A. Basic Radar Meteorology

These notes are intended to help you to brush up radar meteorology and to introduce you to English terminology used in IRIS manuals.

A.1 Introduction

A weather radar sends pulses of microwaves and measures, how much is reflected by targets in the atmosphere. ”Targets” are mainly raindrops, hail, snow.

A radar antenna focuses the microwaves to a beam of 1 degree. The beam grows wider in distance: at distance of 200 km it is already 4 km wide !

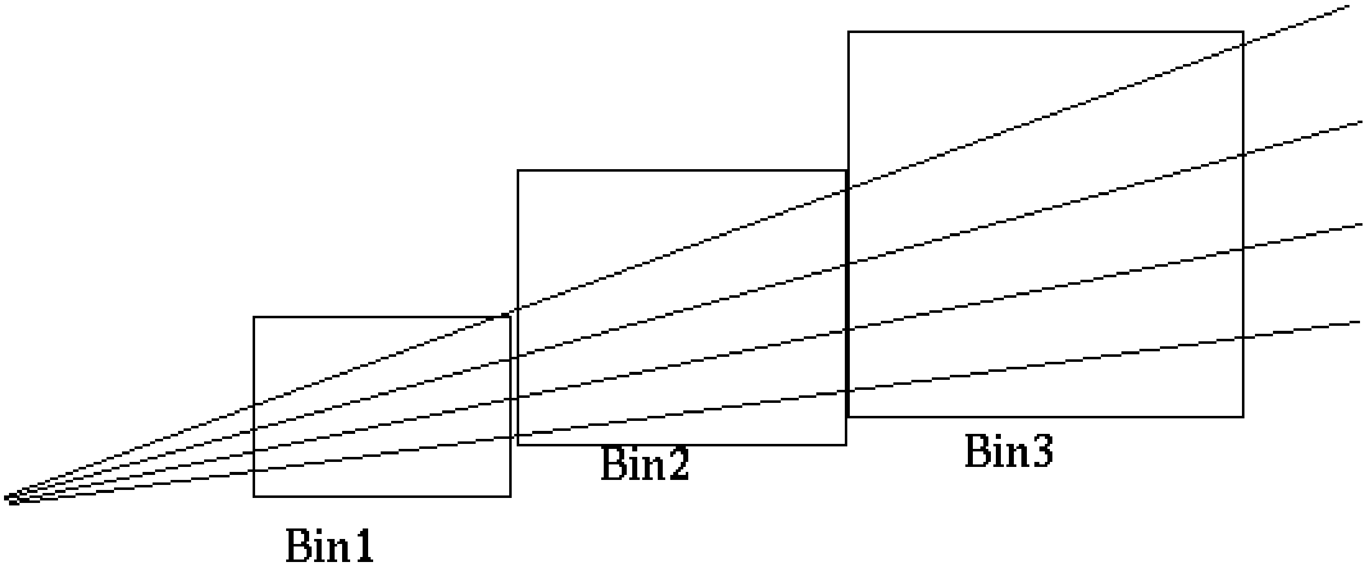
Microwaves travel at the speed of light. Measuring the time when the reflection comes back to antenna, we can count how far the target is.

When a microwave pulse meets some raindrops, very small amount is reflected (scattered) and most of the waves go on. This is because typically raindrops are size of 1 mm distance of 10 cm from each other. This means we can see “rain behind the rain”. This also means a radar has to be very sensitive: we send about 250 kW and receive 10^{-13} W.

We can move the antenna up and down (elevation) and round in horizontal plane (azimuth). Typically, in a measurement task, we take a low elevation and measure in all azimuths, then increase the elevation a little, and measure in all azimuths again, and so on, so we get data from all directions at different ranges. This pack of data is called a polar volume, “polar” because it is measured in polar coordinates the center being the antenna.

The radar alternates between sending and receiving at “pulse repetition frequency”, (PRF). That is typically between 100 and 1000 times a second. When the antenna is moving in azimuth direction all the time, each pulse is sent in slightly different direction. In signal processing, we process the data from same distance from different pulses. These are called samples. Slices in distance which are processed are called bins. In the image in next page, value of each bin is processed from four samples. The distance between samples is determined by antenna speed and PRF. To get reasonable values, usually some 32–128 samples are processed together.

Figure A–1: Range Bin Geometry



A.2 Reflectivity

It is convenient to say things in atmosphere reflect the radiation, but backscattering is the accurate physical term. It is measured in Z (radar reflectivity factor) and often expressed in dBZ (radar reflectivity).

The famous radar equation from classical optics says

$Z = \frac{Pr^2}{LCK}$ where

- P is the measured average power (in Watts) of several samples at the radar
- r is the range to the bin
- L is attenuation
- C is radar (hardware) constant
- K is the refractive index and depends on the dielectric properties of the particle

So for meteorologists

$$Reflectivity = \frac{(Watts\_Received * Distance\_Squared)}{(Attenuation * Hardware\_Constant * Rain\_or\_Snow\_Constant)}$$

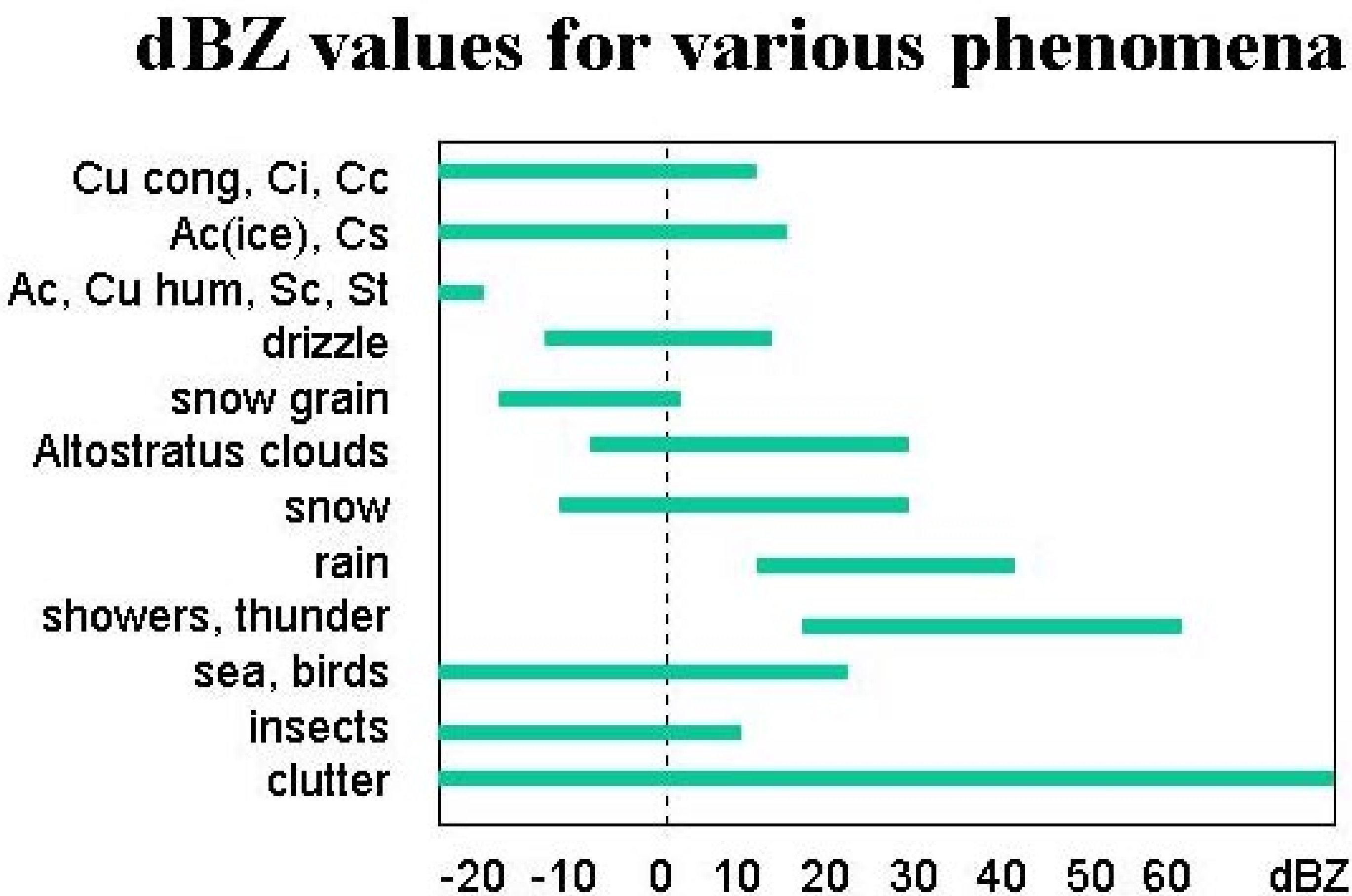
For cloud physics, Z is a sum $\Sigma N_i D_i^6$ where N_i is the number of particles with diameter D_i per unit volume in the atmosphere. That means, that one droplet with diameter 4 mm gives 4096 times as much energy as a 1 mm droplet. And that we can't know if there is one droplet of 2 mm or 64 droplets of 1 mm.

Z varies between 0.001 and 10 000 000. To get understandable numbers, we use decibel scale:

$$dBZ = 10 \log \frac{(Z\ mm^6 m^{-3})}{(1\ mm^6 m^{-3})}$$

Typical values for various phenomena in the atmosphere are shown in figure below. You can see that reflectivity strength alone is not enough for target identification !

Figure A–2: dBZ Values for Various Phenomena



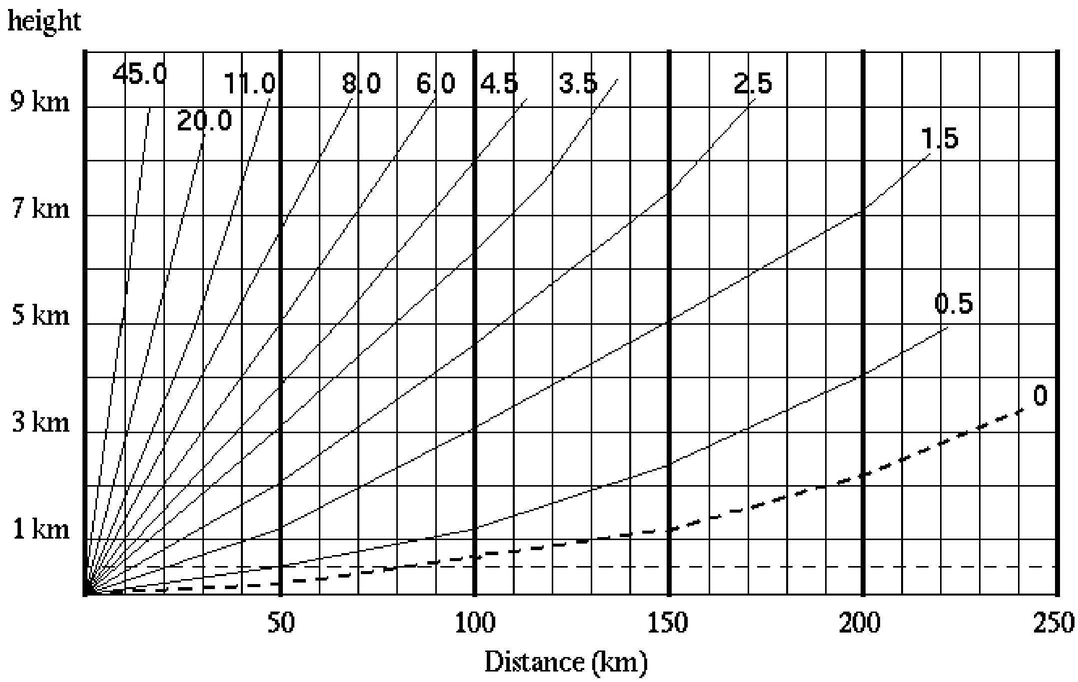
For hydrology, we need an equation to combine radar reflectivity to rainfall rate. All of these equations are empirical and approximate, since Z is proportional to D6 and precipitation rate R (mm/h) is proportional to D3.7. Also, we have to assume something about drop sizes. For 64 drops of diameter 1 mm or one drop, diameter 2 mm, Z is same, R is not ! Good first guess is the classical Marshall Palmer equation

$Z = 200\ R^{1.6}$ which equals to $R=(Z/200)^{0.625}$

A.3 Geometry

Earth is spherical. Microwaves do not follow the surface. Because of the atmospheric optics, they usually bend down a bit, at a radius of 4/3 the earths. In the picture below is shown the height of some radar beams as function of distance from radar at different elevations.

Figure A–3: Beam Height vs. Range



Though nominal beam width is 1 degree, some energy is spread to other angles, too. These are sidelobes.

A.4 Problems in interpretation of radar images

Echoes not related to rain

- Reflection of microwaves from ground or water surface, radar mirage
- Birds, insects, chaff from aeroplanes
- Solid targets such as masts and buildings
- Other microwave sources such as the sun and other radars
- Second trip echoes

Echo intensity differences not related to differences in precipitation intensity

- Calibration issues: nowadays electrical calibration can effect 2–3 dB.

- Beam blocking: Near antenna buildings can shade partially or totally echoes from certain direction
- Attenuation in rain: echoes behind heavy rain can disappear especially if wavelength is small. Attenuation correction can compensate if echo is too weak but can not help if there is no echo.
- Water phase: ice, melting ice and water scatter microwaves differently. Bright Band can be 7 dBZ
- Drop size: especially melting hail. 2 mm droplet = 64 of 1 mm droplets

Even if the measurement is OK, there isn't a 100% correlation with a gauge

- Far from antenna the beam is rather high. It can overshoot a precipitating cloud. Or the rain can evaporate below the measurement height. Orographical enhancement can take place. In cold winter winter, difference can be 10 dB between measurement height and surface. Vertical reflectivity profile correction can help to fix quantitative errors, but if there is no measurement the correction does not help.

A.5 Doppler wind measurements

Doppler radar has two advantages to a non–Doppler radar: clutter cancellation and wind products.

A Doppler radar measures speed of the reflector like a policeman's traffic radar. More specifically, it studies the phase how the phase of microwaves compared to the sent pulse is changing between samples (see page 1). (To get good Doppler measurements, we need plenty of samples processed together (64 is good). This sets limits to antenna speed.)

- A non–moving target has no phase shift.
- A target whose movement has no component in direction of the radar beam, has no phase shift.
- A phase shift of exactly 2p looks like no phase shift.
- A phase shift of 2p+d looks like phase shift d.
- A phase shift of n*2p+d looks like phase shift d. This is called aliasing.

The maximum speed which can be measured unambiguously is

$$V_{\max} = \frac{PRF * \lambda}{4}$$

where λ (lambda) notes wave length.
Typical PRFs in weather radars are between 250 and 1200 Hz. Why doesn't everybody just use 1200 Hz and get nice winds ? Because PRF also determines the maximum unambiguous range.

$$R_{\max} = \frac{c}{2 * PRF} = \frac{SpeedOfLight}{2 * PulseRepetitionFrequency}$$

This leads us to the Doppler dilemma: we can measure either high speeds or far away from radar And we want both. That is why there is Dual PRF techniques, some single PRF algorithms and hybrid tasks employing different PRF for different elevations.

A.6 Clutter cancellation

We can define *clutter* as echoes from hills, buildings, masts, sea, and *noise* as marks in the image caused by electronics of the equipment. Goal of clutter cancellation is to remove clutter without distroying rain data

To illustrate a Doppler filter we study speed spectra of a bin. That is, Doppler speed of each sample (see page 1), horizontal axis being speed (towards or away from radar, zero in the middle). If all samples indicate no speed we know the target is not moving. However, even antenna movements gives some speed. And there is cases when it's raining at the hills.

The next image shows a Doppler spectra from a bin, which contains clutter (speed near zero) and rain moving toward the radar (big hump on the left) as well as some noise (small humps everywhere, seen alone on the right). To find the right settings for the Doppler filter, we can move the red lines closer to each other (less rain data is destroyed) or further from each other (more clutter is cancelled).

Figure A–4: Typical Spectrum Plot