Implications of orbital multi-angle photopolarimetric observations in the 1.378-µm spectral channel to retrieve microphysical properties and composition of stratospheric aerosols of natural or artificial origin

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Main objective:

To discuss a straightforward way of studying stratospheric aerosols in passive photopolarimetry by using observations in the strong 1.378-μm water-vapor absorption band. The essence of this study is: (i) to model theoretically the photopolarimetric signal carried by the sunlight diffusely reflected by stratospheric aerosols; (ii) add realistic measurement errors to this signal; (iii) verify whether a multi-angle orbital photopolarimeter would have the capacity to retrieve the requisite aerosol parameters from these simulated error-laden measurements.

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Basic assumptions:

1. The amount of water vapor in the troposphere is sufficiently large that strong absorption in the 1.378-μm water-vapor band extinguishes any contribution of the surface, tropospheric aerosols, and liquid-water clouds to the outgoing radiation detected by the satellite instrument.

2. Cirrus clouds are absent in the instrument's field of view.

3. The stratospheric aerosols are homogeneous spherical particles dominated by H_2SO_4/H_20 drops, characterized by a monomodal gamma-size distribution

$$n(r) = const \times r^{(1-3v_{eff})/v_{eff}} \exp\left(-\frac{r}{r_{eff} v_{eff}}\right), \qquad (1)$$

where $n(r)dr$ **is the fraction of particles with radii from** r **to** $r + dr$, r_{eff} **and** v_{eff} **are the effective radius and effective variance of the size distribution.**

Numerical technique

Vector radiative transfer equation:

$$\mu \frac{\mathrm{d}\mathbf{I}(\tau,\mu,\varphi)}{\mathrm{d}\tau} = -\mathbf{I}(\tau,\mu,\varphi) + \frac{\omega}{4\pi}\int_0^{2\pi} d\varphi' \int_{-1}^{1} d\mu' \mathbf{Z}(\tau;\mu,\varphi;\mu',\varphi')\mathbf{I}(\tau,\mu',\varphi'), \quad (2)$$

$\mathbf{I} = [I, Q, U, V]^T$ - **intensity column vector of the diffusely reflected light,**

$$I(\theta,\varphi) = \mu_0 R_{11}(\tau_0,\mu,\mu_0,\varphi-\varphi_0)F_0, \quad (3)$$

$$Q(\theta,\varphi) = \mu_0 R_{21}(\tau_0,\mu,\mu_0,\varphi-\varphi_0)F_0, \quad (4)$$

$$U(\theta,\varphi) = \mu_0 R_{31}(\tau_0,\mu,\mu_0,\varphi-\varphi_0)F_0, \quad (5)$$

where $\mu = \cos\theta$, $\mu_0 = \cos\theta_0$, $\{\theta_0, \varphi_0\}$ – **solar zenith and azimuth angles,** $\{\theta, \varphi\}$ – **satellite zenith and azimuth angles,** τ_0 – **optical thickness of the stratospheric aerosol layer,** $\mathbf{R}(\tau_0,\mu,\mu_0,\varphi-\varphi_0)$ – **4x4 reflection matrix.**

We consider $I(\theta,\varphi)$ **and the normalized parameters:**

$$q(\theta,\varphi) = \frac{Q(\theta,\varphi)}{I(\theta,\varphi)}, \quad u(\theta,\varphi) = \frac{U(\theta,\varphi)}{I(\theta,\varphi)} \quad . \quad (6)$$

Computational scheme

In all computations, the Lorenz-Mie theory and the invariant-imbedding technique were used.

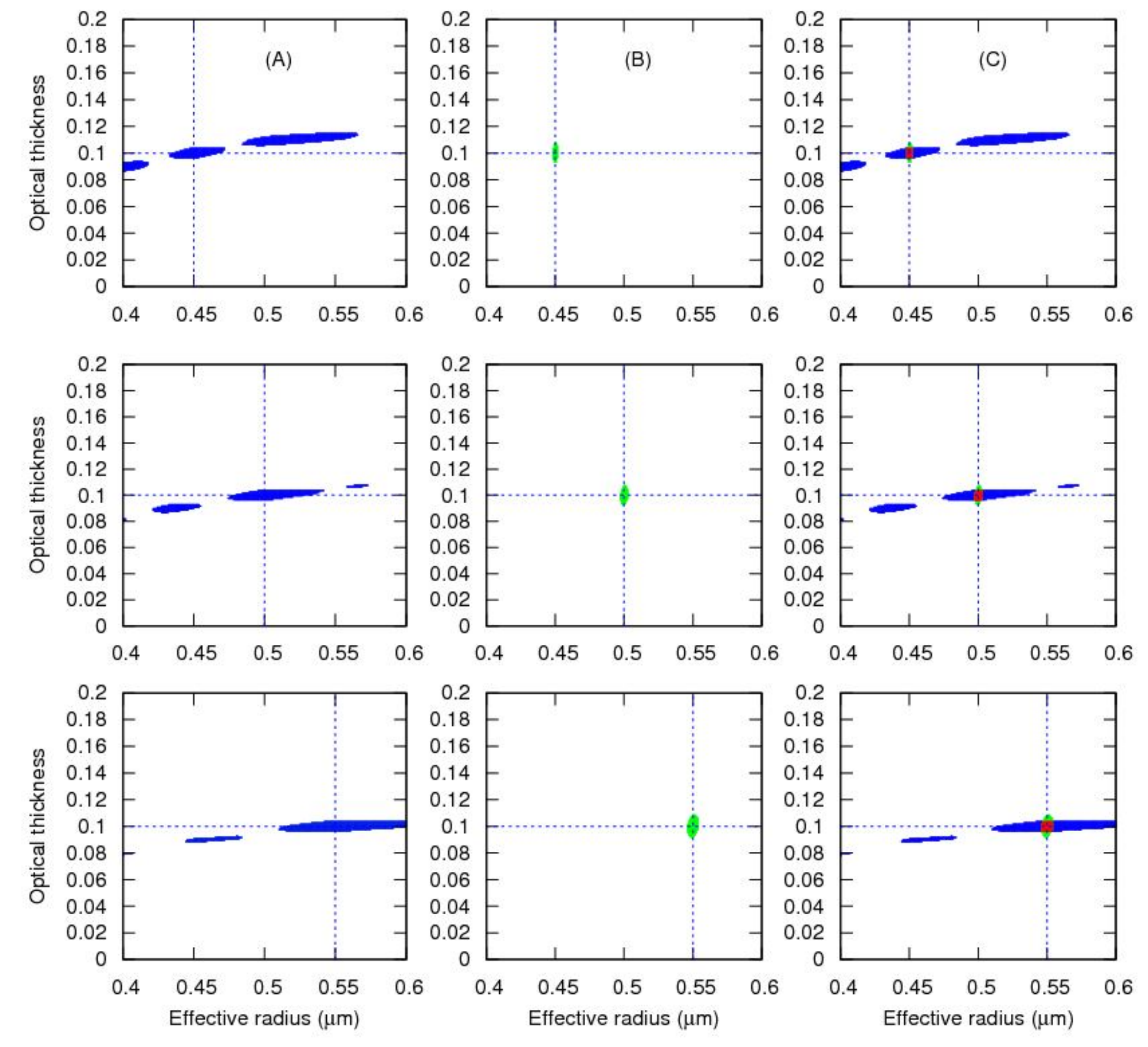
Mainly, the analysis of the results of computations was carried out for fixed value of $\mu_0 = 0.8$, $0.2 \le \mu \le 1$ ($\Delta\mu = 0.2$), $\varphi - \varphi_0 = 60°$ **and** $120°$. **Such observation geometry corresponds to 9 scattering angles and covers the scattering-angle range** 82° – 145°. $1.38 \le m \le 1.48$, $0.01 \le \tau \le 0.2$, $0.4\ \mu\text{m} \le r_{\text{eff}} \le 0.6\ \mu\text{m}$, $v_{\text{eff}} = 0.15$.

In order to simulate the retrieval of aerosol characteristics from observations, such criteria were adopted:

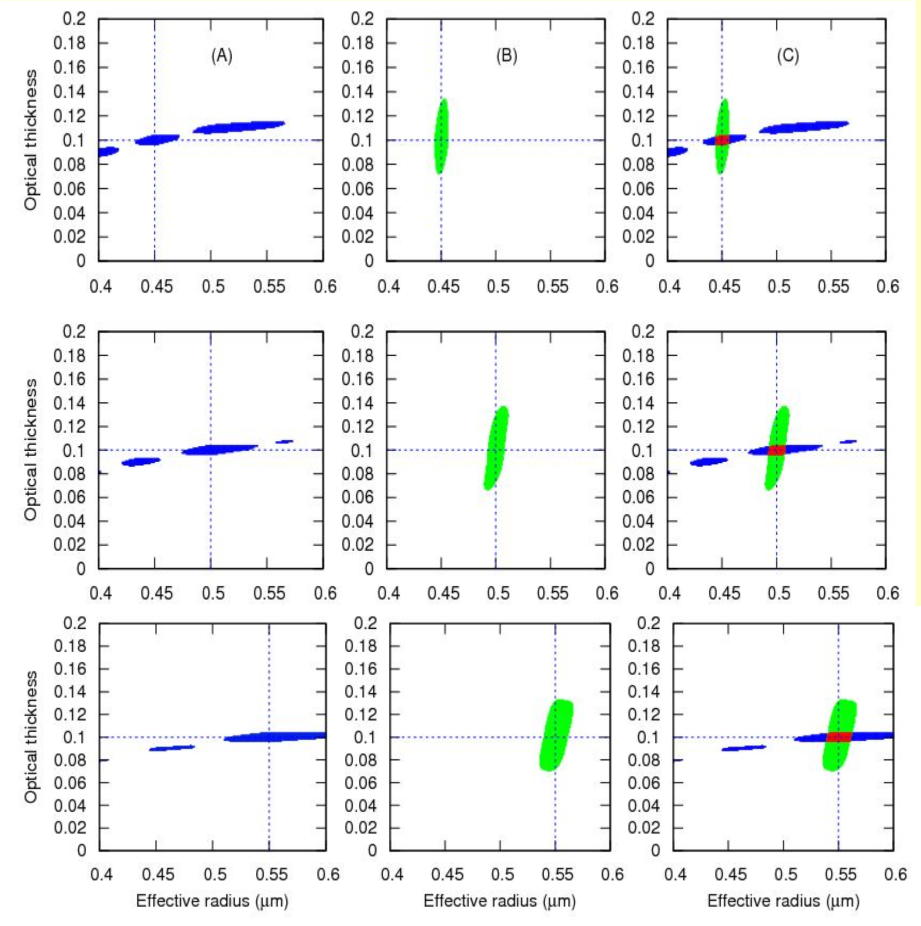
(A): $$\frac{1}{N_{angl}} \sum_{j=1}^{N_{angl}} \frac{\left| I_c^j - I_s^j \right|}{I_s^j} \le \varepsilon_I, \qquad \varepsilon_I = 0.04 \tag{7}$$

(B): $$\frac{1}{N_{angl}} \sum_{j=1}^{N_{angl}} \frac{1}{2}\left(\left| q_c^j - q_s^j \right| + \left| u_c^j - u_s^j \right| \right) \le \varepsilon_P, \qquad \varepsilon_P = 0.0015,\ 0.005, 0.015 \tag{8}$$

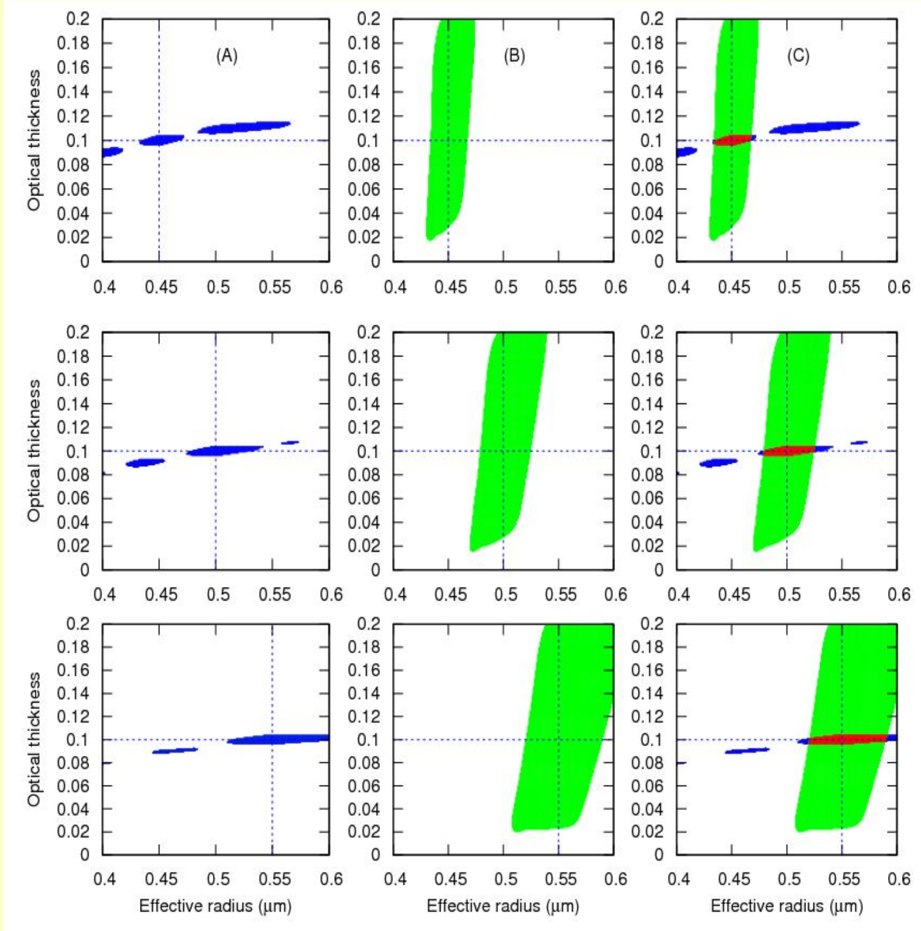
(C) = (A) $\wedge$ (B) (9)



Simultaneous retrieval of the optical thickness and effective radius for three standard aerosol models with the same *a priori* known refractive index $m = 1.42$, $N_{angl} = 9$, $\varepsilon_I = 0.04$, $\varepsilon_P = 0.0015$.

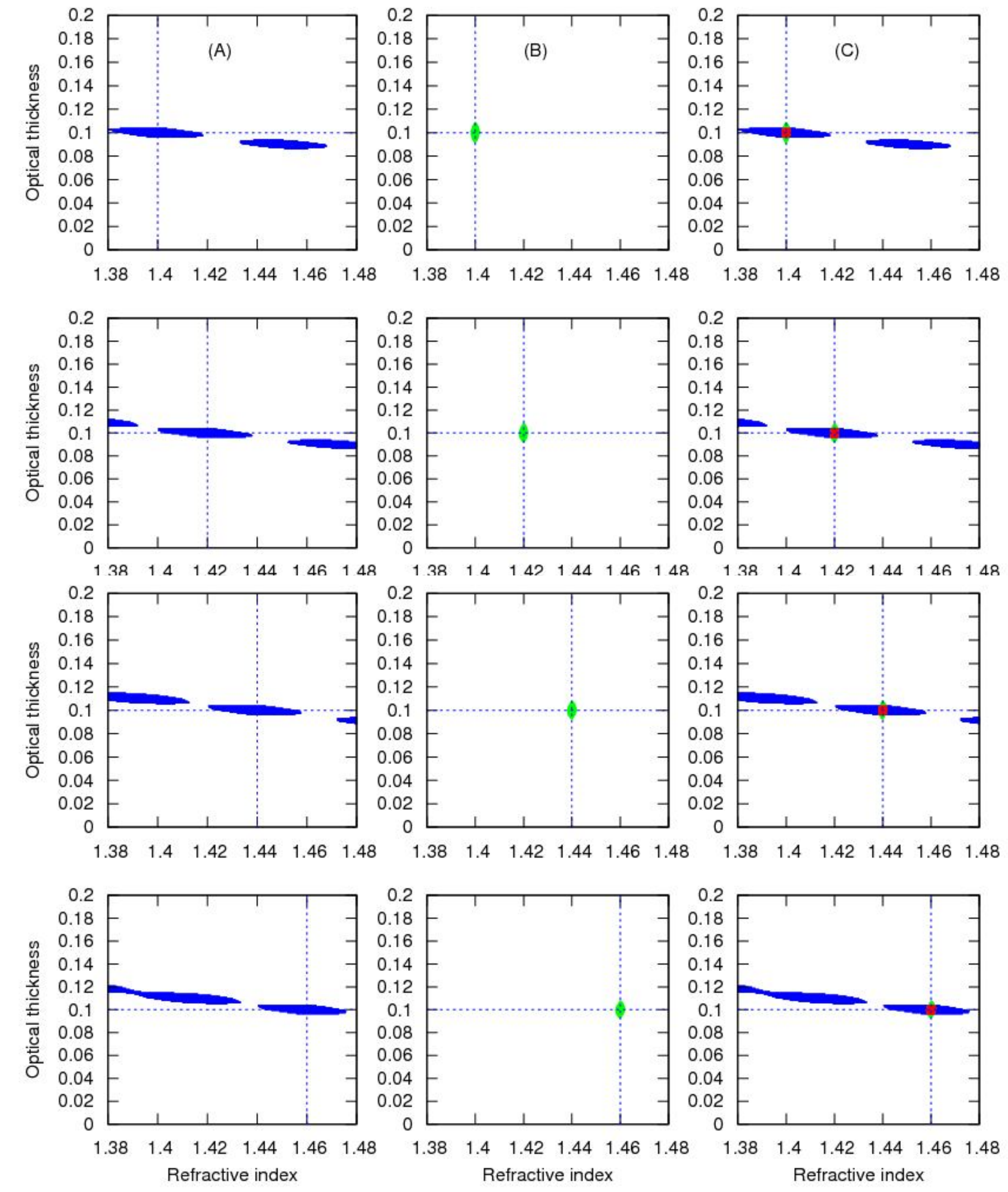


(a)

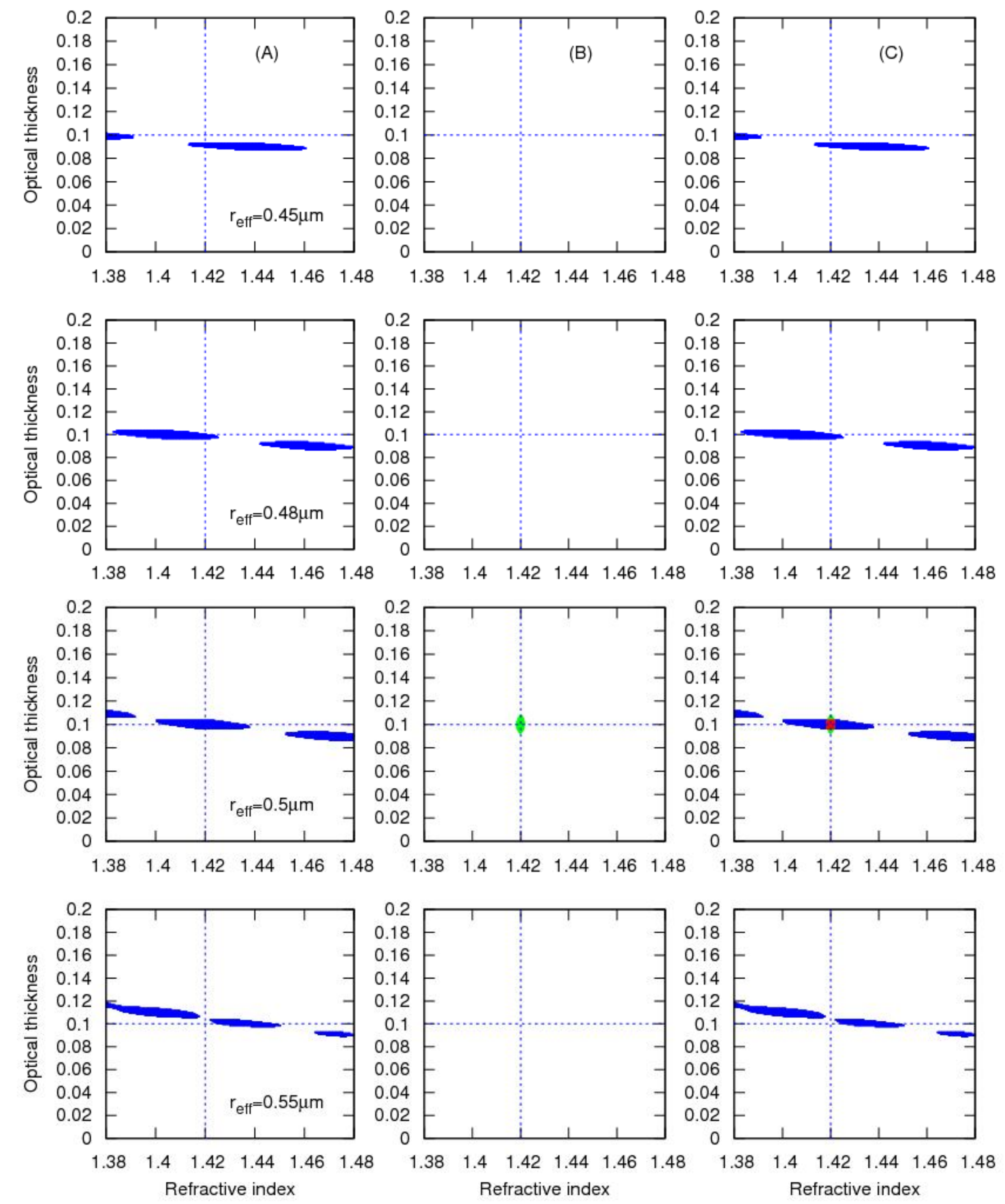


(b)

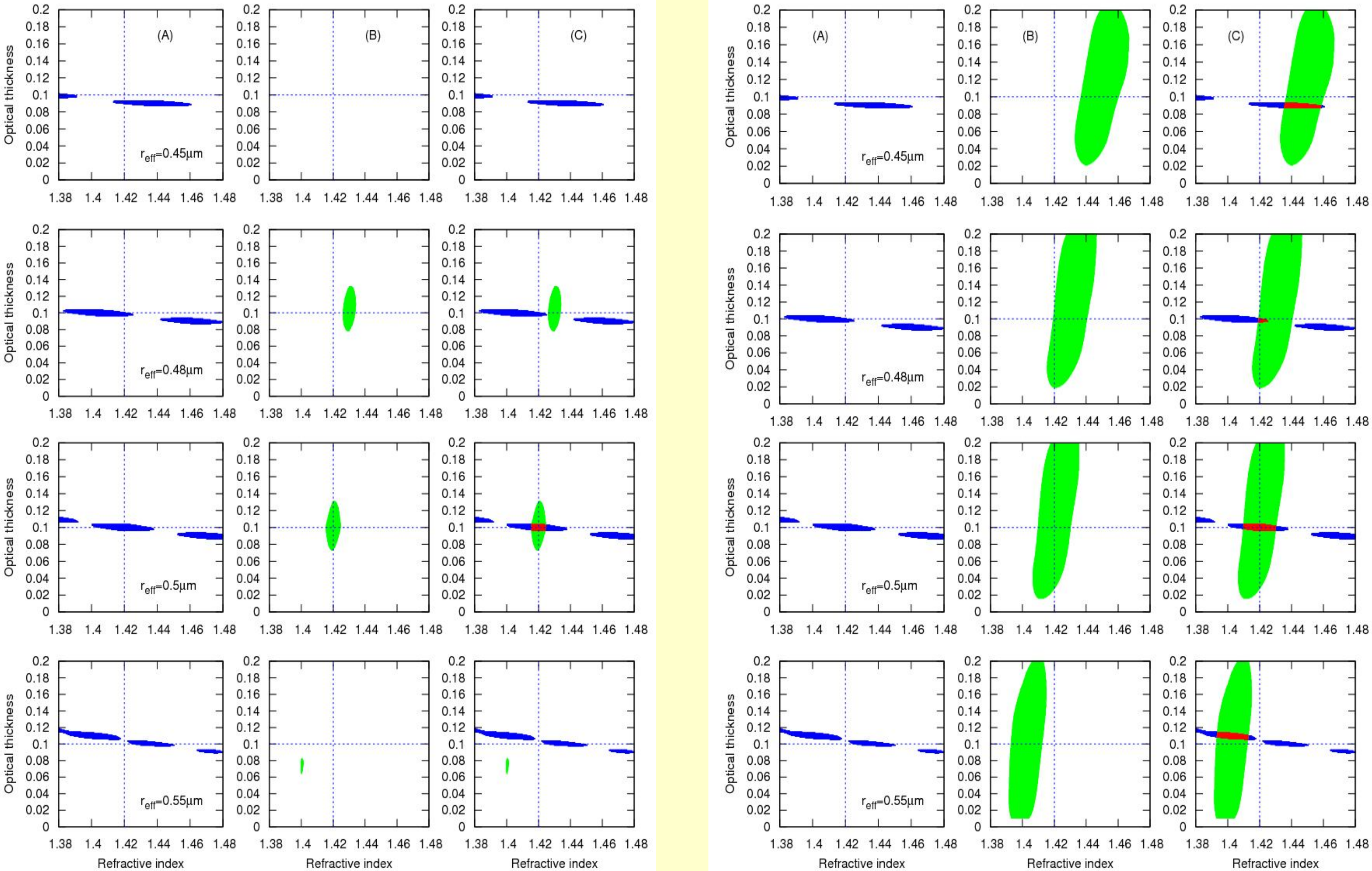
Simultaneous retrieval of the optical thickness and effective radius for three standard aerosol models with the same *a priori* known refractive index m = 1.42, N_{angl} = 9, ε_P = 0.005 (a) and ε_P = 0.015 (b).



Simultaneous retrieval of the optical thickness and refractive index for four standard aerosol models with the same *a priori* known effective radius r_{eff} = 0.5 μm, N_{angl} = 9, ε_P = 0.0015**.**

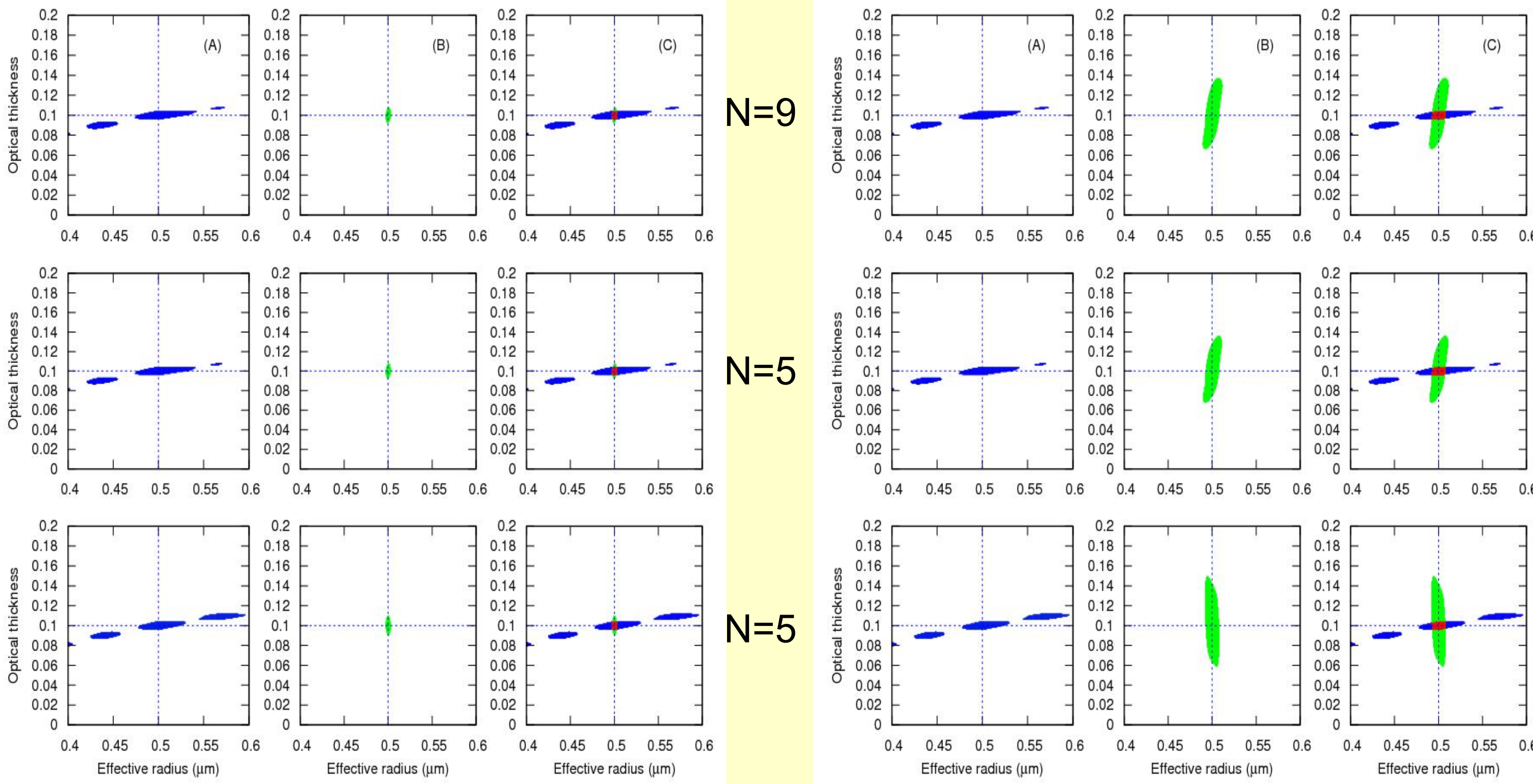


Simultaneous retrieval of all three aerosol parameters $N_{angl} = 9$, $\varepsilon_P = 0.0015$.



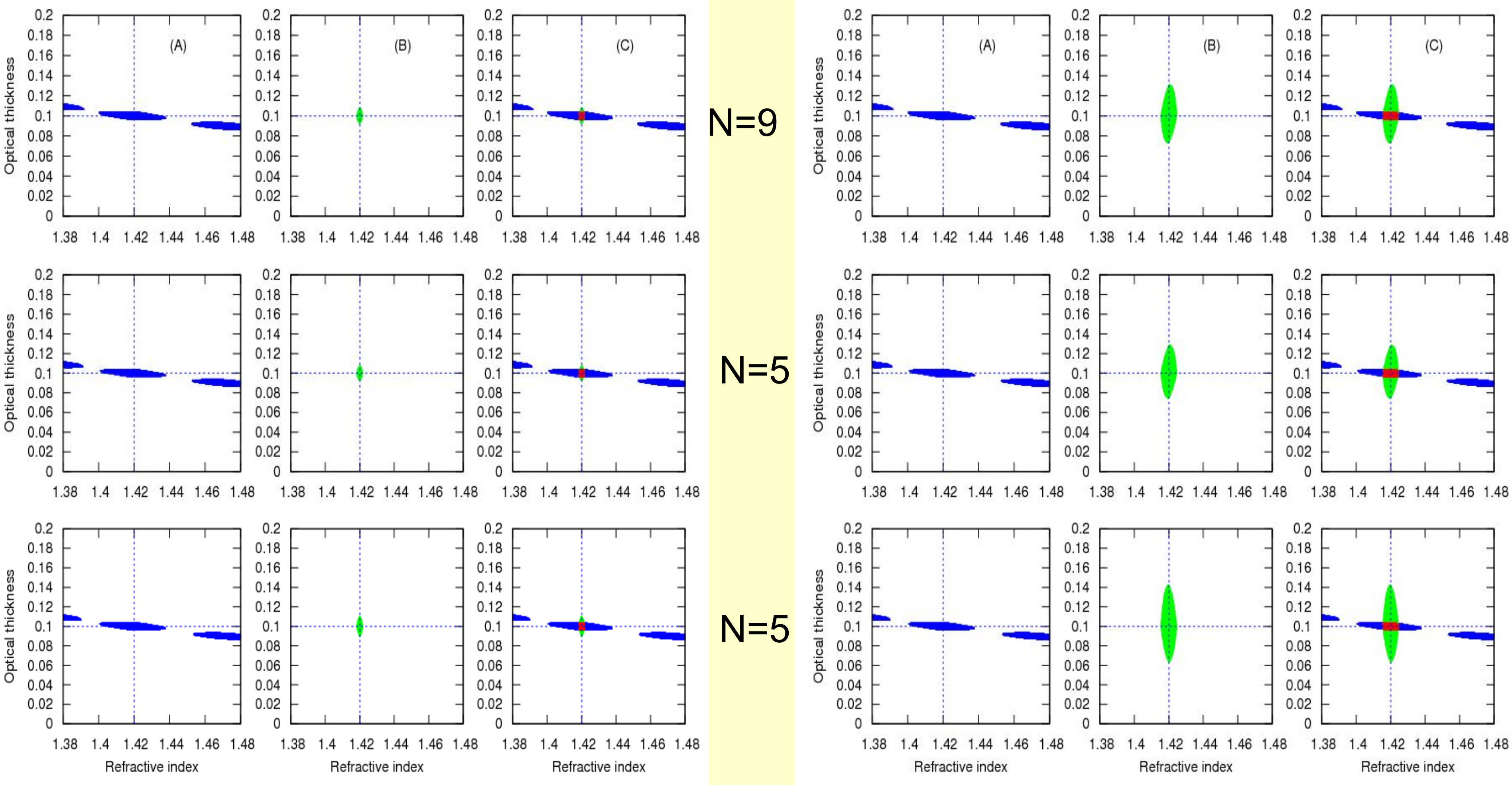
(a) **(b)**

Simultaneous retrieval of all three aerosol parameters $N_{\mathrm{angl}} = 9$, $\varepsilon_P = 0.005$ **(a) and** $\varepsilon_P = 0.015$ **(b).**



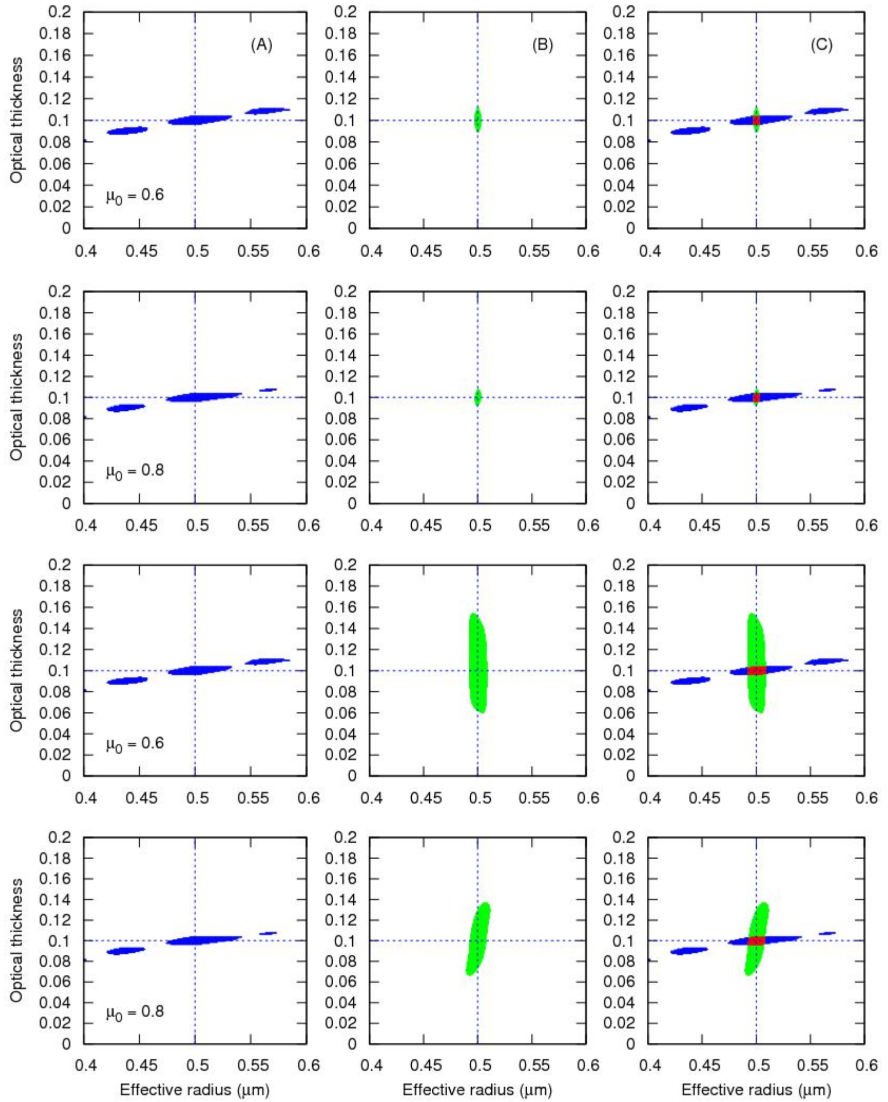
(a) **(b)**

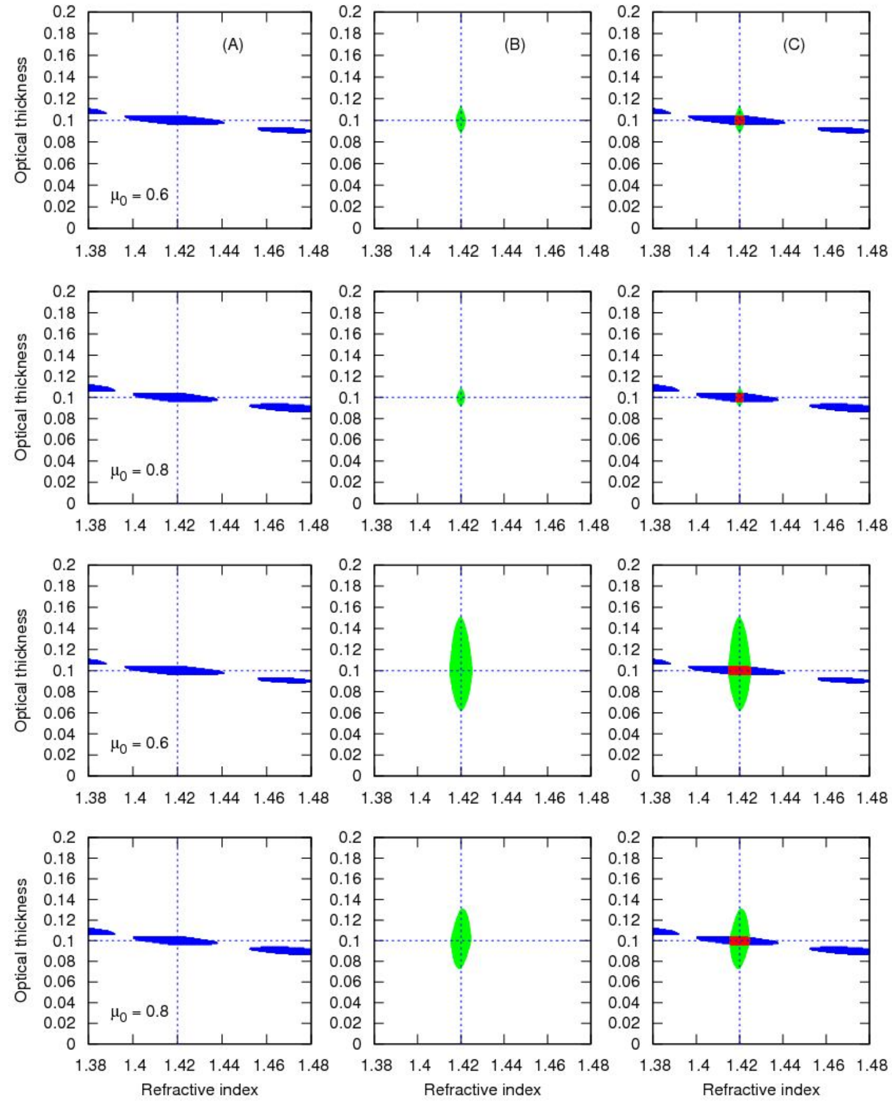
Simultaneous retrieval of the optical thickness and effective radius for *a priori* known refractive index m = 1.42, N_{angl} = 9 and 5, ε_P = 0.0015 (a) and ε_P = 0.005 (b).



(a) **(b)**

Simultaneous retrieval of the optical thickness and refractive index for *a priori* known effective radius $r_{eff} = 0.5$ μm, $N_{angl} = 9$ **and** 5, $\varepsilon_P = 0.0015$ **(a) and** $\varepsilon_P = 0.005$ **(b).**





(a) **(b)**

Simultaneous retrieval of the optical thickness and effective radius (a) and refractive index (b) for μ_0= 0.6 and μ_0= 0.8, ε_P = 0.0015 (two upper rows) and ε_P = 0.005 (two lower rows).

Conclusion

In favorable circumstances, a high-precision multi-angle photopolarimeter has the capacity to yield the optical thickness, size and refractive index of stratospheric aerosols with exceedingly high accuracy by making 1.378 μm observations. Also such photopolarimeter can be used to monitor man-made particulates injected in the stratosphere for geoengineering purposes which are now actively discussed. The multi-angle photopolarimeter (ScanPol) with a 1.378-μm channel is being developed in Ukraine as part of the planned satellite mission AEROSOL-UA.

Some complicating factors that can be encountered in practice and should be further analyzed:

The amount of water vapor in the troposphere may be insufficient to extinguish the contributions from the surface, liquid-water clouds, and tropospheric aerosols to the scattered electromagnetic radiation reaching the orbital instrument. It is therefore essential to be able to reject such “contaminated” pixels. This can be achieved, for example, by having a 0.910-μm spectral channel providing independent information on the water vapor amount.

Depending on the age of stratospheric aerosols, they can be a mixture of two or more components with different size distributions and refractive indices.

At a certain stage in their evolution stratospheric aerosols can be at least partly nonspherical (e.g., dominated by volcanic ash particles). An indication of nonsphericity would be nonzero backscattering depolarization measured by a lidar.

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Thank you for your attention!