XI. Thunderstorms in Trivandrum.

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I.—Introduction and Summary.

Thunderstorms are a regular feature of Trivandrum weather. They present well-marked seasonal and diurnal variations. The maximum activity occurs during the months March to May and in October. In the following paper, an analysis is made of the seasonal variations of thunderstorms in Trivandrum and they are discussed together with the variations of other meteorological elements, humidity, temperature and air movement both at Trivandrum and at Augustia (6,200 ft. above sea level) in the light of Simpson's theory of thunderstorm formation. According to Simpson, whenever there are strong humid, ascending air currents in the atmosphere accompanied by condensation of moisture, splitting of water-drops and separation of electricity occur. The conditions that have been recognized as essential for the formation of strong humid ascending air currents are (1) sufficient moisture in the atmosphere and (2) a vertical temperature-gradient exceeding the adiabatic lapse-rate. So far as these two factors go, they are satisfied at Trivandrum at all the months of the year. The reason why, then, thunderstorms do not occur at all seasons is shown to be connected with the existence of strong horizontal winds at and above the level of the Western Ghats in the months June to September and November to February, and the comparative absence of such steady air movements during the rest of the year. Strong horizontal winds prevent the formation of strong ascending currents.

II.—Statistics of Thunderstorms.

Observations of thunderstorms in Trivandrum made during the years 1856–1864 by Mr. J. A. Broun have been discussed in

Proc. Ind. Assn. Cult. Sci. 7, 107–114, 1921–22.

the Indian Met. Memoirs Vol. X, part 1 by Sir J. Eliot. Further records have been kept in the Trivandrum observatory from 1892 onward, when they were begun by Dr. A. C. Mitchell.

Table I gives the number of days on which thunder was heard in the different months of the years 1902–1914.

Table II gives the number of days on which lightning was seen with or without thunder.

TABLE I. *Number of days on which thunder was heard.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	TOTAL.
1902	3	1	13	28	23	10	0	0	6	16	14	8	122
1903	2	2	6	26	17	10	0	0	2	11	8	7	91
1904	2	2	9	19	13	8	4	0	0	22	9	1	89
1905	0	4	4	23	15	2	0	0	2	10	9	0	69
1906	0	5	7	14	19	3	0	3	1	20	13	8	90
1907	2	1	17	22	21	5	2	1	14	19	12	7	113
1908	7	8	14	17	12	6	1	0	1	8	7	2	83
1909	1	7	14	22	11	1	1	2	0	14	14	7	94
1910	1	6	13	18	12	5	4	3	1	11	15	0	89
1911	0	1	12	6	17	5	1	0	3	15	8	10	78
1912	1	4	7	24	22	6	0	0	3	14	10	0	101
1913	3	4	5	20	21	4	1	2	2	10	10	6	88
1914	2	3	13	19	16	8	1	2	5	14	11	7	101
Average	2	3	10	20	17	6	1	1	3	15	11	5	93

TABLE II. *Number of days on which lightning was seen with or without thunder.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	TOTAL.
1902	3	2	16	29	30	14	0	2	8	22	18	11	155
1903	2	4	10	30	22	12	0	0	2	15	15	9	121
1904	2	6	14	22	22	9	4	1	2	22	9	4	117
1905	0	10	13	26	26	2	0	0	5	11	16	4	113
1906	7	3	12	15	20	5	0	7	4	22	13	10	118
1907	2	7	26	25	25	8	5	1	5	24	15	7	150
1908	9	11	17	20	15	6	2	0	4	10	7	3	104
1909	1	10	16	23	18	3	1	2	0	18	19	8	119
1910	1	6	14	19	14	11	5	3	1	14	17	0	105
1911	2	2	16	10	19	8	1	1	6	15	16	12	108
1912	2	7	10	28	28	19	1	3	10	15	16	3	142
1913	4	6	6	24	25	8	1	2	8	14	17	7	122
1914	3	4	18	22	18	9	1	2	10	21	16	9	133
Average	3	6	14	23	22	9	2	2	5	17	15	7	124

It will be observed that the maximum thunderstorm activity occurs during March to May. There is also a secondary maximum in October. The distribution of thundery weather during the year is shown graphically in Figure 1.

An examination of the records also shows that the thunderstorms begin either to the north or east of Trivandrum, except just previous to the burst of the monsoon or when depressions are

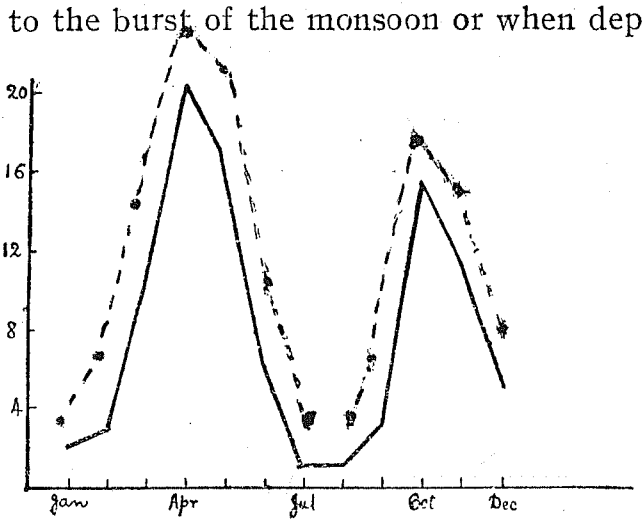

FIG. 1.

travelling close to Trivandrum (when they may begin in any direction) and that they are most active during the afternoon hours 2 to 5 p.m.

III.—MODE OF FORMATION.

The most satisfactory theory of thunderstorm formation is that due to Dr. G. C. Simpson.[1] He showed that splashing of water drops by air currents produces electrification, positive on the drops and negative in the air. When there is opportunity for a large breaking up of water drops, a large quantity of electrification is produced. In the region of humid ascending atmospheric currents, there would be condensation of moisture due to adiabatic cooling, and if the ascending currents are strong, the condensed drops would not be allowed to fall down but would be carried up until they reach a certain size and thereafter their shape would get so much out of the spherical that they would become unstable and break up into smaller drops. Dr. Lenard has shown that the limiting size of waterdrops beyond which they cannot grow without breaking up is about 5 millimetres in diameter and the limiting velocity which drops of this size would acquire on free fall is nearly equal to 8 metres per second. Hence, no drops could fall through an ascending current of air with a vertical velocity greater

[1] Phil. Trans. Roy. Society, 209, p. 379, 1909.

than 8 metres per second. The drops would be carried up, reach a certain size, break up, and again be carried up, grow, and break up. Dr. Simpson showed that enough electricity could be produced on the drops by such splashing as would be sufficient to account for the electricity carried down by rain.

Accepting this theory, we shall see how the conditions are favourable for the formation of thunderstorms in the months of March, April and May and in October and November, and how they are unfavourable during the other months.

The conditions favouring strong ascending currents accompanied by large condensation are:—

1. Enough moisture in the lower air for clouds to form as a result of upward movement;

2. A rate of fall of temperature with height approaching or exceeding the adiabatic lapse rate for saturated air; and

3. Absence of strong horizontal winds for a few kilometres above the earth's surface.

I. We shall take these points one by one.

Table III gives the actual pressure of the vapour present in the atmosphere in the different months of the year at Trivandrum and at Augustia peak (Lat. 8° 37′ N., Long. 77° 30′ E., height 6,200 ft. above sea level and distant 22 miles from Trivandrum, a high solitary peak in the Western Ghats where an Observatory was maintained by the Government of Travancore during the years 1856–1858 and in 1864 under the direction of Mr. J. A. Broun for taking magnetic and meteorological observations).

They are taken from the Indian Met. Memoirs Vol. X, parts I and II and are based on 24 hourly observations of the wet and dry bulb thermometer during the years 1856–1864 at Trivandrum and 1856–1858 at Augustia.

Month.	Trivandrum.		Augustia (height 6,200 ft.).	
	Mean vapour pressure in inches of mercury.	Humidity. %	Mean vapour pressure in inches of mercury.	Humidity. %
January ..	0·69	74	0·39	93
February ..	0·68	71	0·38	83
March ..	0·78	75	0·45	89
April ..	0·83	77	0·50	90
May ..	0·87	82	0·49	97

Month.	Trivandrum. Mean vapour pressure in inches of mercury.	Trivandrum. Humidity. %	Augustia (height 6,200 ft.). Mean vapour pressure in inches of mercury.	Augustia (height 6,200 ft.). Humidity. %
June ..	0·82	86	0·49	98
July ..	0·79	86	0·48	99
August ..	5·79	86	0·47	97
September ..	0·77	83	0·46	97
October ..	0·79	85	0·46	97
November ..	0·77	83	0·44	97
December ..	0·68	76	0·39	94

So far as moisture is concerned, there is plenty of it in all seasons of the year. Indeed, it is doubtful whether there are many other places on earth where there is so much of moisture at all seasons of the year.

II. It is not possible to get an accurate idea of the lapse rate of temperature at Trivandrum without observations with sounding balloons. We can, however, get much useful information from a consideration of the mean temperatures at Trivandrum and Augustia during the different months of the year.

Table IV, gives the mean temperatures at Trivandrum and Augustia based on 24 hourly observations ; 1856–64 at Trivandrum, and 1856–58 at Augustia.

Month.	Mean temperature at Trivandrum in °C.	Mean temperature at Augustia in °C.	Difference in °C.
January ..	24·6	12·0	12·6
February ..	25·6	13·5	12·1
March ..	26·9	15·3	11·5
April ..	27·0	16·4	10·6
May ..	26·7	15·2	11·5
June ..	25·3	14·8	10·5
July ..	24·8	14·3	10·5
August ..	24·8	14·2	10·6
September ..	25·0	14·0	11·0
October ..	25·0	14·0	11·0
November ..	25·0	13·6	11·4
December ..	24·7	12·2	12·5

The minimum difference occurs during the months of June and July and even in those months, the lapse rate is 0·36° C per 100 metres (6,200 ft.=1,890 metres) a quantity far exceeding the adiabatic lapse rate for saturated air. According to Hann, the

temperature gradient for 100 metres for saturated air at 25° C under conditions of dynamical equilibrium to a height of 2,000 metres from sea level is 0·43° C per 100 metres (Handbuch der Meteorologie, page 182). We have no data as regards temperatures higher up. So far, then, as the first two conditions for ascensional movement are concerned, they are satisfied in all parts of the year. The answer to the question why thunderstorms do not occur in all months of the year, will be clear when we have discussed the third condition.

IV.—Character of the air movement in Trivandrum.

The character of the air movement in Trivandrum is affected to a great extent by the close neighbourhood of the Western Ghats. For about 20 miles to the east of Trivandrum, the country is undulating with hills and hollows, and beyond it, rises the Western Ghats to an average height of 5,000 ft. During the months June to September, when the S.W. monsoon is in full swing, there is a strong steady wind from about N. 60° W. with little diurnal variation. During the months November to April, the air movment consists of land and sea-breezes. The N.E. winds, that obtain during this period in the south of the Peninsula to the east of the Ghats, do not penetrate into Trivandrum, sheltered as it is, by the protecting effect of the Ghats. The months May and October are months of transition.

Since the air movement at Trivandrum is largely affected by the proximity of the high Western Ghats, it is more useful to consider the air movement at a higher level where the winds would be less hampered by geographical peculiarities. For this purpose, we shall consider the air movement at Augustia. In his discussion of Augustia meteorological observations, Sir J. Eliot summarises the general character of the air movement thus :—

"The air movement at Augustia differs essentially in many respects from that prevailing at Trivandrum. The peak is the highest point of the South Travancore Hills.

In the months of December, January and February, when steady and moderate strong N.E. winds obtain in the south-west of the Bay and are continued as E.N.E. winds across the districts of Tinnevelly and Madura and when light local land and sea breezes obtain in the Travancore Coast districts and the neigh-

bouring sea area, the air movement at Augustia is determined by (and is a continuation of) the massive atmospheric current from the N.E. over the Bay which is strongest in the S.E. of the Bay and Southern India. In this season, 5% of the wind observations are of Calms, 64% of the winds are from East and 21% from N.E. and only 10% from other directions. The air movement is hence remarkably steady and is on the mean of all the data, from E.N.E., or more exactly, N. 80° E.

"Similar conditions obtain during the third period (June to Sept). The air movement at Augustia is then determined by the S.W. monsoon air current over the Arabian Sea. During this period, in the years 1856–58, about 4% of the observations were of Calms, 21% were winds from N.W. and 72% from W. and hence only 3% from the remaining six points. Winds are hence even steadier in this season than in the first season of the year. The mean wind direction is W.N.W.

"The air movement during the remaining five months of the year is essentially of a transitional character. During the second period comprising the months of March, April and May the mean winds in South Madras shift in direction from East in March and April to West in May, in which month, they are practically indentical in direction with the mean winds in June. The mean direction of the winds at Augustia during this period shift *pari passu* with the change of direction of the air movement in Southern India and the resultant is almost nil.

"The conditions in the fourth period including the months October and November are similar to those of the second period except that the transition or change is inverse to that of the second period.

"The number of Calms reported is large; 16% of the wind observations received during this period in 1856–58 were of Calms, so that they were almost as numerous as during the first transitional period March to May. It is also noteworthy that Calms are more numerous in this, as in the second season, during the day than during the night and are most frequent from 11 A.M. to 4 P.M."

Summary of weather conditions at Augustia.

December, January and February	Calms	5%
	East	64%
	N.E.	21%
	Other directions	10%
March, April and May ..	Calms	19%
	East	25%
	S.W.	33%
	Other directions	23%
June to September ..	Calms	4%
	West	72%
	N.W.	21%
	Other directions	3%
October to November ..	Calms	16%
	West	25%
	East	32%
	Other directions	27%

It will be noticed that the time of maximum thunderstorm activity coincides with the time of minimum horizontal air movement at Augustia. *Absence of strong horizontal winds in the higher layers is a* sine que non *of strong ascending currents favourable to thunderstorm development.*

During the months of March and April, when the general gradient is undefined and is too weak to exercise any control over the air movement, ascending currents begin to rise with the heat of the sun and form detached cumulus heads. These cumuli grow and with the setting in of a light humid breeze from the sea in the afternoon, they grow into large masses often crowned with false cirrus, especially to the north-east of Trivandrum where the land rise is the most marked.

By about 3 P.M. the whole sky is clouded and occasional crashes of thunder are heard. This continues for varying intervals of time and is often accompanied by rain. Ordinarily, the sky clears by about 6 P.M. and a clear night follows. As the season advances, however, the thunderstorm continues at night. The general character of the weather is very similar in October.

These considerations should apply to other places where thunderstorms are seasonal. All along the west coast of India and in Ceylon, the setting in of the monsoon is preceded by a period of thunderstorm activity.