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**Update of the CIMo Guide**

Update of Part I, Chapter 3 "Measurement of atmospheric pressure"

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| **Summary and purpose of document**This document provides the proposed modification to the CIMO Guide Part I, Chapter 3 “Measurement of atmospheric pressure” for review by the CIMO ET-OpMet members. On the basis of the restructured document provided by Tilman Holfelder most changes have been made by Jitze van der Meulen. The sections on mercury barometers are kept apart as Annex A (and B), based on the decision of the CIMO Management Group. Section 3.6 on “Traceability assurance and calibration” still needs an update, as the new strategy for traceability assurance (annex 1A of the updated chapter 1, Part I of the CIMO Guide) is not fully implemented. |

**Action proposed**

The Meeting is invited to review this document and give advice on the necessary changes in section 3.6. The final document should then be submitted to the CIMO Editorial Board for the forthcoming update of the CIMO Guide.

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Chapter 3.Measurement of atmospheric pressure

# 3.1 General

## 3.1.1 Definition

The atmospheric pressure on a given surface is the force per unit area exerted by virtue of the weight of the atmosphere above. The pressure is thus equal to the weight of a vertical column of air above a horizontal projection of the surface, extending to the outer limit of the atmosphere.

Apart from the actual pressure, pressure trend or tendency has to be determined as well. Pressure tendency is the character and amount of atmospheric pressure change for a 3 h or other specified period ending at the time of observation. Pressure tendency is composed of two parts, namely the pressure change and the pressure characteristic. The pressure change is the net difference between pressure readings at the beginning and end of a specified interval of time. The pressure characteristic is an indication of how the pressure has changed during that period of time, for example, decreasing then increasing, or increasing and then increasing more rapidly.

Important note: In the Manual of the GOS (WMO No. 544) a mandatory requirement is stated on reporting atmospheric pressure, which is expressed as follows:

*3.3.2.1 Barometric readings shall be reduced from local acceleration of gravity to standard (normal) gravity The value of standard (normal) gravity (symbol gn) shall be regarded as a conventional constant gn = 9.806 65 m/s*

This statement is related to readings from **mercury barometers** only in order to reduce the gravity impact on the collumn of mercury to derive the correct pressure value. Because the use of mercury barometers is obsolete, this statement should **not** be regarded anymore. See also Annex 3.A.

## 3.1.2 Units and scales

The basic unit for atmospheric pressure measurements is the pascal (Pa) (or newton per square metre, Nm-2). It is accepted practice to add the prefix “hecto” to this unit when reporting pressure for meteorological purposes, making the hectopascal (hPa), equal to 100 Pa, the preferred terminology. This is largely because one hectopascal equals one millibar (mbar), the formerly used unit. Further details on the mandatory use of SI units are explained in volume I, chapter 1 of this Guide. Note that units, used for barometer readings, like "mm Hg", "in Hg" or "mbar" are not defined within SI and to avoid any confusion may not be used for the international exchange of data when reporting atmospheric pressure (see also Annex A of this chapter).

The scales of all barometers used for meteorological purposes should be graduated in hPa. If other units are used to read, conversion is necessary. Some conversion factors are provided in Annex A of this chapter.

Because pressure data is reported in hectopascals only, in this chapter only the unit hPa will be used.

## 3.1.3 Meteorological requirements

Analysed pressure fields are a fundamental requirement of the science of meteorology. It is imperative that these pressure fields be accurately defined as they form the basis for all subsequent predictions of the state of the atmosphere. Pressure measurements must be as accurate as technology will allow, within realistic financial constraints, and there must be uniformity in the measurement and calibration procedures across national boundaries.

The level of accuracy needed for pressure measurements to satisfy the requirements of various meteorological applications has been identified by the respective WMO commissions and is outlined in Part I, Chapter 1, Annex 1.E, which is the primary reference for measurement specifications in this Guide.

These requirements should be considered achievable for new barometers in a strictly controlled environment, such as those available in a properly equipped laboratory. They provide an appropriate target accuracy for barometers to meet before their installation in an operational environment.

For barometers installed in an operational environment, practical constraints will require well-designed equipment for a National Meteorological Service to maintain this target accuracy. Not only the barometer itself, but the exposure also requires special attention. Nevertheless, the performance of the operational network station barometer should not be below the stated criteria.

## 3.1.4 Methods of measurement and observation

### 3.1.4.1 General measurement principles

For meteorological purposes, atmospheric pressure is generally measured with electronic barometers, aneroid barometers or hypsometers. The latter class of instruments, which depends on the relationship between the boiling point of a liquid and the atmospheric pressure, has so far seen only limited application and will not be discussed in depth in this publication.

Mercury barometers are still in use, but no longer recommended, taken into account the Minamata convention on mercury (Part I, Chapter 1, 1.4.2). NMHS are encouraged to take appropriate measures to replace mercury barometers with modern alternatives (Chapter 3.1.5). Therefore WMO regulations and requirements for mercury barometers is kept apart as Annex A. This information on observation practices with mercury barometer is maintained in that Annex to inform the reader only on this obsolete practice

Most barometers with recent designs make use of transducers which transform the sensor response into pressure-related quantities. These are subsequently processed by using appropriate electrical integration circuits or data-acquisition systems with appropriate smoothing algorithms. A time constant of about 10 s (and definitely no greater than 20 s) is desirable for most synoptic barometer applications.

There are several general methods for measuring atmospheric pressure which will be outlined in the following paragraphs.

A membrane of elastic substance, held at the edges, will be deformed if the pressure on one side is greater than on the other. In practice, this is achieved by using a completely or partially evacuated closed metal capsule containing a strong metal spring to prevent the capsule from collapsing due to external atmospheric pressure. Mechanical or electrical means are used to measure the deformation caused by the pressure differential between the inside and outside of the capsule. This is the principle of the well-known aneroid barometer.

Pressure sensor elements comprising thin-walled nickel alloy cylinders, surrounded by a vacuum, have been developed. The natural resonant frequency of these cylinders varies as a function of the difference in pressure between the inside of the cylinder, which is at ambient atmospheric pressure, and the outside of the cylinder, which is maintained as a vacuum. Although pressure is reported, in fact these sensors measure the density of the gas (air) inside.

Absolute pressure transducers, which use a crystalline quartz element, are also commonly used. Pressure exerted via flexible bellows on the crystal face causes a compressive force on the crystal. On account of the crystal’s piezoresistive properties, the application of pressure alters the balance of an active Wheatstone bridge. Balancing the bridge enables accurate determination of the pressure. These types of pressure transducers are virtually free of hysteresis effects.

An old, inaccurate and therefore rather obsolete method to determine pressure based on the measurement of the boiling point of a liquid, usually water. The boiling point (temperature) of a liquid is a function of the pressure under which it boils. Once this function has been determined, the temperature at which the liquid boils may be used in a hypsometer to determine the atmospheric pressure.

### 1.4.2

 to read out (in case of manually readings), non-vibrating

Special effort in positioning is required to prevent any artificial wind impact. Such impact is typical for indoor measurement due to the build-up of pressure outside the building and generating errors which are sometime larger than 1 hPa. For further details, see 3.1.4.3.2

### 3.1.4.3 Sources of error: general comments

Errors in the measurement of pressure may be caused by an inappropriate placement of the sensor. The instrument must be placed in an environment where external effects will not lead to measurement errors. These effects include wind, radiation/temperature, shocks and vibrations, fluctuations in the electrical power supply and pressure shocks. It is important that every meteorological observer or technical staff should fully understand these effects and is able to assess whether any of them are affecting the accuracy of the readings of the barometer in use.

In case of manual readings the instrument (or its display) should be quick and easy to read. Instruments must be designed so that the resolution of their readings is less than the required measurement uncertainty;

### 3.1.4.3.1 The effects of temperature

Instrument readings should not be affected by temperature variations. Instruments are suitable only if:

(a) The instrument is designed to be temperature independ or compensated for the whole temperature domain, to be proven by adequate calibration and tests.

(b) Procedures for correcting the readings for temperature effects will ensure the required accuracy; and/or

(c) The pressure sensor is placed in an environment where the temperature is stabilized so that the required accuracy will be met.

Most instruments measure the temperature of the pressure sensor in order to compensate for temperature effects. It is necessary to control and calibrate these temperature-compensating functions as part of the standard calibration activity.

### 1.4.3.2s

limited (WMO, 2012)

### 1.4.3.3

***3.1.4.3.4 The effects of hysteresis***

Some barometers (in particular aneroid barometers) are affected by hysteresis, with an impact larger than 0.1 hPa. To demonstrate that any hysteresis is within the required measurement uncertainty, calibrations must be performed in both ascending and descending pressure steps.

***3.1.4.3.5 Transport and use a non-stabilized environment.***

Barometers may be sensitive to vibrations and shocks affecting the adjustment of the equipment. Special care must be taken to avoid any chock impact during transport and the instruemnts should be placed in an vibration free environment of mounted using vibration damping material.

### 3.1.4.4 Maintenance: general comments

The following maintenance procedures should be considered:

(a) The instruments and especially the pressure inlet should be kept clean and free.

(b) The installation height of the sensor and the mounting should be checked.

(c) The instruments must be calibrated (and adjusted if appropriate) regularly. The interval between two calibrations must be short enough to ensure, that the total absolute measurement error will meet the accuracy requirements defined in this chapter;

(d) Any variations in the accuracy (long-term and short-term) must be much smaller than the tolerances outlined in section 3.1.3. If some instruments have a history of a drift in calibration, they will be suitable operationally only if the period between calibrations is short enough to ensure the required measurement accuracy at all times;

(e) If the instrument has to be calibrated away from its operational location, the method of transportation employed must not affect the stability or accuracy of the barometer. Effects which may alter the calibration of the barometer include mechanical shocks and vibrations, and displacement from the vertical and large pressure variations such as may be encountered during transportation by air.

### 3.1.4.5 Implications of the Minamata Convention for the pressure measurement

The United Nations Environment Programme (UNEP) Minamata Convention on Mercury comes into force globally in 2020, and bans all production, import and export of mercury barometers (see Chapter I, 1.4.1). Therefore mercury barometers are no longer recommended and it is strongly encouraged to take appropriate measures to replace mercury barometers with modern alternatives. Electronic barometers are now-a-days state of the art and can provide an economical, accurate and reliable alternative to their dangerous, mercury-based precedents and offer significant advantages in terms of data storage and real-time data display.

# 3.2 Electronic barometers

Most barometers with recent designs make use of transducers which transform the sensor response into a pressure-related electrical quantity in the form of either analogue signals, for example, voltage (DC or AC with a frequency related to the actual pressure), or digital signals, for example, pulse frequency or with standard data communication protocols such as RS232, RS422, RS485 or IEEE488. Analogue signals can be displayed on a variety of electronic meters. Monitors and data-acquisition systems, such as those used in automatic weather stations, are frequently used to display digital outputs or digitized analogue outputs.

Current digital barometer technology employs various levels of redundancy to improve the long-term stability and accuracy of the measurements. One technique is to use three independently operating sensors under centralized microprocessor control. Even higher stability and reliability can be achieved by using three completely independent barometers, incorporating three sets of pressure transducers and microprocessors. Each configuration has automatic temperature compensation from internally mounted temperature sensors. Triple redundancy ensures excellent long-term stability and measurement accuracy, even in the most demanding applications. These approaches allow for continuous monitoring and verification of the individual sensor performances.

The use of digital barometers introduces some particular operational requirements, especially when they are used with automatic weather stations, and formal recommendations exist to ensure good practice (see the Abridged Final Report of the Eleventh Session of the Commission for Instruments and Methods of Observation(WMO-No. 807), Annex VII). Meteorological organizations should:

(a) Control or re-adjust the calibration setting of digital barometers upon receipt and repeat these operations regularly (annually, until the rate of drift is determined);

(b) Ensure regular calibration of digital barometers and investigate the possibility of using calibration facilities available nationally for this purpose;

(c) Consider that certain types of digital barometers may be used as travelling standards because of their portability and good short-term stability;

(d) Consider that the selection of a specific type of digital barometer should not only be based on stated instrument specifications but also on environmental conditions and maintenance facilities.

Manufacturers should:

(a) Improve the temperature independence and the long-term stability of digital barometers;

(b) Use standardized communication interfaces and protocols for data transmission;

(c) Enable the power supply of a digital barometer to function over a large range of DC voltages (for example, 5 to 28 VDC).

## 3.2.1 IC based variable capacitive sensors

Capacitive pressure sensors use the electrical property of capacitance to measure the displacement of a diaphragm. The diaphragm is an elastic pressure sensor displaced in proportion to changes in pressure. It acts as one plate of a capacitor which detects strain due to applied pressure to become a variable capacitor. The change in value of the capacitance causes this electrical signal to vary. This is then conditioned and displayed on a device calibrated in terms of pressure. Common technologies use metal, ceramic and silicon diaphragms. Because this measurement is temperature dependent, sensor temperature is measured as well for compensation to meet the accuracy requirements.

Silicon-diaphragm sensors are popular in integrated circuit (IC) technology today (with sizes of about 1μm). For this technique the absolute pressure is measured suing a vacuum based chamber (pressure smaller than 10-3 hPa).

## 3.2.2 Digital piezoresistive barometers

Measurements of atmospheric pressure have become possible by utilizing the piezoelectric (piezoresistive) effect. A common configuration features four measuring resistors placed onto the flexible surface of a monolithic silicon substratum interconnected to form a Wheatstone bridge circuit.

Axially loaded crystalline quartz elements are used in digital piezoresistive barometers and are a type of absolute pressure transducer. Crystalline quartz has been chosen because of its piezoelectric properties, stable frequency characteristics, small temperature effects and precisely reproducible frequency characteristics. Pressure applied to an inlet port causes an upward axial force by means of flexible bellows, thus resulting in a compressive force on the quartz crystal element. Since the crystal element is a substantially rigid membrane, the entire mechanical structure is constrained to minute deflections, thereby virtually eliminating mechanical hysteresis.

The fully active Wheatstone bridge mentioned above may consist either of semiconductor strain gauges or piezoresistive gauges. The strain gauges are either bonded to a thin circular diaphragm, which is clamped along its circumference, or atomically diffused into a silicon diaphragm configuration. In the case of diffused devices, the silicon integrated chip itself is the diaphragm. Applied pressure presents a distributed load to the diaphragm which, in turn, provides bending stress and resultant strains to which the strain gauges react. This stress creates a strain that is proportional to the applied pressure and which results in a bridge imbalance. The bridge output is then proportional to the net difference in pressure acting upon the diaphragm.

This mode of operation is based on the fact that the atmospheric pressure acts on the sensor element covering a small evacuated cell, through which the resistors are submitted to compressive and tensile stresses. By the piezoelectric effect, the values of resistance change proportionally with atmospheric pressure. To eliminate temperature errors, the sensor often incorporates a built-in thermostat.

The output from the Wheatstone bridge, which is fed from a direct-current source, is transduced into a standard signal by an appropriate amplifier. A light-emitting diode or liquid crystal display usually presents the measured pressure values.

In a modern version of the pressure transducer using a piezoelectric transducer, two resonance frequencies of the piezoelectric element are determined. By calculating a linear function of these frequencies and with an appropriate set of variables obtained after calibration, a pressure is calculated by a microprocessor which is independent of the temperature of the sensor.

## 3.2.3 Cylindrical resonator barometers

Cylindrical resonator barometers use a sensing element which is a thin-walled cylinder of nickel alloy. This is electromagnetically maintained in a “hoop” mode of vibration. The input pressure is sensed by the variation it produces in the natural resonant frequency of the vibrating mechanical system. Cylinder wall movement is sensed by a pick-up coil whose signal is amplified and fed back to a drive coil. The air pressure to be measured is admitted to the inside of the cylinder, with a vacuum reference maintained on the outside. The natural resonant frequency of vibration then varies precisely with the stress set up in the wall due to the pressure difference across it. An increase in pressure gives rise to an increase in frequency.

The thin cylinder has sufficient rigidity and mass to cater for the pressure ranges over which it is designed to operate, and is mounted on a solid base. The cylinder is placed in a vacuum chamber and its inlet is connected to the free atmosphere for meteorological applications. Since there is a unique relationship between the natural resonant frequency of the cylinder and the pressure, the atmospheric pressure can be calculated from the measured resonant frequency. However, this relationship, determined during calibration, depends on the temperature and the density of the gas. Temperature compensation is therefore required and the air should be dried before it enters the inlet.

## 3.2.4 Aneroid displacement transducers

Contact-free measurement of the displacement of the aneroid capsule is a virtual necessity as regards precision pressure-measuring instruments for meteorological applications. A wide variety of such transducers are in use, including capacitive displacement detectors, potentiometric displacement detectors, strain gauges placed at strategic points on the sensor, and force-balanced servo-systems which keep the sensor dimensions constant regardless of pressure.

All sensitive components must be encased in a die-cast housing. Unless designed with adequate temperature compensation, this housing must be kept at a constant temperature by an electronically controlled heater. Condensation of water must be completely prevented. An effective technique is to put a hygroscopic agent, such as silica gel crystals, into the die-cast housing and to prevent water vapour diffusion into the housing by connecting a long plastic tube (approximately 25 m) with a bore of 2 mm or less between the pressure port and a static head (see section 3.1.4.3).

The pressure-sensor housing must be airtight, allowing external connection to the compartment where the pressure is to be measured.

## 25

Details on general exposure requirements are provide in 3.1.4.2. Electronic barometers

## 3.2.6 Reading electronic barometers

An electronic barometer measures the atmospheric pressure of the surrounding space or any space that is connected to it via a tube. In general, the barometer should be set to read the pressure at the level of the instrument. On board a ship or at low-level land stations, however, the instrument may be set to indicate the pressure at mean sea level, provided that the difference between the station pressure and the sea-level pressure can be regarded as constant.

Electronic barometers give accurate readings on a digital read-out, normally scaled in hPa but readily adaptable to other units, if required. Provision can usually be made for digital recording. Trend in pressure changes can be presented if the unit is microprocessor-controlled.

The accuracy of electronic barometers depends on the accuracy of the barometer’s calibration, the effectiveness of the barometer’s temperature compensation (residual air method, temperature measurement and correction, use of a thermostat) and the drift with time of the barometer’s calibration.

Circuits may be attached to primary transducers which correct the primary output for sensor non-linearities and temperature effects and which convert output to standard units. Standard modern barometer versions comprise the barometer sensor, the microcomputer unit (including the display) and an interface circuit to communicate with any data logger or automatic weather station.

Electronic barometers which have more than one transducer or sensing element generally calculate a weighted mean of the outputs from each of the sensors and establish the resultant pressure with a resolution of at least 0.1 hPa. During calibration, each of the sensing elements can be checked with a resolution of 0.01 hPa.

## 3.2.7 Sources of error and inaccuracy

### 3.2.7.1 Drift between calibrations

Drift between calibrations is one of the key sources of error with barometers. It is often greater when the barometer is new and decreases with the passage of time. Step jumps in calibration may occur.

In order to maintain the acceptable performance of a barometer, the calibration corrections applied to the readings must be checked at relatively frequent intervals, for example, starting annually, for early detection and replacement of defective sensors.

The need to check frequently the calibration of electronic barometers imposes an additional burden on National Meteorological Services, particularly on those with extensive barometer networks. The ongoing cost of calibration must be taken into consideration when planning to replace mercury barometers with electronic barometers.

### 3.2.7.2 Temperature

Most electronic barometers are adequately compensated for temperature, which can be proven during calibration or testing. In case electronic barometers are not sufficiently compensated for temperature, these instruments must be kept at a constant temperature if the calibration is to be maintained. The temperature should be near the calibration temperature. In case electronic barometers are not temperature-controlled at all and these devices are prone to greater error. Most depend on accurate temperature measurement of the sensing element and electronic correction of the pressure. This assumes that there are no thermal gradients within the sensing element of the barometer. In situations where the temperature changes reasonably quickly, this can result in short-term hysteresis errors in the measured pressure.

The change in calibration may also be dependent on the thermal history of the barometer. Prolonged exposure to temperatures changes may result in medium to long-term calibration shifts.

The electronics of the barometer can also introduce errors if it is not held at the same temperature as the sensor element. Electronic barometers are very often used in extreme climatic conditions, especially in automatic weather stations. In these situations, the barometer can be exposed to temperatures well in excess of its manufacturer’s design and calibration specifications.

### 3.2.7.3 Electrical interference

As with all sensitive electronic measurement devices, electrical barometers should be shielded and kept away from sources of strong magnetic fields, such as transformers, computers, radar, and so forth. Although this is not often a problem, it can cause an increase in noise, with a resultant decrease in the precision of the device.

### 3.2.7.4 Nature of operation

Apparent changes in the calibration of an electronic barometer can be caused by differences in the way in which the barometer is operated during calibration, as compared with its operational use. A pressure read on a barometer that is run continuously and, therefore, warmed up will read differently from that read in a pulsed fashion every few seconds.

# 3.3 Aneroid barometers

## 3.3.1 Construction requirements

The principal components are a closed metal chamber, completely or partly evacuated, and a strong spring system that prevents the chamber from collapsing under the external atmospheric pressure. At any given pressure, there will be an equilibrium between the force caused by the spring and that of the external pressure.

The aneroid chamber may be made of materials (steel or beryllium copper) that have elastic properties such that the chamber itself can act as a spring.

A means is required to detect and display the changes in deflection which occur. This may be a system of levers that amplify the deflections and drive a pointer over a scale graduated to indicate the pressure. Alternatively, a ray of light may be deviated over the scale. Instead of these mechanical analogue techniques, certain barometers are provided with a manually operated micrometer whose counter indicates the pressure directly in tenths of a hectopascal. A reading is taken when a luminous indicator signals that the micrometer has just made contact with the aneroid. This type of aneroid is portable and robust.

## 3.3.2 Achievable measurement uncertainty

The achievable measurement uncertainty of 0.3 hPa is possible for a well designed and constructed aneroid barometer. To achive this uncertainty the following rules should be considered:

(a) It should be compensated for temperature so that the reading does not change by more than 0.3 hPa for a change in temperature of 30 K;

(b) The scale errors at any point should not exceed 0.3 hPa and should remain within this tolerance over periods of at least one year, when in normal use;

(c) The hysteresis should be sufficiently small to ensure that the difference in reading before a change in pressure of 50 hPa and after a return to the original value does not exceed 0.3 hPa;

(d) It should be capable of withstanding ordinary transit risks without introducing inaccuracies beyond the limits specified above.

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Details on general exposure requirements are provide in 3.1.4.2. Electronic barometers

## 3.3.4 Reading aneroid barometers

### 3.3.4.1 Accuracy of readings

An aneroid barometer should always be read in the same orientation (vertical or horizontal) as during calibration. It should be tapped lightly before being read. As far as possible, it should be read to the nearest 0.1 hPa. Optical and digital devices are available to reduce the errors caused by mechanical levers.

### 3.3.4.2 Reductions applied to barometers

In general, aneroid barometers should be set to read the pressure at the level of the instrument. On board a ship or at low-lying land stations, however, the instrument may be set to indicate the pressure at mean sea level, provided that the difference between the station pressure and the sea-level pressure can be regarded as constant.

## 3.3.5 Sources of error and inaccuracy

### 3.3.5.1 Incomplete compensation for temperature

In an aneroid barometer, if the spring is weakened by an increase in temperature, the pressure indicated by the instrument will be too high. This effect is generally compensated for in one of the following ways:

(a) By means of a bimetallic link in the lever system; or

(b) By leaving a certain amount of gas inside the aneroid chamber.

In most ordinary aneroid barometers, the compensation obtained by these methods is complete only at one particular compensation pressure. It is desirable that all aneroid barometers and barographs used at meteorological stations should be properly compensated for temperatures over the full range of pressure. In digital read-out systems suitable for automation, such complete corrections can be applied as part of the electronic system.

### 3.3.5.2 Elasticity errors

An aneroid barometer may be subjected to a large and rapid change in pressure. For example, a strong gust of wind would cause an aneroid barometer to experience a rapid increase in pressure followed by a more gradual return to the original value. In such circumstances, the instrument will, owing to hysteresis, indicate a slightly different reading from the true pressure; a considerable time may elapse before this difference becomes negligible. However, since aneroids and barographs at surface stations are not usually directly exposed to such pressure changes, their hysteresis errors are not excessive.

There is also a secular error caused by slow changes in the metal of the aneroid capsule. This effect can be allowed for only by comparison at regular intervals, for example, annually, with a standard barometer. A good aneroid barometer should retain an accuracy of 0.1 hPa over a period of one year or more. In order to detect departures from this accuracy by individual barometers, a regular inspection procedure with calibration and adjustment as necessary should be instituted.

# 3.4 Barographs

## 3.4.1 General requirements

Of the various types of barographs, only the aneroid barograph will be dealt with in detail here. For synoptic purposes, it is recommended that charts for barographs:

(a) Be graduated in hPa;

(b) Be readable to 0.1 hPa;

(c) Have a scale factor of 10 hPa to 1.5 cm on the chart.

In addition, the following requirements are desirable:

(a) The barograph should employ a first-class aneroid unit (see section 3.5.2);

(b) The barograph should be compensated for temperature, so that the reading does not change by more than 1 hPa for a 20 K change in temperature;

(c) Scale errors should not exceed 1.5 hPa at any point;

(d) Hysteresis should be sufficiently small to ensure that the difference in reading before a change in pressure of 50 hPa and after a return to the original value does not exceed 1 hPa;

(e) There should be a time-marking arrangement that allows the marks to be made without lifting the cover;

(f) The pen arm should be pivoted in a “gate”, the axis of which should be inclined in such a way that the pen rests on the chart through the effects of gravity. A means of adjustment should be provided for setting the position of the pen.

Marine barographs are subject to special requirements, which are considered in Part II, Chapter 4.

## 3.4.2 Construction of barographs

The principle of the aneroid barograph is similar to that of the aneroid barometer, except that a recording pen is used instead of a pointer. This involves some change in the design of the capsule stack, and usually means a decrease in the overall magnification and an increase in the number and size of the capsules used.

The “control” of the barograph may be expressed as the force required to move the pointer over one unit of the scale (1 hPa) and is, thus, equal to the force required to prevent the pen from moving when the pressure changes by 1 hPa. It is a measure of the effect that friction is likely to have on the details of the record.

The force required to overcome the movement of the capsule when the pressure changes by 1 hPa is 100 A newtons, where A is the effective cross-sectional area of the capsule in square metres. If the magnification is X, the force necessary to keep the pen from moving is 100 A/X newtons and varies as A/X. For a given type of capsule and scale value, the value of X will be largely independent of A, so that the control of a barograph pen may be considered to vary approximately with the effective cross-sectional area of the capsule.

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Details on general exposure requirements are provide in 3.1.4.2. and

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## 3.4.4 Sources of error and inaccuracy

In addition to the sources of error mentioned for the aneroid (see section 3.3), the friction between the pen and the paper is important. The control of the pen depends largely on the effective cross-section of the aneroid. In a well-made barograph, the friction of the pen is appreciably greater than the total friction at all the pivots and bearings of the instrument; special attention should, therefore, be given to reduce such errors, for example, by having a sufficiently large aneroid capsule.

A first-class barograph should be capable of an uncertainty of about 0.2 hPa after corrections have been applied and should not alter for a period of one or two months. The barometric change read from such a barograph should usually be obtained within the same limits.

## 3.4.5 Reading a barograph

The barograph should be read without touching the instrument. The time mark and any inspection of the instrument involving lifting the cover, and so on, should always be made after the reading is completed.

### 3.4.5.1 Accuracy of readings

The chart should be read to the nearest 0.1 hPa. The barometric change should be obtained within the same resolution limits.

### 3.4.5.2 Corrections to be applied to barograph readings

The temperature compensation of each individual instrument should be tested before the instrument is used, and the scale factor should be adjusted by testing in a vacuum chamber. If the barograph is used only to find the barometric change, the corrections are not usually applied to the readings. In this case, the accurate setting of the pen position is not important. When absolute pressure values are required from the barograph, the record should be compared with the reading of an electrical barometer or a good aneroid barometer at least once every 24 h and the desired values found by interpolation.

## 3.4.5 Transport

If a barograph has to be transported by air or transported at a high altitude, the pen arm should be disconnected and precautions should be taken to ensure that the mechanism is able to withstand the overload caused by exceeding the normal measuring range of the instrument.

# 3.5 Barometric change and Pressure tendency

# 3.5.1 Pressure tendency and pressure tendency characteristics

At surface synoptic observing stations, pressure tendency and the pressure tendency characteristic should be derived from pressure observations from the last 3 h (over 24 h in tropical regions). Typically, the pressure tendency characteristic can be expressed by the shape of the curve recorded by a barograph during the 3 h period preceding an observation (WMO, 2010b). In the case of hourly observations, the amount and characteristic can be based on only four observations, and misinterpretations may result. Therefore, it is recommended that the characteristic should be determined on a higher frequency of observations, for example with 10 min intervals (WMO, 1985). Nine types of pressure tendency characteristics are defined (see WMO, 2010a, p. II-4-8).

## 3.5.2 Measurement of a barometric change

Several methods are available to stations making observations at least every 3 h as follows:

(a) Digital electronic barometers usually display the pressure tendency together with the actual pressure

(b) The change can be read directly from a barograph; or

(c) The change can be obtained from appropriate readings of the barometer, corrected to station level.

The error of a single barometric reading is mainly random, assuming that the barometer functions perfectly. Therefore, when two independent readings are subtracted to find the amount of change, the errors may be cumulative. Errors are partly systematic in nature, so that in the relatively short period of 3 h, the errors are likely to have the same sign and would, therefore, be diminished by subtraction.

# 3.6 Tracebility assurance and calibration

## 3.6.1 General requirements of a barometer comparison

In view of the importance of accurate pressure observations, especially for aeronautical and synoptic purposes, and of the various possible errors to which barometers are subject, all station barometers should be checked regularly by an inspector. Some guidance is given in the following sections regarding the equipment to be used for checks, the frequency with which these should be carried out, and other related topics. Where precision aneroid barometers are used as station barometers, they should be checked frequently (e.g. every 6 months) against a reference digital barometer or traveling standard, and a permanent record of all such checks should be kept on a suitable card or in a special logbook.

The following symbols may be used to denote various categories of barometers in a National Meteorological Service:

A: A primary or secondary standard barometer capable of independent determination of pressure to an uncertainty of 0.05 hPa or less;

B: A working standard barometer of a design suitable for routine pressure comparisons and with known errors, which have been established by comparison with a primary or secondary standard;

C: A reference standard barometer used for comparisons of travelling standard and station barometers at field supervising stations of a National Meteorological Service;

S: A barometer (mercury, aneroid, electronic) located at an ordinary meteorological station;

N: A portable precision aneroid barometer of first quality;

Q: A portable precision digital barometer of first quality, to be used as a travelling standard (Q stands for quality);

M: A portable microbarograph of good quality and accuracy.

In order that barometer correction programmes be conducted on the same basis by all National Meteorological Services, it is desirable that uniform practices be followed in the quality of the equipment used, the frequency of comparisons, the procedures to be followed, the permissible changes in index correction, and the criteria for remedial action.

## 3.6.2 Equipment used for barometer comparisons

### 3.6.2.1 Primary standard barometer (A)

There are different opinions regarding the best type of primary standard barometer (WMO, 2010c). One possible primary standard for atmospheric pressure consists of a precision dead weight tester that produces a calibrated pressure related to the precision weights used and the local gravity field. This type of barometer is relatively simple and does not suffer from the problem of excessive drift experienced by mercury barometers in a polluted environment.

Considering the cost of such primary standards and the constraints on their use and maintenance, these barometers are most frequently used in high-level calibration laboratories.

### 3.6.2.2 Working standard barometer (B)

The working and reference standards, and the travelling standards used to compare barometers, should have high stability over long periods. These standards may be electronic barometers. They should be fully and carefully corrected for all known errors, which should have been established by two or more recent comparisons with barometers of a higher category.

### 3.6.2.3 Travelling standard barometer (C)

A reliable travelling standard barometer must retain its index correction during transit to within 0.1 hPa. It should be standardized with reference to the working or reference standard before and after each tour. Once standardized, it should on no account be opened or adjusted in any fashion until after the final comparison at the station of origin of the tour. A travelling standard barometer needs to be carried in a high-quality, cushioned travelling case to protect it during transit.

### 3.6.2.4 Specifications of portable electronic barometers (Q)

The barometer must have a history of reliability with low drift corrections, as determined by several comparisons with a standard barometer both over a period of one year or more and over the maximum pressure range in which the barometer must be expected to operate.

Electronic barometers with multiple pressure transducers under independent microprocessor control are preferred. The temperature-compensation mechanism for the barometer must be proven to be accurate. The method for taking measurements from the pressure transducer must be contact-free and the barometer itself sufficiently robust to withstand the type of shock that may be encountered during transportation.

## 3.6.3 Barometer comparison

### 3.6.3.1 International barometer comparison

Great importance is attached to international barometer comparisons. The WMO Automatic Digital Barometer Intercomparison was carried out in De Bilt (Netherlands) from 1989 to 1991 (WMO, 1992). Only by such comparisons is it possible to ensure consistency in the national standards of pressure-measuring instruments and thus prevent discontinuities in pressure data across international boundaries.

### 3.6.3.2 National barometer comparison

The recommended procedure for such comparisons is given in section 3.10.4.

The programme of comparisons includes the following:

(a) Comparison of national working standard B with primary or secondary standard barometer A, at least once every two years. If barometers A and B are located at the same centre, no travelling standards are required;

(b) Comparison of reference standard C with national working standard B, at least once every two years by means of travelling standards;

(c) Comparison of station barometer S with reference standard C, at least once every year, by means of travelling standards, or by comparison with the working standard B, every one to two years, depending upon the known characteristics of the barometers being used. It is a matter of policy whether the comparison occurs at the station or at a central calibration facility. In the latter case, travelling standards are not required.

It should be understood that the error of each barometer at the end of any link in a chain of comparison is determined with respect to the primary or secondary standard barometer A, so that the results of corrected barometric pressure readings are on an absolute basis at each stage.

### 3.6.3.3 Inspection of station barometers

For the inspection of station barometers, portable barometers (type N, Q, M) are suitable; however, note section 3.2.7.3. Electronic barometers may also be used as travelling standards, provided that they have the necessary stability and accuracy.

### 3.6.3.4 Checking electronic barometers

It is important to calibrate electronic barometers at intervals of about one year. Extended calibration intervals may be chosen if the drift characteristics has been proven to be within the required measurement uncertainty. It is standard procedure to calibrate an electronic barometer at a calibration facility immediately before its dispatch to a meteorological observation station. At the station, a number of comparison readings of pressure between the electronic barometer and the travelling standard should be taken at different pressures (either over an adequate period of time or using a pressure generator). The readings should be taken with all barometers at the same height, when the wind speed is less than 12 m s‑1and when the pressure is either steady or changing by less than 1 hPa h–1. Any electronic barometer whose mean difference from the travelling standard exceeds 0.25 hPa should be regarded as unserviceable and returned to the calibration facility for recalibration.

If at all possible, it is advisable to install two independent barometers at a meteorological observing station, for intercomparison practices and checks.

## 3.6.4 General procedure recommended for the comparison of barometers at different locations

The comparison of barometers is essential and should be undertaken in the following ways:

(a) If barometer “1” is to be compared with barometer “2”, a qualified person should carry the travelling standard(s), preferably of the P or Q category, from barometer “1” to barometer “2”, and then return to “1”, thus closing the circuit. This procedure is applicable both between and within countries. Barometer “1” is usually at the central laboratory of a national standards organization or at the laboratory of a National Meteorological Service. Barometer “2” is at some other location.;

(b) For standardization purposes, the travelling standards should be placed next to the barometer to be compared and all the instruments given equal exposure for a sufficient long interval before official comparative readings are begun.;

 (c) Comparative readings should not be taken if the standard shows the pressure to be fluctuating rapidly. Preference should be given to barometrically quiet periods (pressure steady or changing only slowly) for making the comparisons;

(d) Comparative readings should be taken at uniform intervals of no less than 15 min in duration;

(e) Experience indicates that at least five comparative readings are required for category S barometers at ordinary stations. At least 10 comparative barometer readings are required for barometers in categories A, B or C for standardization purposes;

(f) If meteorological conditions permit, the comparative readings in the latter cases should be taken at different pressures covering both high and low pressures;

(g) Records should include temperature, the readings of the travelling standards and barometers being compared, the wind speed, direction and gustiness, the corrections for gravity, temperature and instrumental error, the actual elevation above sea level of the zero point of the barometers, and the latitude, longitude, place name and date and time of observations;

(h) With respect to comparisons using travelling standards, barometer “1” must be the highest class of standard barometer available at the point of departure. Barometer “1” should be of category A or B, with category C being the lowest acceptable quality. Two sets of comparisons of the travelling standards are necessary with barometer “1”, at the following points in time:

(i) Before the travelling standards are carried by hand from where barometer “1” is located to the place where barometer “2” is located;

(ii) After the return of the travelling standards to their point of origin, following transit to and from the location of barometer “2”. The “before” and “after” comparisons should be checked against each other. If agreement with barometer “1” is within satisfactory tolerances for each of the instruments involved, it can be assumed that the comparisons between the travelling standards and barometer “2” are also within the required tolerances, provided that due care has been taken during all phases of the comparison process. However, if there is a significant disagreement or if a known mishap has occurred which might have affected the instruments, or if the validity of the comparison data is in question for any reason, the comparison exercise is deemed invalid and the whole process must be repeated;

(i) As far as practical, all discrepancies should finally be expressed with respect to a primary or secondary reading of a category A barometer. This will ensure a common basis for all comparisons. In each case, the report of comparisons should indicate the standard used;

Note: When a programme involving the elimination of residual barometric errors is adopted, there will be a homogeneous system of barometric observational data conforming to a single standard, which will permit the elimination of errors in horizontal pressure gradients from instrumental sources.

(j) Comparisons are necessary both before and after the relocation of barometers at a laboratory or a station to ensure early detection of the development of a defect.

# 3.7 Adjustment of barometer readings to standard and other levels

In order to compare barometer readings taken at stations at different altitudes, it is necessary to reduce them to the same level. Whereas various methods are in use for carrying out this reduction, WMO has recommended a standard method detailed in the next paragraphs.

The recommended method is described in more detail in WMO (1954, 1964,1968). WMO (1966) contains a comprehensive set of formulae that may be used for calculations involving pressure.

## 3.7.1 Standard levels

The observed atmospheric pressure should be reduced to mean sea level (see Part I, Chapter 1) for all stations where this can be done with reasonable accuracy. Where this is not possible, a station should, by regional agreement, report either the geopotential of an agreed “constant pressure level” or the pressure reduced to an agreed datum for the station. The level chosen for each station should be reported to the WMO Secretariat for promulgation (*i.e.* the WMO metadatabase for observing stations, OSCAR/metadata).

## 3.7.2 General reduction formula

Reduction formula for sea-level pressure feasible for stations below 750 m (from WMO, 1964, p. 22, equation 2):

  (3.1)

where p0 is the pressure reduced to sea level in hPa; pS is the station pressure in hPa; Kp is the constant = 0.014 827 5 K/gpm; Hp is the station elevation in gpm; Tmv is the mean virtual temperature of the fictitious air column below station level in K, (Tmv = TS + (a · Hp)/2 + eS · Ch); TS is the station temperature in K; TS = 273.15 +t, t is the station temperature in °C; a is the assumed lapse-rate in the fictitious air column extending from sea level to the level of the station elevation level = 0.006 5 K/gpm; eS is the vapour pressure at the station in hPa; and Ch is the coefficient = 0.12 K/hPa.

The same formula is often used in the exponential form:

  (3.2)

where gn is the standard acceleration of gravity = 9.806 65 m s–2 and R is the gas constant of dry air = 287.05 J/kg/K.

## 3.7.3 Reduction formula for low-level stations

At low-level stations (namely, those at a height of less than 50 m above mean sea level), pressure readings should be reduced to mean sea level by adding to the station pressure a reduction constant C given by the following expression:

  (3.3)

wherep is the observed station pressure in hectopascals; Hp is the station elevation in metres; and Tv is the mean annual normal value of virtual temperature at the station in kelvins.

Note: The virtual temperature of damp air is the temperature at which dry air of the same pressure would have the same density as the damp air. WMO (1966) contains virtual temperature increments of saturated moist air for various pressures and temperatures.

This procedure should be employed only at stations of such low elevation that when the absolute extreme values of virtual temperature are substituted for Tv in the equation, the deviation of the result due to the other approximations of the equation (used for height rather than standard geopotential, and with C to be small compared with p) is negligible in comparison.

# Annex 3.A. metods of Measurement with

As outlined in 3.1.4.5 (Implications of the Minamata Convention for the pressure measurement) the use of mercury barometers is not recommended anymore. The reason tois

This Annex is kept in this Guide for information only.

## A.1 Units and scales

Some barometers are graduated in “millimetres or inches of mercury under standard conditions”, (mm Hg)n and (in Hg)n, respectively. When it is clear from the context that standard conditions are implied, the briefer terms “millimetre of mercury” or “inch of mercury” may be used. Under these standard conditions, a column of mercury having a true scale height of 760 (mm Hg)n exerts a pressure of 1 013.250 hPa.

The following conversion factors will then apply:

 1 hPa = 0.750062 (mm Hg)n

 1 (mm Hg)n = 1.333224 hPa

In the case where the conventional engineering relationship between the inch and the millimetre is assumed, namely 1 in = 25.4 mm, the following conversion factors are obtained:

 1 hPa = 0.029530 (in Hg)n

 1 (in Hg)n = 33.8639 hPa

 1 (mm Hg)n = 0.03937008 (in Hg)n

Scales on mercury barometers for meteorological purposes should be so graduated that they yield true pressure readings directly in standard units when the entire instrument is maintained at a standard temperature of 0 °C and the standard value of gravity is 9.806 65 m s–2.

Barometers may have more than one scale engraved on them, for example, hPa and mm Hg, or hPa and in Hg, provided that the barometer is correctly calibrated, adjusted and compensated for use under standard conditions.

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## A.2.3 Exposure of mercury barometers

The general exposure requirements of mercury barometers have been outlined in the preceding sections. Mercury barometers have additional exposure requirements above those already mentioned. It is always preferable to hang the mercury barometer on an inside wall. For very accurate work, the best position would be in an unheated basement room with no windows and with a small electric fan to prevent any stratification of temperature.

In order to obtain uniform lighting conditions for reading the barometer, it is advisable to use artificial lighting for all observations. For this purpose, some sort of illuminator – which can provide a white and slightly luminous background for the mercury meniscus and, if necessary, for the fiducial point – may be provided. If no illuminator is used, care should be taken to provide the meniscus and the fiducial point with a light background, by such means as pieces of milk glass, white celluloid, or a sheet of white paper. Artificial light should also be provided for reading the barometer scale and the attached thermometer. Care should, however, be taken to guard against heating the barometer with artificial light during a barometer reading.

The barometer should be mounted in a place where it is not subject to vibration, preferably on a solid wall. The instrument must be mounted with the mercury column in a vertical position. Errors due to departure from verticality are more critical for asymmetric barometers. Such barometers should be mounted with their longest axis vertical in order that a true setting of the mercury surface to the fiducial point remains correct even when the instruments are tilted from the vertical.

To protect the barometer from rough handling, dust and air currents, it is recommended that the instrument be placed in a box furnished with a hinged door with provisions for sufficient ventilation to prevent stratification of the air inside.

Great care should be taken when transporting a mercury barometer. The safest method is to carry the barometer upside down in a wooden case furnished with a sling. If the barometer cannot be accompanied by a responsible person, it ought to be transported in a suitable sprung crate with the cistern uppermost. The barometer should not be subject to violent movements and must always be turned over very slowly. Special precautions must be taken for some individual types of barometers before the instrument is turned over.

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Annex 3.B. Correction of MERCURY barometer readings to standard conditions

Correction for index error

The residual errors in the graduation of the scale of a barometer should be determined by comparison with a standard instrument. They may include errors due to inaccurate positioning or subdividing of the scale, capillarity and imperfect vacuum. Certificates of comparison with the standard should state the corrections to be applied for index error at no fewer than four points of the scale, for example, at every 50 hPa. In a good barometer, these corrections should not exceed a few tenths of a hectopascal.

Corrections for gravity

The reading of a mercury barometer at a given pressure and temperature depends upon the value of gravity, which in turn varies with latitude and altitude. Barometers for meteorological applications are calibrated to yield true pressure readings at the standard gravity of 9.806 65 m s–2 and their readings at any other value of gravity must be corrected. The following method is recommended for reducing such barometer readings to standard gravity. Let B be the observed reading of the mercury barometer, Bt the barometer reading reduced to standard temperature but not to standard gravity, and corrected for instrumental errors, Bn be the barometer reading reduced to standard gravity and standard temperature, and corrected for instrumental errors, Bca be the climatological average of Bt at the station, gφH the local acceleration of gravity (in m s–2) at a station at latitude φ and elevation H above sea level, and gn the standard acceleration of gravity, 9.806 65 m s–2.

The following relations are appropriate:

  (3.A.1)

or:

  (3.A.2)

The approximate equation 3.A.3 may be used, provided that the results obtained do not differ by more than 0.1 hPa from the results that would be obtained with the aid of equation 3.A.2:

  (3.A.3)

The local acceleration of gravity gφH should be determined by the procedure outlined in the following section. The values so derived should be referred to as being on the International Gravity Standardization Net 1971 (IGSN71).

Determining local acceleration of gravity

In order to determine the local value of the acceleration of gravity at a station to a satisfactory degree of precision, one of two techniques should be used. These techniques involve, in the first case, the use of a gravimeter (an instrument for measuring the difference between the values of the acceleration of gravity at two points) and, in the second case, the use of the so-called Bouguer anomalies. Preference should be given to the gravimeter method. If neither of these methods can be applied,the local acceleration of gravity may be calculated using a simple model of the Earth.

Use of a gravimeter

Suppose g1 represents the known local acceleration of gravity at a certain point O, usually a gravity base station established by a geodetic organization, where g1 is on the IGSN71, and suppose further that g represents the unknown local acceleration of gravity on the meteorological gravity system at some other point X for which the value g is desired. Let Δg denote the difference in gravity acceleration at the two places, as observed by means of a gravimeter. That is, Δg is the value at point X minus the value at point O on a consistent system. Then, g is given by equation 3.A.4:

  (3.A.4)

Use of Bouguer anomalies

If a gravimeter is not available, interpolated Bouguer anomalies (AB) may be used to obtain g at a given point. It is necessary that a contour chart of these anomalies be available from a geodetic organization or from a network of gravity stations spaced at a density of at least one station per 10 000 km2 (no more than a 100 km distance between stations) in the vicinity of the point.

Gravity networks of somewhat less density can be used as a basis provided that a geodetic organization considers that this method is expected to yield more reliable results than those that could be obtained by using a gravimeter.

The definition of the Bouguer anomaly (AB) is derivable from equation 3.A.5:

  (3.A.5)

where (gφ,0)s is the theoretical value of the acceleration of gravity at latitude φ at sea level, as given by the formula actually used in computing the Bouguer anomaly. This formula expresses the value as a function of latitude in some systems. H is the elevation of the station (in metres) above sea level at which gs is measured, gs is the observed value of the acceleration of gravity (inm s–2); AB is the Bouguer anomaly (in m s–2); and C is the elevation correction factor used in computing the Bouguer anomaly (for example, using a crustal specific gravity of 2.67, this factor is 0.000 001 968 m s–2).

When g is desired for a given station and has not been measured, the value of gs should be computed by means of equation 3.A.5, provided that the appropriate value of AB for the locality of the station can be interpolated from the aforementioned contour charts or from data representing the Bouguer anomalies supplied by a suitable network of gravity stations, as defined.

Calculating local acceleration of gravity

If neither of the preceding methods can be applied, the local value may be calculated less accurately according to a simple model. According to the Geodetic Reference System 1980, the theoretical value (gφ,0) of the acceleration of gravity at mean sea level at geographic latitude, φ, is computed by means of equation 3.A.6:

  (3.A.6)

The local value of the acceleration of gravity at a given point on the surface of the ground at a land station is computed by means of equation 3.A.7:

  (3.A.7)

where g is the calculated local value of the acceleration of gravity, in m s–2, at a given point; gφ,0 is the theoretical value of the acceleration of gravity in m s–2 at mean sea level at geographic latitude φ, computed according to equation 3.A.6 above; H is the actual elevation of the given point, in metres above mean sea level; and H’ is the absolute value in metres of the difference between the height of the given point and the mean height of the actual surface of the terrain included within a circle whose radius is about 150 km, centred at the given point.

The local value of the acceleration of gravity at a given point within height H above mean sea level of not more than about 10 km, and where that point lies over the sea water surface, is computed by means of equation 3.A.8:

  (3.A.8)

where D is the depth of water in metres below the given point; and D’ is the mean depth of water, in metres, included within a circle whose radius is about 150 km centred at the given point.

At stations or points on or near the coast, the local value of acceleration of gravity should be calculated, so far as practicable, through the use of equations 3.A.7 and 3.A.8 on a pro rata basis, weighting the last term of equation 3.A.7 according to the relative area of land included within the specified circle, and weighting the last term of equation 3.A.8 according to the relative area of the sea included within the circle. The values thus obtained are then combined algebraically to obtain a correction which is applied to the final term in the right-hand side of both equations, as shown in equation 3.A.9:

  (3.A.9)

where αis the fraction of land area in the specified area, and H’ and D’ refer to the actual land and water areas, respectively.

Corrections for temperature

Barometer readings must be corrected to the values that would have been obtained if the mercury and the scale had been at their standard temperatures. The standard temperature for mercury barometers is 0 °C. With reference to scales, some barometers have scales which read accurately at this same temperature, but some read accurately at 20 °C.

The temperature correction necessary for adjustable cistern barometers (Fortin-type barometers) is different from that required for fixed-cistern barometers, though the principle reasons leading to the necessity for temperature corrections are the same for both types, namely, the fact that the coefficient of cubic thermal expansion of mercury is different from the coefficient of linear thermal expansion of the scale. Thus, a certain correction term is required for both types of mercury barometer.

A fixed-cistern barometer requires an additional correction. The reason for this is that an increase in temperature of the instrument causes an increase both in the volume of the mercury and in the cross-sectional areas of the (iron) cistern and the (glass) tube. Owing to these area changes, the apparent rise of the mercury resulting from a temperature increase is less than would be the case if the areas remained constant. This is because some of the mercury from the barometer goes to occupy the capacity increment produced by the expansion of the cistern and tube.

The scale of a fixed-cistern barometer must, for a variety of reasons, undergo a calibration check against a primary standard barometer of the adjustable-cistern type. Some manufacturers decrease the volume of mercury by such an amount that the readings of the test barometer agree with the readings of the standard barometer at 20 °C. Correction tables can be generated for fixed-cistern barometers using the readings from a primary standard barometer whose scales are accurate when 20 °C is used as the reference temperature.

Temperature corrections for mercury barometers

Researchers have conducted exhaustive studies for temperature corrections for mercury barometers, the results of which are summarized below:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 1. | (a) Scale correct at 0 °C and additionally(b) Hg volume correct at 0 °C | CtCt,V | == | –B (α – β) · t–B (α – β) · t – (α – 3η) · t ·4V/3A |
| 2. | Scale correct at 0 °C andHg volume correct at 20 °C | Ct,V | = | –B (α – β) · t – (α – 3η) · (t – 20) · 4V/3A |
| 3. | (a) Scale correct at 20 °C(b) Hg volume correct at 0 °C(c) Hg volume decreasing by an amount equivalent to 0.36 hPa | CtCt,VCt,V | === | –B [α · t – β · (t – 20)]–B [α · t – β · (t – 20)] – (α – 3η) · t · (4V/3A)–B (α – β) · t – (α – 3η) · t · (4V/3A) |
| 4. | Scale correct at 20 °C and(a) Hg volume correct at 20 °C(b) Hg volume decreasing by an amount equivalent to 0.36 hPa | Ct,VCt,V | == | –B [α · t – β (t – 20)] – (α – 3η) · (t – 20) · (4V/3A)–B (α – β) ·t – (α – 3η) · (t – 20) · (4V/3A) |

where:

Ct = temperature correction;

Ct,V = additional correction for fixed-cistern barometers;

B = observed barometer reading;

V = total volume of mercury in the fixed-cistern barometer;

A = effective cross-sectional area of the cistern;

t = temperature;

α = cubic thermal expansion of mercury;

β = coefficient of linear thermal expansion of the scale;

η = coefficient of linear thermal expansion of the cistern.

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