# Chapter 8

# Active Remote Sensing of the Atmosphere

## 8.1 Radar sounding of rain

The Radar (Radio Detection and Ranging) is an active instrument that sends out and detects electromagnetic radiation. The basic principle of any radar system is to measure the distance to an object by measuring the travel time of the signal.

A weather radar uses wavelengths that are little affected by air molecules and cloud droplets, but interact with rain drops. Typical wavelengths $\lambda$ are in the order of 5–10 cm. Table 1 gives an overview of frequency bands used for radar remote sensing.

Example: The Tropical Rainfall Measuring Mission (TRMM) uses a spaceborne radar at 13.8 GHz. It was launched into orbit in 1997.

| Band | Frequency [GHz] | Wave length [mm] | Examples |
|---|---|---|---|
| L | 1 – 2 | 300 – 150 | |
| S | 2 – 4 | 150 – 80 | Precipitation radars USA |
| C | 4 – 8 | 80 – 40 | Precipitation radars Germany |
| X | 8 – 12 | 40 – 25 | |
| $K_u$ | 12 – 18 | 25 – 17 | |
| K | 18 – 27 | 17 – 12 | |
| $K_a$ | 27 – 40 | 12 – 7.5 | |
| W | 95 | 3 | Cloud radars |

A radiation pulse is emitted and the backscattered signal is received after travel time t. The distance (range) $r$ to the scattering object is then

$$r = 1/2ct \tag{8.1}$$

with $c$ the speed of light.

For a circular paraboloid antenna, the beam width (the full width at half maximum of the main lobe) is given by

$$\Theta = \frac{\lambda}{d} \tag{8.2}$$

with $\lambda$ wavelength and $d$ the antenna diameter. The transmitted power $P_t$ is then emitted into a solid angle

$$\Omega_t = 2\pi \left(1 - \cos\frac{\Theta}{2}\right) \tag{8.3}$$

The transmitted radiance is then

$$L_t = \frac{P_t}{\Omega_t A} \tag{8.4}$$

where $A$ is the antenna area.

Assume that the sampled volume is filled with scatterers with scattering coefficient $\sigma$ and scattering phase function $p(\psi)$. Then the backscattered radiance (towards the antenna) is given by

$$L_r = \Delta r \frac{\sigma}{4\pi} L_t p(180°)\Omega_r \tag{8.5}$$

with $\Omega_r = A/r^2$. $\Delta r = 1/2c\Delta t$ with the pulse duration $\Delta t$.

The received power $P_r$ is then

$$P_r = L_r A \Omega_t \tag{8.6}$$

Remember that for Rayleigh scattering

$$p(180°) = \frac{3}{2} \tag{8.7}$$

and

$$\sigma = \pi a^2 \frac{8}{3} \left(\frac{2\pi a}{\lambda}\right)^4 \left|\frac{n^2 - 1}{n^2 + 2}\right|^2 N \tag{8.8}$$

with $a$ the radius of the scattering particles, $n$ the refractive index of the scatterers and $N$ the number of scattering particles per unit volume. In terms of the drop diameter $D = 2a$ and using $|K| = (n^2 - 1)/(n^2 + 2)$ we get for the backscattering cross section

$$\sigma \cdot p(180^\circ) = \frac{\pi^5}{\lambda^4}|K^2| \sum_{\text{particles per volume}} D^6 \tag{8.9}$$

Introducing the so called radar reflectivity factor $Z$:

$$Z = \sum_{\text{particles per volume}} D^6 \tag{8.10}$$

one gets for the received power

$$P_r = \text{const.} \cdot \frac{|K^2|Z}{r^2} \tag{8.11}$$

This is the radar equation.

There is no unique relation between the radar reflectivity factor $Z$ and the cloud liquid water or the rain rate. Emirically one can write a relation between the radar reflectivity factor $Z$ and the rain rate $R$:

$$\frac{Z}{Z_0} = a \left( \frac{R}{R_0} \right)^b \tag{8.12}$$

with $Z_0 = 1\text{mm}^6/\text{m}^3$ and $R_0 = 1\text{mm/h}$. The empirical coefficients may vary for different situations (e.g. summer versus winter). E.g. the German Weather Service (DWD) uses $a = 256$ and $b = 1.42$.