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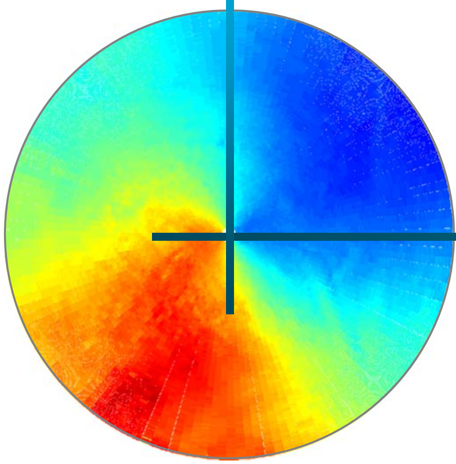

A short course on radar meteorology

Tobias Otto
Herman Russchenberg

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Radar Meteorology

Radar: **R**adio **D**etection **A**nd **R**anging

An electronic instrument used for the detection and ranging of distant objects of such composition that they scatter or reflect radio energy.

Radar Meteorology:

The study of the atmosphere and weather using radar as the means of observation and measurement.

Meteorology:

The study of the physics, chemistry, and dynamics of the Earth's atmosphere.

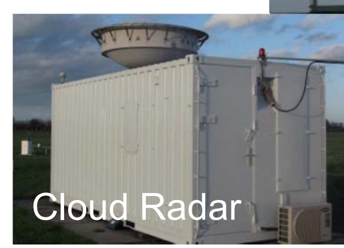
Reference: AMS Glossary

Microwaves

HF	3 - 30	MHz
VHF	30 - 300	MHz
UHF	300 - 1000	MHz
L	1 - 2	GHz
S	2 - 4	GHz
C	4 - 8	GHz
X	8 - 12	GHz
Ku	12 - 18	GHz
K	18 - 27	GHz
Ka	27 - 40	GHz
V	40 - 75	GHz
W	75 - 110	GHz
mm	110 - 300	GHz

mobile phones

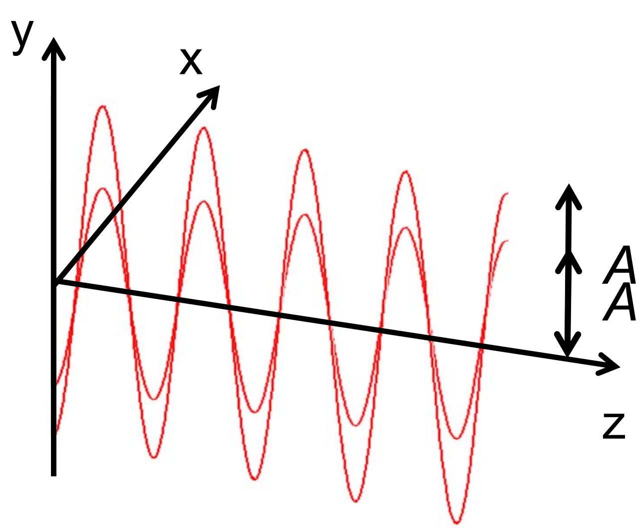
WLAN



Reference: Radar-frequency band nomenclature (IEEE Std. 521-2002)

Information in microwaves

Electromagnetic waves are transversal waves, i.e. their direction of oscillation is orthogonal to their direction of propagation.



1. Amplitude
   can be related to the strength of precipitation / rain rate

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Information in microwaves

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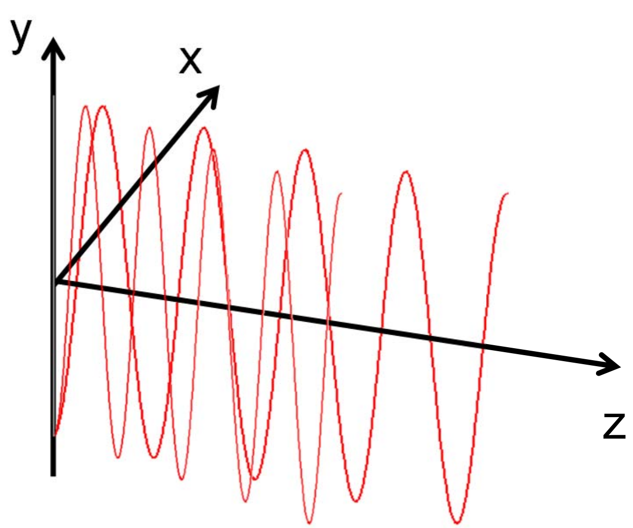

1. Amplitude
   can be related to the strength of precipitation / rain rate
2. Frequency
   Doppler shift, relative radial velocity of the precipitation

Information in microwaves

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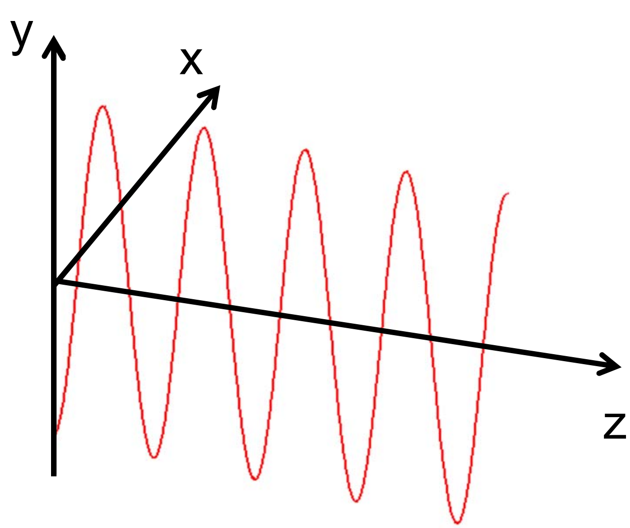

1. Amplitude
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   can be used to measure refractive index variations

Information in microwaves

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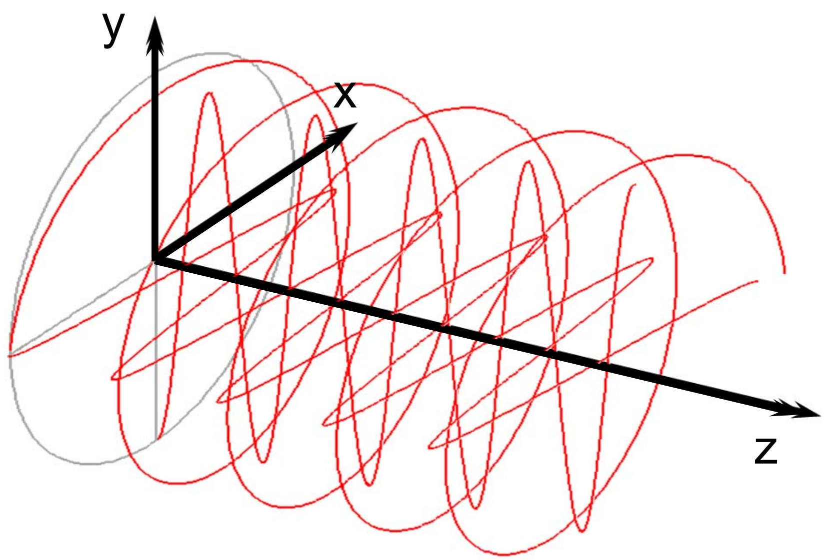
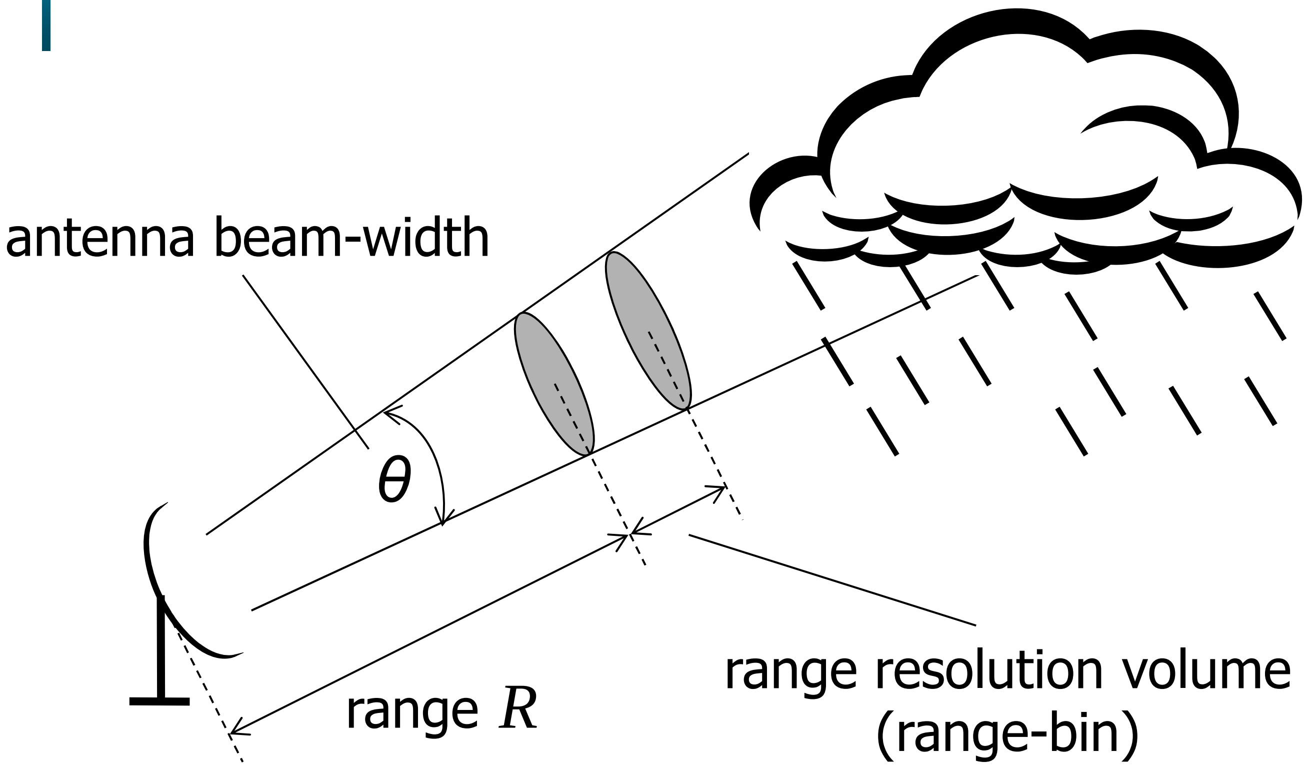


1. Amplitude
   can be related to the strength of precipitation / rain rate
2. Frequency
   Doppler shift, relative radial velocity of the precipitation
3. Phase
   can be used to measure refractive index variations
4. Polarisation
   hydrometeor / rain drop shape

Radar Resolution



$$\Delta r = \frac{c}{2B}$$

c .. speed of light
B .. bandwidth of the transmitted signal

→ Δr is typically between 3m - 300m,
and the antenna beam-width is between 0.5° - 2° for weather radars

Radar Equation for Weather Radar

$$P_r = \frac{\pi^3 P_t G_t G_r \ \theta^2 c}{1024 \ln 2 B \lambda^2} \cdot |K|^2 \sum_{\text{unit volume}} D_i^6 \cdot \frac{1}{R^2}$$

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Radar Reflectivity Factor z

$$z = \sum_{\text{unit volume}} D_i^6 \left(\frac{\text{mm}^6}{\text{m}^3} \right)$$

→ spans over a large range; to compress it into a smaller range of numbers, a logarithmic scale is preferred

$$Z = 10 \log_{10} \left(\frac{z}{1\text{mm}^6 / \text{m}^3} \right) (\text{dBZ})$$

To measure the reflectivity by the weather radar, we need to:

- know the radar constant *C*,
- measure the mean received power P_r,
- measure the range *R*,
- and apply the radar equation for weather radars:

$$z = P_r C R^2$$

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Raindrop-Size Distribution *N(D)*

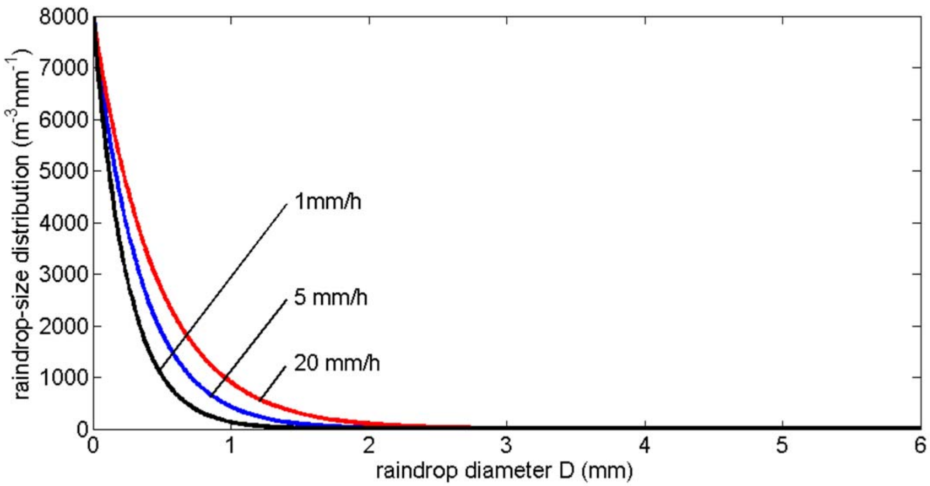
$$z = \sum_{\text{unit volume}} D_i^6$$

where *N(D)* is the raindrop-size distribution that tells us how many drops of each diameter *D* are contained in a unit volume, i.e. 1m^3.

Often, the raindrop-size distribution is assumed to be exponential:

$$N(D) = N_0 \exp(-\Lambda D)$$

concentration (m^{-3}mm^{-1})   slope parameter (mm^{-1})



Marshall and Palmer (1948):

N_0 = 8000 m^{-3}mm^{-1}
Λ = $4.1 \cdot R^{-0.21}$

with the rainfall rate *R* (mm/h)

Reflectivity – Rainfall Rate Relations

reflectivity (mm^6m^{-3})

$$z = \int_D D^6 N(D)dD$$

liquid water content (mm^3m^{-3})

$$\mathrm{LWC} = \frac{\pi}{6}\int_D D^3 N(D)dD$$

raindrop volume

rainfall rate ($mm\ h^{-1}$)

$$R = \frac{\pi}{6}\int_D D^3 v(D) N(D)dD$$

terminal fall velocity

→ the reflectivity measured by weather radars can be related to the liquid water content as well as to the rainfall rate:

power-law relationship $z = aR^b$

the coefficients *a* and *b* vary due to changes in the raindrop-size distribution or in the terminal fall velocity.

Often used as a first approximation is *a* = 200 and *b* = 1.6

2nd Part - Outline

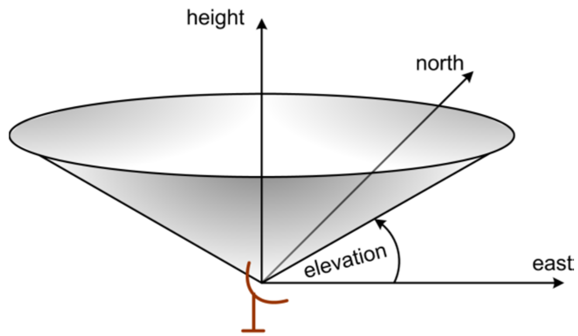
→ radar geometry and displays

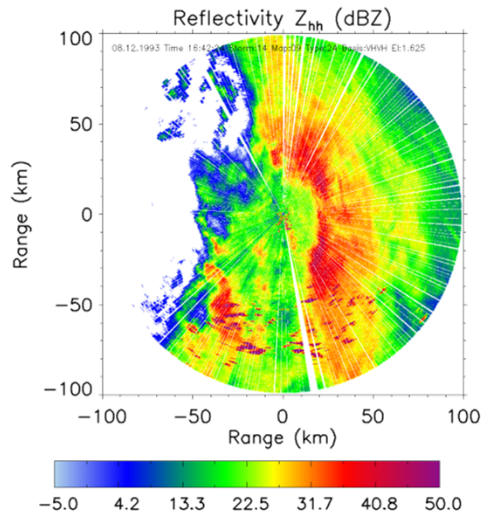
→ Doppler effect

→ polarisation in weather radars

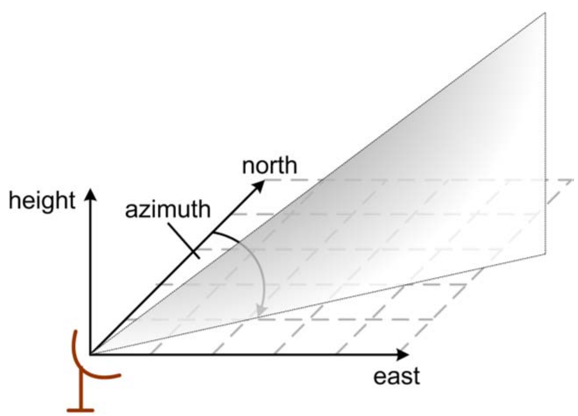
Radar Display

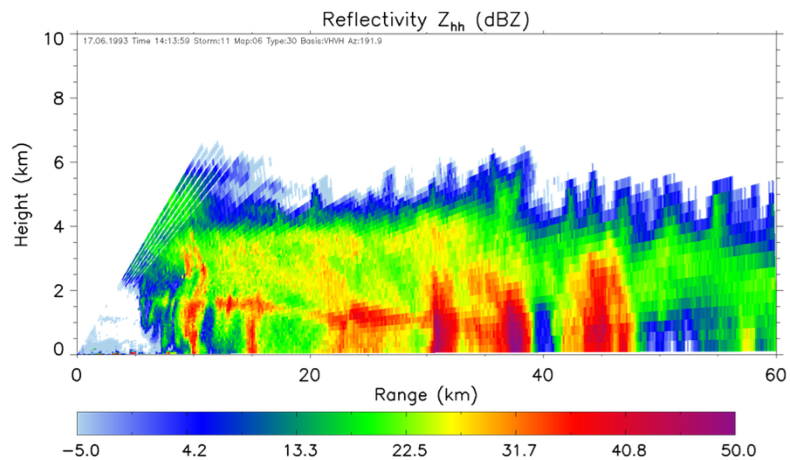
PPI (plan-position indicator):





RHI (range-height indicator):





Data: POLDIRAD (DLR, Oberpfaffenhofen, Germany), Prof. Madhu Chandra

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Doppler Effect

http://en.wikipedia.org/wiki/File:Dopplerfrequenz.gif

$$f_d = \frac{2v_r}{\lambda} \qquad v_{r,\max} = \pm\frac{\lambda}{4T_s}$$

f_d .. frequency shift caused by the moving target

v_r .. relative radial velocity of the target with respect to the radar

λ .. radar wavelength

T_s .. sweep time

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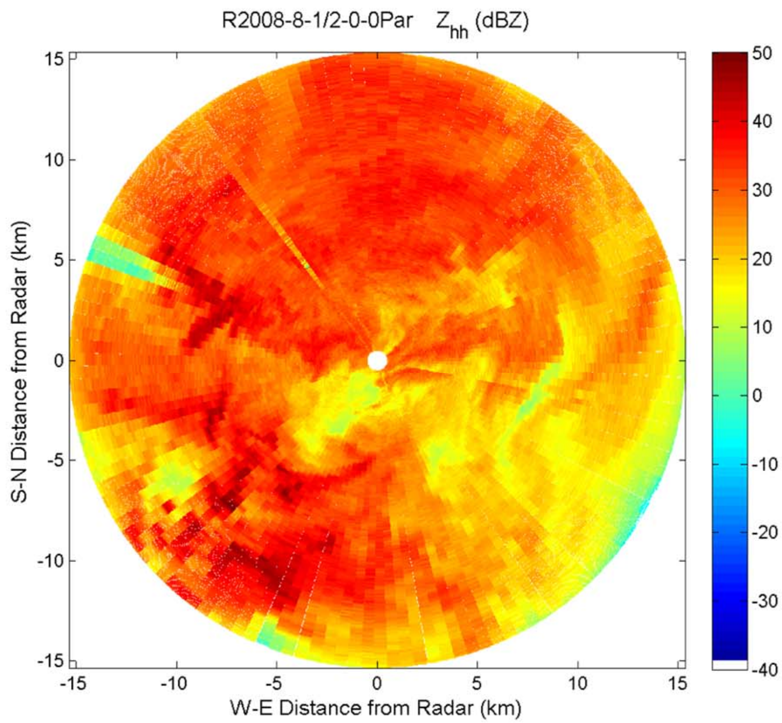
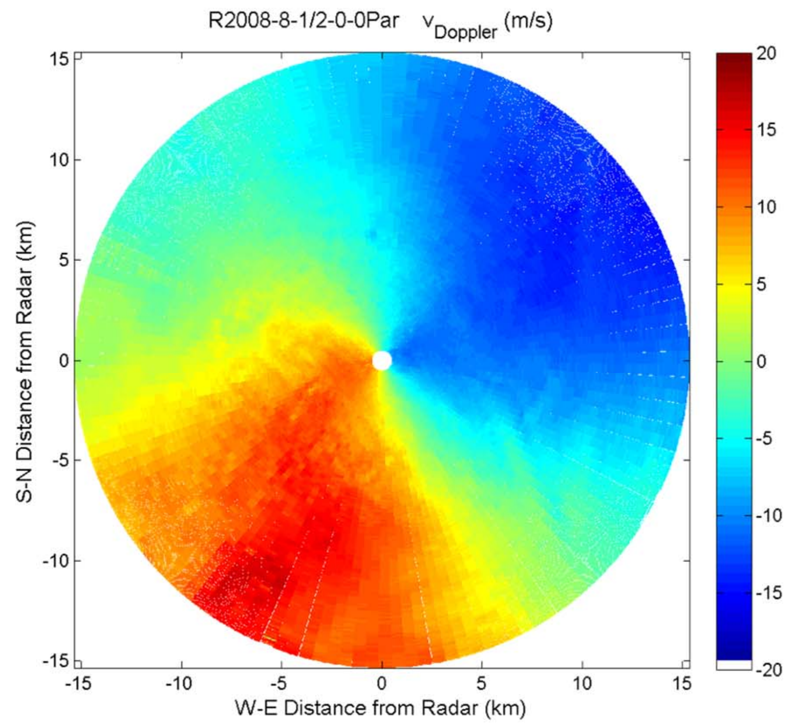
Weather Radar Measurement Example (PPI)



Reflectivity (dBZ)



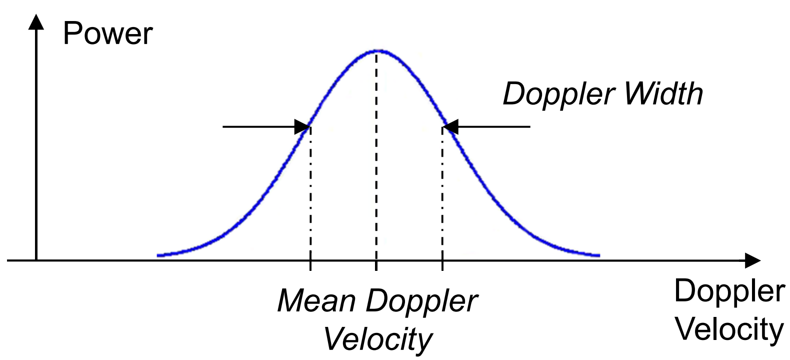
Doppler velocity (ms^{-1})

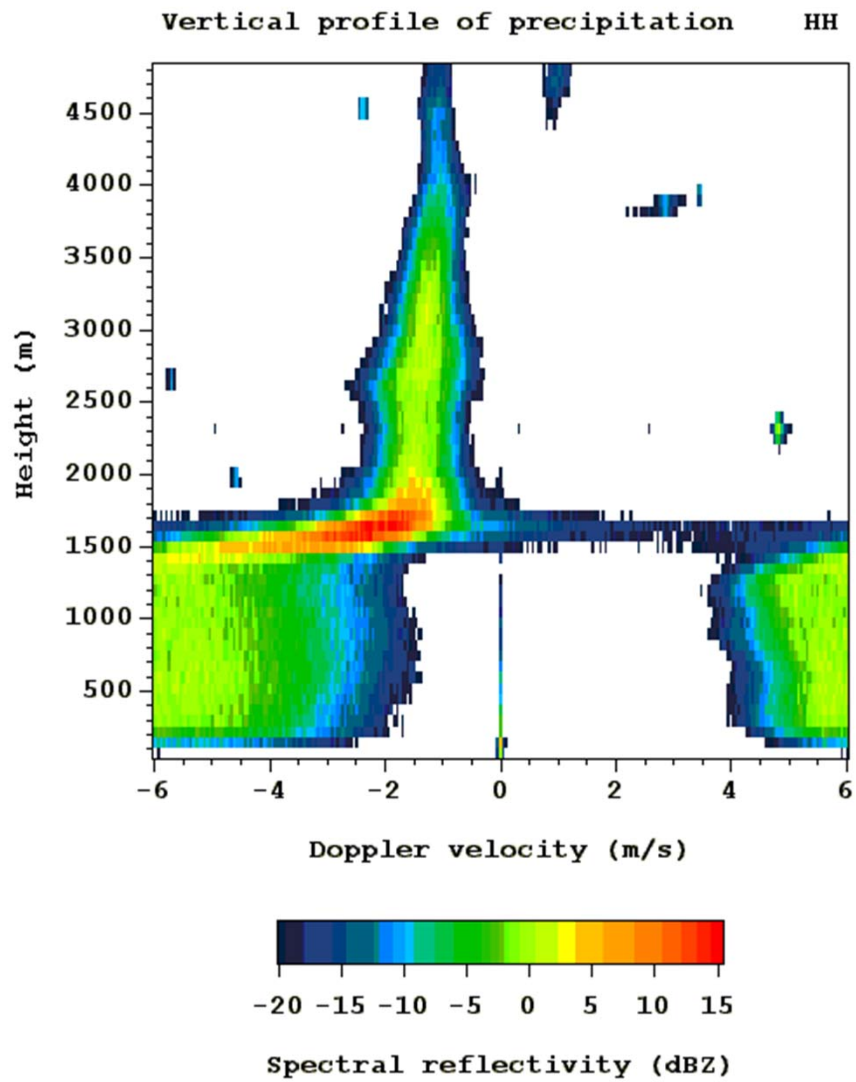
Data: IDRA (TU Delft), Jordi Figueras i Ventura

Combining Reflectivity and Doppler Velocity

Doppler Processing (Power Spectrum):

Mapping the backscattered power of one radar resolution volume into the Doppler velocity domain.





Figures: Christine Unal

2nd Part - Outline

→ radar geometry and displays

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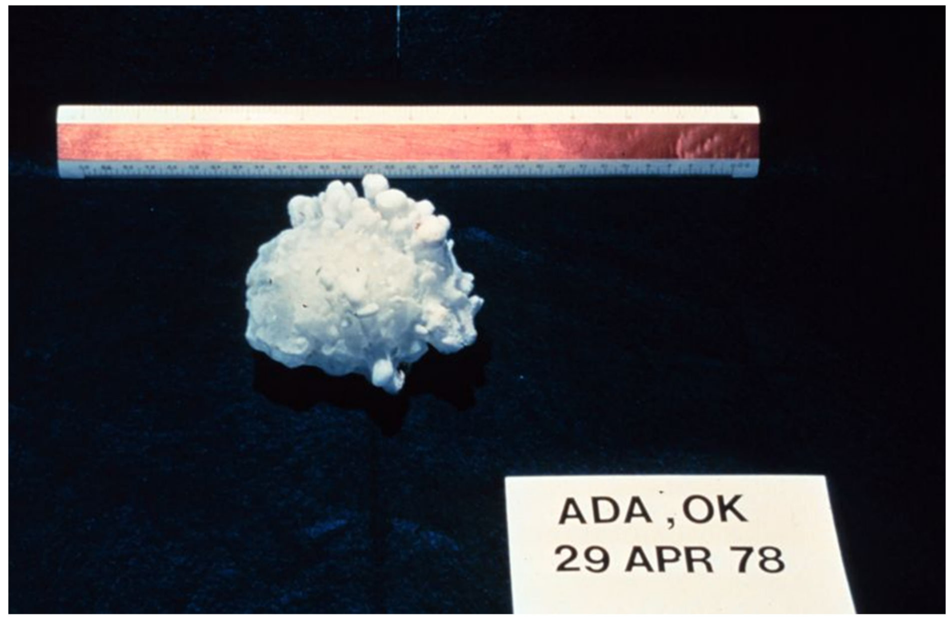
Can Polarimetry add Information

➔ yes, because hydrometeors are not spheres

- ice particles
- hail
- raindrops



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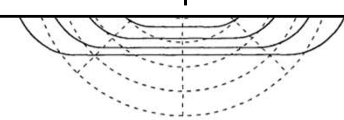
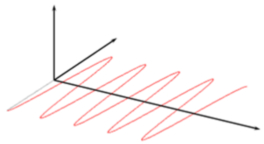
http://commons.wikimedia.org/wiki/Category:Hail



Observed shapes of raindrops

8.00 mm 7.35 5.8 5.30 3.45 2.70

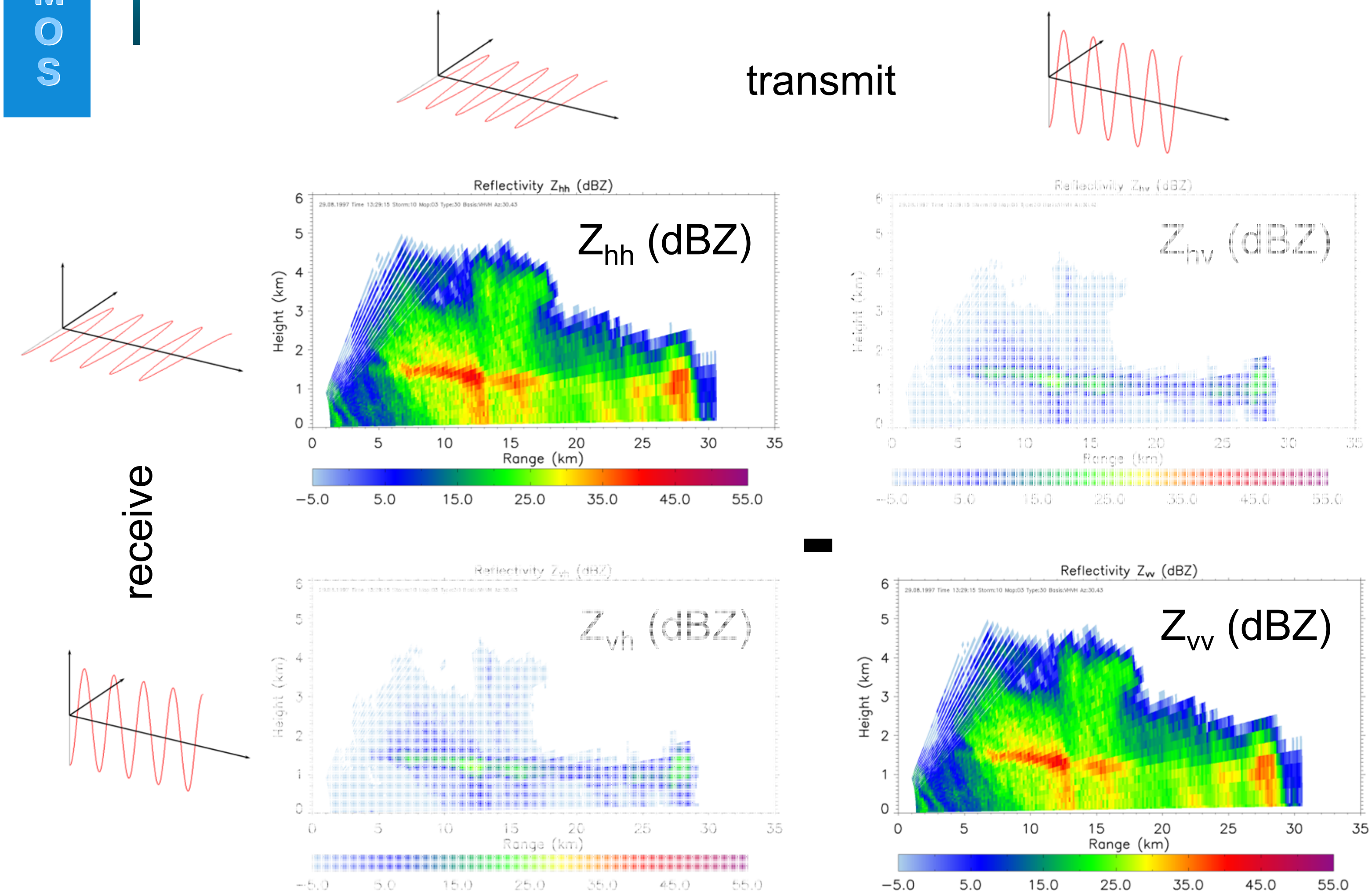
Measurement Principle



transmit

Data: POLDIRAD (DLR, Oberpfaffenhofen, Germany), Prof. Madhu Chandra

Measurement Principle

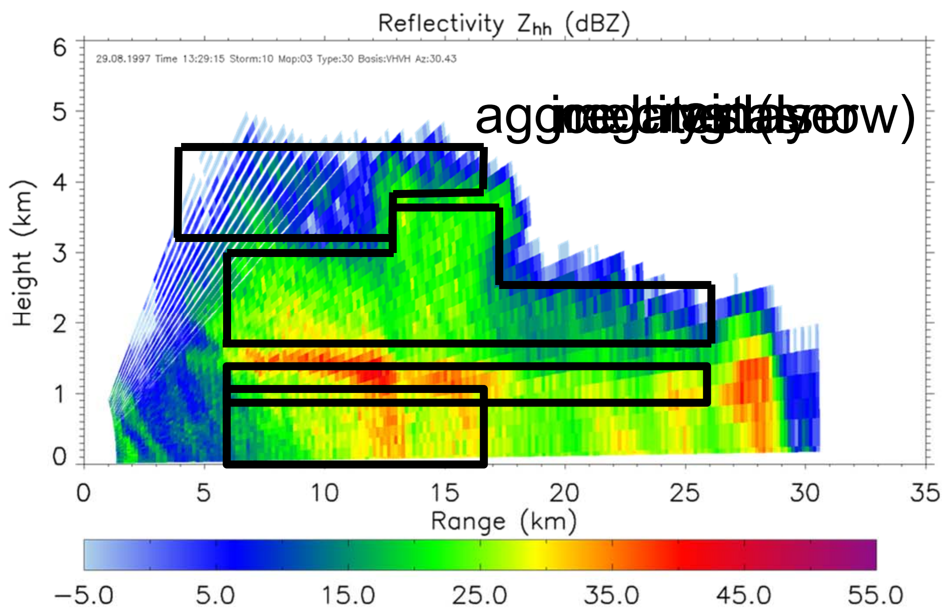


$= Z_{dr}$

differential reflectivity

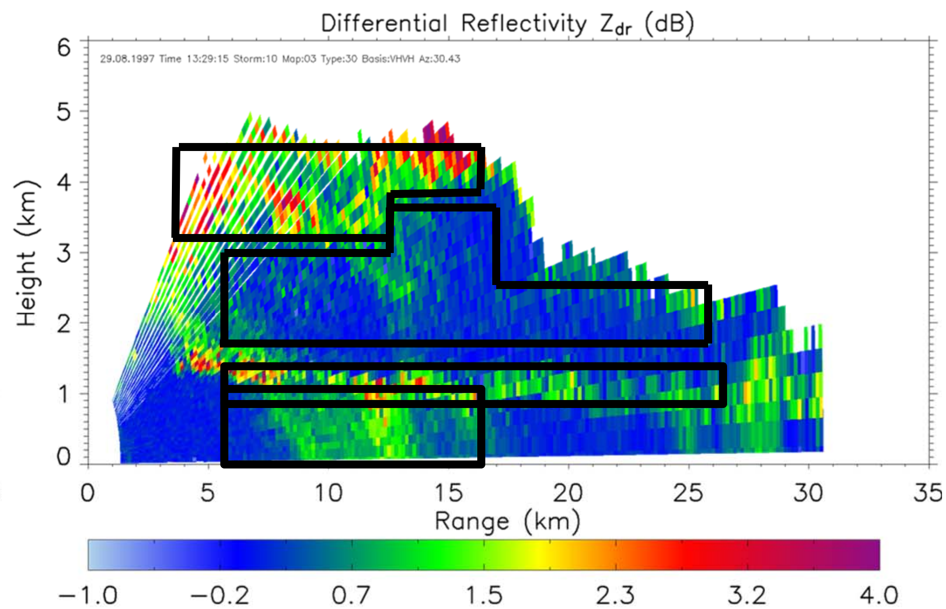
Data: POLDIRAD (DLR, Oberpfaffenhofen, Germany), Prof. Madhu Chandra

Hydrometeor Classification



Reflectivity

$$Z_{hh} = 10\log CR^2 \overline{P}_{hh} \left(\text{dBZ}\right)$$

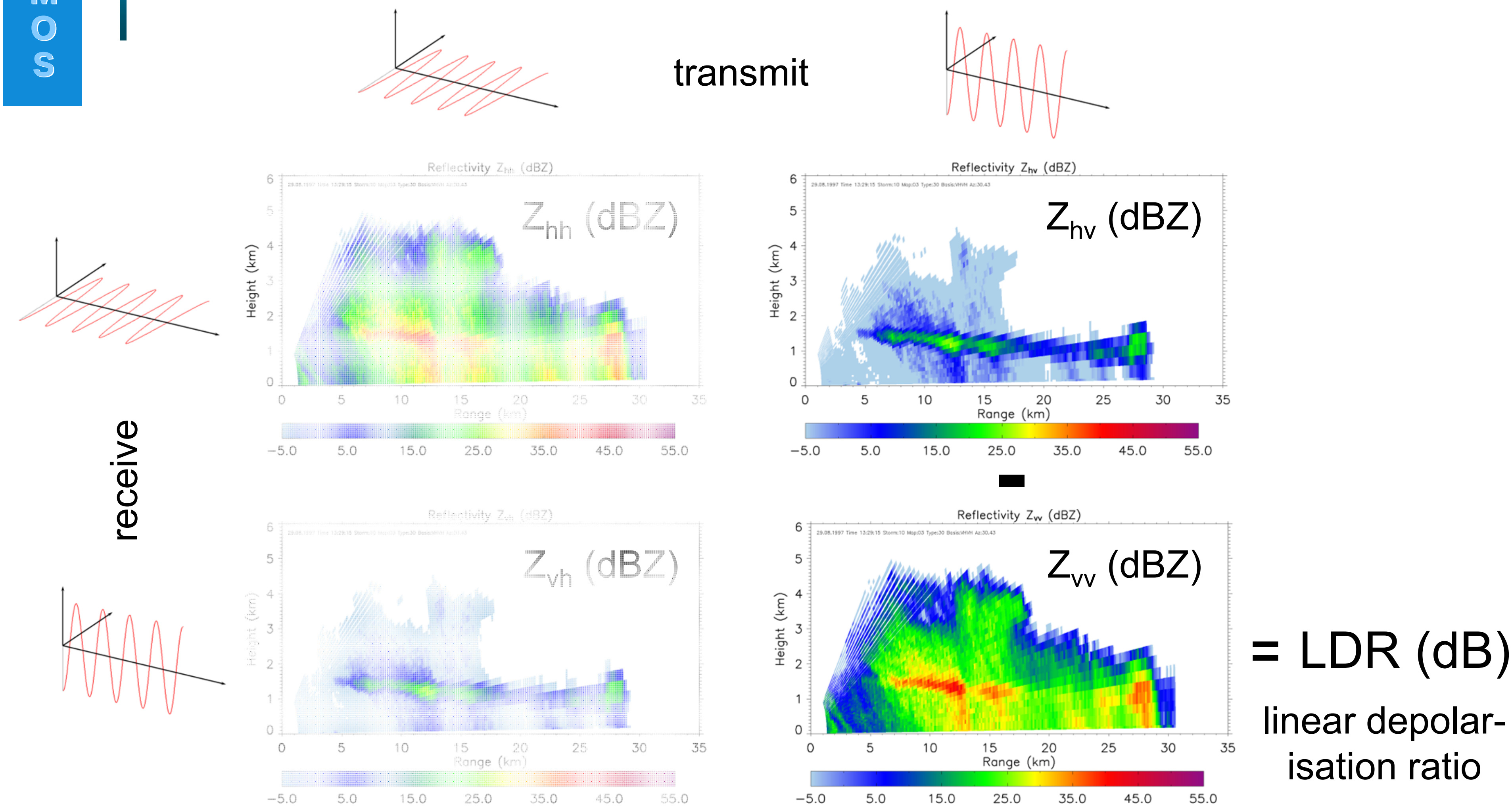


Differential Reflectivity

$$Z_{dr} = 10\log \frac{\overline{P}_{hh}}{\overline{P}_{vv}} \left(\text{dB}\right)$$

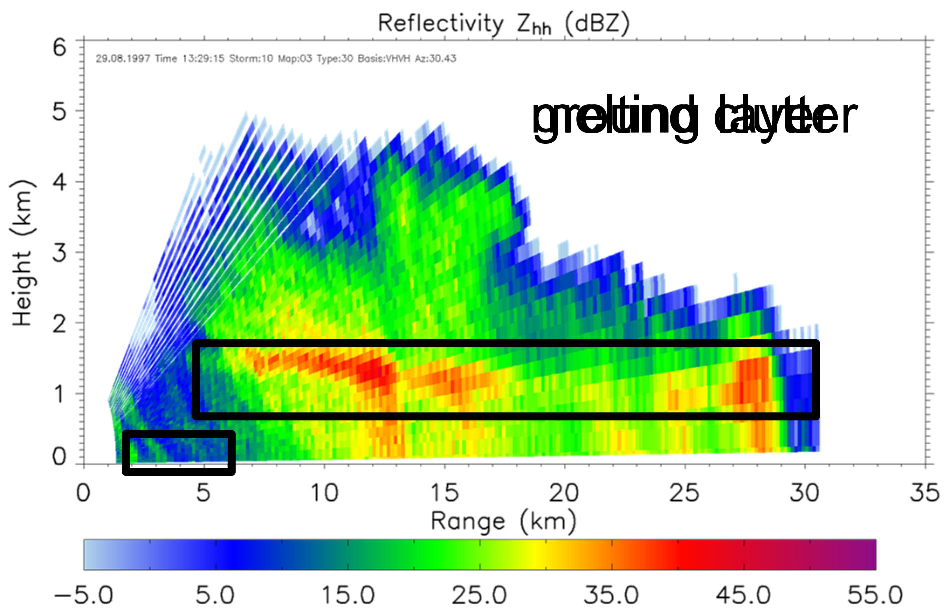
Data: POLDIRAD (DLR, Oberpfaffenhofen, Germany), Prof. Madhu Chandra

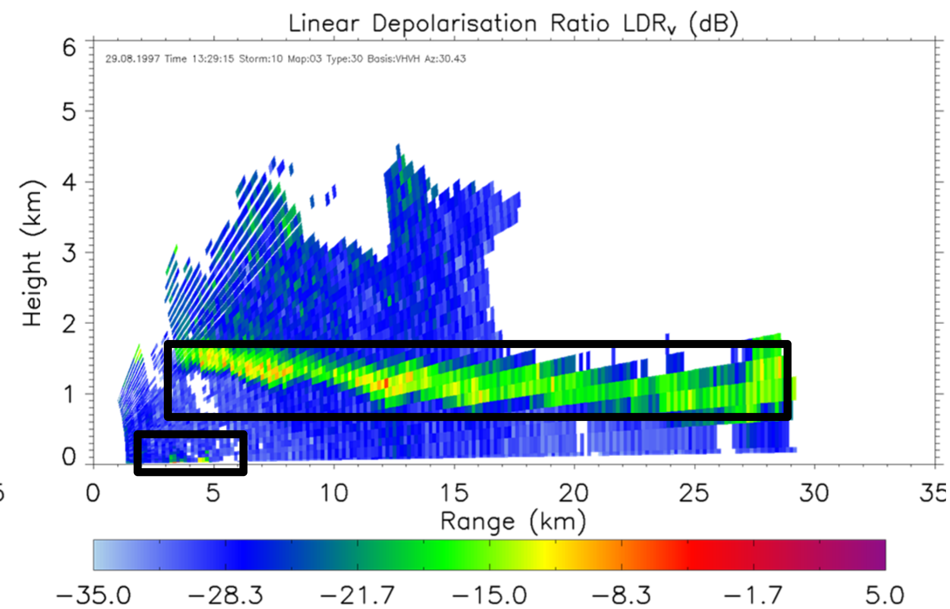
Measurement Principle



Data: POLDIRAD (DLR, Oberpfaffenhofen, Germany), Prof. Madhu Chandra

Linear Depolarisation Ratio





Reflectivity

$$Z_{hh} = 10 \log C R^2 \overline{P}_{hh} \left(\mathrm{dBZ}\right)$$

Linear Depolarisation Ratio

$$LDR = 10 \log \frac{\overline{P}_{hv}}{\overline{P}_{vv}} \left(\mathrm{dB}\right)$$

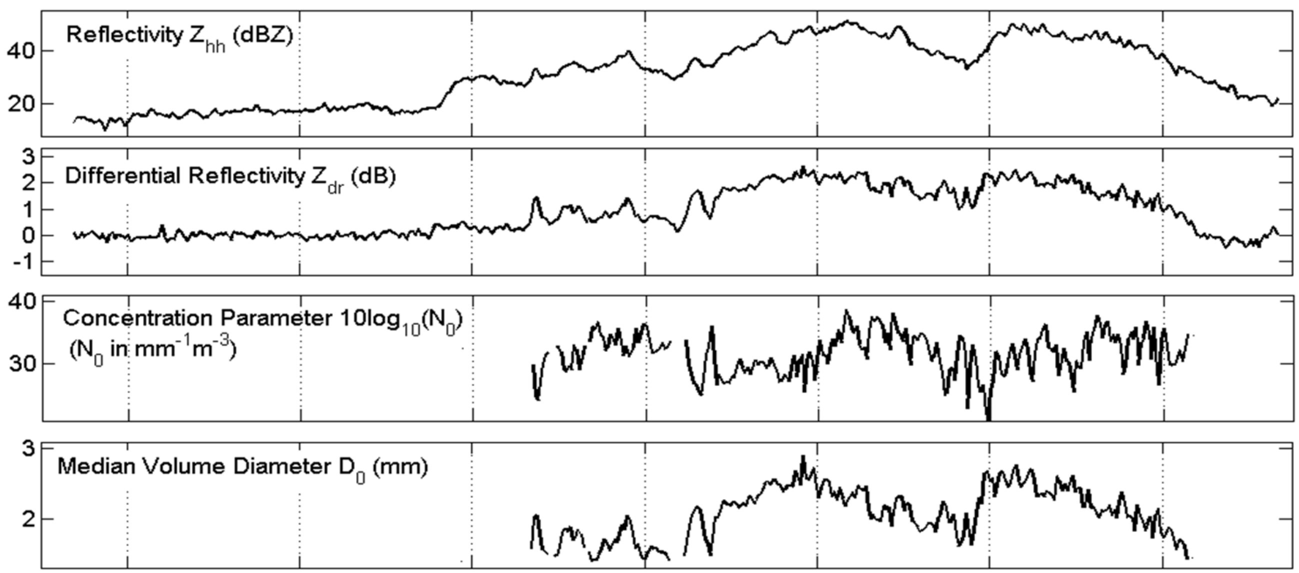
Data: POLDIRAD (DLR, Oberpfaffenhofen, Germany), Prof. Madhu Chandra

Estimation of raindrop-size distribution

$$N(D) = N_0 \exp(-\Lambda D)$$

concentration ($m^{-3}mm^{-1}$) slope parameter (mm^{-1})

1. the differential reflectivity Z_{dr} depends only on the slope parameter Λ, so Λ can be directly estimated from Z_{dr}
2. once that the slope parameter is known, the concentration N_0 can be estimated in a second step from the reflectivity Z_{hh}



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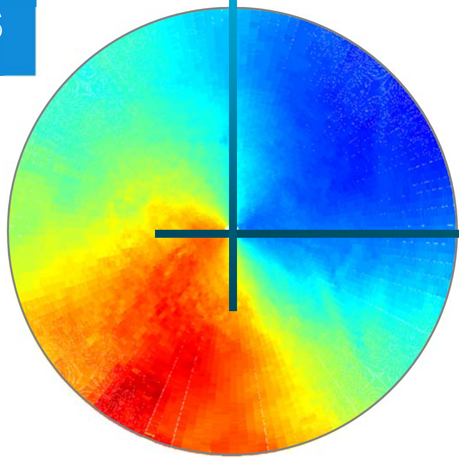

A short course on radar meteorology

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http://rse.ewi.tudelft.nl
http://radar.ewi.tudelft.nl (for information on PARSAX)

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R. J. Doviak and D. S. Zrnić, “Doppler Radar and Weather Observations”, Academic Press, 2nd edition, 1993.

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http://collegerama.tudelft.nl/mediasite/SilverlightPlayer/Default.aspx?peid=1805993fac954c3fba5855bce7e6a86e1d

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S/X data: horizontal and vertical profiling