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# DIURNAL VARIATION OF PRESSURE IN THE MEDITERRANEAN AREA

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# DIURNAL VARIATION OF PRESSURE IN THE MEDITERRANEAN AREA

By H. Jameson, D.Sc.

**Summary.**—The monthly changes in the 24-hr. and 12-hr. barometric oscillations in the Mediterranean Sea were studied by means of harmonic dials.

The monthly changes in the 24-hr. oscillation differ considerably from one another in different areas of this sea. The monthly changes in certain neighbouring land areas are plotted for comparison, but throw no light on the changes at sea. From a comparison between inland and coastal stations near or on part of the north Mediterranean coast, an attempt was made to deduce the 24-hr. oscillation in the strip of sea affected by land and sea breezes, and to connect this with the observed times of maximum land and sea breeze.

The monthly changes in the 12-hr. oscillation in all the marine areas considered give approximately a standard pattern of harmonic dial, with changes in amplitude, but constant phase, from May to October, and changes in both amplitude and phase during the remainder of the year, causing a counterclockwise rotation of the dial point. Phases in winter veer from the constant summer value. Land stations in southern France and north-west Italy give a similar dial, but the values of the 12-hr. oscillation available from Algerian stations suggest a different type of dial in that region.

The mean yearly phase of the 12-hr. oscillation at sea differs appreciably and systematically from that for land stations. A similar phenomenon has been noted for the tropics.

Harmonic dials of the 12-hr. oscillation for tropical marine regions are compared with those for the Mediterranean Sea. The marked difference between summer and winter in the Mediterranean dials reappears, in a somewhat modified form, in the northern and even in the southern tropics.

**Purpose of investigation and data used.**—Tables were required to correct barometric pressures and tendencies in the Mediterranean Sea for diurnal variation, and the Marine Branch of the Meteorological Office was asked to provide these.

As this diurnal variation, and particularly its 24-hr. component, might be expected to vary much more with position in an enclosed sea like the Mediterranean than in the open ocean, the data were extracted and studied for each of a number of separate areas. For convenience in working with the Hollerith cards held in the Branch (which are punched for position according to the Marsden system) the areas selected were, in general, Marsden "squares" (see Fig. 1).

Square 143, however, was broken up into two separate areas, the "rectangles" 30–38° N., 10–20° E., designated 143S, and 38–40° N., 10–16° E., designated 143N. The area 38–40° N., 16–20° E., in which there were very few observations from British ships, was ignored. In square 179, as the British data contained very few observations from the Adriatic Sea these were deleted, and the data refer only to that part of 179 west of Italy. The observations in square 142 are nearly all from ships proceeding between Port Said and the western Mediterranean, and are therefore for localities south of Crete. The observations in 141 are mainly near Port Said.

The data from which these tables were prepared consisted of observations taken by voluntary observers aboard British merchant ships with mercury barometers. Although there is in the Branch a large amount of Hollerith marine data derived from German sources and consisting mainly of observations from German vessels, only the British Hollerith data were used for the tables.

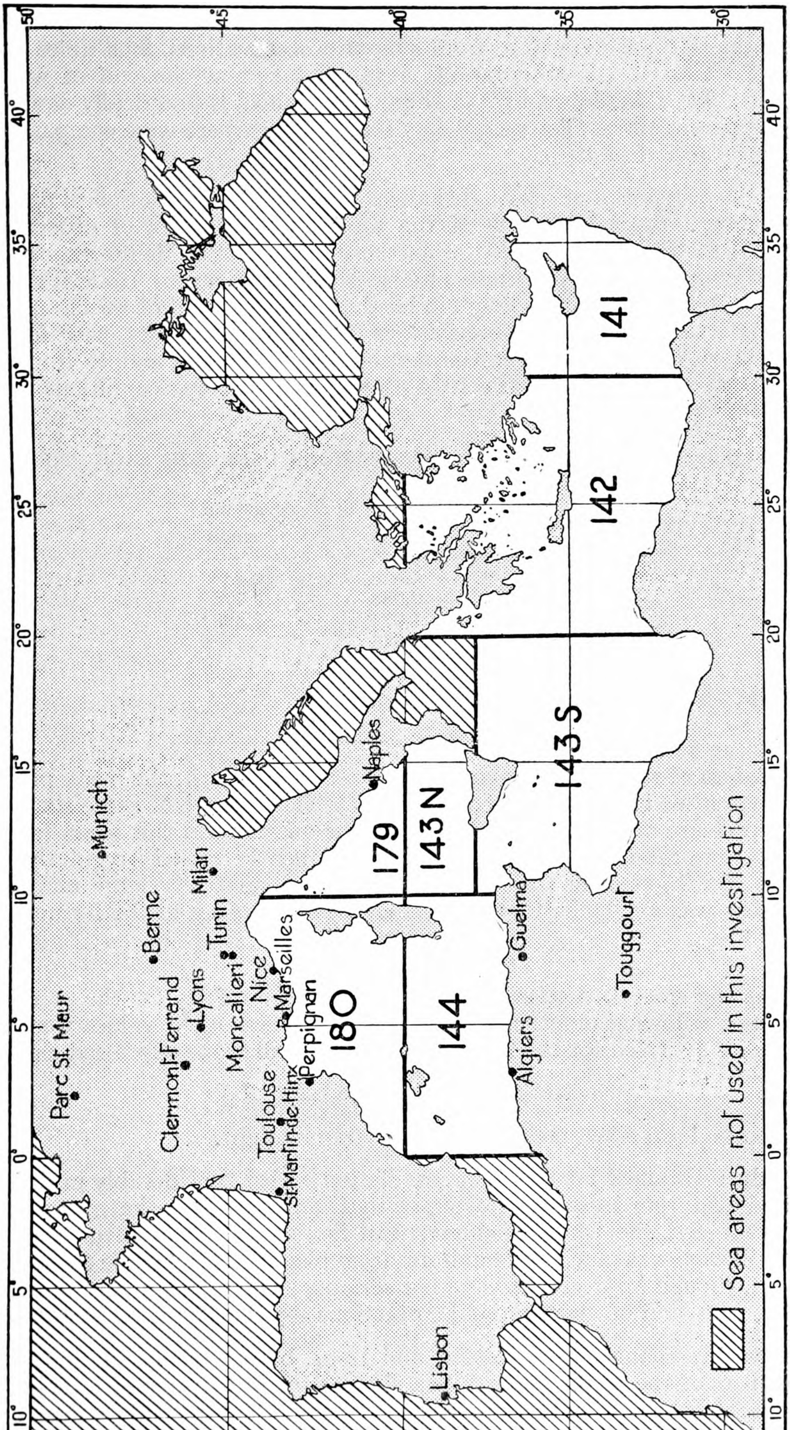


FIG. 1—SEA AREAS EXAMINED IN THIS INVESTIGATION

This was partly to save time and partly because the German data contained aneroid readings whose value for this purpose was uncertain. Moreover, parts of the German data were from synoptic observations, four times a day, in G.M.T. The British observations were all taken at the end of watches, at 0h., 4h., 8h., 12h., 16h. and 20h. ship's time, which is practically equivalent to local apparent time. The period was 1920–39, but there were comparatively few observations after 1930.

For the investigation of seasonal changes in the diurnal variation of pressure, which followed the preparation of the tables, the numbers of observations were found to be insufficient in the northern areas of the Mediterranean Sea, and were supplemented by those observations, on German Hollerith cards, which were taken every four hours in local time (at the end of watches). The approximate total number of observations, British and German, used for each area, is shown in Table I. The German observations were mainly from 1906 to 1939, with gaps caused by the 1914–18 war and post-war conditions.

TABLE I—TOTAL NUMBER OF OBSERVATIONS USED FOR EACH AREA

| Area | Number of observations British | German |
|---|---|---|
| 180 | 4,818 | 10,488 |
| 179 | 2,088 | 4,776 |
| 143N | 1,974 | 5,238 |
| 144 | 11,646 | .. |
| 143S | 12,972 | .. |
| 142 | 16,128 | .. |
| 141 | 4,470 | .. |

**Presentation of results.**—In each area and for each month, the mean pressure was computed for each of the six local times. The average of these six means gave the pressure mean for the month, and the offsets from this mean for each local time were tabulated. As these offsets frequently varied irregularly from month to month, even in those areas for which a relatively large number of observations was available, they were smoothed according to the formula

$$f_s = \tfrac{1}{4}\,(f_0 + 2f_1 + f_2)$$

where $f_s$ is the smoothed offset and $f_0$, $f_1$, $f_2$ are the offsets for the preceding, current, and following months, respectively. The smoothed values were then harmonically analysed for the 24-hr. and 12-hr. oscillations expressed as

$$a_1 \sin\,(t + A_1) + a_2 \sin\,(2t + A_2)$$

where $t$ is the local time, measured from local midnight.

The values obtained for the 24-hr. oscillation varied considerably in different areas, and also from season to season, so that it was evident that mean values for the year and the whole Mediterranean Sea would be of little use. The 12-hr. oscillation was much more uniform from place to place, while the seasonal variations, though appreciable, were not serious. The tables finally drawn up, therefore, consisted of mean annual corrections for the 12-hr. oscillation only.

The monthly changes in the 24-hr. and 12-hr. barometric oscillations in the various areas of the Mediterranean Sea showed many features of interest, and are discussed below. For this discussion, the smoothed monthly values of the phase and amplitude of each oscillation were plotted in polar co-ordinates, to form a harmonic dial.

On these harmonic dials the phases are shown not as angles, but as the corresponding times at which the oscillation reaches its minimum value (for the 12-hr. oscillation, the morning minimum). In the 24-hr. oscillation, therefore, 270° corresponds to 24h., 360° to 18h., and so on. In the 12-hr. oscillation, 270° corresponds to 12h., 360° to 9h., and so on.

No corrections were made for non-cyclic changes of the barometric pressure. Such corrections are small, and will make no appreciable differences to the general shape of the dials.

**The 24-hr. oscillation.**—The harmonic dials for this oscillation showed considerable differences in the various areas. The more southerly areas, 141, 142, 143S and 144, have generally much greater amplitudes in the summer half of the year than in the winter half. The phases, however, and the change in phase from one month to the next may differ considerably between neighbouring areas.

In the more northern areas, 180, 179 and 143N, winter shows, on the whole, the greatest amplitudes. Here again the phases differ considerably in neighbouring areas, even when the amplitudes are high.

As has been mentioned above, the British observations in these northern areas were supplemented by German observations. The agreement between British and German data was not very good, probably because the number of observations was insufficient. Finally the British and German cards for area 180 were combined to form one set of observations, while a second set was formed by taking both British and German cards for each of the areas 179 (west of the Italian coast) and 143N, which together form one suitable geographical area.

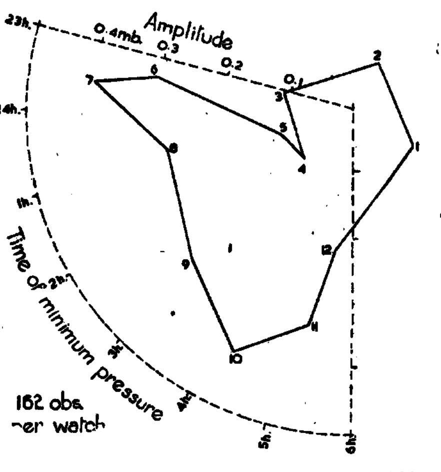


FIG. 2—24-HR. OSCILLATION, AREA 144
(British cards)

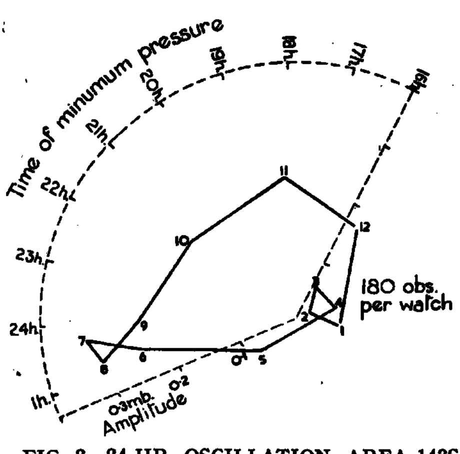


FIG. 3—24-HR. OSCILLATION, AREA 143S
(British cards)

Figs. 2–4 show the harmonic dials for the 24-hr. oscillation in the areas 144, 143S and 142, with averages of 162, 180 and 224 observations per watch,* respectively. Owing to smoothing, the effective averages per watch will, of course, be double these figures. The dials for areas 144 and 142 show some resemblance, with the months of largest amplitudes giving minimum pressures in the early hours of the morning. The greatest amplitudes are in or near the summer, and in both cases the dial point moves in a counter-clockwise rotation. In area 144 the largest amplitudes begin and end about two months later than in area 142.

*i.e. per observation hour.

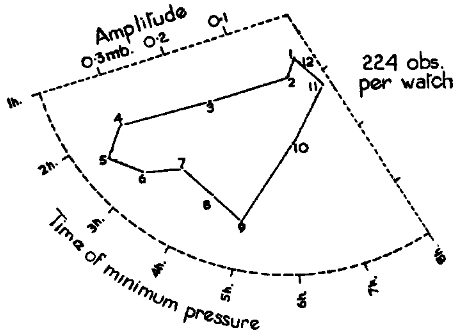


**FIG. 4—24-HR. OSCILLATION, AREA 142**
(British cards)

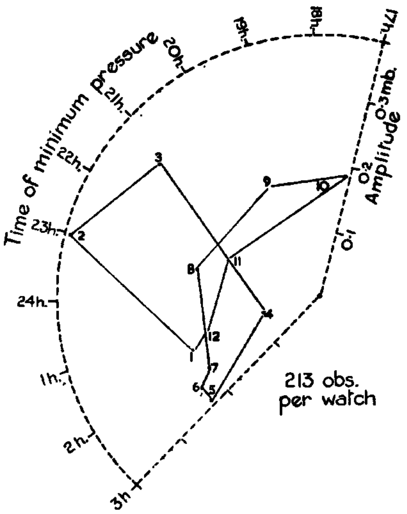


FIG. 5—24-HR. OSCILLATION, AREA 180
(British and German cards)

In area 143S, for the months of larger amplitude the phases of the 24-hr. oscillation have veered considerably from the phases of the larger amplitudes in areas 142 and 144. The dial point moves generally clockwise, and the times of minimum pressure for the larger amplitudes range from 18h. to 1h. As with areas 142 and 144, the larger amplitudes are in or near summer.

For area 141 the mean number of observations per watch is only 62, and the dial is very irregular. No diagram for this area is therefore given. The largest amplitudes are in May and June, with the times of minimum pressure between 1h. and 2h.

Figs. 5 and 6 show the harmonic dials, taken from combined British and German observations, for areas 180 and 179 + 143N. In the dial for area 180 the greatest amplitudes are in February and March, and the amplitudes for most of the remaining months of the year do not show a great range of magnitude among themselves. There is, however, a considerable and irregular change in the phases throughout the year.

The neighbouring area, 179 + 143N, shows an entirely different type of harmonic dial. In the summer half of the year, the times of minimum pressure range approximately from 23h. to 2h. while in the winter half there is almost a complete reversal of phase, the times of minimum pressure ranging from

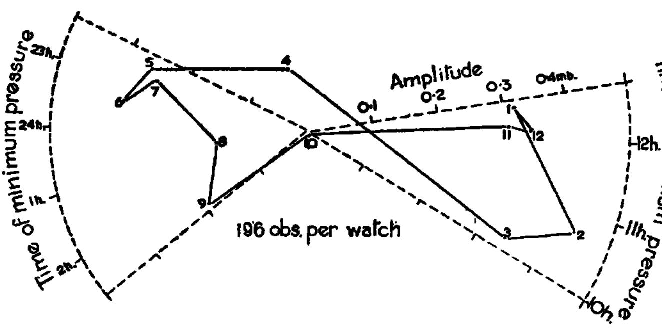


FIG. 6—24-HR. OSCILLATION, AREA 179 + 143N
(British and German cards)

10h. to 13h. Amplitudes in winter are appreciably higher than in summer. The reversal of the phase between summer and winter in this area is interesting, as none of the other areas show it so clearly, though there is just a suggestion of it in the neighbouring areas 144 and 143S, where the small winter oscillations show a tendency to reversal.

For comparison with these results over the sea, data from land stations in the Mediterranean area were examined. For both the 24-hr. and 12-hr. pressure oscillations, mean phases and amplitudes for each month have been published by Angot[1*] for a selection of stations all over the world. Of these, the most suitable stations for comparisons with the Mediterranean marine data are Naples, Milan, Moncalieri (Turin), Marseilles, Lyons, Clermont-Ferrand, Perpignan, Toulouse ; all these stations are of low or medium altitude above sea level. In a later paper[2] Angot gave three-hourly means of pressure for Nice, and amplitudes and phases computed from these data have been added to those extracted from the earlier paper.

The phases and amplitudes given in the earlier paper are not entirely based on observations at the stations themselves. In many cases it has been necessary to complete the data by interpolation from other stations. Details of the stations used for this purpose are given in Table II, which also gives altitudes and periods. M. Angot stated[1] that the method of interpolation used should give results correct generally to 0·01 mm. (0·01 mb.), at worst to 0·02 or 0·03 mm. (0·03 or 0·04 mb.). The interpolation should not, therefore, seriously affect the computed values of the harmonic constants. The results were given in local apparent time.

TABLE II—LAND STATIONS USED FOR COMPARISON WITH MEDITERRANEAN MARINE DATA

| Station | Altitude | Period | Stations used for interpolation |
|---|---|---|---|
| | ft. | | |
| Milan .. .. | 480 | 25 years | No information |
| Moncalieri (Turin) | 850 | 1867–86 | Berne, Parc St. Maur (Paris), Munich |
| Lyons (Parc de la Tête d'Or). | 575 | 1879–84<br>1886–87 | None |
| Clermont-Ferrand | 1,270 | 1878–87 | Berne, Munich, Parc St. Maur |
| Toulouse .. .. | 635 | 1839–62<br>1874–87 | St. Martin de Hinx, Lyons, Parc St. Maur |
| Naples .. .. | 490 | 1870–79 | None |
| Nice (Mont-Gros).. | 1,115 | 1889–1900 | None |
| Marseilles .. .. | 245 | 1878–87 | Lisbon, Parc St. Maur, Brussels |
| Perpignan.. .. | 105 | 1872–86 | Lisbon, Parc St. Maur, Greenwich |

For the 24-hr. oscillation, the inland stations, Milan, Moncalieri, Lyons, Clermont-Ferrand and Toulouse, show approximately the same type of annual variation, the amplitude increasing markedly from winter to summer, while the phase backs, so that the times of maximum and minimum pressure are retarded in the summer. The total range of the phase is only about an hour or two. The data for these inland stations were therefore averaged vectorially. The harmonic dial thus obtained (from the unsmoothed data) is shown as Fig. 7. It may be considered the general type for the inland regions just north of area 180. The variations of amplitude and phase throughout the year shown in this dial are clearly explicable in terms of solar heating.

* The index numbers refer to the bibliography on p. 17.

Perpignan, though only about 10 miles from the coast, gives almost the same type of dial, though the range of the phases is appreciably greater, about four hours. It affords a striking contrast to the harmonic dials for the coastal stations, Marseilles, Nice, Naples, and suggests that the factors which affect the 24-hr. oscillation at the coast do not extend many miles inland.

The harmonic dials for the three coastal stations show some points of similarity. The amplitudes are all small; no mean monthly amplitude at Naples, and only July at Nice exceeds 0·2 mb.; the amplitudes at Marseilles are rather larger, but only July exceeds 0·3 mb. The largest amplitudes are in the summer, and the phases during the remaining months of the year usually veer from summer values. The times of minimum pressure during the summer are about 20h. 30m.–22h. at Marseilles, 20h.–22h. at Nice, and 19h.–21h. at Naples. With these similarities it seemed reasonable to take vector means of the data for these coastal stations, the resulting harmonic dial (also unsmoothed), shown as Fig. 8, should give an approximate representation of the 24-hr. oscillation on these coasts.

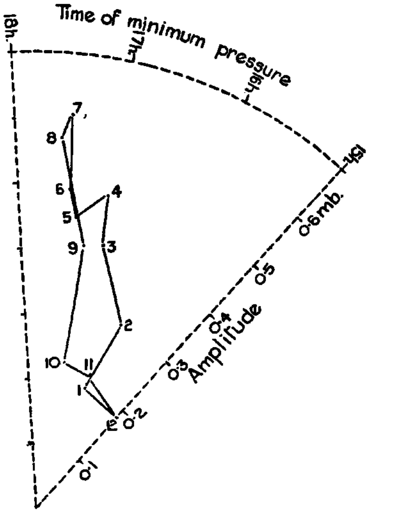


FIG. 7—24-HR. OSCILLATION, MEAN OF MILAN, MONCALIERI, LYONS, CLERMONT-FERRAND, TOULOUSE

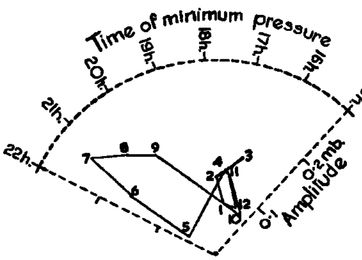


FIG. 8—24-HR. OSCILLATION, MEAN OF MARSEILLES, NICE, NAPLES

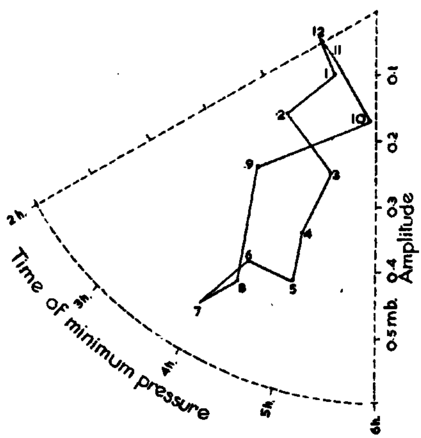


FIG. 9—24-HR. OSCILLATION, VECTOR DIFFERENCE BETWEEN MEAN COASTAL AND MEAN INLAND OSCILLATION

It is interesting to compute the oscillations which, if combined with the mean inland oscillations (Fig. 7), will give the mean coastal oscillations (Fig. 8). These oscillations are shown as Fig. 9. This dial shows no resemblance to the dial for area 180, but may represent the pressure oscillations in that strip of water nearest the coast, which is affected by the sea breeze. The interesting feature of Fig. 9 is the uniformity of the phase.

On this assumption, that Fig. 9 represents the 24-hr. oscillation in the strip of sea affected by land and sea breezes, the times of the maximum difference of pressure between the inland area (represented by Fig. 7) and this strip were computed for each month. These times (given to the nearest tenth of an hour) are shown in the table below :—

TABLE III

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | 4·1h. | 3·8h. | 4·9h. | 4·9h. | 5·1h. | 4·9h. | 4·7h. | 4·9h. | 4·5h. | 5·3h. | 3·9h. | 2·5h. |
| | 16·1h. | 15·8h. | 16·9h. | 16·9h. | 17·1h. | 16·9h. | 16·7h. | 16·9h. | 16·5h. | 17·3h. | 15·9h. | 14·5h. |

The amplitudes during the winter may be too small to give reliable figures, but between March and October the times remain fairly steady about 5h. and 17h. These might be expected to be the times of maximum land and sea breeze. However, the times of maximum land and sea breezes in the Gulf of Lions and on the French Riviera are given as about daybreak and about 13h. respectively.[3] The computed time for maximum land breeze, 5h., agrees reasonably well with this statement, but the computed time for maximum sea breeze is considerably later. A partial explanation may be this. The time 13h. probably refers to the sea breeze in the surface layers. This is a function not only of the pressure difference between land and sea, but also of the amount of mixing, due to convection, between the surface layers and those above. This convection will generally be a maximum in the middle of the day, and the effect will be to accelerate the time of maximum sea breeze in the surface layers.

The data on which Fig. 5 is based must include an appreciable proportion of observations taken in the coastal waters affected by land and sea breezes. If Fig. 9 really represents the 24-hr. oscillation in these coastal waters, it is possible to get a rough idea of the way in which the harmonic dial for area 180 would be modified if the observations in these coastal waters were removed. If the dial shown in Fig. 9 is reversed, multiplied by a factor which depends on the percentage of observations in area 180 that are affected by land and sea breezes, and the average amount of this effect, and then vectorially compounded with Fig. 5, the resulting dial will represent the 24-hr. oscillation in that part of area 180 which is not affected by land and sea breezes. The multiplying factor is unknown, but, whatever its value, the result will be to accelerate the times of maximum and minimum pressure in area 180, and hence to bring them nearer the corresponding values for the land stations (Fig. 7).

The only land data available for north Africa[4] were hourly values of pressure deviation for January, April, July and October for four stations, one of which, Setif, was at 3,350 ft. The data for the other three stations were examined. Some of the hourly values were only interpolated, but those based on observed values gave two sets of six observations at four-hourly intervals, the one set starting at 23h. G.M.T., the other at 1h. Values of amplitude and phase for the 24-hr. and 12-hr. oscillations were computed for each set of observations, the results averaged vectorially, and the phases reduced to mean local time.

The harmonic dials for Algiers, 194 ft., Guelma, 919 ft., and Touggourt, 249 ft., are shown in Fig. 10. Touggourt, about 250 miles from the coast, shows a dial similar to the inland French and Italian stations (Fig. 7), with, however, much greater amplitudes, as might be expected from a desert station, and with the times of minimum pressure about 2½ hr. later. Guelma, about 30 miles from the coast, has times of minimum pressure much earlier than those in Fig. 7, and has not the expected shape for an inland dial, while the four

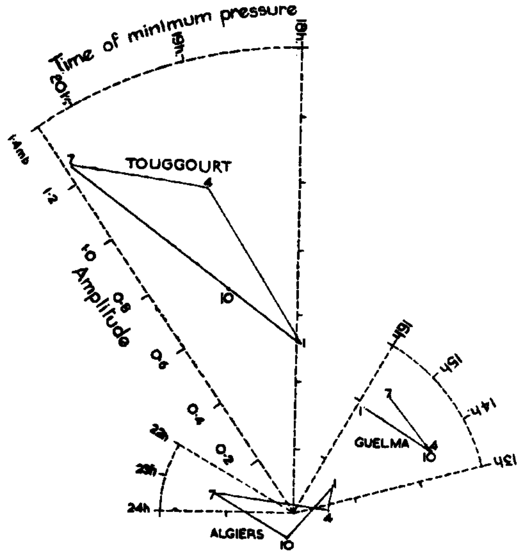


FIG. 10—24-HR. OSCILLATION, ALGERIAN STATIONS

points for Algiers agree with the coastal dial of Fig. 8 in giving small amplitudes for the 24-hr. oscillation.

None of these Algerian data are helpful for a discussion of the dial for area 144, to the north of them.

**The 12-hr. oscillation.**—This oscillation is of a much more general character than the 24-hr. oscillation and less affected by locality ; its variations in the course of the year are much less pronounced than those of the 24-hr. oscillation. These characteristics are all well shown in the Mediterranean data.

Figs. 11–13 show the harmonic dials for this oscillation in the areas 144, 143S and 142. Areas 144 and 142 show much agreement in details. There is very little change in the phase of the oscillation between May and October, but the amplitude is appreciably lower in June and July than in August and September. From October to May the variations, both in phase and amplitude, are relatively great, the dial point moving counter-clockwise, while the phase veers from summer values. In the area 143S, there is again very little change in phase during the summer, and a change in amplitude, between June–July and August–September, of approximately the same amount as in areas 144 and 142. The phase veers from summer values during the winter months, and the dial point moves in a counter-clockwise direction between October and May, but the changes in amplitude and phase during these months, and the mean amount of veer of the phase from summer values, are much smaller than for areas 144 and 142.

For area 141 the dial, based on only 62 observations per watch, is much more irregular, and is therefore not shown. The amplitude is of the order of 0·4 mb. with no marked variations during the year, and the phase veers in the winter from summer values, its total variation in the year being about 35°.

Harmonic dials were drawn for the areas 180 and 179 + 143N for the British and German cards separately. The annual variation of the 12-hr. oscillation showed little agreement between British and German cards, probably because of insufficient data. The British and German data were therefore combined, and harmonic dials drawn for areas 180 and 179 + 143N (Figs. 14 and 15). Although the average number of observations per watch was of the same order

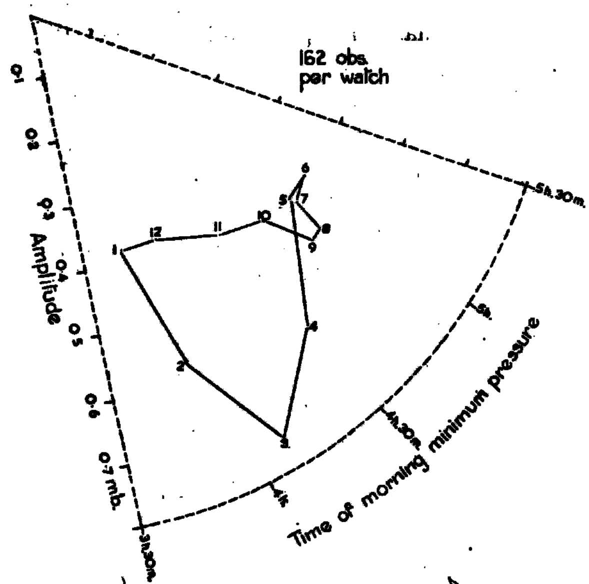


FIG. 11—12-HR. OSCILLATION, AREA 144
(British cards)

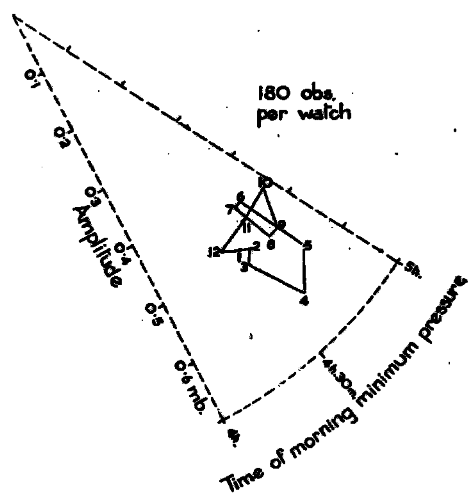


FIG. 12—12-HR. OSCILLATION, AREA 143S
(British cards)

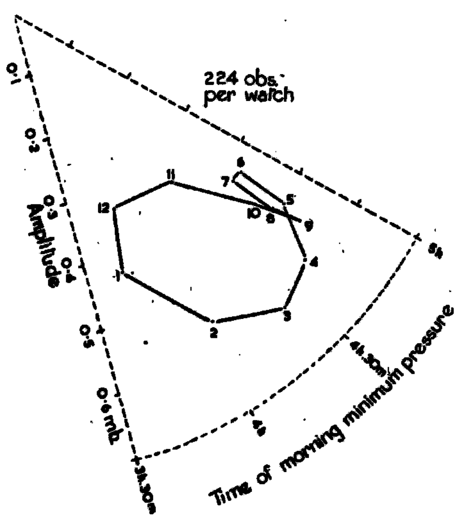


FIG. 13—12-HR. OSCILLATION, AREA 142
(British cards)

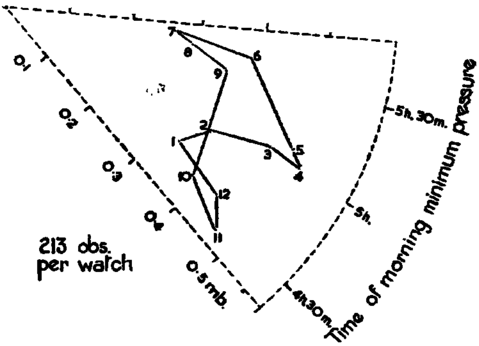


FIG. 14—12-HR. OSCILLATION, AREA 180
(British and German cards)

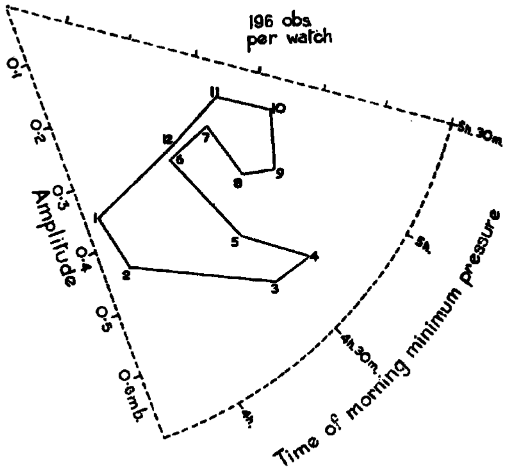


FIG 15—12-HR. OSCILLATION, AREA 179 + 143N
(British and German cards)

as in areas 142, 143S, and 144, the dials are much more irregular. This may be because the northern areas are much more land-locked than the southern.

The areas 180, 179 and 143N were then treated as one area, and the pressure means obtained were smoothed as before, and then harmonically analysed. The harmonic dial thus obtained is shown as Fig. 16. It shows a distinct resemblance to the dials for areas 144 and 142 (Figs. 11 and 13), which suggests that the irregularities of Figs. 14 and 15 are due to insufficient observations.

Fig. 17 shows the harmonic dial obtained by taking the average of the barometric means for Milan, Moncalieri, Lyons, Clermont-Ferrand, and Toulouse. This is the same type of dial as shown by areas 144 and 142, and seems to be the standard type for a large part of the Mediterranean area. The counter-clockwise circuit of the dial point in the colder months is, however, much smaller for the north of the Mediterranean Sea and for the land to the north of it than for areas 144 and 142.

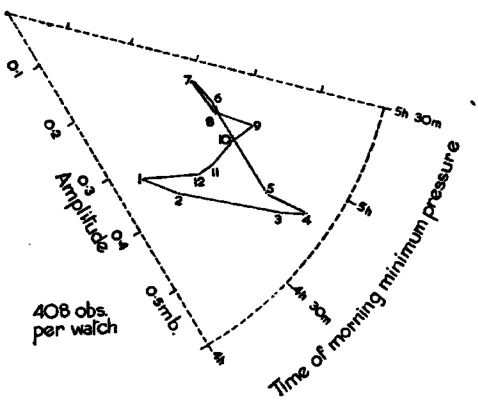


FIG. 16—12-HR. OSCILLATION,
AREA 180 + 179 + 143N
(British and German cards)

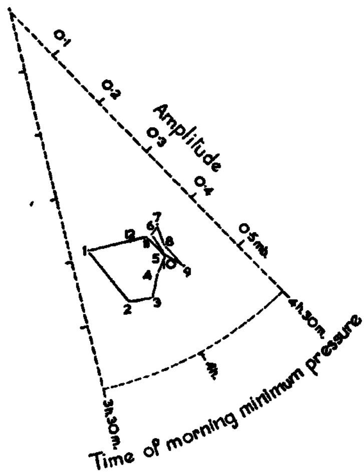


FIG. 17—12-HR. OSCILLATION,
MEAN OF MILAN, MONCALIERI,
LYONS, CLERMONT-FERRAND,
TOULOUSE

Fig. 18 shows the dial obtained by taking the average of the barometric means for the three coastal stations, Marseilles, Nice and Naples. Although irregular, it suggests that, with more data, the same type of dial would be obtained as in Fig. 17.

The annual variation of the 12-hr. oscillation in the Mediterranean Sea and southern France and western Italy, therefore, seems to consist of a change of amplitude, with constant phase, during the summer half of the year, May to October, with a minimum in June or July and a maximum in September, and changes in both amplitude and phase during the remainder of the year, the phase always showing a veer from the summer value. The minimum amplitude is in December or January and the maximum in March or April, while the maximum veer of the phase from summer values occurs about January. The changes during the winter half of the year are represented on the harmonic dial by a counter-clockwise rotation of the dial point, the area encircled during this rotation varying considerably in different parts of the region examined.

The harmonic dials (4 months only) for Algiers, Guelma and Touggourt were also plotted (Fig. 19), but it is not possible to deduce very much from these regarding the shapes of the complete dials. It is obvious, however, from that diagram that they must differ very considerably from the standard type already found for the Mediterranean Sea and some of the land to the north of it. The much higher values of the amplitude at Touggourt suggest very considerable local effects superposed on the general 12-hr. wave.

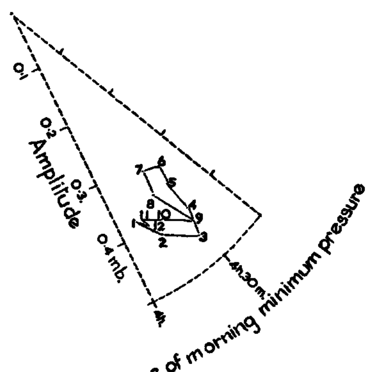


FIG. 18—12-HR. OSCILLATION, MEAN OF MARSEILLES, NICE, NAPLES

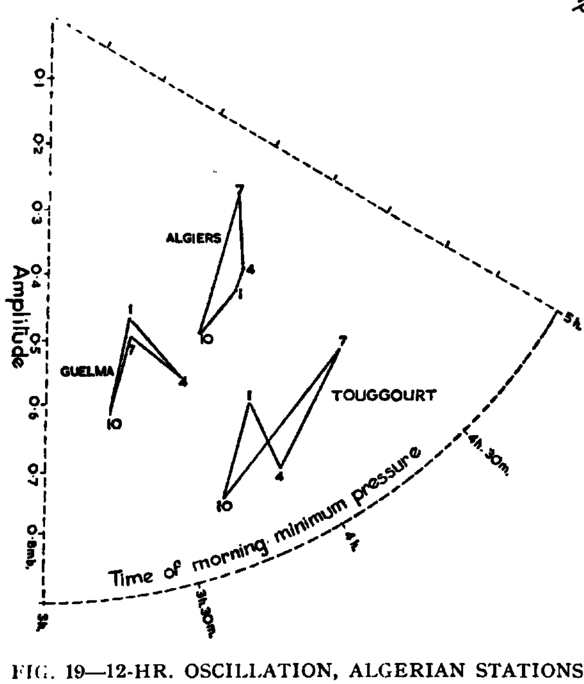


FIG. 19—12-HR. OSCILLATION, ALGERIAN STATIONS

An interesting feature of the 12-hr. oscillation is that the mean annual phases for the marine areas seem to differ appreciably and systematically from those for the land stations. The scalar means of the monthly phases, which in the 12-hr. oscillation should give a fair approximation to the mean annual phase, are given in Table IV.

TABLE IV—MEAN ANNUAL PHASES

| Station | Mean annual phase | Area | Mean annual phase | | | Station | Mean annual phase |
|---|---|---|---|---|---|---|---|
| | | | Observed | Simpson's formula | Difference | | |
| | ° | | ° | ° | ° | | ° |
| Milan .. | 145 | 180+179 | 124 | 145 | +21 | Naples .. | 144 |
| Moncalieri | 148 | +143N | | | | Nice .. | 139 |
| Lyons .. | 149 | 144 | 134 | 148 | +14 | Marseilles | 131 |
| Clermont-Ferrand | 151 | 143S | 129 | 148 | +19 | Algiers .. | 145 |
| | | | | | | Perpignan | 154 |
| Toulouse | 157 | 142 | 136 | 148 | +12 | Guelma .. | 165 |
| Mean .. | 150 | Mean | 131 | 147 | +16 | Touggourt | 151 |

At all the inland stations the phase veers appreciably from the values for marine areas, while coastal stations generally show intermediate values. The difference between the mean annual phase for the sea area 180 + 179 + 143N and that for the five inland stations to the north of it is 26°, which corresponds to a difference of 52 min. in the times of maximum and minimum pressure, the land times being earlier. The difference between the mean for the whole Mediterranean and for the same five stations is 19°. The differences from marine values for Guelma and Touggourt, inland stations in Algeria, are not so reliable, being based on four months only for each station, but are of the same sign and order of magnitude.

**Comparison of Mediterranean with tropical results.**—A phenomenon similar to that shown by Table IV, though not so marked, has been found for tropical seas.[5] The mean phase for all marine areas between 20°N. and 20°S., in all oceans, was found to be 148°. The mean phase for the same regions, computed from a formula given by Simpson[6] and based on land observations, was 154°. The differences for the separate zones are given in Table V, and it will be seen that, except in the southernmost zone of the Indian Ocean, all the values computed from the formula veer from those computed from marine observations.

TABLE V—MEAN ANNUAL PHASES IN TROPICAL OCEANIC ZONES

| Ocean | Zone | Mean annual phase | | |
|---|---|---|---|---|
| | | Observed | Computed | Difference |
| | | | *degrees* | |
| Atlantic .. .. .. | 10–20°N. | 143 | 153 | +10 |
| | 0–10°N. | 144 | 153 | + 9 |
| | 0–10°S. | 145 | 155 | +10 |
| | 10–20°S. | 145 | 155 | +10 |
| Pacific .. .. .. | 10–20°N. | 151 | 154 | + 3 |
| | 0–10°N. | 146 | 154 | + 8 |
| | 0–10°S. | 149 | 154 | + 5 |
| | 10–20°S. | 148 | 154 | + 6 |
| Indian .. .. .. | 10–20°N. | 150 | 153 | + 3 |
| | 0–10°N. | 148 | 153 | + 5 |
| | 0–10°S. | 149 | 153 | + 4 |
| | 10–20°S. | 159 | 154 | − 5 |
| Mean .. .. .. | | 148 | 154 | + 6 |

The values of the mean annual phase on Simpson's formula were also computed for mid points in the four marine areas tabulated in Table IV. The results are shown in that table. The differences from observed values are of the same order as the differences between the values for the marine areas and the land stations to the north. The mean difference is 16°, which corresponds to a difference of 32 min. in the times of maximum and minumum pressure, almost three times as large a difference as the average for the tropics.

It might be suggested that this difference between the land and sea values of the phase is due to the more rapid heating and cooling of the soil, as compared with the water surface, this effect being superposed on the general 12-hr. wave. This explanation, however, would not account for the comparatively small differences found in the tropics, where they might be expected to be much greater than those in the Mediterranean area.

It is of interest to compare the harmonic dials for the 12-hr. oscillation in the Mediterranean area with those for tropical marine regions. In the investigation already referred to, of which a summary[5] was published in 1941, values of the harmonic constants for the 24-hr. and 12-hr. oscillations were computed for each month for four zones of latitude in each ocean, 10–20°N., 0–10°N., 0–10°S., 10–20°S., thus giving six zones in each hemisphere. Harmonic dials for the 12-hr. oscillation have been drawn from those values (unsmoothed), but, although the number of observations available should have been ample to show monthly differences in such a well marked oscillation, the dials showed irregular changes, either because the monthly climatic changes in the tropics are small compared with those in higher latitudes, or because of the large areas over which the observations were averaged. Those for the zones that are nearest to the Mediterranean area, 10–20°N. in the Atlantic Ocean and the same zone in the Indian Ocean, are shown as Figs. 20 and 21.

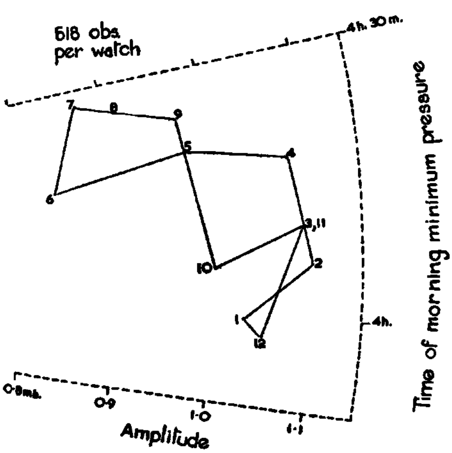


FIG. 20—12-HR. OSCILLATION, ATLANTIC OCEAN, 10–20° N.

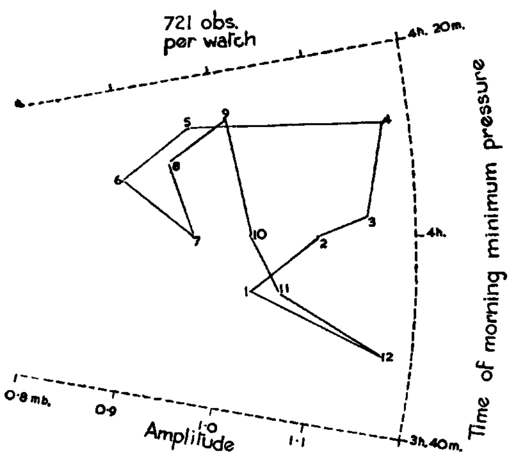


FIG. 21—12-HR. OSCILLATION, INDIAN OCEAN, 10–20° N.

For each month, the amplitudes and phases were averaged over the six northern zones, irrespective of the mean number of observations in each zone. The harmonic dial thus obtained is shown in Fig. 22. A similar dial, for the six southern zones, is shown in Fig. 23.

The comparative regularity of the dial for the six northern zones suggests that this represents fairly well the type for the northern tropics, with little

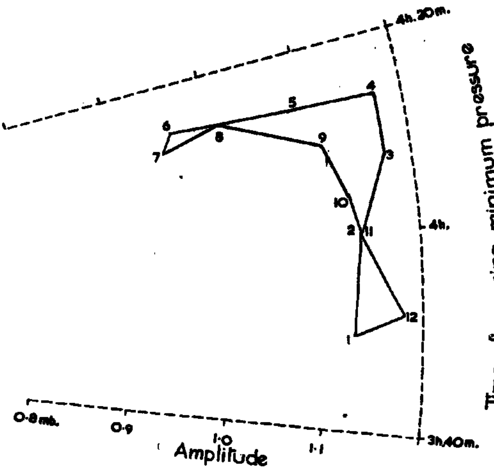


FIG. 22—12-HR. OSCILLATION, MEAN OF SIX NORTH TROPICAL ZONES

**Mean number of observations per watch ranged from 171 to 721 in the various zones**

change in phase during the months of the northern summer, but appreciable changes in amplitude, with a minimum in June or July; in the winter half of the year the amplitude remains fairly steady, but the phase shows a regular swing, veering from the summer value until it reaches its greatest difference from it about the winter equinox, and then backing until it again reaches the steady summer value.

The dial for the six southern zones resembles that for the northern zones, but the changes in phase are smaller. The dial suggests that the reversal of the seasons in the southern hemisphere is already beginning to have an effect. It is somewhat surprising that the marked difference between summer and winter in the 12-hr. harmonic dials of the Mediterranean region should, though in a somewhat altered form, reappear in tropical regions and even beyond the equator. If this difference is typical, not only of the Mediterranean area, but of the greater part of the temperate zone, its occurrence in tropical regions may be explained as due to the much greater proportion of land in the northern hemisphere, and hence the greater effect of solar radiation there on pressure changes.

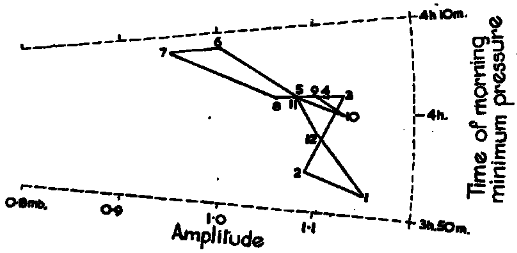


FIG. 23—12-HR. OSCILLATION, MEAN OF SIX SOUTH TROPICAL ZONES

**Mean number of oscillations per watch ranged from 206 to 668 in the various zones**

The chief difference between Fig. 22 and the Mediterranean dials seems to be that the counter-clockwise rotation of the dial point from October to May, which occurs in the latter dials, is missing in the tropical curve. Those changes in amplitude which combine with the changes of phase to give this rotation may be due to the seasonal changes in solar heating in higher latitudes, which superpose local effects on the general 12-hr. oscillation. The smallest amplitudes during the rotation seem to occur, on the whole, near the winter solstice, when solar radiation is least. Against this argument, however, is the fact that this rotation is most prominent in the marine areas 144 and 142, where solar heating should have far less effect than over land even several degrees further north.

The changes in amplitude in the summer months and in phase in the winter months are common to the tropics and the Mediterranean area.

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