Estimation of Forest Canopy Cover by Combining ICESat-2/ATLAS Data and Geostatistical Method/Co-Kriging

Jinge Yu, Hongyan Lai, Li Xu, Shaolong Luo, Wenwu Zhou, Hanyue Song, Lei Xi, and Qingtai Shu

***Abstract*—Accurately estimating forest canopy cover (FCC) is challenging by using traditional remote sensing images at the regional level due to the spectral saturation phenomenon. In this study, to improve the estimation accuracy, a new method of FCC wall-to-wall mapping was suggested based on ice, cloud, and land elevation satellite/advanced topographic laser altimeter system (ATLAS) data. Specifically, one dataset of FCC's observations was combined with preprocessed ATLAS data and topographic factors to build a random forest regression (RFR) model. Moreover, the Co-Kriging method was used to generate spatially explicit values that are required by the RFR from the point data of ATLAS parameters, and then the wall-to-wall mapping of the FCC was conducted. The results showed that the RFR model had an accuracy of relative root-mean-square error (rRMSE) = 0.09 with a coefficient of determination (R^2) = 0.91. The best-fit semivariogram models between primary variables and covariates were asr and TR (Model: Gaussian model, R^2 = 0.94, the residual sum of squares (RSS) = 1.73×10^{-6}), landsat_perc and NDVI (Model: spherical model, R^2 = 0.46, RSS = 1.58×10^{-4}), and photon_rate_can and slope (Model: exponential model, R^2 = 0.77, RSS = 6.45×10^{-4}), respectively. FCC validation result showed that the FCC's wall-to-wall mapping was in great agreement with the dataset-2 (R^2 = 0.79; rRMSE = 0.11).**

***Index Terms*—Co-Kriging (CK), forest canopy cover (FCC), Ice, Cloud, and Land Elevation Satellite/Geoscience Laser Altimeter System (ICESat-2 ATLAS), random forest regression (RFR), semivariogram, validity validation.**

I. Introduction

FORESTS play an important part in the global carbon cycle as they dominate the dynamics of the terrestrial carbon cycle [1]. Policy and management decisions to manage forest resources require reliable and up-to-date information on forest structure; therefore, there is an increasing need to generate timely and accurate information on forest structure. Forest canopy cover (FCC) is defined as the proportion of the vertical projection area of the canopy [2]. It is an important parameter of forest inventory that reflects forest structure characteristics and growth state [3], [4]. However, obtaining timely and reliable forest inventory data is often labor-intensive and time-consuming, especially across extensive areas [5], [6]. Remote sensing technology offers a practical and economical approach for measuring and monitoring vegetation cover and structure in large areas [7]. Unfortunately, traditional optical remote sensing lacks forest vertical structure information [8] and is easily affected by weather and saturation [9], [10]. Although microwave remote sensing can obtain forest information through the canopy in all-weather, it is easily affected by terrain and saturation issues [11]. Therefore, more accurate and efficient FCC estimation methods are needed to improve forest-resource monitoring based on RS data.

Light detection and ranging (LiDAR) can penetrate the forest canopy to obtain 3-D information quickly and accurately [12], [13]. From the data source perspective, it overcomes the saturation problem of optical and SAR data, and it has unique advantages in the inversion of forest structure parameters [14]. Due to the advancement of LiDAR technology, platforms that are equipped with different types of LiDAR have started to appear one after another, and the applications in forestry have been further expanded [15], [16], [17]. Nevertheless, employing airborne LiDAR for large-scale canopy observation is impractical given their limited spatial coverage [18]. For observation of large-scale forest parameters, spaceborne LiDAR provides an alternative method, such as the Ice, Cloud, and Land Elevation Satellite/Geoscience Laser Altimeter System (ICESat/GLAS) and the ICESat-2/advanced topographic laser altimeter system (ICESat-2/ATLAS) [19]. ICESat, as the first spaceborne LiDAR system, became operational in 2003 and its data from the GLAS has been used successfully to estimate the canopy cover [18]. A successor mission to ICESat, ICESat-2, was launched on 15 September 2018 after ICESat expired in 2009 [20]. ATLAS uses the multibeam, micropulse, photon-counting LiDAR technology [21]. Dense sampling and wide spatial coverage are advantageous for mapping large-scale forest structures [22], [23], [24] and biomass estimation [25].

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Jinge Yu, Hongyan Lai, Li Xu, Shaolong Luo, Wenwu Zhou, and Qingtai Shu are with the Faculty of Forestry, Southwest Forestry University, Kunming 650224, China (e-mail: yjg721@swfu.edu.cn; lhy19931006@163.com; xl15121267342@swfu.edu.cn; luoshaolong@swfu.edu.cn; 1723074419@swfu.edu.cn; shuqt@swfu.edu.cn).

Hanyue Song is with the College of Carbon Neutrality, Fujian Agriculture and Forestry University, Fuzhou 350002, China (e-mail: shy@swfu.edu.cn).

Lei Xi is with the Institute of Ecological Protection and Restoration, Chinese Academy of Forestry, Beijing 100091, China (e-mail: swfuxilei@swfu.edu.cn).

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