Winds and Waves

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Everyone knows how strong the wind is and how big the waves are. Yet take a group of six people out on the ocean during a windy day, get them to independently estimate the wind strength and wave height and see how many different answers you receive. Why is this? The very variable nature of winds and waves makes them difficult to simply describe.

Winds

Wind is a constantly varying phenomenon in both direction and speed, with periods of stronger winds (gusts), and lighter winds (lulls) that may last from a second or two through to a minute. All forecasts and warnings issued around the world use a 10 minute average wind speed and direction to smooth out these short lived variations.

The wind gusts and lulls are the result of turbulence of the airflow, caused in part by frictional effects with the earth's surface. The rougher the earth's surface, the greater the frictional effects and the gustier the winds become. This fact explains why you may encounter a band of gustier winds downwind of cliffs or islands, often most pronounced on either side of the sheltered region. These effects may be felt a considerable distance away from the feature that is producing the gustier conditions - up to a surprising 30 times its height downwind. It may come as a surprise that the ocean surface also has a similar effect. In light wind conditions when the sea surface is smooth, there is little friction and hence the wind gusts tend to be low. A gust factor (percentage difference between the maximum wind gusts and the average wind speed) of 15% on top of the mean wind speed is common for wind speeds up to about 12 knots. As the wind speed increases and the height of the waves increases, the frictional effects also increase and the winds become gustier. These large waves also act like miniature hills and valleys, accelerating the wind over the wave crests and reducing the speed in the troughs. These effects, and those that are discussed below, produce gust factors that increase with wind speed. In gale force conditions (see Table 1) a gust factor of 40% or so is to be expected.

Bureau Warning	**Mean Wind Speed**
Strong Wind	25 – 33 knots
Gale	34 – 47 knots
Storm Force	48 – 63 knots
Hurricane Force	64 knots and above

Table 1. Terminology used in official Bureau of Meteorology warnings (as from 1st Nov 2006).

It is also worthy to remember that the force of the wind on a sail increases with the square of the wind speed. This is easiest to explain if we look at a simple example. Take a 25 knot gust as a point of reference (25 knots being a gust that starts to gain the attention of the average sailor) and say it applied a force of one unit on the sail. A 35 knot wind gust will exert twice that force and at 50 knots the force will be four times as great. If we now look at a 75 knot gust (the gust that is to be expected in a typical storm) the force of the wind on the same sail is nine times as great as that of a 25 knot gust.

The stability of the lowest levels of the atmosphere (a measure of how rapidly the air temperature cools with height) is also important. The speed of the wind normally increases with height above the sea, with the greatest increase occurring over the first 10 metres. This is the height at which all official wind forecasts refer to in an attempt to minimise surface friction effects. Therefore the wind experienced over the deck of a yacht will normally be significantly lighter than that measured at the mast head. When conditions are stable (a temperature inversion, where the temperature increases with height, may be present) surface winds are light and gust factors are low because the winds above the surface are not mixed down. Conversely in unstable conditions, typically found in hot weather or when there are sharp showers around, the wind above the surface is brought to the surface at irregular intervals, creating very gusty conditions.

In showery conditions or when there are thunderstorms about wind squalls may also be experienced. These last longer than wind gusts but are still relatively short lived bursts of stronger winds. They normally last from 1 to 10 minutes and are most commonly generated by the downdrafts that accompany heavy rain or hail showers. These wind squalls are strongest in the direction that the wind is blowing at the height of the middle of the cloud producing the showers and is almost always a different direction to the prevailing surface wind direction. These downdrafts also fan out from the shower or storm, explaining why successive wind squalls may be experienced from different directions. Wind squalls may sometimes be mentioned in forecasts, although the speed and direction will rarely be mentioned due to their highly variable nature.

Measuring the wind

Most serious sailors will have some familiarity with the anemometer that is used to measure the wind speed and the wind vane used to measure direction. The most common form of anemometer is a cup counting device, which consists of three cups that spin in the wind. An electronic device counts the number of rotations of the cups and converts them into a wind speed. It sounds simple but there are a few things to remember.

The most obvious one of these is to remove the effects of the yacht's motion from the measured wind speed. There are several anemometers on the market that will do this simple vector calculation for you. This is fine, assuming the yacht is moving steadily. Caution is required when the yacht is ploughing through heavy seas – slowly rising up a crest then surging into the following trough. If the anemometer computer is averaging the yacht speed over any more than a couple of seconds the yacht's movement will not be reliably removed from the reported wind speed. The technique by which the yacht speed is being determined can also be suspect.

What these instruments actually measure depends upon a number of factors. Most important of these is how the anemometer is exposed. A typical yacht mounting would be on a short spar close to the top of the mast. The wind speed measured is therefore dependent upon the height of the mast. An anemometer on a 6 metre mast will measure a wind that is much lighter to that measured on top of a 20 metre mast. The upwash effects of the wind blowing upwards out of the head sail or around the mast itself (if the anemometer is mounted too close to it) is also important. This effect will vary depending upon whether the yacht is sailing into the wind or down wind, being greatest into the wind, and upon the sail configuration.

Also important is the response time, averaging period and calibration of the anemometer. Check the calibration certificate of your anemometer. Most commercial anemometers are only calibrated up to around a 30 knot mean wind speed, which is sufficient for most purposes. What they measure beyond this is anyone’s guess. The response time of the anemometer relates to how quickly the cups spin up and spin down as the wind speed varies. An anemometer that is very responsive to slight changes in wind speed in light wind conditions can be prone to overspin in strong wind conditions, over reading the wind speed. Any anemometer that does not spin down sufficiently rapidly will under report the wind lulls, effectively over reporting wind speed. The sampling interval of the anemometer is also to be considered. Small, responsive anemometers may report a one second wind gust. The anemometers the Bureau of Meteorology uses, designed to handle wind speeds up to 120 knots, reports a 3 second wind gust that will be lower than the 1 second gust.

The average wind speed is more meaningful, but requires an accurate averaging technique. Humans have a natural tendency to pay more attention to the stronger gusts and ignore the lulls, leading to an upward bias in estimated average wind speed. The best anemometers let you select the averaging period, with 10 minutes being the period that reflects the wind fields produced by identifiable weather systems rather than individual cloud lines of topographic features.

There are a few other factors that affect wind speed. The heel of the yacht can initially increase wind speed, then decrease it once it becomes too great. In rough conditions where the yacht is pitching or rolling significantly, the acceleration and deceleration of the mast head through the air can add considerably to the reported wind speed. Some anemometers can compensate for the mast movement by averaging over a few seconds. However very few can handle extreme excursions of the mast that last several seconds.

In choosing an anemometer it is worth selecting one that is of a sturdy design. Make sure it has a calibration certificate and that it clearly outlines its response characteristics. You do not want an anemometer with flexible shafts leading to the cups as they may bend and produce erroneous readings.

Wind direction is more straight-forward. Most direction sensors will report the magnetic wind direction, relating the wind direction to the Earth’s magnetic poles. All official weather observations will be relating to the true or geographical wind direction. Whereas the magnetic wind direction varies with location and slowly changes over the years (typically the variation from true north is between plus or minus12 degrees for most parts of Australia), true wind direction remains the same no matter where you are on the globe.

Measuring wave height

While wind measurements are assisted by instrumentation, wave measurements rarely are. Only in a few locations around the Australian continent are we fortunate to have wave rider buoys that report measured wave heights in real time. Wave height is the vertical height between successive wave crests and troughs. The wave height referred to in all international observations, forecasts and warnings is known as the significant wave height. This is the height an experienced sailor will report as the prevailing wave height. It is NOT the average wave height but the height of the highest one third of all waves. This is approximately 1.6 times greater than the true average wave height as most people ignore the relatively common small waves. In statistical terms this means you will typically encounter a wave height that is equivalent to the significant wave 15% of the time, or one in seven waves.

Although the significant wave height is referred to in forecasts and warnings it is the relatively infrequent “rogue” waves that will bring most yachts unstuck. These waves are always present and will be encountered if you are sailing in a storm for any length of time. Scientifically they are referred to as the maximum wave height and in reality this is a very difficult parameter to define exactly as the maximum wave height reported by a fleet of yachts in a storm will be highly variable. A couple of rules of thumb come in handy here to work out the most likely maximum wave that 50% of the yacht will encounter. The one in one thousand wave (a wave that will typically be encountered every 2.5 hours) will be 1.86 times the significant wave height. The one in two thousand wave, typically experienced every 5.5 to 6 hours, will be twice the significant wave height. So if you are sailing into storm force conditions where the mean wind speed averages 48 knots or more you need to be prepared for significant wave heights of at least 7 metres and there is a 50% chance of experiencing a few waves of 14 metres in height. If we take this a step further and look at what the 5% chance of experiencing a “rogue” wave is, for the one in 2000 wave the maximum expected wave is approximately 2.4 times the significant wave height. In the above example this means that if you have a fleet of 20 yachts in seas with a 7 metre significant wave height, one yacht is likely to experience a 17metre high wave every 5 to 5 to 6 hours.

It is also worthy to remember that the longer a storm lasts and the greater the distance from land, the larger the waves become.

The above points are simple concepts, but ones that should be remembered whenever you venture out onto the ocean. Whereas much of the above discussion is purely of academic interest in moderate breezes and small seas, a good understanding of what is likely to be encountered as the wind speed increases may change the way you look at what a gale, storm force and hurricane force wind warning is telling you.