Unveiling non-gray surface of cloudy exoplanets: the influence of wavelength-dependent surface albedo and cloud scattering properties on retrieval solutions

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Direct-imaging spectra hold rich information about a planet's atmosphere and surface, and several space-based missions aiming at such observations will become a reality in the near future. Previous spectral retrieval works have resulted in key atmospheric constraints under the assumption of a gray surface, but the effect of wavelength-dependent surface albedo on retrieval has not been shown. We explore the influence of the coupling effect of cloud and wavelength-dependent surface albedo on retrieval performance via modeling suites of Earth-like atmospheres with varying cloud and surface albedo parameterizations. We show that the retrieval degeneracy between the cloud properties and wavelength-dependent surface albedo leads to biased results of atmospheric composition and cloud properties. The multi-epoch visible band observations offer limited improvement in disentangling this degeneracy. However, the constraints on atmospheric composition from the combination of UV band (R ~ 6) + visible band (R ~140) are consistent with input values to within 1 σ. If short bandpass data is lacking, an alternative solution to reduce the retrieval uncertainties would be to have the prior constraints on planetary cloud fraction with less than 20% uncertainty. Under the assumption of known cloud scattering properties, the retrieved surface spectral albedos also show promising constraints on the surface composition when the surface cover is Earth-like vegetated areas or the ocean, which may aid in characterizing the planet's habitability.

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