Basics of dual-polarization radar (1)
Introduction

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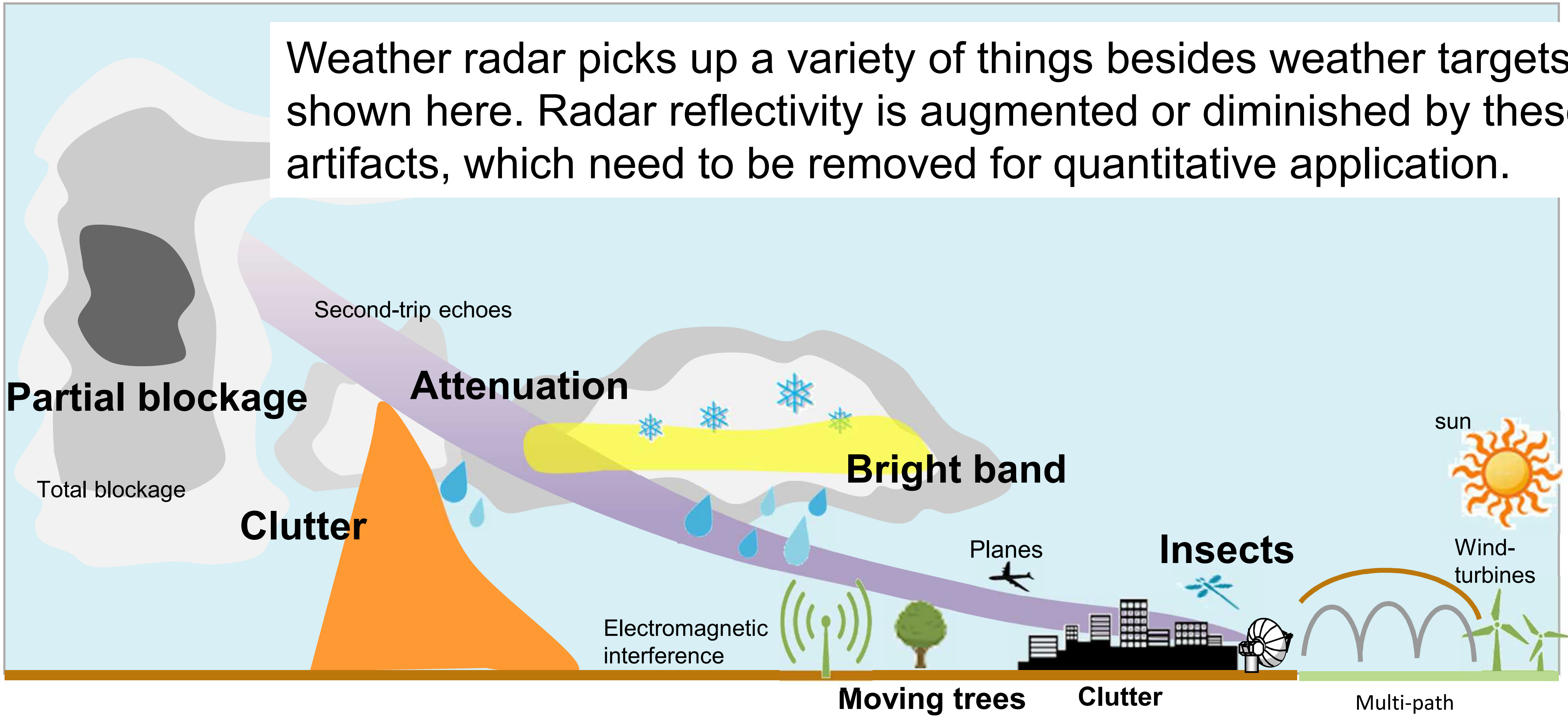
1 Basics of dual-polarization radar : Introduction

Radar is an important tool in precipitation monitoring and meteorological disaster mitigation. Conventional single-polarization Doppler radar is commonly used in this context.

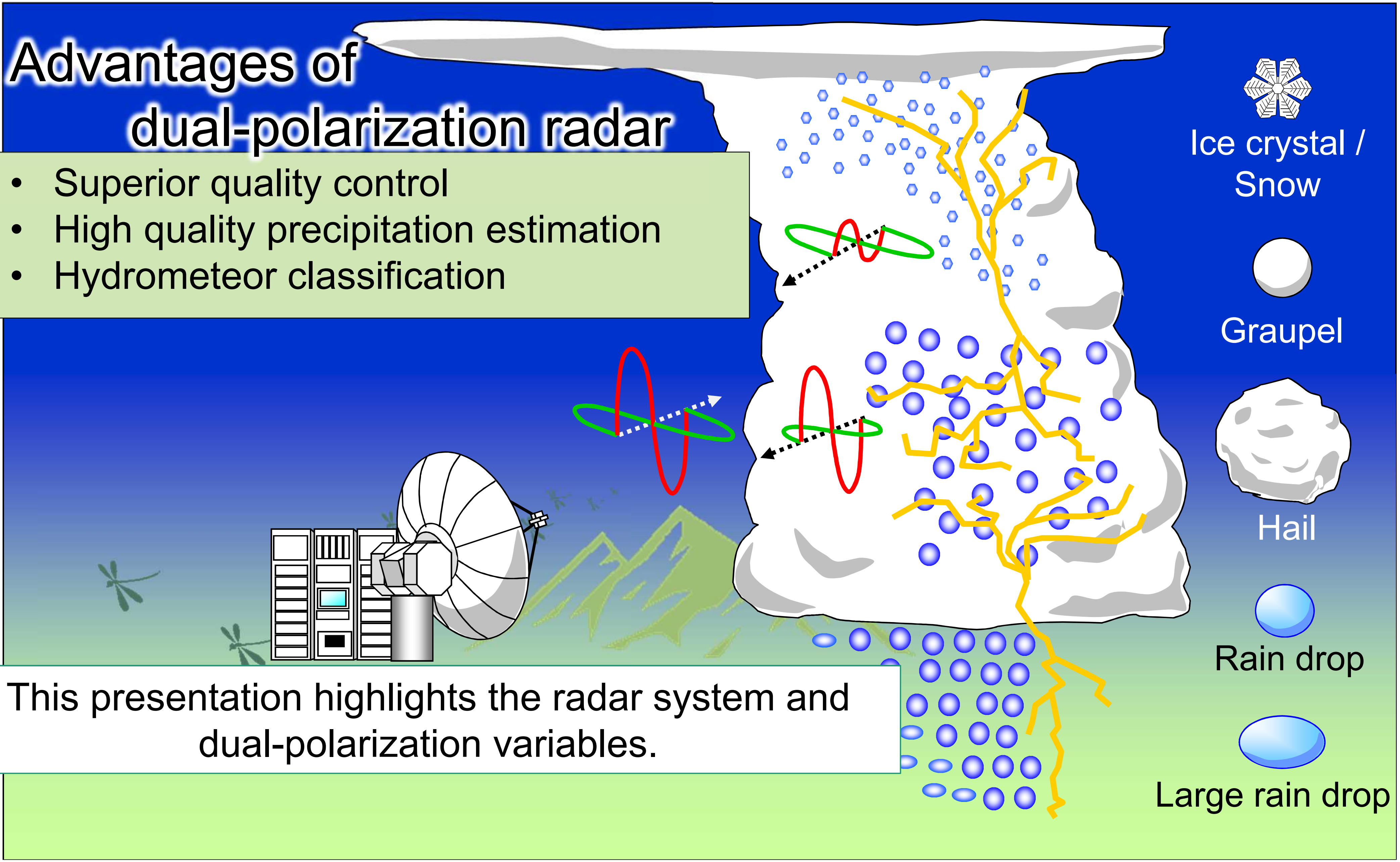
Weather radar picks up a variety of things besides weather targets, as shown here. Radar reflectivity is augmented or diminished by these artifacts, which need to be removed for quantitative application.



1 Basics of dual-polarization radar : Introduction

Advantages of dual-polarization radar

- Superior quality control
- High quality precipitation estimation
- Hydrometeor classification



This presentation highlights the radar system and dual-polarization variables.

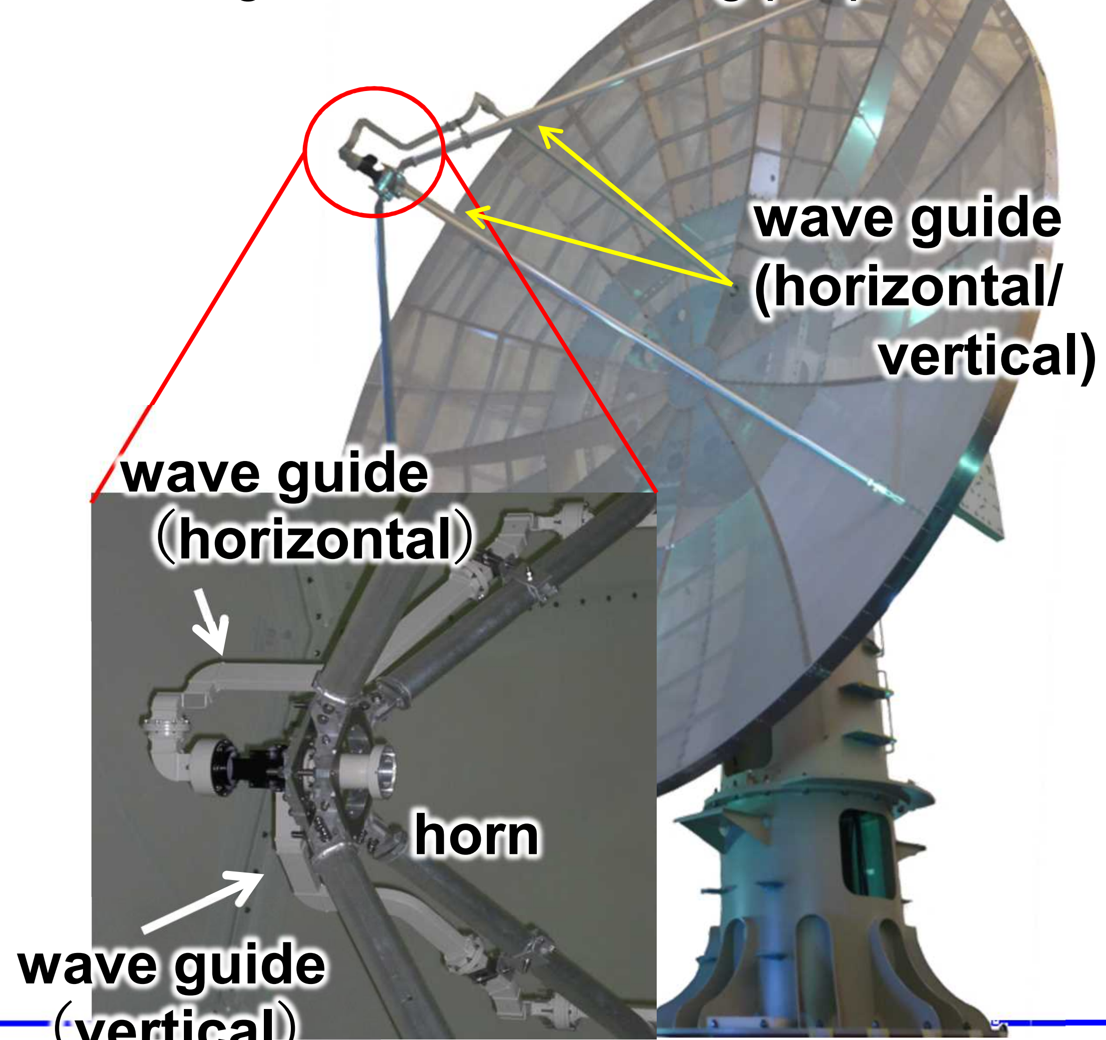
1 Basics of dual-polarization radar : Introduction

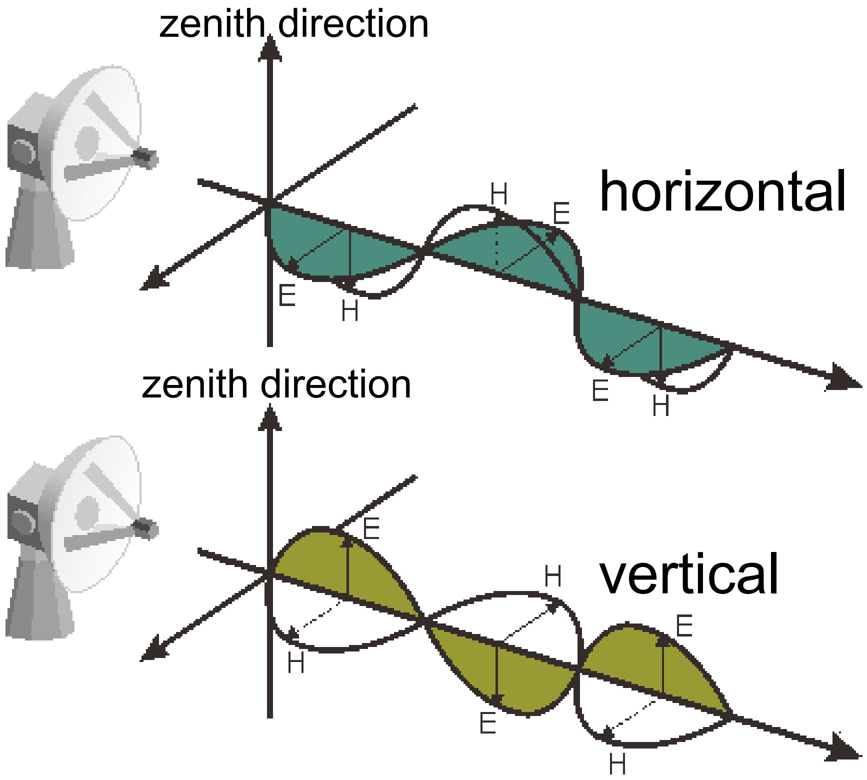
Contents

1.1 Dual-polarization radar system

Capacity for transmission and reception of two orthogonal polarizations.

Transmitted polarizations must be switchable as fast as the timescale of changes in the scattering properties of the target and the propagation medium.

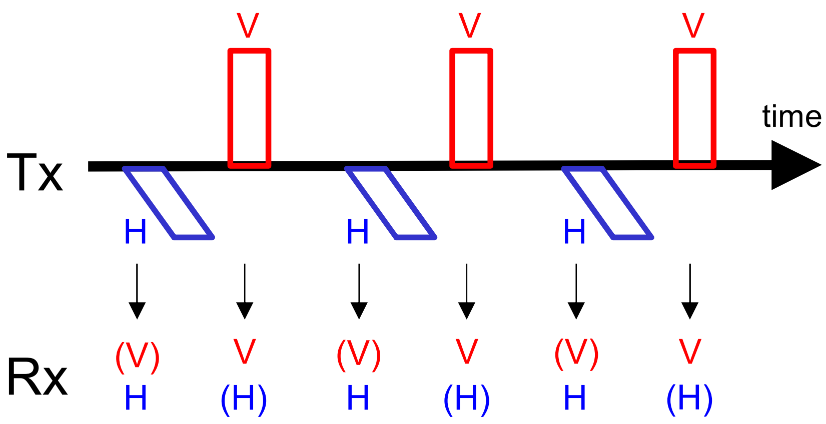




1.1 Dual-polarization radar system

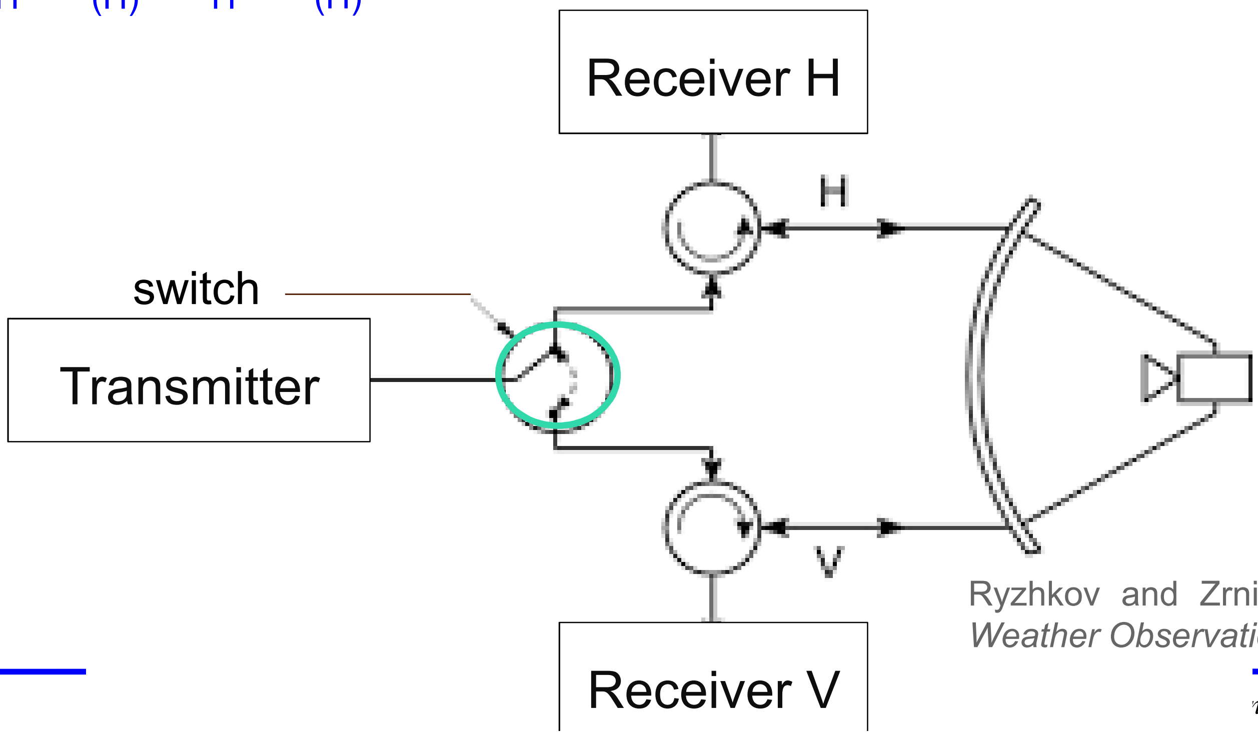
Previous mainstream design (currently used for research)

ALT: Alternate Transmitting and Receiving or AHV-mode (FHV-mode)



Advantages:
- No high power requirement
- Linear depolarization ratio capacity (for simultaneous Rx)

Disadvantages:
- H/V wave asynchronicity (lower quality)
- Low pulse rate (samples)
- Expense and delicateness of H/V switchers

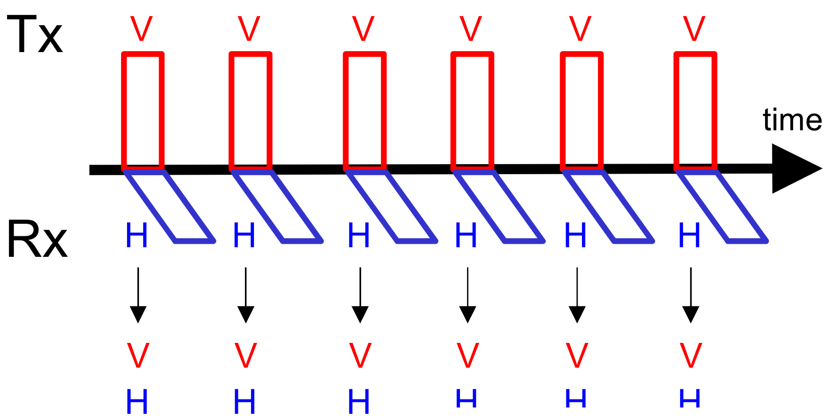


Ryzhkov and Zrnic 2019: *Radar Polarimetry for Weather Observations*. Springer, 486 pp.

1.1 Dual-polarization radar system

Current mainstream usage with elimination of disadvantages

STAR: Simultaneous Transmitting and Receiving or SHV-mode

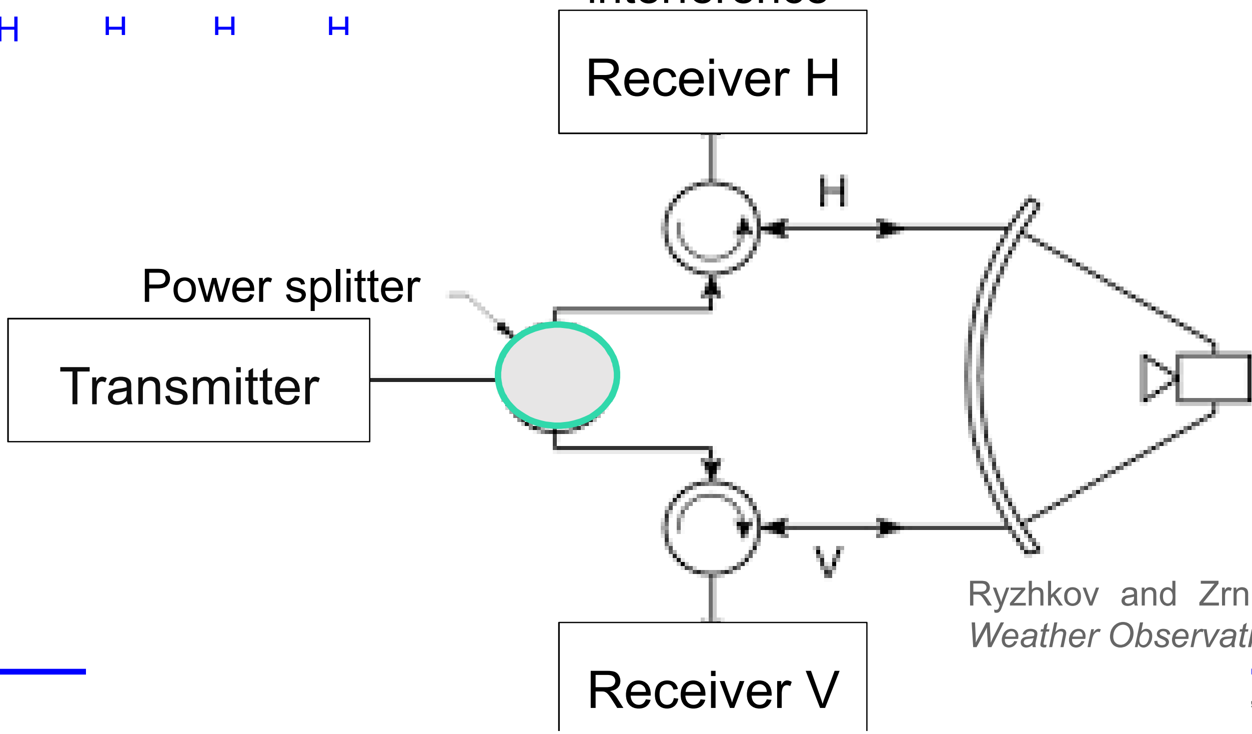


Advantages:

- H/V wave synchronicity (high quality)
- High pulse rate (samples)
- No H/V switcher requirement.

Disadvantages:

- High power requirement (divided power usage)
- No linear depolarization ratio capacity
- Requirement for high-quality antenna to prevent H/V interference



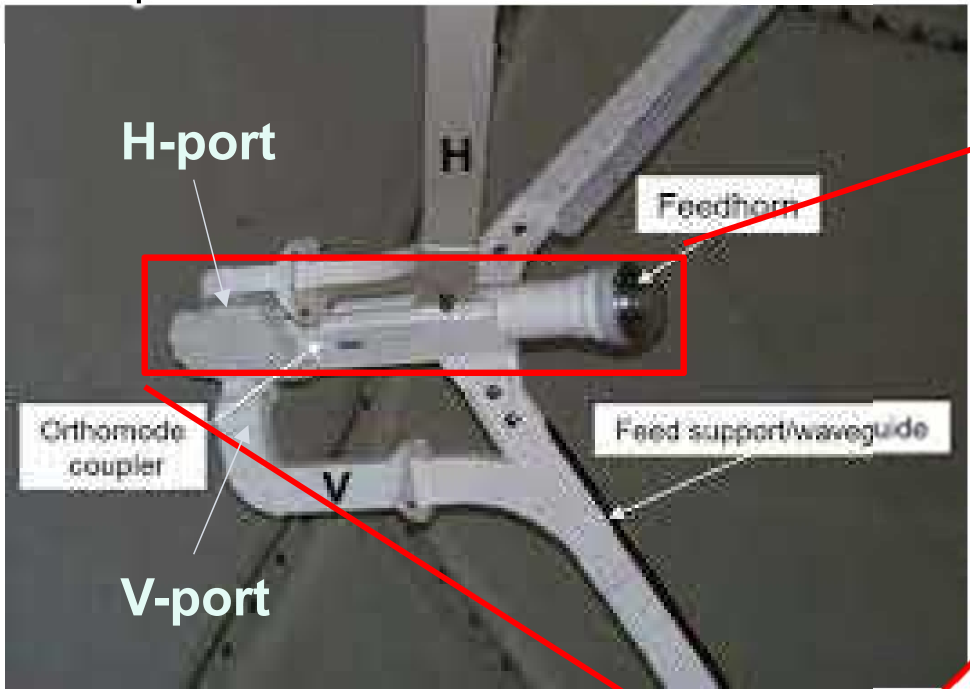
Ryzhkov and Zrnic 2019: *Radar Polarimetry for Weather Observations*. Springer, 486 pp.

1.1 Dual-polarization radar system

- Orthomode Transducer (OMT):

A waveguide component that combines H/V orthogonal polarized waves for STAR-mode

Dual-polarization horn framework



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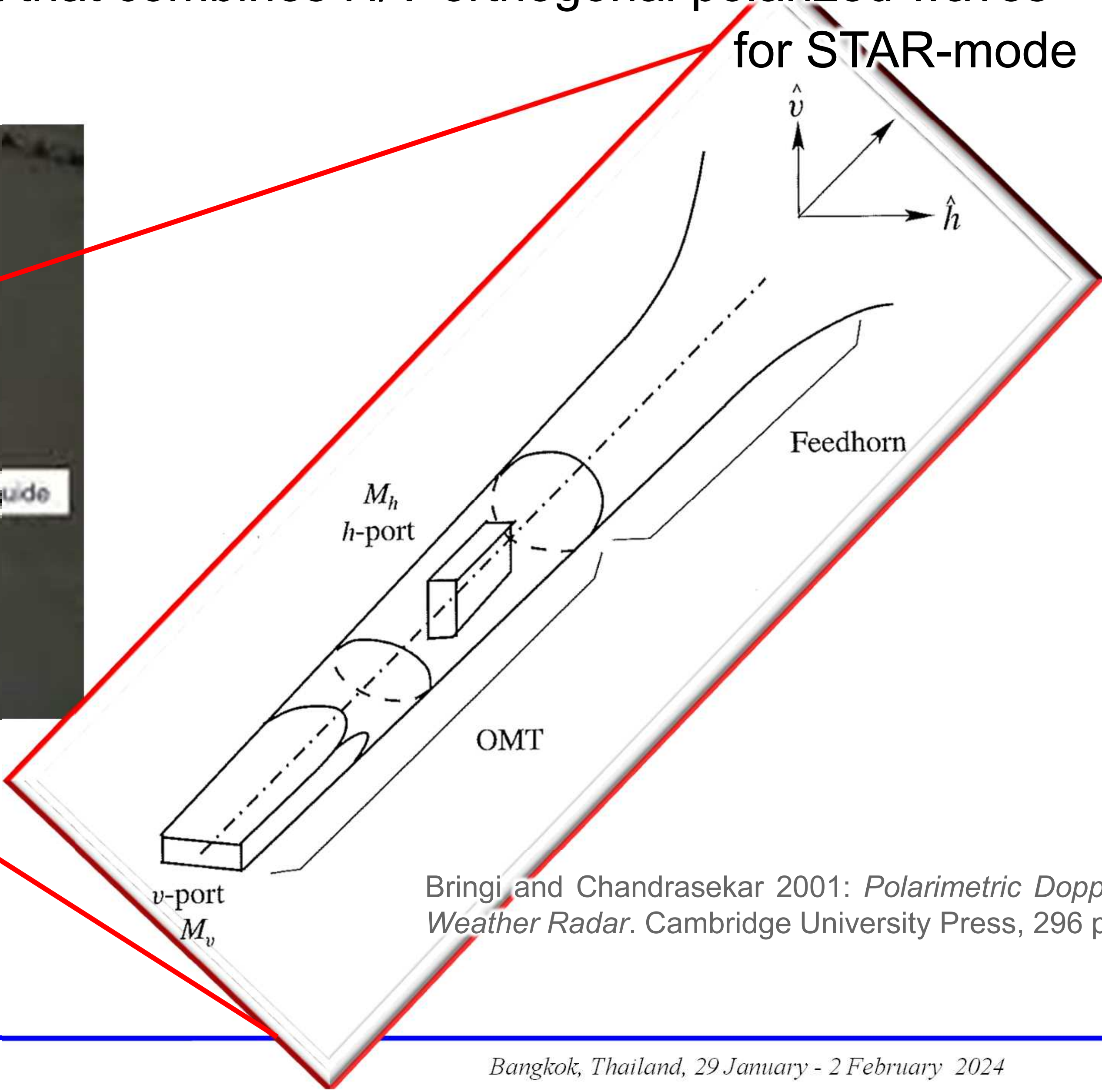
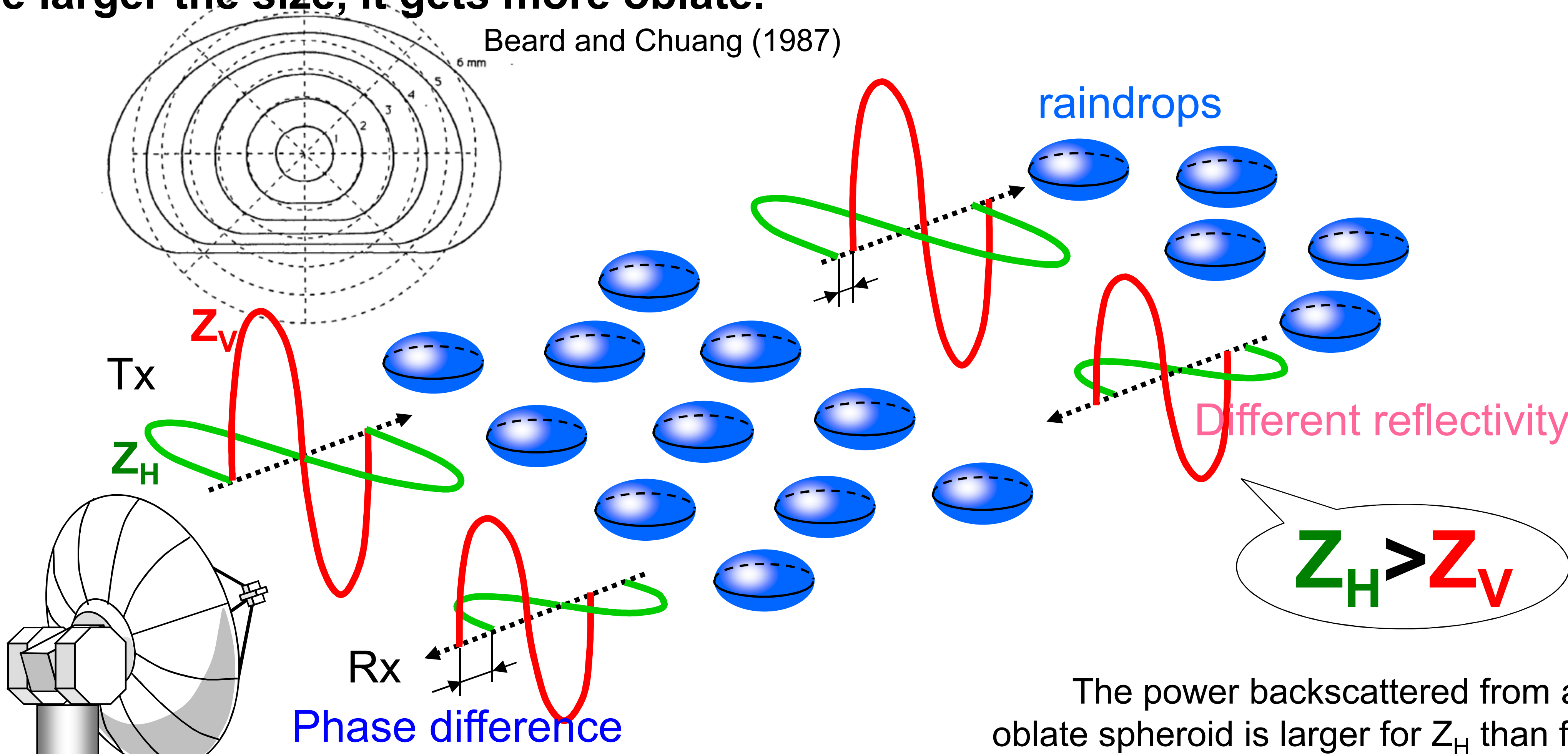


Bringi and Chandrasekar 2001: *Polarimetric Doppler Weather Radar*. Cambridge University Press, 296 pp.

1.2 Dual-polarization variables

Raindrop

The larger the size, it gets more oblate.

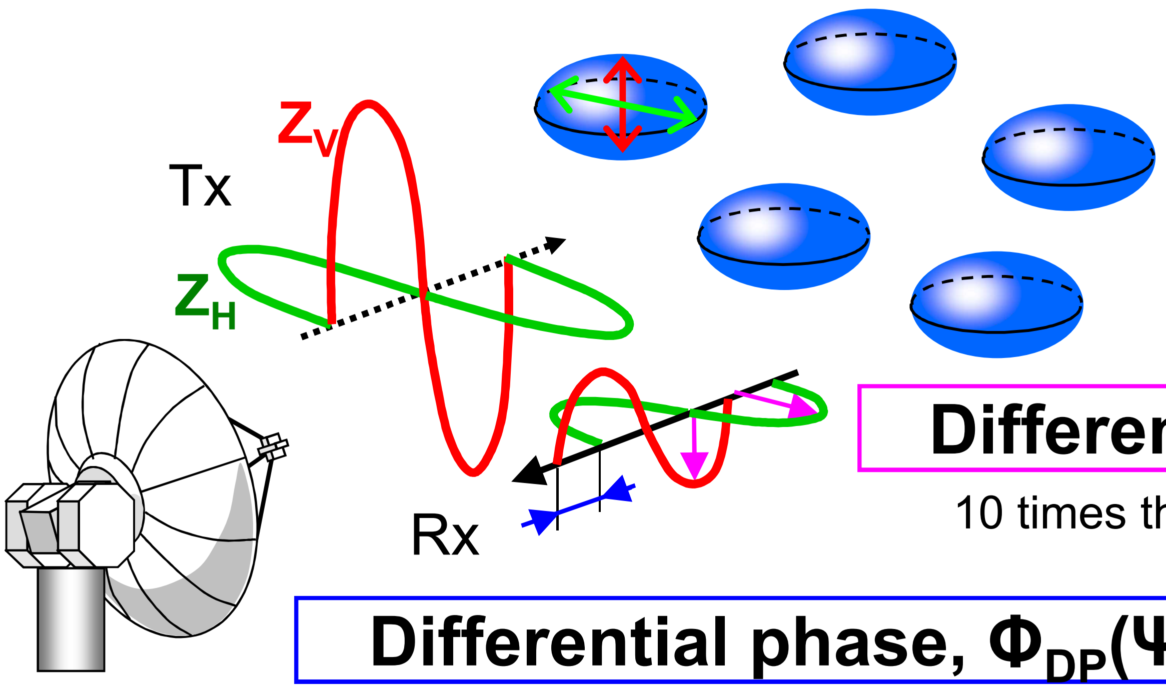


Beard and Chuang (1987)

The power backscattered from an oblate spheroid is larger for Z_H than for Z_V assuming Rayleigh scattering

In a medium with oblate particles, the phase of the incident beam is altered due to attenuation differences (resulting in propagation speed differences) in the vertical and horizontal.

1.2 Dual-polarization variables



Differential reflectivity, Z_{DR}

10 times the logarithm of the ratio Z_H and Z_V

$$Z_{DR} = 10\log_{10}\left(\frac{Z_H}{Z_V}\right)$$

Differential phase, $\Phi_{DP}(\Psi_{DP})$

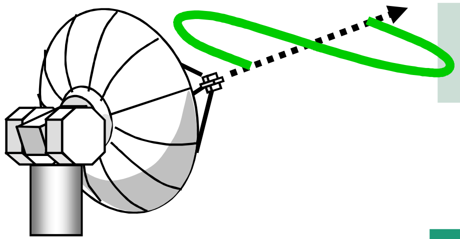
An integral parameter termed the differential phase.

Correlation coefficient, ρ_{hv}

The correlation of the vertical and horizontal time-series data.

1.2 Dual-polarization variables

Conventional Doppler weather radar



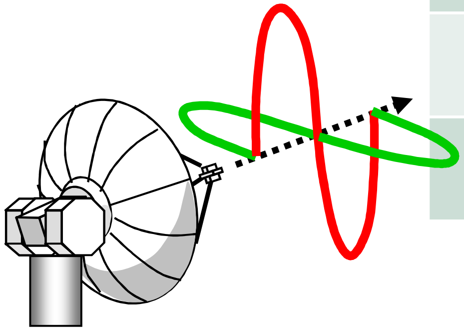
Observed variables
Reflectivity factor Z
Doppler velocity V
Velocity width W

&

Derived texture
S(Z)
S(V)
S(W)

+

Dual–polarization weather radar



Observed variables
Differential reflectivity Z_{DR}
Correlation coefficient ρ_{hv}
Differential phase Φ_{DP}

&

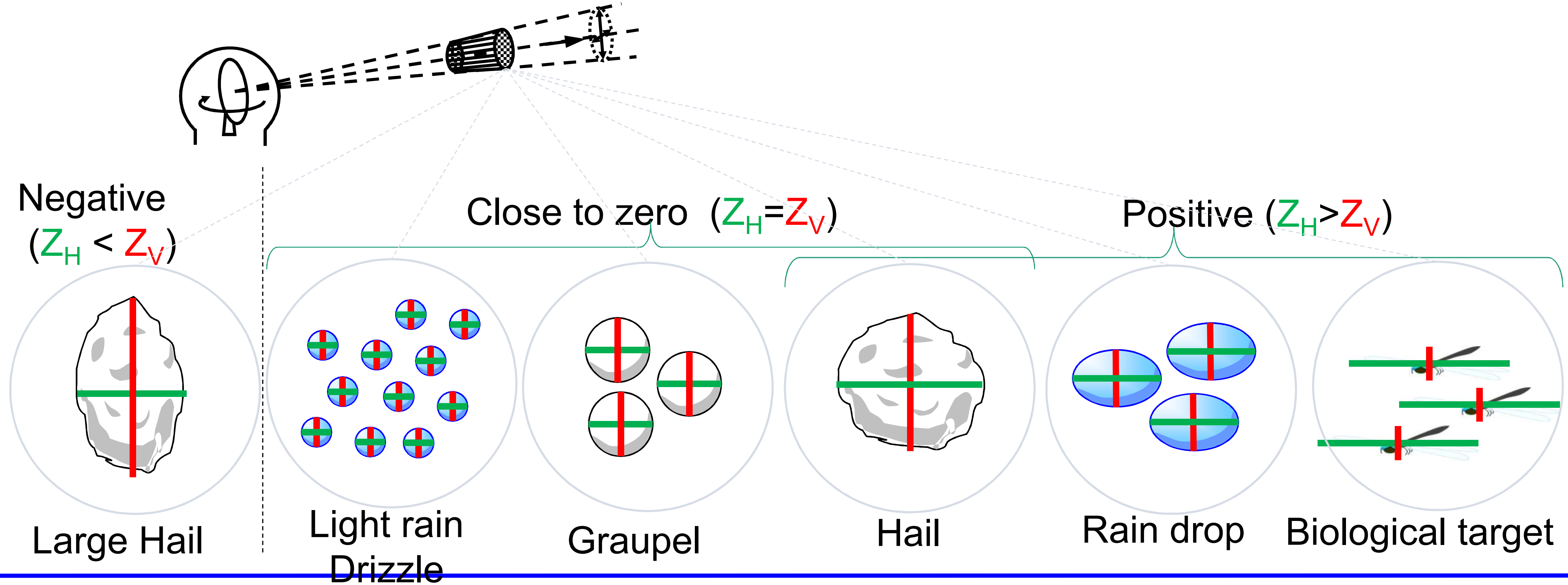
Derived texture
$S(Z_{DR})$
$S(\rho_{hv})$
$S(\Phi_{DP})$

Spatial derivative
Specific differential phase K_{DP}

1.2.1 Differential reflectivity Z_{DR}: Shape of particle

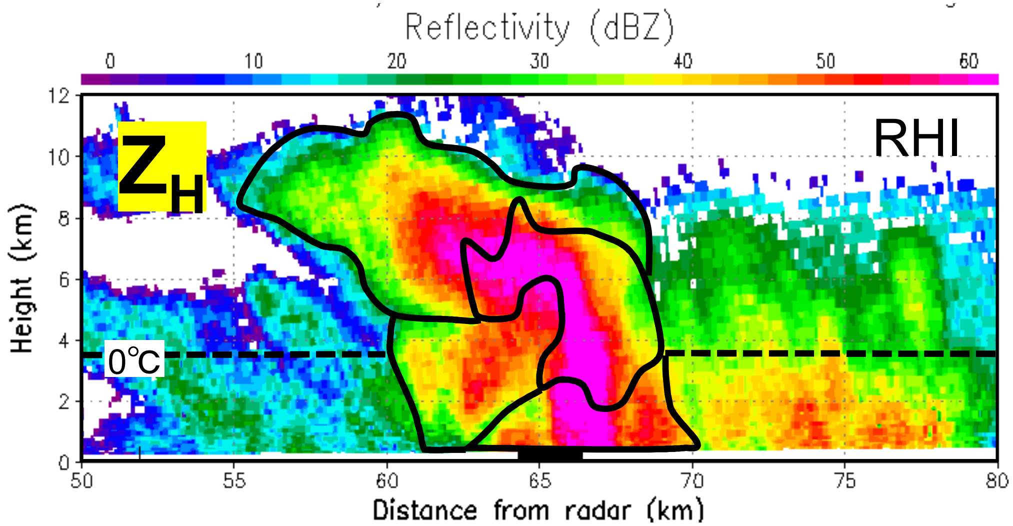
$$Z_{DR} = 10 \log_{10} \left(\frac{Z_H}{Z_V} \right)$$

- Reflects aspect ratio of scattering targets.
- Possible range of values : generally -4 to 10 (dB)
- Useful for Rain rate estimation and hydrometeor classification
- Affected by precipitation attenuation (Correction is needed)

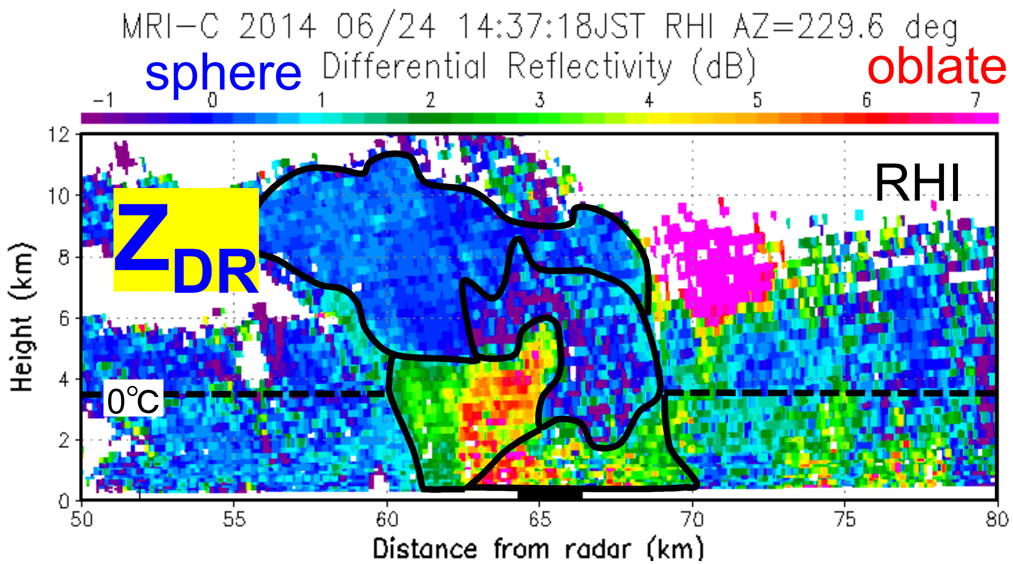


1.2.1 Differential reflectivity Z_{DR}: Shape of particle

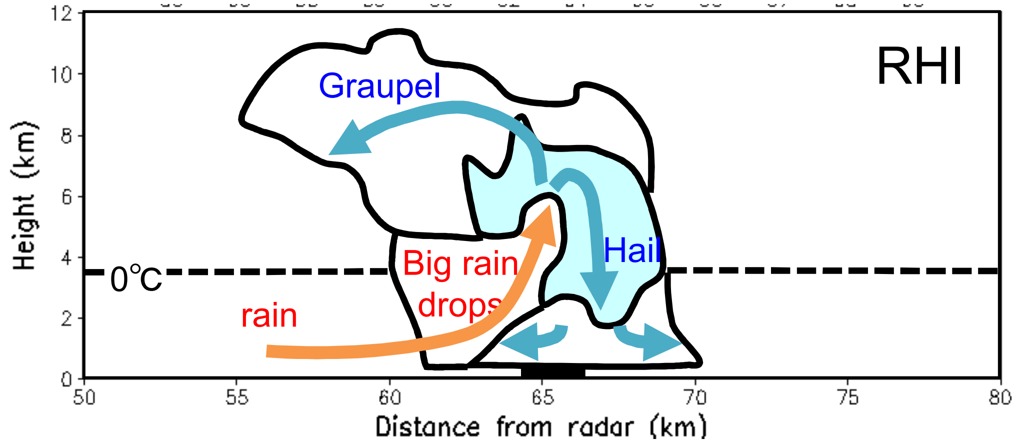
Comparisons of Z and Z_{DR} suggest that the precipitation may be separated as hail, rain, drizzle or snow (Seliga and Bringi, 1976).



A cross-section of convective echo sample observed by JMA(MRI) C-band radar.
(Z_H, Z_{DR}, expected hydrometeors)

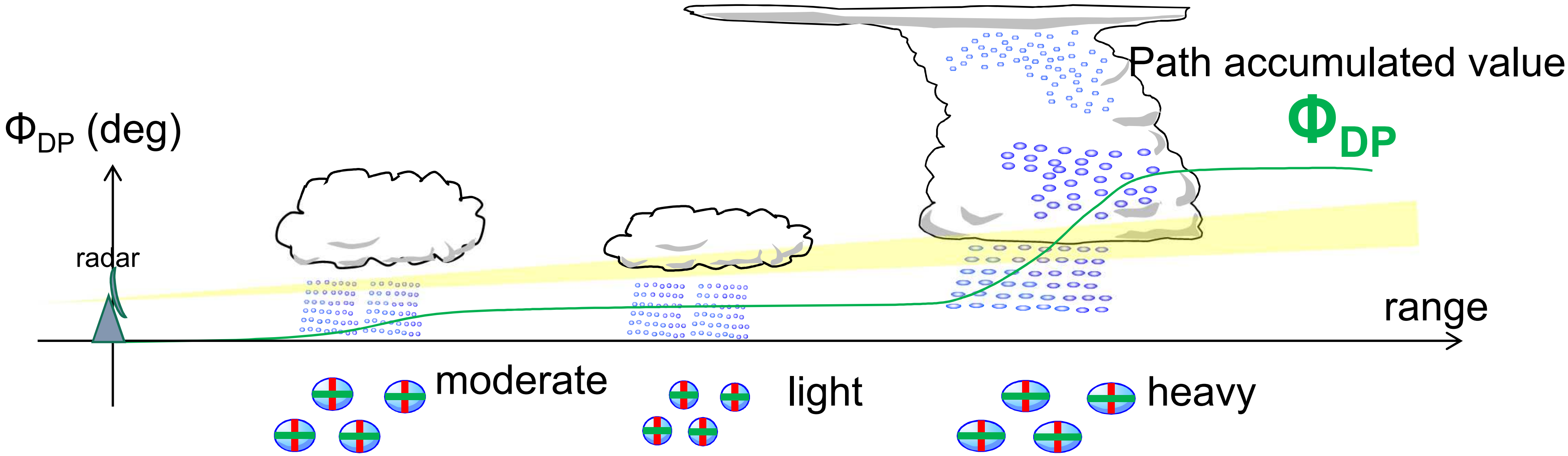


Distribution of Hydrometeors



1.2.2 Differential phase Φ_{DP}: Accumulation of rain

- Reflects aspect ratios of precipitation particles on the beam path.
- Possible range of values : folded in -180 to 180 deg (0 – 360 deg)
- In rain region, monotonically increasing with range (continuous)
- Not attenuated because this is phase measurement
- Useful for attenuation correction of Z, Z_{DR}.

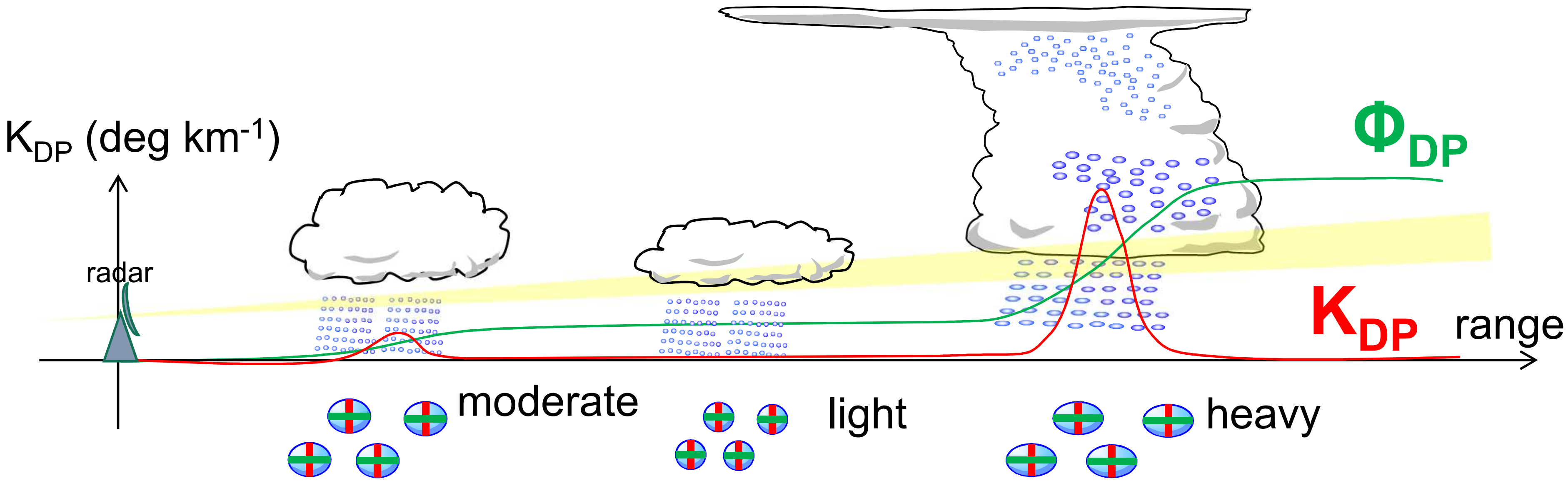


1.2.3 Specific differential phase K_{DP}: Rain rate

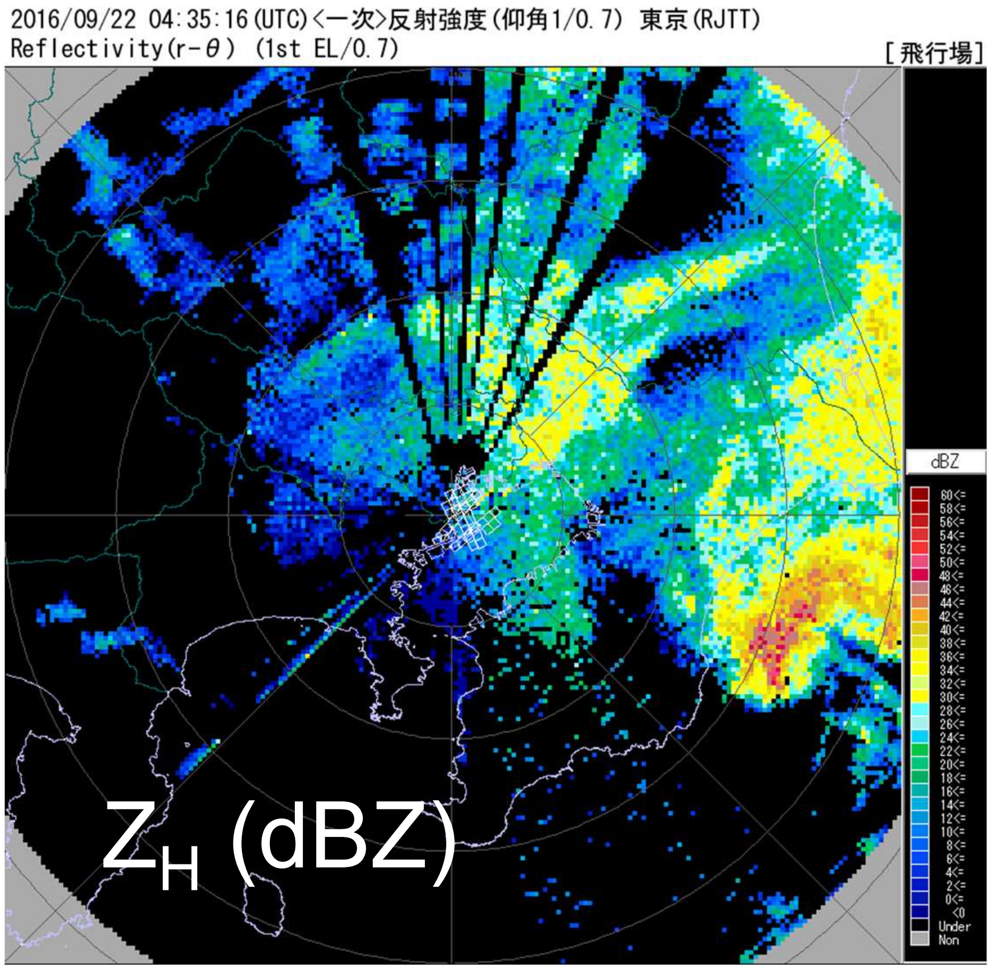
$$K_{DP} = \frac{1}{2}\frac{d\Phi_{DP}}{dr}$$

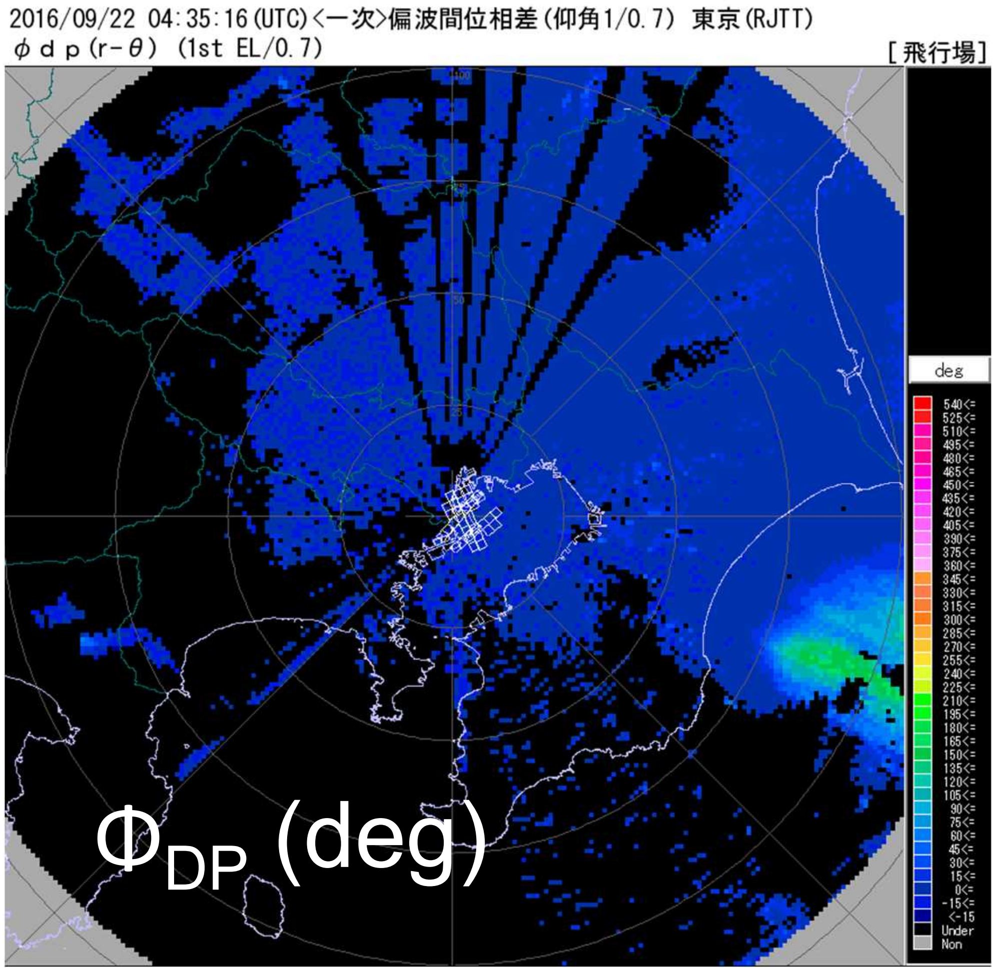
Appropriate range derivatives (e.g. Hubbert and Bringi 1995, Maesaka et al. 2012, etc)

- Reflects aspect ratios of precipitation particles.
- Possible range of values : generally -1 to 20 (deg km^{-1}) for C-band
- Overcoming issues of attenuation and partial beam blockage.
- Useful for rainfall rate estimation (especially for heavy rain)
- Disadvantage is noisy value in low SNR region (e.g. light rain)

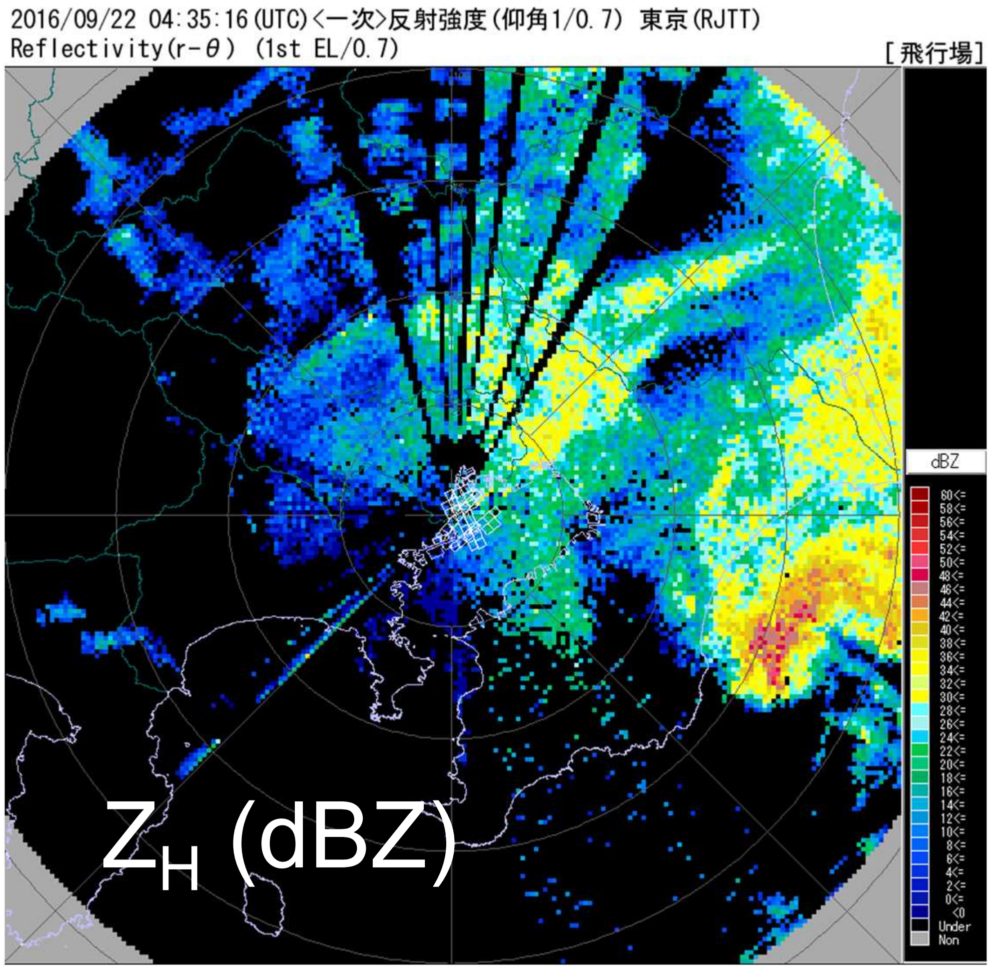


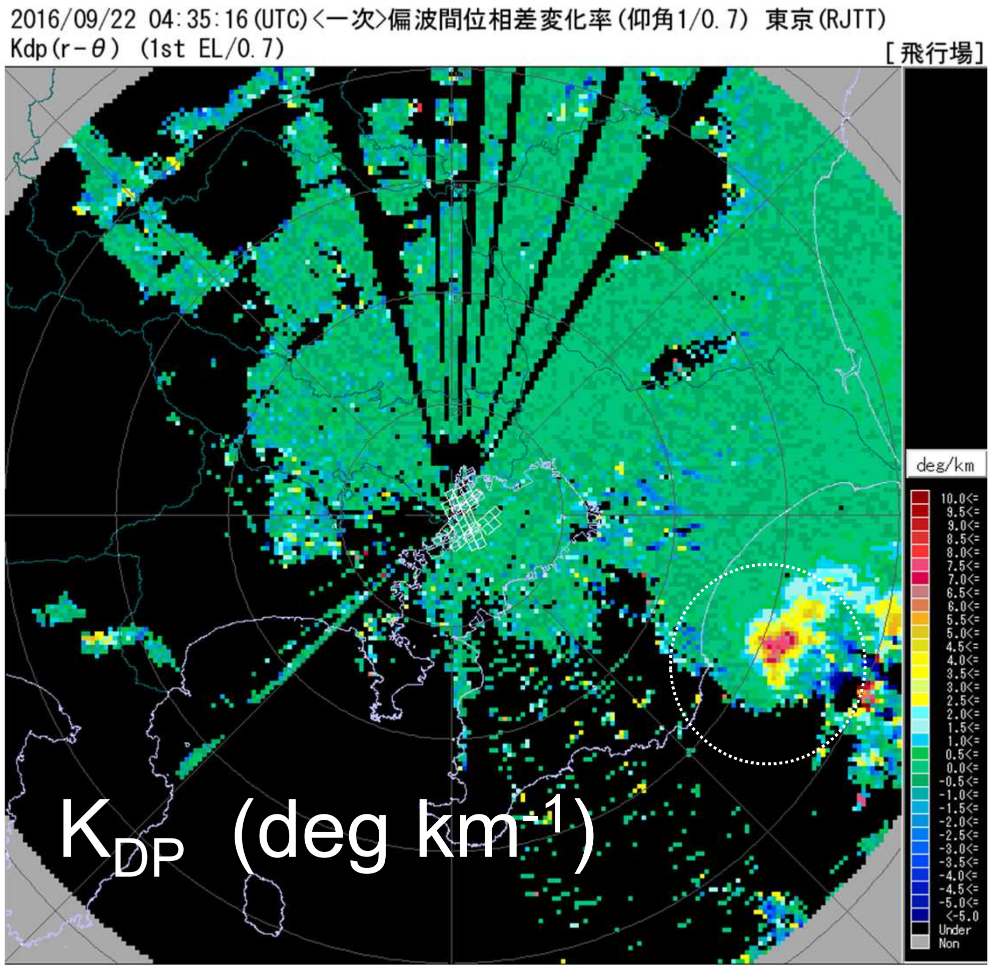
1.2.3 Differential phase Φ_{DP} and Specific differential phase K_{DP}





1.2.3 Differential phase Φ_{DP} and Specific differential phase K_{DP}

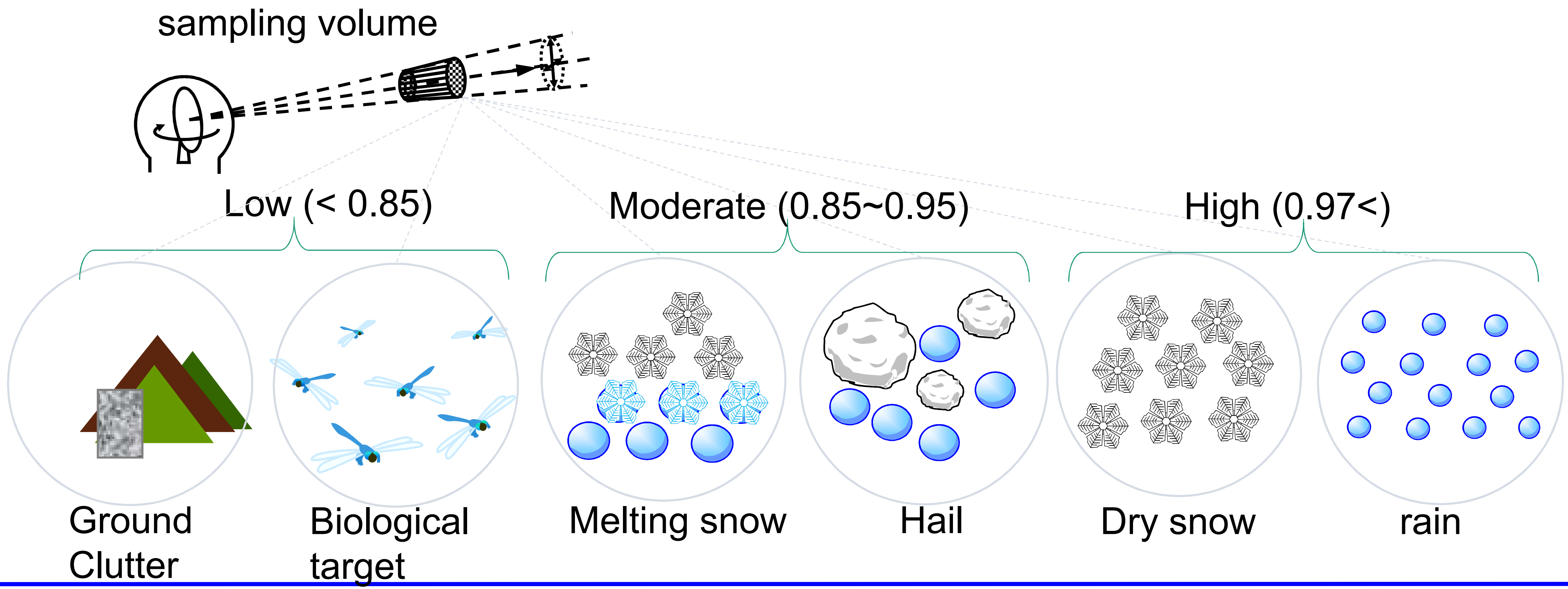




The estimation of rain rate around convective echoes using Z sometimes results in overestimation or underestimation. Previous studies have shown that precipitation intensity estimates above 20 mm/h are better than Z (e.g. English et al. 1991).

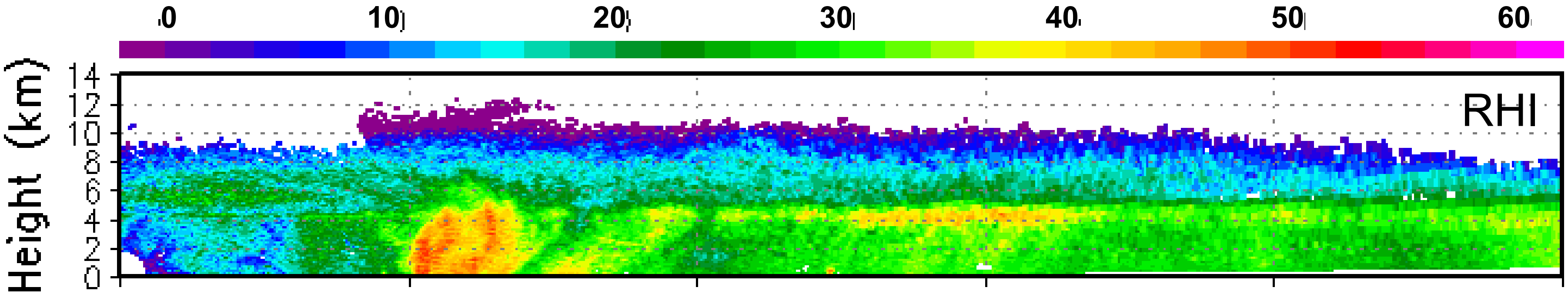
1.2.4 Correlation coefficient: ρ_{hv}: Diversity in shape

- Reflects statistical diversity of scattering targets within a range bin.
- Possible range of values : 0 to 1 (unitless)
- Useful for QC and hydrometeor classification
- Lower values in low SNR region (Correction is needed)

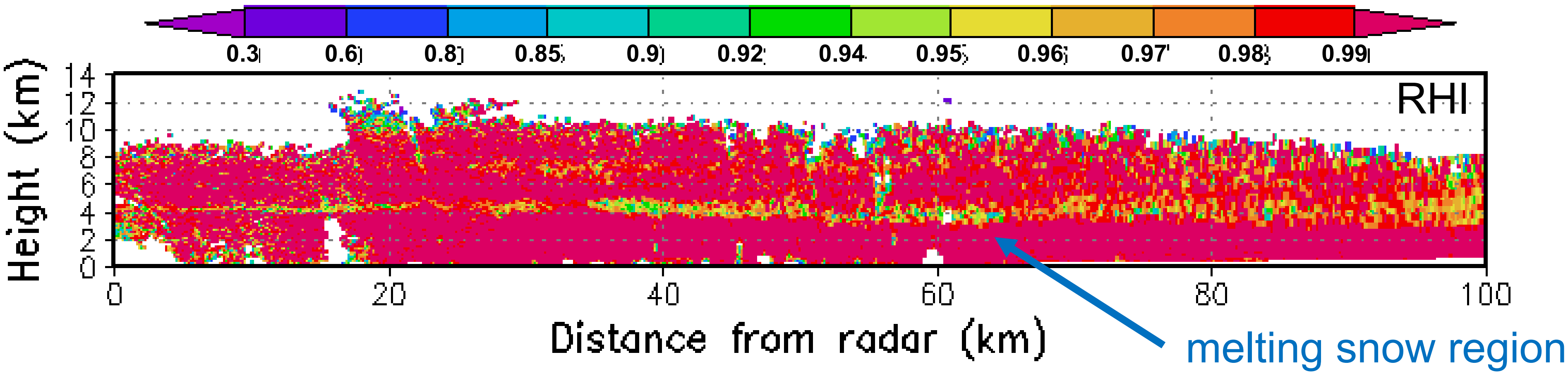


1.2.4 Correlation coefficient: ρ_{hv}: Diversity in shape

Reflectivity factor Z_H (dBZ)



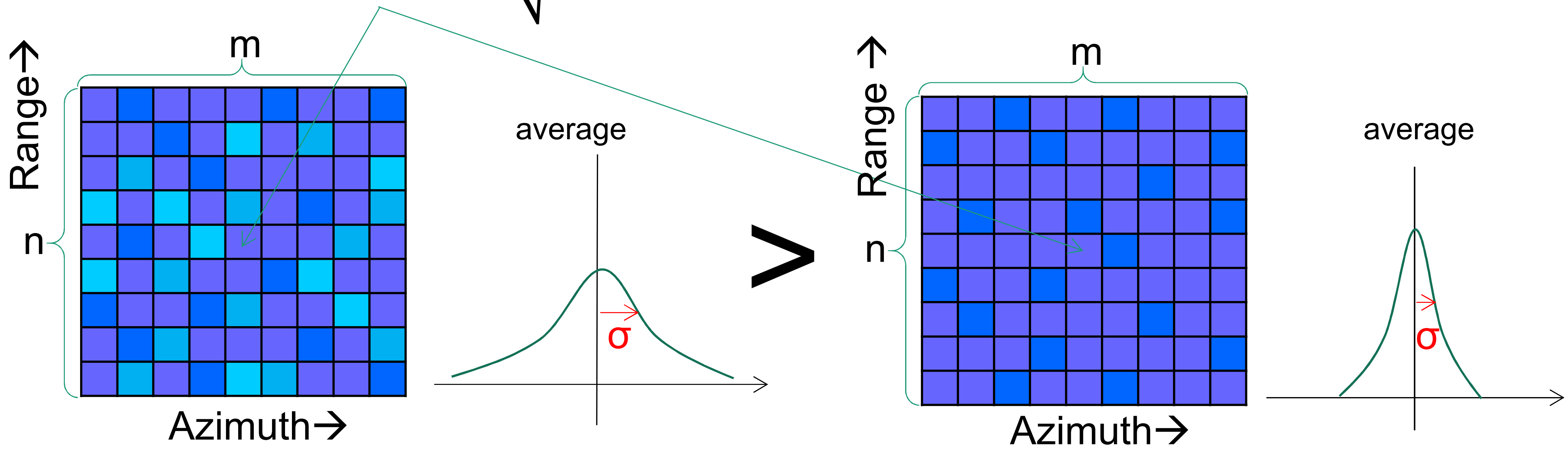
Correlation coefficient ρ_{hv}



1.2.5 Texture : Spatial Fluctuation

- Generally defined as standard deviation of a variable.
- Reflects the roughness of the value distribution of the variable.
- Reflects the characteristics of targets (depends on the variable)
- Useful for QC and hydrometeor classification

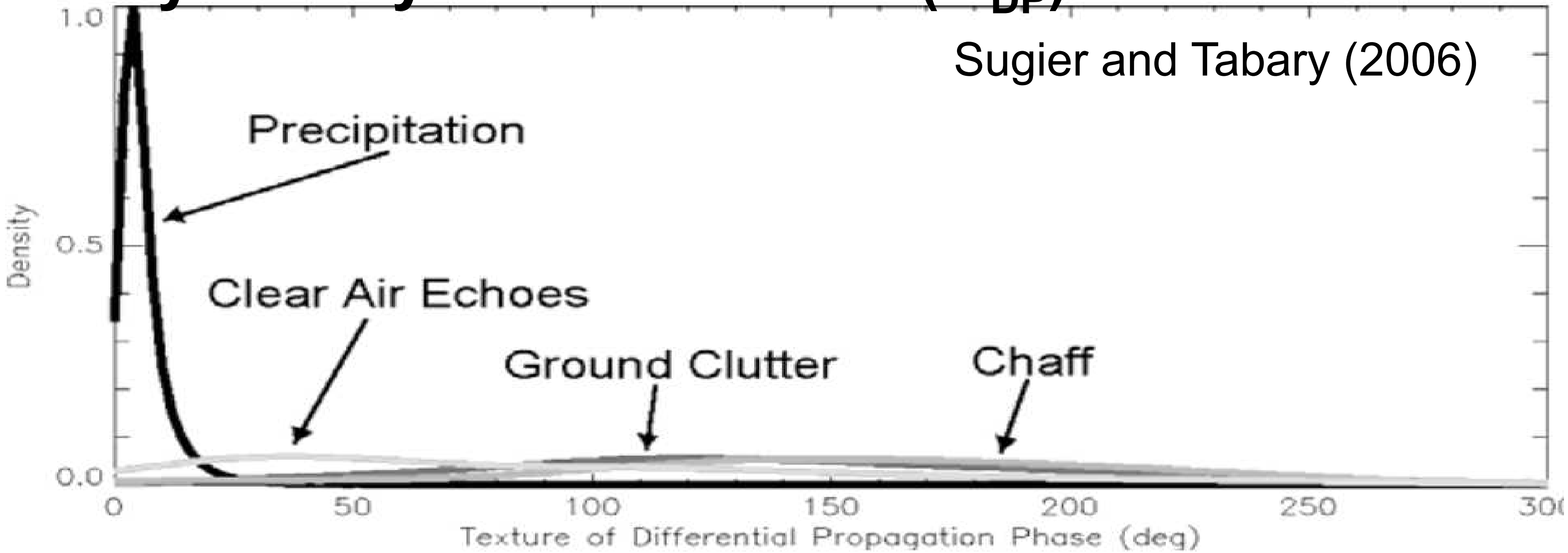
$$Texture(X_{a,b}) = \sqrt{\frac{\sum_{i=-(m-1)/2}^{(m-1)/2} \sum_{j=-(n-1)/2}^{(n-1)/2} \left(X_{a,b} - X_{a+i,b+j}\right)^2}{mn}}$$



1.2.5 Texture : Spatial Fluctuation

- $S(\Phi_{DP})$: Standard deviation of Φ_{DP}
  - Reflects sparseness or non-uniformity of scattering targets within sampling volume
  - Possible range of values : larger than 0
  - Can clearly indicates precipitation echo
  - Useful for hydrometeor classification and QC

Probability density distribution of $S(\Phi_{DP})$



1.3 Importance of monitoring

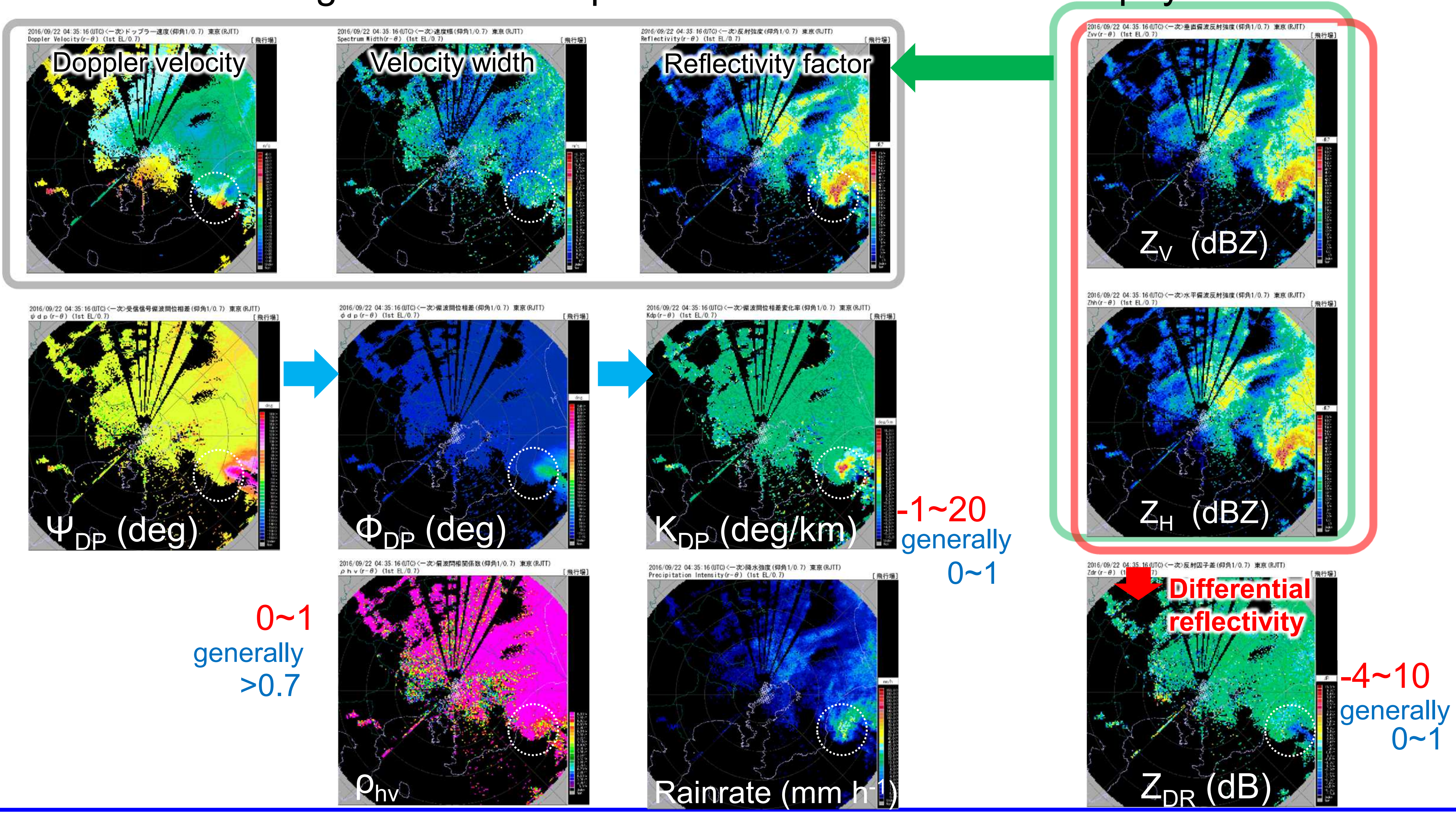
- Accurate data are required for dual-polarization radar application.

- Understanding the characteristics of polarization variable will support:
  - Superior quality control
  - High quality precipitation estimation
  - Hydrometeor classification

- It is therefore desirable to gradually adopt dual-polarization from the basics upward.

1.3 Importance of monitoring

- Daily check of data quality.
- Understanding the relationship between variables and microphysics.



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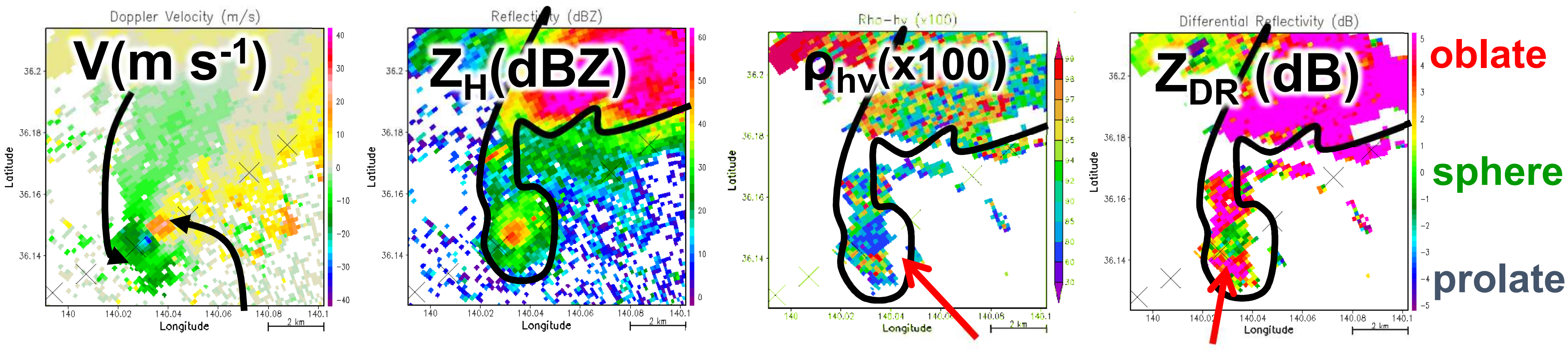
1.3 Importance of monitoring

Clarification of the microphysical process from the signatures of individual variable.

Target	Z_H (dBZ)	ρ_{hv}	Z_{DR} (dB)
Rain	small to large 25 to 60*1	large 0.97 < *1	small to large 0.4 to 4*1
Hail	large 50 < *2	middle 0.95 < *1	middle to large 3 to 8*2
Clear echo (Insects, Chaffs)	small < 25	small < 0.8	large 5 <
Tornadic debris	small to large 20 <	small*3 < 0.8	small*3 - 0 -

(for C-band, wet hail)

*1 : Doviak and Zrnic 1993
*2 : Anderson et al. 2011
*3 : Ryzkov et al. 2005



tornadic debris signatures (TDS)

1.3 Importance of monitoring

- Accurate data are required for dual-polarization radar application.
- Understanding the characteristics of polarization variable will support:
  - Superior quality control
  - High quality precipitation estimation
  - Hydrometeor classification
- It is therefore desirable to gradually adopt dual-polarization from the basics upward.

1.4 Summary

- **Dual-polarization radar system**
  - Capacity for transmission and reception of two orthogonal polarizations
  - STAR-mode is the mainstream design with elimination of disadvantages
- **Dual-polarization variables**
  - Differential reflectivity: Z_{DR}
  - Differential phase: Φ_{DP} / K_{DP}
  - Correlation coefficient: ρ_{hv}
  - Textures of variables: e.g. $S(\Phi_{DP})$
- **Importance of monitoring**
  - Contributing to stable quality operation
  - Contributing to understanding the meteorological phenomena
  - Contributing to step-by-step development of dual polarization products

Thank you for attention

Next is about Quality Control (QC)