SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 3741.*)

"Diurnal Atmospheric Variation in the Tropics, and Surveying with the Aneroid."

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THE regularity of the changes in atmospheric pressure in tropical countries makes it possible to use the aneroid barometer, without a separate recording barometer, as an instrument of precision. It is therefore of much greater value in the tropics than in the temperate zones: on the other hand, diurnal variation in tropical countries is much more pronounced, and a knowledge of this phenomenon is essential to accurate work.

Although it is fully described in meteorological works, diurnal variation in the tropics, as far as is known to the Author, is not dealt with in works on surveying. The phenomenon has been much discussed, but its causes are not known. It exists in all countries, and consists of a so-called "12-hour wave," i.e., two distinct undulations every 24 hours, the night wave reaching its maximum and minimum about 10 P.M. and 4 A.M. respectively, whilst the maximum and minimum of the day wave occur about 9 A.M. and 3.30 P.M. respectively.

In England, the ranges of the night and day waves average about 0·3 and 0·6 millimetre: they are, however, practically undistinguishable during any one day's observation. Only by the harmonic analysis of a whole year's observations can the curves be traced. The reason for this obscuration of the diurnal variation lies in the extreme irregularity of atmospheric pressure arising from cyclonic and anti-cyclonic conditions which greatly exceed the regular daily variation.

The aneroid may be successfully employed for surveying purposes in the temperate zones, if a self-registering barometer is kept at the base-station of the survey and the readings in the field are booked, together with the time of reading. Self-recording barometers, both on the aneroid and mercury principle, are made for measuring altitudes up to 16,000 feet, and are not more expensive than a good plain surveyor's aneroid. The recording instrument and the working aneroid should be standardized together at Kew, and the respective index errors tabulated. Without the assistance of a recording instrument, the aneroid is of limited use in the temperate zones, and even with its help accurate results are more difficult and tedious to obtain than in the tropics.

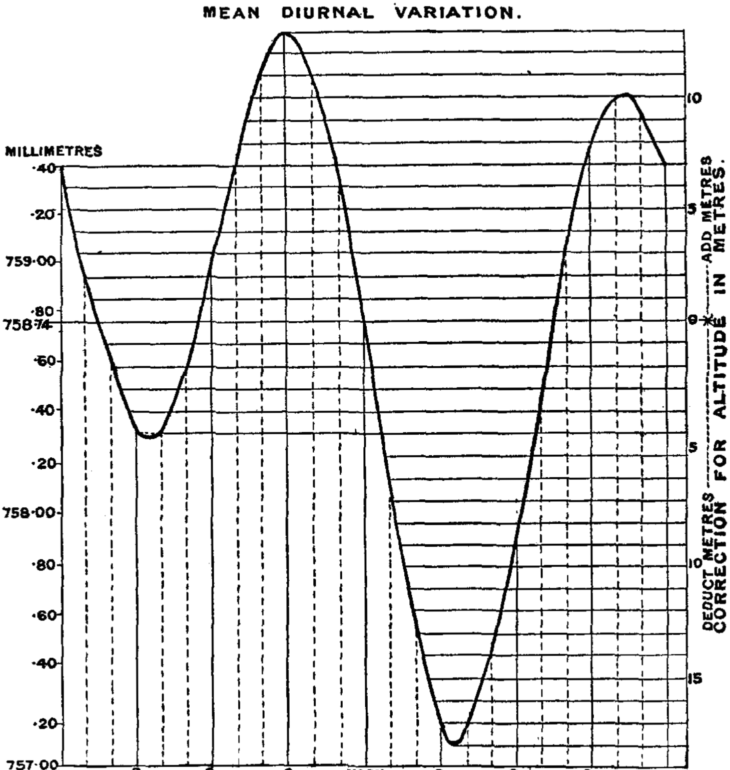
Within the tropical zone, the irregular movements of the barometer are comparatively slight. Between 10° north and south of the equator cyclones are almost unknown. Strong winds and violent rains produce extremely small effects upon the barometer. There is a gradual rise in the mean height during the dry monsoon, and a corresponding fall during the wet monsoon, but the movement is slow and the variation small.

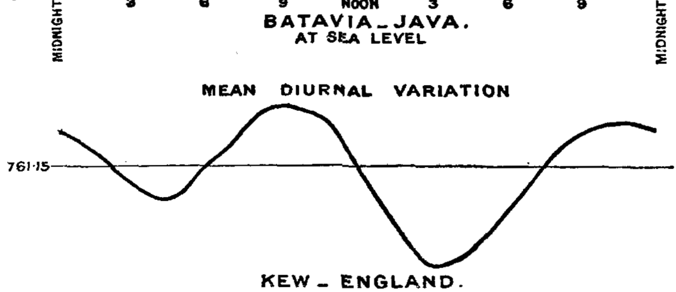
In Java, which is about 7° south of the equator, the "12-hour waves" have an average range at sea-level of 1·34 millimetre at night and 2·87 millimetres during the day, or about 4½ times that of England. Batavia, the capital of Java, possesses a meteorological station of the first rank and of high reputation. The records are published in English and are supplied to the Meteorological Office at Westminster. Hourly readings have been taken at Batavia for 40 years. The following Table gives the mean of 35 years of hourly

Month.	Mean Height of Barometer.	Range of Variation.	
		Night Wave.	Day Wave.
	Millimetres.	Millimetre.	Millimetres.
January	758·70	1·52	2·77
February	758·75	1·52	2·82
March	758·65	1·38	2·92
April	758·27	1·36	2·92
May	758·34	1·34	2·77
June	758·70	1·21	2·62
July	759·01	1·10	2·74
August	759·12	1·19	2·98
September	759·29	1·18	3·16
October	758·82	1·34	3·07
November	758·62	1·45	2·91
December	758·51	1·50	2·76

readings at Batavia, and in *Figs. 1* these are represented graphically and compared with the mean of the readings at Kew during 1905. *Figs.* 2, drawn to a smaller scale, show the mean of the hourly readings during the month of February, 1905, at Batavia and at Kew. When only the hourly readings of a single day are taken, the "12-hour waves" at Kew are undistinguishable, but those at Batavia are usually almost as regular as the monthly mean. The mean height of the barometer varies in England about fifteen times as much as in Java.

Figs. 1.

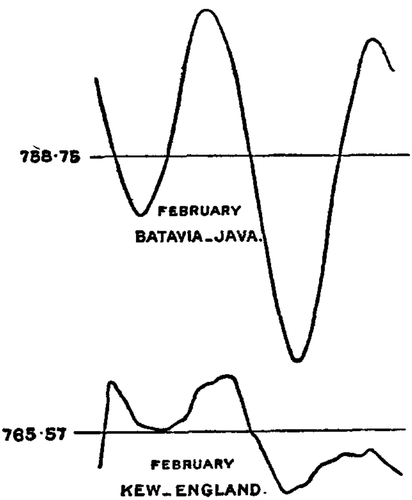




Diurnal variation is also affected by altitude above sea-level. In the temperate zones, it varies both in range and phase; in the tropics only in range. In all cases the range decreases with the altitude

Figs. 3 and *4* show curves made in Java by the Author from hourly readings taken at 416 metres and 730 metres above sea-level. The range decreased in approximate proportion to the altitude. If this decrease be maintained in equal proportion, the waves would cease at an elevation of about 2,500 metres. In Madras, however, in

Figs. 2.



latitude about 13° north, where the diurnal variation at sea-level is approximately the same as at Java, the wave at 2,700 metres above sea-level was found to be only one-half that at sea-level, indicating that in that region the waves continue at an elevation of more than 5,000 metres.[1]

[1] The following record of the above observation is extracted from a standard and recent work by Dr. Julius Hann, "Lehrbuch der Meteorologie," Leipzig, 1906.

MADRAS 13° 4′ N, 77° 9′ E, 7 METRES ABOVE SEA.

Heights in millimetres above or below the mean height.

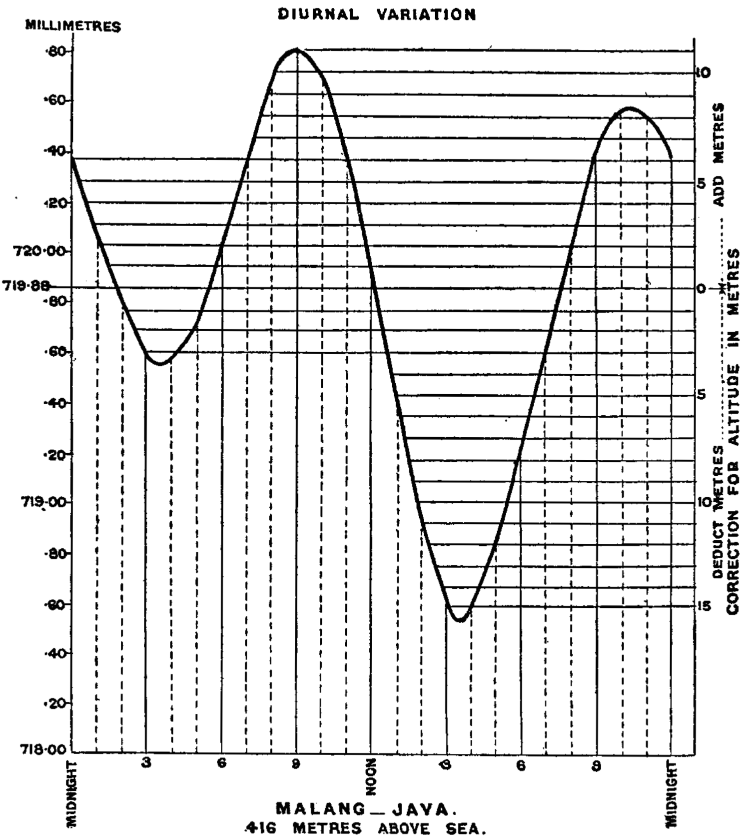
M.N.	2	4	6	8	10	N.	2	4	6	8	10	M.N.
0·45	−0·29	−0·57	−0·02	1·15	1·49	0·57	−0·82	−1·56	−1·13	−0·04	0·73	0·75

DODABETTA PEAK 11° 24′ N, 76° 8′ E, 2,631 METRES ABOVE SEA.

M.N.	2	4	6	8	10	N.	2	4	6	8	10	M.N.
0·12	−0·55	−0·82	−0·34	0·52	1·02	0·55	−0·29	−0·62	−0·34	−0·22	0·54	0·48

In consequence of the fact that in the tropics the phase is unchanged at different altitudes, it is a simple matter to construct a curve of local diurnal variation at any altitude. The upper curve in *Figs. 1* may serve as a standard curve for the tropics. The range of local variation can be found anywhere by observations of the night wave at 10 P.M. and 4 A.M., or of the day wave at 9 A.M. and

Fig. 3.

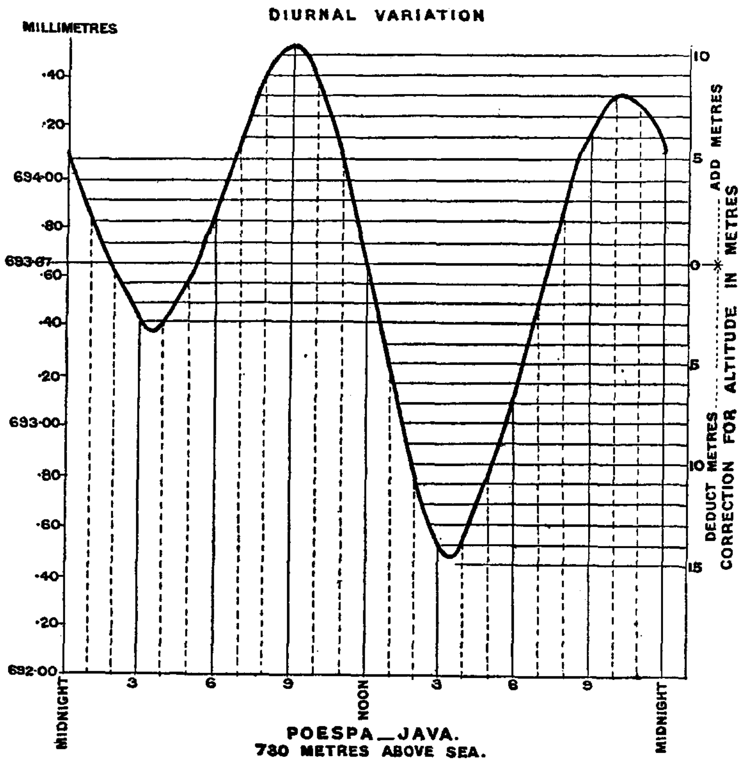


3.30 P.M. It is more satisfactory to take hourly readings and to plot the complete curve, but if it be necessary to commence work on arriving at the station, the curve can be drawn with sufficient accuracy for use and afterwards corrected. The range being determined, the local curve can be constructed from the standard curve, by using proportional compasses or by means of the slide-rule.

The scale of corrections for altitude must, of course, be drawn in each case independently, because the value in decimals of a millimetre of pressure for each metre of altitude varies with the altitude. The altitude scale most generally used by English instrument-makers is that of Sir George Airy, which is shown in the Table on p. 326.

Taking as an example the curve shown in *Fig. 3* at Malang in Java, where the mean height is 719·88 metres, the Table gives a

Fig. 4.



value for 1 metre of altitude in terms of atmospheric pressure of 0·087 millimetre. The diurnal wave range was found to be 2·27 millimetres, therefore the total range was equivalent to 26 metres, from which value the altitude scale was easily constructed.

As will be seen from *Figs. 1*, the range of the day wave in the tropics at sea-level is equivalent to over 100 feet of altitude. During some parts of the day, the change in a quarter of an hour is

Height.	Barometer.	Height.	Barometer.	Value of 1 Metre in Terms of Atmospheric Pressure.
Feet.	Inches.	Metres.	Millimetres.	Millimetre.
0	31·000	0	787·393	0·09433
250	30·717	76·20	780·205	0·09367
500	30·436	152·40	773·068	0·09233
750	30·159	228·60	766·032	0·09200
1,000	29·883	304·80	759·022	0·09050
1,500	29·340	457·20	745·229	0·08883
2,000	28·807	609·59	731·691	0·08733
2,500	28·283	761·99	718·382	0·08567
3,000	27·769	914·39	705·326	0·08333
4,000	26·769	1,219·19	679·927	0·08042
5,000	25·804	1,523·99	655·416	0·07742
6,000	24·875	1,828·78	631·819	0·07467
7,000	23·979	2,133·58	609·061	0·07117
8,000	23·125	2,438·38	587·370	0·07025
9,000	22·282	2,743·17	565·958	0·06692
10,000	21·479	3,047·97	545·562	

equivalent to a difference in altitude of 5 feet, and at such times, it is literally possible to tell the time of day by the height of the barometer.

In most of the tropical countries visited by British surveyors, there are meteorological stations whose records are open to inspection at the Meteorological Office in Westminster, where much other useful information and advice can be obtained by the engineer having to undertake surveying work abroad.

The Author, in conjunction with two other engineers, carried out some surveys for the utilization of water-powers in Java, during the months of June, July and August, 1907, and a brief description of the methods adopted may possibly be of service to others. The physical conditions were such that to have used an ordinary levelling instrument would have been almost impossible, and even with a tacheometer and stadia rod the work would have been difficult and slow. The survey embraced points at a difference of elevation of 1,200 feet, the highest point being 2,500 feet above the sea. In some places the ravine consisted of a succession of waterfalls, sometimes over 100 feet in height, and its sides were very precipitous, reaching at places a depth of 500 feet. The torrent bed at many places was formed by a mass of enormous boulders, pointing to the existence in former times of far greater hydrodynamic forces than are now apparent.

The self-imposed limit of accuracy in the survey was 5 per cent., the object being to ascertain the available power obtainable from the stream, and the site best suited for the hydraulic installation. It is probable that the accuracy obtained did not exceed an error of 1 per cent. The procedure with the aneroid was fivefold:—

A. *The determination of the mean height of the barometer, and the characteristics of diurnal variation at sea-level.*—This was done by taking hourly readings during the week at the nearest point available.

B. *The determination of the elevation above sea-level of the principal station at the highest point of the survey.*—This was ascertained by reading the aneroid before starting, applying the correction for time, and also the difference between the day's mean height and the average mean height of the week's hourly readings. On reaching the upper station, the correction for time was applied, and hourly readings were taken to ascertain the characteristics of the diurnal variation at that point. As it was not of much importance to obtain with great exactness the absolute elevation of the upper station above the sea, the result given by the procedure described was considered accurate enough for the purpose. If greater exactness had been required, the operation could have been repeated.

C. *The determination of the difference of elevation between the upper and lower limits of the survey.*—As a matter of fact, the lower limit was passed on the way to the upper station and recorded. As it was essential, however, to determine this difference of elevation with the greatest possible accuracy, a succession of readings was taken, the aneroid being rapidly carried on horseback to and fro between the upper station and the lowest point of the survey.

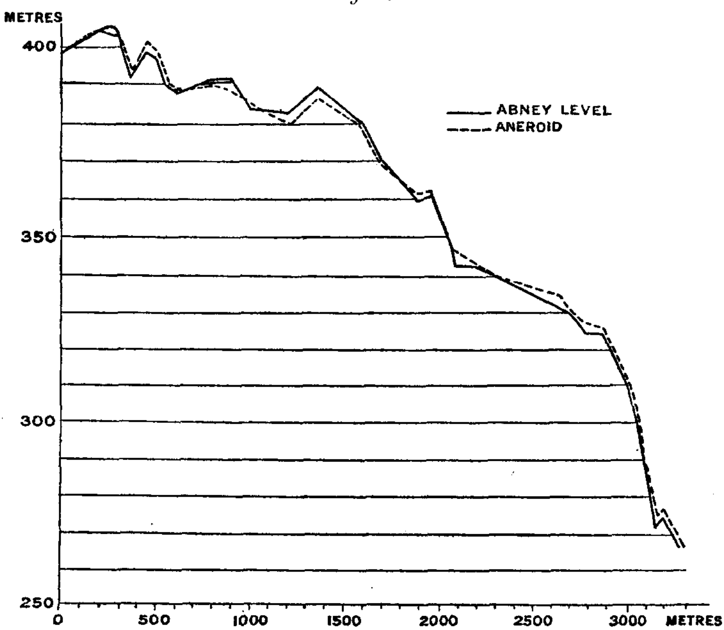
D. *The determination of the elevation of certain intermediate fiducial points along the line of survey.*—This was done in order to diminish the number of journeys to the river-bed: the elevation was obtained in each case by taking repeated readings.

E. *The determination of the actual longitudinal profile of the line of survey.*—The profile was obtained by reading the aneroid at the ends of each measured base, correcting for time, and checking by reference to the fiducial points as stated under D.

Contoured maps were available, made from Government surveys, which furnished useful checks and supplied the topography of the surrounding country, but they were of no use for the river-bed itself.

The aneroid work was supplemented and checked by the Abney reflecting hand-level. One engineer went in advance, measuring the bases, for which purpose a line of thin rattan was found best,

Fig. 5.



PROFILE OF TOENTANG VALLEY – JAVA

odd distances being taped. At the waterfalls, a special rattan line was dropped from the top of the fall, and so carried by the current to the last station at the bottom of the fall, where the end was cut off and the remainder measured. The second engineer carried a prismatic compass for taking the alignment, which was done by backsight and foresight. He carried also an Abney reflecting-level, for measuring the vertical angle of the base, and was accompanied by two rod-men, having bamboo rods provided with disks, placed at the height of the observer's eye. This operation was also done by backsight and foresight. The side-slopes of the sides of the ravine were taken by this engineer. The third engineer carried the aneroid, and also made the sketches.

Fig. 5 shows the profile of one of the surveys. The plan, plotted by means of "latitude and departure," needs no explanation; the profile, however, will serve to show the respective functions of the aneroid and the Abney reflecting level. The full line gives the results arrived at by the Abney level, and the dotted line indicates those obtained by the aneroid.

The final difference of 2 metres between the two instruments was checked by repetitions of the readings at various stations on the way homeward. In each case the aneroid, when corrected for time, read 2 metres higher than when used on the survey. It was therefore assumed that the final difference represented a uniformly increasing error due to irregular variation, and it was so treated.

The intermediate difference between the results of the two instruments was due to tardy or irregular action of the aneroid, mainly arising from the rapidity of the survey. Even the best aneroid procurable is defective in registering any great multiplication of movement, such as occurs between the metallic vacuum and the index hand, and is, therefore, prone not only to tardiness in its response to fluctuations of atmospheric pressure, but also to other irregularities. The hand-level, on the other hand, requires some skill in its use, and is always liable to cumulative error. By always taking backsight and foresight and the mean of the two readings, both index error and personal error are to a great extent eliminated in the Abney level, but in general it may be said that the final result is more correctly given by the aneroid, and the intermediate differences by the hand-level.

The whole survey, of which *Fig, 5* is the profile, was completed in a day. It included alignment by means of the prismatic compass; side-slopes for determining the contours, together with sketches of the intervening features; and photographs of the falls. The work illustrated on the sketch was only about one-tenth of the total amount of survey completed in the manner described, but in every case the agreement between the aneroid and the hand-level was found to be as close as in the profile illustrated.

The Paper is accompanied by five tracings, from which the Figures in the text have been prepared.