A New Method of Studying the Fine Structure of Air Movements in the Free Atmosphere

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(Manuscript received December 9, 1952)

Abstract

A new method of measurement of the fine structure of air movements in the atmosphere is described. It depends on the use of radar equipment to follow and track the position of freely falling strips of light metal foil which have been distributed by aircraft or balloon in the region under investigation. The method is capable of direct measurement of vertical air velocity, divergence, and the fine structure of wind in the free atmosphere. The results of some preliminary investigations of the method are described.

1. Introduction

There are many aspects of meteorology in which observations of air movement are necessary. In particular, a knowledge of the horizontal and vertical air motions in and around clouds is of the utmost importance in a study of the physical processes that result in cloud formation and the release of precipitation. Few direct measurements have been made, however, of any of the commonly experienced atmospheric motions other than wind at heights greater than a few tens of metres above the earth's surface. For the most part these motions are deduced from other observations and the accuracy obtainable is not high.

Many different methods of measurement have been used in the past. These have included observation, both visual and by radio or radar, of balloons; visual observation of smoke either in the form of continuous trails or puffs; visual observation of the behaviour of soaring birds; observations both in gliders and powered aircraft of the vertical accelerations experienced in turbulent air; observations both visual and radio that depend on the fluctuations in atmospheric refractive index due to turbulence; and radar observations of the motion of freely falling raindrops in clouds. In addition deductions can be made of air movements from measurements of pressure and temperature fluctuations.

Since early 1949 the authors have been investigating the possible applications of a new radar method of studying air movements. In certain cases the method used appears to have marked advantages over those previously employed. This paper describes the method and its application to certain problems of cloud physics, and outlines a number of other ways in which the method may prove useful in the future.

2. The method

The method depends on the use of radar equipment to follow and track the position of freely falling strips of light metal foil,

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known during the last war as "window". The foil is distributed either by aircraft or balloon in the area in which the air movement is to be investigated. Single bundles of foil may be dropped and observed, or the motion of a continuous line examined. The most valuable technique appears to be that in which a series of bundles is dropped in some definite pattern and their relative motion observed. The minimum separation of the individual bundles is made such that they can be resolved by the radar equipment used.

The length of each strip of foil is about half the wavelength of the radio signals radiated by the radar equipment. There are some tens of thousands of strips of foil in each bundle which weighs between 10 and 100 grams. The echo from a single bundle approximates to that from a sphere 1 metre in diameter and it can be followed by the radar out to ranges of some tens of kilometres. The foil falls at about 100 cm/sec. in still air and the radar can be used to track accurately both its horizontal and vertical motion. The foil used by the authors spins about its long axis which remains horizontal during its descent. Due to the spin it does not fall vertically but spreads out sideways. The resulting dispersion eventually results in a weaker radar echo, and the maximum period for which a single bundle of foil can be followed accurately with the radar at present in use is between 15 and 20 minutes. The foil is stiffened by means of paper backing which becomes wet in cloud and rain allowing the foil to become limp and fall at a greatly increased rate. This fact limits its use to investigations in clear air or outside clouds.

The radar equipment used operates on a wavelength of 10 cm and is accurate to about 30 metres in range and 15 minutes in angle. It is possible to track the foil accurately out to about 50 km, though it is visible to over 100 km. The antenna can be rotated continuously about a vertical axis, either manually or by means of a motor drive, and the echo is displayed on a cathode ray tube by intensity-modulating the trace which is rotated in synchronism with the aerial. This is the familiar Plan Position Indicator type of display. The antenna can also be rotated about a horizontal axis, thus scanning the sky from the horizon to the zenith. Both elevation angle and azimuth angle are continuously indicated on dials. When the azimuth is held constant, and the antenna is scanned in elevation, a second intensity-modulated display can be used to depict a vertical cross-section through the atmosphere.

Single bundles of foil can be tracked with precision radar of the gun-laying type but it was found difficult to locate them initially and the form of display was unsatisfactory. It was concluded that rapid scanning in elevation and azimuth and an intensity-modulated display were both essential features for satisfactorily tracking the foil.

3. Applications of the method

Three main applications of the method have been studied so far. These are the measurement of vertical air velocity, divergence or convergence of air in the horizontal plane, and the fine structure of wind.

(a) *Vertical velocity*

It is clearly possible to track the foil in the vertical plane and calculate its rate of fall. The vertical air velocity in the region can then be deduced provided that the velocity of fall of the foil in still air is known.

The first experiments in the use of the technique were made during an investigation in which it was desired to know the vertical air velocity in one particular location. Individual bundles of foil were dropped, either from aircraft or released from a balloon by a temperature or pressure controlled mechanism, at a desired altitude and their subsequent motion plotted.

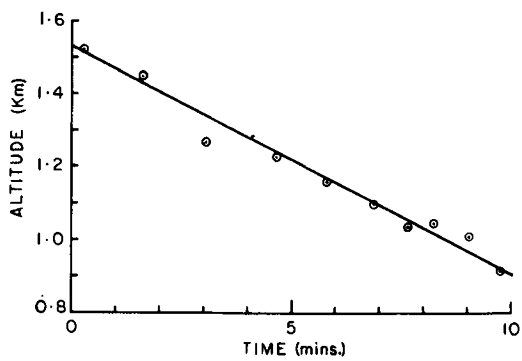

Fig. 1. Path of a single bundle of foil dropped from an aircraft in clear air. The rate of fall is very close to the laboratory determined value of 100 cm/sec.

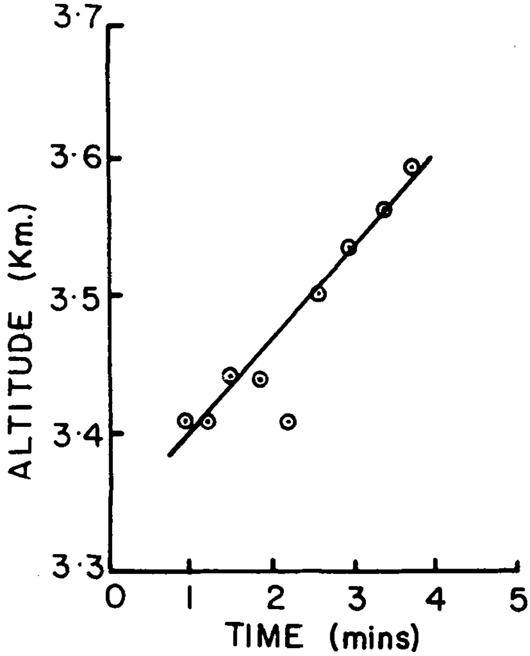

Fig. 2. Path of a single bundle of foil dropped from an aircraft in the clear space between two extensive cloud layers. The rate of rise implies an upward air velocity of about 200 cm/sec.

On most occasions the observed rate of fall of the foil in the atmosphere corresponded, within the accuracy of the experiment, with the value obtained in still air in the laboratory. However, on other occasions abnormal results were obtained and the foil either rose more or less uniformly or followed a complicated path. Figure 1 represents a normal fall and is an observation made in clear air of the motion of a single bundle of foil dropped from an aircraft. Figure 2 shows the result obtained when a bundle was dropped in clear air between two extensive layers of cloud. The rate of rise of the foil corresponds to an upward air velocity of some 200 cm/sec. An observation in which the foil followed a curved path is shown in Figure 3 which represents a drop made in clear air from a balloon.

In some instances a knowledge of the relative velocities of adjacent air parcels is of more interest than the absolute velocity. Here an examination of the motion of a line of foil, can give the necessary information. The foil is dropped from an aircraft which descends at a rate equal to the terminal velocity of the foil

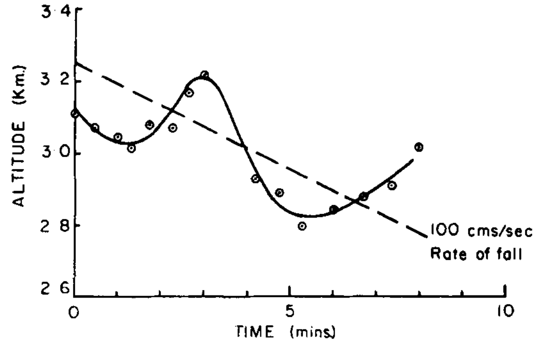

Fig. 3. Path of a single bundle of foil released in clear air from a balloon by a temperature actuated catch: the still air rate of fall is superimposed on the figure.

so that the latter is initially in one horizontal plane. One result obtained when using this form of distributing the foil is shown in Figure 4, which is a photograph of the cathode ray tube display of a radar mounted in an aircraft. The aircraft was used to sow a line of foil above a cumulus cloud and was then flown at right angles to the line and above it. The figure shows the line some minutes after sowing when it had developed a downward kink in the region of the cloud. The cloud itself had meanwhile started to sink and eventually disappeared. This form of distributing foil may also prove useful in an examination of orographic effects and in displaying pictorially the presence of lee waves behind mountain ranges.

The above observations relate to low altitudes, but the method has obvious applications to high altitude measurements where other methods are difficult. A few observations have been made of single bundles of foil released from a balloon by a pressure-actuated catch at altitudes above 12 km. From this

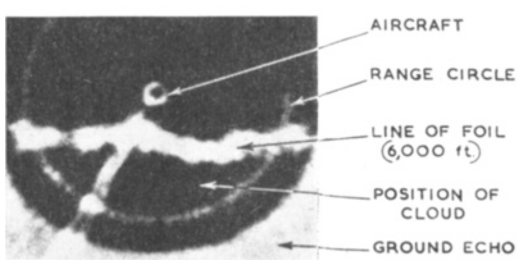

Fig. 4. Photograph of the display tube of an airborne radar showing a line of bundles of foil dropped above the top of a dissipating cumulus cloud.

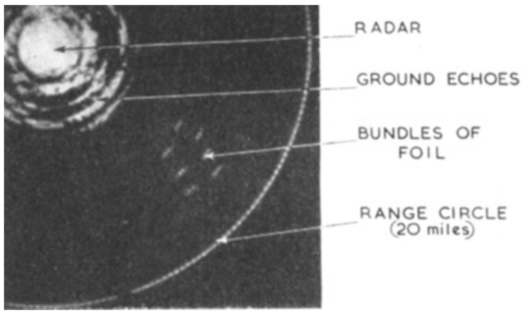

Fig. 5. Photograph of the radar display showing a series of bundles of foil dropped by an aircraft around a convective cloud.

level down to 10 km, where the windspeed was at its maximum value, the wind shear was high and could be gauged by the way in which the foil spread out in the horizontal direction.

(b) *Motion in the horizontal plane*

A powerful method of measuring relative air movements in a horizontal plane is to observe the motion of a number of individual bundles of foil dropped from an aircraft in the form of a circle or a polygon. To keep the figure horizontal the aircraft descends during the drop as described before. The change of area of this figure with time then gives a measure of the divergence or convergence at that level.

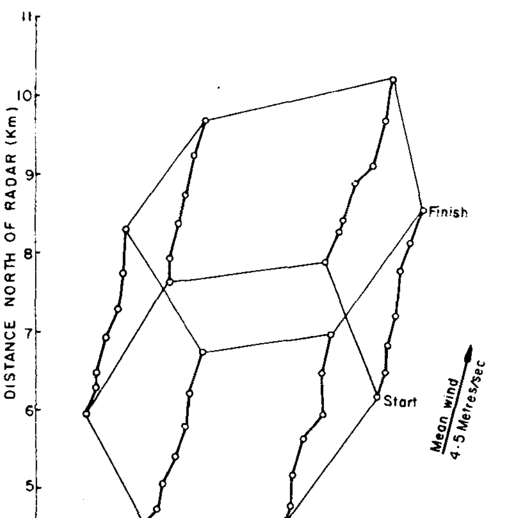

Fig. 6. Plot of the position of the centres of the echoes from six bundles of foil at successive three minute intervals. The foil was dropped in clear air from an aircraft at a constant height. The heavy lines indicate the paths of the individual bundles and the light lines the closed figures whose area is measured and plotted in Figure 7.

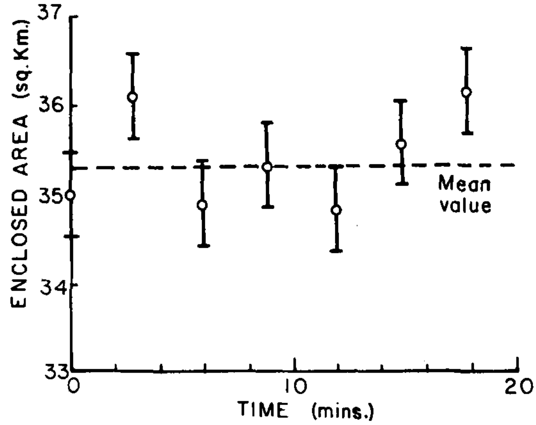

Fig. 7. The variation of enclosed area as a function of time for the experiment shown in Figure 6. The plotted points show both the measured area and the probable error of measurement. Clearly there was no significant change of area with time.

The appearance of the PPI radar display during the course of such an experiment made in clear air is shown in Figure 5. The position of the centre of the echo from each bundle is shown plotted at successive 3-minute intervals in Figure 6. The variation of the enclosed area as a function of time is shown in Figure 7, from which it is seen that no significant change occurred.

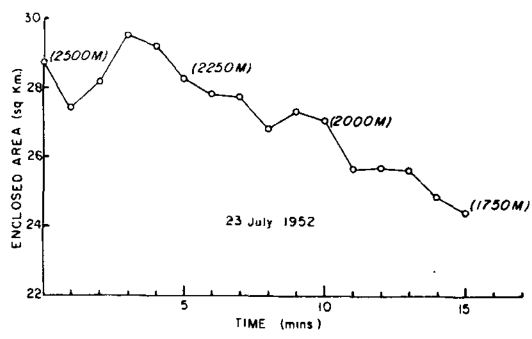

Fig. 8. Results of a drop round a cumulus cloud 1100 metres deep with its base at 1600 metres. The figure shows the variation of enclosed area with time. The approximate altitude of the circle of foil is shown by the figures in italics.

Two results which are of marked interest were obtained from experiments performed on 23 and 29 July, 1952. In these cases bundles of foil were dropped from an aircraft at intervals of about 1 minute while circling clouds at a short and relatively constant distance from them. Figures 8 and 9 show the variation as a function of time of the area bounded by the individual bundles. The air in which the foil was dropped on 23 July was clearly converging as shown in Figure 8. A second experiment was performed shortly after that shown in the figure but in clear air away from the cloud. No significant change in the enclosed area occurred, so that the region of convergence was restricted to the locality of the cloud.

In the case of the experiment on 29 July, 1952, represented by Figure 9, the area of the figure first increased and then decreased to about the original value. During the first phase the cloud was observed to be dissipating, then when convergence started it built up again. Subsequently the cloud was observed to rain.

These observations show, in a quantitative way, the presence of areas of convergence and divergence near convective clouds. It is proposed to supplement them later with simultaneous observations of the vertical motion of the individual bundles of foil. The information then available should lead to direct confirmation, or otherwise, of theories postulating the entrainment of air into cumulus cloud.

(c) *Fine structure of wind.*

An examination of the motion of the individual bundles of foil, distributed by an aircraft in lines or other patterns, enables measurements to be made of the wind vector at any desired point. Thus the wind structure throughout an area of some hundreds of square kilometres can be readily measured. The minimum separation of individual bundles of foil such that they can be resolved on the radar is about 1 km, and the maximum distance beyond which accurate measurement is impossible due to other equipment limitations is about 100 km, thus the scale of wind measurements possible through the use of this technique is from 1 to 100 km.

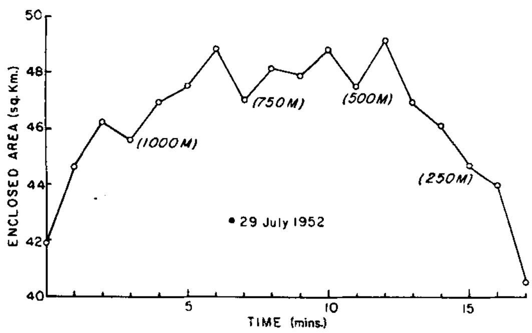

Fig. 9. Result of a drop round a cumulus cloud 600 metres deep with its base at 900 metres.

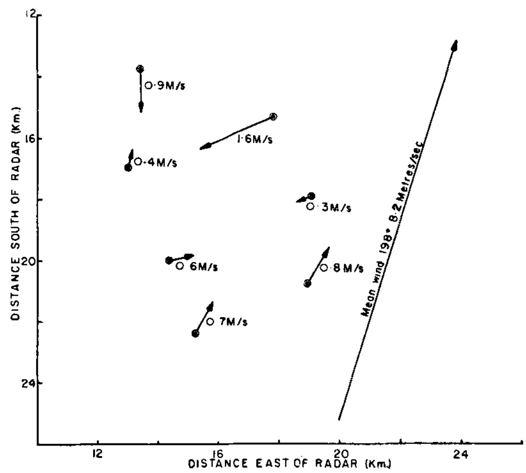

Fig. 10. The fine structure of wind in the region surrounding a convective cloud. The mean wind vector is shown and the difference between actual and mean wind at the position of each bundle of foil averaged over a 3 minute interval.

The fine structure of wind in the region surrounding a convective cloud, as determined by the use of this technique, is shown in Figure 10. The wind vector at the position of each bundle of foil was first determined and then the mean wind vector calculated. The vector departure from the mean wind at each position was then calculated and plotted. Evidence of convergence is again indicated.

4. Conclusion

The preliminary investigations that have been made of air movements, by tracking with radar bundles of metal foil distributed by aircraft or balloons, suggest that this new technique will prove a powerful tool for research in atmospheric physics. The method is capable of detecting and measuring vertical and horizontal air movements over considerable areas, and appears to be very useful in studies of convective clouds. It is likely that the method will also be of use in the investigation of the waves formed in the lee of mountains or of atmospheric oscillations. A study of the rate of dispersal of the foil, by an examination of the dimensions of the echo, could also prove useful in studies of small scale turbulence, particularly in the upper atmosphere where other methods of measurement are difficult. This type of investigation may, however, have to await the availability of a different type of echoing material which falls vertically without marked dispersal in still air.

5. Acknowledgement

The authors wish to acknowledge the ready cooperation of the Royal Australian Air Force in providing aircraft for these experiments.