



PROBING CLOUD AND SURFACE PROPERTIES IN DISK- INTEGRATED EARTH'S OBSERVATIONS

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with

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DISK-INTEGRATED OBSERVATIONS OF EARTH: EARTHSHINE

- Sunlight scattered by Earth's atmosphere and reflected from the lunar surface
- The Moon acts as a diffuse mirror
- Resemble the way we can observe the Earth as an exoplanet



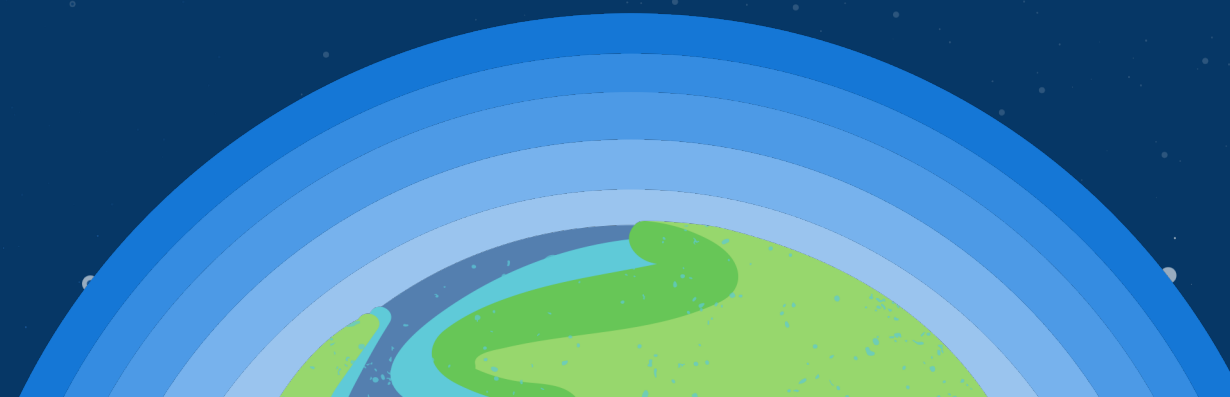
HOW TO STUDY THE EARTH AS AN EXOPLANET

SATELLITE OBSERVATIONS

- high spatial resolution
- local properties
- low spectral resolution

EXOPLANETS OBSERVATIONS

- spatially unresolved
- disk-integrated properties
- high spectral resolution



EARTHSHINE IN POLARISATION

- **Polarisation:** no need to correct for the transmission through Earth's atmosphere
- Enhance the contrast between the planet and the star
- More information on the properties of the planet



WHAT CAUSES POLARISATION?

SINGLE SCATTERING



MOLECULES

CLOUD DROPLETS

SURFACE REFLECTION



OCEAN GLINT

DEPOLARISATION

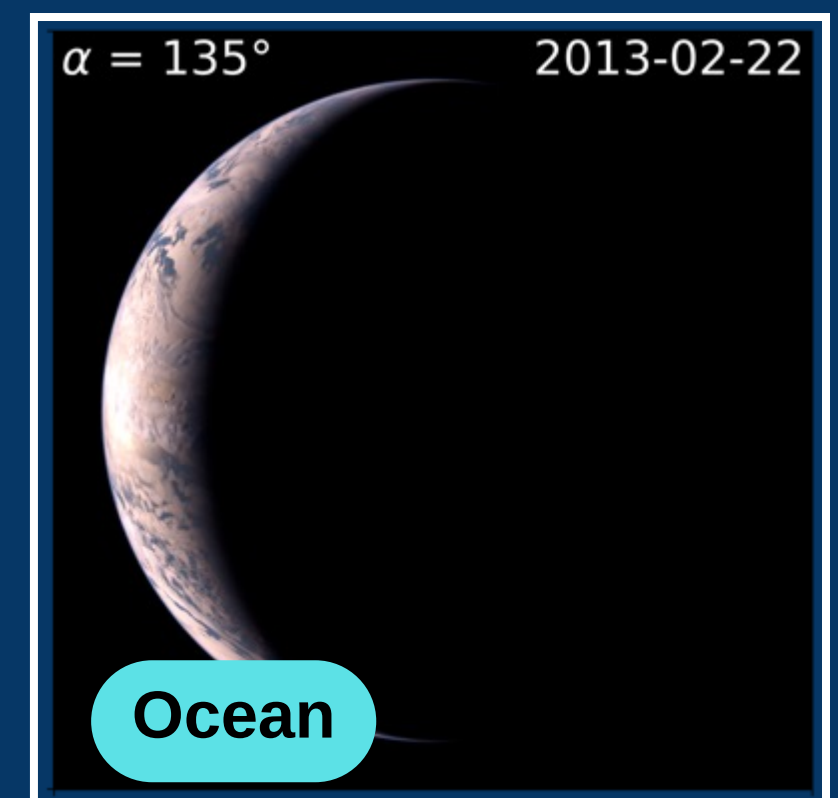
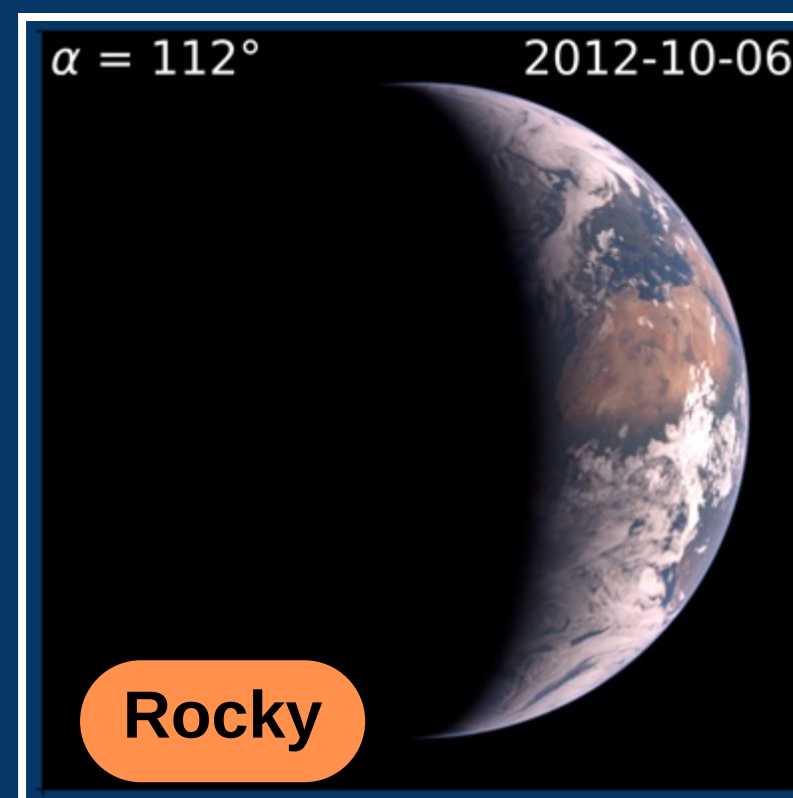
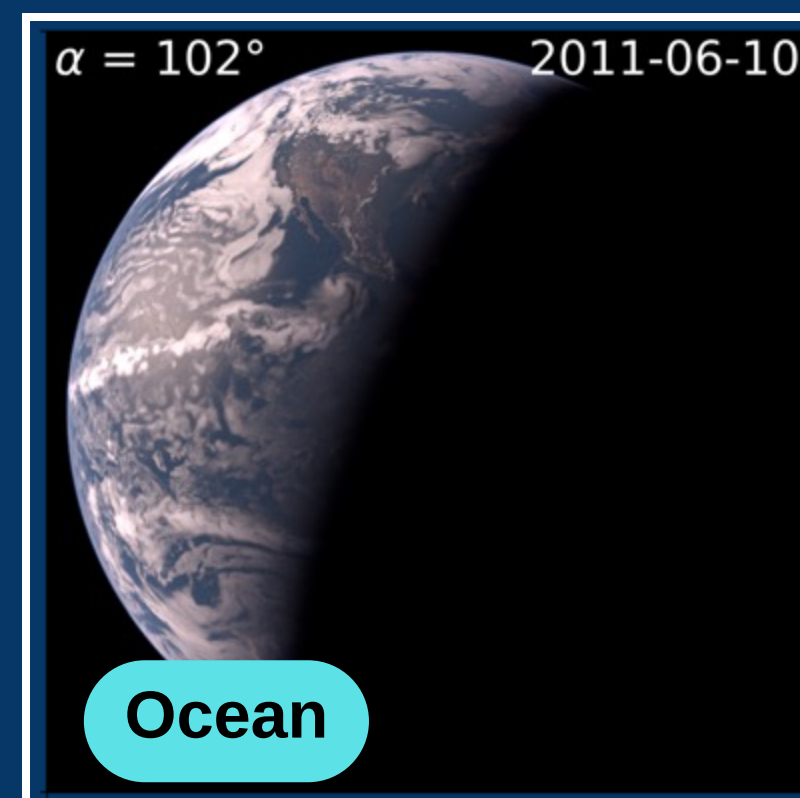
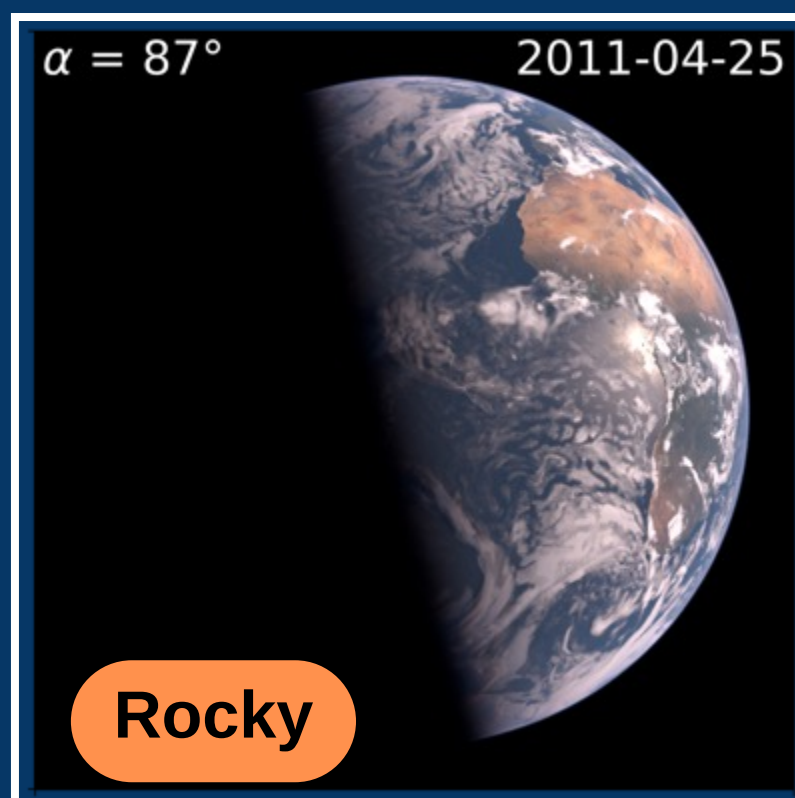
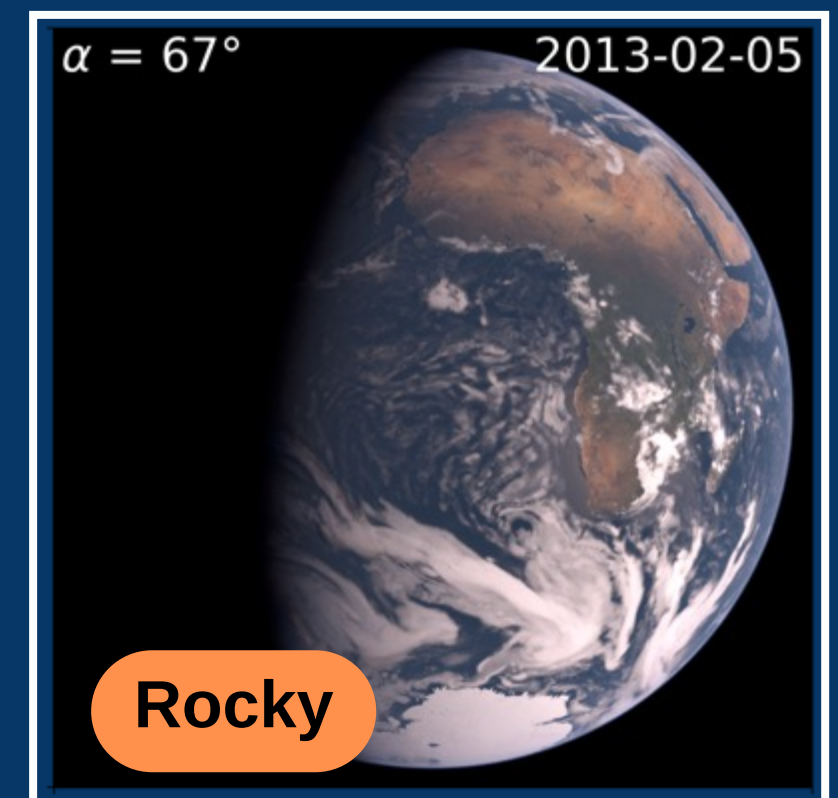
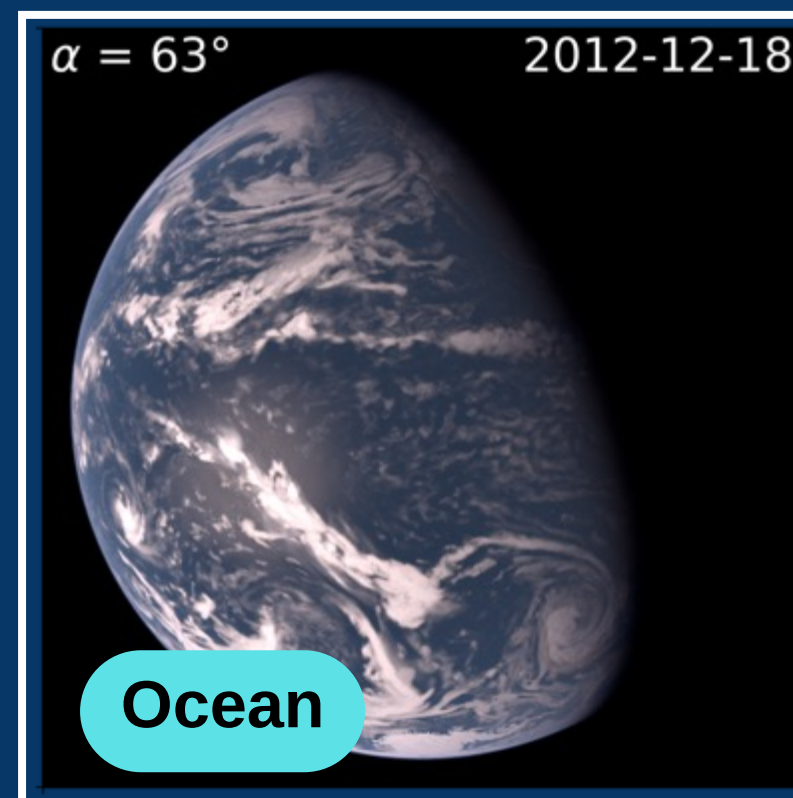
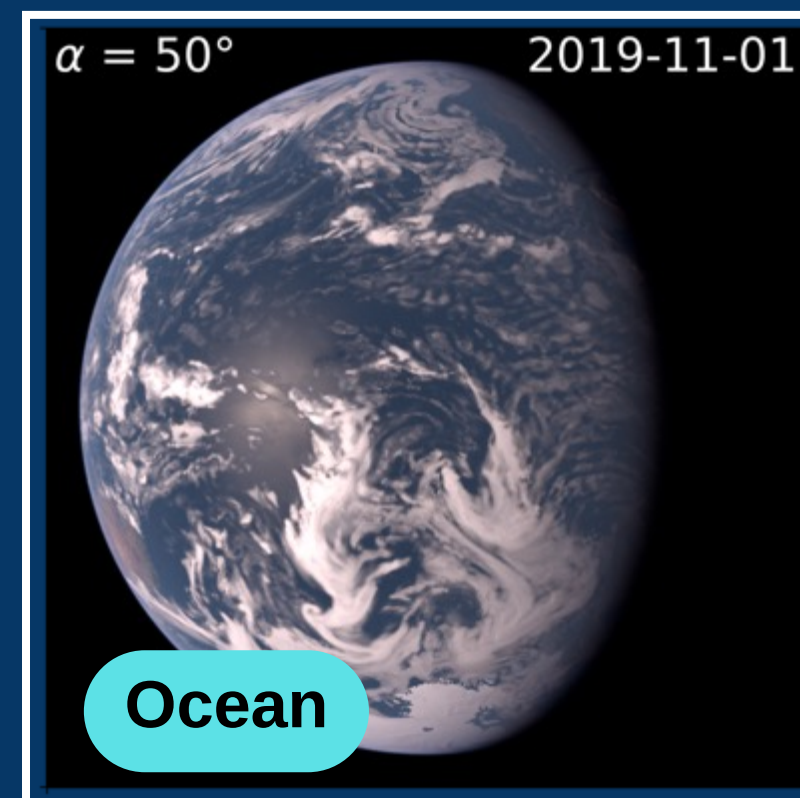
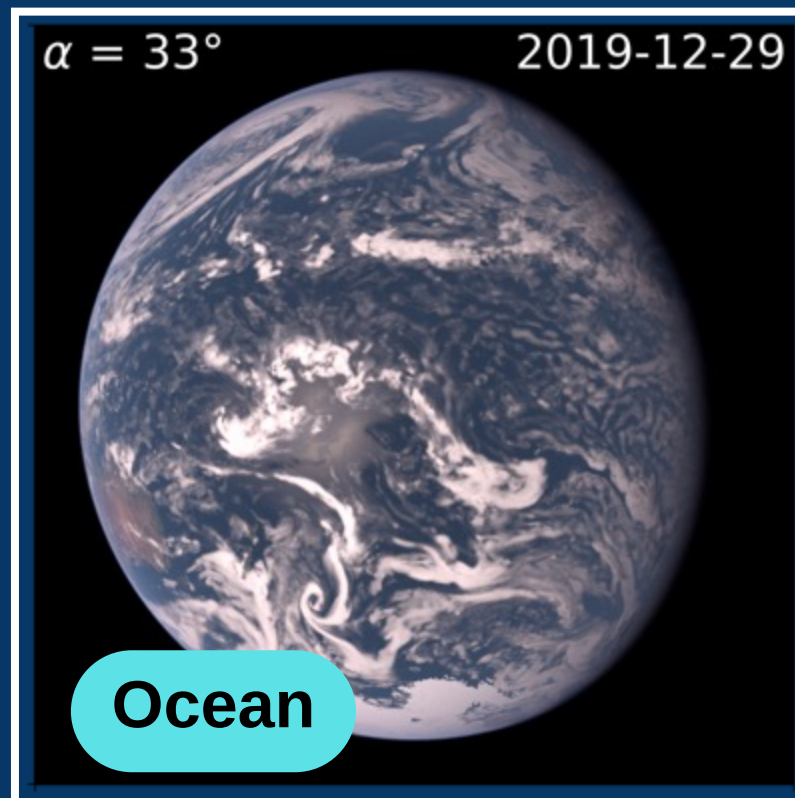


CLOUDS AND AEROSOLS



CATALOGUE OF THE OBSERVATIONS

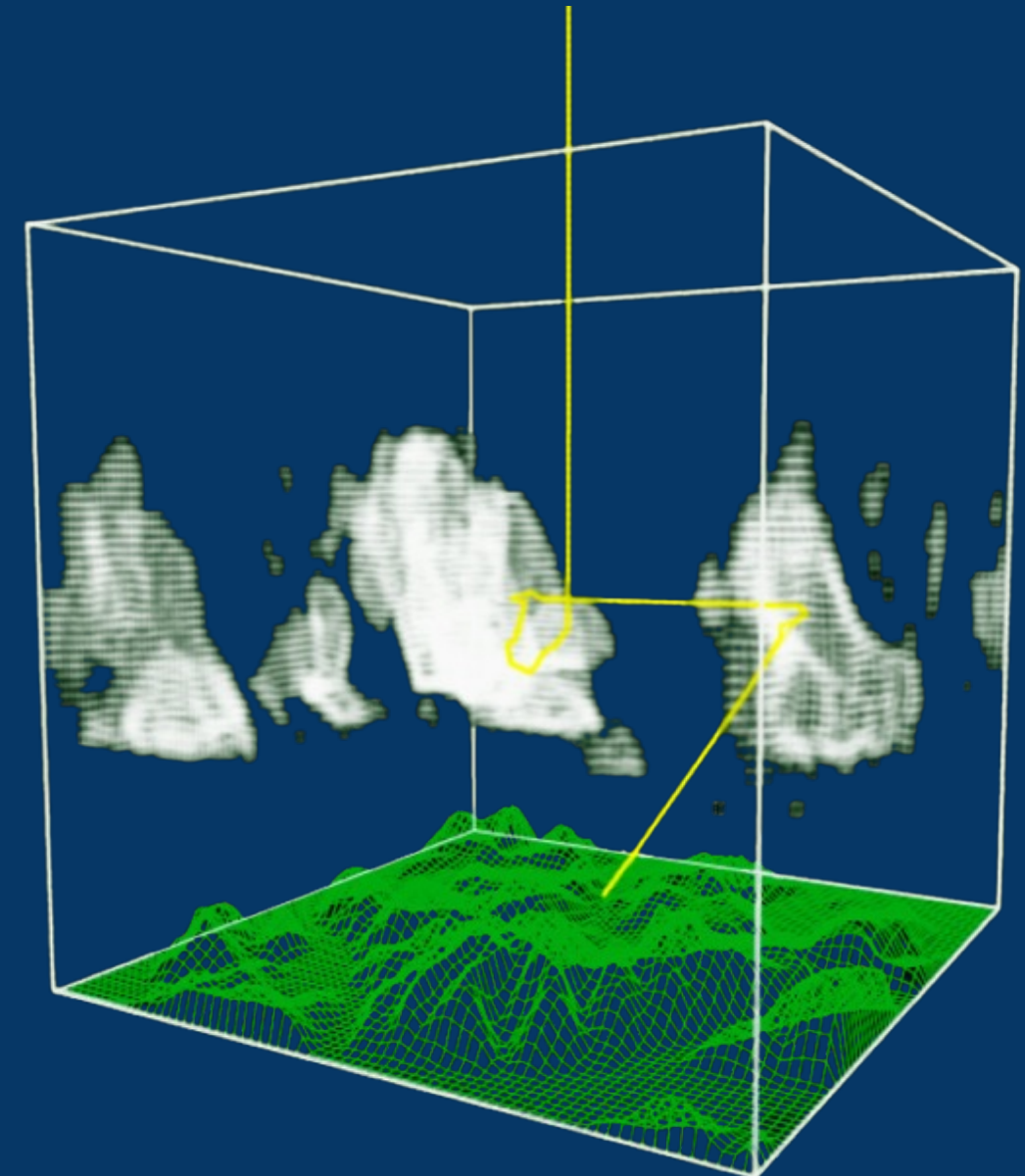
Rocetti+ 2024c (in prep.)



MODELLING EARTHSHINE

MYSTIC – Monte Carlo code for physically correct Tracing of photons in Cloudy atmospheres

- Realistic 3D atmospheres
- Inhomogeneous clouds and surfaces

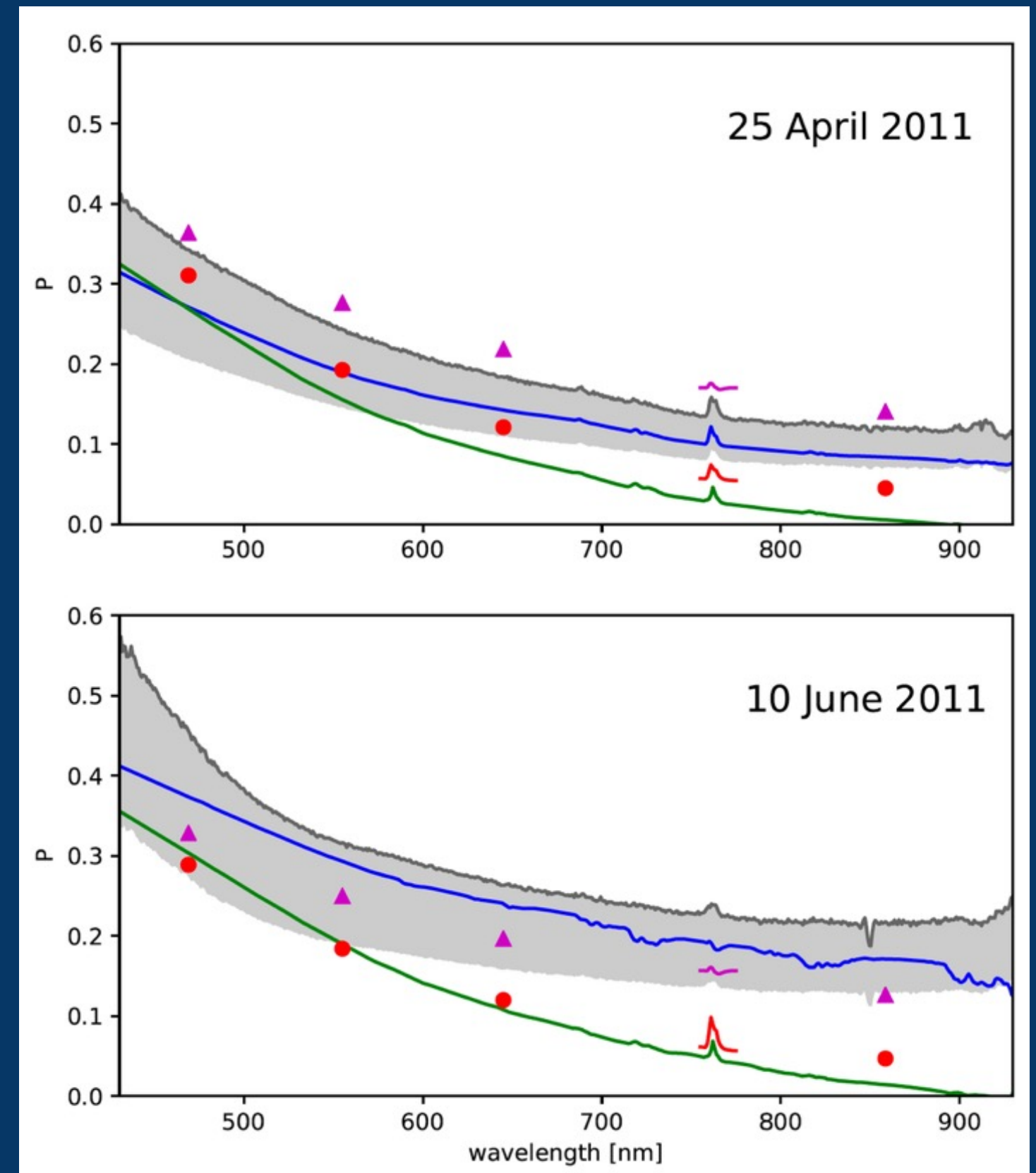


Mayer&Kylling 2005

Emde+ 2016

MODELLING EARTHSHINE

- Emde+ 2017 showed the importance of the ocean glint feature
- Simulations could not fit the observations in polarisation
- Simplistic assumptions on clouds and planetary surfaces



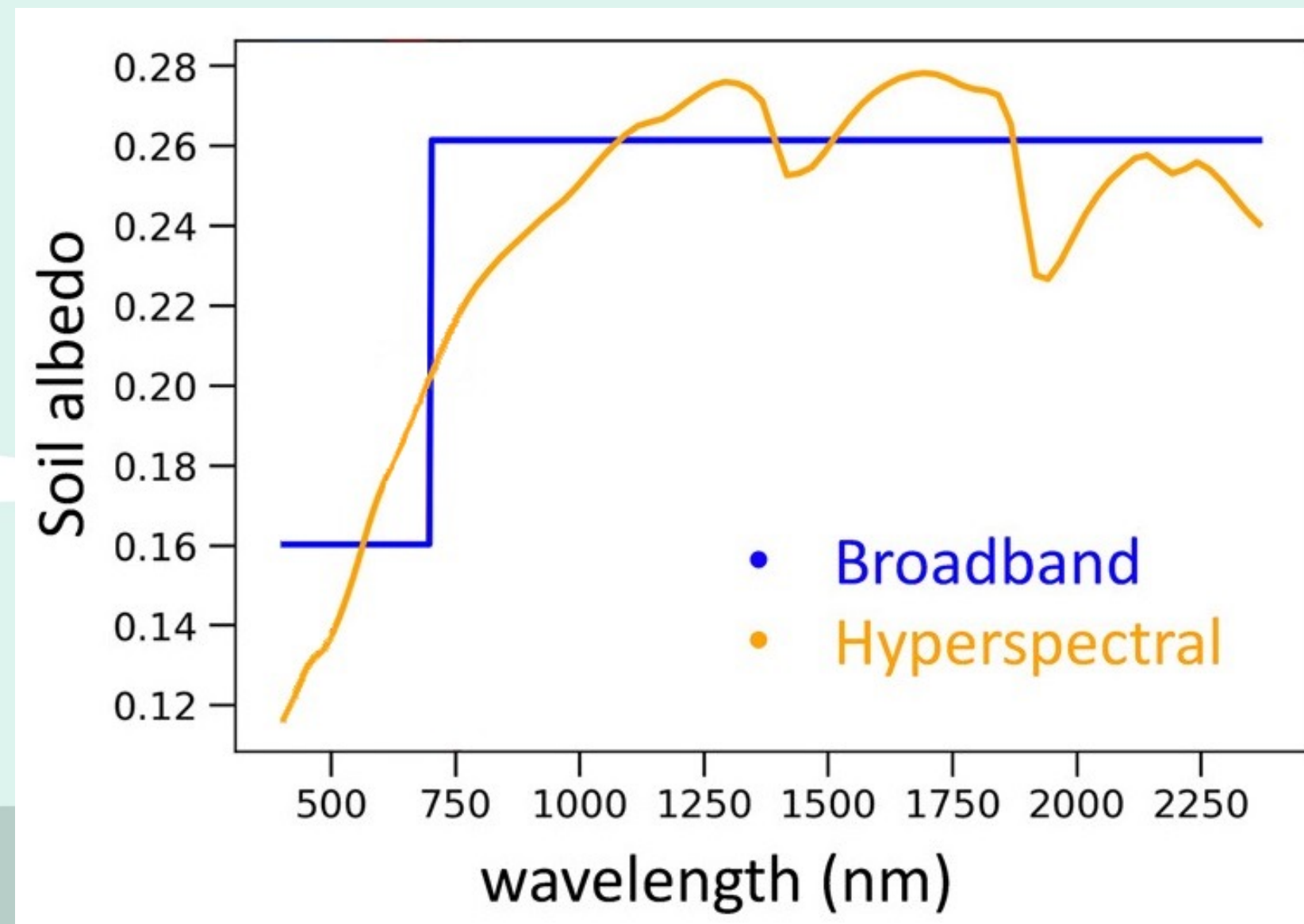
Emde+ 2017



Hyperspectral Albedo Maps

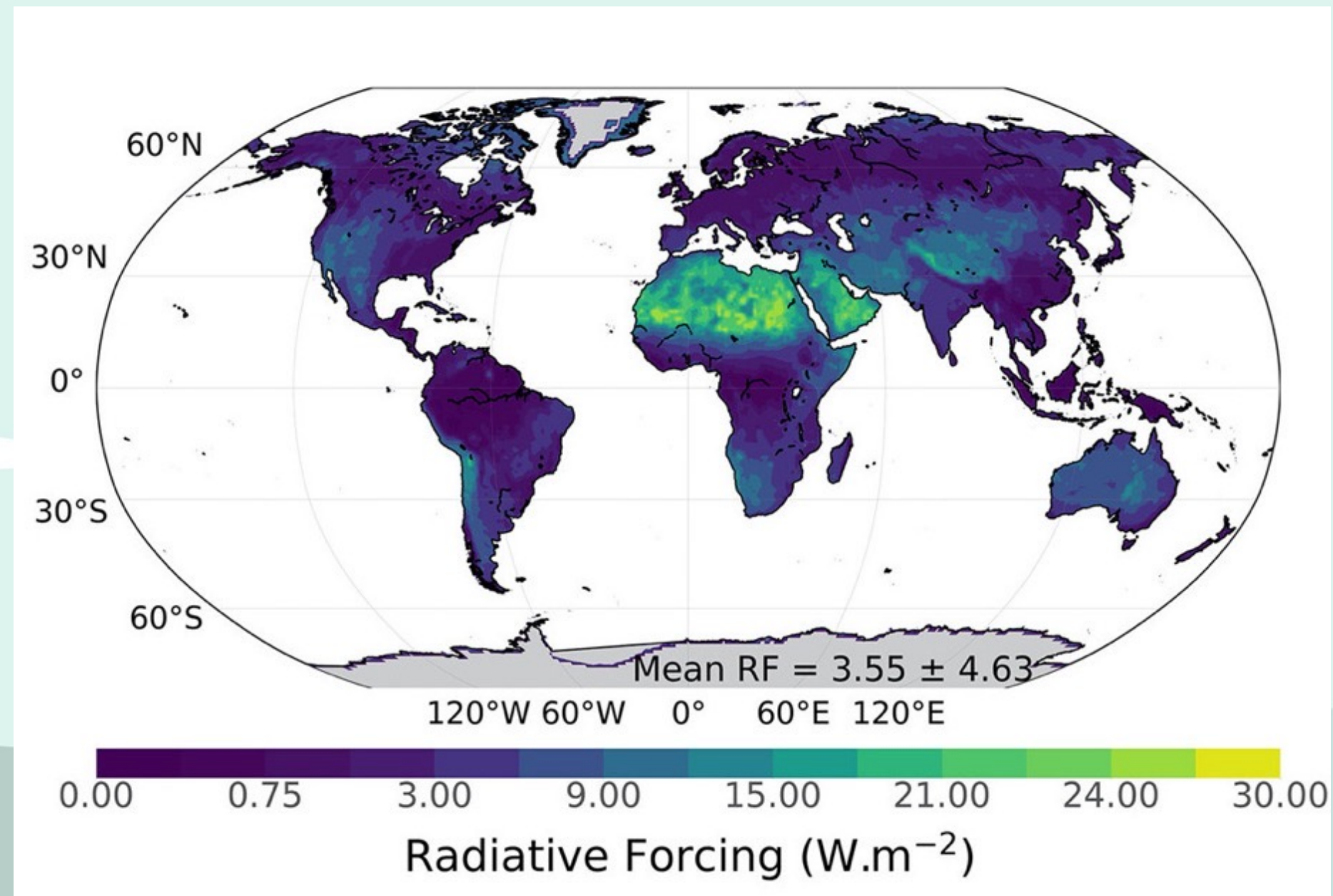
Why should we care?

- Surface albedo is crucial to estimate the energy budget of the planet
- Earth System Models (ESMs) use a two broadband albedo approach



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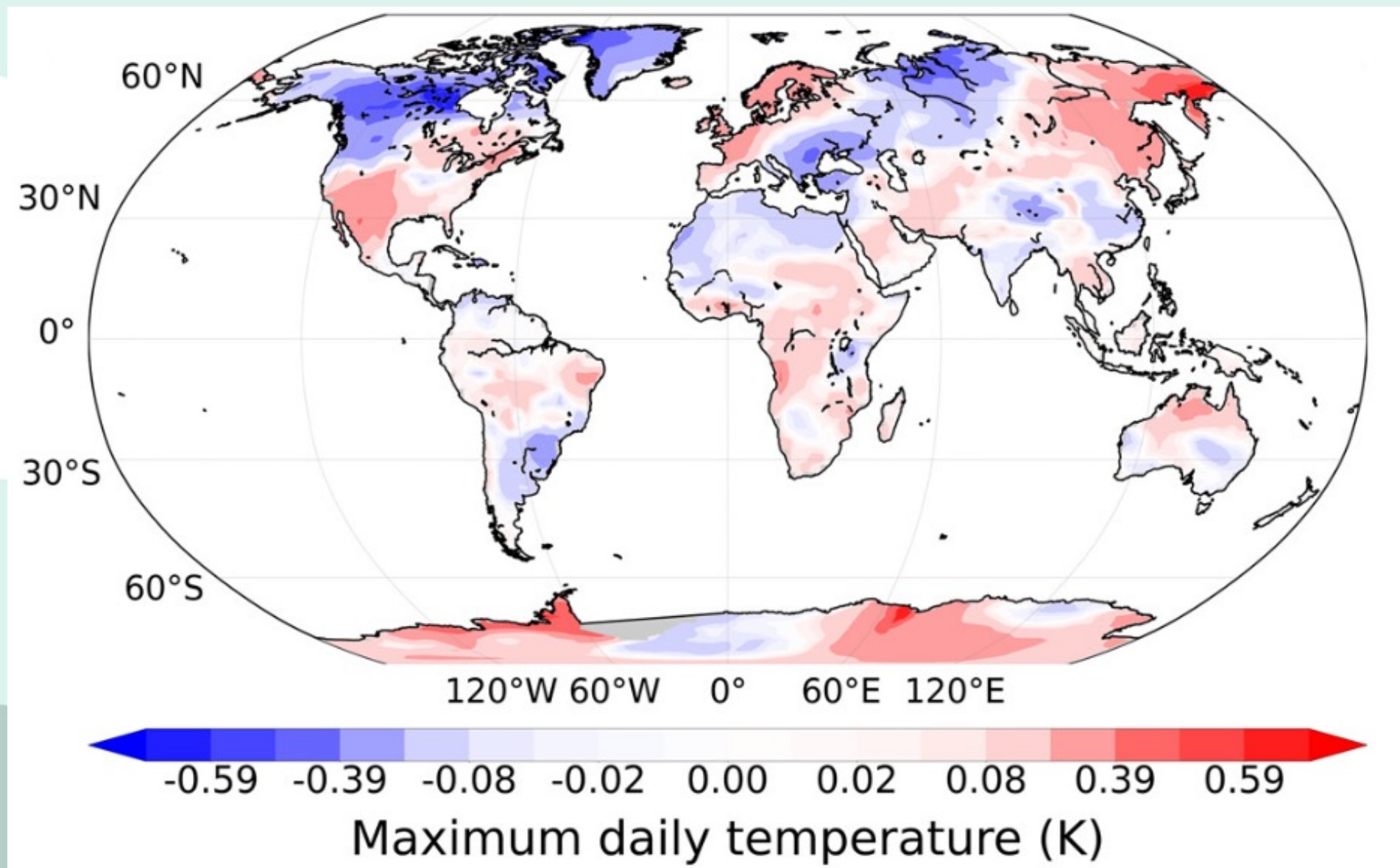
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Braghiere+ (2023)

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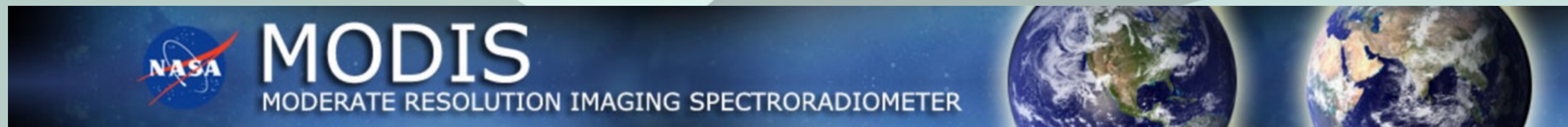
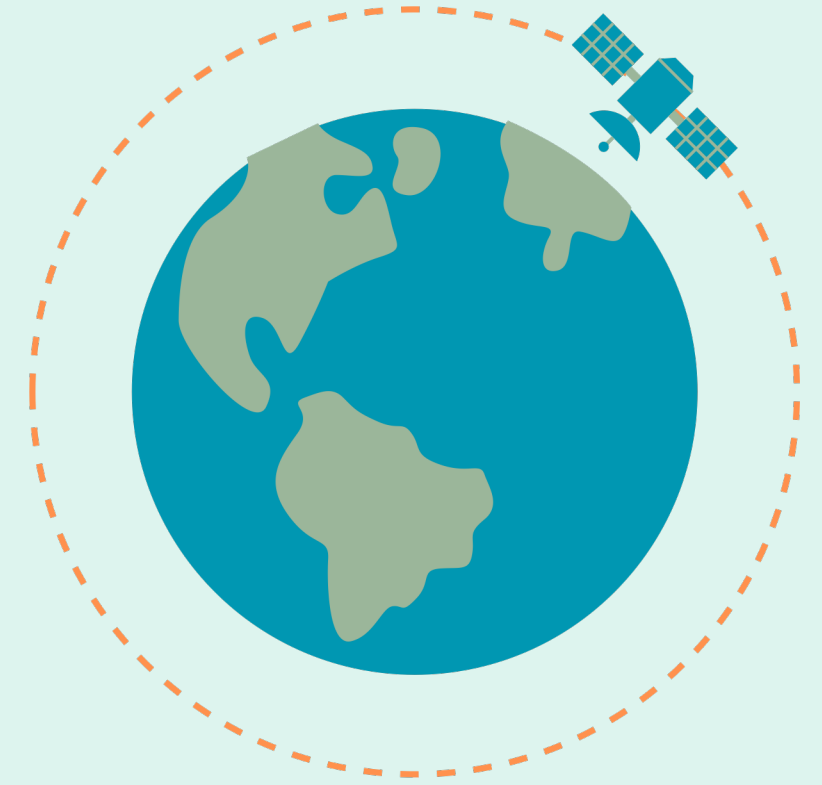


**Hyperspectral nature
of Earth's albedo
causes deviations in
climatological
patterns**
(precipitation, surface
temperature)

Braghiere+ (2023)

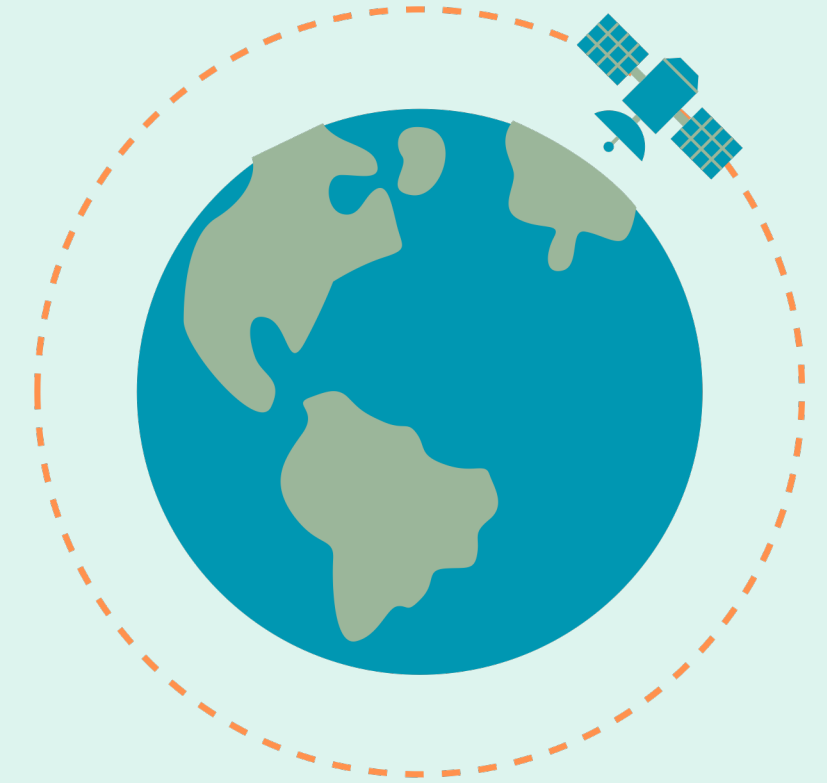
MODIS albedo product

- MODIS Surface Reflectance dataset (MCD43C3, Version 6.1)
- Detailed albedo maps across seven spectral bands in the visible and near-infrared



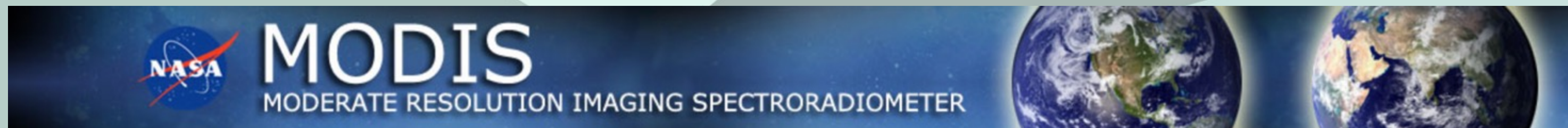
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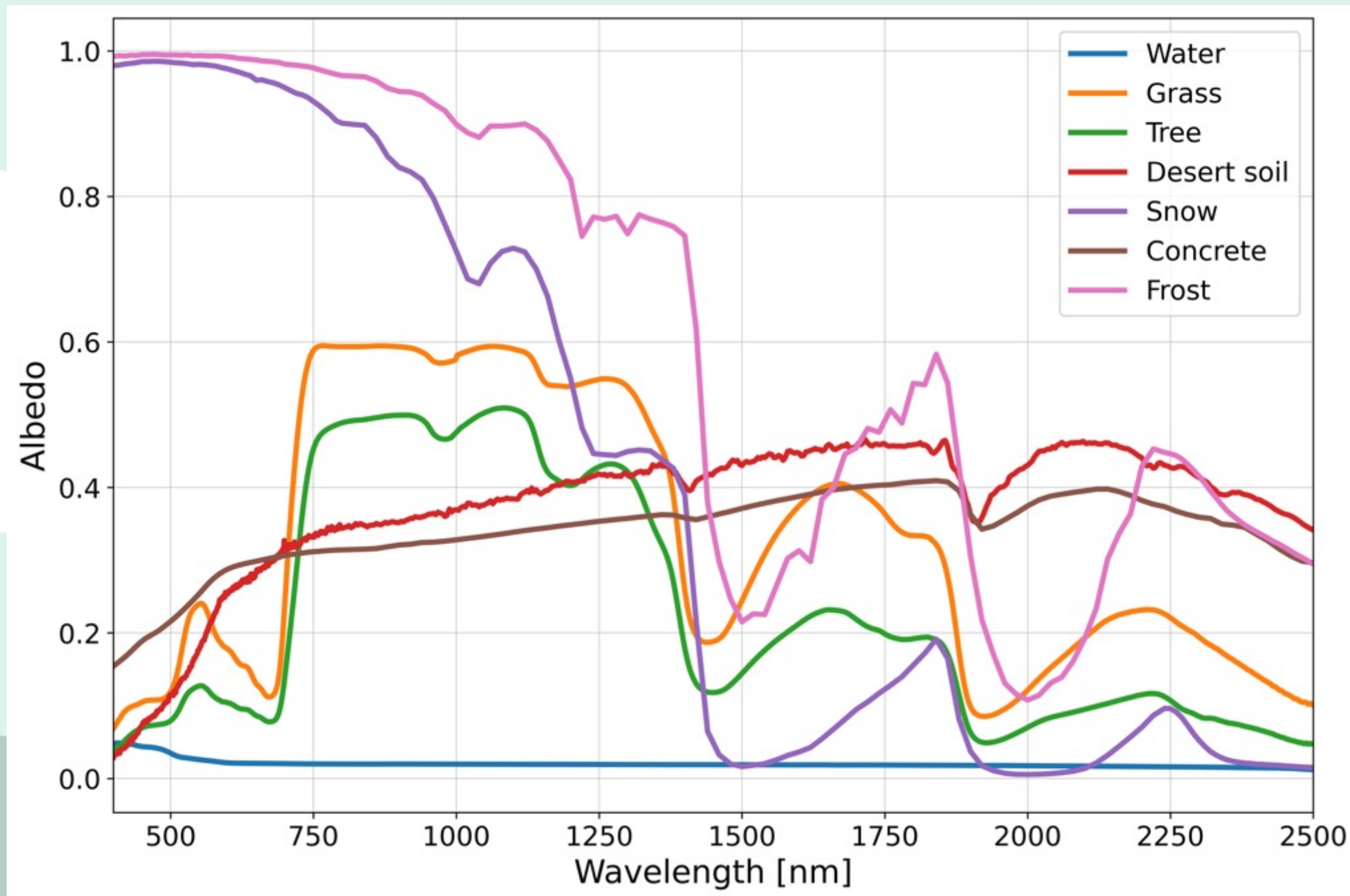
MODIS climatology

- We average the MODIS dataset over a 10-years period (2013 to 2022)
- Fill missing values in the albedo dataset



Soils and vegetation spectra

- Laboratory and in-situ measured spectra



26635 spectra
82 countries
3 datasets:

LUCAS

ECOSTRESS

ICRAF/ISRIC

Principal Component Analysis (PCA)

Soils and
vegetation
reflectivity
spectra



PCA
regression
algorithm



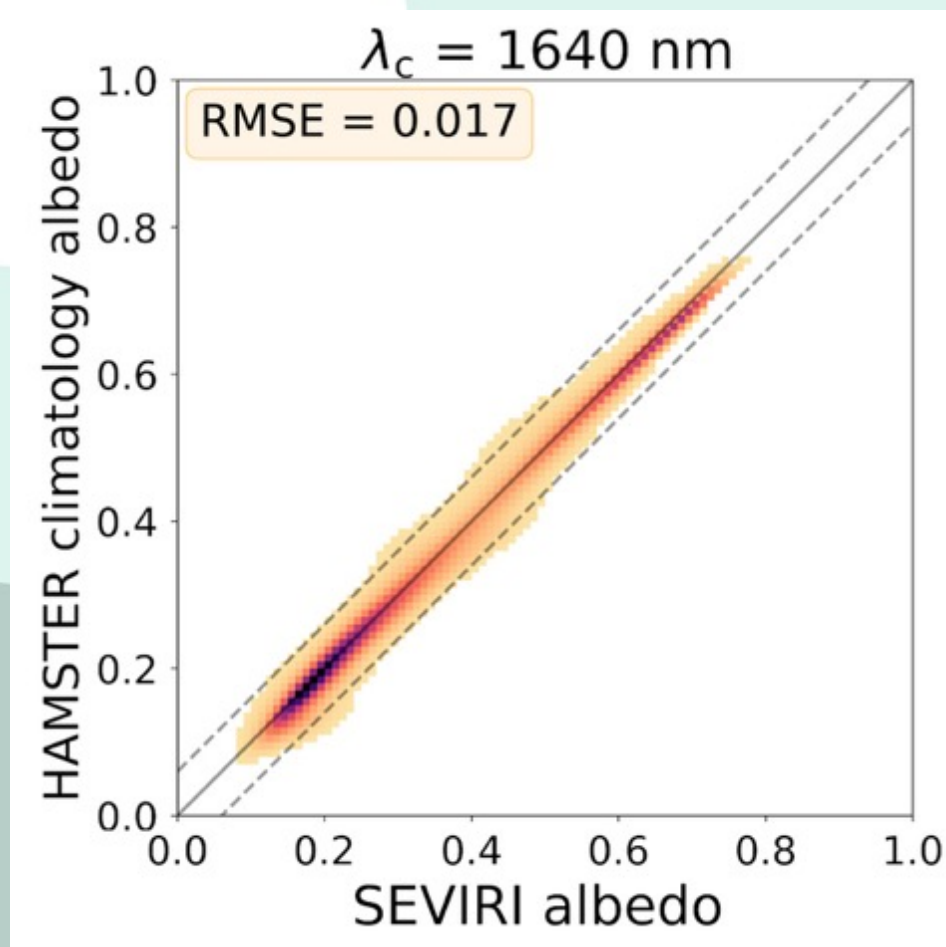
MODIS
climatology



Introducing HAMSTER

Global hyperspectral albedo maps

- Spectral resolution: 10 nm
- Spatial resolution: 0.05° (or finer)
- Temporal resolution: 1 day



**Hyperspectral
Albedo Maps
dataset for high
Spatial and
TEmporal Resolution**

Validated against SEVIRI and
TROPOMI land surface
products

Rocetti+ 2024a

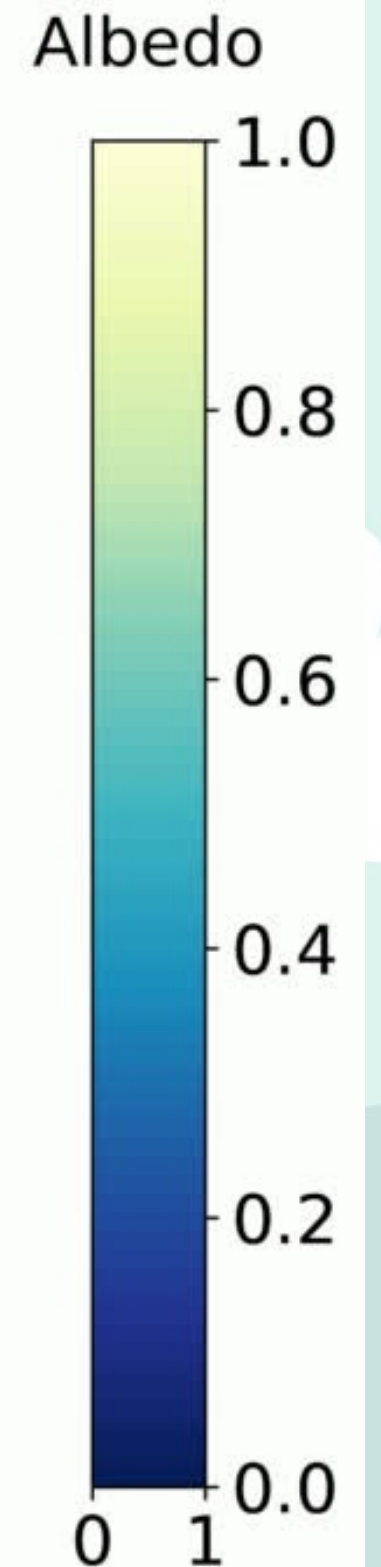
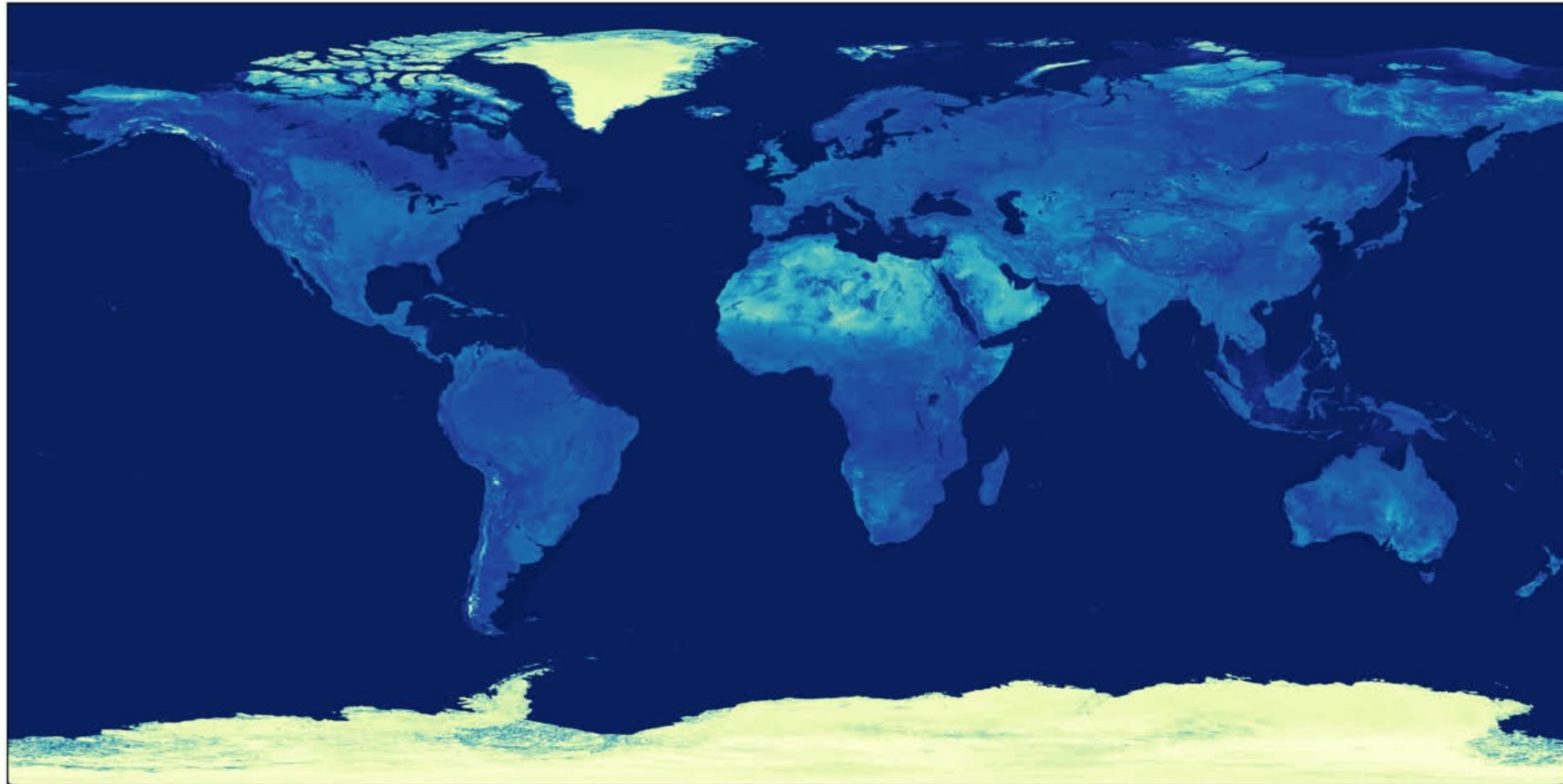




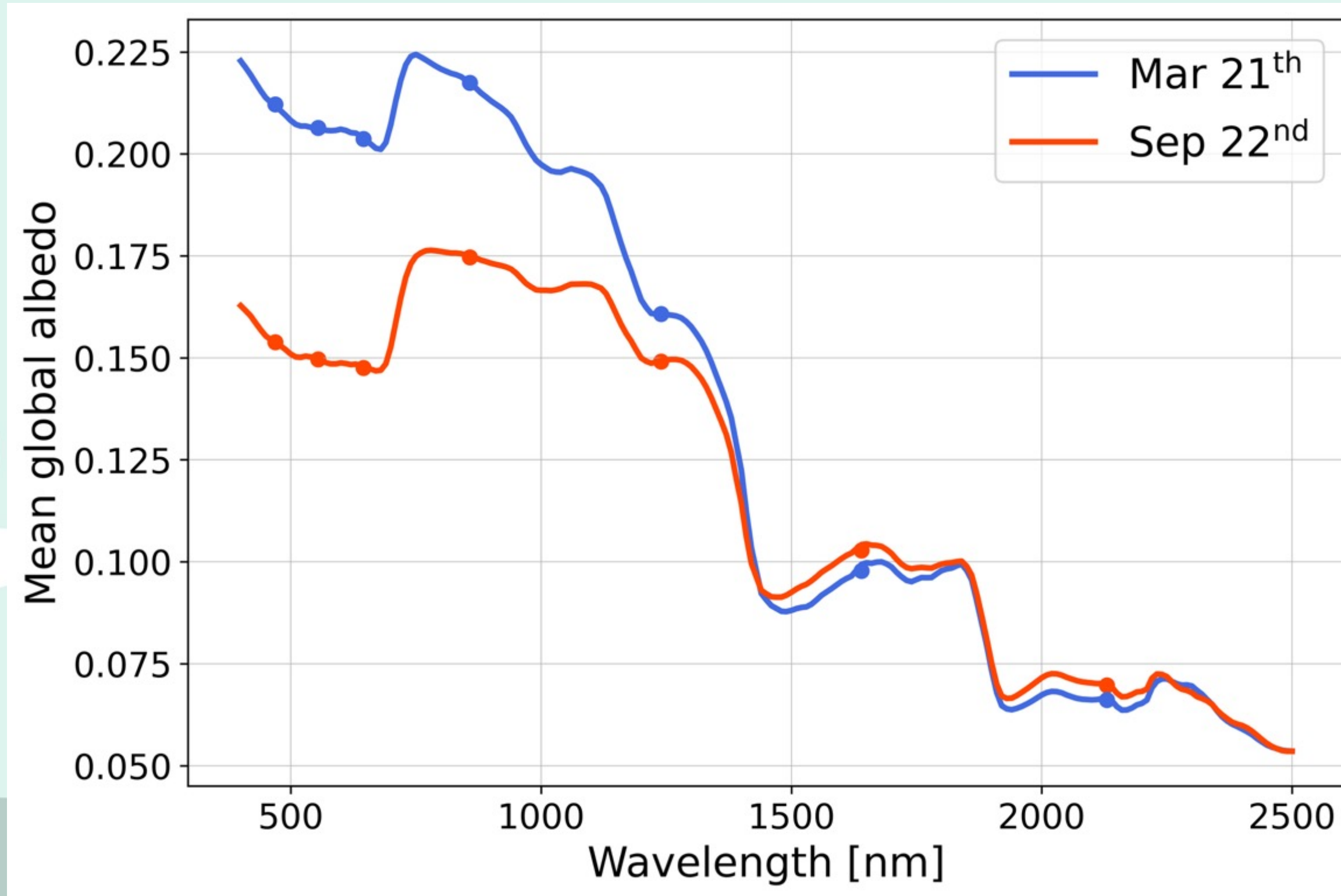
Mean global albedo

Rocetti+ 2024a

$\lambda = 760 \text{ nm}$



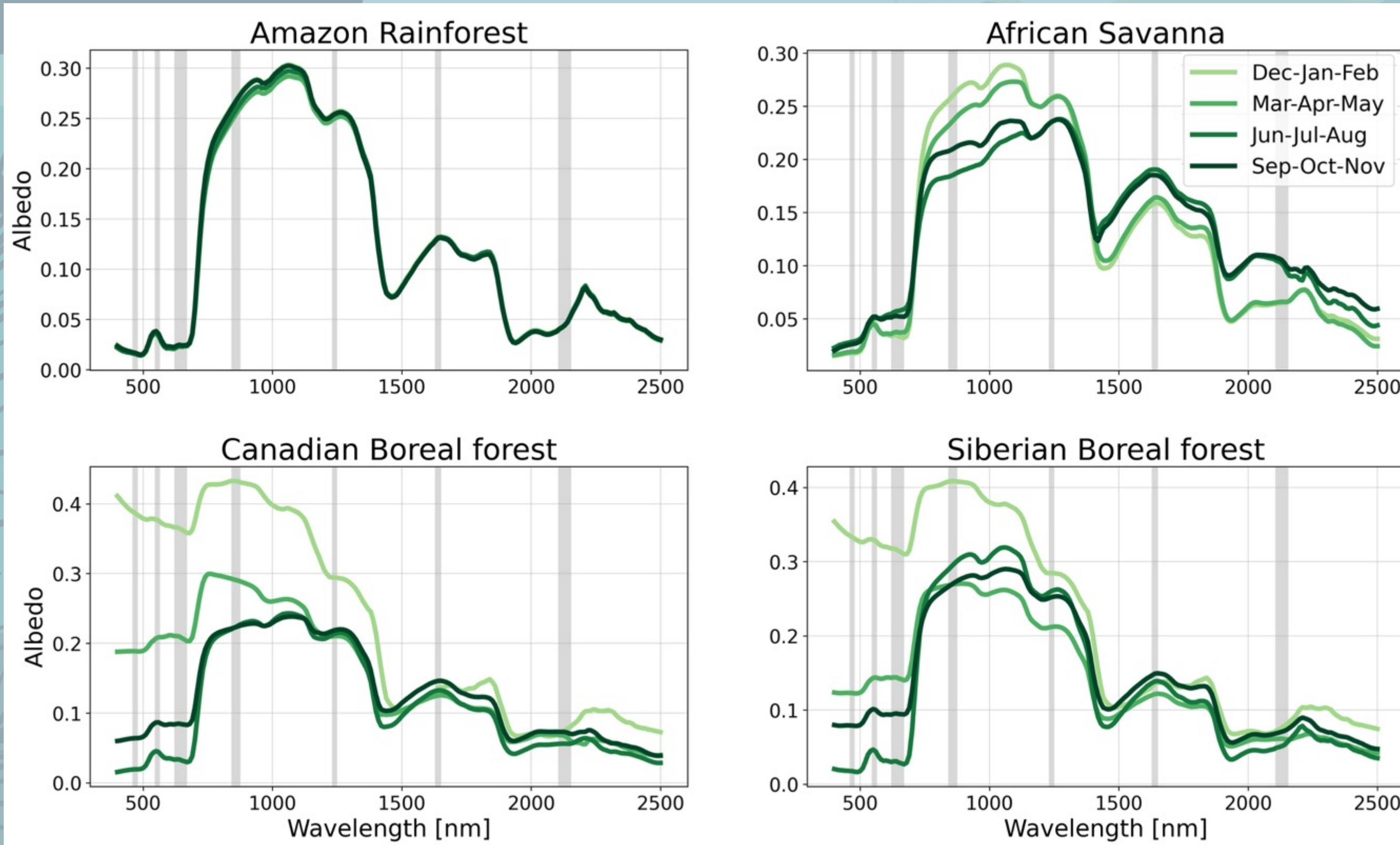
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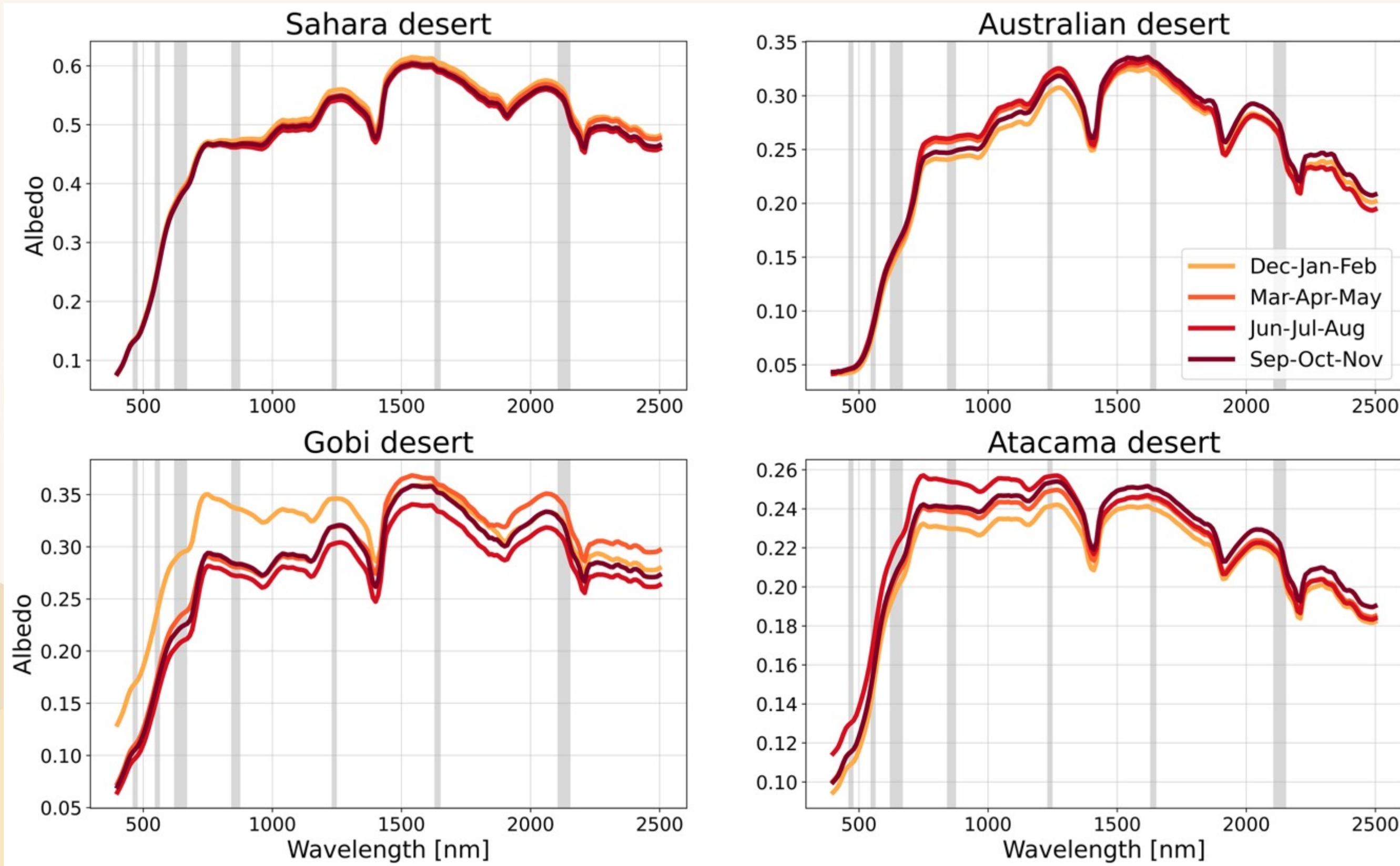
Rocetti+ 2024a



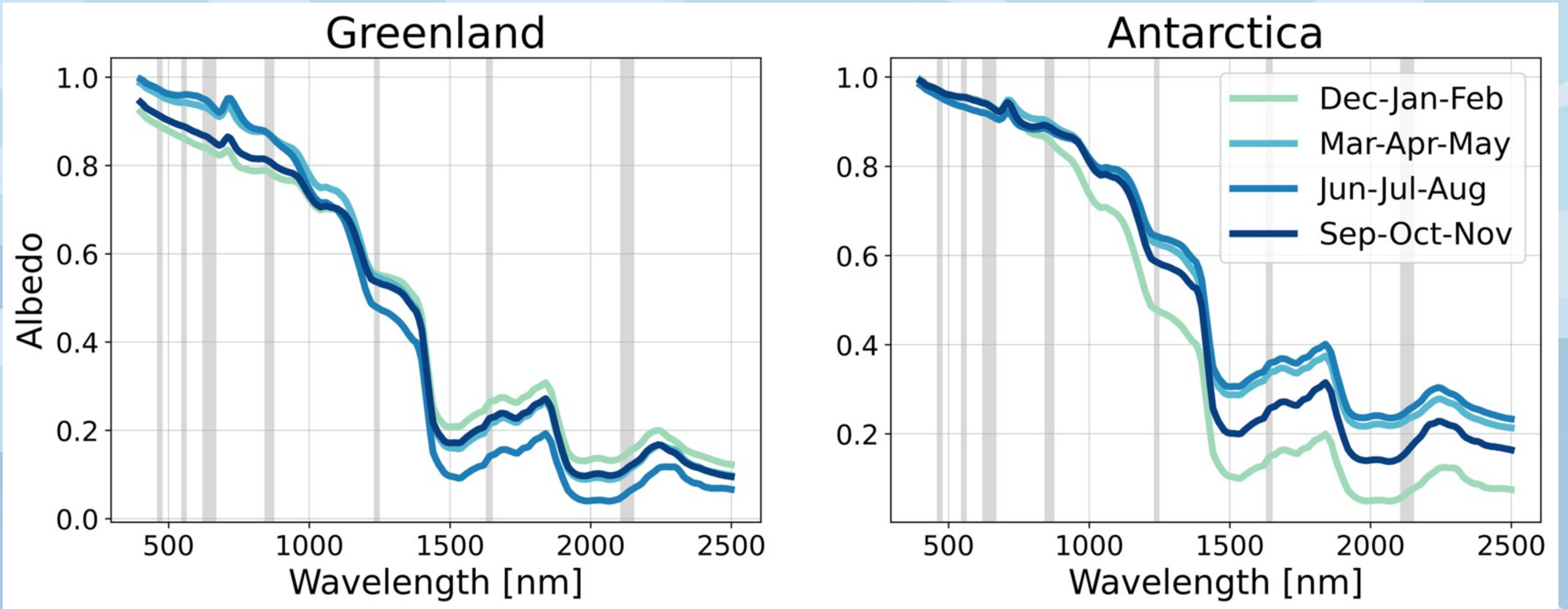
Forests



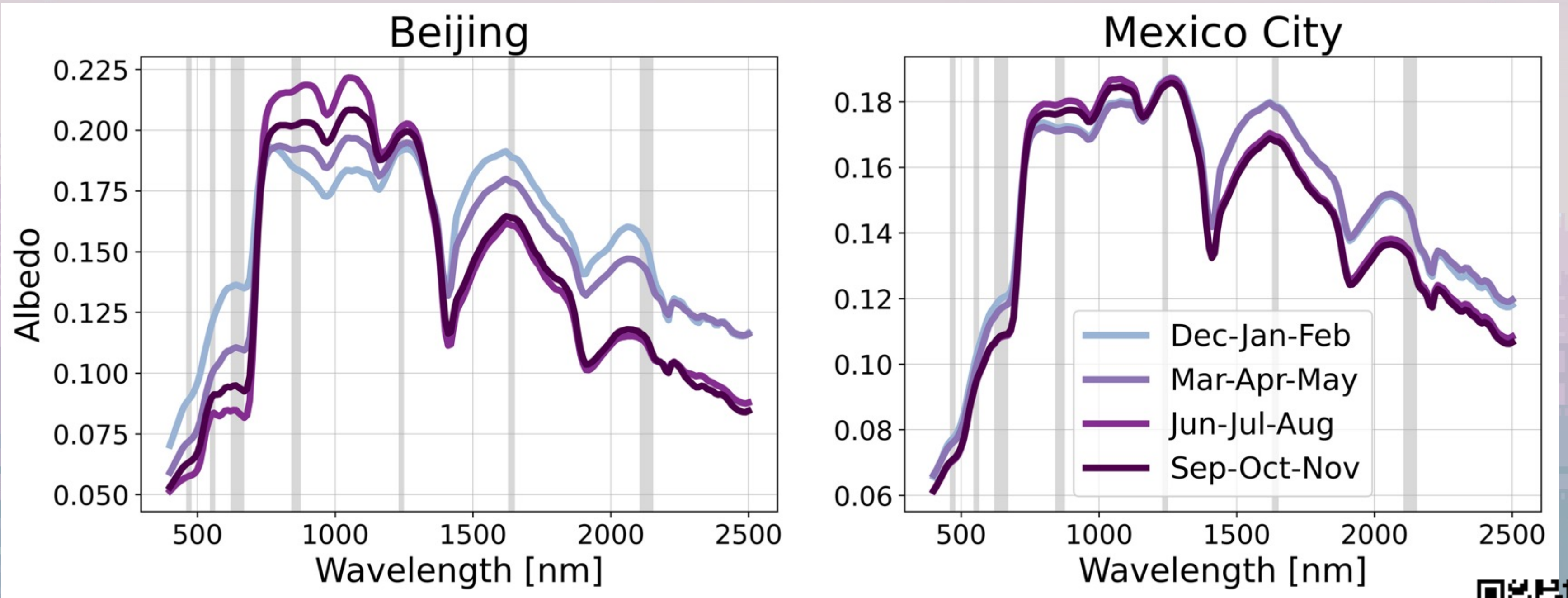
Deserts



Ice sheets



Cities



The background is a solid teal color. It features several stylized, light blue clouds of various sizes and shapes. The clouds are composed of overlapping rounded rectangular shapes, giving them a soft, fluffy appearance. They are scattered across the frame, with some larger clouds in the top-left and bottom-center, and smaller ones in the top-right, middle-left, and middle-right.

Clouds

CLOUDS

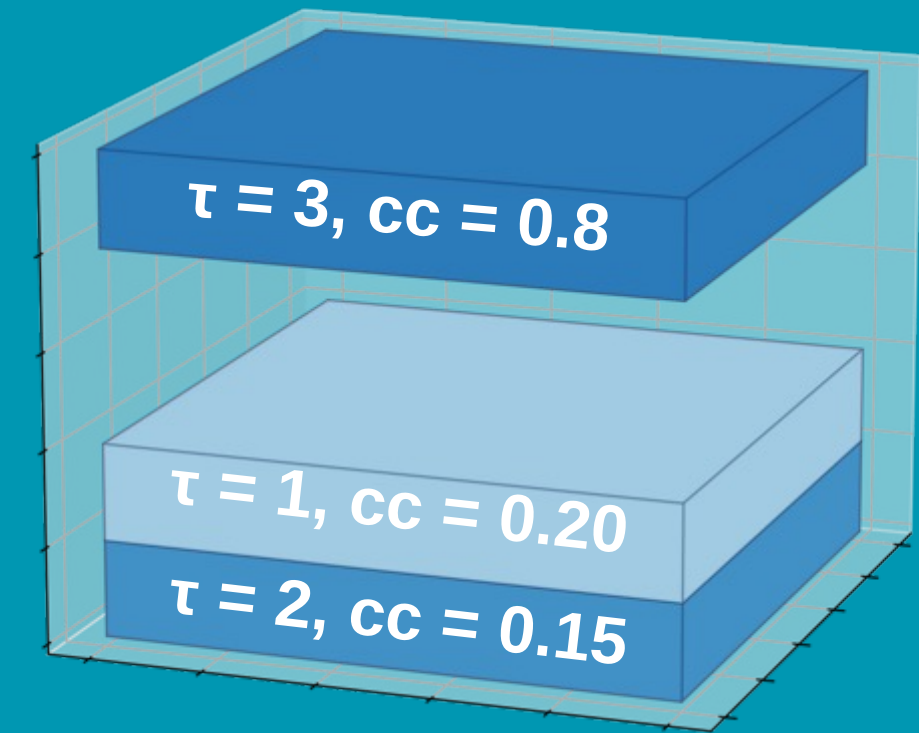
- Reflectivity of the planet strongly depends on cloud assumptions and modelling
- ERA5 reanalysis product – global weather forecast model



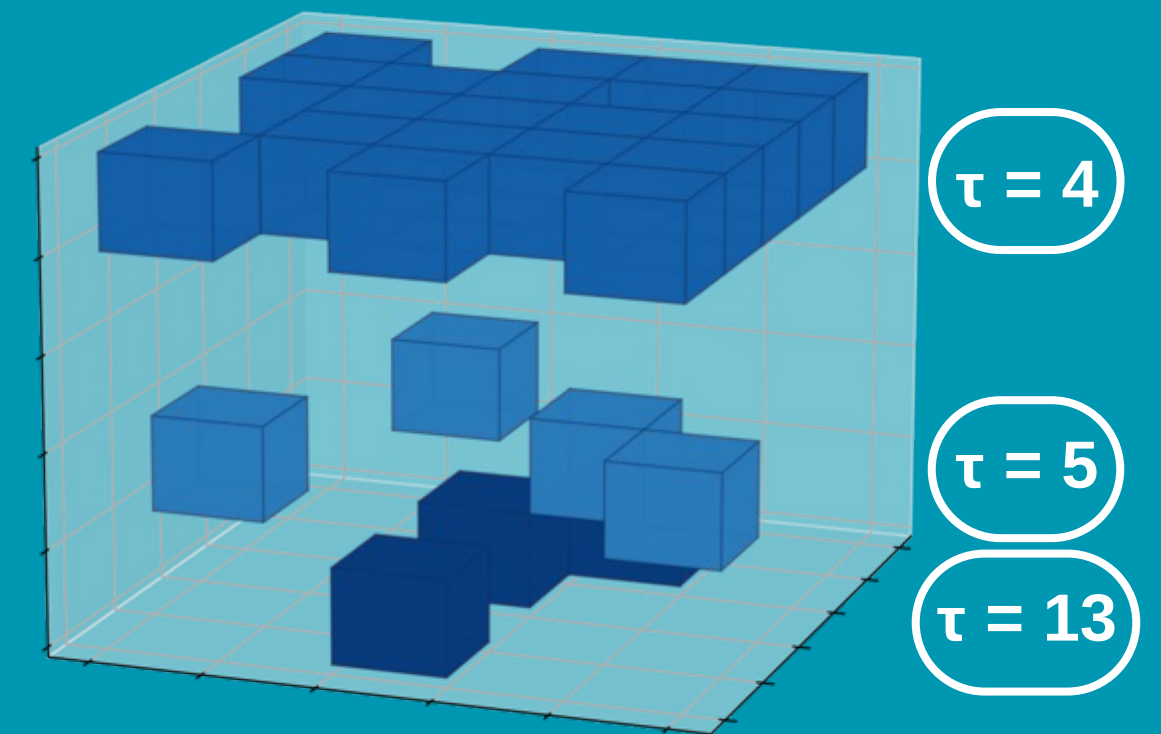
Roccetti+ 2024b (in prep.)

3D CLOUD GENERATOR

- Cloud generator: dividing clouds in subgrids (Hogan & Bozzo 2018)
- Sub-grid horizontal variability of cloud cover lowers the reflectance of the cloud field
- Fundamental step towards realistic radiances from TOA



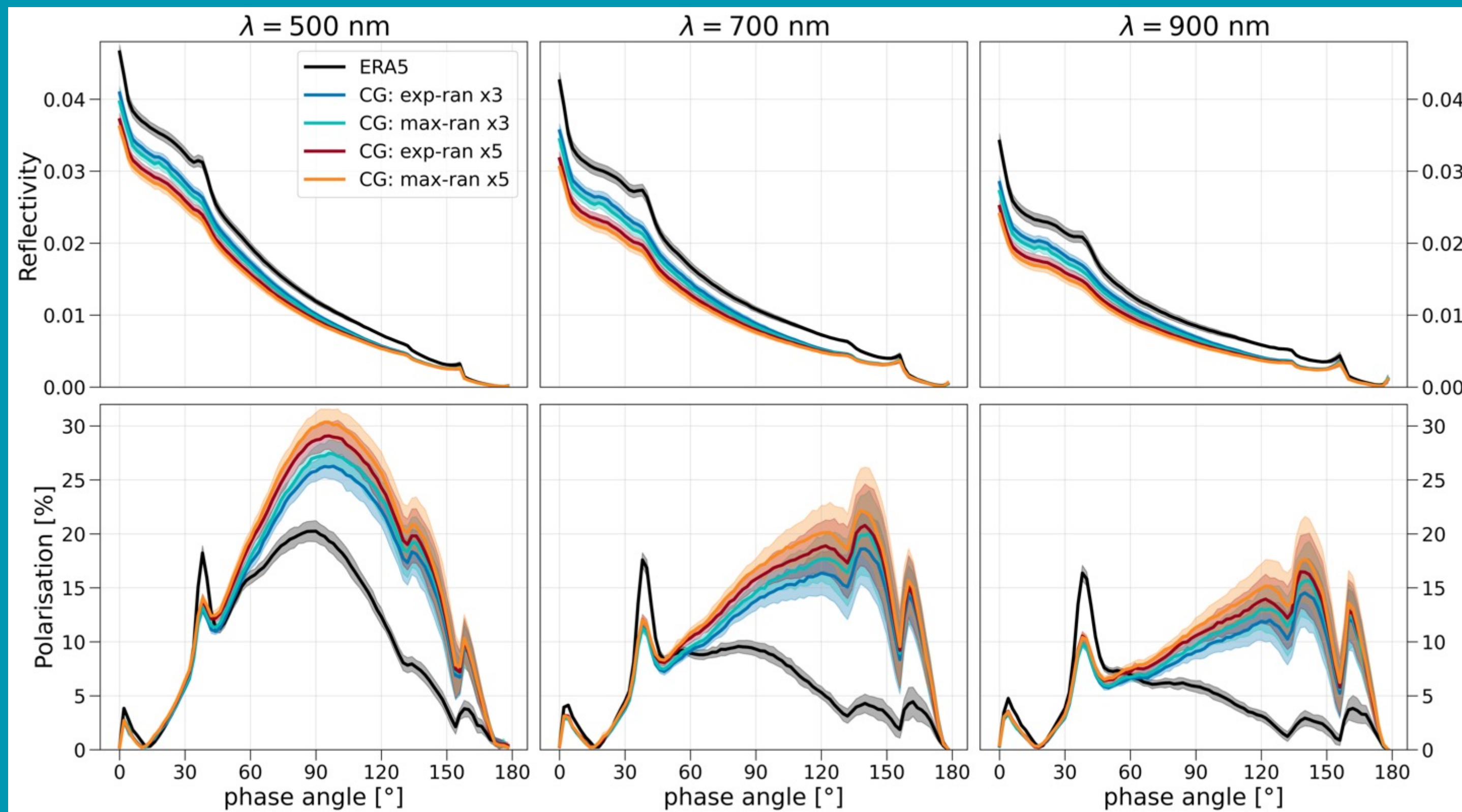
**Clouds inhomogeneity
affects radiative response**



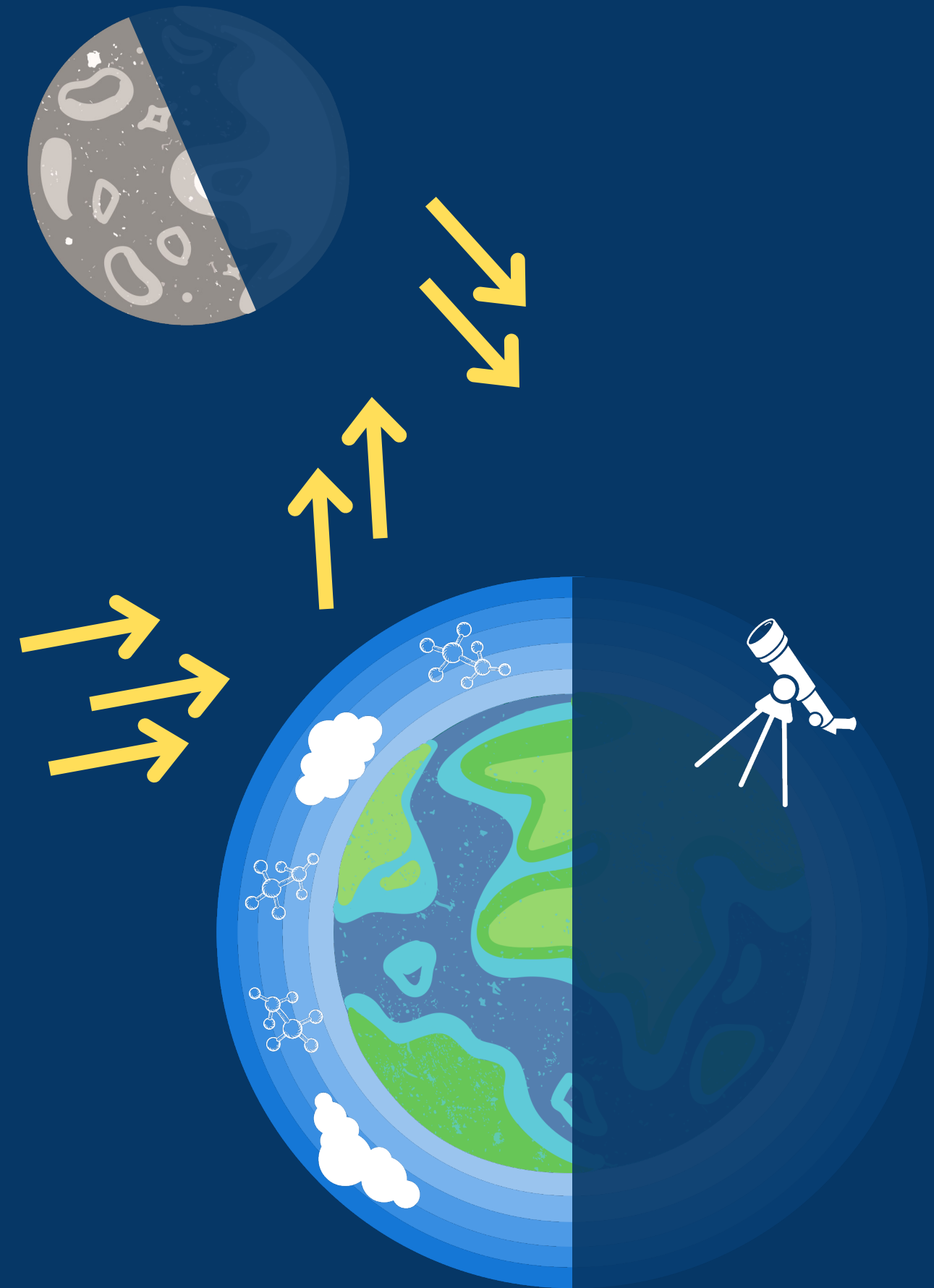
Rocetti+ 2024b (in prep.)

CLOUDS ZOOM-IN

Rocetti+ 2024b (in prep.)

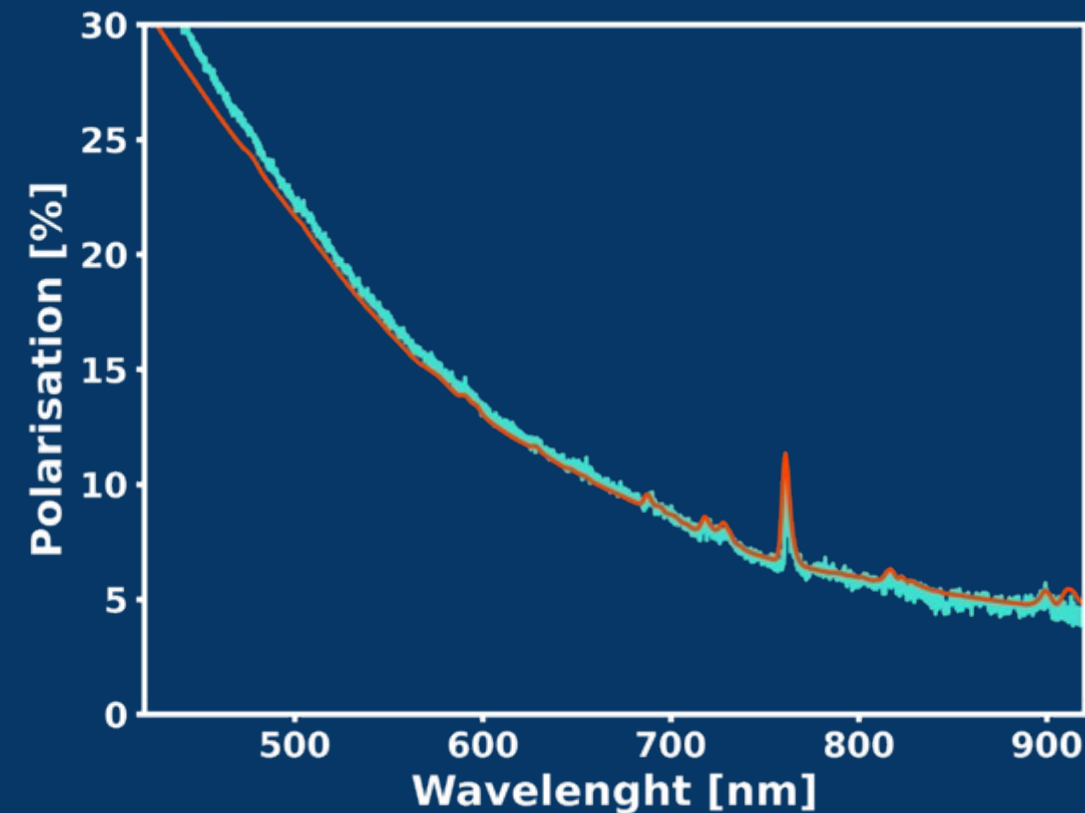
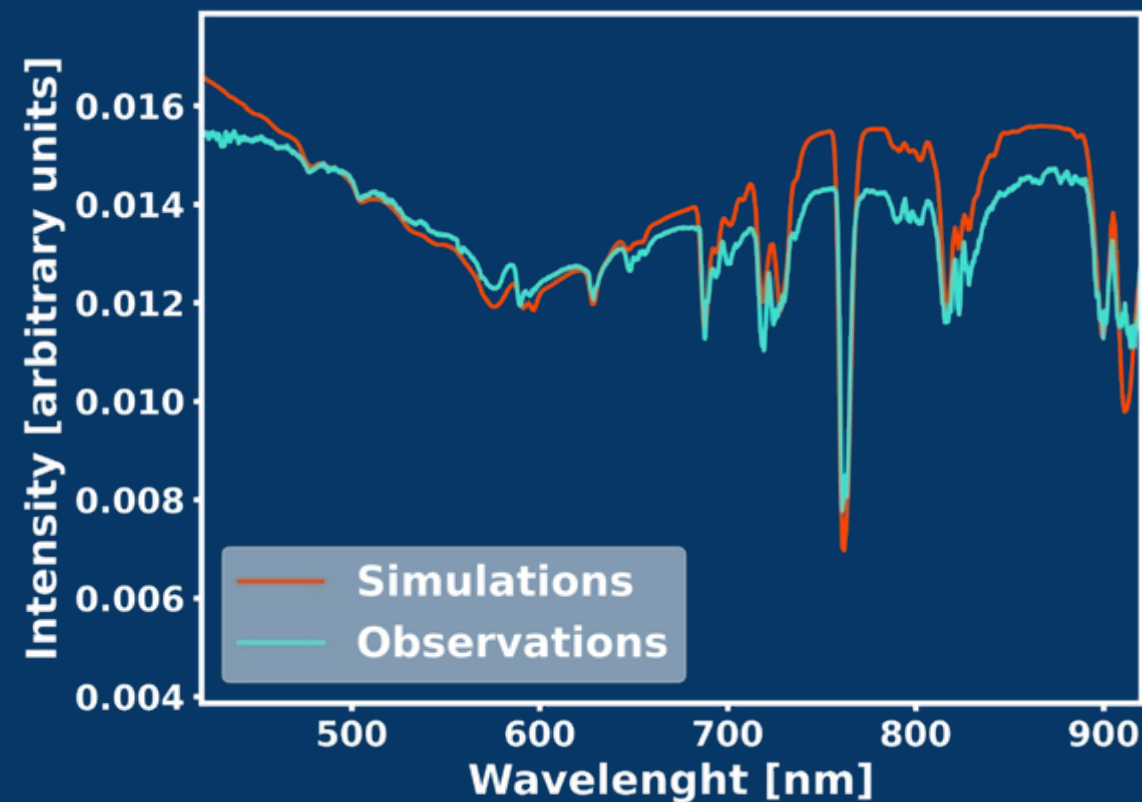
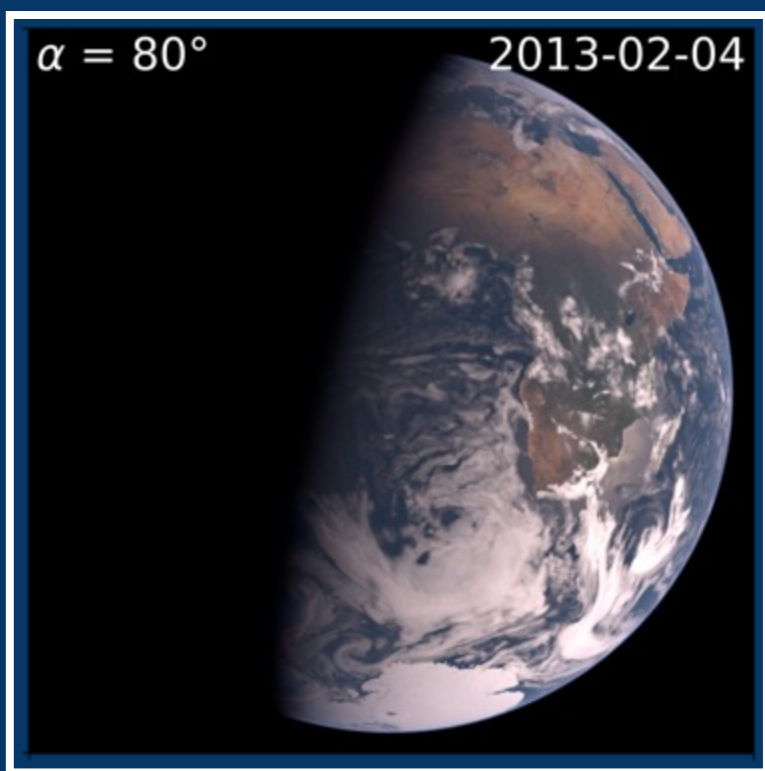
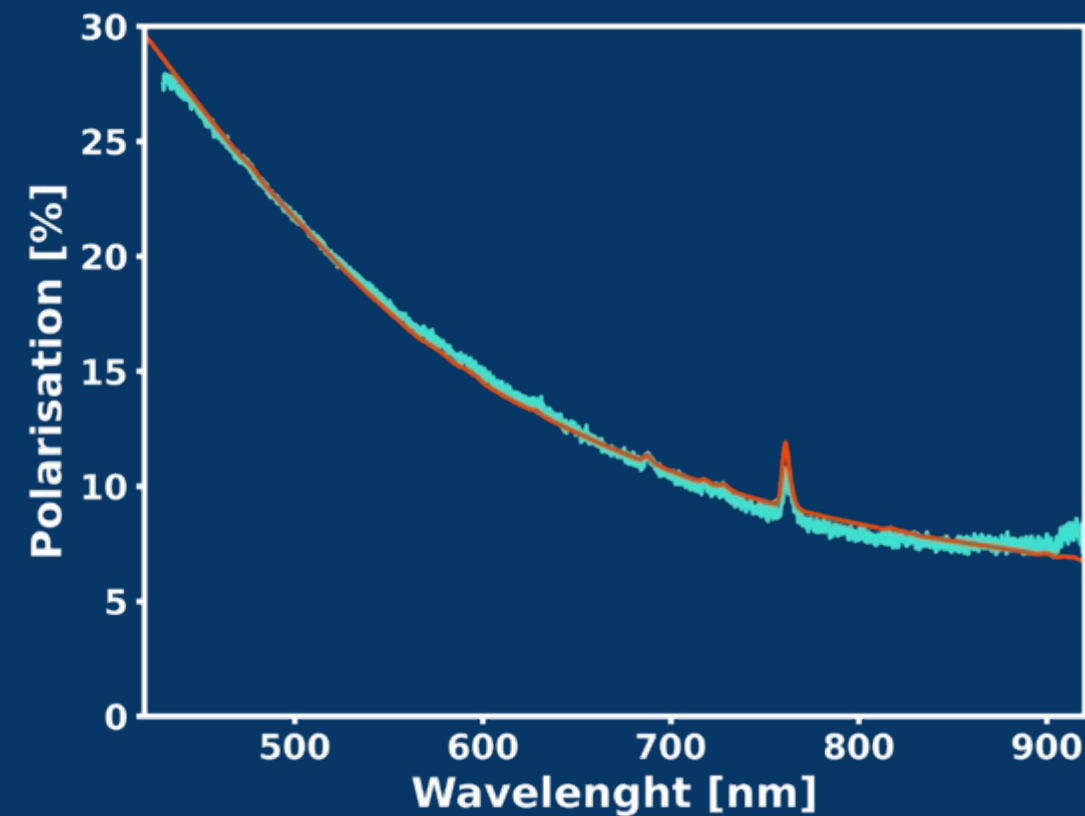
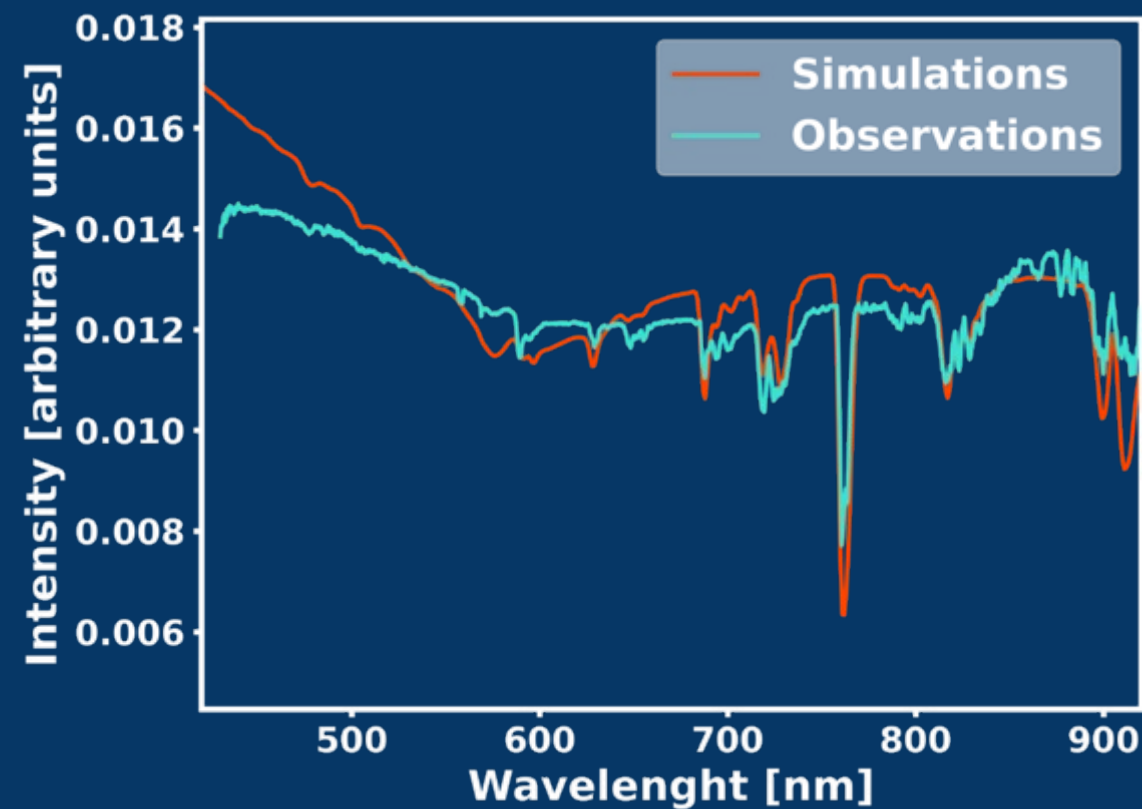
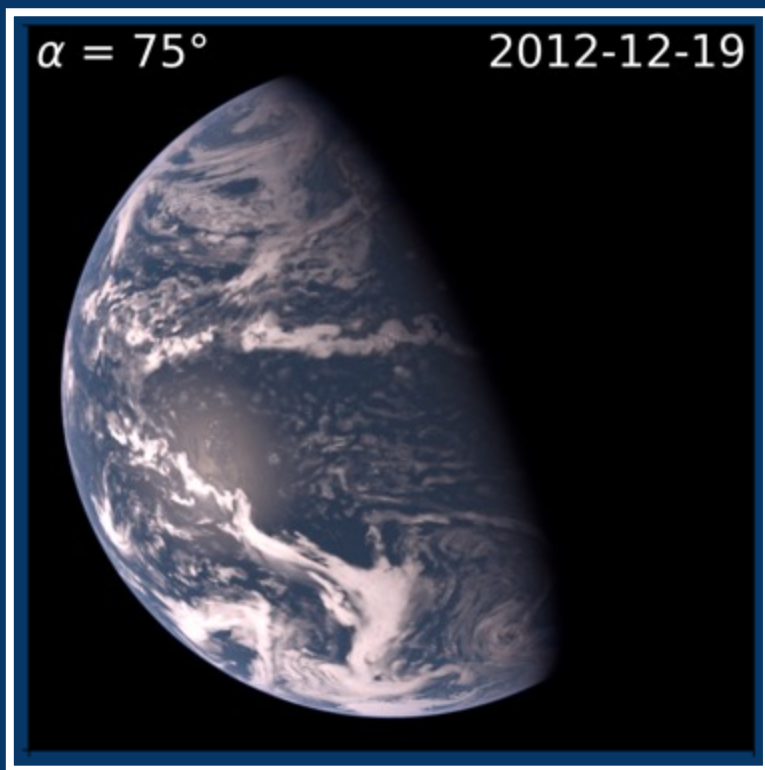


Modelling Earthshine observations



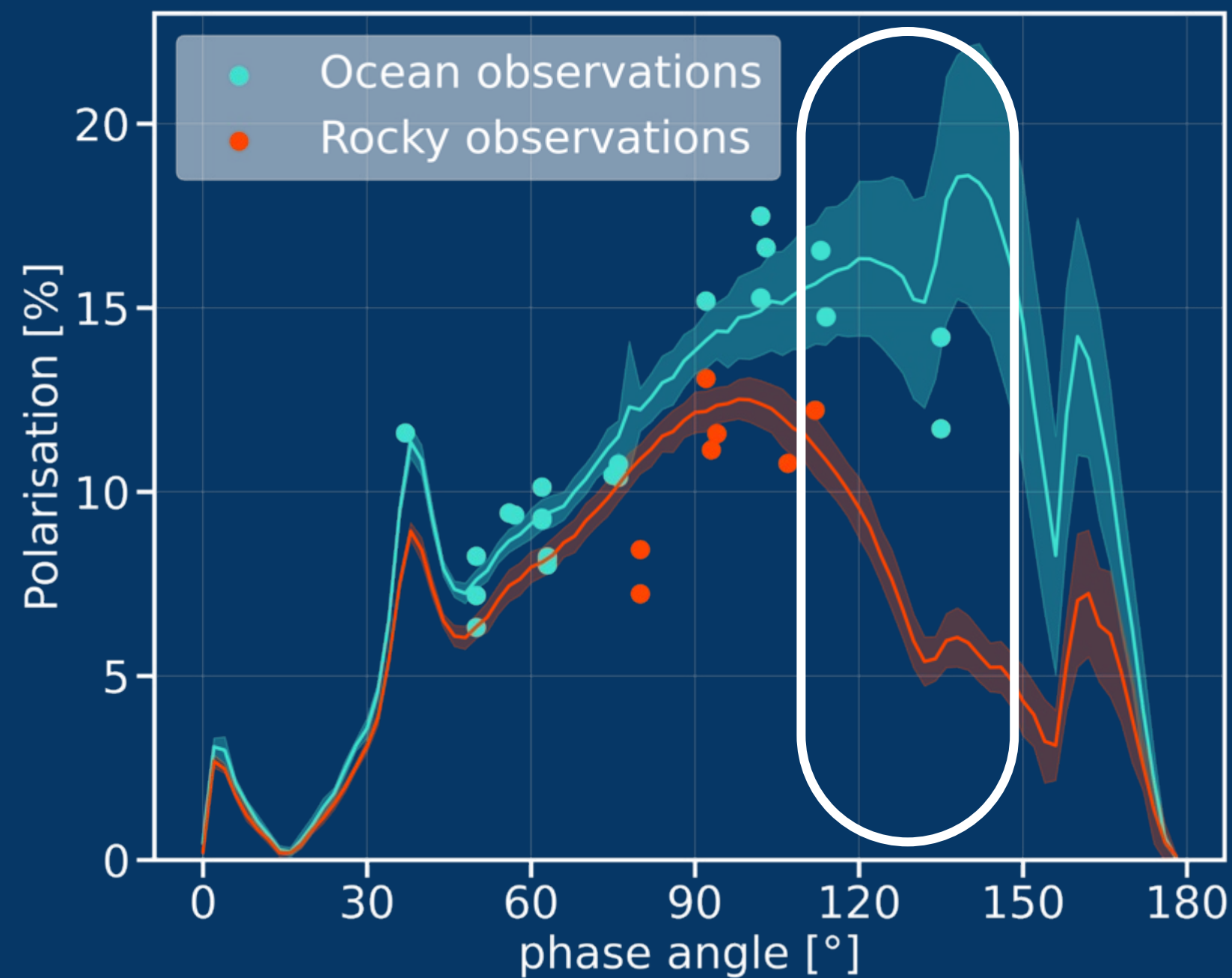
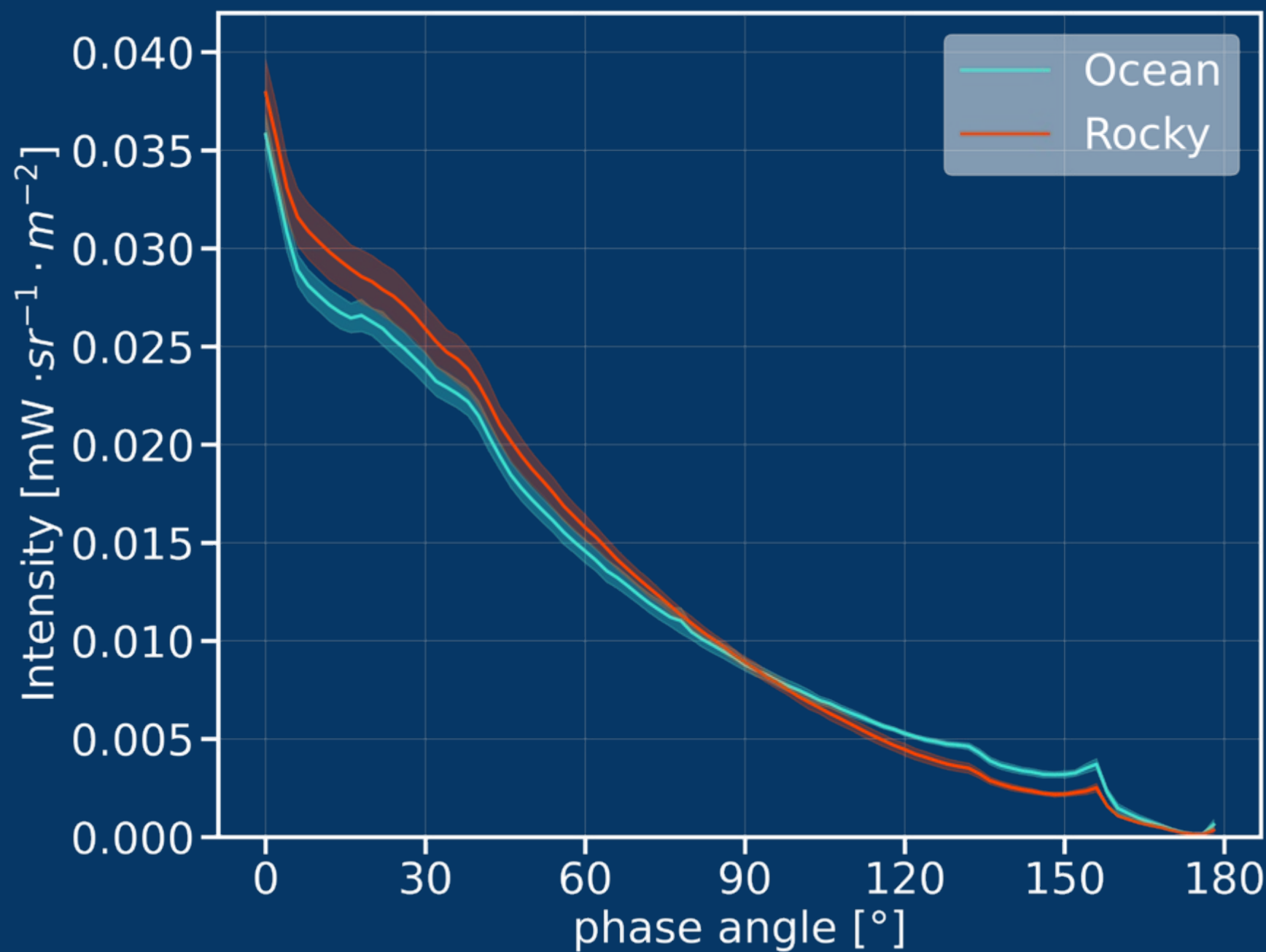
COMPARISON WITH OBSERVATIONS

Clouds +
planetary surfaces



SURFACE VARIABILITY: OCEAN VS. LAND

$\lambda = 700 \text{ nm}$



Rocchetti+ 2024c (in prep.)

TAKE HOME MESSAGES

- Earthshine allows to characterise Earth as a spatially unresolved exoplanet at different phase angles
- Polarisation is very sensitive to planetary surface and clouds
- HAMSTER is important to represent the spectral variability of land surface albedo and is relevant for Earth remote sensing applications and ESMs
- Correctly representing the radiative response of clouds is key for ESMs and exoplanet atmospheres models



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