ELECTRONIC MEASUREMENT OF BAROMETRIC PRESSURE: A Comparison of Omega Model EWS-BP-A, Setra Model 276, Setra Model 278, Vaisala Model PTB101B, and Apogee Instruments Model BPS

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ABSTRACT

Four barometric pressure transducers, ranging in price from $145 to $580, were evaluated over the course of the last year and a half. A fifth, recently discovered sensor has been found to perform better than the cheapest of the other four sensors, and at a fraction of the cost. All of the transducers performed satisfactorily in our lab environment over the time periods and the range of temperatures tested. The Setra 278 was the most stable sensor with the Vaisala sensor close behind. The Setra 276 is good for measurements at room temperature, but its operating range of -18 to 79°C may not be suitable for outdoor use in extremely cold environments. The Omega EWS-BP-A is a cost-effective alternative that is suitable for general laboratory use where measurements of relative daily and weekly changes are more important than absolute accuracy. However the Apogee BPS makes more precise measurements than the Omega transducer at a much lower price. We continue to monitor the performance of these sensors to evaluate long-term drift of their output.

INTRODUCTION

Barometric pressure (or atmospheric pressure) is the force exerted on the ground surface by the atmosphere. Barometric pressure is expressed in many different units:

1 atmosphere = 14.7 lb/in^2 = 760 mm Hg = 760 torr = 1.013 bars = 101.3 kPa

The SI unit of pressure is the Pascal (Pa) and barometric pressure is best expressed in kilopascals (kPa). The standard barometric pressure (101.3 kPa) is the pressure at sea level at 15°C and 45° latitude. Barometric pressure decreases with increasing elevation. To compare pressure conditions among locations, meteorologists correct pressure to its sea-level equivalent (Eq. 1),

$$dP = 1013.25\{1-[1-(E / 44307.69231)]^{5.25328}\} \quad (1)$$

where *dP* is the reduction in pressure (in millibars) resulting from the site elevation and *E* is meters above sea level.

The first measurements of barometric pressure were made centuries ago using a mercury manometer, and even now mercury barometers are a standard reference instrument due to their inherent accuracy. Liquid manometers, however, have three disadvantages: 1) they are delicate and require perfectly vertical and level mounting, 2) their readings must be manually temperature-corrected, and 3) they do not have an electronic output.

Electronic barometric pressure transducers can be interfaced with a datalogging system for continuous measurement and recording. Better quality transducers are fully temperature compensated. We tested five electronic barometric pressure transducers in our laboratory (Table 1). Two of the sensors are available either directly from the manufacturer or from Campbell Scientific (model numbers in parentheses).

Table 1. Specifications of the five barometric pressure sensors evaluated.

	Apogee Instr. BPS	**Omega EWS-BP-A**	**Setra 276**	**Setra 278 (CS100)**	**Vaisala PTB101B (CS105)**
Price	$45	$145	$357	$578 ($540)	($580)
Range (kPa)	15 to 115	70 to 108	80 to 110[a]	60 to 110[b]	60 to 106
Accuracy at room temp.	*±1.5 kPa*	*±0.38 kPa*	*±0.075 kPa*[c]	*±0.05 kPa*	*±0.05 kPa*
Temperature Range (°C)	-40 to 125	0 to 60	-18 to 79	-40 to 60	-40 to 60
Output (VDC)	0.2 to 4.8[d]	1 to 5	0.5 to 4.5[e]	0 to 2.5	0 to 2.5
Supply (VDC)	5	8 to 24	4.9 to 7.1[f]	9.5 to 28	10 to 30

[a]Also available in 60 to 110 kPa range for same price
[b]Also available from Setra in 50 to 110 and 80 to 110 kPa range for same price
[c]±0.25% of the full scale range (30 kPa in this case)
[d]Typical range. Varies from 0.13 to 0.27 VDC on low end and from 4.7 to 4.9 VDC on high end.
[e]Also available in 0.1 to 5.1 VDC output range
[f]Also available in 9.0 to 14.5 and 21.6 to 26.0 VDC ranges

DIFFERENCES AMONG THE TRANSDUCERS

Five sensors are compared ranging in price from $45 to $580 (Table 1). The specified accuracies of the three more expensive sensors (Setra and Vaisala) are similar at room temperature. The Setra 278 and Vaisala PTB101B sensors are similar in design and circuitry and are calibrated to self-correct for hysteresis and for temperature, zero, and span changes. The Setra 276 has one internal electrode while the Setra 278 and Vaisala PTB101B have a dual electrode design. The addition of a second, reference electrode enables more precise temperature compensation. The two dual electrode models should thus perform better than the 276 over a range of temperatures and have less long-term drift. The Omega EWS-BP-A is designed to be wall mounted indoors and is temperature compensated. Its low price makes up for its narrow temperature range and reduced accuracy relative to the Vaisala and Setra sensors. The Omega transducer seemed an ideal choice for laboratory applications, but was recently surpassed both in economy and precision by a prototype of the Apogee Instruments BPS.

Our tests were conducted on four out of the five transducers over the course of about 1.5 years. The Apogee Instruments BPS was added toward the end of the evaluation period, so long-term drift data have not yet been generated for that sensor.

RESULTS

Sensor Performance in the Laboratory

The Setra, Vaisala, and Omega transducers were connected to a Campbell Scientific 21X datalogger for 82 days, then switched to a Campbell Scientific CR1000 datalogger for the remainder of the evaluation period (Figure 1). The Apogee transducer was added on day 523. All readings shown in Figure 1 were taken at room temperature (22 ± 2 ^{o}C) in the laboratory. Multipliers and offset values for the Setra and Vaisala transducers were provided by the manufacturer. The multipliers and offset values for the Omega and Apogee transducers were calculated based on the measurement and output ranges given in their manuals. The offsets for the latter two sensors were further refined by determining the difference between their output pressure and the barometric pressure reported by a local weather station. Local barometric pressure data were retrieved via http://anythingweather.com. Data are reported as barometric pressure at sea level and must be corrected for the elevation of the sensor measurement. The correction can be performed using a convenient online calculator: http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/barfor.html.

Comparison of the Setra and Vaisala Sensors to a Mercury Manometer

Manual readings of the mercury barometer in the USU Chemistry department were made and compared to the readings of each of the three more expensive sensors (Table 2). The Hg-barometer measures pressure with a resolution of 0.1 mm Hg (0.013 kPa). The 182-ft. (55.5-m) elevation difference between the Crop Physiology Lab (4608 ft) and the chemistry lab on campus (4790 ft) were accounted for using an online calculator: http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/barfor.html.

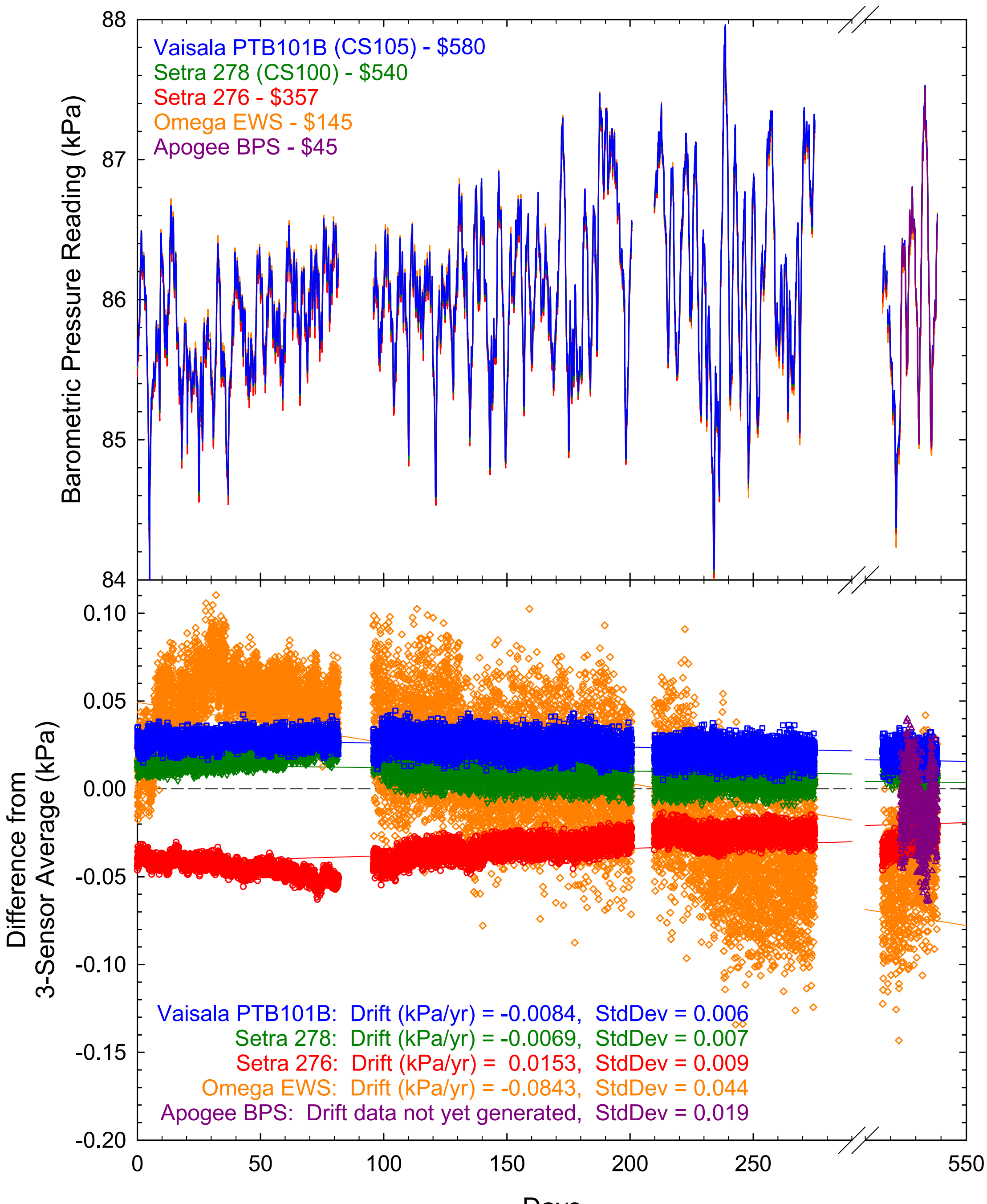

Figure 1. ***Top:*** **One-second barometric pressure readings at 30-minute intervals over the course of 538 days.** ***Bottom:*** **Sensor differentials were calculated by subtracting the average of the three most precise (Setra and Vaisala) sensor readings from each individual sensor reading. Yearly sensor drift was calculated by multiplying the slope of each line (daily drift) by 365. The standard deviation of the points from the line indicates the random noise in the sensor. The standard deviation could have been reduced by incorporating a running average command into the datalogger program.**

Table 2. Comparison of barometric sensor outputs to Hg-manometer/barometer readings made on March 30, 2005 at 11:40 (reading #1) and on April 7, 2005 at 14:50 (reading #2). In all cases the absolute deviations from the reference barometer were less than 0.06 kPa.

Barometer/Sensor	Reading #1 (kPa)	Difference #1 from Hg-manometer (kPa)	Reading #2 (kPa)	Difference #2 from Hg-manometer (kPa)
Hg-manometer	85.939	0.000	85.155	0.000
Setra 276	85.903	-0.036	85.159	+0.004
Setra 278	85.948	+0.009	85.182	+0.027
Vaisala PTB101B	85.962	+0.023	85.207	+0.052
Mean of the Differences		*-0.001*		*+0.028*

Drift

Over the course of 538 days, drift in the response of the Vaisala and Setra transducers was negligible (Figure 1). The Omega transducer drifted considerably more, but still less than 0.1 kPa per year. Omega recommends manually recalibrating the transducer on an annual basis using a Handheld Differential Pressure Calibration Kit (Omega Model PCL-200-KIT-D). Drift in the Apogee BPS has not yet been determined.

Temperature Response

The temperature response of the three more expensive sensors was evaluated by varying the temperature of the sensor environment between 10 and 51^{o}C over a 2-week period. All three sensors were affected by temperature (Figure 2), but the Setra 278 had a smaller temperature coefficient (slope of the line) than the other two sensors over the range of temperatures tested.

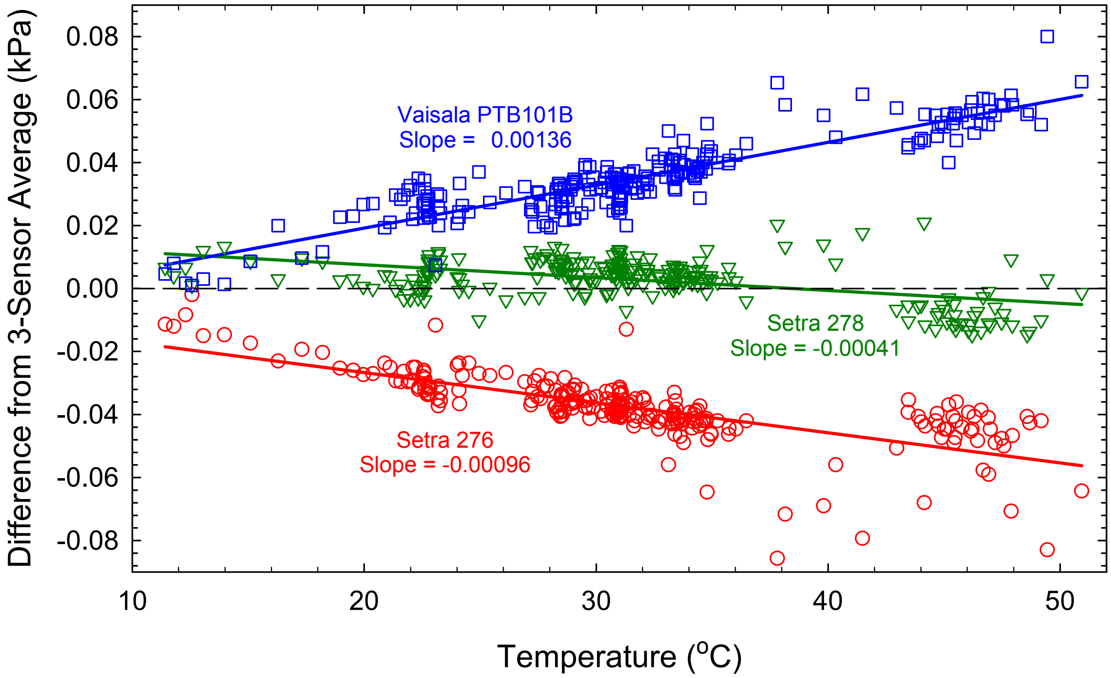

Figure 2. Sensor differentials across a temperature range from 10 to 51°C. Sensor differentials were calculated by subtracting the average of the three sensor readings form each individual sensor reading. The slope of each line indicates the influence of temperature on sensor output.

DISCUSSION

All of the transducers performed satisfactorily in our lab environment over the time periods and the range of temperatures tested. The Setra 278 was the most stable sensor, as indicated by its small drift and low standard deviation from the average line (Figure 1, bottom) and its superior temperature compensation (Figure 2). The Setra 276 is good for measurements at room temperature, but its operating range of -18 to 79°C may not be suitable for outdoor use in extremely cold environments. The Omega EWS-BP-A is a cost-effective alternative that is suitable for general laboratory use where measurements of relative daily and weekly changes are more important than absolute accuracy, but must be recalibrated periodically during long-term use. On initial inspection the Apogee BPS looks to be a cost-effective alternative to the other transducers evaluated thus far. We continue to monitor these sensors to evaluate their long-term drift.

APPENDIX

Wiring the transducers to a CSI 21X datalogger:

All of the transducers can be connected to a Campbell Scientific 21X datalogger. Table A1 indicates the wiring for excitation and differential measurement of the Vaisala, Setra, and Omega transducers. The Omega EWS, Setra 278 and Vaisala PTB101B require 12V power. The datalogger switches 12 VDC power to the sensor before measurement, then powers down the sensor after the measurement to conserve power. The three Setra and Vaisala sensors require an external trigger which can be powered by either an excitation or a control port. CR21X dataloggers supply 5 V excitation, but excitation from CR10X and CR1000 dataloggers is limited to 2.5 V. With CR10X or CR1000 dataloggers, a control port can supply the external trigger and a separate instruction is then used to read the sensors (see “Wiring the transducers to a CSI CR1000 datalogger” below).

Table A1. Campbell Scientific 21X datalogger wiring for the four barometric pressure transducers.

Sensor	Black to	White or Yellow to	Green to	Red to	Brown or Blue to	Clear or Silver to
Omega EWS	High port	Jumper H to L with 250Ω resistor.		12V power	Jumper L to ⏚.	
Setra 276	⏚	Low port	High port	Ex channel	none	⏚
Setra 278	⏚	Low port	High port	12V power	Ex channel	none
Vaisala PTB101B	⏚	Low port	Ex channel	12V power	High port	Case

Programming a 21X datalogger:

For excitation and differential measurement of each sensor, a P8 instruction (`Ex-Del-Diff`) is used. A brief delay between the excitation and the differential measurement is necessary for the Setra 278 and Vaisala PTB101B sensors, but is not necessary for the Setra 276 sensor. With the following multipliers and offsets the sensors will output barometric pressure in kPa.

Example 21X program:

```
; Read the Setra 276 Barometric Pressure Sensor
1:      Ex-Del-Diff  (P8)
   1:   1          Reps
   2:   5          5000 mV slow range
   3:   1          DIFF Channel
   4:   1          Excite all reps w/ Exchan1
   5:   1          Delay (0.01 sec units)
   6:   5000       mV excitation
   7:   1          Loc [ Setra_276 ]
   8:   0.0075     Mult
   9:   76.25      Offset

; Read the Setra 278 Barometric Pressure Sensor
2:      Ex-Del-Diff  (P8)
   1:   1          Reps
   2:   5          5000 mV slow range
   3:   2          DIFF Channel
   4:   2          Excite all reps w/ Exchan2
   5:   10         Delay (0.01 sec units)
   6:   5000       mV excitation
   7:   2          Loc [ Setra_278 ]
   8:   0.02       Mult
   9:   60         Offset

; Read the Vaisala PTB101B Barometric Pressure Sensor
3:      Ex-Del-Diff  (P8)
   1:   1          Reps
   2:   5          5000 mV slow range
   3:   3          DIFF Channel
   4:   3          Excite all reps w/ Exchan3
   5:   100        Delay (0.01 sec units)
   6:   5000       mV excitation
   7:   3          Loc [ Vaisala ]
   8:   0.0814     Mult
   9:   60         Offset

; Read the Omega EWS-BP-A Barometric Pressure Sensor
3:      Volt  (Diff) (P2)
   1:   1          Reps
   2:   5          5000 mV slow range
   3:   4          DIFF Channel
   4:   3          Loc [ Omega ]
   5:   .00949     Mult
   6:   60.95      Offset
```

Wiring the transducers to a CSI CR1000 datalogger:

All five transducers can be connected to a Campbell Scientific CR1000 datalogger (Table A2). The Omega EWS, Setra 278 and Vaisala PTB101B require 12V power. The datalogger switches 12 VDC power to the sensor before measurement, then powers down the sensor after the measurement to conserve power. With the CR1000 either a control port or the Switched 12V port can supply the external trigger to switch power to the sensors. A separate instruction is then used to read the sensors. The high and low differential channels used to measure the Omega EWS must be jumpered by a 250-ohm resistor, and the low differential channel must be jumpered to ground. The Setra 276 and Apogee BPS require 5V power and can be wired directly to the 5V power supply port.

Table A2. Campbell Scientific CR1000 datalogger wiring for the four barometric pressure transducers.

Sensor	Black to	White or Yellow to	Green to	Red to	Brown or Blue to	Clear or Silver to
Apogee BPS	SE Channel 7	none	⏚	5V power	none	none
Omega EWS	DIFF H1	Jumper H1 to L1 with 250Ω resistor.		SW12V power	Jumper L1 to ⏚ .	
Setra 276	G	DIFF L2	DIFF H2	5V power	none	⏚
Setra 278	G	⏚	SE Channel 5	12V power	Control Port 1	none
Vaisala PTB101B	G	⏚	Control Port 2	12V power	SE Channel 6	⏚

Programming a CR1000 datalogger:

The CR1000 can be programmed using the CRBasic Editor software within Loggernet version 3.1 or later. In Table A1 and in the programming example below, the Omega EWS sensor is wired to switched 12V power. The Setra 278 and Vaisala PTB101B are wired to 12V power and a control port is used to switch power on and off. The Setra 276 and Apogee BPS are wired to the constant 5V power supply. The multipliers and offsets used in the example program convert sensor output to barometric pressure in kPa. The manufacturer's recommended multiplier and offset values are used for the Vaisala PTB101B and Setra 276 and 278. Multipliers and offset values for the Omega EWS and Apogee BPS were calculated based on their output and measurement ranges. Offsets were further refined by comparing sensor output to locally reported barometric pressure (http://anythingweather.com). Local data are often reported as barometric pressure at sea level and must be corrected for elevation. An online calculator simplifies the correction: (http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/barfor.html).

Example CR1000 program (wiring shown in Table A2):

```
'Main Program
BeginProg
	Scan(1,Sec,1,0)
		'Omega EWS Barometric Pressure Sensor measurement Omega_EWS:
		SW12 (1 )
		VoltDiff (Omega_EWS,1,mV5000,1,True ,0,250,0.00949,61.75)
		'Setra 276 Barometric Pressure Sensor measurement 'Setra_276':
		VoltDiff(Setra_276,1,mV5000,2,True,0,250,0.0075,76.25)
		'CS100 Barometric Pressure Sensor measurement 'Setra_278':
		PortSet(1,1)
		VoltSE(Setra_278,1,mV5000,5,1,0,_60Hz,0.02,60)
		'CS105 Barometric Pressure Sensor measurement 'Vaisala':
		PortSet(2,1)
		VoltSE(Vaisala,1,mV5000,6,1,0,_60Hz,0.0184,60)
		'Apogee BPS Barometric Pressure Sensor measurement 'Apogee':
		VoltSE(Apogee,1,mV5000,7,1, 20000,_60Hz,0.0218,12.2)
	NextScan
EndProg
```