Why the wind instruments on yachts over-read

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I have become increasingly puzzled as to why sailors report wind speeds that are far greater than those recorded by nearby weather stations and more worryingly, greater than the wind speeds in the forecast. Clearly there is a psychological factor related to bragging rights, but this still doesn't explain why an experienced sailor will recall seeing 35 knots true wind on the cockpit readout in a strong sea breeze, yet the nearest weather station (and the forecast) only mentions 20 knots mean wind speed. Are there local pockets of gale force winds along our coast that are not predicted by the weather forecasters? A bit of research and a splash of science, mixed with a small dose of psychology, reveals a more likely answer.

Summary

When you correct the measured wind speed for the height of the mast above water, then make another correction for the pitching and rolling motion of the yacht, a gust of wind that reads 39 knots on the display corresponds to a wind forecast or weather station report of about 23 knots. How can this possibly be? Read on…..

Assumptions

I make two assumptions initially:

- the anemometer is correctly calibrated by the manufacturer, and
- the reading we are investigating – the true wind speed – has been correctly calculated from apparent wind speed using the rest of the yacht's instruments.

It is quite possible that neither of these assumptions is true (especially the second one), but that doesn't affect this analysis or the conclusions.

Some science

The first bit of science to apply is to correct for "the atmospheric boundary layer". When the wind blows over the water, the air very close to the water is slowed down by friction as it tries to pass over the waves. The air really close to the water hardly moves at all, but as you get further up and away from the sea surface, the speed gradually increases until you reach a height that the friction effect becomes negligible. The region of atmosphere from the sea surface to this height where friction isn't felt is called the boundary layer. (It is the same physics that explains why you need to keep the underwater part of the hull smooth – that's all about the boundary layer of water next to the hull).

This boundary layer friction effect means that if you measure the wind speed at, say, 3m above sea level, it is going to be a lot less than at, say, 20m above sea level. Clearly, meteorologists knew all about this; long ago (maybe 100 years?) the world meteorology community agreed that the standard height for wind readings should be 10m above ground. So the vast majority of weather station anemometers are mounted 10m above the

ground[1,2]. There is a complication in that the ground itself will be at some height above sea level (a different amount at each weather station[3]), but that does not negate the analysis being put forward here[4]. The reading displayed from the anemometer on a yacht should be corrected to the 10m wind speed, but it isn't (except in the most sophisticated of on-board systems used e.g. for the America's Cup). The amount of correction to apply is a bit uncertain because the amount of friction effect depends on how rough the water surface is and how strong the wind is blowing , but there is an equation that is often used for typical conditions (for the mathematically inclined, it is a $1/9^{th}$ power law[5]). So if we have an anemometer sitting at the top of the mast at, say, 20m above sea level and it reads 35 knots, the corresponding wind speed at 10m height (the meteorological standardized reference height) would be about 32.5 knots i.e. 7.5% less.

The next bit of science to apply is a correction for the pitching and rolling motion of the yacht. These motions throw you around a fair bit when on deck, but, as anyone who has been up the mast in a seaway knows, those motions are very much worse high up. Consider the simplified case of a yacht sailing with the wind on the beam, and the yacht is just rolling from about 5 degrees port roll to 5 degrees starboard roll (i.e. a total of 10 degrees angle from one side to the other). When the top of the mast is rolling into (towards) the wind, the anemometer will be pushed into the wind and so it will rotate faster and produce a higher reading on the display during that part of the roll cycle. Now the smart people reading this will say "aha! But when the yacht is rolling away from the wind in the second half of the roll cycle, the reading on the display will be correspondingly reduced, therefore cancelling out the increase from the first part of the roll motion". That is largely true (leaving out some minor scientific niceties about inertia and data smoothing), but we also need to look at the psychology of how the display reading is interpreted by the sailor….

Some psychology

When we have finished a rough passage or race and returned to harbour, almost all of us will remember the highest wind speed we saw on the display. Some of us might also have a fairly hazy estimate of the average wind speed, but it is that highest figure which is talked about in the bar. So let us revisit the rolling motion effect just described above, bearing in mind that the typical sailor will report the highest reading seen on the display.

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[1] "Wind speed is a 10-minute average speed from the standard height of 10 metres." http://www.bom.gov.au/catalogue/observations/about-coastal-observations.shtml

[2] One of the few local anemometers that is not 10m above ground is the one on the Swan River at Inner Dolphin ("Melville Water" station). For practical installation reasons it is only 7.5m above the low water level.

[3] For heights above sea level of WA coastal stations, see http://www.bom.gov.au/catalogue/observations/wa-coastal-stations.shtml

[4] The process of correcting the anemometer readings for the altitude of the weather station (in addition to correcting for the height of anemometer above ground level) is very complicated and would rely on several assumptions. If this were attempted, the wind speed report at most coastal weather stations would be less than it is currently reported. Therefore the discrepancy between the weather station wind speed and the onboard display would often become even greater than I have estimated in this analysis.

[5] coefficient of 0.11 recommended over open water for neutral stability atmosphere https://en.wikipedia.org/wiki/Wind_profile_power_law

Back to the science

Let us suppose the average wind speed at the masthead is 35 knots, and let us assume the time taken to go from 5 degrees port roll to 5 degrees starboard roll and back again is 5 seconds (fairly typical). If you do the sums, the anemometer reading will change throughout the one roll cycle from about 31 knots at its lowest to 39 knots at its highest. Note that the average is still 35 knots. In other words, the maximum reading on the display has got 4 knots included in it due to the roll motion of the yacht, and that amount is not wind speed.

Putting it all together

So the 39 knots observed as the maximum on the display is really only 35 knots wind speed at the masthead. Next we correct that 35 knots at the masthead down to the standard 10m height, which brings the wind speed down to 32.5knots. So the 39 knot reading on the yacht corresponds to a 32.5 knot reading of the same wind gust at a nearby weather station readout. But wait, there's more…

So far we have been comparing the display reading with the gust recorded at a weather station. Gusts last just a few seconds (the BoM standard is 3 second duration[6]), whereas the mean wind speed reported by BoM (and most other weather sources) is the average wind speed over a 10 minute period. This is also the wind speed referred to in the forecast (with one qualifying statement I'll mention in a minute). We are probably all familiar by now with the warning given in weather forecasts, that "wind gusts can be up to 40% stronger" than the forecast mean speed. So our gust of 32.5 knots corresponds to a mean wind speed of about 23 knots.

So the cockpit readout of 39 knots corresponds with a weather station mean wind speed, or a forecast wind speed, of 23 knots. And there you have it; almost.

Variation of wind over the ocean

There is still the possibility that the yacht has been sailing in a region of the ocean which has experienced much higher wind speeds than at any of the nearby weather stations. This has quite serious implications; if it is true, then for a weather forecast of, say, 20 knots mean wind speed, you could find yourself sailing in maybe 30 knots. It is extremely difficult to know whether this happens, but there are two factors which suggest that it does not happen; or at least, not often and not by very much.

a) Weather forecasts.

The weather forecasts are for a fairly large area of ocean e.g. Yanchep to Mandurah and offshore to Rottnest Island, and the weather forecasters recognise this. They need to be cautious (but realistic) in their forecasting by providing a forecast wind speed that is towards the maximum average wind speed likely anywhere within the forecast area. Therefore this approach to forecasting already absorbs most of the local variation effects when comparing yacht recordings with forecasts.

b) Weather reports

On two occasions when strong winds were reported by a fleet, I have examined the records of nearby weather stations. The first occasion was about 10 years ago when the FSC cruising fleet was sailing south to Quindalup and reported winds "of up to 40 knots". I was part of the fleet and was completely baffled. I don't have an anemometer on board, but

[6] http://www.bom.gov.au/catalogue/observations/about-coastal-observations.shtml

I reckoned from the sea state observed and the sail combination required that it was blowing around 25 knots. I was the furthest offshore of the fleet, so might reasonably expect to have experienced the strongest winds . When I got home I examined the records of all the weather stations from Ocean Reef in the north to Cape Naturaliste in the south (including Rottnest, Swanbourne, Garden Island, Mandurah, Bunbury and Busselton), for the period from 12 hours before the yacht reports to 12 hours after. The highest mean wind speed was 26 knots and the highest gust was 32 knots, both of them several hours after the yachts were tucked up in harbour.

The second occasion was more recently, in October during the Geraldton to Denham race. Wind gust of 45 – 50 knots were quoted. Looking through all the nearby station reports from Geraldton to Carnarvon (including North Island well offshore), the highest mean speed was below 30 knots and the highest gust about 35 knots.

Surely if there were local cells of very high winds, one of these many stations would have recorded them at some point in time? It might be argued that the weather stations are more sheltered than the positions of the yachts, but this is unlikely for Rottnest and Cape Naturaliste for the Quindalup episode, and North Island for the Denham race.

Conclusion

I conclude, albeit tentatively, that local cells of extreme wind speeds are not a likely explanation for the discrepancy between the high wind speeds recorded on sailing yachts and the much lower speeds recorded at weather stations. The reason is simply that the anemometer at the masthead is not measuring the same thing as the weather stations are reporting.

Happy to be proven wrong though!