Application of the dual-polarization radar data in numerical model: Construction of simulator

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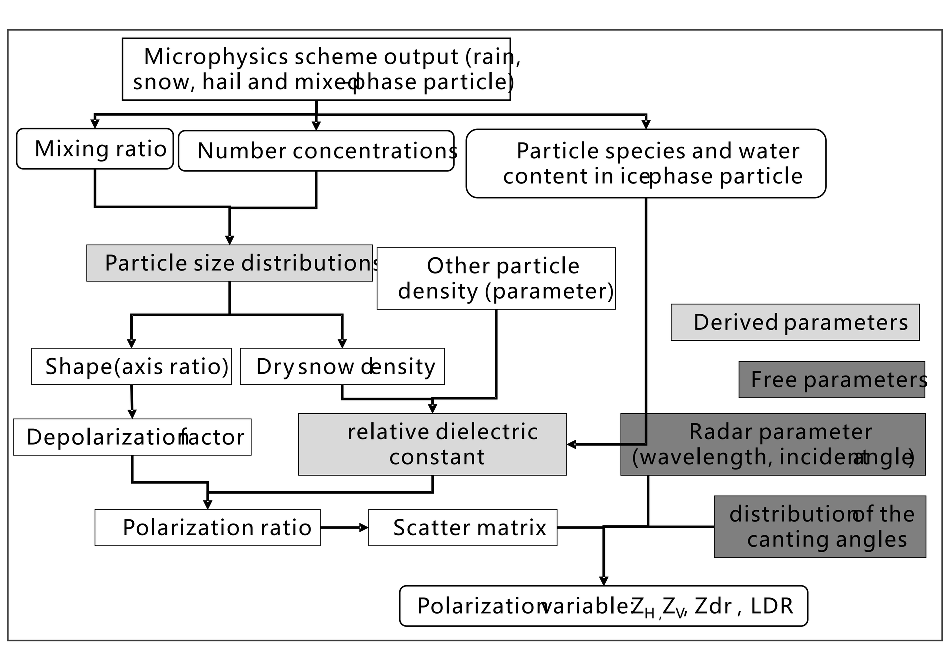
Introduction

As an enhanced radar, the dual-linear polarization radar transmit and receives horizontal/vertical pulse, so it can achieve more information of precipitation particles from the polarimertric observable variables , include ZH, ZDR, KDP, CC. Explicit description of clouds and microphysical processes is key part for improving numerical model quantitative precipitation forecasts. So the efficient use of polarimetric radar data which stands for clouds and precipitation particles' macro and micro characteristics in NWP is one of important research field. The observation operators for radar link the model hydrometeor fields to polarimertric observable variables. Some polarimetric radar simulators already exist in the literature. However, there are little works about polarimetric radar simulators in China and many meteorologists have made many progresses in the microphysics and statistical characteristics of precipitation particles. So we will develop a simulator for S band dual-linear polarization radar.

Construction of simulator

The simulator considers four hydrometeors (i.e., cloud ice, snow, rain, hail), takes as input the mixing ratios and number concentrations of Morrison microphysics scheme and the axis ratio, relative dielectric constant and canting angles of particles, calculates the reflectivity at horizontal and vertical polarizations, the differential reflectivity, the specific differential phase and so on.



$$Z_{HH,X} = \frac{4\lambda^4}{\pi^4|K_p|^2}\int N(D)(AS_{HH}^2 + BS_{vv}^2 + 2CS_{HH}S_{VV})\,dD\ ;\ \mathrm{mm^6m^{-3}} \quad (1)$$

$$Z_{HV,X} = \frac{4\lambda^4}{\pi^4|K_p|^2}\int N(D)C(S_{VV} - S_{HH})^2\,dD\ ;\ \mathrm{mm^6m^{-3}} \quad (2)$$

$$Z_{VV,X} = \frac{4\lambda^4}{\pi^4|K_p|^2}\int N(D)(BS_{HH}^2 + AS_{vv}^2 + 2CS_{HH}S_{VV})\,dD\ ;\ \mathrm{mm^6m^{-3}} \quad (3)$$

$$K_{dp,X} = \frac{180\lambda}{\pi}\int N(D)(A-B)(S_{HH} - S_{VV})dD\ ;\ \mathrm{deg\,km^{-1}} \quad (4)$$

Fig.1 Diagram of the dual linear polarization radar simulator

Particle spectrum: calculate slope and intercept of cloud ice, snow, rain, hail's spectrum from the mixing ratios and number concentrations.

DSD: $N(D) = N_0 D^{\mu}\exp(-\lambda_s D)$

slope: $$\lambda_s = \left[\frac{cN\Gamma(\mu+d+1)}{q\Gamma(\mu+1)}\right]^{\frac{1}{d}}$$

intercept: $$N_0 = \frac{N\lambda_s^{\mu+1}}{\Gamma(\mu+1)}$$

axisratio: describe the shape of particle

rain: $R = 1.012 - 0.01445D - 0.01028D^2$ (1 ≤ D ≤ 4 mm)

$R = 1.0048 + 5.7\times10^{-4}D - 2.628\times10^{-2}D^2 + 3.682\times10^{-3}D^3 - 1.677\times10^{-4}D^4$ (D < 1 or D > 4 mm)

hail: $$R = \begin{cases} 1. & D<10 \\ 0.75 & 10\le D<50 \\ 1. & 50\le D \quad \text{(tumbling motions)} \end{cases}$$

snow/ice: R = 0.75

ε_r: different materials have different ε_r

Pure rain	ε_{rain}	= 70.9
Dry hail	ε_{dh}	= 3.17
ice	ε_i	= 2.025
Dry snow	ε_{ds}	$= 1 + 1.7\rho_d + 0.7\rho_d^2$
Mixture	ε_{iw}	$= \varepsilon_i\left(1 + \frac{3f\left(\frac{\varepsilon_w-\varepsilon_i}{\varepsilon_w+2\varepsilon_i}\right)}{1-f\left(\frac{\varepsilon_w-\varepsilon_i}{\varepsilon_w+2\varepsilon_i}\right)}\right)$

melting ice (snow-hail) model: snow and hail will melt near melting level, forming snow/hail aggregate-liquid water mixture. The mixture is assumed to exist only when q_r and q_s coexist below 0℃ level. First we confirm the height where snow begin to melt, then calculate water content of ice-phase particle (F), for exfoliation of water, assume actual water content is ln(1+F).

Application of simulator in 2D ideal squall line case

The test case is 2D ideal squall line case in WRF version 3.4. 1. The initial CAPE is 2200 J kg^{-1}, the height of 0 ℃ level is 4 km, the horizontal wind profile has a shear of 0.0048 s^{-1} in the lowest 2.5 km. The model is initialized with environmental temperature and moisture profiles, convection is initially triggered by adding a thermal with max perturbation of 3K centered at a height of 1.5 km.

Tab.1 model confuration

domain	set-up	physics	set-up
H-resolution	250 m	Microphysics	Morrison
H-grids	1200	Planetary Boundary layer	1.5-order TKE scheme
vertical level	80		
model top	20 km	radiative transfer	neglected
time step	3 s	surface fluxs	zero

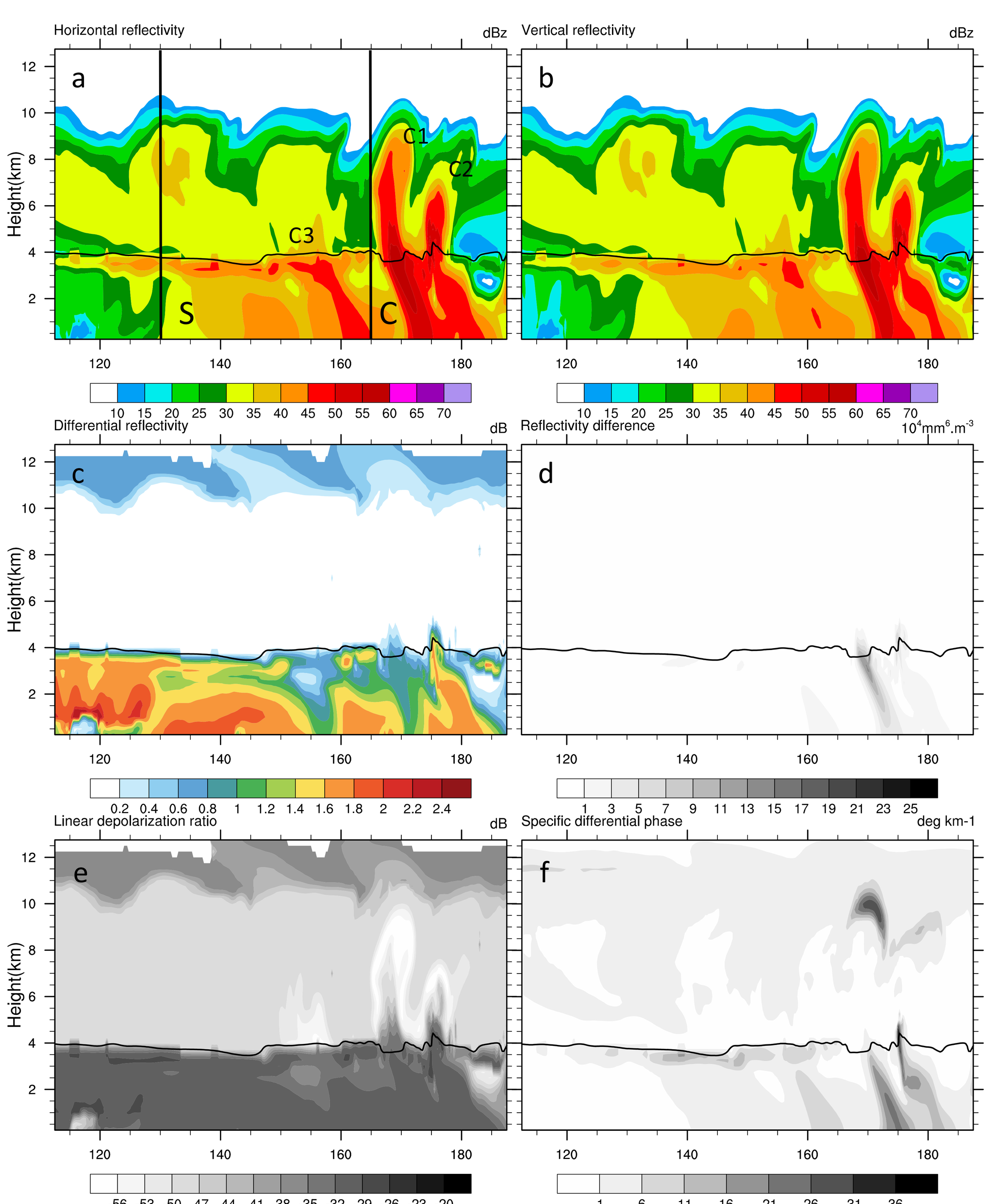


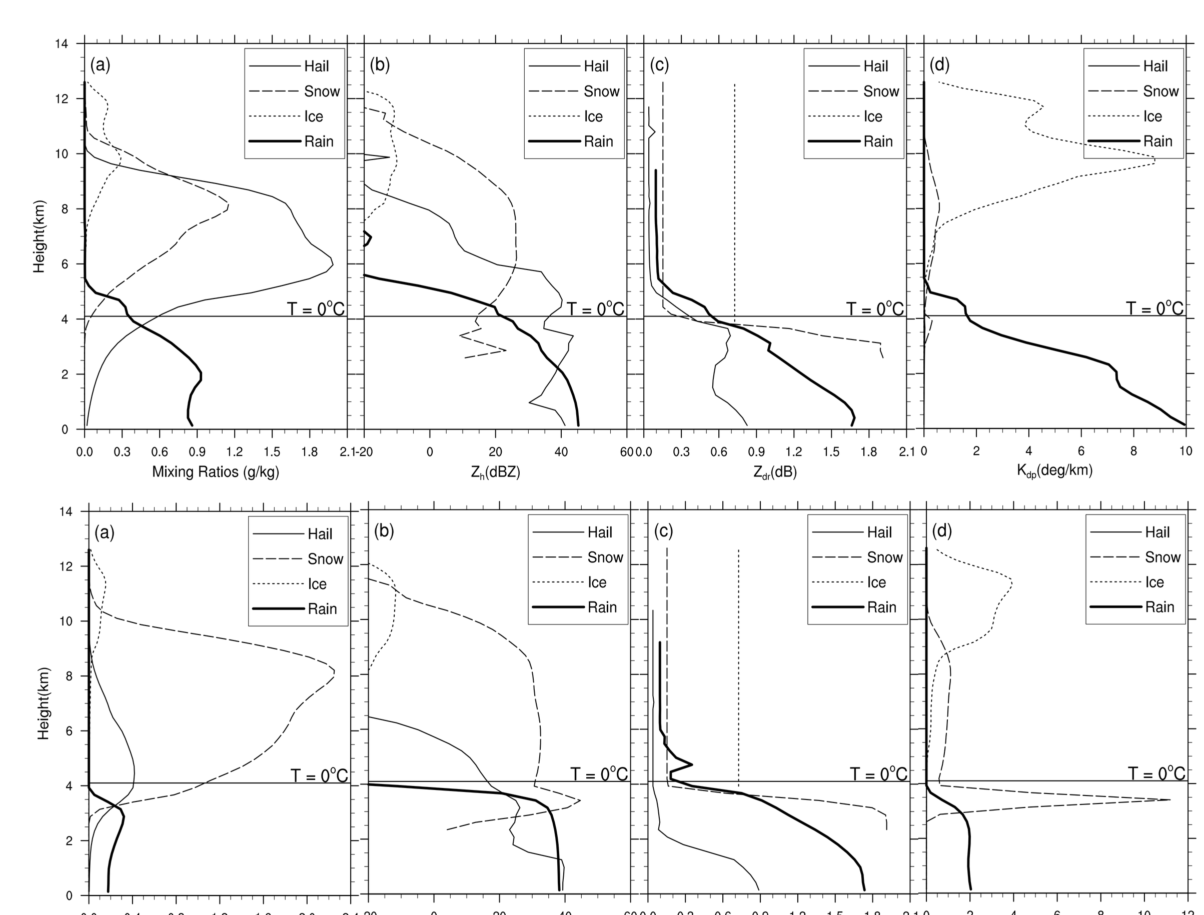
Fig.2 The vertical cross sections of simulated (a) Zh, (b) Zv, (c) Zdr, (d) Zdp, (e) LDR, (f) Kdp at 250 m-in into 2D squall-line simulation

x=170-175 km, z=4.1 km, high Zh(55 dBz),low Zdr(1 dB),Qh 6 g/kg.

x=176 km and 186 km, exist two weak Zdr columns, the center values is 1.8 and 0.8 dB, extend 1 km above melting level, center values of Qr is 4.8 g/kg and updraft outstrip 15 m/s.

x=115-155 km, there is bright band below melting level, Zh > 40 dBz, Kdp > 16 °/km

Fig.3 Vertical profile of area averaged at the convection (up) and stratiform (down) region



Z_h in convection is contributed by rain and hail below melting level, while hail and snow are mainly source above melting level.

Zh in strat-iform has a bright band (Zh > 40 dBz) which is mainly con-tributed by melting snow.

We assume ice and snow's ε_r is constant, so their Zdr are also constant above melting level.

Tab.2 The max value of simulated polarization variable for four hydrometeors

species	Z_H (dBZ)	Z_{dr} (dB)	K_{dp} (deg km^{-1})	LDR (dB)	Z_{dp} (10^4mm^{6}m^{-3})
Ice	-4.6	0.7	29.89	-36.4	0.0
Snow	48.6	1.9	22.32	-27.8	20.0
Rain	52.0	2.45	36.72	-27.7	25.1
hail	60.1	1.8	0.34	-26.3	24.5

Conclusion

Based on the Rayleigh-Gans scattering theory , a dual-linear polarization radar simulator at S band of wavelength 10 cm has been developed. The simulator considers four hydrometeors (i.e., cloud ice, snow, rain, hail), takes as input the mixing ratios and number concentrations of microphysics scheme and the axis ratio, relative dielectric constant and canting angles of particles, calculates Z_h, Z_v, LDR,Kdp. Realistic polarimetric radar signatures of mature 2D ideal squall-line are produced in the simulated field: the hail has high horizontal reflectivity and low differential reflectivity (Zdr hole); the Zdr column in convection regions; the bright bands of horizontal reflectivity and specific differential phase; the linear relationship between the horizontal reflectivity and differential reflectivity factor of rain (rain line).