MEASUREMENT OF VERTICAL CURRENTS IN THE ATMOSPHERE, MAINLY OF THERMAL ORIGIN, WITH PILOT BALLOONS.

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Summary.—The paper discusses the results of some measurements of vertical currents in the atmosphere obtained with liftless balloons at Poona. These balloons were first carried up to different heights in the atmosphere varying from about 0·5 km. to 2·0 km. and released there by means of timed fuses. On clear days in the dry season, vertical currents are generally weak in the mornings and marked in the afternoons : on one occasion, the upward velocity went up to 14 km./hr. The vertical currents observed on some days with cumulus and cumulo-nimbus clouds are also described.

In the particular ascents discussed in the present note, the vertical currents were mainly thermal in origin and not due to flow of air over obstacles.

Introduction.—It is well-known that vertical currents of considerable intensity and extent are of fairly frequent occurrence in the atmosphere. Measurements of such currents are however few, the main reason for their scarcity being that the vertical velocities are generally small compared to the horizontal velocities of air movement. In Europe, manned balloons and pilot balloons have been used for their investigations[1—4]. In the Forschungs-Institut of the Röhn-Rossitten Gesellschaft[5] which devotes special attention to the scientific study of motorless flying, sail-planes (gliders) have been utilised for studying the vertical currents developed under a wide variety of conditions, such as those associated with wind movement over hilly country, convection over insolated ground, growth of cumulus and cumulo-nimbus clouds and movement of line-squalls. In Britain, the up and down movements caused by eddies in gusty weather have been inferred from the fluctuating readings of accelerometers carried in aeroplanes.[6] The systematic use of tailed balloons for the measurement of upper winds in India has provided many examples of marked vertical currents but few of them have been published, the only exception being the results obtained at Agra on a day of slightly disturbed weather.[7] In the present note are discussed some experiments carried out at Poona on the measurement of vertical currents in the atmosphere by the use of liftless balloons.

Method used.—The pilot balloons used for investigating the vertical currents were provided with tails of 25 metres length with paper flags attached to them at $6\frac{1}{4}$, $12\frac{1}{2}$ and 25 metres and small bags of sand near the lowest flag. The weight of the sand and the amount of hydrogen in the balloon were so adjusted that the combined system of balloon, tail, flags and sand had no resultant free lift. This system was carried up to the required height by means of another balloon and released there by means of a timed fuse. The sand-bag practically eliminated the slant of the tail, and the flags, in addition to serving as end-marks for the moving base-line, also

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helped to damp out any tendency to pendular motion of the tail. Except when the altitude of the balloon was more than 65°, the angle subtended by the balloon and flags as read in the scale of the eye-piece of the theodolite could be used to determine with fair accuracy the height of the balloon. Readings of azimuth, altitude and tail-length were taken every half-minute. The balloons used were of rubber and either of 90″ or 70″ size, the weight of the sand-bag being usually 50 gms. The no-lift condition was adjusted to within 2 or 3 gms., the small net lift being generally positive. With the particular weight of balloons, load and free lift, a residual free lift of 2 gms. would mean a rate of ascent of about 1·5 km./hr.*

Results.—The balloons were released at different times of the day varying from 8 hrs. to 18 hrs. Notes on some of the successful ascents made on different days are given below. In the tables which follow, the following symbols have been used.

H_0 —Height above ground in kilometres at which liftless balloon was detached

H_x, H_n —Maximum and minimum heights reached by liftless balloon.

t—Duration of flight of liftless balloon in minutes.

24TH DECEMBER 1930.—Clear, anticyclonic weather prevailed over Poona on this day and four successful ascents were made.

TABLE I.

Ascents on 24th December 1930.

Time hrs., I. S. T.	H_0 (km.)	H_x (km.)	H_n (km.)	t (min.)
1103	0·5	0·7	0·5	10
1234	1·1	1·3	1·1	34
1411	1·25	1·3	0·8	19
1618	1·4	1·8	0·5	49

The height-time curves of the balloons are shown in *Fig. 1.* The

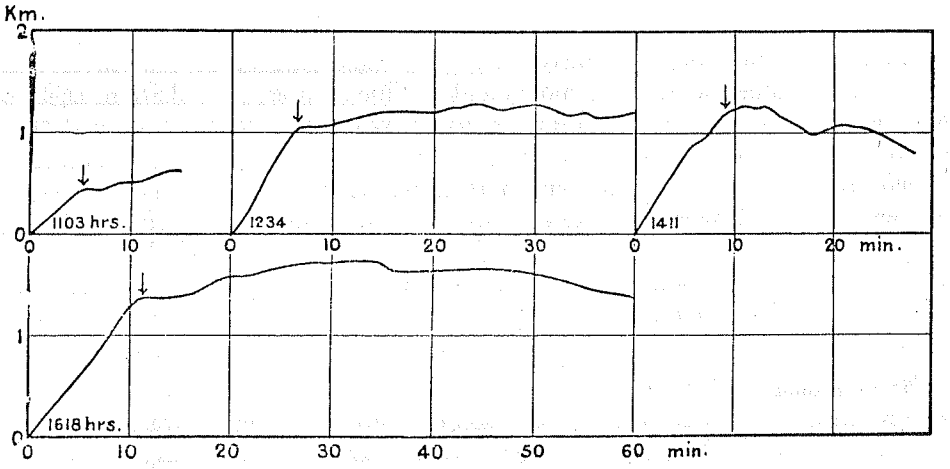

Fig. 1. Height-time curves of some Pilot Balloons sent up on 24th December 1930.

*As there would be a small, slow leakage of gas from the balloon and as the amount of the leakage would vary from balloon to balloon, it was not considered worth while to make a correction on this account.

time at which the liftless balloon was detached is indicated by an arrow. The first ascent shows an abnormally low rate of ascent for the combined system of balloons being only 6 km./hr. against the normal 7·5 km./hr. The second and third ascents show an excess rate of ascent of about 2 km./hr. The ascent at 1411 hrs. shows a downward current of 5 km./hr. lasting for about 5 minutes followed by an upward current. The last ascent shows an upward current lasting for 2-3 minutes. It is probable that the gradual descent of the last balloon which commenced about 50 min. after release was due to leakage of gas. On the whole, the vertical currents were feeble on this day.

20TH JANUARY 1931.—There were eight ascents on this day, details about which are given in *Table 2* below:—

TABLE 2.

Ascents on 20th January 1931.

Time (hrs.)	H_o (km.)-	H_x (km.)	H_n (km.)	t (min.)
0839	0·4	0·4	0·3	7
0921	0·9	0·9	0·8	19
1006	0·8	0·8	0·6	11
1049	2·0	2·1	1·9	44
1216	3·1	3·2	3·1	6
1307	1·9	2·2	0·2	64
1445	0·6	1·7	0·1	100
1652	Liftless balloon not released.			

On this day also, the weather was clear over Poona, although a western disturbance was active in the North-West Frontier Provinces and the Punjab. The trajectories of the balloons sent up between 0839 and 1216 hrs. showed that at those times there was a southeasterly wind up to about 1·3 km. above ground and a westerly wind above. In the afternoon, there were large and irregular changes of horizontal movement probably connected with the mixing of the lower and upper layers of air

In *Fig. 2* are shown the height-time curves of all the balloons sent up on this day and the trajectories of those sent up at 1216 and 1445 hrs. The height-lines of the morning

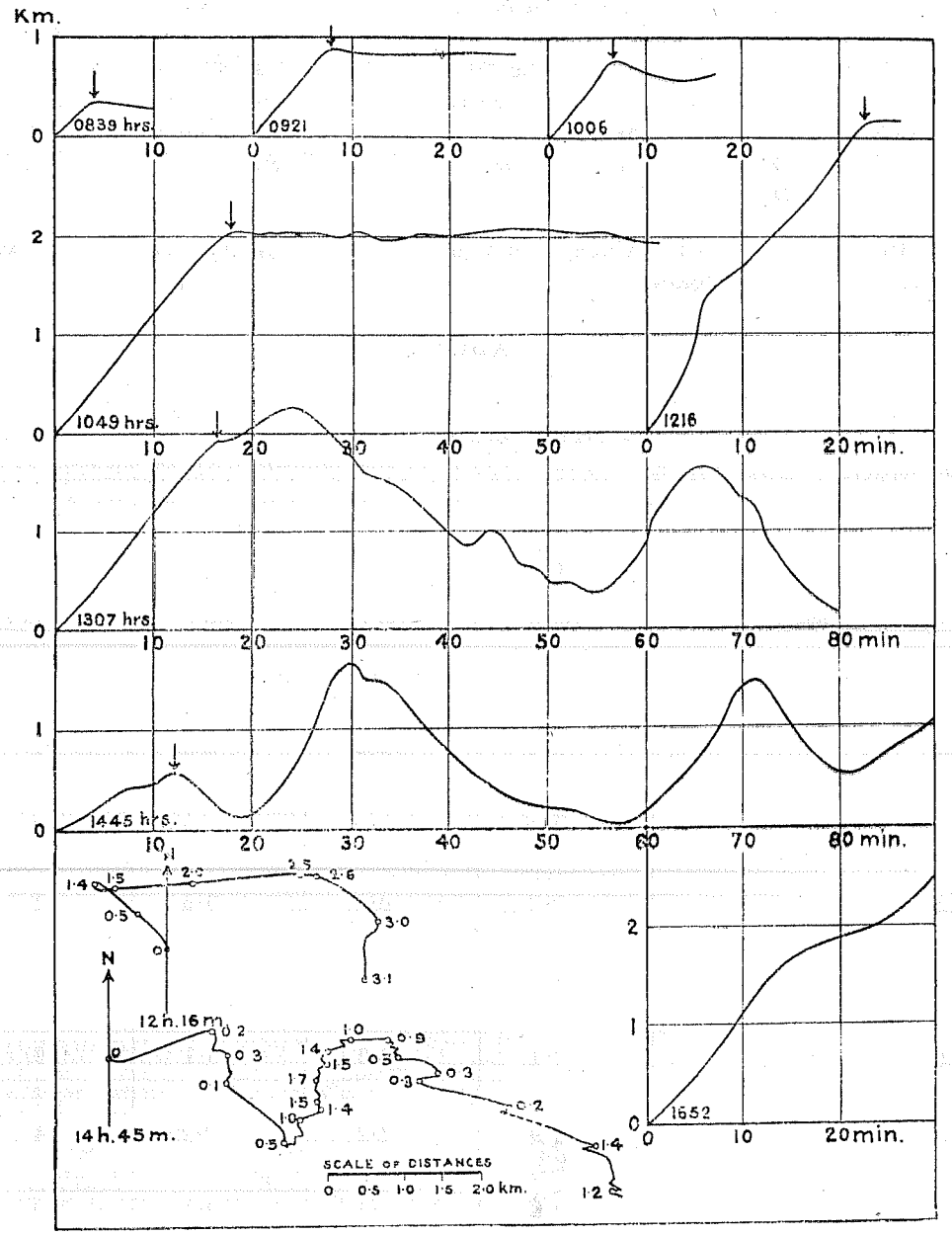

Fig 2. Height-time curves and trajectories of some Pilot Balloons sent up on 20th January 1931.

flights do not show strong vertical currents, but the flight at 1216 hrs. shows abnormally high rate of ascent before the release of the liftless balloon. The two balloons sent up at 1307 and 1445 hrs. show vigorous up and down currents lasting for comparatively long periods of time.

In the second of the above two flights, the mean rate of ascent of the combined system before the release of the liftless balloon was only 3 km./hr. against 7·5 km./hr. which would normally be expected. Upward and downward velocities going up to 14 km./hr. and 9 km./hr. respectively were shown by the latter course of

the liftless balloon. In the flight commencing at 1652 hrs. although the liftless balloon was not released, there are unmistakeable signs of vertical currents.

11TH FEBRUARY 1931.—There was a very weak low pressure area over the east Central Provinces connected with a western disturbance. The weather over Poona was clear. The times and other details of the ascents are tabulated below.

TABLE 3.

Ascents on 11th February 1931.

Time (hrs.)	H_o (km.)	H_x (km.)	H_n (km.)	t (min.)
0827	0·9	1·4	0·9	21
0921	1·2	1·5	1·2	11
1003	Liftless balloon not released.			
1033	1·7	2·3	1·7	12
1123	Liftless balloon not released.			
1301	1·8	2·0	1·8	8
1350	0·8	1·2	0·8	21

The height-time curves and trajectories of all the ascents on this day are given in *Fig. 3.* The trajectories show an interesting change of upper wind during the day. In the morning, there was an easterly current about 0·9 km. deep near the

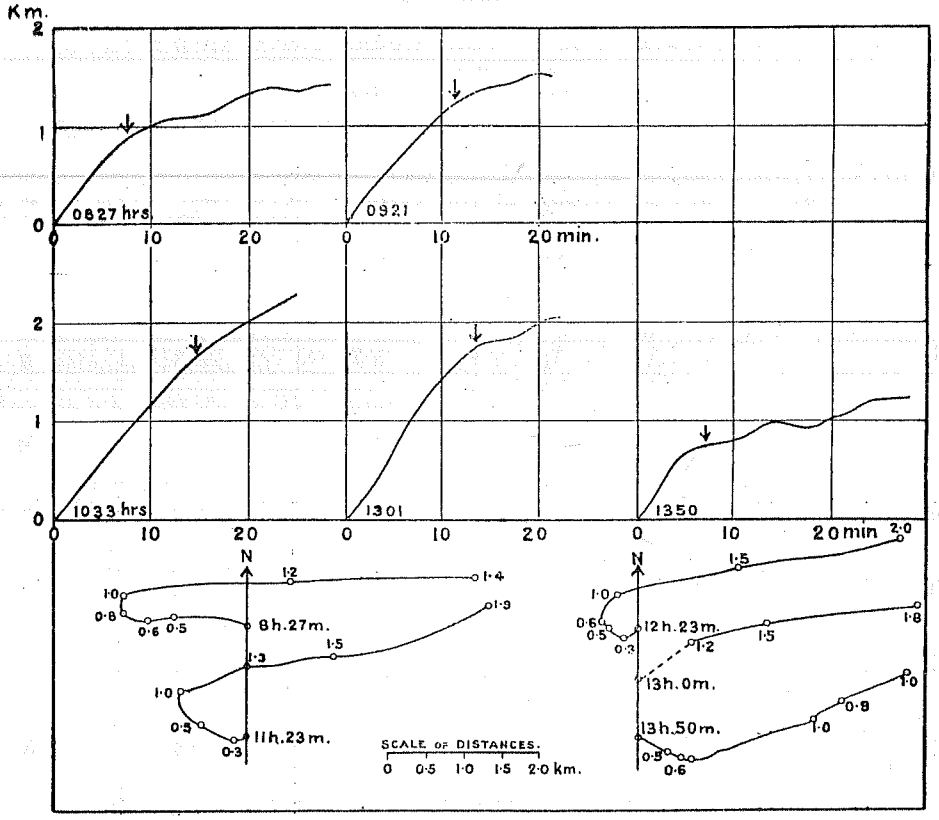

Fig. 3. Height-time curves and trajectories of some Pilot Balloons sent up on 11th February 1931.

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surface with a westerly current above. The former became shallower with the progress of the day and disappeared by 1300 hrs. The height lines of the ascents, which are given in the same figure show that although there were vertical currents, they were rather feeble. The strongest currents were shown by the balloons sent up at 1350 hrs., the vertical velocities going up to only 3 km./hr.

The ascents on this day show that from the mere fact that there exist two superposed streams from different directions, one cannot infer that the vertical currents that may be developed will be intense. The lapse-rates of temperatures in the two layers and the change of temperature taking place at the transition will naturally determine the stability as regards vertical displacements. Unfortunately, no temperature data are avilable to compare conditions on this day with those on 20th January 1931.

29TH MARCH 1933.—There were only two successful ascents on this day, one at 0817 hrs. and the other at 1243 hrs. The liftless balloon was released at 1·0 km. in the first ascent and at 0·6 km. in the second. The first showed only an ascending current with an average strength of 3 km./hr. and the second both ascending and descending currents of about the same average strength.

8TH APRIL 1933.—This was also a clear day, but it was cooler than normal in the central parts of the country, Gujarat and the eastern parts of Bombay Deccan. Information about the ascents is contained in *Table 4*.

TABLE 4.

Ascents on 8th April 1933.

Time (hrs.)	H_o (km.)	H_x (km.)	H_n (km.)	t (min.)
1004	1·2	1·7	1·2	9
1049	1·7	3·0	1·7	20
1242	1·3	2·6	1·3	19
1330	0·4	0·7	0·4	16
1419	1·8	2·4	1·8	20
1507	0·6	0·9	0·3	30
1559	0·8	1·1	0·7	29

The height-time curves of the balloons are shown in *Fig. 4*. Perhaps owing to

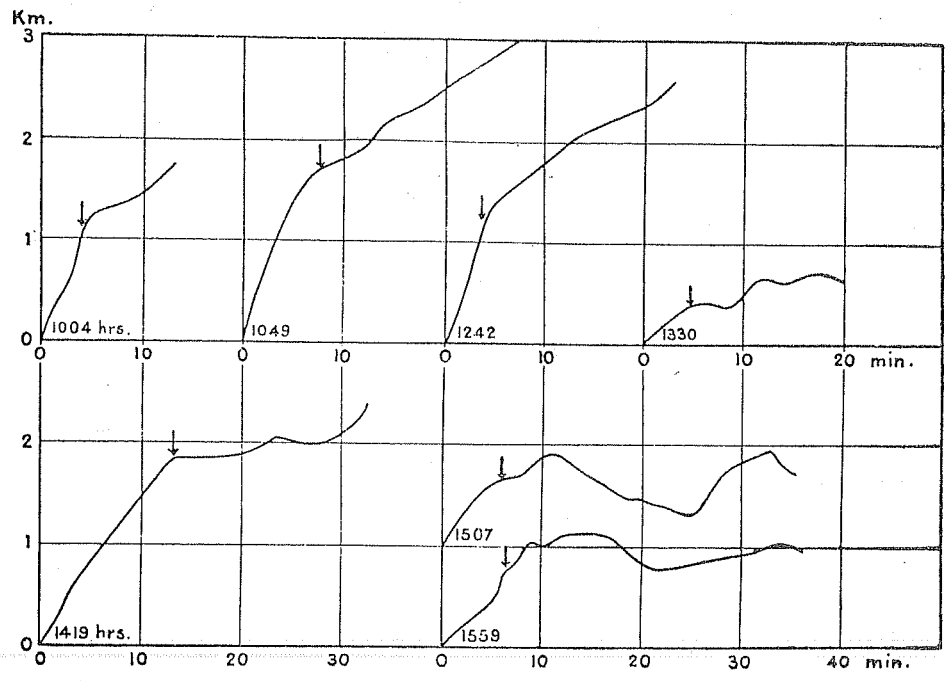

Fig. 4. Height-time curves of some Pilot Balloons sent up on 8th April 1933.

the extra instability due to the coolness of the upper air, the rates of ascent were exceptionally high in the first three ascents before the release of the liftless balloons and there were also strong upward movements of the liftless balloons. One is tempted to suspect that there was some error in free lift, but the original records do not show any special reason for suspicion. Assuming that there was no error in the measurement, the intensity of the ascending currents were from 4 to 10 km./hr. The afternoon ascents show both ascending and descending currents. For example, the flight commencing at 1507 hrs. shows descending currents of 2-6 km./hr. and ascending currents going up to 6 km./hr.

10TH APRIL 1933.—There were only two ascents on this day; both were made in the afternoon at a time when there was growing cumulus. The first ascent commenced at 1533 hrs. and the second at 1637 hrs. Thunder was heard between 1615 and 1725 hrs. It is interesting to note that in the second ascent, there was sustained upward current from the ground up to 3·3 km., the average upward velocity being about 4 km./hr. and the maximum velocity about 7 km./hr.

9TH OCTOBER 1934.—There was an extensive, diffuse low pressure area lying over the whole of the Bay of Bengal and part of the Deccan. On the afternoon of this day, there were thunderstorms at Poona and its neighbourhood; rain fell at Poona between 1552 and 1600 hrs. Twelve special ascents were made on this day, particulars of eight of which are given in *Table 5*.

TABLE 5.

Ascents on 9th October 1934.

Time (hrs.)	H_o (km.)	H_x (km.)	H_n (km.)	t (min.)
0930	1·1	1·1	0·2	9
0941	2·6	3·2	2·6	16
1015	1·1	2·0	1·1	23
1105	1·3	1·3	1·2	4
1245	2·3	2·8	2·2	11
1325	0·7	1·7	0·7	25
1408	1·6	1·7	1·6	0
1516	0·5	1·7	0·5	33

The height-time curves of all the ascents and the trajectories of three of them are shown in *Fig. 5*. The ascent at 1245 hrs. showed a large upward current of nearly

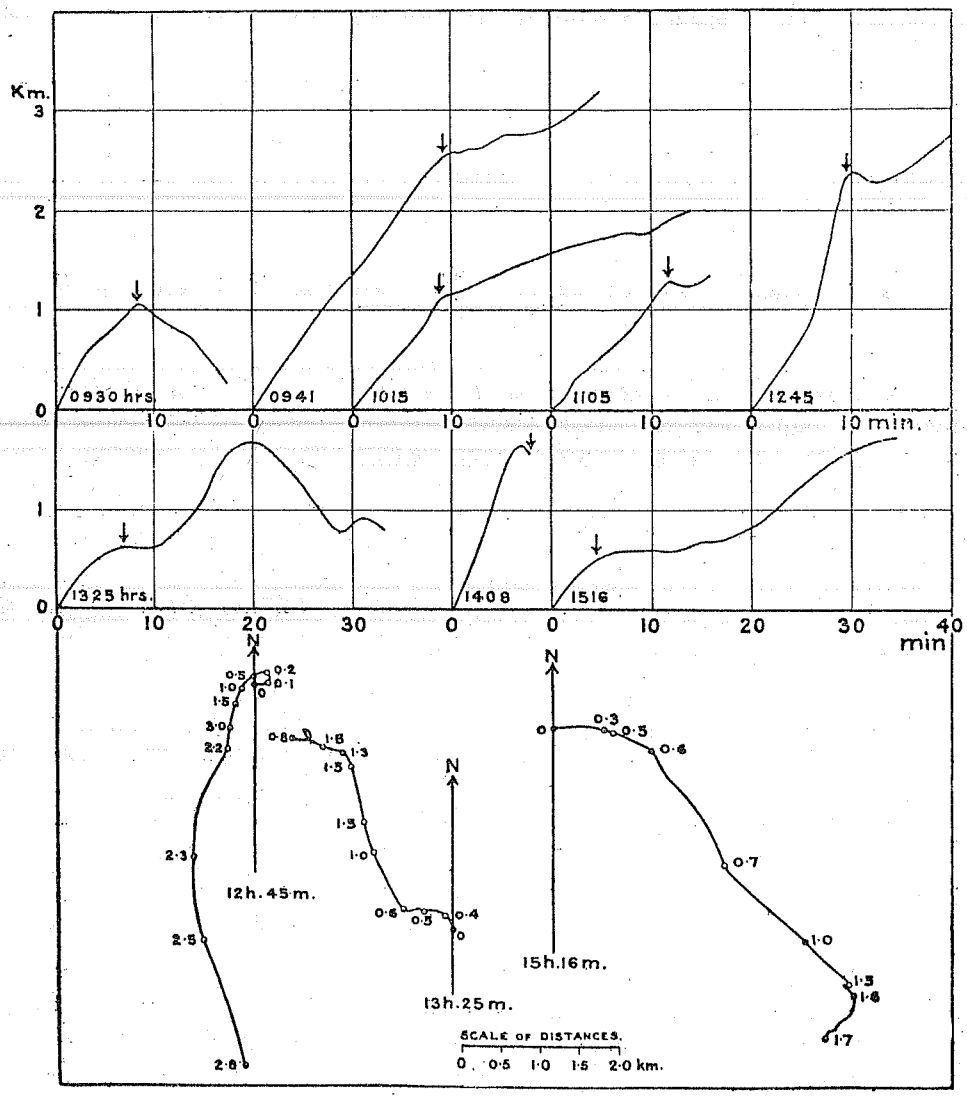

Fig. 5. Height-time curves and trajectories of some Pilot Balloons sent up on 9th October 1934.

16 km./hr.* before the release of the liftless balloon. Both upward and downward currents were shown by other ascents also, the one sent up at 1325 hrs. indicating up and down currents of about 8 km./hr. It is interesting to note that there were considerable differences between the trajectories of the balloons sent up at 1245, 1325 hrs. and 1516 hrs. the first one showing a northerly, the second a southerly and the third a northwesterly wind between 0·5 and 1·5 km. The autographic charts of wind and temperature, which are reproduced in *Fig. 6 (Plate I)*, show weak winds with fluctuating direction till 1525 hrs. and moderately strong westerly to west-northwesterly wind later. The fall of dry bulb and rise of wet bulb temperature a little before the onset of the westerly wind is noteworthy. It suggests that the westerly wind was of the nature of a sea-breeze[8]. Rain commenced about half an hour after the beginning of the westerly wind.

12TH OCTOBER 1934.—On this day, the low pressure area in the Bay was concentrating into a depression. Thundershowers occurred extensively in the Deccan. There were cumulus and cumulonimbus clouds at Poona and four special ascents were made, all in the afternoon, particulars of which are given in *Table 6.*

TABLE 6.

Ascents on 12th October 1934.

Time, (hrs.)	H_o (km.)	H_x (km.)	H_n (km.)	t (min.)
1318	1·6	2·0	1·6	8
1343	1·4	2·0	1·4	10
1421	0·6	1·7	0·6	16
1540	0·8	1·2	0·8	4

The height-lines and trajectories of these are reproduced in *Fig. 7.* There

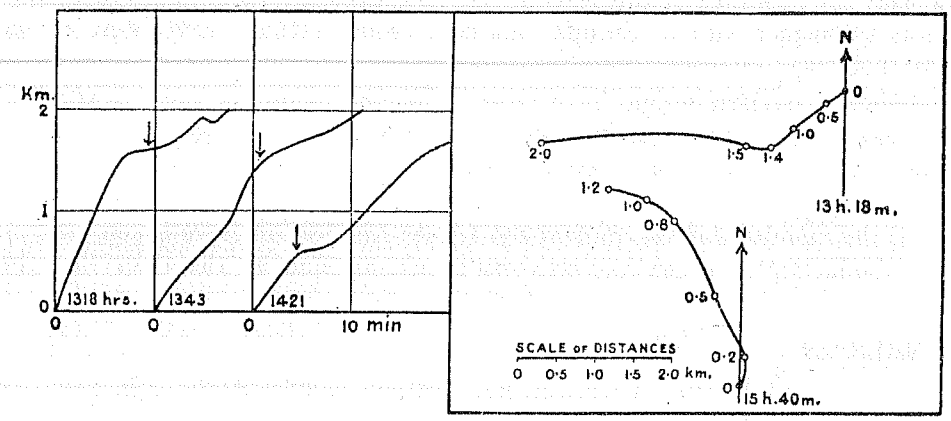

Fig 7. Height time curves and trajectories of some Pilot Balloons up on 12th October 1934.

was a shower between 1445 and 1455 hrs. and another between 1550 and 1620 hrs. Vertical currents going up to 7 km./hr. are noticeable in all the height-lines. The trajectories show that a northeasterly current at 1421 hrs.† was replaced by a southeasterly at 1540 hrs. The autographic charts from Poona are reproduced in *Fig. 8 (Plate II).*

*To obtain this, the normal rate of ascent calculated from the net free lift and weight was assumed.

†Trajectory not reproduced.

Discussion.—The trajectories of the ascents of the no-lift balloons were examined with reference to the contour of the surrounding country to see if the vertical currents could be associated with topographical features. No definite connection could be established and it may therefore be taken that the currents revealed by these particular ascents were mainly due to thermal turbulence. It should be remembered that the releases of the no-lift balloons generally took place at heights varying from 0·5 to 2 km. above ground, while the variations of ground-level in the region of travel of the balloons were not more than 0.2 km.

The strength of the up and down currents recorded above may be compared with some of those observed in Europe. German workers, using liftless pilot balloons released from aeroplanes have observed vertical currents going up to 10 km./hr. (2·8 mps.) on a hot afternoon. An upward wind of nearly 12 km./hr. (3·2 mps.) was experienced at a böenfront by Kronfeld flying in his sail-plane 'Wien' between the heights of 950 and 1600 metres. Still stronger were the currents encountered by Bedau in a towering cumulus in which the vertical velocity went up to more than 21 km./hr. (6 mps.). The readings obtained in England with accelerometers carried in aeroplanes flying in gusty weather showed vertical currents whose most frequent velocities lay between 2 and 5 km./hr. but occasionally went up to 18 km./hr. (17 ft./sec.) in cumulus clouds.

Recently, regular flights of pilot balloons with extra ballast to reduce the slant of the tail have been made at Poona and these show that measurable vertical currents are noticeable in the first two kilometers on more than 50% of the sunny days between 10 hrs. in the morning and sunset. Even on clear days, their magnitude may be as much as on cumulus days. The maximum upward velocity that has been observed with pilot balloons is 15 km./hr. in heavy cumulus weather. There have however, been other occasions, especially during thunderstorms, when sounding balloons having a normal rate of ascent of about 16 km./hr. have been carried down from heights of about 10 km. to 2 or 3 km. and again been carried up. These facts show that the intensity of the vertical currents experienced in India are about the same as those met with in Europe, but it is probable that they often extend to greater heights.

Gliders of modern design have rates of descent as low as 2 to 3 km./hr. and it is clear that on most sunny days in the Deccan (and presumably in other parts of the country as well) the thermal currents that are developed after 10 o'clock would be capable of sustaining soaring flight of gliders for a few hours at a time.

All the members of the staff of the Upper Air Section have taken part in this work in some way or other, and our best thanks are due to them for their hearty co-operation.

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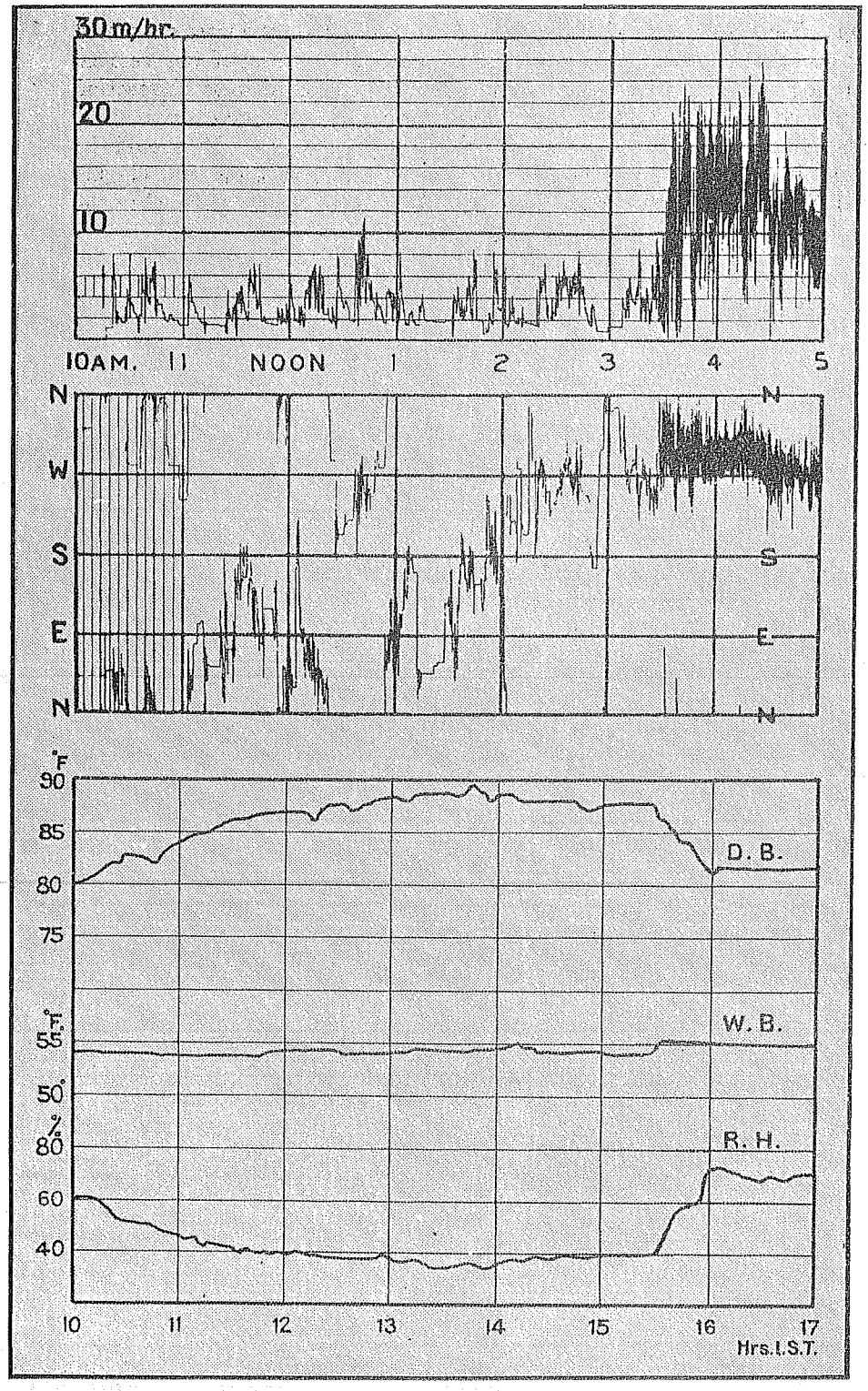

FIG. 6 WEATHER AT POONA ON 9-10-1934.

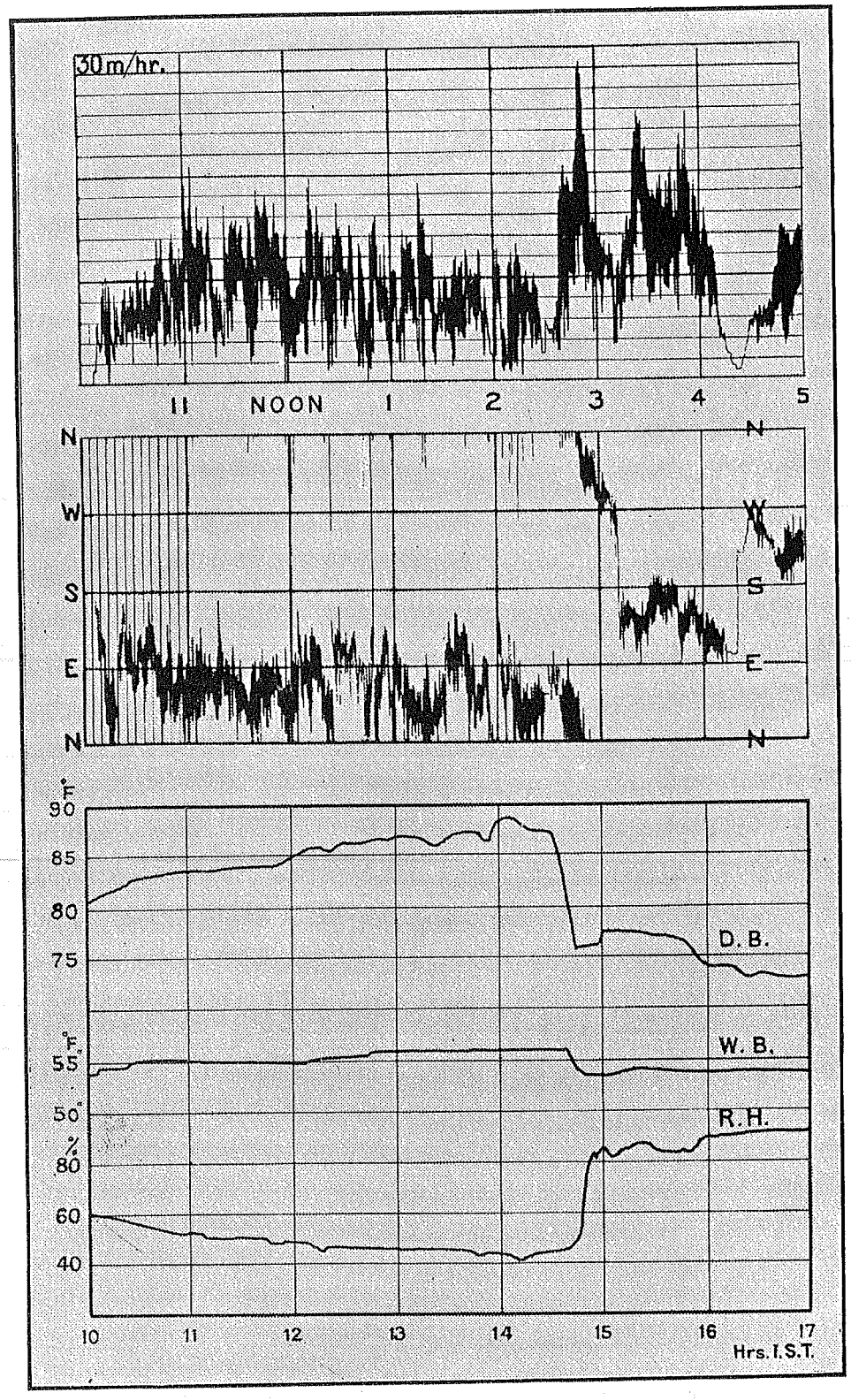

FIG. 8. WEATHER AT POONA ON 12-10-1934.