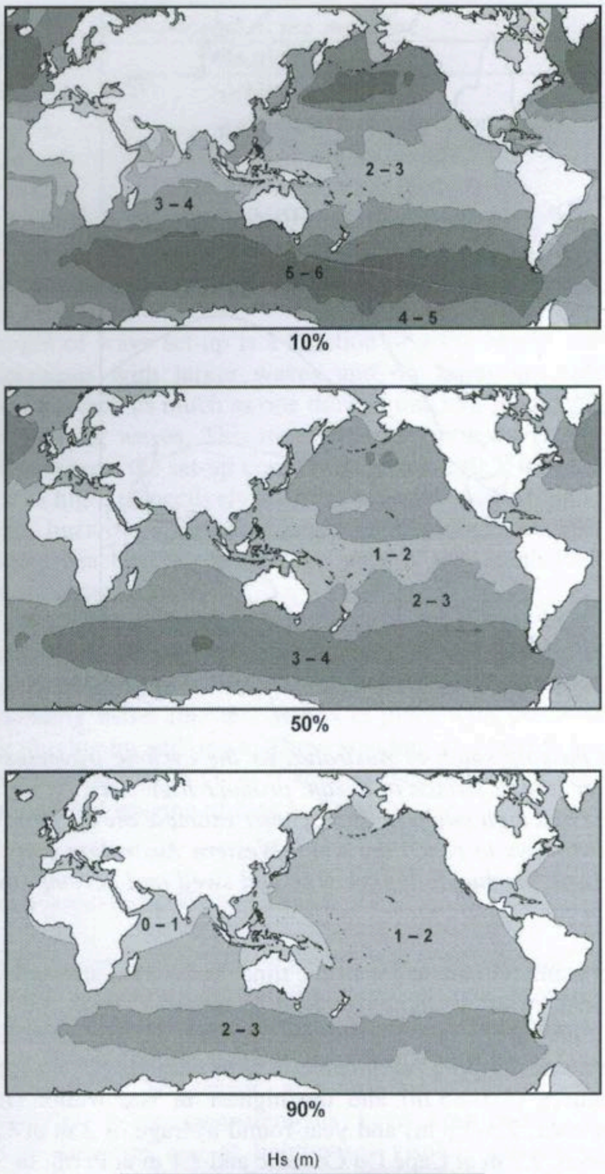


Figure 1.15 Average global wave heights. Note the dominance of high waves south of Australia year round, with deepwater waves south of Western Australia exceeding 5-6 m for 10%, 3-4 m for 5% and 2-3 m for 90% of the year (based on satellite data from Young and Holland, 1995).

monsoonal winds generate low short seas (Hb <1 m, T ≈ 3-5 sec) along all west-facing shores.

The highest seas and most damaging waves are generated by the periodic summer *tropical cyclones*, which also impact the northwest (Fig. 1.8). The cyclones can produce waves to several metres and up to 10 s in period. They however only occur infrequently at any one location.

Sea Waves

Four types of sea waves impact parts of the Western Australian coast. In the south while the mid latitude cyclones pass often well south of the continent (40-50°S), the coast is usually under the direct influence of *high pressure systems* and their westerly wind stream. These winds generate westerly sea conditions, which are superimposed on top of the swell. The occurrence and size of the seas is entirely dependent on local wind conditions. Under strong westerly winds they may reach a height of a few metres with periods of several seconds.

Wave Shoaling

To reach the shore deepwater, swell and seas must cross the continental shelf and nearshore zone, and in doing so considerable wave transformation can take place. Exposed beaches fronted by deeper shelf and nearshore zones and free of reef receive most of the deepwater energy, as along much of the South Coast. Four factors combine to lower waves along the coast.

- *Calcarenite reefs*: Submerged Pleistocene calcarenite reefs parallel much of the Central West and parts of the Leeuwin and Carnarvon coasts. The moderate to high deepwater waves either break on or are attenuated in crossing the reefs, resulting in lower waves at the shore. At the same time the sea breeze seas, generated between the reefs and the shore, become in places more important for beach processes than the attenuated ocean swell.
- *Coral reefs*: Along Ningaloo Reef and in the Kimberley, fringing coral reefs provide additional protection to much of the shore. The intertidal reefs cause heavy wave breaking with always low energy conditions in lee of the reefs.

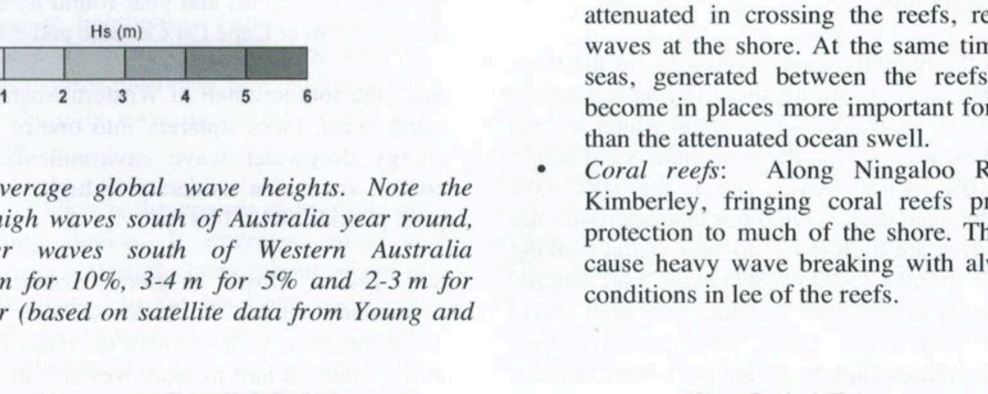


Figure 1.16 Monthly mean wave height and period for Cape Sorell (42°S), Cape Du Couedic (36°S) and Perth (32°S). Box indicates mean annual wave height and period.

- *Islands*: Numerous bedrock, calcarenite and reef islands and island groups extend around the coast, from the Recherche Archipelago in the south to numerous small islands along the west coast, many associated with the calcarenite reefs, and larger groups off Shark Bay and the northern Carnarvon, Pilbara and Kimberley coasts. All islands will block and intercept ocean waves and cause lower energy wave shadows in their lee.
- *Low nearshore gradients*: North of Exmouth Gulf a wide shallow continental shelf and low nearshore gradients dominate all the way to Cape Leveque. The low gradients result in greater wave attenuation and lower waves at the shore.

The breaker wave climate, as opposed to the deepwater wave climate, is therefore a function of the deepwater wave height, less the amount of wave energy (and height) lost as the waves cross the continental shelf and nearshore zone. This loss can range from near zero on deep, steep shelves, to 100% on wide and/or shallow shelves, particularly on sections of the west coast protected by calcarenite reefs. As a consequence of the calcarenite reefs and islands, and the variable coastal orientations along the Western Australian coast, breaker wave height, derived from deep ocean waves, ranges from a maximum average of 3 m to zero.

Freak waves, king waves, rogue waves and tidal waves

Freak waves do not exist.
All waves travel in wave groups or sets. A so-called 'freak', 'king' or 'rogue' wave is simply the largest wave or waves in a wave group. The fact that these waves can also break in deep water, due to over steepening, also adds to their demeanour.

Unusually high waves are more likely in a sea than a swell. For this reason they are more likely to be encountered by yachtsmen than surfers or rock fishermen.
Tidal waves arrive on the Western Australian coast twice each day. These are related to the predictable movement of the tides and not the damaging *tsunamis* with which they are commonly confused. Tidal waves are discussed in the next section.

How to estimate wave height from shore

Wave height is the vertical distance from the trough to the crest of a wave. It is easier to make a visual measurement when waves are relatively low and if there are surfers in the water to give you a reference scale. If a surfer is standing up and the wave is waist height, then it's about 1 m; if as high as the surfer, about 1.5 m; if a little higher, then it's about 2 m. For big waves, just estimate how many surfers you could 'stack' on top of each other to get a general estimate, i.e. two surfers, about 4 m, three, about 6 m and so on. Many surfers prefer to underestimate wave height by as much as 60% and a substantial number still estimate height in the old imperial measure of 'feet', using the USA or Hawaiian system. In Hawaii this system has been criticised as it attracts inexperienced surfers to what they think are lower wave conditions.

Actual wave height	Surfer's (under) estimate	% underestimated
0.5 m	1 ft (0.3 m)	60%
1.0 m	2 ft (0.6 m)	60%
1.5 m	3 ft (0.9 m)	60%
2.0 m	5 ft (1.5 m)	80%
2.5 m	6 ft (1.8 m)	70%
3.0 m	8 ft (2.4 m)	80%

Tides

Tides are the periodic rise and fall in the ocean surface, due to the gravitational force of the moon and the sun acting on a rotating earth. The amount of force is a function of the size of each and their distance from the earth. While the sun is much larger than the moon, the moon exerts 2.16 times the force of the sun because it is much closer to earth. Therefore, approximately two-thirds of the tidal force is due to the moon and are called the *lunar* tides. The other one-third is due to the sun and these are called *solar* tides.
Because the rotation and orbit of the earth and the orbit of the moon and sun are all rigidly fixed, the *lunar* tidal period, or time between successive high or low tides, is an exact 12.4 hours; while the *solar* period is 24.07 hours. As these periods are not in phase, they progressively go in and out of phase. When they are in phase, their combined force acts together to produce higher than average tides, called *spring tides*. Fourteen days later when they are 90° out of phase, they counteract each other to produce lower than average tides, called *neap tides*. The whole cycle takes 28 days and is called the lunar cycle, over a lunar month.

The actual tide is in fact a wave, more correctly called a *tidal wave,* and not to be confused with tsunamis. Tidal waves consist of a crest and trough, but are hundreds of kilometres in length. When the crest arrives it is called *high tide* and the trough *low tide*. Ideally, the tidal waves would like to travel around the globe. However the varying size, shape and depth of the oceans, plus the presence of islands, continents, continental shelves and small seas, complicate matters. The result is that the tide breaks down into a series of smaller tidal waves that rotate around an area of zero tide called an *amphidromic point*. The Coriolis force causes the tidal waves to rotate in a clockwise direction in the Southern Hemisphere, and anticlockwise in the Northern Hemisphere.

Tides in the deep ocean are zero at the amphidromic point and average less than 20 cm over much of the ocean. However three processes cause them to be amplified in shallow water and at the shore. The first is due to shoaling of the tidal waves across the relatively shallow (< 150 m) due to wave shoaling processes and increase in northwest, height (tide range) up to 1 to 9 m across much of the deep) continental shelf. Like breaking waves they are amplified and in some locations even break as a tidal bore. Secondly, when two tidal waves arriving from different directions converge, they may be amplified. Finally, in certain large embayments the tidal wave can be amplified by a process of wave resonance, which causes the tide to reach heights of several metres, as occurs in King Sound.