15th Conference on Atmospheric Radiation@Vancouver July 10, 2018

On the Order of Atmospheric Scattering, Its Polarization and Computation Efficiency

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主要内容
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① Background

② Polarized Radiative Transfer

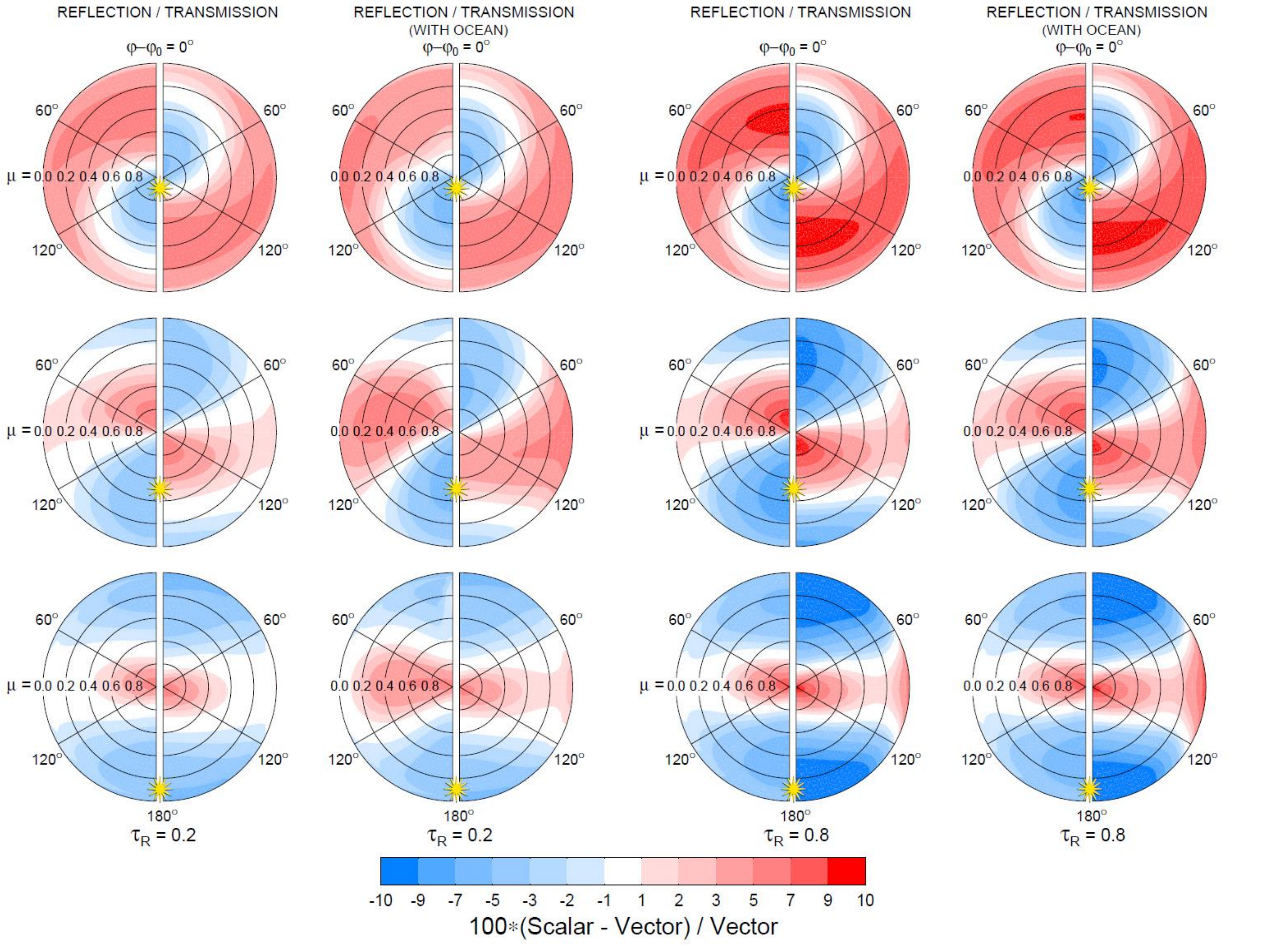
③ N-Appr method

④ N-Plus method

⑤ Summary

Background

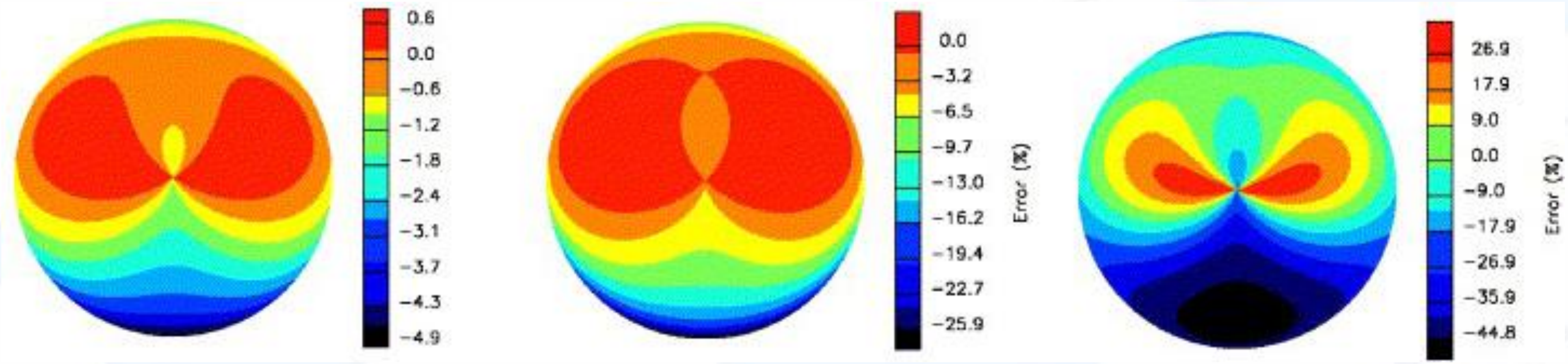
1. Properties of Atmosphere scattering:
2. More polarized instrument (PARASOL, 3MI, SGLI, APS, SPEX, MSPI…)
3. Errors due to neglecting polarization
4. Hyperspectral Measurements for Gases such OCO2, TanSAT are much polarized sensitive



M.I.Mishchenko et al, 1994

Errors due to neglecting polarization in O2-A Band

θ_0=40 , Albedo=0.3 , No Aerosol



Weak absorption

Moderate absorption

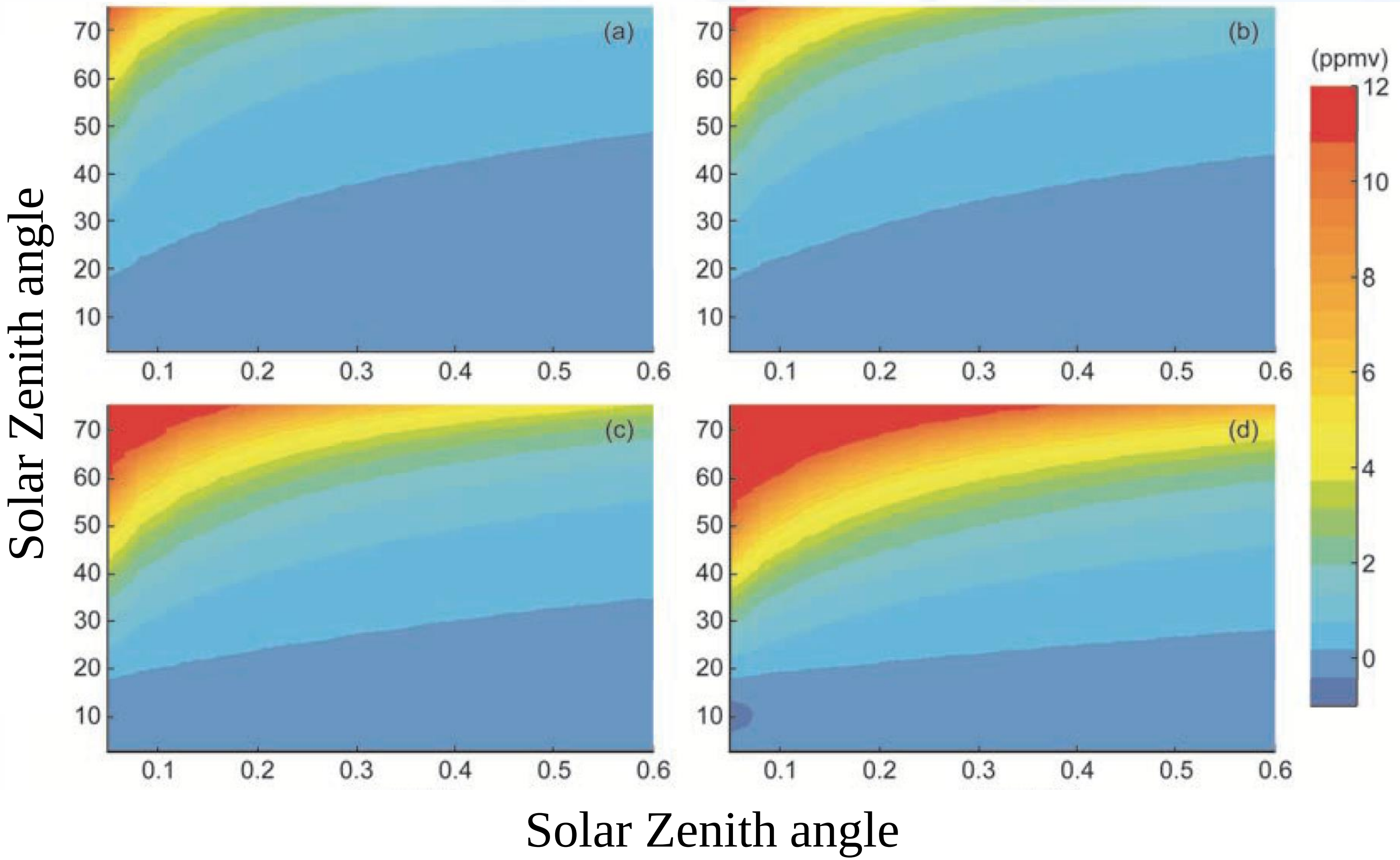
Strong Absorption

Table 2
Retrieval and smoothing errors and errors from neglecting polarization for January and July scenes in Park Falls, WI, USA

Scenario	Retrieval error (ppm)	Polarization error (ppm)	Smoothing error (ppm)
January	1.8	7.4	1.0
July	0.4	0.4	0.1

Vijay Natraj , JQSRT , 103, 245

XCO2 retrieval errors due to neglecting polarization



Bai et al.. **Science Bulletin, 2018, 63: 766–776**

Radiative Transfer Equation

$$\mu \frac{d\mathbf{I}(\tau,\Omega)}{d\tau} = \mathbf{I}(\tau,\Omega) - \mathbf{J}_1(\tau,\Omega) - \mathbf{J}_m(\tau,\Omega)$$

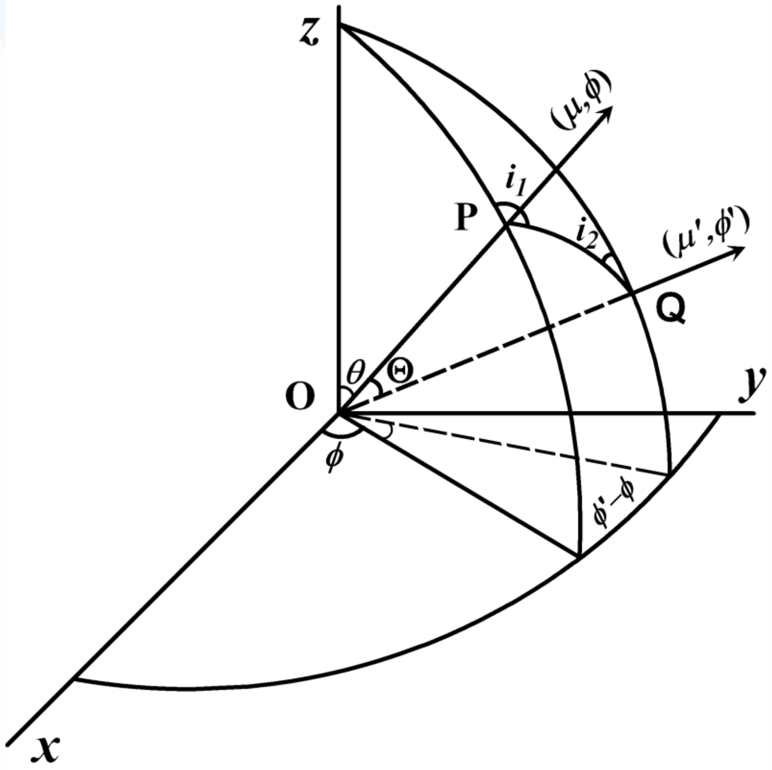
$$\mathbf{J}_m(\tau,\Omega) = \frac{\omega}{4\pi}\int_0^{4\pi} \mathbf{I}(\tau,\Omega')\mathbf{M}(\tau,\Omega;\Omega')d\Omega'$$

$$\mathbf{J}_1(\tau,\Omega) = \frac{\omega}{4\pi}\pi\mathbf{F}_0 \exp(-\tau/\mu_0)\mathbf{P}(\tau,\Omega;-\Omega_0)$$

$$\mathbf{I} = [I,Q,U,V]^T$$

Coordinate system

$$\mathbf{I} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} \qquad \vec{\mathbf{P}} = \begin{pmatrix} a_1 & b_1 & 0 & 0 \\ b_1 & a_2 & 0 & 0 \\ 0 & 0 & a_3 & b_2 \\ 0 & 0 & -b_2 & a_4 \end{pmatrix}$$



a_i, b_i depend on scattering angle Θ

$$\vec{\mathbf{M}} = \vec{L}(\pi - i_2)\vec{\mathbf{P}}(\Theta)\vec{L}(-i_1)$$

Numerical Algorithms

1. MC: (Kattawar & Plass, 1968; Roberti & Kummerow, 1999; Wu & Lu, 989)
2. Adding-doubling method (De Haan et al., 1987; Evans & Stephens, 1991; Hansen, 1971)
3. Inverse of matrix method (Schulz et al., 1999; Siewert, 2000)
4. Successive order of Scattering (Duan, 2004; 6s; Pstar)
5. SCIATRAN (2009?)

N-Appr method

It is supposed that just the first a few orders are needed

How & What ?

Two order scattering approximation

- Vijay Natraj & Robert Spur, *JQSRT* 107,2007
- Sergey Korkin et. al., *JQSRT* 113,2012

N-Approaximation method

$$\mathbf{I} = \mathbf{I}_1 + \mathbf{I}_2 + \mathbf{I}_3 \cdots\cdots\cdots + \mathbf{I}_\infty$$

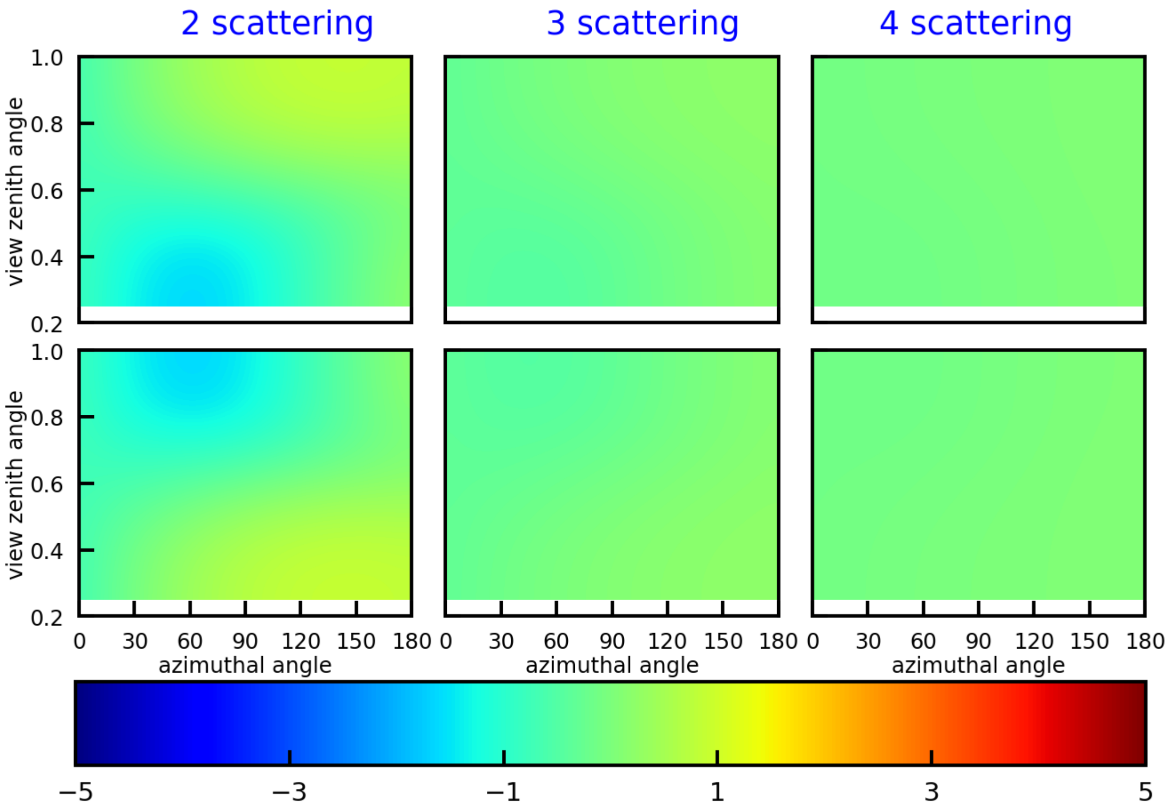
$$\mathbf{I}^* = \sum_{i=1}^{n} \mathbf{I}_i + \sum_{i=n+1}^{\infty} [I_i, 0, 0, 0]^T$$

SOSVRT: A polarized radiative transfer model based on Successive order of Scattering

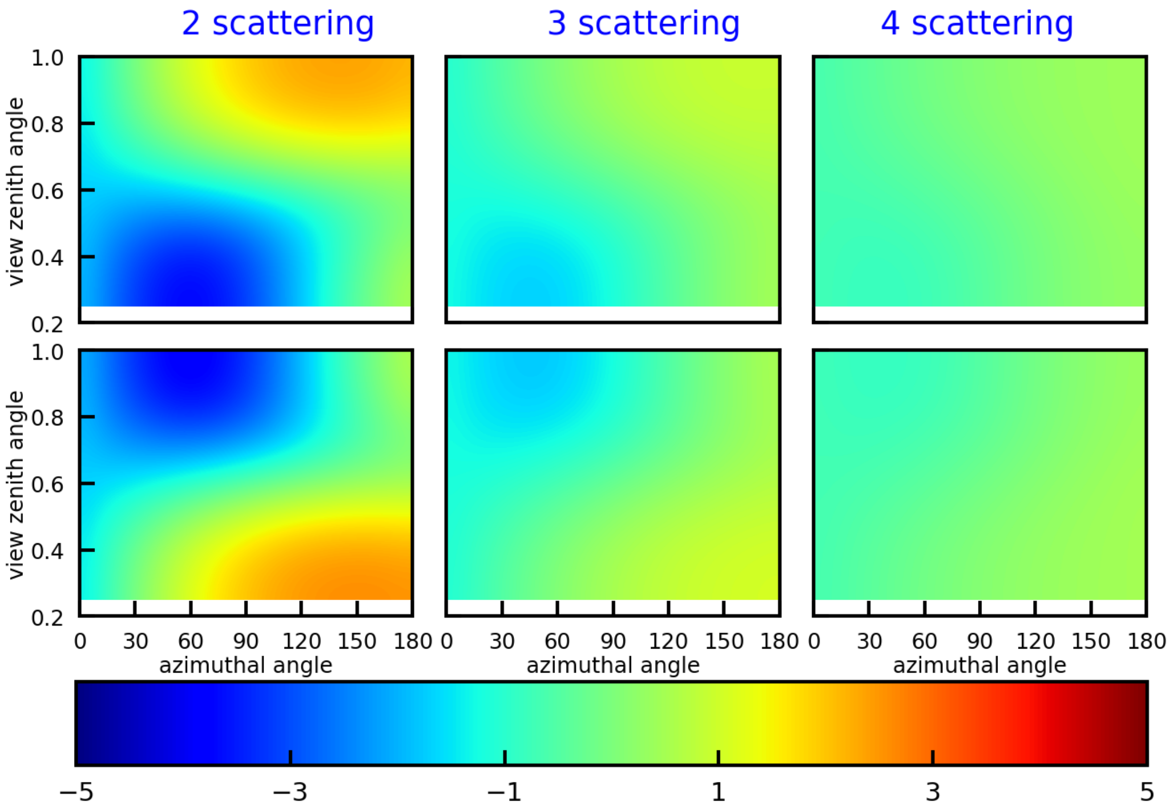
CASE A: pure molecular atmosphere with different optical depth

CASE B: molecular with aerosol, where the aerosol is supposed to be exponentialy decreased with height, the scale height is set to be 1.8km for aerosol, and 7.8km for molecular

N-APPR

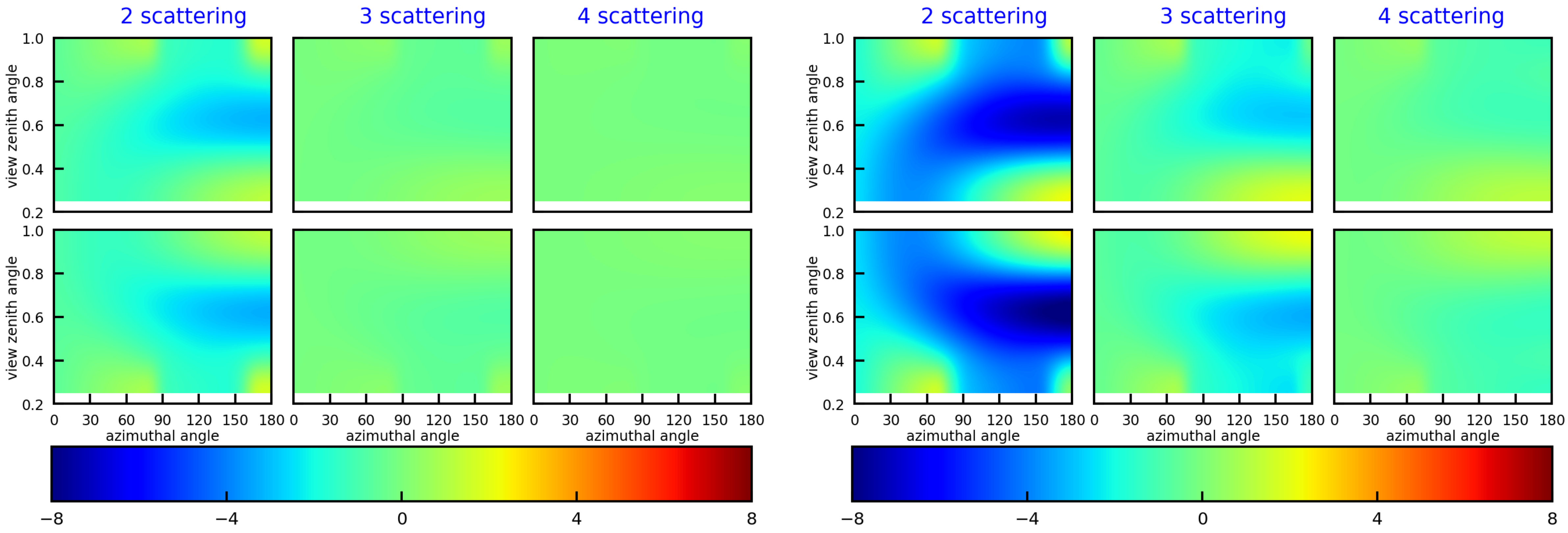


$$(I - I_{true}) / I_{true} \times 100\% \quad \tau = 0.2$$



$$(I - I_{true}) / I_{true} \times 100\% \quad \tau = 0.5$$

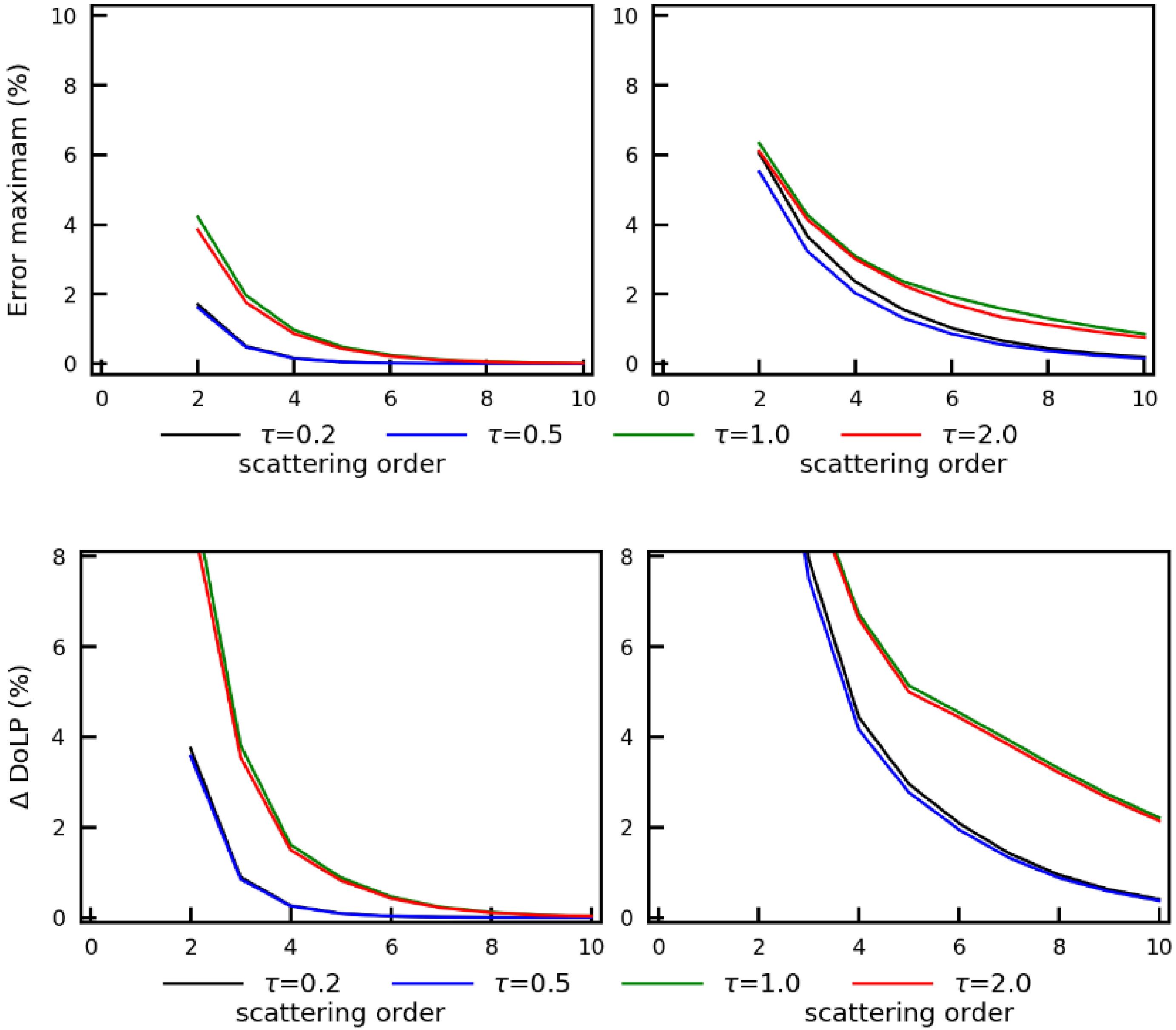
N-APPR

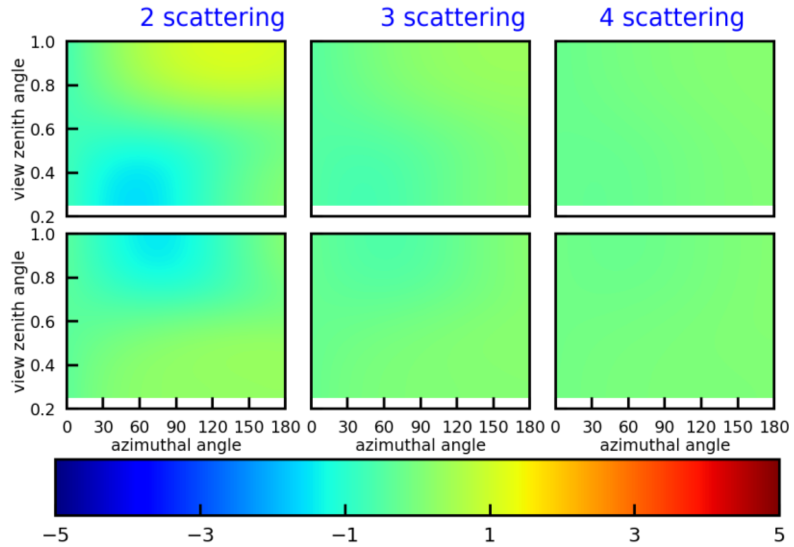


ΔDoLP τ=0.2

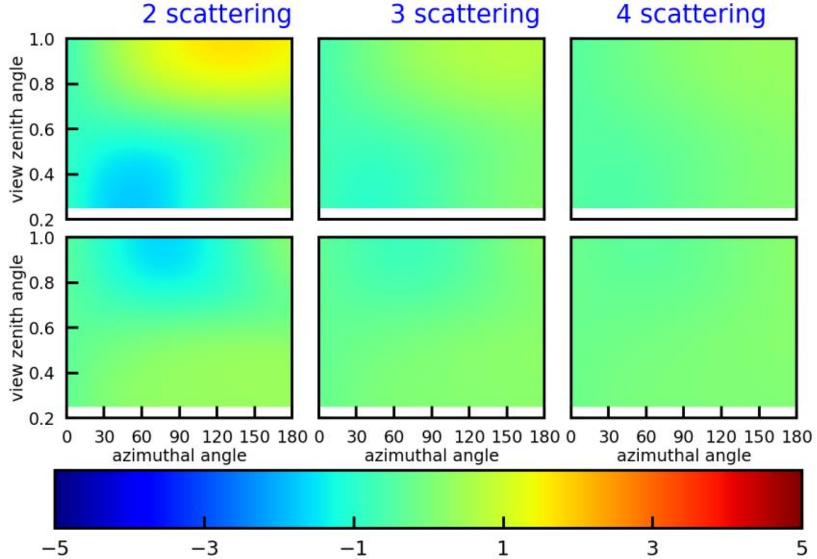
ΔDoLP τ=0.5

N-APPR No Aerosol

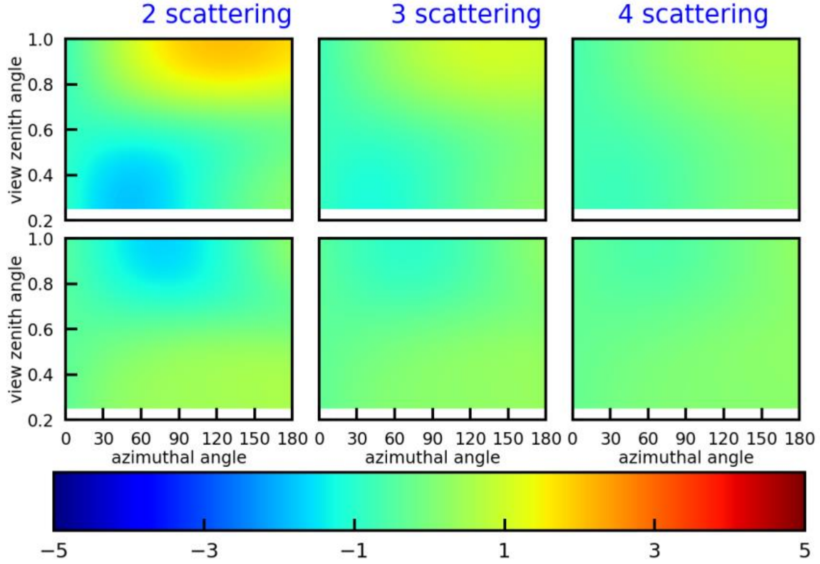




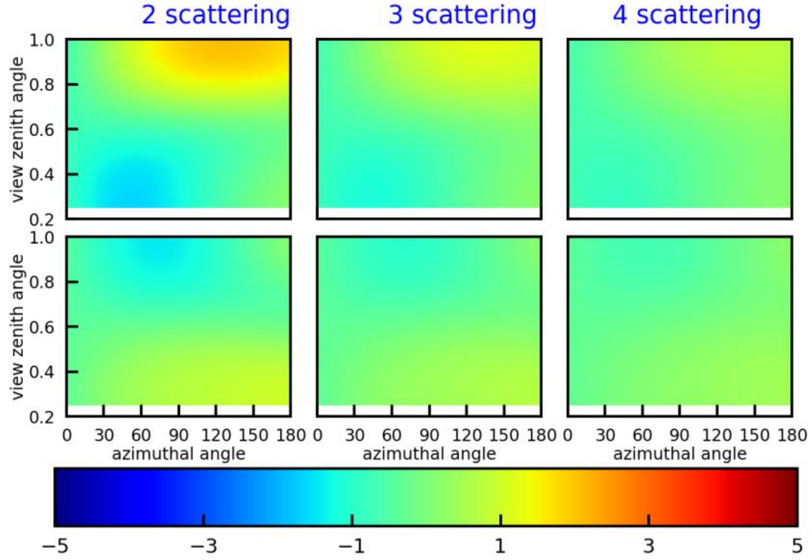
$\tau_{aerosol}=0.2$



$\tau_{aerosol}=0.5$

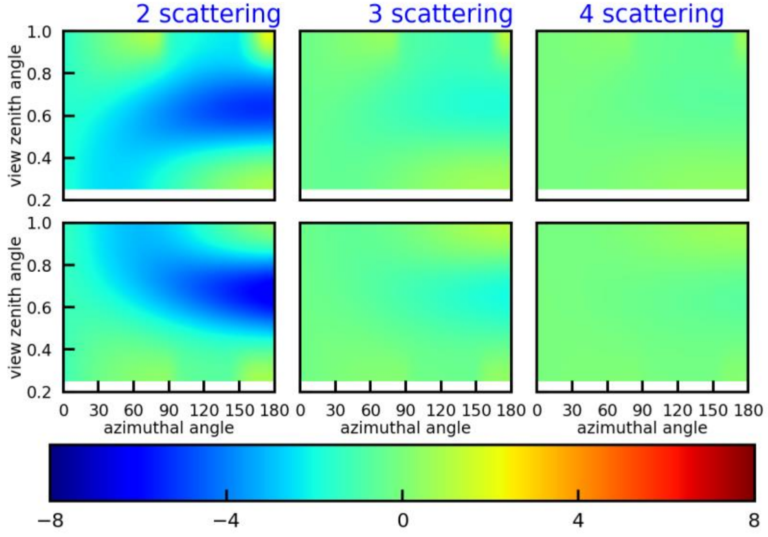


$\tau_{aerosol}=1.0$

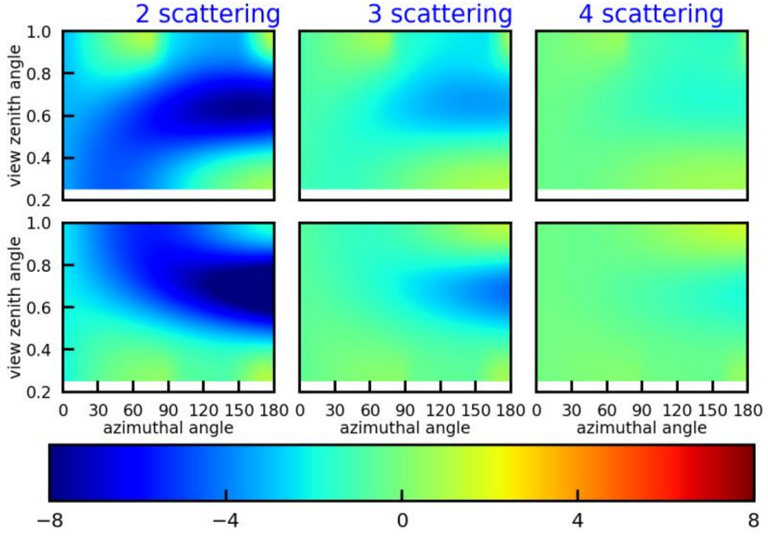


$\tau_{aerosol}=2.0$

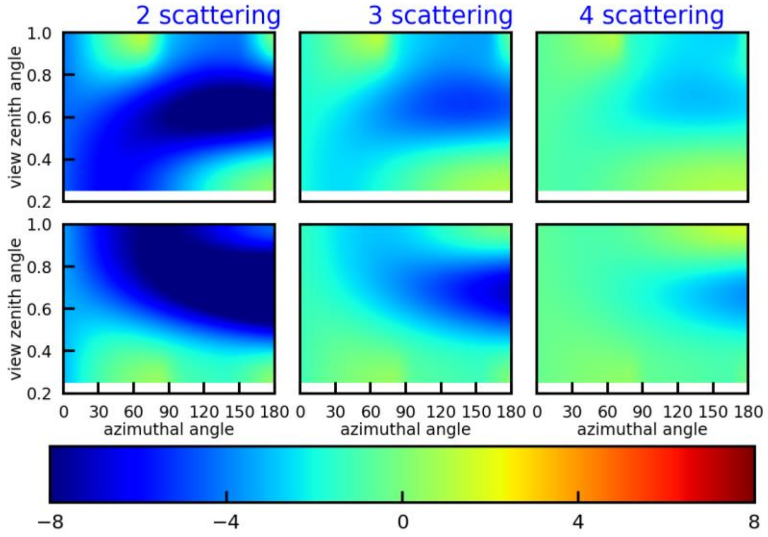
$(I-I_{true})/I_{true}\times 100\%$ $\tau_{mol}=0.156$



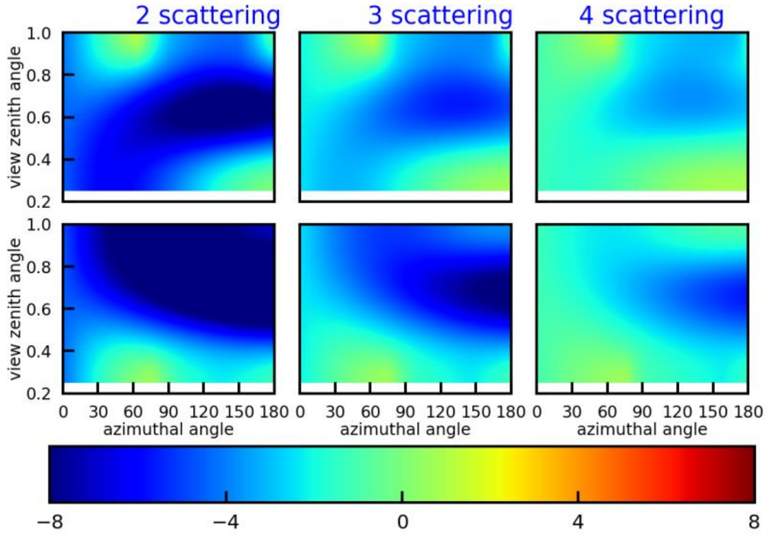
$\tau_{aerosol} = 0.2$



$\tau_{aerosol} = 0.5$



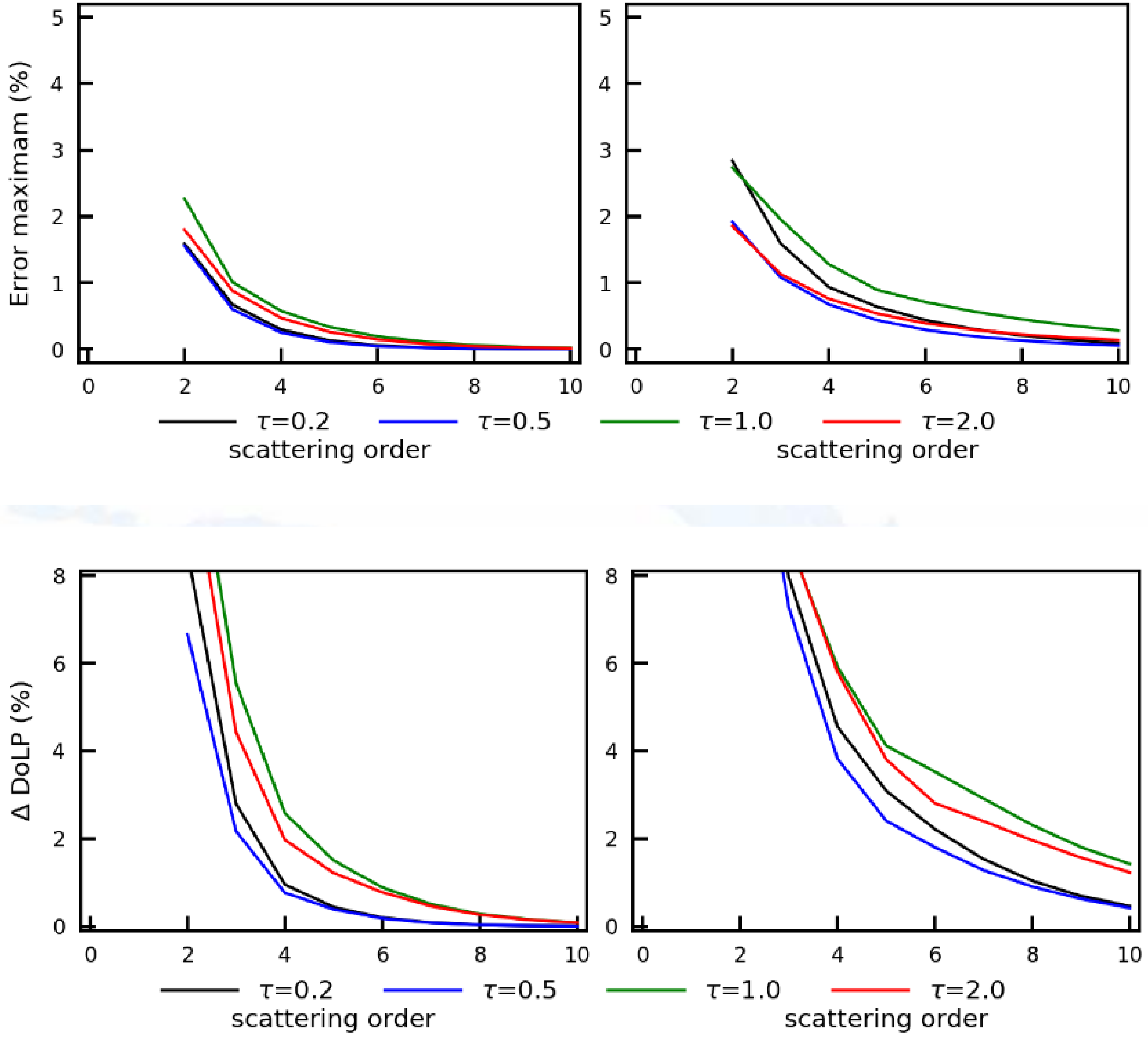
$\tau_{aerosol} = 1.0$



$\tau_{aerosol} = 2.0$

$\Delta DoLP \quad \tau_{mol} = 0.156$

N-APPR with Aerosol



N-PLUS method

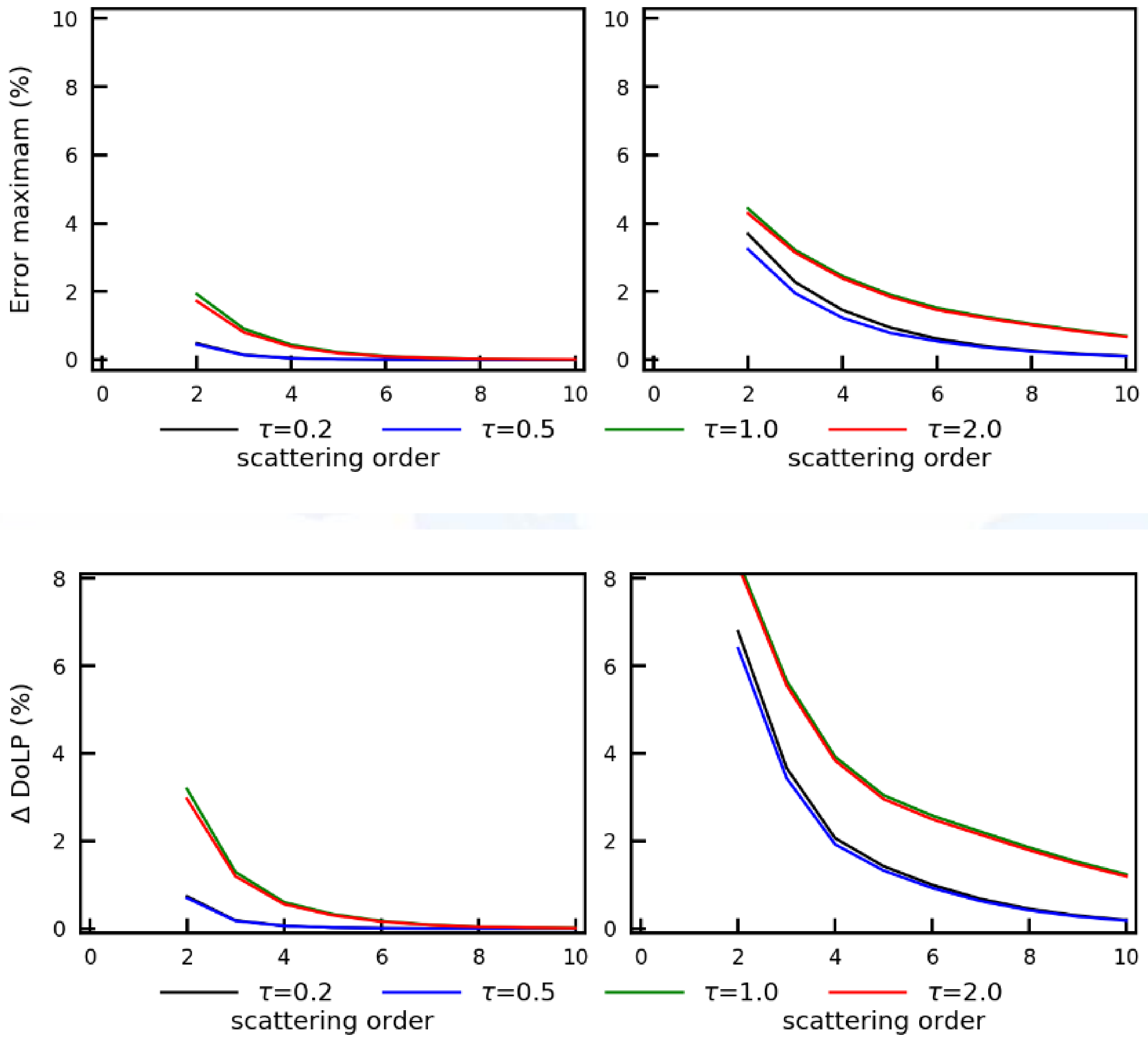
$$\mathbf{I} = \mathbf{I}_1 + \mathbf{I}_2 + \mathbf{I}_3 \cdots\cdots\cdots + \mathbf{I}_\infty$$

$$\mathbf{I}^* = \sum_{i=1}^{n} \mathbf{I}_i + \sum_{i=n+1}^{\infty} \left[I_i, 0, 0, 0 \right]^T$$

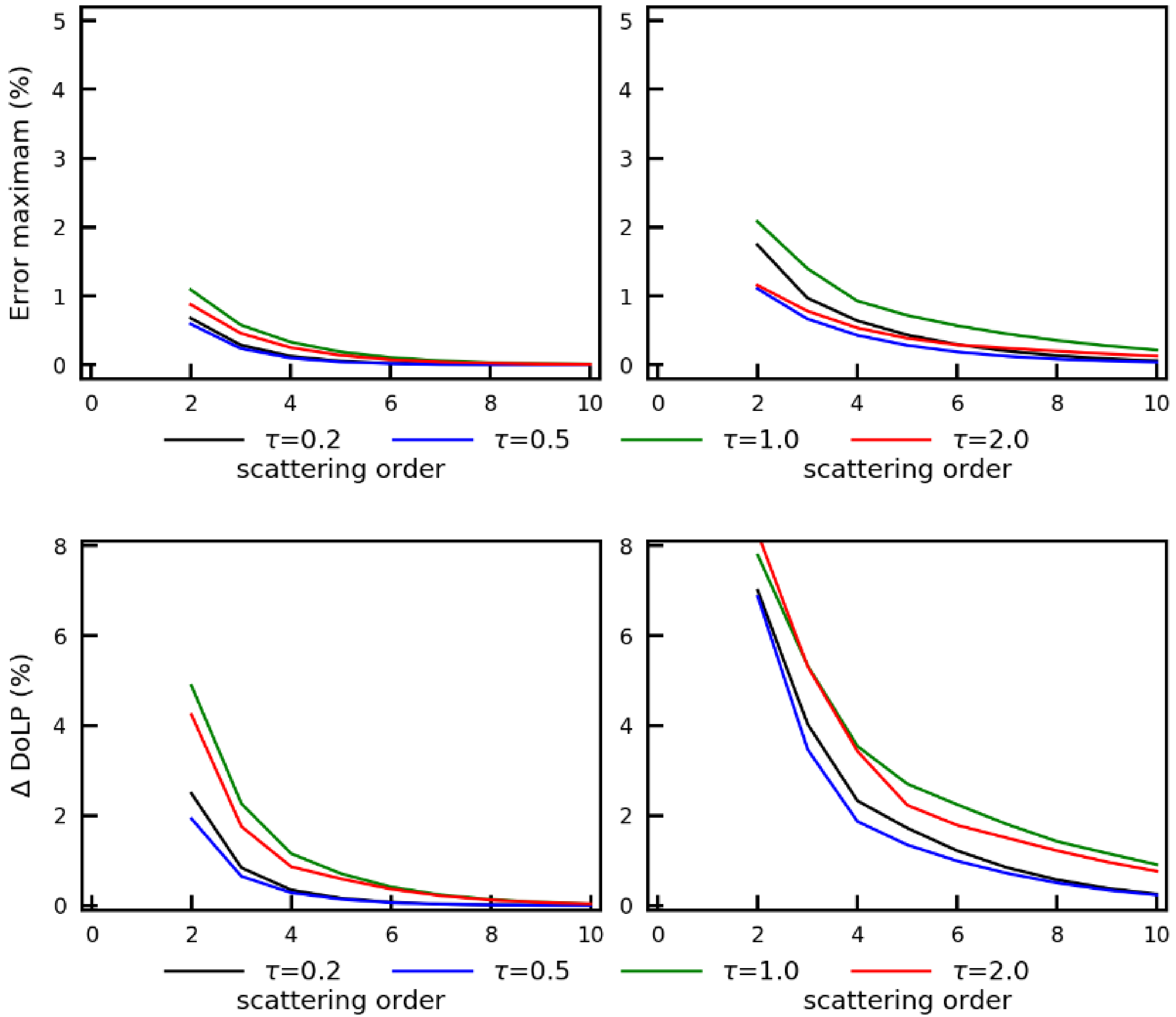
$$\mu \frac{d\mathbf{I}}{d\tau} = -\mathbf{I} + \frac{\omega}{4\pi} \mathbf{M}(\mu, \phi; \mu_0, \phi_0) \mathbf{F}_0 \, e^{-\tau/\mu_0}$$

$$+ \frac{\omega}{4\pi} \int_0^{2\pi} \int_{-1}^{1} \mathbf{M}(\mu, \varphi; \mu', \phi') \mathbf{I}^*(\mu', \phi') d\mu' d\phi'$$

N-PLUS No Aerosol



N-PLUS with Aerosol



Summary

- N-PLUS method, a correction of the N-appr method, is a little bit more accurate, and efficient
- the number of scattering must be carefully considered, especially for polarization sensitive instruments such as OCO2, TanSAT, Where two scattering is not accurate enough

谢谢！

THANK YOU
FOR YOUR TIME.

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