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Observations of some meteorological phenomena from the Kodaikanal Observatory

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ABSTRACT. The paper describes observations of haze, clouds and growth of convection over the plains, made from the Kodaikanal observatory during winter months of 1950. The height above sea level of the top of the haze layer has been evaluated by measuring the angle of dip of the haze line below the horizontal. It is generally found that the top of the haze layer is some 1000 to 2000 ft below the level of the Kodaikanal Observatory, although there are day to day as well as diurnal variations of this height. By measuring the height of top of fair weather cumulus clouds it is estimated that the convection layer grows at an average rate of about 600 ft per hour from 0900 Ist till the maximum temperature epoch on a day of fair weather.

1. Introduction

By virtue of its elevation, a high level station affords opportunities for the study of certain types of meteorological phenomena. Such a study is not possible from a low level station because in the former case the observer is above the level of the phenomena while in the latter case the observer is below that level. The observations reported in the present paper belong to the former category and were made in the winter months of 1950.

2. Topographical

A brief account of the topography of Kodaikanal and the surrounding country is of interest in connection with the observations discussed below. Fig. 1 is a map of Madura district showing the location of Kodaikanal and also of some of the important physical features.

Kodaikanal town stands on the southern crest of the Upper Palnis at an average elevation of about 7000 ft above sea level. The Palni range is an off-shoot of the Western Ghats, and runs roughly in an east-west direction. Its greatest length is about 40 miles and maximum breadth about 25 miles. It forms two fairly distinct portions known as the Upper Palnis and the Lower Palnis. The Lower Palnis which constitute the eastern half, consist of several peaks ranging in elevation from about 3000 to 5000 ft. The Upper Palnis vary in elevation from about 6000 to 8000 ft.

The observatory is located on the top of a hill at an elevation of nearly 7700 ft above sea level. Standing on the anemometer tower of the observatory one gets a panoramic view of the surrounding country. Towards southwest and south the view

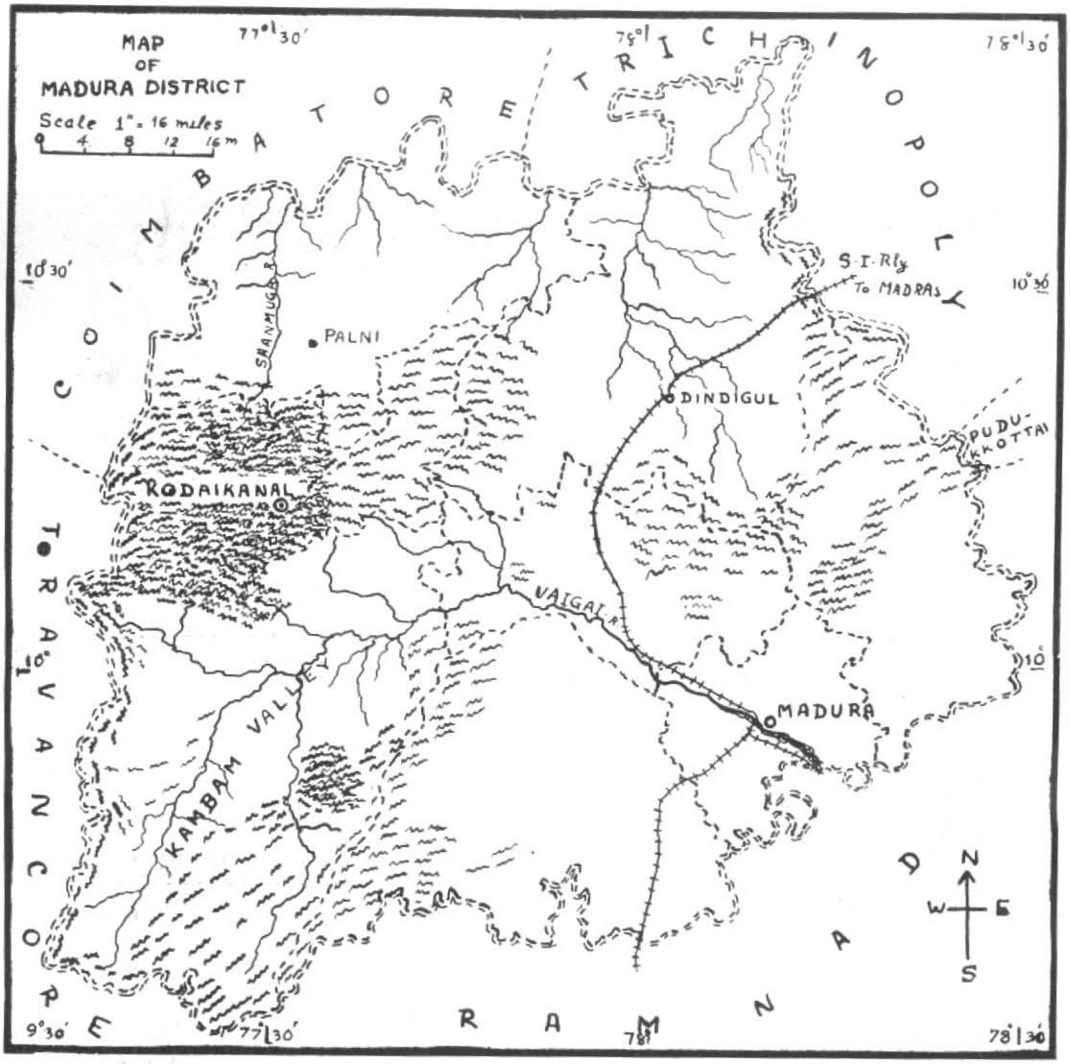


Fig. 1. Map of Madura District

does not extend beyond a few miles being cut off by a chain of hills which lie on the border between Travancore and Madura. The tallest of these known as Vembadi Sholai Hills is about 4 miles to the west of the observatory and its highest point is 8218 ft above sea level. From northwest to north although one does not get a direct view of the plains, it is possible to see Nilgiris, about 100 miles away in the northwesterly direction on days of good visibility. About six miles towards the northeast is Perumal Malai whose peak rising to an elevation of 7326 ft above sea level is a prominent landmark in this direction. Towards east and southeast one gets a magnificent view of the plains of Madura and Ramnad stretching as far as the eye can reach, and on nights of good visibility the lights of Madura city (about 50 miles away along the line of sight) can be clearly seen from the observatory. From southeast to south stretches the long Kambam valley. The greater part of this valley is not directly visible from the observatory, but from a place called "Coaker's Walk" about three miles to the southeast where the hill rises almost per-

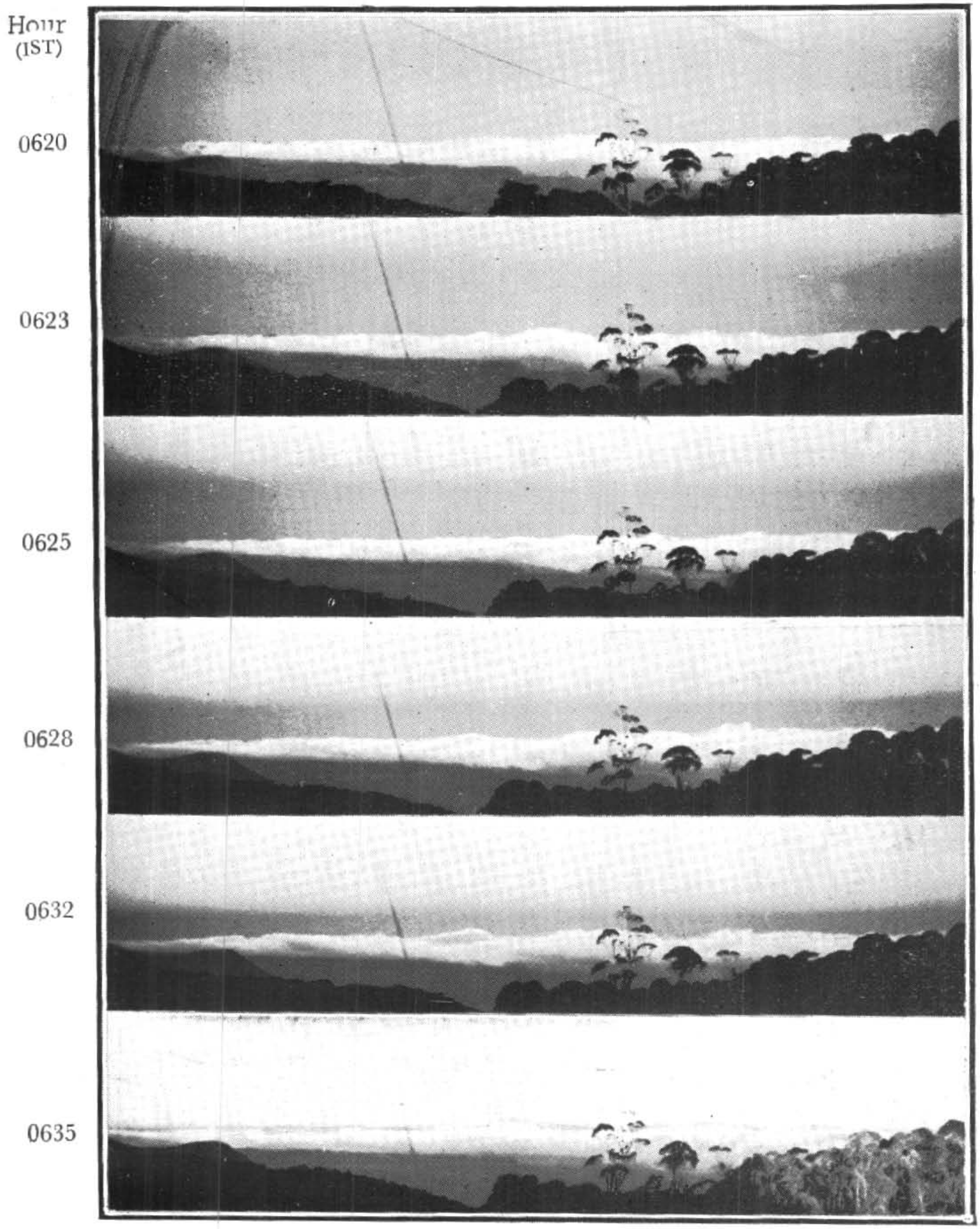
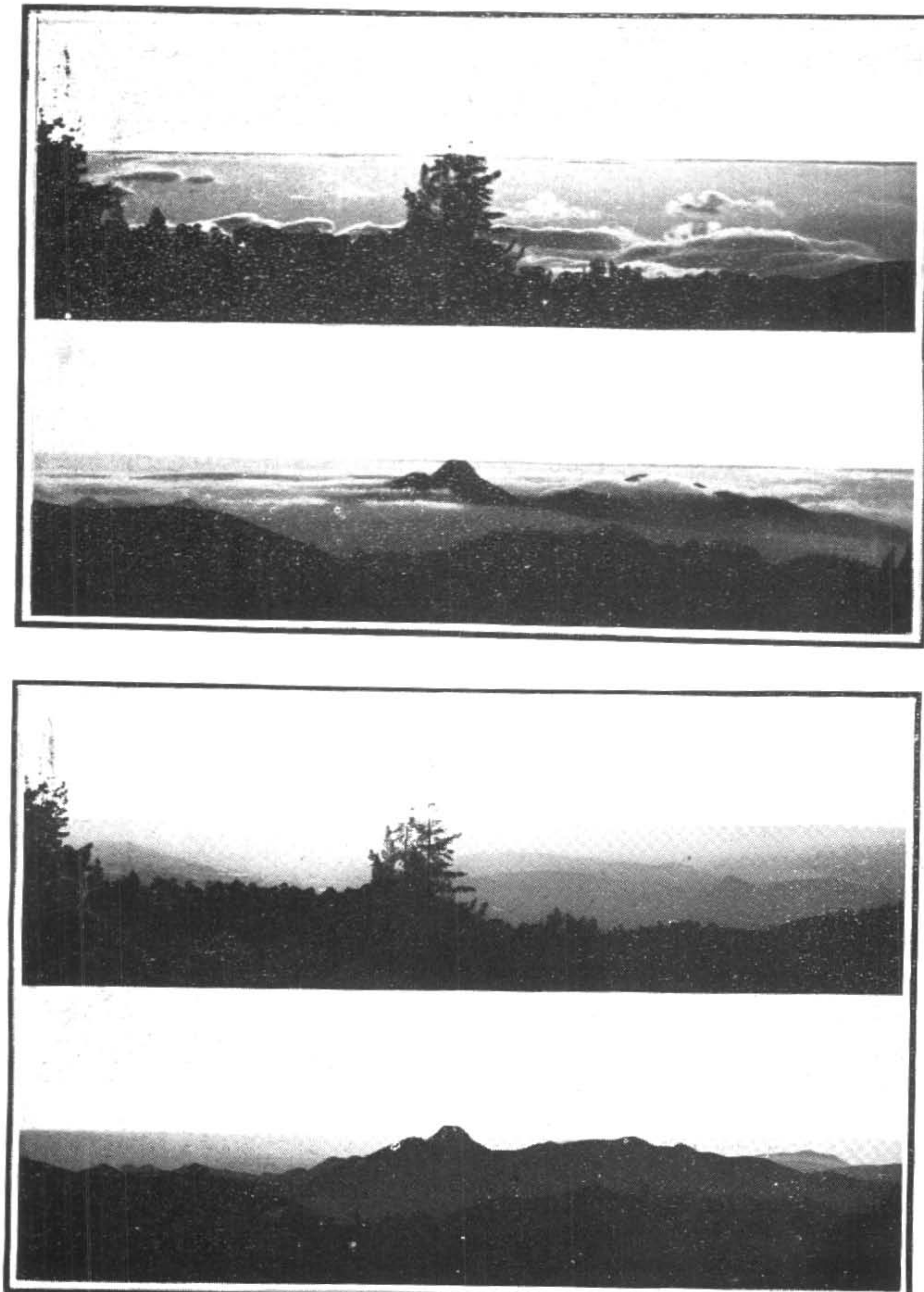


Fig. 2. Earth Shadow moving down the western sky

(Morning—6 January 1950)



(a)

(b)

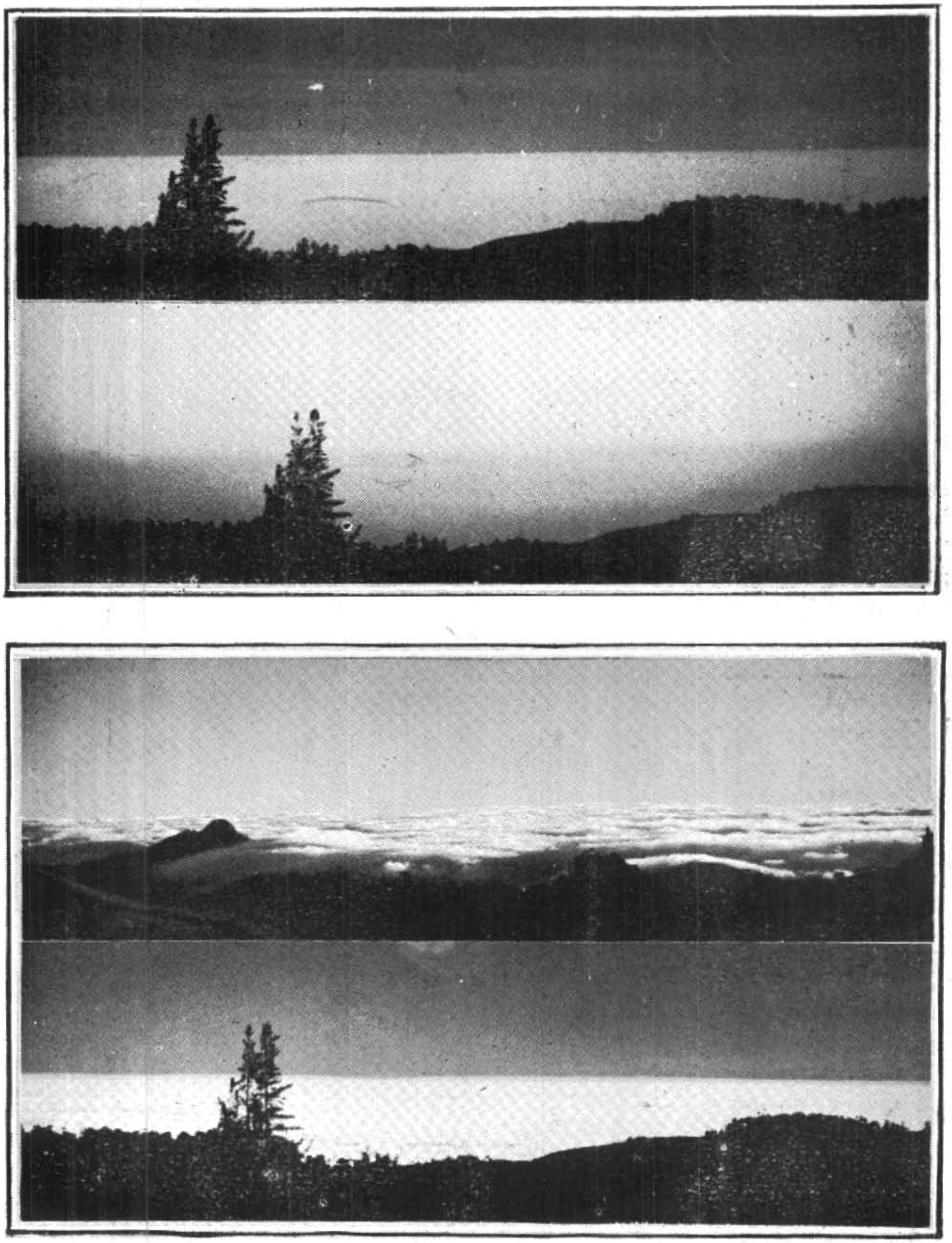
(c)

(d)

Fig. 3. Haze over the Plains as seen from Kodaikanal Observatory before sunrise

(a,b) Morning— 5 January 1950

(c,d) Morning—24 January 1950



(a)

(b)

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Fig. 4. Haze and Stratocumulus over the Plains as seen from Kodaikanal Observatory

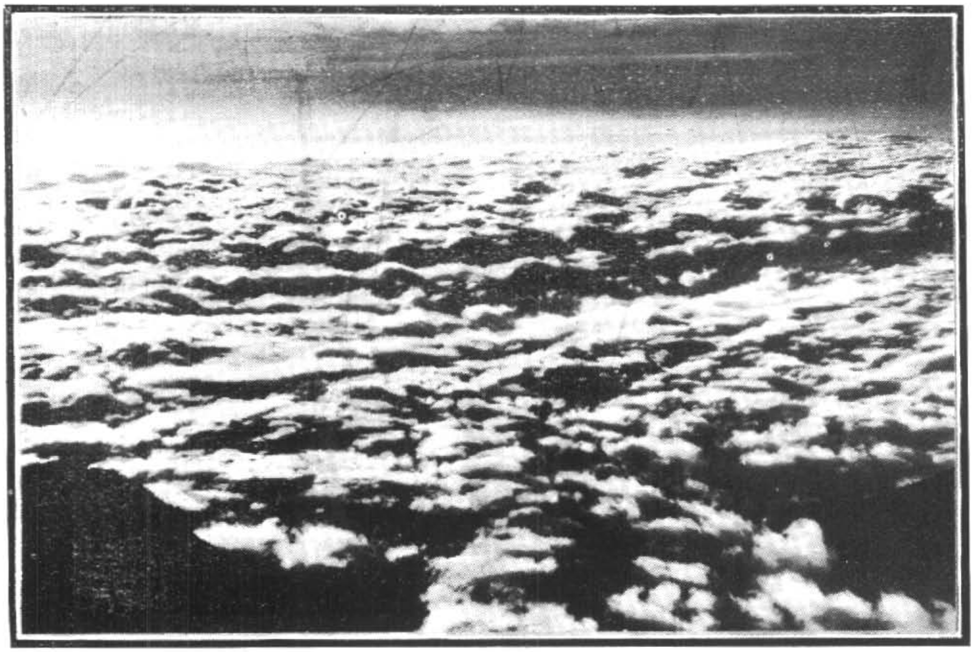
(a) Milky sea of haze after sunrise—6 February 1950

(b) Haze after sunset—15 January 1950

(c) Sc cloud sea showing waves—Morning, 21 January 1950

(d) Sc cloud sea with smooth surface—23 January 1950

(a)



(b)

Fig. 5 (a) Kambam Valley seen from Coaker's Walk
(b) Sc clouds enveloping Kambam Valley
(22 January 1950)

pendicularly from the plains nearly 7000 ft below, one commands a wonderful view of this valley and of the plains beyond.

3. Earth shadow, Haze and Stratocumulus clouds

In Kodaikanal, skies of remarkable purity and brilliance are observed on some clear days in the winter month of January. This is the time when the atmosphere has been cleansed of suspended impurities by the rains of the northeast monsoon during the preceding months, and insolation is not yet powerful enough to set up convection currents of sufficient intensity to transport the haze from the plains below to the level of Kodaikanal.

(*a*) *Earth shadow*—A striking phenomenon observed on all clear days is the progressive march of the earth shadow across the sky preceding sunrise and following sunset. Fig. 2 shows a set of photographs of the earth shadow moving down the western sky between 0620 and 0635 IST on 6 January 1950. As will be seen from the picture, the boundary of the earth shadow becomes more and more distinct as the sun approaches the horizon from below.

(*b*) *Haze over the plains*—On all clear winter mornings before sunrise when the wind is calm or light, the plains to the east and southeast appear enveloped in an ocean of haze which extends as far as the horizon. The place where the sky and the haze ocean meet can be seen as a sharp semi-circular arch running from north to south interrupted only by a tree or hill in the foreground. The sky above the haze line is remarkably clear and fine on many days. At times banks of stratocumulus clouds can be seen below the haze line.

Figs. 3 (a) and (b) are photographs of the haze line taken before sunrise on 5 January 1950, in the direction of Madura and Perumal Malai respectively. The haze line on this day practically coincided with the top of Perumal peak. Figs. 3 (c) and (d) are similar photographs taken on 24 January 1950. The haze line was lower than the top of Perumal peak on this day.

Shortly after sunrise the contrast between the sky and the haze layer is generally less conspicuous. However, on some days the haze layer after sunrise appears like a milky sea extending all over the plains. Fig. 4 (a) is a photograph of this phenomenon taken at 0835 IST on 6 February 1950.

The haze over the plains can be seen from the observatory throughout the day with varying degrees of contrast in different directions. In the afternoons the haze line is somewhat higher and not as sharp as it is in the mornings before sunrise. Towards evenings the visibility of the haze layer improves on some days and even after sunset it can be seen against the background of the sky. Fig. 4 (b) is a photograph taken well after sunset on 15 January 1950.

(*c*) *Sea of stratocumulus clouds*—On certain mornings when the lower atmosphere over the plains is more humid after a passing spell of disturbed weather, the silvery surface of a sea of stratocumulus clouds can be seen stretching over the plains as far as the horizon. Shortly after sunrise on some days the wavy surface of the cloud sea can be seen glittering and sparkling brilliantly, while on some other days the sea surface appears comparatively calm and smooth. Fig. 4 (c) taken shortly after sunrise on 21 January 1950 and Fig. 4 (d) taken at 0850 IST on 23 January 1950 illustrate these two types. Fig. 5 (a) is a view of the plains from Coaker's Walk on a clear day. Fig. 5 (b) is a photograph taken from the same place of a vast expanse of stratocumulus clouds enveloping the Kambam valley and the plains beyond on the morning of 22 January 1950 shortly after sunrise.

4. Height of top of Haze layer and sea of stratocumulus cloud

From the nature of the phenomena as seen from the observatory, we may regard the haze layer and the cloud sea as extending uniformly beyond the horizon. In this case, the height of top of the haze layer and the cloud sea can be easily calculated.

Referring to Fig. 6, let C be the centre of the earth and O the observer at a height x above sea level. Let the broken arc represent the upper boundary of a uniform layer of haze (or sheet of cloud) at a height y above sea level ($y<x$). Then, neglecting the effect of refraction, it is easily seen from the figure that the haze layer will be visible up to the point B on the "haze horizon". If θ is the angle of dip of the horizon

below the horizontal OH and a the radius of the earth, then,

$$\frac{a+y}{a+x}=\text{Cos }\theta$$

Since θ is usually a small angle of the order of 1° or less, we have —

$$x-y=\frac{a}{2}\,\theta^2$$

If x and y are expressed in feet and θ in minutes of arc,
since a=3960 miles=3960×5280 feet,
the above relation becomes

$$\theta=1.063(x-y)^{\frac{1}{2}} = 1.063\ h^{\frac{1}{2}}\ ....(1)$$

where, $h=x-y$, is the *depth of the haze layer or cloud sea below the level of the observer.*

The effect of atmospheric refraction is to make the ray OB slightly curved. In this case it can be shown [1] that the relation between θ and h is

$$\theta=0.98\,h^{\frac{1}{2}} \quad .. \quad .. \quad (2)$$

Thus, with a sufficient degree of approximation, we may assume that *the depth in feet of the top of the haze layer or cloud sea below the observer is equal to the square of the dip of the horizon expressed in minutes of arc.*

Again, neglecting the effect of refraction, the distance d of the horizon from the observer is given by

$$d = \sqrt{2\,ah}$$

If h is expressed in feet and d in miles, this becomes

$$d = 1.226\ h^{\frac{1}{2}} \quad ... \quad (3)$$

Table 1 gives some numerical values of d and θ for certain values of h.

Since the height of the observatory above sea level is 7700 ft, it is seen from the above table that the maximum distance that will be visible from the observatory is about 100 miles. Hence, the maximum horizontal distance up to which the phenomena should extend for the validity of the calculations of height using the dip angles is about 100 miles.

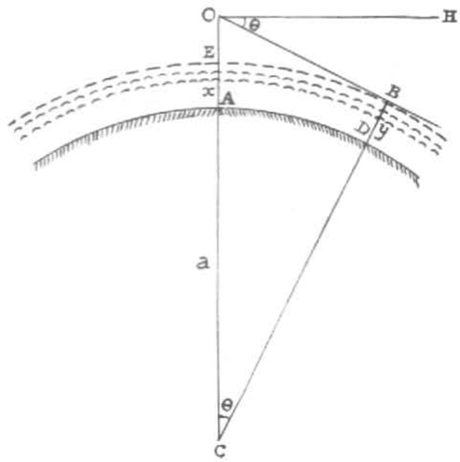


Fig. 6

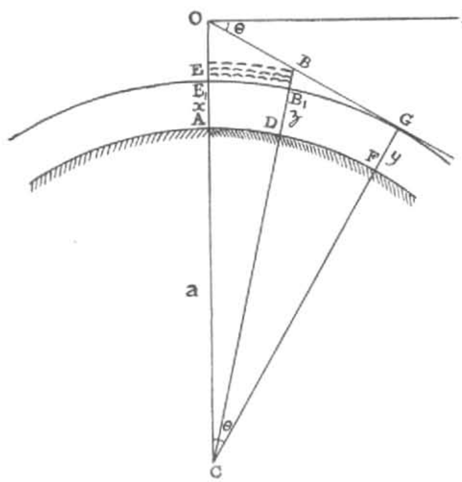


Fig. 7

However, as will be seen from the next section, the measured values of dip angle were generally less than a degree so that uniformity of the phenomena over a horizontal distance of 80 miles or less is all that we have to assume.

TABLE 1

h (feet)	7700	7000	6000	5000	4000	3000	2000	1000	500	100
d (miles)	108	103	95	87	78	67	55	39	27	12
θ (minutes)	88	84	77	71	65	55	45	32	22	10

We shall now consider to what extent the calculated values of height using the dip angle will be in error when the haze layer or cloud sea does not extend as far as the horizon.

Referring to Fig. 7, let the dotted arc EB represent the top of the haze layer or cloud sea at a height z above sea level. We assume that the layer does not extend to the horizon so that the line OB is not tangential to the arc EB at B as in the previous case but is tangential to the arc E_1B_1 at the point G.

From the right-angled triangles COG and CBG we have

$$\frac{BG^2}{OG^2}=\frac{(a+z)^2-(a+y)^2}{(a+x)^2-(a+y)^2} \text{ is nearly equal to } \frac{z-y}{x-y}$$

Therefore,

$$\frac{x-z}{x-y}=1-\frac{BG^2}{OG^2}$$

Let $OB=k.OG$,
where k is a numerical factor <1

Then,

$$x-z = (x-y)\ (2k-k^2) = h\ (2k-k^2) \quad \ldots \quad (4)$$

where h is the computed value of the depth of the haze layer below the level of the observer, and $x-z$ is the actual value of this depth. Table 2 gives the values of $x—z$ for certain values of k.

TABLE 2

k	1	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{4}$
$x-z$	h	$\frac{15}{16}h$	$\frac{3}{4}h$	$\frac{7}{16}h$

It is seen from this table that when the haze layer or cloud sea does not extend up to the horizon, but extends up to three-fourths of this distance, the value of h calculated on the assumption that it extends up to the horizon will be in excess of the actual value only by 6 per cent. When the layer or sheet extends only half the distance to the horizon, the real value of the height will be 25 per cent less than the calculated value.

6. Results of measurements

The dip of the "haze horizon" was measured on a number of days using a Cooke theodolite with which angles could be measured correct to 20 seconds of arc. The measurements were usually made in three directions, *viz*., (a) towards the direction of Perumal Malai (NE), (b) towards the direction of Madura (ESE), and (c) towards Kambam valley (S). The elevation of the haze layer above sea level in each of these directions was calculated from the measured values of the dip angle using formula (1). On a few days when a sea of stratocumulus clouds lay over the plains, the corresponding angles were measured and heights calculated for the top of the cloud sea. The results for some selected days are given in Table 3.

7. Rate of growth of fair weather cumulus clouds

On a day of fair weather in winter, isolated cloudlets begin to make their appearance over the plains by about 0900 IST. The number and size of the cloudlets rapidly increase, and after some time the cloudlets in the far distance appear as though they are linked to one another. Watching through the theodolite, the distant cloud line appears to be gradually lifting up. At first, the cloud line is below the haze line, but it gradually approaches the latter. The maximum cloud amount usually occurs before the cloud line has reached the haze line. By the time the cloud line has reached the haze line, the clouds have already begun to dissipate, and thereafter, the remnants of the distant cloud line appear to be swimming on the surface of the ocean of haze, especially when viewed through a polaroid suitably oriented. If we make the plausible assumption that the cloud growth is more or less uniform over the plains up to a distance of about 100 miles from Kodaikanal, then we may picture the cloud growth as the gradual lifting up of a cloud ocean. The most distant cloud line forms the "clouds horizon", and knowing the dip of this horizon, we can calculate the height of top of these clouds. Results of such measurements for two typical days are given in Table 4.

Fig. 8 (p. 276) gives a graphical representation of the cloud growth as a function of time for the above two days. On 16 January 1950, the average rate of growth was about 1000 ft per hour up to 1030 IST, after which it decreased to about 400 ft per hour up to 1230 IST. On 20 January 1950, the average rate of growth was about

TABLE 3

Date	Time of observation (IST)	Dip of haze cloud horizon (minutes)			Height (asl) of haze layer or cloud sea (feet)			Remarks
		NE	ESE	S	NE	ESE	S	
13-1-50	0615	32	33	35	6680	6610	6480	Plenty of cirrus in the eastern sky above haze line. Moderate E wind.
14-1-50	0620	46	45	46	5580	5680	5580	Cirrus at low angle. Stratocumulus clouds in front over plains. Light NE wind.
15-1-50	0615	52	52	52	5000	5000	5000	Cirrus in the eastern sky at low angle. Light E wind.
16-1-50	0615	38	42	41	6260	5940	6020	Stratocumulus clouds towards E and S. Haze line not sharp. Moderate E wind.
18-1-50	0630	50	62	—	5200	3856	—	Cirrus streamers at low angle from E to S. Moderate E wind.
	1430	—	13	—	—	7530	—	Very hazy over the plains from NE to SE.
	1715	5	—	24	—	—	7120	Haze has spread over Kodaikanal. Moderate SSE wind.
19-1-50	1235	40	40	—	6100	6100	—	Observation through polaroid. Moderate S wind.
	1745	—	20	—	—	7300	—	Dense haze over the plains with fairly sharp top from E to S. Haze has spread to Kodaikanal. Moderate NW wind.
21-1-50	0625	23	38	29	7170	6260	6860	Vast sea of stratocumulus clouds over the plains as far as the eye can reach. Sky above cloud sea remarkably fine. Light SSE wind.
23-1-50	0825	38*	55	54	6260	4680	4780	A vast silvery sea of stratocumulus clouds over the plains from E to S. The sea ends a little to the east of Perumal Malai. *Haze line seen towards NE.
24-1-50	0630	47	56	44	5490	4560	5760	Haze line sharp ; patches of clouds at low angle in the eastern sky. Light NE wind.
3-2-50	0830	19	8	17	7340	7640	7410	Remarkable sea of milky haze with a bluish tinge. Haze seen over Kodaikanal town. Light ENE wind.
6-2-50	0830	30	17	14	6800	7410	7500	Remarkable sea of milky haze over the plains. Haze very dense and haze line extremely sharp. Moderate SE wind.

TABLE 4

Date	Time (IST)	θ (minutes)	Level of cloud top below Kodaikanal (feet)	Height of cloud top asl (feet)
16.1.50	0920	60	3600	4100
	0940	56	3136	4564
	1000	55	3025	4675
	1015	51	2601	5099
	1030	49	2401	5299
	1100	46	2116	5584
	1130	46	2116	5584
	1215	41	1681	6019
	1235	40	1600	6100
20.1.50	0930	67	4489	3211
	1045	59	3481	4219
	1155	54	2916	4784
	1247	51	2601	5099
	1315	47	2209	5491
	1342	44	1936	5764
	1400	41.5	1722	5978
	1435	40	1600	6100
	1455	36	1296	6404
	1505	34	1156	6544
	1520	33	1089	6611
	1535	32	1024	6676
	1555	29	841	6859
	1630	25	625	7075
	1700	17	289	7411
	1810	14	196	7504

600 ft per hour from 0930 to 1500 IST, after which it decreased to 450 ft per hour between 1500 and 1700 IST

8. Discussion of Results

The top of the quasi-permanent haze layer in the winter months marks the upper limit of the lower atmosphere over the plains which is affected by convection and turbulence resulting from diurnal ground heating. The depth of the layer affected by convection and turbulence depends upon the total heat energy absorbed by the ground as well as on the amount of moisture and the prevailing lapse-rate in the lower atmosphere. Because of the admixture of haze which

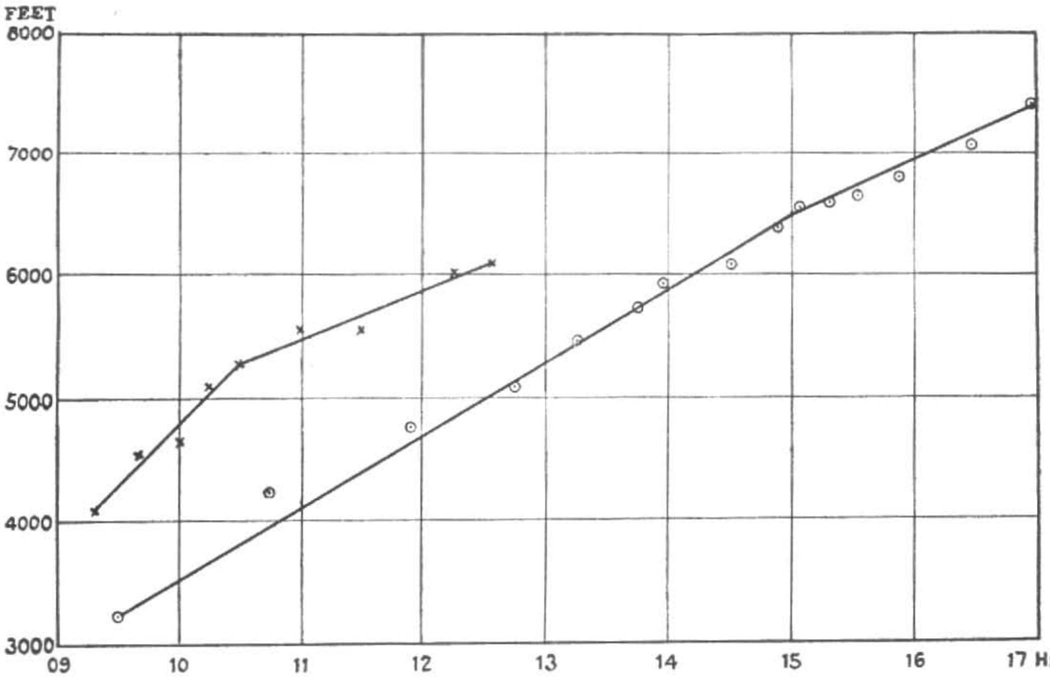


Fig. 8

imparts a distinct colour to this column, it is clearly demarcated from the upper atmosphere when viewed from the elevation of the Kodaikanal Observatory.

An interesting point brought out when the cloud growth is watched through a telescope is that not only the top but also the base of the layer of fair weather comulus clouds is lifting up with advance of day. Consequently, the vertical thickness of the cloud layer increases to a smaller extent than the increase in height of the top of the clouds above sea level. In fact, towards the later stages, the thickness of the clouds is seen to decrease although the clouds are still lifting up.

This observation is easily understood when we look into the mechanism of formation of fair weather cumulus clouds over the plains. Adiabatic ascent of air resulting in the formation of these clouds is essentially brought about by diurnal heating, and the condensation level which marks the cloud base is the *convection condensation level*. When the vertical currents have reached the convection condensation level, the distribution of temperature and moisture content in the column from the surface to this level is such that the dry bulb temperature follows the dry adiabatic, the wet bulb temperature follows the saturation adiabatic and the humidity mixing ratio follows the isohygric through this level. Active cloud formation sets in when the vertical currents have reached the convection condensation level. The air above this level is, however, stable and since the normal distribution of moisture content in the atmosphere is such that the humidity mixing ratio decreases with height, there will be an abrupt fall in the moisture content above the convection condensation level. If now, due to further addition of heat at the ground level, the convection currents are sustained and a greater depth of the atmosphere is thoroughly stirred and mixed up, it can be easily seen that the convection condensation level will also be elevated.

After the maximum temperature epoch as the ground begins to cool, the vertical currents gradually die out, and the atmosphere settles down to a stable stratification. An inversion develops near the ground which progressively increases in intensity and vertical thickness during the night till sunrise on the next day. The vertical extent of the inversion layer will be very much less than that of the convection layer. When convection is arrested and if the wind is calm or light, the haze particles gradually settle down. This explains the remarkably sharp nature of the haze line observed on certain mornings before sunrise (Fig. 3).

We see from Table 3 that the haze layer is generally some 1000 to 2000 ft below the level of the Kodaikanal Observatory in the winter months. This explains the remarkably fine and brilliant skies observed at Kodaikanal on certain days during this month. One of us (R.A.) who visited various places in the Eastern, Central and Western Himalayas during the summer months of 1948 and 1949 found that even at elevations of 12,000 to 14,000 ft in the Himalayas, the *summer skies* are definitely hazy and far less pure than the best skies observed at Kodaikanal. Results of aerological soundings show that convection and turbulence extend to heights of 15,000 ft or more over north India in the summer months.[2]

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