Issues and Improvements in HCA

Issues

- Errors in measurements
- Radar measurements at farther ranges
- Layered structure
- Mixed phase and multi-species
- Type of precipitation

Ways to improve

- Improve radar measurements at signal processing and post processing including low-pass (9/25 gates) and speckle filtering
- Include more radar variables, adjust membership functions
- Determine proper weight
- Quantify confidence of radar measurements

Different schemes of classification algorithm

(1) $$A_i = \sum_j P_i(V_j)$$

(2) $$A_i = \frac{\sum_j W_j P_i(V_j)}{\sum_j W_j}$$

Vector of weights W

(3) $$A_i = \frac{\sum_j W_{ij} P_i(V_j)}{\sum_j W_{ij}}$$

Matrix of weights W

(4) $$A_i = \frac{\sum_j W_{ij} Q_j P_i(V_j)}{\sum_j W_{ij} Q_j}$$

Matrix of weights W and quality vector

Membership function parameters for meteorological echo (MS) and two classes of nonmeteorological echo (Park et al. 2008)

P(Z(dBZ))

	GC/AP	BS	DS	WS	CR	GR	BD	RA	HR	RH
x1	15	5	5	25	0	25	20	5	40	45
x2	20	10	10	30	5	35	25	10	45	50
x3	70	20	35	40	20	50	45	45	55	75
x4	80	30	40	50	25	55	50	50	60	80

$P(Z_{DR}(dB))$

	GC/AP	BS	DS	WS	CR	GR	BD	RA	HR	RH
x1	-4	0	-0.3	0.5	0.1	-0.3	f2-0.3	f1-0.3	f1-0.3	-0.3
x2	-2	2	0.0	1.0	0.4	0.0	f2	f1	f1	0.0
x3	1	10	0.3	2.0	3.0	f1	f3	f2	f2	f1
x4	2	12	0.6	3.0	3.3	f1+0.3	f3+1.0	f2+0.5	f2+0.5	f1+0.5

$P(\rho_{hv})$

	GC/AP	BS	DS	WS	CR	GR	BD	RA	HR	RH
x1	0.5	0.3	0.95	0.88	0.95	0.90	0.92	0.95	0.92	0.85
x2	0.6	0.5	0.98	0.92	0.98	0.97	0.95	0.97	0.95	0.90
x3	0.9	0.8	1.00	0.95	1.00	1.00	1.00	1.00	1.00	1.00
x4	0.95	0.83	1.01	0.985	1.01	1.01	1.01	1.01	1.01	1.01

$P(LK_{DP})$

	GC/AP	BS	DS	WS	CR	GR	BD	RA	HR	RH
x1	-30	-30	-30	-30	-5	-30	g1-1	g1-1	g1-1	-10
x2	-25	-25	-25	-25	0	-25	g1	g1	g1	-4
x3	10	10	10	10	10	10	g2	g2	g2	g1
x4	20	10	20	20	15	20	g2+1	g2+1	g2+1	g1+1

P(SD(Z)(dB))

	GC/AP	BS	DS	WS	CR	GR	BD	RA	HR	RH
x1	2	1	0	0	0	0	0	0	0	0
x2	4	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
x3	10	4	3	3	3	3	3	3	3	3
x4	15	7	6	6	6	6	6	6	6	6

$P(SD(\Phi_{DP})(deg))$

	GC/AP	BS	DS	WS	CR	GR	BD	RA	HR	RH
x1	30	8	0	0	0	0	0	0	0	0
x2	40	10	1	1	1	1	1	1	1	1
x3	50	40	15	15	15	15	15	15	15	15
x4	60	60	30	30	30	30	30	30	30	30

$$f_1 = -0.50 + 2.50 \times 10^{-3} Z + 7.50 \times 10^{-4} Z^2$$
$$f_2 = 0.68 + 4.81 \times 10^{-2} Z + 2.92 \times 10^{-3} Z^2$$
$$f_3 = 1.42 + 6.67 \times 10^{-2} Z + 4.85 \times 10^{-4} Z^2$$
$$g_1 = -44.0 + 0.8Z$$
$$g_2 = -22.0 + 0.5Z$$

Z is in dB

Example of the matrix of weights W

	Class	Z	Z_{DR}	ρ_{hv}	Kdp	SD(Z)	SD(Φ_{DP})
1	GC/AP	0.2	0.4	1.0	0.0	0.6	0.8
2	BS	0.4	0.6	1.0	0.0	0.8	0.8
3	DS	1.0	0.8	0.6	0.0	0.2	0.2
4	WS	0.6	0.8	1.0	0.0	0.2	0.2
5	CR	1.0	0.6	0.4	0.5	0.2	0.2
6	GR	0.8	1.0	0.4	0.0	0.2	0.2
7	BD	0.8	1.0	0.6	0.0	0.2	0.2
8	RA	1.0	0.8	0.6	0.0	0.2	0.2
9	HR	1.0	0.8	0.6	1.0	0.2	0.2
10	RH	1.0	0.8	0.6	1.0	0.2	0.2

Example: Z_{DR} has the highest classification capability for graupel or big drops (W_{62} = W_{72} = 1.0), whereas K_{DP} is not useful at all (W_{64} = W_{74} = 0.0) for these hydrometeor types

Confidence factors or quality vector

The quality of radar variables is determined by

1. attenuation / differential attenuation
2. nonuniform beam filling (NBF) (Ryzhkov, 2007)
3. statistical error / cross-correlation coefficient
4. signal-to-noise ratio
5. partial beam blockage

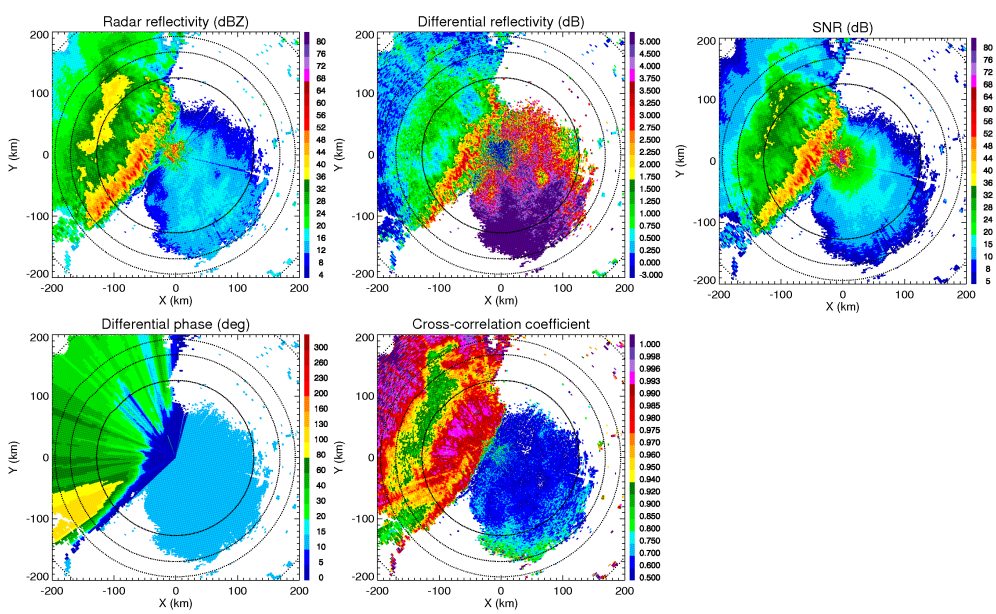
$$Q = [Q_Z, Q_{Zdr}, Q_{\rho hv}, Q_{Kdp}, Q_{sdz}, Q_{sdp}]$$

An example of confidence factor for Z_{DR}

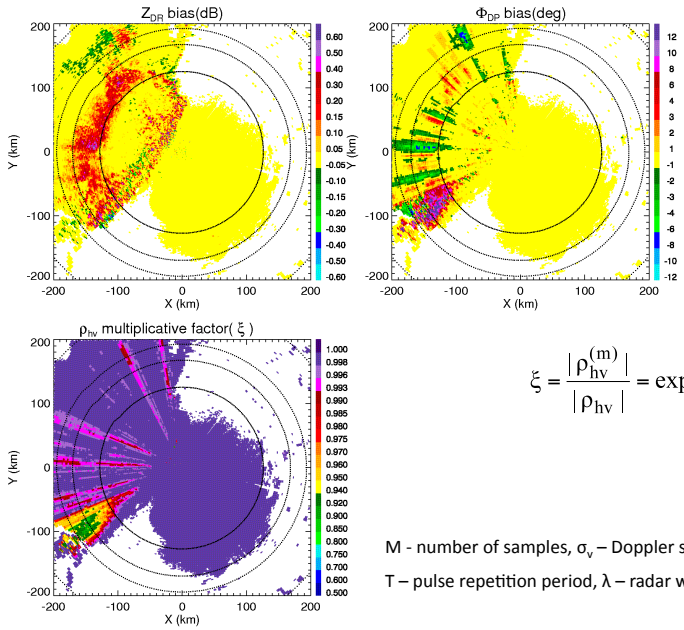
$$Q_{Zdr} = \exp\left\{-0.69\left[\left(\frac{\Phi_{DP}}{\Phi_{DP}^{(Zdr)}}\right)^2 + \left(\frac{\Delta Z_{DR}}{\Delta Z_{DR}^{(t)}}\right)^2 + \left(\frac{1-\rho_{hv}}{\Delta\rho_{hv}^{(t)}}\right)^2 + \left(\frac{snr^{(Zdr)}}{snr}\right)^2 + \left(\frac{\alpha}{\alpha^{(t)}}\right)^2\right]\right\}$$

1. Differential attenuation | 2. NBF | 3. Statistical measurement error | 4. Low signal-to-noise ratio | 5. PBB

Composite plot of Z, Z_{DR}, Φ_{DP}, ρ_{hv}, and SNR at a 0.43º elevation angle measured by KOUN radar at 0646 UTC 13 May, 2005. Dotted contours represent slant ranges Rbb, Rb, Rt, and Rtt (associated with the melting layer) as functions of azimuth.



Composite plot of ΔZ_{DR}, $\Delta\Phi_{DP}$, and ξ at a 0.43º elevation angle at 0646 UTC 13 May, 2005. Dotted contours in the figure indicate slant ranges Rbb, Rb, Rt, and Rtt (associated with the melting layer) as functions of azimuth.



Ω is a 3 dB antenna beam width (deg),

$\Delta\Phi_{DP}$, Φ_{DP}, θ, ϕ are expressed in deg,

Z and Z_{DR} are expressed in dB

$$\Delta Z_{DR} = 0.02\,\Omega^2\left(\frac{dZ}{d\theta}\frac{dZ_{DR}}{d\theta} + \frac{dZ}{d\varphi}\frac{dZ_{DR}}{d\varphi}\right)$$

$$\Delta\Phi_{DP} = 0.02\,\Omega^2\left(\frac{d\Phi_{DP}}{d\theta}\frac{dZ}{d\theta} + \frac{d\Phi_{DP}}{d\varphi}\frac{dZ}{d\varphi}\right)$$

$$\xi = \frac{|\rho_{hv}^{(m)}|}{|\rho_{hv}|} = \exp\left\{-1.3710^{-5}\Omega^2\left[\left(\frac{d\Phi_{DP}}{d\theta}\right)^2 + \left(\frac{d\Phi_{DP}}{d\varphi}\right)^2\right]\right\}$$

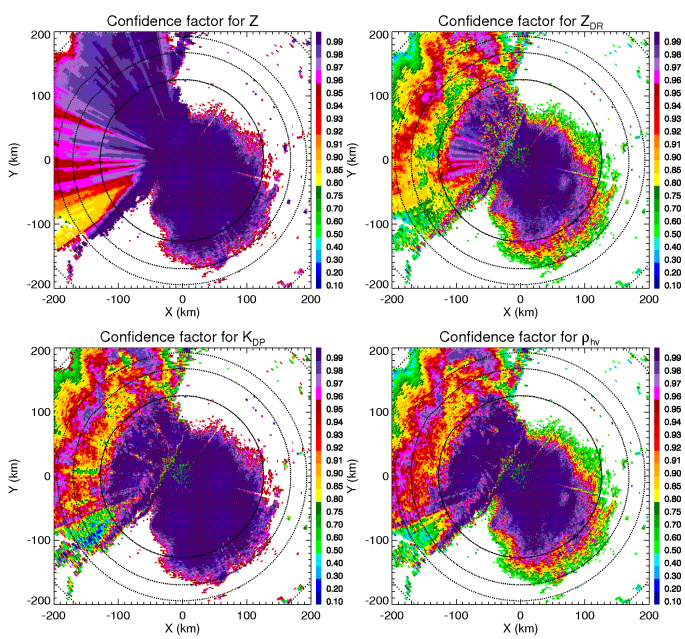
$$SD(Z_{DR}) \approx 3.51\left(\frac{1-\rho_{hv}^2}{\sigma_{vn}M}\right)^{1/2}$$

M - number of samples, σ_v – Doppler spectrum width,

T – pulse repetition period, λ – radar wavelength

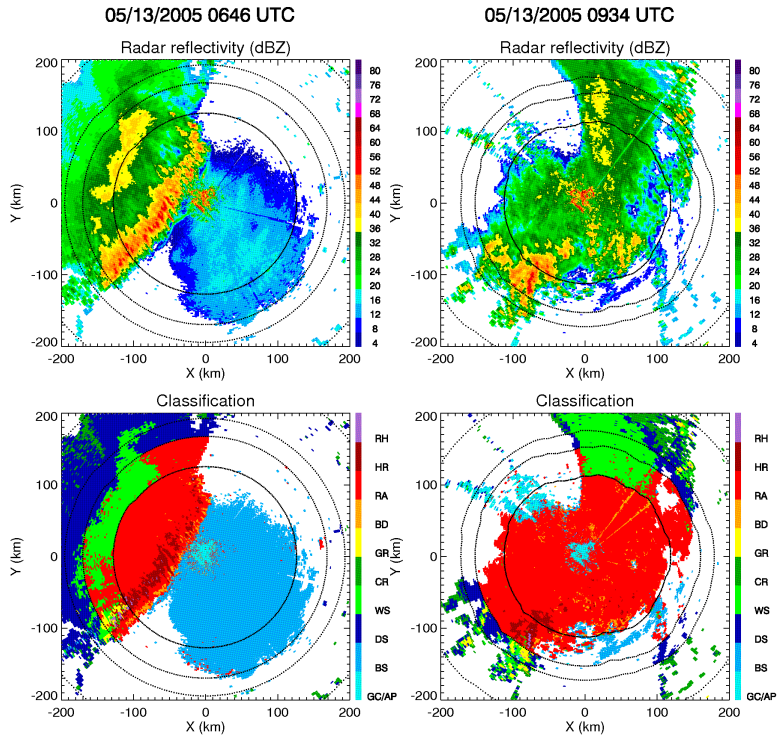
$$\sigma_{vn} = 2\sigma_v T/\lambda$$

Composite plot of confidence factors of Z, Z_{DR}, K_{DP}, and ρ_{hv} at a 0.43º elevation angle at 0646 UTC 13 May, 2005. The slant ranges Rbb, Rb, Rt, and Rtt (associated with the melting layer) as functions of azimuth are overlaid on the image in dotted contours.



1. Impact of attenuation in the southern flank of the squall line
2. Impact of low ρ_{hv} within the melting layer
3. Impact of low SNR at the echo periphery

Results of classification



Classification steps

1. Estimation of the confidence vector
2. Computation of the aggregation values
3. Polarimetric detection of the melting layer
4. Designation of classes based on the height and depth of the melting layer and the broadening of the radar beam
5. Vertical continuity checks
6. “Sanity” checks
7. Despeckling