CHAPTER I

The Structure of the Atmosphere as disclosed by the Observations of Pilot Balloons at Ditcham

This book gives the results of 200 observations of pilot balloons or ballons sondes. The process of observation consists in watching the progress of small balloons as they rise through the air and are carried along by the winds. The majority of the observations were made at Ditcham in Hampshire, on the southern slopes of the South Downs. Fourteen ascents in May, 1907, were made at Totland Bay in the Isle of Wight, and two, on July 1st, 1907, at Chobham Common.

From the observations the height and horizontal distance of the balloon are computed, generally from minute to minute, by methods which will be described and discussed.

The purpose of the investigation is to determine whether the wind in the upper air is the same in direction or velocity as that at the surface, and to form a numerical estimate of the deviations that are observed. If we regard the air as composed of a series of horizontal layers or strata each with its own special wind velocity and direction at the time of observation, it is evident that the balloon rising with approximately steady upward motion will be carried along first by the surface current, and subsequently by the currents in the successive layers. We may suppose without inaccuracy that very little time is lost in adjusting the velocity of the balloon to the flow of the air current in which it happens to find itself at any moment, because the whole mass of the balloon is quite trifling compared with the forces that would be required to hold it against a flowing current of air; and we are therefore justified in assuming that the horizontal distance traversed in any minute represents the average velocity of the layer passed through by the balloon in its journey aloft during that minute. Thus the horizontal velocities of the air in successive layers may be regarded as given by the observations. The thickness of the layers traversed in successive minutes depends upon the rate at which the balloon is ascending. In many cases this has been assumed to be uniform, and reasons will be given for considering that this assumption is sufficiently nearly justified for the results to be relied upon as giving at least a general representation of the true motion of the atmosphere in successive layers.

For the sake of uniformity the heights in the atmosphere will be given in kilometres, and for general purposes we shall consider the atmosphere as made up of a pile of layers each a kilometre in thickness. The highest of the observations deal with a pile of 18 such kilometre layers, which took 80 minutes or more to observe, but the large majority were much less thick. In some ascents only one or two kilometre layers were traversed, but a large number included five kilometre layers.

On each occasion the balloon was watched until one or other of the following events happened; either the balloon became invisible because it entered the clouds, or it was seen to burst and begin a precipitate descent, or it became so small that the observer was no longer able to identify the speck in the telescope. Sometimes this last event happened in consequence of the gradual diminution of the speck beyond the power of the eye to identify it, and on other occasions the observer after taking his eye from the telescope could not again find the speck. Sometimes in hazy weather the balloon was lost to sight when, had it been clear, its diameter would have been easily discernible.

A large number of the ascents were made in the evening, as at that time the convection movements due to the heating of the ground by the sun's rays no longer interfere much with the uniform ascent of the balloon; moreover the haze, which was found to interfere with the observations during cloudless days, was less at that time than at an earlier hour; it was also found that near the time of sunset, when the sky was becoming less bright, the balloon illuminated by the sun's rays became very easy to see at long distances; in some cases a balloon was watched for many minutes after the sun had set on the earth's surface, the balloon shining brightly and looking like a planet seen through a telescope; on one occasion a balloon was seen to burst under such circumstances at a horizontal distance of about 40 miles. The time of sunset was also convenient because it corresponded nearly with one of the hours of observation for the Daily Weather Report of the Meteorological Office.

The heights reached, and in many cases the immediate cause of the termination of the experiment, are given in the general table of results.

It will be understood from this description of the mode of procedure that from each ascent one can form a mental picture of the successive currents of air traversed by the balloon in its journey. It is true that the geographical position of the balloon will be different for each minute, but these differences are so small compared with the extent of the atmospheric current that the variation in position may be disregarded; and as a general rule we may regard the position of the successive currents as applicable to the atmosphere immediately above the observer at the time of the commencement of the ascent.

The mental pictures thus obtained of the succession of air currents which constitute the structure of the atmosphere over the observing station are of the most varied and sometimes of the most complicated character. In order to enable the reader to carry with him an idea of the sort of structure which may be disclosed by the observations of a pilot balloon the various features have been classified according to some prominent characteristic which is easily recognised in the diagrams representing the results of the ascents.

A further note must be made before proceeding to consider the different types of structure which have been disclosed by the observations. The wind close to the surface is influenced by the shape of the ground and other obstacles from which the upper layers are free. Hence the variations close to the surface are often of a specially complicated character having little relation to the structure of the atmosphere as a whole. Generally speaking the wind increases from its surface value in direct proportion to the height above sea level (see Chapter IX), with some little veer in direction until a height of between half a kilometre and a kilometre is reached. Thereafter the effect of the surface may be regarded as no longer applicable. The surface wind is accordingly a very unsatisfactory datum to which to refer the variations in the upper air. Generally speaking the wind gradually approximates to that computed as the "gradient wind" (see page 32) from the distribution of pressure at the surface. In many ways the gradient wind is a better datum than the observed surface wind and it has been noted in the tables and marked on the diagrams whenever a reasonably satisfactory computation could be made. In some cases however the distribution of pressure in the neighbourhood of the station is too irregular and too ill-defined for a satisfactory computation of the gradient wind to be made.

With this explanation we proceed to refer to some of the principal types of structure of the atmosphere which a study of the diagrams has disclosed. It must be remembered that they are necessarily limited to the occasions when balloons can be followed with a telescope. These are generally occasions of clear weather. During rain, or when there is fog or low cloud, observations are not possible.

The figures that follow are taken from cardboard models prepared to show the distribution of wind direction and velocity with height. Each card shows by its direction and length the wind direction and velocity at each kilometre of height[1]. In general the light coloured cards represent winds from between 300° (W.N.W.) through North to 120° (E.S.E), that may be supposed to come from polar regions; the dark cards winds from 120° through South to 300°, that may be supposed to come from equatorial regions. This classification is only approximate, since it is evident that, for example, a Northerly wind at the station may be a current of air that has been drawn from an equatorial region, but has curved round and passes over the station from a Northerly direction.

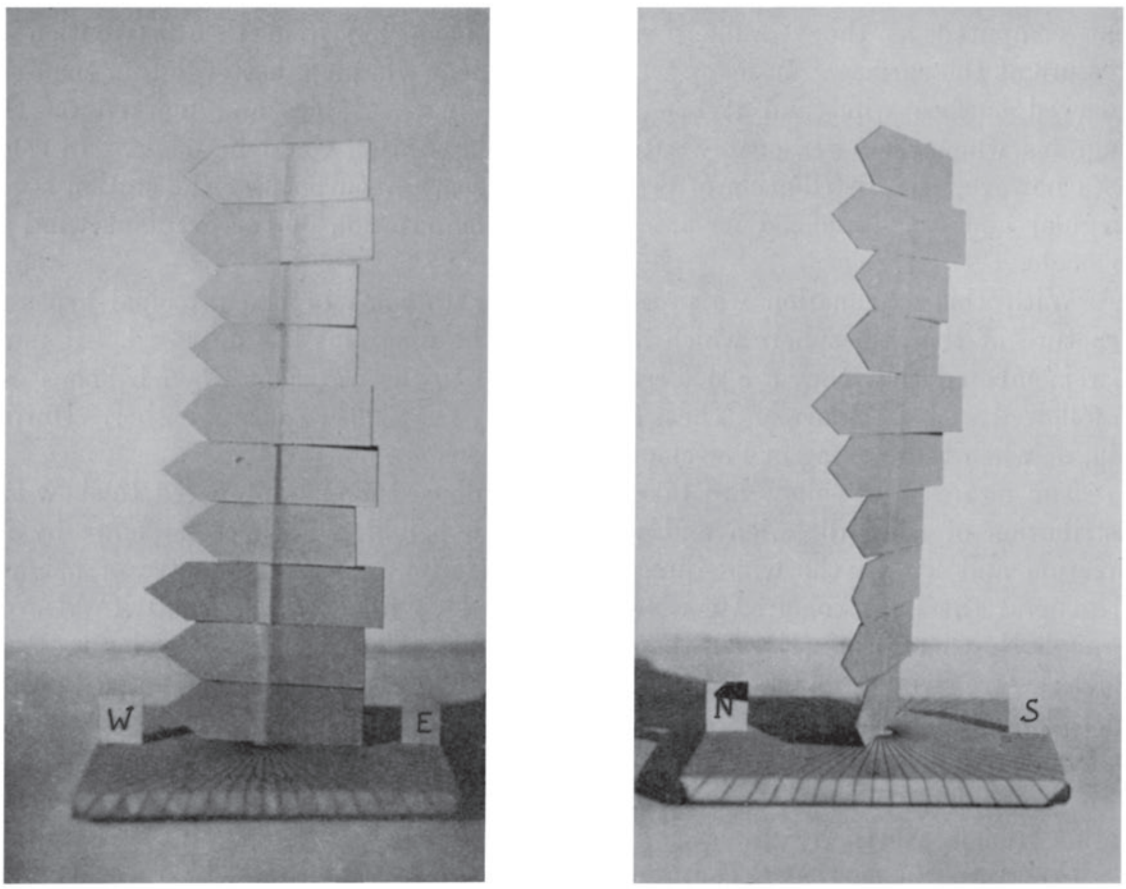
(*a*) "*Solid*" *current*. The first characteristic type is that which we may call the "solid" current, that is to say that after the interference of the surface has been passed, and the gradient velocity approximately reached the wind remains steady both in direction and velocity in the upper layers. This case is illustrated by the diagram representing the result of the ascent on May 5th, 1909 (Fig. 1).

(*b*) Continued increase of velocity beyond that of the gradient wind. In some cases it is possible to explain the increase of wind velocity by the change in the distribution of pressure in the upper layers without any discontinuous change in the air supply by reference to the distribution of pressure and temperature on the surface. Often however no such explanation is evident. These cases are illustrated by the results of ascents on Sept. 1st, 1907 and Oct. 1st, 1908 (Figs. 2 and 3).

[1] The arrow-head flies with the wind.

(*c*) Decrease of velocity in the upper layers. In this case after the gradient velocity has been reached the velocity falls off showing that the regime indicated by the surface pressure is over, and a new distribution commences, arising so far as we know from causes unrelated to the surface conditions. Sometimes the new regime is itself indicated by the observations at higher levels; not infrequently the observations had come to an end before the conditions in the higher levels were disclosed. This class is illustrated by the result of the ascent on May 7th, 1909 (Fig. 4).

(*d*) Reversals, or great changes of direction in the upper layers. Reversals of



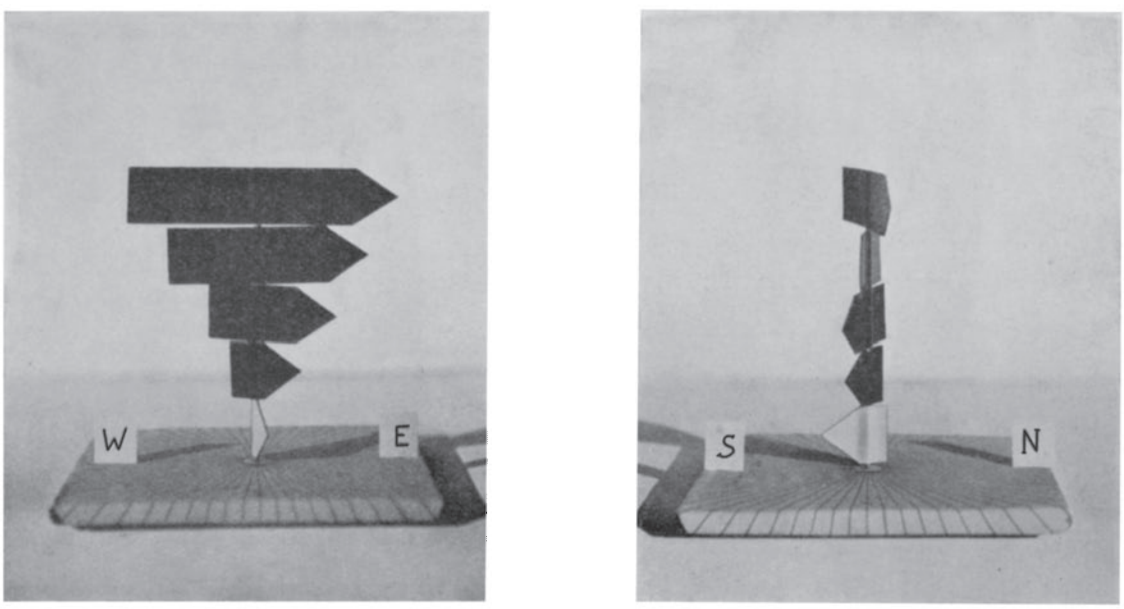
a *b*

Fig. 1. Model representing the vertical wind distribution on May 5, 1909, 6.43 p.m. Class (*a*).
a. From South side. *b*. From West side.

direction are nearly always preceded by the falling off of the velocity to a light air. These cases may therefore perhaps be regarded as a continuation of ascents similar to those of class (*c*) if it had been possible to continue the observations. In these cases we see the superposition of distinct systems of currents without any specific relation between them that can be accounted for by a knowledge of surface conditions. This class is illustrated by the result of the ascent of Nov. 6th, 1908 (Fig. 5).

(*e*) Upper wind blowing out from distant low pressure centre; frequent reversals in the lower layers. A number of cases present themselves in which the upper wind is completely at variance with the gradient wind, either in direction, in velocity, or in both. In many of these cases it seems as though the upper wind were blowing outwards from the region overlying a low pressure system. The wind in the upper layers is often far in excess of the gradient value, and increases as in class (*b*); there are cases in which the structure might be classified with either class. This class is illustrated by the result of the ascent of April 29th, 1908 (Fig. 6).

(*f*) The wind in the Stratosphere. In several ascents balloons have been followed to great heights and have been kept in sight after they have entered the region of the stratosphere. It has been found from the results of the ascent of ballons sondes that after a certain height is reached, a height that varies from day to day and from place to place, the ordinary diminution of temperature with height ceases, and that the column of air above this height remains at approximately the



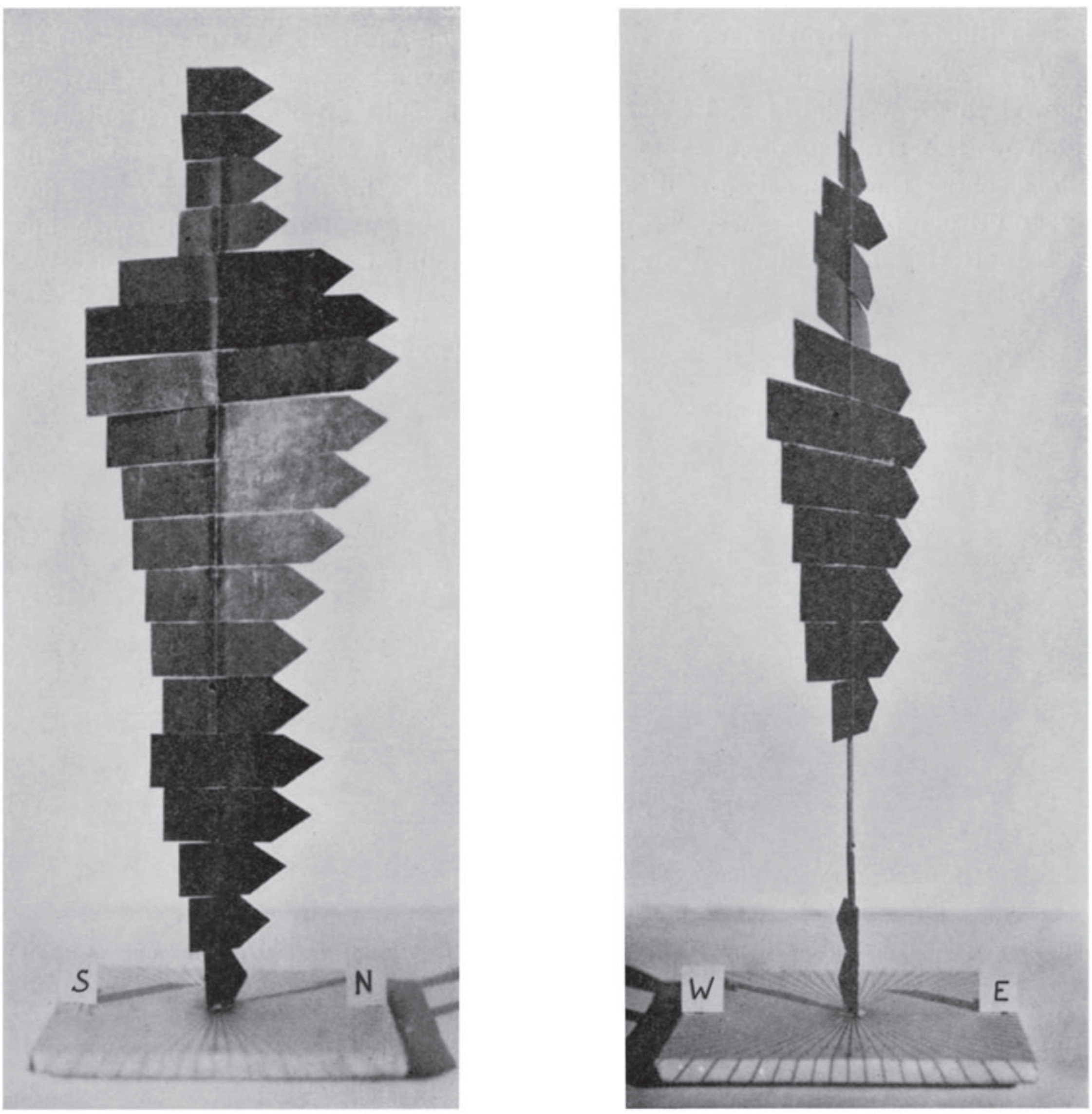
a *b*

Fig. 2. Model representing the vertical wind distribution on Sept. 1, 1907, 10.22 a.m. Class (*b*).
a. From South side. *b*. From East side.

same temperature as far as the observations have continued. This upper region of the atmosphere has been called the Stratosphere or Isothermal Layer. It has been found that at a height corresponding roughly with the commencement of the stratosphere the wind velocity usually decreases, sometimes in a very marked way. This class is illustrated by the results of ascents of July 29th and Oct. 1st, 1908 (Figs. 3 and 7). So far as observations of the movements of balloons are concerned the region thus identified is a region of lighter winds as compared with those of the strata beneath.

Mr W. H. Dines, F.R.S., informs me that he has had a few cases of no appreciable decrease in velocity up to 16 km.

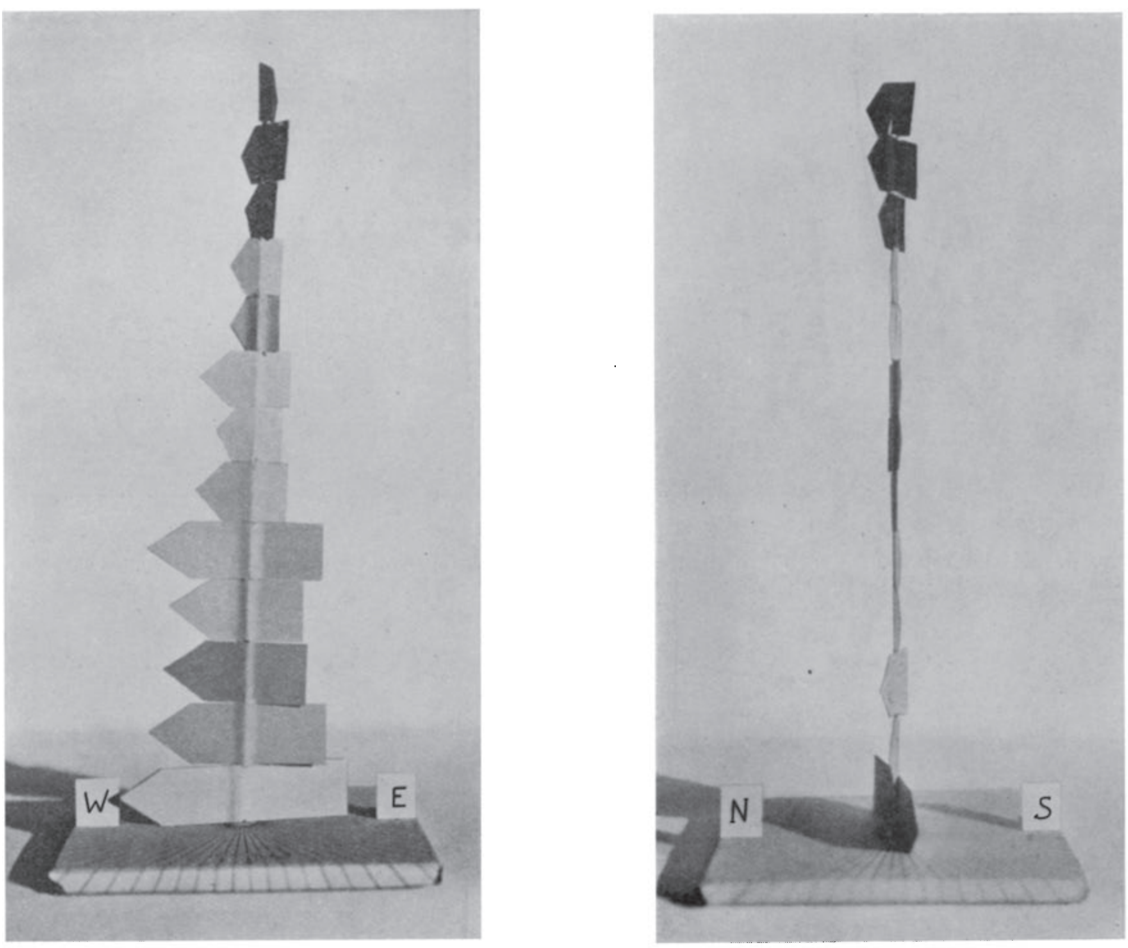
It will be noticed that in many cases equatorial winds have polar winds above them. The frequency is too great for this to be merely coincidence, but it is quite possible that this superposition represents the condition of clear weather necessary for the observation of balloons. It may be argued that in the converse case when an equatorial wind is above a polar one we should get conditions favourable for the



a *b*

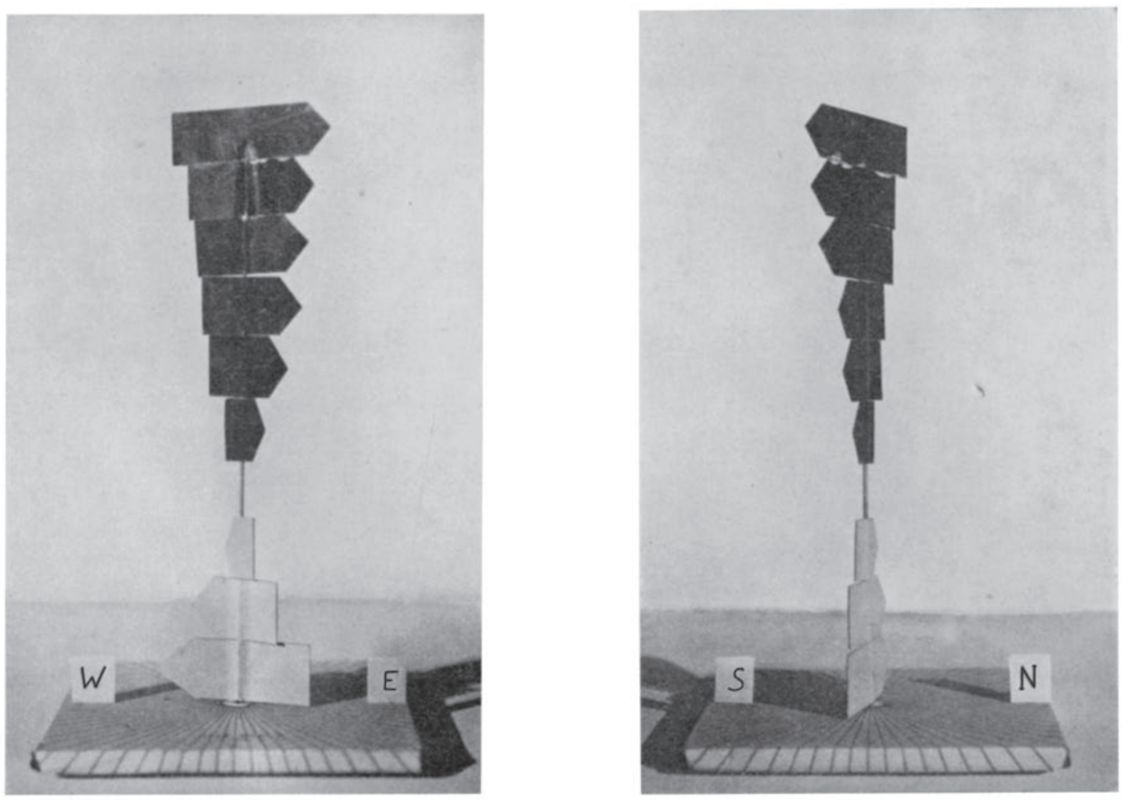
FIG. 3. Model representing the vertical wind distribution on Oct. 1, 1908, 4.20 p.m. Class (*b*).
a. From East side. *b.* From South side.

formation of clouds and rain, and consequently conditions unfavourable for the observation of balloons, and some evidence will be brought forward to show that this is sometimes the case.



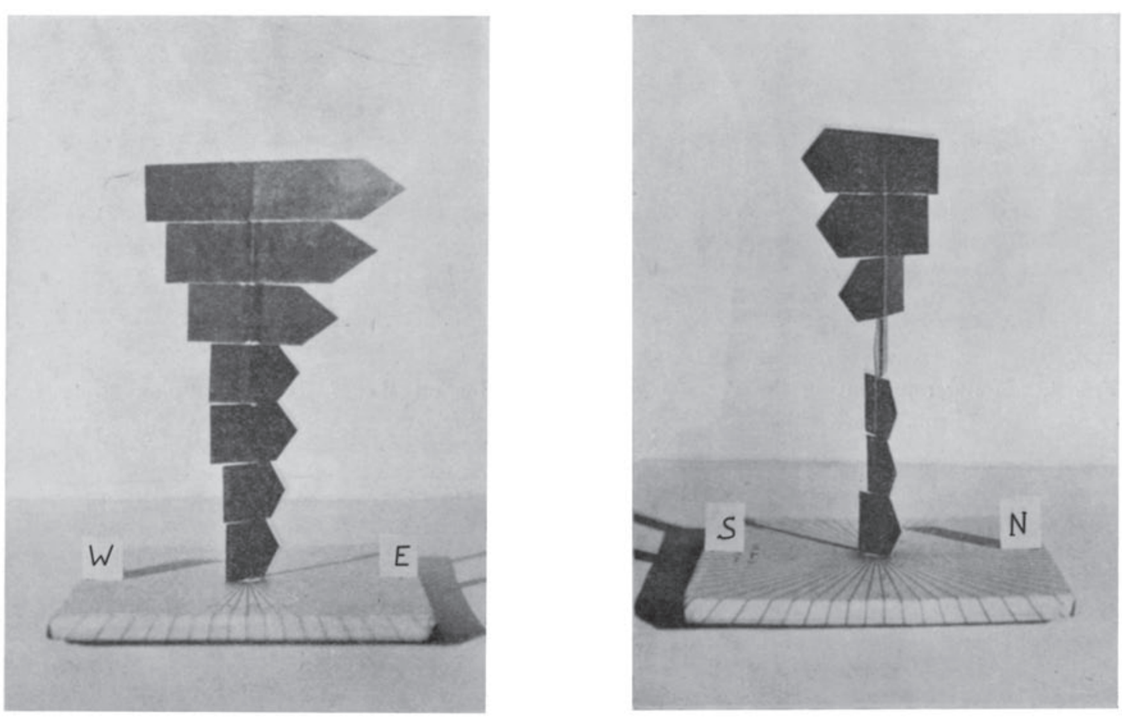
a *b*

FIG. 4. Model representing the vertical wind distribution on May 7, 1909, 6.29 p.m. Class (*c*).
a. From South side. *b.* From West side.



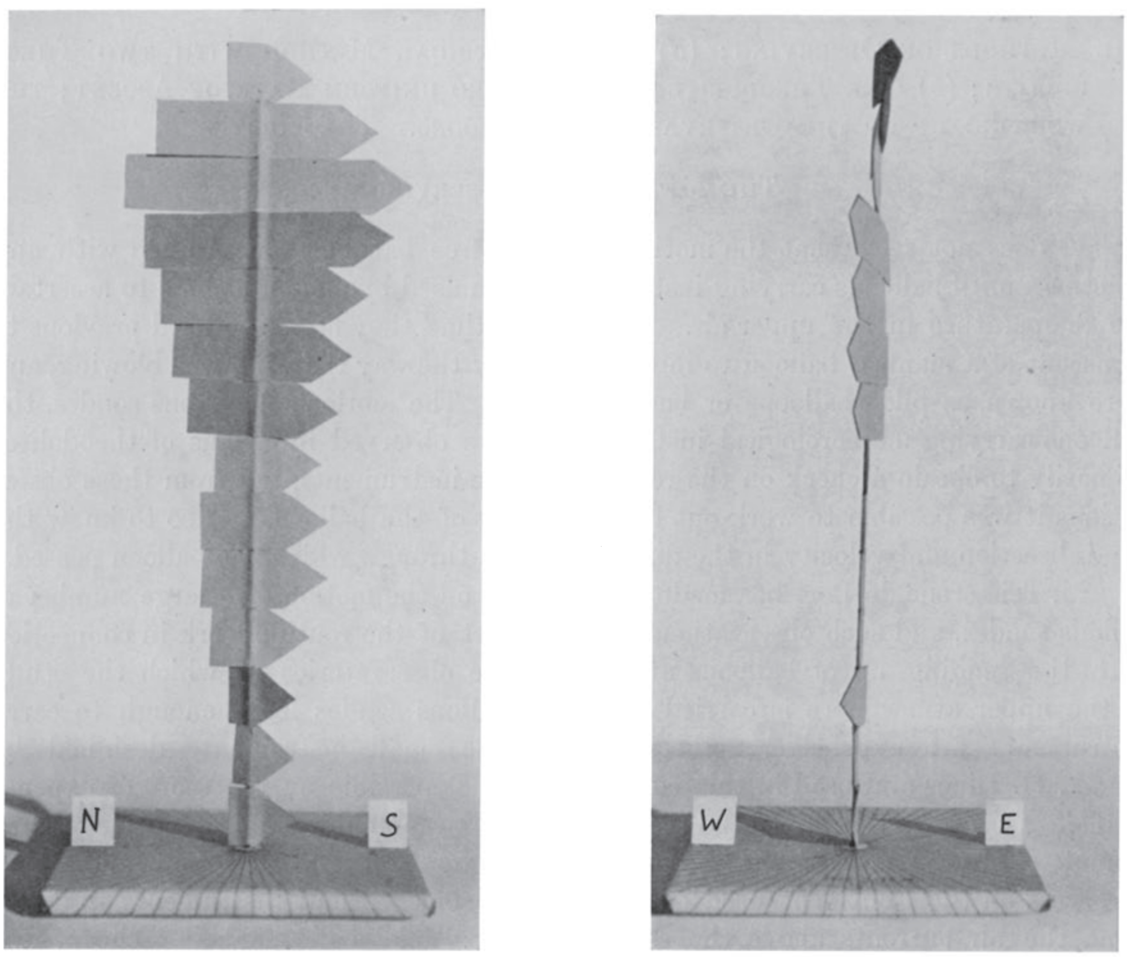
a *b*

FIG. 5. Model representing the vertical wind distribution on Nov. 6, 1908, 10.59 a.m. Class (*d*).
a. From South side. *b*. From East side.



a *b*

FIG. 6. Model representing the vertical wind distribution on April 29, 1908, 3.57 p.m. Class (*e*).
a. From South side. *b*. From East side.



a *b*

FIG. 7. Model representing the vertical wind distribution on July 29, 1908. Class (*b*).
a. From West side. *b*. From South side.

CHAPTER II

THE METHODS OF OBSERVING; (*a*) TRIGONOMETRICAL METHOD WITH TWO THEODOLITES; (*b*) ONE THEODOLITE WITH ASSUMED UNIFORM RATE OF ASCENT; THE WORKING UP OF THE OBSERVATIONS. BALLOONS. THEODOLITES

THE METHODS OF OBSERVING

IT does not seem that the motion of small free balloons was studied with any exactness until balloons carrying instruments were used by meteorologists to ascertain the temperature in the upper air. Before that time they had been used previous to an ascent of a manned balloon to indicate roughly the way the wind was blowing, and were known as pilot balloons or ballons d'essai. The motions of ballons sondes, the balloons carrying meteorological instruments, were observed by means of theodolites primarily to obtain a check on the readings of the instruments, but from these observations it was possible to work out the trajectory of the balloon, and so to know the wind direction and velocity in the different layers through which the balloon passed.

M. Teisserenc de Bort has made observations on the motion of a large number of ballons sondes, and such observations are now part of the routine work in connection with the sending up of balloons at most of the observatories at which the study of the upper atmosphere is carried on. But ballons sondes large enough to carry instruments are expensive, and even with the small instrument, designed by Mr W. H. Dines and used in this country, it is not possible on the score of expense to make ascents except on special occasions, and a large number of consecutive ascents cannot easily be carried out. Some years ago Professor Hergesell and other observers on the Continent used quite small balloons without instruments to determine the air currents above the earth's surface. The balloons being cheap, and being much more easily sent up in windy weather, it was possible to use this method on many more occasions than was the case with larger balloons, and far smaller quantities of hydrogen were necessary for their inflation.

The series of observations discussed in the following pages was begun at the close of the year 1906 and has been continued at intervals up to the present time.

Two methods of observing are in use (*a*) the two theodolite method, and (*b*) the one theodolite method.

(*a*) The two theodolite method.

A base line is selected, at each end of which is an observer with a theodolite. The base line should be as long as possible, but the balloon at one end must be clearly visible to the observer at the other. It is an advantage if each station is