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School on "Exploring the Atmosphere by Remote Sensing Techniques"
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"The CSA"
(The Center for Agrometeorology)

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Please note: These are preliminary notes intended for internal distribution only.

CSA

Centro Servizi Agrometeorologici

per il Friuli - Venezia Giulia

Via Carso 3, loc. Scodovacca - 33052 Cervignano d.F. (UD)

The CSA deals with meteorology and agrometeorology in the Friuli - Venezia Giulia region, by means of theese three centers:

- Forecast Center (http://www.forecast.csa.fvg.it)
- Radar Center (http://www.radar.csa.fvg.it)
- Agrometeorological Center (http://www.agromet.csa.fvg.it)

The radar center is working since Jan 1998 and deals with both operational and research activity, providing real-time radar data and maps

About Radar Meteorology

Weather Radar Target: distribution of hydrometeors contained in the atmosphere

Liquid Phase Hydrometeors:
- raindrops
- cloud droplets

Mixed Phase Hydrometeors:
- graupel
- wet snow

Solid Phase Hydrometeors:
- hail
- crystals
- dry snow

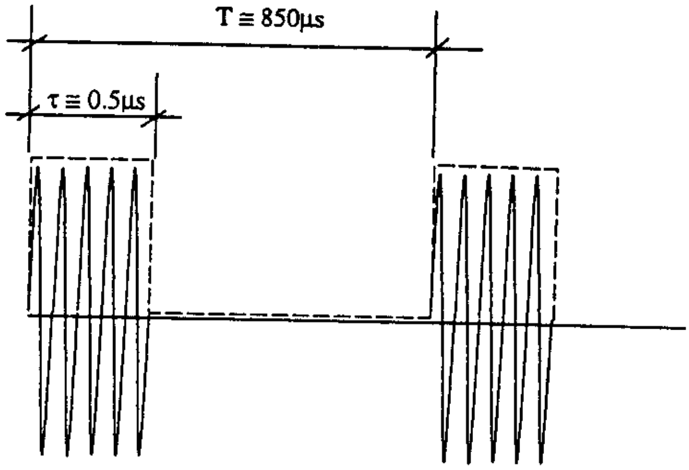
Radar Meteorology: observation of the atmosphere by means of the weather radar and study of the echoes associated with the meteorological phenomena.

Applications:
- weather surveillance
- hydrology
- cloud physics
- nowcasting

- THE DOPPLER RADAR (TRANSMITTING ASPECTS)

Transmitted signal:

RF pulses



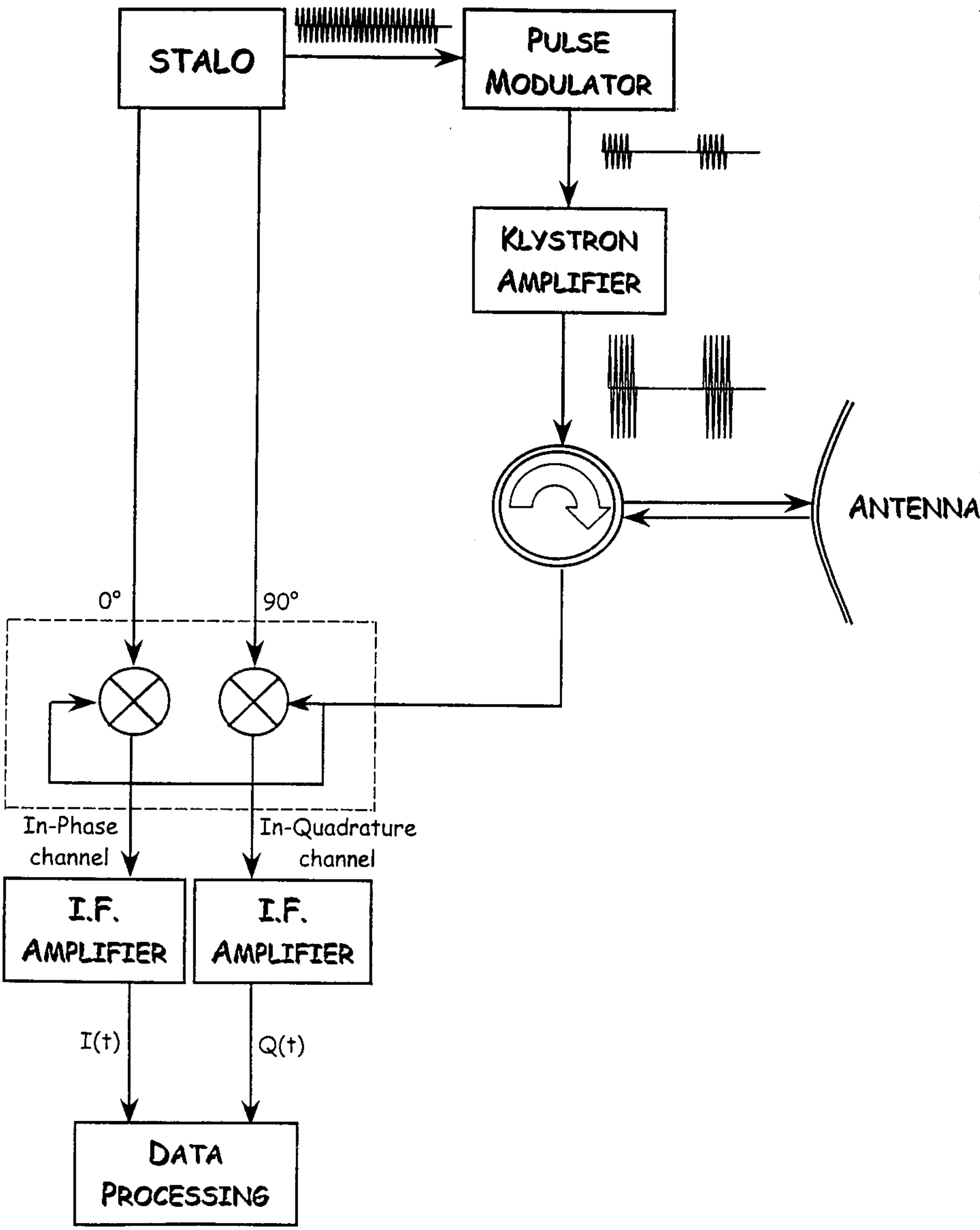
Wavelenght: 3 cm (X band), 5 cm (C band), 10 cm (S band)
Peak power: hundreds of kilowatt
Average power: hundreds of watt

A Doppler radar can have either a

KLYSTRON AMPLIFIER
or a
MAGNETRON OSCILLATOR.

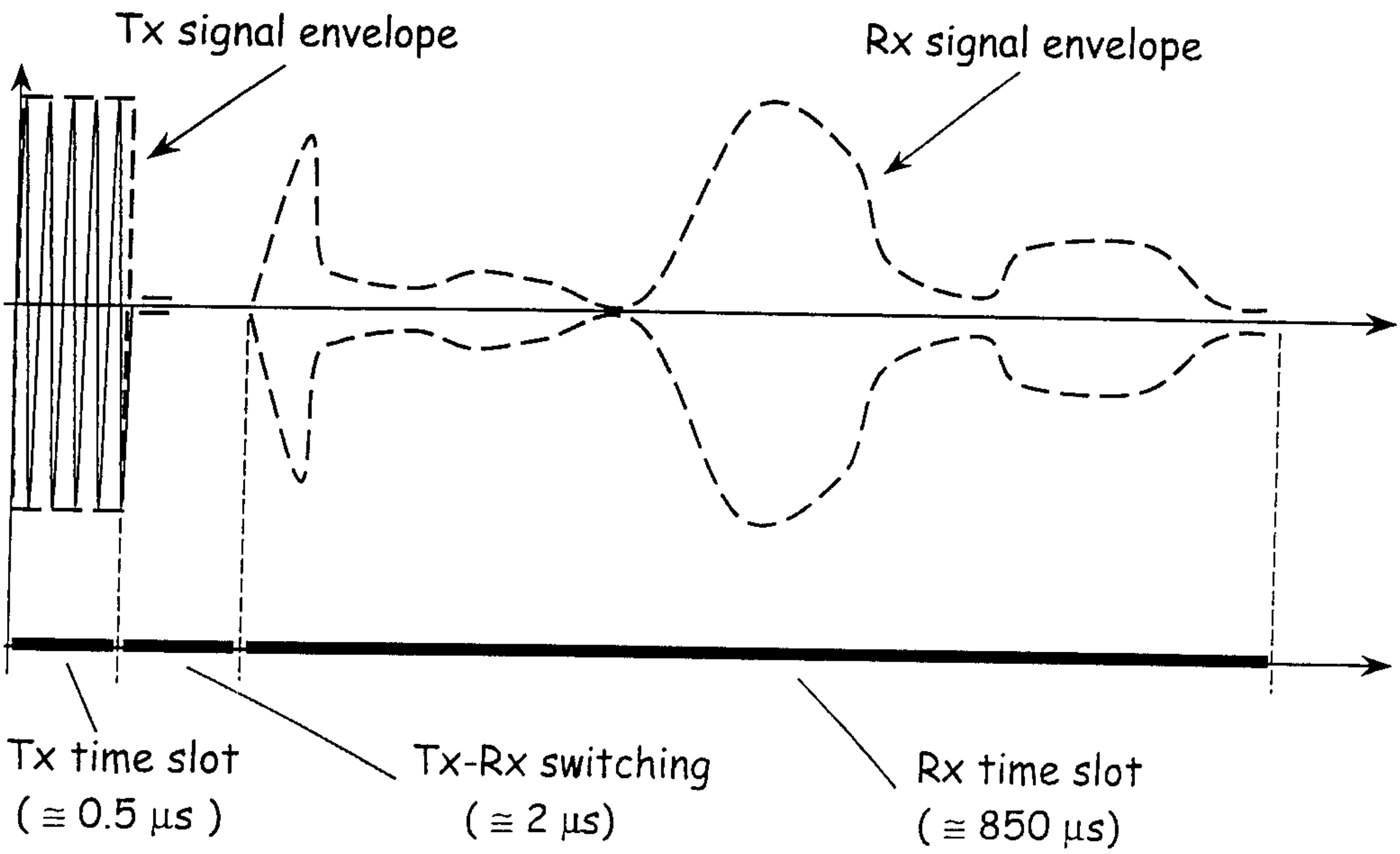
To have a good accuracy in doppler measurements a high pulse phase coherency is needed, i.e. pulses should start with the same RF phase. This is easier to obtain by a klystron, because it amplifies the RF pulses generated by a low power stabilized oscillator. A magnetron (high power microwave oscillator) is phase inchoerent, and the high power RF signal must be synchronized.

SIMPLIFIED DOPPLER RADAR BLOCK'S DIAGRAM



THE DOPPLER RADAR (RECEIVING ASPECTS)

Received signal: a continuous sinusoid modulated both in amplidude and phase (or frequency)



The carrier amplitude contains the information related to the water content of the target, while the phase shifting contains the information related to the Doppler velocity.

Both the amplitude and the phase of the R.F. carrier are functions of the time. At a certain time corresponds a certain distance from the radar (half of the path the electromagnetic field travels in that time).

The Doppler radar usually has two synchronous detectors, that provide two analogic signals whose amplitudes are proportional to the echo amplitude $|A|$ and whose phases are sinusoidal functions of the echo phase $\Psi_e = [4\pi r/\lambda] - \Psi_t - \Psi_s$, where Ψ_t is the transmitter phase and Ψ_s is the phase shift upon scattering:

$$I(t) = k \cdot |A| \cos(\Psi_e) U(t - 2r/c);$$

$$Q(t) = -k \cdot |A| \sin(\Psi_e) U(t - 2r/c);$$

For echoes from stationary scatterers, Ψ_e is time independent.

If the target is moving and just r changes in time (Ψ_s does not), the phase changes in time as well and its time rate $d\Psi_e/dt = (4\pi/\lambda) \cdot v$ is the Doppler shift.

ABOUT THE WEATHER TARGET

Because water drops can vibrate as they fall in air, Ψ_s is not in general time independent, and that causes fluctuations in the Doppler shift that will broaden the Doppler spectrum.

Reflectivity's Definition

Considering a distribution N(D) of spherical water droplets, the quantity

$$Z \equiv \frac{1}{\Delta V} \sum_i D_i^6 = \int_0^\infty N(D) \cdot D^6 \cdot dD$$

is called "reflectivity factor", or commonly just "reflectivity".

This is the radar terminology for indicating the water droplets backscattering cross section per unit volume.

Z values span many orders of magnitude, and thus a logaritmic scale is normally used:

$$Z(dBZ)=10 \log Z(mm^6/m^3)$$

Precipitations can produce Z values from about 20 dBZ up to 60÷70 dBZ in the case of heavy rainfall or hail.

THE WEATHER RADAR EQUATION

The relationship between the received R.F. signal power, the other radar's parameters and the target's reflectivity (i.e. its backscattering cross section) is normally assumed to be the following:

$$P_R = k \cdot \frac{P_T \cdot Z}{r^2}$$

where :

How The Weather Radar Works

The radar antenna can round both in azimuth and elevation.

VOLUMETRIC SCAN: the whole half-space above the radar is observed. The antenna makes a set of rounds at different elevations.

SECTORIAL SCAN : just a portion of atmosphere is observed. This scan mode is less time-consuming than the first one, and it is used especially for storm tracking.

Wavelength Considerations

For weather radar applications three wavelengths are normally used:

3 cm (X-band) ⇨ high sensibility, high attenuation, small antenna dimension (Doppler On Wheels)

10 cm (S-band) ⇨ low sensibility, negligible attenuation (rainfall estimation), low resolution

5 cm (C-band) ⇨ trade-off between the previous ones (cloud physics at mid-latitudes)

MEASURED QUANTITIES

- **Reflectivity (Z)** ⇨ drop size distribution

DOPPLER RADAR:

- DOPPLER VELOCITY (V) ⇨ target movement
- SPREAD OF DOPPLER VELOCITY (σV) ⇨ target turbolence

POLARIMETRIC RADAR:

- DIFFERENTIAL REFLECTIVITY (Z_{DR}) ⇨ geometrical shape
- OTHER

WHAT'S ZDR ?

Polarization of the transmitted field can be

Horizontal ⇓ Z_H

Vertical ⇓ Z_V

Differential Reflectivity $Z_{DR} = Z_H / Z_V$

Z_{DR} MEANING

Z_{DR} is an index of the ratio between the horizontal and the vertical dimension of the hydrometeors

Note that:

cloud droplets are spherical $\Rightarrow Z_{DR} \approx 0$ dB

hailstones are spherical $\Rightarrow Z_{DR} \approx 0$ dB

raindrops are oblated, because they fall down

Z_{DR1} < Z_{DR2} < Z_{DR3}

For raindrops, Z_{DR} increases as the drop diameter increases

Z_{DR} APPLICATIONS

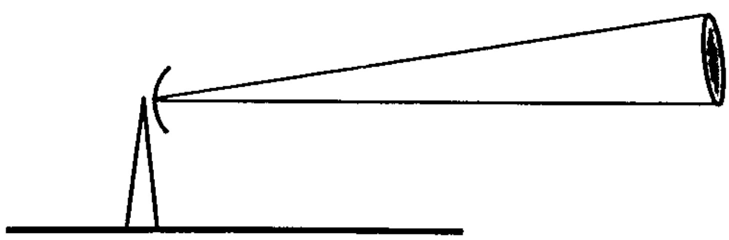
- **Particle identification:** on the basis of the couple of values that Z and Z_{DR} assume, it is possible to distinguish between several different types of hydrometeor.

- **Rainfall estimation:** the information about the mean drop shape provided by ZDR let we obtain better results in rainfall intensity estimation.

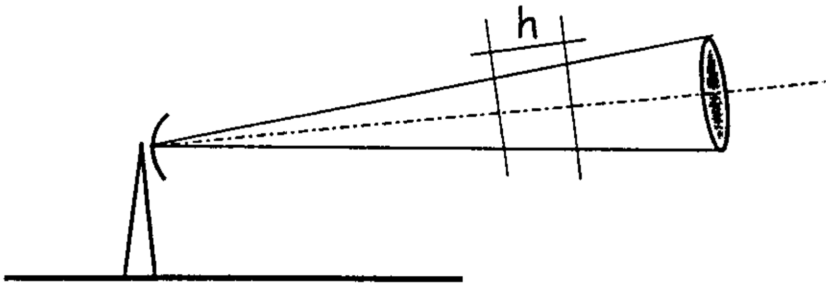
RADAR RESOLUTION AND USEFUL RANGE

The radar antenna has a radiation pattern with a main lobe and several secondary lobes.

For sake of semplicity, radar beam can be idealized as a cone whose width coincides with the 3dB width of the antenna's main lobe (θ_{3dB}).



The radar transmits RF square pulses. After each of them a RF sinusoid modulated both in amplitude and in phase (which is the sum of the echoes due to the hydrometeors contained in the radar beam) is received. The envelope of that signal is digitalized and processed.



Every sample contains the information related to a truncated cone ("resolution volume" or "range bin") whose heigth is

$$h = c \cdot \tau / 2$$

where τ is the lenght of the transitted pulse.

Note that even if h reamins constant, the width of the beam does not and then

THE RESOLUTION VOLUME INCREASES AS THE DISTANCE INCREASES.

Remember that one of the assumptions for deriving the weather radar equation is that the resolution volume must be uniformley filled.

This is the first reason that limits the useful radar range. The second one is the

EARTH'S CURVATURE

Conclusions:

- quantitative measurements can be done up to about 100÷120 km far from the radar. This is the limit for Doppler and Polarimetric measurements.

- qualitative measurements can be done up to 250 km far from the radar. Besides this limit many of meteorological phenomena (except convective systems) can be missed.

Fig. 13 - Earth's curvature effect on radar operative ranges and altitudes

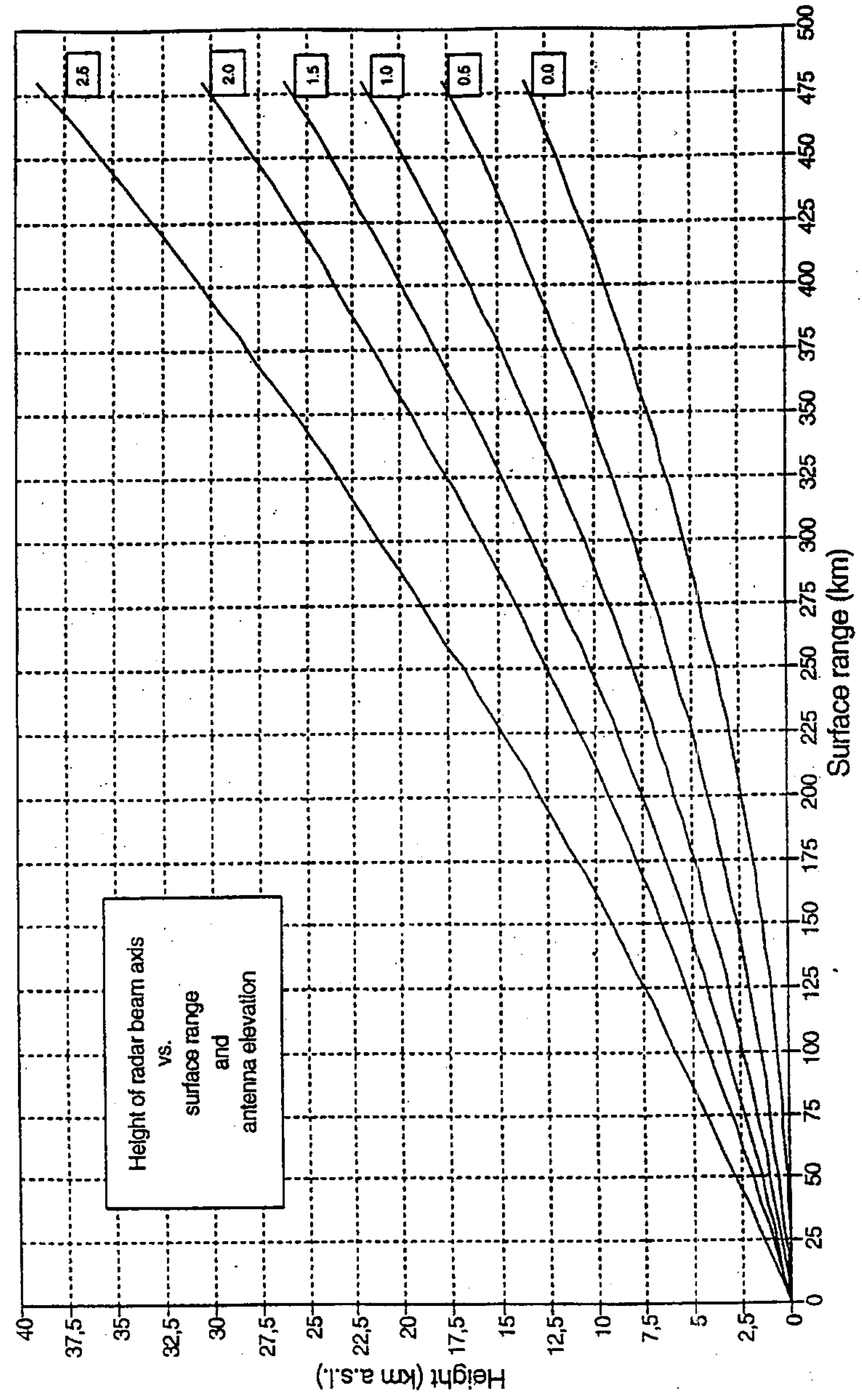
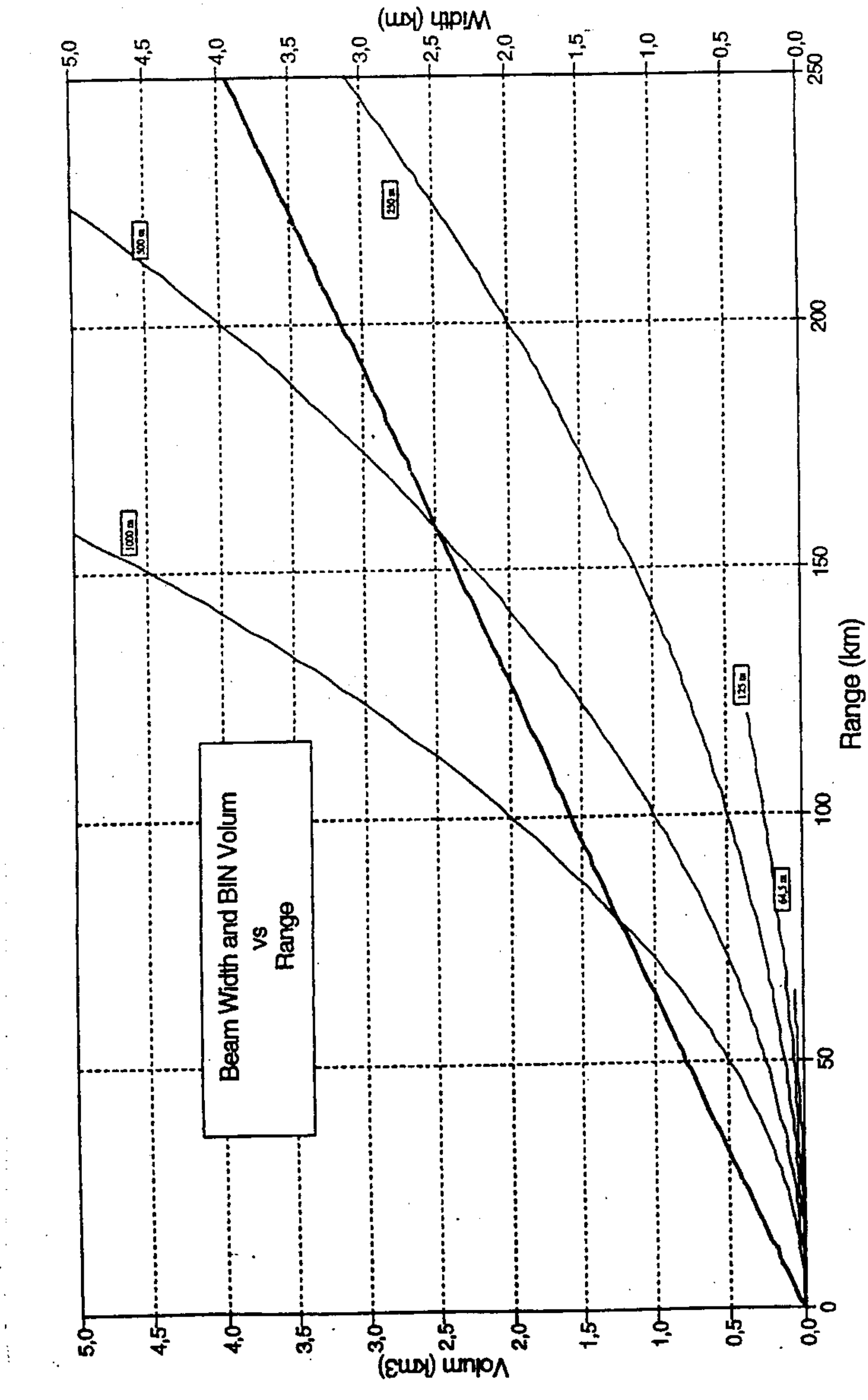


Fig. 13a - Increase of range-bin volume and width with range



About Measurement Errors

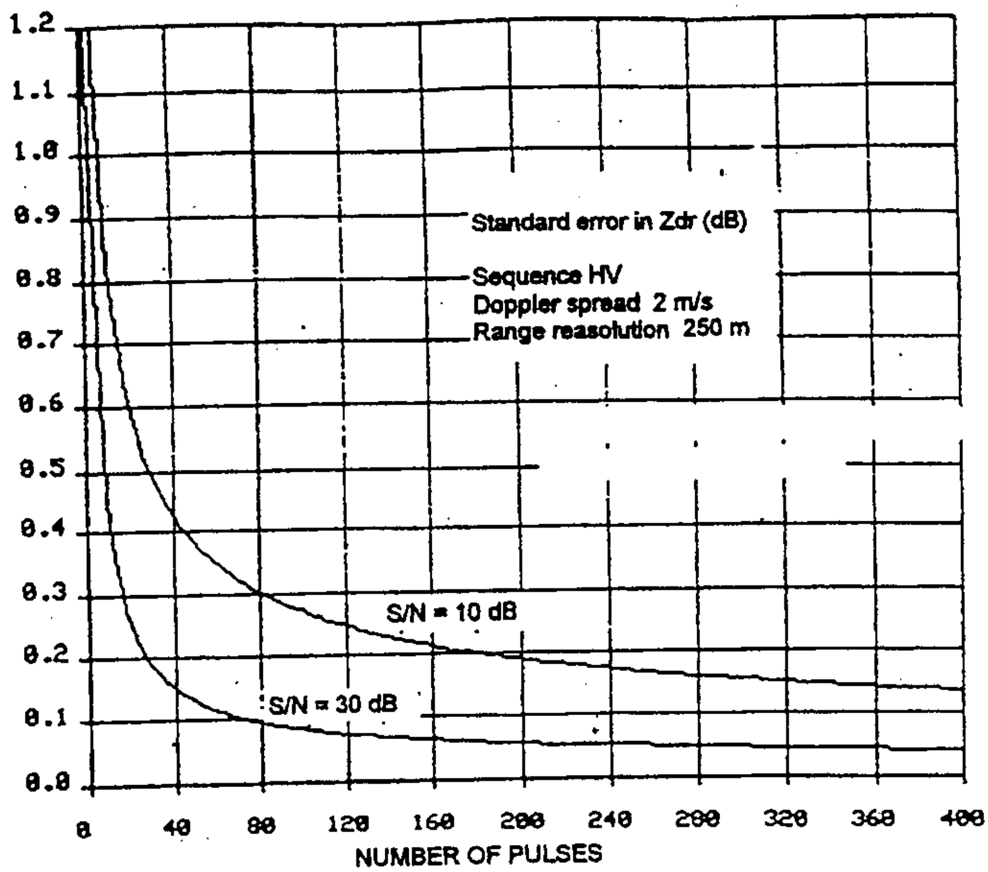
The weather target is not stationary, therefore a statistical analisys on the received signal has to be made.

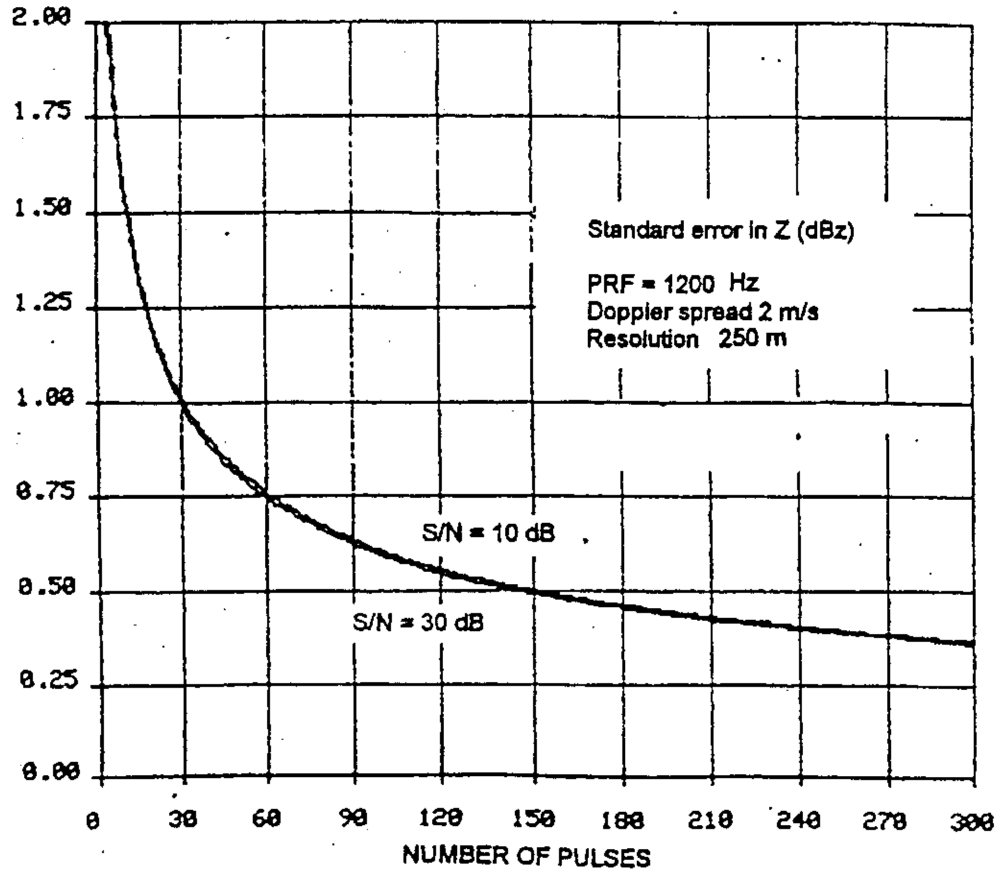
For each radar beam, **n** RF pulses are transmitted in sequence. Thus, for each range bin **n** samples are processed in order to obtain one value (for each quantity) characterizing the resolution volume.

Both the speed of the antenna (i.e. the time requested for the whole scan) and the uncertainty on every quantity's value depend on n.

If n increases, the speed of the antenna must be reduced and the uncertainty decreases.

NOTE: Zdr is useful only if its uncertainty is kept below 0.2 dB (see the particle identification masks). Thus polarimetric measurements can require much time, up to 10 minutes for one volumetric scan.


Standard error in Zdr (dB)
Sequence HV
Doppler spread 2 m/s
Range reasolution 250 m
S/N = 10 dB
S/N = 30 dB
NUMBER OF PULSES


Standard error in Z (dBz)
PRF = 1200 Hz
Doppler spread 2 m/s
Resolution 250 m
S/N = 10 dB
S/N = 30 dB
NUMBER OF PULSES

RADAR PRODUCTS

PPI (PLAN POSITION INDICATOR)

The antenna rounds pointing at a certain elevation ⇨ radar data are collected on a conical surface whose vertex coincides with the antenna.

The PPI map is the projection of that conical surface on a ground parallel plane.

PPI's characteristics:
- very simple to generate;
- can be plotted in real-time;
- data refer to a non-constant altitude.

CAPPI (CONSTANT ALTITUDE PPI)

It is possible, from a whole data set, to extract a map (CAPPI) which refers to a constant altitude.

CAPPI's characteristics:
- cannot be plotted in real time (scan must be ended);
- data don't refer exactly to a constant altitude if the number of elevations is too low.

Good CAPPI ⇨ high time-consuming scan

RHI (Range Height Indicator)

It is a vertical section of the atmosphere passing through the radar position.

RHI's characteristics:
- a vertical scan is needed;
- can be plotted in real time;
- high vertical resolution can be obtained;

VMI (Vertical Maximum Intensity)

This map shows the maximum reflectivity value above every point.

VMI's characteristics:
- cannot be plotted in real time;
- it makes sense for reflectivity only;
- it probably is the map which best summarizes the weather situation.

... OTHERS ...

CLUTTER IDENTIFICATION

CLUTTER: all echoes we're not interested in (especially ground echoes)

Several algorithms can be used for decluttering radar maps, on the basis of:

- statistical clutter databases
- Digital model of the terrain
- doppler velocity
- spatial variance of Z_{DR}
- other

But:

decluttering is not easy, because:

- ground clutter's position varies in radar maps due to the changes of the refractive index of the atmosphere
- ground clutter echo intensity varies as well (wet or dry surface, ...)
- ground clutter's doppler velocity is not always null (for example, leaves can vibrate ...)
- Using polarimetric measurements is time-consuming
- Many radars don't have polarimetric capabilities at all

We use a combined method (at least two clutter markers must be positive) which seems to work fine.

Clutter removal is very important in the generation of precipitation maps

Bright Band

It's a very common feature in stratiform precipitation

Ice particles melt below the freezing level and their reflectivity assumes the maximum value before they are completely melted.

The bright band can cause a misleading in rainfall estimation. The relations that are normally used are valid for raindrops only (i.e. below the bright band).

The detection of the bright band gives information about the zero-level height and can be very helpful in particle identification

ATTENUATION

Wavelengths normally used in radarmeteorology are attenuated by atmospheric gases and hydrometeors.

	Light rain	Heavy rain / hail
S-band	negligible	negligible
C-band	negligible	significant
X-band	significant	critical

NOTE: rainfall attenuates H-polarized fields more than V-polarized fields (due to drops oblateness)

thus

Attenuation has significant effects on Z_{DR} (it can assume even negative values)

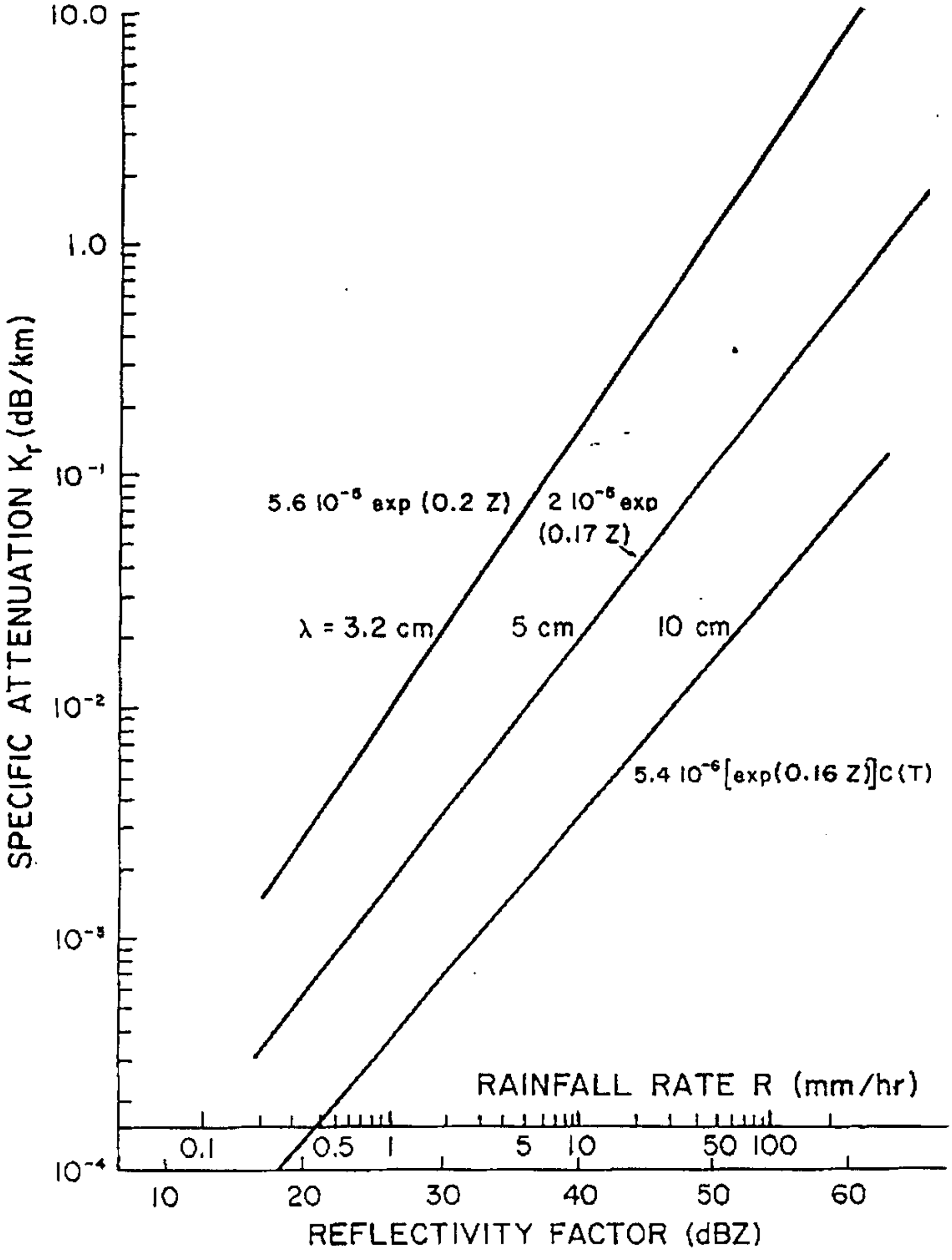


Fig. 3.5 Specific attenuation versus rainfall rate (T = 18°C). The Laws and Pars

Radar volume ⇔ 3-D **polar** database

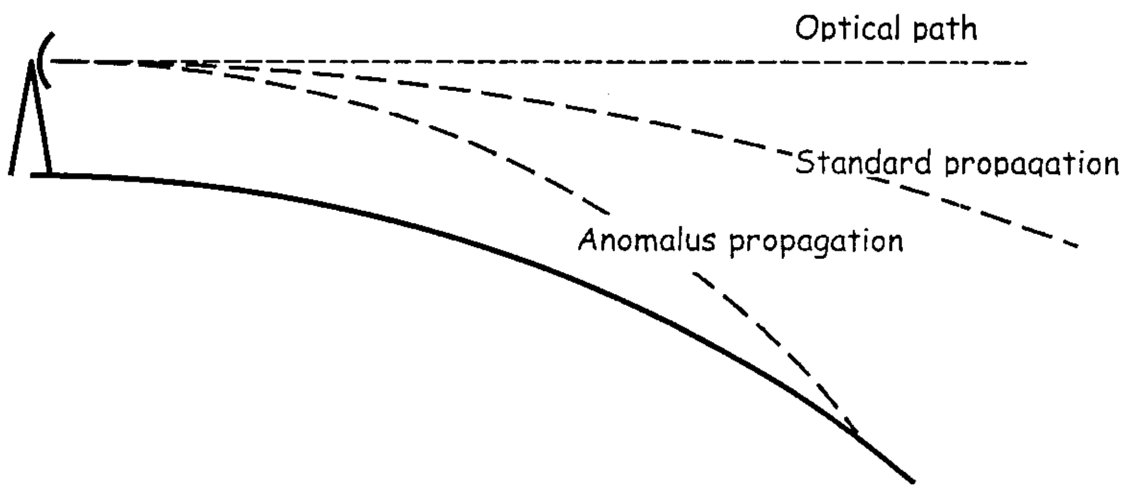
Usually a 3-D **cartesian** database is built starting from the radar volume. To evaluate the height of every range bin, a value of $4/3 \cdot R_0$ for the equivalent Earth's radius is assumed,

but

it is possible, and it frequently happens, that

ANOMALOUS PROPAGATION

occurs



CONSEQUENCES: - strong ground clutter echoes
- second trip echoes

Rainfall Estimation

Problems:

- radar cannot directly measure rainfall intensity
- the radar cannot make measurements at the ground level
- unpredictable phenomena can take place while raindrops are falling

Anyway:

- precipitation maps are the most requested radar products
- by using radar in rainfall estimation (instead of rain gauges) it is possible to cover a wide area (100 km range) with just one instrument

Note:

- relevant errors can affect the estimation

Estimation algorithms:

- **Z-R algorithms**

  $Z = a \cdot R^b$ (Z [mm^6/m^3], R[mm/h])
  If a=200, b=1.6 ⇨ Marshall-Palmer relation

- **(Z, Z_{DR})-R algorithms**

  $Log_{10}(R) = 0.835 + 0.1 \cdot (Z - 30 - 4.86 \cdot Z_{DR})$ (Z [dBZ], Z_{DR}[dB])
  ⇨ Sachidananda-Zrnic

PSEUDO-CAPPI's Construction