ON THE MEASUREMENT OF PRECIPITATION AT SEA

BY

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Introduction.

This paper contains a description of some experiments made with the measurement of precipitation at sea. The measurements were carried out on board the ocean weather ship «Polarfront I», stationed at 66° N, 2° E (Station «M») in the Norwegian Sea from the 1st of June 1949. Different experiments have been made, and comparisons have been carried out between gauges exposed in different places on the decks and at different heights above the decks, gauges mounted on gimbals and some not, gauges without, and some equipped with, wind shield and different mountings of the wind shield — always using the same type of gauge and wind shield as the standard types of the Norwegian Meteorological Service. A comparison has also been made with a gauge mounted in a rescue dinghy drifting about 50 metres from the ship.

Further, some statistics about precipitation amount, and precipitation number of occasions, together with wind and sea observations, have been worked out for the period March 1950 to April 1952.

Finally, comparisons have been made between the precipitation amounts measured at ocean station «M» and at some coastal stations in North-Western Norway within two certain periods with corresponding weather conditions at all stations.

1. The Station.

The ocean weather ship «Polarfront I» is a rebuilt corvette (former name «Saxifrage») of 902 ton d.w. Dimensions of the ship: 193 feet from bow to stern, and greatest breadth 33 feet. Height from mean water line to edge of rail forward: 17 feet and amidships: 14 feet. Height from mean water line to roof of wheelhouse: 26 feet, and to roof of balloon shelter: 19 feet. The difference between the highest and lowest water line is about 1½ feet. Fig. 1 shows the relative dimensions of the ship, and fig. 2 a photograph of «Polarfront I» «on duty».

The maximum speed of the ship is about 16 knots, but «on station» the speed usually does not exceed 5 knots. The ship is as a rule drifting athwart the wind direction for more than 22 hours a day (even if wind speed exceeds storm) — usually always with starboard side to windward.

2. Sources of Errors in Measuring Precipitation at Sea and Means to Determine or Reduce the Errors.

Precipitation measurements at sea are subject to the same errors as on land and, in addition, to other errors seldom of consequence ashore. The principal errors are due to:

1. Effects of the wind,
2. Splash or shadowing from objects nearby,
3. Evaporation from the gauge and other small error sources.

Besides this, precipitation measurements at sea are influenced by:

4. A tilted orifice of the gauge,
5. Admixture of sea spray.

1. *Effects of the wind.*

Raindrops, and particularly snow flakes, will to a certain degree, according to their fall velocity, move along the streamlines that pass around, over and under any obstruction, such as a gauge.

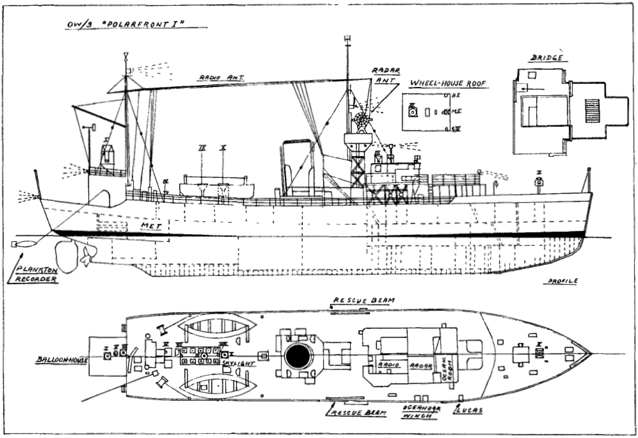

Fig 1.

This, and above all, the movement up the windward side of the gauge, will tend to reduce the number of raindrops (or snowflakes) that will fall into the gauge relative to the number falling on an equal area of the sea surface like that of the gauge orifice. The stronger the wind, the greater will be the difference.

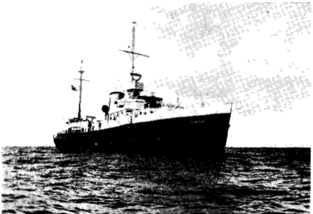

Fig. 2.

Owing to small friction, the wind at sea is somewhat stronger than it is on land stations in general. Fig. 3 shows the number of observations in relation to mean wind speeds (means during the 12 hour period since the last observation) for 686 observations made at station «M» and fig. 4 the relation between the amount of precipitation measured and the wind speed for the same observations (curve A: total precipitation (385 mm) curve B: rain, drizzle (262 mm), curve C: Precipitation in solid form has occurred during the measuring period (123 mm).)

It will be seen that the mean wind speed lies between 4 and 5 BF (measured 30 feet above the sea surface) so that station «M» is, indeed, a very exposed place in comparison with most land stations.

To avoid or reduce the errors caused by the wind diverting some of the catch, several types of wind shield have been constructed.[1] On land

[1] e.g. Nipher's wind shield. The Norwegian type of wind shield, see: Th. Hesselberg: Zur Wirkung des

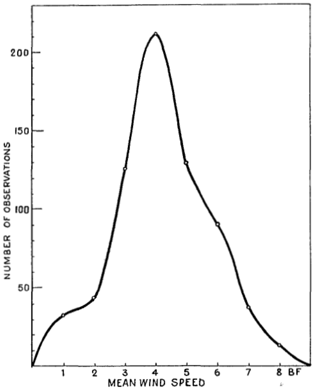

Fig. 3. The relation between number of observations and mean wind speed during the 12 hour periods of observation.

stations the gauges are usually placed low and in protected spots, such as behind hedges or in natural depressions in order to reduce the wind speed near the orifice. On a ship's deck, however, possibilities in that way are very restricted, but are not without importance (See below gauge No. 19 and No. 20).

The effects of upward and downward wind currents are in general that a gauge with a horizontal orifice in the first case will catch less, in the last case more, than what is falling on a horizontal area of equal size of the sea surface. These effects are nearly unavoidable on a ship — and by far the most serious source of error when measuring precipitation on a ship. All other effects may, to a certain degree, be nearly eliminated — or determined.

What is essential in order to reduce the effect of vertical currents to a minimum, is to find a place on the deck and a method of mounting the gauge so that the local wind vector near the gauge orifice is as nearly parallel to the plane through the upper rim of the gauge as possible when the ship is rolling or pitching. The mean vertical wind component can roughly be measured by means of a vertical wind vane — or as done on the «Polarfront I», by means of observing the flow of snow flakes in front of a search-light, and by measuring the height of wet snow accumulated on rods placed perpendicular on the decks at different distances from the rails. A few centimeters above the deck, the wind component is always nearly parallel to the deck, — and at considerable height above the deck (e.g. perhaps about 10 metres above the balloon-house roof) the flow is almost uninfluenced by the ship and the wind vector nearly horizontal. The local wind speed will vary in accordance with the convergence and divergence of the streamlines. Fig. 5 shows the local wind speed measured at three points across the balloon-house roof at three different heights above the roof. (The wind speed is taken as the mean of several periods of the rolling of the ship. Relative wind direction on the starboard beam.)

By two methods of mounting the gauge, parallelism between the local wind vector and the plan

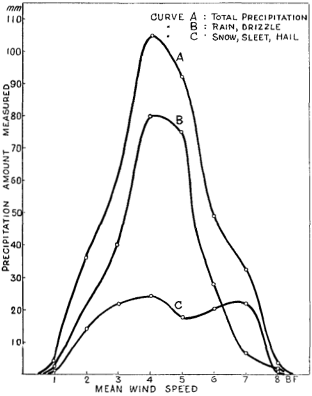

Fig. 4. The relation between amount of precipitation and mean wind speed during the observation periods.

Schirms auf die Niederschlagsmessungen. Met. Ann. BD. 2, NR. 4, Oslo 1945.

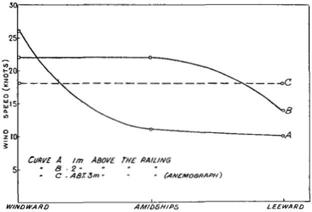

Fig. 5. Local wind speed measured on the balloon-house roof.

through the upper rim of the gauge will probably be almost obtained, viz.:

a. by mounting the gauge on gimbals with compensating shield for wind pressure high enough where the wind vector is nearly horizontal, and,

b. by mounting the gauge low on deck and with orifice parallel to it.

It is, however, impossible to account for the effects of the upward and downward currents because the fall velocity of the raindrops (and snowflakes) will vary with size, and the vertical component of the wind relative to the gauge orifice will vary with the rolling of the ship. In addition, the wind usually is gusty and turbulent. It should also be borne in mind that in a region where the mean wind vector has an upward directed component, less precipitation will fall (reduced to a horizontal plane), than on places where the flow is horizontal owing to the wind carrying the small drops the fall velocity of which is less than the vertical component of the wind, upwards.

Observation of the mean direction and speed of the local wind is difficult and cannot be accurate. Consequently it seems impossible, however, on the basis of wind observations, to decide whether a place on a ship's deck is a better exposure place for a gauge than any other place in the neighbourhood, provided that other conditions are nearly equal. The effects of upward and downward currents can probably only be estimated by comparing the catch of gauges mounted in different places and at different heights above the decks in relation to mean wind speed. This will, by the way, only give relative comparison values. There should accordingly also be carried out comparison with gauges mounted in the vicinity where conditions are independent of the ship. This has really been done at station «M», but only for wind speeds less than 5 BF (see below gauge No. 21).

2. *Splash or shadowing from objects nearby* can easily be minimised, provided that the ship is drifting athwart the wind. On the other hand, when the ship is moving with relative wind from ahead or from astern, shadowing by higher objects such as bridge, masts and rigging may cause considerable errors. This is not of very great importance since the ship drifts more than 22 hours a day on an average.

3. *Evaporation from the gauge and other small error sources.*

Evaporation from the gauge will probably be of the same magnitude as at land stations. The result of 5 measurements (May 1950) gave an evaporation from the gauge of 0,1—0,2 mm a day by relative humidity 80—90 % and wind speed 2—3 BF. Since the mean relative humidity is generally high, this error will be of very little importance.

On account of the generally small precipitation amounts, some special small measuring glasses have been used. The measuring glass is placed on a table mounted on gimbals and read off with dim light from behind (fig. 6).

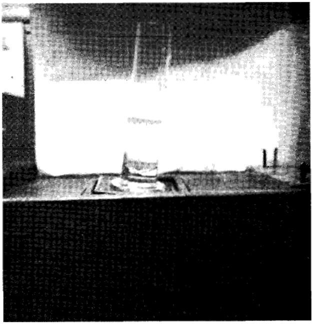

Fig. 6.

4. *A tilted orifice of the gauge.*

When the gauge is firm on the ship, the rolling of the ship prevents the orifice of the gauge from maintaining a horizontal position. If the deviation angle (φ) from the horizontal position is known at all times, correction for reducing the precipitation amount to the horizontal plane can be computed (correction factor $k = \frac{1}{\cos\varphi}$).

Fig. 7 shows a registrating clinometer and fig. 8 the diagram where the angle φ_{max} can be measured from the central line. φ can also be read off

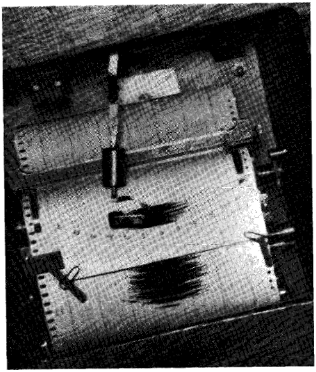

Fig. 7.

on a transparent scale. The weight with the registrating pen moves in the plane transverse of the ship.

It will be seen from the diagram (fig. 8) that the angle φ_{max} has very variable values owing to the great amplitude variation of the rolling of the ship, yet one may compute the approximate average value of φ_{max} at any time.

The profile of the sea waves is approximately a trochoide on condition that the waves do not break. When the gauge orifice is always parallel to the surface of the waves which e.g. approximately is the fall when the gauge is mounted in the dinghy (gauge No. 21) φ is the angle between the tangent to the trochoide and the horizontal axis along the propagation direction of the waves. However, the trochoide does not deviate much from a sine curve — moreover, the sea wave profile usually consists of a complex system of many

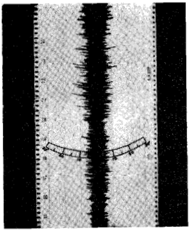

Fig. 8.

waves. The result is usually neither a trochoide nor a sine curve; but to form an idea about the magnitude of the correction factor (k), one may, however, simplify the problem and look upon the wave profile as a sine curve $y = a \sin x$ with amplitude and wave length equal to the average sea wave amplitude and wave length.

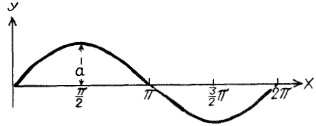

Fig. 9.

Thus

$$\frac{a}{2\pi} = \frac{\frac{h}{2}}{l}$$

or

$$a = \frac{\pi h}{l}$$

where l is the wave length and h is the wave height (double amplitude). Usually the period of the waves, not the wave length is observed. The relation between period (P in sec.) and wave length (l in metres) is:

$$l = \frac{g}{2\pi} \cdot P^2$$

hence,

$$a = \frac{2\pi^2 h}{g P^2} \qquad (1)$$

When N is the true amount of precipitation and N_o the amount measured per unit time,

$$N = \frac{N_o}{|\cos\varphi|}$$

where φ is the inclination angle of the gauge. Multiplying with $|\cos\varphi| \cdot dt$, we get

$$N \, |\cos\varphi| \, dt = N_o \, dt$$

and integrated over the time interval T,

$$N \int_o^T |\cos\varphi| \cdot dt = \int_o^T N_o \, dt = M = \text{amount of}$$

precipitation measured during the time interval T. The true amount of precipitation during the time interval T is

$$N\,T = \frac{M}{\frac{1}{T}\int_o^T |\cos\varphi| \cdot dt}$$

or the correction factor

$$k = \frac{1}{\frac{1}{T}\int_o^T |\cos\varphi| \cdot dt} \qquad (2)$$

The equation of the sine curve (fig. 9) is:

$$y = a \sin x$$

Thus

$$\frac{dy}{dx} = tg\,\varphi = a \cos x \qquad (3)$$

or

$$|\cos\varphi| = \frac{1}{\sqrt{1 + a^2 \cos^2 x}} \qquad (4)$$

The propagation speed of the wave is

$$v = \frac{dx}{dt} \qquad (5)$$

Substituting (4) and (5) into Eq. (2), we get

$$k = \frac{1}{\frac{1}{vT}\int_o^T \frac{dx}{\sqrt{1 + a^2 \cos^2 x}}}$$

Regarding the time interval T as the time for the passage of one fourth of a wave length, we get

$$v\,T = \frac{\pi}{2} \quad \text{and}$$

$$k = \frac{1}{\frac{2}{\pi}\int_o^{\frac{\pi}{2}} \frac{dx}{\sqrt{1 + a^2 \cos^2 x}}}$$

which may be written

$$k = \frac{1}{\frac{1}{\sqrt{1+a^2}}\frac{2}{\pi}\int_o^{\frac{\pi}{2}} \frac{dx}{\sqrt{1 - \frac{a^2}{1+a^2}\sin^2 x}}} = \frac{1}{\frac{1}{\sqrt{1+a^2}}\frac{2}{\pi} \cdot K} \qquad (6)$$

The expression

$$K = \int_o^{\frac{\pi}{2}} \frac{dx}{\sqrt{1 - \frac{a^2}{1+a^2}\sin^2 x}} \text{ is an elliptical}$$

integral of the first order. Using the tabulated values of K with $\varphi = \text{arc} \sin \sqrt{\frac{a^2}{1+a^2}}$ as argument, the correction factor (k) can be computed for every actual wave height (h) and wave period (P) by substituting Eq(1) into (6). Fig. 10 shows the relation between k, h and P.

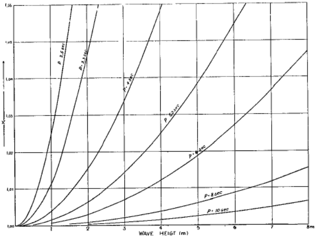

Fig. 10.

When the gauge is mounted firm to the ship the inclination angle (φ) of the gauge can be measured by means of the clinometer (fig. 7). The amplitude (a) is given by Eq. (3):

$$\left(\frac{dy}{dx}\right)_{max} = tg\,\varphi_{max} = (a \cos x)_{max} = a \qquad (7)$$

Substituting $a = tg\,\varphi_{max}$ into Eq. (6), we get:

$$k = \frac{1}{\cos \varphi_{max} \dfrac{2}{\pi} \displaystyle\int_0^{\frac{\pi}{2}} \frac{dx}{\sqrt{1 - \sin^2 \varphi_{max} \sin^2 x}}} \qquad (8)$$

Eq. (8) can be evaluated in the same way as Eq, (6). Fig. 11 shows the relation between k and φ_{max}

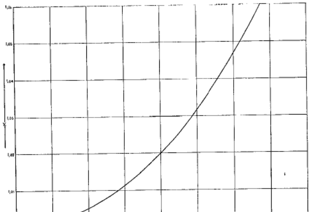

Fig. 11. The relation between the correction factor (k) and the average greatest rolling angle of the ship (φ_{max}).

In reality this correction (or error if not corrected) plays a very little part compared with other errors, e.g. the effects of the wind on the catch. It should therefore not be considered as important to measure the angle φ_{max} There is no simple relationship between the rolling of the ship and the wave height or the wind speed — it depends on both together with the characteristic frequency of the ship itself. Furthermore, the rolling of the ship is to a high degree dependent on the angle between wind and wave direction. — For high wind speed, the wind pressure will act as a damper on the movement of the ship. Fig. 12 shows a diagram where the observed average max. rolling angle of the ship (φ_{max}) is plotted in relation to the observed wave height (code). There is in fact

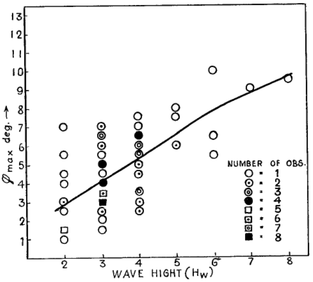

Fig. 12. The relation between observed wave height (code) and the average greatest rolling angle of the ship (φ_{max}).

great dispersion between the points — but in this connection it seems, however, to be sufficient to count with the curve through the means — or, in practice, to observe the wave height, and take the angle φ_{max} from the diagram (fig. 12).

It happens very seldom that this correction exceeds 0,1 mm because of the general small amounts of precipitation measured at station «M».

When the gauge is mounted on gimbals, the orifice will maintain a horizontal position provided that the wind speed is low. The wind pressure on the gauge and its suspension will, however, cause the orifice to deviate from the horizontal position when the wind speed is high — particularly when a wind shield is mounted on gimbals firm to the gauge. In order to compensate the wind pressure on the shield, the following arrangements have been tried:

a) Wind shield mounted firm to the gauge above the plane through the gimbal bolts (see below gauge No. 4). A compensating shield was fas-

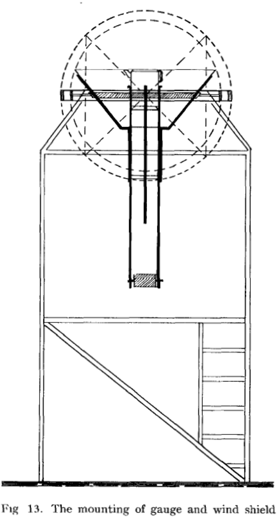

Fig 13. The mounting of gauge and wind shield (Gauge No. 20).

tened to the suspension below this plane in such a way that the wind pressure momentum with respect to the axis in every actual position of the suspension should be equal for both upper and lower shield, provided that the local wind speed is equal at both shields. — This construction appeared to be useless in practice because of the variation of the wind pressure on both shields, causing the

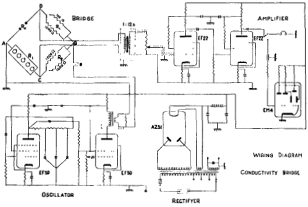

Fig. 14.

suspension to be put in heavy vibration and it broke down already with a wind speed less than 6 BF.

b) Wind shield firm to the gauge. The gimbal bolts fastened to the shield with a conical ring at such a height that the wind pressure momentum with respect to the axis of rotation should be equal above and below this axis in any actual angle position of the suspension (gauge No. 12 and No. 20. See fig. 13). This arrangement of gauge and wind shield proved to be quite good. The orifice of the gauge remained nearly horizontal even in storm and heavy rolling of the ship.

The rim of the gauge was always mounted level with the upper edge of the wind shield.

5. *Admixture of sea spray.*

The amount of sea water which will fall into the gauge on account of sea spray can be determined, when

1. the salinity of the total catch (s $^0/_{00}$)
2. the salinity of the local sea water (S $^0/_{00}$)
3. the total catch (measured mm)

are known.

There are many methods of determining the salinity (defined by $S = 0{,}03 + 1.805\ Cl$, where Cl is the weight of chlorine in gr. per kg. water):

1. Chlorine titration
2. Hydrometer method
3. Refraction of light
4. Electrolytical conductivity measurement (in relation to temperature).

The first and the last method have been used on the «Polarfront I». A special conductivity bridge has been constructed for this use:

(See wiring diagram fig. 14, and photograph fig. 15. Manufactured by C. Dahm, Bergen).

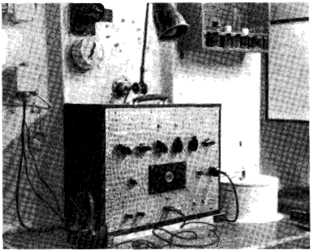

Fig 15 The conductivity bridge.

In a Wheatstones a.c.-bridge with rectifyer the resistance in an electrolytical cell (R_x) which is filled with water from the gauge, is measured by comparison with a variable resistance (R_v) and two fixed resistances R_1 and R_2 (both 100 or 1 000 Ohm), connected to each branch of the bridge. The variable resistance (R_v) consists of 5 decades with each unit resistance respectively 1000, 100, 10 1, and 1/10 Ohm, — as far as possible inductionless. The points A and B are fed with sine-formed a.c. power of 800 cycles from the oscillator. An amplifier, which acts selectively upon the chosen frequency, is connected over the bridge (point C and D). As indicator a telephone or magic eye (EM 4) has been used.

When R_v is adjusted to minimum current through the bridge,

$$R_x = R_v \cdot \frac{R_1}{R_2}$$

$$\text{or } R_x = R_v \text{ when } R_1 = R_2$$

provided that the phase difference between C and D is zero.

The conductivity cell (type Phillips GM 4221, — see fig. 16) has platinum electrodes coated with «platinum black» to prevent polarisation. The cell constant is abt. 1,50.

From the mixture of rain and sea water the electrolytical resistance of which is to be determined, about 5 ml is put into a glass with inner diameter about 2 mm larger than the diameter of the cell. The cell is put into the glass and connected to the bridge by shielded wire, and the glass is placed into a water bath. The water container is made double in order to attain good thermal insulation, and equipped with a thermometer and a stirring arrangement (see fig. 17).

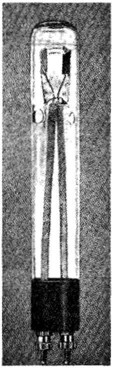

Fig. 16.
The conductivity cell

Provided there is a temperature difference of say 15° C between the water bath and the water in the cell, it takes 10—12 minutes for the temperature gradient to be even.

The bridge was calibrated by means of samples of water with known salinity (determined by chlorine titration with an accuracy of ± 0.02 ‰) — and for four temperatures, viz., 15, 20, 25 and 30° C. Since the relation between temperature and conductivity for constant salinity is nearly linear, the conductivity was first determined for the exact temperatures 15, 20, 25 and 30° C, and the inverse values (resistance) for each temperature plotted against salinity on a diagram (fig. 18). As the actual resistance values by precipitation measurements may vary from about 13 Ohm to about 1000

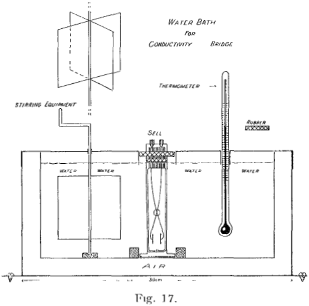

Fig. 17.

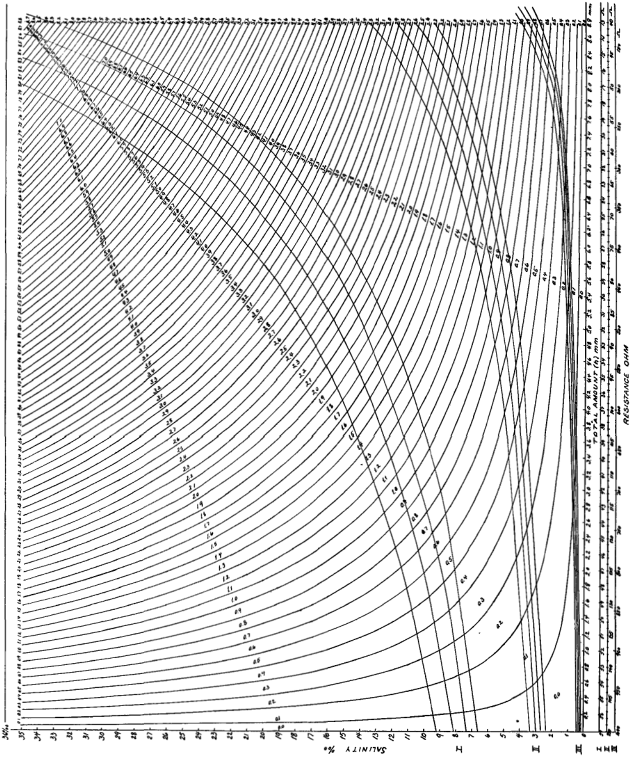

DIAGRAM FOR DETERMINATION OF AMOUNT OF SEA·WATER SPRAY (h_S mm)

Fig. 18.

Ohm (for larger values the correction for admixture of sea water $h_s = o$), three sets of curves are plotted on the diagram: the first from 13 to 57 Ohm, the second from 40 to 150 Ohm and the third set from 150 to 1000 Ohm, — in order to raise the accuracy of the readings. For temperatures between 15, 20, 25 and 30° C should be interpolated between the curves.

The bridge is constructed for an accuracy of $\pm$ 0.1 Ohm up to a resistance of say 500 Ohm, from where the limits of accuracy are somewhat less. The current through the cell will warm the solution in the cell, but since the temperature in the cell is always lower than that of the water bath, these two errors will tend to counteract each other. When the cell is connected to the bridge, it takes, however, less than half a minute to set the instrument right and to read it off.

Provided that the temperature of the catch is determined with an accuracy of $\pm$ 0.5° C, the accuracy of the determination of salinity by means of the bridge is calculated to be:

Salinity	Max. error			
0 — 7.5 ‰	less than	0.1 ‰		
7.5—13.2 ‰	between	0.1	and	0.2 ‰
13.2—18.2 ‰	»	0.2	»	0.3 ‰
18.2—25.5 ‰	»	0.3	»	0.4 ‰
25.5—abt. 28 ‰	»	0.4	»	0.5 ‰
35 ‰ (or pure sea water)	about			0.7 ‰

In order to determine how much sea water is mixed with the precipitation when the salinity (s) of the mixture is known, the salinity of the sea water is set constant = 35 ‰, and its density also constant = 1.03.

Hence
$$h_s = \frac{h}{(35/s - 1)\,1.03 + 1}$$

where h_s is the amount of sea water and h = total catch (mm). h_s as a function of h and s is also plotted on the diagram (fig. 18) for every second 0.05 mm-value of h_s. The value h_s is read off between these curves.

The hydrographical measurements of the surface sea water salinity at station «M» have stated that there are very small variations from an average value of 35.176 ‰ (calculated on the basis of measurements made about every second day from 1948 to 1951). The greatest deviation from this mean was 0.70 ‰.

When putting S = 35.2 ‰ and the density of sea water at 20° C = 1.0252 instead of 1.03, the error in h_s will exceed 0.1 mm when h = 33.3 mm and $s > 25$ ‰. This happens only when the gauge is nearly filled with sea water in a storm. Under such conditions other errors mentioned above will probably be of much greater magnitude, but it follows, however,that a gauge should be exposed at a place which in degree is protected against direct spray from the sea without being shadowed by higher objects.

The conductivity bridge has been used on «Polarfront I» from November 1951. From observations made before, samples were brought ashore and the salinity determined by means of chlorine titration.

The observations made at station «M» have shown that the salinity in the catch may vary within great limits i.e. from less than 0.20 ‰ to considerably more than 35 ‰, or more than the salinity of the sea water (maximum 42.2 ‰). This is possibly due to deposition of salt at different places, rigging, masts., etc. during storms. This circumstance makes the determination of admixed sea water in the catch less accurate, — i. e., in general, overrated.

The diagrams fig. 19a and fig. 19b show a relation between the mixing ratio (sea water: total catch in per cent) and the observed average wind speed. As evident from these curves, the admixed sea water increases with wind speed. From a certain point the curves bend rapidly upward, which probably suggests that spray from the sea is reaching the gauge directly when the wind speed exceeds this value. Fig. 19a represents a gauge on the foredeck (gauge No. 9), — and fig. 19b a gauge mounted on the lifeboat-deck more protected against direct spray from the sea (gauge No. 20).

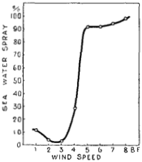

Fig. 19 a. Gauge No. 9.

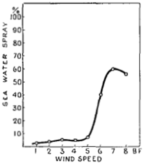

Fig. 19 b. Gauge No. 20.

The relation between sea water spray (in per cent of the total catch) and mean wind speed during the obervation periods.

3. Apparatus, Technical Data and Periods of Measurements.

The first rain gauge was mounted on board the weather ship «Polarfront I» on the 1st of June 1949. Comparative measurements have been made from the 1st of January 1950 — at first with 2, later with 3 and 6 gauges at the same time, mounted at different places on the ship.

The list below comprises places of exposure, some technical data regarding the mounting of gauge and wind shield, and periods of measurements. «Exposure No.» relates to fig. 1 (Roman numerals).

Gauge No.	Exposure		Technical data	Period of measurement	Fig No
	Place	No			
1	Roof of Balloon-house.	I	Gauge mounted on gimbals without wind shield. Height above the deck 1 70 m (8.10 m above sea surface).	1949: June + Aug + Sept + Nov. 1950: Jan. + March	20
2	»	I	Gauge mounted on gimbals without wind shield, — 2.95 m above the deck (9 35 m above sea surface)	1950 May + 13th to 30th Sept	21
3	»	I	Gauge mounted on gimbals. Wind shield firm to the frame Height above the deck 3.05 m (9 45 m above sea surface).	1950: July + 1st to 13th Sept.	No
4	»	I	Wind shield fastened to the gauge mounted on gimbals with rim 0.40 m above the gimbal bolts. (A compensating shield mounted on the suspension below the gimbal bolts.) Height above the deck 3.20 m (9.60 m above sea surface).	1950. 15th to 30th Oct. + Dec.	22
5	»	I	Wind shield and gauge mounted on gimbals with rim 3 cm above the gimbal bolts Height above the deck 2.90 m (9.30 m above sea surface).	1951: Feb + April + June	23
6	»	IV	Same as gauge No. 5. Height above the deck 1.02 m (7 42 m above sea surface).	1951: Aug. + 1st to 15th Oct	24
7	»	V	Gauge mounted firm to the ship without wind shield 1.80 m above the deck (8 20 m above sea surface)	1951. April	No
8	»	VI	Gauge mounted on gimbals without wind shield. Height above the deck 0.80 m (7 20 m above sea surface)	1951. April	No
9	Foredeck 6 5 m from bow	II	Gauge mounted on gimbals without wind shield with orifice 2.15 m above the deck (7.05 m above sea surface).	1950: Jan + March + May + Sept + 15th to 30th Oct. + Dec. 1951: Feb.	25
10	»	II	Wind shield tight to outer gimbal ring. Height of the gauge above the deck 2.25 m (7.15 m above sea surface)	1950. July	No.
11	Roof of Wheel-house	III	Gauge mounted on gimbals without wind shield. Height above the deck 0.90 m (9.90 m above sea surface).	1950: March + May + July + Sept. + 15th to 30th Oct. + Dec 1951: Feb. + April	26
12	»	III	Gauge and wind shield mounted on gimbals with rim 8 8 m above the gimbal bolts. Height above the deck 0.85 m (9.85 m above sea surface).	1951: June + Aug. + 1st to 15th Oct + Nov	27
13	»	BI	Gauge placed on the deck without wind shield.	1950: Sept + 15th to 30th Oct. + Dec.	28

Gauge No.	Exposure		Technical data	Period of measurement	Fig. No.
	Place	No.			
14	Roof of Wheel-house	MII	Same as gauge No. 13	1950: Sept + 15th to 30th Oct + Dec.	28
15	»	SIII	Same as gauge No. 13	—»—	28
16	Lifeboat deck abaft of the skylight.	IV	Gauge mounted firm to the ship without wind shield. Height above the deck 1.10 m (5.60 m above sea surface).	1951. 19th to 27th Feb. + 19th to 30th April	No
17	Lifeboat deck above the skylight	VII	Same as gauge No. 16. Height above the deck 1.65 m (6.15 m above sea surface).	1951: June	No.
18	»	VIII	Same as gauge No 17.	—»—	No
19	»	IX	Gauge and wind shield mounted firm to the ship (like the standard arrangement for land station.) Orifice even with upper edge of lifeboat shelter 2.46 m above the deck (6 96 m above sea surface).	1951: Aug. + 1st to 15h Oct. + Nov. 1952: Jan. + March	29
20	Lifeboat deck ahead of the skylight.	X	Gauge and wind shield mounted on gimbals with orifice 8.8 cm above the gimbal bolts in the same plane as gauge No. 19.	—»—	29
21			The gauge mounted in a rescue dinghy with orifice about 18 cm above the sea surface. Dimensions of the dinghy: Length 1.37 m, breath 0.80 m. Weight with frame and gauge: 18 5 kg. Upper edge of the rubber ring abt. 3 cm above the gauge orifice.	1951: From Aug	30

4. Results of Measurements and Discussion of the Different Exposure Arrangements Based on Comparisons.

The comparisons below refer to 1380 observations where the precipitation heights have been measurable ($\geqq$ 0.1 mm). Further comparison between gauge No. 19 and No. 20 has been continued from March 1952 and is still going on.

The observations are usually made twice a dav (at 06 and 18 G.M.T.) and comprise the following items:

1. Total catch (mm).
2. Result of titration (s ‰ or R Ohm)
3. Amount of precipitation (corrected) (mm)
4. Weather observations:
   a. Past weather during the period of observation
   b. Precipitation form
   c. Mean wind speed during the observation period
   d. Max. wind speed during the observation period
   e. Mean wave height during the observation period
   f. Observed sea spray
5. Relative wind direction in proportion to the ship during the period of observation.
6. Movements of the ship during the period of observation.

The «Normal» (gauge No. 21).

On land stations one may procure a «normal» by placing a gauge in a crater with orifice parallel to the slope, multiplying the catch by the cosecant of the angle the orifice makes with the horizontal.

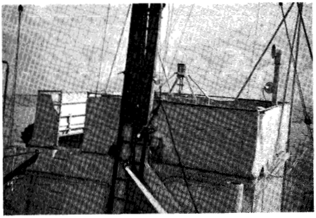

Fig. 20. Gauge No. 1.

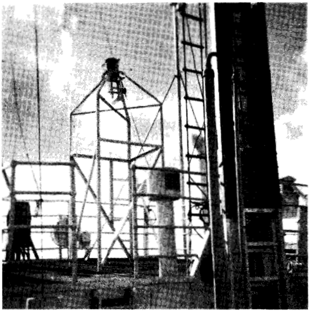

Fig 21. Gauge No. 2.

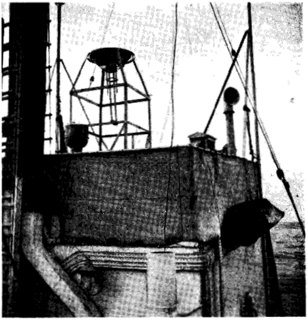

Fig. 23. Gauge No. 5.

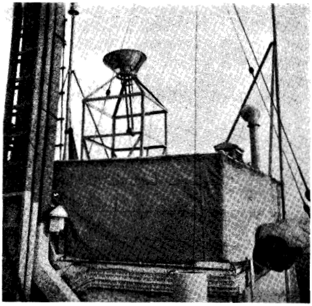

Fig. 22. Gauge No. 4.

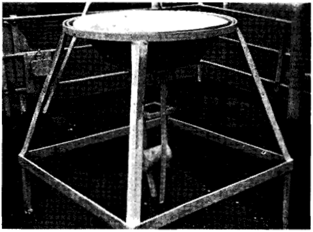

Fig. 24. Gauge No. 6.

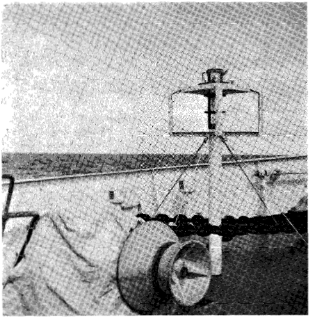

Fig. 25. Gauge No. 9.

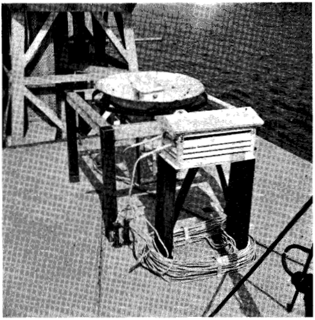

Fig. 27. Gauge No. 12.

Fig. 26. Gauge No. 11.

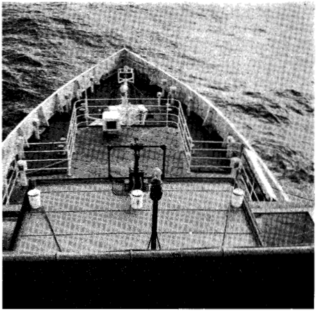

Fig. 28. Gauge Nos. 13, 14 and 15.

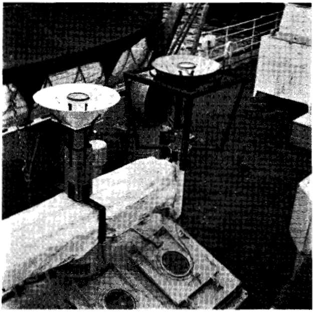

Fig 29. Gauge Nos. 19 and 20.

Fig. 31. The dinghy is hauled in.

On the weather ship one has tried to make a similar «normal» by placing the gauge in a rescue dinghy drifting about 50 metres to the windward side of the ship. The dinghy is made of a rubber ring and rubber bottom. The gauge was placed in a wooden frame mounted in the dinghy. When precipitation measurements were to be taken, the dinghy was hauled in (see fig. 31).

On account of spray from the sea the dinghy could only be used when the wind speed was less than 5 BF, and naturally the periods of observations could not be bound to synoptical observation hours. The other gauges on board the ship were exposed simultanously.

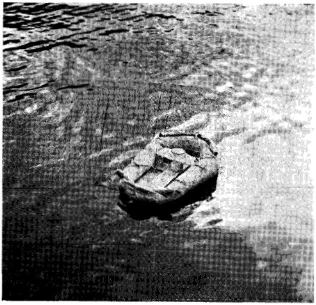

Fig. 30 Gauge No. 21.

The «Sub-normals» (gauge No. 11 (III) and No. 12·(III)).

These gauges were kept unchanged during long periods to serve as preliminary «normals» by comparisons with other gauges. The exposure of the gauges was by no means ideal, but they proved to catch more than the others (except the gauges mounted on the life-boat deck). Generally, on the wheel-house roof no splash or interception of the precipitation, by higher objects nearby (except when the relative wind is from astern) will occur. The height of the wheel-house roof is about 2.5 metres above the bridge platform which is surrounded by a railing equipped with a wind shield reaching 1.50 metres above the deck. This will to some extend reduce the upward component of the wind and probably also the local wind speed at some height above the roof near the gauge orifice when the relative wind is abeam.

Since the effects of the wind are by far the most serious sources of error when measuring precipitation on a ship, the amounts of precipitation caught by the different gauges have been grouped in accordance with the wind speed observed during the periods of observation, and the differences represented grafically (in per cent of the precipitation measured simultaneously by the «Normal» or the «Sub-normals») in relation to mean wind speed during the same 12 hour periods of observation.

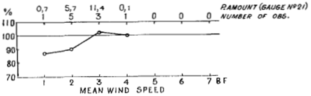

Fig 32. Comparison of gauge No 21 with gauge No 12.

Comparison of the «Sub-normal» (gauge No. 12 (III)) with the «Normal» (gauge No. 21).

Fig. 32 shows a comparison between the two gauges. The numbers above give the amount of precipitation measured by gauge No. 21, and the second row, the number of observations.

It will be seen from the diagram that the differences are very small (mean 2.2 %) and there is no systematical dependence between the wind speed and the catch. Since gauge No. 21 could only be exposed by a wind speed less than 5 BF and the number of observations hitherto are very few (10), most of them taken by wind speed 2 and 3 BF, one cannot expect the effect of the wind to be very prominent. — Total amount of precipitation gauge No. 21: 17.9 mm, — gauge No. 12: 17.5 mm. Total mean wind speed: 2.4 BF.

A. Observation place: Balloon-house roof (I, V and VI).

Results of measurements.

Gauge No.	Precip. measured (corrected) mm	Precip. measured gauge No. 11 mm	Catch in per cent of gauge No.11			Number of obs.	Mean wind speed BF	Remarks
			Total	Rain	Snow, sleet, etc			
1	23.7	36 0	65 8	57.9	80 8	35	5.0	
2	51.2	61.9	82.7	82.6	83.8	44	4.0	
3	15 0	18.4	81.5	81.5	—	17	3 6	
4	23.0	39.2	58 7	65 2	49 1	48	4.4	
5	34 9	52.6	66.3	53.8	69.5	79	4 2	1951: Feb.+Apr.
5	4.6	4.9[1]	93.9[1]	—	—	17	3 2	1951. June
6	34 7	48.5[1]	71 5[1]	—	—	42	3.8	
7	12.9	29.3	44.0	—	—	38	4.8	
8	23.9	29 3	81 6	—	—	38	4.8	

[1]) Gauge No. 12 (III).

Gauge No. 1. (I).

Fig. 33 curve A shows a comparison between the catch of gauge No. 11 and Gauge No. 1 (total precipitation). It is evident from this diagram that the difference between the catch of the two gauges increases with increasing wind speed. Gauge No. 1 is placed in an upward wind current, and the stronger the wind, the fewer the raindrops which will fall into the gauge (Similar curves for precipitation only in liquid form (rain, drizzle) and in solid form (snow, hail, sleet) have given the approximately same features, and are omitted here)

Gauge No. 2. (I).

Higher up above the balloon-house roof the mean stream-lines of the flow will turn more and more horizontally, but at the same time the local wind speed near the gauge orifice will in general become stronger (except when the gauge is placed low near the railings on the weather side where there is a marked convergence in the flow). Fig. 33 curve B shows the catch of gauge No. 2 in relation to gauge No. 11: The effect of the wind is somewhat greater for low but smaller for high wind speed than in the first case (gauge No. 1).

Gauge No. 3. (I).

(See fig. 33 curve C). The wind shield which in this case is firm to the frame, will shadow the gauge when the ship rolls to the leeward side — analogous with a gauge with wind shield mounted vertically on the windward side of a slope at land stations.

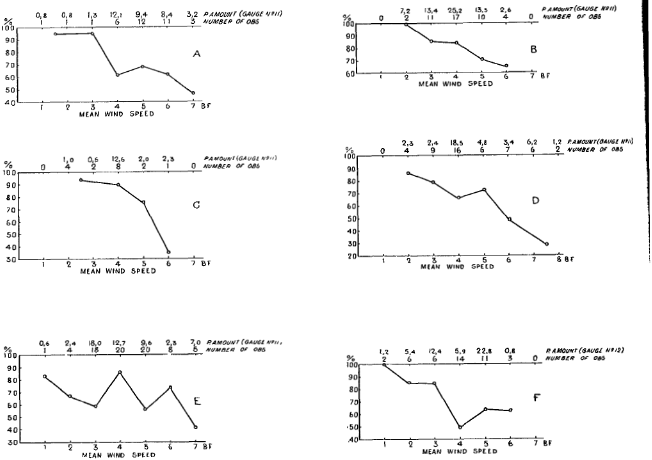

Fig. 33. Comparison of gauge No. 11 with gauge No. 12.

Gauge No. 4. (I).

(See fig. 33, curve D). On account of the wind pressure on the wind shield (the compensating shield had to be dropped after a short time), the shadowing effect of the shield opposite the gauge will probably be greater than in the former case (gauge No. 3). Besides this, both shield and gauge are on the average tilted with orifice turned off from the wind and the relative fall direction of the raindrops.

Gauge No. 5. (I).

(See fig. 33, curve E). In this case both wind shield and gauge are on the average turned against the wind due to the wind pressure on the shield. Most of the precipitation occurred in the form of snow or hail (abt. 80 %). It is likely that some of the snow will blow out of the gauge (snow-receiver) again when the ship rolls against the wind when the sea runs high.

From June 1951 the comparisons have been done with a gauge equipped with wind shield (gauge No. 12 (III)). During this month, gauge No. 5 caught 93.9 % of gauge No. 12, but the amount of precipitation was only 4.9 mm.

Gauge No. 6. (IV).

(See fig. 33, curve F). The gauge with wind shield was placed low on deck with orifice at the same height as the railing which was covered with canvas. The railing will have the similar effect as of a huge shield, but between the catch of this gauge and gauge No. 12 (III) there is, however, a marked difference, increasing with wind speed.

Gauge No. 5 (I), gauge No. 7 (V) and gauge No. 8 (VI).

Finally a comparison has been made between the catch of gauge No. 11 and 3 gauges mounted on the balloon-house roof at different heights

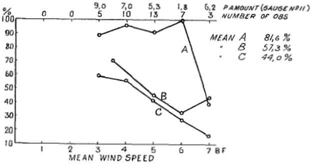

Fig. 34. Comparison of gauge No. 11 with gauge No. 8 (Curve A), gauge No. 5 (Curve B) and gauge No. 7 (Curve C).

above the deck. Fig. 34 shows the result where curve A represents gauge No. 8, curve B gauge No. 5 and curve C gauge No. 7.

Further fig. 35 shows the catch expressed in per cent of the catch of gauge No. 11 in relation to the height of the gauges above the deck (gauge Nos. 1, 2, 7 and 8). The gauges were unshielded. The curve has a minimum at a certain height above the deck, probably due to convergence of the stream lines and a maximum vertical component of the local wind (see fig. 5).

From these comparisons it should be evident that the balloon-house roof at any height above the deck (up to 3 metres) is a bad place for a rain gauge, which, however, accords very well with the experience made with roof exposures on land stations.

When the ship is rolling, the local wind speed near the gauge will increase and decrease periodically, and to a higher degree the higher the gauge is mounted above the deck. On account of this and because of the difficulties which would be

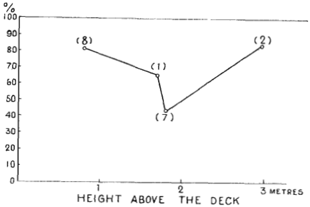

Fig. 35. The relation between the catch of gauge Nos. 1, 2, 7 and 8 (in per cent of the catch of gauge No. 11) and the height of the gauges above the deck.

combined with the emptying of the gauge in a storm, a higher mounting of the gauge has hitherto not been tried.

B. Observation place: Fore deck. (II).

Results of measurements

Gauge No.	Precip. measured (cor.) mm	Precip. measured gauge No 11	Catch in per cent of gauge No. 11 Total	Rain	Snow etc.	Number of obs.	Mean wind speed BF
9	128.0	157.5	81.3	83.9	75.9	166	4.3
10	6.1	9.5	64.2	—	—	11	3.3

Gauge No. 9. (II).

Fig. 36 shows a marked decrease in the percentage catch of gauge No. 9 with increasing wind speed in relation to gauge No. 11. — A gauge on the foredeck is much exposed to sea spray, particularly when the ship moves against the waves. The mean salinity of all measurements was 27.3 ‰ i. e. the gauge caught about 78 % sea water.

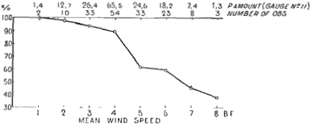

Fig. 36. Comparison of gauge No. 11 with gauge No. 9.

Gauge No. 10. (II).

The relative catch of this gauge in proportion to gauge No. 11 was less than the former, probably on account of the shadowing effect of the wind shield (analogous with gauge No. 4).

C. Observation place: Wheel-house roof (B I, M II, S III).

Results of measurements.

Gauge No.	Precip. measured (cor.) mm	Precip. measured gauge No. 11	Catch in per cent of gauge No. 11 Total	Rain	Snow etc.	Number of obs	Mean wind speed BF
13	72.3	78.3	92.3	—	—	48	4.1
14	72.3	78.3	92.3	—	—	48	4.1
15	59.1	78.3	75 5	—	—	48	4 1

These measurements were made with the intention of ascertaining how great an influence the effect of the wind would have on the catch of gauges mounted low on deck along a cross-line of the ship, and of making a comparison of gauge No. 11 with a gauge nearby (gauge No. 14) placed as low on deck as possible.

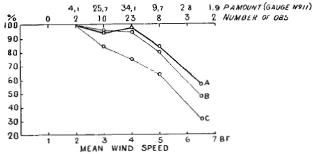

Fig. 37. Comparison of gauge Nos. 13, 14 and 15 with gauge No. 11.

Fig. 37 represents the catch of the three gauges Nos. 13, 14 and 15 expressed in per cent of the simultaneous catch of gauge No. 11 in relation to mean wind speed. (Curve A: gauge No. 13, curve B: gauge No. 14 and curve C: gauge No. 15). About 30 % of the precipitation occurred in the form of snow or hail. Result: The catch decreases from leeward to windward side, and more rapidly the stronger the wind. From leeward (gauge No. 13) to midships (gauge No. 14) there is no marked difference.

Expressed in statistical terms, taking the amounts measured during periods of half a month and grouped in accordance with mean wind speed:

Mean wind speed	Mean amount measured Gauge No 13 in per cent of gauge No. 14	Standard deviation %	Degrees of freedom	Feducial intervals t_{o5}
2	100		0	
3	108	15.0	4	89.4—126.6%
4	96	8.9	4	84.9—107.1%
5	106	14.2	2	69.7—142.3%

For all groups the gauges Nos. 13 and 14 are likely to catch approximately the same amount.

A similar comparison of gauge No. 11 with gauge No. 14 (M II) (1.80 m ahead of gauge No. 11) gives:

Mean wind speed	Mean amount measured Gauge No 14 in per cent of gauge No. 11	Standard deviation %	Degrees of freedom	Feducial intervals t_{o5}
2	98		0	
3	85	9.1	2	62.6— 97.4%
4	99	15.6	3	67 9—130.1%
5	96	39.7	2	0 —194.5%

The percentage dispersion is great, probably due to the different exposure of the gauges: When the ship rolls to the windward side, the orifice of gauge No. 14 will turn against the wind, while the orifice of gauge No. 11 will remain nearly horizontal or turned off from the local wind near the deck. When the ship rolls to the leeward side, the opposite will be the case. The relative wind speed near the orifices is greater in the first case than in the latter. The gauges were not equipped with wind shields.

D. Observation place: Lifeboat deck (IV, VII, VIII, IX and X).

A gauge mounted on a ship's deck has much in common with a gauge exposed on a roof of a house ashore. In general roof exposures are considered bad, except when the roof has approximately the same height as the surrounding buildings, and the gauge is placed at some distance from the edges. A wide cornice would serve as a huge shield, favouring the catch in strong winds.[1]

Something like that one may consider the lifeboat deck abaft of the bridge. The ship has here her maximum breadth (33 feet) and the lowest point on the deck above the water line (3.5 meter). The rails and lifeboats will serve as something like a cornice on a house, when the ship is drifting athwart the wind. When the ship moves against the wind or with relative wind direction less than 10—15° on each side of the bow, the gauge will be shadowed by the bridge and the funnel, or at some distance abaft these obstructions, probably influenced by the lee effect. This happens only occasionally when the ship moves back to her

[1] C. F Brooks: Needs for Universal Standards for Measuring Precipitation, Snowfall and Snowcover. Riga 1938, page 4

fixed position, and a few minutes four times a day when the sounding balloons are launched.

Gauge No. 16, 17 and 18 were only preliminary experiments (mounted firm to the ship without wind shields).

Gauge No.	Precip. measured (cor.) mm	Precip. measured gaugeNo.11	Catch in per cent of gauge No. 11	Number of obs.	Mean wind speed BF
16	22.3	17 9	124.6	30	4.8
17	4.6	4 8[1]	95.8[1]	15	3 0
18	4.9	4.8[1]	102.1[1]	15	3.0

[1] Gauge No. 12.

Gauge No. 16 (IV).

This gauge was placed amidships low on deck with the orifice at about the same height as some iron cases, winches etc., on the deck, about 1.40 meter below the upper edge of the lifeboat shelters. 75 % of the precipitation occurred in the form of snow. The catch was probably influënced by eddies caused by the balloon-house abaft of the gauge.

Gauge No. 17 (VII) and No. 18 (VIII)

were fastened to the railing on each end of the skylight, 0.80 meter below upper edge of the lifeboat shelters. All precipitation occurred in the form of rain.

Gauge No. 19 (IX) and No. 20 (X)

were mounted with the orifice level with the upper edge of the lifeboat shelters, symmetrically on each side of a line through the central points of the lifeboats, both equipped with wind shield, gauge No. 19 firm to the ship and gauge No. 20 mounted on gimbals.

Results of measurements.

Gauge No.	Precip measured (cor.) mm	Catch in per cent of gauge No. 20			Number of obs.	Mean wind speed BF
		Total	Rain	Snow etc.		
19	160.4	99.0	101 4	92.5	158	4.7
20	162.0	—	—	—	158	4 7

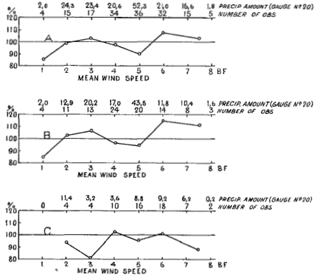

Fig. 38. Comparison of gauge No. 20 with gauge No. 19.

Fig. 38 shows a comparison between the catch of the two gauges in relation to mean wind speed, curve A: total precipitation, curve B: rain, drizzle and curve C: snow, sleet, hail.

As to the differences between the amount measured by the single observations, 86 % of all fell within the interval ± 0.3 mm.

The purpose of these comparisons was also to ascertain whether a gauge mounted on gimbals would catch more or less than a gauge mounted firm to the ship when other conditions are nearly equal. As this would also be influenced by the rolling of the ship, which on the other hand depends on the wave height, a comparison between the catch of the gauges has also been made in relation to the mean wave heights observed during the 12 hours period since the last measurement (see fig. 39). The numbers along the abscissa indicate coded wave height (1: 0.25 to 0.75 metres, 2: 0.75 to 1.25 metres etc.). The diagram shows no systematical dependence between the percentage dif-

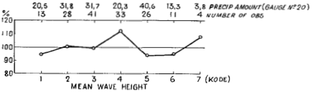

Fig. 39. Comparison of gauge No. 20 with gauge No. 19 in relation to the mean wave height (code) observed during the 12 hour periods of observation.

ference of the catch and the wave height, so one should possibly not consider the mounting of the gauge on gimbals as important. The total difference was 1 %. (These comparisons have been continued and have confirmed the assumption above. See below part 7.)

The catch of gauge No. 20 has also been compared with the amount measured by gauge No. 12 (III) during a period of 2½ months. Results:

Gauge No.	Precip. measured (cor.) mm	Catch in per cent of gauge No. 20	Number of obs.	Mean wind speed BF
12	64.5	78.1	69	3.8
20	82.6	—	69	3.8

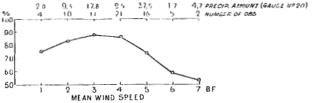

Fig. 40. Comparison of gauge No. 20 with gauge No. 12.

Fig. 40 shows the catch of the gauges in relation to wind speed. Gauge No. 20 caught obviously more than gauge No. 12, especially in strong winds.

Finally fig. 41 shows a comparison of gauge No. 20 with gauge No. 21 (the «Normal»). Gauge No. 20 caught 6.8 % more than gauge No. 21. Mean wind speed was 2.4 BF. The differences between the single measurements were all — except one — within the interval ± 0.2 mm.

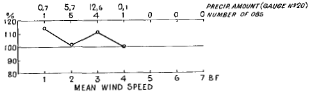

Fig 41. Comparison of gauge No. 20 with gauge No. 21.

5. Summary of Results of Measurements.

The table below gives, column A: Monthly amount of precipitation (from March 1950 to June 1951 measured by gauge No. 11 (III), — from August 1951 to March 1952 by gauge No. 20 (X)), — column B: Number of days when precipitation has occurred (≧ 0.0 mm), — column C: Number of «rain days» (≧ 0.2 mm), — column D: Number of «wet days» (≧ 1.0 mm) — and column E: Number of days when observations have been made.

The next 4 columns represent:

Column F: Mean wind speed for all observation terms during which precipitation has occurred (in BF), — column G: Number of days with maximum wind speed ≧ 6 BF, — column H: Mean wave height (code), — column I: Total number of observation terms (12 hours) during which precipitation has occurred.

In the 3 next columns one has distinguished between: Column J: «Continuous precipitation» (amount), — column K: Showers (amount) and column L: «Continuous preciptation» and showers both observed during the same observation term (amount).

Column M gives the number of days on which showers have been observed.

The most significant feature with this table is obviously the moderate amounts of precipitation (column A) — in comparison with the average amounts on coastal (and also inland) stations in Norway. The total sum of precipitation measured every second month from March 1950 to March 1952 gives for the year: 349.7 mm. In Norway only the inner districts south of Dovre and in Troms and Finnmark have a yearly «normal» precipitation amount less than 350 mm. (The amount of precipitation measured at these stations in 1950 and 1951 differed very little from the normal.)

The average amount of precipitation measured by the single observations appears from column B, C, D and E: The average amount per day was 1.0 mm, while the average amount per day on which precipitation had fallen was 1.2 mm.

The precipitation frequency has on the other hand, in relation to mean values for coastal stations in Norway, been great. From columns B and E it appears that precipitation has been observed 333 days of 378 (or 88 %) on which the ship has been «on station».

The «rain days» (≧ 0.2 mm) comprise 55 % of the total number of days «on station» and 62 % of the total number of days on which precipitation has occurred, i. e. in 38 % of the number of days when precipitation has occurred, the amount has

Period	Measured mm	Number of days				Wind and wave obs.				Measured mm with			Number of days with showers
		$\geqq$0.0 mm	$\geqq$0.2 mm	$\geqq$1.0 mm	«On station»	ff	$\geqq$6BF	H_w	Σ	●	▽	●+▽	
	A	B	C	D	E	F	G	H	I	J	K	L	M
1950													
March	36.0	31	19	11	31	5.0	26		54	17.1	4.2	14.7	22
May	14 9	17	7	4	29	3.8	6		32	12.8	2.1	—	14
July	9.5	21	5	3	31	3.2	1		28	7.8	—	1.7	5
September	68.5	26	18	14	28	4 1	12		38	52.0	10.4	6.1	18
October[1]	15.9	14	8	5	14	3.9	4		23	0.9	3.6	11.4	11
December	23.4	27	20	8	28	4.7	17		51	6.7	10.1	6.6	24
1951													
February	33.1	29	25	12	30	4.4	9		54	8.3	16.7	8.1	27
April	29.5	28	19	6	30	4.8	19		52	12.7	5.1	11.7	24
June	4 9	21	8	1	28	3.3	1		37	1.0	3.0	0.9	15
August	50.6	27	13	7	30	3.4	1	2.4	43	45.1	0.6	4.9	8
October[2]	11 3	9	7	3	13	4.8	9	4.0	14	9.7	0.4	1.2	3
November	20.4	27	12	6	28	4.6	18	3.2	42	8.6	6.8	5.0	23
1952													
January	31.7	27	21	11	28	5.0	25	3.6	47	4.1	15.5	12.1	24
March	35 3	29	25	8	30	5.5	26	4.2	53	28.4	4.6	2.3	19
Total	385.0	333	207	99	378		174		568	215.2	83.1	86.7	237
Mean						4.4		3.4					

[1] 17. to 31. Oct. 1950 [2] 1. to 14. Oct. 1951.

been less than 0.2 mm. On account of this large number of observations by which the amount measured is of nearly the same magnitude as the measuring errors, it should be clear that the comparisons between the catch of the different gauges is to a certain degree less reliable.

«Wet days» ($\geqq$ 1.0 mm) comprise 26 % of all days «on station» and 30 % of the total number of days on which precipitation has occurred. The greatest amount measured on one day was 20.6 mm (August 11th, 1951). A precipitation amount greater than 10 mm a day has only occurred 6 times during the whole period.

Mean wind speed has been computed to about 5 BF during the winter months and somewhat more than 3 BF in the summer. The mean for the whole period was 4.4 BF. A relation between mean wind speed and number of observations is shown graphically in fig. 3.

The number of days on which maximum wind speed has been equal or greater than 6 BF comprises 46 % of all days «on station».

Column H gives the mean wave heights observed (kode). From August 1951 to March 1952 the mean was found to be 3.4 — or about 1.7 metres. From the diagram fig. 12 this corresponds to a mean rolling angle (φ_{max}) of the ship of approximately 5°. (It should be mentioned that this angle has been observed greater than 40° several times.)

On the oceans the precipitation occurs as frontal precipitation or as a result of convection of cold air over warmer water (and to a less degree of drizzle due to cooling of warm air over colder water). Columns J, K and L give the approximate relation between the amount of precipitation observed as «continuous precipitation» and showers. (When both «continuous precipitations» and showers have occurred during an observation term (column L), the amount has been equally divided on each.) Result: 67 % or about 2/3 of the total amount measured has occurred as «continuous precipitation», mostly in connection with passage of fronts. In addition to this, one should probably believe that a great part of the rest (33 %) is due to convecting warm air above colder in connection with cold fronts or occlusions.

Showers have on the other hand occurred rather often at station «M», but they have in general given very small precipitation amounts (column M). Obviously they are more frequent in the winter than during the summer months, since the

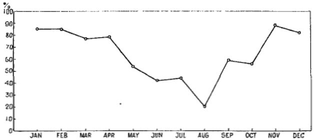

Fig. 42. Number of days on which showers were observed in per cent of total number of days "on station" (March 1950 to March 1952).

most of them occur in connection with advecting cold air from the North. This is made more perspicuous in fig. 42 where the ordinate indicates the frequency (number of days with showers in per cent of total number of days «on station») — and the abcissa the month of the year. Showers have been observed on 63 % of all days «on station». Lightning was observed on September 7th, 1950.

6. Comparisons with Land Stations.

When in harbour (Bergen) a comparison was made (1950) with the precipitation measured at Fredriksberg, a station situated in the middle of the town 43 m above M.S.L. and some 2 km from the mooring place of the weather ship. The results expressed in per cent of the amounts measured at Fredriksberg were:

Gauge No. 2: 115.4 %
« » 9: 112.6 %
» » 11: 105.5 %

Mean wind speed was 2.3 BF, with wind direction varying from S to NNW. — The conditions in harbour are, however, very different indeed, from those at station «M».

The mean pressure charts exhibit on an average high pressure over the Norwegian Sea and low over land (Scandinavia) in the summer, and the opposite during the winter months. The cyclone tracks vary with the seasons, so a comparison between station «M» and a coastal station in Norway for the time observations have been made, would give nothing but a hint of the relative magnitude between climatological data concerning precipitation amount and precipitation frequency etc. For example, the precipitation amount measured at weather station Røst (67° 30' N, 12° 04' E) during the same period as above was 561 mm, and the number of days on which precipitation occurred 197,— i.e. 160 % of the amount measured at station «M» and the quotient between the number of days with precipitation was approximately as 2 : 3. The «normal» (1901—1930) annual precipitation amount for Røst is 713 mm.

One may probably get a better basis of comparison by studying the amounts measured at ocean station «M» and several land stations within certain periods of time with corresponding weather phenomenas at all stations, e.g., during the passage of a marked front system or during a period with showers (outbreak of cold air). Below two examples are briefly discussed:

A. *Front passage.*

Fig. 43a shows a part of the weather chart on September 4th 1950 at 18*h* G.M.T.: From a Low situated over South Iceland an occluded front extends south-eastwards over the Faroe Islands and the North Sea, moving towards the North-East. No precipitation had occurred either at station «M» or at the land stations from Sula fyr (63° 05' N, 08° 28' E) to Andenes (69° 19' N, 16° 07' E) during the last 12 hours.

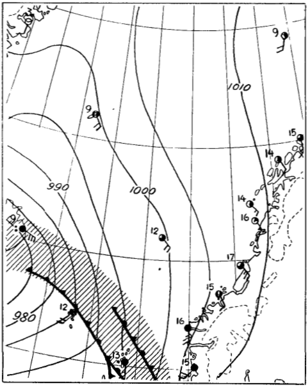

Fig. 43 a.

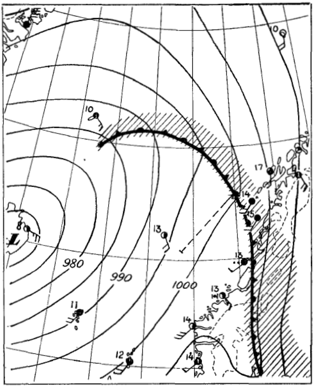

Fig. 43 b.

At 18*h* on the 5th the front has passed station «M» and Sula fyr (Fig. 43b). The Low is quasi-stationary and decreases slowly in intensity. Precipitation has fallen on all stations along the coast of Helgeland south of Skålvær (65° 52′ N, 12° 11′ E) during the last 12 hours. Amount of precipitation measured at station «M»: 3.4 mm.

During the next 24 hours the front is obviously retarded due to greater friction over land. It has turned more parallel to the coast while moving further towards the North-East or East, and at 06*h* on the 7th (fig. 43c) all stations south of Lofoten have been passed by the front. During the next 12 hours no precipitation occurred either at these stations or at station «M».

On fig. 44 the precipitation amounts measured during the period from the 4th at 18*h* to the 7th at 06*h* have been plotted and some smoothed isohyets have been drawn, without taking into account details in the topography causing local variations.

The air-masses which passed station «M» during this period were approximately in thermal equilibrium with the sea, or slightly warmer (mean difference + 0.1° C, max. difference 1.4° C). At Myken (66° 46′ N, 12° 29′ E) the sea temperature was approximately 1° C higher than at station «M».

From the radio soundings at station «M» it appears that the air-masses ahead and behind the front had low relative humidity (app. 70 %) in the lower layers and almost the same temperature distribution from app. 1500 metres to 6000 metres. The lower layers were partly «conditional instable», otherwise the air columns were stable stratified. The sounding (5.IX.03*h*) through the warm mass aloft showed a rise in temperature of 6—9° C from 1500 metres to above 9000 metres, almost stable stratification (except for the layer below 800 m which was conditional instable) and high relative humidity. In spite of slight convective instability in the surface layers, the conditions would probably not be favourable for occurrence of instability showers when the air-masses pass across the sea, and none of the stations concerned observed any Cumulo-nimbus clouds or showers during the period under review.

On the other hand, when these air-masses strike the mountain ridges along the coast of Helgeland and are lifted, instable stratification is likely to occur («Lifting Condensation Level» of the

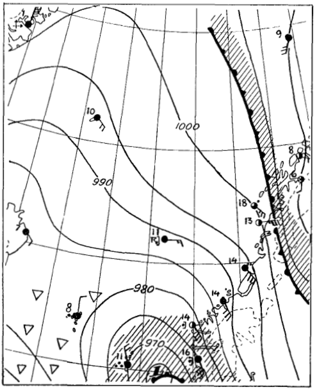

Fig. 43 c.

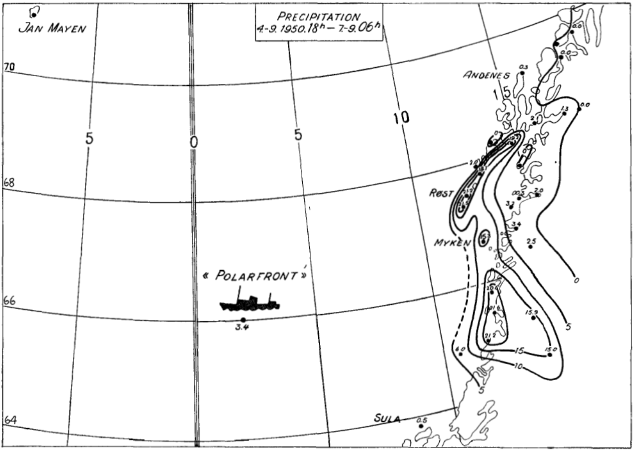

Fig. 44.

surface mass considerably lower than the mean height of the mountains). — One should therefore believe that this and other orographical effects, like retardation of the front with deformation of the frontal surface, are probably in this case due to the almost greatest part of the difference in amount of precipitation measured at station «M» and the stations ashore.

From the precipitation chart fig. 44 it appears that the amount of precipitation measured at station «M» is of the same magnitude as that of the inner fjord districts of Salten and South-Helgeland. The outer coastal districts have got considerably more, and stations situated in the rain shadow of mountains less, or no, precipitation (e.g. Borge (68° 20' N, 13° 53' E)).

B. *Showers.*

Fig. 45a shows the weather situation on April 17th 1951 at 18*h* G.M.T.: A Low of approximately 990 mb in deepening, is situated over Northern Norway, moving slowly towards NNE, effecting a flow of cold maritime arctic air from the North over station «M» and from the North-West over the stations in Lofoten and along the coast of Nordland.

Fig. 45b shows a part of the weather chart at 06*h* on April 21st. The Low is now situated northeast of North Cape, and the deepening has culiminated. During this period the surface wind has blown from the NNE or from the N over Jan Mayen, while at station «M» and the land stations, backing to NW and WNW respectively. The mean surface wind speed remained steady during the period under review: Station «M» 5—6 BF and the coastal stations slightly more. Upper wind over station «M» was steadily blowing from the W or NW with increasing speed towards the end of the period.

The average amount of precipitation per 24 hours of the period is plotted in fig. 46 and some smoothed isohyets are drawn. It should be mentioned that the real distribution of precipitation is certainly far more complicated than this chart shows on account of great local variations caused by the topography.

The main feature of the precipitation chart is maximum zones over Lofoten and the inner districts of Helgeland. Along the outer coastal region the distribution of precipitation was even, about 2 mm or approximately five times the amount measured on the weather ship.

As convective currents are excessively influenced by local conditions near the ground (such as sea or land temperature, obstructions, surface wind speed and wind direction relative to obstructions etc.) and above all depend on the air stability, one might probably by studying another apparent similar weather situation, get another picture of the distribution of precipitation over sea relative to that over land. — But, anyway, the precipitation intensity over sea and especially in shower situation, increases very rapidly in the vicinity of land when moving with the wind towards a high coast. This has been experienced many times on the voyages between station «M» and Bergen (without hitherto being able to prove it by reliable measurements).

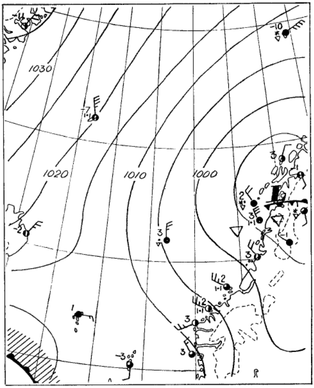

Fig. 45 a.

7. Final Remarks.

Referring to a precipitation chart of A. Supan («Grundzüge der physischen Erdkunde», Leipzig 1903, Taf. XI) concerning the annual precipitation amount on the continents, the Atlantic and the Norwegian Sea, a maximum of more than 2000 mm should be situated at approximately 50° N, 30° W, while the precipitation amount on station «M» is estimated to something between 1000 and 2000 mm per annum, decreasing towards the land (Norway). On the basis of the results of the measurements made at station «M», this seems to be very improbable.

This investigation concerns only measurements made every second month within two years. The measurements have, however, been carried on from March 1952 with two gauges (gauge No. 19 (IX) and 20 (X)), giving a result entered in the table below:

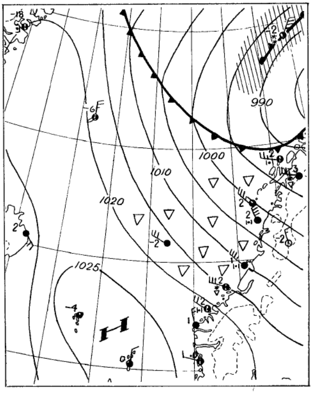

Fig 45 b.

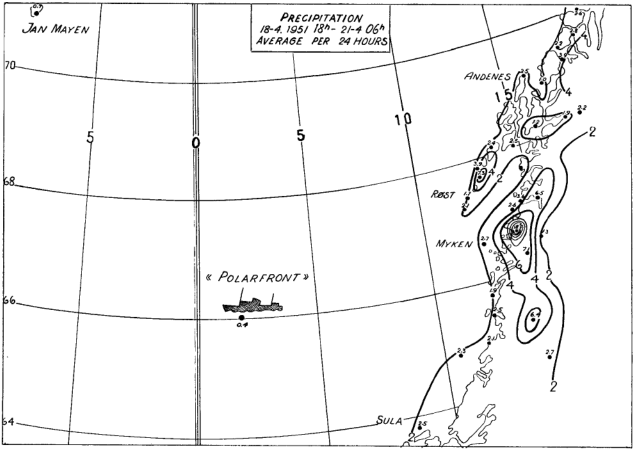

Fig. 46.

Month	Gauge No. 20	Gauge No. 19	Percentual catch of gauge No. 19 in relation to gauge No. 20
1952			
May	8.7 mm	9.2 mm	105.7
July	51.8 -	52.9 -	102.1
September......	11.8 -	12.3 -	104.2
October[1]	5.8 -	5.5 -	94.8
December	49 4 -	51 3 -	103.8
1953			
February	26.0 -	25.8 -	99.2
April	28.8 -	32.2 -	111.8
June	12.1 -	12.4 -	102.5
August	36.7 -	37.5 -	102.2
October[2]	9.1 -	10.0 -	109.9
November	38.4 -	37.4 -	97.4
1954			
January........	18.3 -	20.3 -	110.9
Total	296.9 mm	306.8 mm	
Mean			103.4

[1] 17. to 31. Oct. 1952. [2] 1. to 17. Oct 1953.

93 % off all differences fell within the limits $\pm$ 0.3 mm.

I am inclined to believe that the amount of precipitation falling at sea might be overrated on account of the relative high number of occurrences. On a ship the intensity of the precipitation may also in general be overvalued due to deficiency of shadowing objects, high relative wind speed, admixture of sea spray etc.

The precipitation frequency (expressed in number of days on which precipitation has fallen in per cent of number of days on which observation has been made) is represented graphically in fig. 47·

Curve A: Station «M» (66° N, 02° E) (1950—1952, every second month).

Curve B: Station «I» (59° N, 09° W) (1950—1952, all months except Jan., Feb., March, Dec. 1950 and Jan. 1952).

Curve C: Station «J» (52°, 30' N, 20° W) (1950—1952, all months except Jan., Feb., and March 1950).

Curve D: The sector 50—55° N, 0—10° E (The North Sea) (1868—1872).

Curve E: The sector 40—55° N, 0—30° W (1868—1872).

The last two curves (D and E) refer to observations made on German merchant ships within irregular periods from 1868 to 1872 (Annalen der Hydrographie 1880; «Regenverhältnisse des Atlantischen Oceans» von Köppen und Sprung).

The curves A, B and C coincide almost with each other, while there is a marked parallelism between these curves and curve D, showing a precipitation frequency of say 30 % less in the North Sea during the years 1868 to 1872 as on the ocean weather stations in 1950 to 1952 for all months. The last curve is displaced one month along the time axis in comparison with the others.

The total precipitation frequency during the period 1950 to 1952 was:

Station «M»: 87.4 %
» «I»: 88.0 %
» «J»: 87.3 %

At Røst (67° 30' N, 12° 04' E) precipitation occurred on 56.6 % of all days during the same period.

The measurements made hitherto on board the ocean weather ship «Polarfront I» are, of course, too sparse a material for making any safety conclusions about the distribution of precipitation on sea relative to that falling over land. Part 6 of this paper should therefore only be perceived as a first attempt at comparing results of measurements made on the Norwegian Sea with those made on land (Norway). Further measurements and comparisons may probably change this picture of precipitation distribution, but I believe that the main features of the comparative results: the relative small amounts connected with the relative large number of occurrences in comparison with land observations in Norway at all events are in accordance with the true conditions.

It would be of great importance if a comparison could be carried out between the gauges mounted on the weather ship and a «normal» situated on a low island as far from the coast as possible while the ship is drifting nearby. This should preferably be done in weather situations with proportionally strong winds and stable air stratification (warm front passages).

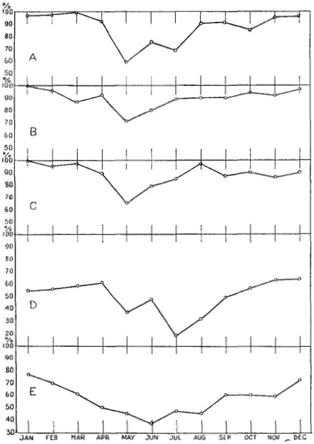

Fig. 47. Precipitation frequency.

Summary.

In part 2 of this paper the different sources of error in measuring precipitation on the weather ship have been discussed and means for determining or reducing the errors have been described. The apparatus used and the results of the measurements are given in parts 3 and 4. In parts 5 and 6 the results of the measurements have been summarized and compared with precipitation measurements made at land stations in Norway. The conclusions made, in order to get a true sample of the precipitation falling on a horizontal area of the sea surface, were briefly these:

1. The best place for the gauge, in order to reduce the effects of the wind to a minimum, was found to be on the lifeboat deck, provided that the ship is drifting athwart the wind direction. To avoid shadowing or splash, the gauge should be placed with its orifice at the same height as the upper edge of the lifeboat shelters. On

account of generally strong winds at sea, the gauge should be equipped with a wind shield.

2. The mounting of the gauge on gimbals should not be considered as important. On the contrary, since the local wind near the deck is approximately parallel to it, it seems as if the mounting of the gauge firm to the ship would provide the best results. The correction due to a tilted orifice due to the rolling of the ship, may usually be neglected.
3. The admixture of sea water in the catch due to spray from the sea, has a very variable value and has to be determined. Electrolytical determination of the salinity of the catch by means of a conductivity bridge was found convenient for use on board the ship.

The amount of precipitation measured at ocean weather station «M» has been considerably less than previously estimated (about 300—400 mm mm per annum). On the other hand, the precipitation frequency has been very high (87 %), and approximately the same for all the ocean weather stations «M», «I» and «J».

Finally I wish to express my thanks to Dr. Th. Hesselberg for valuable advice in making this investigation. Mr. W. Hårvig has prepared most of the diagrams and the officers and crew of the ow/s «Polarfront I», especially Mr. B. Svendsen, Mr. I. Hjelmtveit and Mr. B. Ytrehus have rendered valuable help in making the observations.