



AIR MINISTRY

METEOROLOGICAL OFFICE

PROFESSIONAL NOTES No. 48.

*(Eighth Number of Volume IV.)*

# THE FALLING TIME OF MARINE BAROMETERS

HISTORICAL NOTE  
AND SOME RECENT OBSERVATIONS

BY

E. GOLD, F.R.S.



Published by the Authority of the Meteorological Committee.



LONDON:

PRINTED AND PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE

To be purchased directly from H.M. STATIONERY OFFICE at the following addresses:

Adnastral House, Kingsway, London, W.C.2; 120, George Street, Edinburgh;

York Street, Manchester; 1, St. Andrew's Crescent, Cardiff;

15, Donegall Square West, Belfast;

or through any Bookseller.

1928.

Price 3d. Net.

## THE FALLING TIME OF MARINE BAROMETERS

### HISTORICAL NOTE AND SOME RECENT OBSERVATIONS

BY E. GOLD, F.R.S.

In 1854 the Kew Committee of the British Association, in consequence of a request from Lieutenant Maury for their advice upon the best form of marine barometer, arranged for tests to be made at sea of barometers with constricted tubes. The tests were made by Mr. J. Welsh of Kew Observatory, who was accompanied by Mr. Adie, the maker of the barometers.

The first tests were made on a voyage in March, 1854, from London to Leith and back. There is no information about the falling time of the barometers estimated according to modern usage; the standard taken at that time was the "time required for the mercury to sink from the top of the tube to its true height after the barometer is placed erect";\* this is not a very definite quantity because it is theoretically infinite for a steady pressure: this time will be referred to as "Welsh" falling time.

The barometers in the first experiment had "Welsh" falling times of 5, 10 and 15 minutes respectively and in later experiments in May, 1854, between Southampton and the Channel Islands barometers with "Welsh" falling times of 5, 10, 18, 21 and 35 minutes were used.

In the first experiments the barometer with a "Welsh" falling time of 5 minutes showed pumping amounting to  $\cdot 064$  in. ( $2\cdot 2$  mb.)† in the mean of ten observations, the greatest amount being  $0\cdot 13$  in. ( $4\cdot 4$  mb.). The barometer with a "Welsh" falling time of 10 minutes showed a mean pumping of  $\cdot 031$  in. (1 mb.) with a maximum of  $\cdot 05$  in. ( $1\cdot 7$  mb.).

In the experiments in the Channel pumping in the barometers with the "Welsh" falling times of 5 and 10 minutes was so great that good observations could not be taken but the barometers with "Welsh" falling times of 18 and 21 minutes showed only slight pumping, the greatest range of pumping being  $\cdot 02$  in. ( $0\cdot 7$  mb.) The barometer with a "Welsh" falling time of 35 minutes showed a range of only  $\cdot 01$  in. ( $0\cdot 3$  mb.).

As a result of these experiments Mr. Welsh recommended that a falling time of 18 to 25 minutes should be adopted as the standard to determine the degree of contraction in the tubes of marine barometers, and this standard was adopted.

In December, 1868, on the recommendation of the Kew Committee, the Meteorological Committee decided to adopt as falling time the time required by the mercury to fall from  $1\frac{1}{2}$  in. ( $50\cdot 8$  mb.) to  $\frac{1}{2}$  in. ( $16\cdot 9$  mb.) above the true height: and

---

\* *Report of Kew Committee*, 1853-54, p. 6.

† in. = inch of mercury; mb. = millibar; 1 in. =  $33\cdot 8632$  mb.

to take 3 to 6 minutes as the limits within which the falling time so defined must lie. This falling time will be called the K.C. falling time.

In 1927 it was decided provisionally to adopt as falling time the time required for the mercury to fall from 50 mb. to 18 mb. above the true height: this makes the falling time very closely the same as the "lagging" time,\* the time required by the mercury to fall from a height  $h$  to a height  $h/e$  above the true height: this will be called the "L" falling time: and limits of 4-5 minutes were selected as those between which the "L" falling time must lie.

It is not possible to say precisely what would be the relation between the "Welsh" falling time and the falling time as defined in 1927, but it appears that Welsh's limits of 18 to 25 minutes were not very different from the limits of 4 to 5 minutes for a fall from 50 millibars to 18 millibars above the true height.

The next reference to the problem which had been considered by the Kew Committee in 1854, comes in 1879, when Sir Francis (then Mr.) Galton drew attention to the fact that owing to the swinging of the barometer the mean position is inclined to the vertical and the apparent reading in an instrument where pumping is prevented by a contraction of the tube will be equal to the true reading multiplied into the secant of the mean inclination.

This note of Sir F. Galton's was considered at a meeting of the Meteorological Committee when Professor (afterwards Sir George) Stokes observed that the effect to which Sir F. Galton drew attention was associated with another effect, namely the depression of the mercury due to centrifugal force arising from the actual swinging of the barometer. Sir G. Stokes pointed out that the correction arising from the two causes is equal to:†

$$\frac{1}{4} H \alpha^2 \left\{ \frac{1 - 4\pi^2 (h_1 - h_2)}{gT^2} \right\}$$

where  $\alpha$  is the inclination of the barometer to the vertical at the extremity of its swing which is supposed small;  $H$  is the barometric height,  $h_1$  is the distance of the surface of the mercury in the *cistern* below the axis about which the barometer swings;  $h_2$  is the height of the surface of the mercury in the *tube* above the axis;  $g$  is the value of gravity, and  $T$  is the time of an oscillation of the barometer. Sir G. Stokes went on to point out that by a suitable selection of  $h_1$  and  $h_2$ , the two terms inside the bracket could be made to neutralize each other so that the correction would become zero.

Thus all that is necessary to get rid of the effect of swinging is to adjust the position of the gimbals on which the barometer

\*See p. 4..

† There is a misprint in the formula in Stokes' note,  $\pi$  having been printed for  $\pi^2$ . It is clear from the numerical example given by Stokes that he had used  $\pi^2$ .

swings. Compensation cannot be effected *accurately* for all heights of the barometer: a change in the height affects not only  $h_1$  and  $h_2$  but also  $T$ . Moreover M. A. Giblett in the investigation mentioned below showed that if  $h_1$ ,  $h_2$ ,  $T$  were selected to give compensation for the natural free period of oscillation of the barometer, compensation would not be effected for forced oscillations whose period differed from the period of free oscillation.

At the same time (in 1879) Sir G. Stokes presented another memorandum to the Meteorological Committee on the effect of sluggishness on the readings of marine barometers. In this memorandum he pointed out that if the barometer is changing at the time of observation the reading taken will correspond with the true height of the barometer at a time  $T$  minutes earlier where  $T$  is the falling time as now defined, i.e. the lagging time or time for the barometer to fall from a height  $h$  above its true height to a height  $h/e$  above its true height where  $e=2.718$ .

As a consequence of this memorandum it was suggested to the Kew Committee that a statement of the falling time should be included in the certificate of a marine barometer.

The note of Sir G. Stokes on the compensation between the effects of centrifugal force and inclination of the barometer is interesting because 42 years later, in 1921, Duffield and Littlewood\* arrived independently at the same conclusion.

After Sir G. Stokes' notes in 1879 no further consideration appears to have been paid to the theory of the marine barometer until 1908, when I was led to consider it as a consequence of the examination of barometer readings on ships in the Channel in comparison with the corresponding readings at the land stations of Falmouth and Brest. At that time I became acquainted with Sir G. Stokes' memorandum on the sluggishness of barometers, which had been reprinted in the *Annual Report of the Meteorological Committee*, but not with his letter on the points raised by Sir Francis Galton. In my investigation I found that in a swinging barometer the mercury would oscillate about a mean level, differing from the true height of the barometer, and with a range of oscillation depending on the constriction of the tube. I found that the pumping of the barometer, which probably arises from the changes in vertical acceleration as the ship passes over a series of long waves, might amount, with barometers of the pattern then in use (with K.C. falling times of between 3 and 6 minutes) to as much as .02 in. (0.7 mb.).

The next investigation, that by Duffield and Littlewood referred to above, arose as a result of some work on the variation of gravity at sea, which had been undertaken by Professor Duffield. A further investigation was undertaken by M. A. Giblett in 1923† as a result of his observations of the effect of the rolling of a ship upon the reading of the barometer. He found from a comparison of the readings of a mercury and an aneroid barometer on a ship in the North Sea that on an average the mercury barometer read

\* *Phil. Mag.*, July, 1921. p. 166.

† *Phil. Mag.*, October, 1923. p. 707.

lower than the aneroid when allowance was made for the index error of the latter instrument. He attributed this depression of the mercury to the effect of the rolling of the ship which would produce a depression without producing appreciable pumping.

No observations appear to have been made since those which Welsh made in 1854, upon the actual range of oscillation of marine barometers when they are pumping. An opportunity occurred recently (in May, 1927) to obtain a few comparative readings of barometers with different falling times on the Fishing Cruiser *Norna*, a vessel about 150 feet long. The observations were made through the courtesy of the Fishery Board for Scotland to whom the *Norna* belongs and of the Captain of the *Norna*, Captain J. Wright.

The barometers were numbered 68, 2223 and 327. They were set up in the *Norna* on the evening of May 21st, 1927, near the entrance to the aft cabin; No. 68 on the fore-aft bulkhead (starboard side) and Nos. 2223 and 327 on the cross bulkhead.

The L. and K.C. falling times of the three barometers were as follows:—

No. 68 :	50 mb. to 18 mb.	53 seconds.
	1½ inches to ½ inch.	56 seconds.
No. 2223 :	50 mb. to 18 mb.	4 minutes 40 seconds.
	1½ inches to ½ inch.	5 minutes approximately.
No. 327 :	50 mb. to 18 mb.	15 minutes 45 seconds.
	1½ inches to ½ inch.	16 minutes 28 seconds.

On May 23rd at 4.15 p.m. with the ship at anchor off Scarinish with a moderate WSW. wind and moderate sea the ranges of oscillation of the three barometers were 2.0 mb., 0.8 mb., and 0.5 mb. respectively. The period of oscillation of the barometers was about 6 seconds which was also approximately the period of the waves, as I observed a gull on the water pass 5 wave crests in about 30 seconds. I had no further opportunity of making observations until May 26th, but one of the ship's officers informed me that he had observed, during a period of roughish water in the Minch, barometer No. 68 pumping about 5 mb. and barometer 327 pumping about 2 mb.

On May 26th between Stornoway and Cape Wrath, with a light northerly wind and a swell from the ENE., the following observations were taken:—

No. 68.		No. 2223.		No. 327.	
Mean Height.	Range.	Mean Height.	Range.	Mean Height.	Range.
mb.	mb.	mb.	mb.	mb.	mb.
22.6	5.1	21.3	2.3	21.1	0.6
24.9	3.9	25.4	1.4	25.2	0.5
25.0	4.1	25.4	1.5	25.0	0.4

and on May 27th near Rattray Head with a N. wind and rather rough sea and the ship mainly rolling the following observations were taken:—

No. 68.		No. 2223.		No. 327.	
Mean Height.	Range.	Mean Height.	Range.	Mean Height.	Range.
mb.	mb.	mb.	mb.	mb.	mb.
18.5	2.8	18.7	0.7	18.2	0.5
18.5	2.5	18.6	0.6	18.4	0.2

I am unable to explain the difference between the mean values of the readings from the three barometers at the different times. They do not appear altogether consistent. I took some readings on May 28th in Leith Roads and the mean values from the three barometers agreed to within  $\cdot 1$  mb.

When a barometer is "pumping" the period of oscillation of the mercury is usually small compared with the  $L$  falling time: it is generally of the order of a few seconds while the  $L$  falling time is several minutes. In such a case the range of pumping ought theoretically to be inversely proportional to the  $L$  falling time. Thus in the case of these three barometers, the range of pumping of No. 327 ought to be about  $1/18$ th and that of No. 2223 about  $1/5$ th of the range of No. 68. Actually the mean values of the ranges are:—

No. 68.	No. 2223.	No. 327.
3.7	1.3	0.4

If the value for No. 68 is taken as correct then the theoretical ranges for No. 2223 and No. 327 should be  $0.7$  and  $0.2$ . These are of the right order of magnitude but are both only about one half the actual values. The actual value for No. 327 is about one third that for No. 2223 as it should be theoretically.

Possibly the explanation of the apparent discrepancy is to be found in the superposition of a variation of much longer period on the variation responsible for the pumping in a period of about 6 seconds. A variation with a period of the order of 5 minutes would produce a range of oscillation inversely proportional to the falling time in the case of barometers 327 and 2223. But in the case of barometer No. 68 (or of any barometer with a smaller falling time than No. 68) the long period variation would be practically constant, and independent of the falling time. It would in fact be determined solely by the length of the period of oscillation and not by a combination of this period and the falling time. [If  $L$  is the falling time and  $T$  the period of oscillation, then the range of oscillation of mercury is proportional to  $1/LT$  so long as  $L$  is large compared with  $T$ . If  $T$  becomes large compared with  $L$ , the range becomes proportional to  $1/T^2$  and the effect of  $L$  disappears.]

It would be desirable to test this point in the event of any further observations being made; to do this it would be necessary to observe the interval between *extreme* limits of pumping. This is different from the period of oscillation of the mercury because individual oscillations do not have the same amplitude.

It appears to me from the results of my brief observations on these three barometers that an instrument with a falling time as small as that of No. 68 would be definitely useless for observations at sea. A barometer with an  $L$  falling time as small as that of No. 2223, namely 4 minutes 40 seconds, can be read with reasonable accuracy but the range of oscillation is larger than is desirable. There was no difficulty in reading barometer No. 327 but in view of the difficulties of construction of a barometer with so large an

$L$  falling time and the fact that the tube has to be of so small a diameter that any impurity in the mercury might appreciably affect the freedom with which it passes through the capillary tube, it does not seem desirable to have a falling time so large as that of 327. The best value for the  $L$  falling time (from 50 mb. to 18 mb.) having regard to the construction of the instrument and the necessity for reducing the pumping as much as possible, seems to be about 10 minutes. This has the further advantage that the time to which the reading of the barometer refers does not differ by more than 10 minutes from the actual time of reading :\* and 10 minutes is the interval adopted by the Conference at Utrecht in 1923 as the period within which synoptic observations should be completed.

---

\* If the barometer is changing at a regular rate, the reading at any time corresponds with the actual height of the barometer  $T$  minutes previously.

