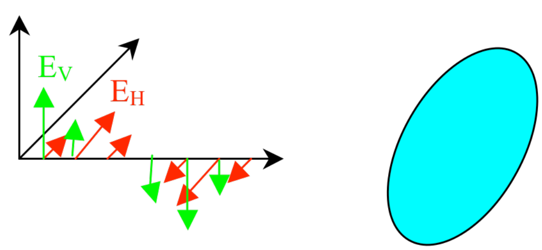
Calculation of Polarimetric Radar Variables

1 Learning Objectives:

- Understand and apply the physical meaning, formal definition and formulas of the following polarimetric radar variables:
  - Reflectivity
  - Differential reflectivity
  - Specific attenuation
  - Differential specific attenuation
  - Specific differential phase.
- Master the procedures of calculating radar variables with an assumed raindrop size distribution (DSD) model and measured DSD data.
- Gain background knowledge about polarimetric radar observables.

2 Introduction

Electromagnetic wave scattering from non-spherical hydrometeors is different for horizontal and vertical polarization, which can be used to accurately characterize cloud/precipitation microphysics.



Polarimetric radar variables, which are the signatures of electromagnetic wave scattering from a targeted medium, depend on the size, shape, orientation, and density (composition) of the hydrometeors. They are as follows:

- Radar reflectivity factors at the horizontal and vertical polarizations ($Z_{H,V}$) are integrations of the DSD weighted by scattering cross section as

$$Z_{H,V} = \frac{4\lambda^4}{\pi^4 |K_w|^2} \int_{D_{\min}}^{D_{\max}} |f_{hh,vv}(D)|^2 N(D) dD \quad [\mathrm{mm^6\ m^{-3}}] \qquad (1)$$

  where D is the equivolume diameter of a hydrometeor, $f_{hh,vv}(D)$ are the backscattering amplitudes at the horizontal and vertical polarizations (depending on the size, shape, orientation, and composition), K_w is the dielectric factor of water, and λ is the radar wavelength. $N(D)$ specifies the drop size distribution.

- The differential reflectivity¸Z_{DR} is defined as the ratio of the reflectivity factors at the horizontal and vertical polarizations and is expressed by

$$Z_{DR} = 10\log\left(\frac{Z_H}{Z_V}\right) \quad [\mathrm{dB}] \qquad (2)$$

- Specific attenuation for horizontally and vertically polarized waves are represented by forward scattering amplitudes $f_{hh,vv}(0, D)$ as follows:

$$A_{H,V} = 8.686\lambda \int_{D_{min}}^{D_{max}} \mathrm{Im}[f_{hh,vv}(0,D)] N(D) dD \qquad [\mathrm{dB\ km^{-1}}] \qquad (3)$$

- Specific differential attenuation:

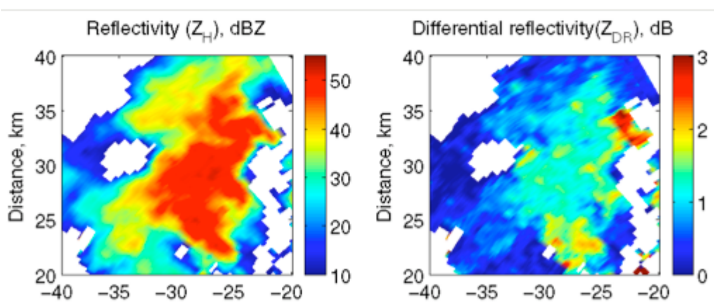
$$A_{DP} = A_H - A_V \qquad [\mathrm{dB\ km^{-1}}] \qquad (4)$$

- Specific differential phase:

$$K_{DP} = \frac{180\lambda}{\pi} \int_{D_{min}}^{D_{max}} \mathrm{Re}[f_{hh}(0,D) - f_{vv}(0,D)] N(D) dD \qquad [\mathrm{degree\ km^{-1}}] \qquad (5)$$

All of the above polarimetric radar variables are expressed in terms of scattering amplitudes and a DSD.

In Norman, Oklahoma the KOUN radar is an experimental dual-pole radar that is operated by the National Severe Storms Laboratory, in close collaboration with its university partners. The radar's data may be processed to reveal important information about the atmosphere, as depicted here.



In summary, polarimetric radar measurements lead accurate QPE (rainfall rate) and detailed information of microphysics such as:

- **Number concentration**
- **Median volume diameter**
- **Shape of drop size distribution**
- **Evaporation rate and**
- **Accretion rate**

3 Hands-on activities

Use the given scattering amplitudes in the forward direction (Tmtxforwd.dat) and that in backward direction (Tmtxbkwd.dat) of raindrops calculated from the T-matrix method. Calculate and plot polarimetric radar variables: Z_{hh}, Z_{DR}, A_{hh}, A_{DP} and K_{DP} at S-band (f = 2.8 GHz).

Part (1)

- Download the data:
  - www.ou.edu/radar/Tmtxforwd.dat
  - www.ou.edu/radar/Tmtxbkwd.dat
- Use the Marshall-Palmer DSD model of

  $$N(D) = 8000\exp(-\Lambda D) \qquad [\# \text{ m}^{-3} \text{ mm}^{-1}] \qquad (6)$$

  with

  $$\Lambda = 4.1R^{-0.21} \qquad [\text{mm-1}] \qquad (7)$$

  and $|K|^2$ factor at a temperature of 10^o in (1) – (5)
- Perform the calculations
- Plot the polarimetric radar variables as functions of rainfall rate changing from 1 mm/hr to 100 mm/hr.

Part (2)

- Repeat Part (1) with the real rain DSD data provided:
  - www.ou.edu/radar/rainDSDs.zip
- Use the velocity formula of

  $$v(D) = -0.1021 + 4.932D - 0.9551D^2 + 0.07934D^3 - 0.002362D^4 \qquad (8)$$

  to calculate rainfall rate of

  $$R = 6\times 10^{-4}\pi\sum_{i=1}^{L} D_i^3 v(D_i)N(D_i)\Delta D \qquad [\text{mm hr}^{-1}] \qquad (9)$$

- Plot the polarimetric radar variables and rainfall rate versus time.
- Plot ZH and ZDR as functions of rainfall rate.
- Compare the results with that obtained in part (1).
- Discuss possible reasons for the differences.