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Measurements of Important Meteorological Parameters' Variations in the Akron Area

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Abstract

The purpose of this paper is to explain the optimal usage of the Kestrel® 4500 Pocket Weather Tracker and discuss the results of several meteorological parameters obtained throughout the course of the year. These parameters include magnetic and true direction, wind speed, crosswind, headwind, temperature, wind chill, relative humidity, heat index, dew point, wet bulb temperature, barometric pressure, altitude, and density altitude. These data parameters can be uploaded and saved onto a computer for long-term storage and future analysis. A MATLAB program was constructed to read these files and calculate wind chill using the currently accepted formula from the National Weather Service. Additionally, the program constructs a polar plot of the wind velocity, giving another representation to monitor the wind speed and its direction.

Introduction

The Kestrel® 4500 Pocket Weather Tracker is a weather meter developed and commercially released by Nielsen-Kellerman (see Figure 1). It has four distinct monitoring functions: digital compass, wind direction, and crosswind and headwind/tailwind. Users can gather measurements and readings on a variety of factors (see “Appendix” for a full list of these parameters) when properly calibrated to specific settings. As such, one major goal of this paper is to learn how to use this equipment and be able to explain to others how to use it effectively to record weather data over the course of a day. Example graphs of the data the weather meter records will then be shown to observe how the different weather parameters vary over time. After learning how to use this equipment, a study must be conducted to determine the overall accuracy of the Kestrel for the settings chosen.

Local weather stations and airports actively measure meteorological parameters and archive the data for the public to view at any time. One such website that allows users to view historical weather data is Weather Underground, developed by The Weather Company [1]. Entering a location, such as a zip code, and a specific date in the Historical Weather page will bring up the data archived by the airport or weather station closest to the inputted location. For this paper, the location and environment used was an open front yard in a neighborhood near the city of Akron (zip code 44685). The nearest airport given when this location was inputted in Weather Underground was the Akron-Canton Regional Airport (located a distance of 3 miles from the location the Kestrel gathered data). Not all 14 types of weather parameters the Kestrel Weather Meter measured was archived by this airport. For this reason, the following parameters will be focused on for comparison in this paper: direction, wind speed, temperature, wind chill, relative humidity, dew point, and barometric pressure.

A MATLAB program was created to read in any downloaded .csv files of the Kestrel data. A formula to calculate the wind chill manually is provided by the National Weather Service, which is as follows (Equation 1):

$$WC = 35.74 + 0.6215T - 35.75V^{0.16} + 0.4275TV^{0.16} \tag{1}$$

where *WC* is the wind chill (°F), *T* is the temperature (°F), and *V* is the wind speed (mph) [4]. This formula is derived from convective heat transfer and wind speed principles [5]. The Kestrel Weather Meter's wind chill is said to be based on the National Weather Service's standards as of November 1, 2001 [2]. As such, a comparison will be done between the Kestrel's recorded wind chill value and the calculated wind chill values utilizing Equation 1 and the values for the wind speed and direction recorded by the Kestrel. This will determine the overall accuracy of the Kestrel's ability to calculate wind chill based on the standard wind chill formulation developed by the National Weather Service.

The MATLAB program also creates a polar plot of the wind velocity using the gathered wind speed and true direction values for the specified day. Examples of such plots can be found in the "Results and Discussion" section of this report. The purpose of the polar plot is to give a better visual representation of how the wind speed and direction are related to each other during the course of a day. The polar plot will be configured in a way identical to the cardinal directions, with 0° North being positioned at the top, 90° East to the right, 180° South at the bottom, and 270° West to the left.

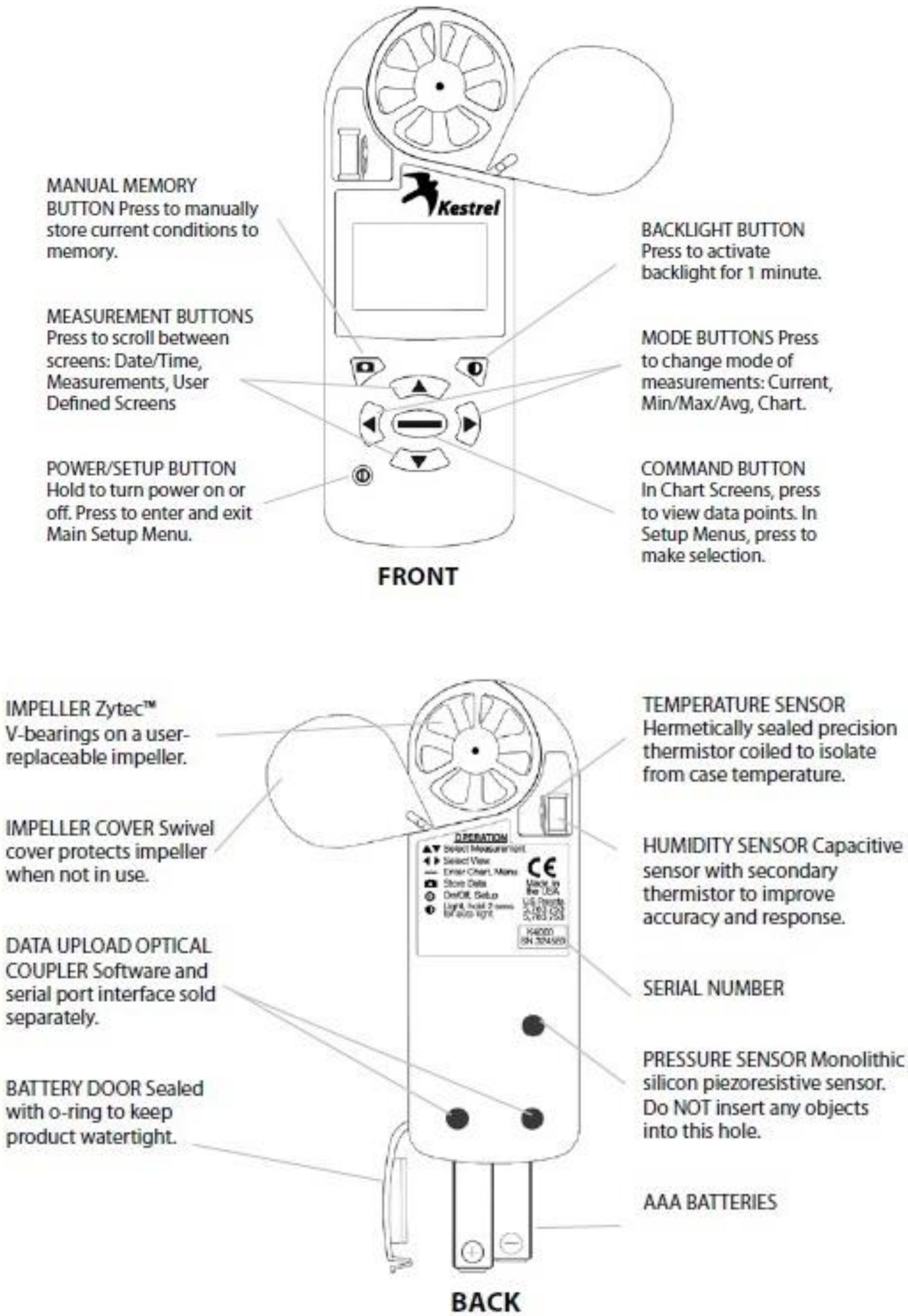

Figure 1: A diagram of the Kestrel® 4500 Pocket Weather Tracker, detailing its physical features [2].

Experimental

The following paragraphs will discuss the setup and operation of the instrument, along with downloading the data for immediate or future interpretation and manipulation.

Start-Up Calibration

When first operating the Kestrel (such as with a new set of batteries), verify that the date and time is set correctly. Removing the batteries or having the batteries die while still in the weather meter will delay its stored time. This can be performed manually at any time in the “Date/Time Setup” screen or when connected to a computer using the Kestrel Communicator Software (discussed later).

Additionally, changing the batteries, or otherwise opening the meter’s battery cartridge door, will disrupt the Kestrel 4500’s digital compass due to the magnetic signature of the AAA batteries [2]. Thus, the user will be prompted to calibrate the digital compass after inserting new batteries to allow the Kestrel 4500 to correct for the magnetic field of the batteries (if the meter does not automatically prompt for a calibration, select the “Compass Cal” option in the System menu). To calibrate the compass properly, hold the Kestrel 4500 vertically upright on a flat, nonmetal surface; rotate it a full three turns, with each turn lasting ten seconds. An error message will appear if not performed correctly. Once finished, the digital compass will not need to be calibrated again until a new set of batteries or the cartridge door is opened again.

If using the Kestrel to measure weather parameters over the course of the day, as performed in this report, it is recommended to calibrate the altitude, pressure, crosswind, and headwind measuring capabilities as well. When the Kestrel is turned on, use the “↑” button to scroll to either the “CROSSWIND” or “HEADWIND” window, and then use the “→” button to reach the “set heading” page [2]. Press the center “Command” button, and select “Manual Set”. Enter the heading as “000°”, which will set the reference direction for measuring crosswind and headwind as North. Next, scroll to the “ALTITUDE” window, use the “→” button to reach the “set ref” page, and set the “reference altitude” to the current elevation above sea level for the location the Kestrel is gathering data at (this value can be found using Google Earth). Setting North as the reference for crosswind and headwind will allow the direction to be compared with the airport’s archived wind direction values, while setting the reference altitude allows for more accurate barometric pressure measurements (both of these settings are discussed in the “Results and Discussion” section of this report).

Tripod and Vane Mount Assembly

The Kestrel 4500 Weather Meter comes with a mini-tripod and vane mount accessory. Both allow for field monitoring for extended periods of time (see Figure 2). The vane mount attaches into the tripod with the weather meter affixed on top of the tripod; it allows the entire unit to spin freely with the wind to monitor the crosswind and headwind more accurately.

Figure 2: Proper setup for the Kestrel® 4500 Pocket Weather Tracker, with mini-tripod and vane mount, for fieldwork.

For the data collected for this investigation, the setup shown in Figure 2 was solely used. Once set up, the data collection rate can be chosen. In the Memory Options menu, turn the “Auto Store” to “On” to allow automatic collection of the properties introduced. Below this option is the “Store Rate”, which can be set to any of the following options listed in Table 1:

MEMORY CAPABILITIES

Store Rate	Total Memory
2 sec	46 min, 40 sec
5 sec	1 hr, 56 min, 40 sec
10 sec	3 hr, 53 min, 20 sec
20 sec	7 hr, 46 min, 40 sec
30 sec	11 hr, 40 min
1 min	23 hr, 20 min
2 min	1 day, 22 hr, 40 min
5 min	4 days, 20 hr, 40 min
10 min	9 days, 17 hr, 20 min
20 min	19 days, 10 hr, 40 min
30 min	29 days, 4 hr
1 hr	58 days, 8 hr
2 hr	116 days, 16 hr
5 hr	291 days, 16 hr
12 hr	700 days

Table 1: The available options the Kestrel 4500 can automatically collect and save data ("Store Rate"), along with the total amount of time it would take until the weather meter reached full memory capacity ("Total Memory") [2].

For this report, data were collected from the 5-second rate up to the 30-minute rate.

Kestrel Communicator Software

In order to interpret the data collected and store it for long periods of time, it must be downloaded through the Kestrel Interface and Kestrel Communicator software. The software comes bundled with the weather meter and is saved on a CD. Instructions on installing the software can be found in a separate guide [3]. Once the software is installed on any computer, the Kestrel Interface can be plugged into any COM Port, and the Kestrel Communicator Software can be opened, bringing up the following window:

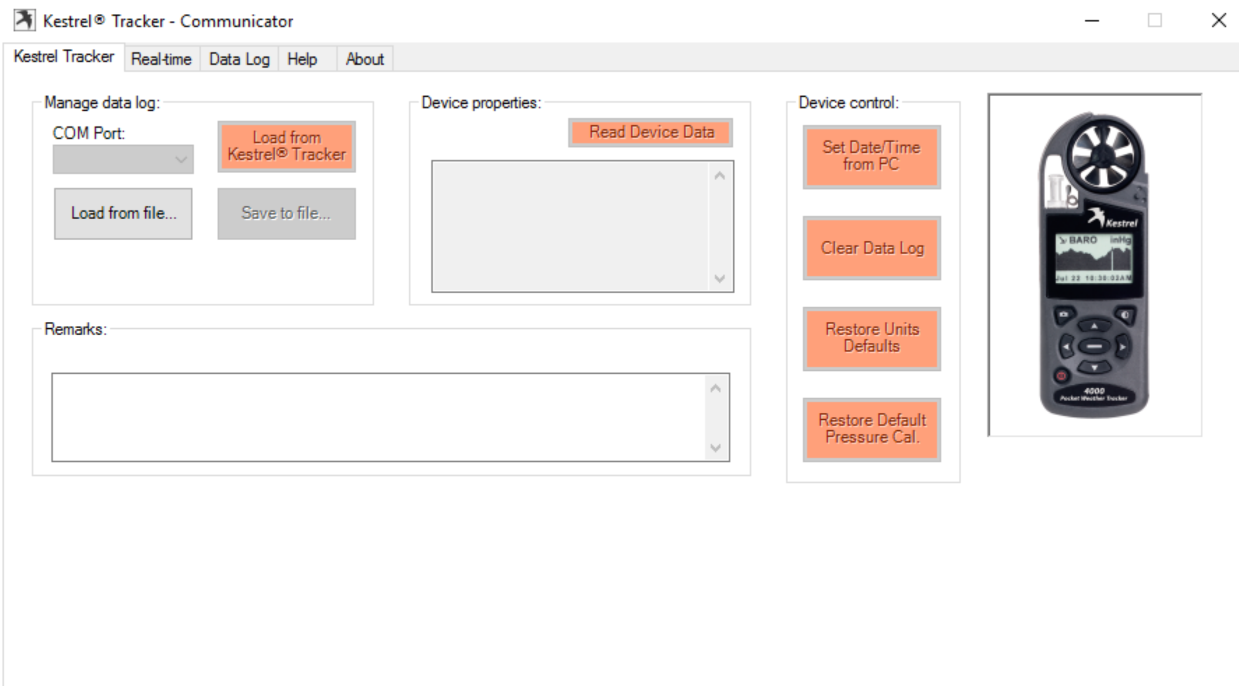

Figure 3: The Kestrel Communicator software window, used to read in saved data from the Kestrel Weather Meters.

Select the proper COM Port that the Kestrel Interface is plugged in to; the COM Port number can be found in the computer's Device Manager. Attach the Kestrel into the Interface, and turn it on. On the Kestrel Communicator Screen, select "Read Device Data" to have the software interact with the weather meter and read in some basic device information, such as its firmware number. Once this information is displayed under the "Device properties" window, select "Load from Kestrel® Tracker"; this will download all the data in the meter's storage system into the Data Log in the Kestrel Communicator Software. Select this tab to display a chart of all the data that is saved in the weather meter. From here, a selected number of data or all of the data can be exported and saved in the computer as a .txt, .xml, or .csv file for long-term storage and future use. Graphs of the data can also be directly saved as a picture file (.png, .jpeg, etc.) immediately in the Data Log screen as well (see "Results and Discussion" for example graphs). Once the data have been uploaded and saved, return to the main Kestrel Tracker page. Select “Clear Data Log”; this will delete the stored data in the Kestrel Weather Meter and allow it to have clear storage for its next use. (It is also on this screen where “Set Date/Time from PC” may be selected to calibrate the weather meter’s time settings to that of the user’s computer).

Results and Discussion

Graphical Analysis

Once data have been uploaded via the Kestrel Communicator Software, graphs of the data sets can be viewed and saved as picture files directly in the software. The following figures show graphs of the 14 parameters for one of the collected daily data sets. For this day, data was collected from 1:30pm to 11:20pm at an interval of 10 minutes (middle of front yard, open environment).

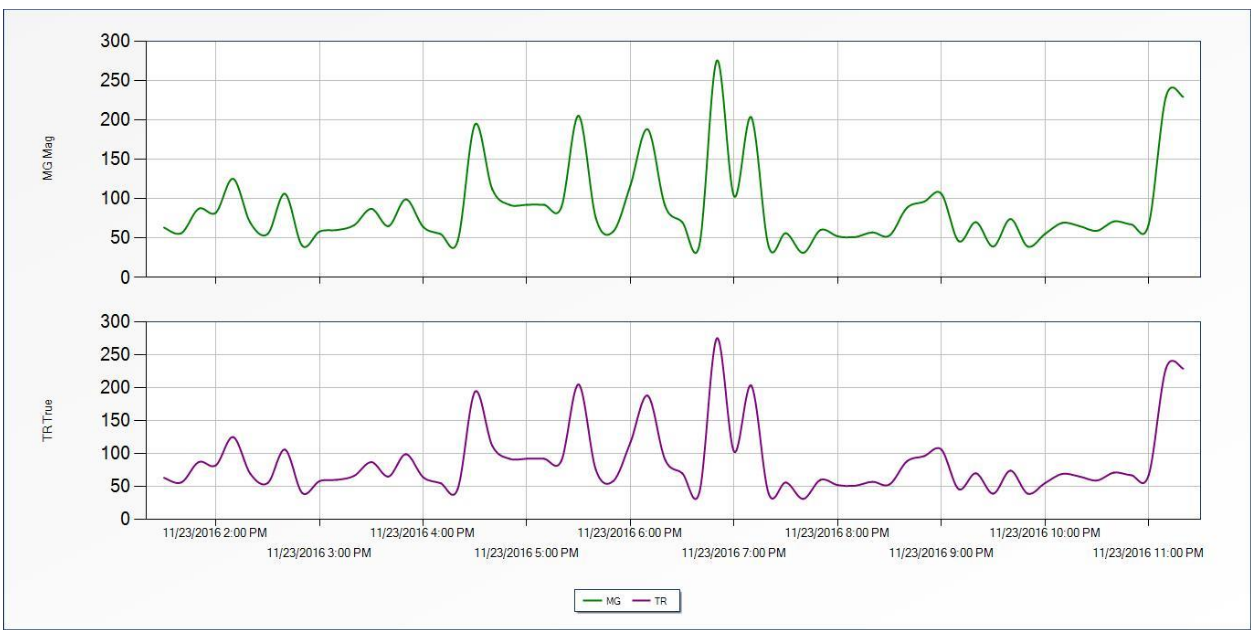

Figure 4: Graphs of the magnetic and true directions (degrees) as a function of time for the date 11/23/2016.

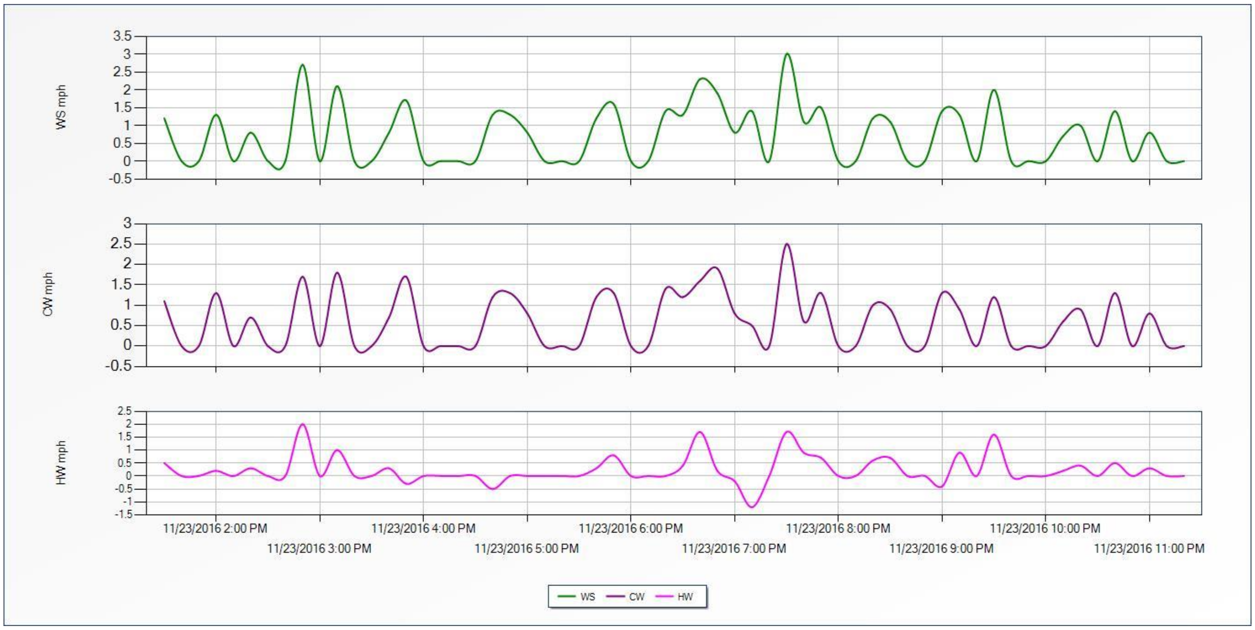

Figure 5: Graphs of the wind speed, crosswind, and headwind (units miles per hour) as a function of time for the date 11/23/2016.

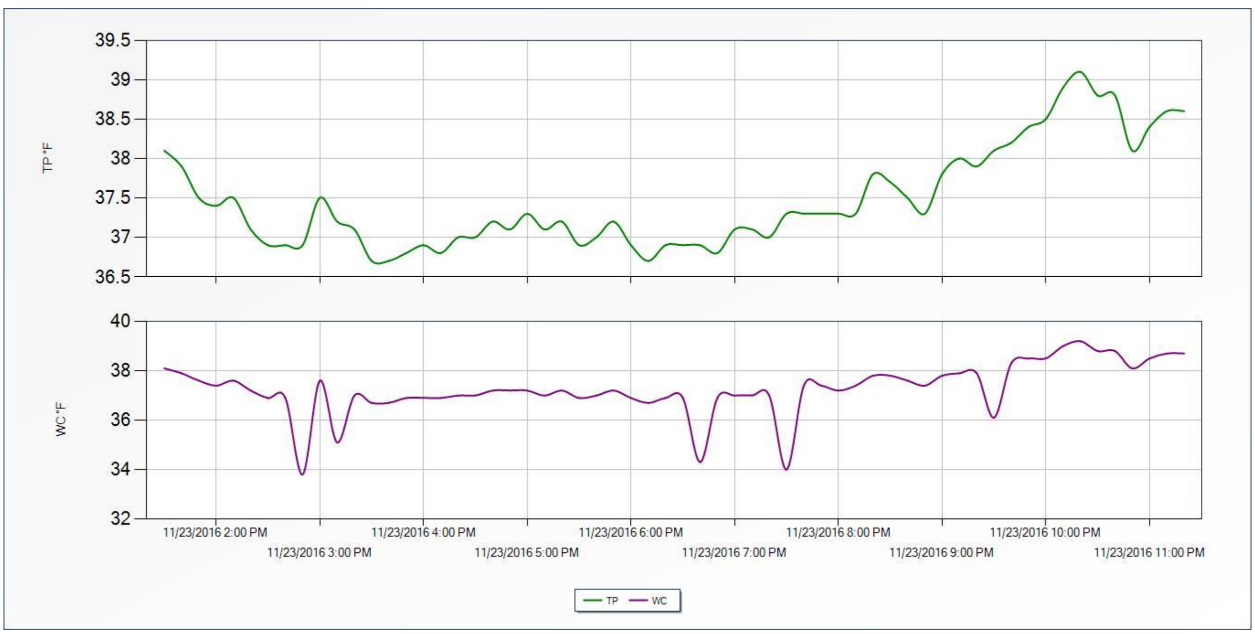

Figure 6: Graphs of the temperature and wind chill (degrees Fahrenheit) as a function of time for the date 11/23/2016.

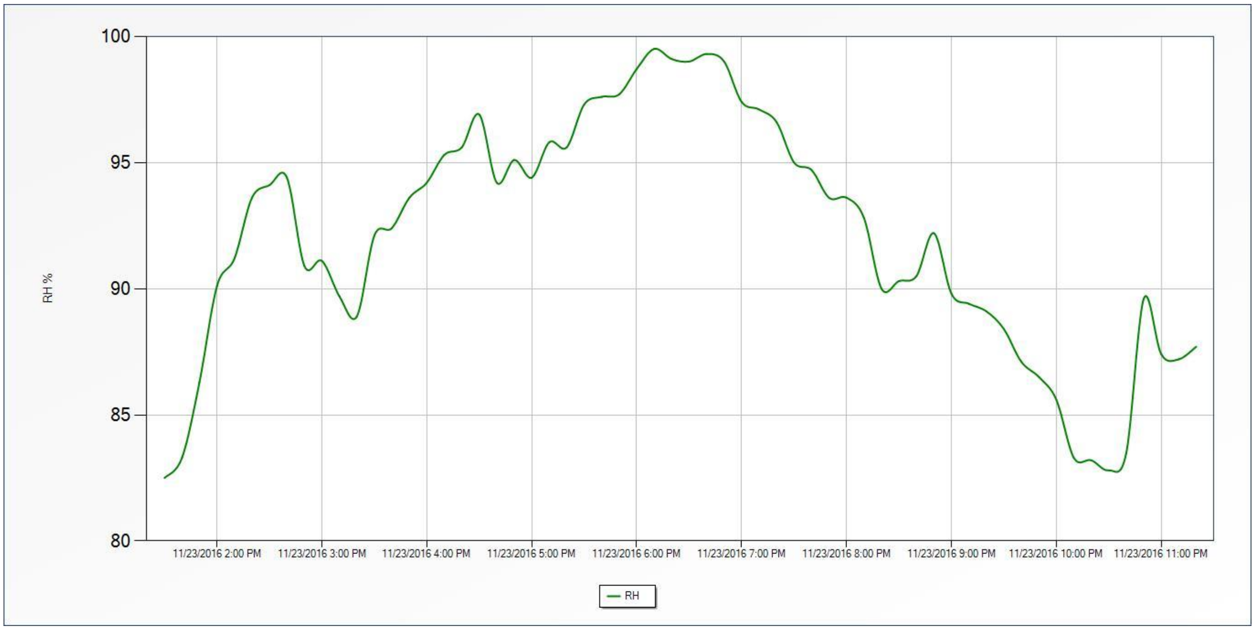

Figure 7: Graphs of the relative humidity (expressed as a percentage) as a function of time for the date 11/23/2016.

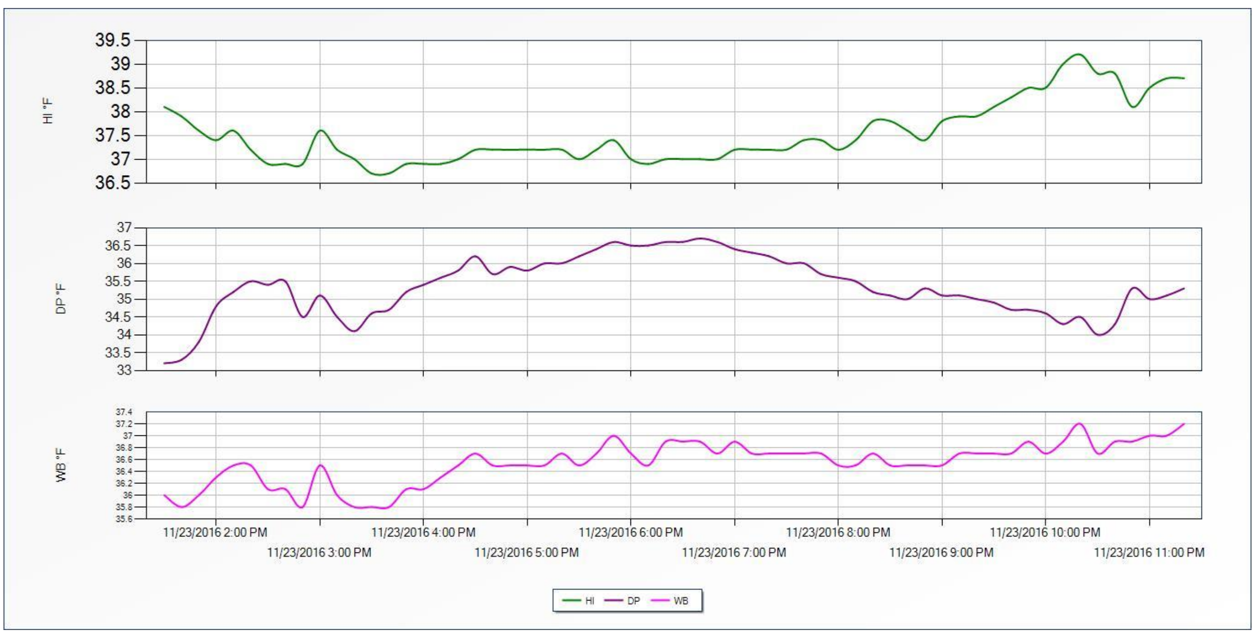

Figure 8: Graphs of the heat index, dew point, and wet bulb temperature (degrees Fahrenheit) as a function of time for the date 11/23/2016.

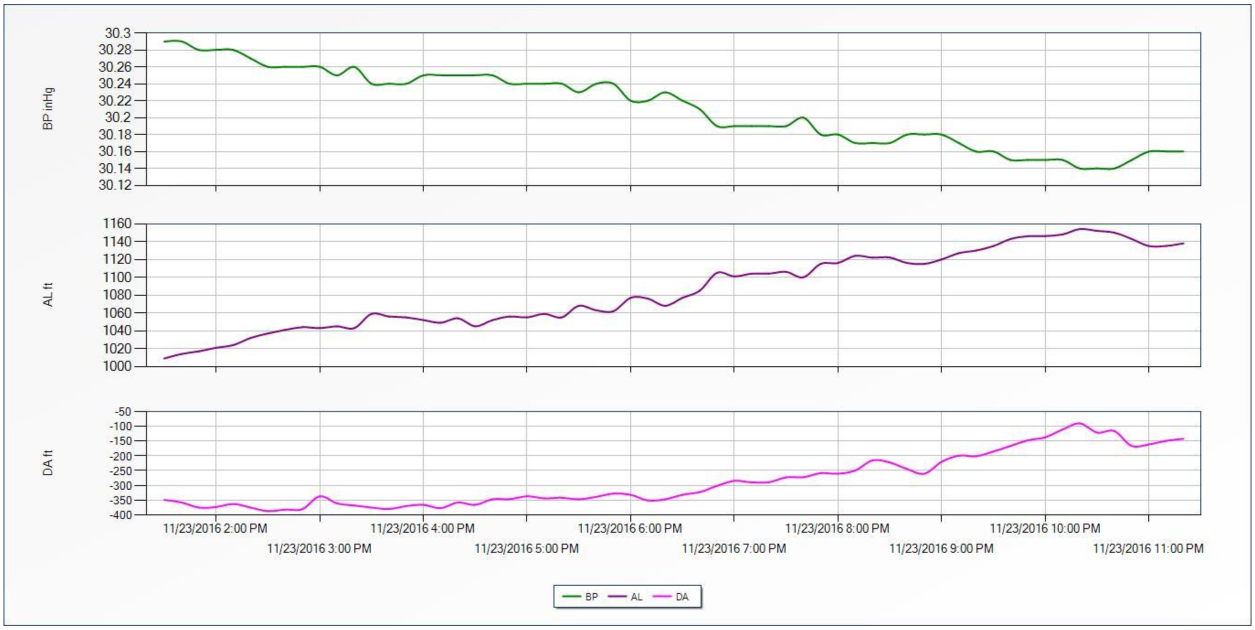

Figure 9: Graphs of the barometric pressure (in Hg), altitude (feet) and density altitude (feet) as a function of time for the date 11/23/2016.

It was determined, upon observation of different interval storage rates, that an interval of either 10 or 20 minutes gave better data compared to shorter intervals, as the latter gave plots with large amounts of noise (see Figure 10). Additionally, with longer intervals, it became possible to gather enough data points to span the entire day's length to calculate daily averages. It should be noted, however, that using larger intervals runs the risk of missing key data points. For example, Figure 11 shows that from 5:00 PM to 9:00 PM the wind speed was constantly 0 mph, which is not what actually occurred. However, with an interval of 20 minutes, only 13 values were recorded by the weather meter. Knowing this, it can be interpreted that the wind was calm during the few instants measurements were saved, but not all other wind speed magnitudes that occurred during this period were recorded. The same applies for all other meteorological parameters.

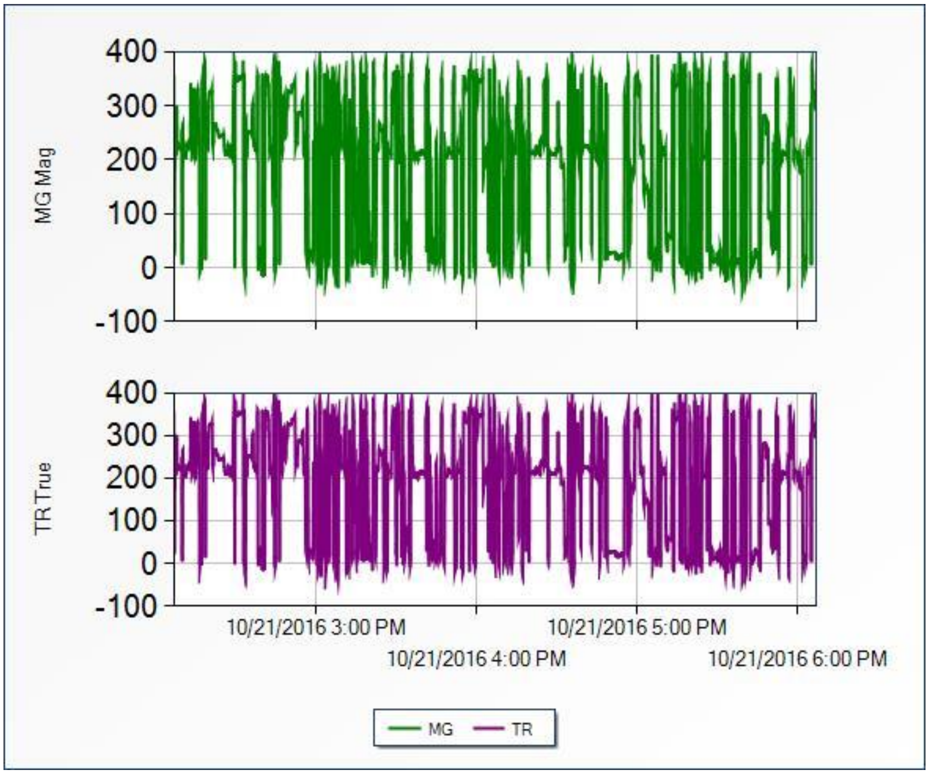

Figure 10: Graphs of the magnetic and true directions (degrees) as a function of time for the date 10/21/2016. For this day, data was collected from 2:06pm to 6:06pm at an interval of 10 seconds. At 6:06pm, the storage capacity of the Kestrel Weather Meter was completely filled and no more data could be gathered.

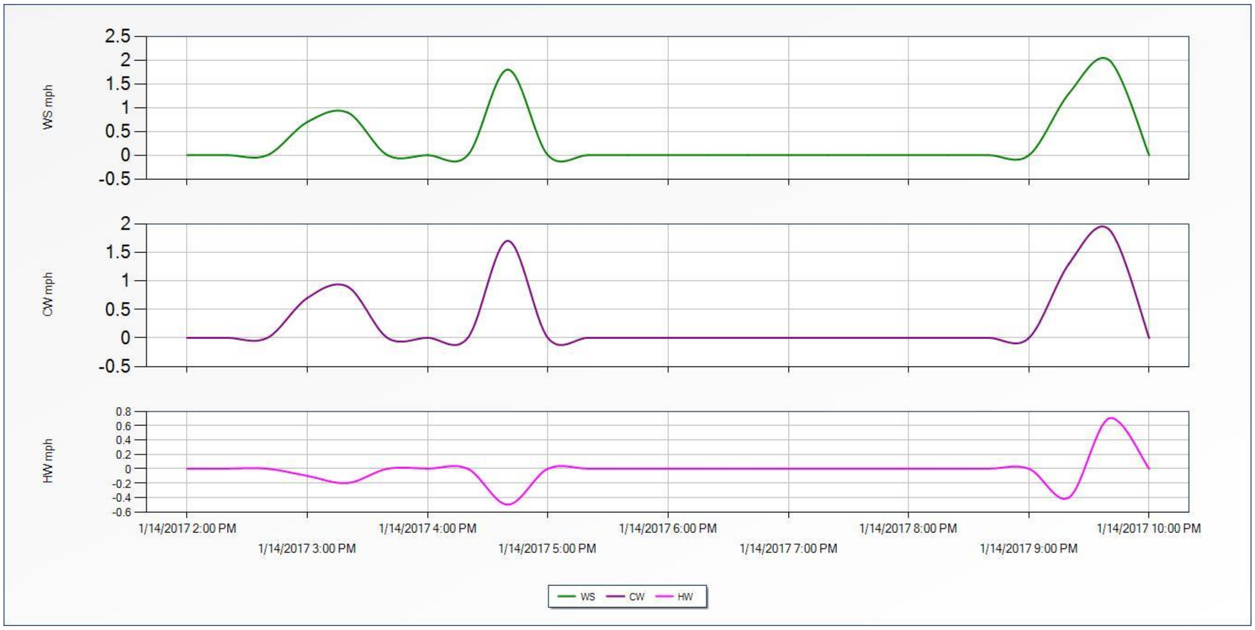

Figure 11: Graphs of the wind speed, crosswind, and headwind (units miles per hour) as a function of time for the date 1/14/2017. For this day, data was collected from 2:00pm to 10:00pm at an interval of 20 minutes.

Figures 4 and 5 show the magnetic and true direction as a function of time and the wind speed, crosswind, and headwind as functions of time, respectively. Crosswind and headwind are quantities relative to the observer's (or in this case, the weather meter's) orientation. By setting the Kestrel's "heading" to 0° North, as stated in the "Experimental" section, and using the tripod and vane mount setup shown in Figure 2, the magnetic or true direction values can be used as the wind speed's direction (both magnetic and true direction values were identical, see "Parameter Averages and Comparison", Table 2). Equations 2 and 3 can be used to calculate and verify the measured crosswind and headwind values for all data sets:

$$Crosswind = V\sin(\theta) \tag{2}$$

$$Headwind = V\cos(\theta) \tag{3}$$

where V is the wind speed and θ is the direction. From this, it can be seen that the crosswind is the perpendicular component of the wind velocity, while the headwind is the component of the wind velocity in the direction of the reference angle (in this case, 0° North).

Figure 9 shows that the pressure decreased steadily during the evening and night, as is expected when considering the ideal gas law. For an ideal gas in a fixed volume, the pressure is directly related to the temperature. As the temperature increases, gas molecules move faster and create a greater force in the container, thus yielding a greater pressure. Assuming a closed environment and that the ambient air is an ideal gas, the barometric pressure should be directly related to the ambient air temperature. Thus, as the temperature decreases during the course of the day, the barometric pressure should indeed be decreasing as well.

However, Figure 9 also shows that the altitude increased, even though the apparatus was stationary the entire time. This observation holds true for the other data sets and must be expected with this instrument for the following reasoning. The Kestrel Weather Meter calculates altitude and barometric pressure based on an inputted “reference” reading that must be set at each location; this reference can be either the altitude or the air pressure. To use the altitude as a reference, one can use Google Earth to find out the altitude of his or her location; to use pressure as the reference, it is recommended to either contact a local airport or check a local weather station website to find out the pressure of a nearby location [2]. Using this value, the meter calculates both the barometric pressure and altitude, with small pressure changes yielding much larger altitude changes. For this reason, using the setup discussed in the “Experimental” section of this report, it is recommended to input a known altitude reading to monitor the pressure more accurately, as the pressure is the only one of these two values actually changing throughout the course of the day. Figure 12 shows this correlation for one of the measured data sets (2/23/2017).

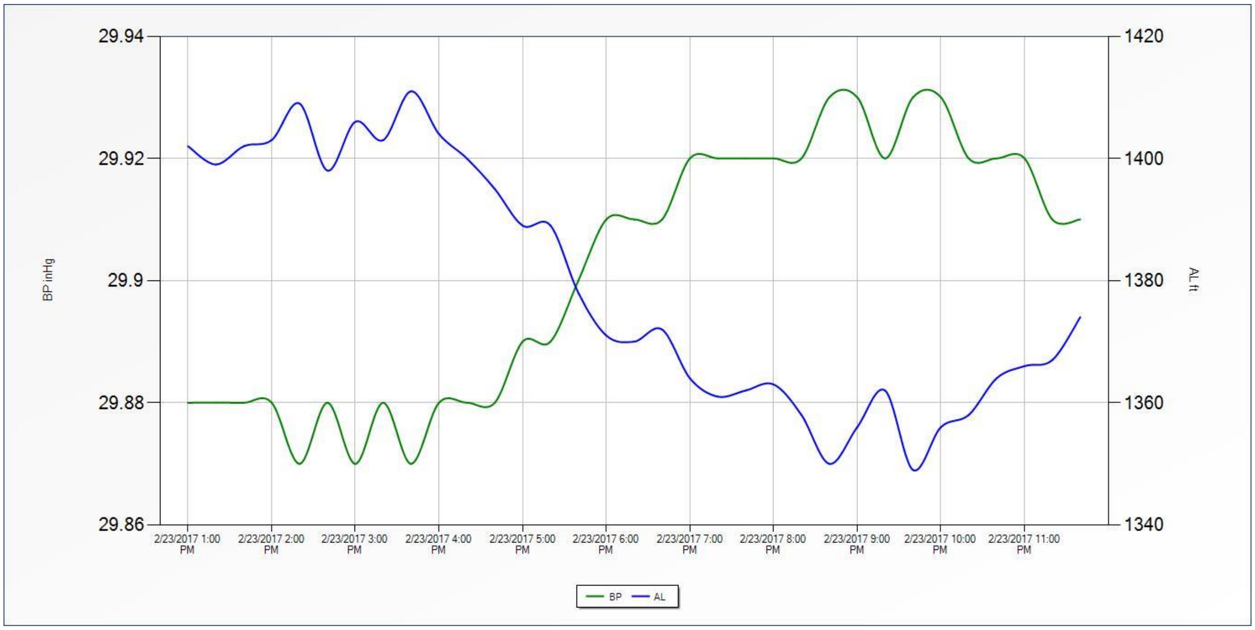

Figure 12: The barometric pressure (in Hg, green line) and altitude (feet, blue line) as a function of time for 2/23/2017. For this day, data was collected from 1:00pm to 10:00pm at an interval of 20 minutes. Note that there is an inverse relationship between the two: as the pressure decreases, the altitude reading increases.

Parameter Averages and Comparison

The website Weather Underground, created by The Weather Company, LLC, collects weather data measured by local airports and saves them for the public to access and view at any time [1]. From the locations used for this report's data, the Akron-Canton Airport was the closest facility to compare datasets. However, not all of the same meteorological parameters are measured and stored for the public; for this reason, averages for the crosswind, headwind, heat index, wet bulb temperature, altitude, and density altitude could not be compared to discuss their accuracy, and thus will not be shown. Note, however, that crosswind and headwind are quantities relative to the observer's (or in this case, the weather meter's) orientation. By setting the Kestrel's "heading" to 0° North, the direction measured by the Kestrel can be compared with the wind direction data collected by the airport (the archived data also does not distinguish between magnetic and true direction. Since the calculated averages for each data set were identical, however, a general direction will be shown for comparison). The following table shows the comparisons between the calculated and archived average values.

Date, Storage Period, and Rate		Magnetic Direction °	True Direction °	Wind Speed mph	Temperature °F	Wind Chill °F	Relative Humidity %	Dew Point °F	Barometric Pressure in Hg
10/26/2016	Average	128.8	128.8	0.0	44.0	44.0	84.5	39.6	28.9
8:02 PM - 10:01 PM	Archived	E	90.0	9.0	40.0	36.0	77.0	35.0	30.4
(5s)	% Deviation		43.2	99.8	10.1	22.2	9.8	13.1	4.7
10/27/2016	Average	208.7	208.7	1.3	43.7	43.3	99.7	43.6	28.9
8:38 PM - 10:38 PM	Archived	WSW	247.5	12.0	50.0	46.8	78.0	43.0	30.1
(5s)	% Deviation		15.7	89.5	12.5	7.5	27.8	1.5	3.8
10/28/2016	Average	247.8	247.8	0.0	48.3	48.3	84.5	43.8	28.9
7:54 PM - 9:54 PM	Archived	WSW	247.5	7.0	49.0	45.0	74.0	39.0	30.3
(5s)	% Deviation		0.1	99.9	1.4	7.4	14.2	12.3	4.5
10/30/2016	Average	211.4	211.4	0.3	50.2	50.2	98.1	49.7	28.9
3:30 PM - 11:31 PM	Archived	NW	315.0	9.0	58.0	58.0	76.0	51.0	30.0
(20s)	% Deviation		32.9	96.4	13.5	13.5	29.1	2.6	3.9
11/11/2016	Average	90.6	90.6	1.8	41.3	40.1	69.9	32.1	29.0
4:14 PM - 11:59 PM	Archived	NNW	337.5	13.0	45.0	42.3	66.0	33.0	30.1
(20s)	% Deviation		73.2	86.1	8.3	5.2	5.9	2.8	3.7
11/12/2016	Average	260.9	260.9	0.8	38.9	38.6	81.6	32.9	29.0
12:41 PM - 11:33 PM	Archived	WSW	247.5	4.0	39.0	36.2	62.0	27.0	30.4
(30s)	% Deviation		5.4	79.9	0.3	6.5	31.6	21.9	4.4
11/16/2016	Average	249.1	249.1	0.9	41.9	41.6	95.6	40.7	29.9
12:25 PM - 11:59 PM	Archived	WSW	270.0	6.0	44.0	45.1	73.0	40.0	29.9
(60s)	% Deviation		7.7	85.7	4.7	7.7	31.0	1.7	0.0
11/18/2016	Average	236.0	236.0	1.4	65.1	65.1	49.1	45.3	30.1
12:36 PM - 11:58 PM	Archived	S	180.0	10.0	65.0	65.0	43.6	42.1	30.0
(2min)	% Deviation		31.1	86.4	0.2	0.2	12.7	7.6	0.3
11/19/2016	Average	247.6	247.6	1.6	51.0	50.3	73.8	41.9	29.9
12:00 AM - 9:42 AM	Archived	SW	225.0	15.5	48.5	44.3	69.6	38.0	29.9
(2min)	% Deviation		10.0	89.7	5.2	13.7	6.0	10.4	0.2
11/22/2016	Average	269.4	269.4	0.4	30.0	29.9	87.9	26.5	30.4
12:45 PM - 11:55 PM	Archived	WNW	292.5	5.0	30.0	24.7	70.0	20.0	30.3
(5min)	% Deviation		7.9	92.0	0.0	20.9	25.6	32.4	0.3
11/23/2016	Average	87.5	87.5	0.7	37.5	37.3	92.0	35.3	30.2
1:30 PM - 11:20 PM	Archived	ESE	112.5	8.4	38.8	33.1	68.6	29.3	30.1
(10min)	% Deviation		22.2	91.6	3.5	12.6	34.1	20.6	0.2
12/4/2016	Average	279.0	279.0	1.6	37.6	36.6	85.6	33.6	30.1
2:00 PM - 10:00 PM	Archived	SE	135.0	11.6	38.3	30.9	67.2	28.1	30.0
(20min)	% Deviation		106.6	86.7	1.6	18.6	27.4	19.6	0.3
12/7/2016	Average	269.0	269.0	2.2	34.4	32.3	74.7	27.1	30.2
1:25 PM - 11:55 PM	Archived	WSW	247.5	10.1	35.0	27.5	57.8	21.3	30.1
(5min)	% Deviation		8.7	78.3	1.5	17.3	29.3	27.4	0.2
12/27/2016	Average	254.1	254.1	2.0	34.0	31.9	89.4	31.1	30.1
2:00 PM - 10:00 PM	Archived	W	270.0	10.2	35.1	27.9	68.6	25.7	30.1
(30min)	% Deviation		5.9	80.1	3.4	14.2	30.2	20.9	0.3
12/28/2016	Average	255.3	255.3	1.0	35.4	34.6	71.7	27.0	30.1
2:00 PM - 10:00 PM	Archived	SW	225.0	10.2	36.0	28.7	57.1	21.5	30.0
(30min)	% Deviation		13.5	90.6	1.7	20.6	25.6	25.4	0.2

1/7/2017	Average	270.0	270.0	3.3	11.1	3.8	85.5	7.5	30.4
2:00 PM - 10:00 PM	Archived	W	270.0	12.4	11.6	-2.9	59.8	0.0	30.4
(20min)	% Deviation		0.0	73.4	4.2	-231.0	43.1	67040.0	0.0
1/8/2017	Average	272.7	272.7	2.0	12.8	9.4	83.9	8.8	30.7
2:00 PM - 10:00 PM	Archived	W	270.0	9.0	13.2	1.7	57.3	0.6	30.7
(20min)	% Deviation		1.0	77.3	2.7	439.8	46.3	1293.9	0.0
1/9/2017	Average	277.6	277.6	1.1	11.7	10.0	98.1	11.2	30.6
12:00 AM - 8:20 AM	Archived	S	180.0	12.3	12.9	-1.2	65.4	3.3	30.6
(20min)	% Deviation		54.2	90.8	9.6	-934.9	49.9	240.2	0.0
1/11/2017	Average	288.2	288.2	1.7	51.3	50.7	89.4	48.1	30.0
2:00 PM - 10:00 PM	Archived	SSW	202.5	16.9	52.0	52.0	78.6	45.3	29.9
(20min)	% Deviation		42.3	89.8	1.3	2.4	13.7	6.1	0.3
1/14/2017	Average	274.9	274.9	0.3	32.8	32.8	81.5	27.8	30.4
2:00 PM - 10:00 PM	Archived	WNW	292.5	4.6	33.4	29.9	64.2	22.5	30.4
(20min)	% Deviation		6.0	94.2	1.7	9.7	27.0	23.4	0.1
1/15/2017	Average	271.6	271.6	0.2	28.4	28.4	89.9	25.6	30.4
2:00 PM - 11:40 PM	Archived	S	180.0	1.8	30.0	28.3	67.6	20.3	30.4
(20min)	% Deviation		50.9	87.4	5.3	0.3	33.0	25.9	0.1
1/19/2017	Average	270.6	270.6	0.9	38.1	37.5	97.4	37.4	30.1
2:00 PM - 10:00 PM	Archived	SSE	157.5	7.6	38.6	33.4	80.6	33.1	30.0
(10min)	% Deviation		71.8	87.8	1.3	12.3	20.8	12.8	0.3
1/22/2017	Average	267.9	267.9	0.4	55.7	55.7	87.3	51.7	29.7
2:00 PM - 10:00 PM	Archived	NE	45.0	9.4	56.6	56.6	73.9	48.2	29.6
(10min)	% Deviation		495.3	95.3	1.6	1.6	18.1	7.3	0.4
1/25/2017	Average	265.0	265.0	2.8	46.3	44.6	93.9	44.6	29.6
12:40 PM - 10:00 PM	Archived	WSW	247.5	13.5	46.6	44.4	79.8	40.6	29.5
(20min)	% Deviation		7.1	79.1	0.5	0.3	17.7	9.9	0.4
1/29/2017	Average	278.3	278.3	1.2	28.1	27.1	88.9	25.2	29.8
2:00 PM - 10:00 PM	Archived	W	270.0	8.0	28.8	21.2	66.0	15.5	29.8
(10min)	% Deviation		3.1	84.6	2.2	27.8	34.7	62.0	0.2
2/2/2017	Average	275.5	275.5	2.4	25.2	22.4	74.2	17.9	30.3
2:00 PM - 11:40 PM	Archived	W	270.0	11.9	25.7	15.4	55.0	11.2	30.3
(20min)	% Deviation		2.0	80.2	2.1	45.5	34.9	59.1	0.1
2/19/2017	Average	288.0	288.0	1.6	54.3	54.2	56.7	37.6	30.2
2:00 PM - 10:00 PM	Archived	WNW	292.5	7.7	57.0	57.0	42.1	33.6	30.1
(20min)	% Deviation		1.5	79.5	4.8	4.9	34.7	11.9	0.3
2/23/2017	Average	280.3	280.3	1.4	61.3	61.4	80.5	54.8	29.9
1:00 PM - 11:40 PM	Archived	WSW	247.5	8.1	62.9	62.9	69.2	52.4	29.8
(20min)	% Deviation		13.3	83.1	2.5	2.5	16.3	4.7	0.4
3/19/2017	Average	173.6	173.6	0.4	36.2	36.0	96.4	35.2	30.4
1:30 PM - 11:50 PM	Archived	WNW	292.5	4.4	36.3	32.9	78.8	30.2	30.3
(10min)	% Deviation		40.7	91.4	0.5	9.5	22.4	16.5	0.2

Table 2: The average values for the data collected via the Kestrel Weather Meter and the data retrieved from the Akron-Canton Airport, with percent deviation calculations using the Akron-Canton Airport's data as the "exact" or "actual" value. The distance between the airport and the location used for measuring data with the Kestrel is 3 miles. The environment of the location used with the Kestrel was an open front yard in a neighborhood (zip code 44685). The wind chill data in red indicates that there was no data archived and saved by The Weather Company, so the average temperature value was used for its comparison.

From the data, the Kestrel appears to be the most accurate when determining the daily air pressure, and the largest errors were found when measuring the wind speed. The temperature tended to be accurate as well, with the largest discrepancies found when using smaller storage intervals. Dew point and humidity had noticeable differences as well, and although the magnetic and true directions measured by the Kestrel matched every day, there were still some days where the average direction differed completely from the wind direction measured by the airport. Wind chill data tended to compare as accurately as the temperature, with the largest errors occurring with extremely low or negative wind chill values archived by the Weather Company.

Each measured average relative humidity value appeared larger than the actual humidity percentage archived. Part of the reason for this inaccuracy is due to keeping the Kestrel outside in direct sunlight. While it is necessary to measure the other conditions out in the open, leaving the Kestrel in direct sunlight heats the air inside the meter’s humidity sensor enclosure, which causes it to measure higher values than normal. Additionally, during the winter months, taking the Kestrel from indoors (temperatures around 70°F) to outside (40°F or below) leads to further disruption of the humidity senor from thermal equilibrium [2]. This, however, was mitigated by providing a steady airflow (at least 2.2 mph, given by the wind or gently blowing on the temperature sensor) and giving the Kestrel Meter at most 20 minutes to stabilize before recording data, as stated in the manual. Therefore, the major error source for large humidity readings came from having the meter in direct sunlight during the day.

Other factors may have contributed to the discrepancies for the other parameters. First, as the data measured by the Kestrel was not done in the exact location as measured by the Akron-Canton Airport, it must be expected that differences will arise due to non-identical environmental setups. This is especially true for the wind speed; choosing a location not as open or at a different elevation above the ground can lead to lower wind speed values measured [5]. Another factor that affects the accuracy of the data is the chosen storage interval rate. While larger intervals led to less noise in the data, there is a much smaller probability that the Kestrel records the data at optimal times. To clarify with an example, setting the Kestrel to collect data at an interval of 20 minutes means only 3 values per parameter are stored per hour (on the hour, and 20 and 40 minutes past the hour). It is possible, especially for the wind speed and directions, that at those times, calm winds were experienced, leading to measured values ranging from 0 to only a fraction of a 1 mph wind. Additionally, the tripod that came with the Kestrel is stated to be only able to withstand wind speeds less than 15 mph. With this, it was impossible to test the accuracy of measuring wind speeds on days with stronger wind gusts, as this would lead to the Kestrel and tripod being knocked over on the ground, thereby losing a day's data when returning to check on the setup after leaving it idle for multiple hours or over the course of an entire day.

Wind Chill and Wind Velocity Polar Plot

As described in the "Introduction", the MATLAB program was constructed to calculate wind chill based off Equation 1 and create a polar plot for the wind velocity for any day's data set. Table 3 shows the wind chill calculation comparisons, and Figure 13 shows an example of the polar plot.

Date	Kestrel's Wind Chill Average (°F)	Calculated Wind Chill Average (°F)	Percent Difference (%)
10/26/2016	44.0	44.1	-0.1
10/27/2016	43.3	44.4	-2.6
10/28/2016	48.3	48.3	0.0
10/30/2016	50.2	50.6	-0.8
11/11/2016	40.1	41.0	-2.3
11/12/2016	38.6	39.0	-1.2
11/16/2016	41.6	42.2	-1.3
11/18/2016	65.1	66.5	-2.0
11/19/2016	50.3	51.3	-1.8
11/22/2016	29.9	30.1	-0.7
11/23/2016	37.3	37.9	-1.7
12/4/2016	36.6	37.4	-2.0
12/7/2016	32.3	33.2	-2.7
12/27/2016	31.9	32.7	-2.5
12/28/2016	34.6	35.2	-1.8
1/7/2017	3.8	5.5	-36.2
1/8/2017	9.4	10.0	-6.6
1/9/2017	10.0	10.3	-2.8
1/11/2017	50.7	51.6	-1.7
1/14/2017	32.8	33.0	-0.7
1/15/2017	28.4	28.6	-0.5
1/19/2017	37.5	38.1	-1.7
1/22/2017	55.7	56.1	-0.9
1/25/2017	44.6	45.7	-2.5
1/29/2017	27.1	27.6	-1.8
2/2/2017	22.4	23.2	-3.5
2/19/2017	54.2	54.9	-1.3
2/23/2017	61.4	62.1	-1.2
3/19/2017	36.0	36.3	-0.7

Table 3: The average wind chill temperatures using the Kestrel's data and Equation (1), along with the percent difference between the two values for each specified date.

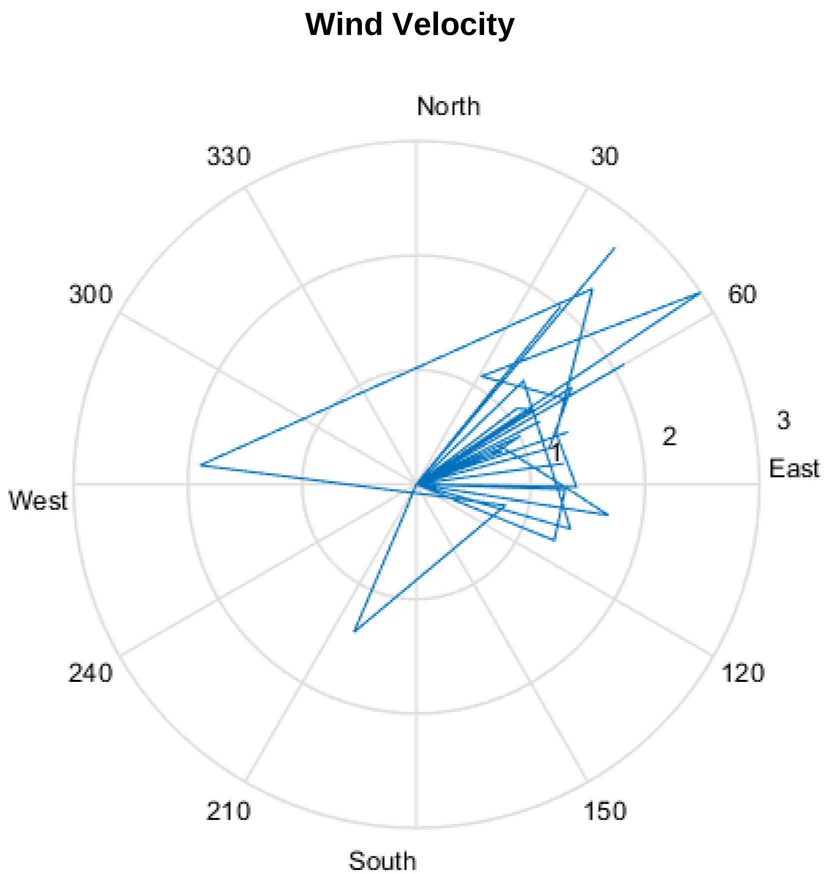

Figure 13: Polar plot of the wind velocity for the data gathered on 11/23/2016, using the wind speed and true direction data. The numbers on the concentric circles represent the magnitude of the wind speed (mph), while the outer numbers represent the polar degrees, with 0 being North, 90 being East, 180 being South, and 270 being West.

Based on the data from Table 3, the Kestrel 4500 Weather Meter's wind chill value is almost equivalent to the calculation used by the National Weather Service, with only one large discrepancy found for the data on 1/7/2017. However, as there were still major percent errors when comparing its average with that gathered by the Akron-Canton Airport, the same conclusions stated before must be drawn for its accuracy.

The polar plot allows the wind speed to be analyzed directly as a function of direction. This will allow users to determine relationships between the wind's speed and direction at any location for any amount of time desired. For example, based on Figure 13, the wind appeared to be blowing mainly from an eastward direction during the date 11/23/2016, with speeds of about 1 mph with gusts of wind coming to upwards of 3 mph. Using another data set, such as from 2/2/2017 (Figure 14), the wind was blowing from a westward direction, with speeds averaging to about 2 mph with gusts upwards of almost 6 mph. Based on the collected measured and archived data, wind velocity varies drastically from day to day. However, most days individually show a general trend in direction.

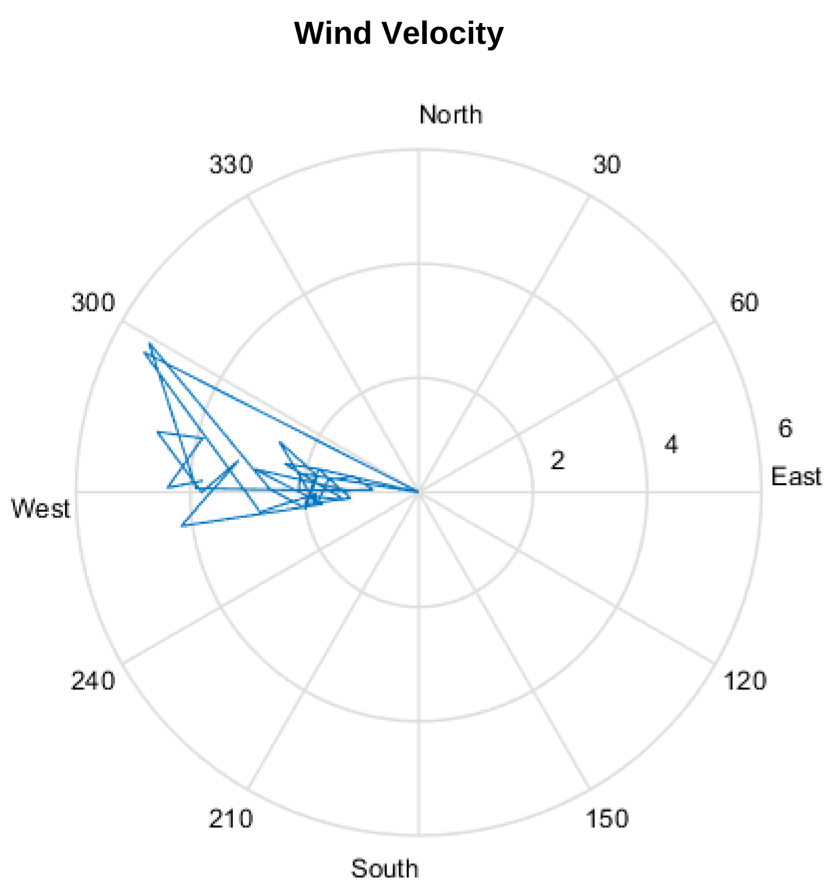

Figure 14: Polar plot of the wind velocity for the data gathered on 2/2/2017, using the wind speed and true direction data. The numbers on the concentric circles represent the magnitude of the wind speed (mph),

while the outer numbers represent the polar degrees, with 0 being North, 90 being East, 180 being South, and 270 being West.

Conclusions

Due to the limitations discussed in this report, it is difficult to ascertain the accuracy of the data. The main limitation is location; as stated in the Kestrel manual, weather fronts vary greatly between locations, and different weather readings occur between locations as close as a mile apart [2]. There are a number of recommendations for future tests of determining the accuracy of the Kestrel's data. First, the company offers a larger and sturdier tripod stand for the weather meter. This product would allow data to be recorded during stronger wind gusts, which would allow opportunities to gather data on such days. If possible, recreating the same environmental setup as performed by the Akron-Canton Airport (or whichever weather-recording facility is closest to the user) would eliminate any discrepancies associated with location; this would also include interval storage rate, removing any buildings or objects that may interfere with measuring wind velocity, and elevation above the ground. Finally, Nielsen-Kellerman has discontinued sales for any of the 4000 series brands of weather meters. If one wishes to gather similar data as performed in this report, the Kestrel 5500 Weather Meter is recommended, as this instrument measures the same 14 meteorological parameters.

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Appendix

The following shows the complete list of the parameters the Kestrel measures, with quoted definitions as described in the manual.

- Heading (true and magnetic direction, based off True North and Magnetic North, respectively). True North refers to the direction of the North Pole based on the meter's position, while Magnetic North refers to the constantly changing position on the Earth's surface where the Earth's magnetic field points downwards [2].
- Altitude – "The distance above sea level. The Kestrel Meter calculates altitude based on the measured station pressure [air pressure of your location] and the input barometric pressure - or 'reference pressure'," [2].
- Barometric pressure – "The air pressure of your location reduced to sea level. Pressure will change as weather systems move into your location. Falling pressure indicates the arrival of a low-pressure system and expected precipitation or storm conditions. Steady or rising pressure indicates clear weather. A correct altitude must be input for the Kestrel Meter to display barometric pressure correctly," [2].
- Wet bulb temperature – "The lowest temperature to which a thermometer can be cooled by evaporating water into the air at constant pressure. This measurement is a holdover from the use of an instrument called a sling psychrometer. To measure wet bulb temperature with a sling psychrometer, a thermometer with a wet cloth covering over the bulb is spun rapidly through the air. If the relative humidity is high, there will be little evaporative cooling and the wet bulb temperature will be quite close to the ambient temperature. Some exercise

physiology guides use wet bulb temperature, rather than heat index, as a measure of the safety of exercise in hot and humid conditions," [2].

- Relative humidity – "The amount of water vapor actually in the air divided by the maximum amount of water vapor the air could hold at that temperature, expressed as a percentage," [2].
- Heat index – "A practical measure of how hot the current combination of relative humidity and temperature feels to a human body. Higher relative humidity makes it seem hotter because the body's ability to cool itself by evaporating perspiration is reduced," [2].
- Dewpoint – "The temperature to which air must be cooled in order for condensation to occur. The difference between dewpoint and temperature is referred to as the 'temperature/dew point spread'. A low dewpoint spread indicates high relative humidity, while a large dewpoint spread indicates dry conditions," [2].
- Density altitude – "The altitude at which you would be, given the current air density. Often used by pilots in order to determine how an aircraft will perform. Also of interest to individuals who tune high performance internal combustion engines, such as racecar engines," [2].
- Wind chill – "The cooling effect of combining wind and temperature. The wind chill gives a more accurate reading of how cold it really feels to the human body. The Kestrel Meter's wind chill is based on the National Weather Service standards as of November 1, 2001," [2].
- Temperature – "The ambient air temperature," [2].