
# Polarization Distribution Models – Model Status and Priorities

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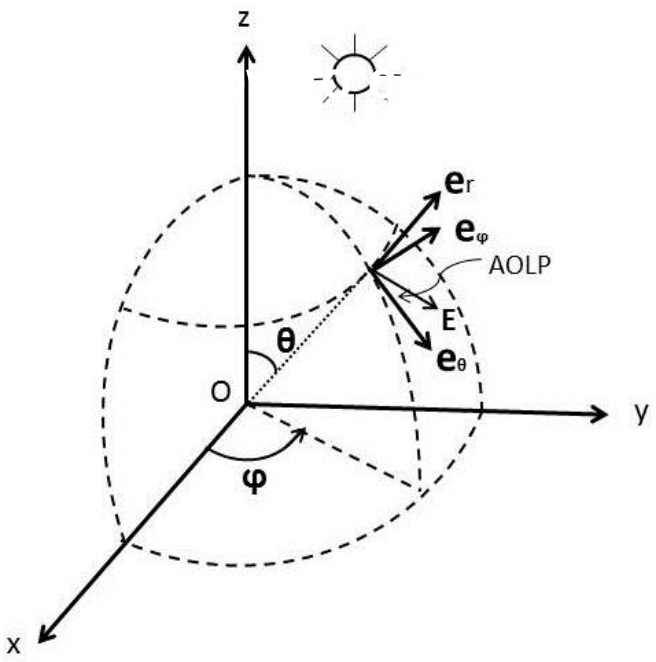
## Introduction

1. Numerical models have been developed to calculate the polarization properties of reflected sunlight from the earth-atmosphere system.
2. The numerical models are expected to make polarization distribution models for reflected solar spectra at any solar zenith angle, viewing zenith angle, and relative azimuth angle, and for any scene type.
3. In this presentation, the status of the models are reported, and priorities of the PDM modeling are outlined.




**Solar radiation reflected from the Earth-atmosphere system is polarized, it has not only I, but also Q, U, and V(~0).**

$$DOP = \frac{\sqrt{Q^2+U^2+V^2}}{I} = I_{pol} / I$$

$$\tan(2 \cdot AOLP) = U / Q$$

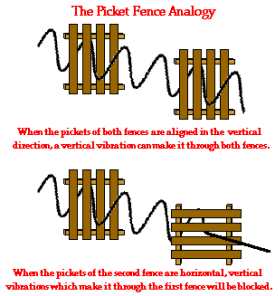
**Correction of polarization error is done as**

$$I = \frac{(C_m / G_0)}{1 + S(AOLP) \cdot DOP} \quad \textit{Instrument's measurement}$$

$$S(AOLP) = \left[ \frac{G_p(AOLP) - G_0}{G_0} \right] \quad \textit{Instrument's dependence on polarization}$$

**Relative error of measured intensity due to polarization**

$$RE = \frac{(C_m / G_0) - I}{I} \approx S(AOLP) \cdot DOP$$




**Instruments with 3% of polarization dependence easily have ~1% errors simply due to a 30% DOP of light!**

# Status of the adding-doubling radiative transfer model (ADRTM)

1. ADRTM:

   This can calculate full Stokes parameters (I, Q, U, V).

2. Atmospheric profiles:

   Any atmosphere profile.

3. Spectral gas absorption:

   Line-by-Line and *k*-distribution plus ozone cross-section table.

4. Molecular scattering:

   Rayleigh with depolarization factor.

5. Particulate absorption and scattering:

   Mie for water clouds (Gamma size distribution);

   PML FDTD for fine-mode aerosols;

   CPML PSTD code is developed for coarse-mode aerosols;

   FDTD and GOM for ice clouds (dataset from Baum).

6. Surface reflection model:

   Cox & Munk with Gram-Charlier expansion plus foam for ocean;

   Wave shadowing effect is integrated in the ocean surface model;

   Lambert model for water-leaving radiance from ocean water volume.

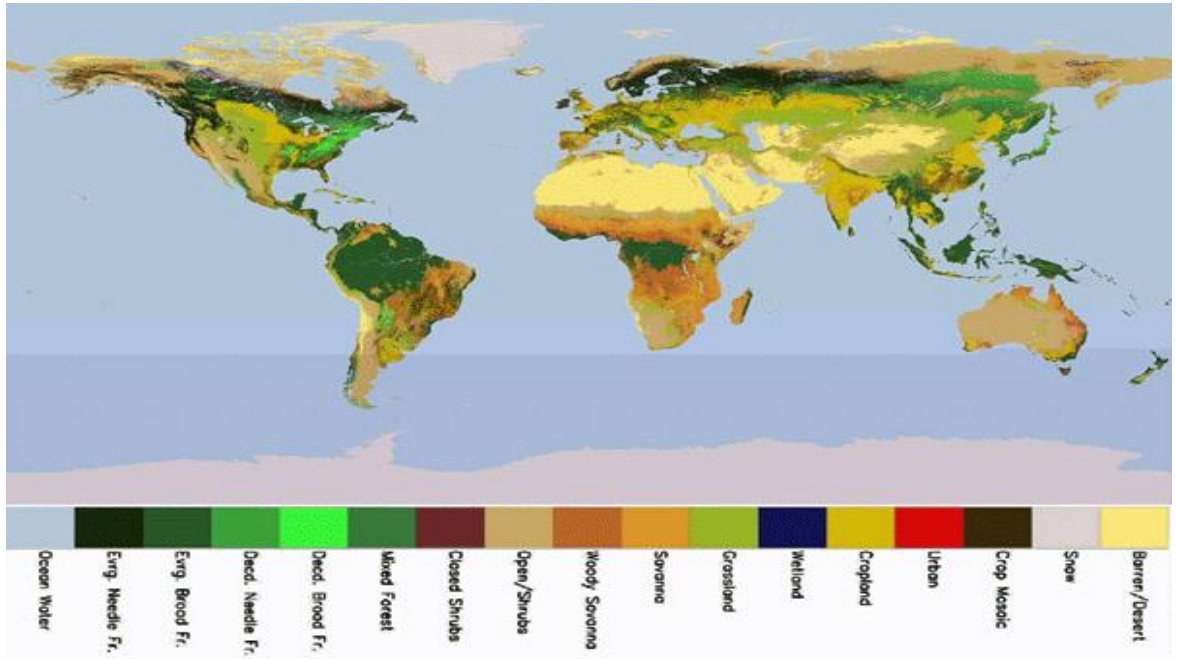
   Rough-surface model plus Lambertian portion for desert/bare land.

   Rough-surface model plus Lambertian portion for evergreen needle-leaf trees, broad-leaf trees, and wintertime deciduous trees.

# The ADRTM is developed for spectral polarization distribution models (PDMs) of different scene types.

ADRTM results of I, DOP, and AOLP are compared with PARASOL data at wavelengths of 490, 670, and 865 nm and at 2 solar zenith angles to fit model parameters for each scene type other than oceans.

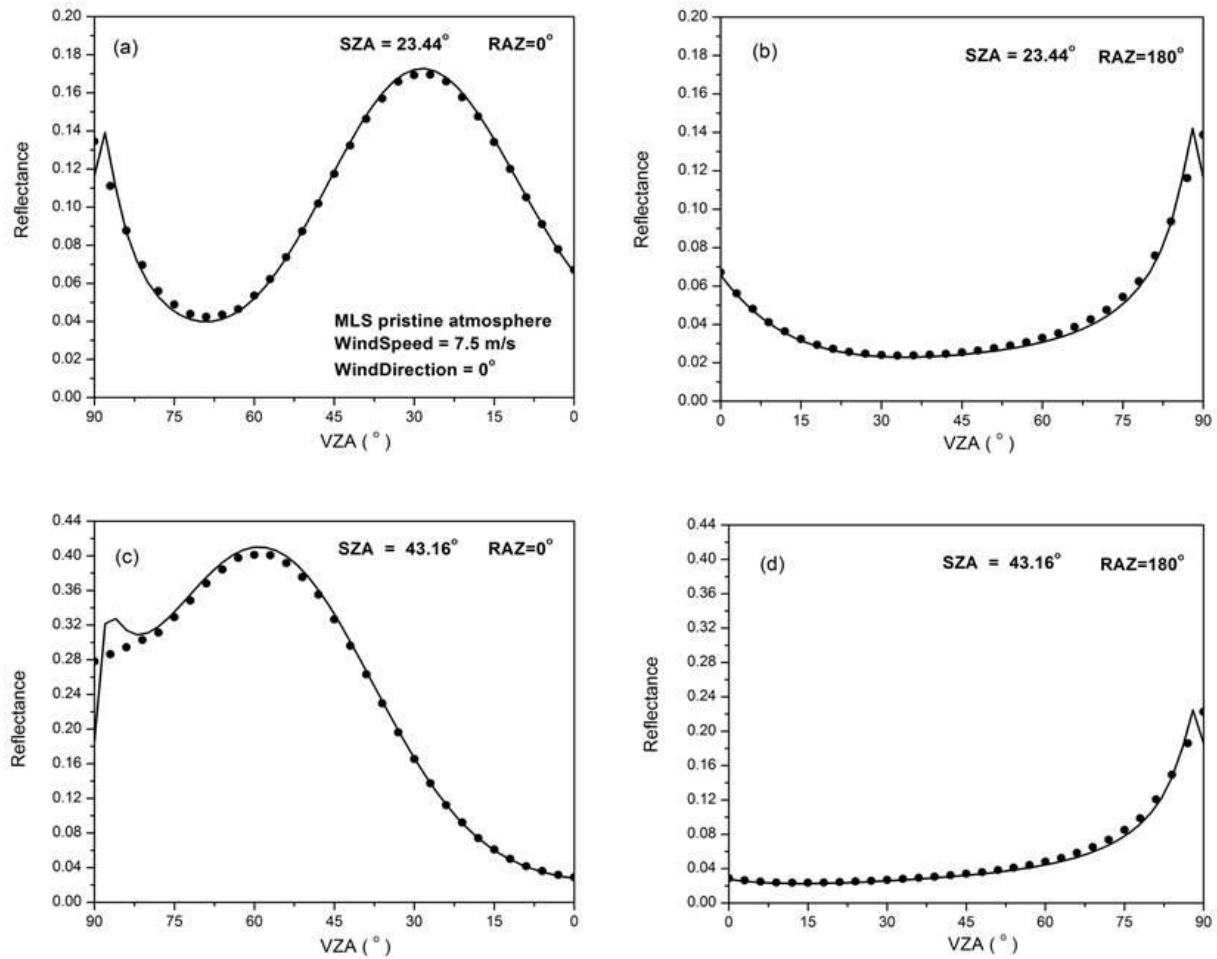
ADRTM with scene-type parameters can calculate I, DOP, and AOLP for any wavelength at any solar and viewing geometries to make PDM lookup tables.



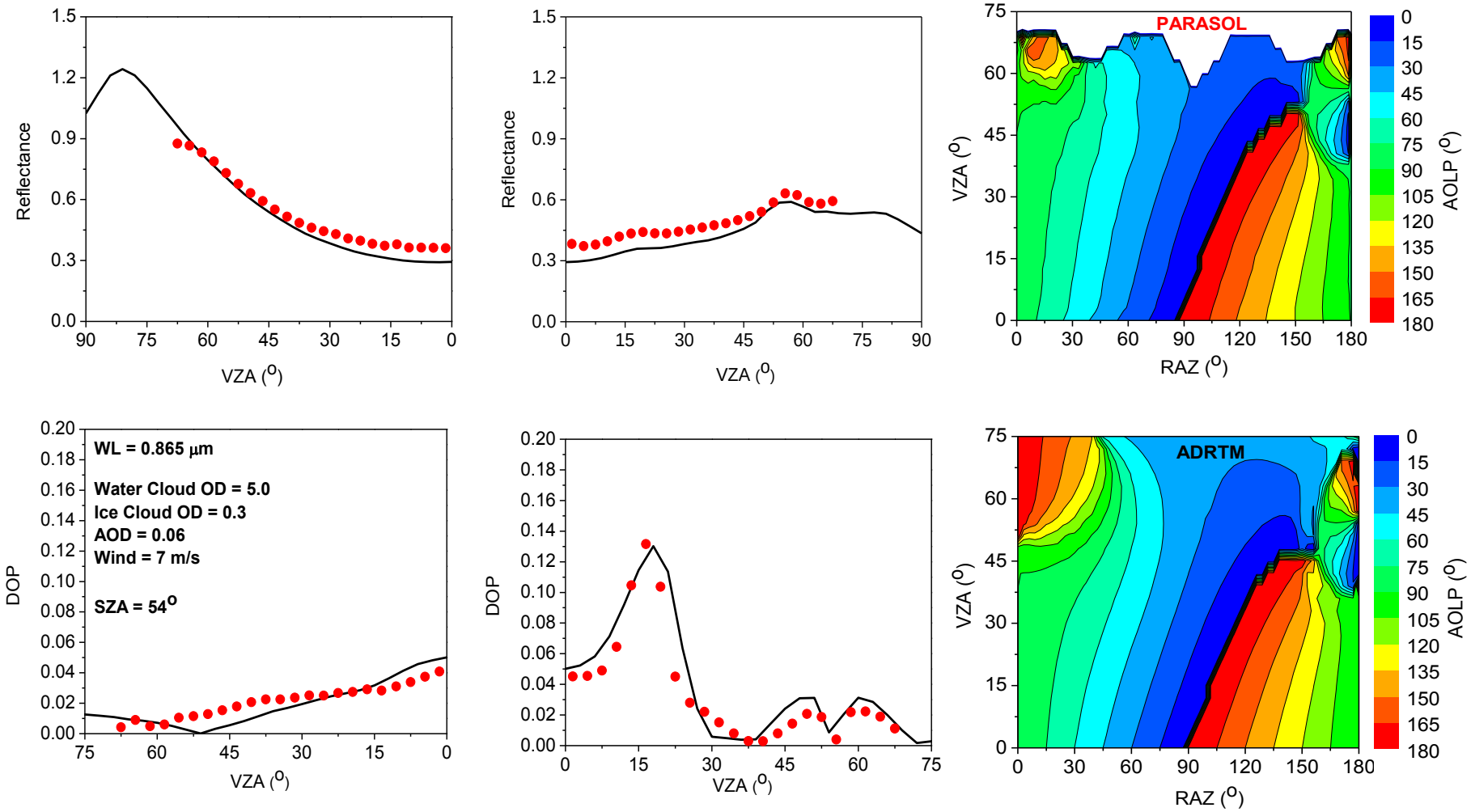

**Scene types for which we have models:**

- **Ocean and other water bodies.**
- **Desert/bare land**
- **Evergreen needle-leaf trees**
- **Evergreen broad-leaf trees**
- **Wintertime deciduous trees**

# Comparing ADRTM reflectance with DISORT results at a wavelength of 670 nm and a SZA of 23.44 deg for clear oceans

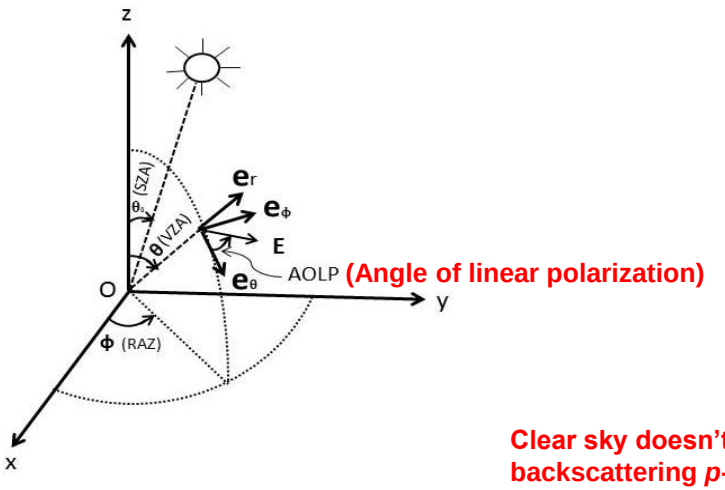


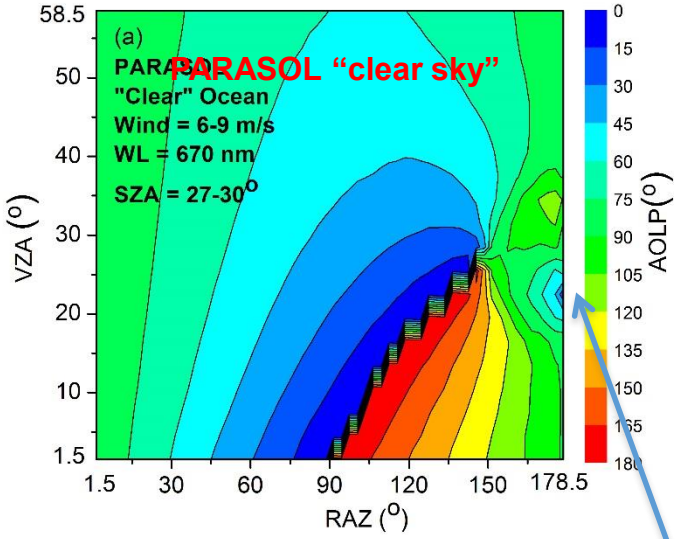
# Comparing ADRTM results with PARASOL data at a wavelength of 865 nm and a SZA of 54 deg for water clouds



# Comparing ADRTM results with PARASOL data at a wavelength of 670 nm and a SZA of 28 deg for super-thin ice clouds

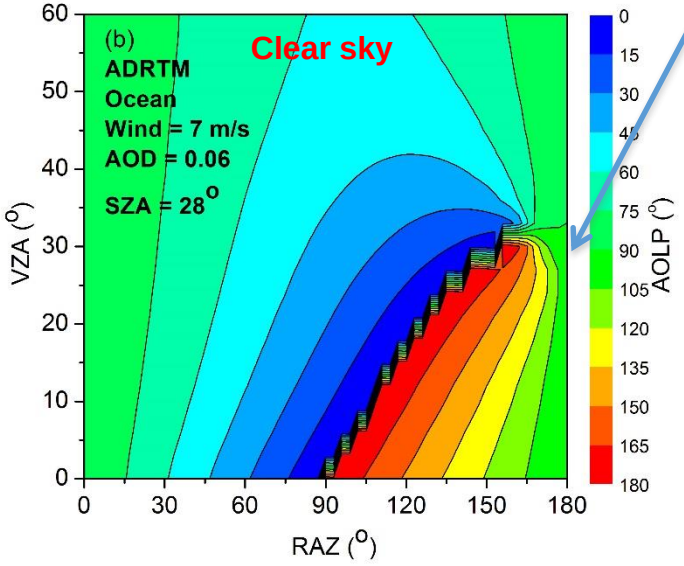
## *P*-polarization feature of clouds (ice)

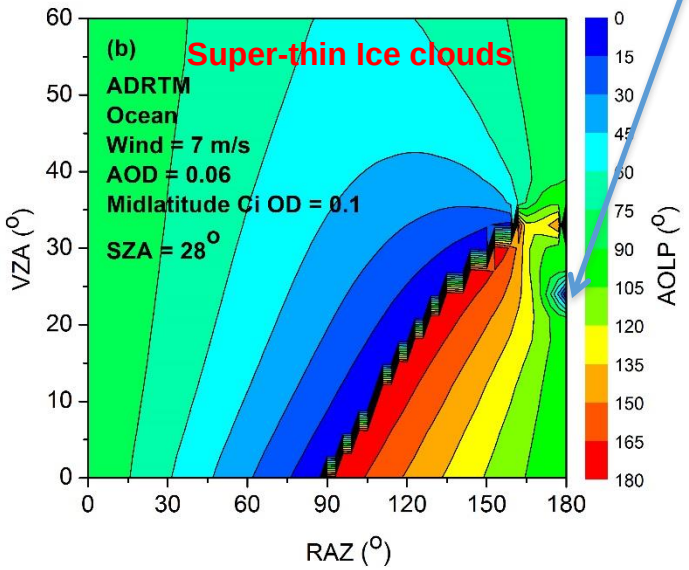



Clear sky doesn't have backscattering *p*-polarization feature

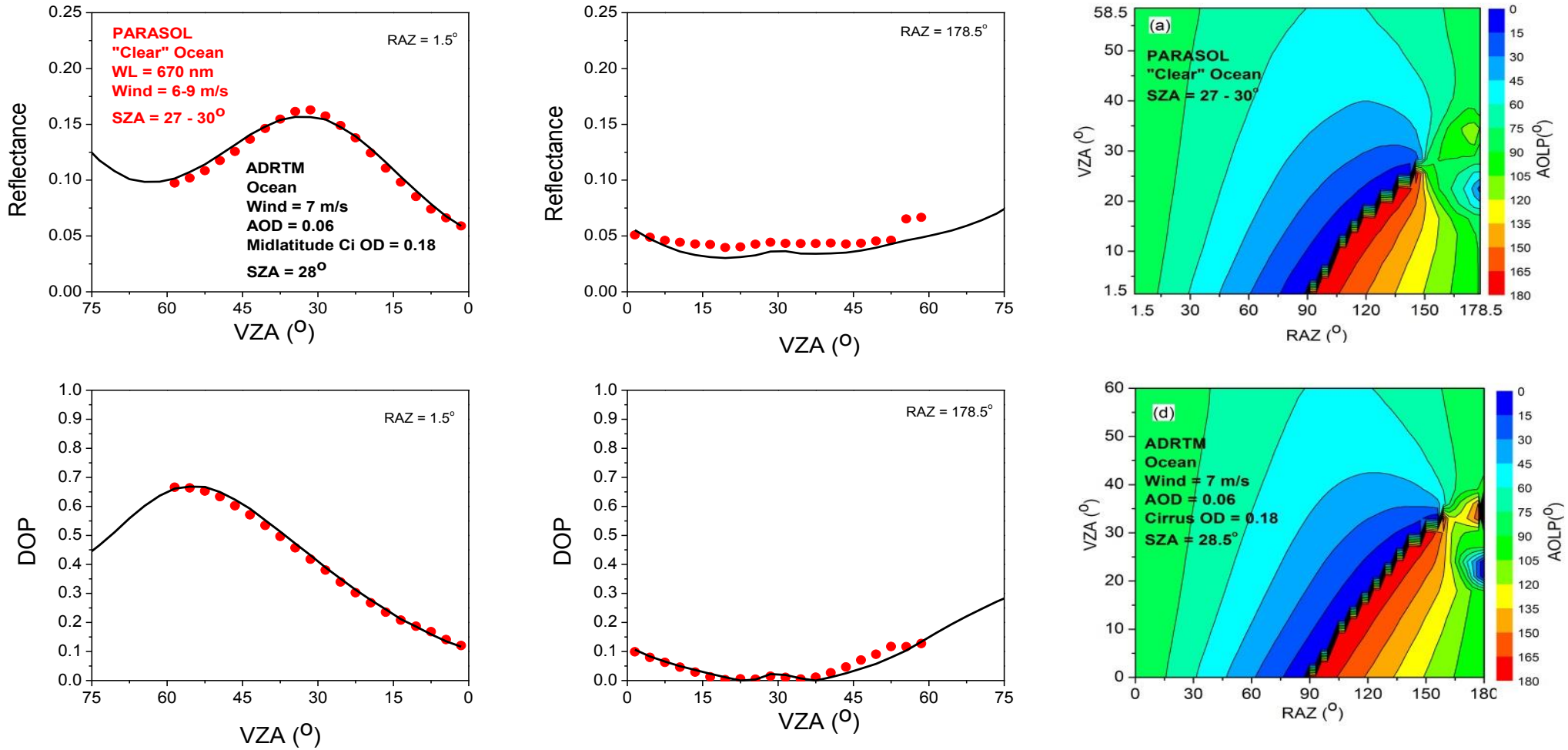
Backscattering *p*-polarization feature



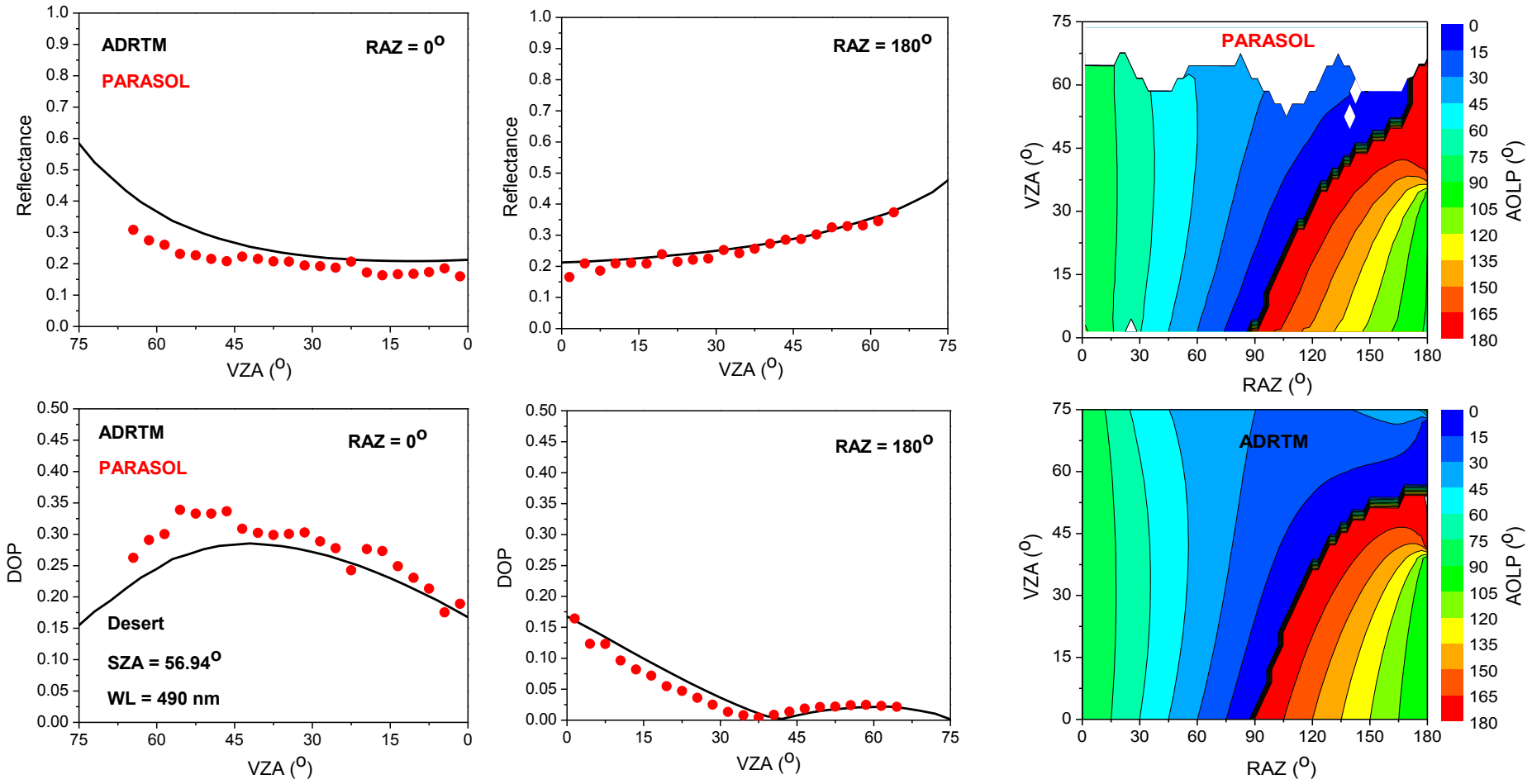



# Comparing ADRTM results with PARASOL data at a wavelength of 670 nm and a SZA of 28 deg for clear oceans.

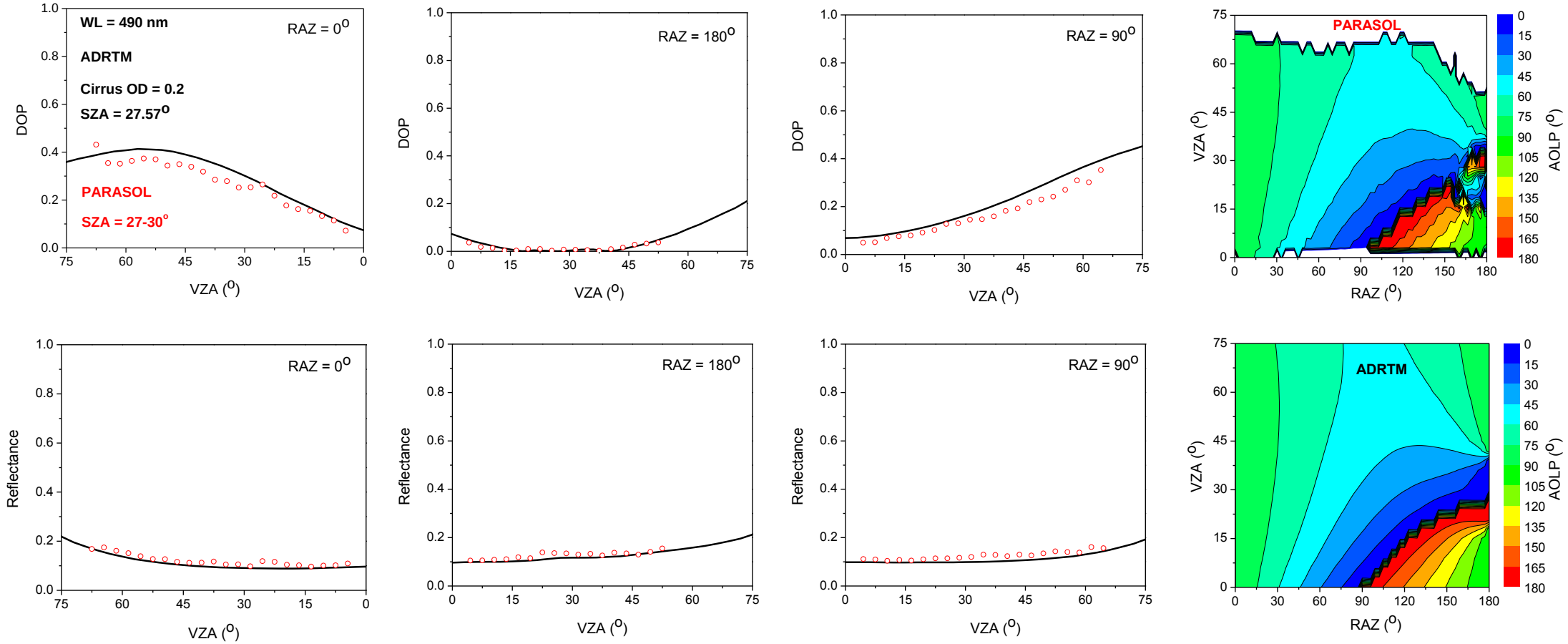
**A layer of super-thin cirrus is added in ADRTM**



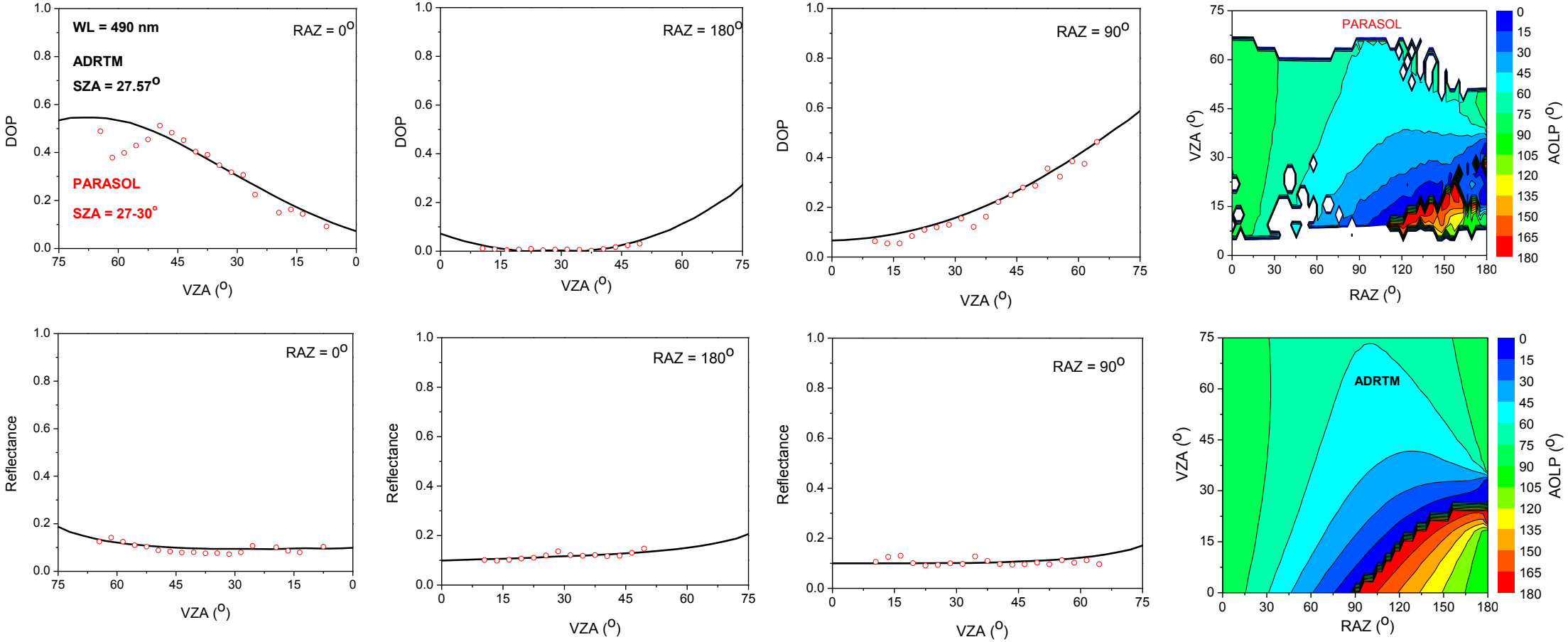
# Comparing ADRTM results with PARASOL data at a wavelength of 490 nm and a SZA of 56.94 deg for desert.



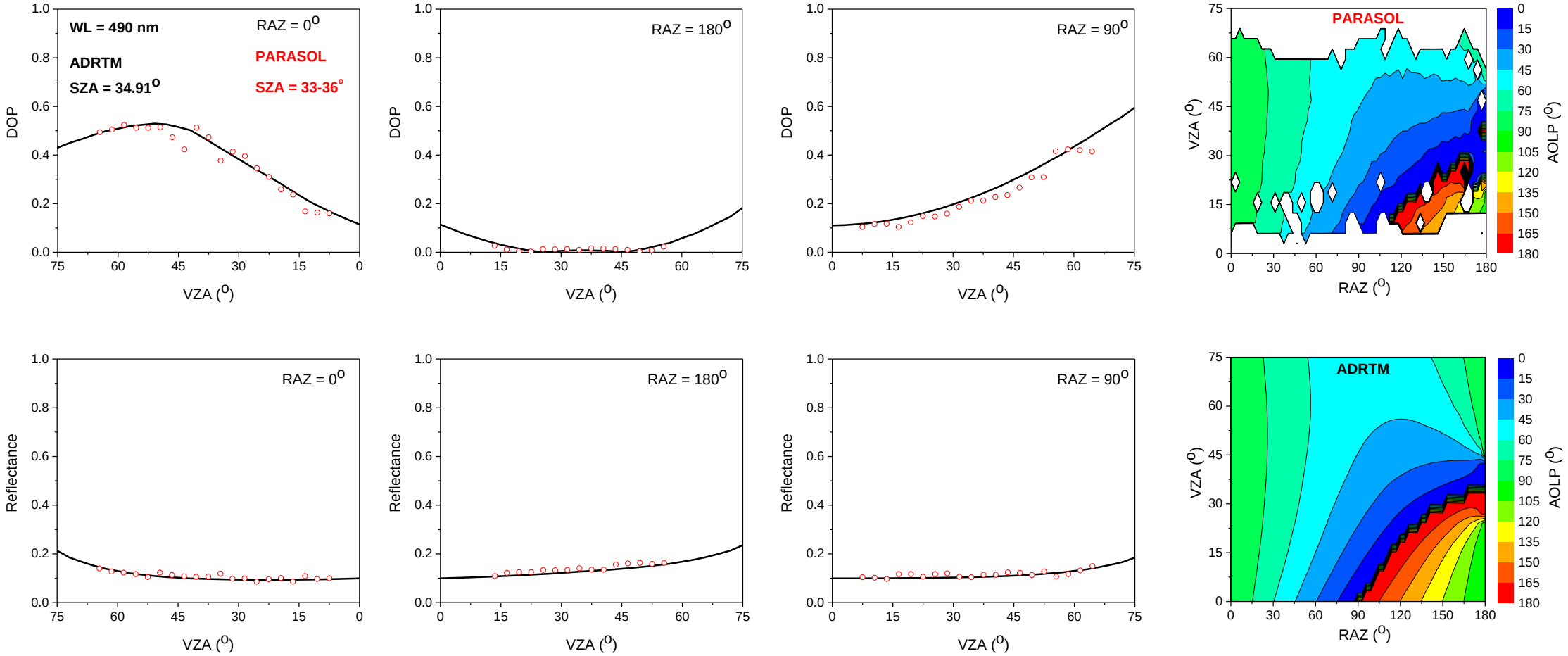
# Comparing model results with satellite data at a wavelength of 490 nm and a SZA of 27.57 deg for evergreen broad-leaf trees



# Comparing model results with satellite data at a wavelength of 490 nm and a SZA of 27.57 deg for evergreen needle-leaf trees



# Comparing model results with satellite data at a wavelength of 490 nm and a SZA of 34.91 deg for deciduous trees in wintertime



# Pathfinder PDM Modeling Priorities

1. Surface model for mixed trees of different seasons.
2. Surface model for other scene types.
3. Background aerosol and super-thin cloud studies.
4. Algorithms for angular interpolation of PDM tables.
5. Data and file structure for the PDM tables.
6. Automation of whole modeling process.

# Conclusion

1. Polarized reflected solar spectra from many scene types can be modeled with the ADRTM.

2. Surface models for some scene types still need to be developed.

3. Background aerosol and super-thin clouds still need to be studied.

4. Spectral PDMs will be made for CLARREO Pathfinder inter-calibration applications at any solar and viewing geometries for any scene types.

References


1. **Wenbo Sun**, Rosemary R. Baize, Gorden Videen, Yongxiang Hu, and Qiang Fu, "A method to retrieve super-thin cloud optical depth over ocean background with polarized sunlight", *Atmos. Chem. Phys.*, 15, 11909-11918, doi: 10.5194/acp-15-11909-2015 (2015).
2. **Wenbo Sun**, Rosemary R. Baize, Constantine Lukashin, and Yongxiang Hu, "Deriving polarization properties of desert-reflected solar spectra with PARASOL data", *Atmos. Chem. Phys*.15, 7725-7734, doi: 10.5194/acp-15-7725-2015 (2015).
3. **Wenbo Sun**, Constantine Lukashin, Rosemary R. Baize, and Daniel Goldin, "Modeling polarized solar radiation for CLARREO inter-calibration applications: Validation with PARASOL data," *J. Quant. Spectrosc. Radiat. Transfer* 150, 121-133 (2015)
4. **Wenbo Sun**, Gorden Videen, and Michael I. Mishchenko, "Detecting super-thin clouds with polarized sunlight," *Geophy. Res. Lett.* 41, 688-693, doi: 10.1002/2013GL058840 (2014).
5. **Wenbo Sun** and Constantine Lukashin, "Modeling polarized solar radiation from ocean-atmosphere system for CLARREO inter-calibration applications," *Atmos. Chem. Phys.* 13, 10303-10324, doi: 10.5194/acp-13-10303-2013 (2013).