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A PRELIMINARY STUDY ON RADAR MEASUREMENTS OF AREAL RAINFALL AROUND HELSINKI

by

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Abstract

A preliminary experiment on radar measurement of areal rainfall rate and amount has been described. An attempt was made to compare the rainfall intensities derived using an ordinary x-band weather radar with raingauge recorded intensities. It seems that the rainfall intensity can be measured with a fair accuracy by means of a relative simplified method provided that the properties of the radar used are thoroughly known and the effect of attenuation can be estimated with a reasonable accuracy.

1. *Introduction*

During the recent two decades numerous investigations have been carried out concerning quantitative measurement of rainfall intensities by radar. In many cases the purpose of these studies has been to find out an operational method for measurement of the precipitation amount over larger areas. Summaries on results achieved until 1964 have been presented among others by BATTAN [2] and ATLAS [1]. Although the usefulness of radar in the measurements of precipitation rates and amount has been clearly ascertained, the accuracy of the method has not been established.

Subjects of concern for the improvement of radar estimates of rainfall are among others the relationship between the precipitation parameters and the quantities measurable by radar in varying conditions, attenuation and additional techniques for a rapid collection of the measured data in digitized form for immediate processing with a computer.

In October 1968 the Institute of Meterology of the University of Helsinki carried out an experimental study on the radar measurement of areal rainfall intensity and amount. Measurements of this kind had not before been made in Finland. Hence the main goal of the experiment was to study the possibilities for a quantitative rainfall measurement with an ordinary x-band weather radar without more refined additional equipment.

2. *Background*

The quantitative measurement of the rate of precipitation by radar is based upon a widely accepted equation in which the radar reflectivity factor (Z) is related to the average received echo power ($\bar{P}_r$):

$$\bar{P}_r = CZ/r^2 \qquad (1)$$

where C = a radar constant (depending on the characteristics of the radar and the refractive index of water), and r = the radar to target range. The radar reflectivity factor Z = the sum of the sixth powers of diameters of raindrops per unit volume of air.

According to numerous investigations on the size distribution of raindrops in space the relationship of Z to rainfall rate R can be specified approximately by an empirical formula

$$Z = aR^b \qquad (2)$$

where a and b are empirical coefficients, decided by the characteristics of rainfall. Substituting this expression in equation (1) we obtain the rainfall rate expressed as a function of quantities measurable by radar:

$$R = (r^2 \bar{P}_r/Ca)^{1/b} \qquad (3)$$

This expression does not take into account the possible attenuation of the transmitted and scattered power. The most effective source of attenuation is the rainfall itself. Like in the case of the radar reflectivity factor the attenuation by rainfall is a function of the drop-size distribution and hence depending on the rainfall intensity between the radar and the target. If this is known, the attenuation (A, in decibels) can be estimated using the expression:

$$A = 2 \int_0^r \alpha R^\beta \, dr \qquad (4)$$

where α and β are empirical coefficients. Detailed derivation of the equations (1) — (4) is presented *e.g.* in [2].

3. *Radar used and the procedure of the measurement and analysis*

The main parameters of the Selenia Meteor 200 RMT 1L radar are:

Wavelength	3.2 cm
Radiated peak output power	200 kW
Pulse length	3* or 0.5 sec
Pulse repetition frequency	245* or 1200 pps
Beamwidth (symmetrical)	1.75°
Effective antenna gain	4000

The measurements were performed applying the s.c. gain-stepping method (*cf. e.g.* Battan [2]). The PPI screen was photographed (on a 35 mm film) when the radar beam swept over the check site with the antenna elevation of 1°. After every exposure the receiver gain was successively increased and the operation was repeated. The time interval required for one series of PPI pictures was about 2—3 minutes. Iso-echo lines were obtained by drawing on the same sketch the contours of echo areas corresponding to different values of receiver gain. The change of gain from one curve to another was on the average the same as a 9 dB step in received power.

The average rainfall intensity at the check site was calculated in the following way: the areas between the iso-echo lines within the check site were measured planimetrically. The power scattered by the precipitation in a region between two adjacent lines was estimated to be the same as the arithmetic mean of the received powers (dBm) corresponding to the respective iso-echo lines bounding this region. Further the rainfall rate corresponding to this received power was computed with the equations

* This value was used in the measurements.

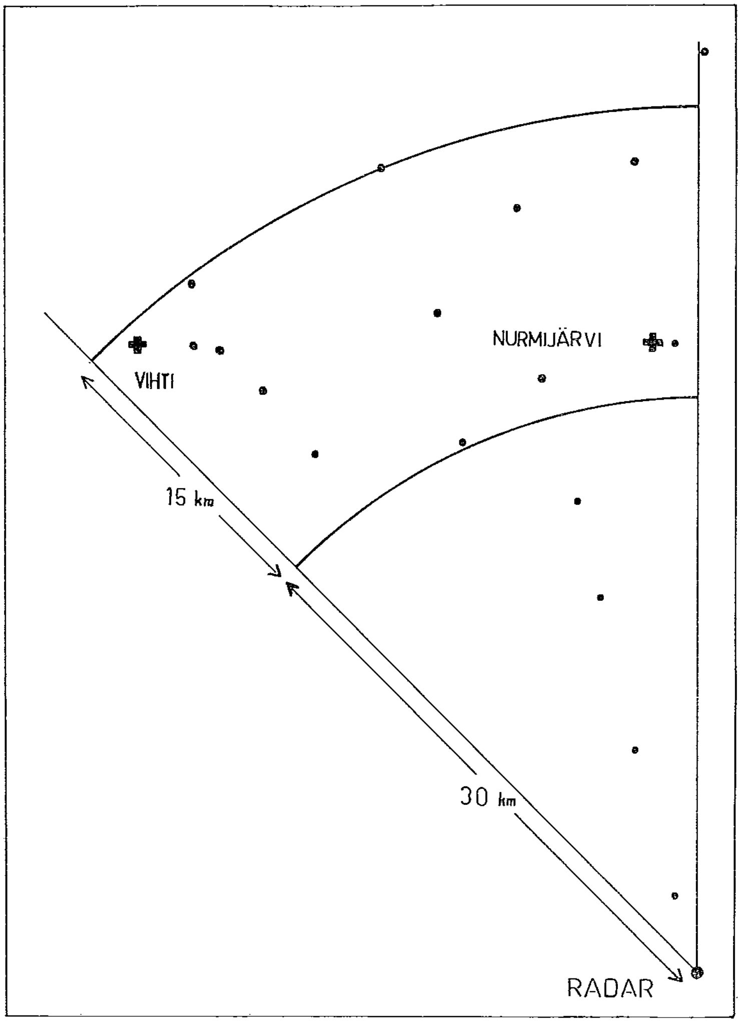

Fig. 1. Check site with the location of raingauges. The area of the site is about 440 km^2.

above using the relationship $Z = 200\ R^{1.6}$ (*cf.* MARSHALL and PALMER [3]). The radar equation applied was that presented by PROBERT-JONES [4]. As the range the average distance of the check site from the location of the radar set, 38.2 km, was used. The mean value of the rainfall intensity over the whole check site was obtained by multiplying the areas between two adjacent iso-echo lines with the respective rainfall rates, by summing the products and dividing the sum with the area of the whole check site.

The average attenuation between the radar and the check site was estimated utilizing the recordings of six raingauges, located on the intervening terrain, with the aid of equation (4). The parameter values applied were $\alpha = 0.013$ and $\beta = 1.15$. These values are based upon a modified Marshall-Palmer's drop-size distribution at temperature 0°C (Wexler and Atlas [6]). The attenuation inside the check site was not considered.

The radar measurements were carried out with intervals of half an hour. The real average rainfall intensity of the check site was worked out by Thiessen's method from the recordings of a network of 13 self-recording raingauges located in the check site (Fig. 1). The average intensity values are means of 10 minute intervals, their midpoint coinciding with the moment of the respective radar observation.

4. *Preliminary results*

The results of two measurement periods are presented in Figs. 2 and 3. The first one, in the midnight between October 12—13, 1968, covered 3 rainfall hours, and the second, October 17, 1968, covered 7.5 rainfall hours. For visualization of the effect of attenuation correction also those rainfall intensities, which would have been obtained without such a correction, are depicted in the figures.

Concerning the first rainfall period the standard error of the radar indicated intensities compared with those obtained from the raingauge recordings is $\pm 44.2\%$. Without an attenuation correction it would have been $\pm 51.1\%$. Regarding the second period the respective numbers are $\pm 88.1\%$ and $\pm 76.1\%$. The high values depend on the failure of the first measurement, in which the rainfall intensity measured by radar, 0.58 mm/h was more than 300% greater than the recorded value, 0.14 mm/h. The error might be caused by the fact that at the beginning of the measurements the radar equipment had not yet reached a sufficient degree of stability. Besides, the raingauge records at the beginning stage of a less intensive rainfall are not too reliable either. If this observation, whose share in the rainfall of the whole period is quite inferior, is left out of consideration, the standard error will be reduced to a value of $\pm 28.3\%$ ($\pm 33.1\%$ without the attenuation correction, respectively).

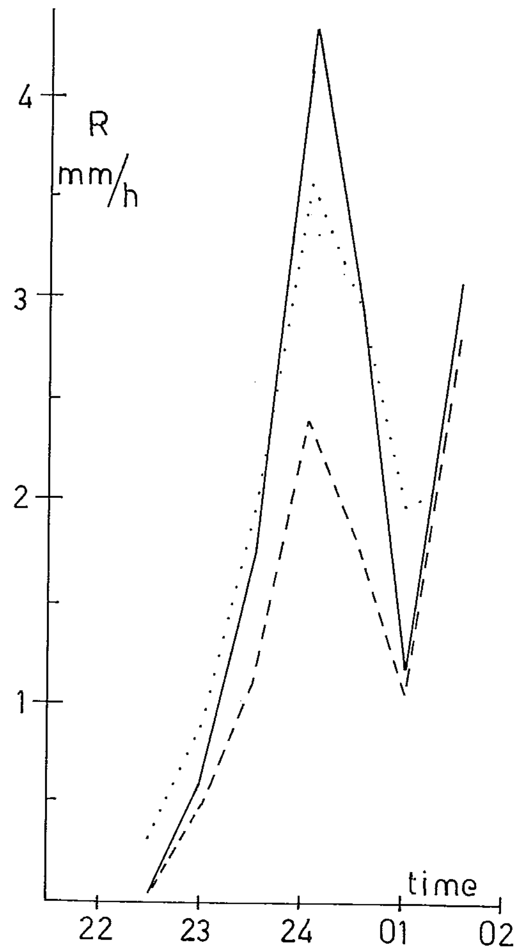

Fig. 2. Radar-indicated and raingauge-recorded intensities during the rainfall period of Oct. 12—13, 1968, as a function of time.
. . . . raingauge recording
— — — — radar indication without attenuation correction
———— radar indication with attenuation correction

The total rainfall amount estimates of the periods considered are in a good accordance. The deviation of the radar measured amount of that recorded by the raingauges was in the case of the first period +0.65% and in the case of the second period −5.1%. Without an attenuation correction the radar method would have led to a considerable under-

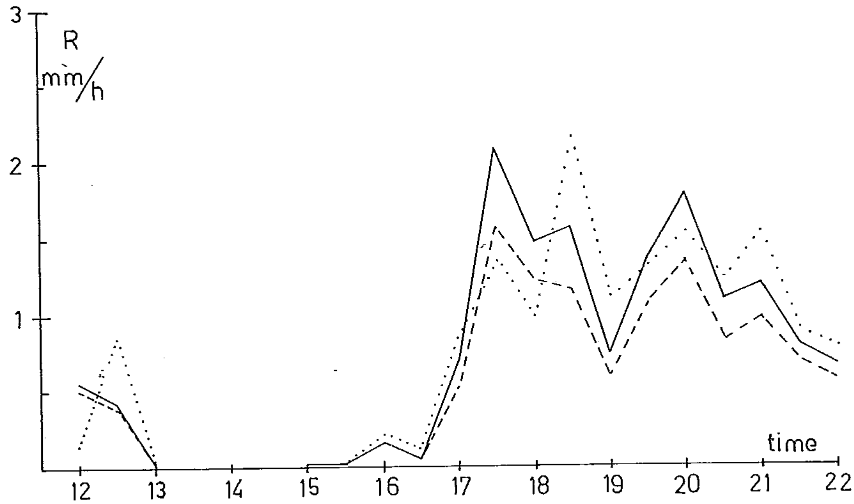

Fig. 3. The same comparison as in Fig. 2 for the rainfall period of Oct. 17, 1968.

estimation, -30.5% concerning the first period and -24.7% concerning the second one.

Through many radar measurements of the rainfall intensities carried out and reported earlier it has been established that radar observations systematically tend to give an underestimation of the real rainfall intensity. One reason to this has been found in the fact that the antenna gain, G, included the equation (1) by the radar constant C, actually is smaller than evaluated by calculations, based upon the geometrical dimensions of the antenna. In our experiment the gain has been defined empirically using a signal generator and a standard gain antenna following a procedure recommended by SMITH [5]. If G would have been calculated from the known expression $G = \pi^2/(\Phi\Theta)$, where Φ and Θ represent the horizontal and vertical beamwidths, the intensities measured by radar would have been 70% less than the values presented in Figs. 2 and 3.

Although the rainfall amounts obtained from simultaneous radar measurements and raingauge recordings are in quite a good agreement as a whole, there occur large discrepancies in individual observations. Main reason to this may be found in the roughness of the measuring method: a step of 9 dB between the iso-echo lines. If at this basis a value of ± 4.5 dB is accepted as a maximum error allowed by the method, only one observation in both rainfall periods exceeds these error limits.

In each case that occurred at the first observation of the period while the intensities still were unassuming and without considerable areal variations.

Since until the fall of 1968 no measurements of the drop-size distribution in precipitation had been made in Finland, the Marshall-Palmer relation $Z = 200\ R^{1.6}$ was applied. Generally taken, however, the coefficient and the exponent are not constant but depend on local factors and the type of rainfall. In the light of the results obtained it seems plausible that with a little larger value of the exponent and a coefficient smaller than 200 the results could have been improved to a certain amount.

The raingauge recordings used represent a mean value of a 10 minute interval. The likelyhood that the moment of the radar observation would allways match well with that mean value is merely a chance, at least partly. This circumstance is certainly responsible for some differencies when comparing the intensities measured »simultaneously». Besides, the sparse raingauge density available has, as we believe, influenced the results by increasing the spreading.

5. *Conclusion*

In spite of the limitations of the method used the preliminary results attained, in particular concerning the total rainfall amounts, were better than expected. Although an analysis of data of a few short measurement periods does not permit any generalizations it seems, in our opinion, as the rainfall intensities could be measured with an appreciable accuracy even with relative simple techniques and methods. This, however, requires an ability to measure the radar parameters accurately and the development of a method of reliable estimation of the attenuation when operating with a 3 cm radar.

Encouraged of the first experiments these measurements have been continued with a somewhat improved radar techniques and a more dense network of raingauges. Also the drop-size measurements have been started. The results achieved will be published in a later report.

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