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AIR MINISTRY

METEOROLOGICAL OFFICE

Scientific Paper No. 4

Pressure Variation over Malaya and the Resonance Theory

by R. FROST, B.A.

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Pressure Variation over Malaya and the Resonance Theory

by R. Frost, B.A.

SUMMARY

An analysis of the hourly observations from six Malayan stations near the equator shows the following features of the semi-diurnal variation of pressure:

(i) The amplitude of the second harmonic is greater near the thermal than the geographical equator.

(ii) The amplitude is greatest when the sun is overhead in March and September, and is greater in January when the sun is nearest to the earth than in July when the sun is farthest away from the earth.

(iii) The mean monthly values of the amplitude show a close relationship with the monthly totals of solar radiation at the equator.

(iv) The mean value of the phase angle of the second harmonic is in phase with the passage of the sun.

(v) The time of maximum phase angle of the second harmonic expressed in local time occurs earlier on the west coast than on the east coast, but a difference in geographical pattern in the time of maximum phase angle occurs between the north-east and south-west monsoon seasons.

The above features are difficult, if not impossible, to reconcile with any resonance theory and an alternative theory is suggested.

INTRODUCTION

In most text books of meteorology, especially those concerned with tropical and equatorial meteorology, the diurnal variation of pressure receives very superficial treatment or is ignored, despite the fact that in the tropics it is the one feature which obtrudes itself and calls for an explanation. This is all the more surprising since close to the equator where the pressure distribution is flat and irregular and the diurnal pressure variation is large (see Figure 1), an accurate knowledge of the latter is essential if any attempt is to be made to correlate the weather and winds with the pressure systems.

With the object in view of obtaining the appropriate pressure corrections for use in synoptic forecasting in Malaya, a harmonic analysis of the hourly observations of pressure from certain stations in Malaya for which long-period means were available was carried out, and the results appear to be of more than local interest. In particular, it appears to be impossible to reconcile the generally accepted resonance theory for the second harmonic of pressure with the variations of amplitude and phase which occur in Malaya, and an alternative hypothesis is put forward.

SOLAR BAROMETRIC VARIATION

General

Figure 1 shows a typical pattern of diurnal variation of pressure in the tropics which is characterized by two maxima of pressure at approximately 1000 and 2200 hours local time and two minima of pressure at approximately 0400 and 1600 hours local time. When the diurnal variation of pressure is subjected to harmonic analysis, it is found that the first and second harmonics contribute almost the entire variation.

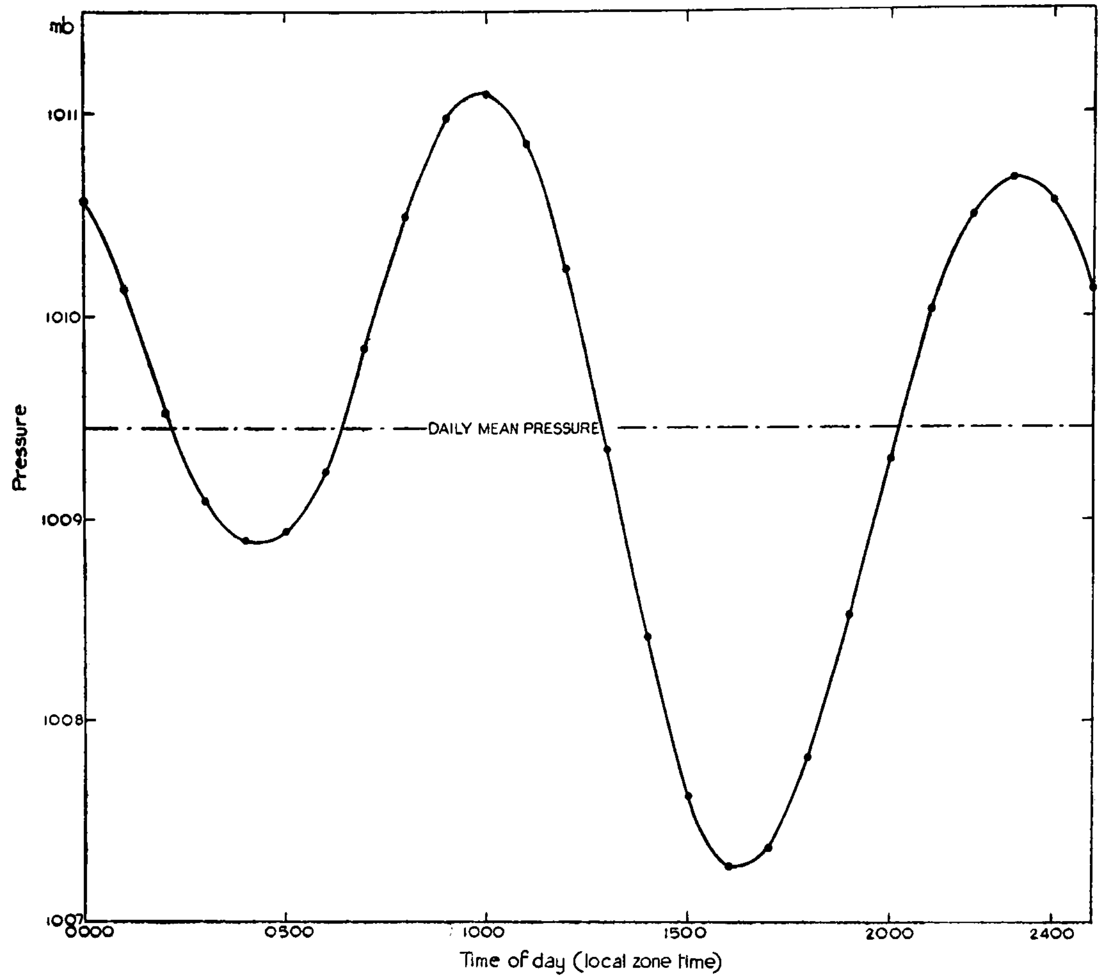

FIGURE 1. Diurnal pressure variation at Bayan Lepas

The first harmonic, the 24-hour component, is usually considered to be due to the alternate daily heating of the air by the sun and the nocturnal cooling of the air by terrestrial radiation; the amplitude varies with the latitude, distance from the sea, cloudiness and orographic features.

The second harmonic, the 12-hour component, which is higher than the 24-hour component, is less easy to explain as on prima facie thermal considerations the first should be very much greater. To account for this Kelvin[1]* put forward the suggestion that the small pressure change, due to the second harmonic of the temperature change, might be amplified by a near resonance with one of the natural frequencies of the earth's atmosphere and much effort has been devoted by Margules,[2] Lamb,[3] Taylor[4] and Pekeris,[5] *inter alios*, to proving that the fundamental period of the free oscillation of the atmosphere is 12 solar hours (compare Wilkes[6]).

* The superscript figures refer to the bibliography on p. 13.

The factor of resonance magnification was estimated as about 100 by Chapman,[7] who considered that the difference between the free and imposed periods could not exceed two or three minutes, and that this difference must be positive. Whipple[8] found great difficulty in accepting the resonance theory on account of the possibility that accurate tuning of the forced to the free oscillation might be upset by the large changes in pressure and temperature associated with changes in the weather and annual variations. Taylor[4] was also led to doubt the validity of the resonance theory despite the general arguments in its favour.

Weekes and Wilkes[6] made a series of calculations with a differential analyser to see what temperature distributions in the vertical were required to give a free period of 12 hours and claimed that the results of rocket experiments and other evidence were consistent with the theoretical atmospheric models. A weakness of this treatment is that the free period is very sensitive to the form chosen for the temperature variation at about 70 kilometres, which is in any case uncertain, and slight variations in this could be fatal to the resonance theory.

Summary of earlier observations

Extensive tabulations of the 24-hour, 12-hour and 8-hour components of the barometric variations have been published by Hann.[9, 10, 11] Schmidt[12] analysed the second of these and found that near the poles the maxima of the 12-hour component did not occur at the same local time as they do in equatorial and temperate latitudes but instead tended to occur at the same Greenwich time. He put forward the hypothesis that the total oscillation should be regarded as being made up of two components, a travelling wave which follows the sun round the earth and a standing wave in which pressure is alternately high at the poles and the equator, but he made no attempt to give a physical explanation of the standing wave.

Simpson[13] discussed Schmidt's hypothesis and concluded that the mean yearly diurnal barometric variation could be represented by the sum of two sinusoidal components, one depending on local time and one depending on Greenwich time. In the first component, which is dominant in the tropics and temperate latitudes and which Simpson called the equatorial wave, he found that the amplitude varied very nearly as $\cos^3 \varphi$ where φ is the latitude, the best representation being given by

$$p_{12} = 1{\cdot}25 \cos^3 \varphi \sin (30t + 154°),$$

where p_{12} is the amplitude of the 12-hour component and t the local time. The phase angle is measured from local midnight, the greatest deviations from the mean phase angle being $-5°$ and $+4°$.

The amplitude of the second component, the polar oscillation, was found to be less than 0·1 millibar and its effect was negligible in all except the polar regions. No theoretical explanation of the polar oscillation has been attempted, and there is some doubt as to its physical reality in view of the poor quality of the data for the polar regions available to Simpson and Schmidt.

In a recent examination of the diurnal variation of pressure on the Greenland ice sheet, Hamilton,[14] using pressure observations free from, or corrected for, temperature errors, found that the maxima and minima occurred at about the same local time as they do in the tropics.

Jameson,[15] who investigated the diurnal variation of barometric pressure over the sea on the assumption that the amplitudes of the third, fourth and higher components were negligible, found that, in the Indian Ocean between the equator and 10° N, the mean yearly values of the 24-hour and 12-hour amplitudes and phases were 0·38 millibar and 357° and 1·20 millibars and 148° respectively, whilst in the Pacific Ocean between the same latitudes the mean yearly values of the 24-hour and 12-hour components were 0·46 millibar and 356° and 1·19 millibars and 146° respectively. He also found that the amplitude of the second harmonic in the tropics remained constant at approximately 1·20 millibars between October and April and fell to about 1·00 millibar in July. The most striking feature of his observations, however, was the variation in phase angle which backed from 154° in January to 143° in April, remained constant at this value until July and then increased again.

The agreement of the amplitudes of the 12-hour components found by Jameson with those derived from Simpson's formula is good, but Jameson found great difficulty in reconciling a real difference of some 5° to 10° in phase from Simpson's value.

Lea,[16] in a preliminary discussion of the pressure observations over Malaya using daily observations at five standard hours over a three-year period, computed the first and second harmonics by the same abbreviated method as Jameson. He found that the mean yearly amplitude of the second harmonic increased from east to west across Malaya and was highest inland. In view of the short period over which the observations were made, especially as the observations were found to have small but systematic errors, Lea was reluctant to accept this finding owing to the difficulty of incorporating such a variation in the accepted resonance theory.

Wilkes,[6] in summing up the observational evidence on the 12- and 24-hour components states "The most striking feature of the data when viewed as a whole is the regularity of the 12-hourly component, which, except in polar regions, varies little (when expressed in terms of local time) either with longitude or with time of year. The amplitude, moreover, decreases uniformly with increase of latitude . . . . . and over North America both magnitude and phase are little affected by proximity either to the coast or to the Rocky Mountains. The 24-hourly component is by contrast very much more variable, both in the sense of having greater random fluctuations and in the sense of depending on geographical factors, markedly on the season, being greatest in the summer, and is approximately in phase with the passage of the sun."

This summing up on the second harmonic is not altogether consistent with the observations from Montevideo and Washington which Wilkes quotes. At the former the amplitude of the second harmonic shows two distinct maxima and minima, the primary maximum and minimum being in September and January with the secondary maximum and minimum in April and July respectively, while the phase angle backs from 162° in November to 145° in January and then increases steadily. At the latter the amplitude has a single maximum in December and a single minimum in July, whilst the phase angle backs from 162° in July to 135° in January.

The 8-hour component is small in amplitude and very variable. According to Allbright[17] the third harmonic is absent over the equator, reaches a maximum value of about

0·2 millibar at about 30° latitude, has opposite meridional phases between northern and southern hemispheres and changes phase between summer and winter.

THE MALAYAN OBSERVATIONS

Long-period records of hourly pressures at mean sea level, available from six stations maintained by the Malayan Meteorological Service in Malaya together with one station in Singapore maintained by the Air Ministry Meteorological Office, have been subjected to harmonic analysis. The observations from Batavia are included for comparison. Table I gives the latitudes and longitudes of the stations, the periods of years over which the observations have been made and the mean hourly pressures at each station.

TABLE I. *Station details*

Station	Latitude	Longitude	Period of observations *years*	Mean hourly pressure (all hours) *millibars*
Kota Bharu	06° 10′ N	102° 17′ E	13	1009·58
Bayan Lepas	05° 18′ N	100° 16′ E	12	1009·46
Kuala Lumpur	03° 07′ N	101° 42′ E	15	1009·50
Kuantan	03° 46′ N	103° 12′ E	13	1009·41
Malacca	02° 16′ N	102° 15′ E	16	1009·50
Mersing	02° 27′ N	103° 50′ E	15	1009·72
Singapore	01° 25′ N	103° 53′ E	10	1009·62
Batavia	06° 11′ S	106° 50′ E	49	1009·85

In a tropical country such as Malaya where the spatial variations of pressure are small and the winds are reversed in successive seasons, the most reasonable pattern to assume for the mean pressure distribution is one of nearly uniform pressure. Since each mean pressure is the average of about 100,000 observations, none of which differs from the mean by more than nine millibars so that the standard deviation of a single observation from the mean should not exceed 4½ millibars, hence the probable error of each mean should not exceed 0·01 millibar, and if we exclude Mersing's pressure it is possible to draw a reasonably smooth and convincing set of isopleths of mean pressure over Malaya to give a very shallow area of low pressure over the land, with the minimum pressure of 1009·4 millibars approximately occurring over the central massif. This suggests that the assumed height of the barometer at Mersing is too high by about six feet.

TABLE II. *Mean yearly amplitudes and phases*

Station	α_1 *mb*	A_1 °	α_2 *mb*	A_2 °	α_3 *mb*	A_3 °
Kota Bharu	0·95	25·5	1·31	143·3	0·10	357·4
Bayan Lepas	0·81	16·9	1·40	148·0	0·05	353·7
Kuala Lumpur	1·11	20·6	1·33	152·4	0·10	357·7
Kuantan	1·00	20·4	1·23	147·1	0·12	339·0
Malacca	1·11	18·1	1·33	146·3	0·08	24·3
Mersing	0·83	15·0	1·22	147·1	0·10	18·9
Singapore	0·75	12·5	1·30	148·1	0·04	18·0
Mean of Malayan stations	0·93	18·7	1·29	148·7	0·08	04·1
Batavia	0·83	25·2	1·33	160·2	0·05	19·1

Denoting the 24-hour, 12-hour and 8-hour components of the pressure variation by $\alpha_1 \sin(15t+A_1)°$, $\alpha_2 \sin(30t+A_2)°$ and $\alpha_3 \sin(45t+A_3)°$ respectively, where t is the local time in hours, α the amplitude and A the phase, Table II shows how the mean yearly amplitudes and phases vary from station to station.

The first harmonic

Tables III and IV show how the phases and amplitudes of the first harmonics vary at different times of the year from station to station.

TABLE III. *Amplitude of the first harmonic*

	Kota Bharu	Bayan Lepas	Kuala Lumpur	Kuantan *millibars*	Malacca	Mersing	Singapore	Batavia
Jan.	0·71	0·82	1·02	0·76	1·02	0·59	0·56	0·72
Feb.	0·89	0·90	1·15	0·88	1·22	0·75	0·73	0·75
Mar.	1·01	0·96	1·23	1·02	1·24	0·92	0·83	0·79
Apr.	1·03	0·86	1·12	1·08	1·19	0·97	0·79	0·82
May	1·01	0·81	1·08	1·10	1·05	0·90	0·71	0·79
June	0·98	0·71	1·06	1·06	1·03	0·82	0·67	0·82
July	1·01	0·74	1·07	1·05	0·99	0·88	0·61	0·90
Aug.	1·06	0·75	1·20	1·11	1·07	0·89	0·72	1·00
Sept.	1·13	0·79	1·16	1·13	1·17	0·95	0·77	1·05
Oct.	1·02	0·81	1·14	1·11	1·11	0·84	0·75	0·91
Nov.	0·81	0·76	1·05	0·94	1·12	0·76	0·70	0·78
Dec.	0·74	0·79	1·04	0·79	1·09	0·63	0·63	0·69

TABLE IV. *Phase of the first harmonic*

	Kota Bharu	Bayan Lepas	Kuala Lumpur	Kuantan *degrees*	Malacca	Mersing	Singapore	Batavia
Jan.	18·4	14·3	18·0	14·7	23·3	6·3	10·9	16·2
Feb.	14·3	8·1	19·0	12·3	19·3	1·9	9·6	17·0
Mar.	9·6	5·1	17·9	10·1	16·7	359·8	9·5	24·0
Apr.	20·4	11·4	22·0	14·0	15·2	10·6	10·0	20·3
May	33·7	19·7	25·5	24·1	16·8	19·4	12·4	30·5
June	31·2	19·9	22·6	23·3	15·0	24·7	23·1	30·5
July	33·9	19·7	18·6	22·6	16·1	21·0	14·2	27·4
Aug.	30·6	16·6	16·1	21·9	12·9	17·3	7·3	25·3
Sept.	32·1	21·4	19·7	25·7	9·9	19·1	8·1	23·6
Oct.	34·3	22·9	24·9	31·1	20·7	23·4	14·0	26·6
Nov.	26·1	24·7	19·7	28·0	24·4	23·1	16·5	29·2
Dec.	21·9	19·3	23·7	17·4	27·0	13·3	21·9	25·9

As can be seen from Tables III and IV, the 24-hour component over Malaya is somewhat variable but, taken in conjunction with Jameson's values, isopleths of α_1 can be drawn parallel to the coasts to give a minimum over the sea and a maximum over the land (see Figure 2). The monthly values of α_1 show two maxima in or near March and in or near

September respectively and two minima in June or July and January. This is at variance with Wilkes'[6] conclusions (from Hann's data[9, 10, 11]) that α_1 is greatest in the summer, but is in general agreement with Jameson's[15] findings.

The values of A_1 are approximately in phase with the passage of the sun, and the mean value of the range of variation of phase angles from all stations in Malaya is almost exactly twice the range of variation in the times of sunrise and sunset—a fact noted by Lea.[16]

The second harmonic

Tables V and VI show how the phases and amplitudes of the second harmonics vary at different times of the year from station to station.

TABLE V. *Amplitude of the second harmonic*

	Kota Bharu	Bayan Lepas	Kuala Lumpur	Kuantan	Malacca	Mersing	Singapore	Batavia
				millibars				
Jan.	1·27	1·36	1·36	1·15	1·35	1·22	1·29	1·33
Feb.	1·25	1·46	1·40	1·22	1·36	1·24	1·32	1·34
Mar.	1·35	1·54	1·47	1·31	1·46	1·30	1·40	1·37
Apr.	1·43	1·57	1·46	1·34	1·45	1·30	1·37	1·36
May	1·33	1·38	1·28	1·25	1·30	1·17	1·27	1·30
June	1·18	1·19	1·13	1·11	1·10	1·02	1·13	1·20
July	1·16	1·15	1·10	1·08	1·10	0·99	1·09	1·20
Aug.	1·25	1·27	1·24	1·19	1·20	1·07	1·16	1·28
Sept.	1·42	1·46	1·37	1·33	1·35	1·28	1·30	1·38
Oct.	1·45	1·53	1·43	1·35	1·43	1·35	1·44	1·40
Nov.	1·40	1·52	1·41	1·28	1·42	1·35	1·38	1·40
Dec.	1·27	1·41	1·42	1·18	1·37	1·28	1·36	1·35

TABLE VI. *Phase of the second harmonic*

	Kota Bharu	Bayan Lepas	Kuala Lumpur	Kuantan	Malacca	Mersing	Singapore	Batavia
				degrees				
Jan.	142·9	149·4	151·9	146·3	147·7	144·0	149·3	157·1
Feb.	136·3	144·2	149·1	142·6	142·9	137·6	144·2	154·1
Mar.	136·8	140·0	149·6	140·7	142·3	139·4	144·8	155·3
Apr.	141·4	147·8	152·7	143·7	146·2	142·2	148·7	158·5
May	142·2	146·7	151·3	146·7	147·3	146·6	148·5	159·9
June	142·1	144·4	150·2	144·4	143·8	146·5	149·3	158·4
July	141·1	140·9	148·2	141·8	141·2	145·7	146·9	157·4
Aug.	142·7	144·3	149·7	145·0	142·4	147·5	148·6	158·3
Sept.	146·6	149·7	153·1	149·9	147·0	151·6	151·5	163·3
Oct.	151·1	158·4	159·5	155·9	152·3	156·6	156·9	166·9
Nov.	148·9	156·9	161·0	156·6	153·3	155·2	157·1	167·3
Dec.	147·9	153·9	153·2	152·0	149·5	149·6	154·9	161·3

The most striking features of the dominant second harmonic are:

(i) Contrary to the accepted theory the amplitudes over Malaya do not decrease with latitude in any month and in general show an increase from south-east to north-west.

(ii) As shown in Figure 2 isopleths of α_2 are greatly influenced by the distribution of land and sea, being greater over land than sea. The pattern of α_2 is similar to that of α_1.

(iii) The amplitudes are everywhere greatest in March and April and again in October and November and are lowest in July with a secondary minimum in January and, as can be seen from Figure 3 in which the monthly amplitudes of the stations are exhibited, these show a close relationship with the monthly totals of solar radiation at the equator.

(iv) The mean yearly phase angle of the second harmonic computed from all stations in Malaya is in good agreement with Jameson's[15] values but the phase angles from individual stations show variation from Jameson's mean of up to 13° and up to nearly 18½°, or 37 minutes, if the Batavia observations are included (see Figure 4).

The values of A_2 are approximately in phase with the passage of the sun and the mean value of the range of A_2 from all stations in Malaya is almost exactly the same as the range of variation in the times of sunrise. In general the time of maximum A_2 expressed in local time occurs earlier on the west coast than on the east coast, the gradient of phase angle increasing from north-east to south-west during the period of the north-east monsoon and from south to north during the period of the south-west monsoon.

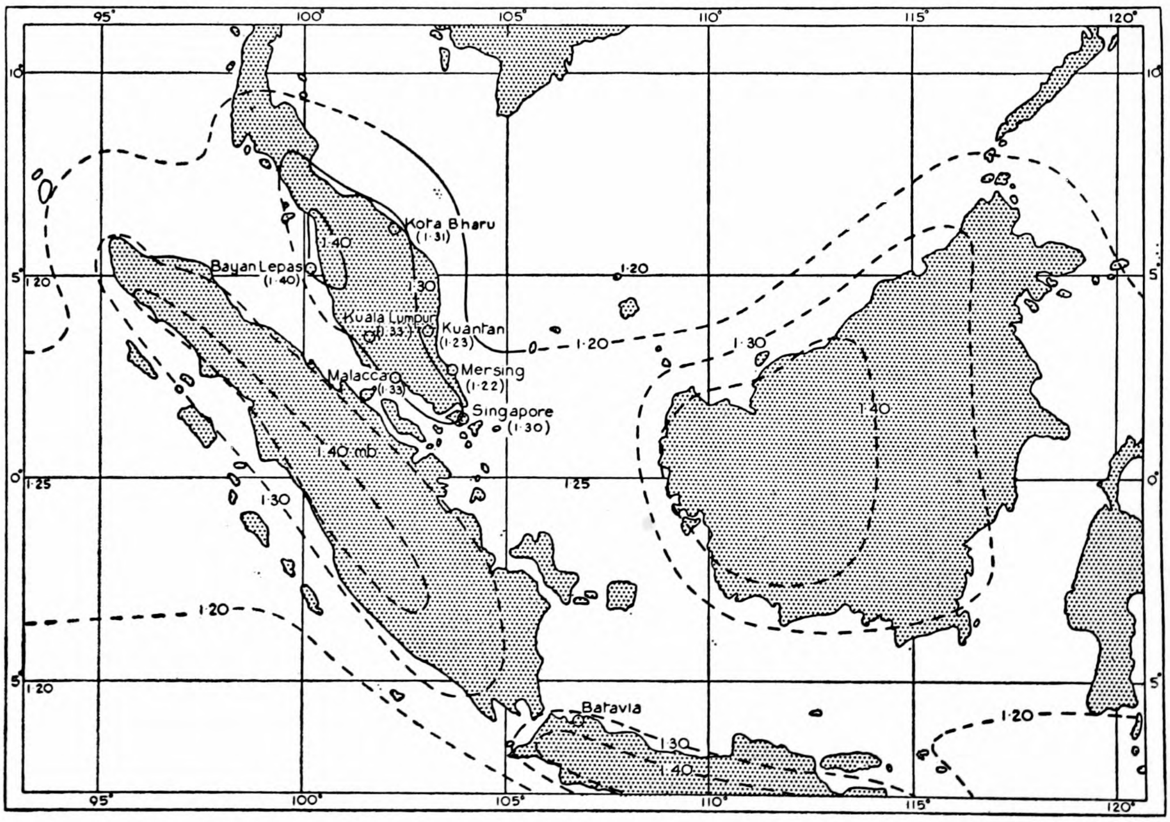

FIGURE 2. Probable distribution of the mean annual amplitude of the second harmonic of pressure

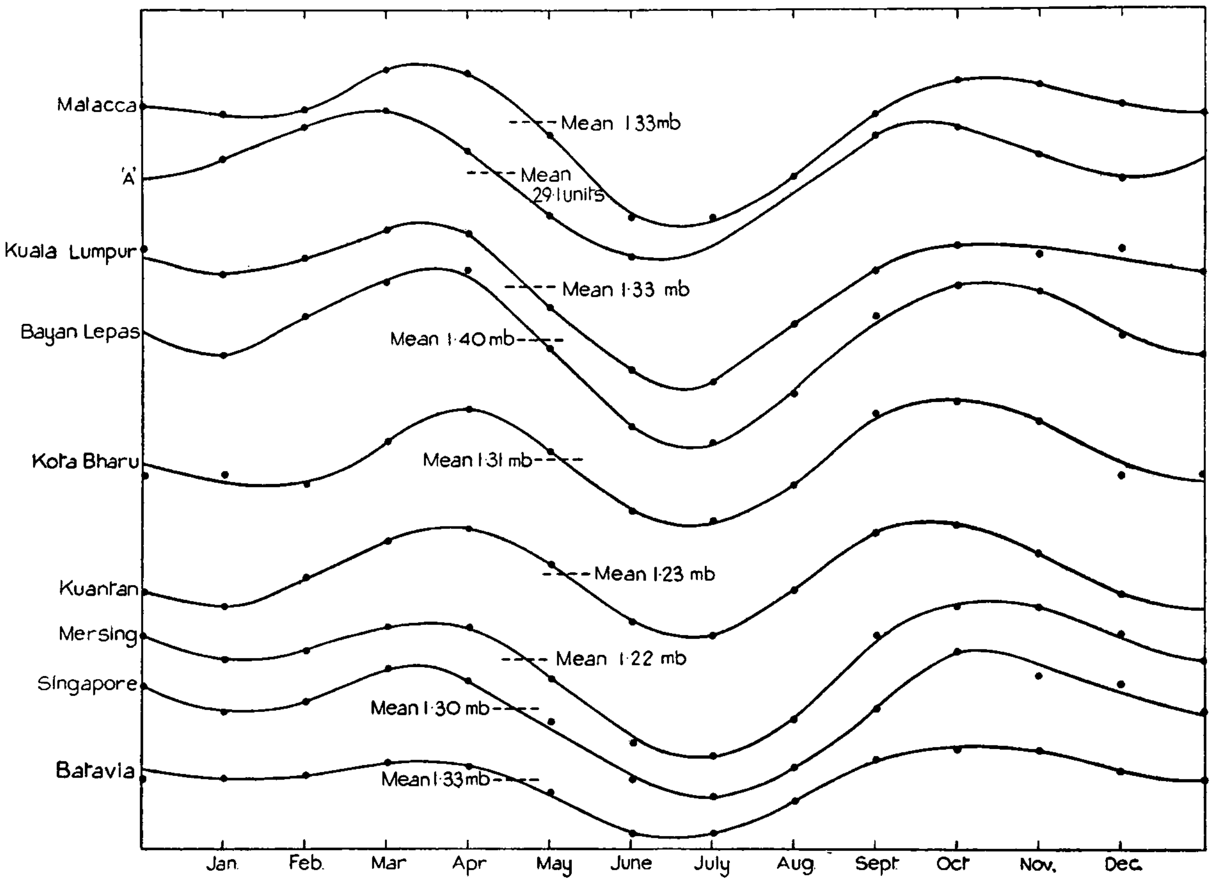

FIGURE 3. Amplitude of the second harmonic of pressure
Vertical scale: 0·5 in. = 0·3 mb.
Curve "A" shows the variation of the monthly totals of solar radiation at the equator and for this curve 0·5 in. on the vertical scale represents 3 units. A unit amounts to 458·4 times the solar constant or 889 gm. cal. cm.$^{-2}$, taking the solar constant to be 1·94 gm. cal. cm^{-2}. min^{-1}. (See Brunt.[18])

The third harmonic

The variations of phase and amplitude of the third harmonic at Malacca at different times of the year are depicted in Table VII.

TABLE VII. *Amplitudes and phase of the third harmonic at Malacca*

	α_3 *mb*	A_3 °		α_3 *mb*	A_3 °
Jan.	0·09	030	July	0·05	074
Feb.	0·08	000	Aug.	0·05	063
Mar.	0·11	011	Sept.	0·12	029
Apr.	0·10	033	Oct.	0·10	013
May	0·06	034	Nov.	0·10	009
June	0·02	073	Dec.	0·09	009

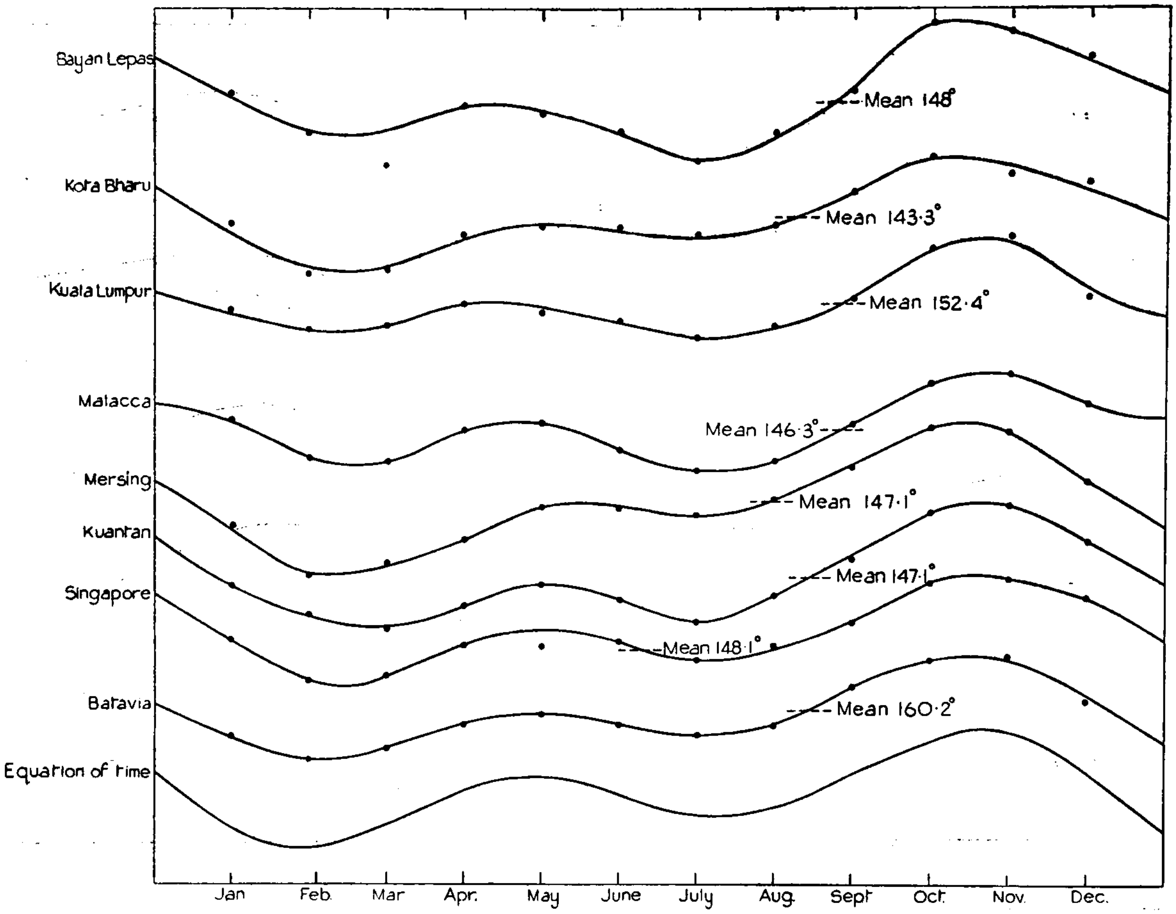

FIGURE 4. Phase angle of the second harmonic
Vertical scale: 0·5 in. = 15°

It can be seen from Table II that over Malaya the mean yearly amplitude of the third harmonic is approximately 0·09 millibar and shows little variation with latitude. As in the case of the second harmonic, α_3 has two maxima, the first in March and the second in September, and two minima, the lowest in June and a secondary minimum in February (see Table VII). The phase angle, A_3, at Malacca varies from about 10° in winter to 75° in summer which is in agreement with the values of A_3 for Singapore in January and July (compare Table VIII).

TABLE VIII. *Comparison of the third harmonics at Malacca, Singapore and Batavia in January and July*

	Malacca		Singapore		Batavia	
	α_3 mb	A_3 °	α_3 mb	A_3 °	α_3 mb	A_3 °
January	0·09	030	0·08	020	0·01	205
July	0·05	074	0·06	075	0·09	030

Unlike the phase angles at Malacca and Singapore the phase angle at Batavia changes by about 180° between summer and winter, and the January but not the July phase angle is out of phase by 180° with the corresponding phase angle in the northern hemisphere.

DISCUSSION OF THE MALAYAN DATA

The following facts relating to the 12-hour component are clearly brought out by the Malayan observations:

(i) α_2 is greater near the thermal than the geographical equator.

(ii) α_2 is greatest when the sun is overhead in March and September, and is greater in January when the sun is nearest to the earth than in July when the sun is farthest from the earth.

(iii) The mean monthly values of α_2 show a close relationship to the monthly totals of solar radiation at the equator.

(iv) α_2 shows an increase approximately downwind across Malaya.

(v) The mean value of A_2 is in phase with the passage of the sun but variations of up to 30 minutes occur between individual stations.

(vi) The time of maximum A_2 expressed in local time occurs earlier on the west coast than the east coast, the gradient of phase angle increasing from north-east to south-west during the north-east monsoon and from south to north during the south-west monsoon, and to be satisfactory any explanation of the semi-diurnal pressure wave must cover these facts.

The first three factors give strong support to the conclusion that the second harmonic as well as the first is in some way or other connected with the solar heating but the last two are difficult to reconcile with the generally accepted resonance theory.

In a search for an alternative explanation, a possible clue is suggested by the manner in which the first and second harmonics of pressure and temperature vary with height. Thus at Batavia, compare Shaw,[19] the amplitude of the first harmonic of temperature falls off rapidly from a value of 2·79°A at the surface to 0·24°A at one kilometre, whereas over the same height interval the amplitude of the second harmonic falls off slowly from 0·88°A to 0·46°A. The corresponding values of the amplitudes of the first and second harmonics of pressure at Batavia and a neighbouring mountain station, Mount Panderango (3,025 metres), are 0·83 and 1·33 millibars and 0·20 and 0·97 millibars respectively.

Consideration of these variations leads to the conclusion that the problem is basically a two-layer problem and that:

(*a*) the first harmonic of pressure is caused by an eddy flux of heat which, directed downwards in a layer of air next to the ground, converts a sub-adiabatic lapse rate at night into an adiabatic lapse rate soon after sunrise, thereby giving rise to a large temperature range between day and night at the surface and a negligible range of temperature at a height of about one kilometre;

(*b*) the second and higher harmonics of pressure are caused by a convective flux of heat directed upwards in the hours around midday when the lapse rate is super-adiabatic, which distributes the heat through several kilometres of the atmosphere and hence gives rise to only small temperature increases at all levels.

In the lowest kilometre above the surface, as a first result of the alternation of the lapse rate between sub-adiabatic at night and adiabatic or slightly super-adiabatic during the day, a pressure gradient is established at all levels directed from the warmer to the colder regions which gives rise to a lateral flow of air in the same direction. As, however, the heating and cooling are continuous, equilibrium of flow is never actually reached although during the day-time and again at night a quasi-steady state is attained. On the assumption that the pressure at the upper level is invariant, the pressure at the surface is a minimum when the mean temperature of the air over the first kilometre is at its highest, that is in the mid-afternoon, and a maximum when the mean temperature of the air is at its lowest, that is just before sunrise. From hydrostatic considerations a rise of 2°A in the mean temperature over the lowest kilometre results in a fall of 0·8 millibar at the surface.

According to this hypothesis the 24-hour variations of temperature and pressure are negligible at a height of approximately one kilometre and hence any variations of pressure at this level resulting from the upward flux of heat beyond this level must be capable of representation by the second and higher harmonics.

Now observations over Malaya show that in the lowest one kilometre (in passing, one kilometre is also approximately the condensation level), the lapse rate becomes dry adiabatic at approximately 1000 hours local time. Cloud soon begins to form after this time and, as the air is conditionally unstable above this level up to great heights at all seasons, these clouds frequently develop into large cumulonimbus clouds which funnel the heat rapidly upwards in the atmosphere up to heights of 15 kilometres. As in the case of the lower layer, when a quasi-steady state is attained, the pressure at a height of one kilometre is a minimum when the mean temperature of the air between 1 and 15 kilometres is highest, that is in the mid-afternoon, and is a maximum when the mean temperature of the air is lowest, that is just before the convective break-through occurs at approximately 1000 hours local time. A simple calculation shows that a rise of 0·5°A in the mean temperature over a height interval from 1 to 15 kilometres would result in a pressure decrease of approximately 1·3 millibars.

On the present argument the maximum of the semi-diurnal component at 1000 local time is caused by convection over land whilst the second maximum at 2200 local time results from the fact that the fundamental period of free oscillation of the earth's atmosphere is 12 solar hours.

If the earth were a uniform land mass the wave set up by convection would be a simple progressive wave having the same amplitude along any circle of latitude. In passing from a land to a sea surface, however, the absence of a forced impulse at the appropriate time results in a damping of the wave motion and the amplitude of the oscillation should accordingly decrease with distance downwind from the coast. The observed differences in amplitude over land and sea in the same latitudes, however, suggest that the damping is small.

It can be seen that on this hypothesis, since α_1 and α_2 are both proportional to the surface heating, the patterns of α_1 and α_2 should be similar to those of the coastlines. Since in general the earlier the onset of convection the greater is the amount of heat carried up to great heights, there should be a rough correlation between the amplitude and the phase angle as in fact is the case. The earlier time of maximum phase angle and the increase in amplitude found downwind across Malaya can be accounted for by the fact that, downwind overland near the coast, horizontal advection would delay the onset of convection and reduce its effect.

Although it does not appear to be possible to give a convincing mathematical treatment of the problem, the simple hypothesis outlined above does appear to afford a reasonably satisfactory explanation of the diurnal variation of pressure.

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