Comparison of Forward Operators for Polarimetric Radars Aiming for Data Assimilation

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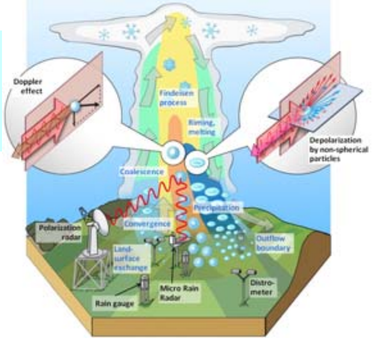
Forward Operators for Polarimetric Radars



(1) WRF

Two-moment microphysical scheme

(Morrison and Gettleman J. Clim... 8)

$$\phi(D) = N_0 D^{\mu} e^{-\Lambda D}$$

N_0 Intercept parameter
Λ Slope parameter

Predict

μ Spectral shape parameter

Prognostic equations for number *N* and mass concentration *q* of hydrometeors

(2) Two types of variable converters

Model variables -> pol. observation

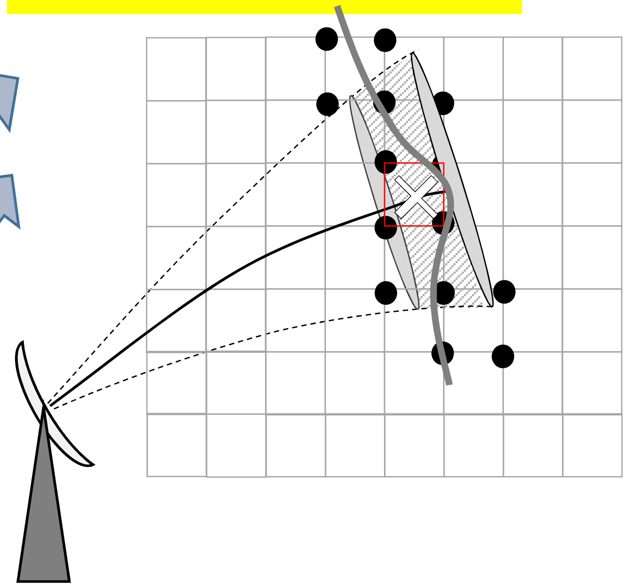
- T-matrix (Mishchenko 2000)
- Fitting of scattering amplitude (Zhang et al. 2001)

Pol. observation -> model variable

- $Q_r - (Z_h, Z_{dr})$
- $Q_r - (K_{dp}, Z_{dr})$
- $Q_r - (K_{dp})$

(Bringi and Chandrasekar 2001)

(3) Space interpolator



- Beam broadening with Gaussian weights in both horizontal and vertical directions
- Consider the bending effect

Variable converters (1) (model to observation)

Oblateness (Brandes et al. 2005)

From spherical rain in the model to spheroid

$$r = 0.9951 + 2.51 \times 10^{-2} D - 3.644 \times 10^{-2} D^2 + 5.303 \times 10^{-3} D^3 - 2.492 \times 10^{-4} D^4$$

T-matrix (direct scattering calculation)

TMX

Drop size D and number of rainwater are provided by the model.

(Doviak and Zrnic 1993, Smyth and Illingworth 1998, Oguchi 1973)

Observation

$$Z_{H,V} = \left(\frac{4\lambda^4}{\pi^4 |K_w|^2}\right) \int_{r2}^{r1} \left|S_{h,v}(D)\right|^2 n(D)\,dD$$

$$K_{DP} = \frac{2 \times 180 \times 10^{-3}\lambda}{\pi} \int_{r1}^{r2} \mathrm{Re}[S_h(D) - S_v(D)]\,n(D)\,dD$$

$$A_H = 8.686 \times 10^{-3}\lambda \int_{r1}^{r2} \mathrm{Im}[S_h(D)]\,n(D)\,dD$$

$$A_{DP} = 8.686 \times 10^{-3}\lambda \int_{r1}^{r2} \mathrm{Im}[S_h(D) - S_v(D)]\,n(D)\,dD$$

The most accurate operator in theory, but not differential (not available for variational DA)

Fitting (indirect scattering calculation)

(Zhang et al. 2001)

$$\left|S_{h,v}(D)\right| = \alpha_{h,v} D^{\beta_{h,v}}$$

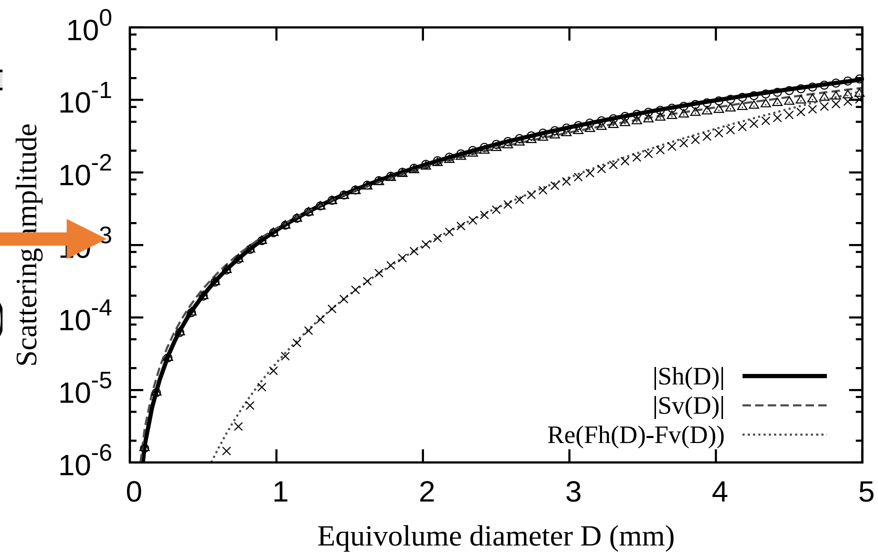
$$Z_{H,V} = \frac{4\lambda^4}{\pi^4 |K_w|^2}\left(\alpha_{h,v}^2 N_0 \Lambda^{-(2\beta_{h,v}+1)} \Gamma(2\beta_{h,v} + 1)\right)$$

$$K_{DP} = \frac{180\lambda}{\pi} N_0 \alpha_k \Lambda^{-(\beta_k+1)} \Gamma(\beta_k + 1)$$

$$A_H = \alpha_H {K_{DP}}^{\beta_H}$$

$$A_{DP} = \alpha_d {K_{DP}}^{\beta_d}$$

α, β are fitting coefficients.



Variable converters (2)

(observation to model)

Z_h, Z_{DR} and K_{DP} are observed by polarimetric radars

Physically based methods

Derived theoretically or fitting with scattering calculation

Suggested by radar meteorologists

(Bringi and Chandrasekar 2001)

Model

$$\mathrm{Qr} = c_1\, Z_h^{a_1} 10^{0.1 b_1\, Z_{DR}}$$

Z_ZD — Used by Li and Mecikalski (2012)

$$\mathrm{Qr} = \mathrm{c}_2 \left(\frac{K_{DP}}{f}\right)^{b_2}$$

KD — Used by Yokota et al. (2014)

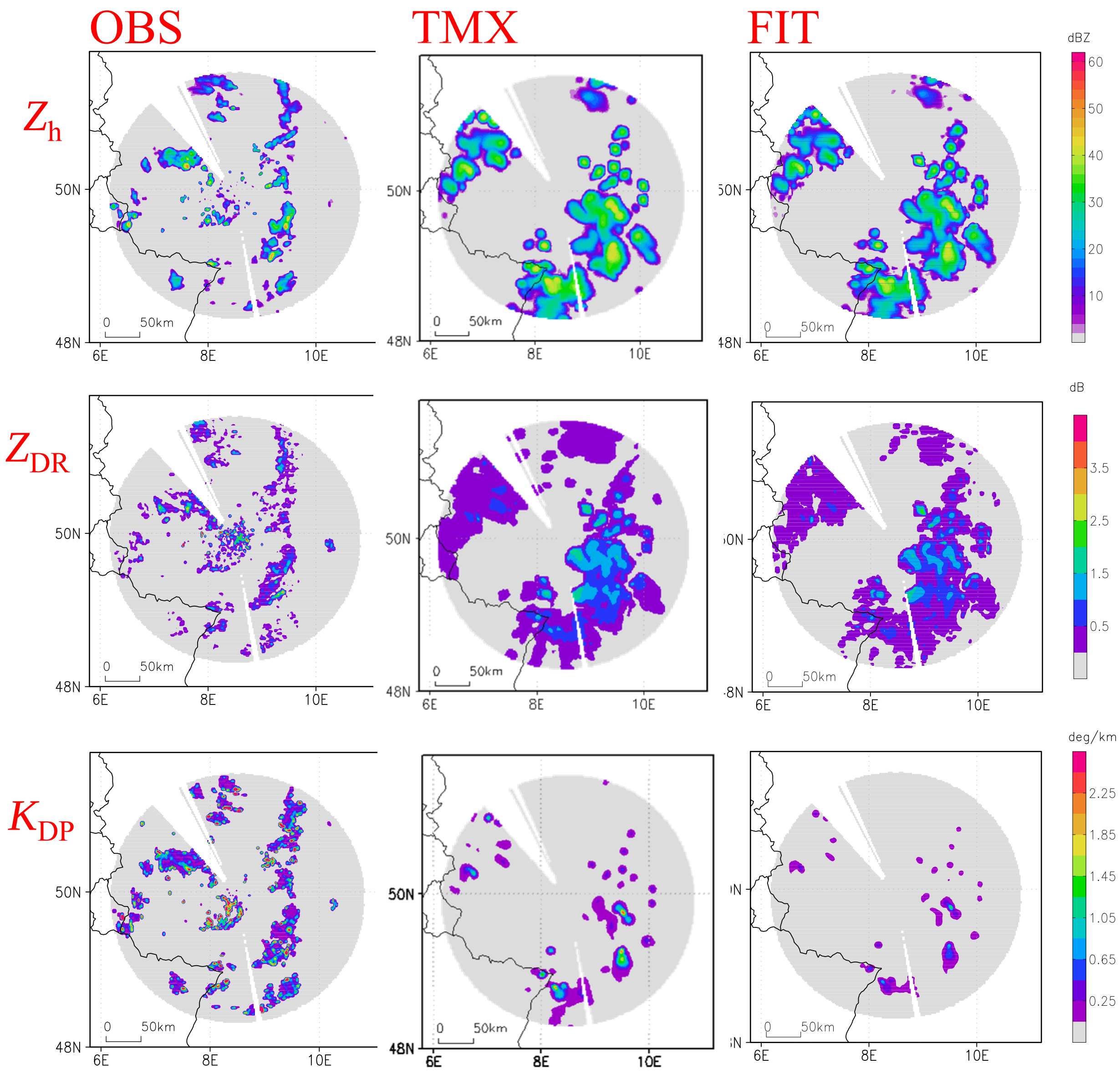
$$\mathrm{Qr} = \mathrm{c}_3 K_{DP}^{a_3} 10^{0.1 b_3\, Z_{DR}}$$

KD_ZD — Used by Li and Mecikalski (2013)

Observation

a_x, b_x, c_x are constants

Horizontal distributions of Pol. parameters (model to obs)



- TMX and FIT captured sporadic clouds with their locations and intensities well.
- Z_h and Z_{DR} with TMX and FIT distribute more widely than OBS.
- Observed K_{DP} shows stronger values.

Statistics (model to obs)

	Z_h (dBZ)		Z_{DR} (dB)		K_{DP} (° km^{-1})	
	AVG	STD	AVG	STD	AVG	STD
OBS	18.99	11.10	0.93	1.05	1.31	1.54
TMX	20.40	10.92	0.60	0.37	0.25	0.36
FIT	19.23	10.37	0.55	0.41	0.25	0.18
TMX - OBS	1.05	15.04	-0.26	0.96	-0.76	1.53
FIT - OBS	-0.10	14.68	-0.30	0.99	-0.91	1.47

- Regarding Z_h, FIT is slightly closer to OBS than TMX.
- In Z_{DR}, both converters look similar.
- K_{DP} of OBS looks strange compared with TMX and FIT.

FIT is mostly the same with TMX, but slightly better

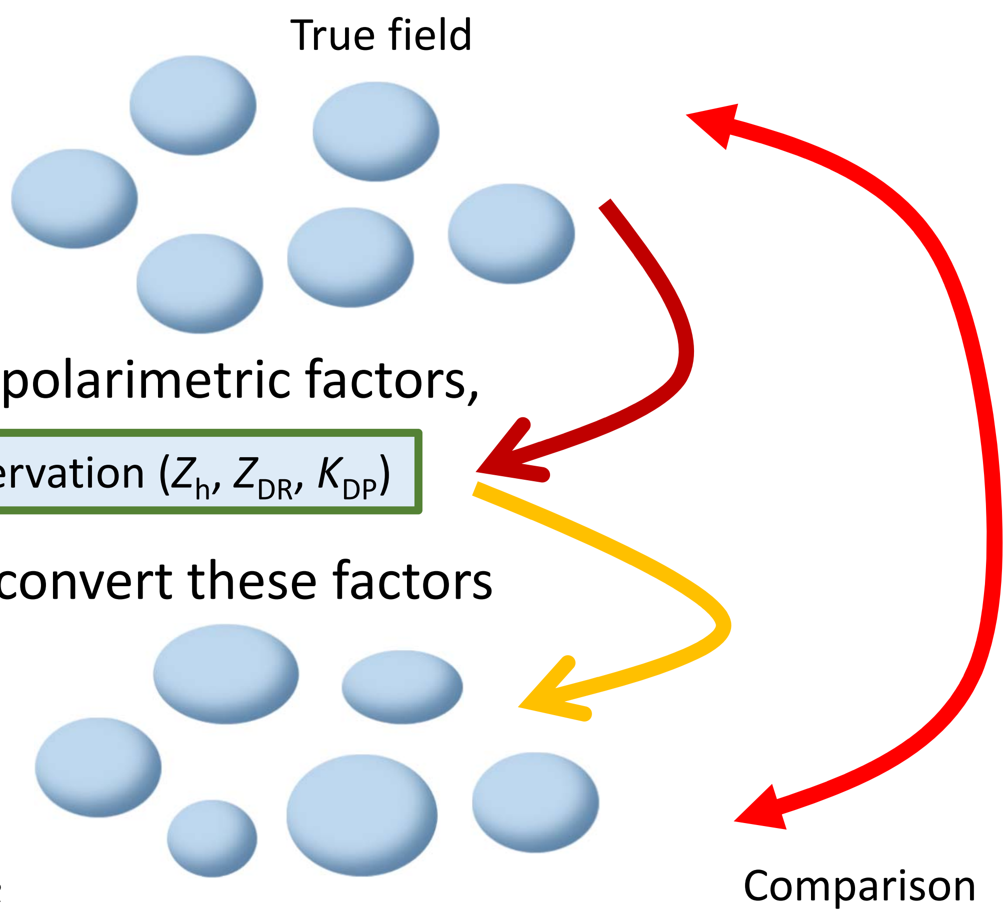
FIT is used as a pseudo-observation generator

1) WRF simulates rainwater,

2) then, FIT converts them to polarimetric factors,

pseudo-observation (Z_h, Z_{DR}, K_{DP})

3) again, Z_ZD, KD, and KD_ZD convert these factors back to rainwater.



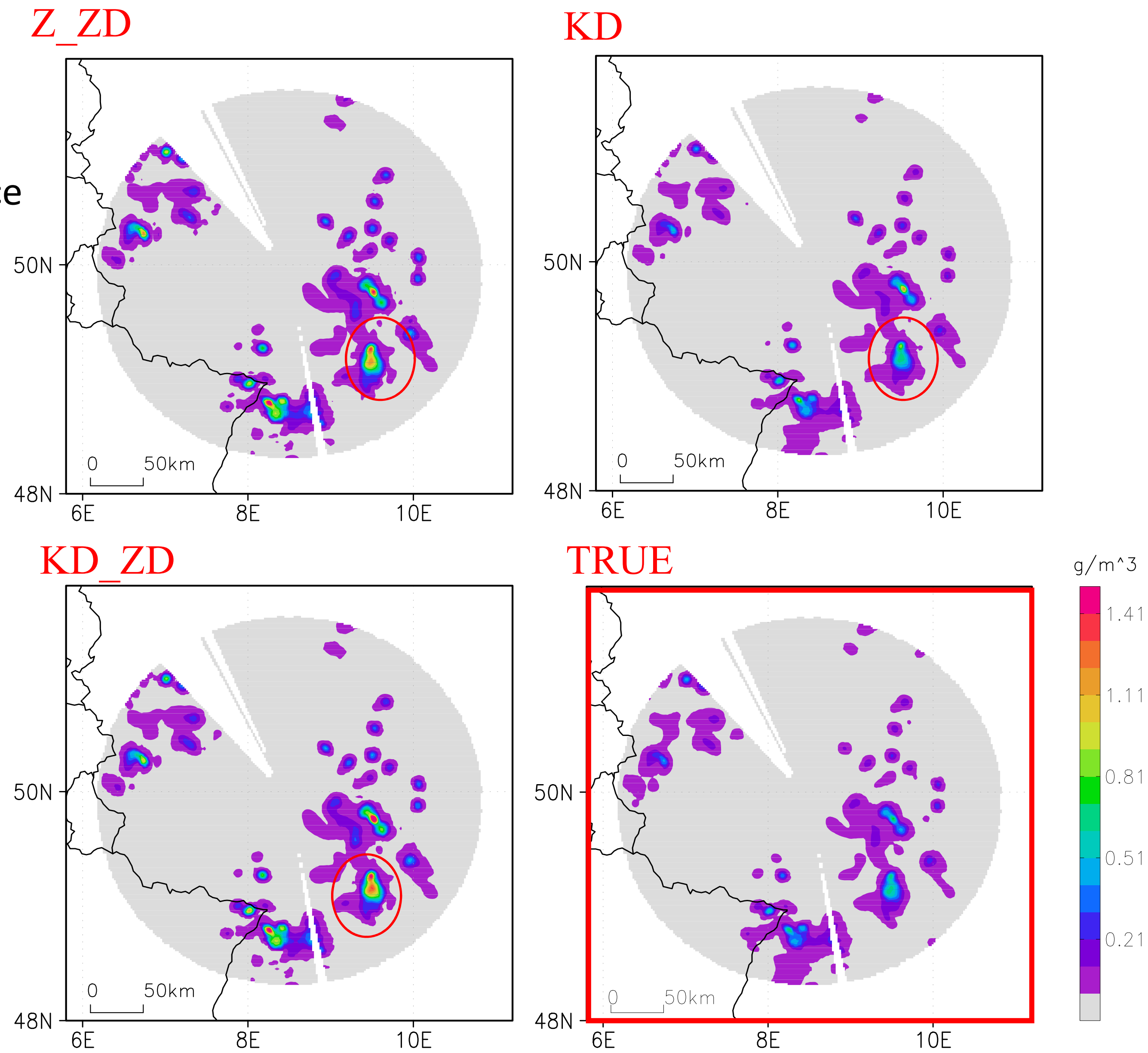
Z_ZD $\quad \mathrm{Qr} = c_1\, Z_h^{a_1} 10^{0.1 b_1\, Z_{DR}}$

KD $\quad \mathrm{Qr} = \mathrm{c}_2 \left(\frac{K_{DP}}{f}\right)^{b_2}$

KD_ZD $\quad \mathrm{Qr} = \mathrm{c}_3 K_{DP}^{a_3} 10^{0.1 b_3\, Z_{DR}}$

Rainwater content (obs to model)

- KD looks mostly fair.
- Z_ZD and KD_ZD produce stronger intensities.



Statistics (obs to model)

			Difference from True	
	AVG	STD	AVG	STD
True	0.08	0.12	—	—
Z_ZD	0.11	0.18	-0.033	0.07
KD	0.07	0.12	0.006	0.03
KD_ZD	0.12	0.22	0.044	0.10

- Average and STD in KD show good agreement with True.
- KD has the smallest bias and STD against True.

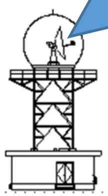
KD is the best.

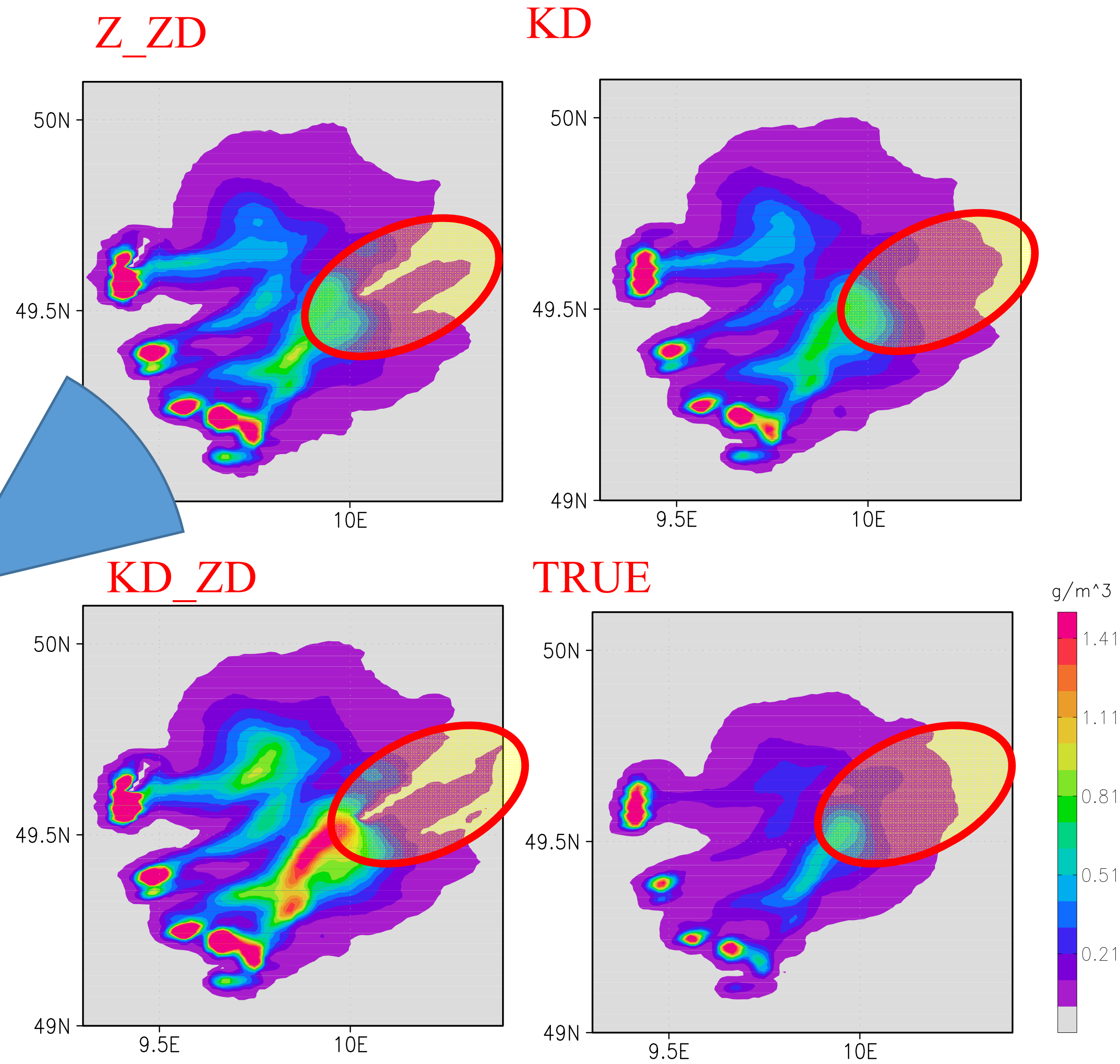
Attenuation effect (obs to model)

Super cell case

Since Z_h and Z_{DR} are affected by A_h and A_{DP}, respectively, only KD is not affected by the attenuation.

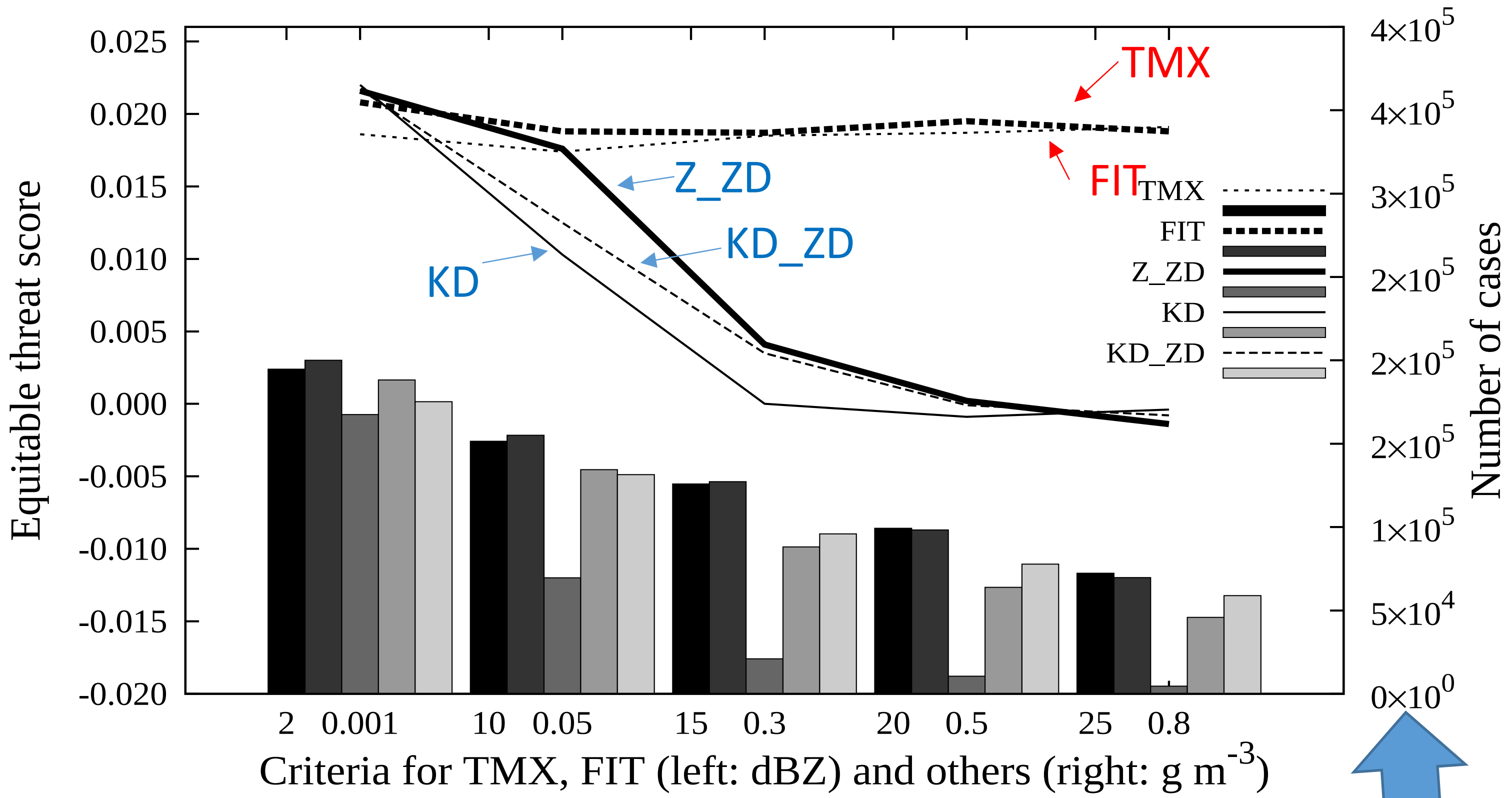
A virtual radar is located at beyond the left-bottom corner.





KD is the best

Equitable threat scores against observation comparison of (model to obs) and (obs to model)



- TMX and FIT are evaluated in dBZ, while Z_ZD, KD, and KD_ZD are in g m^{-3}. Since it is hard to compare factors in different units each other, we carefully chose criteria to capture similar numbers.
- TMX and FIT look better than other converters, but values of the threat scores are quite low.

Numbers of samples of each bin

Conclusions of the comparison

- FIT is close to TMX, but slightly better.
- KD is the best in Z_ZD, KD, and KD_ZD.
  ← KD_ZD and Z_ZD are affected by the attenuation.
- (model to obs) type converters are better than (obs to model) type.
  however, since threat scores are quite low, we need further examinations through DA.