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Fog precipitation on Table Mountain

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SUMMARY

Fog precipitation on Table Mountain has been measured over a period of one year by means of two raingauges, one of which was equipped with a fog-catcher. The evaluation of the records is complicated by the uncertainty of the fog precipitation during rain and drizzle. It is shown that satisfactory results can be obtained if at least two sets of instruments are installed on the mountain, one of them in the middle of the plateau and the other some 200 m lower.

The fog precipitation for the year on the plateau was found to be 3,294 mm and the rainfall to be 1,940 mm. The mean intensity of rainfall was 1·84 mm/hr and that of fog precipitation 3·75 mm/hr. Although the latter appears to be rather high, it is much lower than the value obtained theoretically. The discrepancy is accounted for by several errors in the measurements, which are discussed, and by fog precipitation supposed to occur on the slopes, which causes the air to reach the plateau with a smaller liquid-water content than calculation indicates.

1. Introduction

The Table Cloth is one of the orographic clouds which are formed in mountain regions all over the world. If, on a fine summer day, air from the SE is forced up Table Mountain under such conditions that condensation can occur on the slopes, the Table Cloth appears. The further ascent is wet-adiabatic, and the water droplets in the air will increase in number, and possibly in size, until the plateau is reached. A certain portion of the cloud droplets which move with the ambient air over the mountain may precipitate on the ground, mainly owing to eddies, but the droplets will tend to be deposited on all obstacles, such as rocks and plants, in the path of the moving air. Vegetation is much better suited than are rocks to catch cloud droplets. Because grass, leaves and twigs move in the wind, and so cause changing turbulent eddies, more water droplets will be deposited by precipitation and contact with the huge surface of plants than on compact obstacles.

Marloth (1904, 1907) noticed the considerable amount of water which was deposited, especially on the vegetation, when the mountain was covered with the Table Cloth in the absence of rain. He arranged a bundle of grass between wires upon the funnel of a raingauge and gathered with this instrument much water from the cloud, whilst an ordinary raingauge collected only little. Since then it has become the practice to measure fog precipitation by means of two raingauges with a fog-catcher attached to one of them. Dieckmann (1931) used a gauze cylinder, with a diameter two-thirds of that of the rain-gauge funnel, projecting 35 cm above the rim of the funnel. He found, as did Marloth, that when fog was present in the absence of rain the gauge with the gauze cylinder collected an appreciable quantity of water, while the standard raingauge showed little.

Grunow (1952) used a gauze cylinder of which the height was twice the diameter, and the vertical cross-sectional area was equal to the catching area of the raingauge to which it was attached. When rain falls at an angle (α) greater than 8° from the vertical the raingauge with the fog-catcher has an increased catching area (see Fig. 1). However, Grunow found that in the absence of fog the raingauge with the fog-catcher collected about the same total amount of rainfall as the standard raingauge over a period of one year, though single comparison shows appreciable differences. This discrepancy is probably due to the nature of the rainfall. For example, when large raindrops fall in strong winds

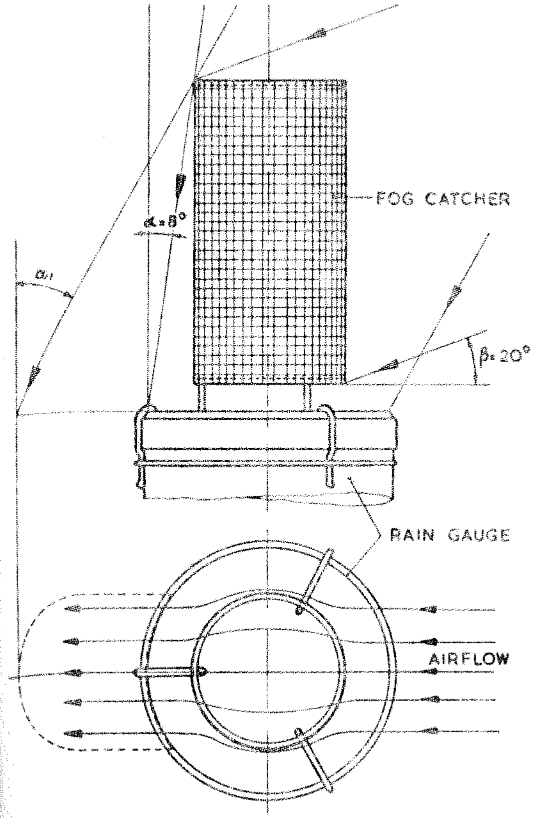

Figure 1. Fog-catcher on raingauge. The area surrounded by the dashed line shows the increment of the catching area due to the fog-catcher for rain falling at angle (α_1).

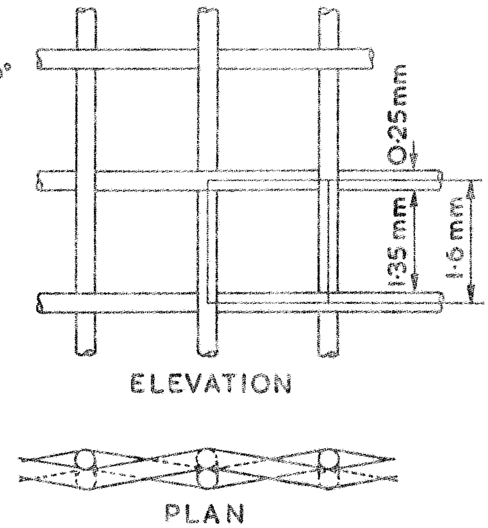

Figure 2. Portion of the gauze on an enlarged scale (Elevation and plan).

some of the drops will be deflected and blown over the funnel, and during light rainfall some of the water which adheres to the gauze will evaporate. On the other hand, when raindrops fall in moderate to fairly strong winds it is most likely that the raingauge with the fog-catcher actually collects more water than the standard raingauge, even though evaporation takes place and a number of the raindrops may be deflected by the gauze. However, when the instruments are within the cloud, Grunow subtracts the precipitation measured with the standard raingauge from that obtained by the raingauge with the fog-catcher without taking into account whether rain falls or not. As he considers this difference to be the amount of fog-precipitation, it appears that continuous observation is necessary to ensure whether fog is present or not.

2. The efficiency of the fog-catcher

Fig. 2 represents a portion of the gauze used in the fog-catcher (see Fig. 1). From the dimensions of the mesh it is found that 29 per cent of the surface of the cylinder is covered with the wires of the gauze and 71 per cent remains for free passage of air. When air containing water droplets flows with a speed of about 10 m/sec against the fog-catcher, eddies will form at the gauze, preventing a smooth airflow through the meshes and increasing the efficiency of the catch. This effect, although important, is disregarded.

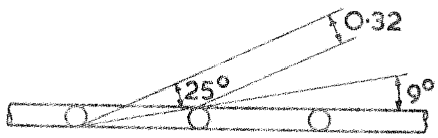

Figure 3. Simplified pattern of the gauze (plan).

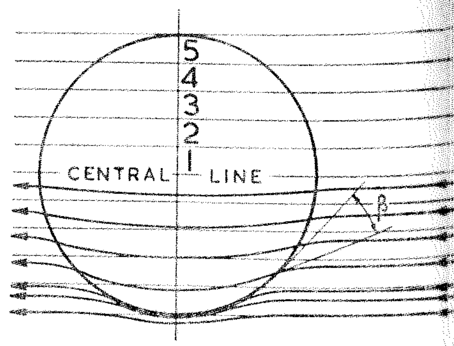

Figure 4. Representation of the laminar airflow through and along the sides of the gauze cylinder.

For the following calculation a simplified pattern of the gauze is considered as shown in Fig. 3, and a laminar airflow is assumed to pass through the meshes and along the sides of the cylinder. The airflow is thus less deflected than by a solid cylinder. On the other hand, it will be shown that only a small portion of the water droplets in the air which strikes the cylinder can pass through it and, therefore, a deflection of air around the cylinder still occurs. In Fig. 4, which represents the airflow, the catching area of the cylinder is subdivided into 10 equal sections (5 to each side of the central line). The angles (β) which are formed between the stream lines and the gauze are by no means under-estimated. When the airstream is normal to the gauze, 71 per cent of the cloud droplets can pass through the meshes as mentioned above; but when the air strikes the cylinder at an angle, β, less than 90°, the percentage which is able to pass through the gauze will be less. Cloud droplets cannot pass through the gauze if β is smaller than 9° (see Fig. 3). For different angles β, the distance (1·35 mm) between the two wires of a mesh has, therefore, to be multiplied by a factor which has been determined graphically. The following Table gives β for the 10 sections of Figure 4 and the corresponding factors for each section.

Section	β (degrees)	Factor
1	82	0·99
2	63	0·87
3	44	0·64
4	25	0·32
5	6	0·00
		2·82

The average factor is 0·56, which gives, when multiplied by 71 per cent, the result that 40 per cent of the cloud droplets which strike the cylinder can pass through the gauze in front. Applying the same calculation to the lee side of the cylinder, the result is obtained that 16 per cent of the cloud droplets in the air which is blown against the fog-catcher can pass through it. However, soon after the inception of the fog, waterdrops appear on the gauze mainly on the windward side. These drops increase in size by coalescence with newly arriving droplets and partly close the meshes. The waterdrops which adhere to the gauze grow until they reach a size large enough to enable them to flow down the gauze and drop into the funnel of the raingauge. It has been observed that in moving cloud almost all the meshes on the windward side of the gauze cylinder were covered with waterdrops, while on the lee side only a few drops were present. This

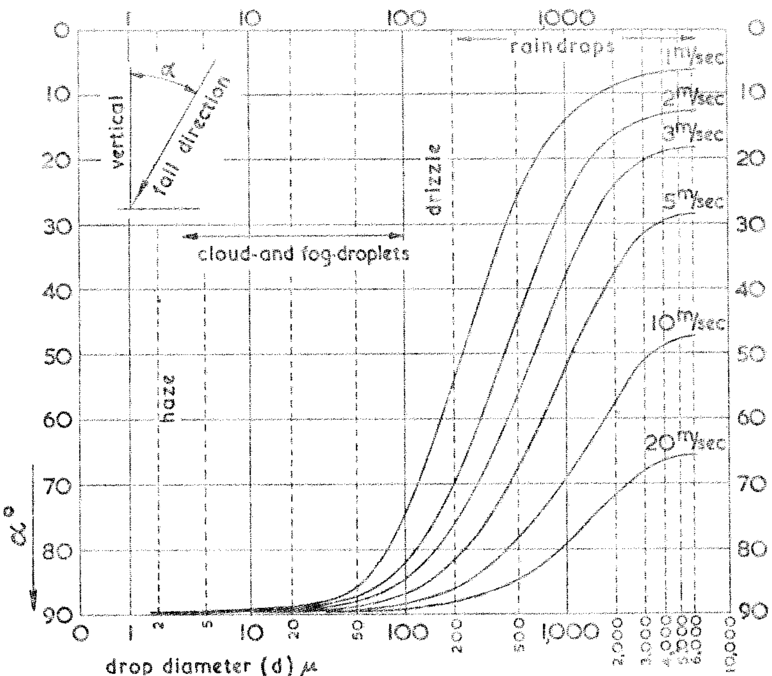

Figure 5. The graph represents the angle (α) at which cloud and rain droplets fall in a horizontal, laminar airstream of different speed as a function of the equivalent drop diameter d in μ. The scale of the abscissa is: $\log (1 + d)$.

implies that a much smaller percentage of cloud droplets than the above calculation indicates is capable of entering the gauze cylinder. Probably less than 10 per cent of the cloud droplets which are blown against the fog-catcher can pass through it.

If gauze with a larger mesh is used, more cloud droplets can pass through the fog-catcher. On the other hand, fine mesh, e.g., petrol gauze, is not suitable for this purpose as the fog-catcher will then nearly act as a solid cylinder. In this case, the airflow is more deflected, and some of the waterdrops which have formed on the gauze will be blown to the sides and off the cylinder without falling into the funnel of the rain-gauge.

For the two reasons, namely that the air which is blown towards the fog-catcher is partly deflected around the cylinder without touching the gauze (see Figs. 1 and 4), and that a certain percentage of the cloud droplets can pass through the meshes, the effective catching area of the gauze cylinder is smaller than that of the raingauge. Therefore, the fog measurements should show a deficiency estimated to be about 25 per cent for a wind speed of 4 m/sec, increasing for higher speeds. It is obvious that measurements with the apparatus are independent of the horizontal direction of the wind.

3. Statement of the Problem

Perturbations of the airflow over mountains make it difficult to obtain exact measurements of rainfall in such regions (Hayes and Kittredge 1949). But even in laminar airflow supposed to follow the configuration of the mountain, the measurements cannot be expected to be as precise as those in a plain, because in an airstream with an upward directed component, raindrops of a certain size may move horizontally or upward, depending on the wind speed. Lütschg (1937) has employed a raingauge which can be exposed so that its catching area is directed to the wind. Brooks (1954), however, shows the impracticability of raingauges that are kept pointed into the wind.

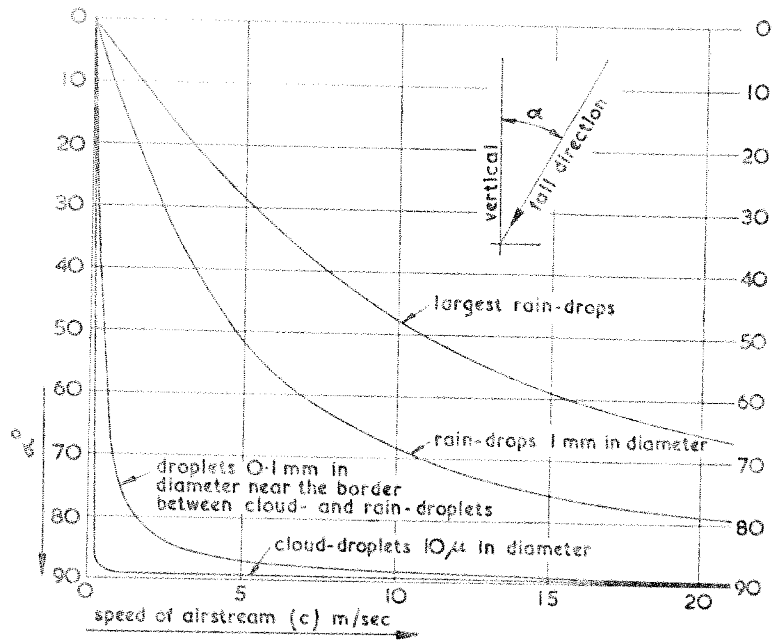

Figure 6. The graph represents the angle (α) at which the largest raindrops, drops of 1 mm, droplets of 0·1 mm, and cloud droplets 10 μ in diameter fall in a horizontal, laminar airstream of speed *c*.

The object of the fog-catcher is to catch fog- or cloud-droplets which are supposed to be blown against the apparatus in a horizontal airstream, and which cannot enter the standard raingauge. When the airstream is inclined at an angle to the horizontal, the catching area will not change much even though the angle be increased to say 20°, but in this case, cloud droplets can enter the standard raingauge. Another problem is to measure fog precipitation during rainfall. It would appear that a solution to this problem could be found if an anemograph and a drop-size recorder were applied. The instrument described by Kopp (1954) may be useful for this purpose. It should, however, be kept pointed into the wind, otherwise the apparatus will generally not be able to catch rain-drops as can be seen from the graphs of Figs. 5 and 6.

Fig. 5 shows the angle α, the deviation from the vertical at which waterdrops of different sizes fall in a horizontal, laminar airstream of speed *c*, assuming them to have attained the speed of the airstream in the horizontal. The terminal velocity of fall for rain-drops, determined by Gunn and Kinzer (1949) and for cloud droplets, from Stokes's law, is used to calculate the graphs. The diagram of Fig. 6 shows the angle α as a function of the wind speed for the largest raindrops, for drops of 1 mm, for droplets of 0·1 mm, and for cloud-droplets of 10 μ diameter.

From these graphs it can be seen that the smallest raindrops travel almost horizontally if the wind speed exceeds only some metres per second. The graphs indicate also the difficulty of distinguishing between fog-precipitation and drizzle. In order to find a solution, the following assumption is made: If the trace of an automatic raingauge without fog-catcher is fairly straight during the time interval under consideration, then 1·0 mm/hr of precipitation can be regarded as the border between drizzle and light rain.

A similar definition is given to distinguish between fog precipitation and drizzle. The limiting rate is assumed to be 0·1 mm/hr. This definition is applied for the evaluation of the records (see § 5).

4. The situation on Table Mountain

In February 1954 two ordinary raingauges (German type with 200 cm^2 catching area) and two South African recording raingauges with a catching area of approximately 127 cm^2 (Nagel 1954), one of each type equipped with a fog-catcher, were installed on Table Mountain some 50 m east of the summit station of the Cableway and about the same distance from the northern precipice of the mountain. Approximately 10 m from the instruments there are large rocks and other obstacles which are normally considered to be a good windbreak to shield the raingauge from excessive wind and thus give more reliable measurements of the rainfall, but they undoubtedly have a disturbing effect on airflow near the ground and will, therefore, affect the fog measurements. To ensure the services of an observer, a place more suitable for the measurements could not be chosen. This was most unfortunate, also because the Table Cloth appears more frequently and is more dense in the middle of the plateau than at the rim. The readings of the two ordinary instruments were taken at 08 hr from 1 March, 1954 to 28 February, 1955 by Mr. L. A. Vermaak, of the Cableway Company, who also attended to the recording instruments and estimated the wind.

From former wind records, taken with a Dines pressure tube anemometer at this station during the period 1935 to 1943, the average wind speed was determined to be 13 m/sec at the times that the Table Cloth covered the mountain. The mean height of the condensation level is supposed to be 300 m below the plateau, so that on the average the Table Cloth comes in direct contact with the upper portion of the mountain over an area of approximately 6 km^2 (about 2 km in a north-south direction and 3 km in an east-west direction).

During rainfall the upper portion of Table Mountain is generally covered by clouds. The station, therefore, is then within the cloud. According to several observers the average height of the base of rain-clouds on Table Mountain is about the same as that of the Table Cloth, the mean top of which is estimated to be 250 m above the plateau.

5. Evaluation and results

There are some differences between the measurements with the ordinary and with the recording instruments, but on the whole the agreement is satisfactory. For the calculations the indications of the recording instruments are used, but are supplemented by the readings of the ordinary instruments for several days, as some charts were blown away in strong winds and lost. The chosen days, given in Table 1, show how the different combinations of precipitation are evaluated, so as to find the amount of fog precipitation which is not measured by the standard raingauge.

In the four columns 'Precipitation' of Table 1, there are given the observers' readings of the ordinary instruments, G_1 (without) and G_2 (with the fog-catcher), and the amounts

TABLE 1. Precipitation measured by the different gauges.

Item	Date (Observations at 08 hr) 1954	Precipitation (mm) Measured G_1	G_2	Recorded SA_1	SA_2	Wind Direction	Speed (m/sec)	Fog precipitation (mm)	Duration of fog precipitation (hours)
i	27-28 Mar.	16·3	29·1	16·2	31·9	S	8	—	—
ii	21-22 Apr.	0·3	36·0	0·2	37·5	SE	12	37·3	10·7
iii	5- 6 Aug.	3·7	88·8	3·6	81·9	WNW	15	55·9	18·3

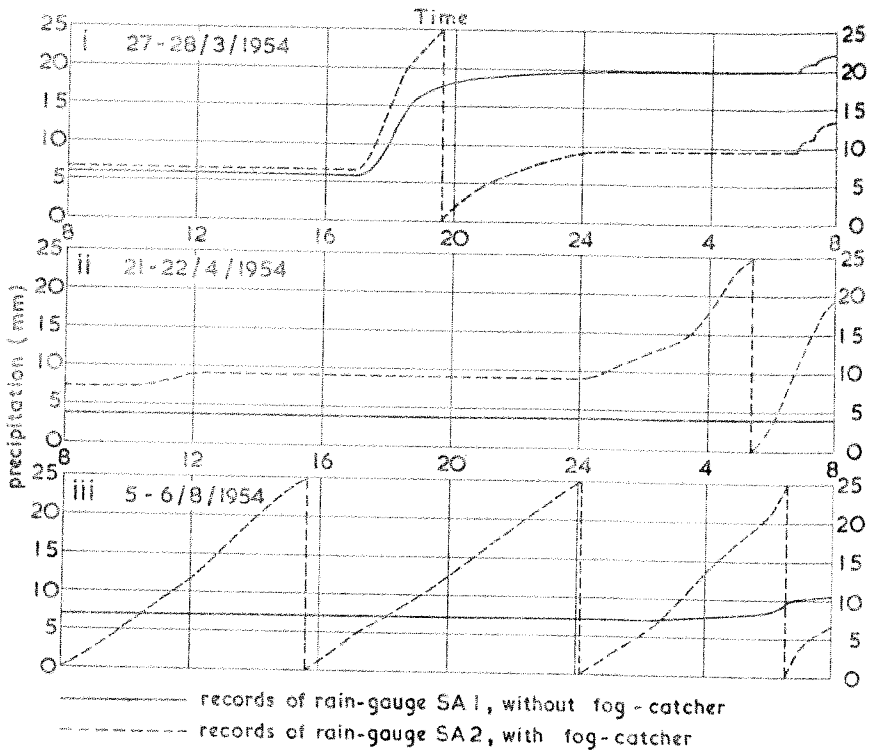

Figure 7. Fog precipitation and rainfall records on Table Mountain.

of precipitation obtained from the records of the automatic instruments, SA_1 (without) and SA_2 (with the fog-catcher). The explanation of the last two columns is given below.

For each day two automatic records are represented in Fig. 7, the full lines referring to the records of the instrument SA_1 without the fog-catcher and the dashed lines to those of the instrument SA_2 with the fog-catcher.

(i) Item i (Table 1) is an example of days with rain. Figure 7, i shows the two records of the automatic instruments. From the traces it can be seen that the precipitation started and ended at the same hour. The two records are parallel to the base line during equal time intervals. The amplitudes of the two records differ from each other owing to the increased catching area of the instrument SA_2. Fog precipitation is most likely to have occurred during the rainfall on this day but could not be determined.

(ii) The trace of the instrument SA_1 in Fig. 7, ii (full line) is almost parallel to the base line. The small amount of precipitation, 0·2 mm, indicated by this record is probably due to eddies which forced some of the cloud droplets into the funnel of the instrument. The dashed line, which represents the record of the instrument SA_2, shows spells of precipitation from 0930 to 1220 hr and from 0010 to 0800 hr, but during the remaining hours of the day the trace is parallel to the base line. The two spells show a total of 37·5 mm of precipitation during 10·7 hr (see diagram ii of Fig. 7).
The small amount of precipitation gathered by the instrument SA_1, although it was not caused by drizzle but by cloud droplets which entered the raingauge, is nevertheless subtracted from the amount collected with the instrument SA_2, because 0·2 mm or so of precipitation would have been measured by any raingauge. Consequently, 37·3 mm of fog precipitation during 10·7 hr is given in the last two columns of Table 1, ii.

(iii) The records in Fig. 7, iii show fog precipitation from 0800 hr to 0220 hr, then drizzle, thereafter rainfall, and finally again drizzle. With the definition given in § 3, fog precipitation on this day is evaluated to be 55·9 mm, occurring during 18·3 hr.

The explanations given above will be sufficient to show how the records are evaluated to find the fog precipitation. Table 2 shows the results obtained.

TABLE 2. Monthly values of rainfall, fog precipitation, duration and mean intensity, from 1 March 1954 to 28 February 1955 on Table Mountain, Station 20/717, 3,500 ft (1067 m) a.s.l.

Month	Mean rainfall over 13 years mm	Rainfall mm	Duration of rainfall hours	Mean rainfall intensity mm/hr	Fog precipitation mm	Duration of fog precipitation hours	Mean fog precipitation intensity mm/hr
Apr. 1954	137	146	84	1·74	281	73	3·85
May 1954	171	426	209	2·04	242	70	3·46
June 1954	157	169	94	1·80	233	68	3·43
July 1954	232	315	202	1·56	292	74	3·95
Aug. 1954	158	172	88	1·95	304	76	4·00
Sept. 1954	141	135	97	1·40	238	68	3·50
Winter	996	1363	774	1·75	1590	429	3·70
Oct. 1954	100	109	64	1·70	274	72	3·80
Nov. 1954	65	62	37	1·68	267	70	3·81
Dec. 1954	40	73	45	1·62	279	74	3·77
Jan. 1955	63	44	26	1·70	398	103	3·86
Feb. 1955	38	227	84	2·70	269	70	3·84
March 1954	64	62	29	2·14	217	58	3·74
Summer	370	577	285	2·03	1704	447	3·80
Year	1366	1940	1059	1·84	3294	876	3·75

6. Discussion of the results

During the measuring period of one year there were 116 days without any precipitation, 126 days with rainfall, 123 days with fog precipitation from the Table Cloth in the absence of rain. Fog precipitation was determined also on 89 of the 126 days with rainfall.

Fog precipitation from the Table Cloth takes place mostly in summer, but from rain clouds when rain is not actually falling more often during winter than in summer. Fog precipitation during rainfall within the cloud could not be detected and is not given, although it undoubtedly occurred. For this reason the fog precipitation, given in Table 2, will probably be an underestimate, especially in winter. Since the measurements were made too far away from the middle of the plateau, as has been mentioned in § 4, there will be further underestimation, especially in summer. The intensity of fog precipitation is not much greater from the Table Cloth than from rain clouds, the average being 3·75 mm/hr.

The intensity of fog precipitation compared with that of rainfall is surprisingly high. This intensity is a function of the liquid-water content of the cloud and the speed with which it moves. The conditions are found to be such that generally clouds drift so fast over Table Mountain that the intensity of fog precipitation, measured and evaluated as explained above, is approximately twice that of the mean rainfall.

Following Schumann (1943), it is found theoretically that, if a laminar airflow is considered, and water from the Table Cloth is not deposited on the slopes, the air on the plateau could contain on the average, approximately 1 g/m³ of water, which is about the same as in rain clouds. Since the mean wind speed was found to be 13 m/sec, the amount of liquid water which passes through 1 m² on the mountain is seen to be $46·8 \times 10^3$ g/hr, equal to 46·8 mm/hr. This amount is about 12 times the value obtained experimentally. The question thus arises how this discrepancy is to be accounted for. It is explained as follows :

(i) The average base of the clouds may be estimated too low, so that the cloud would contain less than 1 g/m³ of liquid water on the plateau.

(ii) It has been mentioned above that the fog measurements show a deficiency for the following reasons:
(a) the effective catching area of the gauze cylinder was too small,
(b) the instruments were situated near the precipice at the western end of the plateau where the cloud is less dense than in the middle of the mountain,
(c) a smooth airflow was obstructed by rocks,
(d) the mean velocity of the air at gauge height was probably less than the average wind speed of 13 m/sec measured at anemometer height.

(iii) The amount of water deposited by fog precipitation on the slopes of the mountain was not measured. Fast airflow over mountains must cause considerable perturbation (Corby 1954). As the slopes of Table Mountain are very rough, eddy motion will be formed and thus air from a somewhat higher layer will be directed downwards so that more cloud- and fog-droplets can be deposited on abundant vegetation than in the case of a laminar airflow. Therefore, the fog precipitation on the slopes might be greater than calculation for a wet-adiabatic ascent indicates. On the other hand the plants may sift out such a great proportion of the water droplets that the air will reach the plateau with a smaller liquid-water content than that which is calculated theoretically.

7. Conclusions

An attempt was made to determine the fog precipitation on Table Mountain. However, measurements only on the plateau proved to be inadequate for the determination of the entire fog precipitation on the mountain. For further investigation it is intended to carry out experiments with larger gauze cylinders. The summit station should be shifted some 500 m to the middle of the plateau at a place where the airflow is not so much disturbed. At least a second station some 200 m lower on the slope is required. Each station should be supplied with a set of instruments consisting of: two recording raingauges, one of which is equipped with a fog-catcher, an anemograph, and a drop-size recorder. A method of identifying fog precipitation during rainfall and of distinguishing between fog precipitation and drizzle has been indicated.

Acknowledgments

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