Polarimetric Weather Radar Remote Sensing

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State of the Art of Weather Radar

- Doppler and dual-polarization
- Cancellation of ground clutter
- Correction of attenuation and propagation effects
- Automatic quality control
- Identification of hydrometeors
- Quantitative estimation of precipitation

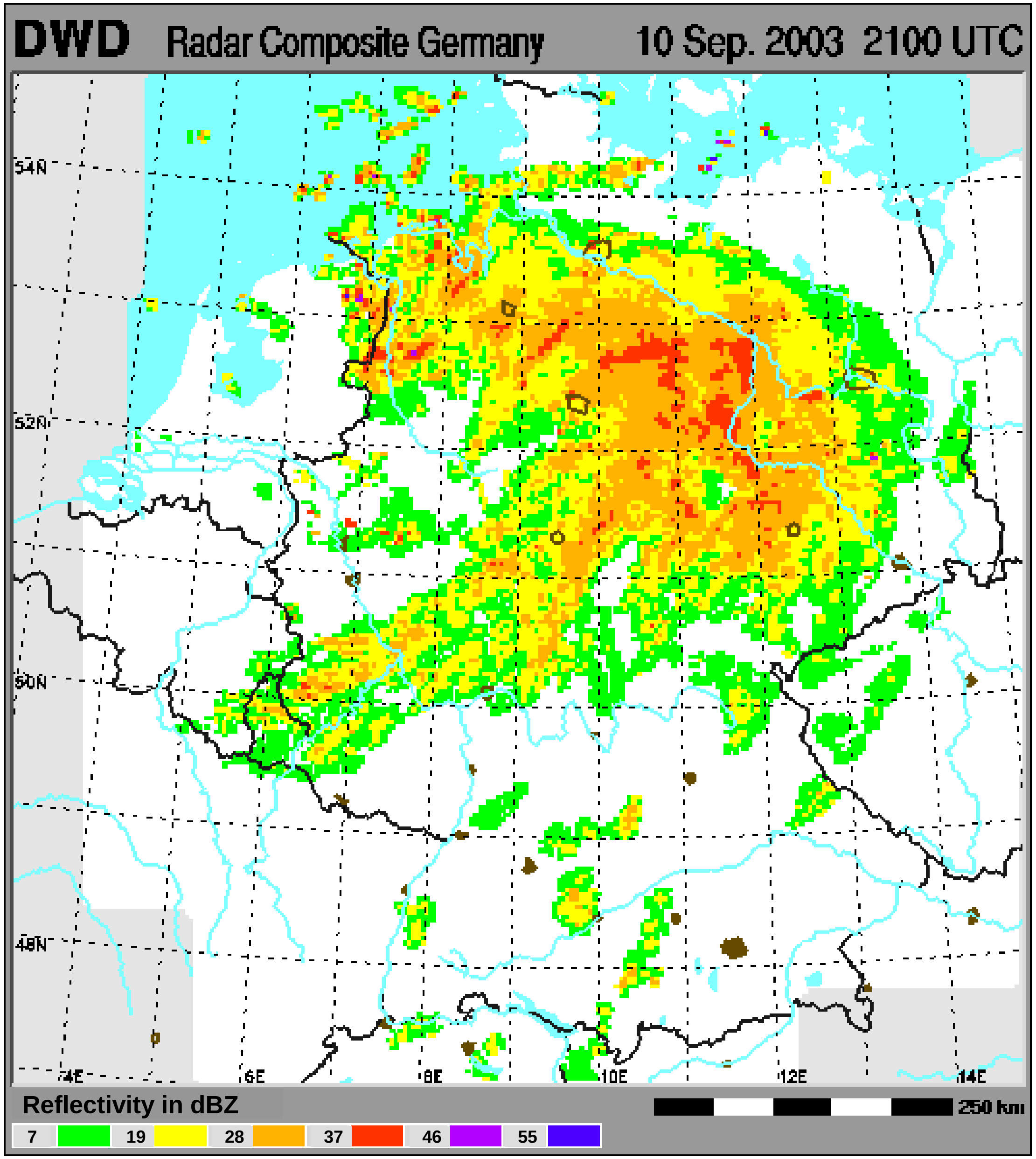
Weather Radar

Combination of 16 weather radars of Deutscher Wetterdienst.

Weather radars are well suited to locate precipitation.

Meteorologists require more:

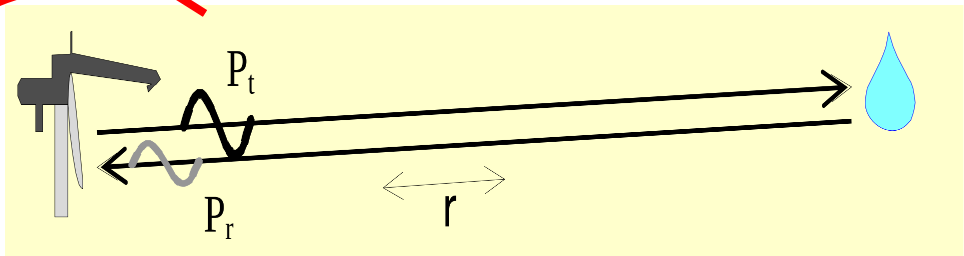
- how much rainfall?
- what kind of hydrometeors?
- how will the weather be in 10 .. 90 minutes?



Radar Principle

Quantification
Identification

Radar: Radio ~~Detection~~ and Ranging



A weather radar measures the power (and phase) of a transmitted electro-magnetic wave packet reflected by a particle:

Radar equation for volume targets:

Radar constant

$$P_r = \frac{P_t \, g^2 \, \lambda^2 \, \theta_0^2 \, h}{1024 \, \ln(2) \, \pi^2 \, r^2} \sum_{Vol} \sigma_i$$

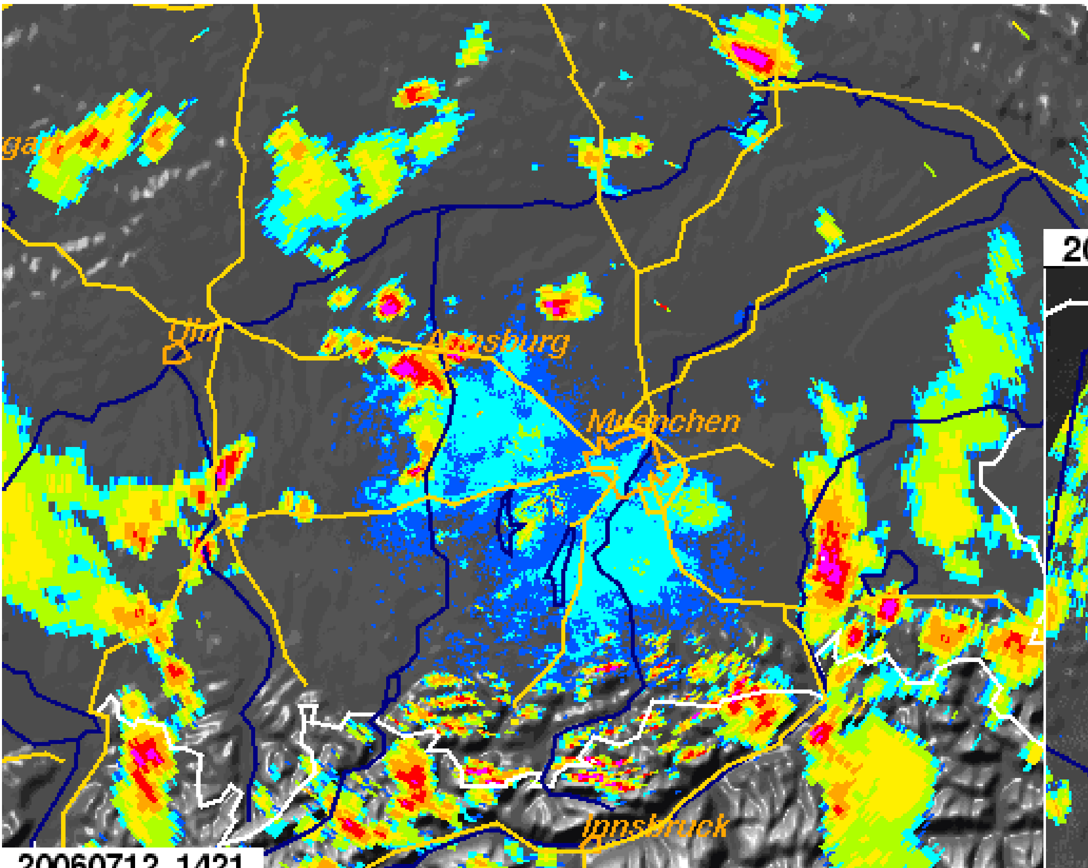
Reflectivity
(sum of the scattering cross-sections)

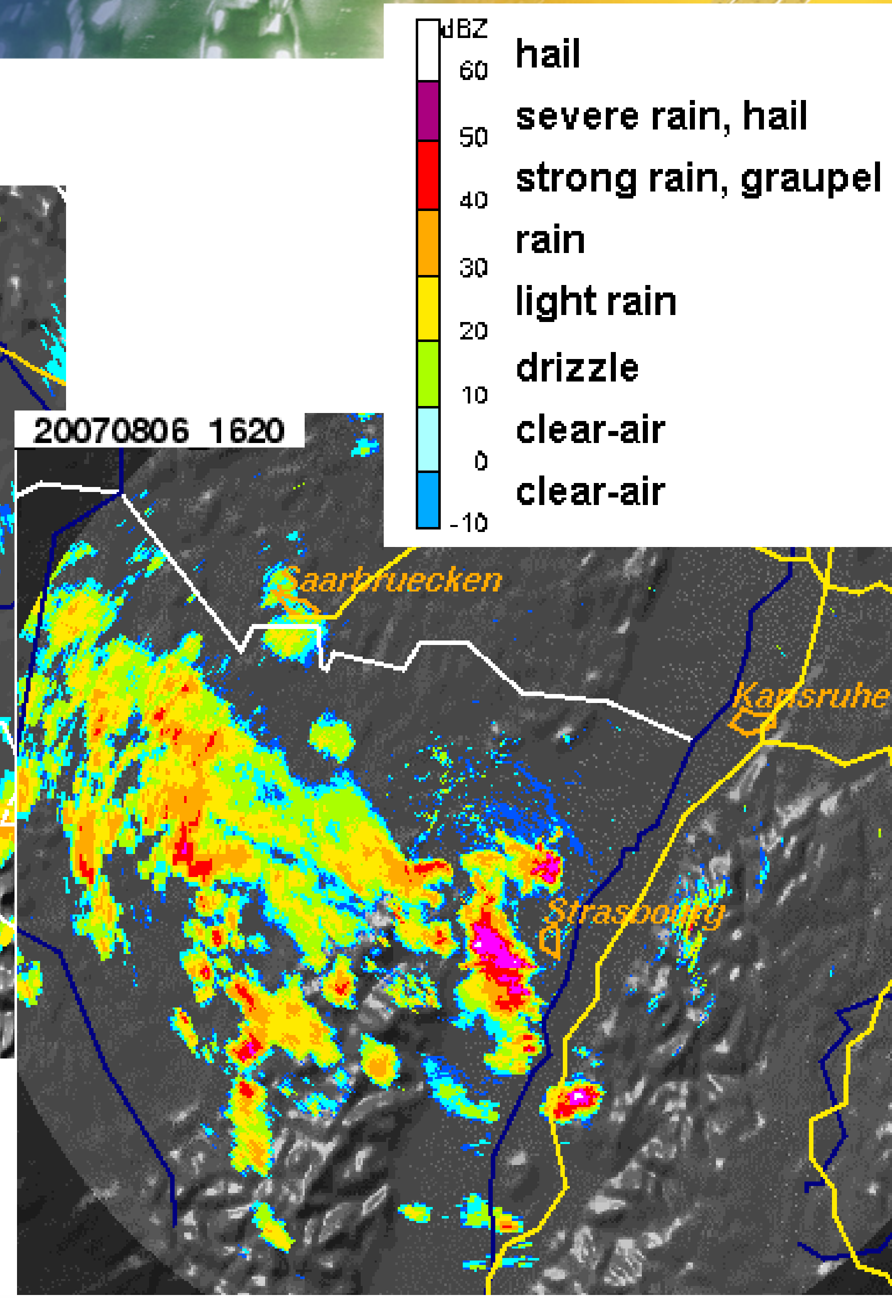
Particles smaller than the wave length:
(C-Band λ = 5 cm, D < 5 mm) Rayleigh-scatter

$$\sigma_i = \frac{\pi^5}{\lambda^4} |K|^2 D_i^6$$

Reflectivityfactor
Unit: $mm^6 \, m^{-3}$
logarithmic
unit: dBZ

Radar Reflectivity Factor

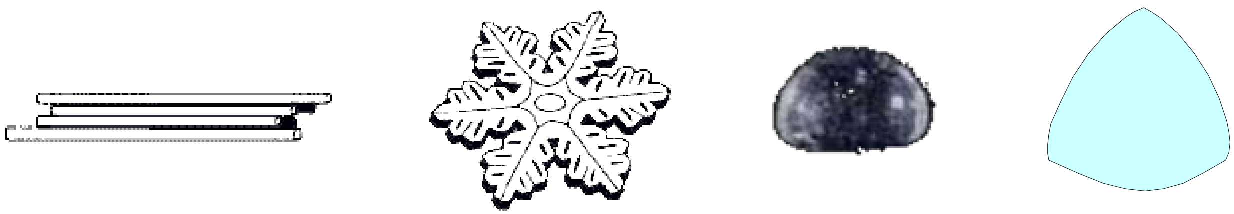




Polarization and Doppler

➡ Microphysics and Dynamics

Cloud and precipitation particles have different shapes, phase, size and falling behaviour

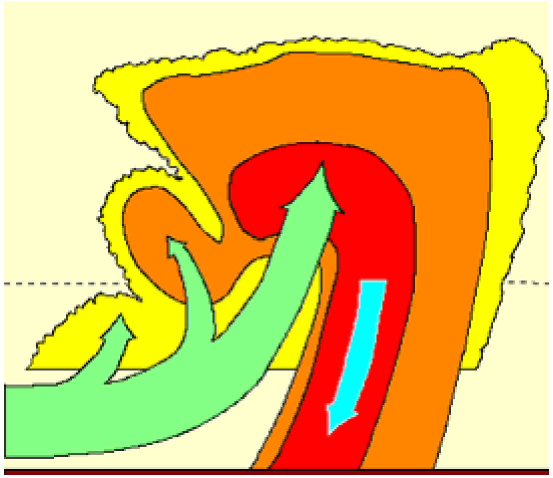


➔ scattering properties ➔ Polarization

Precipitation is directly related to atmospheric motion.

➔ Hydrometeors are displaces

➔ Doppler shift of waves



Polarization and Doppler Radar Development

1960
Doppler Radar
(research)

1985
Doppler Radar
(operational
in Europe)

1995
bistatatic
Doppler Radar

2002
dual-Doppler+Lidar
Assimilation in NWP

1976
polarimetric Radar
(research)
(R-Z-ZDR)

1986
(R-KDP)

1990
polarimetric Radar
(operational, without
substantial success)

2004
polarimetric Radar
(operational,
MeteoFrance)

Weather Radars in Europe (2005)

- (almost) all are Dopplerized
- rapidly increasing number of polarimetric radars

Polarization Doppler Radar POLDIRAD

1986 installed as the first fully polarimetric weather radar in Europe.
Operations normally for research, not for operational service

www.pa.op.dlr.de/poldirad

Samples of research projects:

- Support of hail fighting in the area Rosenheim / Miesbach / Bad Tölz
- Thunderstorm and hail
- Propagation of waves
- Aircraft icing
- Vertical transport of pollutants by thunderstorms
- Thunderstorm and lightning
- Wake turbulence
- Aviation, thunderstorms and snow

. . .

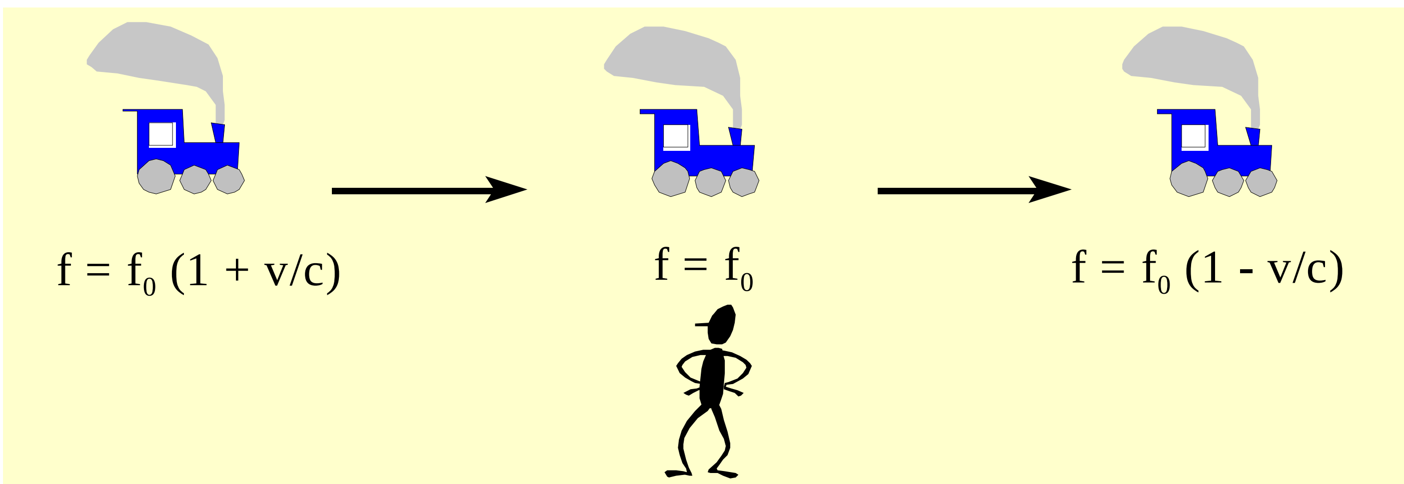
Technical Characteristics

Frequency	5.5035 GHz
Wave Length	5.45 cm
Peak Power	250 kW
Pulse Rep. Freq.	400 - 2400 Hz
Pulse Length	0.5, 1.0, 2.0 µs
Beam Width	1.0°
Maximum Range	300 km
Products	Reflectivity Doppler Velocity Diff. Reflectivity Depolar. Ratio Different. Phase

Doppler

The Doppler effect describes the observed frequency change at a relative motion between:

- signal source and (propagation speed of the signal c)
- observer (relative motion with speed v)



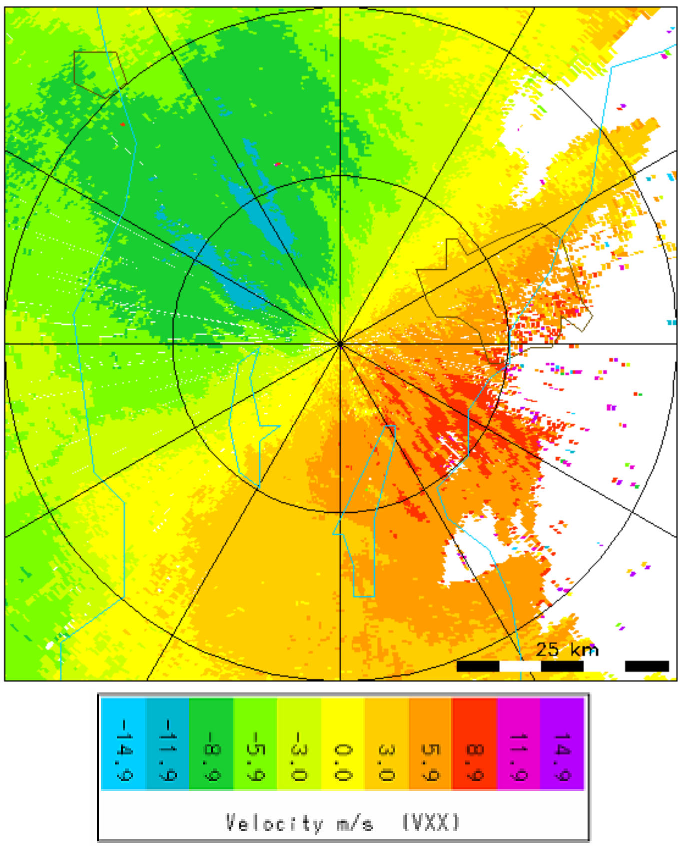
example sound: $v = \pm 20$ m/s, $f_0 = 5$ kHz, $c = 300$ m/s => $f = 5 \pm 0.333$ kHz

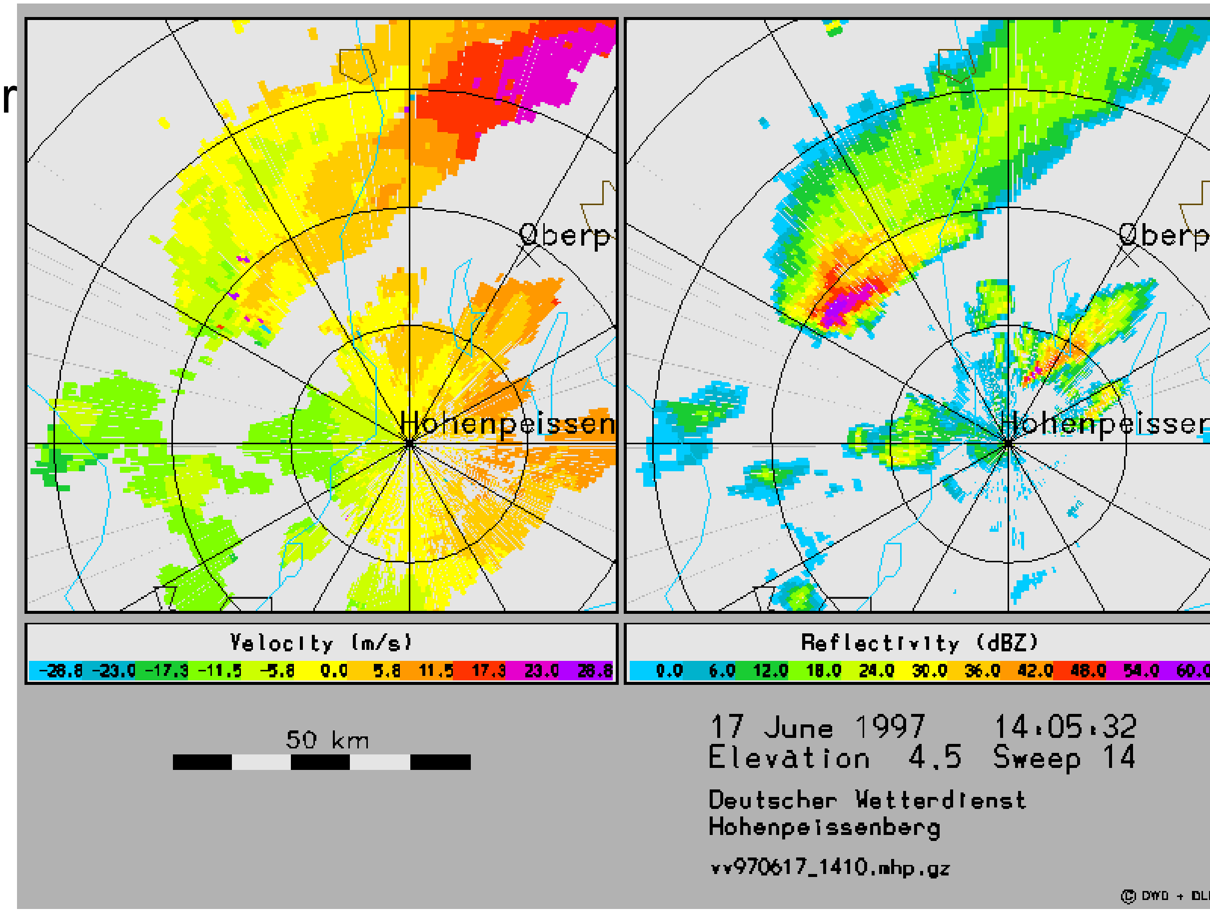
example radar: $v = \pm 20$ m/s, $f_0 = 5$ GHz, $c = 3\times 10^8$ m/s => $f = 5 \pm 0.000000333$ GHz

Interpretation of the Doppler Velocity

blue/green towards radar

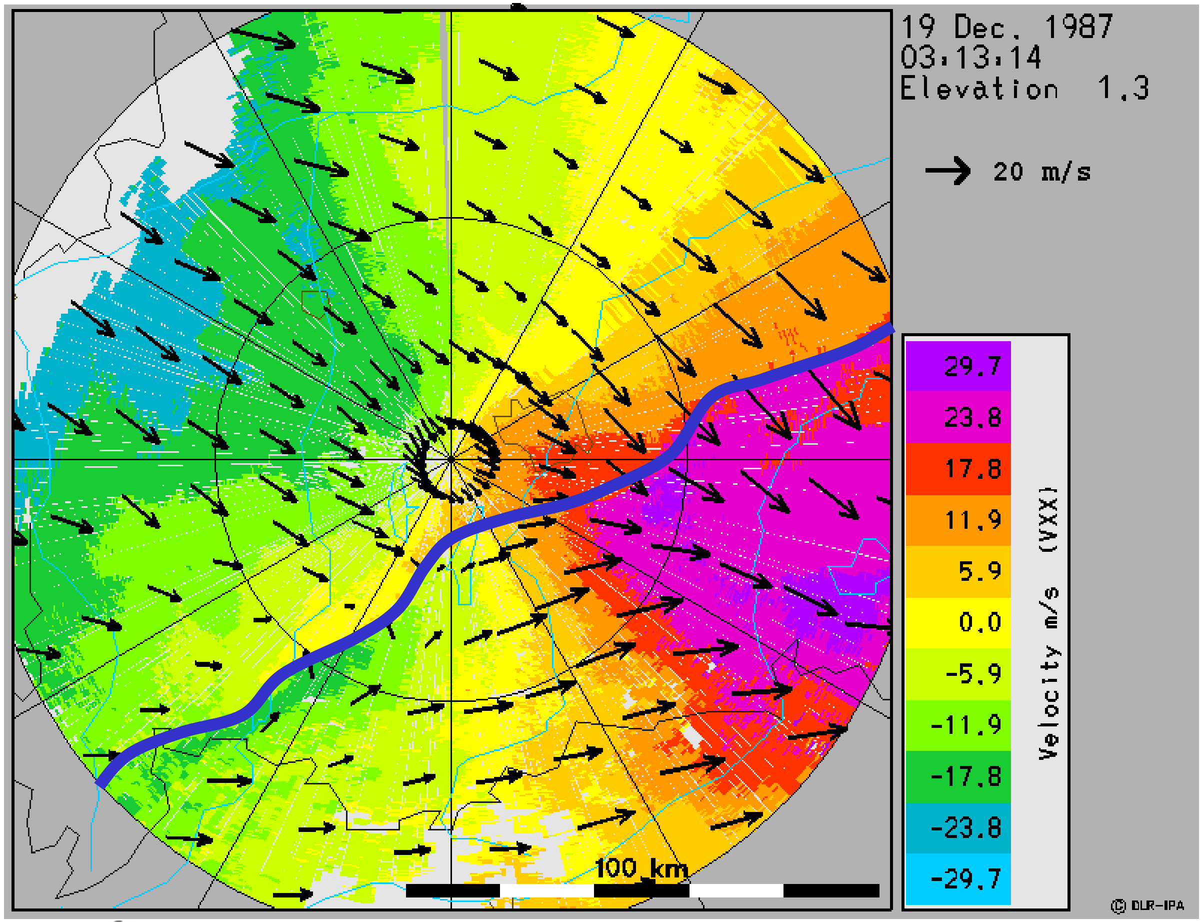
red/orange away from radar

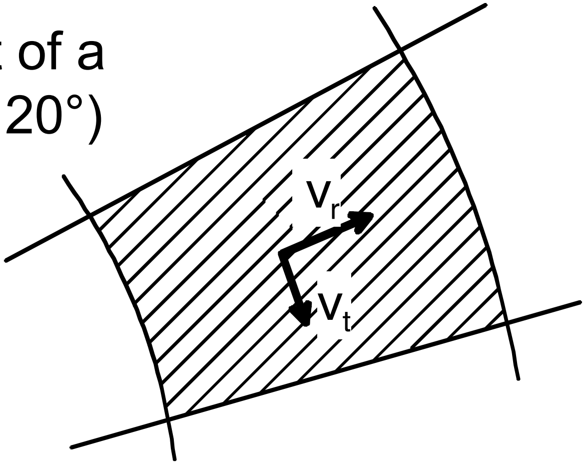




Uniform Wind Technique

Assumption of a constant wind field along a segment of a circle. Average over a sector segment (app. 20 km x 20°)





$$v_r = u_0 \sin\phi \cos\theta + v_0 \cos\phi \cos\theta$$

$$v_t = \partial v_r / \partial\phi$$

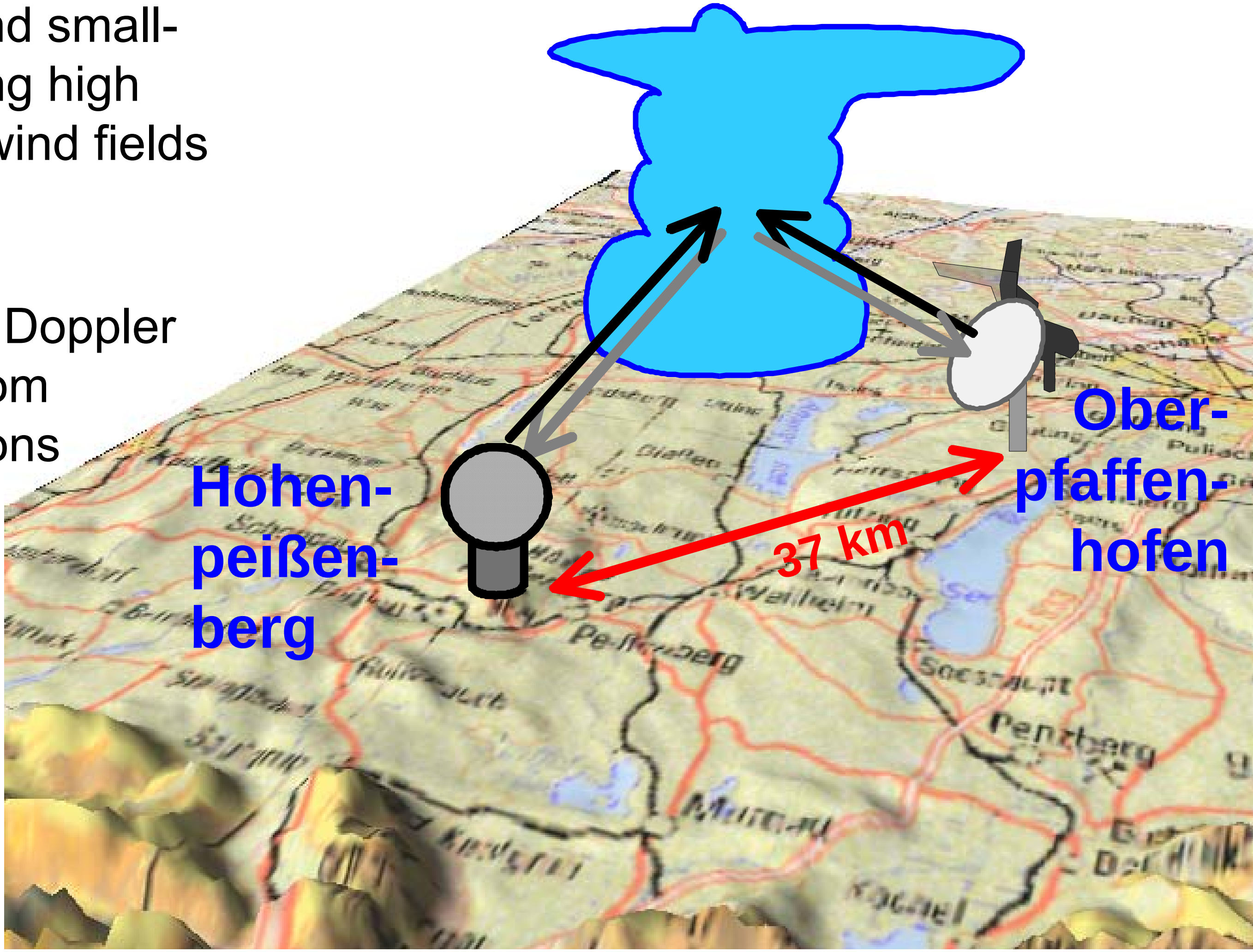
Size of segment:

- get $\partial v_r / \partial\phi$ sufficient accurate
- wind constant within segment.

Dual- Doppler Radar Observations

- For research and small-scale nowcasting high resolution 3-D wind fields are required

- Combination of Doppler observations from different directions using more than one radar

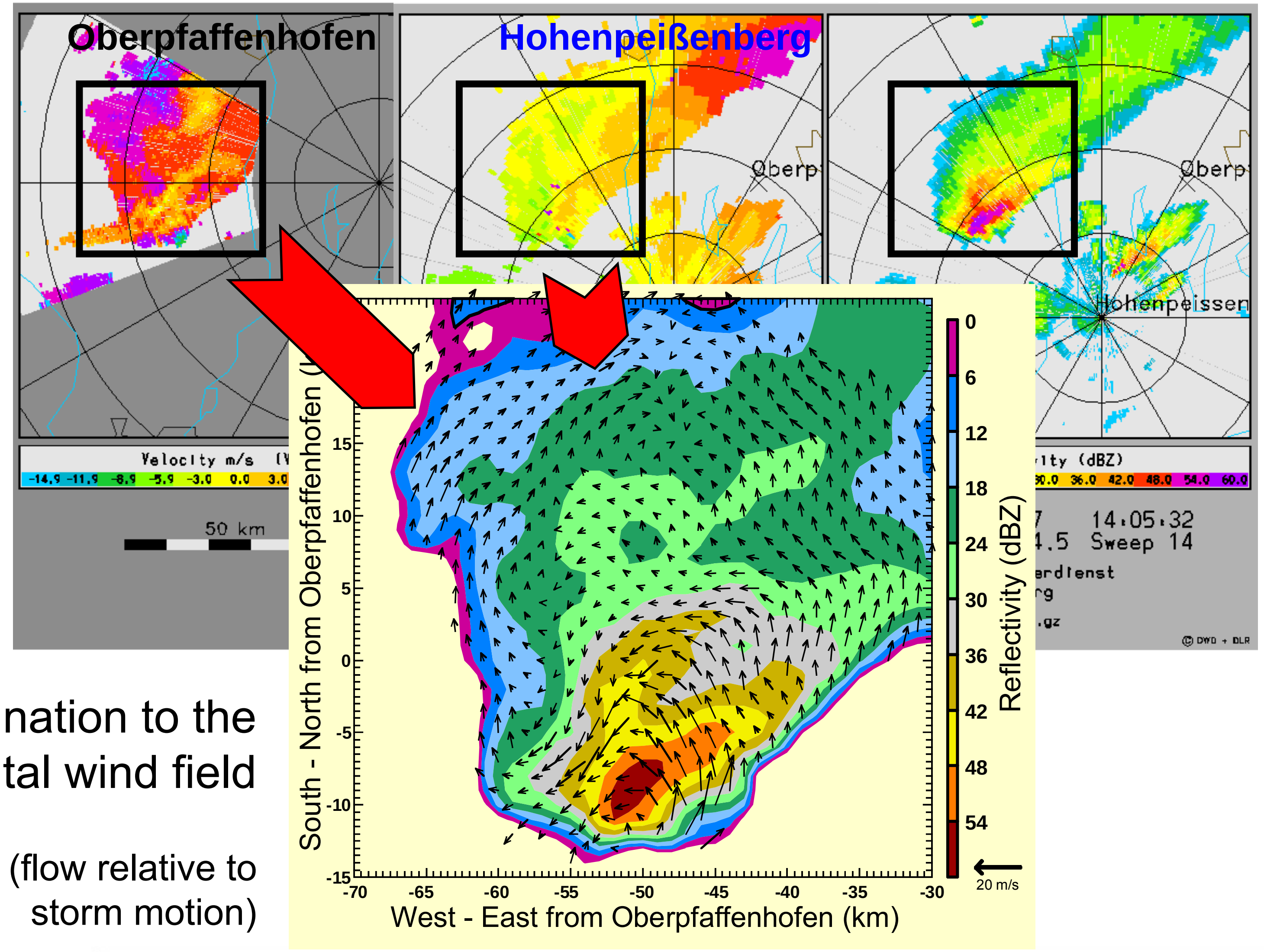


Dual-Doppler Analyse

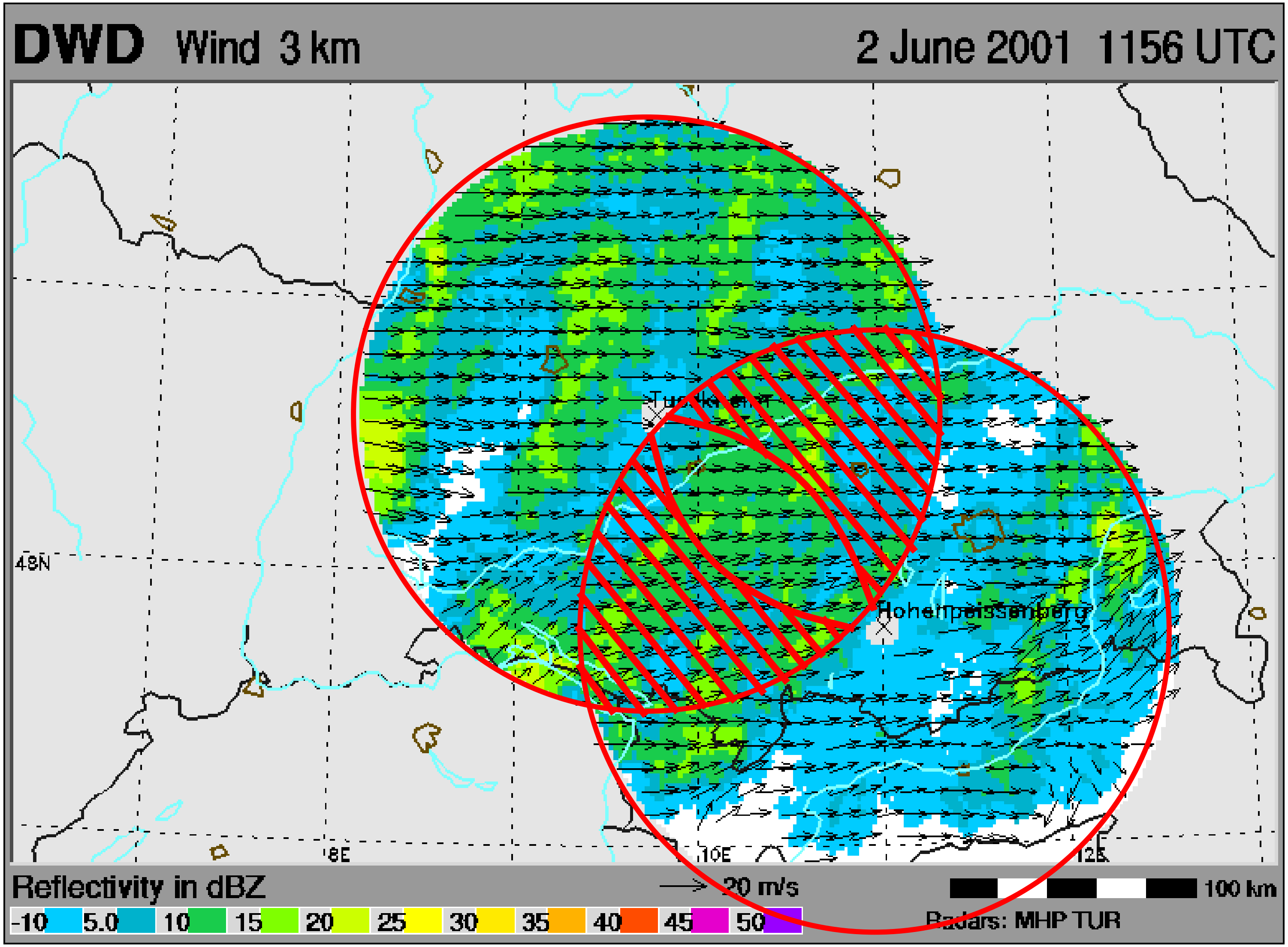
Doppler-velocity measured by the individual radars

Combination to the horizontal wind field

(flow relative to storm motion)



Doppler Wind Field using dual-Doppler and Uniform Wind



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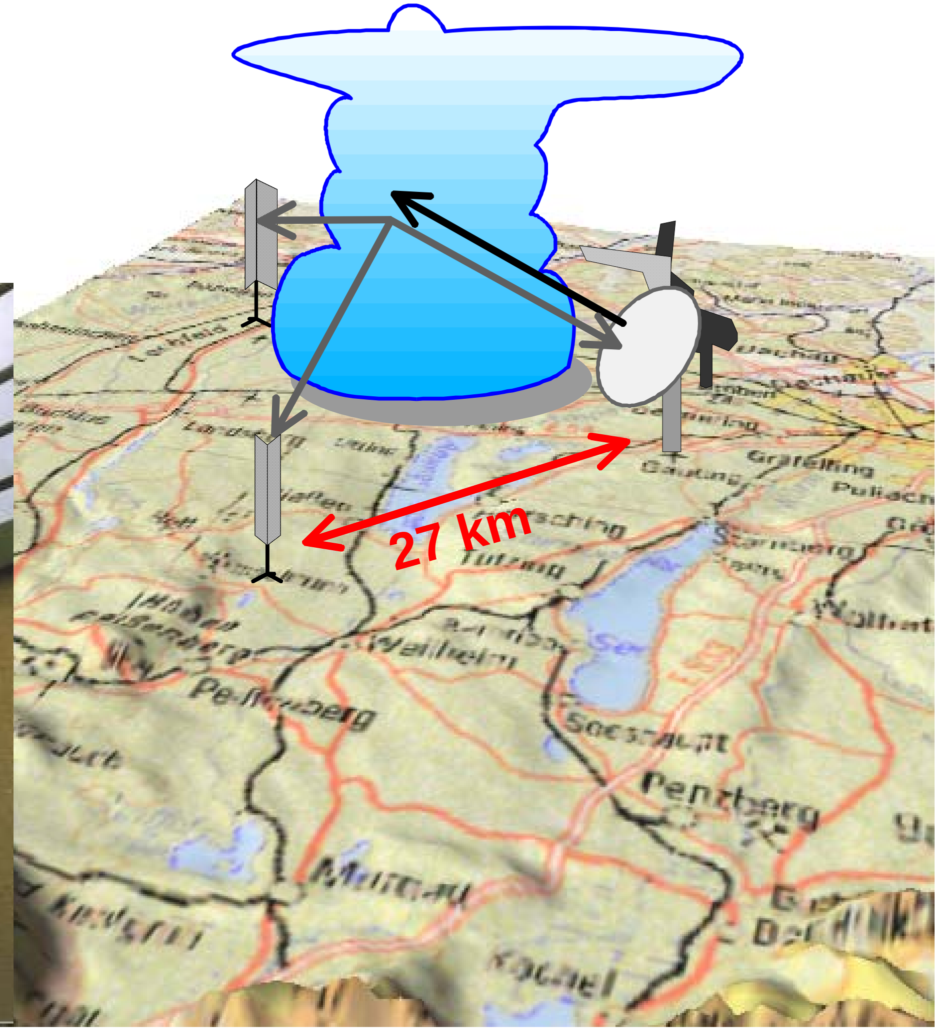
Bistatic Doppler Radar

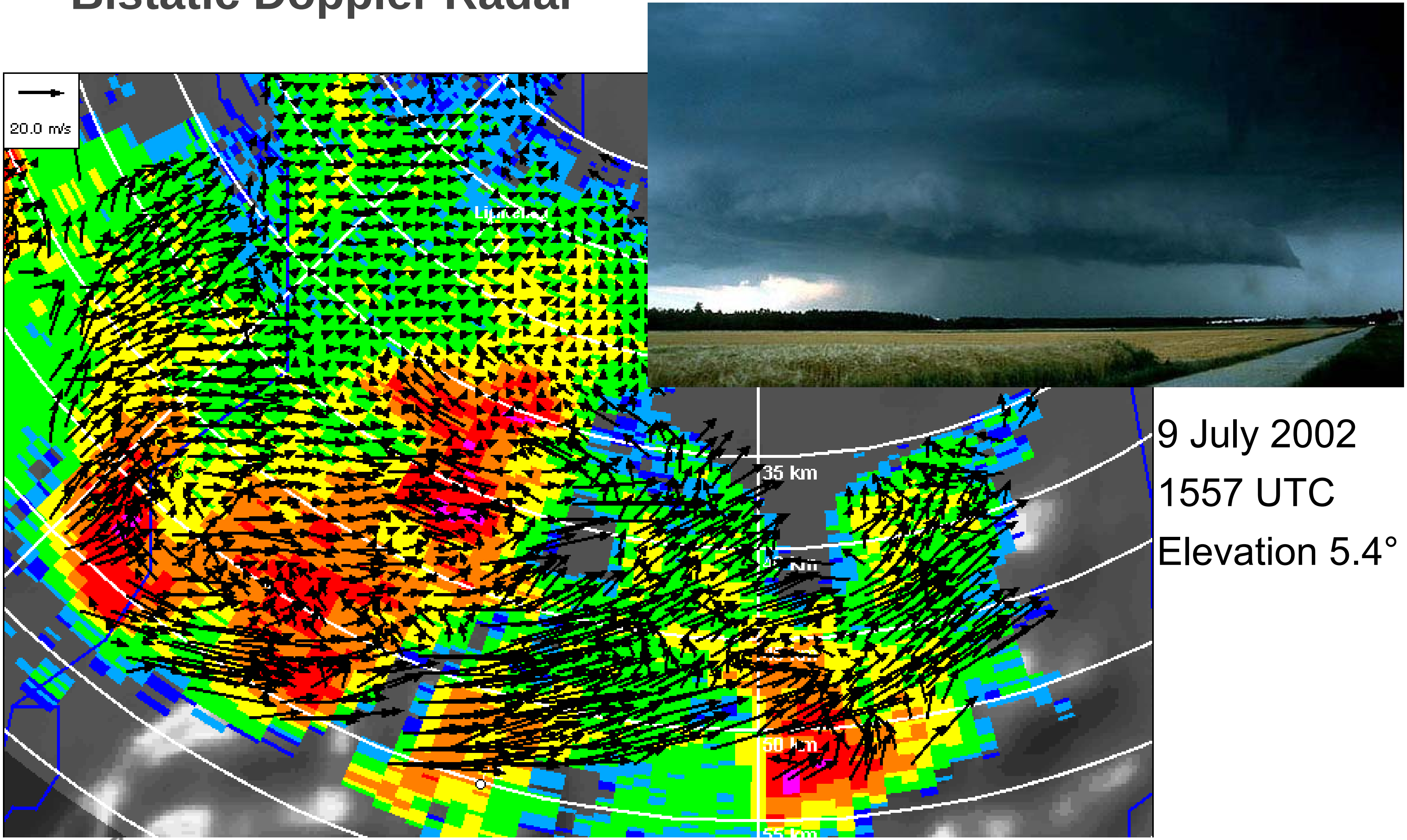
1 active Doppler radar

\+ one or more passive bistatic receivers.

DLR system:
first system operating with a magnetron

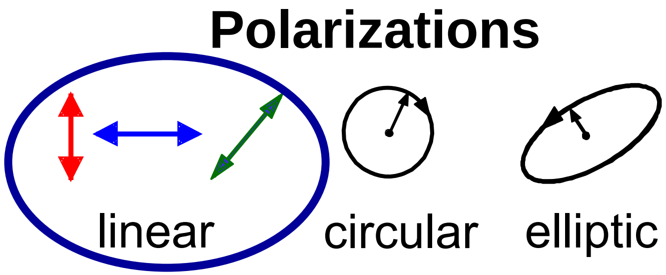


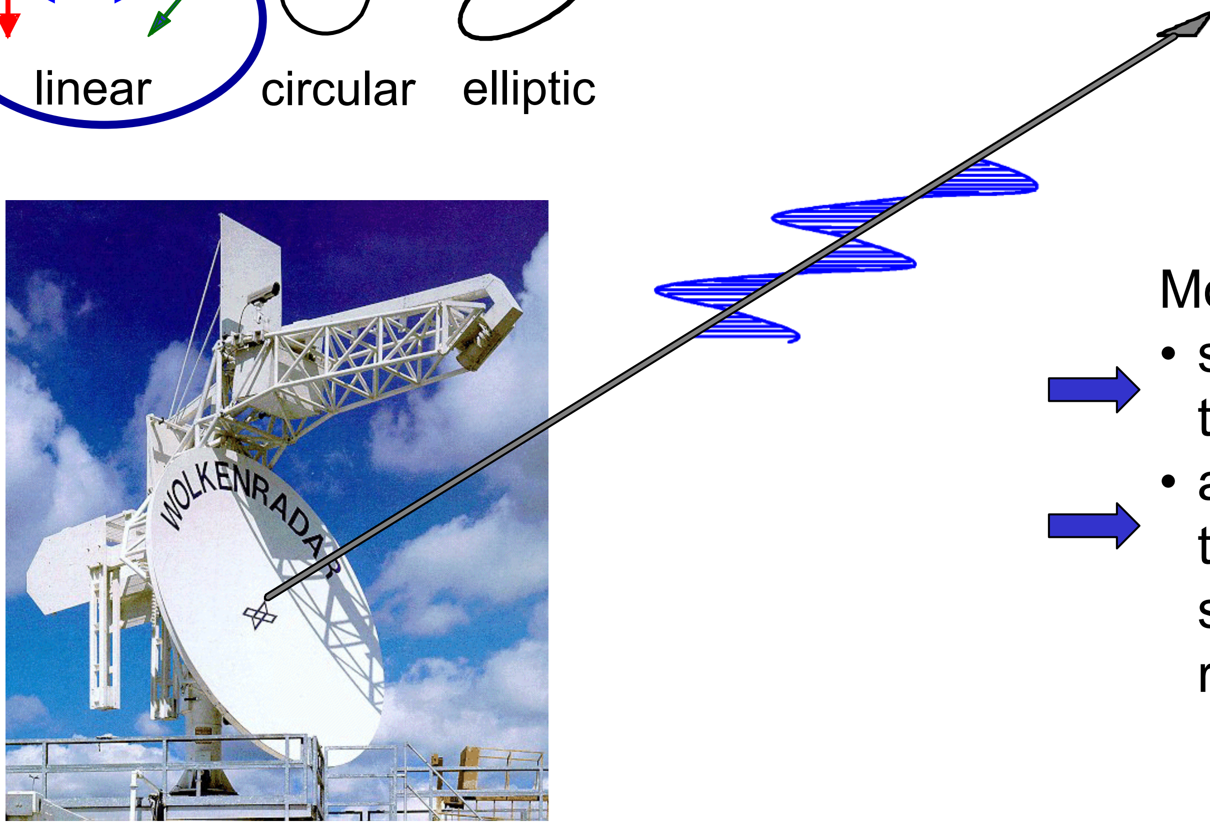
Bistatic Doppler Radar



9 July 2002
1557 UTC
Elevation 5.4°

Polarimetric Radar Observations

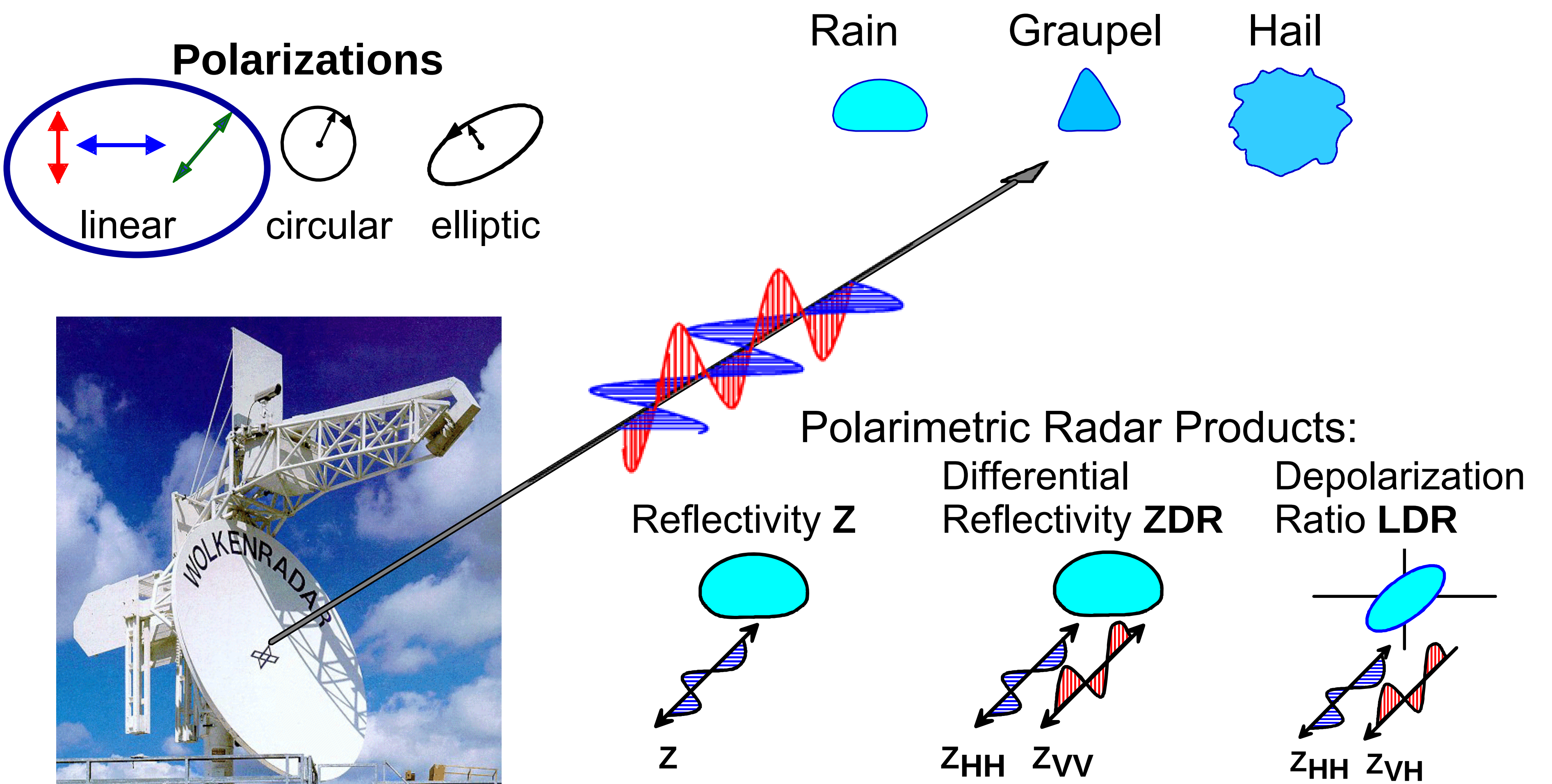




Modes:

- simultaneous H and V transmit and receive
- alternating H and V transmit (pulse to pulse), simultaneous H and V receive

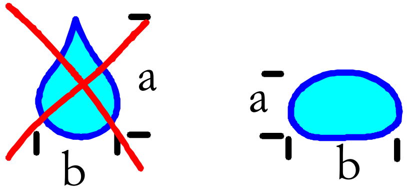
Polarimetric Radar Observations



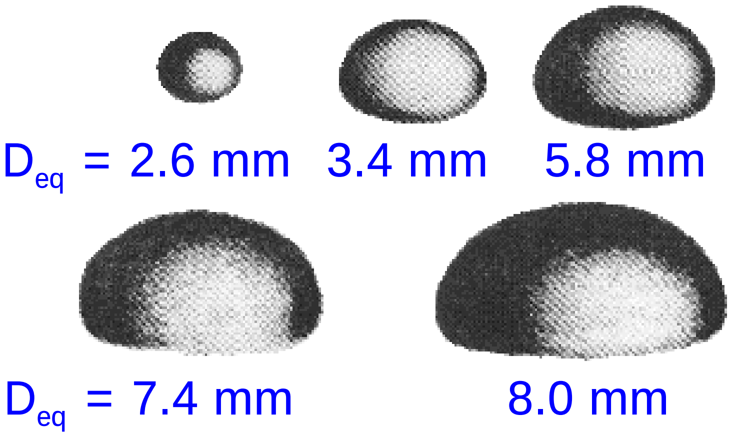
Correlation coefficient between H and V: ρ_{HV}
Differential propagation phase between H and V: ϕ_{DP}

Example: shape of falling raindrops

Falling raindrops (app. 2 – 8 m/s) have a oblate shape due to aerodynamics.



Observations in a vertical pointing wind channel (Univ. Mainz), 5 mm drop.



Rain rate and radar reflectivity

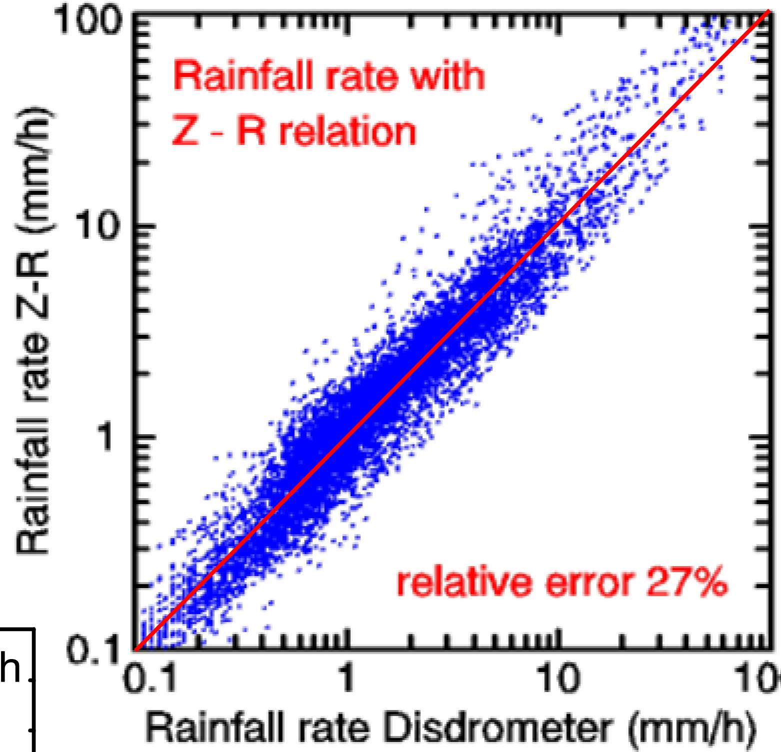
Empirical relation between rain rate *R* and reflectivity *z*

$$R = a\, z^b$$

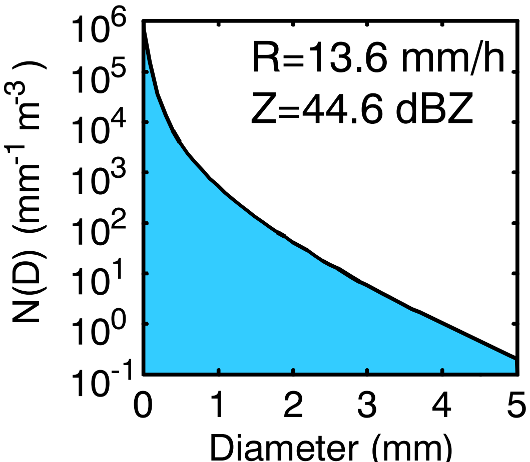
z in $mm^{-6}\, m^{-3}$

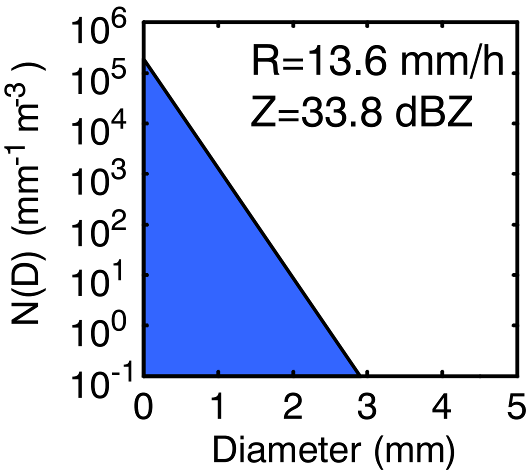
R in mm/h

Coefficients *a* and *b* depend on drop size distribution.



7000 1-minute drop size distribution, Oberpfaffenhofen, 1996

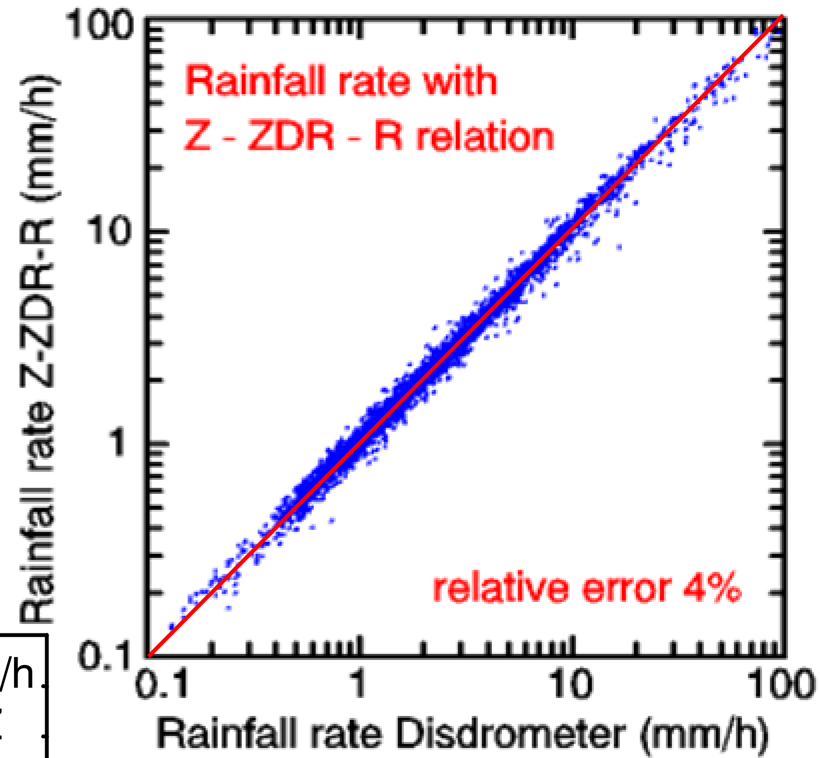




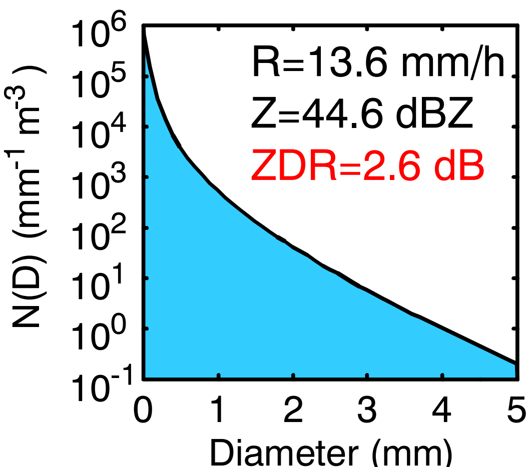
Rain rate and polarimetric radar measurements

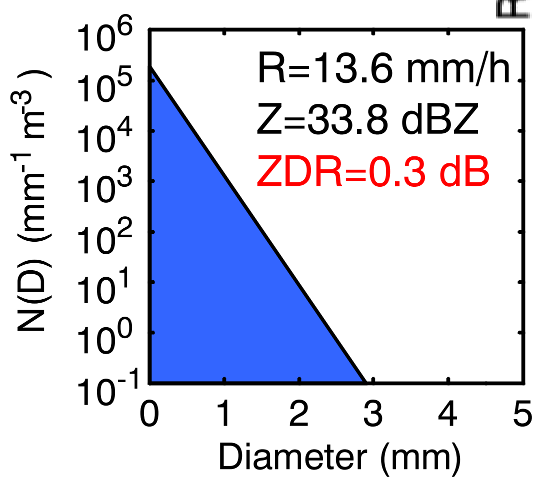
Additional information about raindrop size distribution by differential reflectivity: sensitive to large drops.

$$R = a\, z^{b}\, ZDR^{c}$$



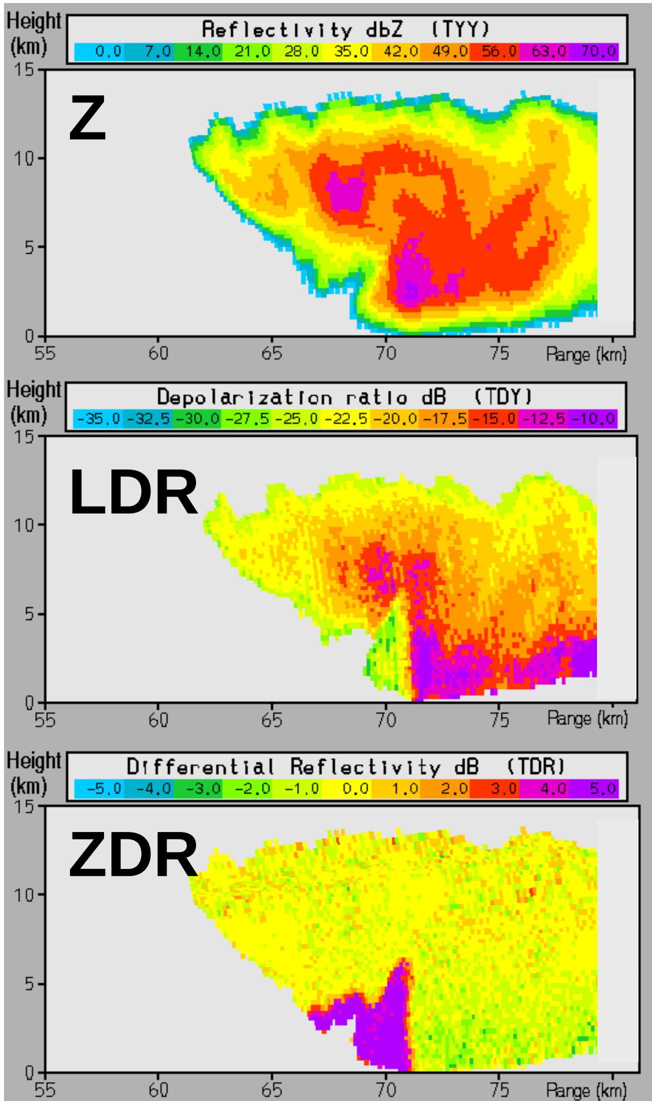
Small errors in polarimetric quantities can give large errors in rain rate estimation.

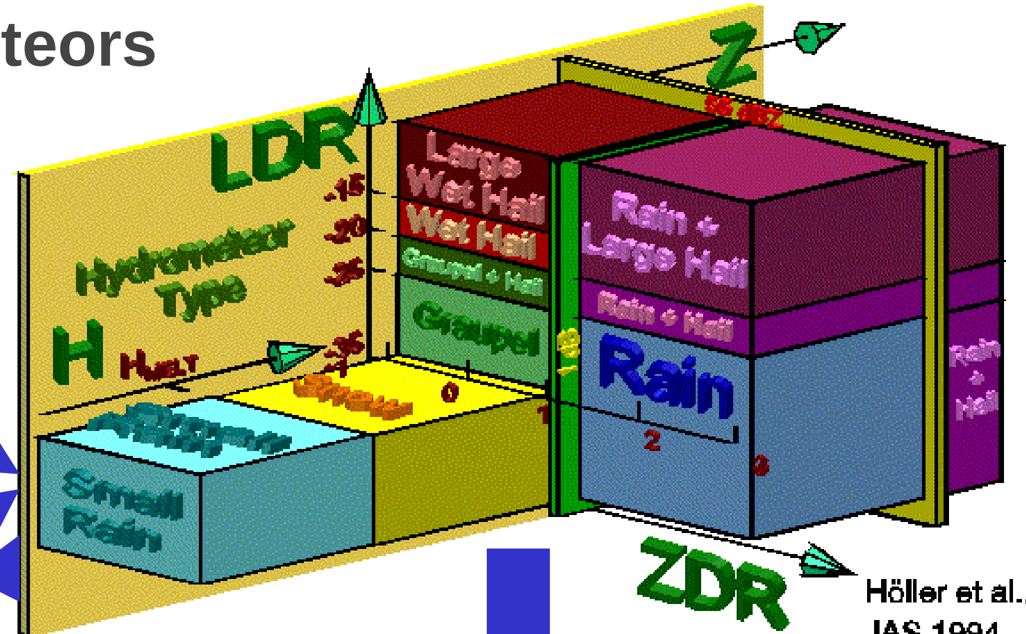




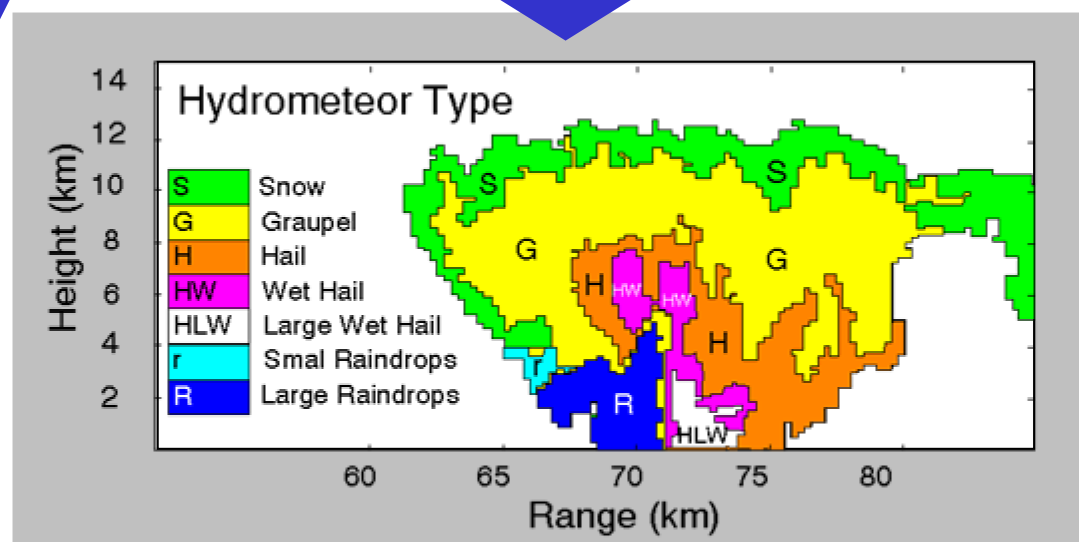
7000 1-minute drop size distribution, Oberpfaffenhofen, 1996

Classification of hydrometeors

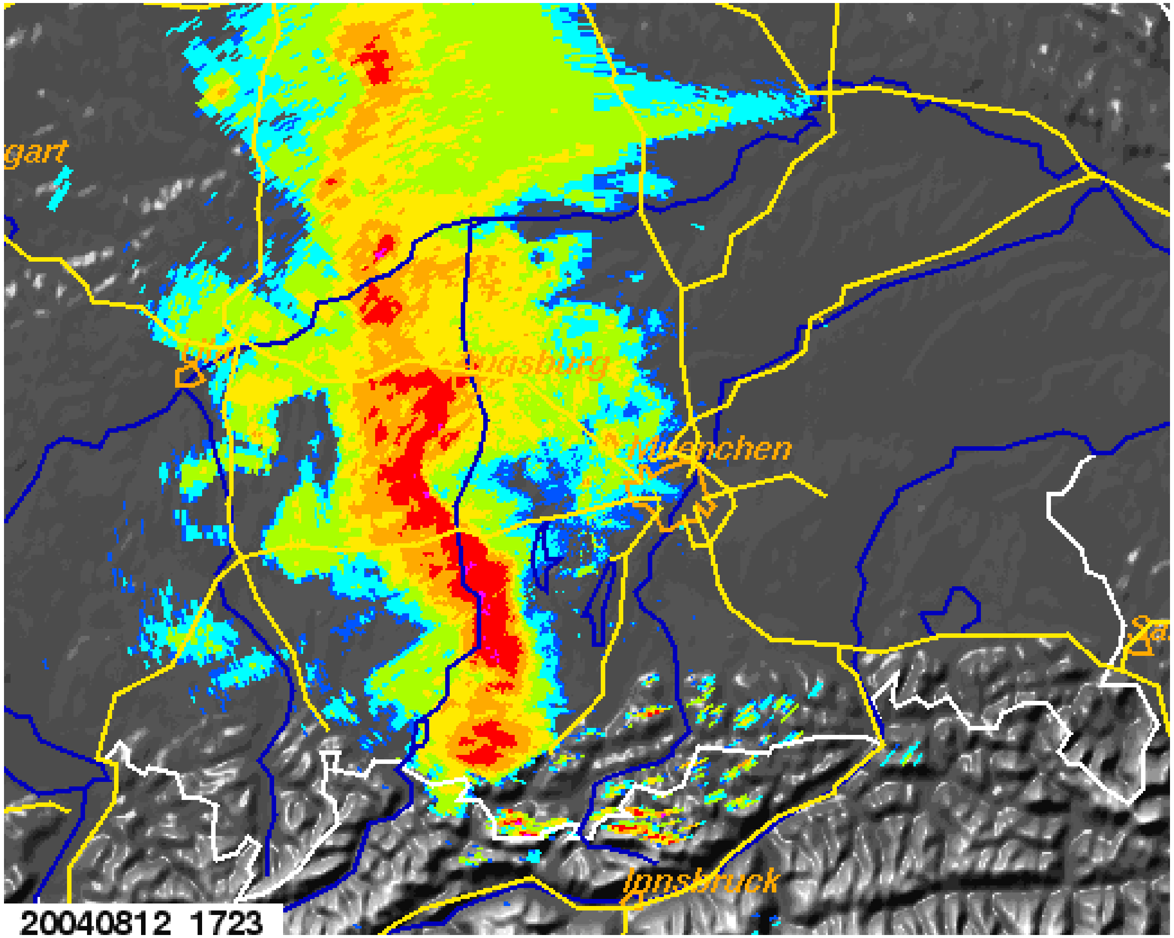




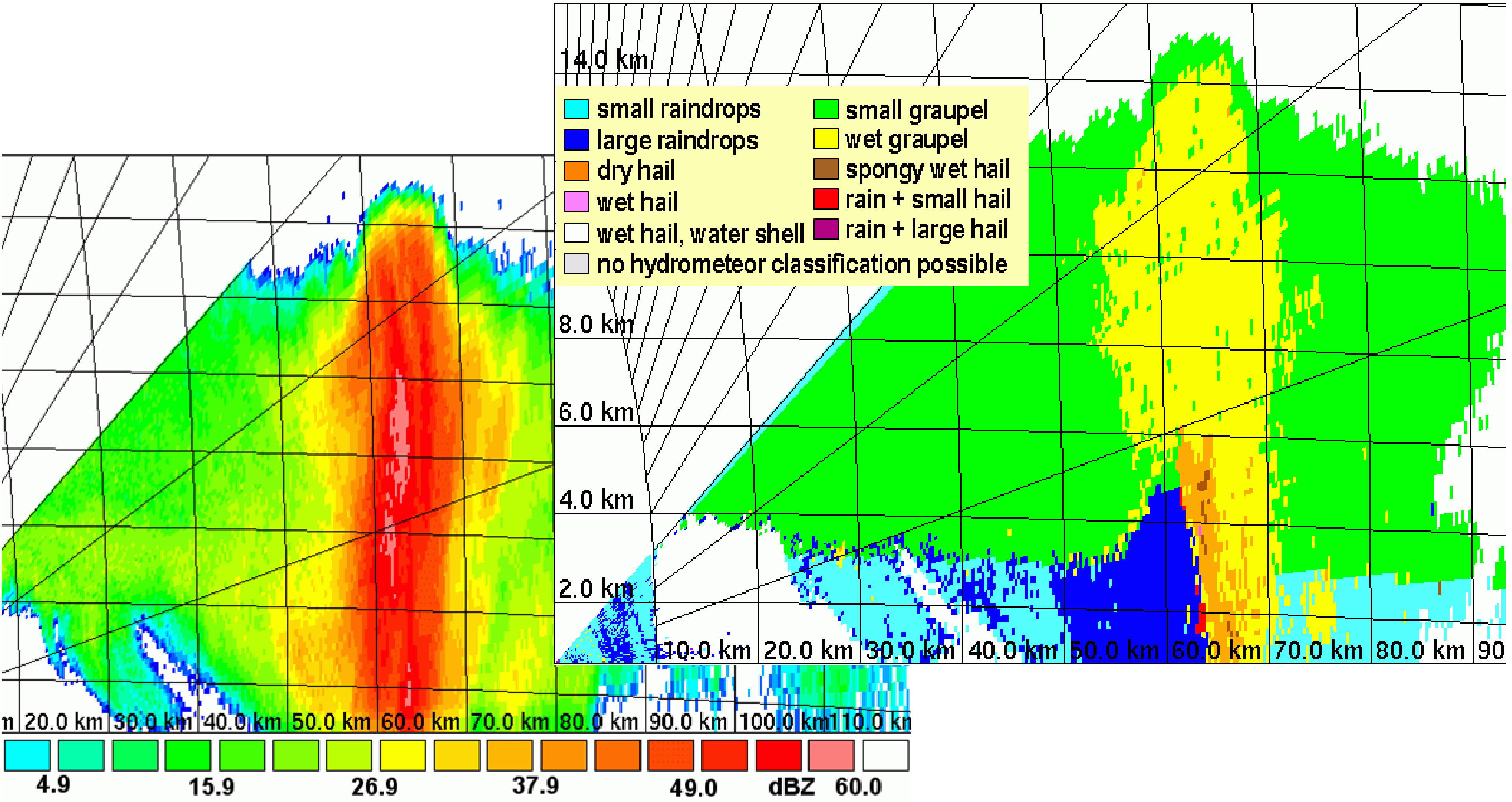
Höller et al., JAS 1994



Thunderstorm line observation 12 Aug. 2004

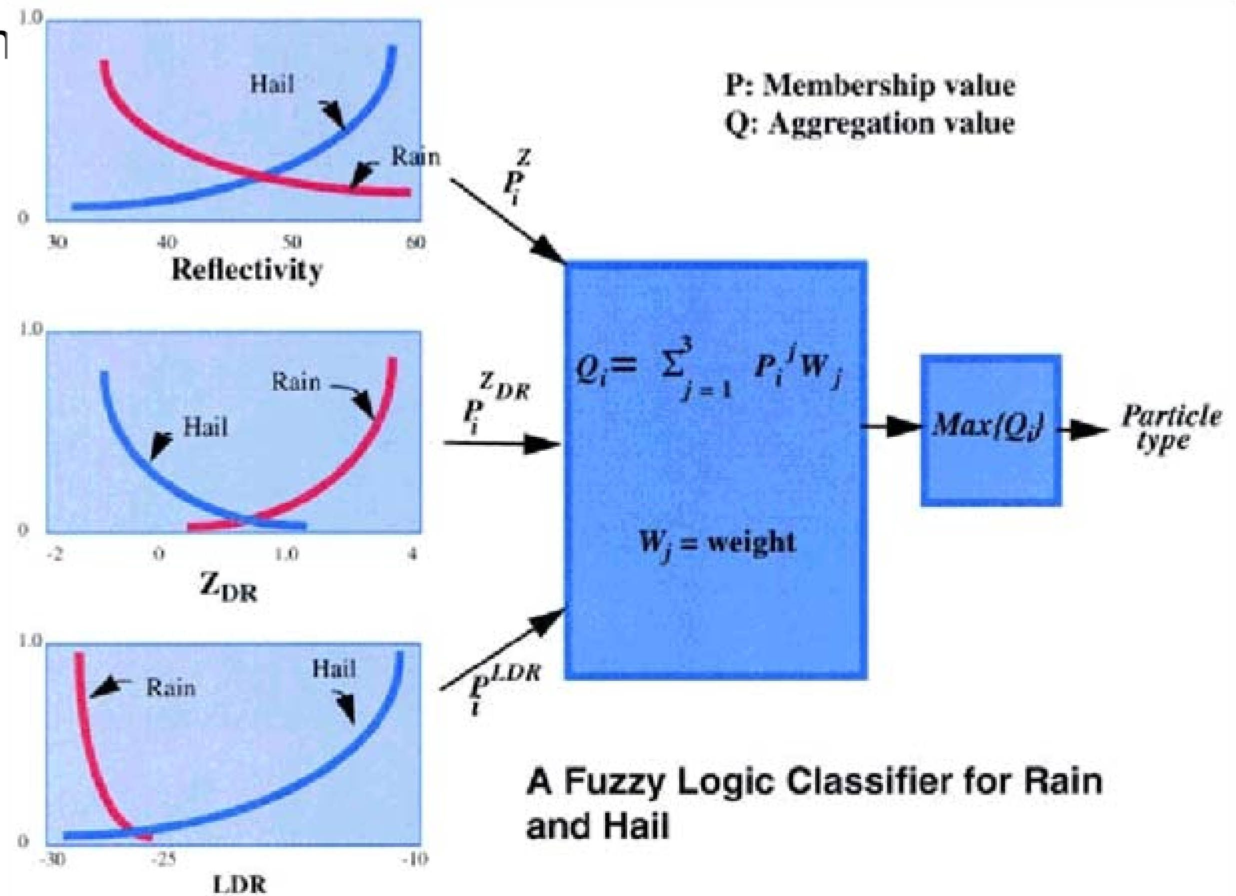


Hydrometeor classification 12 Aug. 2004



Classification by Vivekanandan et al. (1999)

- Additional parameters like correlation coefficient $\rho_{HV}(0)$ and specific differential phase K_{DP}.
- Decision tree becom difficult to define
- „*Fuzzi Logic*“ will be used to identify the most probable particle class.

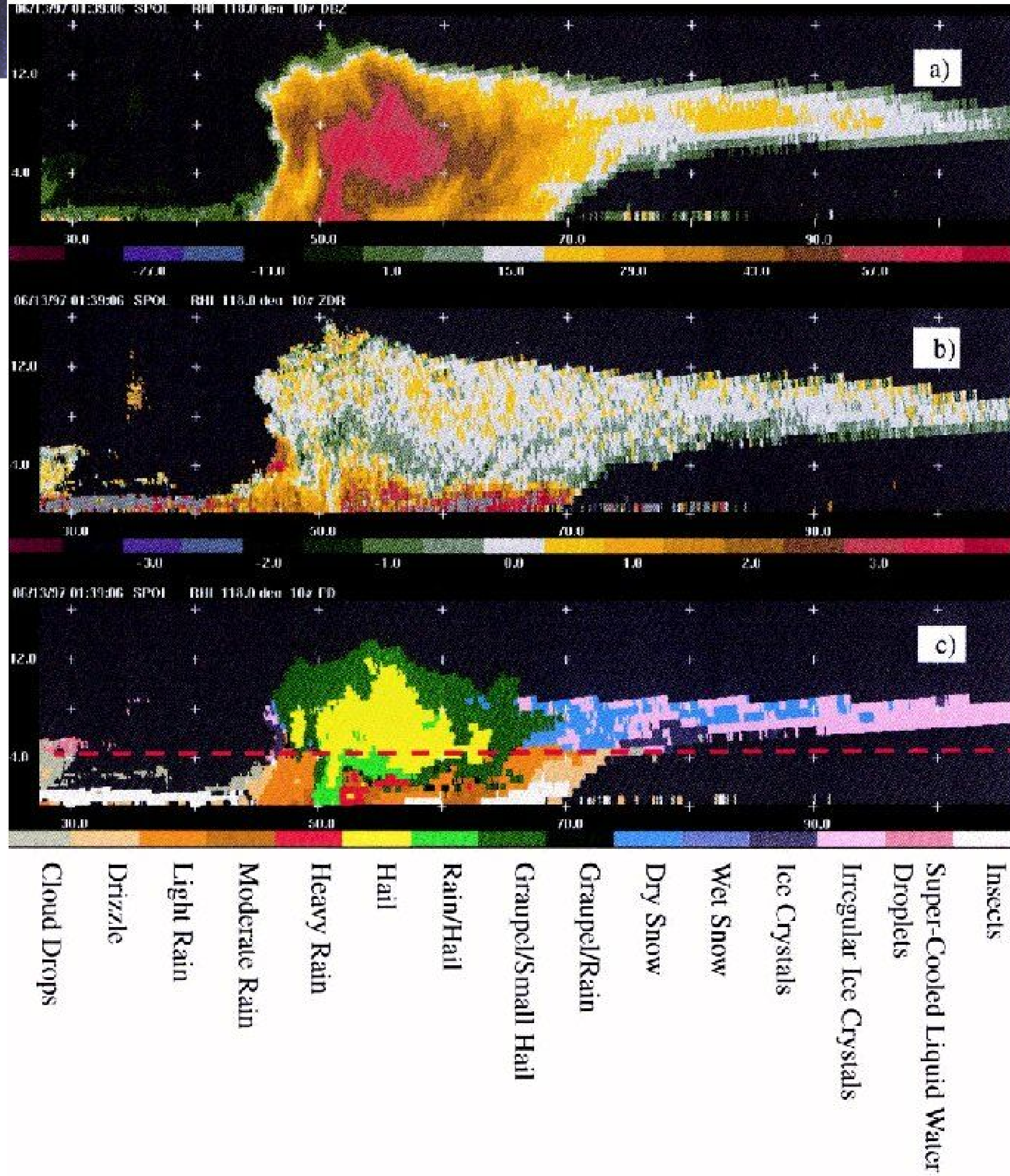


A Fuzzy Logic Classifier for Rain and Hail

Reflectivity

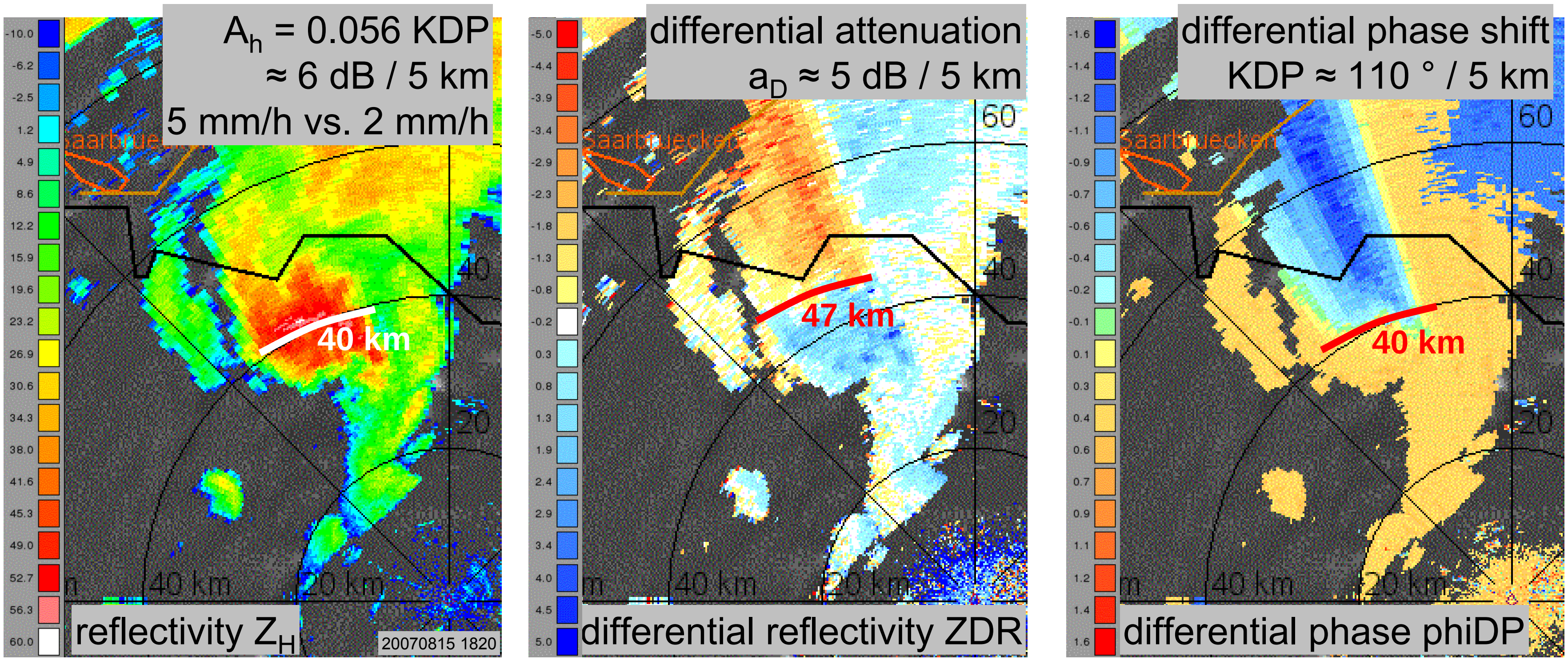
Differential reflectivity

Classification

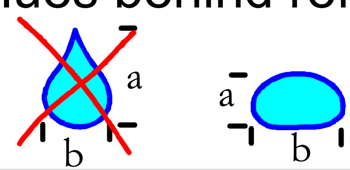


Attenuation and Propagation degrades Classification

- Attenuation can't be recognized easily (C-Band)

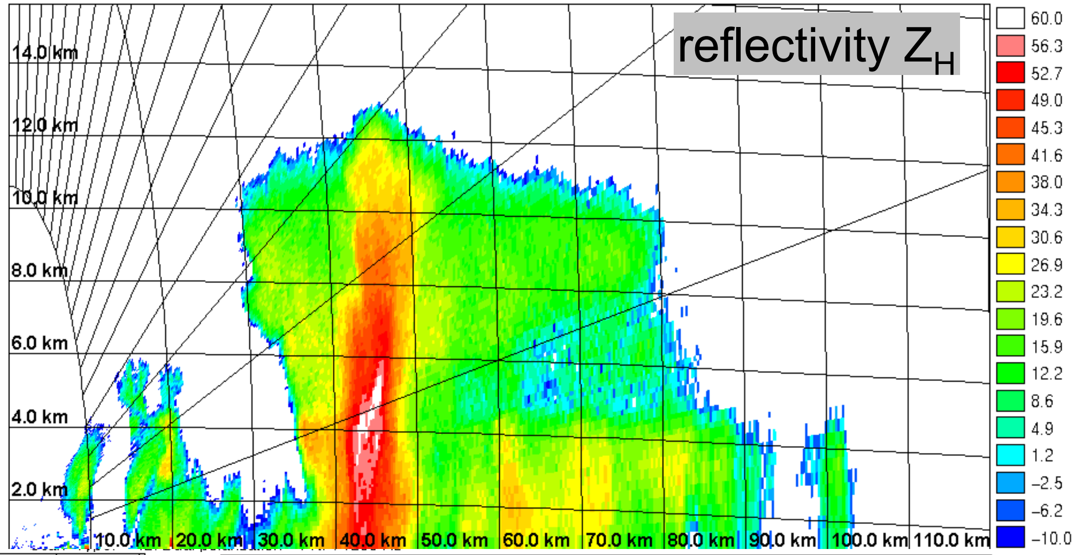


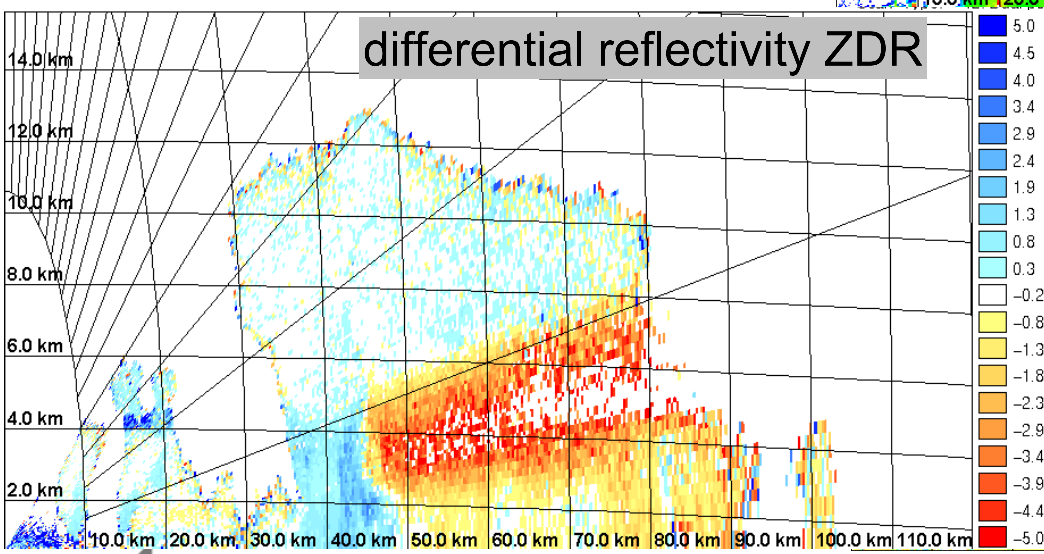
- Frequently observed are negative ZDR values behind reflectivity cores
  - negative ZDR is not expected in rain

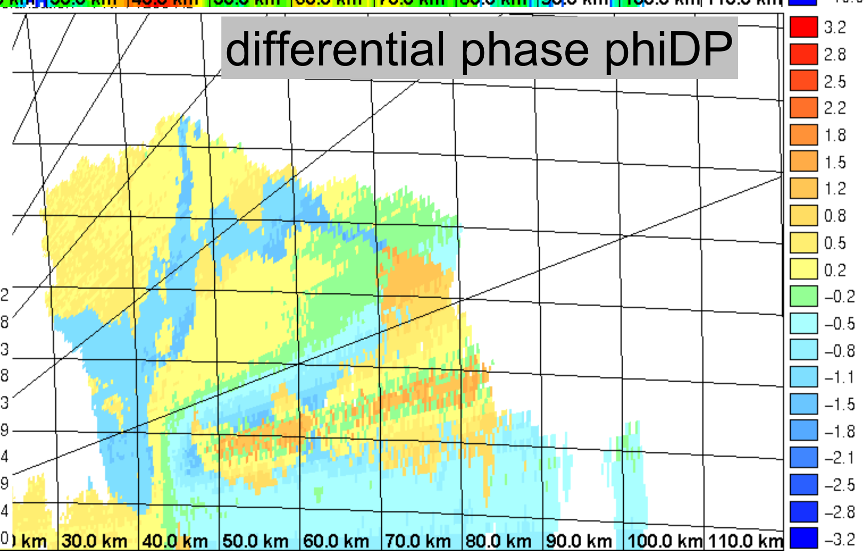


Attenuation: Vertical Cross-Section (RHI)

- strong attenuation at 3 – 4 km height (below melting layer), high Z and LDR indicate presence of hail.
- hail spike (flare echo) ????
- must be wet melting hail with shedding water shell.
- unknown particle properties → no correction possible

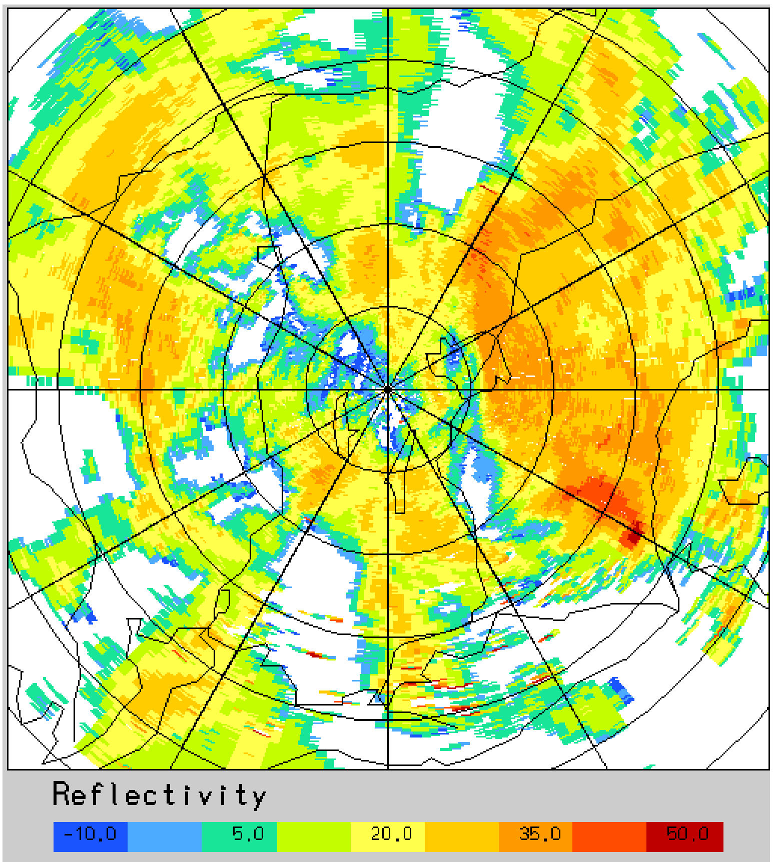




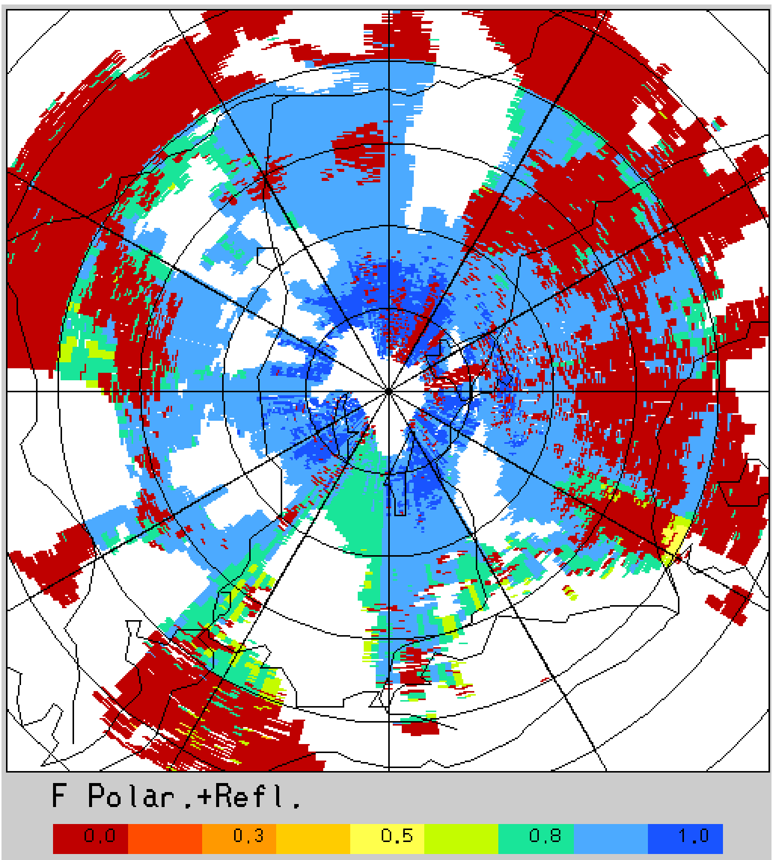


Quality index field for polarimetric radar products

Reflectivity



Quality control settings for use of polarimetric data for rain rate estimation.



bad good

From Research to Application

Further presentations:

- ground clutter
  (Jens Reimann)
- hydrometeor classification
  (Jörg Steinert)
- Doppler moments
  (Ondrej Suchý)
- rain rate estimation
  (Patrick Tracksdorf)
- attenuation correction
  (Tobias Otto)

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