The CLARREO Science Definition Team Meeting April 28-30th in Berkeley, CA.

Deriving Polarization Properties of Desert-Reflected Solar Spectra with PARASOL Data

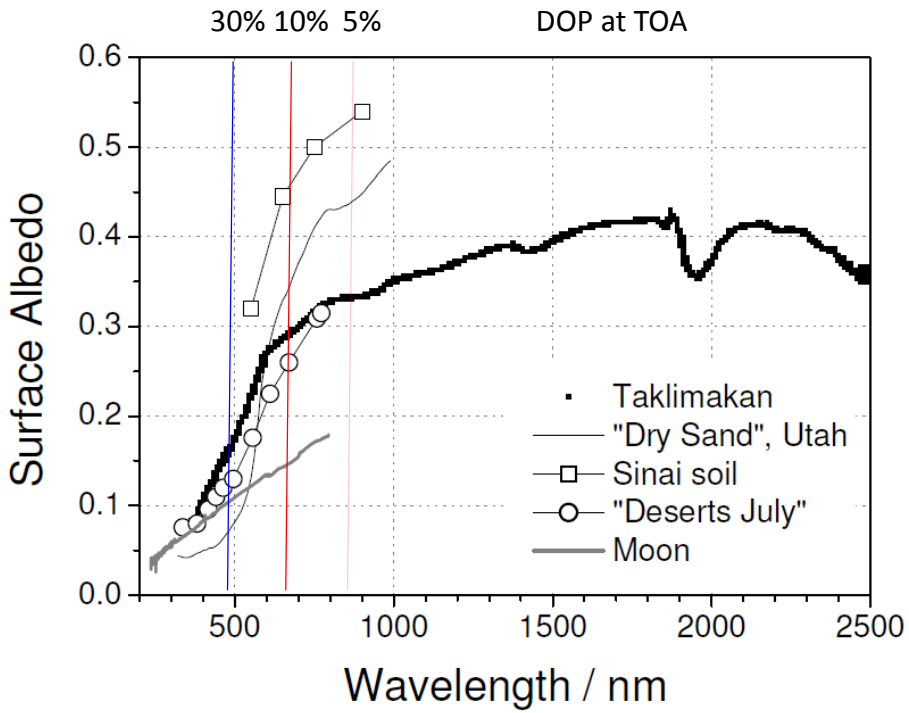
Wenbo Sun, Rosemary R. Baize, and Constantine Lukashin

Introduction

1. Reflected solar radiation from desert is strongly polarized by sand particles.
2. To date, there is no reliable desert surface reflection model to calculate desert reflection matrix.
3. In this study, the PARASOL data are used to retrieve physical properties of desert. These physical properties are then used in the ADRTM to calculate polarization of desert-reflected light for the whole solar spectra.

Why modeling polarized RS from desert?

- **Sunlight is strongly polarized by desert surface**
- **Desert polarization to solar radiation is a strong function of wavelength**
- **Empirical PDMs from PARASOL data can be obtained only at 3 wavelengths, cannot be applied to whole solar spectrum**



Theory for modeling polarized RS from land surface

$$R(\theta_s, \theta_v, \varphi) = fR_L + (1-f)\frac{\pi\rho_{specular}(n)}{4\cos^4\beta\cos\theta_s\cos\theta_v}P(Z_x, Z_y)$$

$$P(Z_x, Z_y) = \frac{1}{\pi\sigma^2}\exp\left(-\frac{Z_x^2 + Z_y^2}{\sigma^2}\right)$$

$$\tan\beta = \sqrt{Z_x^2 + Z_y^2}$$

$$Z_x = \frac{\sin\theta_v\cos\varphi - \sin\theta_s}{\cos\theta_v + \cos\theta_s}$$

$$Z_y = \frac{\sin\theta_v\sin\varphi}{\cos\theta_v + \cos\theta_s}$$

Once we know f n R_L σ, we can calculate land surface reflection matrix elements.

Physical surface model of desert

1-f = 5% quartz-rich polarizer with facets

$$\sigma = 0.164$$

+

f = 95% Lambert non-polarizer

Refractive index of quartz

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA VOLUME 55, NUMBER 10 OCTOBER 1965

Interspecimen Comparison of the Refractive Index of Fused Silica*†

I. H. MALITSON

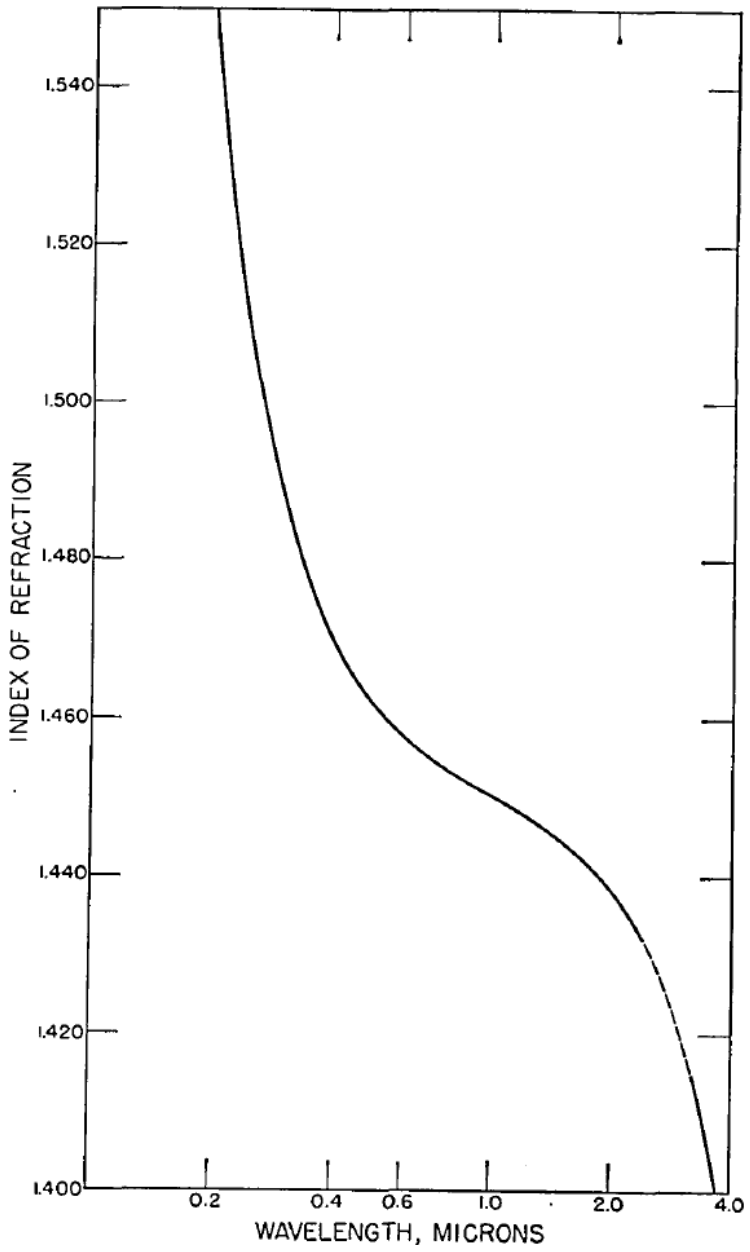
National Bureau of Standards, Washington, D. C. 20234

(Received 14 May 1965)

The index of refraction of optical quality fused silica (SiO_2) was determined for 60 wavelengths from 0.21 to 3.71 μ at 20°C. The dispersion equation

$$n^2-1=\frac{0.6961663\lambda^2}{\lambda^2-(0.0684043)^2}+\frac{0.4079426\lambda^2}{\lambda^2-(0.1162414)^2}+\frac{0.8974794\lambda^2}{\lambda^2-(9.896161)^2},$$

where λ is expressed in microns was found to yield an absolute residual of 10.5×10^{-6}. The variation in index between 12 specimens was determined. Dispersive properties of the material and thermal coefficient of index are graphically presented. A comparison with previous NBS index data is discussed.



Desert dust AOD

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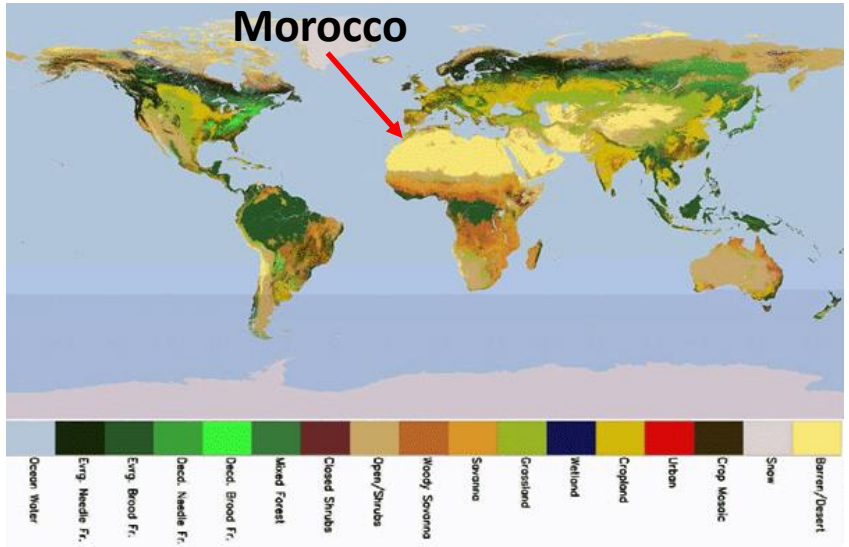
TELLUS

Spectral aerosol optical depth characterization of desert dust during SAMUM 2006

By C. TOLEDANO[1]*, M. WIEGNER[1], M. GARHAMMER[1], M. SEEFELDNER[1], J. GASTEIGER[1], D. MÜLLER[2] and P. KOEPKE[1], [1]*Meteorological Institute, Ludwig–Maximilians–Universität, Theresienstr. 37, 80333 Munich, Germany;* [2]*Leibniz Institute for Tropospheric Research, Permoserstr. 15, 04318 Leipzig, Germany*

(Manuscript received 28 December 2007; in final form 1 August 2008)



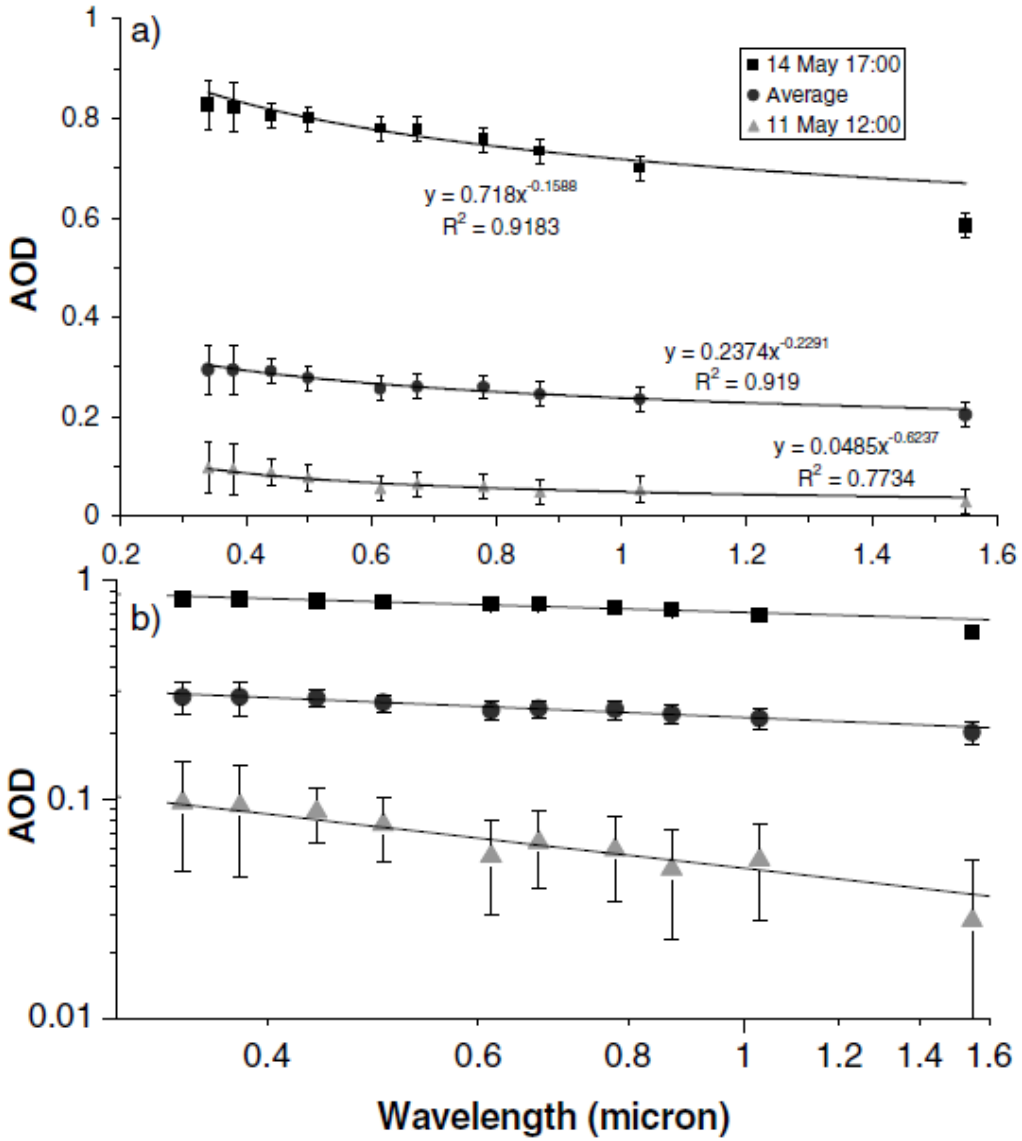


Fig. 4. (a) Wavelength dependence of the aerosol optical depth for average conditions (circles), severe dust (squares) and background conditions (triangles); (b) Same in log–log scale.

Desert spectral reflectance

Remote Sens. **2009**, *1*, 915-933; doi:10.3390/rs1040915

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Article

Remote Sensing and Spectral Characteristics of Desert Sand from Qatar Peninsula, Arabian/Persian Gulf

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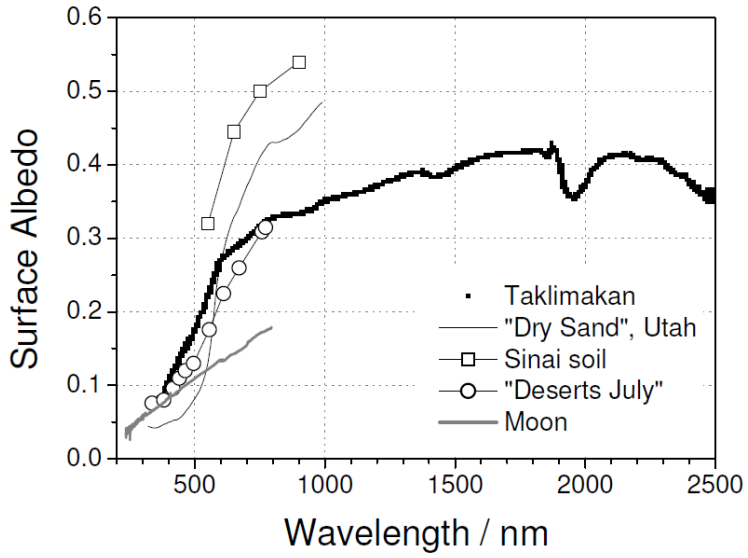
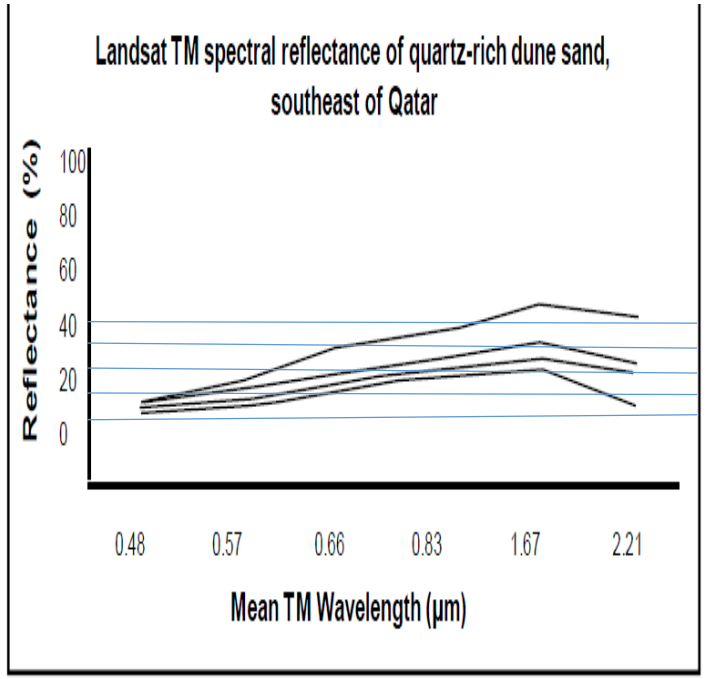
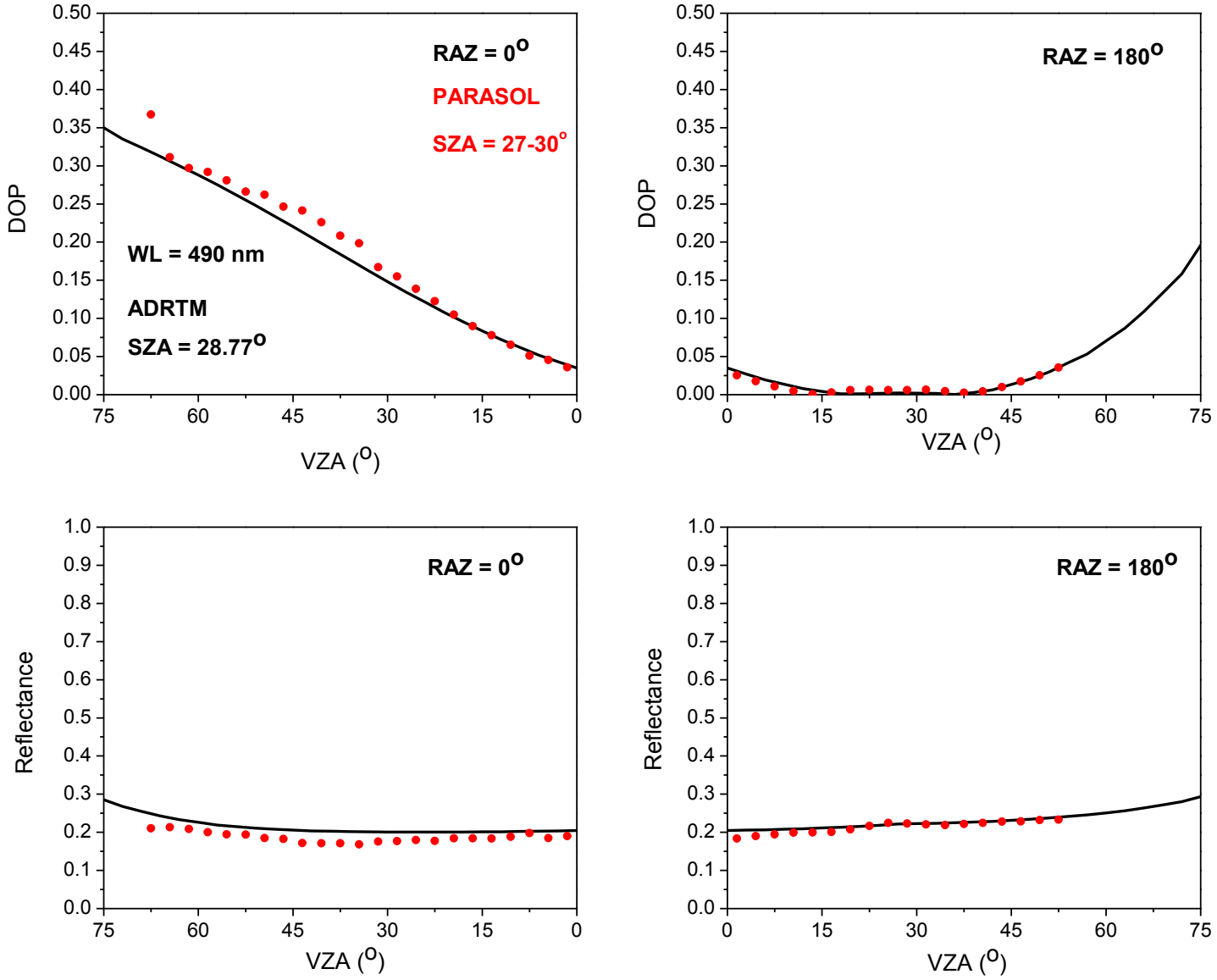
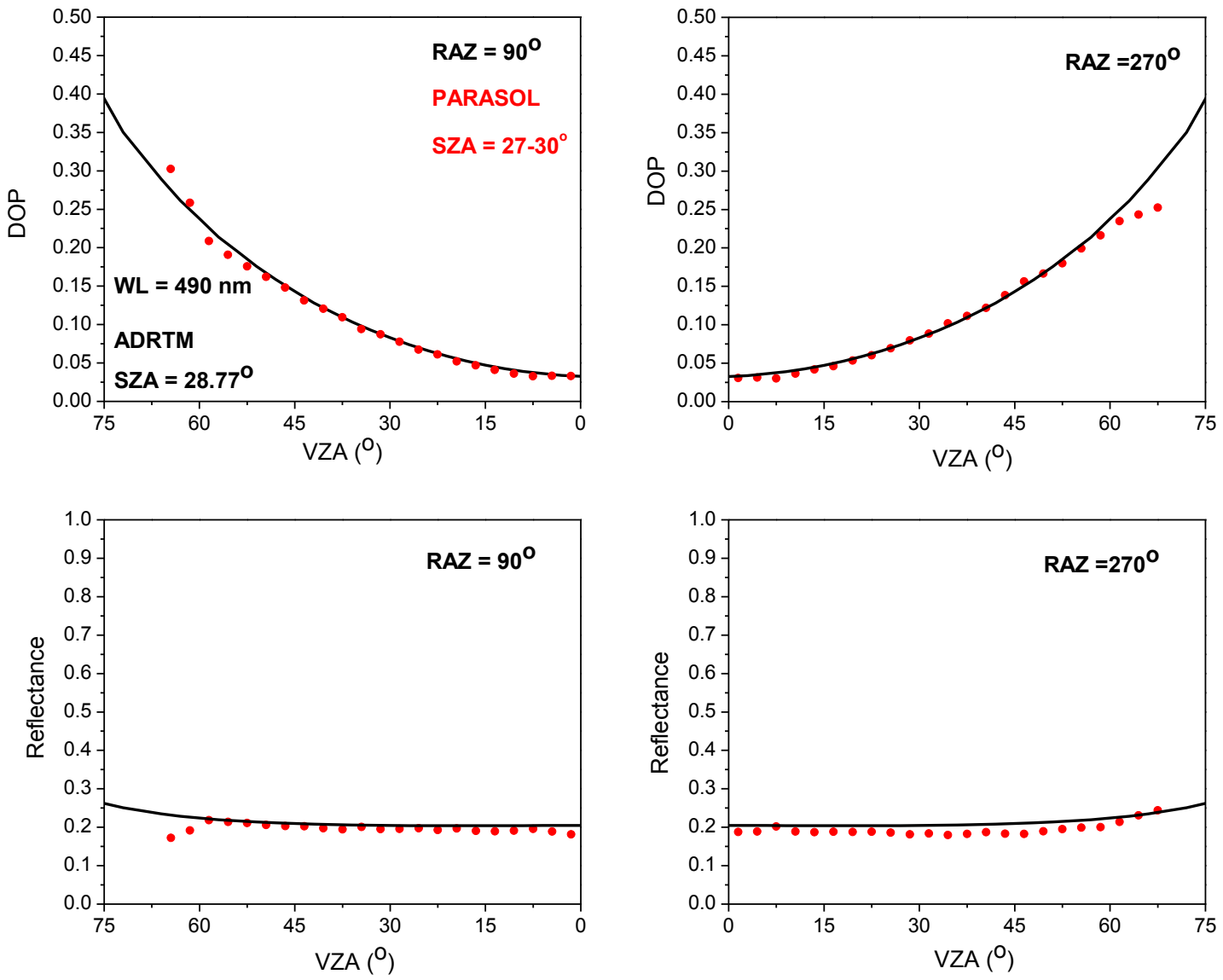
[2] Environmental Science Program, College of Arts and Science, The University of Texas of the Permian Basin, 4901 East University, Odessa, TX 79762, USA





Comparing model results with satellite data at a wavelength of 490 nm and a SZA of 28.77 deg

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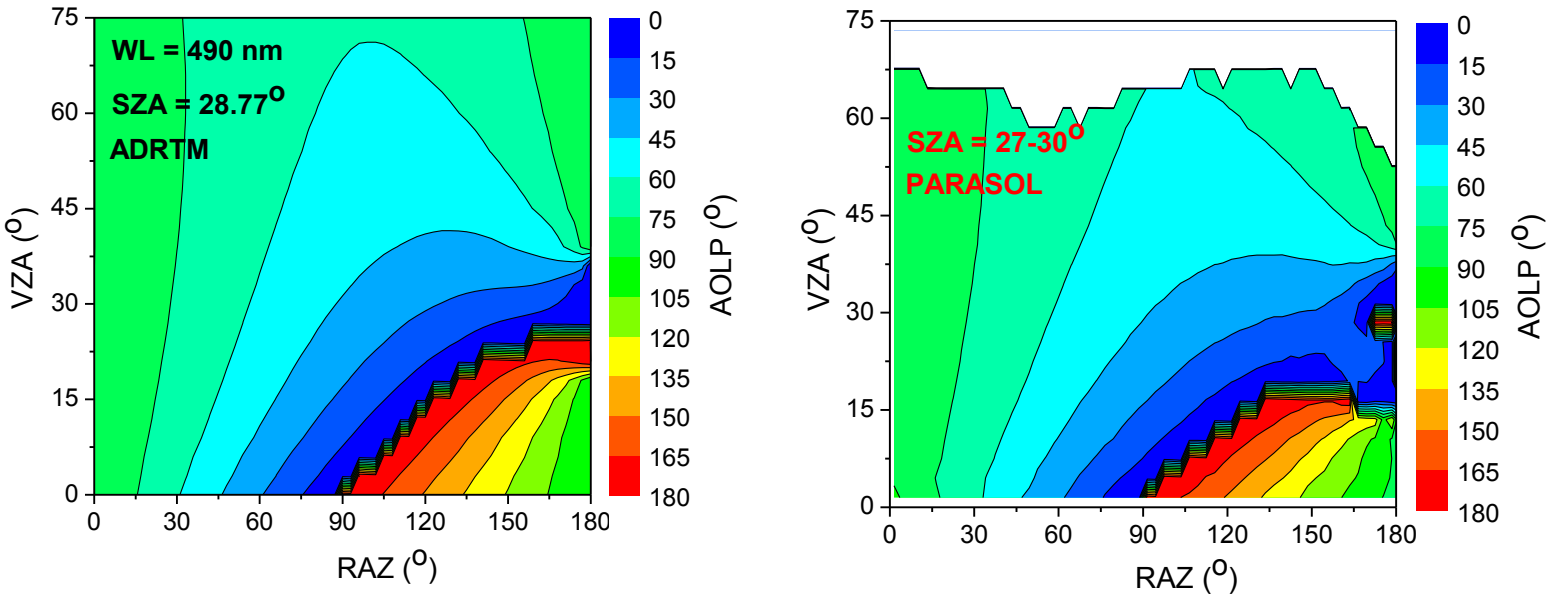
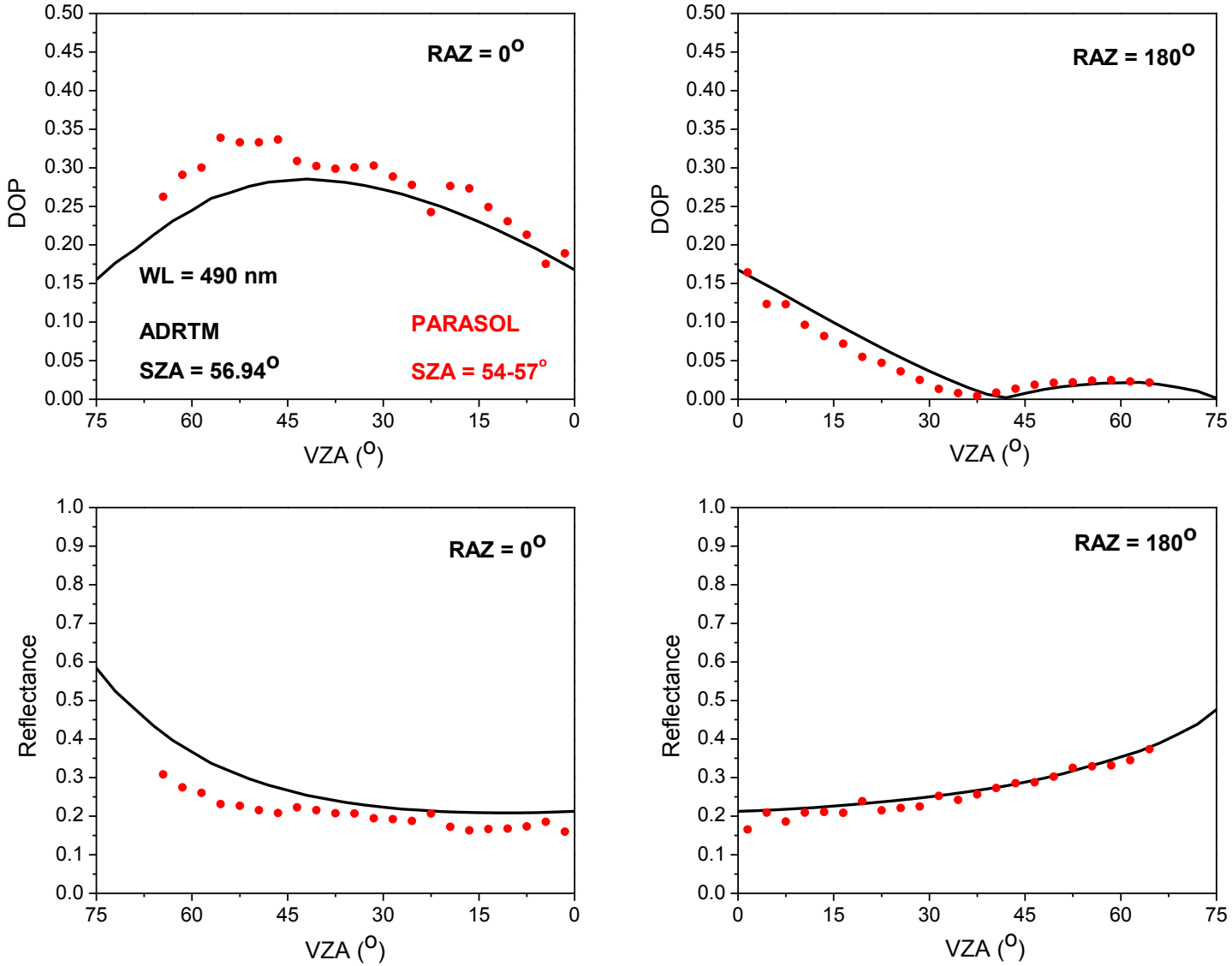
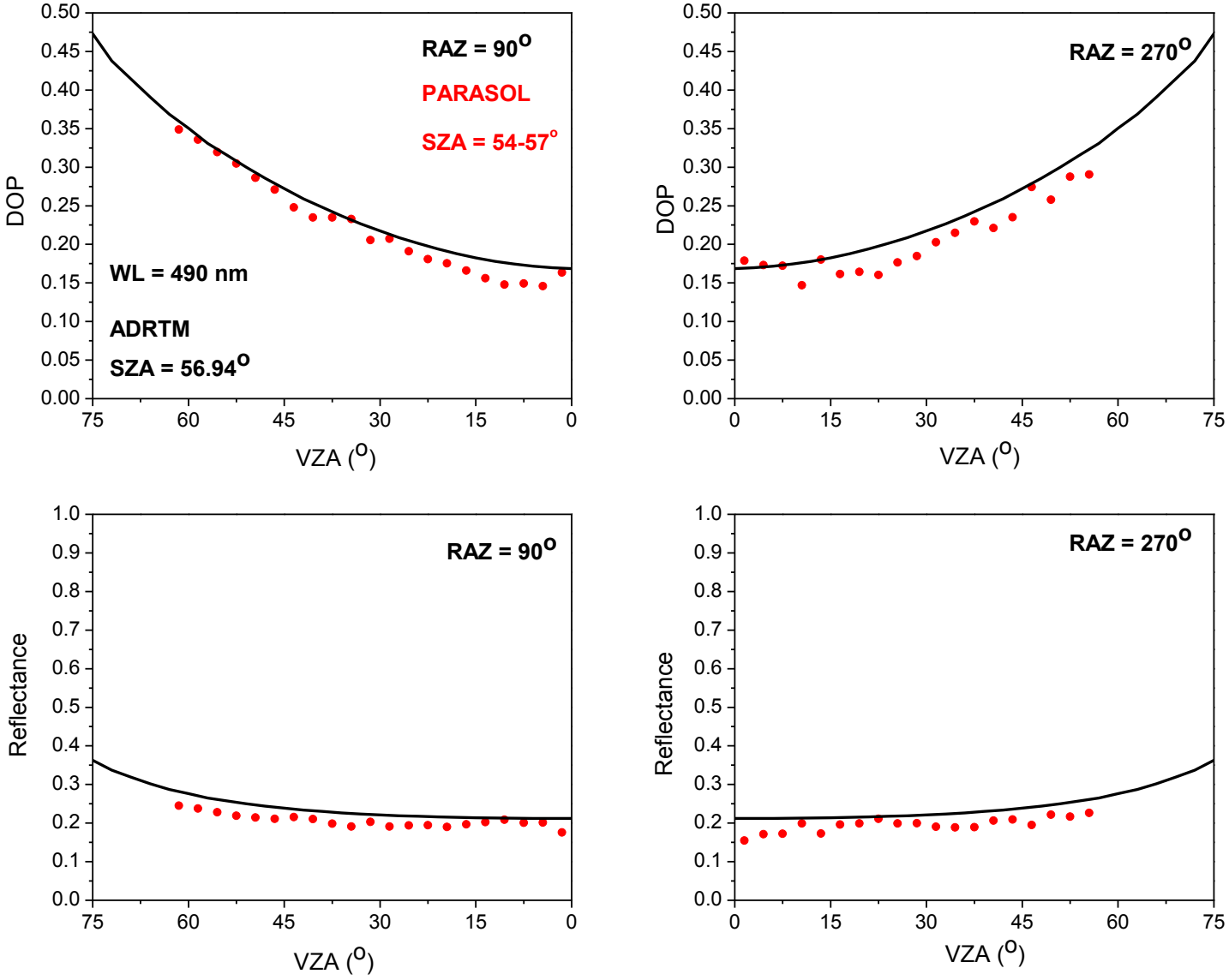
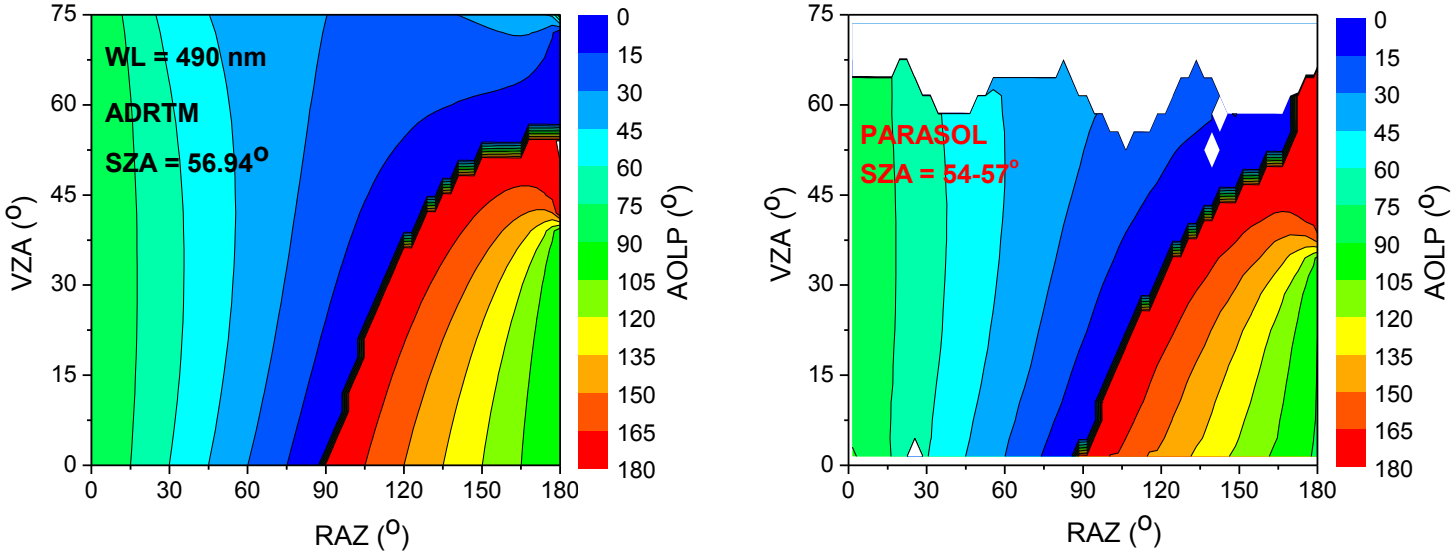
PARASOL
SZA = 27-30°
WL = 490 nm
ADRTM
SZA = 28.77°
DOP
VZA (°)
RAZ =270°
DOP
VZA (°)
RAZ = 90°
Reflectance
VZA (°)
RAZ =270°
Reflectance
VZA (°)


WL = 490 nm
SZA = 28.77°
ADRTM
VZA (°)
RAZ (°)
AOLP (°)
0
15
30
45
60
75
90
105
120
135
150
165
180
SZA = 27-30°
PARASOL

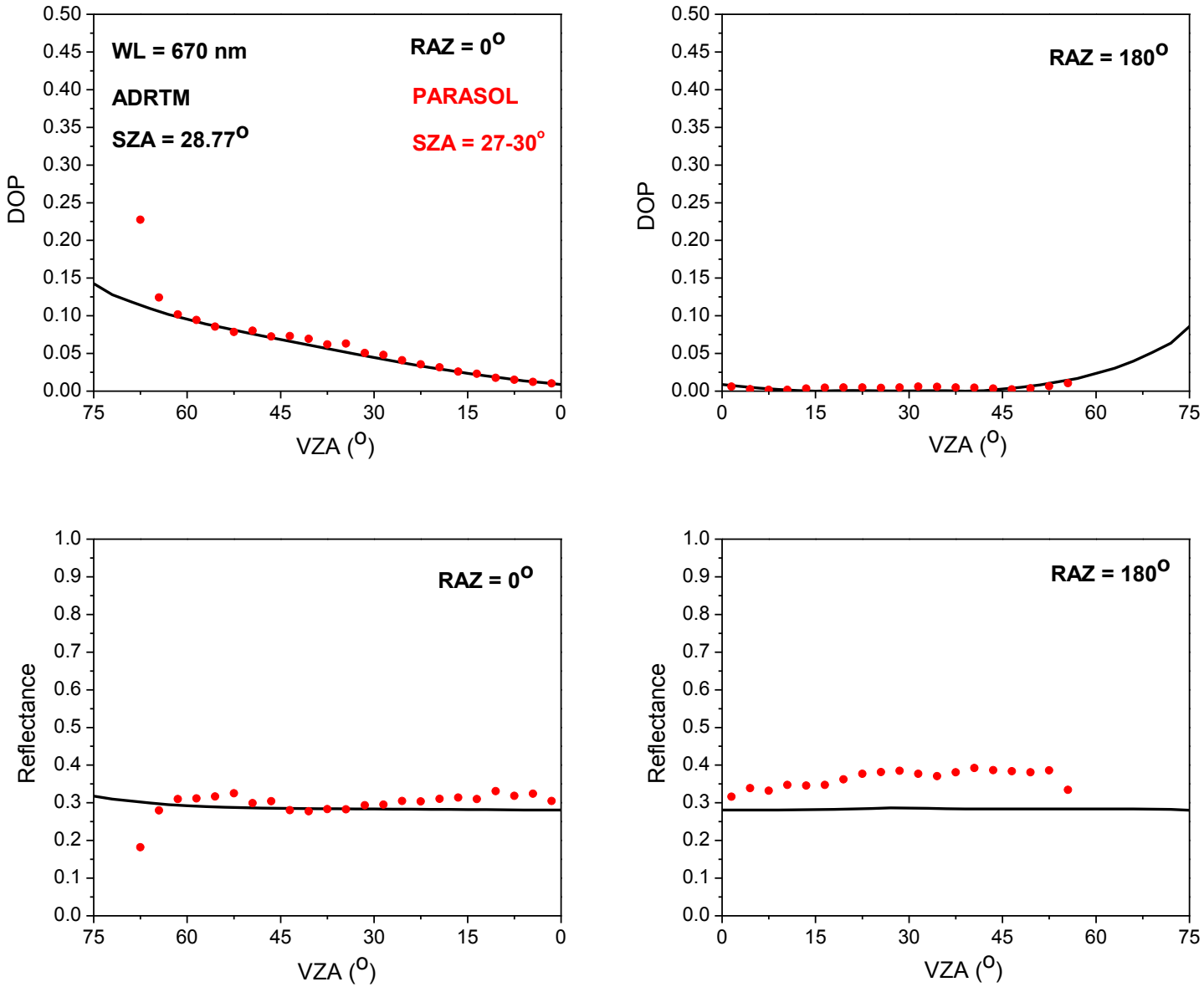
Comparing model results with satellite data at a wavelength of 490 nm and a SZA of 56.94 deg

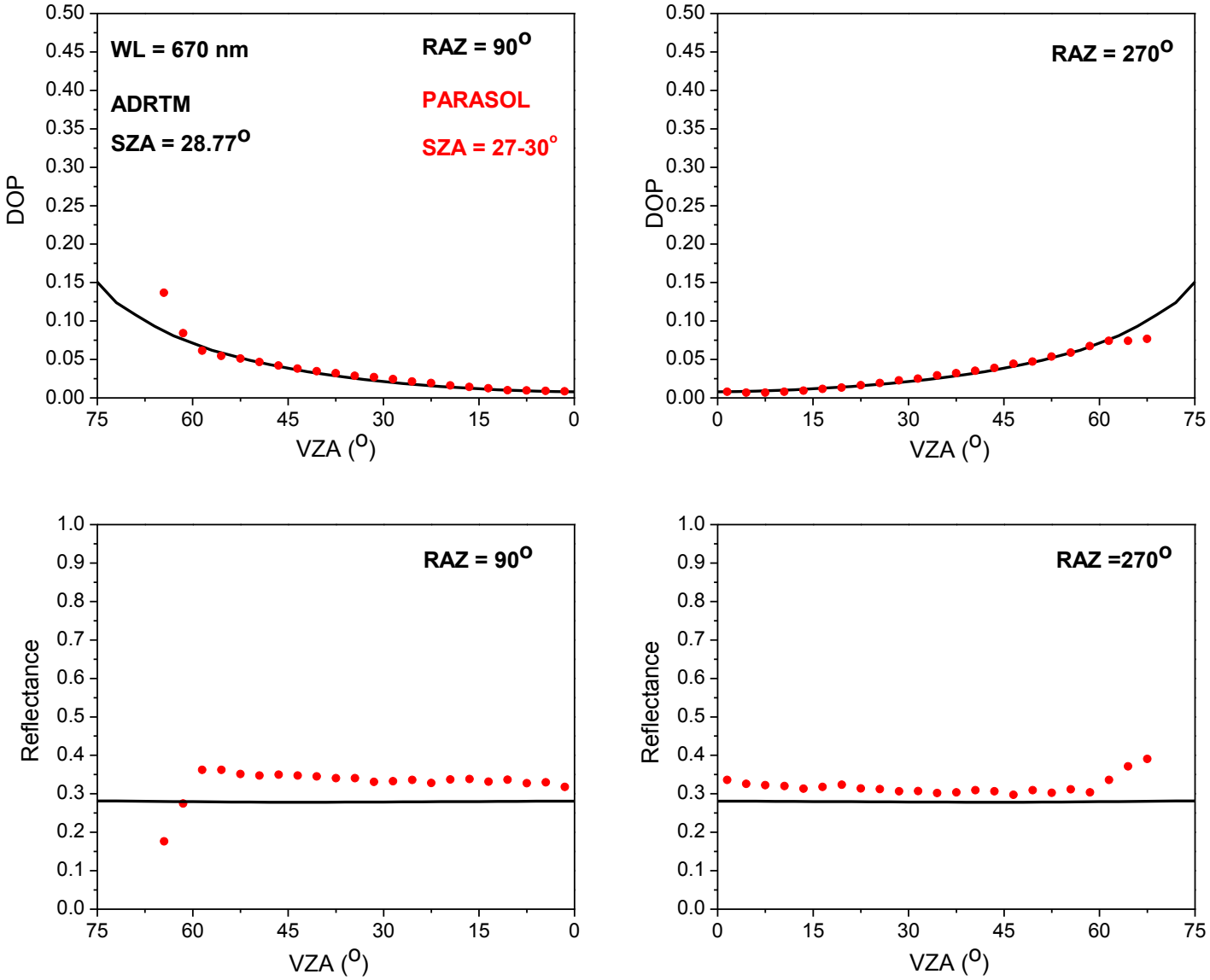


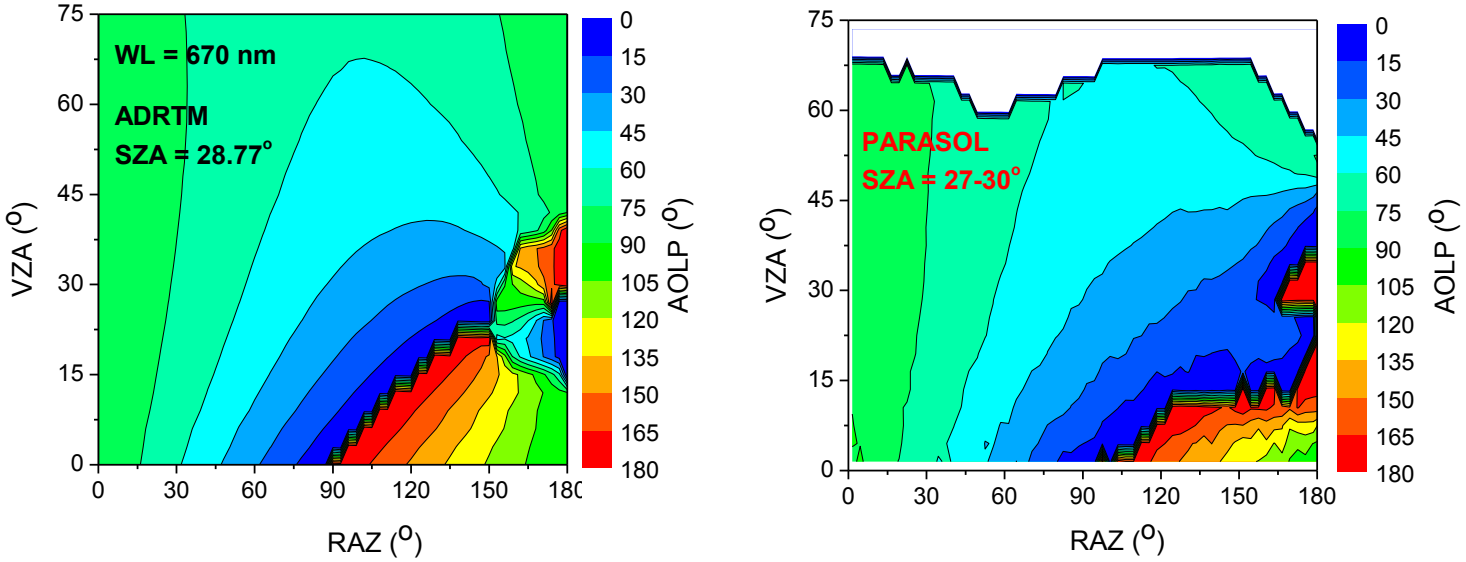

RAZ = 90°
PARASOL
SZA = 54-57°
WL = 490 nm
ADRTM
SZA = 56.94°
DOP
VZA (°)
RAZ = 270°
DOP
VZA (°)
RAZ = 90°
Reflectance
VZA (°)
RAZ = 270°
Reflectance
VZA (°)


WL = 490 nm
ADRTM
SZA = 56.94°
PARASOL
SZA = 54-57°
VZA (°)
RAZ (°)
AOLP (°)
0
15
30
45
60
75
90
105
120
135
150
165
180

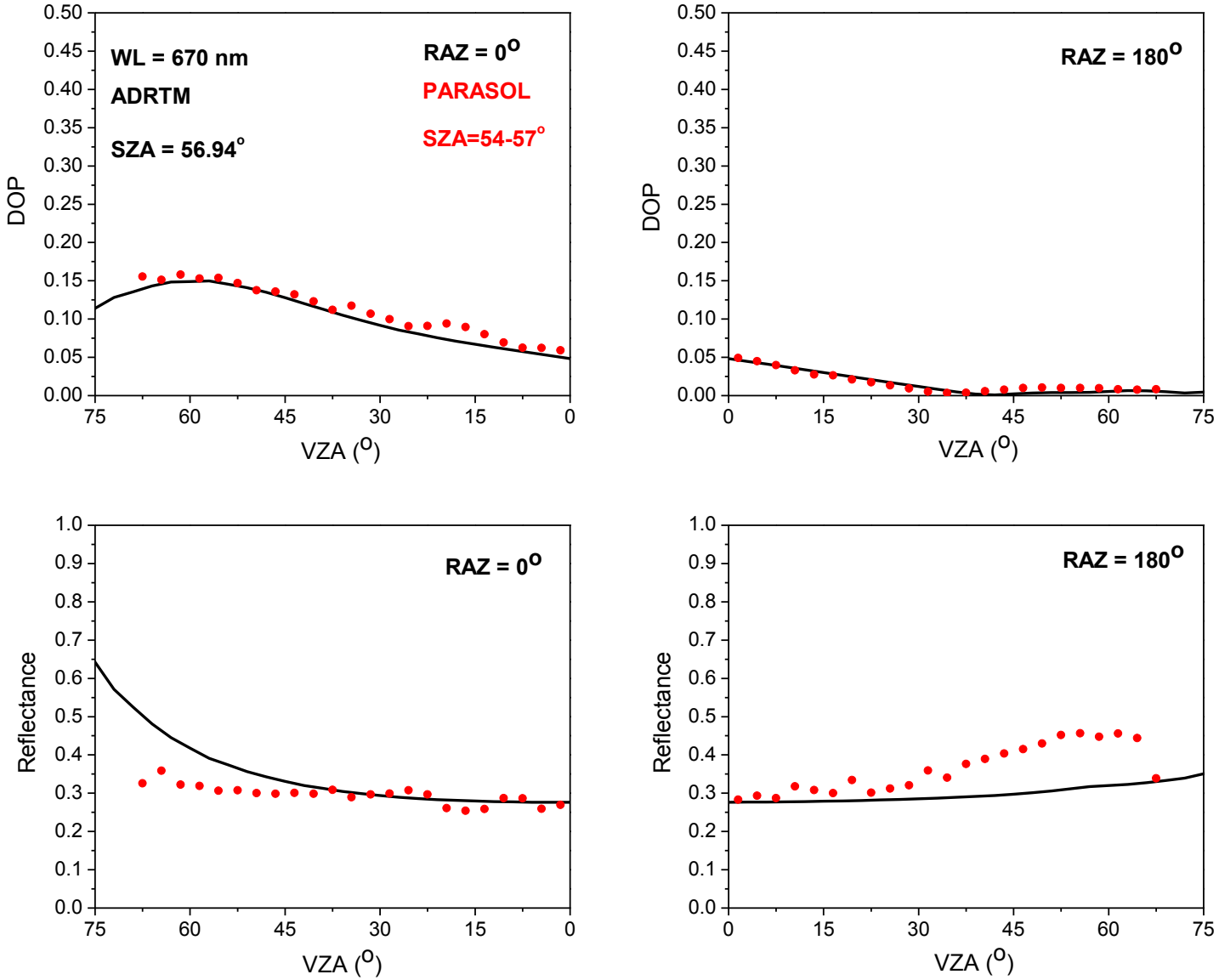
Comparing model results with satellite data at a wavelength of 670 nm and a SZA of 28.77 deg

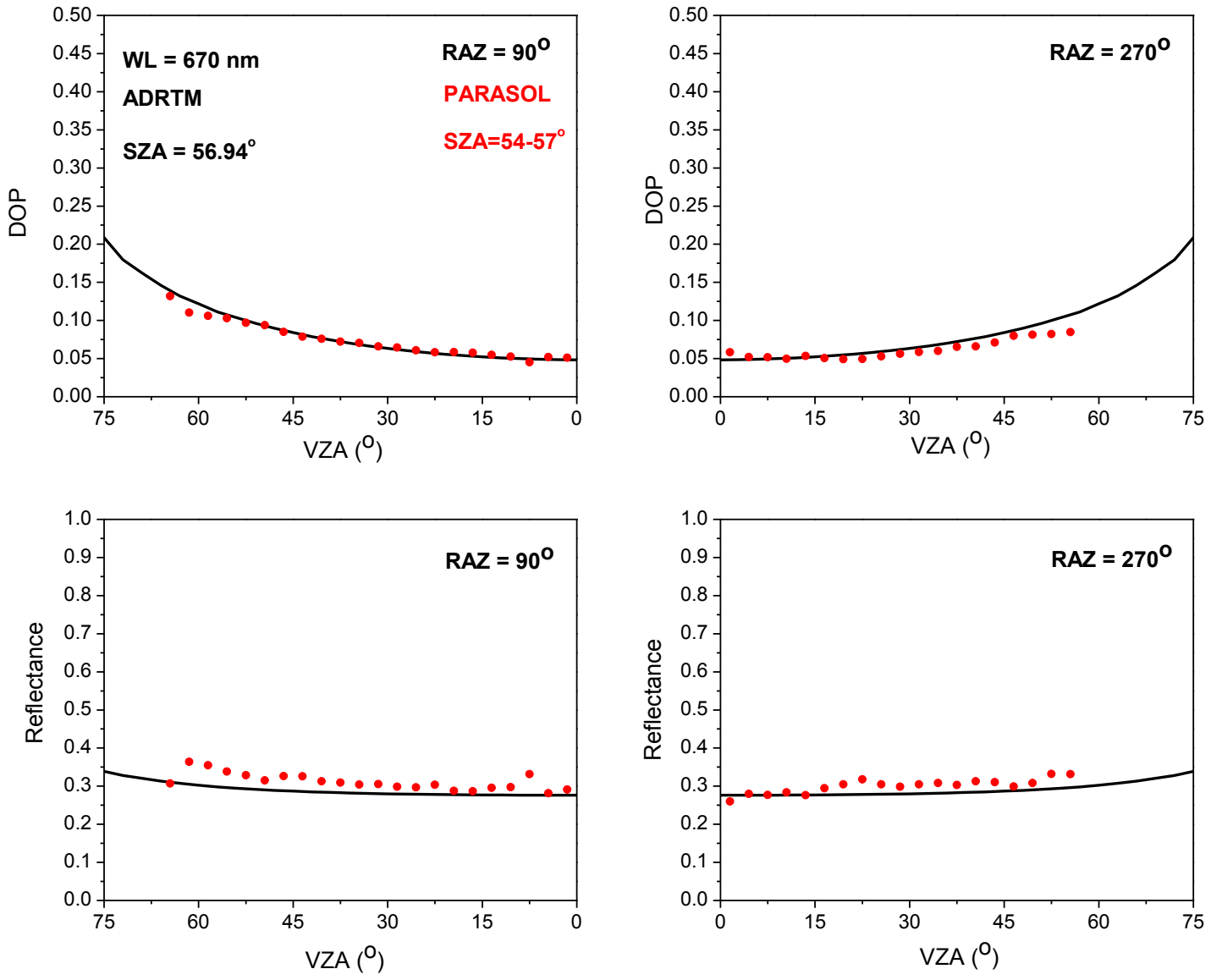


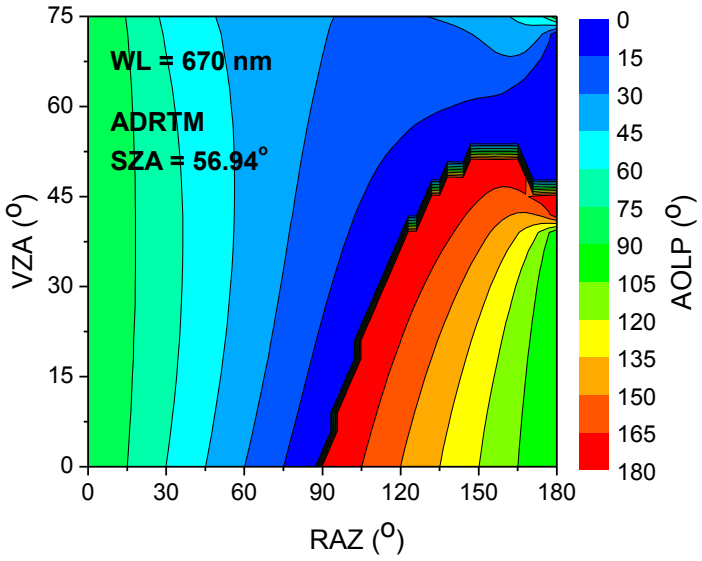

WL = 670 nm
ADRTM
SZA = 28.77°
RAZ = 90°
PARASOL
SZA = 27-30°
DOP
VZA (°)
RAZ = 270°
DOP
VZA (°)
RAZ = 90°
Reflectance
VZA (°)
RAZ =270°
Reflectance
VZA (°)

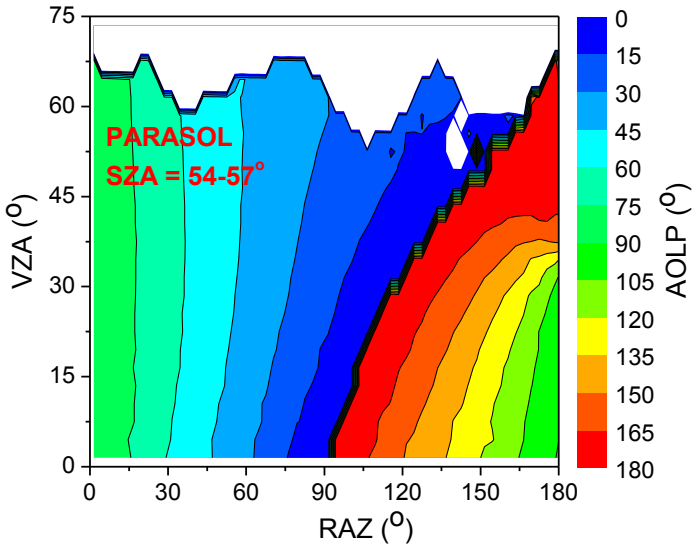

WL = 670 nm
ADRTM
SZA = 28.77°
VZA (°)
RAZ (°)
AOLP (°)
0
15
30
45
60
75
90
105
120
135
150
165
180
PARASOL
SZA = 27-30°

Comparing model results with satellite data at a wavelength of 670 nm and a SZA of 56.94 deg

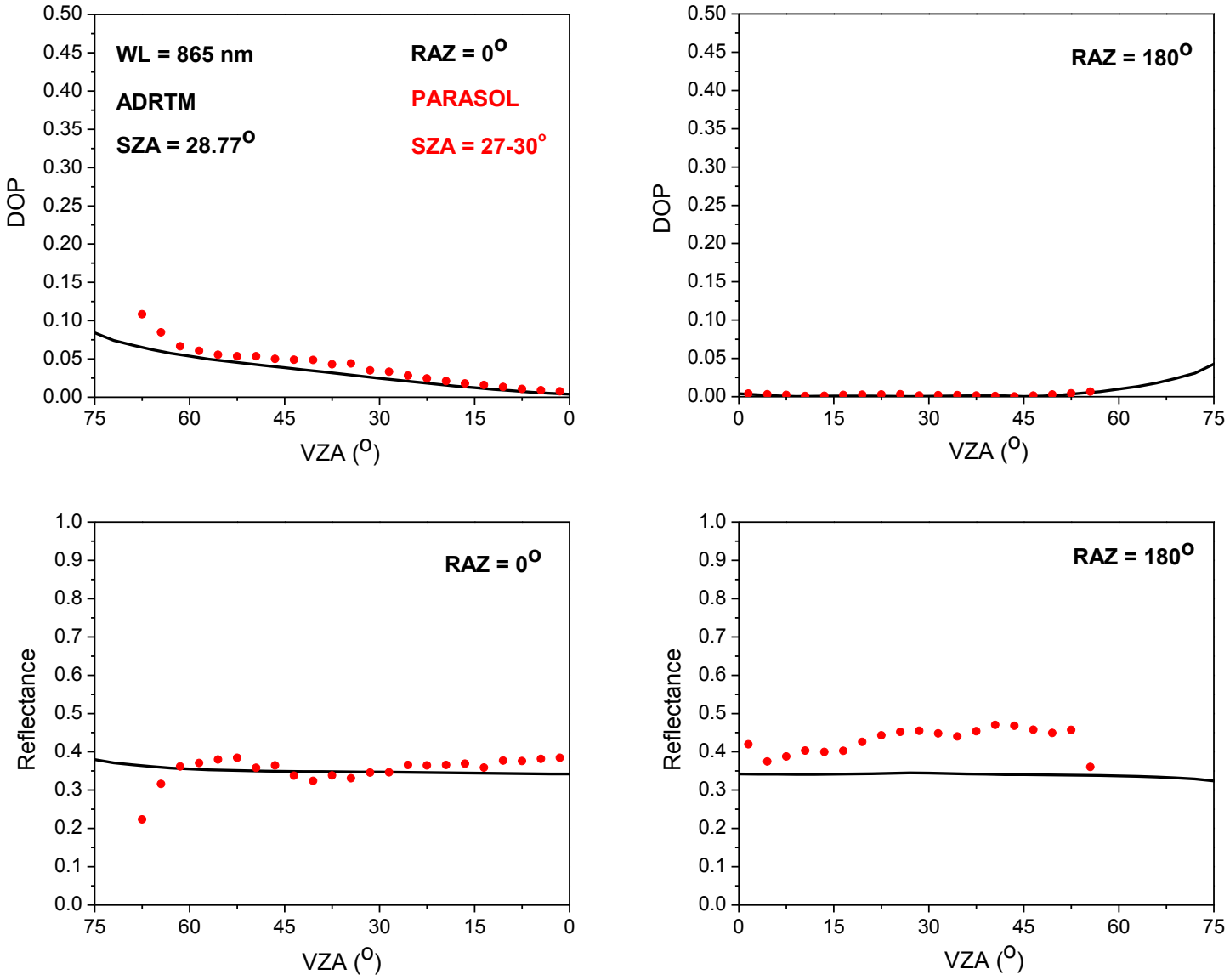


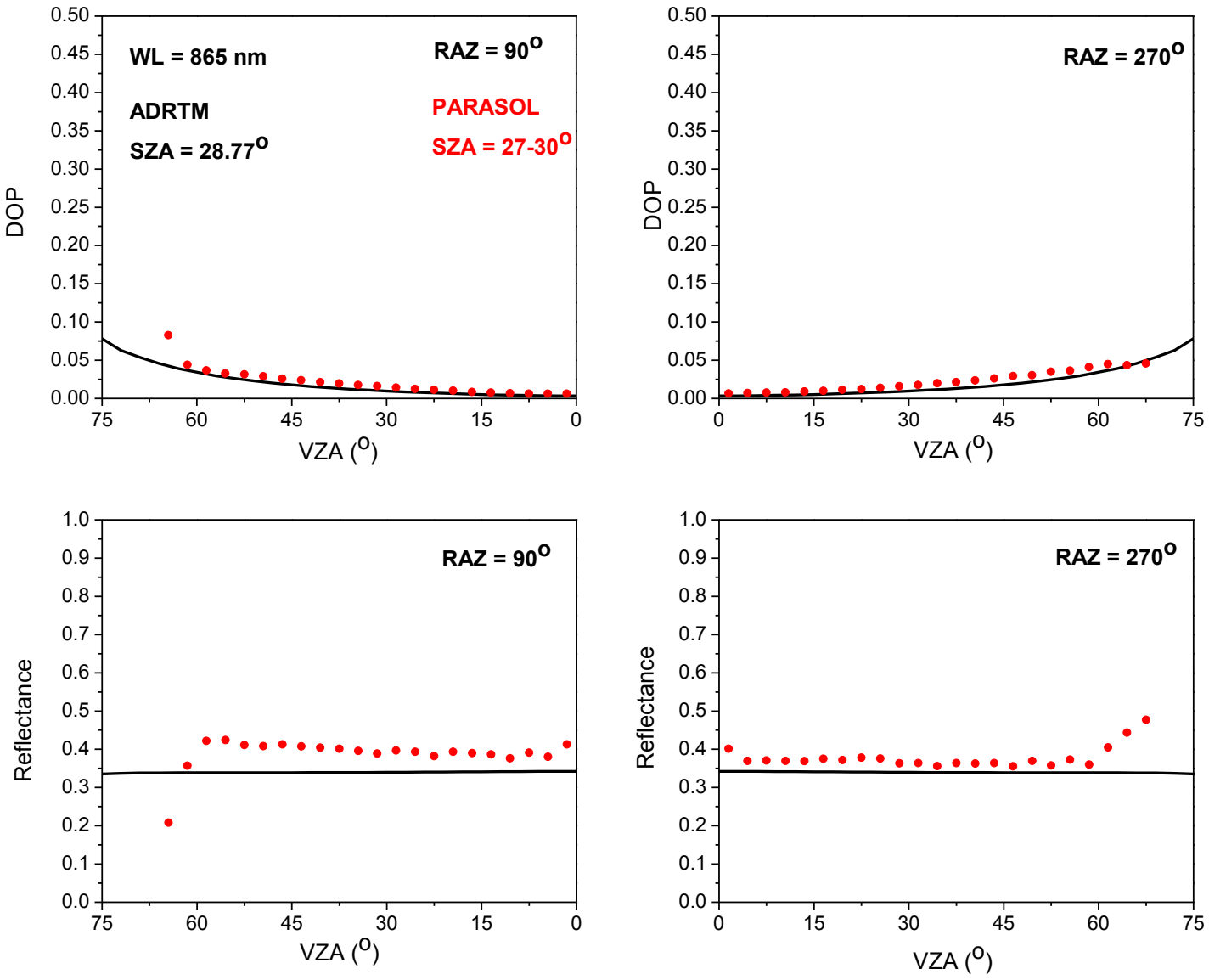

WL = 670 nm
ADRTM
SZA = 56.94°
RAZ = 90°
PARASOL
SZA=54-57°
DOP
VZA (°)
RAZ = 270°
Reflectance

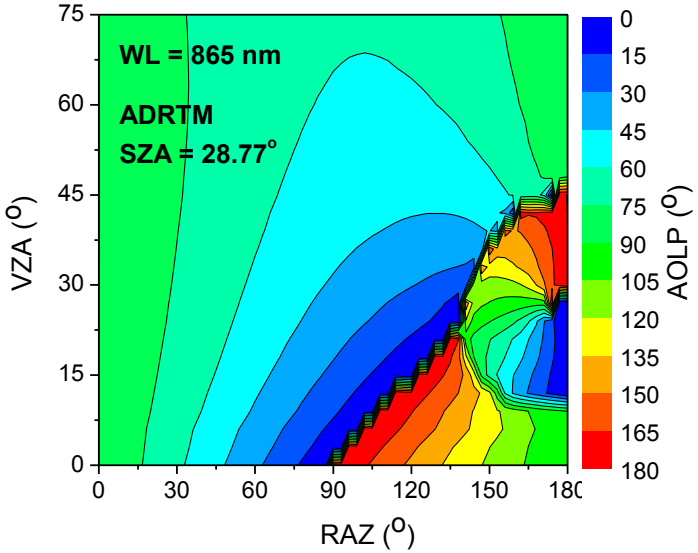

WL = 670 nm
ADRTM
SZA = 56.94°
VZA (°)
RAZ (°)
AOLP (°)
0
15
30
45
60
75
90
105
120
135
150
165
180

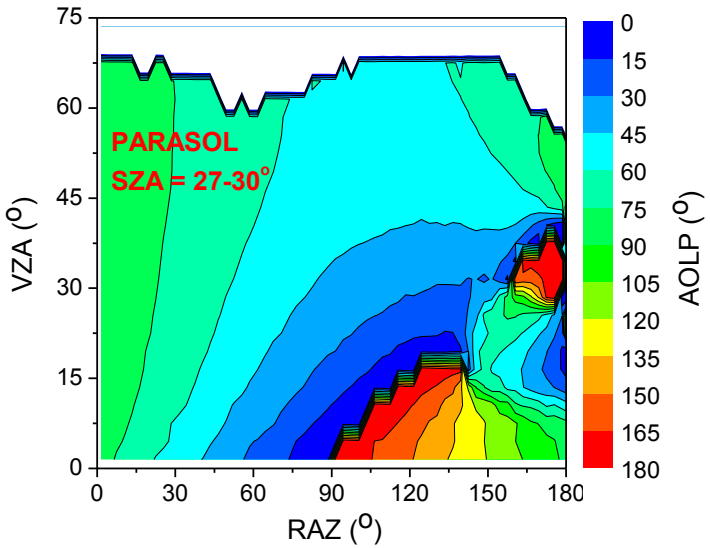

PARASOL
SZA = 54-57°
VZA (°)
RAZ (°)
AOLP (°)
0
15
30
45
60
75
90
105
120
135
150
165
180

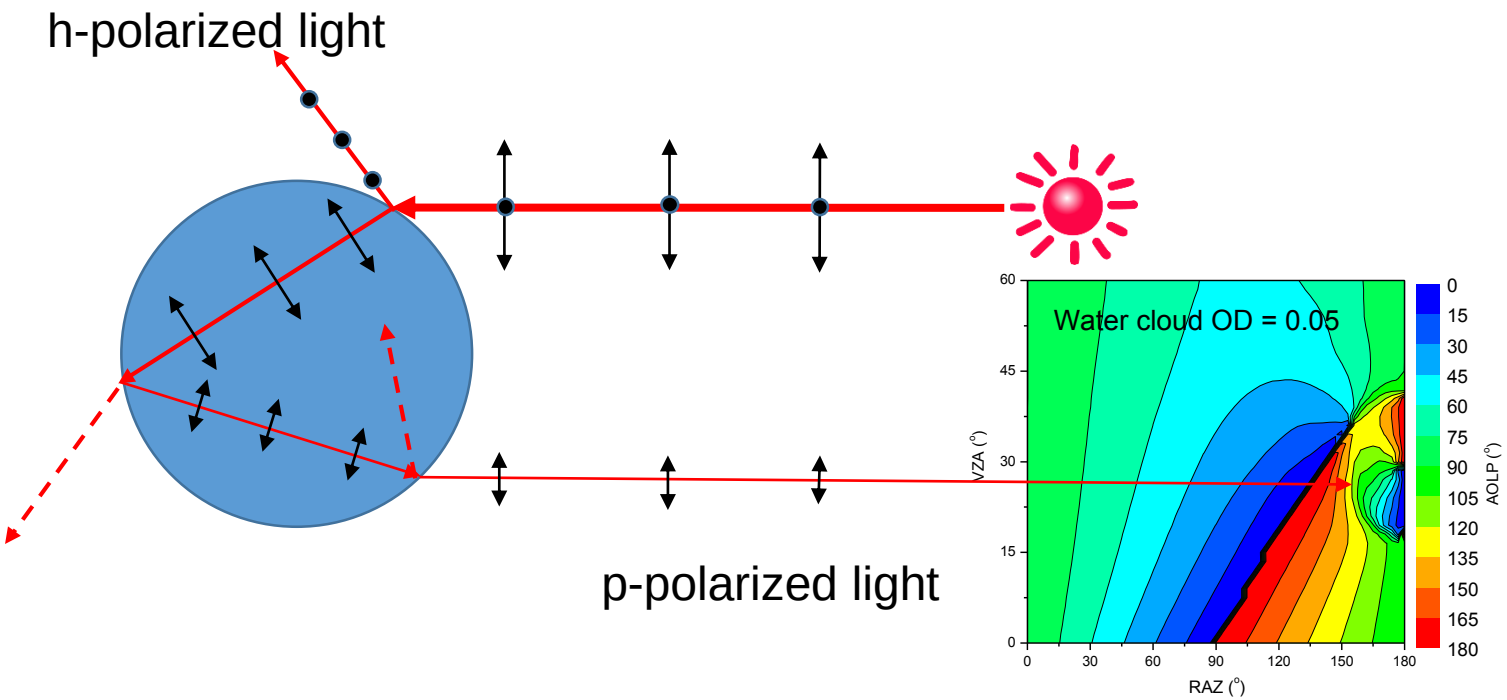
Comparing model results with satellite data at a wavelength of 865 nm and a SZA of 28.77 deg



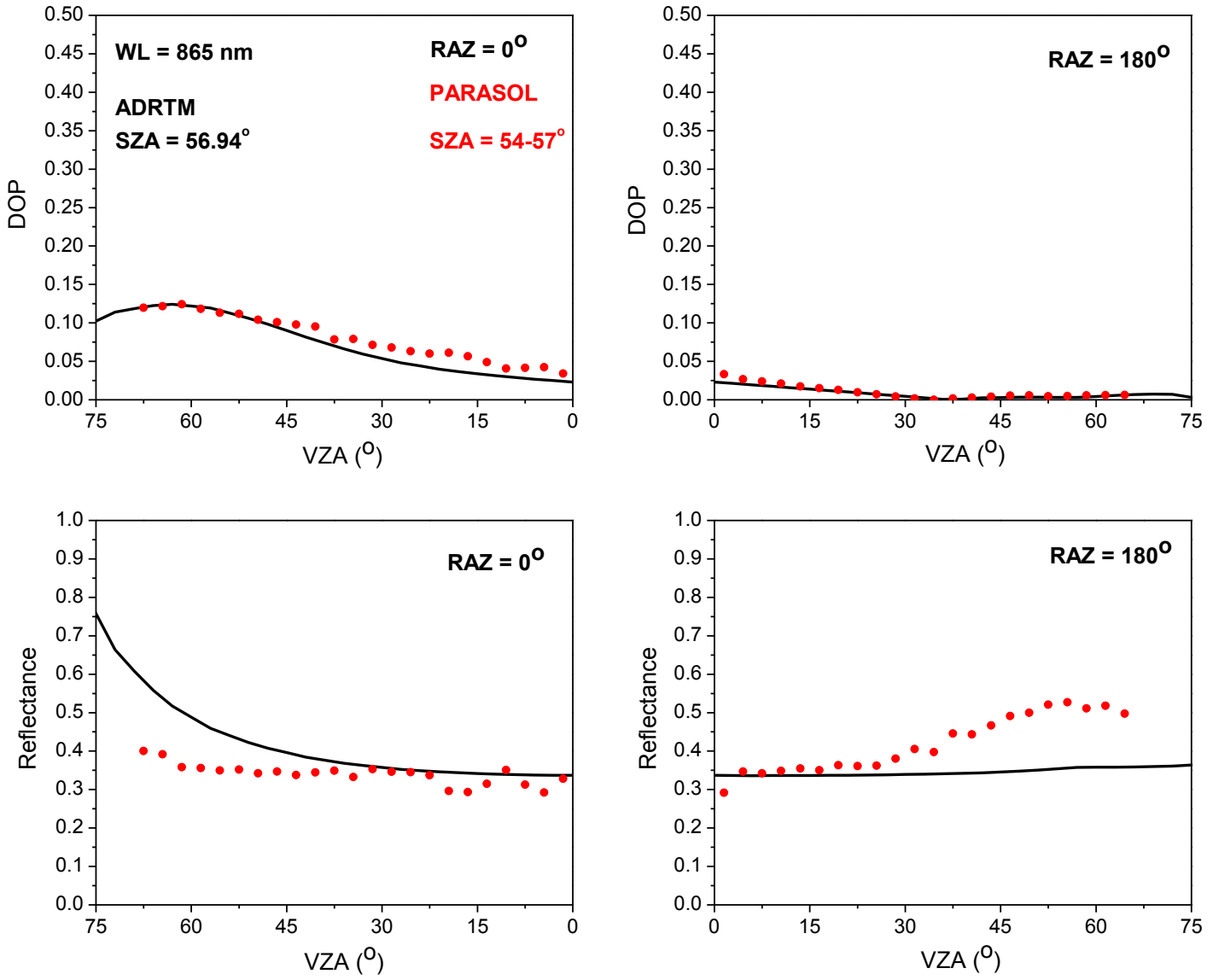

WL = 865 nm
ADRTM
SZA = 28.77°
RAZ = 90°
PARASOL
SZA = 27-30°
DOP
VZA (°)
RAZ = 270°
Reflectance

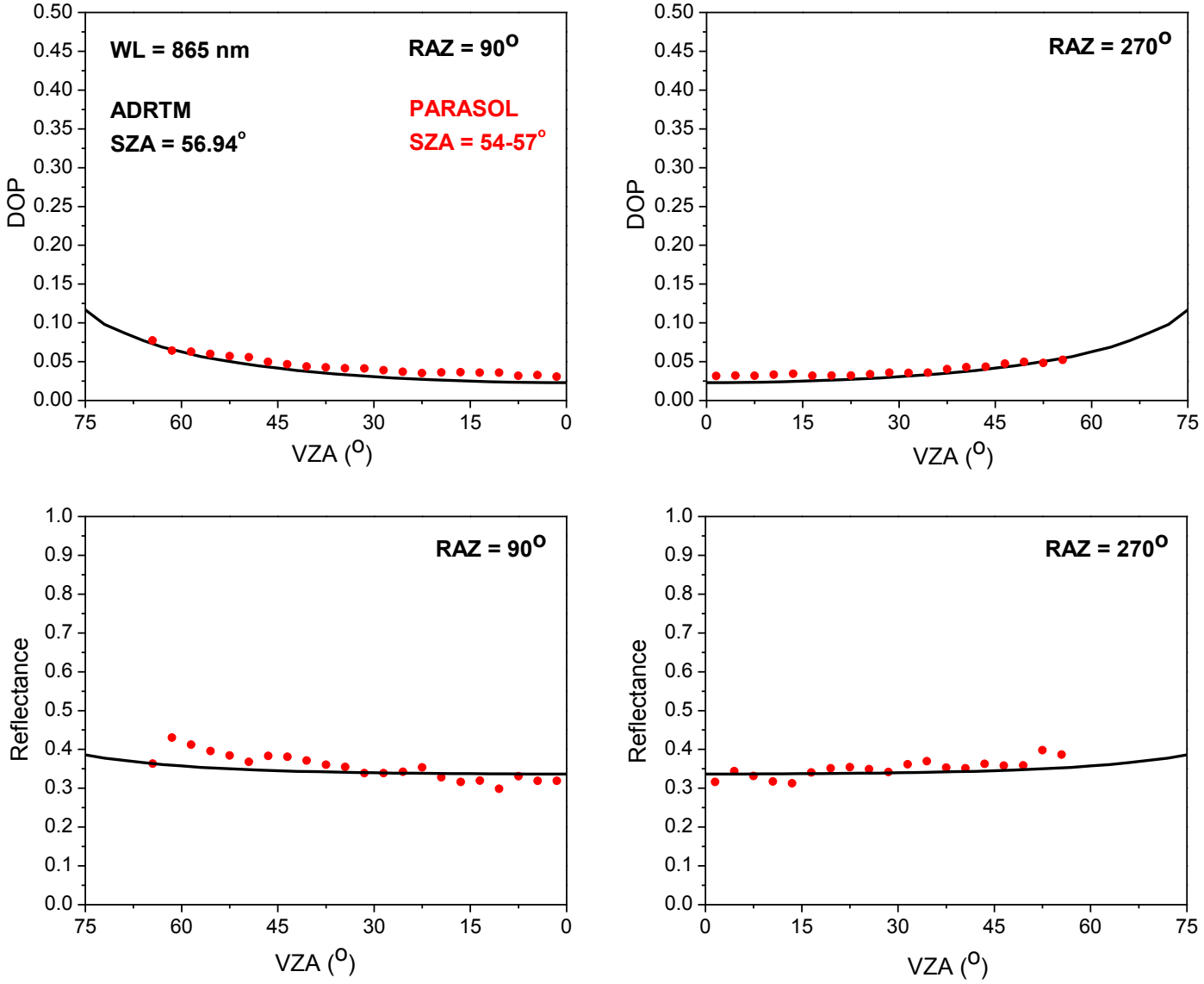

WL = 865 nm
ADRTM
SZA = 28.77°
VZA (°)
RAZ (°)
AOLP (°)

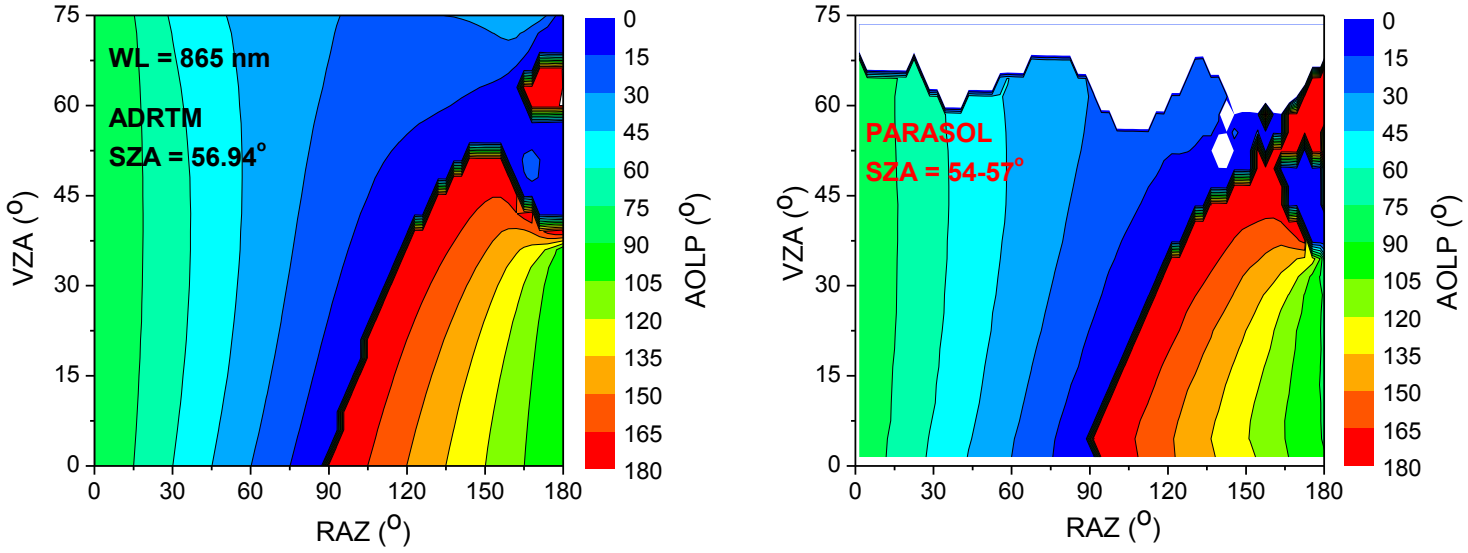

PARASOL
SZA = 27-30°
VZA (°)
RAZ (°)
AOLP (°)


h-polarized light
p-polarized light
Water cloud OD = 0.05
VZA (°)
RAZ (°)
AOLP (°)

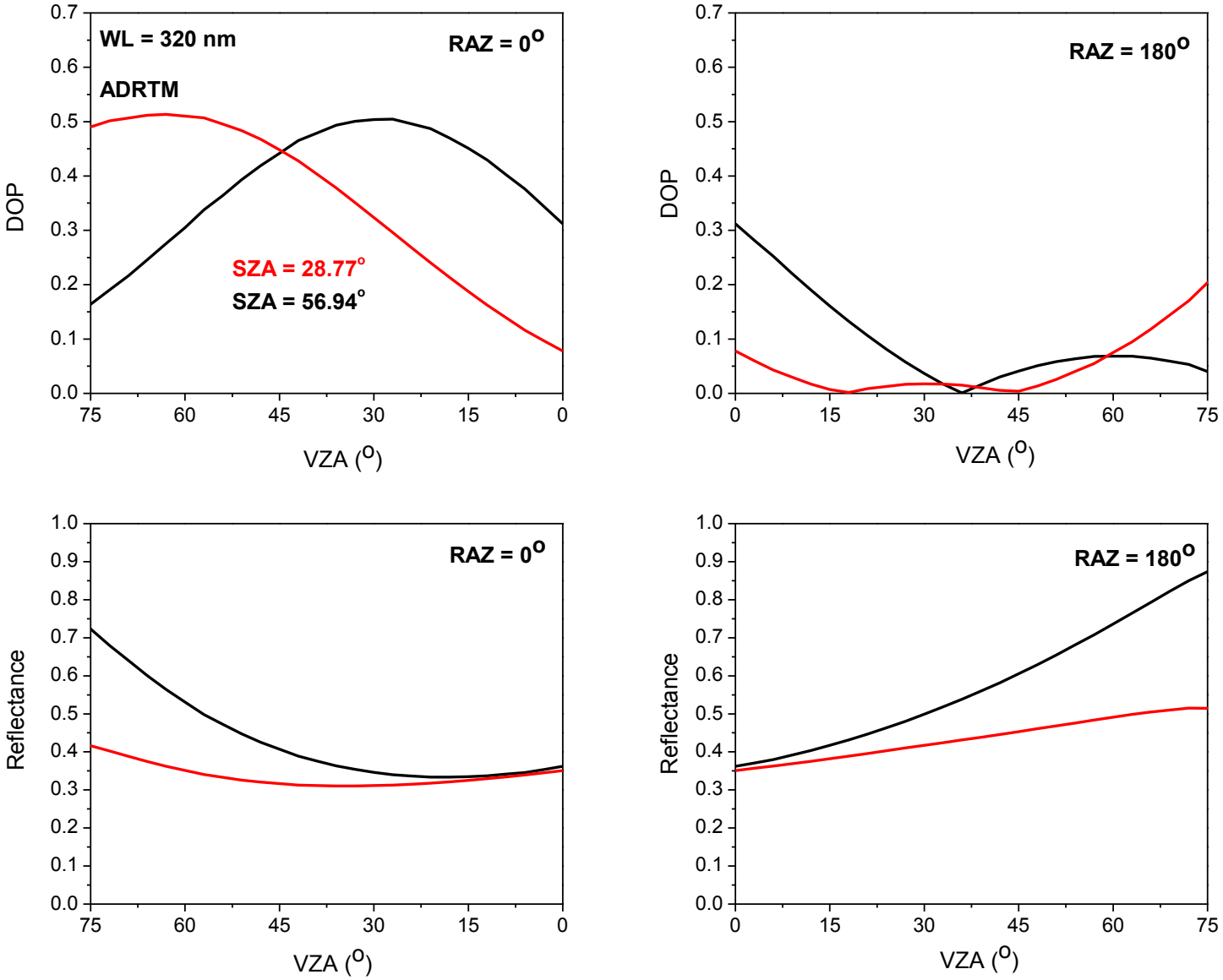
Comparing model results with satellite data at a wavelength of 865 nm and a SZA of 56.94 deg

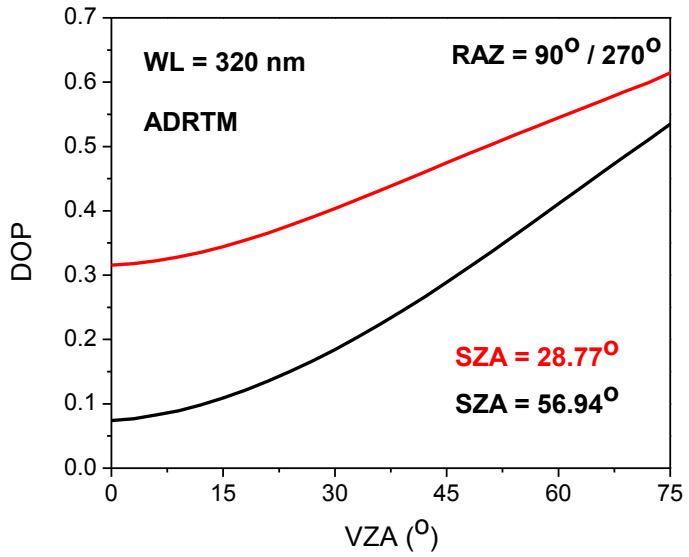


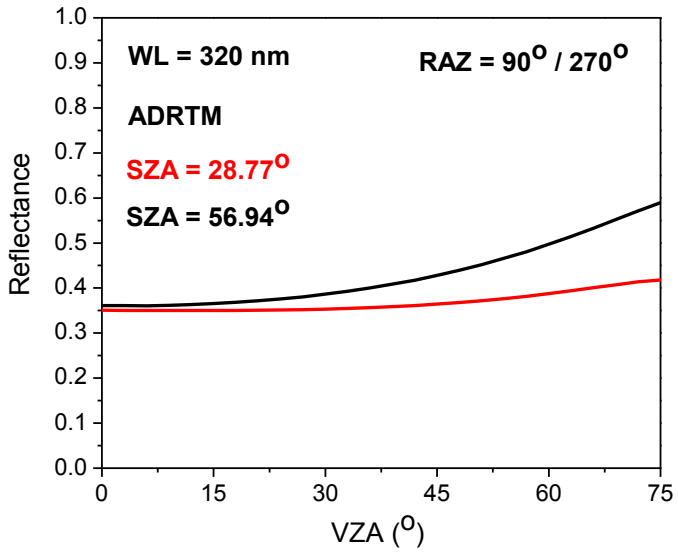

WL = 865 nm
ADRTM
SZA = 56.94°
RAZ = 90°
PARASOL
SZA = 54-57°
DOP
VZA (°)
RAZ = 270°
Reflectance

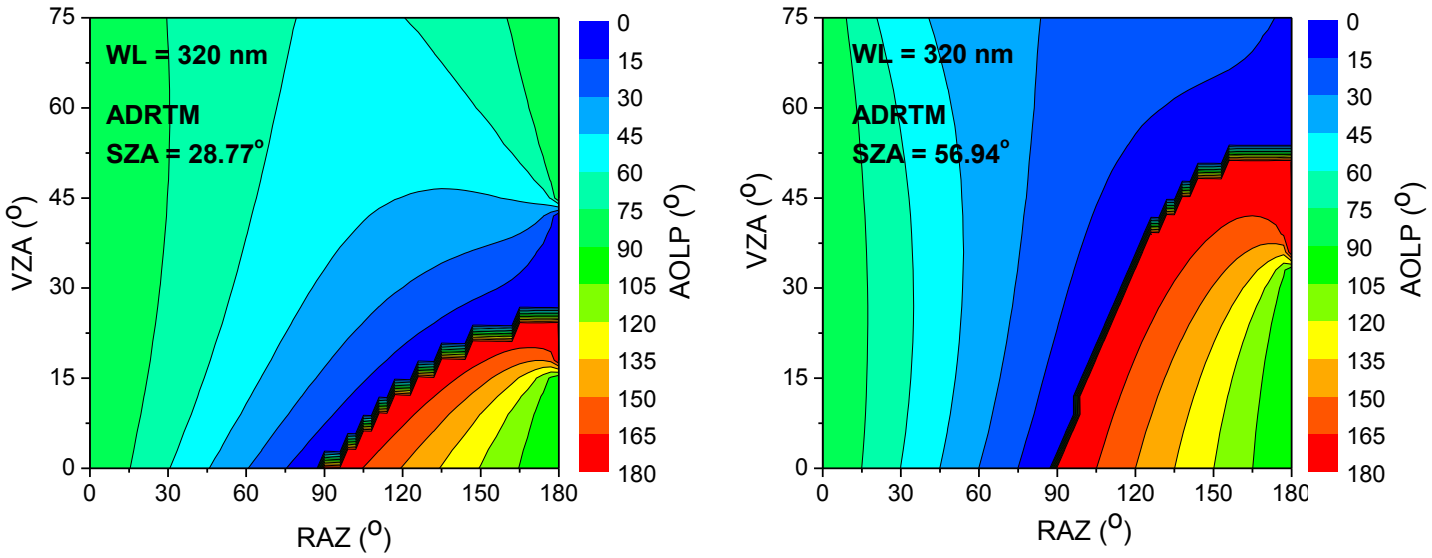

WL = 865 nm
ADRTM
SZA = 56.94°
VZA (°)
RAZ (°)
AOLP (°)
0
15
30
45
60
75
90
105
120
135
150
165
180
PARASOL
SZA = 54-57°

Model results at a wavelength of 320 nm

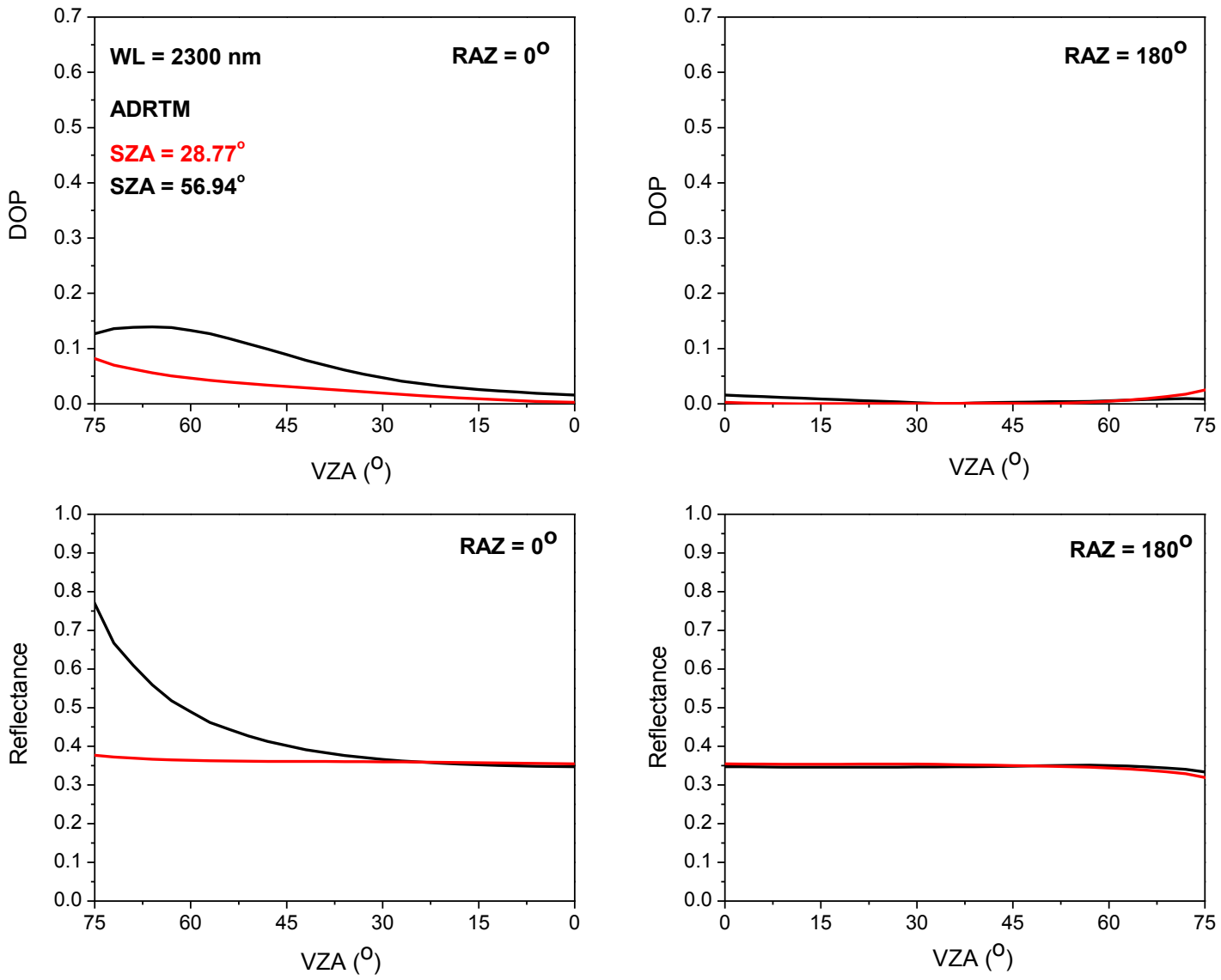


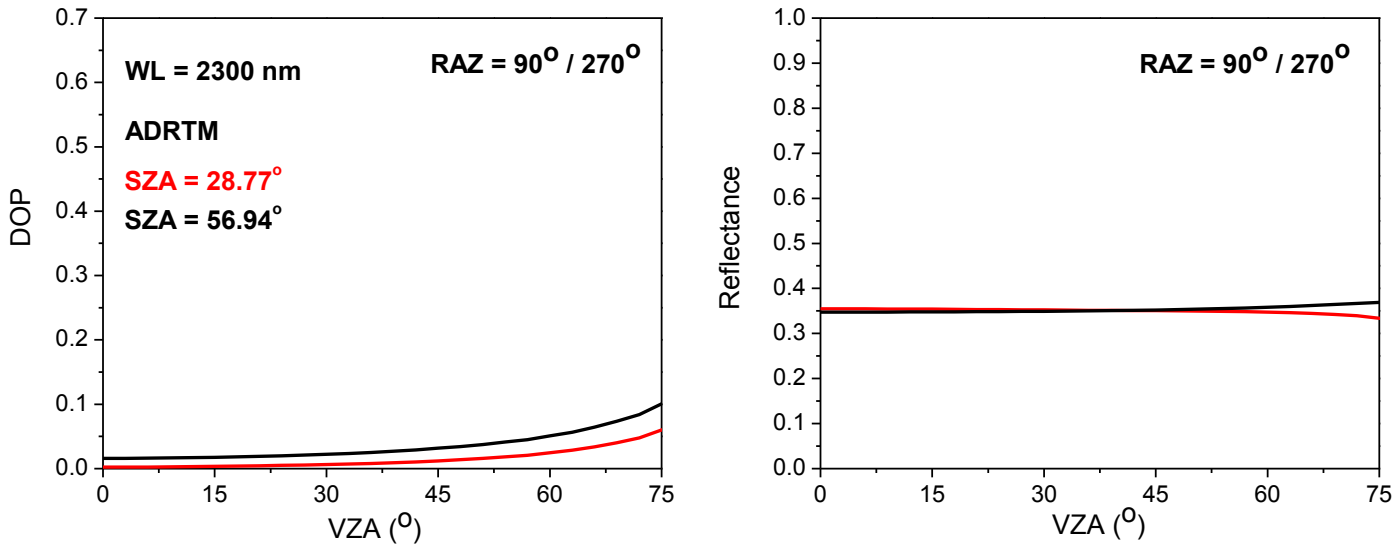

WL = 320 nm
ADRTM
RAZ = 90° / 270°
SZA = 28.77^{O}
SZA = 56.94^{O}
DOP
VZA (^{O})
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
15
30
45
60
75

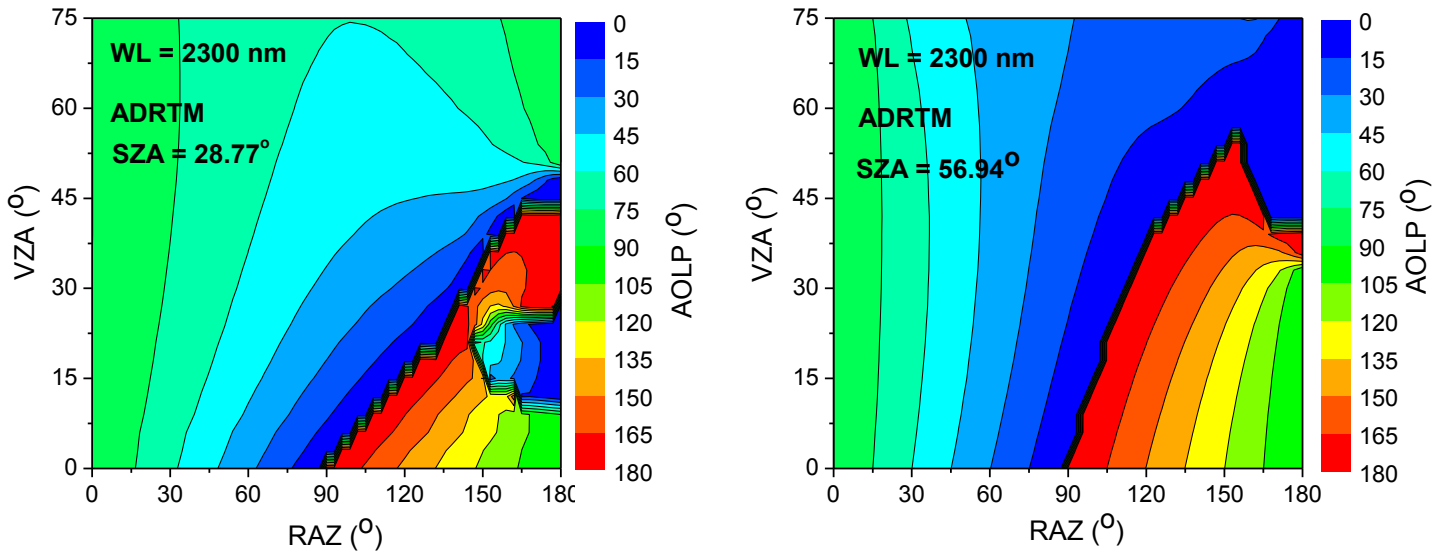

WL = 320 nm
ADRTM
RAZ = 90° / 270°
SZA = 28.77^{O}
SZA = 56.94^{O}
Reflectance
VZA (^{O})
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
15
30
45
60
75


WL = 320 nm
ADRTM
SZA = 28.77°
VZA (°)
RAZ (°)
AOLP (°)
0
15
30
45
60
75
90
105
120
135
150
165
180
WL = 320 nm
ADRTM
SZA = 56.94°
VZA (°)
RAZ (°)
AOLP (°)

Model results at a wavelength of 2300 nm




WL = 2300 nm
ADRTM
SZA = 28.77°
SZA = 56.94°
RAZ = 90° / 270°
DOP
VZA (°)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
15
30
45
60
75
RAZ = 90° / 270°
Reflectance
VZA (°)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
15
30
45
60
75


WL = 2300 nm
ADRTM
SZA = 28.77°
VZA (°)
RAZ (°)
AOLP (°)
0
15
30
45
60
75
90
105
120
135
150
165
180
WL = 2300 nm
ADRTM
SZA = 56.94°
VZA (°)
RAZ (°)
AOLP (°)

Next: Snow/Ice Land

Using the same algorithm as for desert, we may derive the polarization properties of light reflected by snow/ice land with PARASOL measurements and solar spectral reflectance from other sources …

Solar spectral reflectance in this process can be updated by the CLARREO data in the future.

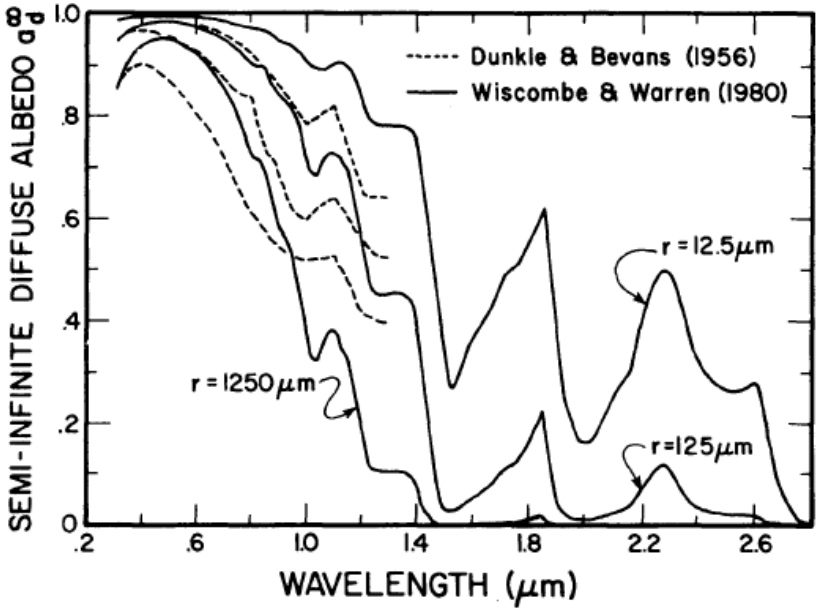
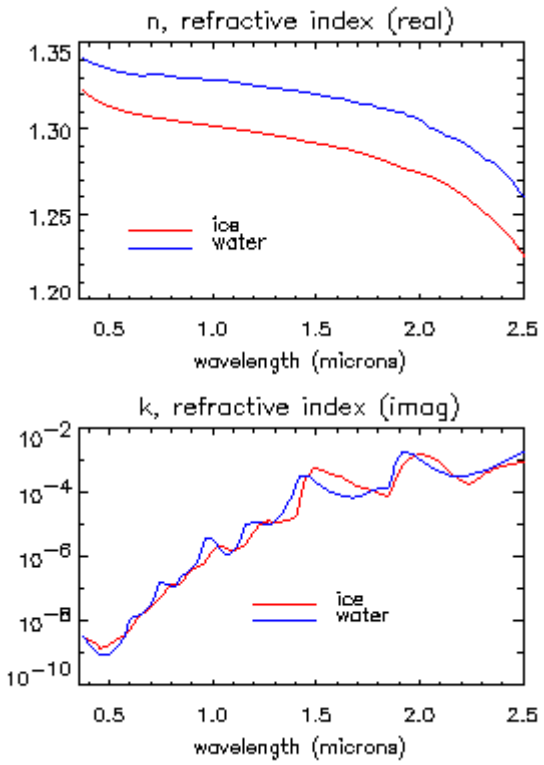


Fig. 1. Model calculations of semi-infinite diffuse albedo as a function of wavelength for various snow grain radii. Dashed lines are calculations by *Dunkle and Bevans* [1956, Figure 3]. Solid lines are calculations using the model of WWI, with the new m_{im} (λ) measured by *Grenfell and Perovich* [1981].

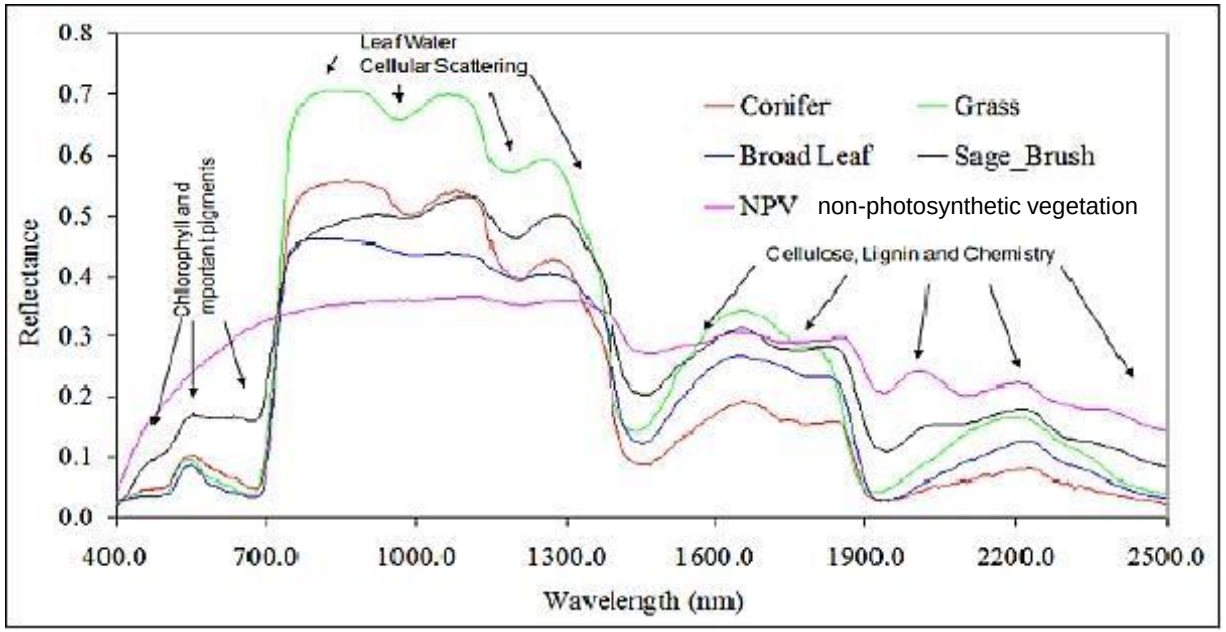


Refractive index of ice

Next after Next: Vegetation Land

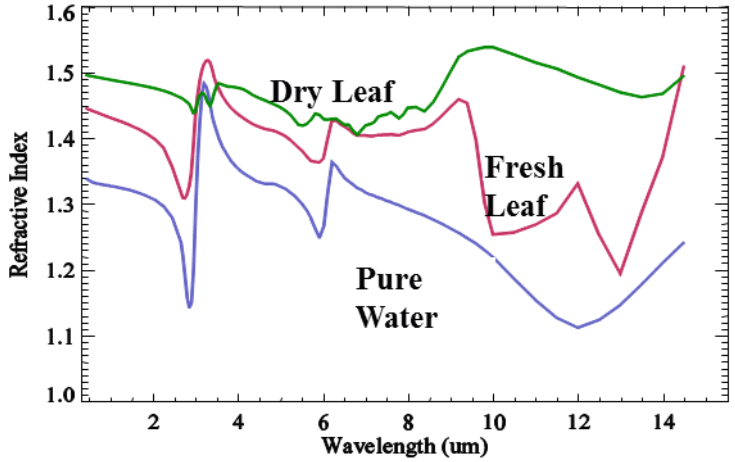
Using the same algorithm as for desert, we may derive the polarization properties of light reflected by vegetation land with PARASOL measurements and solar spectral reflectance from other sources …

Solar spectral reflectance in this process can be updated by the CLARREO data in the future.



A set of rock forming minerals and vegetation reflectance spectral measured from 400 to 2500 nm in the solar reflected light spectrum (NASA/JPL AVIRIS)

Broad leaf DOP can be ~70% for Wavelength < 865 nm



Leaf refractive index by Variational Kramers-kronig Analysis (Chen and Weng, 2012)

Summary

1. **An algorithm for deriving spectral polarization state of sunlight from desert is developed.**
2. **PARASOL data at 3 polarized channels are used in estimating desert surface physical properties.**
3. **Using the physical properties of desert surface, polarization state of radiation from desert at any solar wavelength and incident and viewing geometries can be obtained with the ADRTM.**
4. **~80% of the Earth surface (Ocean and Desert) polarization spectra can be modeled now.**
5. **Modeling for the polarization state of solar radiation from snow/ice and vegetation surface is under study.**

Reference:

Wenbo Sun, Rosemary R. Baize, Constantine Lukashin, and Yongxiang Hu, “Deriving Polarization Properties of Desert-Reflected Solar Spectra with PARASOL Data”, Atmos. Chem. Phys. (Submitted)