Long-Term Stability of Some Barometric Pressure Sensors

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ABSTRACT

A variety of pressure sensors have been tested in the laboratory for accuracy and long-term stability. The Paroscientific 215-AT, Rosemount 1201F1B, and Setra 270 were found to be the most accurate, maintaining 0.1-mb accuracy over long periods. These were followed by the AIR DB-1A with 0.5 mb in most units tested. The Paroscientific and AIR sensors require the least power and are the most suitable for remote deployments. Results on several inexpensive sensors show that some are worthy of consideration if accuracy requirements can be relaxed somewhat. The AIR DB-1A was selected for use in the barometric pressure module for the IMET (improved meteorology) system.

1. Introduction

The IMET (improved meteorology) system (Weller and Hosom 1989) has been developed at the Woods Hole Oceanographic Institution for the acquisition of high-quality data on research buoys and ships. The first objective in the development was that the sensors be reliable and accurate. We report here on investigations that contributed to the selection of a barometer.

The WOCE (World Ocean Circulation Experiment) standard for the measurement of barometric pressure (WOCE 1990) has two figures: a targeted system accuracy of 1 mb and an optimal sensor specification of 0.2 mb. There are a number of effects that make the 0.2-mb figure unrealizable as a total measurement accuracy on a buoy. Temperature and acceleration effects can limit the overall accuracy, although measurements of the motion of our buoys have returned maximum values of vertical acceleration of only about 0.5 m s^{-2}. The choice of a port is critical to prevent wind effects from causing accuracy deterioration in high wind conditions.

Developments in design over the past 10–15 years have yielded pressure sensors that use a variety of means for measuring the deflection of a membrane separating a vacuum chamber from ambient pressure. Given the five criteria on which a choice of sensor might be made (i.e., accuracy, stability of calibration with time and temperature, power consumption, reliability, and economy), it is possible to find sensors that satisfy various combinations of these factors to varying degrees. Except for the basic Paroscientific pressure sensor (Wearn and Larson 1982), we could find no evaluations in the literature on which to base a choice. We then decided to compare a variety of sensors, including less expensive sensors, to get an idea of the level of performance that might be expected of them as well as high quality sensors designed as barometers.

Power consumption is crucially important on our buoys where power comes from batteries and solar panels. Low enough power consumption (i.e., 50–250 mW) allows us to leave the sensor on all the time. Consumptions above this range require that the power be switched on for a measurement and then switched off again. The resulting increase in circuitry, programming, and cost, and the concomitant decrease in reliability, make this a less desirable alternative. From an overall engineering standpoint, the less power required, the better.

The comparisons described below were initiated to provide a guide for our selection of a barometer for the IMET system, not as an exhaustive investigation of sensor characteristics. Accuracy and long-term stability were monitored in our laboratory, but temperature and acceleration effects were not investigated. Although these are important, sensors in a remote location have a particularly stringent requirement for stability. Effects that are, in principle, repeatable, such as variation with temperature, can be compensated for with appropriate secondary measurements. What short- and long-term drifts occurred during a deployment cannot be known. We must be able to trust the pre- and postdeployment calibration checks as giving an accurate representation of the sensor's performance during the deployment. For this reason, we feel that the calibration drift of a sensor is particularly significant in our application. The tests described below were designed primarily to measure the drift in the sensor cal-

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ibration over a period several times the length of a typical buoy deployment (i.e., 6–8 months).

2. Sensors tested

The tested sensors were selected from two groups: sensors designed and marketed as barometers (i.e., optimized for the 800–1100-mb pressure range) and 0–15-psi (pounds per square inch, or 0–1030 mb) pressure sensors. We include all of the former that were readily available at the time and a sampling of the latter distributed broadly over price.

Since we have had considerable experience with the AIR DB-1A (Payne 1988) and the Paroscientific model 215-AT, these were included. Also in the high-performance category were the Rosemount model 1201F1B, the Setra Systems model 270, and the Aanderaa model 2810. In addition, Setra loaned us a single model 470 for 2 months for evaluation. Two other sensors with lower performance specifications were included to learn what kind of performance might be expected from standard pressure sensors over a variety of price ranges. These included the Heise model HPO and the SenSym SCX15. A Paroscientific model 760-16B was purchased as a secondary standard against which to compare all the rest. Except for the AIR and the Heise, two of each type were purchased and tested. We used five old and four new AIR sensors that we had available. Specifications of all tested sensors that could be gleaned from the manufacturer's literature appear in Table 1. Prices are as of late 1992 and range at the time of purchase from about $40 to $3700.

Operating principles. All of the sensors detect the movement of a diaphragm separating a reference vacuum chamber from atmospheric pressure with changes in pressure. A wide variety of techniques are used to sense this movement. The SenSym SCX15 sensor, designed for measuring pressure, uses a strain gauge to detect it, as does the Aanderaa 2810, although it has circuitry included to limit the temperature sensitivity of the strain gauge sensor. More expensive sensors designed for use as barometers use a variety of techniques from capacitative (AIR, Setra), to mechanical coupling, to a strained quartz bar (Paroscientific). The Heise HPO is unique with its optical sensing of the diaphragm position.

3. Method

The AIR DB-1A and the Setra 470 have digital outputs, the Setra an RS-232 output, while the AIR has a choice between serial RS-232 and parallel. The Paroscientific 215-AT has an FM frequency output. All the rest have analog voltage outputs. We attempted to record all sensors automatically, the voltage analog models through a 12-bit analog-to-digital (A/D) board in our logging IBM-compatible personal computer (PC). The board was not capable of sufficient precision,

TABLE 1. Sensor characteristics.

Manufacturer model	AIR DB-1A	Paros. 215-AT	Paros. 760-15A	Rosemount 1201F1B	Setra 270	Setra 470	Aanderaa 2810	Heise HPO	SenSym SCX15
Output range	0–1300 mb	40–36 kHz	0–1040 mb	0–5 V dc	0–5 V dc	800–1100 mb	0.48–0.52 V	0–5 V dc	0–90 mV
Pressure range (mb)	1–1300	0–1040	0–1040	900–1050	800–1100	800–1100	920–1080	0–1100	0–1100
Sensitivity/resolution	0.01 mb	3.9 Hz mb^{-1}	0.01 mb	33 mv mb^{-1}	17 mv mb^{-1}	0.01 mb	0.24 mV mb^{-1}	4.5 mV mb^{-1}	0.08 mV mb^{-1}
Linearity	na	0.005%FS	0.005%FS	0.03%FS	0.05%FS	0.012%FS	na	na	0.1%FS
Hysteresis	na	0.005%FS	0.005%FS	0.005%FS	0.01%FS	0.010%FS	na	na	na
Repeatability	na	0.005%FS	0.005%FS	0.005%FS	0.01%FS	0.010%FS	na	na	0.2%FS
Thermal error	na	na	na	0.09%FS max	0.006%FS °C^{-1}	0.006%FS °C^{-1}	na	0.007%FS °C^{-1}	2%FS max
Accuracy	0.5 mb	0.01%FS	0.01%FS	0.1%FS	0.05%FS	0.02%FS	0.2 mb	0.05%FS	0.2%FS
Temperature correction	Internal	*	Internal	Internal	Internal	Internal	Internal	Internal	None
Stability (yr)	0.3 mb	na	na	0.23%FS	0.2%FS	0.05%FS	na	na	0.1%FS
Temp range (°C)	−30/50	−54/107	−54/107	−20/50	−18/80	0/45	−30/35	−7/66	0/70
Power supply	50 mW	12 mW	na	780 mW	192 mW	450 mW	6–150 mW	340 mW	36 mW
Voltage	+8–16	6–35	115 V ac	12	24	5	−6	20/40	12
Current	6.3 mA oper. 0.01 mA stdby	2 mA	na	65	8	90	1–25 mA	17 mA	3 mA
Price	$1260	$2695	$3695	$2079	$995	$1200	$1178	$915	$40
Factory calibration	$100	$290	$290	$250	$90	$180			

* The Paroscientific 215-AT has a frequency output that is an analog of temperature. The calibration constants supplied by Paroscientific make use of this output in the pressure calculation to correct the pressure for temperature effects.

however, so only the AIRs and Paroscientific model 76-16B were logged automatically.

Useful observations began in November 1988 with the acquisition of the Paroscientific model 760-16B (Paroscientific Lab Standard, hereinafter referred to as the PLS) barometer for which the manufacturer states an absolute accuracy of 0.1 mb. This was used as a standard of comparison. It contains digital electronics to convert pressure and temperature frequency signals and apply a temperature correction to the computed pressure. It has a six-digit front panel readout as well as an RS-232 port. In October 1989 the PLS began drifting rapidly. Paroscientific personnel determined that something was outgassing in the vacuum reference chamber and that the getter, a substance for collecting gas molecules in a vacuum, had become saturated. They replaced the sensor under warranty, and the unit has performed quite well since May 1990 when it was returned to us. We lost 1 month of data in May 1989 while the PLS was returned to Paroscientific for a calibration check and 7 months from October 1989 to May 1990 when we were establishing that the PLS was drifting and Paroscientific was repairing it. To watch for repetitions of such gross anomalies, we have made weekly comparisons with our Haas type A-1 mercury barometer that has a stated absolute accuracy of 0.3 mb. The difference, except for an anomaly described above, has been constant at 0.2 ± 0.1 mb over the entire course of the observations. The model 760-16B was calibrated by Paroscientific with NIST-traceable standards before purchase and after repair. Checks by Paroscientific in May 1989 and after the termination of observations showed differences with the Paroscientific standard of −0.03 and 0.01 mb, respectively, using the calibration constants determined after the repair. This performance justifies our use of the model 760-16B as a standard.

The barometers were placed in an interior room and maintained in a temperature range of 19°–22°C during the observations. We did not have the equipment to cycle temperature; thus, we tested the long-term stability of the sensors only within this narrow temperature range. All of the sensors designed as barometers have outputs that are internally corrected or provide the data for correction (Paroscientific model 215-AT) over a reasonably wide temperature range. The SenSym SCX15 pressure sensor would require circuitry to correct for temperature in any field deployment.

a. Digital sensor observations

From 3 November 1988 until 22 October 1989, data were logged from the AIRs and the PLS by hand, once or twice per weekday. From 23 May 1990 to 19 February 1992, the outputs of the PLS, the AIRs, and Setra 470 during the loan were logged on a PC. Once per hour, over the course of about 30 s, 10 sets of readings (each the internal average of 10 measurements in the AIR) were acquired at 1-s intervals from the sensors, a mean and standard deviation were computed, and the date, time, means, and standard deviations were written to a disk file. The data extended over a total of 2.7 years.

b. Analog sensor observations

Data from the analog barometers were recorded manually, usually once per day except for weekends and various other short periods, from 6 September 1990 to the end of the comparison on 19 February 1992, except as noted for individual sensors. This represents a total of 1.5 years of data. A bridge circuit as recommended by SenSym was constructed and the bridge input and output voltages read. All voltages were read with a Hewlett Packard model 3478A digital multimeter that has an accuracy of 0.007% of reading for the voltages that we measured. The period of the frequency outputs of the Paroscientific model 215-AT sensors were measured with a Hewlett Packard model 5384A frequency counter. The result of combining the possible aging rate since the last calibration and inaccuracy due to room temperature resulted in an accuracy in computed pressures of about 0.01 mb. The PLS was read at the same time for comparison.

c. Calibrations

Manufacturers' calibrations were used for all of the analog sensors except for the SenSym SCX15, which did not come with a calibration, and the Aanderaa, whose calibration was valid only when the sensor was plugged into an Aanderaa data logger. For these uncalibrated sensors, we used the first month's data from the sensor with the PLS as a calibration standard. Calibration constants for each individual AIR are contained in its EPROM (erasable, programmable memory).

4. Results

Performance was evaluated by computing and plotting the difference between each sensor and the PLS, and then computing various statistical products for the difference. A linear regression was fitted by least squares, and the mean for each sensor was computed. The standard deviation of data about the curve and the mean were also computed. These statistics appear in Table 2 with the length-of-data interval in months for each sensor. A plot of barometric pressure from the PLS for the whole comparison period is shown in Fig. 1 to illustrate the range of pressures experienced by the sensors.

a. Digital output sensors

1) AIR MODEL DB-1A (FIG. 2)

Figures 2a–d are plots of the difference between the AIR sensors and the PLS versus year-day, with the year-day value 1 corresponding to 1 January 1988 (yearday 1988). Apparent in the plots are the differences in short- and long-term fluctuations from one unit to another. Note that hand-recorded data are included in the graphs for dates before May 1990.

The AIR conversion algorithm in the sensor software includes digital compensation for sensor temperature. The sensors are calibrated over the ranges of 1°–45°C and 800–1060 mb. Data are supplied with the sensor showing the difference, for each temperature–pressure point, between the value computed by the sensor and the value from the AIR standard. AIR states the accuracy as ±0.5 mb for 1 year after calibration. The AIR DB-1A sensors purchased in 1990–91 generally show better behavior over those acquired in 1984–85. Since AIR has a policy of making incremental improvements without changing model designation, the 1990–91 group is probably more typical of sensors being manufactured now. Our history of use of DB-1As goes back to four of their first seven units, purchased in 1983. During 1984–85, we acquired 10 DB-1As that include serial numbers 30–197 used in this comparison. Four of them were replacements of the original four. The AIR had some manufacturing problems in the early years of production of the DB-1A that seem largely to have been overcome. We purchased 13 in 1990–91 and have not experienced any problems with them.

Most of the 1984–85 sensors have had one or more parts replaced, including the pressure cell, the reference cell, and the analog and digital circuit boards. A replacement of any of these parts was followed by a recalibration by AIR. One exception is serial number 54, which has not been modified or recalibrated since its purchase in 1984.

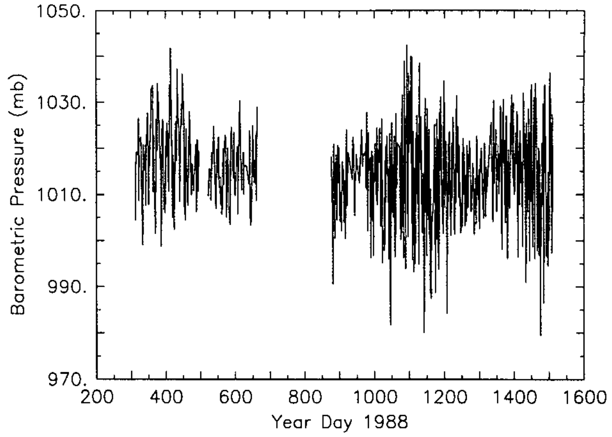

FIG. 1. Barometric pressure record from the PLS for the duration of comparison.

Serial numbers 1825–1850 were calibrated in June 1990. Although their comparison periods are short, all of them were uniformly stable.

2) SETRA MODEL 470

The model 470 is based on the same basic sensor as the 270 but the linearization (and conversion to barometric units) and temperature correction is done digitally instead of by analog circuitry. Since we had the model 470 for only 2 months, we cannot provide an evaluation equivalent to the other sensors. Over the 2 months it was at least as accurate as the model 270. We would expect long-term stability to be as good as, or better, since there are fewer analog components to affect the output.

TABLE 2. Statistics of sensor data.

Sensor and serial number	Bias (mb)	Slope (mb yr^{-1})	Std dev (mb)	Mean (mb)	Std dev (mb)	Interval (months)
AIR 34	−0.27	−0.108	0.09	−0.02	0.10	26.99
AIR 54	−0.12	−0.111	0.09	−0.42	0.10	26.99
AIR 67	−0.61	−0.138	0.25	−0.99	0.25	26.99
AIR 70	−0.24	0.342	0.30	0.69	0.32	26.95
AIR 80	1.52	−0.537	0.25	0.06	0.31	26.99
AIR 197	1.83	−1.033	0.10	−0.99	0.30	21.03
AIR 1825	1.07	−0.257	0.05	0.33	0.06	6.96
AIR 1834	0.55	−0.127	0.04	0.19	0.04	6.96
AIR 1849	1.25	−0.294	0.07	0.44	0.07	4.66
AIR 1850	0.37	−0.077	0.03	0.16	0.03	4.66
Paroscientific 34214	0.05	−0.071	0.04	−0.03	0.04	10.75
Paroscientific 34219	0.27	−0.222	0.03	0.05	0.05	6.80
Rosemount 506	0.09	−0.068	0.05	0.00	0.05	17.45
Rosemount 507	0.06	−0.043	0.04	0.00	0.04	17.65
Setra 185772	0.14	−0.109	0.07	0.00	0.08	17.65
Setra 188257	0.14	−0.105	0.05	0.00	0.07	17.48
SenSym A	0.64	−0.475	0.08	0.00	0.21	17.53
SenSym B	0.67	−0.507	0.07	0.00	0.21	17.53
Heise	1.53	−0.916	0.59	0.01	0.64	10.81

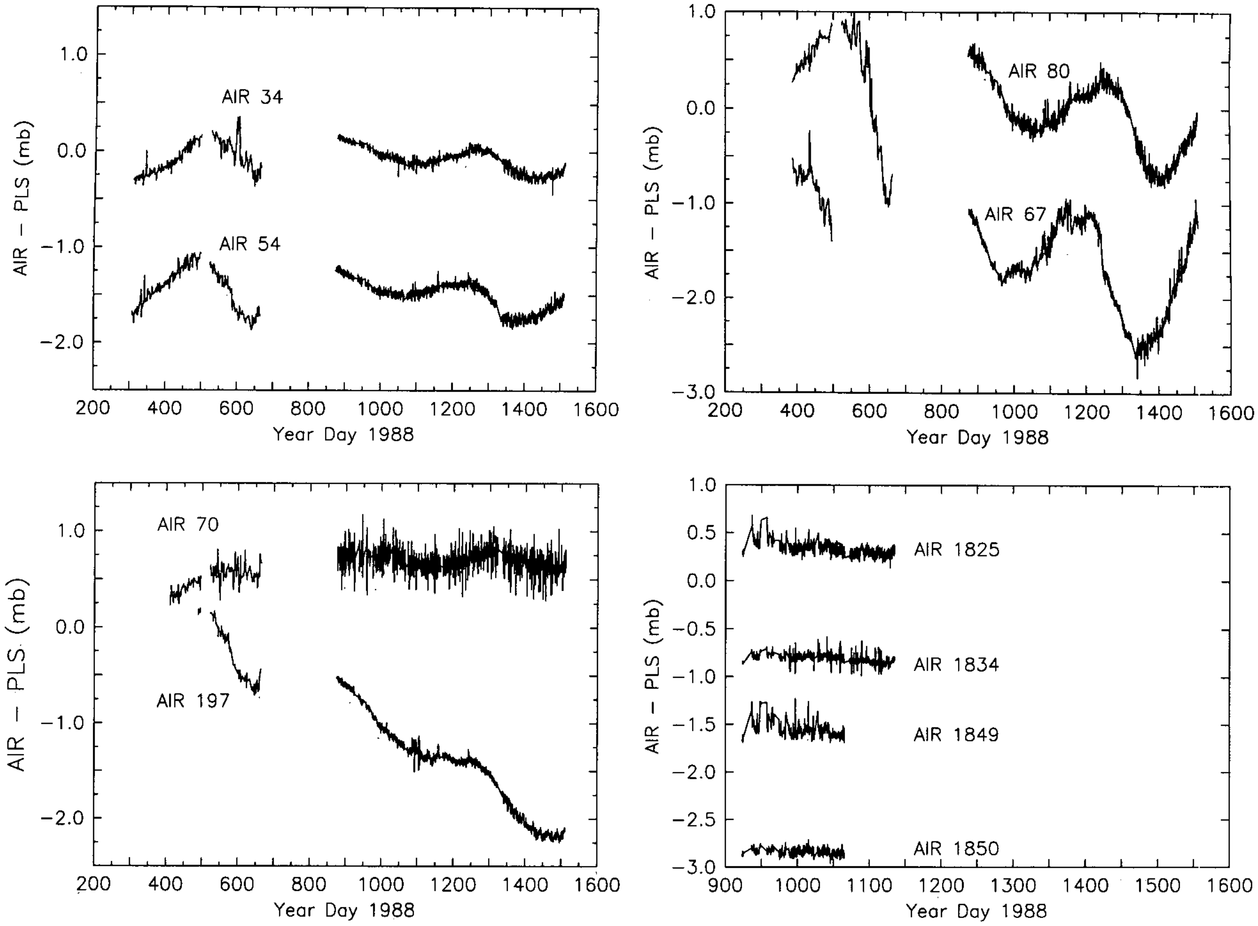

FIG. 2. Differences between individual AIR sensor outputs and Paroscientific PLS outputs vs year-day where year-day 1 is 1 January 1988. The data include hand and automatically recorded data. (a) AIR 34 and 54. The latest calibration of AIR 34 was in 1986. Its output agreed with the standard within 0.5 mb throughout the comparison in spite of a calibration that was 5.5 years old at the end. The latest calibration of AIR 54 was in 1984. Its data are offset by −1.0 mb. AIR 67 and 80. The latest calibration of AIR 67 was in 1989. Its behavior has been erratic in spite of the replacement of pressure cell, reference cell, and analog board between its purchase and the start of the comparison. The latest calibration of AIR 80 was in 1989. Replacement of the analog board just prior to the comparison did not prevent some large fluctuations. Its data are offset by −0.5 mb. (c) AIR 70 and AIR 197. The latest calibration of AIR 70 was in 1989. Random scatter in individual points is larger than the other AIRs in spite of replacement of the pressure cell and analog and digital boards between its purchase and the start of the comparison. The latest calibration of AIR 197 was in 1989. The cell was damaged by us through overranging in some pressure cycling tests. The cell was replaced and the sensor recalibrated before the start of the data shown, but it has drifted fairly steadily. Its data are offset by −1.0 mb. (d) AIR 1825, 1834, 1849, 1850. AIR 1834, 1849, and 1850 are offset by successive increments of −0.1 mb.

b. Analog output sensors

1) PAROSCIENTIFIC MODEL 215-AT (FIG. 3)

The model 215-AT has two frequency outputs, one for pressure and one for temperature. The calibration supplied by Paroscientific for pressure includes the correction for temperature as a function of the frequency out of the temperature circuit. The calibration used throughout the comparison for the two Paroscientifics was dated 25 August 1988 for serial number 34219 and 10 October 1988 for serial number 34214.

The SN 34219 was removed from the test system after about 6.5 months because it was required for an instrument deployment. Short-term agreement with the PLS was better than 0.05 mb. A calibration check in May 1992 showed it to be still within 0.1 mb of the PLS. Long-term drift is then negligible. The SN 34214 was also quite stable with a short-term stability of about 0.05 mb relative to the PLS until it began drifting rapidly in August 1991. Paroscientific determined that the getter in the vacuum reference cell was the problem and replaced it, but we saw no point in continuing the comparison with a new sensor.

While they were in the comparison, both sensors were stable and remained close to the PLS with rms differences of 0.06 and 0.05 mb.

We have used Paroscientific sensors for measuring barometric pressure in our vector-averaging wind re-

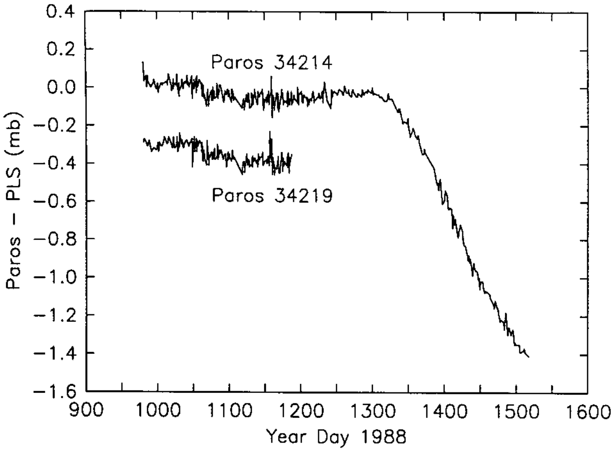

FIG. 3. Differences between Paroscientific model 215-AT, SNs 34214 and 34219, and PLS outputs vs year-day. SN 34219 is offset by −0.4 mb.

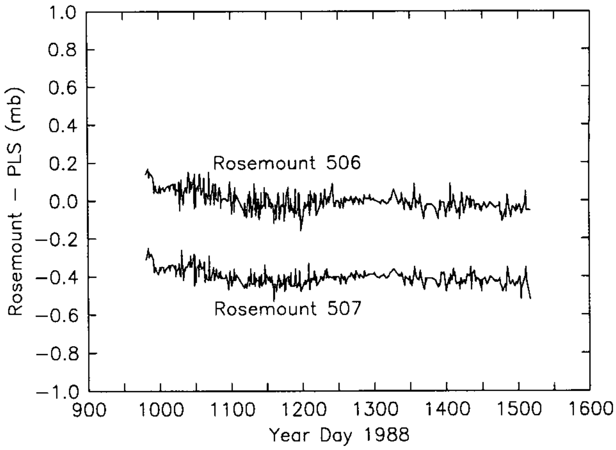

FIG. 4. Differences between Rosemount model 1201FB, SNs 506 and 507, and PLS outputs vs year-day. SN 507 is offset by −0.4 mb.

corders for years and have found them to be accurate, stable, and fairly reliable. Recently we learned, however, that the internal parts do wear out after 5–7 years (L. Krezner 1992, personal communication) and that indicated pressures become unreliable at this point. Until they suffer such a failure, they are generally stable to within 0.1–0.2 mb over long periods. Recently we have experienced some failures of the vacuum reference cells in both fairly new and older sensors.

2) ROSEMOUNT MODEL 1201F1B (FIG. 4)

Both sensors had excellent stability and accuracy with standard deviations of approximately 0.1 mb for the entire 18-month test period. The calibrations used were done by Rosemount in October 1988. Thus they retained an accuracy equal to that of the PLS over a 3.5-yr period. Their rms differences with the PLS are 0.06 and 0.04 mb. A version of the 1201F1B is available that requires both positive and negative volt supplies but consumes about two-thirds (500 mW) the power of the 12-V version tested.

The model 1201F1 has been in production for at least 20 years and it was preceded by other 1201 models. It is a mature sensor. In situations where ample power was available, and if price were not an impediment, the Rosemount would be an excellent choice.

3) SETRA MODEL 270 (FIG. 5)

The two Setra model 270 sensors, SNs 185772 and 188257, were originally calibrated in August and September 1988. During the comparison they stayed within limits of the 0.2-mb difference from the LS, which is an excellent performance. Their rms differences with the PLS are 0.08 and 0.07 mb.

4) AANDERAA MODEL 2810 (FIG. 6)

The model 2810 has four bridge resistors diffused onto a silicon membrane separating the vacuum cell from ambient pressure. Its unique way of compensating for the temperature sensitivity of the sensor is to maintain the sensor at a temperature of 35°C. Because of this, the power consumption varies inversely with ambient temperature.

Problems with the Aanderaa sensor prevented us from obtaining useful results from the comparison. After several months of comparison, it was apparent that both sensors were drifting at rates of 0.4 and 0.9 mb per month. After analysis of the units, Aanderaa determined there was outgassing in the vacuum cells and replaced the sensors. The replacements were extremely noisy, however, and a meaningful comparison could not be made with these either. Figures 6a and 6b show the data for the original sensors and their respective replacements.

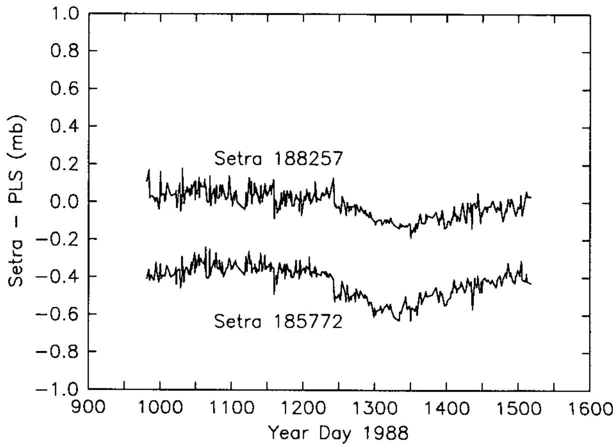

FIG. 5. Differences between Setra model 270, SNs 185772 and 188257, and PLS outputs vs year-day. SN 188257 is offset by −0.4 mb.

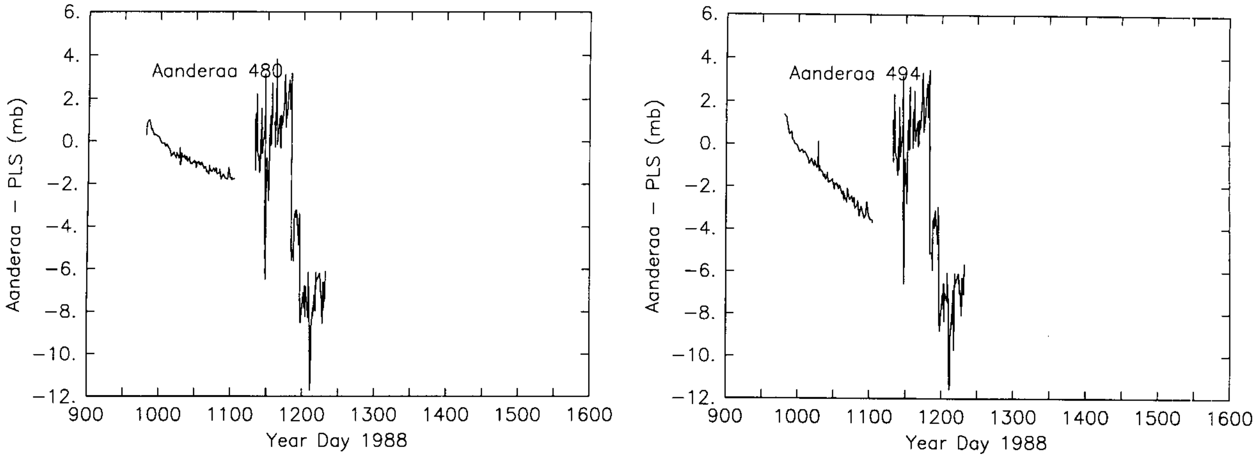

FIG. 6. Differences between Aanderaa model 2810, SNs 480 and 494, and PLS outputs vs year-day. The internal sensors were replaced during the data gap just after day 1100. SN 480 is the upper figure.

Aanderaa states that it has designed its sensors for use with its own reading units and that highest accuracy and stability are achieved with these reading units. A schematic of the circuit shows, however, a relatively straightforward strain gauge bridge and associated circuitry. It is difficult to see why making measurements with a regulated power supply and a good high-impedance voltmeter should not return results equivalent to those with an Aanderaa scanning unit.

Aanderaa loaned us a model 3010 scanning unit just before the completion of this paper, but both of the 2801 barometers had drifted far outside of their design range. A subsequent loan of two more barometers shows one to be stable to 0.1 mb and the other to be drifting at a rate of about 0.2 mb per month over the 3 months of observations.

The remaining sensors were designed as pressure sensors, not as barometers, and were included to broaden the group of instruments examined.

5) SENSYM MODEL SCX15 (FIG. 7)

If we ignore the steeper slope of the first 60 days, the outputs drift at a rate of about 0.05%FS yr^{-1}, where FS denotes full scale. The rms values of the SenSym–PLS differences over the whole comparison period are both 0.2 mb, or about 0.02%FS, and the mean differences are both 0.0 mb. Both numbers are within the manufacturer's specifications and represent good stability for an inexpensive sensor.

6) HEISE MODEL HPO (FIG. 8)

We originally purchased two model 623 pressure sensors. Both drifted badly, and company engineers acknowledged that they had a problem with the vac-

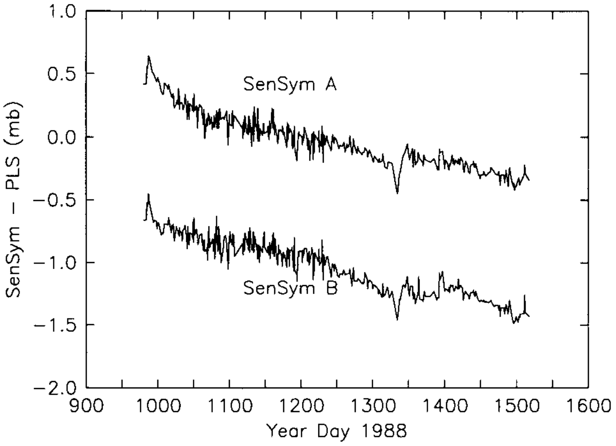

FIG. 7. Differences between two SenSym model SCX15 sensor outputs and PLS outputs vs year-day.

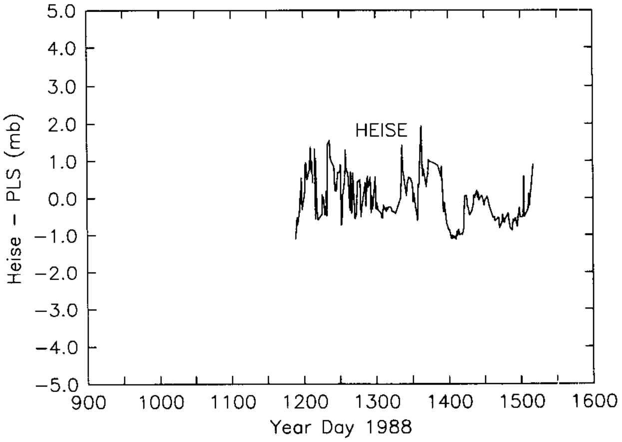

FIG. 8. Difference between Heise model HPO and PLS output vs year-day.

uum reference. Subsequently, the model was withdrawn and redesigned, the replacement being designated the model HPO. We were loaned one of these for the remainder of the comparison, which was added to the system 2 April 1991. The rms value of the difference between the HPO and the PLS was 0.7 mb during the remaining 10.5 months of the comparison, and nearly all of the points fell within +1.5 to −1.0 mb. This is within a factor of 2 of the manufacturer's stated accuracy given in Table 1.

5. Discussion of results

To repeat a point made earlier, this investigation focused on long-term calibration stability and did not examine the effects of environmental conditions such as temperature variation and acceleration on the accuracy of the sensors tested.

The highest accuracy and calibration stability were achieved by the Paroscientific 215-AT, the Rosemount 1201F1B, and the Setra 270. All three are capable of 0.1-mb accuracy and can maintain this accuracy for several years. The Paroscientific and the Rosemount are also the most expensive sensors we tested. Each has an additional drawback in our view. The power requirements of the Rosemount are very high for remote operation. Although the Paroscientific requires less power than any other barometer we tested and is very stable, its 5-year effective lifetime limits its economy. The Setra also requires more power than we would like, but its price is lower, comparable to the AIR DB-1A. The Setra 470 was probably at least as accurate as the 270 but its power consumption was even higher. We have used, and continue to use, the Paroscientific sensors in our VAWR (vector-averaging wind recorder), partly because their frequency output is handled very easily by the VAWR circuitry. They have been accurate and reliable except for the lifetime problem. We now discard them routinely after 5 years.

The AIR DB-1A was next in accuracy. Even though the older units tested did not always remain within the manufacturer's stated ±0.5-mb accuracy limits, newer units have. The AIR has a very low power consumption, second only to the Paroscientific, and since it has a digital output, it is simpler to interface it to a digital data logger. It is substantially less expensive than the Paroscientific or Rosemount. We currently use, and plan to continue to use, the AIR DB-1A in the barometric pressure module. In approximately 15 buoy deployments of IMET barometric pressure modules of 6–8 months each, and several years of ship operations, there have been no failures and the sensors have remained within the ±0.5-mb specification when checked.

We were disappointed at the problems we had with the Aanderaa model 2810 and have no idea if this is typical of the sensor.

Performance of the 0–15-psi pressure sensors varied primarily with price. This might be expected since the industrial pressure sensor field is quite competitive. The Heise HPO performance, ±0.6 mb, is probably typical of a rugged industrial pressure sensor in this price range.

The SenSym SCX15 sensors performed surprisingly well with an rms error of ±0.2 mb. Note that this is at constant temperature. Their performance in the field would depend completely on the temperature compensation that was added to them.

The best barometers have sufficient accuracy that the limiting factor in a field deployment is the design of the pressure port, which protects them from dynamic effects of the wind. There are very few examples of general purpose, omnidirectional ports in the literature. We use one designed by G. Gill (1976) for the National Data Buoy Center.

Because of the level of competition, the quality of the low-cost pressure sensors is improving. Pike and Bargen (1976) constructed their own barometers for the First Global Atmospheric Research Program (GARP) Global Experiment drifting-buoy program to achieve sufficient accuracy and low cost. It is gratifying to note that, today, their problem would be identifying which of the many sensors available would represent the best trade-off of accuracy versus cost and power consumption. We did not make a concerted effort to find the best inexpensive sensors available when we started this investigation, and there almost certainly are better sensors available now.

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REFERENCES

Gill, G. C., 1976: Development and testing of a no-moving-parts static pressure inlet for use on ocean buoys. NOAA Data Buoy Office Progress Report, Contract No. 01-6-038-115, 43 pp.

Payne, R. E., 1988: The MR, a meteorological data sensing, recording and telemetering package for use on moored buoys. *J. Atmos. Oceanic Technol.*, **5**, 286–297.

Pike, J. M., and D. W. Bargen, 1976: The NCAR digital barometer. *Bull. Amer. Meteor. Soc.*, **57**, 106–111.

Wearn, R. B., Jr., and N. G. Larson, 1982: Measurements of the sensitivities and drift of Digiquartz pressure sensors. *Deep-Sea Res.*, **29**, 111–134.

Weller, R. A., and D. S. Hosom, 1989: Improved meteorological measurements from buoys and ships for the World Ocean Circulation Experiment. *Proc. Oceans '89*, Seattle, WA, 1410–1415.

WOCE, 1990: U.S. WOCE Planning Report Number 15: The U.S. Contribution to WOCE Air–Sea Flux Estimates. U.S. WOCE Office, 46 pp.