Spectral polarization distribution models (PDMs) for NASA CLARREO Pathfinder's inter-calibration applications

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- **Empirical Polarization Distribution Models (PDMs) based on PARASOL data**
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Introduction

1. Climatology requires highly accurate solar radiation data for climate trend.

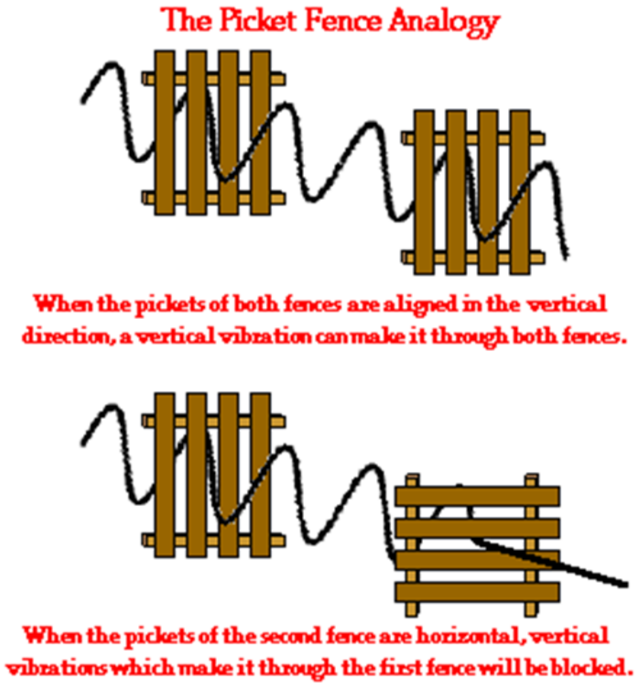
2. Solar radiation from the Earth is polarized by Earth-atmosphere system during reflection and scattering.

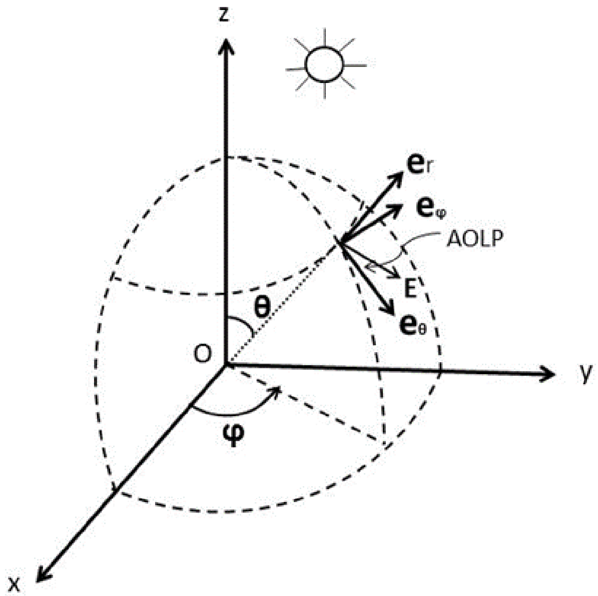
3. Many satellite sensors have some polarization dependence. To ensure the accuracy of data, Polarization Distribution Models (PDMs) are needed to correct the polarization-induced error in measurements.

4. Empirical PDMs based on PARASOL data only have 3 channels, cannot be applied to all solar/viewing angles and other wavelengths.

5. PDMs, based on RT models checked by measurements, over whole solar spectra and all incidence and viewing geometries are needed for correction of polarization-induced measurement errors.

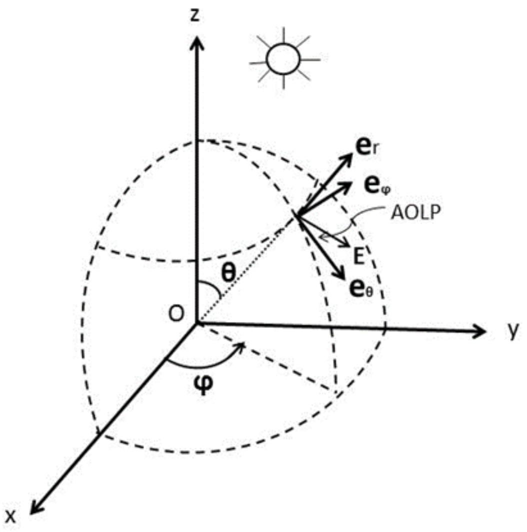
Sensors with polarization dependence have errors in their measurements due to the polarization of incidence.





Any arbitrarily polarized incoherent radiation can be represented by the linear sum of an unpolarized part and a 100% polarized part as

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} I - \sqrt{Q^2 + U^2 + V^2} \\ 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} \sqrt{Q^2 + U^2 + V^2} \\ Q \\ U \\ V \end{bmatrix}$$



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

$$I_{unpol} = I - \sqrt{Q^2 + U^2 + V^2} = (1 - DOP) \cdot I$$

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

$$\tan(2\psi) = \frac{U}{Q}$$

Correction of radiance measurement errors caused by polarization

Correction of polarization error in intensity is done as

$$I = \frac{(C_m / G_0)}{1 + S(AOLP) \cdot DOP}$$

$$S(AOLP) = \left[\frac{G_p(AOLP) - G_0}{G_0} \right]$$

Relative error of measured intensity due to polarization

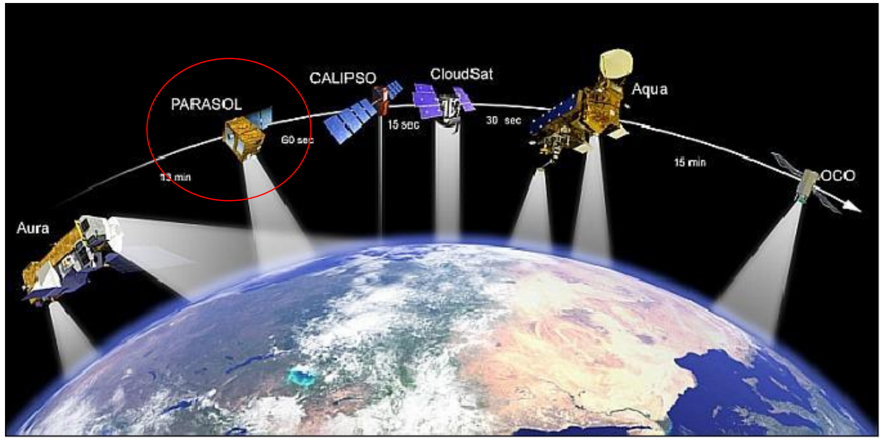
$$RE = \frac{(C_m / G_0) - I}{I} \approx S(AOLP) \cdot DOP$$

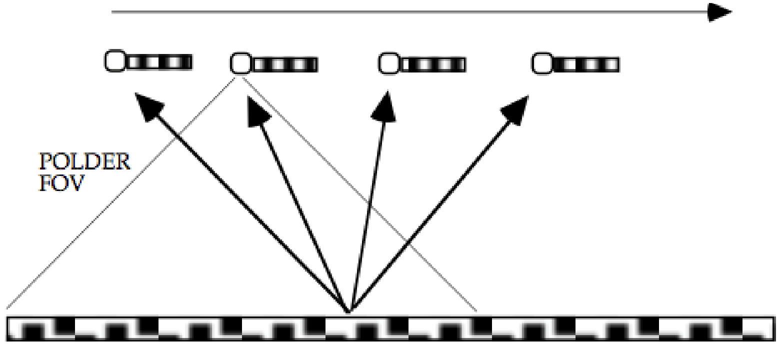
Instruments with 3% of polarization dependence have ~1% uncertainty solely due to a 30% DOP of light!

Empirical Polarization Distribution Models (PDMs) based on PARASOL data

POLDER Overview

- POLDER instrument was flying onboard PARASOL satellite
- Part of A-Train, 705 km altitude
- 9 spectral channels from blue (443 nm) to infrared (1020 nm)
    - 3 polarization bands: 490 nm, 670 nm, 865 nm
- Pixel resolution for Level-1B data: 5.3×6.2 km (at nadir)
- Absolute accuracy: 2-3% [Riédi et al., EarthCare Mtg, 2007][Nadal, Bréon, 1999]
- Up to 14 views per pixel (collected off-line): multi-angular sampling improves PDMs' precision
- Current status: after ~9 years in orbit PARASOL was decommissioned on Dec. 18, 2013



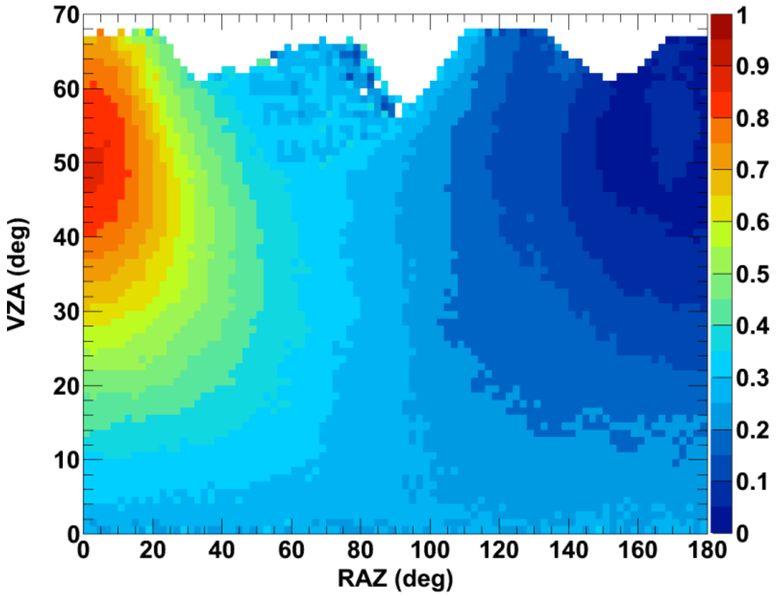


Empirical PDMs

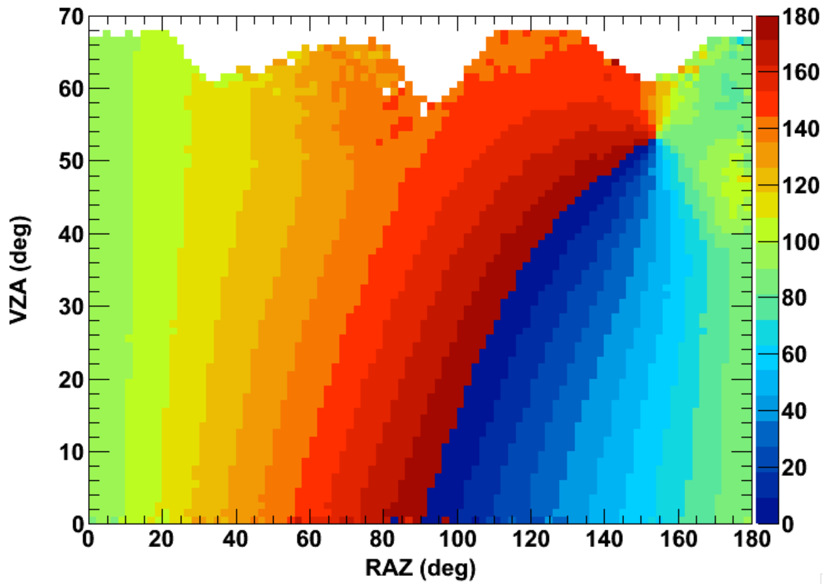
- Use Stokes parameters (I,Q,U) from POLDER's 3 polarization bands
- Empirical PDMs: DOP and AOLP constructed using 2006 POLDER dataset
  - DOP (AOLP) as a function of RAZ and VZA for given SZA range.
  - Stratify PDMs by surface type, scene type (clear/cloudy), aerosol optical depth (AOD) (clear), wind speed (clear), cloud fraction, cloud type, cloud optical depth
  - Use PDM uncertainties to estimate polarization contribution to reflectance

Selection Criteria
All 2006
Ocean
50^o < SZA < 60^o
λ = 865 nm
2 m/s < WindSp. < 10 m/s
0.2 < AOD < 0.3

DOP



AOLP (deg)



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);

FDTD/DDA for 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 for desert/bare land;

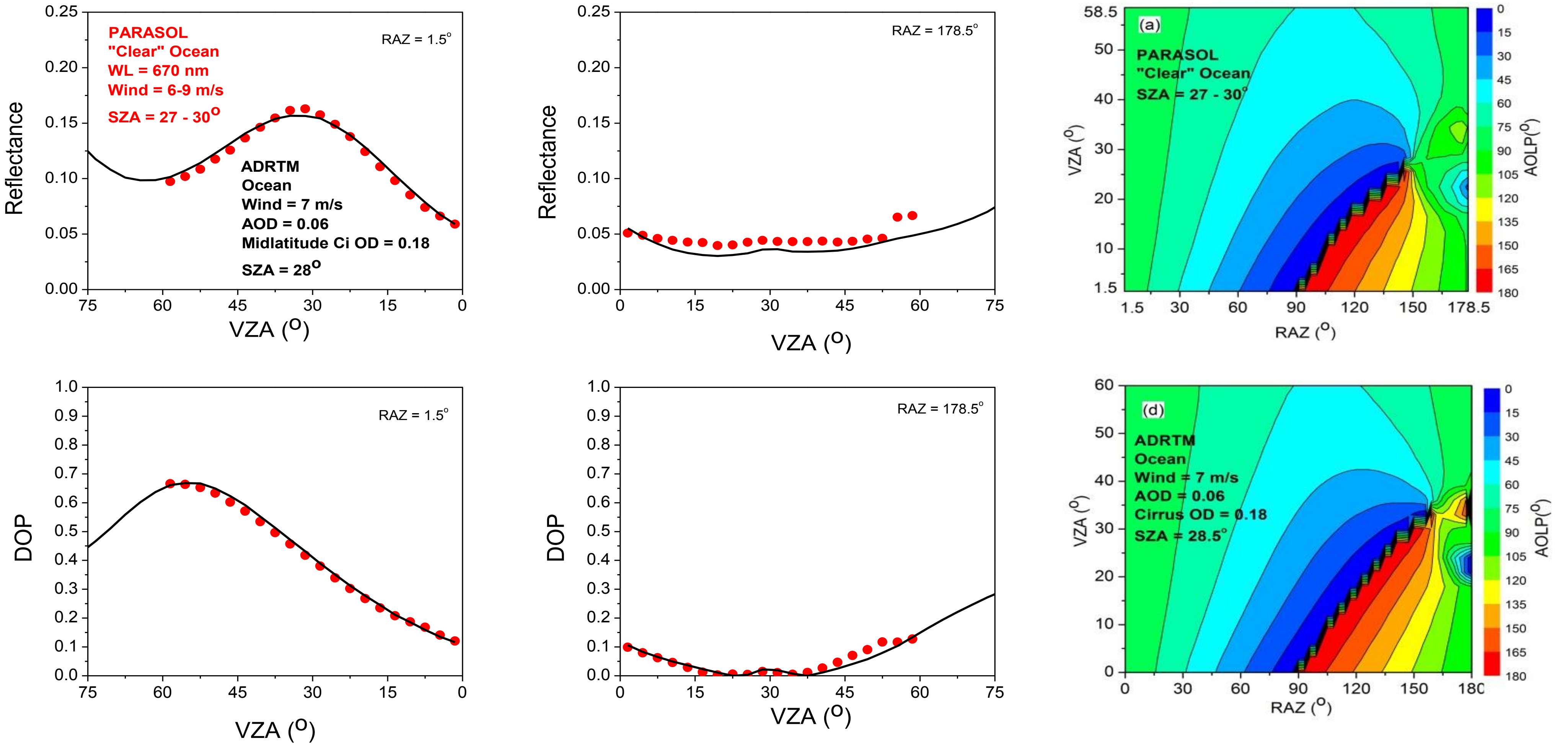
Rough-surface model for evergreen broad-leaf trees and grassland;

Models for other vegetation land and snow surface are under development.

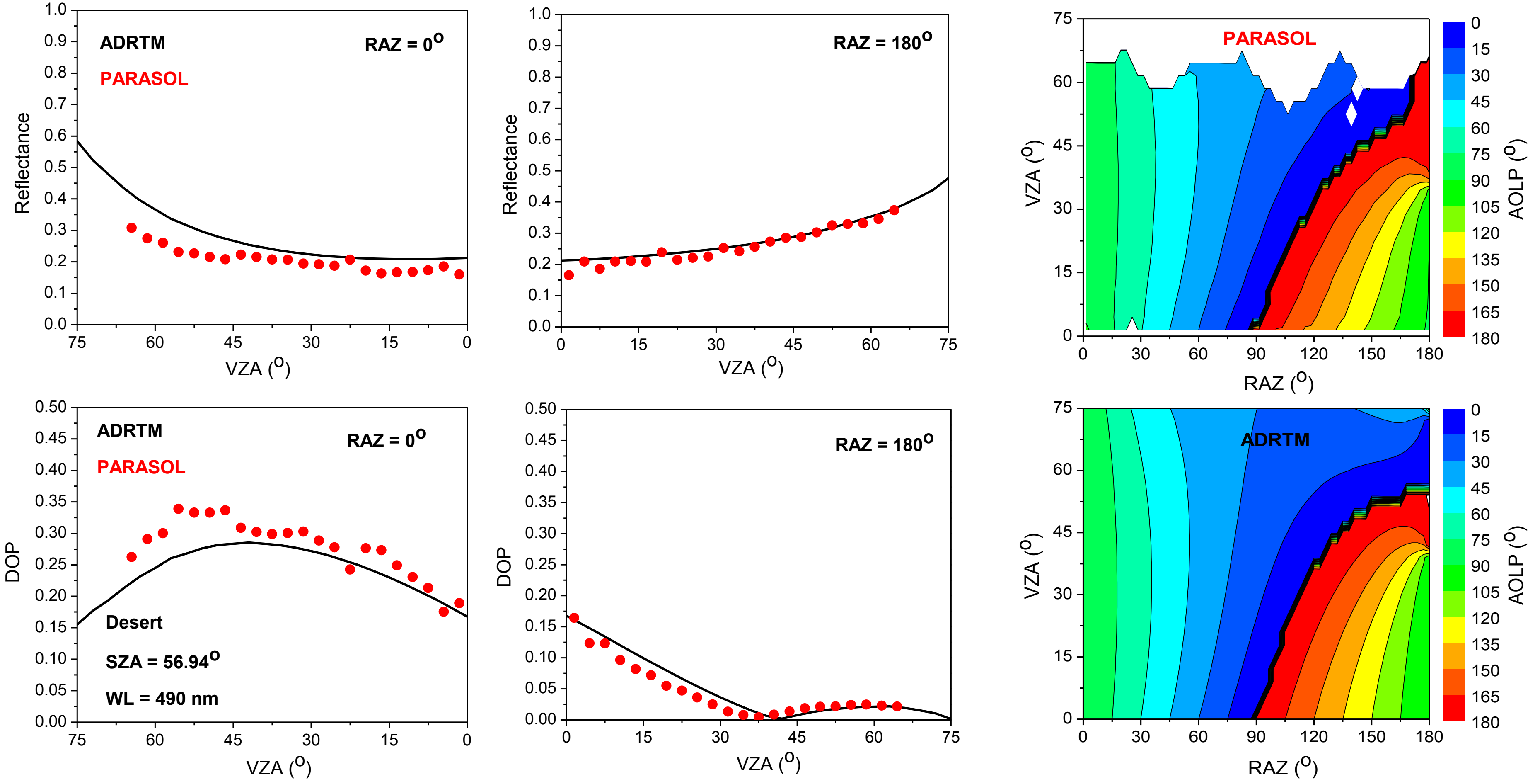
Modeling polarized solar radiation for various scene types

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

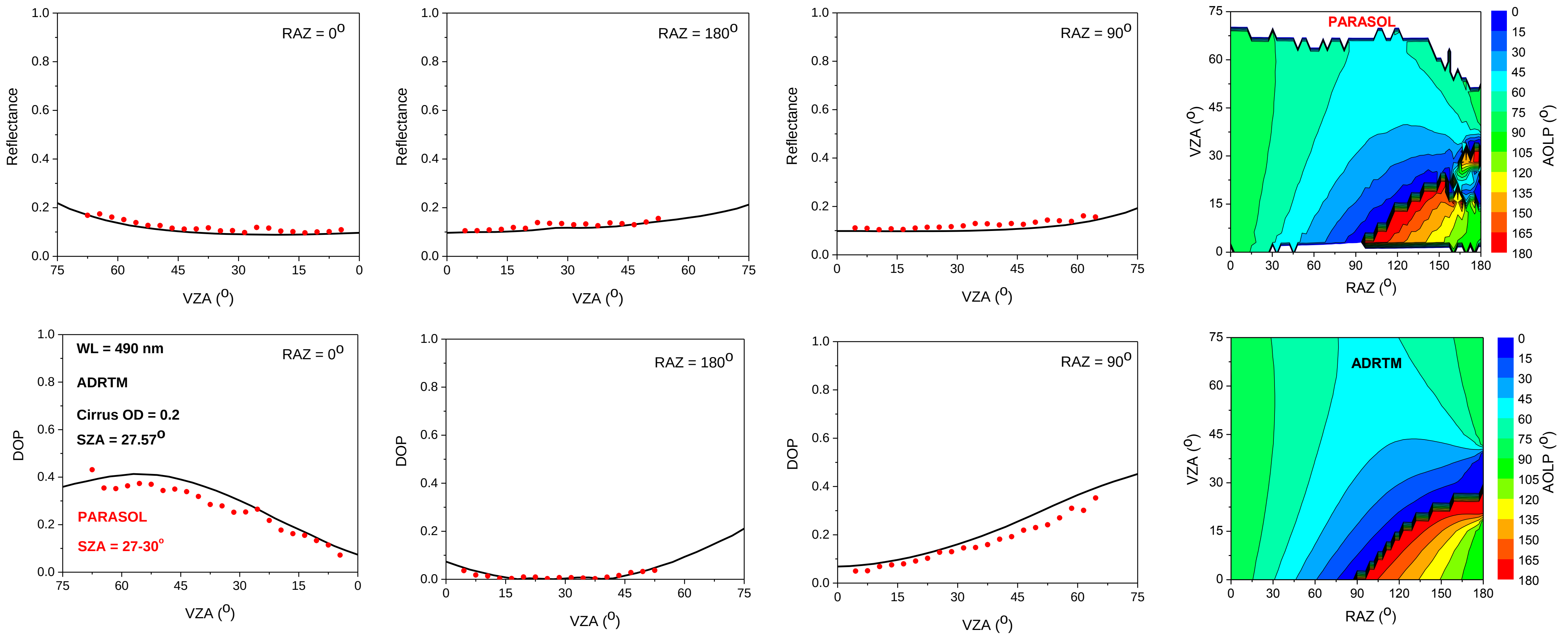
A layer of super-thin cirrus is added in ADRTM to approach to the PARASOL data for “clear” sky



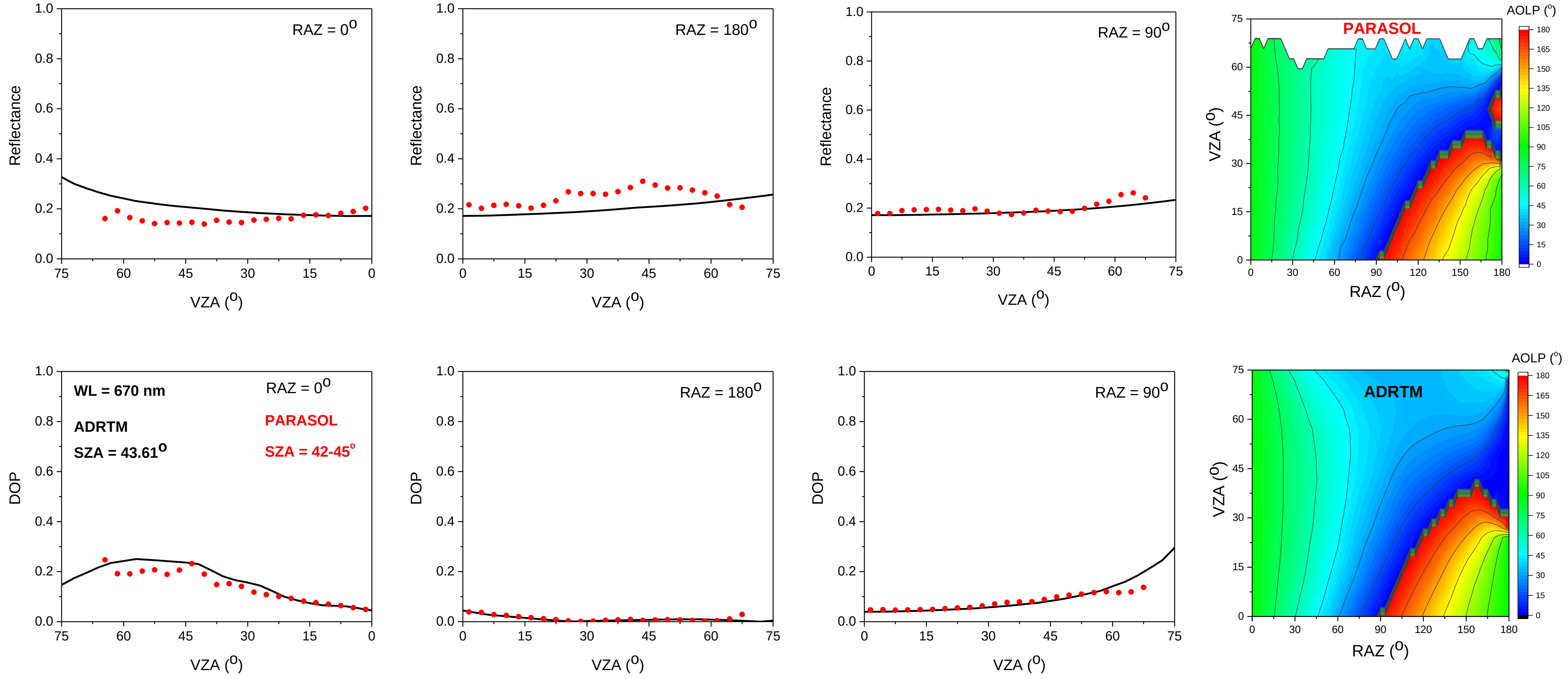
Comparing ADRTM results with PARASOL data at a wavelength of 490 nm and a SZA of 56.94 deg for clear desert.



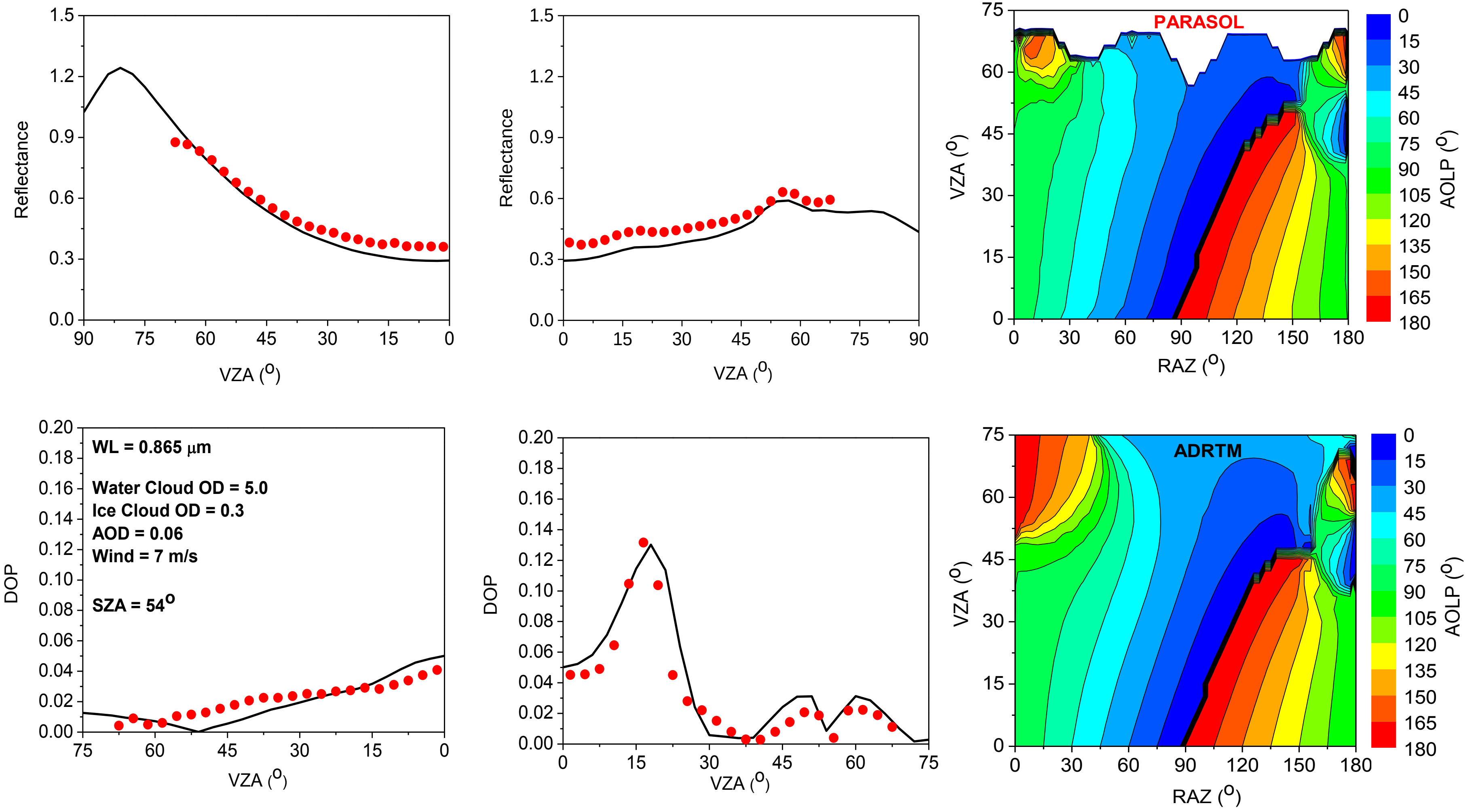
Comparing model results with satellite data at a wavelength of 490 nm and a SZA of 27.57 deg for evergreen broad-leaf trees



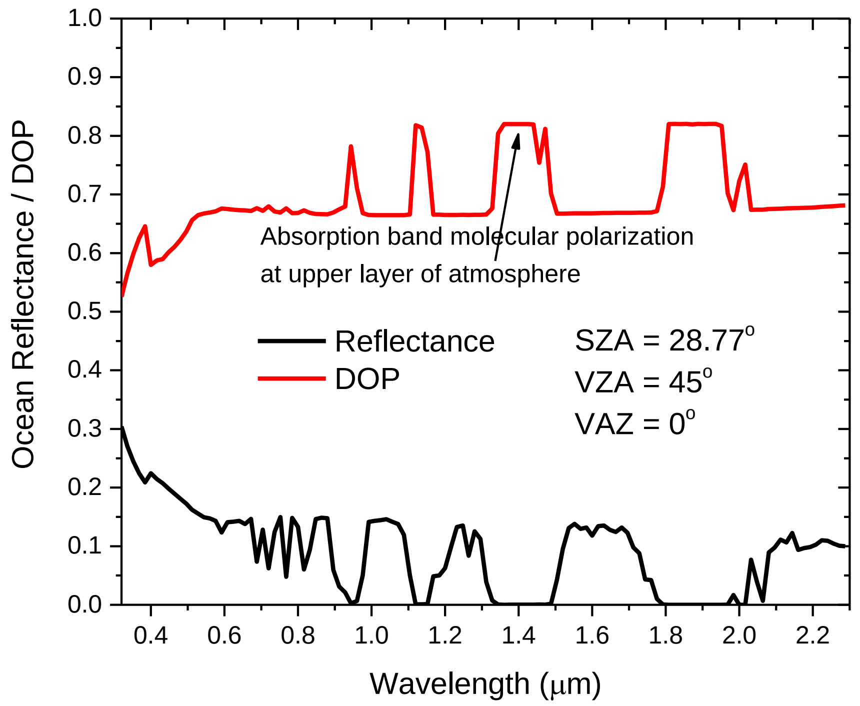
Comparing model results with satellite data at a wavelength of 670 nm and a SZA of 43.61 deg for grassland

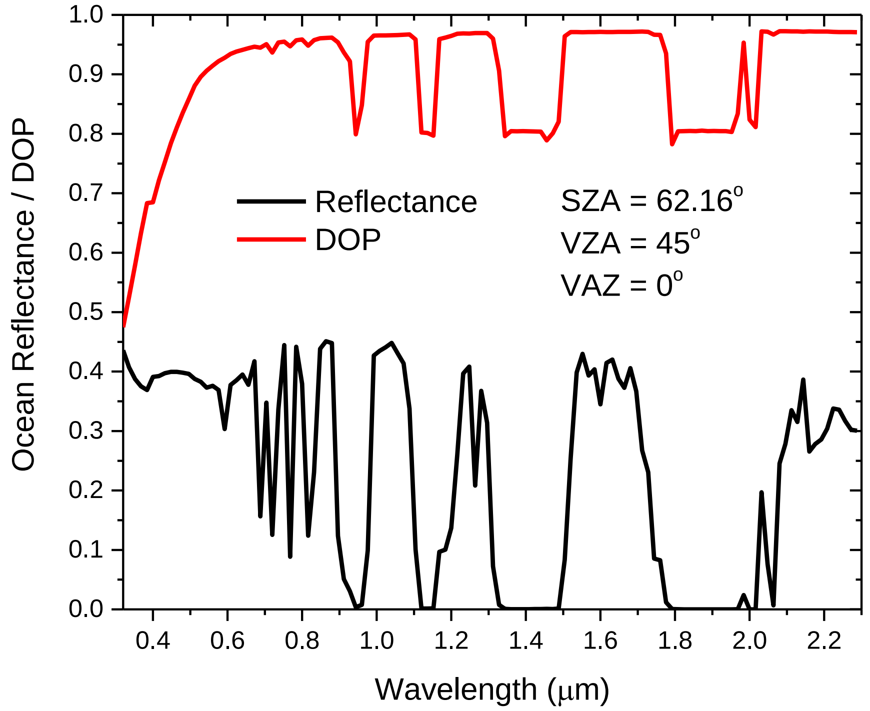


Comparing ADRTM results with PARASOL data at a wavelength of 865 nm and a SZA of 54 deg for water clouds

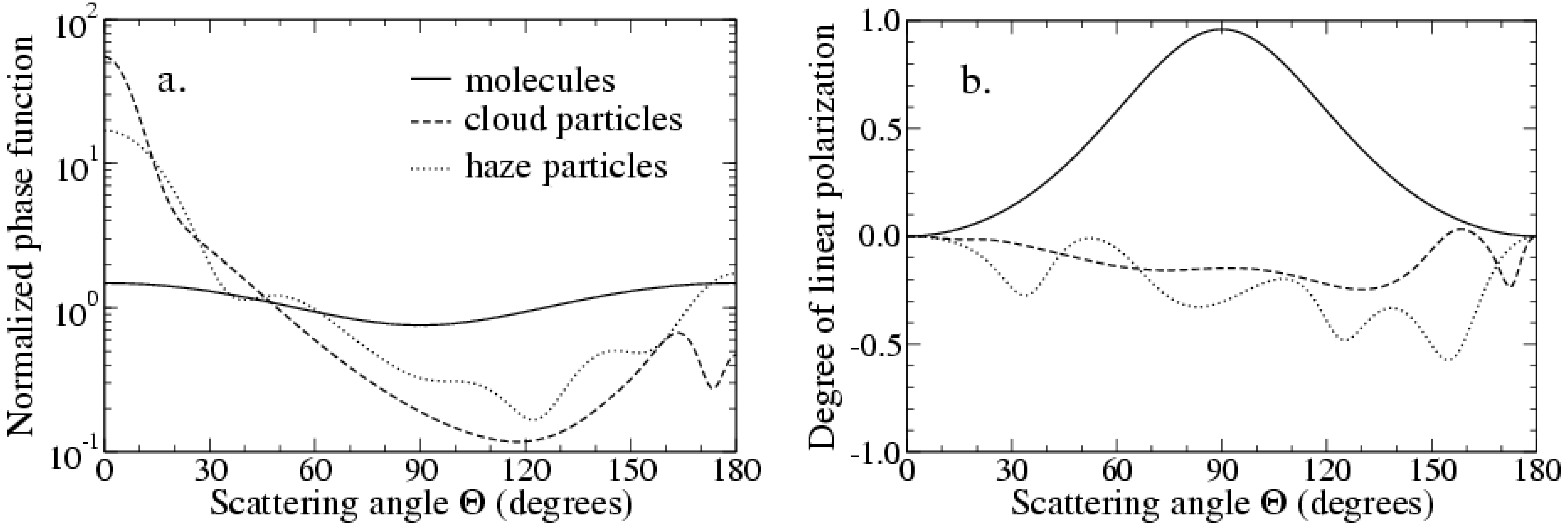


Spectral reflectance and degree of polarization of solar radiation from oceans





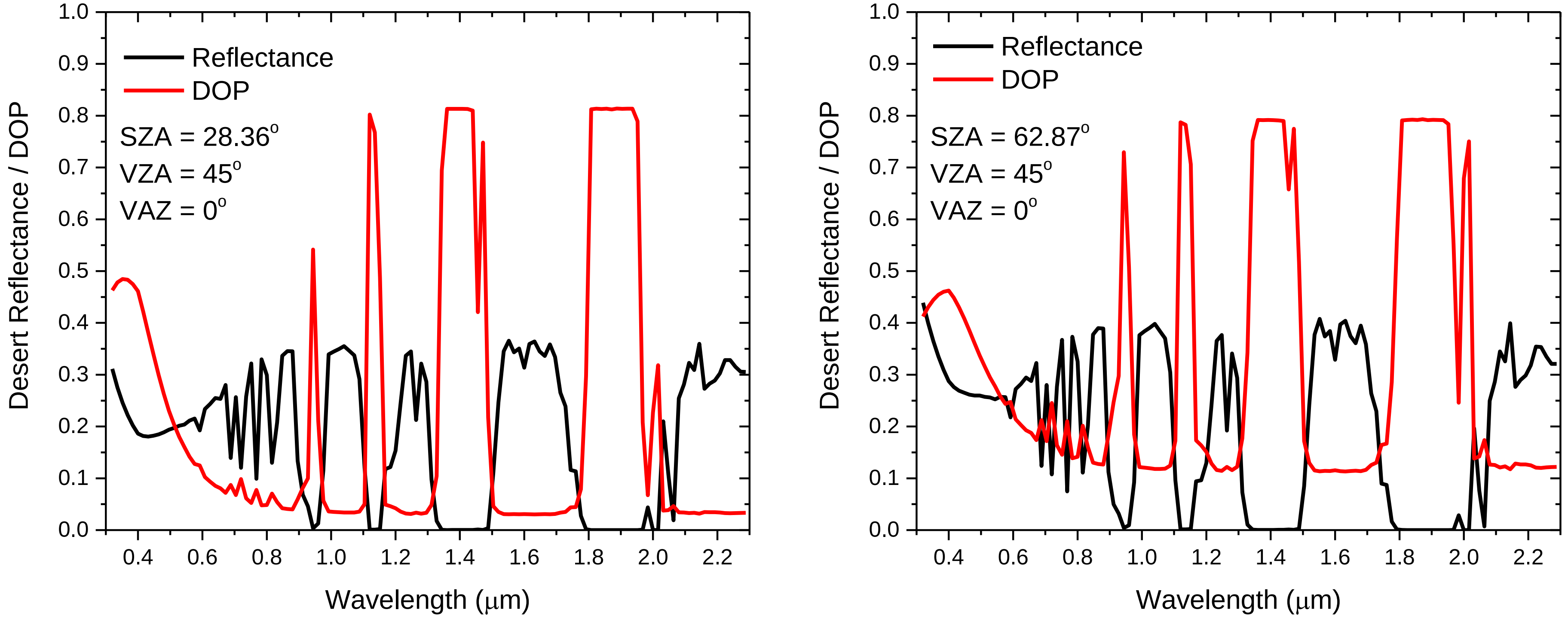
Why upper layer molecules have strong polarization?



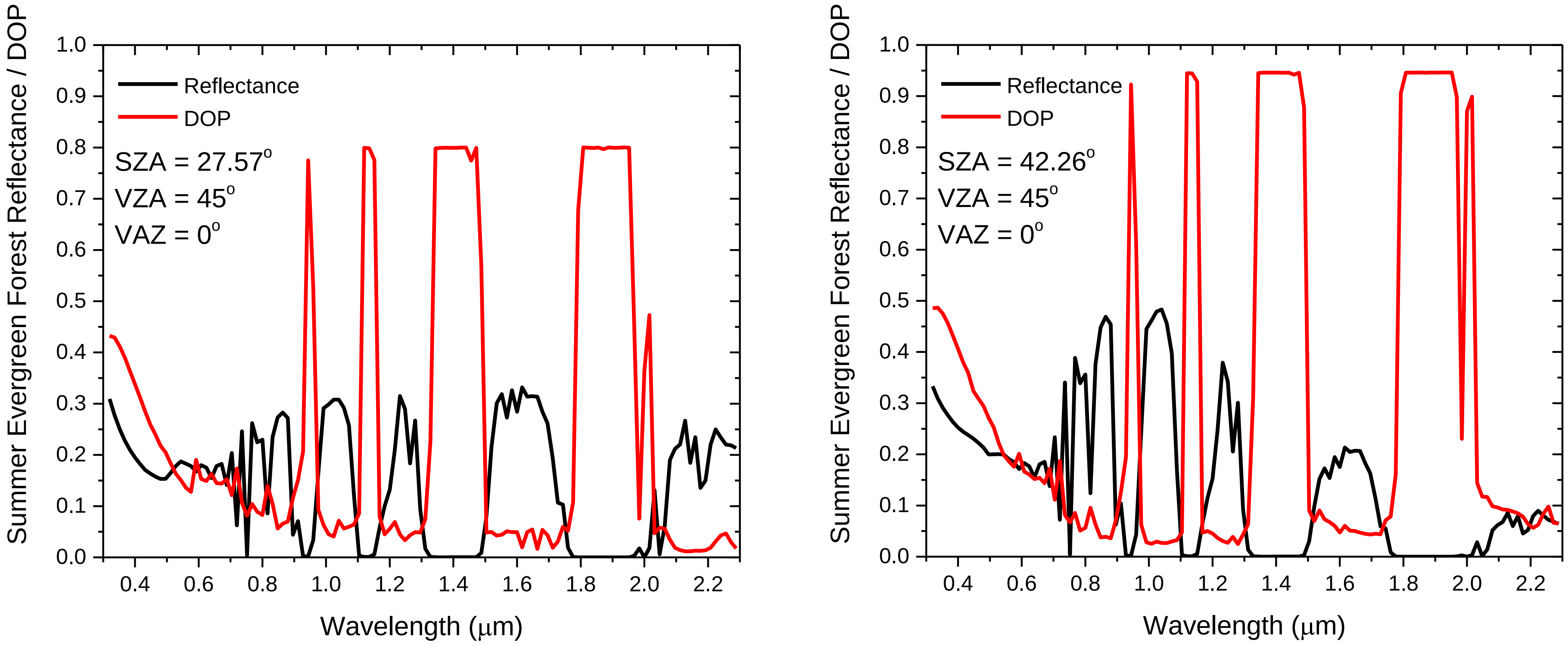
Phase function and degree of linear polarization of different natural particles

(Stam et al. 2004)

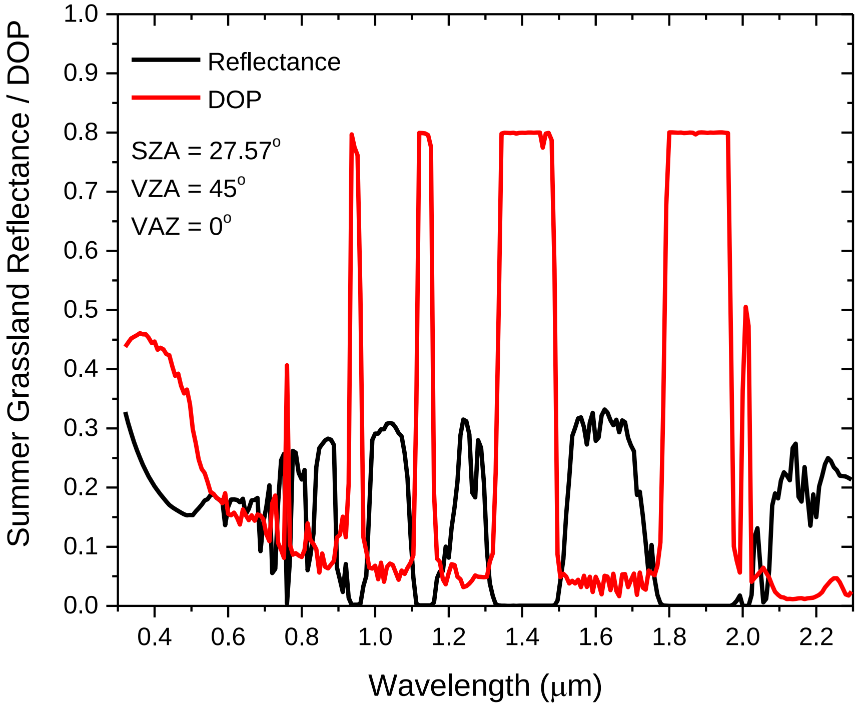
Spectral reflectance and degree of polarization of solar radiation from desert

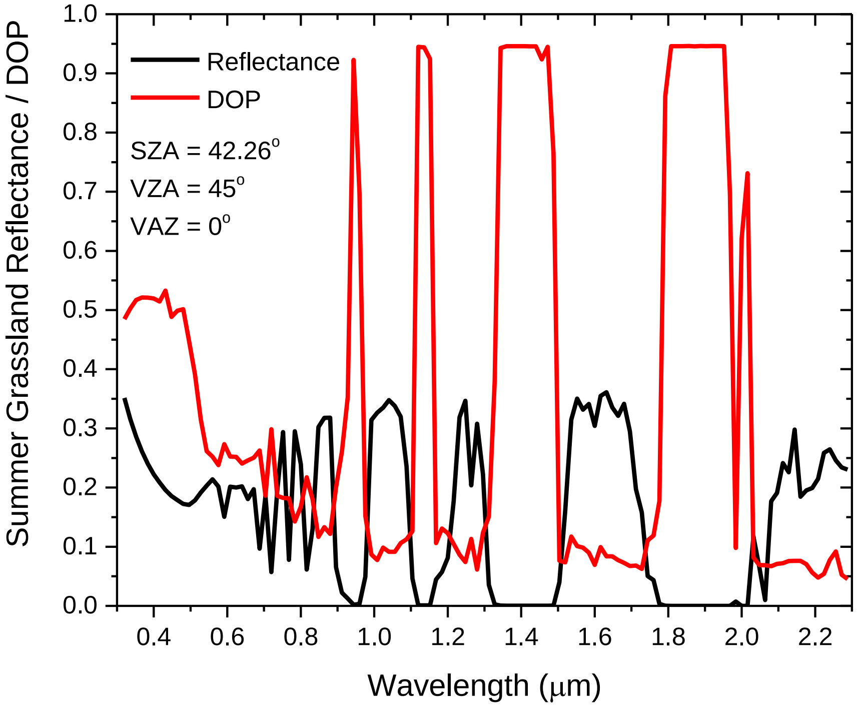


Spectral reflectance and degree of polarization of solar radiation from summer evergreen broad-leaf forest

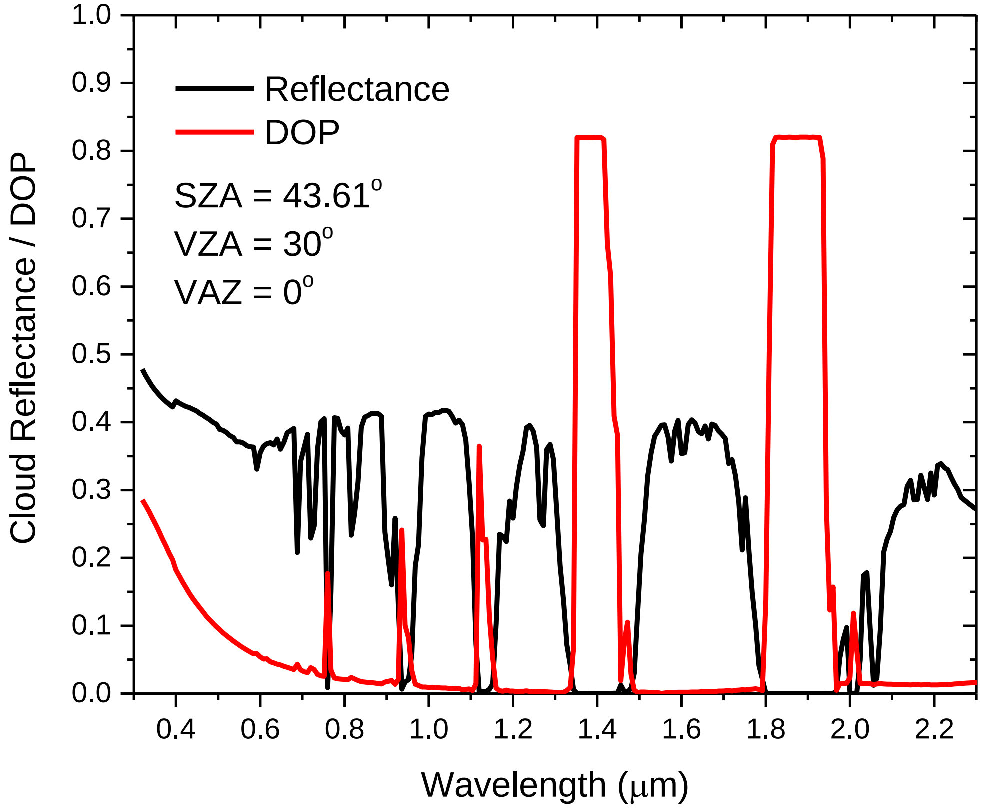


Spectral reflectance and degree of polarization of solar radiation from summer grassland





Spectral reflectance and degree of polarization of solar radiation from thick water clouds



PDM Module

- **Algorithm Input: scene type**
  - wavelength
  - geometry (RAZ/VZA/SZA)
  - CLEAR SCENE?
    - aerosol optical depth, wind speed
  - CLOUDY SCENE?
    - cloud type (water/ice/mixed), cloud fraction, cloud optical depth
- **Internal inputs**: theoretical and empirical PDMs in the form of HDF4-formatted lookup tables
- **Function**: Given the input wavelength, either find appropriate band (if within POLDER bandwidth) or interpolate as needed
  - Theoretical case: interpolate between SZA. Uncertainties to be implemented in the future
  - Empirical case: interpolate between bands only. Propagate DOP and AOLP uncertainties to find uncertainties in interpolated values
- **Output**: DOP and AOLP value and their corresponding uncertainties.
  - At present: theoretical or empirical DOP and AOLP mean values based on selection. Future option: weighted mean and combined uncertainty using the theoretical and empirical PDMs
  - For $\lambda < 490$ nm or $\lambda > 865$ nm (outside POLDER range) only theoretical value is output

Conclusion

- The polarization states of reflected solar spectra for major Earth scenes are modeled for CLARREO PDMs.
- Ocean, as a special scene type, strongly polarizes light. However, all other scene types under CPF orbits only strongly polarize light at wavelengths shorter than approximately 0.9 microns.
- The spectral PDMs reduce the risk of the CPF mission by correcting measurement errors due to the polarization of spectrally-resolved reflected solar radiation.

References

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