ATMOSPHERIC MICRO-OSCILLATIONS

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ABSTRACT

Micro-oscillations in the atmosphere of the order of magnitude of minutes have been known and studied for many years. In 1936 Macelwane, and in 1939 Benioff, with their respective electromagnetic microbarographs showed that the spectrum of these micro-oscillations extends down into the order of seconds. The two different types of microbarographs respond to the same types of stimuli and low-level turbulence is an important source of the micro-oscillations. It is shown that fronts, as such, are not a source of these micro-oscillations, although micro-oscillations may accompany a front. The microbarograph has produced observational evidence supporting Haurwitz's theoretically derived conclusion that there is a similarity between internal wave patterns and convective patterns. It is shown that electromagnetic microbarographs are useful in studying cumulus activity.

1. Introduction

The atmospheric micro-oscillations to be discussed can be divided into two rather broad classes which will be arbitrarily designated as *short-period* and *long-period*. Those micro-oscillations having a period of less than one minute will be called short-period oscillations and those having periods greater than a minute will be called long-period oscillations. In 1889, Helmholtz (10) demonstrated that certain atmospheric oscillations having periods of 5 to 10 min were due to layers of air of different density at their interface flowing over each other. In 1937, Suzuki and Oomori (16) discussed internal waves in the atmosphere; they found that, for periods ranging between 300 sec and 720 sec, such oscillations were associated with quasi-horizontal surfaces of discontinuity at some height above the earth's surface.

In 1925, Goldie (7) reported on the occurrence of short-period gustiness at Falmouth, England, which he was able to correlate with 7- to 10-sec periods of the surf. In 1934, Bradford (3) advanced the hypothesis that certain microseisms are caused by atmospheric micro-oscillations of the same period. To test this hypothesis, Macelwane designed an electromagnetic microbarograph. The atmospheric micro-oscillations recorded by this instrument were arbitrarily classified, according to the different periods, into three classes by Macelwane and Ramirez (13):

(1) Very fast oscillations of varying amplitudes, associated with extremely local disturbances caused by such things as the opening and closing of the door to the instrument room;

(2) Oscillations of very irregular periods varying from 2 to 8 sec. These were quite variable and were found only when the wind speed exceeded 7 to 8 mph. It was also found that to a maximum of wind speed corresponds a maximum amplitude of the micro-oscillations; and

(3) Oscillations made up of longer periods varying from 8 sec to minutes. These were found to be associated with major atmospheric changes.

In 1939, Benioff and Gutenberg (1) reported that with the Benioff microbarograph they had been able to identify elastic waves from gunfire, traffic, blasting, surf, and more or less regular wave trains. They found, too, that their instrument reacted very strongly to local convection. They also noted a time relationship between changes in the character of atmospheric oscillations and the passage of cold fronts. In 1941 they (2) reported on further investigations with the Benioff microbarograph, and among other things showed that three similar instruments recording at the same point react practically identically to a given impulse.

2. Electromagnetic microbarographs and their records

The Macelwane microbarographs in use at present differ from the model described by Macelwane and Ramirez (13) only in refinements of construction. Recording is done galvanometrically on a photographic-type seismic recorder. In 1946, a twenty-second Leeds and Northrup galvanometer was employed, while in 1938, and at present, a six-second Leeds and Northrup galvanometer is used. When adjusted as described by Macelwane and Ramirez (13), the Macelwane amplitude scale is such that 1 cm trace deflection is approximately equal to a sudden change of pressure of 3 dynes per square centimeter. The natural period of the instrument is about 0.12 sec.

The Benioff microbarograph in use is essentially the same as that described by Benioff and Gutenberg (1). At present a 0.5 sec Sprengnether galvanometer is being used. The amplitude scale for the Benioff instrument is about 1 dyne per square centimeter for 1 mm of trace deflection.

The microbarograms vary in appearance from straight lines to overlapping lines; both regular and irregular wave forms are recorded. There is a considerable range of periods and short periods are frequently superposed on long periods. To date, the most satisfactory method of reading these microbarograms for comparison with weather elements is to select the most representative period and amplitude for each hour. Although subjective, this method has been found to be the most satisfactory scheme yet tried. For convenience, double amplitudes are measured and recorded.

3. The oscillations

The data on which the rest of this report is based were largely gathered in the summer of 1946 (12), at which time the Institute of Technology, Saint Louis University, cooperated with the U. S. Navy and the U. S. Coast and Geodetic Survey in operating both the Benioff and Macelwane microbarographs at Sitka, Alaska; Bozeman, Montana; Rapid City, South Dakota; Tucson, Arizona; Florissant, Missouri; Chicago, Illinois; and San Juan, Puerto Rico. In 1948, Saint Louis University contracted with the Office of Naval Research to investigate in detail the nature and origin of the recorded atmospheric micro-oscillations (12).

For reasons as yet unknown, the 1946 microbarograms from Rapid City were so complex as to defy detailed analysis; because of this, these records have been set aside until more is known concerning the general nature of atmospheric micro-oscillations. At San Juan, weather observations were available only at three-hourly intervals; hence these records were not compared with the records from the other stations, for which hourly weather observations were available. For the five stations used, the distance and azimuth from the microbarograph site to the nearest weather station, and the periods during which the microbarographs were operated, are shown in table 1. The U. S. Weather Bureau furnished hourly weather observations for these stations, as well as six-hourly surface maps, upper-air maps, and winds-aloft data from the stations nearest each of the microbarograph sites.

TABLE 1. Location data for 1946 microbarograph operations.

Station	Distance	Azimuth	Period
Florissant	4 miles	198°	6/30/46–8/22/46
Chicago	6	270°	6/20/46–8/ 6/46
Tucson	10	210°	6/27/46–7/ 4/46 7/21/46–7/28/46
Bozeman	9	323°	7/20/46–9/ 1/46
Sitka	1	0°	6/25/46–8/ 5/46

It is proposed to discuss first the oscillations themselves, from a statistical viewpoint. Secondly, the relation between weather phenomena and the micro-oscillations will be discussed. Finally, the 1948 data from the tripartite station at Florissant, Missouri, will be discussed.

The range of periods for the Macelwane microbarograms was from 1 to 1400 sec with a mean of 81.70 sec. For the Benioff microbarograms, the range of periods was from 1 to 360 sec with a mean of 34.80 sec. Pearson-type frequency distributions were derived, using the method of Craig (6); the distributions derived appear to have no theoretical significance.

Correlation with weather elements.—As the records were taken for summer conditions, it is to be expected that the separation of the microbarograph sites and the weather stations will have an effect on the degree of correlation between certain weather elements of a localized nature and the microbarograms at the time (1).

Even a casual study of the summertime microbarograms reveals that there is a diurnal variation of the oscillations. Because this diurnal variation appeared to coincide in time with that of the temperature, the median hourly amplitude of the micro-oscillations was determined for Florissant, Bozeman, Tucson, and Sitka, as were the median hourly temperatures for these stations. For each station the times of minimum median hourly amplitude and maximum hourly amplitude agree rather well with the times of minimum and maximum hourly temperature respectively. This suggests a cause and effect relationship. The application of statistical correlation techniques produced no significant results. However, this is not surprising, since the temperature variation is a function of several physical quantities. The diurnal variation of temperature during the summer is a good index of the diurnal variation of low-level turbulence and low-level turbulence is a phenomenon which readily can be conceived as producing many of the types of micro-oscillations recorded.

By way of illustration, the 1946 data from Tucson are reproduced. There were fifteen days between 27 June and 28 July 1946 when there were hourly records of temperature and of amplitude. The minimum median hourly amplitude of 1 mm occurred from 0100 MST to 0900 MST and from 2300 MST to 2400 MST. The maximum median hourly amplitude of 11 mm occurred at 1600 MST. The minimum median hourly temperature of 74F occurred from 0400 MST to 0500 MST and at 0700 MST; the maximum median hourly temperature of 97F occurred at 1500 to 1600 MST. Fig. 1 is a graphical representation of the data. Included in this figure are the actual minimum hourly amplitudes for Tucson, which was the only station of the five for which this rough parallelism between the minimum hourly amplitude curve and the median hourly amplitude curve was so pronounced.

The minimum hourly amplitude curve for Tucson (fig. 1), in conjunction with the temperature curve, suggests that the turbulence associated with cumulus clouds may also be a source of these micro-oscillations. The ground surface in the vicinity of Tucson is highly favorable to the occurrence of afternoon convection due to surface heating. Comparison of these curves suggests that the first effect of afternoon convection is dampening of the micro-oscillations due to a reduction of incoming energy by formation of a cloud cover. By 1600, the convective activity has reached its peak, producing an increase in micro-oscillations accompanied by decreasing surface temperature. By 1700, the clouds have begun to dissipate, as a rule, causing a brief rise in temperature accompanied by a fall in amplitude of the micro-oscillations.

A brief comparison with synoptic data of the prolonged periods of high-frequency large-amplitude oscillations that occur from time to time led to the discovery that, at Tucson in particular, such activity was occurring coincident with the passage of a cold front. However, on 6 October 1948, a well developed cold front passed over the tripartite station at Florissant, and during the time when this front was actually over the station the microbarographs traced practically straight lines. For some time before the frontal passage and a few hours subsequent to the passage, the activity was moderately intense. The fact that all three microbarographs at Florissant were practically dead at the time of the frontal passage shows conclusively that the source of these micro-oscillations of this character is not something that is essential to the concept of a front.

The Florissant data for 1946 were analyzed with respect to the weather elements listed above, comparisons being made with both the Macelwane and the Benioff microbarograms. The period covered was from 30 June to 22 August 1946. Table 2 and table 3 present the convective weather elements occurring at Florissant, as compared with the Macelwane and the Benioff microbarograms, respectively. The weather elements are arranged in order of decreasing intensity of turbulent motion, except that it is not intended to suggest that increasing intensity of precipitation is necessarily a sign of increasing turbulent motion. The records from both instruments indicate that as the intensity of convective phenomena increases the representative amplitude increases. This further substantiates the indications that some form of turbulent motion is a source of atmospheric micro-oscillations. The four-mile separation between Florissant and the Weather Bureau station at Lambert Field is used to explain the fact that the mean amplitude associated with light rain is greater than for showers. In general, summertime showers will have less horizontal extent than will light rain; therefore a shower observed at Lambert Field could easily pass sufficiently far from the microbarograph site so that there would be little or no response by the microbarograph, but this is less probable with steady rain. This, of course, implies that the amplitudes recorded are a function of the proximity of the source as well as the intensity of the source (1).

Table 4 gives the distribution of convective activity of all types with respect to representative periods on the Macelwane microbarograms from Florissant. Included are only those weather observations in which

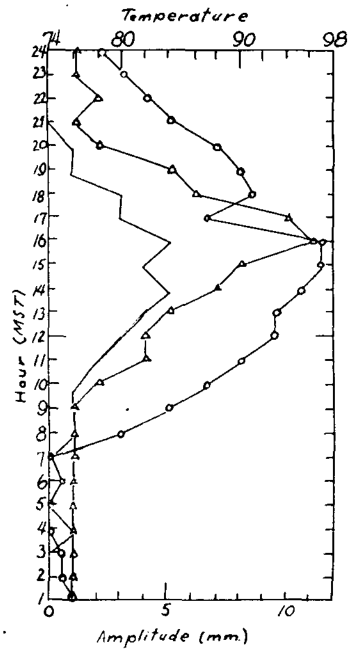

FIG. 1. Diurnal variation of temperature (circles) and Macelwane amplitudes (triangles) at Tucson, Arizona for July 1946. Median hourly values plotted, except curve to left is actual minimum hourly values of amplitudes. Microbarograph site ten miles from weather station.

TABLE 2. Comparison of convective weather elements at Florissant with Macelwane microbarograms.

Weather element	Number of cases	Amplitude range mm	Mean amplitude mm
TRW+	2	14–15	—
TRW	6	3–15	9.0
TRW–	16	1–18	8.3
T	4	3– 9	6.0
RW–	44	0–13	3.3
R–	12	2–11	6.5

TABLE 3. Comparison of convective weather elements at Florissant with Benioff microbarograms.

Weather element	Number of cases	Amplitude range mm	Mean amplitude mm
TRW+	1	8	—
TRW	6	2–8	5.3
TRW–	10	1–9	3.9
T	2	3–5	—
RW–	41	0–8	2.4
R–	12	1–8	4.3

Table 4. Distribution of convective elements with respect to micro-oscillation periods at Florissant (Macelwane instrument).

Period sec	Number	Period sec	Number	Period sec	Number
0	9	260	6	280	3
1–20	9	320	1	640	2
21–30	38	340	2	710	1
31–40	38	360	6	760	5
41–50	6	400	6	800	2
51–60	2	440	4	840	1
61–70	4	450	3	900	1
81–100	4	460	2	980	1
120	1	500	4	1100	3
160	2	520	1	1400	1
210	1	550	2		
				Total	175

convective elements are specifically identified, using the three-hourly reports as a basis. Attention is directed to the fifty-one cases for which the periods were in excess of 300 sec. Suzuki and Oomori (16) in 1937 discussed internal waves in the atmosphere; they found periods ranging from 300 sec to 720 sec. They also found that such waves were associated with quasi-horizontal surfaces of discontinuity at some height above the earth's surface. Here we find twenty-nine per cent of the positively identified cumulus developments which were observed at three-hourly intervals during a seven weeks period in midsummer to be associated with micro-oscillations of the same order of magnitude as for internal waves. There were also thirty-four instances of micro-oscillations having periods in excess of 300 sec at times when no convective phenomena occurred and when conditions were favorable to the existence of internal waves in the atmosphere. Thus, if we can consider the micro-oscillations recorded to have been caused by the phenomena mentioned, these instances can be regarded as observational evidence in support of Haurwitz's (9) theoretically derived conclusion that there is a close relationship between internal wave patterns and convective patterns.

The cases of zero deflection on the microbarograms can be explained as cases for which the cumulus developments reported at Lambert Field were not present at Florissant, four miles away. This implies that for a cumulus development to cause a response by the microbarograph, it must pass sufficiently close to the microbarograph site. This latter concept of proximity of a cumulus development to the microbarograph site, when considered in the light of the wide range of periods associated with cumulus developments, suggests that the period of oscillation is a function of the horizontal dimensions of the cloud which has passed over the microbarograph site; *e.g.*, when a thunderstorm of a given size passes over the microbarograph site the longer periods are representative of the portion of the storm which passed directly over the microbarograph and the very short period oscillations are produced by turbulent motion occurring around the periphery of the storm. Such a conclusion is in agreement with the hypothesis, advanced by Brunt (4), of convection cells which are similar to, or are a more complex form of the Bénard cells; or of the thunderstorm cell described by Byers and Braham (5).

Occurrences of fog, smoke, and haze at Florissant during the summer of 1946 were also compared with the microbarograms. Table 5 and table 6 present the comparisons with the Macelwane and Benioff microbarograms respectively. It should be noted that the Macelwane microbarograms were compared with these weather elements directly, while the Benioff microbarograms were compared with these elements in wind speed groups according to the wind speed and weather element occurring together. The difference between these tables is of considerable interest. Both tables show that there are micro-oscillations occurring simultaneously with fog, smoke, and haze. From the comparison with the Macelwane microbarograms (table 5) it is apparent that fog, smoke, and haze, of themselves, are not related to the intensity of the micro-oscillations. The comparison with the Benioff microbarograms (table 6) shows that increasing intensity of the micro-oscillations accompanies increasing wind speed. This, too, suggests that low-level turbulence is one of the sources of these atmospheric micro-oscillations, it being generally accepted that for any appreciable amount of smoke particles or fog droplets to be supported in the atmosphere there must be some vertical motion.

Table 5. Comparison of fog, smoke, and haze at Florissant with Macelwane microbarograms.

Weather element	Number of cases	Amplitude range mm	Mean amplitude mm
Fog	51	0–20	5.1
Ground Fog	33	0– 5	1.2
Smoke	151	0–20	2.9
Haze	9	3– 6	4.1

Table 6. Comparison of Benioff amplitude versus wind speed for fog, ground fog, smoke, and haze at Florissant.

Weather element	0–4 mph	5–9 mph	10–11 mph	15–19 mph
Fog	0 mm	1–3 2 mm*	2–8 4 mm*	10–13 11 mm*
Ground Fog	0–1 0 mm*	0–2 1 mm*	—	—
Smoke	0–2 0 mm*	1–5 2 mm*	—	4–5 4 mm*
Haze	—	1 mm	—	11 mm

Note: Upper value denotes range in millimeters and lower (*) value is mean in millimeters.

The comparisons of the Macelwane microbarograms and hourly weather reports for the four other stations gave comparable results.

TABLE 7. Florissant wind speed versus median amplitude.

Speed mph	Macelwane amplitude mm	Benioff amplitude mm
0–4	1	0
5–9	2	1
10–14	4	3
15–19	6	3
20–24	9	7

The study of the relation between microbarograms and surface winds was in agreement with the findings of Macelwane and Ramirez (13). It was found that the amplitude of the oscillations increases with increasing wind speed. Table 7 shows the distribution of wind speed versus median amplitude for the Florissant data.

Tripartite Data.—The tripartite station at Florissant has been in operation since September 1948. The Macelwane microbarographs in use there have been adjusted to deflect the same amount for a given sudden change in pressure; they were operated side by side for several days to check this adjustment and it was found that the records from the three instruments were practically identical (fig. 2). Benioff and Gutenberg have found similar results with the Benioff instruments (2).

The tripartite records were studied with a view toward identifying a given impulse as having passed each of the three stations. During the period 1 October 1948 to 16 February 1949, the greater part of the oscillations occurring at Florissant were high-frequency oscillations. There were found to be marked differences in the appearances of the records from each of the three stations. The records from the microbarograph in the vault were least disturbed at all times. Those from Station 2 were generally next, although on some occasions the Station 2 records were more perturbed than those from Station 1. The records from Station 1, up on a ridge, were generally most perturbed. None of the high-frequency oscillations could be identified at each of the stations with any degree of assurance, although there were instances when a particular oscillation could be identified at two of the stations but not at the third.

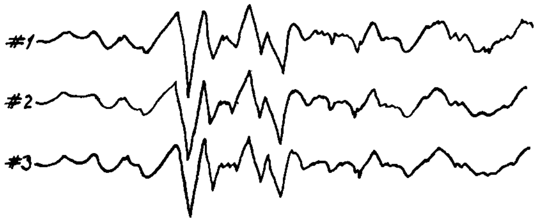

FIG. 2. Tracings of records from Macelwane microbarographs at Florissant, Missouri, for 14 November 1948. The three instruments were side by side in the vault at this time. Instrument No. 1 now at Station One, instrument No. 2 now at Station Two, and instrument No. 3 now in vault.

During the night of 14 February 1949, a number of long-period oscillations were recorded at the tripartite station which could be identified on each of the three microbarograms. These oscillations produced traces that were nearly sinusoidal; the periods were of the order of magnitude of one hundred seconds. The record from the vault was quite well defined and free of superposed high frequency oscillations; the records from Stations 1 and 2 showed superposed high frequencies, but the waves were well defined. Table 8 gives the Lambert Field weather for the period during which these oscillations occurred.

TABLE 8. Lambert Field weather observations for 14 February 1949.

Time CST	Ceiling (100's of ft)	Sky	Visibility miles	Weather and obstructions to vision	Wind Dir.	Wind Speed
1700	W1	×	¼	ZR-F	NW	3
1715	W1	×	¼	ZR-F		
1725	W1	×	¼	R-F	NW	4
1732	W1	×	¾	R-F	S	7
1739	W1	×	¼	R-F	SE	9
1745	W1	×	¼	R-F		
1755	W1	×	½V	R-F	N	4
1800	W1	×	½V	R-F	N	4
1815	W1	×	½V	R-F		
1825	W1	×	½V	TR-F	NE	5
1828	W1	×	½V	TR-F	NE	4
1845	W1	×	½V	TR-F		
1855	W1.5	⊕	½	TR-F	SSW	4
1902	W2	×	½	TR-F	NE	4
1915	W2	×	½	TR-F		
1925	W2	×	½	TR-F	NE	4
1945	W3	×	½	R-F	NE	4
2000	W3	×	½	R-F	NE	3
2025	W2	×	½	R-F	S	2
2128	W2	×	1	R-F	WNW	10
2225	W4	⊕	2	R-F	WSW	9
2326	W9	⊕4⦶	3	R-F	W	12

Using the formulae for direction published by Macelwane (14), and that for speed used by Ramirez (15), the direction and speed of the source of two of these oscillations were computed. The first instance occurred about 1955 CST, passing each station at the time indicated:

Station 2	1955 + 51 sec
Vault	1956 + 03 sec
Station 1	1956 + 12 sec.

The speed was computed to be 41 mph and the azimuth to the source was computed to be 267°. The second oscillation occurred about 2312 CST with the times of passage as indicated:

Station 2	2312 + 28 sec
Vault	2312 + 41 sec
Station 1	2312 + 43 sec.

The computed speed is 47 mph and the computed azimuth to the source is 300°. There is a rather suggestive agreement between these two values and the Columbia, Missouri *RAWIN* for 2100 CST 14 February 1949, the 4000-ft wind being 260°, 45 knots.

4. Conclusions

The Macelwane and Benioff microbarographs are responding to the same stimuli, as is shown in the study of Saint Louis records for both instruments. This is further borne out by the report of Benioff and Gutenberg (1) in 1939 concerning the effects of convective activity on the Benioff microbarograph.

Atmospheric turbulence is an important source of the micro-oscillations. At present the investigation has not proceeded sufficiently to permit specifying with any degree of certainty the levels at which this turbulence is occurring, although the studies of diurnal variation of amplitude and of the relation of wind speed to microbarograph amplitudes indicate that low-level turbulence is an important source of the oscillations. The increase of amplitude with increasing intensity of convective activity indicates that sources of turbulence at some height above the ground are also of some importance. This would suggest that the microbarographs should be of some value to persons engaged in crop dusting by airplanes, as it has been found that such endeavors are a function of the degree of surface turbulence (8).

Nothing that is essential to the concept of a front is causing these oscillations, although weather phenomena which frequently occur with a front may produce extended periods of extreme activity by the microbarograph; but these same weather phenomena would produce similar activity when they occur without a front.

Both the 1946 data and the tripartite data from Florissant provide evidence that internal waves and convective elements have horizontal dimensions of the same order of magnitude. But, more than this, they provide further evidence in support of the convective cell theory proposed by Brunt (4), and by Byers and Braham (5). The sequence of events visualized as accompanying such a cell, highly simplified, is as follows: the cell consists essentially of a ring vortex (11) with descending velocities around the outer periphery of the ring and ascending velocities around the inner periphery of the ring. The descending current, as it approaches the ground, is decelerated and the decelerating force results in an increased pressure gradient at the ground. At the ground the converging currents at the lower portion of the cell also result in an increased vertical pressure gradient below the ascending current. As this cell moves more or less horizontally through the air, these vertical pressure gradients move along with the cell; thus as a cell passes over the microbarograph site the instrument will first react to an increase in pressure. Then the pressure will decrease, followed by an increase associated with the ascending velocities, then a decrease, again followed by an increase in pressure associated with the outer descending current. Such a hypothesis demands two complete oscillations for a complete convective cell.

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