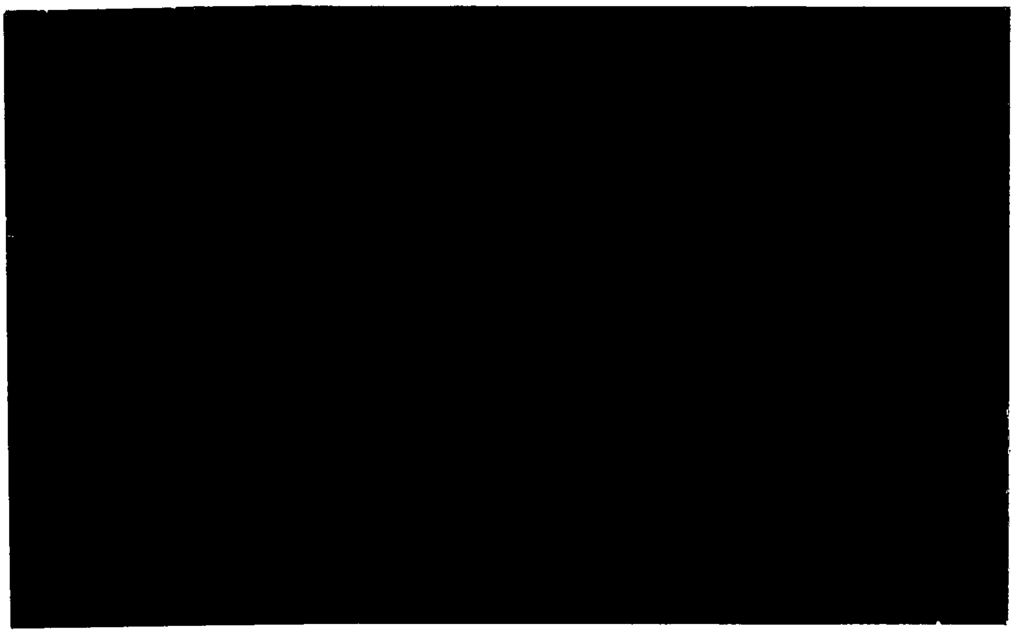

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The choice of the parameters of a radar for meteorological applications

by

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Summary:

After a survey of the possible applications of meteorological radars the most important technical requirements are discussed. The choice of the proper wavelength, the processing of the radar signal and the increased possiblilities with Doppler capability are treated in particular. The paper closes with a table giving the most important technical specifications for three radar systems of different complexities.

Zusammenfassung:

Nach einer Uebersicht über die möglichen Anwendungen meteorologischer Radargeräte werden die wichtigsten technischen Anforderungen, die an ein solches Gerät zu stellen sind, diskutiert. Im besonderen werden die Wahl der richtigen Wellenlänge, die Verarbeitung des Radarsignals und die zusätzlichen Möglichkeiten bei Dopplerbetrieb behandelt. Am Schluss folgt eine Tabelle mit den wichtigsten Spezifikationen für drei Radarsysteme mit verschieden grossem technischem Aufwand.

Résumé:

Après avoir passé en revue les applications possibles d'un radar météorologique, on discute les besoins techniques les plus importants d'un tel système. On examine plus spécialement le choix de la longueur d'ondes la plus judicieux, le traitement du signal-radar et les possibilités supplémentaires qu'offre un radar Doppler. L'articl se termine par une table qui contient les spécifications techniques les plus importantes de trois variantes de radar de compléxité différente.

1. Introduction

The purpose of this memorandum is to investigate the optimum characteristics of a weather radar, taking into account the special conditions in Switzerland. Many of the aspects of weather radar are discussed by Shreeve, 1970, and will not be repeated here. After a brief survey of the different applications, the main points which will be discussed are :

a. The choice of wavelength, which in Shreeve's report is based only on a consideration of attenuation thus neglecting problems due to ground-clutter and limited resolution of the radar beam;

b. Some aspects of dynamic range of the receiver and data processing, and

c. The improvement resulting from using Doppler facilities.

The whole field of radar meteorology is rapidly developing and new possibilities open up at the same rate as progress is made with digital hardware.

An open problem is to decide how severely will the attenuation affect 5 cm waves. From our experience at Locarno it should be all right. But what we really need to answer this question is good experimental data about this point; all we have at present are theoretical data (see Crane, 1970) and some preliminary results of our experiments being carried out now here at the Weather Radar Branch in Sudbury. To get conclusive results about this point, we have to wait for the end of this experiment in August 1971.

Doppler facilities definitely increase the useful information considerably but with it, the complexity of the processing equipment also increases. Considering both these facts, I feel that at least the possibility of later installing the Doppler facilities should be kept in mind when buying the radar.

After all the theoretical considerations the final decision as to what will be bought will be influenced strongly by what is readily available.

2. Different Applications

Obviously, the choice of the different parameters depends on the main application of the radar. We will, therefore, discuss briefly four different uses and point out the key parameters.

If we want to investigate thunderstorms and hail growth the main emphasis has to be devoted to fast data acquisition (one complete scan every minute), high resolution of the radar beam (of the order of 300 m to 1 km) and large dynamic range so that we can investigate early stages of development as well as mature ones. RHI and PPI displays are both desirable. The attenuation must be small. This excludes 3 cm waves for the investigation of thunderstorms except for the very early stages. But as the differences in echo intensity change rapidly over orders of magnitude in thunderstorms, larger attenuation may be tolerated than when the radar is used for hydrological purposes. As the attenuation in widespread rain, responsible for the biggest part of the precipitation, is smaller than in thunderstorm rains, the attenuation requirements for hydrological purposes will be automatically fulfilled for a radar usable in thunderstorm investigations.

When using a radar to measure the amount of precipitation, the main emphasis has to be put on the stability of the radar (transmitter and receiver), the high resolution of the radar beam and the automatic data processing. Ground clutter is a problem but as Austin and Schaffner, 1970, point out, it is possible to distinguish between ground targets and precipitation on the basis of the fluctuation properties of the target. Alternatively, as discussed later, an even better way exists to distinguish between ground targets and precipitation by using a Doppler technique.

If the radar will be used for cloud investigations, its main emphasis has to be placed on the sensitivity. The inexpensive way to achieve this is to use a short wavelength but it can also be done with a sensitive receiver, high power transmitter and a large antenna.

For short term forecasting the points mentioned in the previous applications are far less important. The main point is the presentation and transmission of the radar data e.g. Marshall, 1970, Bigler, 1970, Raytheon, 1968. However, very little advantage is taken of the great possibilities offered by digital techniques now available. But at present, many studies are being made to reduce, process, store, and transmit the data flow. The most helpful feature which the radar of the future will have for short term forecasting is a mean of storing the data of the past hour (e.g. 10 scans) and replaying it on command on a display during 10 sec. This will not only give a good idea of the development and motion but it will also make it easy to distinguish between ground clutter and weather targets if this is not done by other means.

3. Choice of the Wavelength

The choice of the wavelength has an influence on the sensitivity, attenuation, resolution and the relative intensity of ground targets versus rain.

Sensitivity

With increasing wavelength the scattering cross section σ of precipitation particles and with it the sensitivity of the radar decreases with the fourth power of the wavelength λ*.

$$\sigma \sim d^6/\lambda^4$$

*Rayleigh approximation is assumed here, an assumption which will be fulfilled whenever the attenuation is small enough to allow quantitative measurements. In the other case, it doesn't matter anyway if the particles are scattering in the Rayleigh or the Mie region, as errors due to attenuation are far bigger than errors due to non-Rayleigh scattering.

As the ground targets are of the order or bigger than the radar wavelength, the Mie theory has to be applied to calculate their scattering cross section, and we find that it is roughly independent of the wavelength. As the power returned from weather targets increases with $1/\lambda^4$ we should take as short a wavelength as possible in order to see precipitation targets in ground clutter. We arrive at the same conclusion when considering the resolution d of the radar beam given by the beamwidth θ and the distance r from the radar :

$$d = r\,\theta = \frac{1.2\ r\ D}{\lambda}$$

To map the structure of thunderstorms, the spatial resolution should not be coarser than 1 km; 300 m would be better. That means a 1^{o} beam will introduce significant errors at ranges greater than 60 km. This problem is due to the fact, that a pulse volume of 1 km^3 is rarely filled homogenously with weather. We find the same problem when using weather radar for hydrological purposes where it is important to measure the reflectivity <u>below</u> the melting layer. Measuring within or above the melting layer may lead to errors of the order of 10 db in estimating the reflectivity. The necessary resolution of 1^{o} will be obtained for 5 cm waves with an antenna of 4 m diameter. This antenna size is probably the largest one obtainable off the shelf.

<u>Attenuation</u> presents the well-known problem when using short wavelengthsin rain. With increasing wavelength the absorbtion cross section σ_t of raindrops and with it the attenuation of the radar beam decreases approximately with the third power of the wavelength:

$$\sigma_t \sim d^3/\lambda^3$$

Hitschfeld and Bordan, 1953, showed that it is not possible to correct for large attenuation. This excludes 3 cm waves for quantitative measurements of precipitation and for investigations of thunderstorms. WMO, 1966, suggests 10 cm waves as the ideal wavelength for weather radars, because for this wavelength attenuation is negligible in all situations. Compared with 10 cm waves, 5 cm waves will improve the resolution by a factor of two, the strength of precipitation echoes compared to ground targets by a factor of 16, but will be attenuated in strong precipitation. According to WMO, 1966, this amounts to 5 db in 1 km of 500 mm/h rain or in 5 km of 100 mm/h rain. Cases of such heavy rain will be very rare in Switzerland, and as theoretical considerations show, it will be possible to correct for this small attenuation by estimating the attenuation from the measured intervening reflectivity. To do this the radar has to be accurately calibrated and the relationship between reflectivity and attenuation must be known. From our experience of calibrating our 5 cm radar in Locarno, and from preliminary results of experiments at Sudbury for the reflectivity-attenuation relationship which agrees roughly with the WMO, 1966, it is concluded that a 5 db error due to attenuation can be reduced to a negligible amount. Therefore, it seems that 5.6 cm represents the best compromise between errors due to attenuation.

4. Data Processing

The data rate at the input of the radar receiver is of the order of 10^7 bit/sec. Out of this enormous quantity of information, we are interested only in about 10^3 bit/sec, and it is the task of the data processing equipment to pick out the right information. At present, much effort is spent by many different groups to find out the best way of data reduction.

The radar signal is composed of the sum of the signals of all the raindrops distributed and moving at random in the pulse volume. The result is a strongly fluctuating signal where the average power Pav contains the information about the precipitation intensity and the fluctuations contain information about the radial movement of the particles relative to the radar. If no averaging is done, the standard deviation is 5.6 db; in other words, the reflected power from a weather target P is 95 % of the time in the limits .1 Pav $<$ P $<$ 10 Pav. This clearly shows that averaging is necessary in order to make meaningful quantitative measurements. Another problem to overcome is the large dynamic range of signals involved and to normalize them in range. This can be solved with the accuracy required by using a logarithmic amplifier and adding the range normalization (see Fig. 1). The cheapest way to integrate, range, normalize and compress the dynamic range so that the whole signal range can be shown at once on the PPI is described by Joss, 1968. Using this technique has the advantage that we have experience with it. The results recorded on film are adequate for investigations of thunderstorms and the support of the cloud seeding experiment in the Bassin Lémanique. The disadvantage lies in the fact, that the amount of data is limited by the resolution of the PPI and the film and that it is hard to get the data in a computer for further analysis. These problems can be partially solved by using digital integrators as proposed by Schaffner, 1968, or Works, 1970. But it seems to me that both these solutions, in spite of reducing the data flow by an order of magnitude and solving the interface problem with the computer, leave us far away from having the optimum data-processing system. But clearly, Schaffner's and Works' approach are going in the right direction by choosing digital hardware which is reliable, easy to replace, needs no alignment and is getting cheaper with every month. These developments being available, it is hard to understand why the U.S. Weather Bureau did choose its own analog integrator (Shreeve, 1969), to equip their radars during the next years.

5. Doppler Capabilities

With a coherent or Doppler radar the radial velocities of the particles relative to the radar can be measured. This opens up three new possibilities to get information about the target:

1. The component of the wind towards the radar can be measured using precipitation as a tracer and giving information about the wind field, shear and turbulence. This is especially desirable for investigations of thunderstorms.
2. Looking vertically, dropsize distributions may be deduced. This information is interesting for research work only, being too complex for operational use.
3. With adequate processing, such as described by Sheats, 1970, the problem of eliminating the ground clutter from the display can be easily solved.

The information mentioned in these three points would definitely be very valuable. However, the difficulty lies in the fact that Doppler receivers and processors for weather radar are in continuous and rapid development and that at present no Doppler radar can be bought off the shelf.

Raytheon developed the CMF, a processor for Doppler information (Groginsky, 1965). Very promising results are described by Donaldson, 1970. But it seems as if the solution of the future lies rather in a digital approach such as Sheats, 1970, than in the CMF, being an analog device with only 20 db dynamic range. Two possibilities exist to get Doppler information: either to develop it now together with the manufacturer of the radar or other companies such as Raytheon or to buy the radar in such a form, that Doppler facilities may be added in a few years, when processors will be develped. This would involve buying a more stable transmitter and local oscillator. The requirements are similar as for an MTI system. In view of the present state-of-the-art, this seems to be the most sensible thing to do.

6. Parameters of Weather Radars

This paragraph intends to give some sensible sets of parameters for 3 alternatives of a weather radar:

	I	II	III
Wavelength	5 cm	5 cm	10 cm
Polarization	vertical or horizontal		
Trans. Power	100 KW to 1 MW		
Pulse Length	.5 µs*	≤ 2 µs	≤ 2 µs
PRF	500		
Receiver	80 db log, .5 db accuracy (for non Doppler processing)		
Display	PPI + RHI		
Antenna Positioning	- Manual and cont. rotation up to 3 RPM		
Antenna Shape	1^{o} conical		
Doppler Capabilities	no	no or yes	yes
Data Processing	Joss,1968	Schaffner,1968 or Works,1970	
Doppler Processing	-	-	Sheats, 1970

*) the pulse length has to be as short as possible in order to allow for area integration and still keep 2 µs resolution.

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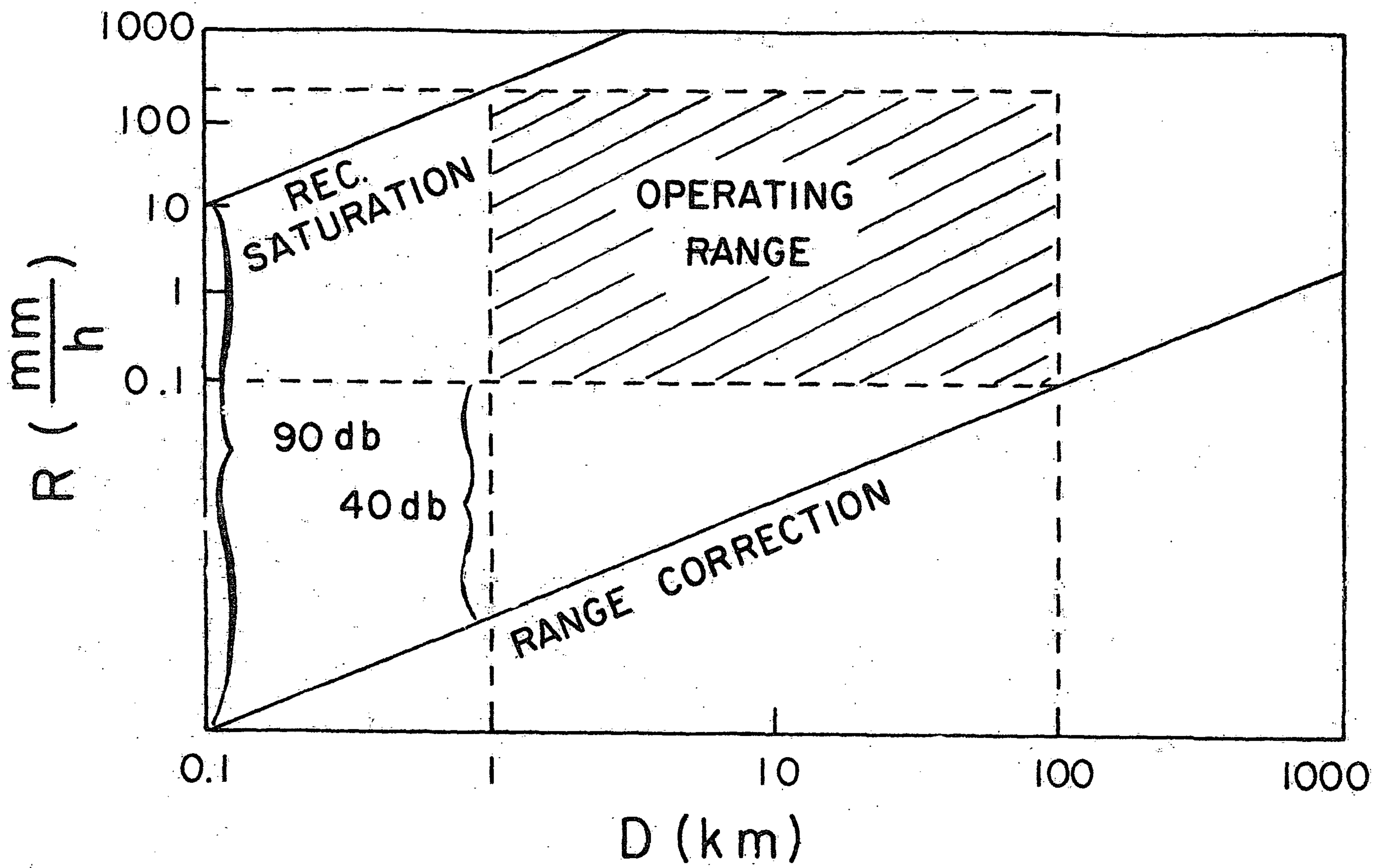

Fig. 1 Assuming a dynamic range of 90 db between the saturation of the log receiver and the thermal noise (of the mixer and the log receiver together) the ability to measure a rain intensity ~~by~~ R at a distance D is plotted. To normalize the signals versus range the range correction has to be added to a signal according to the distance where it is coming from.