KONINKLIJK NEDERLANDS
METEOROLOGISCH INSTITUUT

Wetenschappelijk Rapport W.R. 57-003 (IV-014)

G. Verploegh

Rainfall measurements aboard the Netherlands Ocean Weather Ships "Cirrus" and "Cumulus"

De Bilt, 1957

KONINKLIJK NEDERLANDS
METEOROLOGISCH INSTITUUT

Wetenschappelijk Rapport
W.R. 57-003 (IV-014)
U.D.C.: 551.408.77 (26)

G. Verploegh

Rainfall measurements aboard the Netherlands Ocean Weather Ships "Cirrus" and "Cumulus"

Abstract

This paper summarizes the results of various experiments, carried out in 1956 on board the Netherlands ocean weather ships, and partly also at the Meteorological Institute at De Bilt, on the measurement of rainfall at sea with the German conical marine rain gauge, of the type shown at the second session of CMM at Hamburg. This rain gauge, which is hoisted in the rigging of the ship at a sufficient height above the deck, proves to be a practical instrument for routine observations. It is found that the disturbance of the air flow by the gauge itself does not give rise to important errors in the readings. However, when securing the gauge in its position, small accidental tilts of the orifice from the "horizontal" plane cannot be avoided. The errors which are thus introduced into the individual observations are generally proportional to the rainfall itself and may form a large percentage of the latter. Since the deviations caused by this effect are both positive and negative the errors in the mean monthly amount of precipitation will generally be less. For the Netherlands observations they amounted to 10-15 pct.

1. Preliminary measurements

1.1. On board the ocean weather ships

In 1956 the Netherlands ocean weather ships "Cirrus" and "Cumulus" have been equipped with rain gauges and since then, readings of the amount of precipiation have regularly been taken, most of these at station M.

The measurements were carried out on an experimental basis; on many voyages two or more rain gauges were installed on the same ship with the object of finding a site where reasonably accurate and representative observations would be obtained and which would also be easily accessible for regular observation.

The experiments were made with German conical marine gauges, manufactured by the firm of Walter Eigenbrodt at Hamburg. The gauges are constructed in such a way that they can easily be suspended in the rigging; the orifice is kept in a "horizontal" position with respect to the ship with the help of three lines.

The amount of precipitation is read directly from a gauge-glass attached to the conical reservoir. During the voyage of the "Cirrus" in March 1956 five rain gauges were installed in this ship, with the object of getting an impression of the differences, which the readings at various places on the ship would show, and also in order to find, if possible, a most favourable site. The investigation was inspired by a somewhat similar but much more extensive one by J. Skaar on board the Norwegian ocean weather whip "Polarfront I" (1). These measurements were taken by Mr. W. van Dijk. One gauge (A) was suspended high in the foremast, 16 m above sea level, one on the bridge-deck on starboard (B), another midship on the roof of the wheel-house (C) and two gauges on the boat-deck astern, one on port (D) and the other midship (E). The gauges B, C, D and E stood at heights of 6, 10, 6 and 8 m above sea surface, respectively.

Eight series of simultaneous readings were taken; the values differed considerably, as would be expected. But no definite conclusion could be drawn as to the specific cause of the differences in each case, though generally the disturbance of the air flow by the ship could be held responsible for the large deviations observed.

The experiments also included measurements of the salinity of five samples of collected rain water. The salinities were converted into percentages of sea water and are given in the following table[1].

---

[1] Reproduced from an internal report by W. van Dijk.

Table I

Sample	Percentage of sea water in gauge: A	B	C	D	E	Precipitation collected in A (mm)	Mean wind speed (knots)
I	0.8	4.6	2.7	2.4	1.5	7.5	20
II	0.9	0.9	0.4	0.6	0.4	14.4	20
III	9.1	9.0	2.5	10.0	1.5	7.4	26
IV	1.9	2.5	3.6	13.0	9.1	6.7	27
V	0.4	1.8	0.7	1.5	0.9	14.5	26

Though these values need not represent real percentages of spray water collected in the gauges, because of the deposition of salt particles from the air, they may serve as an indication of the relative exposure to spray.

The measurements, however small in number, suggest that the amount of spray water may normally be neglected in gauges which are sited at a level above 16 m. That is so far as ocean weather ships are concerned. It might be expected that at this height the disturbing effect of the ship on the air flow would also be relatively small.

1.2. Measurements at the Meteorological Institute at De Bilt

The accuracy of rainfall measurements with a gauge of this type high in the mast has been investigated by trying to find an answer to the following questions:

a) Owing to the variability, both in time and in space, of the precipitation local measurements of the rainfall over an area of given dimensions will be subject to certain deviations from the mean amount. Now, what is the standard deviation of measurements made with standard rain gauges within an area having the dimensions of a ship's deck ?

b) What is the accuracy of the readings with a conical marine gauge ?

c) What is the influence of the elevated position of a suspended conical gauge on the accuracy of the readings ?

d) By how much will the standard deviation of the observations be increased when the gauge is suspended high up in the rigging of a ship, as compared to the situation on land ?

For an answer to the first three questions experiments have been made on an open grass lawn near the Meteorological Institute at De Bilt.

A) To find an answer to the first question 12 gauges of an ordinary type were set out in a triangular grid (see figure 1). The outer legs of the triangle (gauges 10, 11 and 12) had a length of respectively 60, 60 and 100 m. The distance between each pair of neighbouring gauges was 10 m, except for the gauges no. 11 and 12, which were installed later and stood further apart.

Though these gauges were made of plastic material, they were of the same size and form of the standard gauge for climatological purposes. The orifice, having an area of 4 dm^2, was 60 cm above the ground. The collected rain water ran through a narrow funnel into a bottle underneath; special care was taken to prevent losses by evaporation. The rainfall was measured twice daily with a special measuring glass, permitting an accuracy of 0,01 mm for a rainfall up to about 2 mm. The measurements started on August 17th and were suspended on September 13th. During this period it rained nearly every day; the weather was generally showery with light, moderate and sometimes heavy showers. There were two days with drizzle.

27 series of simultaneous readings were obtained, totalling 312 individual observations. For each series the mean precipitation was calculated, together with the differences of the individual observations from this mean value. For the computation of the standard deviation the series were taken together into some classes according to increasing amounts of rainfall. Table II gives the results.

Table II

Mean precipitation of each class	Standard deviation with regard to the mean of the series		Number of observations	Number of series
mm	mm	%		
14.2	0.24	1.7	10	1
7.6	0.12	1.5	34	3
4.2	0.11	2.5	42	4
1.7	0.07	4.3	84	7
0.7	0.04	5.3	72	6
0.3	0.05	16.6	46	4
0.1	0.03	31.2	24	2
All obs. 2.6	0.08	3.2	312	27

It may be inferred from these figures that the standard deviation of measurements, made with the instrumentation used, has a minimum

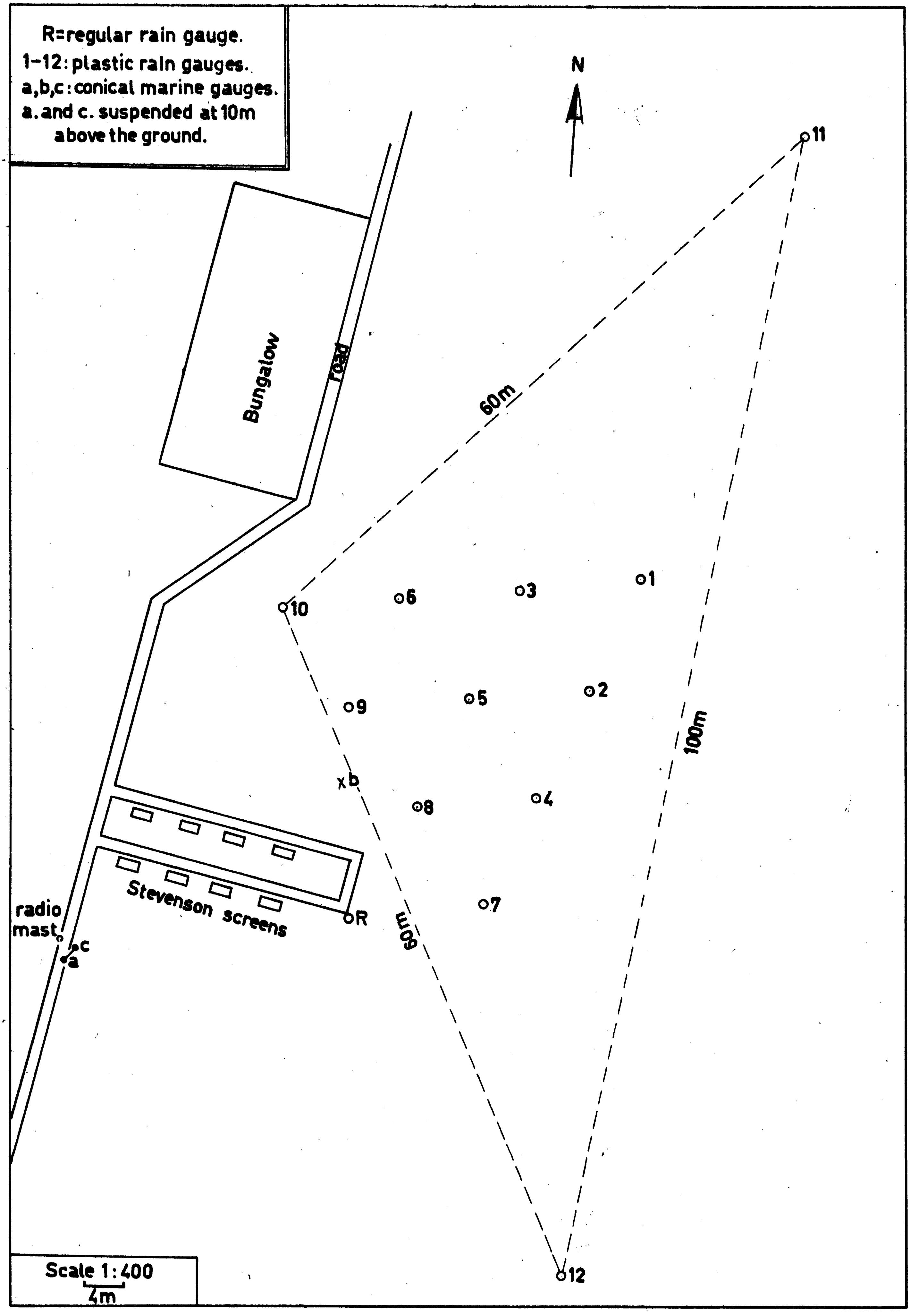

Fig 1 Lay out of the grid of rain gauges at the K.N.M.I. at De Bilt

value of about 0.04 mm. The larger amounts of precipitation, 4 mm and more, all resulted from showers. Here the scatter is somewhat larger and presumably originated also from local variations in the precipitation itself.

The same percentages of the standard deviation are found when only the three outer gauges (10, 11, 12) are considered.

The readings of the regular climatological rain gauge (situation, see fig. 1) were in good agreement with the mean values of the 12 gauges. On 21 occasions the deviations were less than the standard deviation, on 26 occasions less than twice this value, while all deviations were less than thrice the standard deviation.

B) On the same lawn one conical gauge was installed, fastened to a fixed standard, the orifice being at a height of about 70 cm above the ground.

The original plan of installing three gauges in a triangular grid on the lawn could not be carried out, since there were not enough gauges regularly at home.

Of 27 observations the differences with the mean reading of the 12 standard gauges showed a standard deviation of 0,29 mm; the mean difference was -0,08 mm, the marine gauge giving the (slightly) lower mean.

C) During the same period observations have also been made with two marine gauges, which were suspended 10 m above the ground on a line, which extended from the ground to the top of a 20 m high radio mast. The two gauges were connected with two horizontal bars of 2 m length. They could not move independently, but the whole sytem was up to a certain extent free to sway in the wind. With the help of three ropes the orifices were kept in a horizontal position as good as could be estimated from ground's view. The exposure of the gauges was perfectly free.

The readings of the gauges agreed well with each other. 12 out of 23 simultaneous readings gave identical values. Only 3 observations resulted in larger differences than thrice the standard error, computed for the 12 gauges on the ground. However, on two of these occasions one of the gauges was clearly seen to be tilted. After leaving these two readings out, the mean difference between the two gauges was found to be negligibly small.

A comparison of the 44 remaining individual readings with the mean precipitation on the ground resulted in a mean difference of -0,03 mm and a standard deviation of 0,16 mm. It might be mentioned apart that on one occasion, after a very rainy night, both gauges collected an amount of 30,0 mm in six hours. The mean wind velocity increased from 10 to 18 knots during the downpour of rain with maximum gusts reaching 37 knots. The gauges were fully exposed to the NE'ly wind. At the same time the "official" rain gauge on the ground registered 29,8 mm. The 12 plastic gauges were overflowed.

These experiments indicate that the conical marine gauge, when suspended above the ground properly in a horizontal position, gives the true mean amount of rainfall as compared with standard gauges on the ground. The scatter of the individual observations is small, the standard deviation being about twice as large as the standard deviation that was computed for the 12 rain gauges on the ground.

2. Measurements with two rain gauges on board the ocean weather ships

During the last three months of 1956 the ocean weather ships were each equipped with two conical rain gauges, which were hoisted up in the rigging of the centre mast high above the wheel-house, one on port, the other on starboard. The height above sea level was approximately 18 m.

On four voyages 120 pairs of observations, with at least one gauge containing a measureable amount of rainfall, were obtained at station M, 42 from the "Cirrus" and 78 from the "Cumulus". The readings were made at the synoptic hours 0600 and 1800 GMT.

The wind velocity and relative direction was observed and recorded during rainy periods. The routine observations also included the duration of the rainfall in time intervals of 5 minutes.

The observations of both ships showed common features. The frequency distribution of the differences of the port and starboard readings, when grouped according to a number of intervals of mean precipitation, revealed that the absolute values of the differences were more or less proportional to the mean amount of rainfall, the differences being both negative and positive. The predominant features of the frequency distributions are given in table III, where the observations of both ships have been taken together. The observations of less than 0,1 mm of precipitation were left out. According to the frequency distribution of the precipitation amounts the four data of a mean rainfall between 1,3 and 2,0 mm could not very well be placed either in the second or the third class. They were also left out in Table III.

Table III

Class (mm)	$\overline{M}$ (mm)	$\overline{d}$ (mm)	σ (mm)	$\overline{\lvert d \rvert}$ (mm)	$\frac{\overline{\lvert d \rvert}}{\overline{M}}$ (pct)	N
0.1-0.5	0.28	+0.01	0.19	0.14	50	33
0.6-1.3	1.02	+0.17	0.61	0.48	47	27
2.0-4.0	3.04	+0.21	1.09	0.88	29	21
4.2-7.0	5.64	+0.79	1.94	1.69	30	14
$>$ 7.0	10.66	+0.71	4.28	3.43	32	7

$\overline{M}$ = mean amount of precipitation in each class
$\overline{d}$ = mean difference: starboard - port
$\overline{\lvert d \rvert}$ = mean absolute difference
σ = standard deviation
N = number of observations

The constancy of the ratio $\frac{\overline{\lvert d \rvert}}{\overline{M}}$ for a rainfall of 2 mm and more leads us to examine the relative differences $\frac{d}{M}$ rather than the differences d itself. Taking all observations into account, we find:

	Cirrus	Cumulus
Mean of $\frac{d}{M}$	+12.6 %	+ 3.7 %
Stand.dev. of $\frac{d}{M}$	46 %	58 %
Mean of $\left\lvert \frac{d}{M} \right\rvert$	33 %	43 %
Number of obs.	42	78

When considering only the observations of a mean precipitation of 2 mm and more, we find:

	Cirrus	Cumulus
Mean of $\frac{d}{M}$	+17.5 %	+ 3.2 %
Stand.dev. of $\frac{d}{M}$	38 %	38 %
Mean of $\left\lvert \frac{d}{M} \right\rvert$	34 %	32 %
Number of obs.	16	26

On both ships the starboard gauges gave the higher readings on the average, but only on the "Cirrus" the effect can be considered to be significant. The figures clearly show that there is a disturbing influence, which gives rise to errors that are proportional to the amount of precipitation and come on top of the normal scatter of the observations. The errors, being both positive and negative, seem to have an accidental cause.

This cause may, at least partly, lie in a small tilt of the gauges. In practice it is hardly possible to fix the gauge with the orifice in an exact "horizontal" position in the rigging, high above the observer, only with the help of lines fastened below. Small deviations of only a few degrees are likely to occur and since the gauge has to be lowered to deck-level for each observation, the deviations will usually be different every time. Small accidental tilts, in combination with the variations of wind velocity and direction and of the speed of fall of the raindrops may easily lead to quite large variations of the relative difference $\frac{d}{M}$. For the simple case of two gauges, which are tilted in opposite directions, the relative difference of the measurements can be estimated from the angle of tilt, assuming the wind direction at right angles to the rotation axis of the tilt.

Under these assumptions the amount of rain water N, collected in one of the gauges, is given by:

$$N = n\,(V\,O \sin\alpha + W\,O \cos\alpha),$$

where n is the water volume of the rain drops per cm^3 of air, V the wind velocity and W the speed of fall of the rain drops. The other symbols are explained by figure 2.

The relative difference of the amounts of rain water collected by the two gauges is given by:

$$\frac{d}{M} = 2\,\frac{N_1 - N_2}{N_1 + N_2} = 2\ tg\,\tfrac{1}{2}(\alpha_1 - \alpha_2)\,.\,tg\left[i - \tfrac{1}{2}(\alpha_1 + \alpha_2)\right]$$

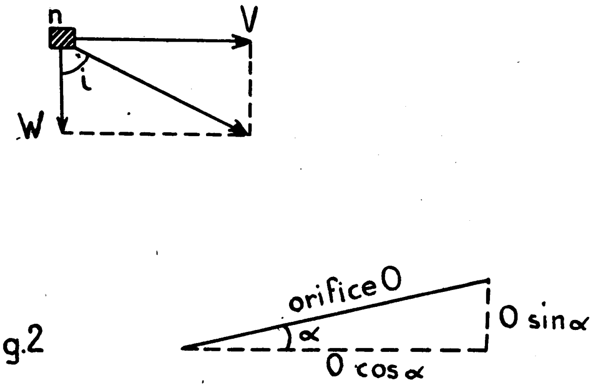

Fig.2

If $\alpha_1 = -\alpha_2$ and supposed the mean wind velocity is about 20 knots and the speed of fall of the rain drops is about 5 mps, so that $tg\,i = 2$, it follows that for instance a ratio $\frac{d}{M}$ of 17,5 %, as is the mean for the "Cirrus" observations, would be caused by $\alpha_1 = -\alpha_2 = 2{,}5^\circ$.

The example shows that even slightly tilted gauges may give rise to rather large errors in the readings. For accurate observations one must impose the condition that the rain gauge be fixed with the orifice in the right horizontal position with respect to the ship. The present way of securing the conical marine gauge appears to be insufficient with respect to this default.

It may readily be understood that under these circumstances no indication could be found of any systematical differences of the two gauges in connection with relative wind directions, the disturbing influence of the tilt of the gauges being too large for these apparently smaller effects.

3. Comparison of Netherlands and Norwegian measurements at station M

A summary of the measurements of the two Netherlands ocean weather ships at station M is given in Table IV. The monthly amounts of precipitation refer to the mean of the readings of the port and starboard gauges. Following Skaar the number of days, on which precipitation occurred (⩾ 0,0 mm), is also given, together with the number of "rainy" days (⩾ 0,2 mm), the number of "wet" days (⩾ 1,0 mm) and the number of days on station.

Table IV

Month 1956	Measured (mm)	Number of days			
		⩾ 0,0 mm	⩾ 0,2 mm	⩾ 1,0 mm	on station
October	93,0	24	23	21	25
November	77,3	26	23	18	27
December	91,8	22	20	15	31

The difference of the monthly amounts of precipitation, i.e. starboard gauge minus port gauge, is for October -8,8 mm, for November +19,1 mm and for December +17,6 mm. The experiments at De Bilt indicate that it may not be expected that the disturbance of the air flow caused by the gauge itself would give important errors in the readings. Since the differences of the starboard and port gauges did not show any correlation with either the wind speed or the relative wind direction, the small accidental tilts of the gauges might be held mainly responsible for the differences observed. On these grounds the monthly amounts of precipitation may be assumed to be accurate within 10-15 per cent, a result which might still be improved by securing the position of the gauge in a better way.

In the last three months of 1956 the mean precipitation frequency (the number of days with a measurable amount of precipitation in per cent of the number of days on station) was 87 %. This is the same figure as Skaar gives on the basis of his long series of observations at station M.

The relative frequency of "wet" days (the number of "wet" days in per cent of the number of days with precipitation) was, however, much higher in the end of 1956 than in the winter months of the preceding years. The Netherlands observations gave frequencies of 87, 69 and 68 pct respectively. For a number of months during the years 1950-1952, when the Norwegian ocean weather ship "Polarfront I" was on station, Skaar gives a detailed summary of the Norwegian measurements. In this summary eight months, falling in the period October _ March, were included. The relative frequency of "wet" days in these "winter months" varied between 22 and 41 per cent.

The amounts of precipitation in the last three months of 1956 were much larger than the monthly amounts measured on board the Norwegian ocean weather ship "Polarfront I" during the preceding years. A summary of the Norwegian data is given in Table V (1, 2).

On the "Polarfront I", according to Skaar, the precipitation was measured from March 1950 to June 1951 by means of a rain gauge on the roof of the wheelhouse (9.90 m above sea surface) and from August 1951 to March 1952 with a gauge on the lifeboat deck ahead of the skylight, 7 m above sea surface. As regards the data of 1956 no mention has been made of the position of the rain gauge (2).

The measured monthly amounts of precipitation are compared with each other in figure 3. Here the monthly amounts of precipitation, measured in the "Polarfront I" during 28 months in the years 1950-1956, have been correlated with the amounts of precipitation of the corresponding months at Nordöyan, a small island off the Norwegian coast. The data are expressed in per cent of the normal precipitation at Nordöyan. The rain station on Nordöyan was chosen because of its correlation with the rainfall at M. For a few coastal stations the pertinent correlation coefficient was found to be:

Skomvaer Fyr	(67.25 N; 11.53 E)	: r = +0.43
Nordöyan	(64.48 N; 10.33 E)	: r = +0.51
Ona	(62.52 N; 6.33 E)	: r = +0.37

The artificial procedure of relating the measured monthly precipitation at station M to the normal monthly values of the precipitation at Nordöyan does not seem to disturb the presentation of the data in figure 3 to a large extent. For, if one correlates the monthly precipitation at Nordöyan of the same months, in per cent of the normal monthly precipitation, with the corresponding data of Skomvaer Fyr, which are taken in per cent of

Table V

Year	Month	Amount of precipitation (mm)		
		Station M "Polarfront I"	Nordöyan Monthly total	Nordöyan Normal
1950	March	36	49	45
	May	15	18	39
	July	10	28	39
	Sept.	69	64	69
	Dec.	23	64	57
1951	Febr.	33	14	52
	April	30	33	28
	June	5	40	42
	Aug.	51	61	46
	Nov.	20	26	74
1952	Jan.	32	106	71
	March	35	79	45
	May	9	24	39
	July	52	60	39
	Sept.	12	81	69
	Dec.	49	76	57
1953	Febr.	26	82	52
	April	29	37	28
	June	12	18	42
	Aug.	37	34	46
	Nov.	38	64	74
1954	Jan.	18	52	71
1956	Jan.	57	58	71
	Febr.	31	27	52
	March	17	31	45
	April	44	61	28
	May	39	57	39
	June	17	98	42

In each of these months the "Polarfront I" was at least 28 days on station.

Year	Month	Station M "Cirrus"and"Cumulus"	Nordöyan		
			During days on station[1]	Monthly total[1]	Normal
1956	Oct.	93	77	80	75
	Nov.	77	69	71	74
	Dec.	92	63	64	57

the normal values at this station, then a correlation coefficient is obtained of not more than +0.54. It is not to be expected, therefore, that a correlation between Nordöyan and station M would yield a much higher coefficient than the value obtained now, if the normal precipitation at M were known and taken into account.

The arrangement of the data in the diagram with respect to the line of regression of "M" on "Nordöyan", which has been drawn in the diagram, shows the variation of the amount of precipitation at "M" with respect to the amount of precipitation at Nordöyan, both taken relative to the monthly normal values at the latter station.

The Norwegian measurements at station M indicate that during the months November - March the deviations from the mean relation are relatively small (within the range indicated by the standard deviation). The Netherlands data, which have been plotted in the diagram afterwards, suggest that the precipitation at station M in the last three months of 1956 has been abnormally high as compared to the Norwegian observations in the preceding years. The number of the observations is, however, too small to permit any conclusion with regard to a possible instrumental cause of the difference noted.

References:

(1) John Skaar. On the measurement of precipitation at sea.
Geof. Publ. Norske Videnskaps-akademi, XIX, 6, 1955

(2) CMM-II 1956 Doc. 37, add. 2, page 4.

---

[1] These data were extracted from the daily weather reports as received at De Bilt by teletype and may therefore contain small errors.

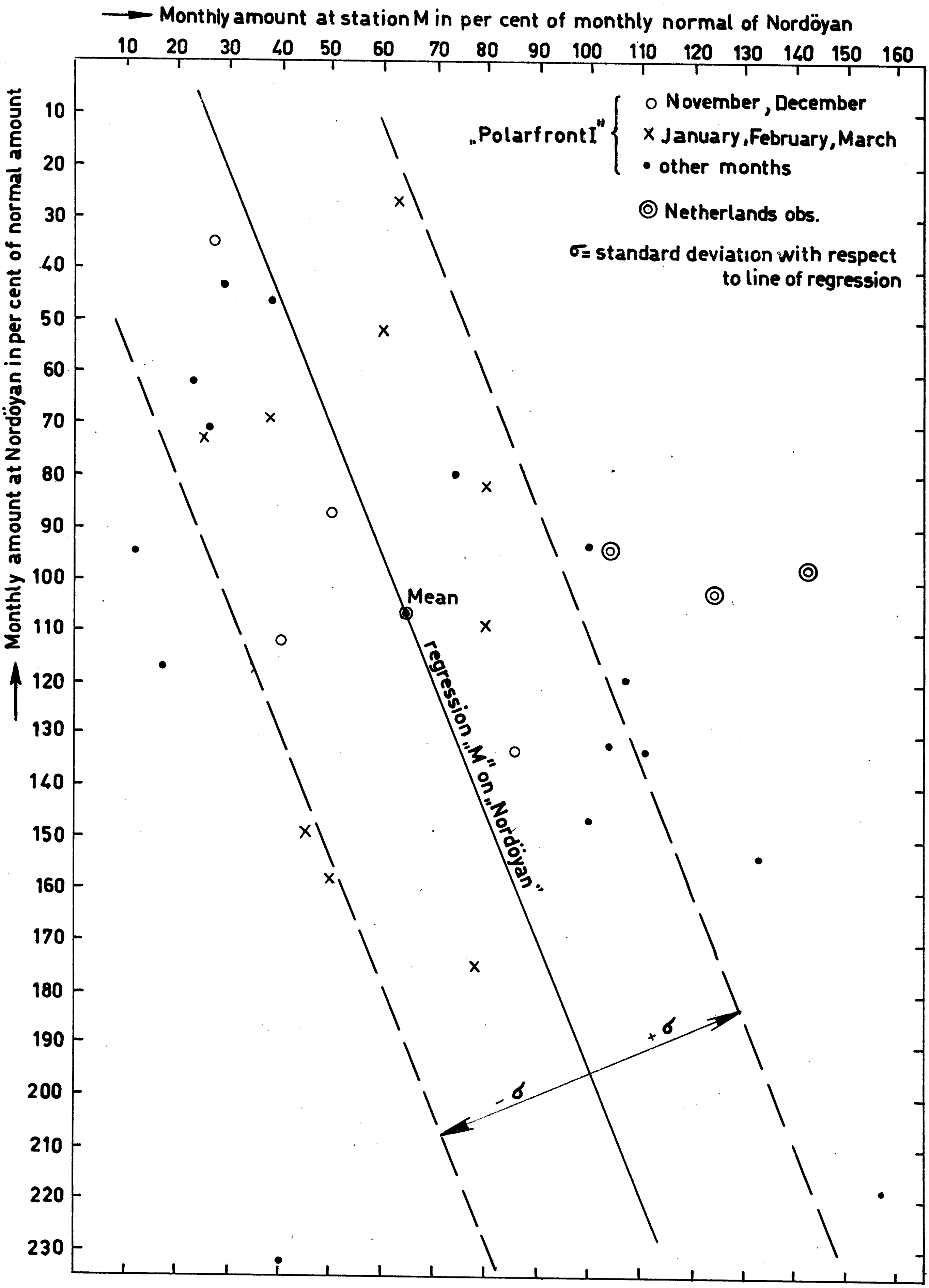

Fig.3 Correlation of monthly amounts of precipitation of station M and Nordöyan