INSTRUMENT TEST REPORT NUMBER 642

The Southern Oscillation and Characterisation of a Kew Pattern Barometer

Jane Warne
Senior Physicist
Physics Laboratory, OEB
19 December, 1995

Authorisation

Jane Warne
Senior Physicist
Physics Laboratory

Distribution

All RDs, ROMs, RESMs, CCSs
STAW, STNM, STIE, STES, SRLR, SROG, SROO, SRPP
SRSI, SRUM, BAPS, OIC Darwin Airport
STCC, SRDS, SRCA, N Plummer, R Hutchinson
STTR, CSR, LIB

7 Pages

1. BACKGROUND

This Instrument Test Report is a copy of a paper [1] presented at the Metrology Society of Australia, 1995 Annual Conference held from the 29 November to 1 December at the National Measurement Laboraotory Lindfield NSW.

2. REFERENCES

1. Metrology Society of Australia, Annual Conference Procedings, p77 -79, 1995.

THE SOUTHERN OSCILLATION AND CHARACTERISATION OF A KEW PATTERN BAROMETER.

J. O. Warne
Bureau of Meteorology
GPO Box 1289K Melbourne Victoria 3001

ABSTRACT

A two year quality control program at Darwin Airport to study a Kew Pattern Barometer, used to monitor the Southern Oscillation, has revealed some interesting data on the way the mercurial barometer responds to pressure fluctuations. Comparisons of the Kew against two electronic and one Digital Aneroid barometer have shown reproducible and significant cyclic differences between the Kew and all other barometers. The differences vary throughout the day, and from month to month, and are correlated with the diurnal pressure variation at the site. Some general discussion is given as to the possible sources of the error, and the consequences of replacing the Kew Barometer for the determination of the Southern Oscillation Index.

INTRODUCTION

ENSO and the Southern Oscillation

ENSO is the acronym used to identify the combined phenomenon of the El Nino and Southern Oscillation. [1] The former is the name for the warm ocean current which in some years appears along the coasts of Ecuador and Peru. The latter, the Southern Oscillation, is the pressure seesaw between the east and west sides of the Pacific Ocean. The strength of the warming of the waters off the South American coast strongly influences the weather patterns across the pacific Ocean. In years of strong El Nino the West Pacific and Australia experience dry conditions while the East pacific and Americas experience wet conditions.

Both variations in the sea surface temperature and pressure across the Pacific are used to predict the timing and depth of swings in the ENSO cycle. This knowledge can then be used in long range forecasting to predict flood and drought cycles in Australia and other Pacific Rim nations

Southern Oscillation Index

One of the major tools used in Australia and internationally for the prediction of swings in ENSO is the Southern Oscillation Index (SOI). It is a measure of the pressure anomaly from the long term mean for Darwin and Tahiti.

The Southern Oscillation Index is calculated using the following formula:-

$$SOI = 10 \times \frac{\left((T-D) - \left(\overline{T-D}\right)\right)}{\sigma_{\overline{T-D}}} \quad .....[1]$$

T = Monthly mean pressure all hours for Tahiti
D = 9:00 - 15:00 Monthly mean pressure for Darwin.
(T-D) = The difference between the Tahiti and Darwin Mean Pressures.
(T-D) = The average of the monthly pressure difference between Tahiti and Darwin from 1876 to 1995
$\sigma_{(T-D)}$ = Standard deviation of the long term mean difference between Tahiti and Darwin.

Kew Barometers and Australia

The pressure measurements for the SOI at both Darwin and Tahiti are made using mercury barometers. The design of the Darwin barometer is a Kew Pattern. The basic design of the barometer is shown in Figure 1. It consists of a fixed mercury cistern with leather washer and a glass tube with air trap. The leather washer acts as barrier to the loss of mercury from the cistern through the breather holes or the introduction of major pollutants to the mercury. The air trap acts as a barrier to stop any air from the cistern getting into the vacuum space and therefore destroying the barometer.

THEORY

Influences on Accuracy of Kew Barometers

A number of factors influence the accuracy of mercury barometers. These include errors in the graduations and the positioning of the scale relative to the cistern, the positioning of the sighting edge to the vernier, the verticality of the barometer, the quality of the vacuum, the purity of the mercury and capillary depression [2].

To overcome these and other problem errors, a number of corrections are applied to any pressure reading [2]. These are corrections for temperature, local gravity, the drift correction and the index correction. The latter involves calibration of the barometer at a number of pressures against a known standard. This correction

compensates for deviations in alignment and accuracy of the scale and the magnitude of the capillary depression.

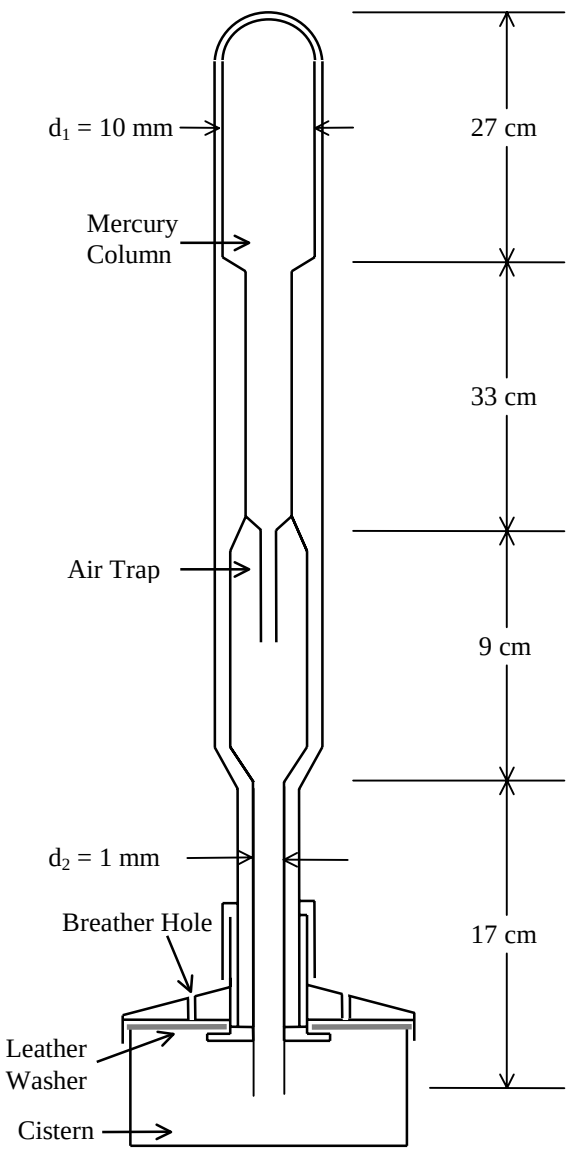

Figure 1 Cross section of a Kew Pattern Barometer

Capillary Depression

Capillary depression is the amount by which a mercury and glass barometer under-read the pressure due to the downward component of force of the surface tension [3]. The higher the meniscus, the greater the capillary depression. It is generally believed that, provided the mercury remains pure, the glass does not foul and the barometer is read in an appropriate manner, the capillary depression can be accounted for by the laboratory calibration [3], [4].

The magnitude of the meniscus is influenced by the diameter of the tube and the surface tension between the glass and the mercury. Under conditions of rising pressure the meniscus may bulge while under conditions of falling pressure it can flatten. This occurs if the ring at which the mercury meets the glass "sticks" due to "friction". The general consensus is that if the barometer is lightly tapped near the top and at the cistern then the meniscus will release and return to its correct form [3], [4], [5].

Response Time or Lag.

Another factor which influences the accuracy of barometer reading is the "lag" or the response time of the barometer [6]. A mercury barometer with a capillary bore (see Figure 1, d_2) of 0.5 to 0.6 mm, has a response time of 7 mins. If the pressure is falling by 2 hPa per hour the barometer will over-read by 0.2 hPa [7]. For the barometers used in this study this should not introduce a significant error since they have a larger bore, d_2, of 1 mm and faster response time of 60 sec.

EXPERIMENTAL

In December 1992 it was found that the Darwin Airport Kew pattern Barometer (S/N 1929) used to determine the SOI had failed. As a consequence the barometer was replaced with another Kew (S/N 2052) on the 3 March 1993. At this time a new system of quality control was instigated.

The Kew barometer was compared monthly to a transfer standard (Negretti and Zambra; Digital Aneroid Barometer DA180). In addition, 3 hourly comparisons of the Kew barometer against an electronic barometer (Vaisala DPA25 S/N 28763) were carried out. This barometer was housed in an environmental box in the field enclosure approximately 50 m from the building where the Kew Barometer was held. On the 22 April 1993, to supplement the quality control program, a second electronic barometer (Vaisala PA11A S/N 433552) was installed on the bench next to the Kew barometer. This second barometer was used as a control for the DPA25 and the Kew barometers.

On the 27 August 93 the DPA25 was moved from the enclosure to the Dines anemograph building 10m away from the original site. A computer program to collect supplementary meteorological data started on the 30 August 1993. This program also automatically collected the data from both the DPA25 and the PA11A and prompted for the measurement of the pressure by the Kew. All the data were analysed regularly to ensure there were no errors in the Kew or variations in the control barometers. All barometers were regularly compared to a transfer standard barometer to ensure there was no long term drift in their calibration.

On the 19 September 1993 at approximately 15:00 the Kew 2052 failed and was replaced with Kew 1928 on

the 22 October 1993. A timing error in the program collecting the PA11A measurements was later detected, this fault invalidated the comparisons of the DPA25 and PA11A from September 93 through to October 94. A new program to collect the data was commissioned on 3 October 1994.

The Kew barometers used have a resolution of 0.05 hPa and an uncertainty to 95% confidence of ± 0.2 hPa. The Electronic barometers have a resolution of 0.01 hPa and an uncertainty of ± 0.2 hPa. This translates to an uncertainty in the mean difference between the Kew and the DPA25 of ± 0.1 hPa.

RESULTS AND DISCUSSION

Figure 2 shows the diurnal difference (Solid Lines) between the DPA25 and Kew for the months of March and June 95. The difference is correlated with the pressure variation at the site. The Kew barometer under-reads compared to the DPA25 as the pressure rises and over-reads as the pressure falls. Similar correlations are observed in the comparisons of the Kew against the DA transfer standard. All months exhibited similar but not identical patterns.

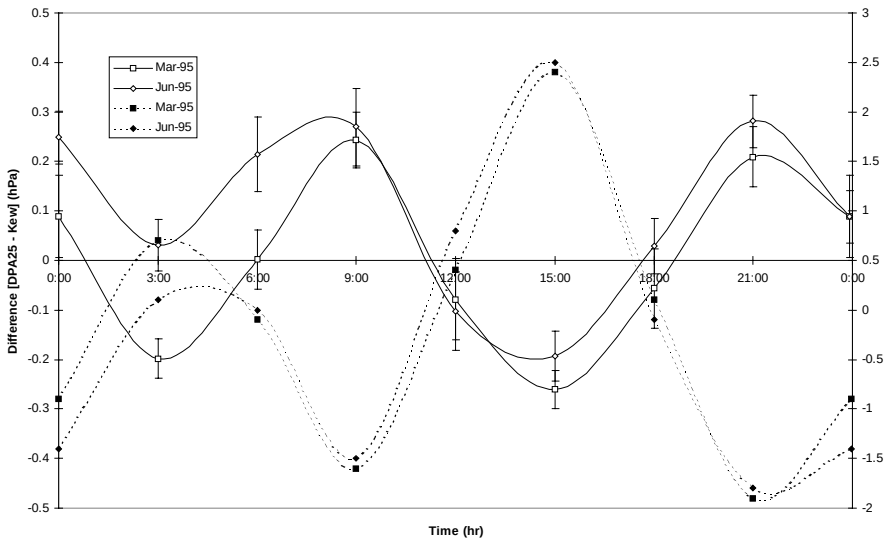

Figure 2 Diurnal Correction (Dotted Lines) for Darwin and the Diurnal Difference between the DPA25 and Kew Barometers (Solid Lines) for the months of March and June 1995.

Comparison of the PA11A and DPA25 data showed no significant difference between the two electronic barometers. This eliminated air-conditioning as either the cause of the cycle or the month to month differences. Analysis of temperature data, (atmospheric temperature and the temperature of the DPA25) showed no significant correlation with the observed behaviour.

Diurnal Pressure Cycles.

The diurnal pressure cycle varies slowly over the year being driven by the heating and cooling of the land mass and by gravitational effects on the atmosphere [8], [9]. From day to day at Darwin, the cycle is very reproducible. A set of empirical corrections have been generated to allow forecasters to compensate for this pressure cycling.

Figure 3 shows these diurnal corrections for Darwin Airport for the months March 93 to June 95. Similarly, Figure 2 shows the diurnal corrections (Dotted Lines) for the months of March and June 95. As can be seen from both figures the strength or amplitude of the diurnal pressure cycle varies from month to month. The cycle, particularly during the early part of the day, has a greater amplitude during the summer months than the winter. This correlates generally with the diurnal difference between the DPA25 and Kew barometers. During the summer months (November to March) the greatest amplitudes are observed while in the winter months (June to September) the amplitude decreases.

A linear regression fit of the diurnal correction against the difference in between the DPA25 and the Kew for 3:00 LST, shows strong correlation. (Slope -0.164 ± s = 0.0280, r^2 = 0.5697 t = -3.5, 99% significance of fit) For other hours of the day the correlation is much weaker.

Figure 4 is a surface plot of the diurnal difference between the DPA25 and Kew barometers for the period March 93 to June 95. Comparison of Figures 3 and 4 demonstrates the overall correlation between the diurnal correction and the observed differences in the DPA25 and Kew measurements of the pressure. At 3:00 and 15:00 LST the pressure is at a minimum, the diurnal correction is therefore at a maximum and the difference between the barometers is at a minimum. At 9:00 and 21:00 LST the pressure is at a maximum, the diurnal correction is therefore at a minimum and the difference between the barometers is at a maximum. Also, as stated before, it can be seen that the amplitude of the difference at a particular hour is correlated to the diurnal correction. For example at 15:00 LST the largest amplitudes are found in July to September in both the diurnal correction and the difference between the barometers.

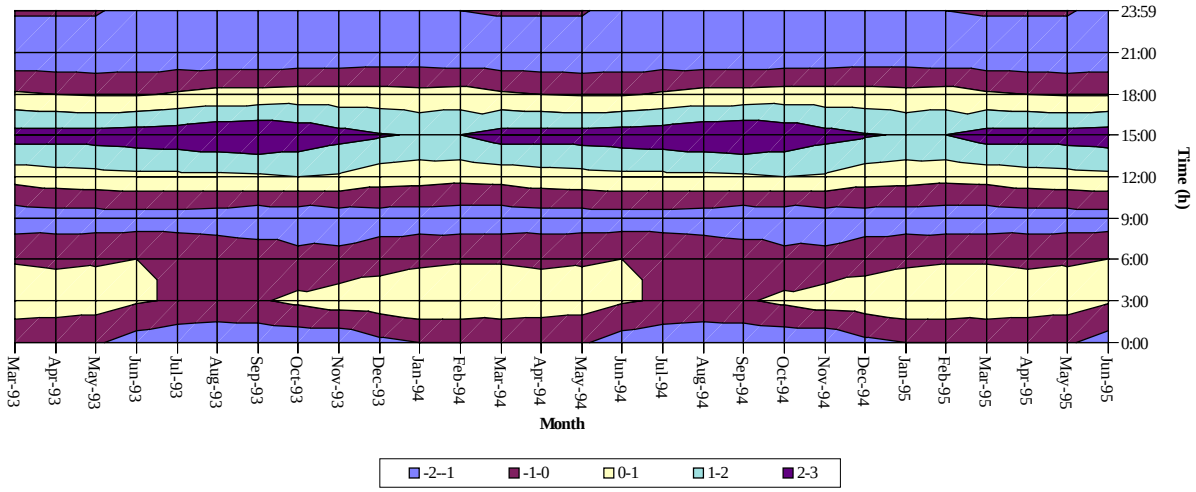

Figure 3 Diurnal correction in hPa for Darwin Airport for the period March 1993 to June 1995

Part of the reason why the patterns do not show higher correlation is the year to year variations in the weather patterns and monsoon. The diurnal correction is calculated from the average of a number of years pressure measurements with the above mentioned weather pattern and monsoon variations removed [8].

Comparisons of Kew barometers at Darwin Airport,

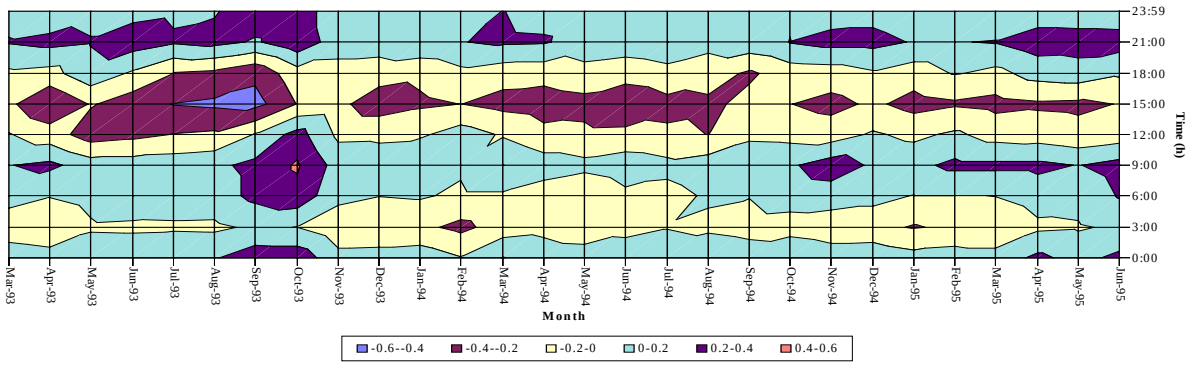

Figure 4 The Difference between DPA25 and Kew in hPa for the period March 93 to June 95.

Darwin Regional Office and other northern stations against digital aneroid barometers revealed similar trends to those observed between the Kews at Darwin Airport and the DPA25. One significant result came out of the comparison of the first Kew which failed (Kew 1929). Comparisons of the differences between the Kew1929 and DA for the time 9:00 to 15:00 LST

before and after the failure were significantly different. Linear regression of the differences verses time of day prior to failure the Kew, (i.e. February to July 91) gave the gradient as 0.795 ± 0.487 hPa/day (r^2 = 0.316, t = 1.60, 88% significance of fit). However after the failure (i.e. October to December 92) the gradient was 4.064 ± 0.595 hPa/day (r^2 = 0.870, t = 9.32, > 99% significance of fit). Examination of the gradient for the difference verses time for Kew1928 for the months October 94 to June 95 did not show a marked difference (gradient = 1.3 to 2.0 hPa/day). Therefore the change in the response of Kew1929 is a likely indicator of the failure of the device and may be a useful diagnostic. Since the failure can only have been caused by contamination of the mercury or air in the vacuum space above the column, the response of the barometer must be in part a function of these two phenomena: contamination and failure of the vacuum.

The SOI

The observed difference in the measured pressure has significant impacts for the meteorological community. Since the Darwin Airport pressure measurements are integral to the determination of the SOI it is clear that errors or differences in the measured pressure due to the method of measurement will impact heavily on it. From equation 1 and Figure 4 it can be seen that the difference between the 9:00 and 15:00 LST pressure observations could be as much as 1 hPa. This translates to as between 5 and 7 SOI units depending on the month ($\sigma_{(T-D)}$ varies between 1.4 and 2). In a more realistic case where the 9:00 to 15:00 LST error is 0.4 hPa this translates to 2 to 3 SOI units. This error is significant. The SOI generally has values between 20 and -20 with

drought and flood conditions forecast at an SOI of ± 10 over a period of two or three months. The error from the measurement method is therefore of the order of 5 to 18% of the whole scale and 10 to 35% of the level used to predict drought and flood conditions.

Sources of the Difference between the DPA25 and Kew

It is clear that the difference between the DPA25 and the Kew is a result of the way the Kew responds to local pressure fluctuations. There are a number of possible explanations for the source of the error all of which need investigation.

One hypothesis is that Kew barometers exhibit a behaviour akin to a long time constant; possibly a consequence of "relaxation" of the mercury or constriction of the mercury flow.

A second hypothesis, is that the error is caused by fluctuations in the meniscus under dynamic pressure conditions. It is assumed that by tapping the barometer near the meniscus any deformation of the meniscus and therefore deviation of the capillary depression determined during calibration will be eliminated. However this is based on experiments carried out under basically static pressure conditions [4], [5].

There also needs to be investigation of the effect of contamination of the mercury on the response of the barometer. Both as a possible diagnostic and for the impact on measurements such as the SOI.

CONCLUSION

Significant effort needs to go into determining the source of the error and impact of the error on the SOI. Kew Pattern barometers are reaching the end of their practical life as an operational meteorological instrument as they are difficult to obtain, maintain and transport and have significant health implications associated with them. At most sites in Australia the Kew barometers are now being removed. However, at Darwin Airport at least one will need to be maintained until there is a better understanding of the phenomenon.

ACKNOWLEDGMENTS

The author would like to thank the staff of Darwin Region for their hard work and enthusiastic assistance with this program. In particular; Steve Fendt and his staff at the airport for collecting the data; Darren Murphy and Phil Dutton for there assistance with the inspections and installation of the Kew barometers; Sam Cleland, Russell Stringer and Peter Bate for help with the quality control of the data and Paul Huysing and Dale Ingarfield for software support.

REFERENCES

1. J. M. Wallace and S. Vogel, "El Nino and Climate Prediction", Reports to the Nation On Our Changing Planet UCAR/OIES and NOAA, Spring 1994, No. 3, p 5 - 23.

2. WBAN, Manual of Barometry, Vol. 1, Ed 1, Washington D. C., U.S. Government Printing Office, Ch 2.6 pp 34 - 67 Fixed - Cistern Type barometers

3. WBAN, Manual of Barometry, Vol. 1, Ed 1, Washington D. C., U.S. Government Printing Office, Ch 2.6 pp 41 - 57 Fixed - Capillarity, Cleanness of Mercury and Friction.

4. W. Catwood and H. S. Patterson, "The Capillary Depressions of Mercury in Cylindrical Tubes and some Errors of Glass manometers.", Trans. Faraday Soc., Vol. 29, 1933, p514.

5. A. W. Porter, "Capillary Ascent or Depression of Liquids in Cylindrical Tubes.", Trans. Faraday Soc., Vol. 29, 1933, p702.

6. E. P. Harrison, "The Effects of Oscillation and of "Lag" on the readings of the Kew pattern barometer", Indian Meteorological Memoirs, Vol. 23 (IV), 1920, p 137.

7. WBAN, Manual of Barometry, Vol. 1, Ed 1, Washington D. C., U.S. Government Printing Office, Ch 2.6 pp 64.

8. B. Haurwitz and A. D. Cowley, "Lunar and Solar Barometric Tides in Australia", Monthly Weather Review, Vol. 96, No. 9, 1968, p 601 - 605

9. S. Chapman and R. S. Lindzen, "Atmospheric Tides", D. Reidel Publishing Co. Holland, 1970, p1 - 23.