Fine-scale Vegetation Composition and Structure Drives Variation in Spatial and Temporal Dynamics of Surface Albedo in Low Arctic Tundra

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Albedo, a measure of the solar reflectivity, is an important biophysical property of the land surface that influences local heating, regulates vegetation-atmosphere interactions and is a strong determinant of Earth's energy balance. In the Arctic, rapid climate warming is driving dramatic changes in vegetation distribution and land surface structure, including a rapid expansion of shrub and tree species into the Arctic tundra. This widespread replacement of vegetation species and structure is expected to have strong impacts on albedo, and as a result, on ecosystem energy balance. At the same time, Arctic vegetation distribution is strongly tied to the presence of permafrost, moisture and nutrient gradients, and fine-scale topographic features resulting in a high degree of spatial heterogeneity. This inherent variability combined with climate-driven changes in vegetation cover creates complex albedo responses in the Arctic. Traditional methods used to quantify albedo change and spatial patterns have been limited by their relatively low spatial resolution (e.g., > 250 m), requiring new, multi-scale observations to characterize the direction and rate of change in surface albedo. In this study, we address this need by combining remote sensing data across scales, from unoccupied aerial systems, high-resolution topography data, to piloted airborne and satellite observations to investigate the links between vegetation composition, structure, functional properties, and topographic features on the resulting spatio-temporal patterns of albedo in western Alaska. We used a time-series (2013 – 2020) Landsat albedo product across three watersheds located in the Seward Peninsula to investigate how sub-pixel patterns influence regional albedo. We observed strong regional albedo seasonality, but also significant differences in albedo patterns across the plant functional types, with tree and shrub species showing lower albedo than low-stature plants. In the winter, albedo is primarily a function of vegetation height, likely because taller vegetation, which is darker than the surrounding snow, extends above the snow layer. In the summer season, vegetation composition and topographic position, a strong driver of tall shrub distribution, were more important for explaining albedo variation than vegetation structure. Our results suggests that changes in vegetation composition and structure will create increasingly complex albedo patterns across the Arctic, and our dataset can be used to inform and benchmark process models predictions of Arctic albedo.