A comparison between two types of widely used weather stations

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Introduction

The popularity of wireless automatic weather stations has grown considerably over the past several years, and a number of online amateur and school networks have sprung up to allow sharing of data from them. Bell *et al.* (2013) estimate that Weather Underground (http://www.wunderground.com) has some 1350 contributors in the UK and Ireland, and over 400 send their data to the Weather Observations Website (WOW) set up by the Met Office and the Royal Meteorological Society (http://wow.metoffice.gov.uk). One of the most popular types of weather station used by amateurs and schools (as well as some professionals) is the Davis Vantage Pro2, which has the great advantage of stating accuracies for all its measured quantities; it accounts for roughly 25% of the weather stations contributing to the Weather Underground network over the UK (Bell *et al.*, 2013), and the London Grid for Learning, for example, has set one up at a school in every borough in London (http://www.weather.lgfl.org.uk). However, when the Davis Vantage Pro2 is bought with the WeatherLink data logger, which connects to a PC, its price of over £600 may be outside the budget of many schools and amateurs.

Many cheaper types of weather station are available and it would be of interest if a field trial were run to compare several of these with those types having a quoted accuracy, such as the Davis Vantage Pro2 or a Met Office MMS network station (Green, 2010). As a start, therefore, I have looked at one of the cheapest and most readily available PC-connectable weather stations, the WH1080 made by Fine Offset Electronics. This (or subtle variants of it) can be found marketed under various names in high-street retailers and online at prices 'on special offer' of around £50, including EasyWeather software. Bell *et al.* (2013) find that this type makes up about 30% of UK observations submitted to Weather Underground. Two Fine Offset WH1080 stations were compared with the Davis Vantage Pro2 over a period of almost a year, and this article reports the results. The Davis Vantage Pro2 is referred to as VP2 and the two Fine Offset stations collectively as FO, or separately as FO1 and FO2.

Table 1 shows the capabilities of the two types of station. Temperature and humidity sensors are mounted inside a radiation screen, which for the VP2 is considerably larger than that with the FO stations. The VP2 can be fitted with a fan unit, which creates a flow of air over the temperature and

Figure 1. The VP2 weather station (centre) and the two FO stations on a garden lawn.

Table 1

Comparison of the capabilities[a] of the VP2 and FO weather stations.

Type	*Temperature*	*Humidity*	*Radiation screen*	*Pressure*	*Rain*	*Wind speed*	*Wind direction*	*Solar radiation*
VP2[b]	0.1 degC precision (±0.5 degC)	1%RH precision (±3%RH, from 0 to 90%RH)	Five plates of 19.5cm diameter	Internal console (±1.0mbar)	214cm^2 collector with 0.2mm bucket	~0.4ms^{-1} steps (±5%)	16-point compass	Optional extra (±5%)
FO	0.1 degC precision	1%RH precision	Eight or nine plates of 7cm diameter	Internal console	55cm^2 collector with 0.3mm bucket	~0.3ms^{-1} steps	16-point compass	No

[a]In addition, both types measure inside temperature and humidity, and calculate a number of derived quantities such as wind chill and dew point.
[b]Figures shown in parentheses are accuracies quoted by the manufacturer.

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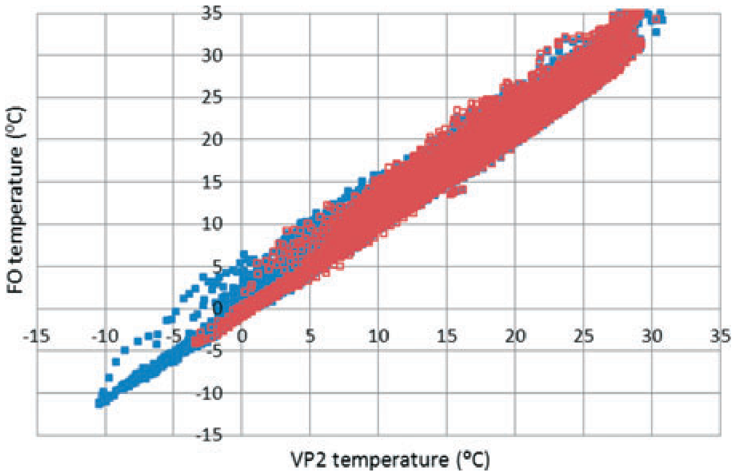

Figure 2. The relationship between temperatures measured by the VP2 and those from the FO1 (blue) and FO2 (red) stations, 23 January to 18 October (FO1) and 14 April to 18 October (FO2) 2012.

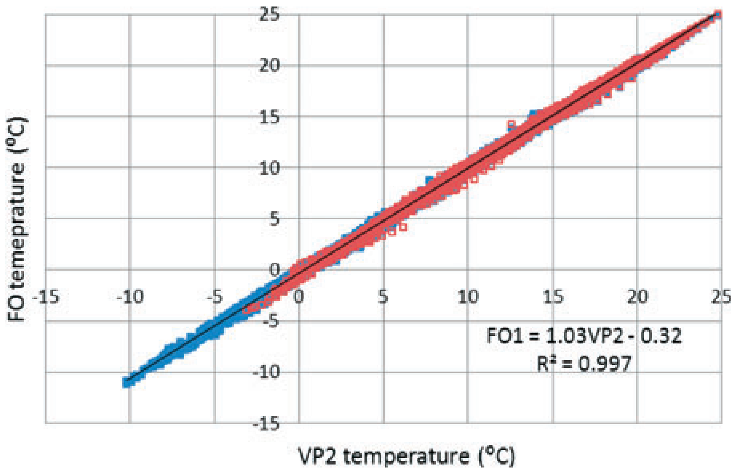

Figure 3. As Figure 2 but for night-time values only. Trend lines are shown for both FO stations, but are indistinguishable on the graph.

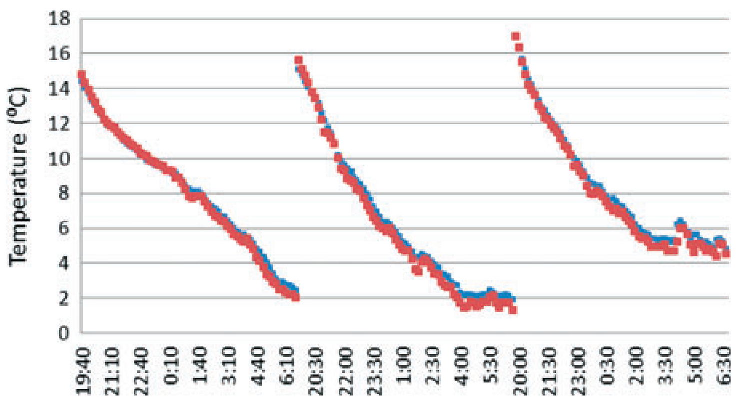

Figure 4. Rapidly falling temperatures measured by the VP2 (blue) and FO1 (red) stations on 26/27, 27/28 and 28/29 March 2012.

humidity sensors in the absence of natural ventilation, but the non-aspirated version was used in this study. This was judged to be a fairer comparison with the non-aspirated FO stations, and is also the configuration used by Burt (2009), who compared a VP2 station against standard Met Office climate station instrumentation.

With both types of station the weather data are transmitted to an internal console, where they are logged onto the memory at a rate selected by the user. The maximum storage period depends on the logging rate; in these comparisons an interval of 10 minutes was used, which would fill the console memory in 17 days (VP2) or 28 days (FO). Data were downloaded typically every 2–3 weeks to a PC via a USB connection, and archived using Microsoft Excel. Hence the consoles do not need to be permanently connected to a dedicated PC, but rather the data can be downloaded as convenient.

The comparison period lasted from January to December 2012, during which time the three weather stations were located together at three different places in Yateley, Hampshire: at the edge of a 2.7m-high garage roof and on lawns in two domestic gardens. Exposure in each case was far from perfect, but was typical of that available to many amateurs, including the author. However, the sensors were adjusted so that measurement of the same quantity was made at the same height above the ground and less than a metre apart horizontally, making the comparisons fair. The temperature sensor and rain gauge of the VP2 station are fixed together, so when the temperature sensor is set at the standard height of 1.25m above the surface, the rain gauge is forced to be at a height of 1.6m rather than the standard height of 0.3m. For practical reasons the anemometers and wind vanes were placed at a height of 2m above the surface (lawn or garage roof). Figure 1 shows the three stations in one of the garden lawn locations. Data from the VP2 and FO1 stations were taken over the whole period, but there are some gaps due to forgetting to download data before the memory was full; in all, some 37 000 rows of data were archived on an Excel spreadsheet. The FO2 station started logging later, on different dates for different sensors.

Results

Temperature

A comparison of the FO and VP2 temperatures over the whole period is given in Figure 2. This shows considerable scatter and a poor agreement between the two types much of the time. However, the accuracy of temperature measurements will be determined not only by the accuracy of the temperature sensor and electronics but also by the effectiveness of the radiation screen. Although this shields the sensor from direct solar radiation, it will itself be warmed to a greater or lesser extent by solar radiation and can in turn warm the air around the sensor, leading to errors in measuring air temperature. The radiation screen will also help prevent errors due to the effect of infrared radiation at night.

Hence, in order to separate out the effects of solar radiation on the screen, temperatures at night (taken to be when solar radiation = 0 Wm^{-2}) were selected. The resulting comparison is illustrated in Figure 3, which shows considerably less scatter. The graph also includes the best-fit linear relationship between the measurements from the two types of station, and the correlation between them (R^2, where $R^2 = 1$ signifies a perfect correlation). The best-fit lines of the two FO stations are indistinguishable, with a gradient close to unity, an intercept of −0.3°C and an R^2 value of 0.997. A calculation of the

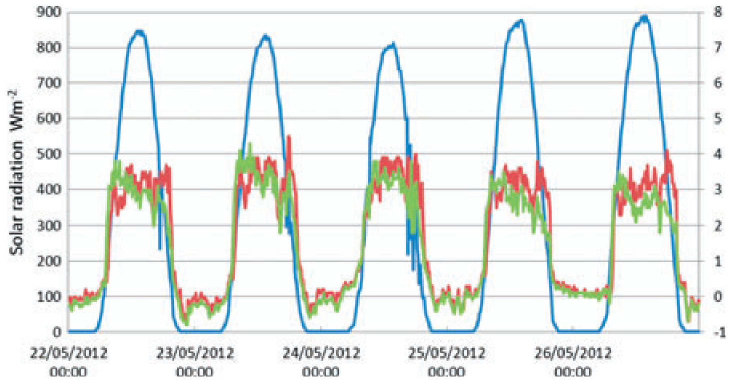

Figure 5. Solar radiation (blue, left-hand scale) and difference between VP2 and FO1 (red) and FO2 (green) temperatures (degC, right-hand scale), 22–26 May 2012.

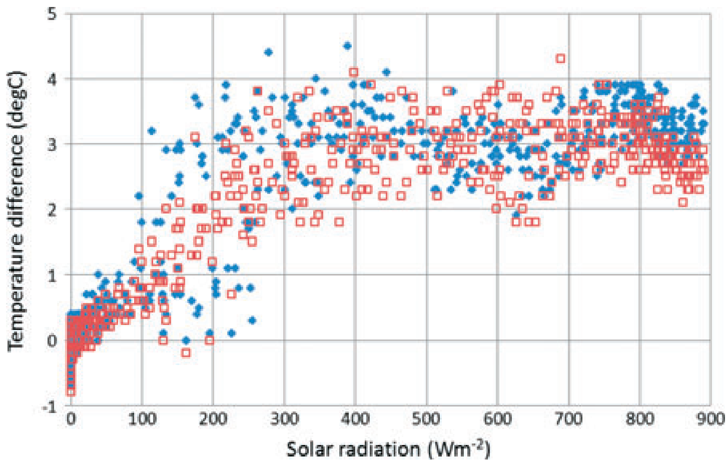

Figure 6. The relationship between solar radiation and the VP2–FO1 (blue) and VP2–FO2 (red) temperature differences, 22–26 May 2012.

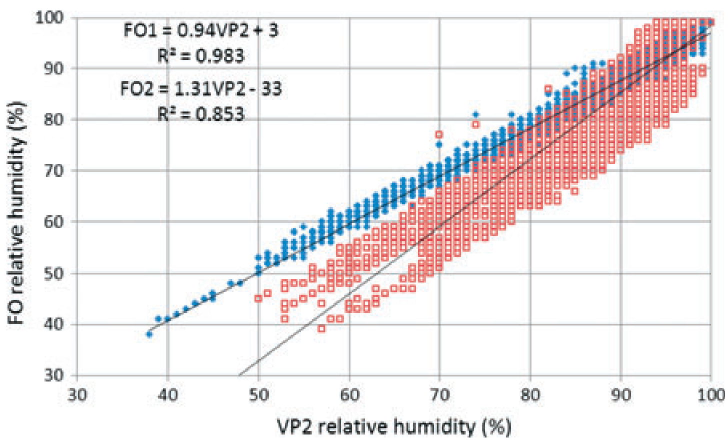

Figure 7. Relative humidity measured by FO1 (blue) and FO2 (red) stations compared with the VP2 station, night-time data only: 23 January to 18 October (FO1) and 14 April to 18 October (FO2) 2012.

distribution of differences shows that the FO1 (FO2) temperature was within ±0.3 degC of the VP2 temperature on 80% (78%) of night-time occasions, and within ±1 degC on 99.2% (99.5%) of occasions.

The response of the VP2 and FO sensors to temperature changes is illustrated in Figure 4, which shows good agreement in rapidly falling temperatures on three successive clear, calm, nights.

The effect of solar radiation on differences between the VP2 and FO temperatures can be illustrated using 5 days of almost unbroken sunshine in May 2012, when winds were also quite light (daytime average about 0.5ms^{-1} at 2m above a lawn). Figure 5 shows the diurnal cycle of solar radiation together with the differences in temperature of both the FO stations compared with the VP2, which sometimes reached above 4 degC. (A positive difference means that the FO read higher than the VP2.) The trend in the temperature difference during the day is dissimilar due to some differential shading. Interestingly, similar differences were found even in much weaker sunlight (250Wm^{-2}) when winds were essentially zero; and in midwinter, even with a breeze, the differences can be a degree Celsius or more.

The relationship between the temperature differences and solar radiation apparent in Figure 5 can be seen even more clearly in Figure 6. The FO radiation screen is not helped by being made of light grey plastic; a separate investigation using an infrared thermometer showed that painting a similar screen white reduced its temperature by 1 or 2 degC in strong sunlight and calm winds. Bell *et al.* (2013) found that daytime temperatures from the UK Weather Underground and WOW networks could be a few degrees Celsius higher than corresponding temperatures from Met Office stations. It therefore would be interesting to make a similar comparison using only the VP2 stations in the amateur networks to see if there is better agreement with the Met Office stations.

As mentioned above, the VP2 temperature measurements will themselves be affected due to heating of the radiation screen by solar radiation; a separate investigation on a day of light (0–0.4ms^{-1}) winds and strong (800Wm^{-2}) sunshine indicated that temperatures reported by the non-aspirated VP2 station (as used in this comparison) dropped by some 1–2 degC when the aspirating fan was switched on.

The consoles of both types of weather station display daily maximum and minimum temperatures, although this information is not downloadable to the PC. A limited comparison of these daily extreme temperatures showed the same features as for temperature itself: the minimum temperatures were in good agreement, but the maximum temperature indicated by the FO stations could be a few degrees Celsius higher than that from the VP2 due to its less effective radiation screen, as discussed above.

Relative humidity

As with the temperature measurement on FO stations, the relative humidity (RH) will also be affected by imperfect solar radiation screening. Hence, the comparison of RH between VP2 and FO stations was carried out using data taken when solar radiation was zero, and is shown in Figure 7. The FO1 measurements agree well with the VP2 station, showing a gradient within 6% of unity, with an offset of 3% RH. However, the FO2 station had a much poorer performance, as can be seen.

The relationship (not shown) between differences in RH and solar radiation is far less clear than that for temperature, but the difference can be as much as 15% RH in strong solar radiation and light winds.

Rainfall

In this comparison, rain gauges were exposed with all the collector openings at the same height, either on a garage roof 4.3m above

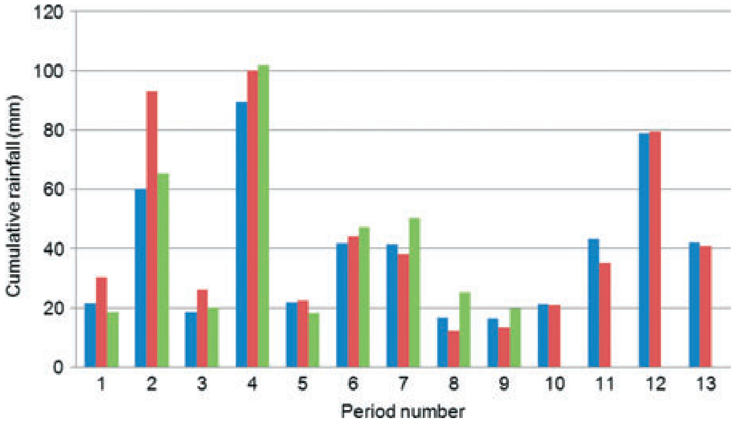

Figure 8. Cumulative rainfall recorded by the VP2 (blue), FO1 (red) and FO2 (green) stations over 13 consecutive periods.

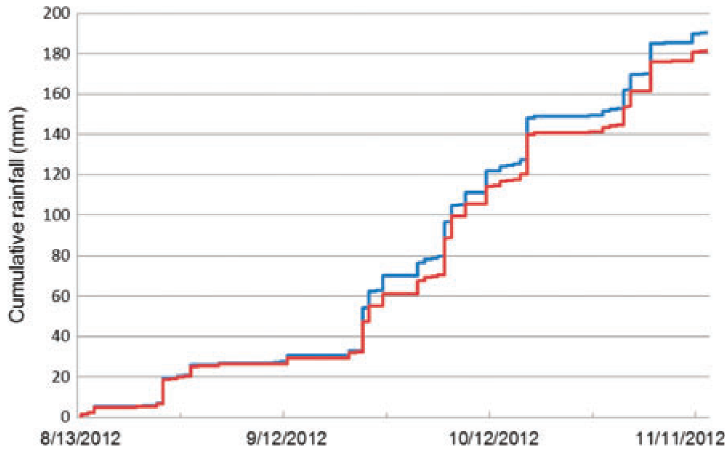

Figure 9. Cumulative rainfall recorded by the VP2 (blue) and the FO1 (red) station over the period 13 August to 12 November 2012, when located above a garage roof.

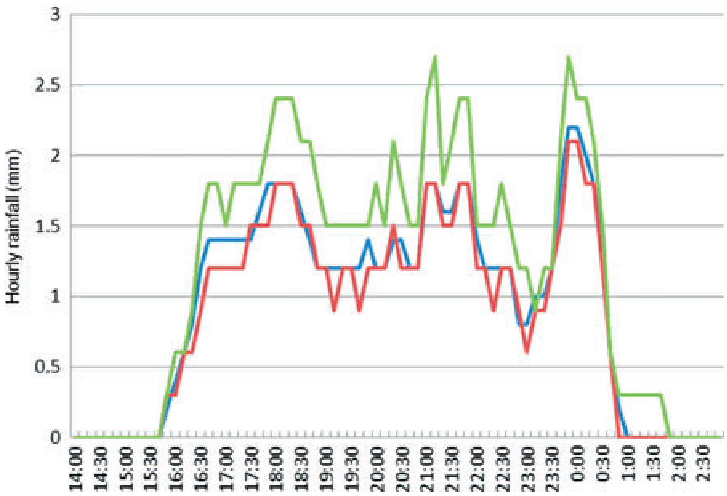

Figure 10. Running hourly total rainfall measured by the VP2 (blue), FO1 (red) and FO2 (green) rain gauges during a period of sustained rain on 12/13 July 2012.

the ground or at 1.6m above a lawn. Both situations are a long way from the ideal exposure for this instrument. All rain-gauge collector openings were set as close as possible to horizontal, and the VP2 gauge was checked and found to be close to the specification of 0.2mm per tip. The two types of station report rainfall rather differently: the VP2 indicates rainfall over the previous (10-minute) sampling interval, whereas the FO shows the running total over the last hour.

Rainfall accumulated by each station over a number of consecutive but unequal periods (generally those between data downloads, 2–3 weeks apart) were calculated and are shown in Figure 8. Considering that the VP2 rain gauge has a collector four times larger in area than that of the FO, the agreement is reasonably good most of the time, but over the first three periods the FO1 gauge recorded some 40–50% more than either of the other two. There is no obvious reason for these discrepancies but they did occur during comparisons when the gauges were located on a small sheltered lawn. It therefore may be due to some differential sheltering or to movement of the gauge collector funnel out of the horizontal. Figure 9 shows cumulative rainfall data from a 3-month period when the gauges were located 1.6m above a garage roof with no possible sheltering effects. Agreement was good until 24 September, when the FO1 gauge fell about 7mm behind the VP2 gauge, but thereafter the two agreed again. (The FO2 gauge was not working during this comparison due to spiders' webs fouling the tipping bucket, which were not discovered and cleared until after the comparisons.)

Behaviour during individual rainfall events was also compared. Figure 10 shows hourly running-average rainfall for a period when rain fell steadily at about 1.5mmh^{-1} for 8h. Figure 11 includes a shorter, more intense event where the rain rate peaked at 14mmh^{-1}. In both these cases the VP2 and FO1 rainfall data agree well (making allowances for the non-coincident 10-minute sample periods), although where data were available in the first event for the FO2 its rainfall total was almost 30% greater than that for the VP2.

Pressure

Pressures read by the two FO stations were set equal to the VP2 pressure at the start of the comparison. Over the period of the comparison, the FO2 pressure drifted only slowly relative to the VP2, at a rate of about 2.3mbar per year, which could easily have been corrected by resetting the FO2 pressure every month. The VP2–FO1 difference was found to be much greater. The pressure sensor in all the stations is located within the display console, and it was noticed that the FO1 pressure spiked during late afternoon when direct sun shone onto it, suggesting that the sensor was sensitive to temperature. To investigate this, the FO1–VP2 and FO2–VP2 pressure differences were plotted against temperature over the course of the comparisons, and these were found to be quite different for the two FO stations (not shown). The FO2 station showed very little sensitivity to temperature, whereas the FO1 station error showed a clear linear relationship of about 0.33mbar per degree Celsius. This could mean pressure errors of one or two millibars if temperatures in the room where the console is located varied by a few degrees Celsius; it certainly means that this console should be kept out of direct sunlight.

Wind speed

Comparisons of the anemometers and wind vanes made during the main period of data collection showed that the instruments were affected by sheltering from obstructions in

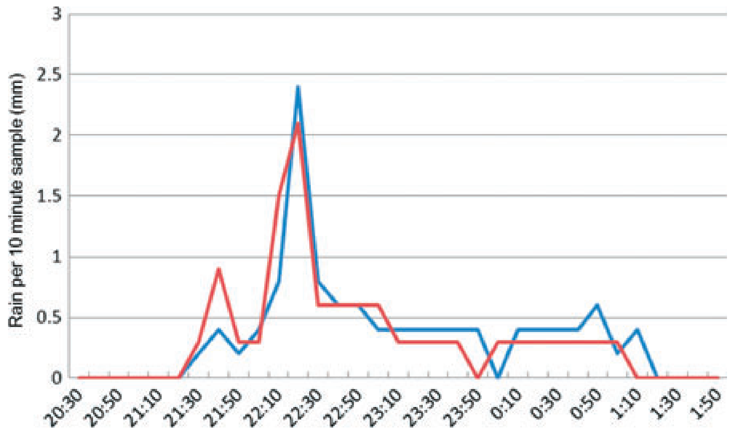

Figure 11. Rainfall per 10-minute sampling period measured by the VP2 (blue) and FO1 (red) rain gauges during a burst of heavy rainfall on 22 November 2012.

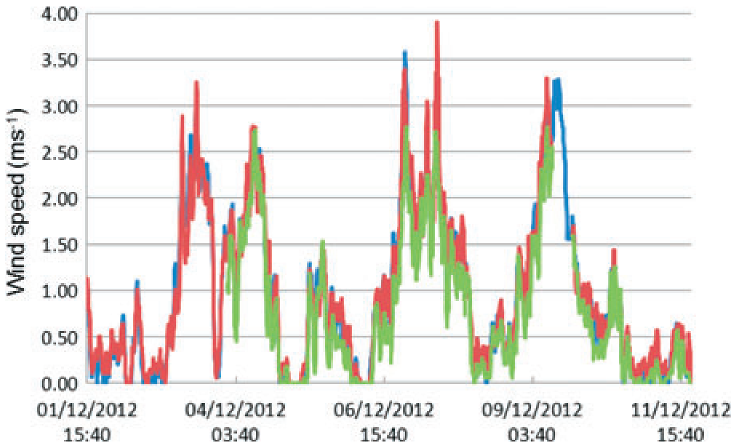

Figure 12. Hourly running-mean wind speeds over the period 1–11 December 2012 from the VP2 (blue), FO1 (red) and FO2 (green) weather stations.

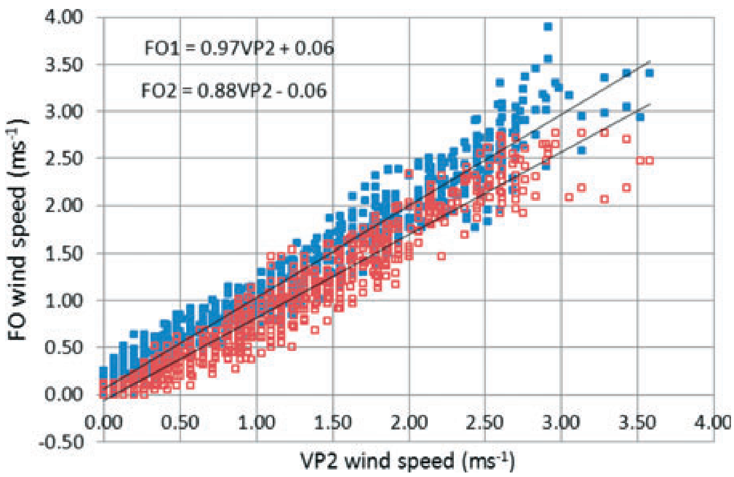

Figure 13. The relationship between hourly running-mean wind speed measured by the VP2 and the FO1 (blue) and FO2 (red) stations during the same period as in Figure 12.

some wind directions, so a comparison of data collected over 11 days without obstructions was undertaken later. A point-by-point comparison of 10min logged wind speed between the stations showed a large amount of scatter. This will be partly because the logging times of the stations are not synchronized (they can be 5min or more apart), so turbulent motion can act to make the recorded speeds quite different. It will also arise from the different values that wind speed is allowed to take in the two types of station (0.4, 0.9, 1.3ms^{-1}, etc., in the case of the VP2; 0.3, 0.7, 1.0ms^{-1}, etc., in the case of the FO), and possibly also because the two stations calculate or average the wind speed they log in different ways. To reduce this scatter, an hourly running mean was taken and this is plotted in Figure 12.

The wind speeds track each other encouragingly well, but the scatter plot of Figure 13 shows that whereas the FO1 wind speed agrees very well with the VP2 (within 3%), the FO2 station reads some 12% lower on average.

Gusts

Both types of weather station take averages of wind speed over a period of 2–2.5s, and then take the maximum of these as a gust. However, the relationship between gust speed and mean speed (not shown) is different for the two types of station: the VP2 gusts are on average twice the mean speed, whereas the FO gusts are about 1.6× mean speed. Hence it is not surprising that the gust speeds do not agree, as shown by Figure 14, in which the FO stations appear to underreport gust speeds by 30–35% compared with the VP2. This may be due to differences in inertia of the anemometer cups, or other sampling differences, and it is possible that the gusts recorded by either station would not agree with those given by a co-located Met Office station.

Wind direction

As with wind speed, wind direction is difficult to compare because lack of synchronisation between measurements allows turbulent motion to make the directions sampled quite different. It was noted by eye that the wind vane on the FO stations oscillates in response to turbulence substantially more than that on the VP2 station. Some point-by-point comparisons were undertaken when all three wind vanes were well exposed on a garage roof and winds were from an unobstructed direction, and by selecting only those data for when wind speed was above zero; these (not shown) indicated reasonable agreement between the FO and VP2 stations, but with a large scatter, particularly with the FO vanes.

To provide a more meaningful comparison, the *distributions* of wind directions from the three stations were studied over several periods, and Figure 15 shows a comparison for one such period. The two FO stations agreed very well with each other, but gave a very different distribution to the VP2. The main reason for this poor agreement arises from the marked reluctance of the FO stations to report the eight 'finer' points of the compass (northnortheast, eastnortheast, eastsoutheast, etc.); these appear on only 6–12% of occasions, whereas the VP2 reported them 46% of the time – about as expected.

To alleviate this problem, data from the 16 compass points were combined into the eight main compass points in the manner $NE_{combined} = NE_{observed} + NNE_{observed}/2 + ENE_{observed}/2$, etc. The result, shown in Figure 16, gives better, but not perfect, agreement between the VP2 and FO stations.

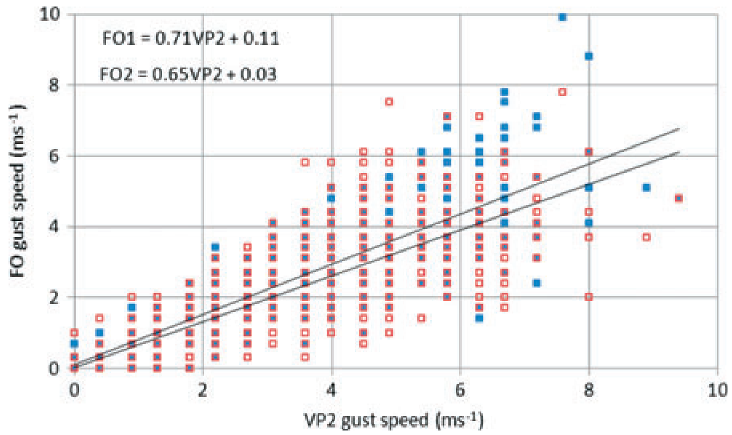

Figure 14. The relationship between gusts logged by the VP2 and the FO1 (blue) and FO2 (red) stations during the period 1–11 December 2012.

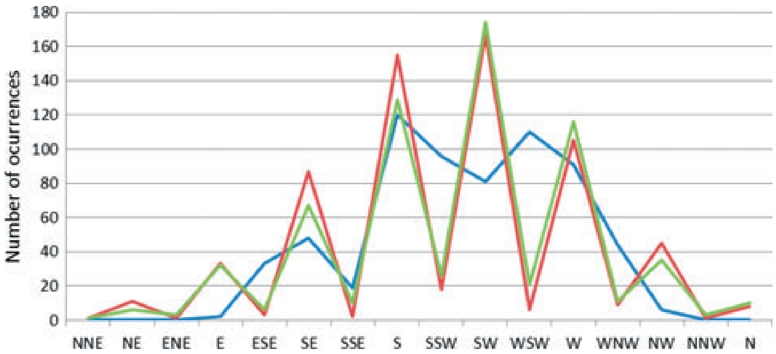

Figure 15. The distribution of 16 wind directions reported by the three stations (blue = VP2, red = FO1, green = FO2) over the period 16–23 November 2012 for all non-zero wind speeds.

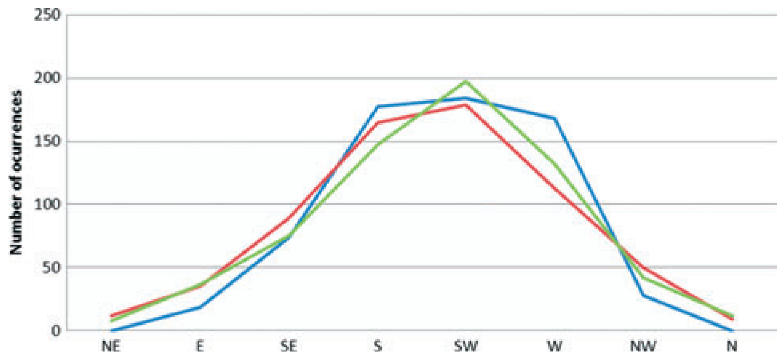

Figure 16. As for Figure 15, but with directions combined into the eight main compass points.

Conclusions

The results are not straightforward to summarise. Temperature measured by both the FO stations at night showed a consistently very good agreement with the VP2, but by day the poor efficiency of the FO radiation screen led to differences of 4 degC or more in light winds and strong solar radiation. Humidity at night showed agreement with the VP2 within a few per cent RH in the case of one FO station, but differences up to 15% RH with the other – and in daytime, humidity was further in error due to the poor radiation screen. Wind speed from one of the FO stations was in very good agreement with the VP2, but the other FO station read about 12% low. Both the FO stations failed to effectively report wind direction to 16 points, but at eight-point resolution they were in reasonable agreement with the VP2. Pressure drift relative to the VP2 was small with one FO station, whereas the other showed a clear temperature sensitivity, which would not be much of a problem if the console was kept at a reasonably stable temperature indoors. Rainfall from one FO station showed good agreement with the VP2 over a 3-month period clear of any possible shadowing effects, but at other times, and with the other FO sensor, agreement was poorer.

From this summary it can be seen that both the FO stations had positive and negative points; it was not the case that one sample clearly outperformed the other. Apart from the daytime temperature errors due to the radiation screen, the extent to which the poorer end of the FO performance is deemed acceptable depends upon the use to which the observations will be put; some users may find this acceptable, others may not.

Obviously robust statements about the accuracy of the Fine Offset WH1080 station are not possible based on a comparison using only two of them, particularly when one example gives good agreement with the VP2 and the other does not, raising the question of which example is the more typical of the type. Finally, it is important to note that this comparison deals only with the accuracy of measurements. When selecting a weather station, however, a whole host of other aspects will need to be taken into account, such as build quality, robustness, functionality, software, wireless range, ease of use and after-sales service. In particular long-term reliability, which will be a critical factor in a choice of weather station, cannot be judged from a relatively short trial period. This article is thus not meant as a guide to choosing a weather station – see chapter 2 of Burt (2012) for a comprehensive discussion of this topic.

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