Impact of polarization on radiative transfer simulation for vicarious calibration of Sentinel-2 MSI.

Level 1 Radiometry Validation Session

Nicolae Marton, Claudia Emde, Vincent Leroy, Nicolas Misk, Yves Govaerts

Rayference

7th Sentinel-2 Validation Team Meeting

13-15 October 2025 | ESA-ESRIN | Frascati (RM), Italy

RAYFERENCE

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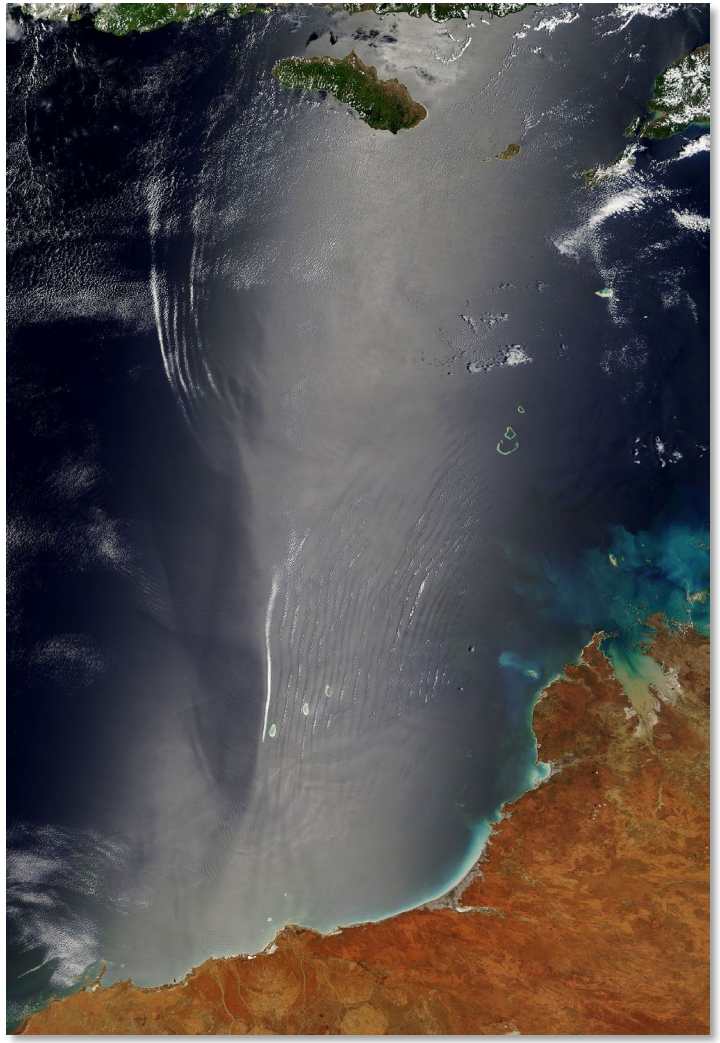
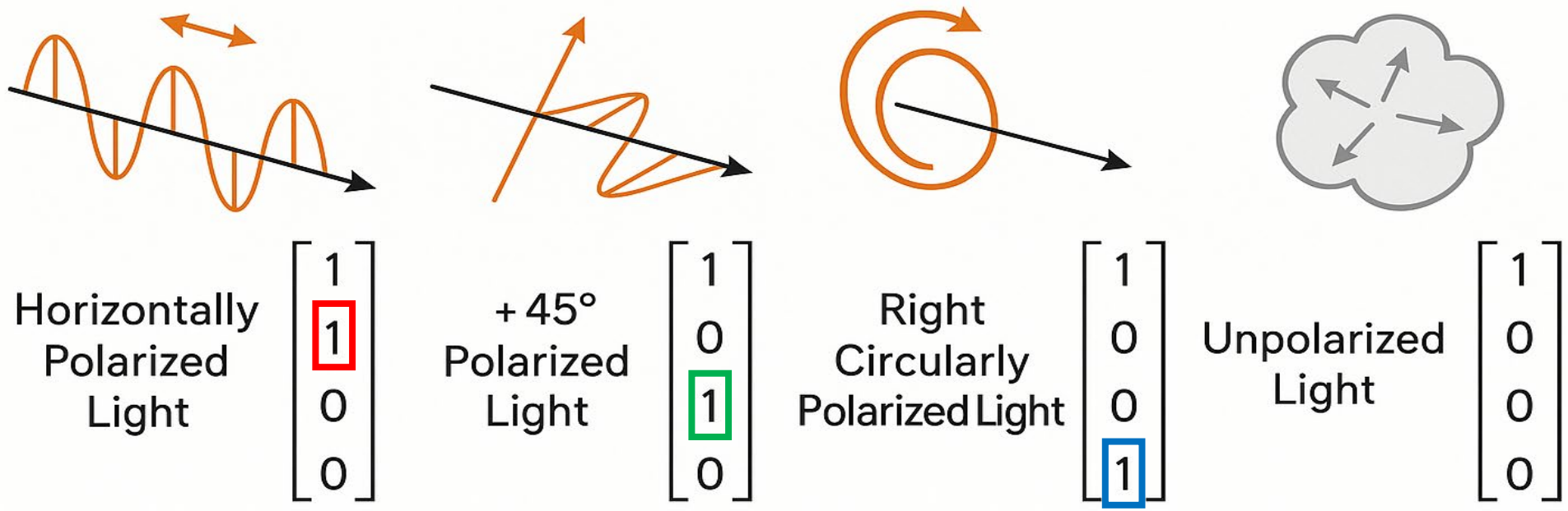
Vicarious Calibration



What is the Impact of polarization on radiative transfer simulation for vicarious calibration based on **sun glint** of Sentinel-2 MSI?

Polarization and Stokes Vector

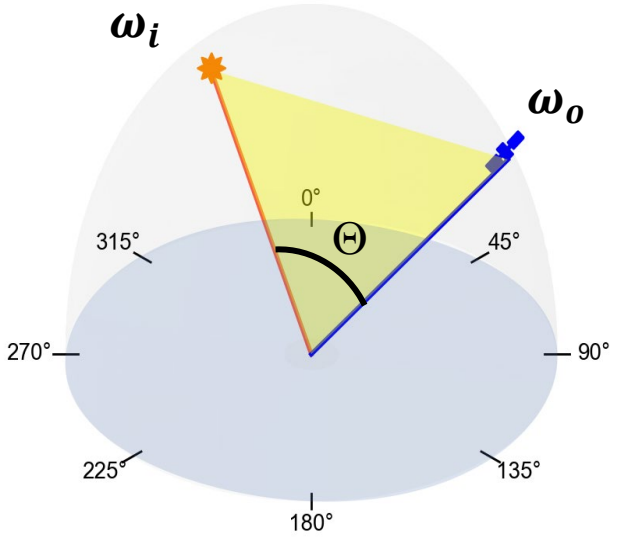
- Polarization describes the direction in which the electric field oscillates.
- Can be represented through the Stokes Vector, $\boldsymbol{s} = [I, Q, U, V]^{\mathrm{T}}$



- Degree of Linear Polarization of light beam: $\mathrm{DLP} = \frac{\sqrt{Q^2+U^2}}{I}$
- Polarized Radiance: $\mathrm{P} = \sqrt{Q^2 + U^2}$

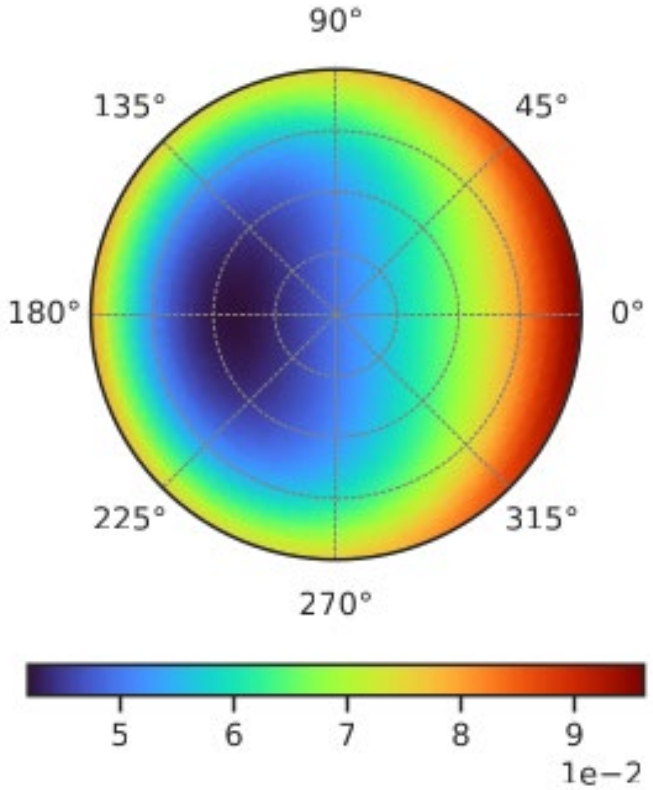
Polarization by Molecular Scattering

- Scatterers polarize light depending on the particle size, shape, and orientation

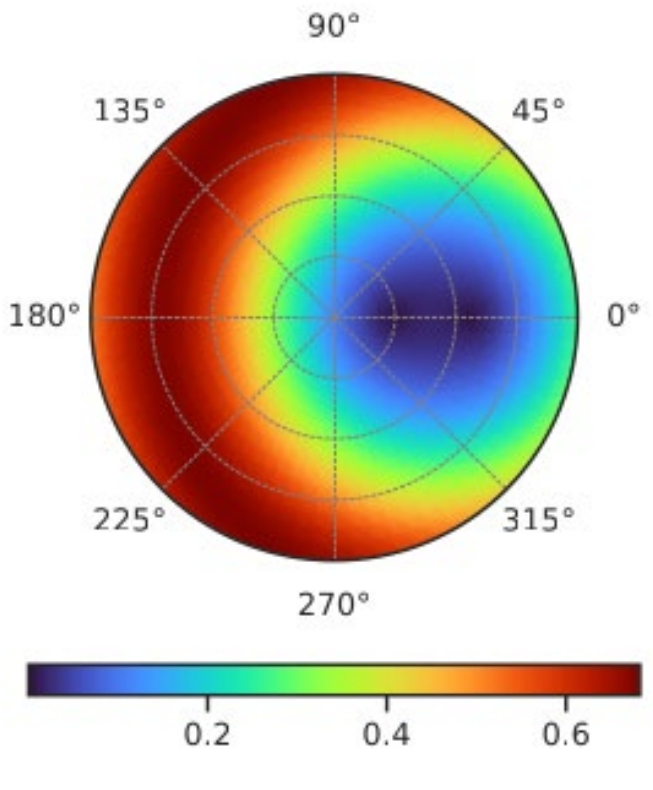


Phase angle Θ

Reflectance



Degree of linear Polarization

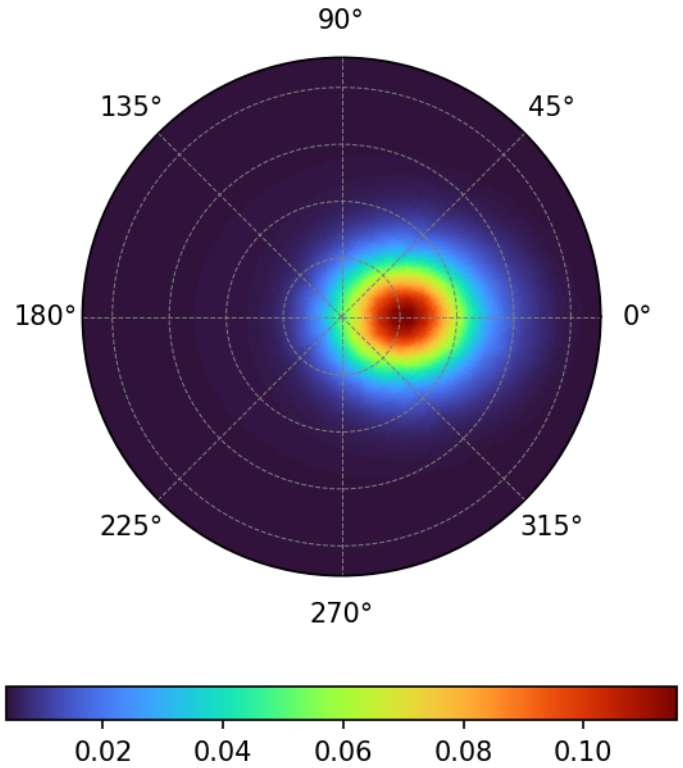


- Molecular scattering is highly polarized for Θ~90°

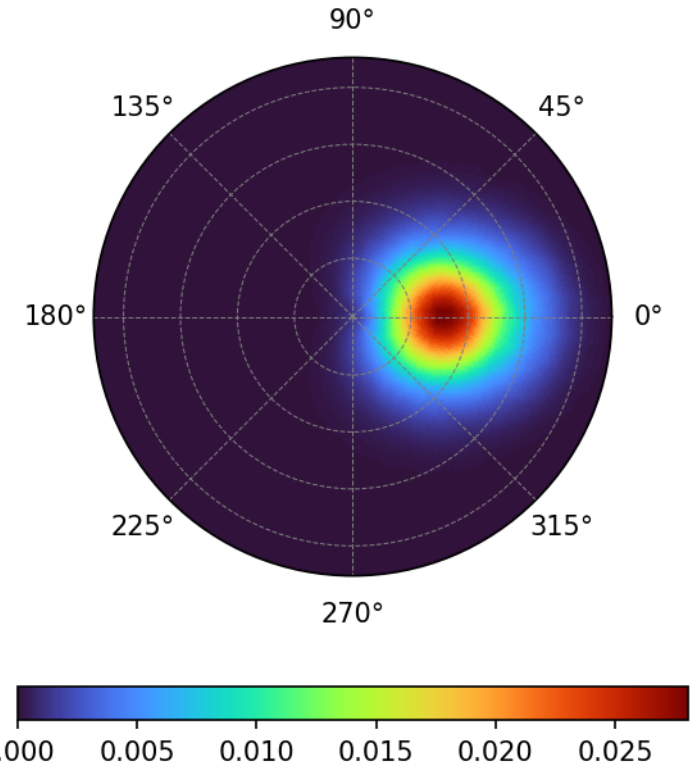
Polarization by Ocean Scattering

- Ocean scattering polarizes light at sunglint angles.

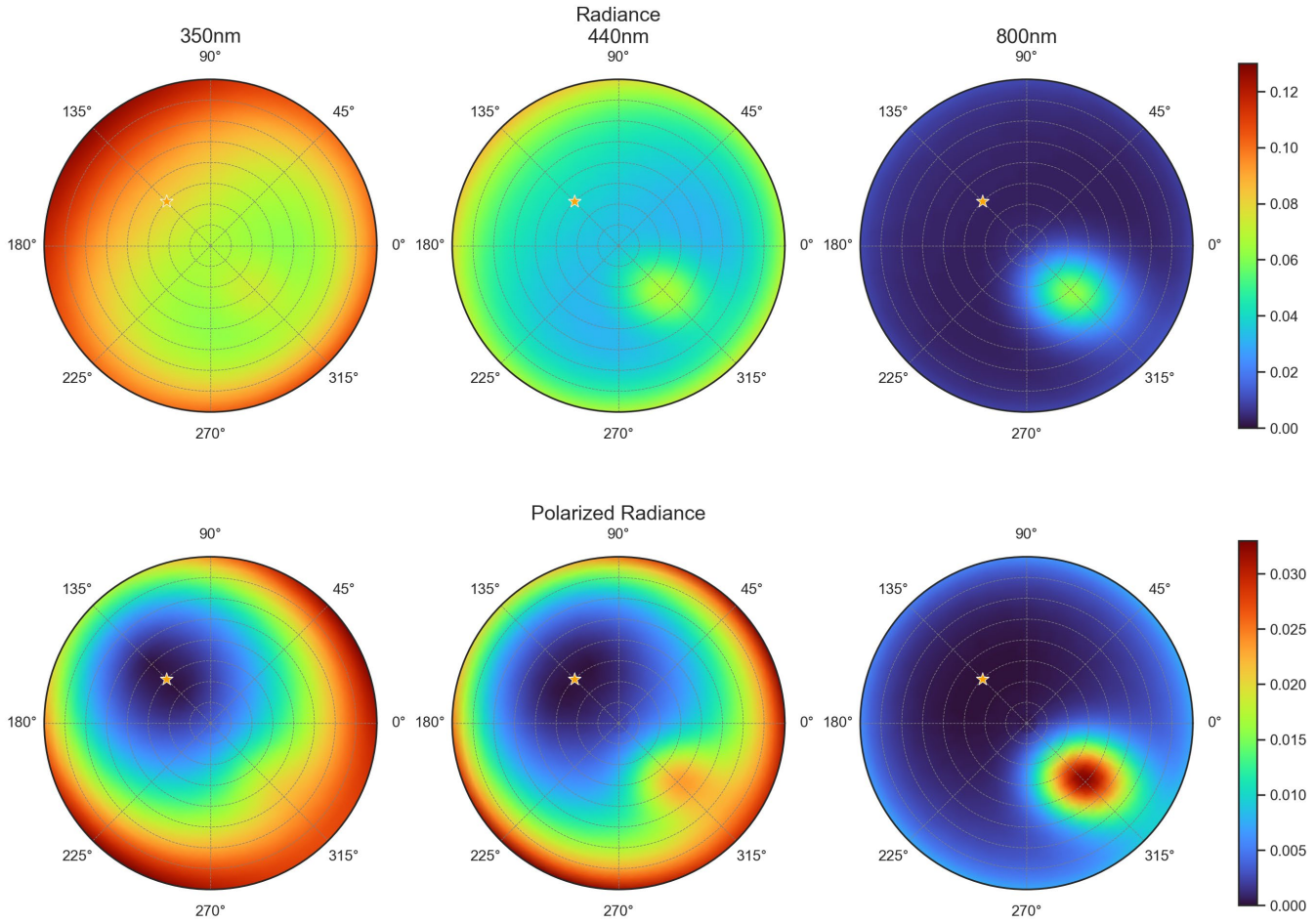
Reflectance



Polarized Radiance



Polarization by Atmosphere and Ocean



Radiance

Polarized Radiance

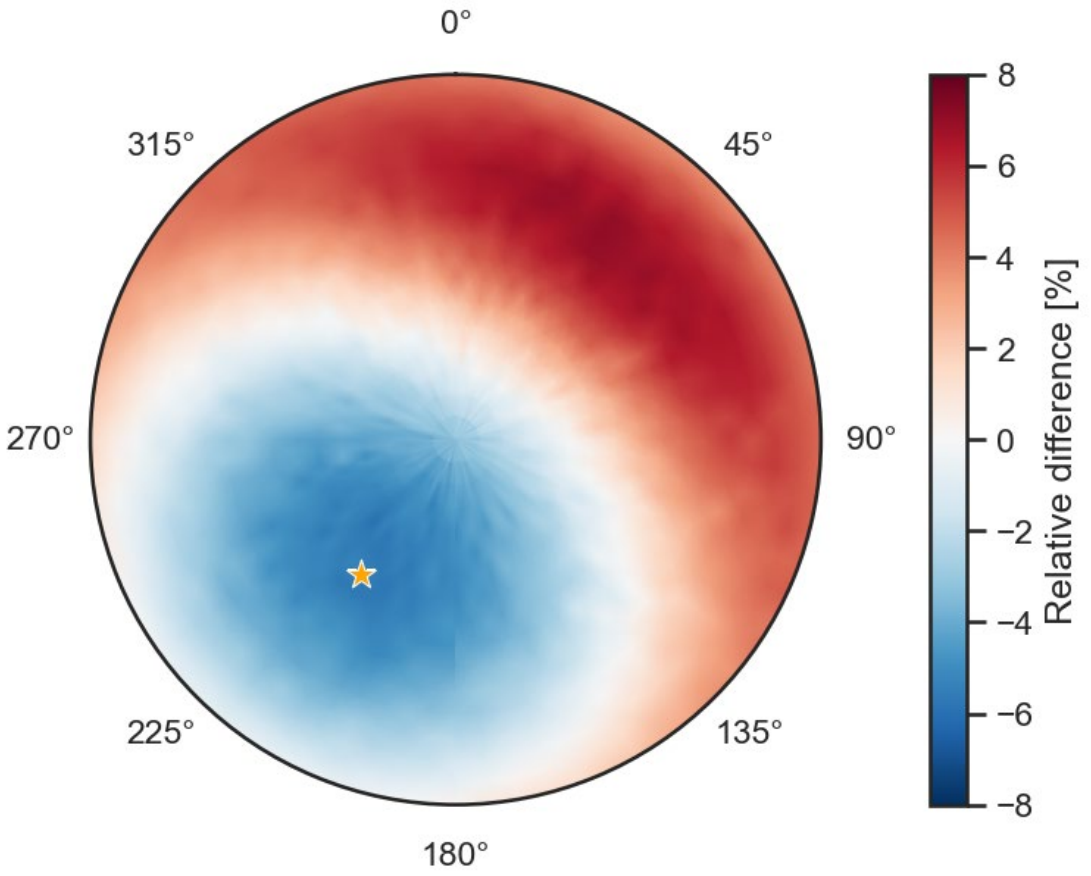
Molecular Scattering

Sunglint Scattering

Error due to neglecting polarization

- Radiative transfer models often neglect polarization
- Errors by this approximation up to ±10%

Reflectance error (400nm)



M. I. Mishchenko, A. A. Lacis, L. D. Travis, *Errors induced by the neglect of polarization in radiance calculations for Rayleigh-scattering atmospheres*, JQSRT, 51 (3), 1994
C. Emde and B. Mayer. *Errors induced by the neglect of polarization in radiance calculations for three-dimensional cloudy atmospheres*. *JQSRT*, 218:151-160, 2018.

Motivation

- Instruments are designed to be insensitive to polarization up to a given percentage.
- Including polarization in a radiative transfer simulation **also impacts the radiance intensity (I)**.
- **Vicarious calibration** applications need an accuracy of **better than 3%.**
- We want to estimate the **effect of neglecting polarization** on sun glint vicarious calibration cases.
- **Sunglint scattering also polarizes light**, we want to investigate if it also introduces errors.

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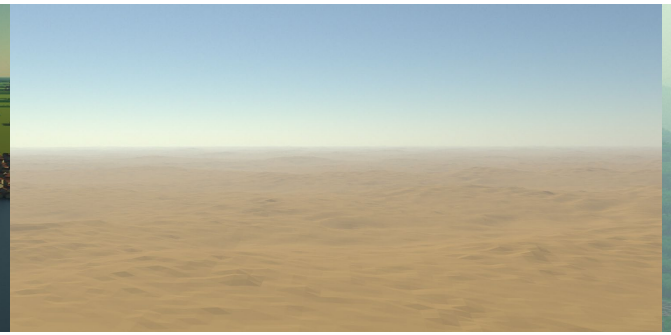
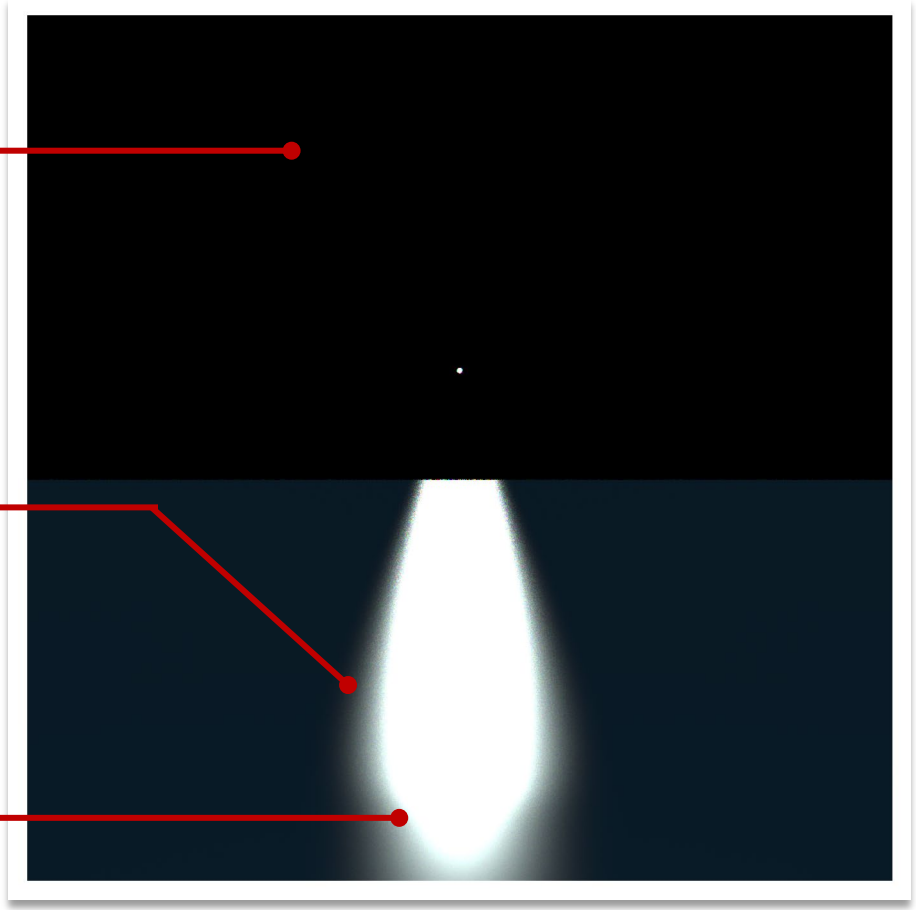



Case study: Ocean with no atmosphere

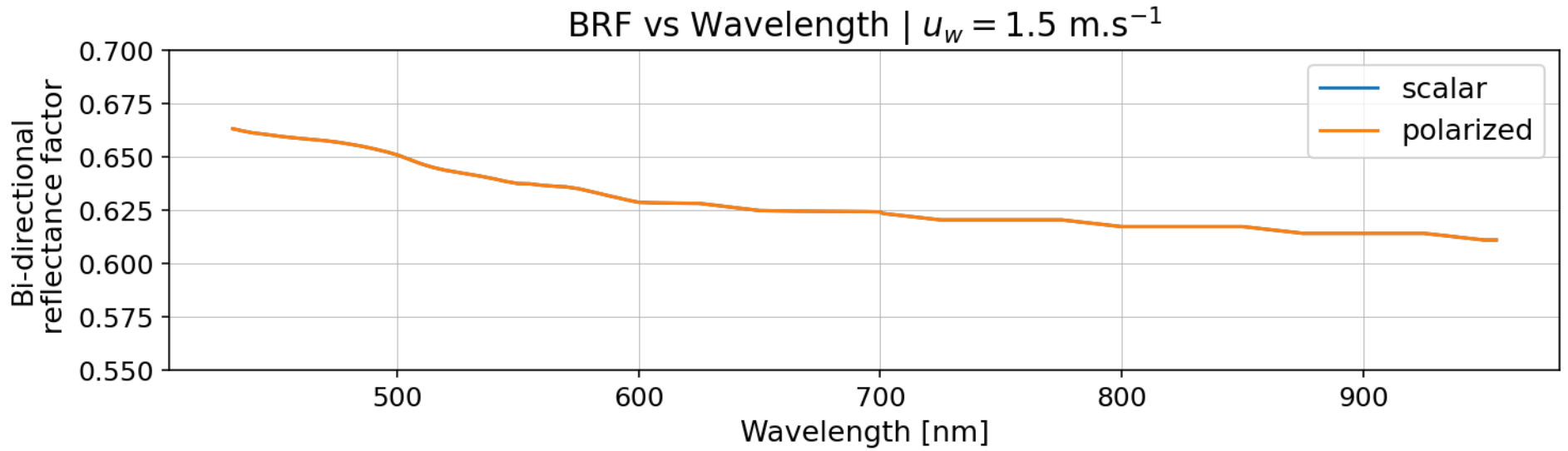
No Atmosphere / Aerosols

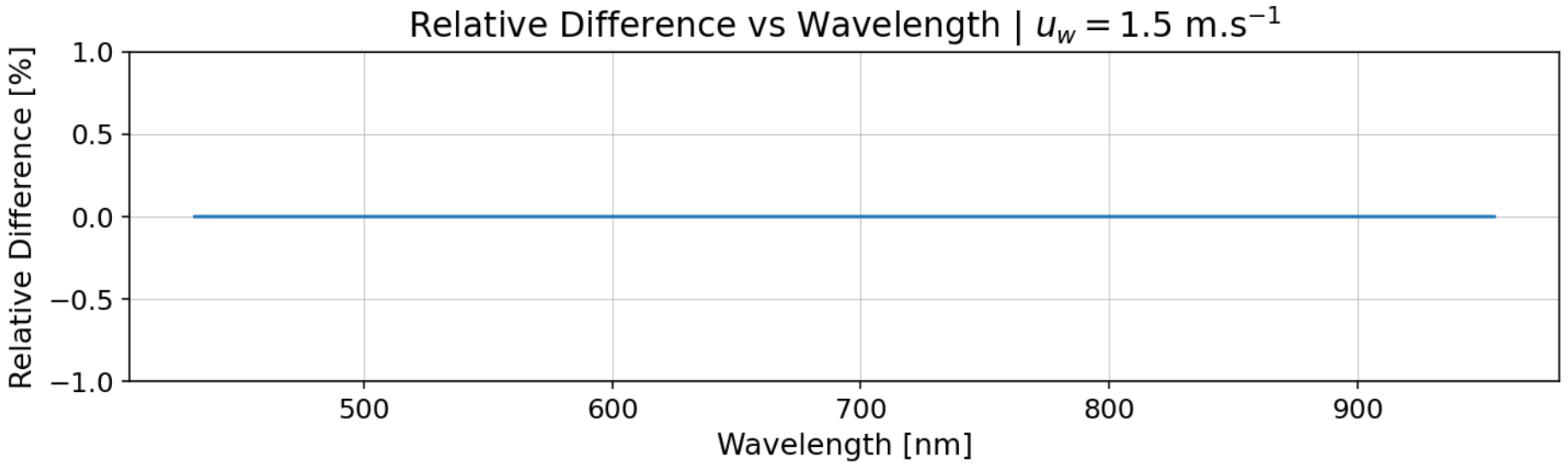
Opaque Ocean Model: Cox and Munk including polarization [1]

Plane parallel geometry



Case study: Ocean with no atmosphere





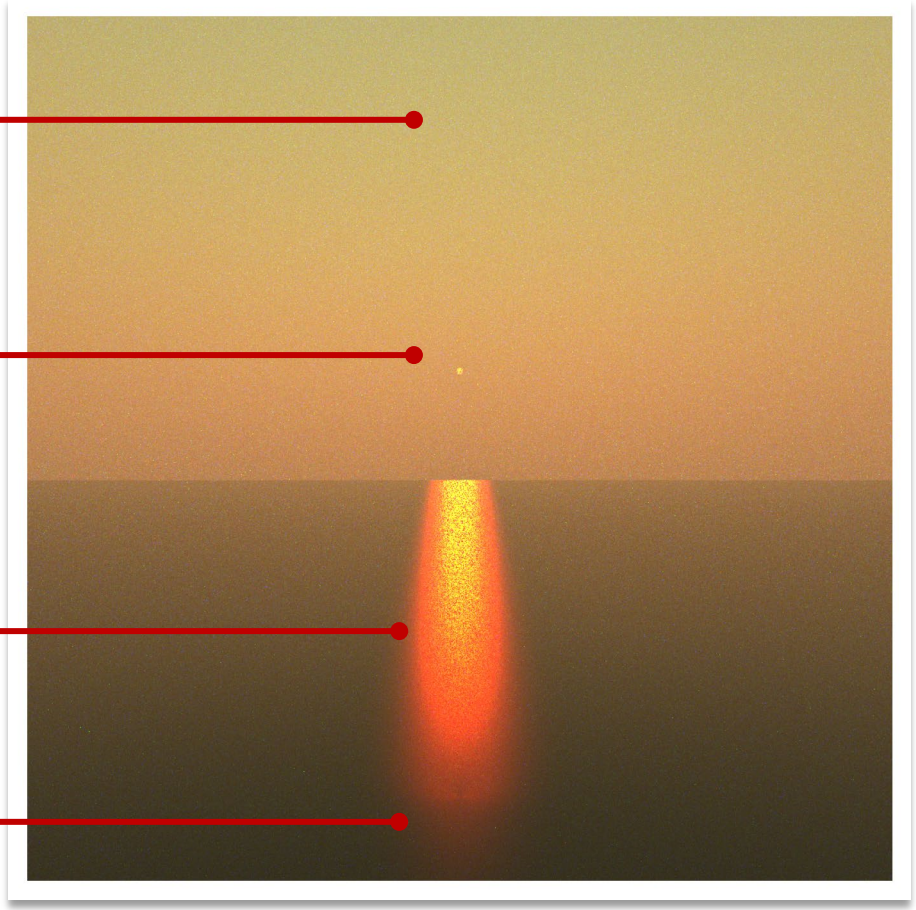
Case study: Ocean with atmosphere

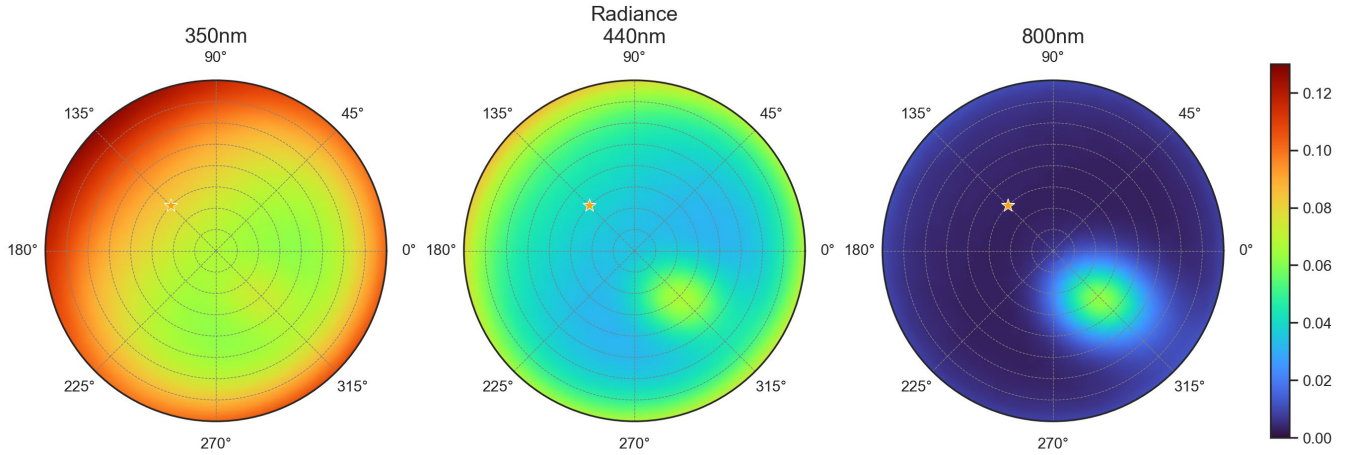
Atmosphere: Standard Atmosphere tropical. [2]

Aerosols: Maritime Clean (OPAC) [3]
- AOT : {0.03, 0.25}

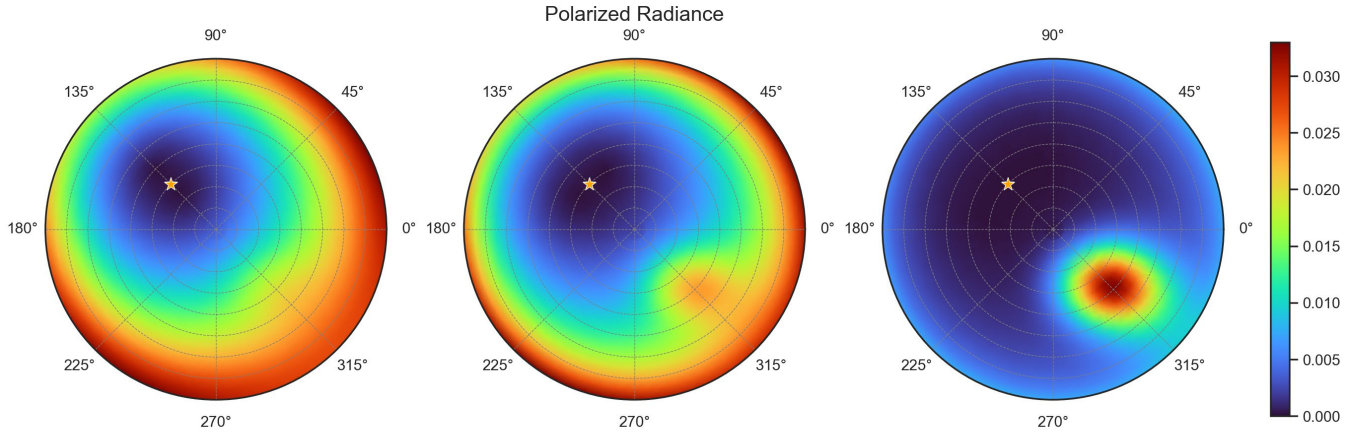
Opaque Ocean Model: Cox and Munk with polarization [1]
- Wind speed: {1.5, 6.0} $m.s^{-1}$

Plane parallel geometry

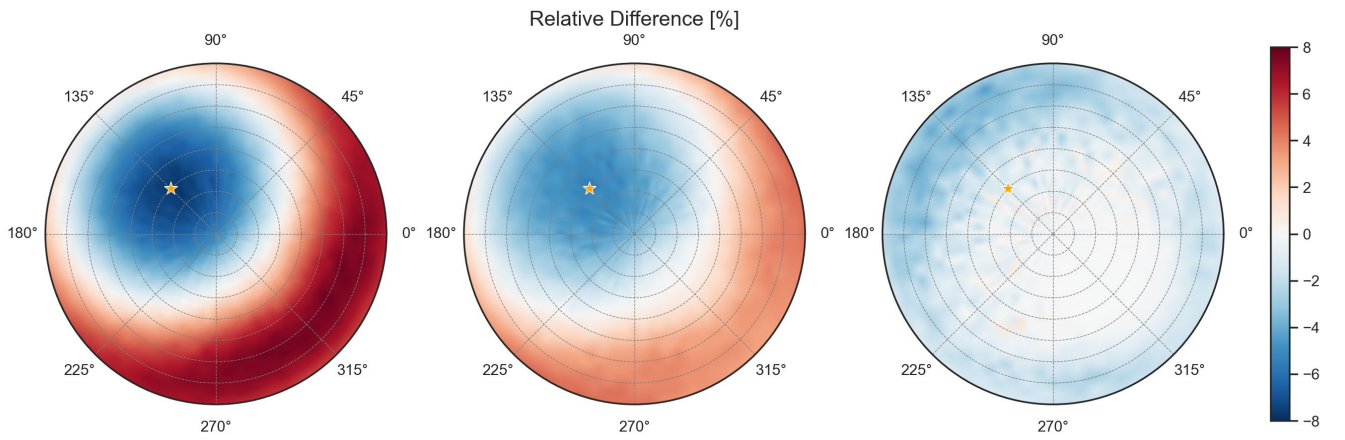




Radiance

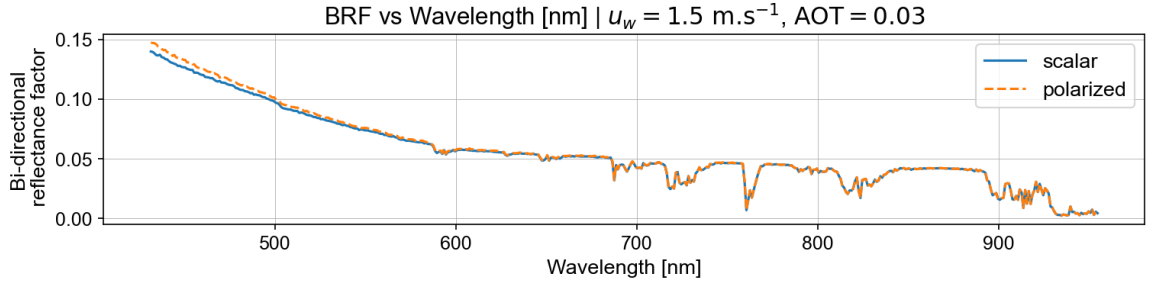


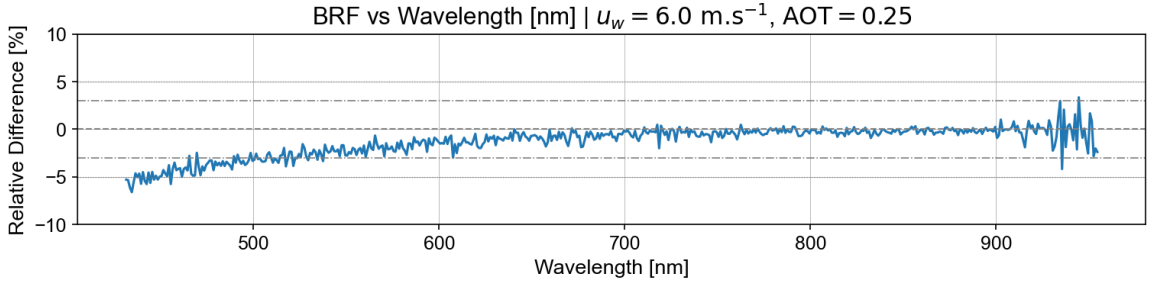
Polarized Radiance

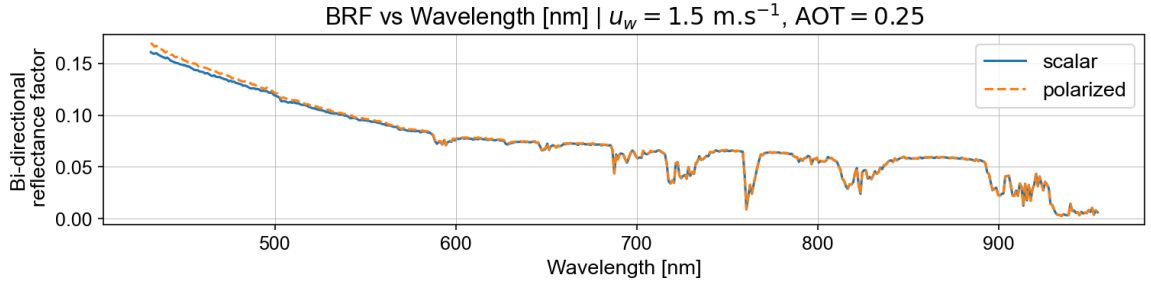


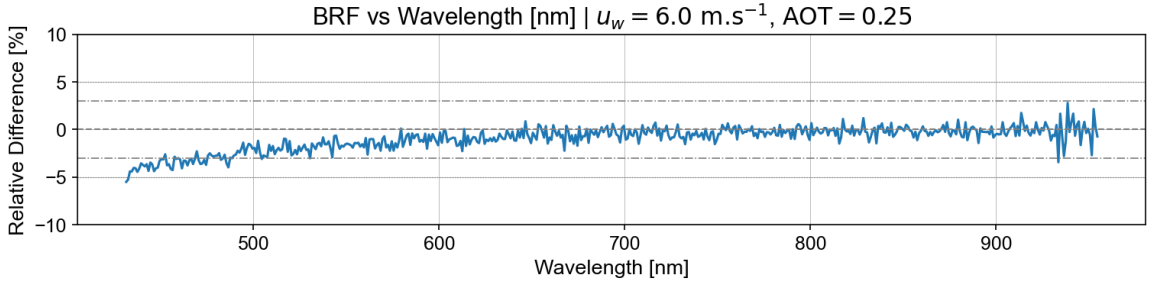
Relative Difference

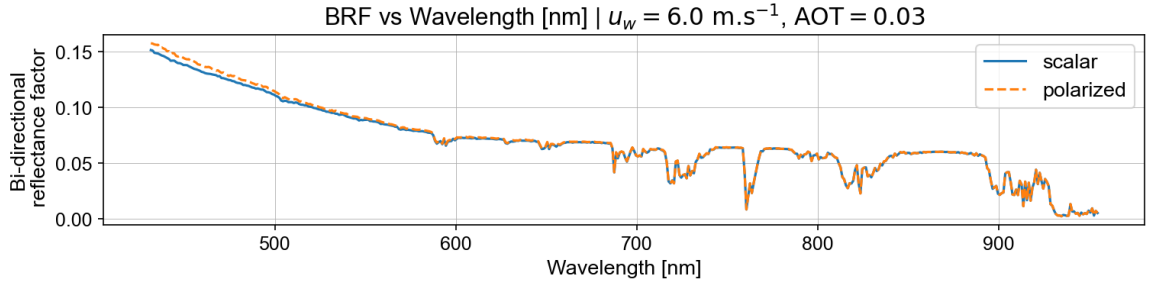
Sensitivity study: Wind speed and AOT (Θ=20°)

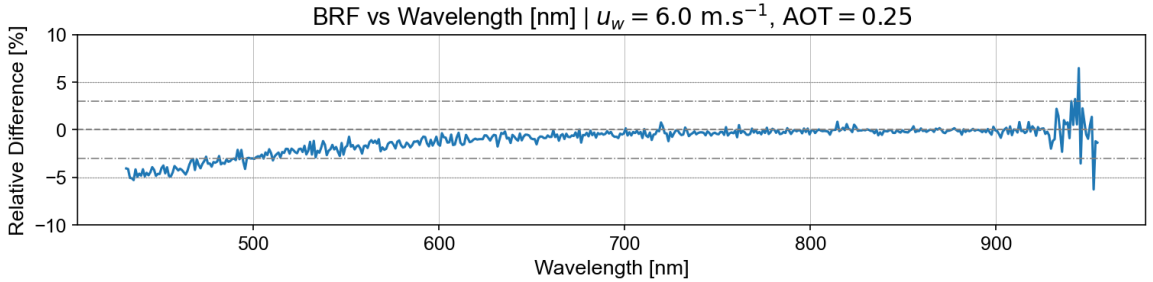


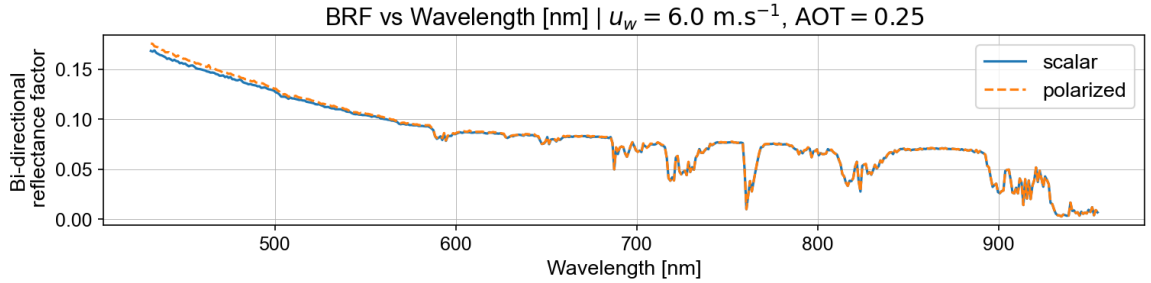


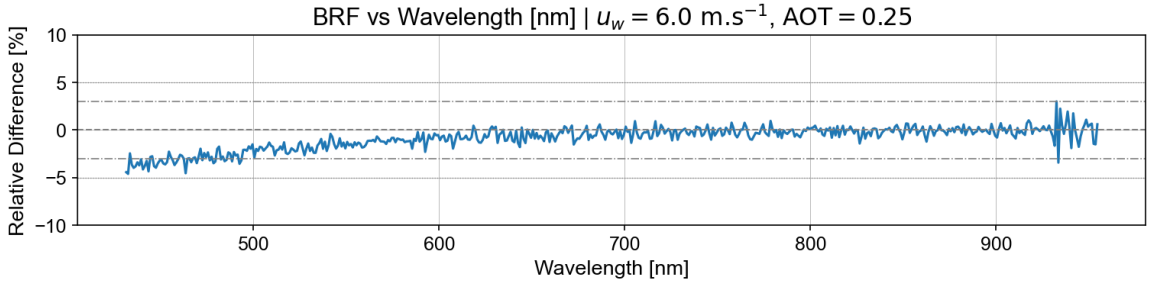




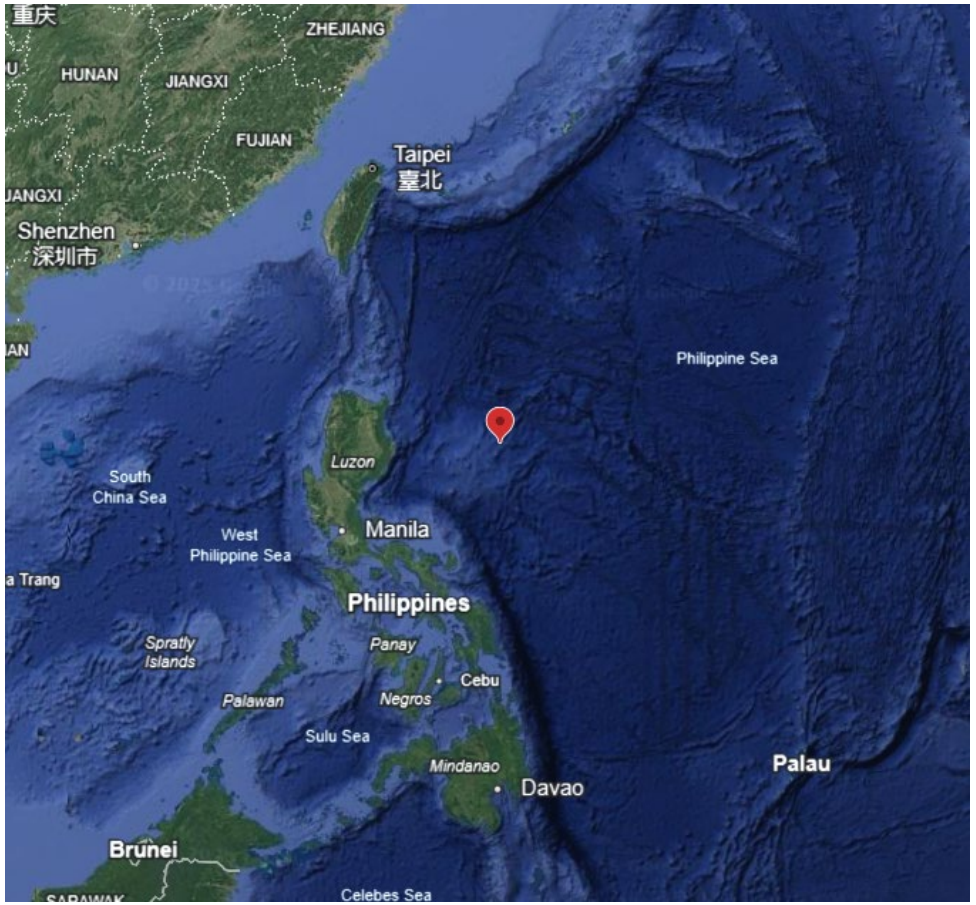


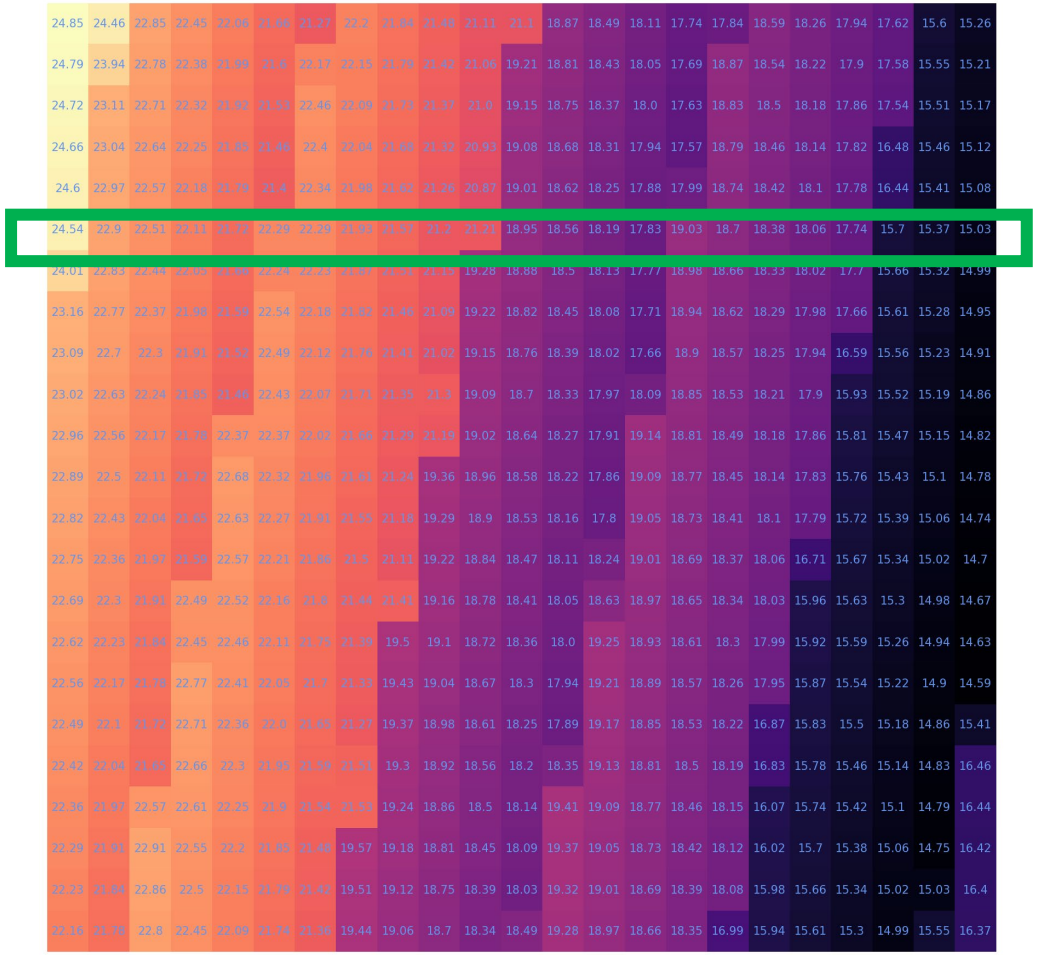






Case Study: S2/MSI Tile geometry





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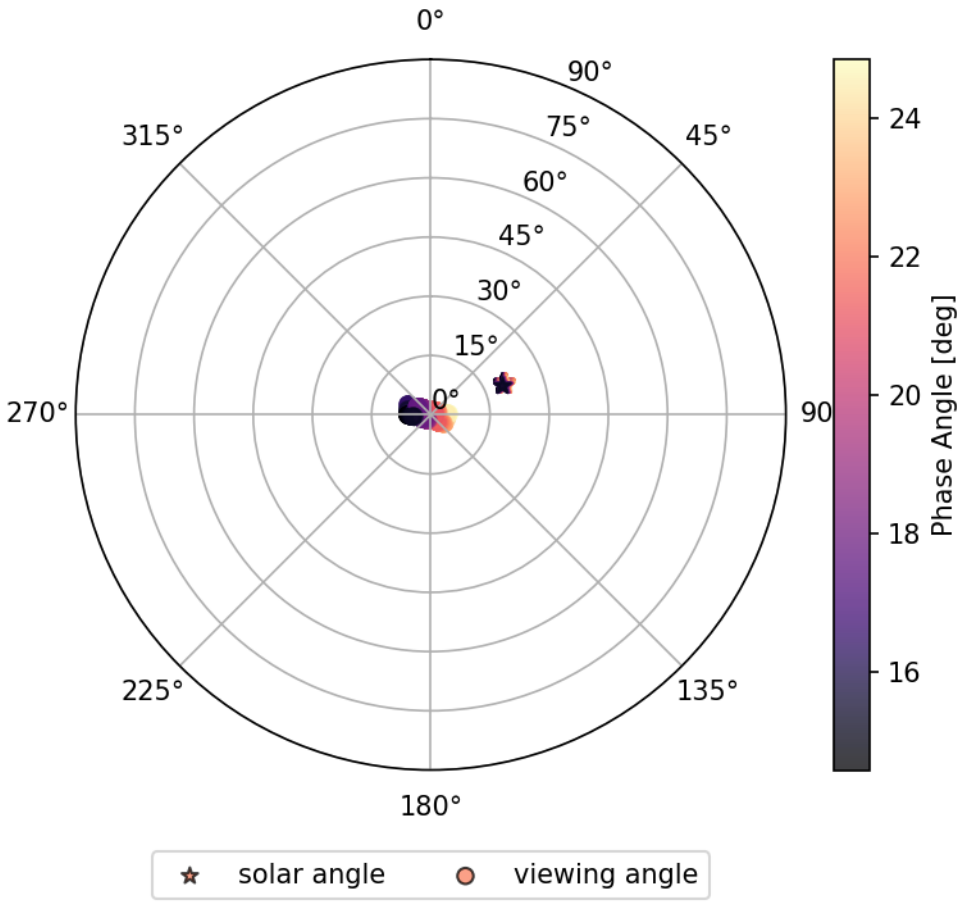
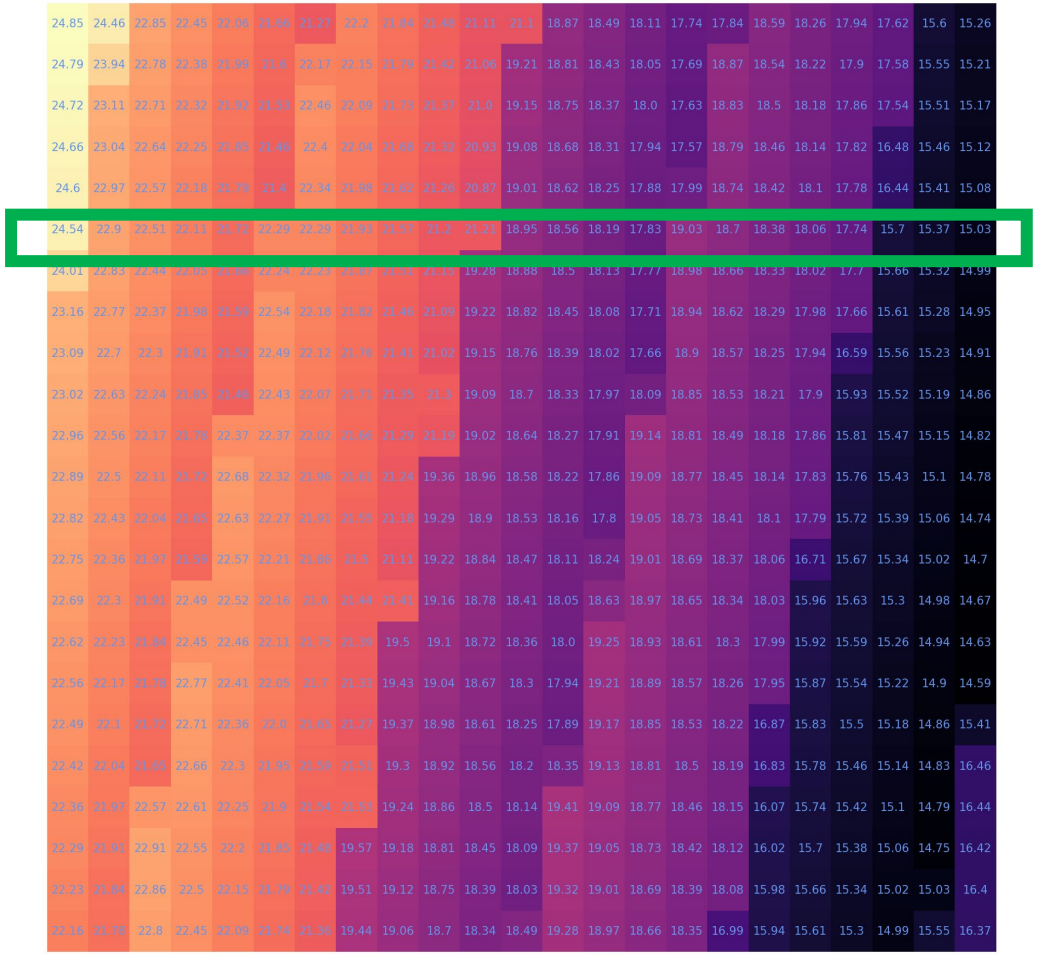
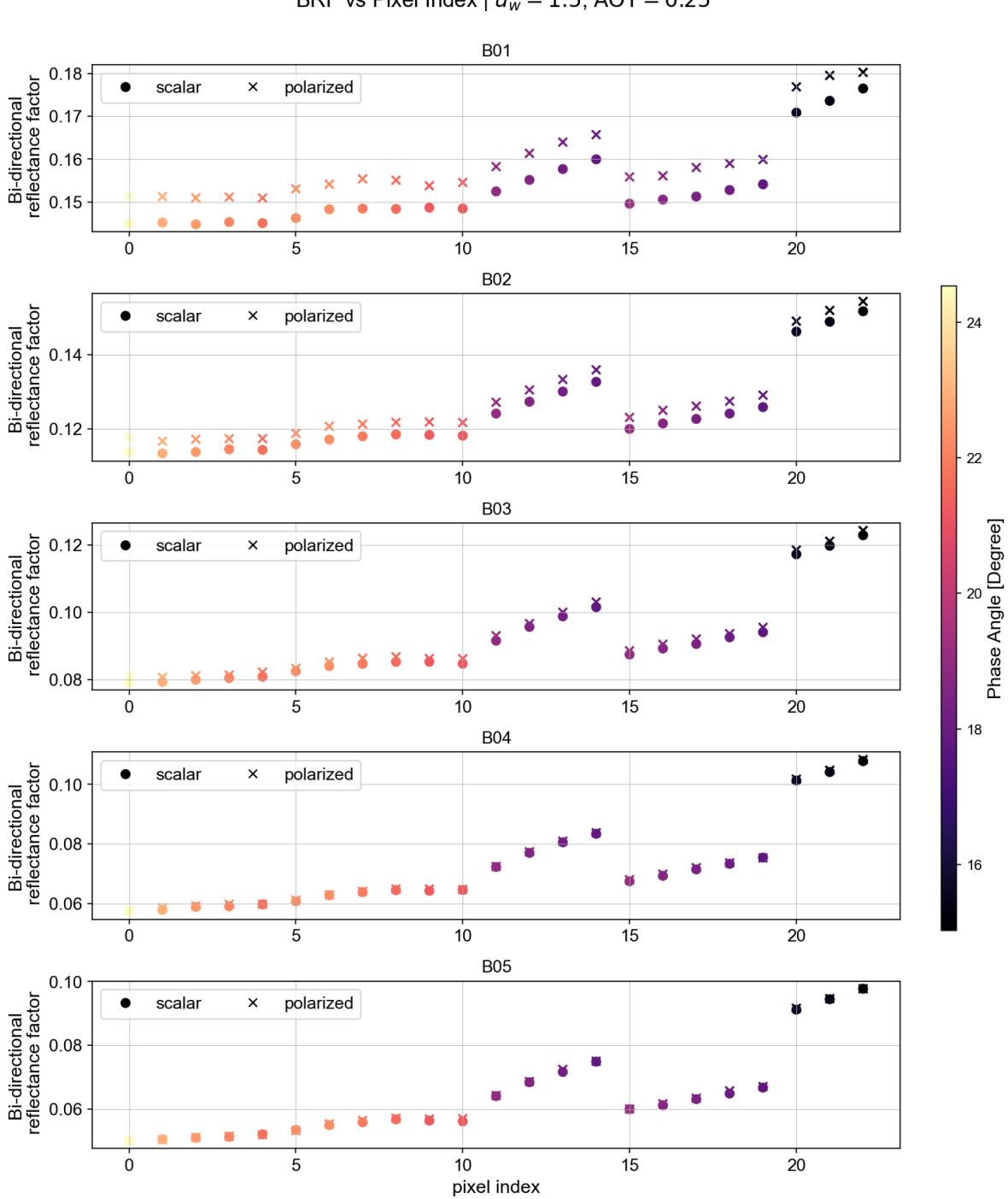
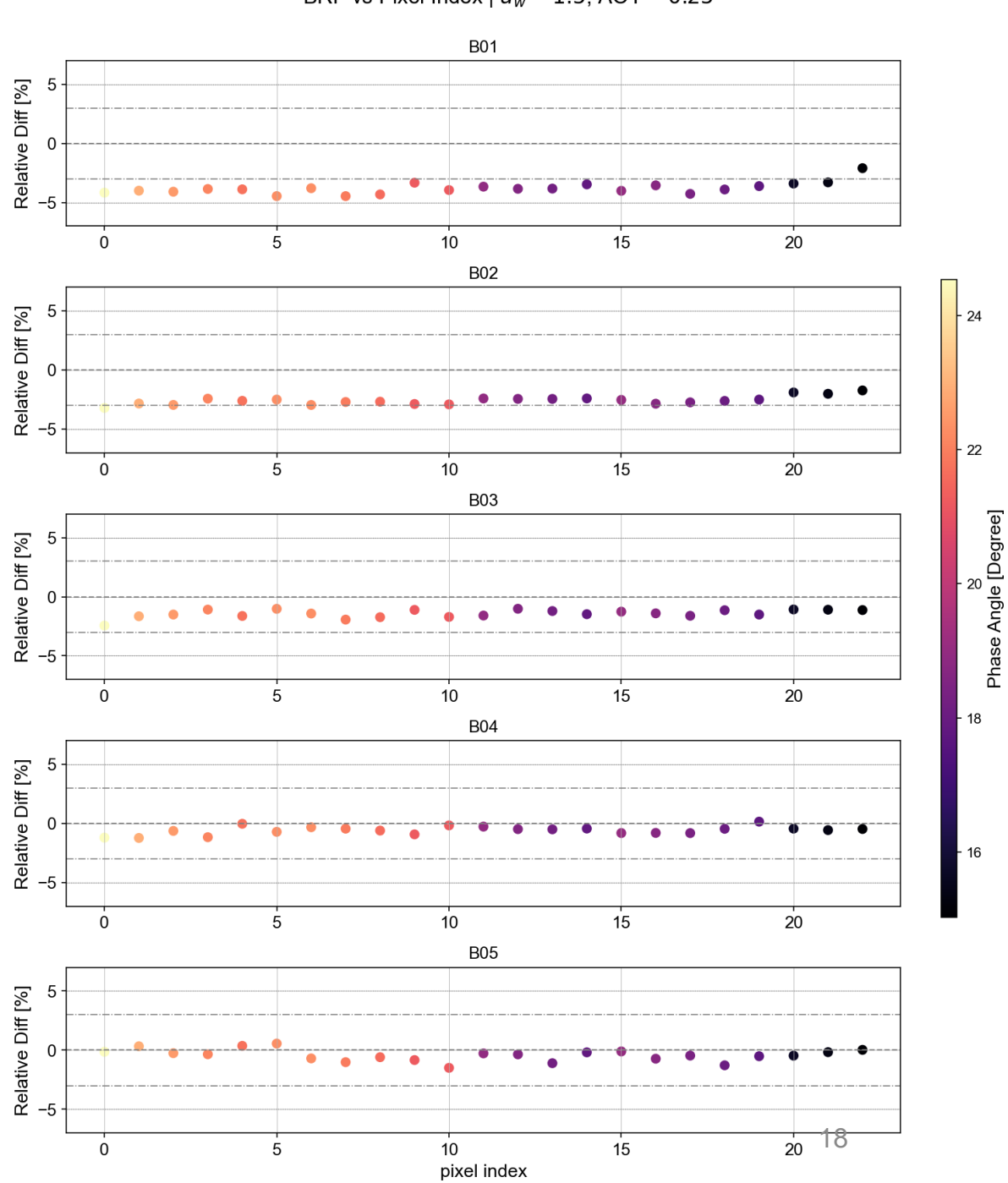
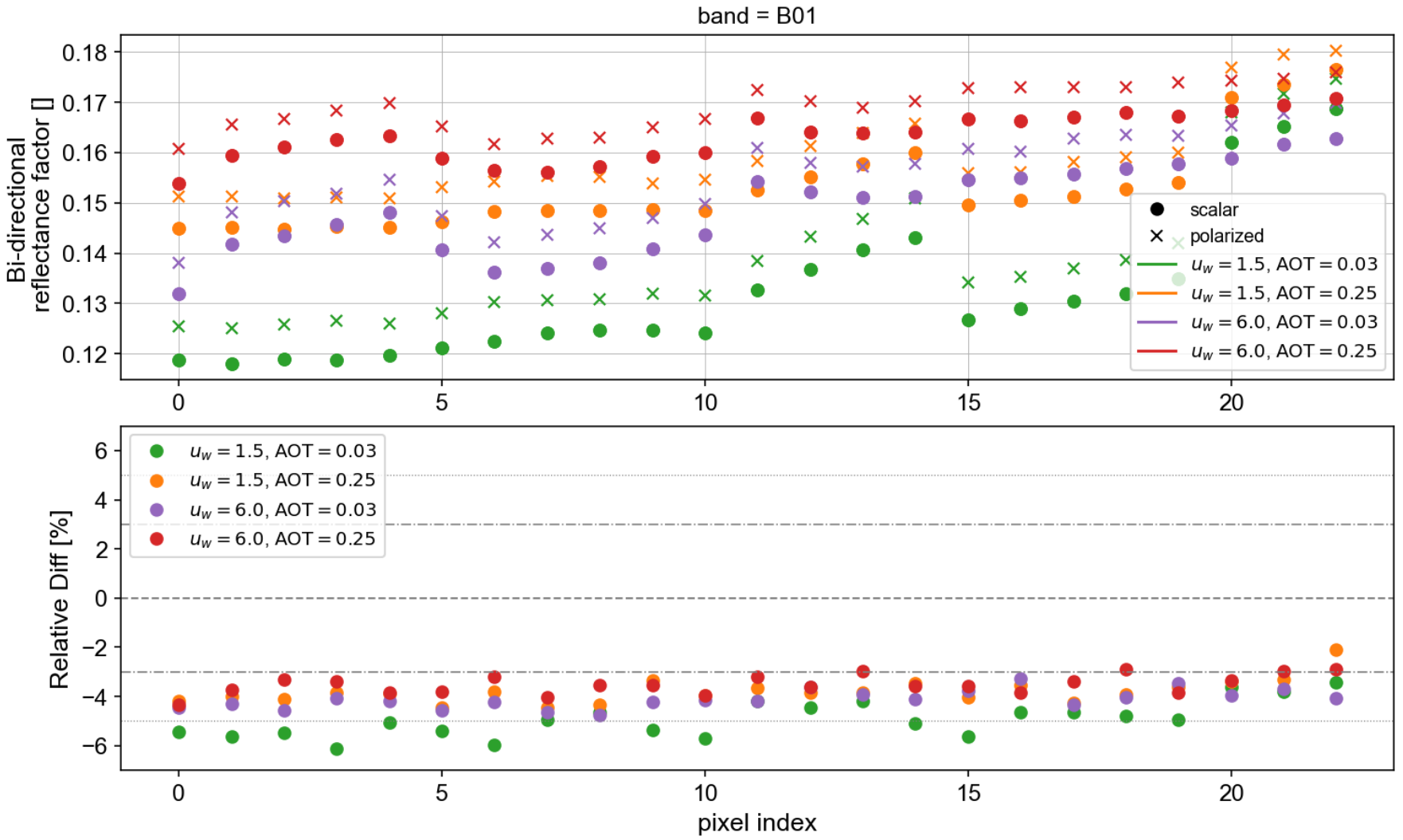





BRF vs Pixel Index | $u_w = 1.5$, AOT = 0.25
B01
B02
B03
B04
B05
scalar
polarized
Bi-directional reflectance factor
pixel index
Phase Angle [Degree]


BRF vs Pixel Index | $u_w = 1.5$, AOT = 0.25
B01
B02
B03
B04
B05
Relative Diff [%]
pixel index
Phase Angle [Degree]

Case Study: Sensitivity Study



Conclusions

- Molecular scattering can introduce errors of up to 10%. **No additional error introduced by sunglint scattering**.
- Typical geometries found in S2/MSI are susceptible to **errors of up to ~4% in band B01**.
- To reach a radiometric calibration accuracy of less than 3%, **polarization should be accounted for lower bands**.
- For interband calibration, **bands B05 and higher are less susceptible to errors** due to neglect of polarization.
- Future work:
  - Investigate effect of spherical shell geometry.
  - Compare results to observation data.

References

[1] Cox, Charles, and Walter Munk. “Measurement of the Roughness of the Sea Surface from Photographs of the Sun’s Glitter.” *Journal of the Optical Society of America* 44, no. 11 (1954): 838–50. https://doi.org/10.1364/JOSA.44.000838.

[2] G.P. Anderson, J.H Chetwynd, S.A. Clough, E.P. Shettle, and F.X. Kneizys. Afgl atmospheric constituent profiles (0-120) km. Technical Report AFGL-TR-86-0110, Air Force Geophysics Laboratory, 1986.

[3] Hess, M., P. Koepke, and I. Schult. “Optical Properties of Aerosols and Clouds: The Software Package OPAC.” *Bulletin of the American Meteorological Society* 79, no. 5 (1998): 831–44.

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Questions?