INSTRUMENT TEST REPORT NUMBER 658

Electronic Barometer Testing - Replacement Barometer Project

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13 December 1999

Authorisation

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20 Pages

Electronic Barometer Tests

Aim

To report the results of testing electronic barometers for the purpose of identifying replacements for current Regional Office Standards (ROS), Regional Office Transfer Standards (ROTS), and Head Office Transfer Standards (HOTS).

Background

Technology currently used by the Bureau of Meteorology for the pressure network is obsolete. Kew-pattern barometers are currently used as ROS. These mercury-in-glass barometers are expensive to maintain, difficult to transport and not extremely robust compared to current electronic technology that at least equals the accuracy and precision of the Kew-pattern barometer if not surpasses it.

A comprehensive background to this work can be found in the Pressure Standards System Project Development Plan. This PDP are available to Bureau of Meteorology staff as Adobe Acrobat PDF files from
ftp://shrike.ho.bom.gov.au/documents/pdps/PressProj.pdf

Instruments Tested

The barometers tested are listed in Table 1 with the manufacturer's specification.

Table 1 Summary of barometers Tested

Manufacturer	Model	Serial Number	Type	Manufacturer's Specifications	
				Accuracy	Stability Per Annum
Druck[1]	141	027/93-2	ROS	0.15hPa	0.05hPa
Druck[2]	740	98-336	HOTS/ROTS	0.15hPa	0.10hPa
ParoScientific[3]	760-16B	56315	ROS	0.10hPa	0.10hPa
Vaisala	PTB220A	S0820001	HOTS/ROTS	0.15hPa	0.10hPa
Vaisala	PTB220A	S0820002	HOTS/ROTS	0.15hPa	0.10hPa

Other equipment used for testing is shown below in Table 2

Table 2 Equipment used in Testing

Equipment	Serial Number	Use
Hass Manometer	3063	Primary standard used for comparisons throughout testing.
ParoScientific 740-15A	51857	Reference barometer for environment testing
Ruska Pressure Controller 7010	47711	Used to control pressure throughout testing.
Heraeus Votsch Climate Chamber. HC4030	43315	Used to cycle temperature throughout temperature cycling test.
Rosemount Temperature Probe Serial Number	363	Used to independently monitor temperature in the temperature chamber throughout temperature cycling tests
DataTaker 500 Serial Number	50281	Used to independently monitor temperature in the temperature chamber throughout temperature cycling tests

[1] Note: The Druck DPI 141 is currently used as a working standard in the Physics Laboratory. More data are available for this instrument's long-term drift characteristics than for the new barometers.
[2] Purchased with additional Enhance Barometric Accuracy Specification.
[3] Note: The ParoScientific is currently used as a working standard in the Physics Laboratory. More data are available for this instrument's long-term drift characteristics than for the newer barometers.

Requirements set for replacement barometers.

Summary of current uncertainties for network heirarchy levels.

Table 3 Summary of current uncertainty

Network Level	95% Uncertainty (hPa) (Any corrections applied are not included in determination of uncertainty)	Current Instrument
Primary Standard	0.03	Hass Manometer
Working Standards	0.06	ParoScientific 760-16B
HOTS	0.06	Digital Aneroid
ROS	0.10	Kew Pattern
ROTS[4]	0.16	Digital Aneroid

Regional Office Transfer Standards (ROTS)

The ROTS are well-travelled barometers that experience a lot of vibration and transport related mechanical shocks. The ROTS are also likely to experience rapid temperature changes and rapid pressure changes through handling and transport.

These barometers are required to have a fast response to change in temperature, and the calibration shall be as independent as possible from ambient temperature or should have a stable predictable response to temperature.

The barometers should have a fast response to rapid pressure changes and recover from such pressure changes without a significant change in calibration.

The barometers are required to exhibit little or no drift over the medium term. These barometers should be compared to the ROS regularly and any drift will be monitored closely.

The uncertainty of the barometers shall be as good as or better than the current technology for ROTS (listed in Table 3).

The maintenance and robustness of the barometers is also taken into consideration, given the expected longevity in the field as travelling transfer standards and the level of maintenance required. These barometers are required to withstand vibration testing in accordance with the Australian Standard for Road Transport.

[4] Uncertainty of the measurement of the ROTS is a combination of the uncertainty of the network chain up to the point. In this report, due to the open nature of the potential ROS, the comparative analysis between the test barometers and the existing technology in terms of uncertainty at the ROTS level will be taken only in the context of the instrument uncertainties. i.e. comparing the uncertainty of the Digital Aneroids to the test ROTS barometers. Effectively the test at the HOTS level is enough to determine if the test instruments are at least the same as the existing instruments.

The networking capability of these barometers is important for future development of automated calibration checks and calibration adjustments. The barometers must be able to be connected to a network of barometers all connected to a PC and be addressable.

Regional Office Standard (ROS)

This barometer type will be housed in temperature stable environments and will not be transported under normal circumstances away from its environment.

The temperature dependence of the barometer should be small or at least should be stable and predictable. The temperature response of the barometer should be rapid enough to respond to temperature changes in an air-conditioned environment. The temperature hysterisis of the barometer shall be small and be independent from any diurnal cycling effects of the air-conditioned environment.

The drift of the barometer should be small and should not be more than the currently acceptable error over any annual period. Currently a correction of 0.16hPa for a ROS is allowed before incorporating a drift correction. HOTS comparisons are performed annually for each ROS. To meet this requirement any replacement barometer for the ROS should not shift in its correction by more than 0.16hPa per year.

The response of the barometer to vibration and transport should be such that any change in the calibration is either permanent or recovers quickly, in a matter of weeks.

The uncertainty of the barometer should be as good as or better than the current technology of the ROS (listed in Table 3).

The barometer should have the capability of being part of an addressable network of instruments, either for calibration checks of the ROS itself or in use as the reference for the ROTS.

Head Office Transfer Standards (HOTS)

The HOTS are required to be transported to the seven Regional offices at least once every year. They are required to be robust and accurate.

HOTS are required to withstand frequent transport and should therefore exhibit no significant shift in calibration after transport.

These barometers are required to have relatively short temperature time-constants, and the calibration of the barometer should be returned quickly to its initial state after a change in temperature has occurred.

These barometers should not change their calibration when exposed to small but rapid changes in pressure of up to 100hPa, and should be relatively quick to respond to changes in pressure and be able to rapidly return to their initial calibration.

The uncertainty of these barometers is required to be as good as or better than the current technology used by the Bureau of Meteorology (listed in Table 3).

The networking capability and instrument interface ability of these barometers is required to be such that the barometers can form part of an addressed network of barometers.

Head Office Working Standards

These barometers are the Bureau of Meteorology's working standard barometers; they are required to be kept under the same conditions as the ROS and hence have the same requirements.

Description of test methods

A series of tests were performed on the instruments listed above to determine their suitability at different levels in the network.

Table 4 Testing performed for each barometer.

Test Performed
• Initial Comparison against Primary Standard
• Assessment on Interfacing and Networking capability.
• Pressure Time Constant Test
• Comparison Against Primary Standard
• Environmental Cycling/Diurnal Temperature Tests
• Temperature Characterisation and time constant Test
• Comparison against Primary Standard
• Vibration Testing
• Long Term Drift Testing - Comparison Against Primary Standard.

Comparison against Primary Standard

Prior to and after the pressure shock tests, the environmental chamber tests and the vibration tests, the barometers were compared to the Hass manometer. All comparisons included an increasing pressure run of 850hPa to 1050hPa. The aim of this was to test if the reference barometer (740-15B SN 51857) or any of the barometers under test had undergone a significant shift in pressure reading due to the testing schedule. One test included a decreasing pressure run over the same range.

For the increasing pressure run, all barometers including the reference, were left to stabilise for at least 30 minutes at each pressure level prior to any measurement being taken.

Check of Interfacing and Networking Capability

A test of the interfacing capabilities and networking capabilities was tested during the development of the software to retrieve the data from the barometers during environmental testing. All barometers were either individually interfaced directly to a PC or put in a network of other instruments interfaced to the PC. All software and hardware interfaces for the barometers were assessed for their ease of use in a network of barometers, robustness and speed.

Pressure Shock Tests

The temporal resolution of the data output was maximised as some barometers responded very rapidly to pressure changes. Each barometer was tested individually.

The test barometer was allowed to stabilise at ambient room pressure. A pressure line was controlled using the RUSKA 7010 pressure controller. The pressure in the pressure line was maintained at overpressure.

Data were collected from the test barometer continuously, via a PC. The measurement rate (rate at which data were collected and the frequency with which they were collected) was monitored throughout the test. The elapsed time and the number of samples received during the test were used to determine this measurement rate. The test was segmented at three points. The measurement rates were measured over these three segments and cross checked against each other and against the overall sample rate for the test.

The barometer was plugged from ambient pressure into the closed pressure system where it remained for two minutes. The barometer was then unplugged and left at ambient temperature for another two minutes.

The barometer was connected to the closed pressure system by a Swagelok® connection. This type of connection is designed to remain airtight until a connection is made. This is the closest simulation of instantaneous pressure change the Physics Laboratory can achieve. There is some time required for the controller to re-establish the constant pressure in the pressure line once the connection between the barometer and the pressure line had been made. The pressure controller was not monitored during this time, with the stabilisation time of the pressure controller on the order of seconds. The magnitude of difference between the unstable and stable state of the controlled pressure was more than an order of magnitude less than the magnitude of the overall pressure change that was being measured. These conditions were considered adequate given that the nature of rapid pressure changes in the atmosphere were unlikely to occur for more than several seconds. The time resolution for this test is in the order of one second. Message outputs from the barometers were of the order of 6 messages per second and the time taken to plug the pressure line in is approximately half a second. Barometers in the field send out a message once every fifteen seconds. The aim of the test was to determine if any serious delays could occur when rapid pressure changes occurred. No estimation of the pressure time constant for the barometers under these conditions was attempted.

Environmental-Diurnal temperature tests.

An environmental chamber Heraeus Vötsch (Model HC 4030) was utilised to control the temperature and was programmed to follow an exaggerated diurnal temperature change (see figure 1).

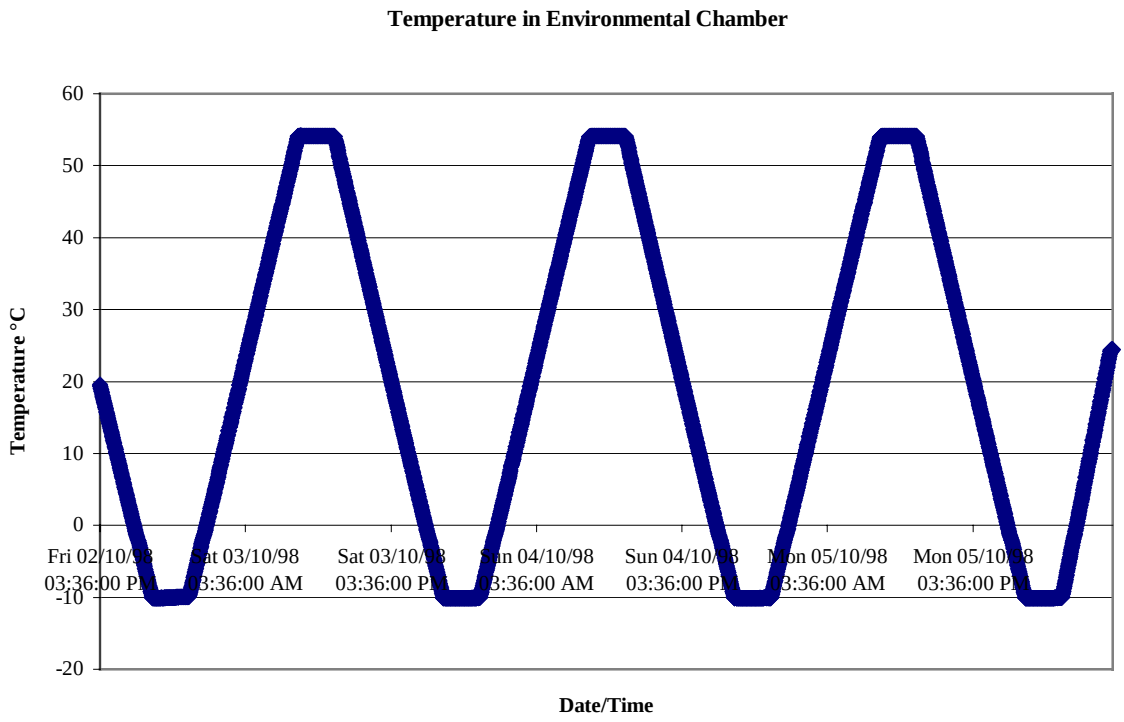

Figure 1 Temperature Cycling of Climate Chamber

The test was conducted twice, half the barometers were tested in each test with each barometer being tested only once. This was the most expedient way to conduct the test given the equipment that was available at the time. The barometers under test were connected with a reference barometer (Paros 740-15B 58157) to the RUSKA 7010 pressure control unit. This formed a closed pressure system. The controller was set to maintain the pressure at 1000hPa in the pressure line. Changes in temperature of different parts of the pressure line were not considered to have a significant impact on the pressure of the line due to the tendency of the gas to equalise in pressure over the small volume and for the RUSKA pressure control unit's quick response to any overall change in pressure.

The barometers under test were placed in the environmental chamber. The reference barometer and controller units were placed outside the chamber. A calibrated temperature probe monitored the temperature inside the chamber.

The barometers were interfaced through a multi-drop network to a PC. The Druck barometers tested did not have the capability of being networked in a multi-drop system. These barometers were connected to the second RS232 port of the PC. A LabVIEW® program was used to control the barometer data collection and time-stamped data.

The temperature measurements were collected using a DataTaker 500 (SN 50281) connected to different PC. The clocks of the barometer logging PC and the temperature logging PC were synchronised at the beginning of the test. The drift of either clock was less than one minute. This order of time change would not have a significant effect on the results of the environmental durability tests. The diurnal temperature test duration was four days.

Once the diurnal test was complete the temperature and pressure data were matched using the time stamps on both data sets.

The effect of rate of change of temperature was not examined in this test; all ramping rates were all equal for the duration of the test.

Temperature characterisation tests.

The environmental chamber (Heraeus Vötsch HC 4030) was utilised to expose the barometers to specific temperatures for a significant amount of time. The temperature was ramped from -10°C to 60°C stopping at 10°C increments for 3 hours at a time. The aim of the test was to determine constant temperature operating characteristics and the influence of the temperature time constant for barometers under test. The temperature profile of this test is shown in Figure 2.

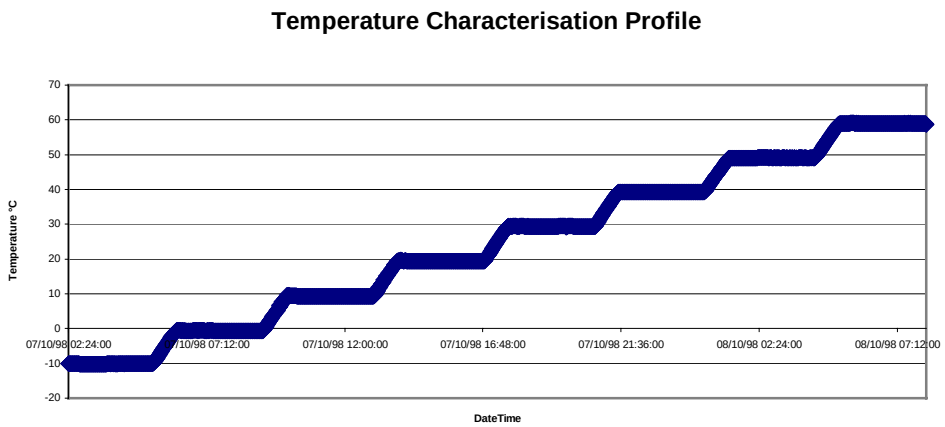

Figure 2 Temperature Characterisation Test: Temperature Profile

The barometers were connected to the reference barometer (Paros 740-15B 58157) and the pressure controller (RUSKA 7010). This formed a closed pressure system. The controller was set to maintain the pressure at 1000hPa in the pressure line. Changes in temperature of different parts of the pressure line were not considered to have a significant impact on the pressure of the line due to the tendency of the gas to equalise in pressure over the small volume and for the RUSKA pressure controller's quick response to any change in pressure.

The barometers under test were placed in the environmental chamber. The reference barometer and pressure controller units were placed outside the chamber. A calibrated temperature probe (Rosemount Slim Line RTD Serial No. 363) monitored the temperature inside the chamber.

The barometers were interfaced through a multidrop network to a PC. The DRUCK barometers tested did not have the capability of being networked in a multidrop system. These barometers were connected to a different port. A LabVIEW® program interfacing the barometers collected the time-stamped data.

The temperature measurements were collected using the DataTaker DataLogger500 (SN 50281) connected to another PC. The PC clocks were synchronised at the beginning of the test and the difference between them did not change by more than one minute over the duration of the test. This order of time change did not affect the results of the environmental durability tests. The temperature characterisation test duration was two days and 17 hours.

Once the temperature characterisation test was complete the temperature and pressure data were matched using the time stamps on both data sets.

Vibration Tests.

The barometers were sent to ASTA Components Pty Ltd for vibration testing to the Australian Standard AS1099.2.6.

All barometers were subjected to the vibration testing inside transit cases.

Results and Discussion

Comparison to the Primary Standard

The summarised results for all comparisons against the Hass manometer can be found in Table 5.

Table 5 Summaries of comparisons to the Hass manometer

	Initial Correction	U95[5]	Correction After Environmental Testing	U95 ν_{eff}=5 k=2.5	Correction after Medium Term Drift Comparison (and Vibration Testing)	U95 ν_{eff}=5 k=2.5
PTB220A S0820001	0.05	0.03	0.05	0.03	0.04	0.04
Cell 1	0.06	0.03			0.06	0.04
Cell 2	0.05	0.03			0.03	0.03
Cell 3	0.05	0.03			0.04	0.04
PTB220A S0820002	0.05	0.03	0.05	0.03		
Cell 1	0.07	0.03				
Cell 2	0.04	0.03				
Cell 3	0.05	0.03				
DPI 740 98-336	-0.00	0.03	-0.01	0.03	-0.07	0.04
ParoScientific 56315	0.13	0.03	0.15	0.03	0.10	0.04
DPI 141 93/027	0.24	0.03	0.15	0.03	0.16	0.04

[5] In accordance with the ISO Guide to Expression of Uncertainty in Measurement, ν_{eff} is effective degree of freedom, k is the coverage factor.

Vaisala PTB220A Grade Cells

- **Results of post test comparisons against the Hass.**

  Vaisala PTB220A grade instruments did not exhibit a significant shift in average pressure when compared to the Hass after the environmental testing or the vibration testing. The individual cells did not shift after all the durability tests had been completed**.**

- **Environmental Durability Tests.**

  All the Vaisala PTB220A instruments corrections were correlated to ambient temperature of the instrument. The PTB220As also exhibited a small hysterisis due to increasing or decreasing temperature. The small magnitude was likely due to the design of the transducer cells that have a small thermal mass and respond quickly to temperature changes. The difference in correction for increasing to decreasing temperature does not significantly contribute to the overall allowable tolerance of the network as it is within the noise of the measurement.

  The magnitude of the hysterisis over large temperature changes compared to other instruments is small. Having a small hysterisis is a useful feature for an instrument intended for field use that will be exposed to diurnal temperature changes and be used out of air-conditioned environments. No hysterisis is the ideal condition for the instruments.

- **Temperature Characterisation Tests**

  The Vaisala PTB 220A exhibited a non-linear temperature dependence with the maximum magnitude of the difference between -10° to 60°C being 0.04hPa. No time response was evident when the ambient temperature was increased rapidly by 5°C.

- **Vibration Testing**

  The result of the vibration testing was based on the results of the post vibration comparison to the Hass to results of the comparison to the Hass before the vibration tests but after the environmental testing.

  The Vaisala PTB220A did not exhibit a shift after vibration testing. This is most likely due to the small mass of the transducer cells.

- **Assessment of Networking and interfacing capabilities**

  The Vaisala PTB 220A had a robust interfacing system using RS232C protocol. In an addressed multidrop network the PTB220A was set up to respond only to an addressed send command. The reply consists of a message which can be defined by the user to include information such as the serial number, pressure from each of the cells, average pressure, trend, or other configurations or representations of pressure measurement available.The maximum data transfer rate for the Vaisala PTB220A model is 9600 baud. It was found that when using a 486 PC the data returned from the instrument were being corrupted. The effect disappeared when the baud rate was reduced to 4800 baud. The barometer was not tested on a different PC to determine if the effect was dependent on the PC connected to the instrument.

  The Vaisala PTB220A software has several useful features. The first is the ability to customise the message string outputs; this allows all the information about the instrument to be transmitted every time the instrument is queried. The second is the ability to open and close the data lines so that the instrument only responds to specific commands without looking for an initial identifier such as an asterisk or the hash key.

- **Summary and recommendation**

  The Vaisala PTB220A barometers performed well on all tests and criteria and have been selected for field trial testing as ROTS and HOTS.

Druck DPI 740

- **Results of post test comparisons against the Hass**

  The DPI 740 exhibited a statistically significant shift of 0.06hPa after vibration tests were complete. There was no significant shift in the correction after the environmental tests were completed. The Druck DPI 740 does not meet the criteria for HOTS and ROTS.

- **Environmental Durability Tests**

  The DPI 740 tested has a correction that was correlated to the temperature of the instrument. The unit exhibited a hysterisis curve. The difference between the increasing ambient temperature correction and the decreasing ambient temperature correction varied with temperature reaching a maximum difference of 0.12hPa at 30°C. The minimum difference was approximately 0.04 hPa in magnitude. The maximum difference of the hysterisis curve occurs at 30°C, a temperature commonly achieved on a field trip environment. The magnitude of the difference would start to significantly affect the accuracy of the network, hence the unit is not suitable for ROTS.

- **Temperature Characterisation Tests**

  The Druck DPI 740 exhibits a slightly non-linear temperature dependence, the maximum magnitude difference between -10°C to 60°C is approximately 0.10hPa. It also exhibited a time response that was fast to reach the 63% jump in correction value however throughout three hours of being maintained at a constant temperature the barometer drifted upwards in its correction by 0.05hPa. The magnitude of this drift was dependent on the absolute temperature.

- **Vibration Testing**

  The Druck DPI 740 exhibited a shift after vibration testing. The DPI 740 was subjected to vibration testing inside its transit case, and indicates that it is not well suited to transport.

- **Assessment of networking and interfacing capabilities.**

  The Druck DPI 740 is addressable, however the unit has a software feature that outputs an error message whenever it receives an unaddressed command. While most error messages generated by the Druck 740 can be masked, there is one error message that cannot be switched off. This error message either scrambles any information returning to the PC in a multi-drop network, or in a daisychained network results in an error reading in the returned message regardless of which barometer is being addressed. In a network of Druck instruments, this error would not be relevant as all commands would be prefixed with the necessary identifiers and an error message would not be generated.

- **Summary and recommendation**

  The Druck DPI 740 exhibited a shift in calibration after vibration testing, this characteristic was considered unsuitable for the intended purpose of a ROTS or HOTS.

  Furthermore, the Druck DPI 740 only has one pressure cell and does not offer greater precision in measurement than any of the other barometers tested for the same purpose. This lack of redundancy is a significant disadvantage.

ParoScientific 760-16B

- **Results of post – test comparisons against the Hass**

  The ParoScientific 760 (Serial No. 56315) correction did not shift significantly after environment testing, and did not shift significantly after vibration testing. Due to the special and stable conditions under which the ROS are to be kept, the ParoScientific is regarded as a suitable instrument for ROS.

- **Environmental Durability Tests**

  The ParoScientific had a correction that was correlated to the ambient temperature of the instrument. The instrument exhibited insignificant hysterisis dependent on increasing and decreasing temperature. This small hysterisis was not clearly defined despite the precision of the instrument meaning that the hysterisis is insignificant compared to the precision of the instrument.

  As a ROS is kept in a protected environment, subject only to small temperature changes, the ParoScientific 760 satisfies the criteria for temperature dependence and hysterisis.

- **Temperature Characterisation Tests**

  The ParoScientific 760 exhibited linear temperature dependence with a very rapid response time. The temperature response was not evident when the ambient temperature was increased rapidly by 5°C.

- **Vibration Testing**

  The ParoScientific exhibited a shift in correction after the vibration tests. The ParoScientific correction did shift and stayed low after the vibration testing, but the shift was less than the significant level of uncertainty. The barometer was tested inside a protective transit case. Head Office comparisons prior to installation and during installation would eliminate any errors introduced by transport.

- **Assessment of networking and interfacing capabilities**

  The ParoScientific interfaced easily to a PC. It has a simple string output stating the current pressure. Using separate commands the serial number can also be obtained. The ParoScientific can be used in an addressed network.

- **Summary and Recommendation**

  The ParoScientific showed a stable linear temperature dependence with no significant hysterisis. The data from the barometer that has been recorded over several years in the Physics Laboratory indicates that the barometer is very stable over a long period of time. For these characterisitics the ParoScientific has been selected for field trials as a replacement for the ROS barometers.

Druck DPI 141

- **Results of post-test comparisons against the Hass**

  The Druck DPI 141 correction shifted significantly after environmental testing, but did not shift further after vibration testing. The shift after environmental testing was 0.1hPa. Such an unpredictable, temperature induced shift in the correction is unacceptable for an instrument that is intended for use as a ROS. As indicated previously in Table 4 a medium term drift comparison tests showed that the Druck DPI 141 shifted back its original correction after being allowed to stabilise for several months.

- **Environmental Durability tests**

  The Druck DPI141 had a correction that was correlated to the ambient temperature of the instrument. The instrument also exhibited a hysterisis due to increasing and decreasing pressure. The difference between increasing and decreasing temperature was not dependent on the temperature. The magnitude of the difference is approximately 0.1hPa. The instrument ceased to output relevant data on the display and through the data output at approximately 46°C as the temperature was increasing from –10°C to 55°C and remained in that state until the ambient temperature decreased to 41°C. During the environmental testing the instrument drifted by approximately 0.14hPa. This shift occurred after four days of diurnal temperature cycling. A shift due to temperature cycling is an unacceptable feature for a ROS, even though such as standard would be kept in a controlled environment. Such a large shift would impact significantly on the uncertainty of the barometer network.

- **Temperature characterisation tests.**

  The Druck DPI 141 had non-linear temperature dependence. The response time of the instrument was evident when the ambient temperature was rapidly increased by 5°C.

- **Vibration Testing**

  The Druck DPI 141 did not exhibit any drift after the vibration tests. It was tested in a protective transit case.

- **Assessment of Networking and Interfacing capabilities**

  The Druck DPI 141 is not RS232 addressable. A carriage return command causes the instrument to output the current pressure reading. These units have a GPIB option, that is addressable and when purchased with this option the instruments can be attached to an addressable GPIB network.

- **Summary and recommendation**

  The Druck DPI exhibited a non-linear response to temperature and a large shift in calibration after temperature testing. These characteristics make the barometer unsuitable for consideration as a ROS.

Summary of Results

Table 6 Summary of Uncertainty analysis

Barometer	U95 (Existing network hierarchies[6])	U95 (Drift correction not included)	Acceptability
Vaisala PTB 220A	0.06hPa (HOTS) 0.10hPa (ROS)	0.04hPa	Acceptable
Druck DPI 740	0.06hPa (HOTS)	0.04hPa	Acceptable
ParoScientific 760-16B	0.10hPa (ROS)	0.04hPa	Acceptable
Druck DPI 141	0.10hPa (ROS)	0.04hPa	Acceptable

Table 7 Summary of Results

Barometer	Pressure Shock Tests	Environmental Testing	Temperature Characterisation	Vibration Testing	Networking and Interfacing
Vaisala PTB 220A	S	S	S	S	S
Druck DPI 740	S	S	S	NS	NS
ParoScientific 760-16B	S	S	S	C	S
Druck DPI 141	S	NS	NS	S	C
S = Satisfactory, NS = Not Satisfactory, C = Conditional					

- Even though the Vaisala PTB220A barometers meet the standards for ROS, diversity in the network hierarchy make the traceability system more robust. Different manufacturers' instruments by virtue of the technology will exhibit different long-term trends. Maintaining the diversity of these barometers is required to monitor these long term trends.

Conclusions and Further Work

The Vaisala PTB 220A barometers have been selected for field trials as HOTS and ROTS.

The ParoScientific 760-16B barometers have been selected for trials for ROS.

In addition to the trials, continued assessment of drift of the PTB 220A and ParoScientific 760-16B barometers must be maintained in the Physics Laboratory to confirm the characteristics of these barometers.

[6] The ROTS level of uncertainty is not quoted here, the instruments are compared to the existing HOTS standards for acceptability.