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THE EFFECT OF WIND ON THE PRECIPITATION DISTRIBUTION OVER A HILLOCK

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An account is given of precipitation measurements on a hillock carried out during June-November 1959 by means of a very dense network of gauges. It was found that the precipitation distribution in the area on a single rainfall could vary considerably owing to the wind conditions. The cause of this phenomenon seems to lie in the aerodynamical conditions around the hillock. When choosing sites for precipitation measurements such aerodynamic effects should be realized.

During investigations concerning local rainfall variations over small, flat, cultivated areas at Ultuna in south-eastern Sweden (17° 40′E; 59° 49′N) the author noticed that precipitation values from gauges placed on slightly sloping ground with horizontal orifices sometimes markedly deviated from those obtained with adjacent gauges placed on horizontal soil-surfaces. This stimulated an investigation into precipitation measurements on the sides and on the crest of a hillock, about 4 m in height and 10 m in width. The nearest surroundings consisted of flat, cultivated country up to a distance of 200 m from the hillock. Fig. 1 shows the topography of the hillock and the gauge sites. The latter are marked with dots.

METHODS

Geiger (1928) found when using gauges with horizontal orifices on the slopes of a hill that the measured precipitations values were incorrect because of the

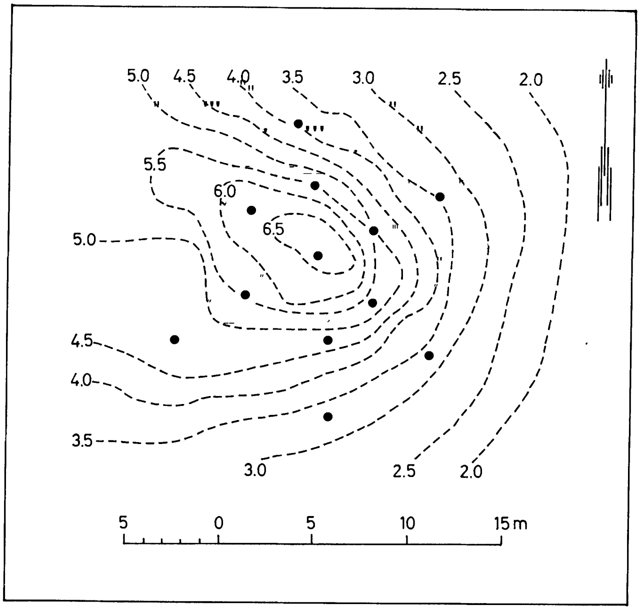


Fig. 1.
General map of the hillock and the gauge sites. Dotted curves show the height above the sea-level in m.

oblique angle which the rain makes with the soil-surface. He also points out (1961) that if the precipitation which falls on a sloping ground surface is to be measured, the orifice of the gauge must be parallel to the same. Many years earlier Horton (1919) had arrived at the same conclusion.

A gauge at an open site catches less rain the higher it is placed above the ground owing to the influence of the wind (e. g. Jevons 1861). Jevons also emphasized that the most correct measurements of rainfall are obtained when the orifices of the gauges are level with the soil-surface.

As the vegetation on the hillock consisted of very short grass the gauges could be placed with their orifices level with and at the same angle as the ground surface. Hence the demand was fulfilled of eliminating as far as possible the influences of the wind and of the orientation of the orifices.

Measurements were made after every rainfall during the period. The measuring device and methods used are described in a previous paper (in press).

The precipitation values have been adjusted to so-called hydrological precipitation. "Hydrological" precipitation is defined as the vertically measured height of the amount of water being collected on a sloping soil-surface, when no run-off, infiltration, or evaporation has taken place (Hoeck 1948). Thus the amount of water per unit area passing through the orifice of the gauge had to be multiplied by the secant of the slope angle. The inclination of the slopes at the sites on the hillock did not exceed 20°.

RESULTS

Variation in the precipitation distribution

The influence of the wind on the precipitation distribution over the hillock is seen from Table 1.

Table 1 shows that at mean wind velocities over 5 m per sec the difference between the precipitation on the windward and on the leeward side in percentage of the mean may be as high as 28 per cent. At wind velocities between 1.0-2.9 m per sec this difference decreases to about 12 per cent. For a total of 22 rainfalls the divergence mentioned above amounts to, on an average, 17 per cent.

Table 2 shows the precipitation on the crest of the hillock. It demonstrates clearly that the measured precipitation on the crest is lower than the mean. especially in high winds.

Table 1.
Precipitation on the windward and on the leeward side of the hillock in relation to the precipitation mean within different intervals of wind velocity

Mean wind velocity m per sec 9.0 m over the ground	No. of rainfalls	Precipitation mean in mm (12 gauges on the hillock)	Highest observed percental deviation from the mean	
			Windward side	Leeward side
5.0	4	7.5	9.3	– 18.7
3.0–5.0	6	32.7	12.5	– 15.0
1.0–2.9	12	92.3	4.8	– 7.0
Total	22	32.5	6.9	– 9.7

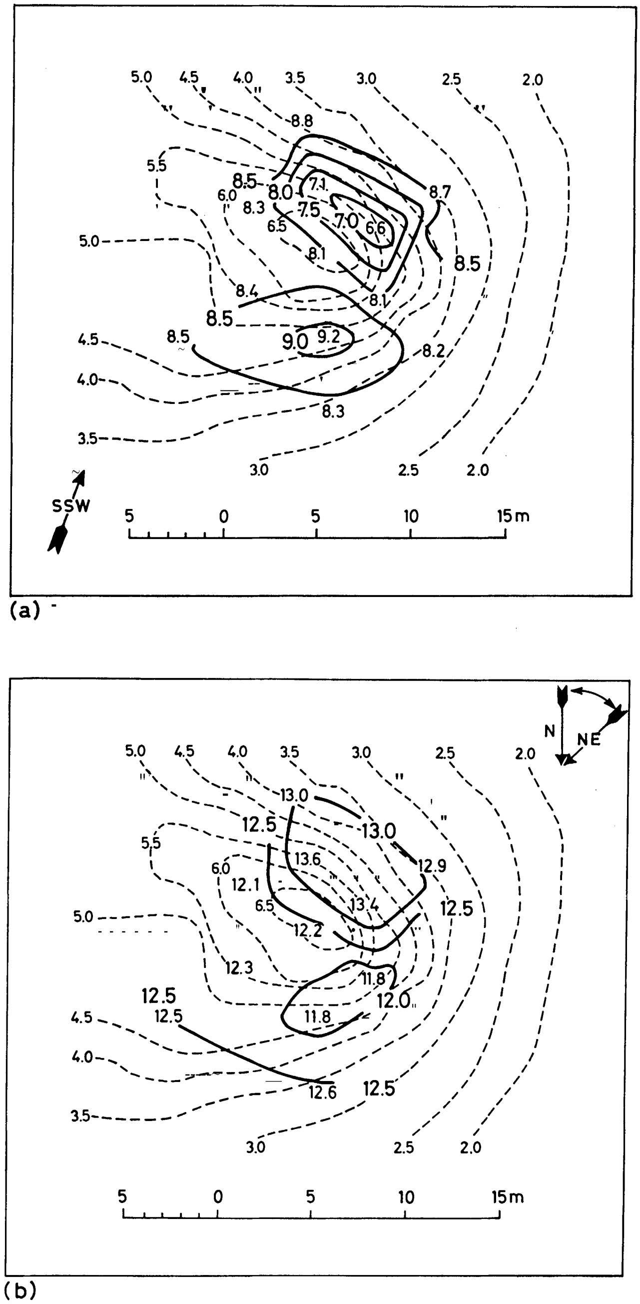


Fig. 2.

Precipitation distributions over the hillock after rainfalls with: (a) strong convection; (b) frontal precipitation with some convection. The cases shown are: (a) 14 July 1959, wind SSW, mean wind velocity 9.0 m over the ground 4.6 m per sec; (b) 2 and 3 August 1959, wind NE-N, corresponding mean wind velocity 2.5 m per sec. Continuous curves show the precipitation in mm, dotted curves the height above sea-level in m.

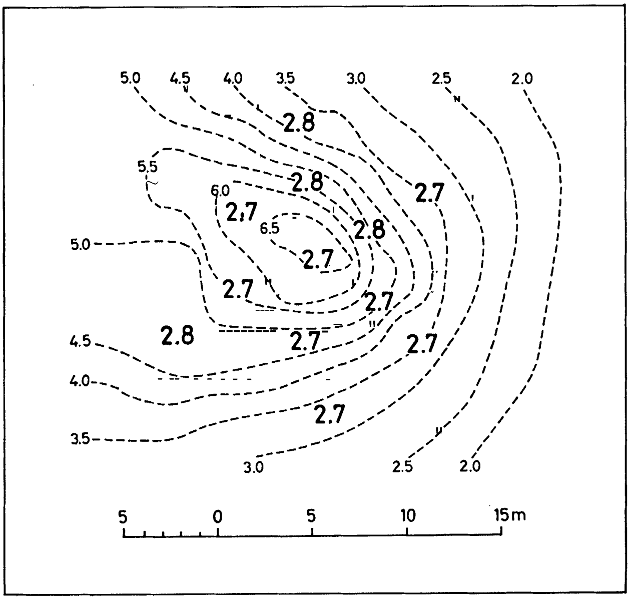


Fig. 3.
Precipitation distribution over the hillock after a rainfall with almost no convection and calm conditions 21 and 22 September 1959. Dotted curves show the height above sea-level in m.

Precipitation maps

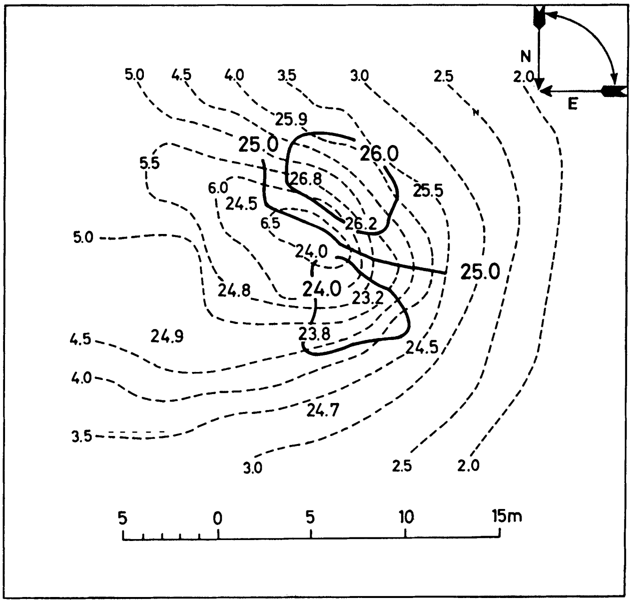
Precipitation maps were drawn for every rainfall.

Fig. 2 shows that the difference in precipitation on the windward side and on the leeward side is considerable; in Fig. 2a about 40 per cent, in Fig. 2b about 15 per cent. In case 2a the mean wind velocity is 4.6 m per sec, in case 2b only 2.5 m per sec.

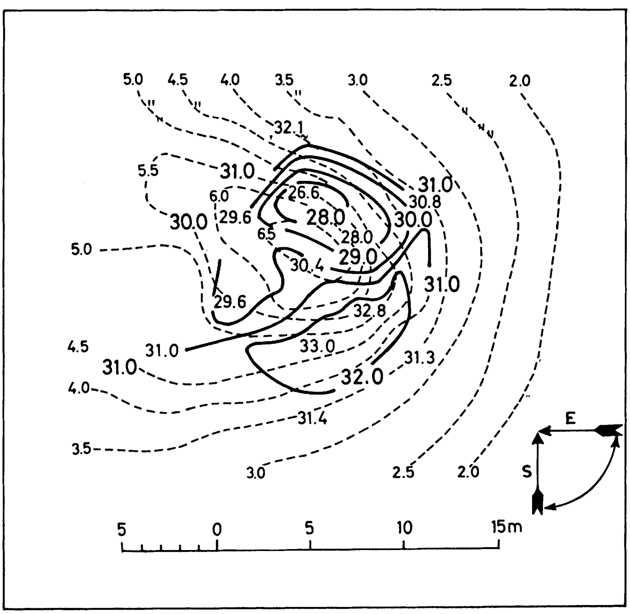
Fig. 3 shows a rainfall with calm conditions. The variation in the precipitation distribution is, as could be expected, relatively small.

The mean difference in the precipitation between the windward- and the leeward side is seen from Fig. 4a, b, c, and d, where rainfalls with wind within the sectors N-E, E-S, S-W, and W-N have been collected. The number of rainfalls forming the basis of the maps in Fig. 4 are 5 (4a), 6 (4b), 4 (4c), and 7 (4d). The windward slope of the hillock has received considerably more precipitation than the leeward side. The difference between the highest and the lowest value in percentage of the mean is in 4a, 14; in 4b, 21; in 4c, 29; and in 4d, 17 per cent.

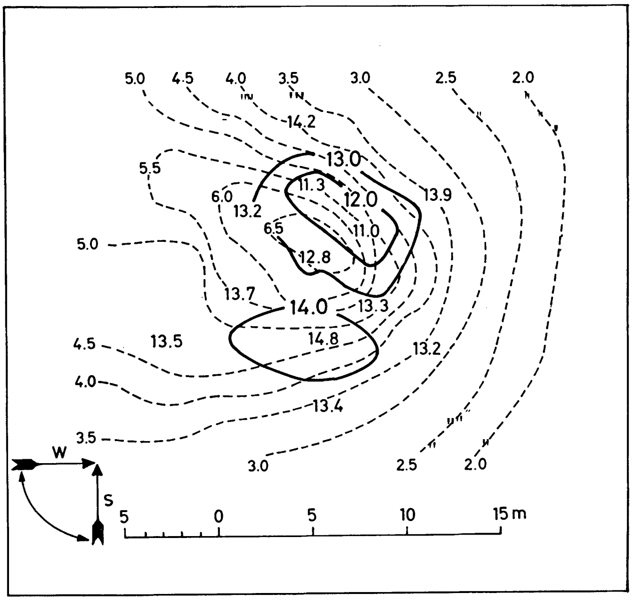
Only 3 rainfalls with calm conditions occurred during the period. The precipitation distribution after summation of the precipitation for these rainfalls is


N
E
5.0
4.5
4.0
3.5
3.0
2.5
2.0
25.9
25.0
26.0
5.5
26.8
6.0
24.5
25.5
6.5
26.2
5.0
24.0
25.0
24.8
24.0
23.2
4.5
24.9
23.8
24.5
4.0
24.7
3.5
3.0
2.5
2.0
5
0
5
10
15m

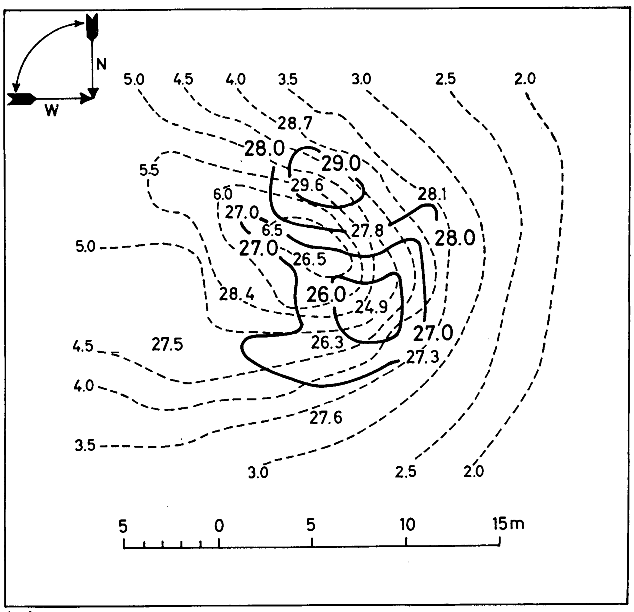
(a)


5.0
4.5
4.0
3.5
3.0
2.5
2.0
32.1
5.5
31.0
31.0
6.0
26.6
30.8
30.0
29.6
28.0
30.0
6.5
28.0
5.0
30.4
29.0
31.0
29.6
32.8
4.5
31.0
33.0
31.0
31.3
32.0
4.0
31.4
E
3.5
S
3.0
2.5
2.0
5
0
5
10
15m

(b)



(c)



(d)

Fig. 4.

Precipitation distribution over the hillock after summation of the precipitation for rainfalls with wind within the sector: (a) N-E; (b) E-S; (c) S-W, and (d) W-N. Number of rainfalls: (a) 5; (b) 6; (c) 4; and (d) 7. Continuous curves show the precipitation in mm, dotted curves the height above sea-level in m.

Table 2.
Precipitation on the crest of the hillock in relation to the precipitation mean within different intervals of wind velocity

Mean wind velocity m per sec 9.0 m over the ground	No. of rainfalls	Precipitation mean in mm (12 gauges on the hillock)	Highest observed percental deviation from the mean on the crest
5.0	4	7.5	– 9.3
3.0–5.0	6	32.7	– 0.9
1.0–2.9	12	92.3	– 2.0
Total	22	132.5	– 2.1

shown in Fig. 5. The variations are fairly small; the difference between the highest and the lowest value in percentage of the mean is about 5 per cent.

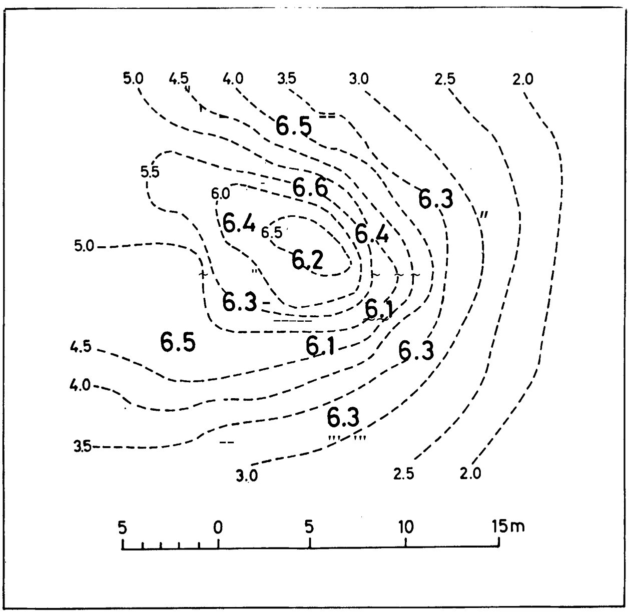


Fig. 5.
Precipitation distribution over the hillock after summation of the precipitation for 3 rainfalls with calm conditions. Dotted curves show the height above sea-level in m.

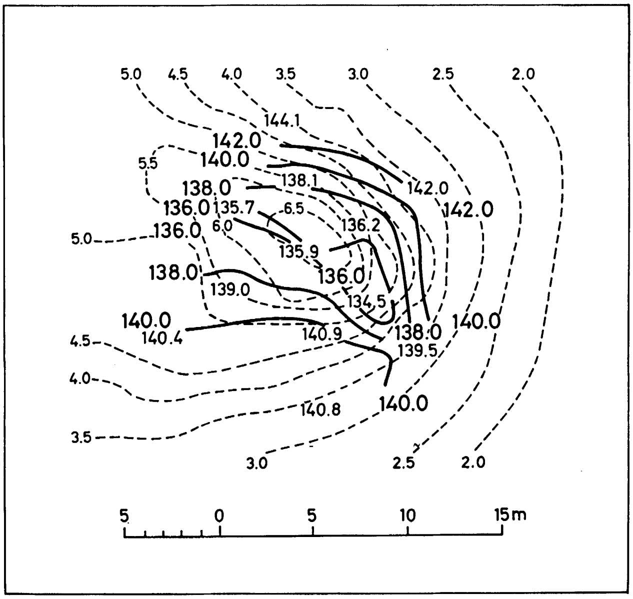


Fig. 6.

Precipitation distribution over the hillock after summation of the precipitation for a total of 25 rainfalls. Period June-November 1959. Continuous curves show the precipitation in mm, dotted curves the height above sea-level in m.

It can be expected that, for a given period, the variation in the precipitation distribution over the hillock is dependent on the wind conditions during the rainfall. If the wind has come from many different directions, the variation will be less than for a single rainfall. The precipitation distribution after summing of the precipitation for all rainfalls June-November 1959, 25 in number, is given in Fig. 6. As can be seen, the variation in the precipitation distribution for this period is considerably less than that which may occur on a single rainfall. The difference between the highest and the lowest value in percentage of the mean is, in this case, 7 per cent (cf. Fig. 2).

CONCLUSIONS

The precipitation distribution over a hillock on a single rainfall may vary considerably owing to the wind conditions. There is a close connection between the precipitation distribution and the direction and the velocity of the wind; the leeward side receives less precipitation than the windward side. This is especially the case for rainfalls in high wind, when the crest of the hillock also has markedly lower precipitation values than the precipitation mean. The cause of this phenomenon seems likely to lie in the aerodynamical conditions around such a hillock, and is hence not an orographic effect in the strict sense of the word. When choosing sites for precipitation measurements, the importance of this aerodynamic effect should, of course, be realized. However, if the precipitation for all rainfalls is added, the percentage variation in the precipitation is considerably less than for a single rainfall, because of the variation in wind direction.

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