A polarized adding-doubling radiative transfer model for simulating multi-layer scattering atmospheres

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2023. 11. 09

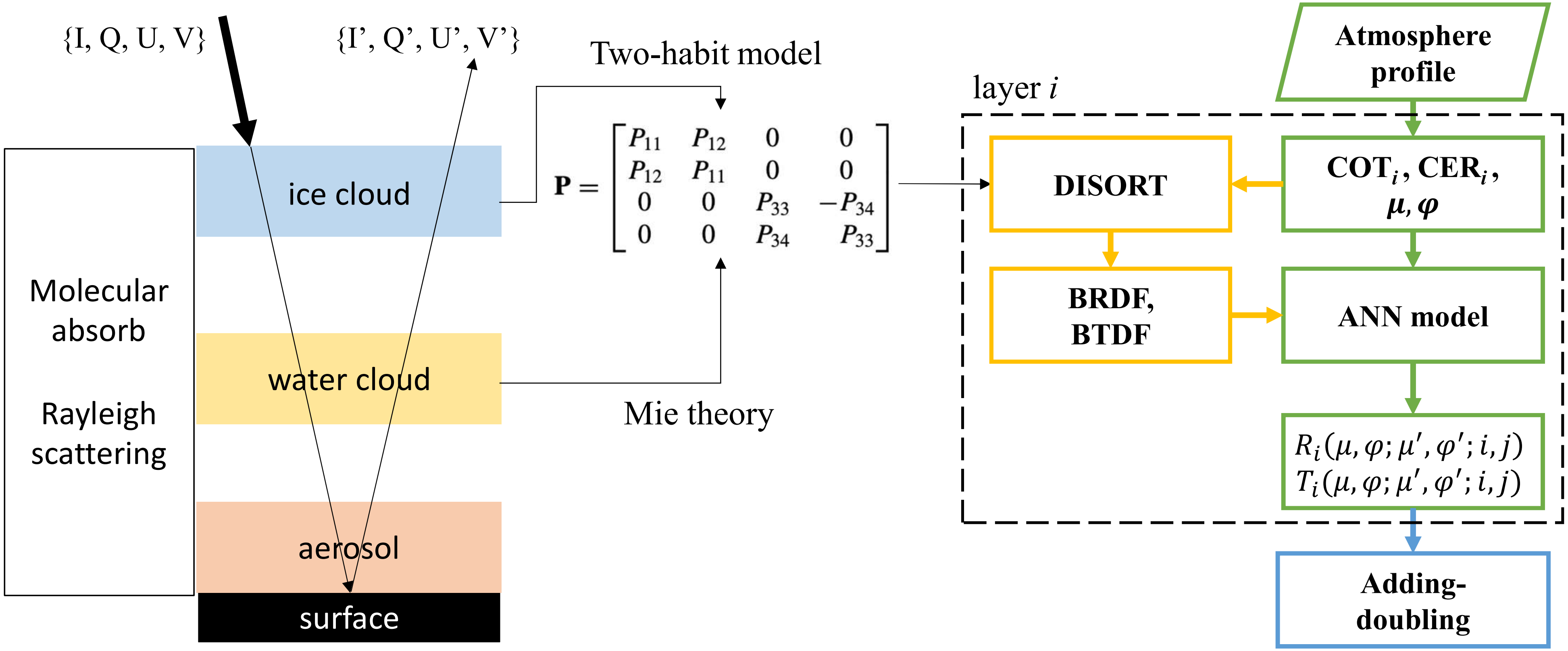
1 Background

- RTMs that solve multi-layered atmosphere
  - RRTM(G/GP) (Lagerquist et al., 2021; Liu et al., 2020; Ukkonen, 2022)
  - libRadtran (Taylor et al., 2016; Brence et al., 2022)
  - Adding-Doubling method (Van de Haulst, 1980; Huang et al., 2015)

- Current NNs are trained to emulate RTMs
  - trained separately for clear/cloudy skies
  - not universal for multilayer clouds (~12% occurrence, Yuan and Oreopoulos, 2013)
  - not applicable for polarized light

2 Method

Multi-layer scattering atmosphere



2 Method

ANN model

Layer	Shape	Activation
Input	6	None
Dense 1	256	LeakyRelu
Dense 2	128	LeakyRelu
Dense 3	64	LeakyRelu
Output	16	None

Activation: LeakyRelu

$$y = \begin{cases} 0.2x, & if\ x \le 0 \\ x, & if\ x > 0 \end{cases}$$

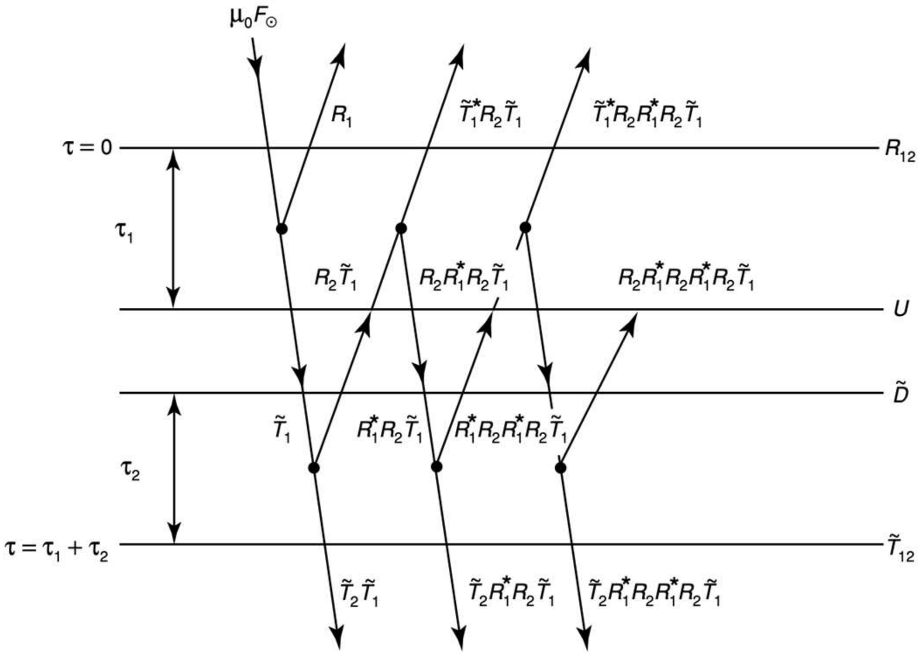
loss: Huber

$$L_\delta(y, f(x)) = \begin{cases} \frac{1}{2}(y - f(x))^2, if\ |y - f(x)| \le \delta \\ \delta|y - f(x)| - \frac{1}{2}\delta^2, if\ |y - f(x)| > \delta \end{cases}$$

$$\delta = 1$$

2 Method

Adding-doubling method



(Liou, 2002)

$$\widetilde{D} = \widetilde{T}_1 + R_1^* R_2 \widetilde{T}_1 + R_1^* R_2 R_1^* R_2 \widetilde{T}_1 + \dots$$
$$= \left[1 + R_1^* R_2 + (R_1^* R_2)^2 + \dots\right] \widetilde{T}_1$$
$$= (1 - R_1^* R_2)^{-1} \widetilde{T}_1$$

$$U = R_2 \widetilde{D}$$

$$R_{12} = R_1 + \widetilde{T}_1^* U$$

$$\widetilde{T}_{12} = \widetilde{T}_2 \widetilde{D}$$

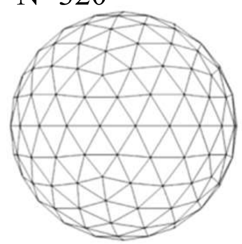
$$R_1^* R_2 = \frac{1}{\pi} \int_0^{2\pi} \int_0^1 R_1^*(\mu, \phi, \mu', \phi') R_2(\mu', \phi', \mu_0, \phi_0) \mu' d\mu' d\phi'$$

↓

$$X(\mu,\varphi) * Y(\mu,\varphi) = f \sum_{i=1}^{N} X_i Y_i \mu_i A_i,$$

$$f = \frac{2}{\sum_{i=1}^{N} A_i} = \frac{2}{S}.$$

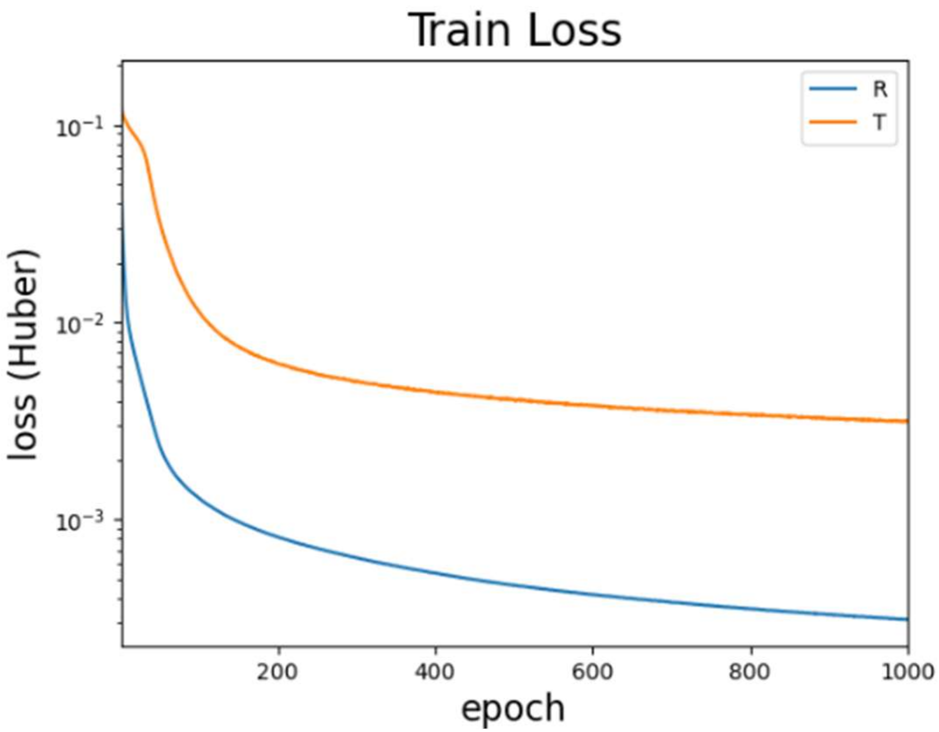
N=320

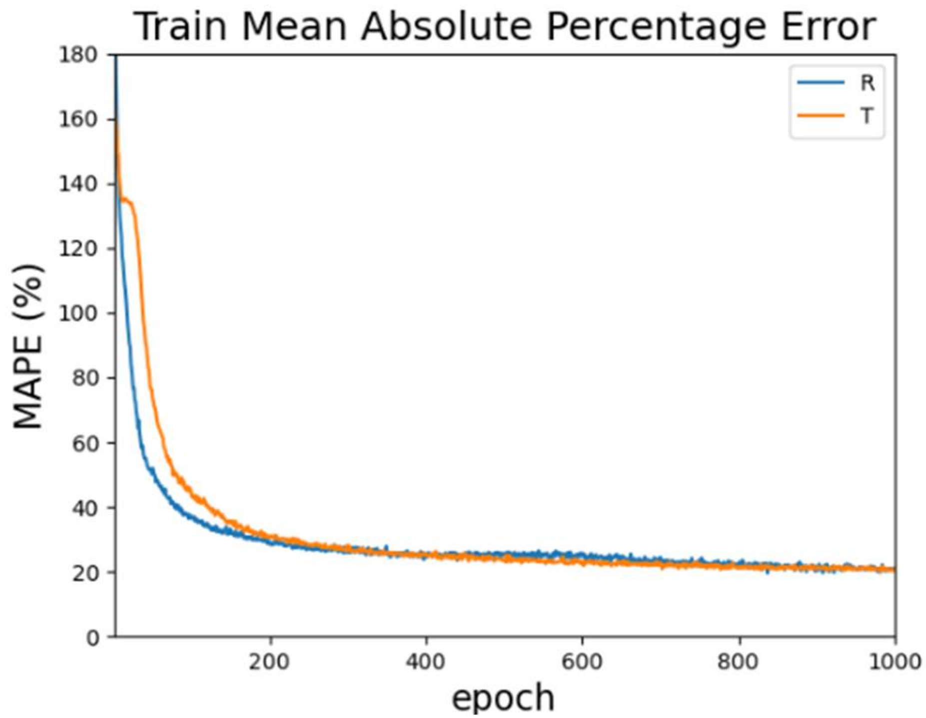


(Wang et al., 2013)

3 Results

ANN training

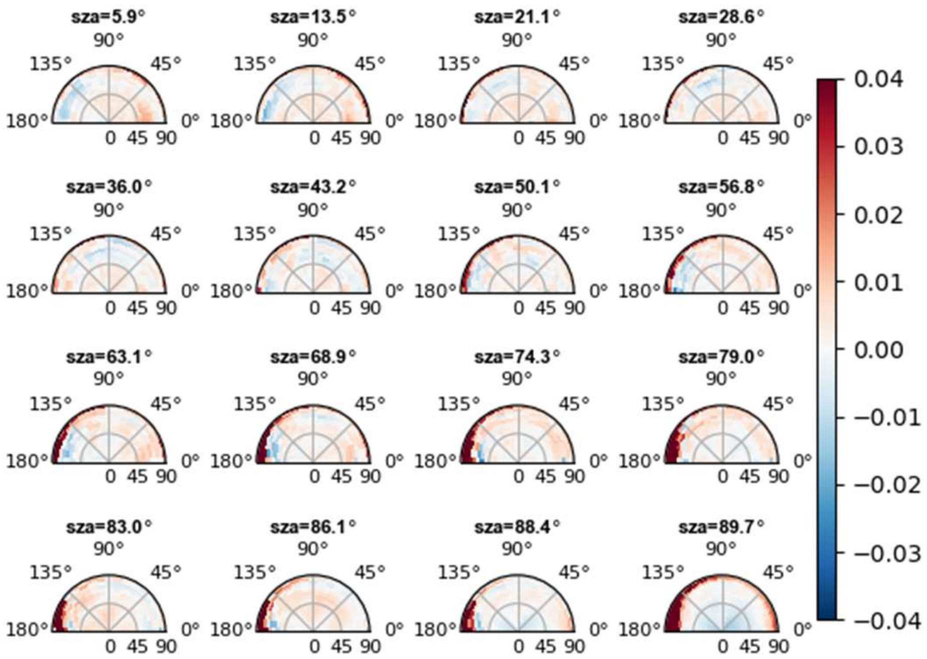




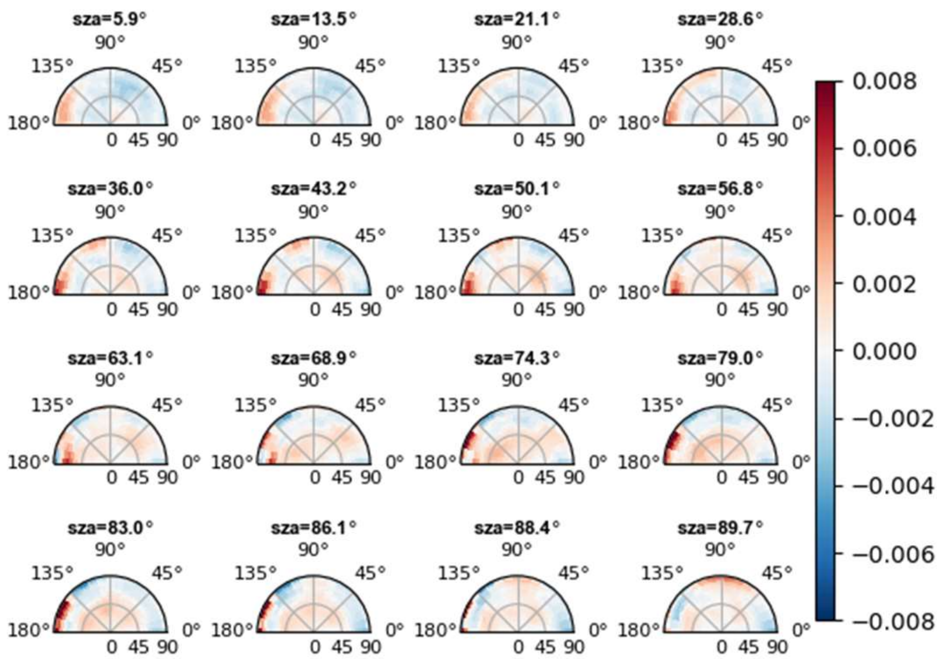
3 Results

Single layer accuracy

Ice cloud
wavelength = 0.8μm
COT=1; CER=10



Bias of R11

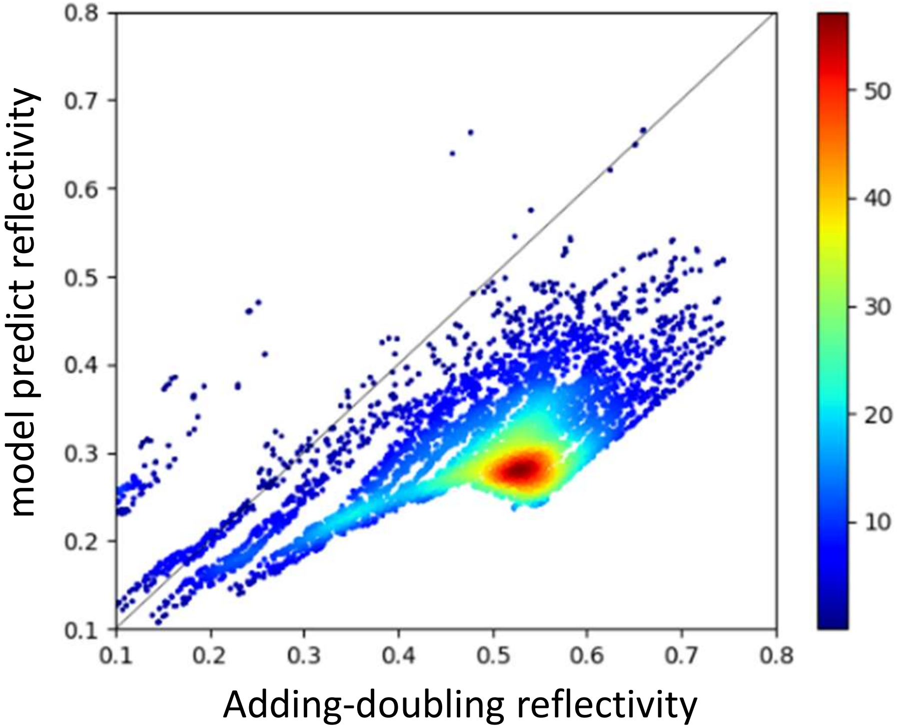


Bias of R12

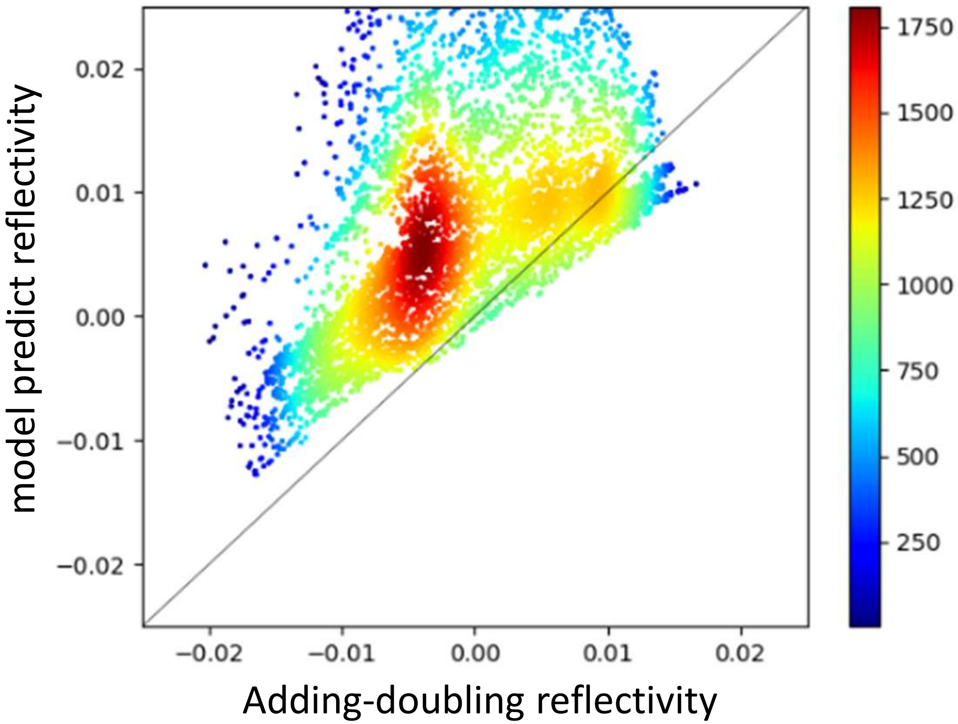
3 Results

Combination of two given layers

R11



R12



4 Conclusion

Polarized adding-doubling RTM

- Acceleration:

  from 7,000s to 7s when calculating BRDF of two-layer cloud

  between 320 incidence angles (10^3 times speed up)

- Accuracy:

  ANN achieved an MAPE of 20% for ice cloud layer

  R = 0.67 for BRDF of two-layer cloud

Problems to be solved

- Underestimate of former scattering
- Improve the accuracy of adding procedure
- Asymmetry effect of polarized light

Thank You!