THE STRUCTURE OF THE SEA-BREEZE AT POONA.

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Summary.—The paper forms a preliminary study of the structure of the sea-breeze which sets in from a westerly to a northwesterly direction at Poona on many evenings in the months February to May. Observations with special pilot balloons made on four days in February to April 1930, considered along with the autographic records at the surface, show that the sea-breeze has the characteristics of a cold front. It is found that an easterly return current in the upper layers begins about an hour before the advent of the sea-breeze. The thickness of the breeze is usually 1—1·5 km. but occasionally it extends to as much as 2·0 km. It is suggested that the breeze from the Arabian Sea gets revived on passing over the Western Ghats owing to the flow down the slope on the eastern side of the Ghats and the higher temperature of the surface air which it meets on the Deccan plateau.

Observations made within the last two years at Poona show that during the months February, March, April and part of May there occurs on many days a sudden onset of fresh gusty wind generally between 15 and 17 hrs. This wind usually comes from some west-north-westerly direction and is slightly cooler and moister than the air previously present. It was considered probable that this regular evening breeze was actual sea-breeze that was penetrating inland. In order to test whether this is so, Dr. Desai and the present writer went on 3rd March 1930 to Lonavla, which is about 33 miles to the WNW of Poona. On that day, a west-north-westerly breeze set in at Lonavla at 16 h. 5 m., with the same suddenness as was usual at Poona and the strength of the wind at an exposed site was 12—15 miles per hour. The wind continued at about the same strength till at least 18h. 30m. The usual west-north-westerly evening breeze at Poona began on that day at 19 h. 25 m. There was thus a time-interval of 3 h. 20 m. between the onset of the breeze at Lonavla and Poona. The calculated speed of the sea-breeze front is about 10 m. p. h. which is slightly less than the average speeds of wind at Lonavla and Poona. We may therefore take it that a front was advancing towards ESE on the afternoon of that day.

In order to study the structure of the breeze a number of pilot balloons were let off before and after the commencement of the breeze on a few days in the hot season of 1930. *Fig. 1* shows the changes of wind, temperature and humidity on the afternoon of 27th February 1930. It will be seen that the breeze commenced at about 18 h. 20 m. on that day. Pilot balloons were sent up at 17 h. 0 m., 17 h. 22 m., 18 h. 20 m. and 18 h. 36 m. The balloons were provided with tails of 50 metres length and flags were attached at 6¼ metres, 12½ metres and 50 metres from the balloon. A sand bag weighing 31 gms. was also attached at the end of the string, partly to keep the tail more nearly vertical and partly to reduce the rate of ascent. The trajectories and tables giving the velocities at different heights of the four balloons are shown in *Fig. 2*. The following points are noteworthy :—

(1) The wind-structure at 17 h. 22 m. was practically identical with that at 17 h. 0 m. above 2·2 km., but the later ascent shows a south-easterly to east-south-easterly wind between 0·5 km. and 2·2 km.

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(2) At 18 h. 20 m., that is, two minutes after the commencement of the breeze at the surface, the westerly wind had penetrated to a height of 0·6 km. and after a region of weak winds up to above 1·2 km. there was a gradually increasing easterly wind up to 3·1 km. (It must be remembered that 0·6 km. represents the thickness of the westerly wind not at the place where the balloon was released but at a distance of about 2 km. to the east of the observatory.)

(3) At 18 h. 36 m., the direction of wind had changed from westerly to north-westerly and its thickness had increased to 1·2 km.; this was succeeded by an east-south-easterly wind which extended to above 2·3 km.

The approximate structure of the advancing sea-breeze as constructed out of the pilot balloon winds is as given in *Fig. 3(a)*. In drawing the diagram the fact that the position of the balloon alters with time has been taken into account. It is evident that the sea air was advancing inland as a cold front with a thickness of about 1·2 km., with a return current of land air above. The trajectories at 17 h. 22 m. and 17 h. 0 m. show that the easterly return current was noticeable about an hour before the arrival of the cold air at the surface, but was not noticeable about an hour and a half earlier.

The difference in the character of the gustiness before and after 18 h. 18 m. is noteworthy,—the former being of the convective eddy type produced by ground heating and the latter of the type produced by movement of stable air over rough ground. Considering that the latter type of wind persisted till about 20 h. 50 m. and that the average speed of wind between 18 h. 20 m. and 20 h. 50 m. was about 8 m.p.h., the farthest distance inward that the sea air would have travelled is about 20 miles to the east of Poona. This is, however, an overestimate and it is probable that the actual distance was smaller, as, with the progress of the night, the contrast between the original and incoming air would become smaller.

Although the balloons were of the same size and had the same net free lift, the rates of ascent were different, and showed variations with height. Owing to the large influence of eddies, however, it is impossible to say definitely whether there was any difference in the rates of ascent in the two air masses. The height curves, however, suggest that in the neighbourhood of the nose of the front, both within and above the cold air mass, there was a slight upward component of velocity, and that about 6 km. behind there was a downward component of motion in the air above 1·2 km.

A second series of four ascents were made on 12th March 1930, but unfortunatley on this day, although the breeze started at 16 h. 25 m., the first ascent was only made at 17 h. 22 m. The other three ascents were made at 17 h. 37 m., 18 h. 8 m. and 18 h. 31 m. The wind before the onset of the breeze was indefinite in direction and of the average velocity of about 5 m. p. h. The fresh breeze came from the north-west with an average velocity of about 16 m. p. h. and a maximum gust velocity of about 30 m. p. h. The anemogram, thermogram and hygrogram are reproduced in *Fig. 4* and the horizontal projection of the trajectories of the four balloons are shown in *Fig. 5*. It will be noticed that the colder current extended to a height of 1·5—2·0 km. and the return upper current to 3·5—4·0 km. and that between 17 h. 22 m. and 18 h. 30 m., there was not much variation in the depth of the current. In the first two flights, however, the maximum wind velocity at about 0·2 km. and the rate of decrease of velocity above that level were greater than in the last two. The height-time curves also show that the rates of ascent of the balloons were generally smaller in the lower current than in the upper. There was a depression over the Punjab on the morning of this day, which weakened and moved over to the United Provinces by the 13th morning.

On 21st March 1930, a series of five flights were made between 15 h. 34 m. and 17 h. 53 m. The breeze set in at 16 h. 35 m. and was accompanied by a slight fall of temperature. There was a feeble gradient for southerly to south-westerly wind.

The wind direction was variable—between E. and S.—for an hour before the ascent and changed to west-north-westerly with the setting in of the breeze (see *Fig. 6*). The mean speed of wind rose from about 5 m. p. h. to about 12 m. p. h. An interesting feature of this day's wind was that it persisted till after 22 h. 30 m., or for a period of about 6 hrs.

The horizontal projection of the trajectories of the balloons are drawn in *Fig.* 7. A diagram showing the structure of the breeze similar to the one for 27th February 1930 is given in *Fig.* 3 (*b*). It will be noticed that as on 27th February 1930, the counter current set in even before the advent of the surface wind. The westerly current had grown to a thickness of 1 km. in less than half an hour. Its thickness was 1·3 km. after 45 minutes and 1·1 km. after 1 h. 20 m. It appears therefore that in this case also the rate of rise of thickness was very high in the first few minutes and that the thickness remained more or less steady afterwards. It may be mentioned that the second and third balloons were lost in cumulus cloud. In order to study how the current dies off at night, it would be necessary to make use of balloons provided with lights and it is hoped to do this in the coming season.

Owing to the long duration of the breeze on this day, it is likely to have penetrated inland to a distance of 40—50 miles east of Poona. The question as to how the strength and thickness of the breeze dies down with distance inland remains to be worked out.

As an instance of a slightly more complicated situation, one may take the breeze on 4th April 1930. On the morning of this day, there was a shallow low over the west Central Provinces and W. Central India which had moved slightly eastwards by next morning. The autographic records are given in *Fig. 8* and the balloon trajectories at 16 h. 49 m., 17 h. 45 m. and 18 h. 46 m. are shown in *Fig. 9*. The thermograph trace and the nature of the gustiness in the anemogram show that the sea-breeze came on at about 18 h. 40 m. But the wind was fresh and from a north-westerly direction even from 15 h. 30 m. It will be seen from the velocity tables that the maximum speed of wind increased in the successive flights and it is probable that the thickness of the north-westerly or west-north-westerly current underwent a sudden increase at 18 h. 40 m.

With the progress of the hot season, the surface wind at Poona in the afternoon hours becomes more and more westerly long before the onset of the sea-breeze, but even then, on most days, one can detect the arrival of the sea-breeze by the change in the type of gustiness.

It is clear from the above that the sea-breeze at Poona comes on as a cold front. When the air is dry, there is little effect on the weather, but when some moisture has already been injected into the atmosphere at 1—3 km. by previous weather conditions (as often happens in April and May), the coming in of the breeze acts as a trigger for the production of cumulus cloud and sometimes even for the development of a thunderstorm.

There remains the important question as to whether the breeze at Poona is to be looked upon as mere ordinary sea-breeze or there are other causes helping to strengthen it and make it more marked. The usual thickness of the sea-breeze near coast stations in India is only about 0·5 to 0·7 km. but here we have seen instances when the westerly current went up to more than 2 km. above Poona. The Western Ghats are about 30 miles to the west of Poona and the coast is about 40 miles farther

to the west. Poona is on the Deccan tableland at a height of about 1,800 ft. above sea-level while the Ghats rise to a height of about 2,500 ft. and the coastal plain west of the Ghats is generally lower than 300 ft. with a few low hills rising here and there. When the see-breeze is to the west of the Ghats, it may be only of the usual thickness and the return current may take place towards the sea above 0·7 or 0·8 km., but when the breeze reaches the Ghats, part of it is lifted up and overflows, the flow being greatest wherever there are cols in the Ghats. Once over the Ghats, the sea air would meet air heated by contact with the surface of the plateau and will therefore have a tendency to spread inland displacing warmer air. We have yet no definite information regarding the depth of the sea-breeze at a place west of the Ghats. It is planned to make a more detailed study of the effect in the summer of 1931 especially in the neighbourhood of the Ghats.

The special pilot balloon observations utilised in this note were carried out enthusiastically by the staff of the Upper Air Section at Poona. Mr. K. P. Ramakrishnan, Assistant in the section, also gave considerable help during the preparation of the note.

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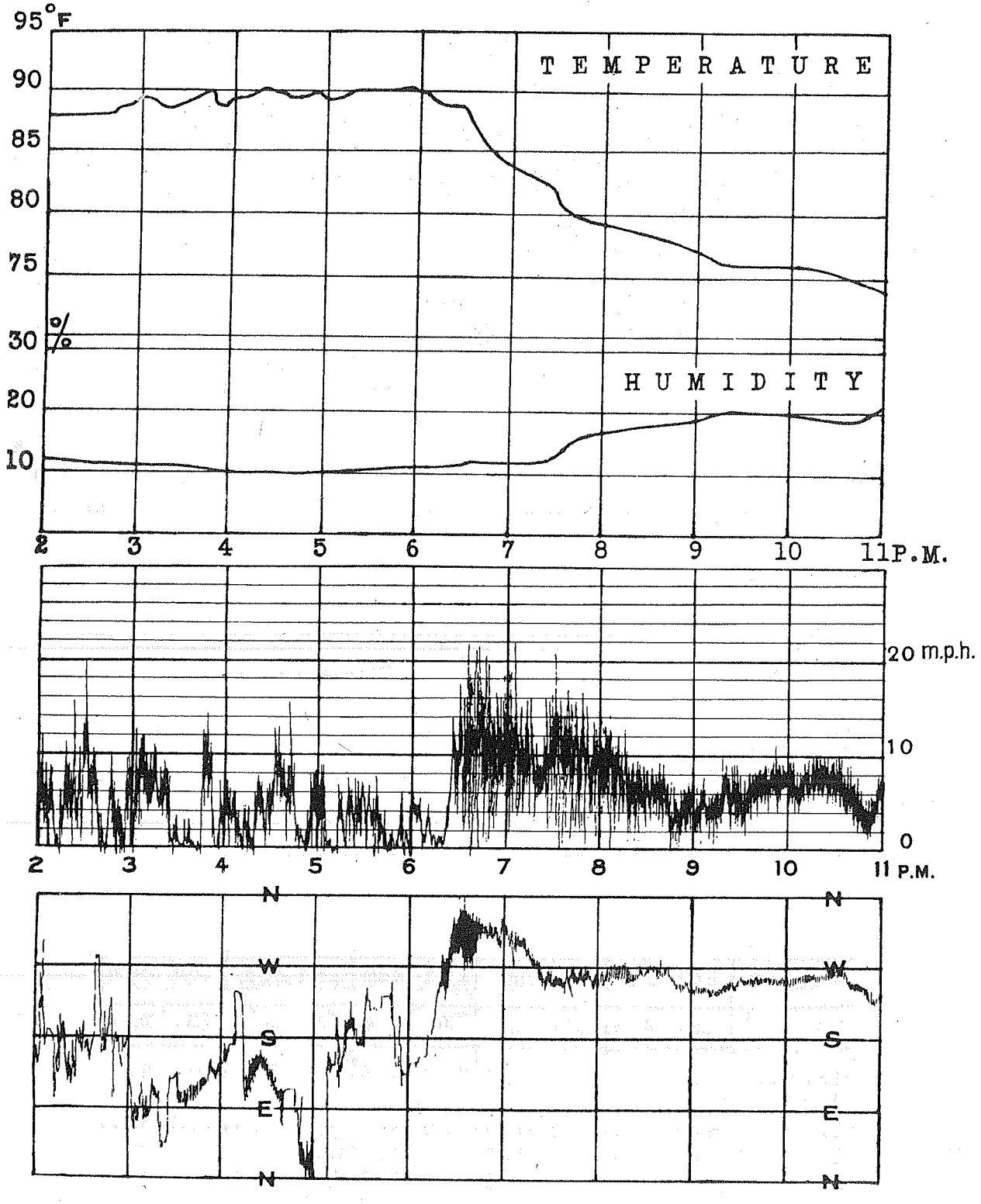
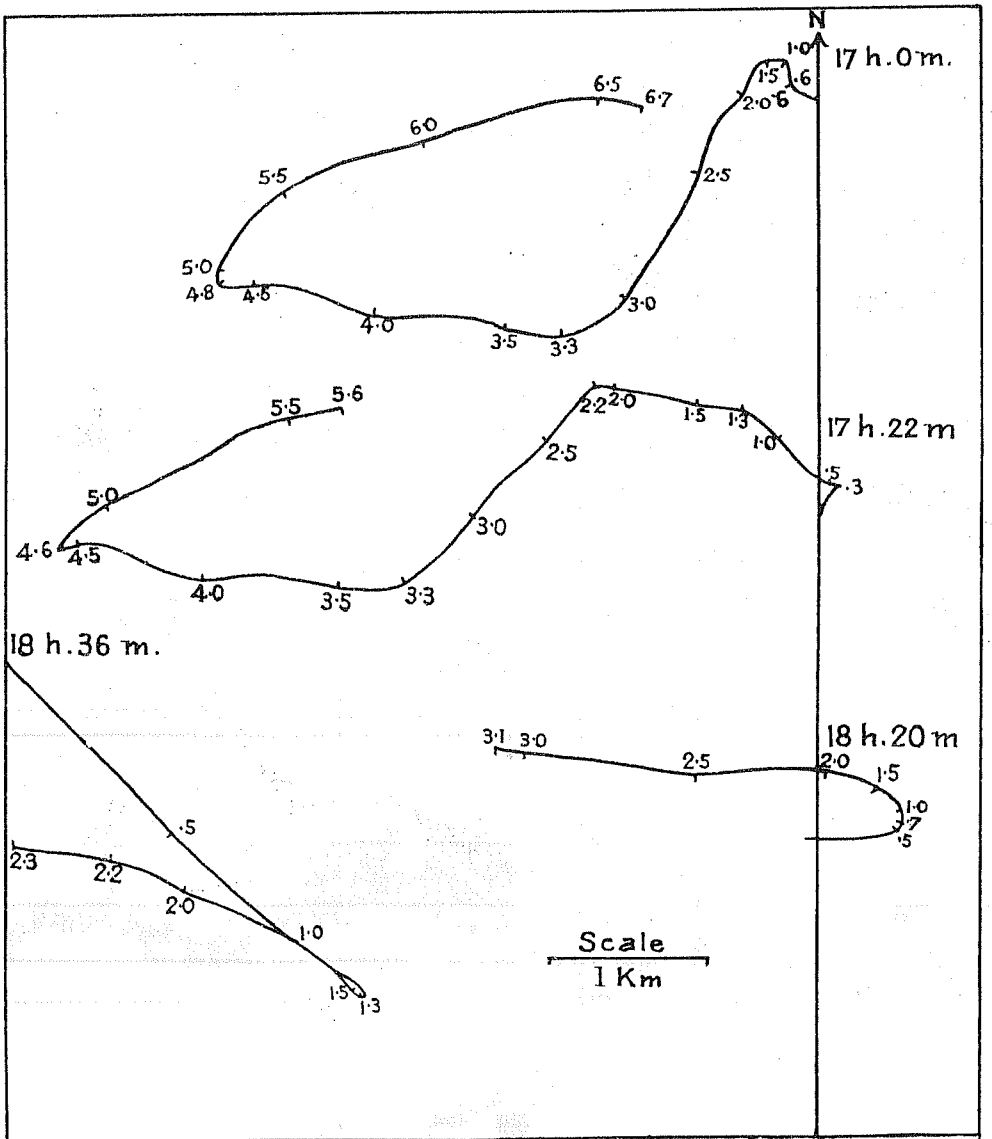


Fig. 1. Temperature, humidity and wind at Poona on 27-2-1930.



17h 0m		17h 0 m		17h 22m		17h 22m		18h 20m		18h 36m	
Km.	m/s	Km.	m/s	Km.	m/s	Km.	m/s	Km.	m/s	Km.	m/s
Gr.	1.2	4.0	3.4	Gr.	1.0	3.0	4.6	Gr.	0.3	Gr.	2.7
0.5	1.6	4.5	2.2	0.3	1.2	3.3	4.9	0.2	4.3	0.5	6.9
1.0	1.0	4.8	1.0	0.5	0.8	3.5	4.3	0.5	1.8	1.0	5.4
1.5	1.0	5.0	2.4	1.0	2.7	4.0	3.9	0.7	1.1	1.3	0.5
2.0	2.1	5.5	4.8	1.5	3.6	4.5	1.9	1.0	1.2	1.5	3.3
2.5	4.6	6.0	5.8	2.0	1.8	4.6	1.3	1.5	2.6	2.0	4.4
								2.0	3.1		
3.0	5.0	6.5	5.8	2.2	2.5	5.0	3.9	2.5	6.1	2.3	7.6
3.5	4.2			2.5	4.6	5.5	5.3	3.0	6.9		

Fig.2. Trajectories of Pilot Balloons sent up on the afternoon of 27. 2. 1930 from Poona and wind velocity tables obtained from them.

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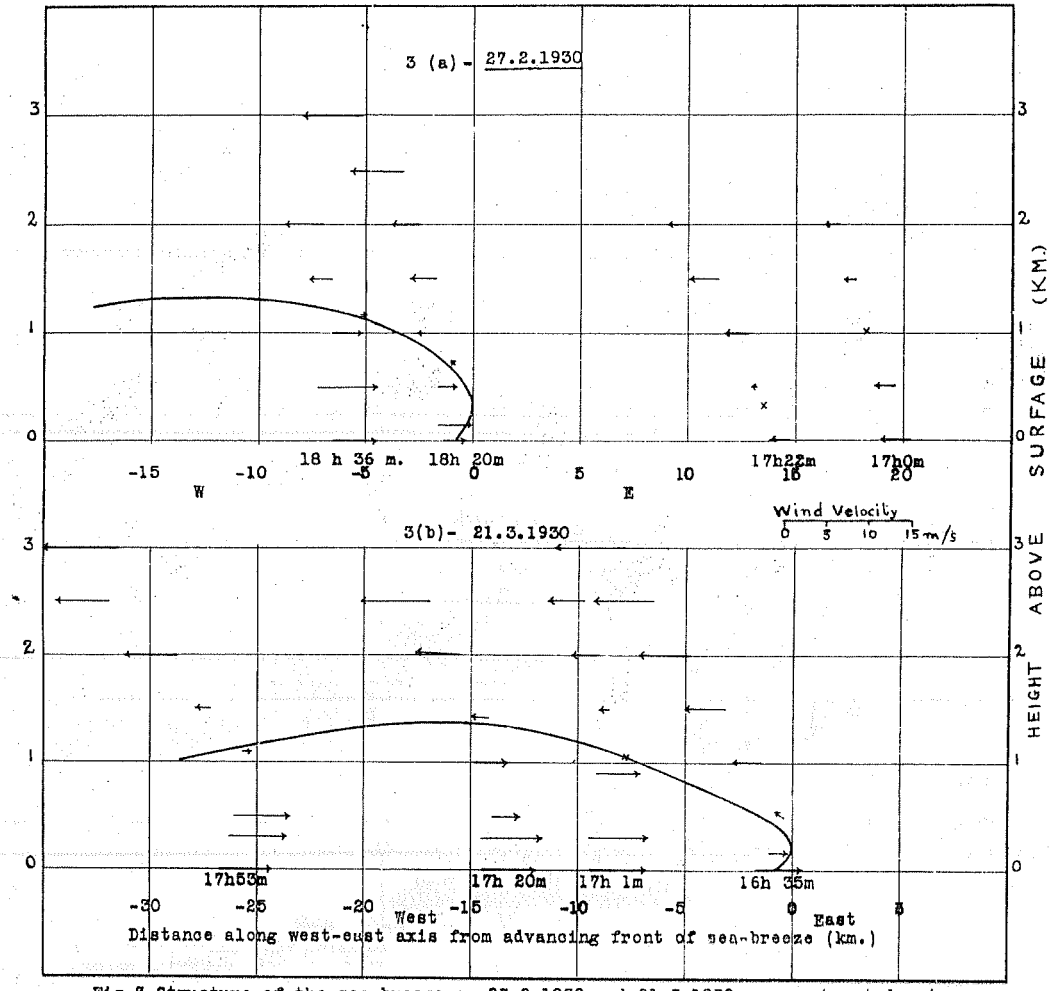


Fig.3. Structure of the sea-breeze on 27.2.1930 and 21.3.1930 as constructed out of the pilot balloon ascents.

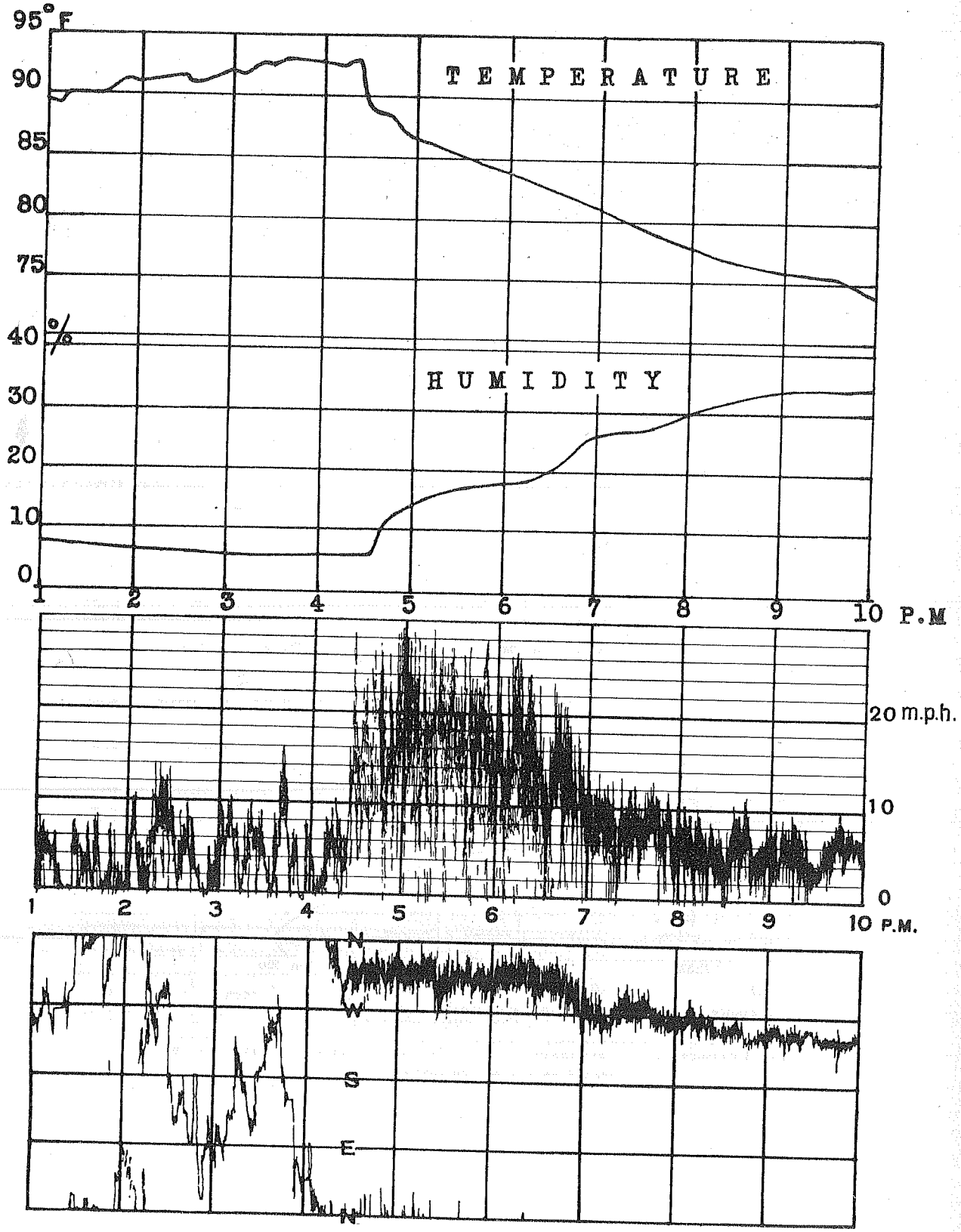
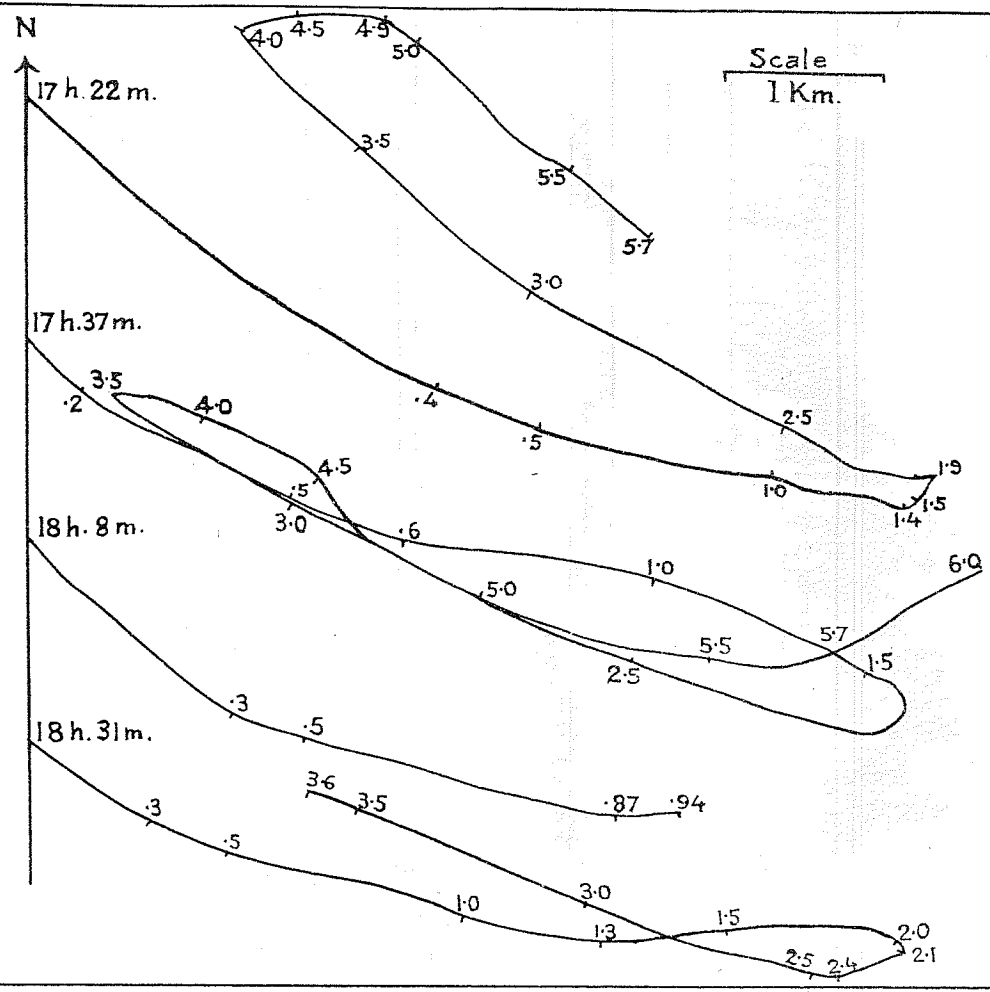


Fig. 4. Temperature, humidity and wind at Poona on 12-3-1930.



17h 22 m		17h 37 m		18 h 8 m	
Km.	m/s	Km.	m/s	Km.	m/s
Gr.	7.2	Gr.	7.6	Gr.	6.8
0.5	18.0	0.2	7.8	0.2	9.5
0.5	10.0	0.5	14.6	0.5	7.9
1.0	4.7	0.6	8.0	0.9	6.0
1.5	1.6	1.0	6.5	18 h 31 m.	
2.0	0.9	1.5	2.7	Km.	m/s
2.5	5.6	1.9	1.4	Gr.	4.5
3.0	7.7	2.0	3.0	0.5	8.4
3.5	8.3	2.5	7.2	1.0	8.0
4.0	0.8	3.0	8.1	1.5	6.0
4.5	4.6	3.4	0.3	2.0	2.0
5.0	3.9	4.0	2.6	2.5	4.8
5.5	8.0	4.5	3.0	3.0	7.2
		5.0	6.3	3.5	8.7
		5.5	6.3		
		6.0	7.4		

Fig.5. Trajectories of Pilot Balloons sent up on the afternoon of 12. 3. 1930 from Poona and wind velocity tables obtained from them.

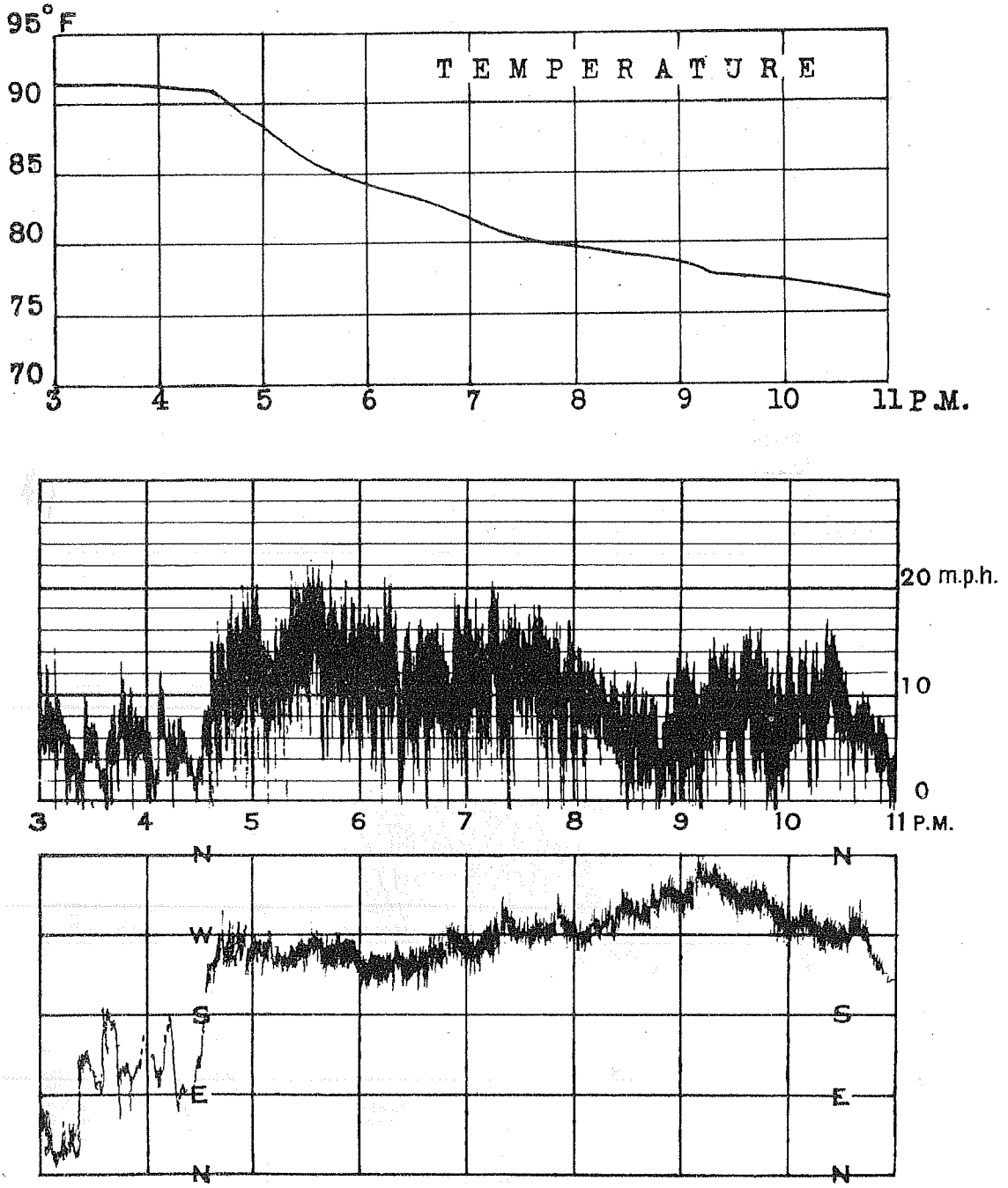
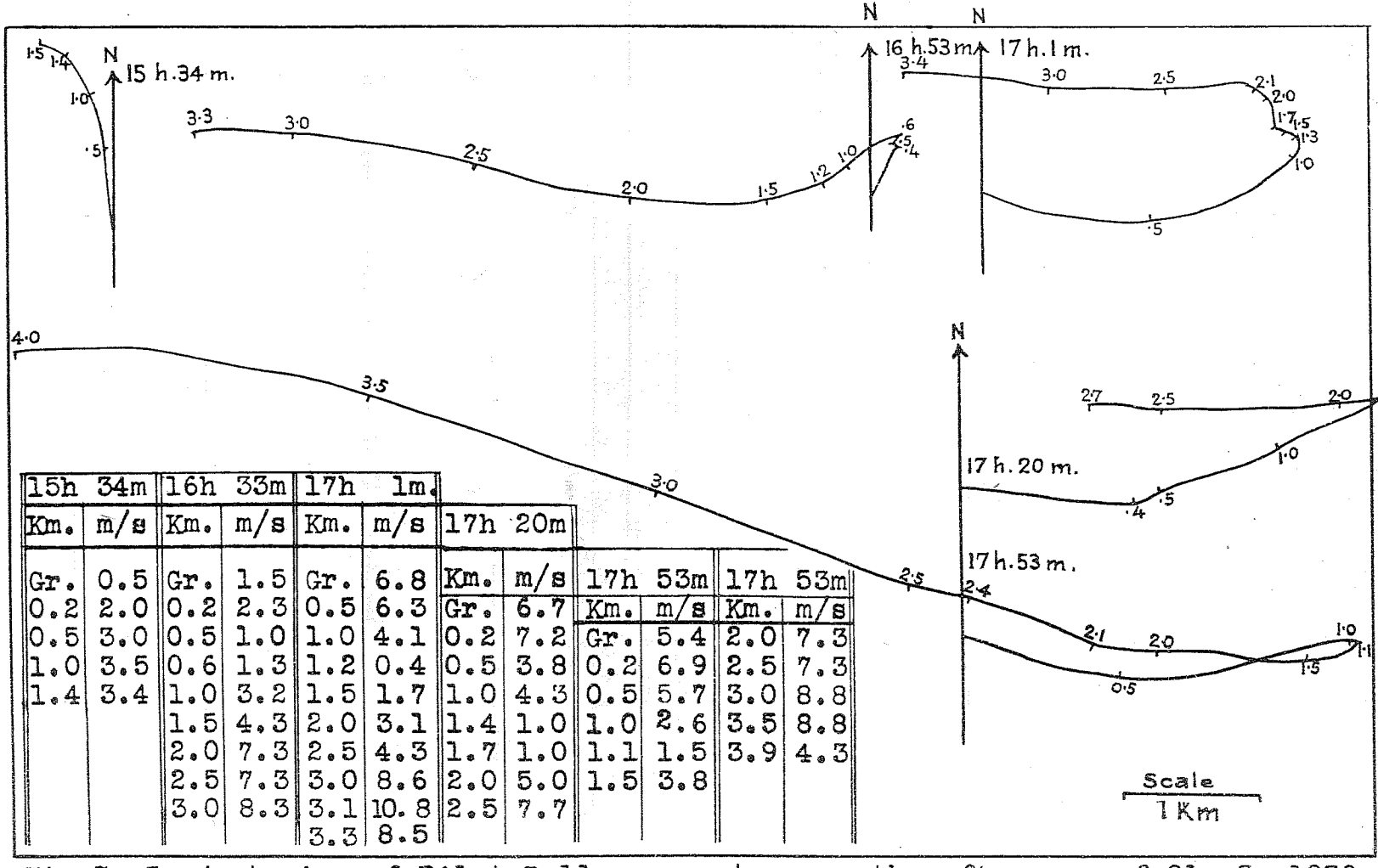


Fig. 6. Temperature and wind at Poona on 21-3-1930.



15h 34m		16h 33m		17h 1m.		17h 20m		17h 53m		17h 53m	
Km.	m/s	Km.	m/s	Km.	m/s	Km.	m/s	Km.	m/s	Km.	m/s
Gr.	0.5	Gr.	1.5	Gr.	6.8	Gr.	6.7	Gr.	5.4	2.0	7.3
0.2	2.0	0.2	2.3	0.5	6.3	0.2	7.2	0.2	6.9	2.5	7.3
0.5	3.0	0.5	1.0	1.0	4.1	0.5	3.8	0.5	5.7	3.0	8.8
1.0	3.5	0.6	1.3	1.2	0.4	1.0	4.3	1.0	2.6	3.5	8.8
1.4	3.4	1.0	3.2	1.5	1.7	1.4	1.0	1.1	1.5	3.9	4.3
		1.5	4.3	2.0	3.1	1.7	1.0	1.5	3.8		
		2.0	7.3	2.5	4.3	2.0	5.0				
		2.5	7.3	3.0	8.6	2.5	7.7				
		3.0	8.3	3.1	10.8						
				3.3	8.5						

Fig.7. Trajectories of Pilot Balloons sent up on the afternoon of 21. 3. 1930 from Poona and wind velocity tables obtained from them.

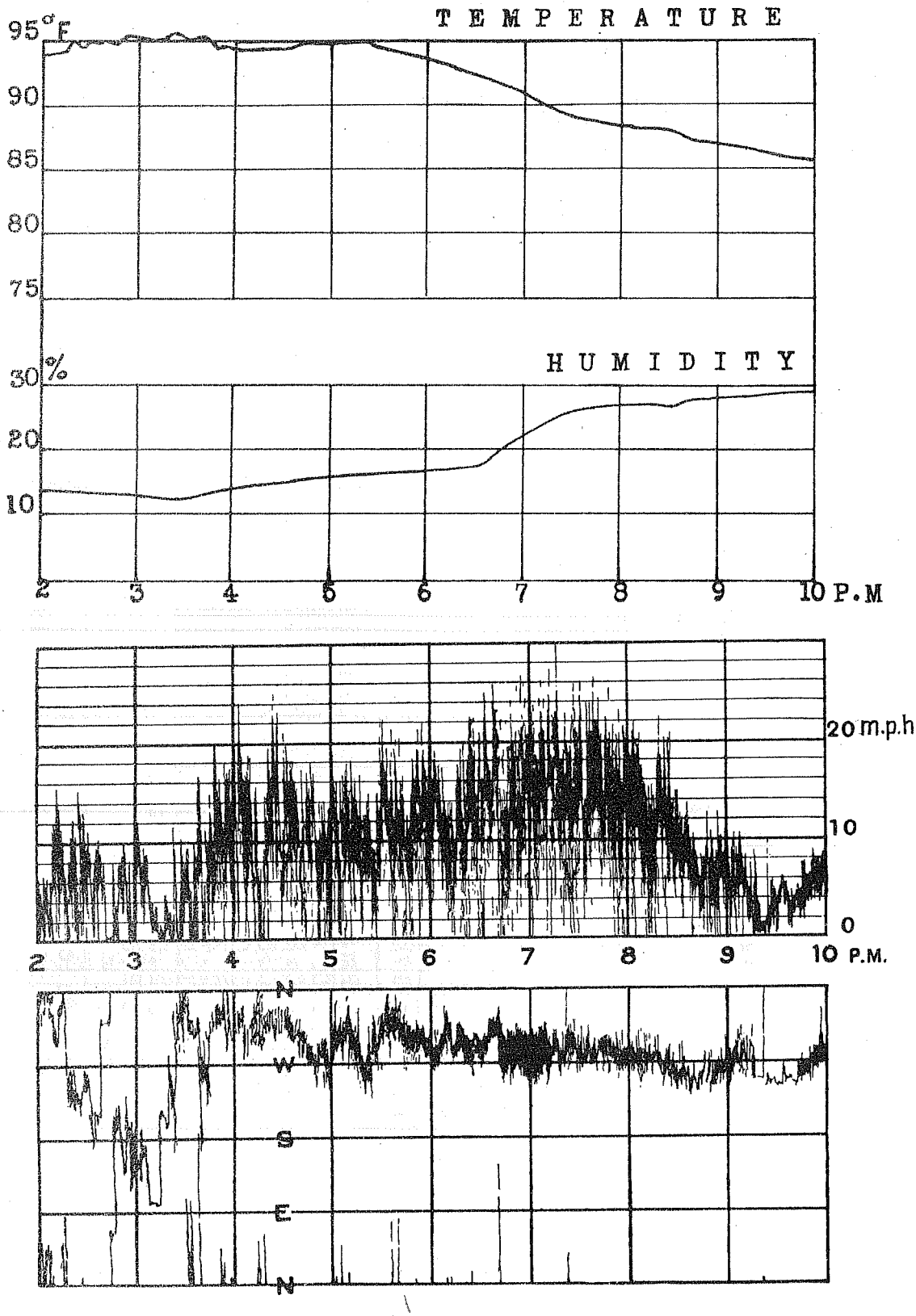
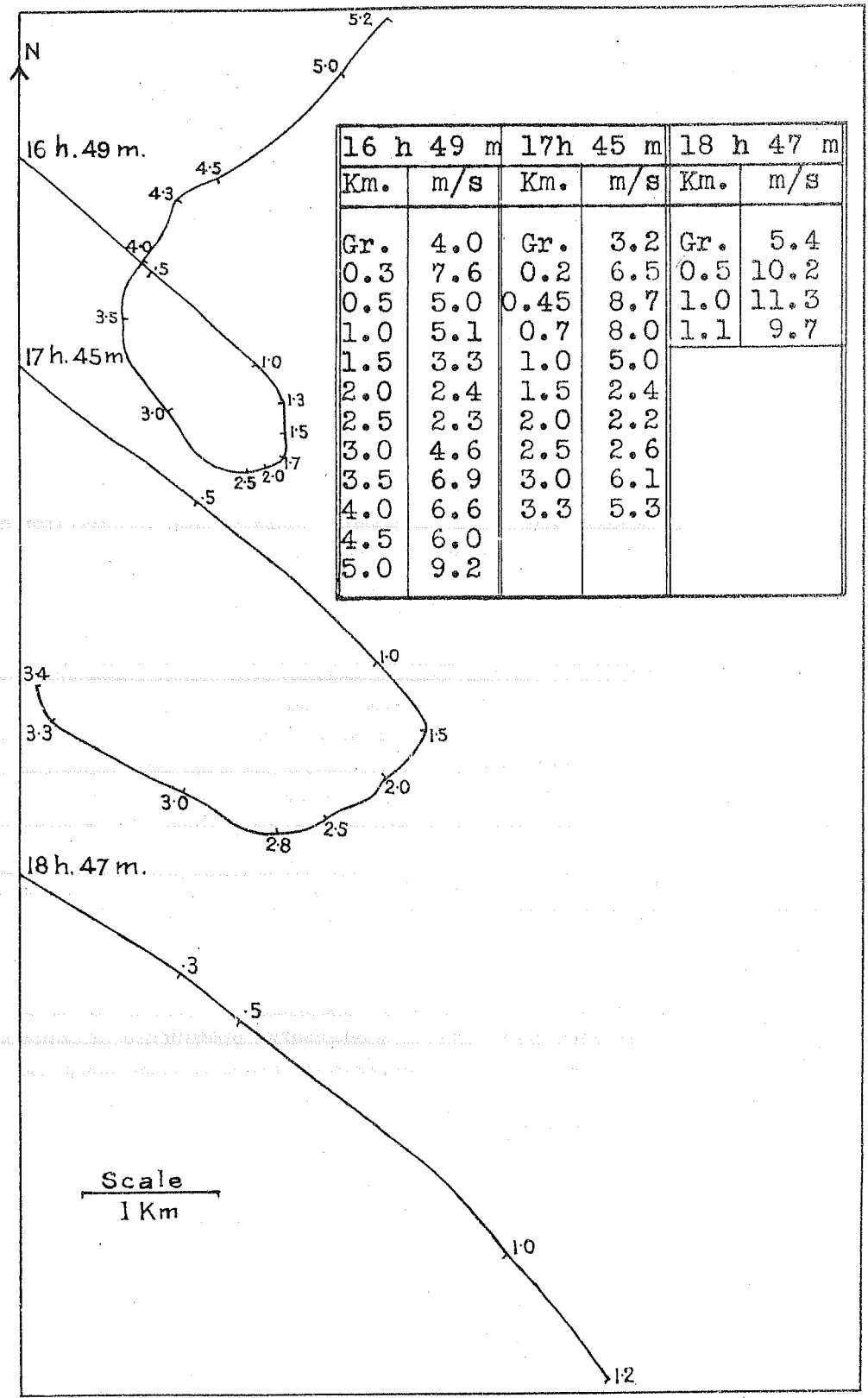


Fig. 8. Temperature, humidity and wind at Poona on 4-4-1980.



16 h 49 m		17h 45 m		18 h 47 m	
Km.	m/s	Km.	m/s	Km.	m/s
Gr.	4.0	Gr.	3.2	Gr.	5.4
0.3	7.6	0.2	6.5	0.5	10.2
0.5	5.0	0.45	8.7	1.0	11.3
1.0	5.1	0.7	8.0	1.1	9.7
1.5	3.3	1.0	5.0		
2.0	2.4	1.5	2.4		
2.5	2.3	2.0	2.2		
3.0	4.6	2.5	2.6		
3.5	6.9	3.0	6.1		
4.0	6.6	3.3	5.3		
4.5	6.0				
5.0	9.2				

Fig. 9. Trajectories of Pilot Balloons sent up on the afternoon of 4. 4. 1930 from Poona and wind velocity tables obtained from them.