

## A method for quick evaluation of meteorological radar echo intensities

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**ABSTRACT.** In operational use of weather radars there is a need for quick estimation and reporting of echo intensities in meteorologically meaningful terms. Simple slide rules for evaluating echo intensities in broad categories related to rainfall rates, taking account of variations in radar parameters have been developed.

### 1. Introduction

A great deal of research has been done on the quantitative measurement of precipitation by radar. Operationally this technique has not, however, yet found widespread use because of the uncertainties of the radar reflectivity vs rainfall relationships and the difficulties of field calibration with a sufficiently dense raingauge network. Most meteorological services use weather radars more in a qualitative way, *e.g.*, detection and tracking of tropical cyclones, thunderstorms and tornadoes. Even so, the need for quick estimation and reporting of radar echo intensities to delineate areas of heavy rain or turbulence has given rise to the common use of radars with calibrated iso-echo systems presenting echoes sliced to different level of intensity successively or simultaneously. These presentations assume not only specific reflectivity-rainfall relationships but also definite values of the radar parameters.

In most situations the forecasters or other users (such as pilots) have neither the facility nor the time to see the radar pictures for themselves and interpret them for their needs. The intensities of echoes are usually reported to them in broad categories (weak, moderate, strong, etc) along with the position, tendency and height of the echoes. Even if the picture itself is seen directly or through a remoting system, there is no simple means of adjusting it for variations in radar parameters which necessarily occur from time to time. When a radar echo intensity

is reported as, say, moderate or strong it should be meteorologically meaningful to the recipient, *i.e.*, he should be able to associate it with some particular rainfall rate although it may not correspond to an exact figure. An iso-echo presentation is no doubt designed to do this, but it could also be misleading if it is not capable of being quickly corrected or adjusted for variation in radar power output, receiver sensitivity, etc.

### 2. The radar equation

To illustrate the practical problem we shall assume the use of a radar with the following specifications which are rather typical of modern equipment in operational use.

Frequency 2890 MHz (wave length  $\lambda=10.35$  cm)

Peak transmitted power ( $P_t$ ) =  $500 \times 10^3$  watts

Pulse width = 1 or 4 micro sec, *i.e.*, Pulse length in linear units ( $h$ ) = 300 or 1200 m

Antenna gain ( $G$ ) = 38 dB

Vertical ( $\theta$ ) and horizontal ( $\phi$ ) beam widths to 3 dB points =  $1.9^\circ$

Minimum detectable signal ( $S_{\min}$ ) = about -110 dBm.

The generally accepted equation for the received power  $P_r$  from a target consisting of precipitation particles of diameter  $d$  at a range  $r$  is that given by Probert Jones (1962),

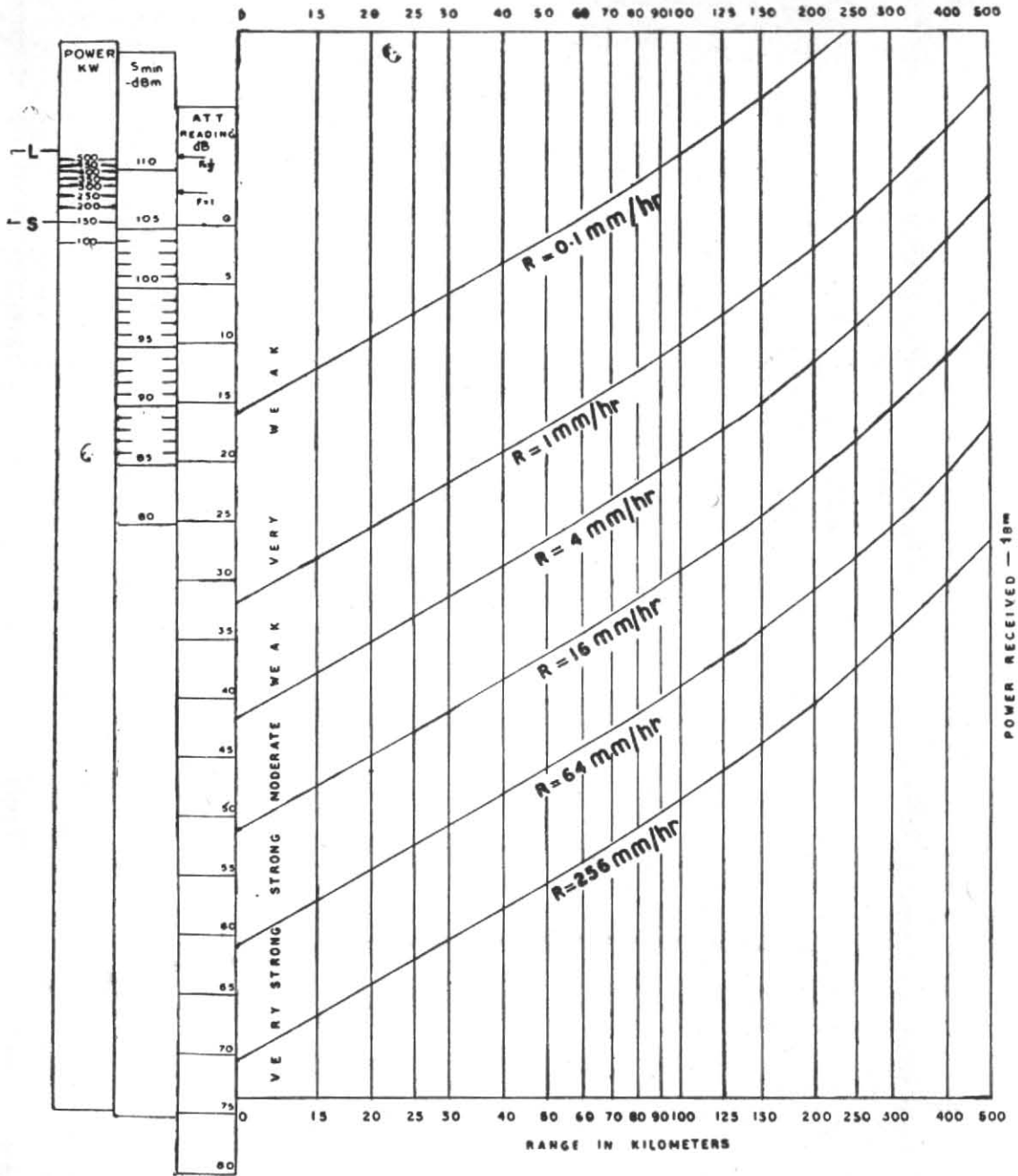


Fig. 1. Echo intensity chart

$$P_r = \frac{\pi^3}{2^{10} \log_e 2} \left[ \frac{P_t h}{\lambda^2} G^2 \theta \phi \right] \cdot \frac{1}{r^2} \times \left| \frac{\epsilon - 1}{\epsilon + 2} \right|^2 \sum_{\text{unit volume}} d^6 \quad (1)$$

where  $\epsilon$  is the dielectric constant of water or ice. If we are interested only in obtaining broad categories of rainfall intensities from the radar data we may make standardising assumptions that the reflectivity factor,

$$Z \text{ in } \text{mm}^6/\text{m}^3 = \Sigma d^6 = 200 R^{1.6}$$

where  $R$  is the rainfall rate in mm/hr. If we confine ourselves to a range of the order of 200 km from the radar, in a tropical area the horizontally transmitted radar beam of  $1.9^\circ$  width is likely to encounter mostly liquid water particles. Hence we may put

$$\left| \frac{\epsilon - 1}{\epsilon + 2} \right|^2 = 0.93$$

Probert Jones' equation omits the attenuation of the beam by intervening precipitation or atmospheric gases. We may ignore precipitation attenuation at the wavelength assumed and correct for gaseous attenuation (assumed to be 0.01 dB/km each way) by introducing a factor  $10^{-0.002r}$ . We may also insert a factor  $X_1 = 10^{-x/10}$  to denote a loss of  $x$  dB in the radar input circuits and another factor  $F$  called the fraction of the beam filled by the precipitation particles. Our working equation then becomes

$$P_r = \frac{\pi^3}{2^{10} \log_e 2} \left[ \frac{P_t h}{\lambda^2} G^2 \theta \phi X_1 \right] \cdot \frac{1}{r^2} \cdot (0.93) \times 200 R^{1.6} \cdot 10^{-0.002r} \cdot F \quad (2)$$

the quantity within the square brackets representing the radar parameters.

For evaluation of echo intensities the received video pulses should be integrated in order to obtain a good approximation to the average intensity. This is done usually by an RC filter in the video amplifier of the receiver (see, e.g., Atlas 1964). We shall take it that our radar has this and the following other facilities which are typical.

- (1) A calibrated step attenuator and continuously variable attenuator in the receiver.
- (2) A level SLICE circuit to set the receiver threshold at a predetermined level. We shall take this to be  $-105$  dBm for the 4 micro-second pulse width and for  $-96$  dBm for the 1 micro-second pulse-width.

(3) A range normalization circuit which compensates range attenuation and gaseous attenuation upto a range of say 200 km upto which we are interested in intensity measurements (Limited to a range of 50 km in the short pulse).

(4) An iso-echo system capable of presenting echoes above thresholds of 5, 10, 15, 20, 25, 30, 35 dB of echo intensity above the receiver threshold assumed in (2) above. The 5 dB steps of echo intensity correspond to  $5/1.6 =$  approximately 3 dB steps of rainfall intensity.

It can be seen by substitution in Eq. (2) that the level slice thresholds assumed above correspond respectively in the long and short pulse operation to a rate of rainfall of 1 mm/hr at 200 km range and at 50 km range. The successive iso-echo levels will therefore correspond roughly to rates of rainfall of 1, 2, 4, 8, 16, 32, 64 and 128 mm/hr. The radar loss  $x$  is assumed to be 7.3 dB.

### 3. Echo intensity chart

Fig. 1 is a miniature reproduction of a chart designed to depict  $R$  as a function of range and received power, based on Eq. (2). In practice the observer would read the intensity of any echo by introducing attenuation by means of a calibrated attenuator, until the echo is reduced to the threshold value on the A-scope. The received power is given by

$$P_r = S_{\text{min}} + \text{the attenuator reading in dB.}$$

Hence, in Fig. 1 we have used a sliding attenuator reading scale the starting point of which can be set against the measured value of  $S_{\text{min}}$  given on another scale. The start of the latter scale can itself be set against the measured transmitted power output ( $P_t$ ) on another sliding scale. Lastly the start of the 'Power Scale' can be set against the mark L or S, as necessary for short or long pulse operation.

The rainfall rate can be read off against the attenuator reading and the range of the given echo.

Thus the intensity of the echo can be quickly determined taking into account the actual measured values of power output and receiver sensitivity. In practice to get an integrated signal the radar may be operated in the SLICE mode and in that case the value to set on the  $S_{\text{min}}$  scale will be the slice threshold value ( $-105$  or  $-96$  dBm). These values again may not be constant; so the actual value measured with a signal generator may be used to set the scale.

TABLE 1

Range (km)	Ht. of base of beam (limited to zero elevation) (km)	Ht. of top of beam (km)	Vertical extent of beam (km)	Horizontal width of beam (km)
10	Almost Zero	0.17	0.17	0.33
50	0.15	0.98	0.83	1.66
100	0.6	2.25	1.65	3.32
150	1.35	3.81	2.46	4.98
200	2.4	5.67	3.27	6.63
300	5.4	10.28	4.86	9.94
400	9.5	16.06	6.56	13.25
500	14.8	23.02	8.22	16.56

TABLE 2

Intensity	Rainfall rate $R$ (mm/hr)	Reflectivity factor $Z$ ( $\text{mm}^6/\text{m}^3$ )
Very weak	<1	<200
Weak	1 to 4	200 to $1.8 \times 10^3$
Moderate	4 to 16	$1.8 \times 10^3$ to $1.7 \times 10^4$
Strong	16 to 64	$1.7 \times 10^4$ to $1.55 \times 10^5$
Very strong	>64	> $1.55 \times 10^5$

TABLE 3

Estimated precipitation	Echo intensity	Theoretical rainfall rate		Reflectivity factor $Z$ ( $\text{mm}^6/\text{m}^3$ )
		(inches/hr)	(mm/hr)	
Very light	Very weak	<0.01	<0.25	< $2.3 \times 10$
Light	Weak	0.01 to 0.1	0.25 to 2.54	$2.3 \times 10$ to $9.4 \times 10^2$
Moderate	Moderate	0.1 to 1.0	2.54 to 25.4	$9.4 \times 10^2$ to $3.7 \times 10^4$
Heavy	Strong	1.0 to 5.0	25.4 to 127	$3.7 \times 10^4$ to $5.0 \times 10^5$
Very heavy	Very strong	>5.0	>127	> $5.0 \times 10^5$

A refinement in Fig. 1 is the addition of the arrows  $F=1$  and  $F=\frac{1}{2}$  on the attenuator scale. In a tropical area for a radar of the assumed specifications (see Table 1) the beam may be considered to be filled by precipitation particles in the case of most clouds upto 200 km. Hence, the start of the scale may be taken as  $F=1$ . If in any case this assumption is not considered valid, the value  $F=\frac{1}{2}$  can be used.

Although Fig. 1 provides for a range of upto 500 km, intensity measurements at long ranges will be seriously vitiated by wide spread of the beam, uncertainties in radio wave propagation conditions, cutting of the freezing level by the beam and the reduction in the factor  $F$ . Hence, it would be appropriate to limit intensity estimates to about 200 km range.

While Fig. 1 gives rates of rainfall in mm/hr, it may be misleading to report intensities in mm/hr because of the uncertainties referred to above. A practical plan would be to report intensities in the five categories as indicated in the figure. These are classified in Table 2.

The classification is rather arbitrary but reasonable. It has the advantage that each category differs from the next one by 10 dB in terms of echo intensity and is, therefore, convenient for use in a radar with the iso-echo system assumed. Most commercially available radars have iso-echo systems with levels at intervals of 5 or 10 dB of echo intensity. Hence, with the suggested system successive iso-echo levels can be usually observed or photographed and taken to represent each category. The classification made in the WMO RADOB code FM 20 E (WMO 1971) is given in Table 3. For direct observation of each rainfall category on the radar, the WMO system would require iso-echo levels at intervals of about 16 dB of echo intensity which are generally not provided in most radars. Hence it is not so convenient for operational use as the classification in Table 2.

4. Intensity slide rule

Still easier evaluation of echo intensity is made possible by another slide rule a miniature of which is shown in Fig. 2. In this case the radar is switched to successive iso echo levels 7, 6, 5, 4, 3, 2, 1, 0 corresponding to thresholds 35, 30, 25, 20, 15, 10, 5, and 0 dB above the 'SLICE threshold of' (-105 dBm or -96 dBm) and the highest level number at which the echo appears is noted. If the radar specifications are as assumed, the echoes appearing at levels 0, 2, 4 and 6 respectively correspond to categories weak, moderate, strong and very strong (categories defined as in Table 2.) However, if the radar power output and slice threshold deviate from the standard values the slide rule of Fig. 2 can be used to take account of these variations. The start (S or L) of the slice threshold scale is set against the current value of  $P_t$  and the start (zero) of iso-echo level scale is set against the value of slice threshold. The intensity is read against the maximum iso-echo level number at which the echo is seen. The method is, of course, valid only for ranges upto which the iso-echo system is designed for operation in each pulse length and it also makes the assumption that  $F=1$ .

It is also dependent on the proper calibration and functioning of the elaborate electronics of the iso-echo and range normalising circuits assumed in Section 2. The chart in Fig. 1 has the advantage that it can be used in the absence of an iso-echo and

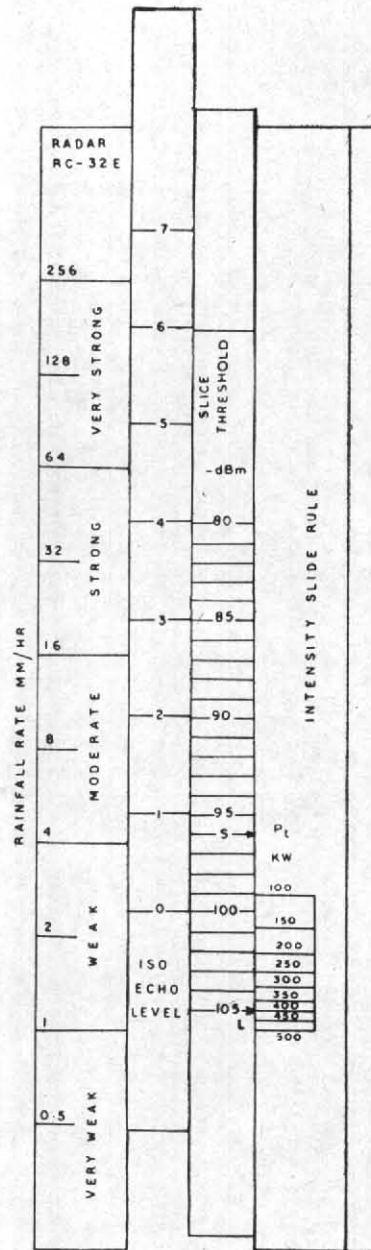


Fig. 2

range normalising system. The radar need have only a calibrated attenuator and an R-C filter. It can also easily be adapted to any other 10 cm radar merely by transposing the origin of the 'attenuator reading' scale to take account of a change in radar specifications.

5. Conclusion

The slide rules illustrated in Figs. 1 and 2, thus provide a simple way of quick estimation and reporting of radar echo intensities in five broad

categories in meteorologically meaningful terms taking account of variations in radar parameters. Periodical monitoring of the power output, minimum detectable signal and level slicing threshold by suitable test equipment are assumed. The other parameters of the radar are assumed to remain reasonably constant over long periods.

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