Linking lidar-derived canopy structure with MODIS black-sky albedo

Lauri Korhonen[1,2], Miina Rautiainen[1], Pauline Stenberg[1]

[1]University of Helsinki, Department of Forest Sciences, Helsinki, Finland
[2]University of Eastern Finland, School of Forest Sciences, Joensuu, Finland

Land surface albedo is one of the essential terrestrial climate variables listed by the Global Climate Observing System. It is defined as the fraction of the incident shortwave radiation that is reflected by the Earth's surface, and is directly related to the planetary radiative energy budget. Cuttings, changes in species composition, and other forest management practices may influence the climate through changes in forest albedo. However, although theoretically the albedo should depend quite strongly on the canopy structure, weak relationships between standard forest inventory estimates and albedo have been reported in empirical studies.

Our objective was to examine if lidar-derived metrics of forest structure can explain the variations in satellite-based albedo estimates better than standard forest inventory data. We estimated canopy cover and mean canopy height directly from the lidar, and regressed these values against MODIS black-sky albedo values. For comparison, we tested also canopy cover and volume estimates produced by the Finnish national forest inventory (NFI).

Our study site is located in the boreal forest of Seitseminen, Finland (61˚54´N, 23˚29´E). The dominant tree species are Norway spruce (*Picea abies* L. *Karst*.) and Scots pine (*Pinus sylvestris* L.). The lidar data was acquired on 2–11 May 2013 as a part for national digital terrain model creation. An area of 21 × 24 km was selected for the study. The pulse density was 0.7 m^{-2} and the maximum scan angle was approximately 15°. Forest canopy cover was estimated as the fraction of pulses that produced echoes > 2 m above ground level. The mean height of the first echoes above this threshold was also calculated. Additional NFI data (© Finnish Forest Research Institute, 2013) were available for the year 2011 and included the volume fractions by tree species and canopy cover. The variables were estimated using multisource k nearest neighbour imputation based on field plot measurements and satellite imagery.

MODIS MCD43A albedo product is a composite of satellite observations from the nearest 16 days, obtained by fitting a bidirectional reflectance distribution function into multiangular data and integrated over the observation angles to obtain estimates of black sky (directional-hemispherical) shortwave albedo. Only the pixels with best quality retrievals were accepted. We used the MODIS albedo composite from 21 August 2013, which had the best overall quality for summer 2013.

Lidar and NFI-based forest attribute maps were converted into MODIS sinusoidal projection and averaged into 500 m resolution corresponding to the MODIS pixels. MODIS pixels containing water bodies were omitted, but other land use categories (including some agricultural fields and small settlements) were included because more than 90% of the land area was forest. Finally, 1230 valid MODIS pixels were available for the regression analysis, where lidar and NFI variables were applied to predict the observed albedo.

The results showed a clear negative correlation between lidar-based canopy cover estimates and MODIS black-sky shortwave albedo (R^2 = 0.34, s.e. = 0.0056). Canopy cover and height were highly correlated (R=0.71), but using the height instead of canopy cover resulted in weaker relationship (R^2 = 0.31) than using canopy cover. Adding both predictors into the model to approximate the forest biomass decreased the standard error only slightly (s.e. = 0.0054, R^2 = 0.38), i.e.canopy cover alone explained most of the variation in the observed albedo.

The NFI variables did not explain variation in albedo as well as the lidar variables. NFI canopy cover and volume estimates produced nearly similar model accuracies (R^2 = 0.20 and 0.19, s.e. = 0.0061 and 0.0062, respectively). However, supplementing the lidar variables with NFI species information improved the model precision. Our best multivariate model included lidar canopy cover, lidar mean height, and NFI pine volume fraction (s.e. = 0.0053, R^2 =0.40).

Lidar-derived metrics of forest structure were capable of explaining the variation in black-sky albedo better than standard forest inventory estimates. Among the studied variables, canopy cover seemed to be the main driver of shortwave albedo, although the inclusion of height and species composition into the model improved the model slightly (R^2 increased from 0.34 to 0.40, standard error decreased from 0.0056 to 0.0053). The spectral properties of the forest understory may also have a significant influence on the albedo, but this effect could not be directly quantified with these data. As a conclusion, lidar based canopy structure variables were shown to be useful in characterizing relationships between forest structure and albedo.