Retrieval of mid-visible land surface albedo over Dehradun, northern India and its sensitivity to atmospheric parameters

Land surface albedo is an important parameter in modulating surface solar absorption and hence energy balance of the Earth. Albedo is not just a manifestation of surface properties, but it represents the coupling with atmospheric conditions as well. An important requirement to accurately estimate the spectral land surface albedo is to consider the absorbing and scattering properties of the atmosphere[1]. Changes in land surface albedo can perturb not only land surface parameters but also influence precipitation and land–ocean circulations[2]. More importantly, the radiative forcing due to aerosols is strongly dependent on the albedo of the underlying surface[3]. It has been observed in the atmospheric radiation measurement programme that the land surface albedo depends on solar zenith angle over snow-free surfaces[4]. Radiative transfer computations have shown that broadband land surface albedo could be estimated from the top-of-atmosphere (TOA) observations using parameterization techniques[5,6]. Here, we attempt to estimate the spectral land surface albedo for the first band (0.52–0.59 μm) of RESOURCESAT-AWiFS sensor by implementing SMART (Simple Model for Atmospheric Radiative Transfer) code with single scattering approximation[7–9]. SMART has been used for aerosol optical depth (AOD) retrievals for airborne and space-borne sensors. The objective of the study is to understand whether the technique can be used to address the growing interest in the retrieval process of surface albedo parameters from one of the widely used Indian satellite sensors. The code decomposes the TOA signal into three parts – reflectance due to molecules, aerosols and surface respectively. The results have been validated against MODIS albedo product[10,11]. This is followed by the sensitivity study of spectral albedo with respect to aerosol asymmetry parameter, single scattering albedo and solar zenith angle for different values of AOD.

The study area chosen was Dehradun city, capital of Uttarakhand, North India, which is surrounded by the Himalayas in the north and Shivalik Hills in the south. The AOD is taken from MODIS atmosphere product MOD08_D3, which is a gridded, level-3 daily joint aerosol/water vapour/cloud product at a spatial resolution of 1 degree[12]. The albedo is retrieved from the radiative transfer simulations and validated against MODIS albedo product MCD43_A3, a combined Terra and Aqua level-3, 16-day albedo product at 500 m spatial resolution[13]. The model is first calibrated for aerosol asymmetry parameter (g) for data from one satellite each for summer and winter seasons with an assumption for single scattering albedo. Dehradun has some small-scale industries, but is not a heavily polluted site and hence, as an approximation, single scattering albedo close to 1 (~ 0.9) is assumed in the model. Also, the aerosol loading is lower compared to the nearby polluted cities like Delhi (~ 250 km), which could be inferred from the AOD measurements[14].

Once the model is calibrated, it is applied over two more sets of AWiFS imagery each for summer and winter seasons respectively, and the results are compared against those of MODIS albedo product. It is found that the results are in good agreement with MODIS product with an average relative error of 5.6% (Table 1). The differences observed in the results with respect to those of MODIS product could be attributed to differences in spectral bandwidths of the corresponding wavelength bands (MODIS: 0.545–0.565 μm, AWiFS: 0.52–0.59 μm) as well as approximation for single scattering by molecules and aerosols. The overall methodology is shown in Figure 1.

Once the model was validated for albedo retrieval, the sensitivity of land surface spectral albedo was studied for solar zenith angle, single scattering albedo and aerosol asymmetry parameter. For the same TOA reflectance recorded onboard, it was found that spectral land surface albedo (ρ_λ) retrieved from inversion of TOA measurements increases with increase of solar zenith angle and AOD (Figure 2 *a*). This could be attributed to the effect of decreasing downwelling transmittance with zenith angle due to the longer optical path that has to be traversed by the incoming radiation. Hence for the same ground conditions, if

Table 1. Details of datasets used for albedo estimation and comparison of results with MODIS product

Season	Summer	Winter
Data for calibration	12 May 2010	15 December 2010
Data for validation (1)	12 May 2011	22 December 2011
Relative difference % (simulated w.r.t. MODIS)	7.61	10.92
Data for validation (2)	23 May 2007	2 November 2009
Relative difference % (simulated w.r.t. MODIS)	3.33	0.56

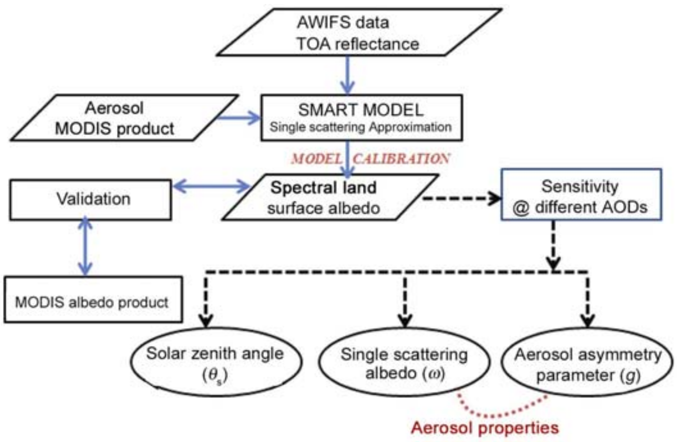

Figure 1. Flowchart showing the overall methodology.

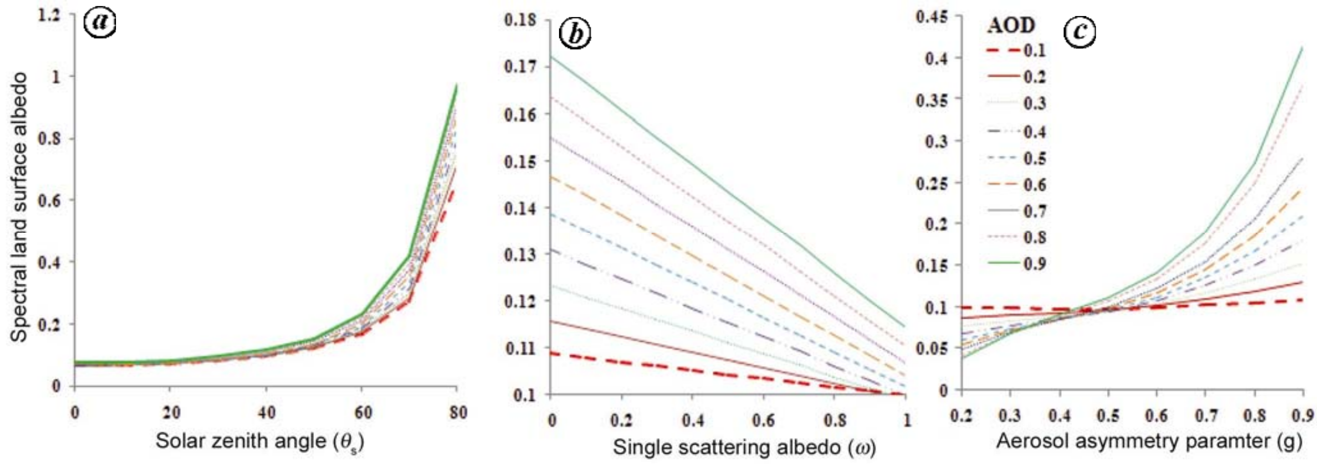

Figure 2. Sensitivity of spectral land surface albedo to (***a***) solar zenith angle, (***b***) single scattering albedo and (***c***) aerosol asymmetry parameter.

solar elevation decreases, the sensor would record lower signal from the target. Also, as AOD increases, transmittance decreases. Hence, in order to maintain the same TOA signal, the land surface albedo should be higher at higher zenith angles and at higher AODs. Figure 2 *b* shows that the surface albedo increases with decrease in aerosol single scattering albedo, as is evident from the fact that the radiation absorbance properties of the aerosols would increase with decrease in surface spectral albedo, thereby decreasing the aerosol reflectance function. Hence, for the fixed TOA reflectance, the surface albedo should be higher to compensate for aerosol reflectance. This fact implies that for the same AOD, low single scattering albedo would result in a lower at-sensor signal as the ground albedo remains fixed, which is expected because of decreasing scattering properties of aerosols with decrease in single scattering albedo. Figure 2 *c* shows that as the aerosol asymmetry parameter increases, spectral albedo increases. This could be attributed to decrease in backward scattering component for the fixed TOA signal and the increase is faster at the extremities of the considered range. Also, as AOD increases, keeping the aerosol asymmetry parameter fixed, spectral albedo of surface decreases till asymmetry parameter reaches a value of 0.4 and then starts increasing. It could be noted here that the model works well for a range of solar zenith angle $\theta_s \in [0°, 80°]$; single scattering albedo $\in [0, 1]$ and aerosol asymmetry parameter $g \in [0.2, 1]$ respectively. The study shows that spectral land surface albedo could be retrieved from AWiFS data using SMART under single scattering approximation for a range of unknown parameters. Further improvements in the results could be achieved using multiple scattering approximations in SMART model and simultaneous AOD measurements at the time of satellite pass. In addition to AOD, knowledge about aerosol single-scattering albedo along with optical and size properties of aerosols is essential to accurately estimate the surface albedo from TOA measurements.

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