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THE ACOUSTIC SOUNDER: POLLUTION FIGHTER'S TOOL

H. Dean Parry

Systems Development Office
Silver Spring, Md.
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Weather Bureau Technical Notes

TN 41 EDL 1 Infrared Cloud Cover Detector. Ferdinand H. Zegel, May 1966. (PB-173-427)

ESSA Technical Memoranda

WBTM EDL 2 Notes on Wind Measurement. Herman H. Crouser, August 1967. (PB-175-774)

WBTM EDL 3 A Wind Vector Component Accumulator. Herman H. Crouser, December 1967. (PB-177-143)

WBTM EDL 4 A Selective Precipitation Indicator. Richard C. Peck, July 1968. (PB-179-344)

WBTM EDL 5 A Viscous Damped Wind Vane. D. T. Acheson and H. H. Crouser, October 1968. (PB-180-551)

WBTM EDL 6 Winds Aloft Measurements Through LORAN C Navigation Aid. Christos Harmantas, October 1968. (PB-183-989)

WBTM EDL 7 A Weather Data Radio Telemetry System. Robert R. Knibb and Francis V. Kohl, January 1969.

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WBTM EDL 9 Remote Readout Panel for a Digital Precipitation Gage. Francis V. Kohl, March 1969. (PB-183-056)

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Robert M. White, Administrator

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George P. Cressman, Director

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THE ACOUSTIC SOUNDER: POLLUTION FIGHTER'S TOOL

H. Dean Parry

ABSTRACT. A measurement of the depth of the mixing layer is shown to be an important parameter in understanding and dealing with the air pollution problem. A model is proposed which uses this measurement and surface wind measurements to provide a good approximation to the ventilation rate. The pure acoustic sounder (PASS) is capable of measuring the depth of the mixing layer by measuring the height and thickness of inversions and the height to which convections extend. The acoustic sounder continuously monitors this depth, even through smog, fog, or low clouds and thereby provides constantly updated information as well as information on the time rate of change of this depth.

1. INTRODUCTION

A recent study has indicated a cause-effect relationship between polluted air and lung cancer. If one believes that smoking causes cancer, one can choose not to smoke. Unfortunately mankind does not have a similar choice about breathing. For those fortunate enough not to die as a result of a polluted atmosphere, there are compelling esthetic reasons to require a minimum standard of air cleanliness. The right to an atmosphere that does not endanger health, assail the sense of small or obscure the beauties of the world around us is a very basic form of liberty which each of us should treasure. Government at the local, state, and national level as a protector of liberty must concern itself with the problem of keeping the air clean.

2. AIR POLLUTION AND WEATHER

Accepting that maintenance of a certain quality of air over a city, state, or region is a proper function of government, it follows that government must have information, on a real time basis, about the mechanism by which the air is polluted. The most casual observation indicates that the severity of pollution is highly variable. Furthermore, it is commonly understood that the reason for this variability is the variability of the weather.

Just as rivers and the oceans regrettably are used as sewers for liquid wastes, the atmosphere serves as a sewer or dumping place for gaseous wastes. The amount of gaseous waste produced by a metropolitan area is nearly constant on any five working days. The same commuters are driving their cars to work. The same factories are operating. The same electric generating plants are operating. The same oil refineries are on stream. The difference in the severity of air pollution from one day to the next is produced by the difference in the atmosphere's capability to assimilate and carry off gaseous wastes. Rain and snow wash out the gaseous wastes. There is no other mechanism operating in or on the atmosphere to decrease the severity of pollution. (In passing, it should be noted that the converse is not true. Ultraviolet components of sunshine act on certain pollutants in the atmosphere to make them even more noxious. This is one source of the strong eye irritants in the polluted atmosphere.) In the absence of precipitation (rain, snow, drizzle, etc.) all pollution dumped into the air stays there. If a small volume of stagnant air must accept the pollutants from a city, a high concentration of pollutants will be produced quickly and there will be a pollution emergency. If there is a strong wind, pollutants will be carried away and no emergency will occur. Even if the winds are light and the pollutants can be mixed through a deep layer of air, the concentration of pollutants will be nominal and no pollution emergency will occur.

Figure 1 represents a somewhat idealized model of a metropolitan atmosphere. The area of the earth's surface occupied by the metropolis is depicted by the square ABCD. The surface EFGH is the top of the layer through which the gaseous wastes are mixed. The mean wind vector for the layer is represented by the arrow in the center of the diagram. It is assumed that the wind is blowing normal to the side of the volume, FBCG.

The depth of the layer through which the pollutants are mixed, FB, is determined by one of two conditions. If there is an unstable layer capped by a temperature inversion, the height will be at the base of the inversion (Figure 2). If no inversion exists, the height of the top of the mixing layer, FB, is determined by the height to which surface convections or surface turbulence extends (Figure 3). The simplest form of a new acoustic sounder is uniquely adapted to measure the depth of the mixing layer since it can detect and measure the height of both inversions and the tops of convections. As it turns out, a considerably more sophisticated form of the acoustic sounder can also measure the wind profile. The meteorology of air pollution is such that during an air pollution event, the wind is always light and nearly constant within the mixing layer. For this reason, the surface wind may be assumed to be representative of the wind in the mixing layer and the only information in addition to the surface wind that is required in order to monitor the magnitude of the pollution threat is the depth of the mixing layer. In other words, in order to determine the pollution threat, only the volume of stagnant air through which the pollutants will be mixed must be known. To know this volume only the height of the mixing layer must be measured. Typically, this height is between a few hundred feet and a few thousand feet. It is measured now by releasing one or more radiosondes each day.

3. THE ACOUSTIC SOUNDER

Although the first acoustic sounder of the atmosphere was built by McAllister, an Australian, in 1968, he may have been a few million years late. Bats have been using a navigation system based on the same principles for at least that long. The acoustic sounder like the bat can "see" in the dark and can "see" through fog and clouds which are opaque to light. Only two kinds of weather disrupt the sounder's operation. The wind noise of strong winds (above about 30 mph for the present design) drown out the echoes. The noise of heavy rain hitting the loudspeaker array also drowns out the signal. These two disruptive kinds of weather occur only a very small percentage of the time, hence the acoustic sounder is a highly reliable instrument.

The version of monostatic acoustic sounder whose results are to be discussed here is depicted by the block diagram of Figure 4. The array of 100 loudspeakers acts as both a sound transmitter (loudspeaker) and a sound receiver (microphone). The tone generator is a simple oscillator. It is activated for 1/10 second by the timer which also connects the antennas to the transmitter amplifier. The transmitter amplifier amplifies the power of the oscillator to about three kilowatts and feeds it into the antenna through the switch. The sound pulse that the speakers produce propagates vertically upward in a quite narrow beam. All layers of the atmosphere send a small part of the sound back downward, with some layers sending back bigger echoes than others. At the end of the 1/10 second, the switch disconnects the antenna from the transmitting amplifier and connects it to the receiving amplifier. The echoes received are far below the threshold of hearing but are amplified in the receiving amplifier by 150 dB. Speed of sound may be assumed constant within a few percent and the time of return of each echo is relatable to the height from which it came. (This is the same ranging principle used in electromagnetic radar.) The amplified echoes are fed into a facsimile type recorder so that each sweep of the recorder represents the echoes from a single pulse. The height is plotted latitudinally across the recorder paper and the echo intensity at any height is proportional to the blackening of the paper at that point on the height scale. Figure 5 is a sample of such a chart. On this chart, time is the abscissa, height is the ordinate and the intensity of the echo at any height and time is the darkening of the paper at the point corresponding to these coordinates. The black vertical stripes across the chart are produced by noise of aircraft landing and taking off from Dulles Airport,which is only a few tenths of a mile away from the acoustic sounder that produced the record of Figure 5.

4. INTERPRETATION OF ACOUSTIC SOUNDER RETURNS

It is obvious from Figure 5 that echoes from various heights in the atmosphere are not the same. The problem of why the atmosphere sends a stronger echo at one level than another has been attacked on two fronts. First, theoretical work by Monin, Tatarski,and many others has shown that backscatter of sound by the atmosphere is caused by the temperature structure function that exists in the atmosphere. Second, empirical observation has shown that strong echoes are sent back from temperature inversions and from convection cells. Theory and observation easily can be brought into congruence and used jointly to further the interpretation of the acoustic sounder returns.

Since this discussion emphasizes a practical application of the acoustic system, empirical relationships will be emphasized. A typical kind of acoustic sounder return is shown in Figure 6. Superimposed on the return is the temperature profile measured by a radiosonde released from a point only 300 meters away from the sounder. The profile is placed at the radiosonde release time on the sounder record and the profile height scale is made to correspond to the height scale of the acoustic record. The straight line sloping upward and to the left from the point at which the temperature profile intersects the ground is the dry adiabat for the temperature and height scales used on the chart and is for reference purposes only. Figure 6 provides a classic example of the returns from an acoustic sounding into a stable atmosphere. There are solid returns through both inversions. The returns from the deep surface inversion contain detail of the temperature structure that is not shown by the radiosonde. At this juncture, it is not possible to say whether these are details in the temperature structure function not reflected in the temperature profile, or whether the macroscale radiosonde smoothes over the meso- and microscale variations in the temperature profile, or whether, as seems most likely, both alternatives occur. There is also a weak return about 100 meters above the upper inversion. In all probability this return comes from a third inversion that is too weak and/or thin to be shown on the temperature profile produced by the macroscale radiosonde,which has very limited resolution. The cause of this weak return must remain somewhat speculative pending the development of a better low level temperature profiler than the present macroscale radiosonde.

Figure 7 shows returns from an unstable atmosphere. Again the black vertical strips are aircraft noise and must be ignored. The insert shows that the lapse rate through the first kilometer is very close to the dry adiabatic (shown by the dashed line). The only returns from the atmosphere are from low-level convections rising from the ground. Convection produces a vertical pattern, whereas the returns from a stable layer are generally horizontal. Thus, the two types of returns are visually differentiable.

To summarize then, the simple monostatic acoustic sounder that is here discussed –

1. Detects the presence of inversions and convections.

2. Measures the heights to which convections are extending and the height and thickness of inversions.

5. APPLICATION OF THE ACOUSTIC SOUNDER RECORDS TO THE AIR POLLUTION PROBLEM

It has been shown above that the height of the pollution mixing layer is determined by the height of the base of the low-level inversion or by the height reached by convection cells. Both the latter heights can be read directly from the analog (facsimile type) record of the acoustic sounder. This is a most promising device for monitoring the air pollution threat. These measurements are available on essentially a real time basis. The only data integration and processing required is done by the facsimile recorder. The maximum delay in reading the required heights is five minutes, the integration time required in the recorder record. The fact that the height of the mixing layer can be monitored on a real time basis also permits measurement of the rate of change of its height. This type of information is of considerable value in predicting whether the pollution level will increase or decrease in the near or intermediate term -- i.e., during the next 12 hours. Such predictions can be used as a basis for restricting the operation of factories and other pollution producing activities, or with favorable indications, lifting such restrictions.

Continuous monitoring also permits detection of small-scale phenomena. Figure 8 is an example of this. Several strong inversion returns appear on this record before 6:00 PM. Suddenly the inversions are destroyed by what appears to be a rapid rising of the air from the surface. Within about an hour the inversions appear to have returned to their original levels. Several radiosondes taken one after another with only very short intervals between would be necessary to detect such small-scale phenomena.

6. CONCLUSIONS

It has been shown that:

1. A measurement of the depth of the mixing layer is an important parameter in understanding and dealing with the air pollution problem.

2. The acoustic sounder is uniquely adapted to making such measurements.

3. The sounder continuously monitors this height and thereby provides constantly updated information as well as trend data.

4. The sounder works in all kinds of weather, with the possible exception of conditions of strong winds and heavy rain -- conditions under which no air pollution problem can exist.

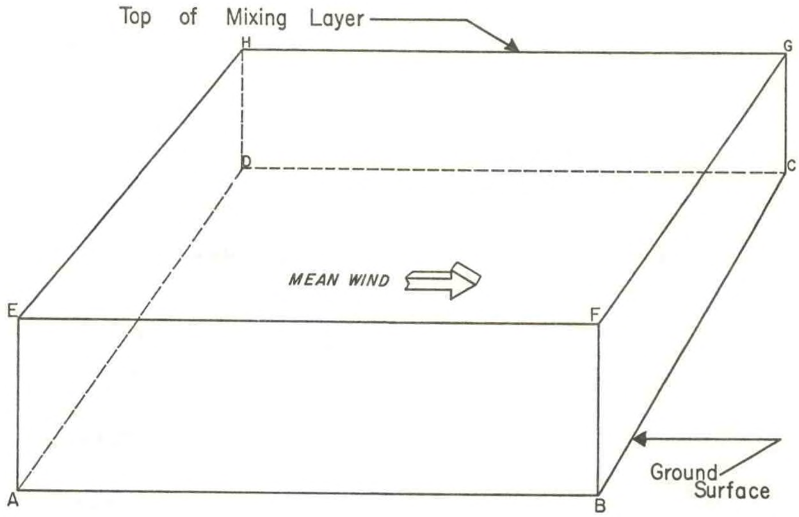

Figure 1. -- Idealized depiction of a metropolitan atmosphere.

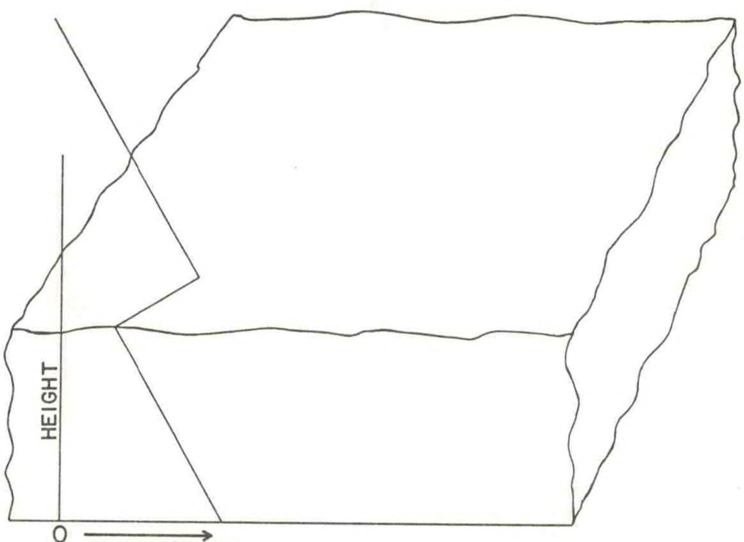

Figure 2. -- Relationship between the polluted surface layer of air and the temperature profile.

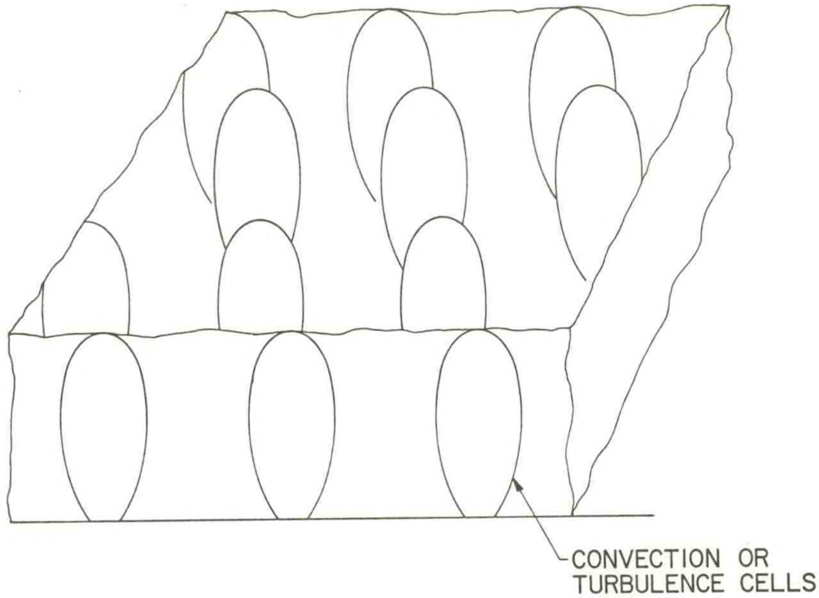

Figure 3. -- Schematic diagram of convection cells in the polluted surface layer of air.

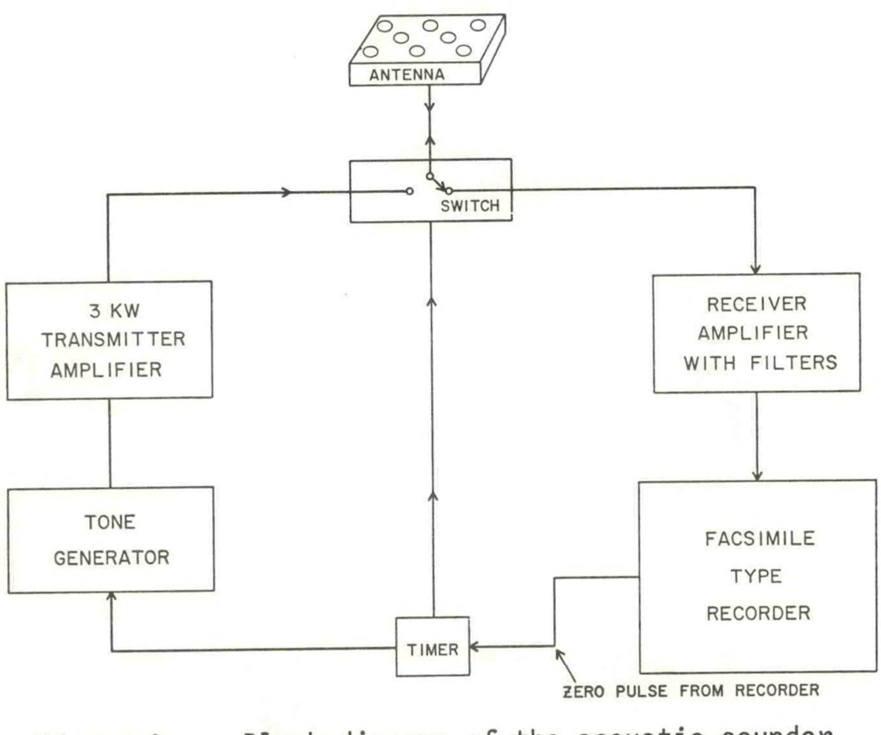

Figure 4. -- Block diagram of the acoustic sounder.

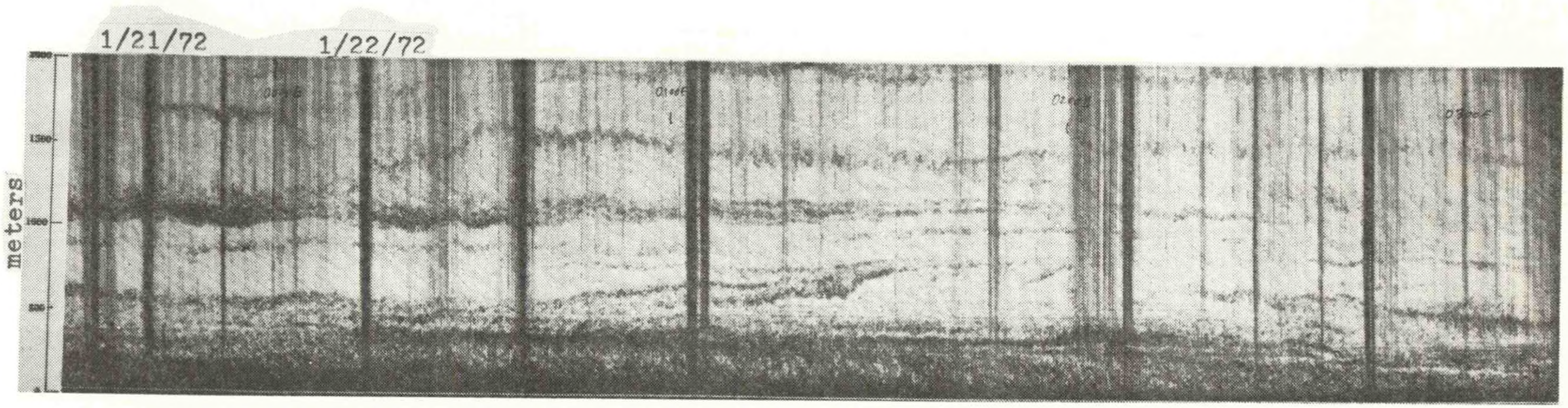

Figure 5. -- Echoes from many levels in the atmosphere.

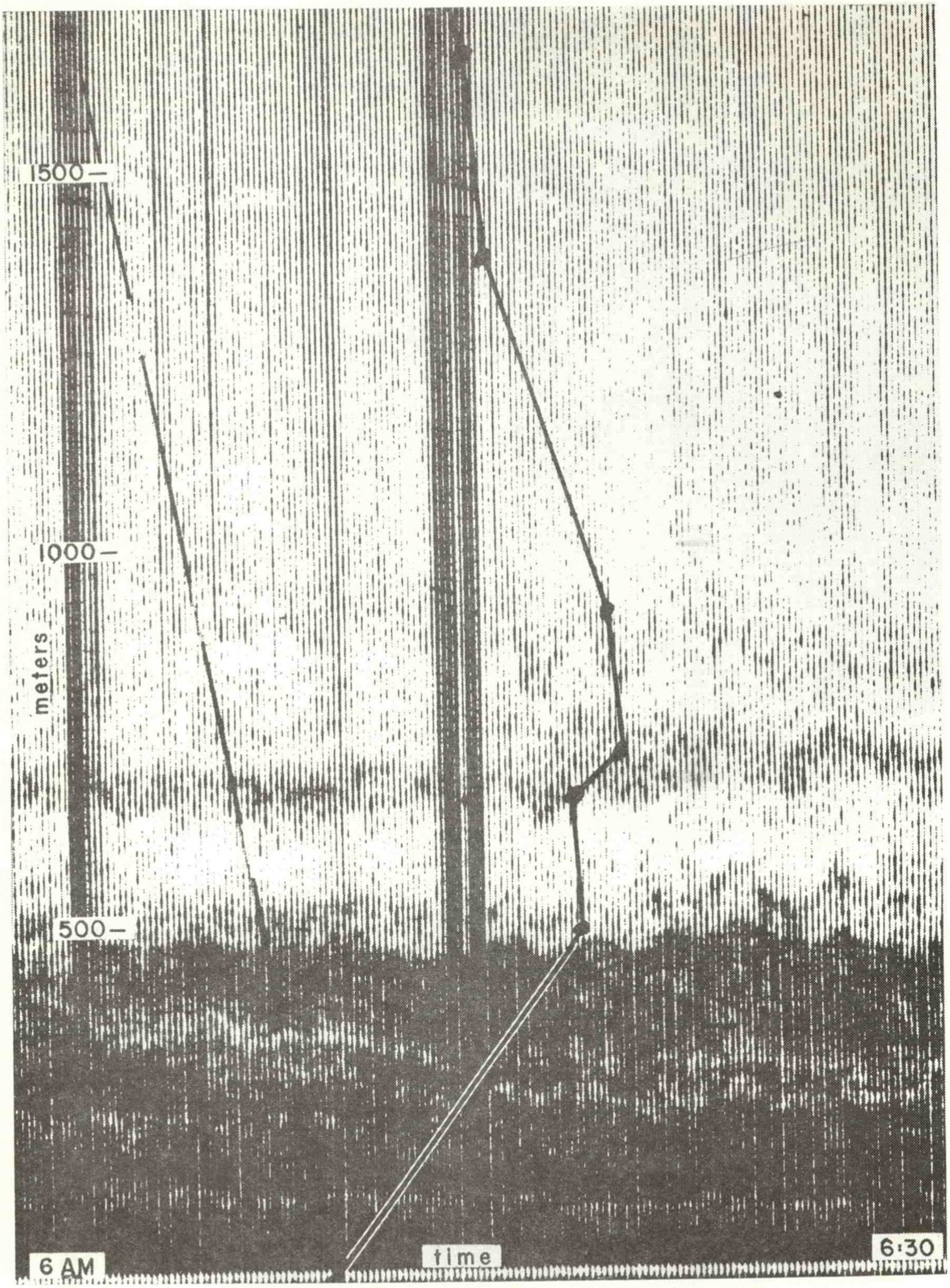

Figure 6. -- Radiosonde temperature profile superimposed on an acoustic sounder record. The return at about 800 m may be due to a thin inversion layer missed by the macroscale radiosonde with limited resolution.

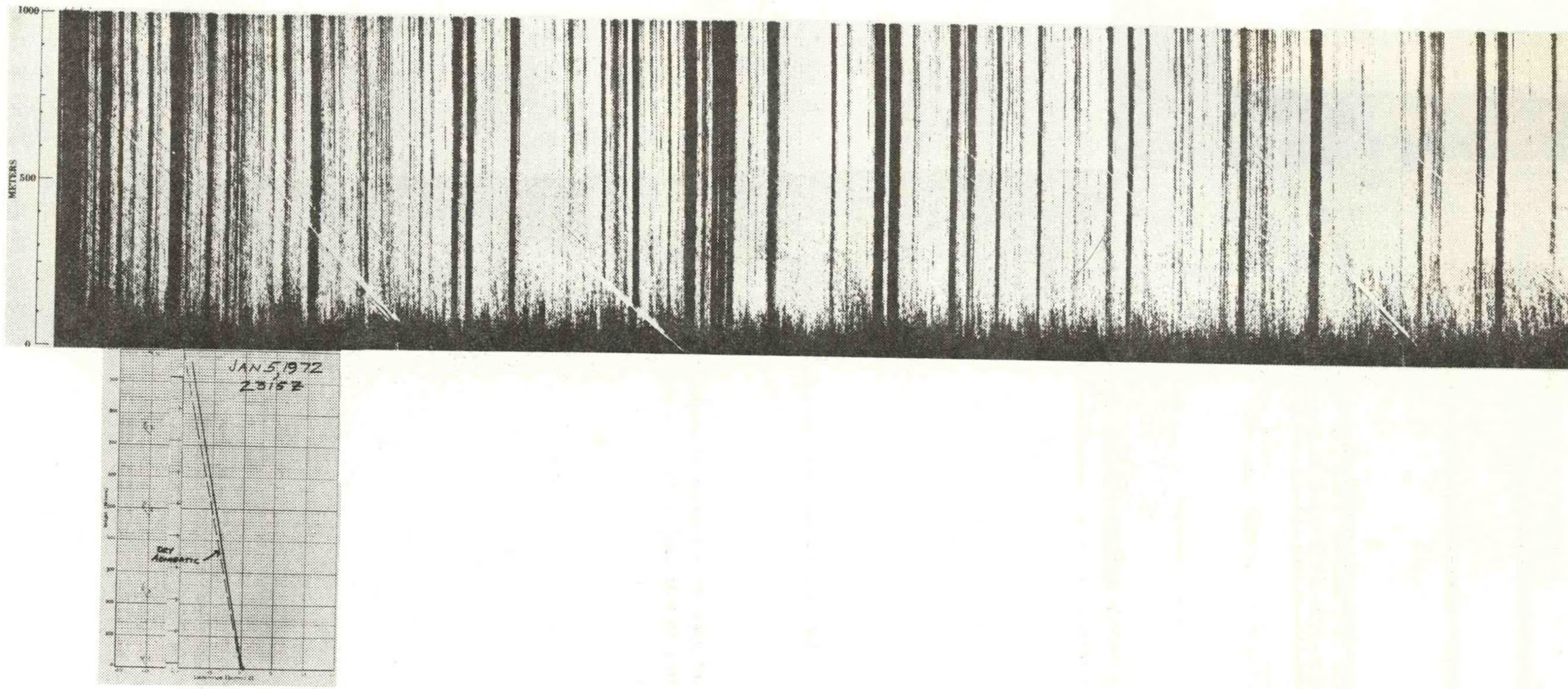

Figure 7. -- Low level convection returns from an unstable atmosphere.

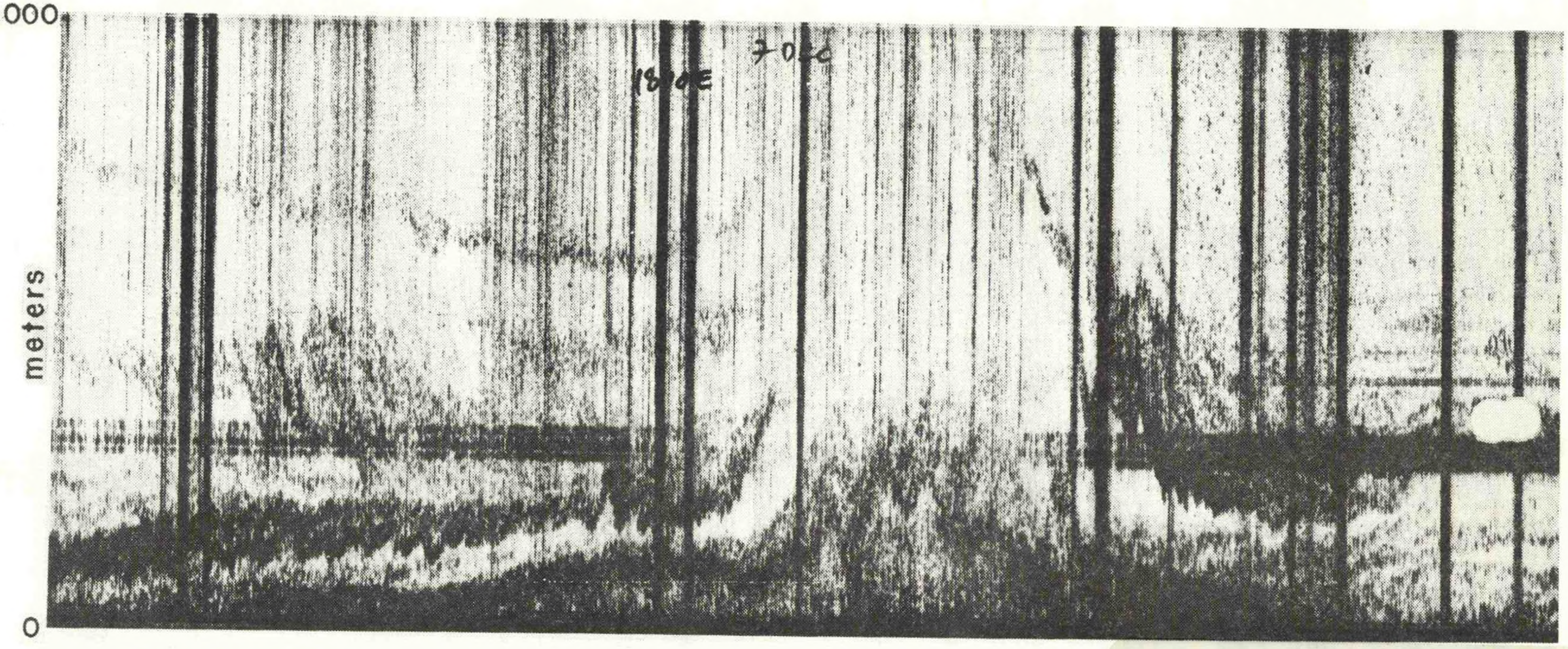

Figure 8. -- A small time scale phenomenon detected by the acoustic sounder.