THE SPATIAL DISTRIBUTION OF FOREST BIOMASS IN CHINA USING REMOTE SENSING AND NATIONAL FOREST INVENTORY

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ABSTRACT

The objective of this study is to retrieve a spatially-explicit map of forest biomass, which is not only an important parameter to evaluate carbon storage but also a necessary initial value for process-based carbon cycle models to simulate carbon dynamics within a region. In this study, we used the latest eighth national forest inventory statistics (2009-2013) and the MODIS Land Cover Type product (MCD12C1) to estimate current spatial distribution of forest biomass in China at 0.05° resolution using a straight-forward downscaling method. The results showed that the total stock of forest biomass in China has increased remarkably to 13.1Pg. The forest biomass in China has a clear spatial pattern, with the highest biomass values occurring in the Da Hinggan, Xiao Xing'an and Changbai mountains of the northeast, and the Hengduan mountains of the southwest. The relatively high values were widely distributed in mountain areas in Sichuan and Yunan provinces of the southwest, and Fujian province of the southeast.

Index Terms— Biomass, remote sensing, forest inventory, spatial distribution

1. INTRODUCTION

Forest biomass resulting from the long-term accumulation of carbon is an important parameter in terrestrial ecosystems for carbon cycle researches. It has been one of the important issues to estimate large-scale biomass storage and dynamics in the study of the global carbon cycle. Estimating the spatial distribution of forest biomass can not only evaluate the size and location of the current carbon storage but also produce a necessary initial value for process-based carbon cycle models to simulate carbon dynamics within a region [1, 2].

Currently, information on forest biomass is available from multi-sources information including ground-based field statistics, remote sensing and radar/lidar, and appropriate combinations of multi-sources data can integrate different advantages and improve the biomass estimates [3]. In recent years, the method of combining remote sensing with ground-based forest inventory statistics and using downscaling method to estimate large scale spatially-explicit distribution of forest biomass or other forest characteristics has been widely used in the USA and European countries, which retains the advantages of the accuracy of field survey and the advantages of the spatial distribution of remote sensing [4-7]. Many researches considered NPP/NDVI or other image-derived indices as the proxies of forest biomass [6, 8]. However, the size of forest cover plays a decisive role in biomass at large scale, and is commonly used as an index of forest biomass [5]. By using this relationship a simple but plausible downscaling method could be developed to estimate the spatial distribution of biomass.

In China, the systematical national forest inventory has been conducted every five years since the 1970s based on large numbers of field plots and provides the most important data source in research on forest carbon storage and carbon sink [9, 10]. With these data, dynamics of carbon storage of living forest biomass at provincial or national levels have been deeply studied, which contributed to understanding of the role of China's forests in the global carbon budget. However, the spatially explicit analysis on forest carbon storage using remote sensing is not still enough [8-12]. By utilizing the latest forest inventory statistics for the period 2009-2013 and the MODIS Land Cover Type product (MCD12C1), we quantitatively estimated the spatial distribution of forest biomass in China using a straight-forward downscaling method based on a forest cover proportion map derived from the MODIS product.

2. DATA AND METHODS

2.1. Data

The eighth national forest inventory statistics (for the period 2009-2013) comes from the statistics of the National Forestry Bureau of China, which is available on the official

website (http://www.forestry.gov.cn/gjslzyqc.html). We used the statistics of forest stand which document the detailed areas and timber volumes by individual tree species and stand ages in each province. The timber volume statistics were used to calculate forest biomass in this study. Forest in Hong Kong, Macao and Taiwan was not included in this study due to the lack of data.

We used the 2009-2012 MODIS Land Cover Type Yearly Climate Modeling Grid (MCD12C1.051 product), which was obtained from https://lpdaac.usgs.gov/products and provides aggregated land cover at 0.05° resolution, as well as the sub-pixel frequency of each class. And we used the sub-grid frequency distribution of forest classes in the International Geosphere Biosphere Programme (IGBP). This information was used to develop a forest cover proportion map which could represent the amount of forest on the ground during the inventory period.

2.2. Methods

Generally, forest inventory statistics can only provide coarse resolution information within a region, but remote sensing can provide the spatially explicit information of forests at high resolution. In this study, our key work is to estimate a spatially-explicit biomass map from inventory statistics using spatially-explicit satellite data. Based on the relationship between forest cover and biomass, a simple but plausible downscaling method was developed to estimate the spatial distribution of biomass in this study [5]. We proposed that the forest biomass density was directly proportional to forest area cover within one pixel. Thus, a forest cover proportion map which represents the forest area proportion within a pixel can effectively reflect the spatial distribution of biomass and allow straightly downscaling of regional forest biomass from statistics to forest cover pixels in an image.

In this study, Forest biomass was computed from the inventory timber volume statistics using the conversion factor continuous function method and the forest cover proportion map was derived from the sub-grid frequency distribution of forest classes from the MCD12C1 product. The overall procedure includes: (1) computation of forest biomass; (2) generation of forest cover proportion map; and (3) downscaling process. Fig. 1 presents the schematic diagram for downscaling forest biomass in this study.

Conversion factor continuous function method. Forest inventory statistics only provide information on timber volume, a factor to convert timber volume to total biomass (biomass expansion factor, BEF) is frequently used to estimate biomass [9]. We used this method to covert timber volumes from the forest inventory statistics to biomass by individual tree species in each province and estimated total forest biomass for each province.

Forest cover proportion map. We used the forest area proportion in a pixel to represent the amount of forest cover which was generated from the sub-pixel frequency of forest classes. We summed the sub-grid frequency of the five forest classes in IGBP (evergreen needleleaf forests, evergreen broadleaf forests, deciduous needleleaf forests, deciduous broadleaf forests, and mixed forests) for each year (2009-2012), and then an average of the four year forest cover maps was obtained with the final pixel value ranging from 0-100% which was considered representative for the ground state of forest during the inventory period.

Downscaling process. Taking the average value of forest biomass density in each province derived from the inventory statistics as a foundation, the forest cover proportion map derived from the MODIS product as a link, the biomass was allocated straightly to the forest cover pixels according to the forest proportion in each pixel. Eq. (1) was used to calculate the forest biomass density in each pixel.

$$b(i) = \frac{B}{A} x(i) \tag{1}$$

Where $b(i)$, the forest biomass density in a pixel (i) (Mg ha^{-1}); B, the total forest biomass in each province estimated from the inventory statistics (Mg); A, provincial pixel-wise integral of the forest area calculated from the MODIS image and $x(i)$, the forest cover proportion in a pixel (i).

3. RESULTS AND DISCUSSION

Fig. 2 illustrates the final downscaled spatial distribution of forest biomass in China. The total storage of forest biomass in China was 13.1 Pg, which has increased remarkably compared to biomass values estimated from previous national forest inventory statistics. From the spatial distribution perspective, a clear spatial distribution pattern was found with most biomass values mainly located in mountain regions. The highest biomass values occurred in the Da Hinggan, Xiao Xing'an and Changbai mountains of the northeast, and the Hengduan mountains of the southwest. Relatively high values were widely distributed in mountain areas in Sichuan and Yunan provinces of the southwest, and Fujian province of the southeast.

The methodology proved to be applicable in combining two independent data sources to one value-added product. And the method used in this study also demonstrated that forest cover maps allowed downscaling of regional forest statistics to pixels in an image straightly and effectively. This study makes some simple assumptions and will not be error free but it is suitable for large-scale biomass mapping. And we believe that the biomass map retrieved and the method in this study can be widely utilized in some other large-scale forestry and ecology applications.

However, clearly there are shortcomings in this study due to several factors. The forest biomass density was calculated provincially which could introduce some abrupt changes in pixel-values along provincial borderlines. The uncertainty of the estimated value in a pixel mainly depends

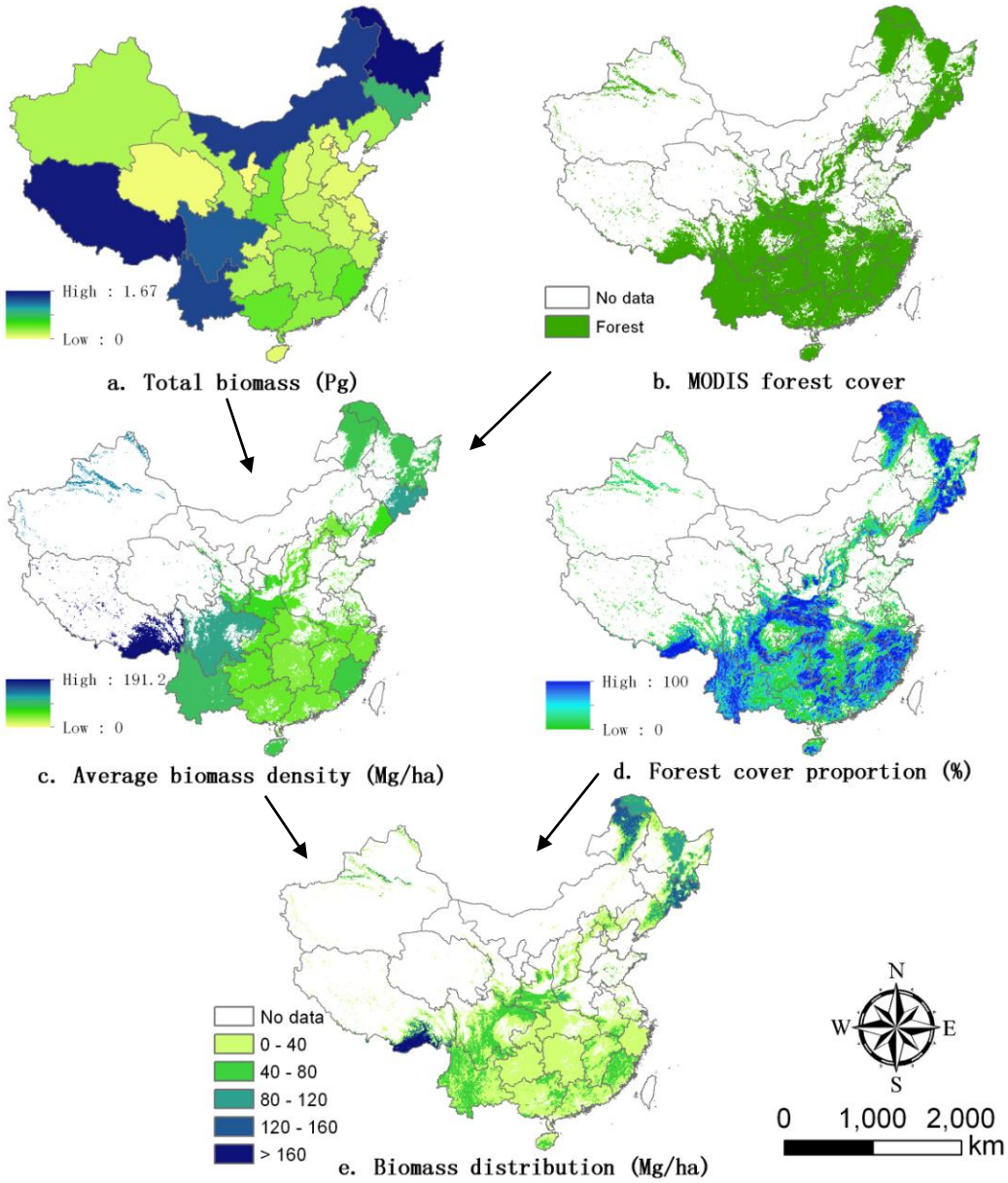

Fig. 1. Schematic diagram for downscaling forest biomass in China.

on the quality of the forest cover proportion map derived from the MODIS product, as well as the computation of biomass values from inventory statistics. Moreover, no suitable validation process was applied to access the accuracy of the pixel-wise biomass estimates within the region due to the huge gap between biomass at pot level (usually 100~400m^2) and that at 5.6 km-resolution level (i.e. 31360000 m^2) in this study.

4. CONCLUSIONS

The method in this study illustrates one straight way of downscaling the aggregated statistics of the forest inventory from the province level to pixel level. We combined the eighth national forest inventory statistics (for the period 2009-2013) and the spatially explicit MODIS Land Cover Type product (MCD12C1) together to quantitatively estimate the spatially-explicit distribution of forest biomass in China at a resolution of 0.05°. The total stock of forest biomass in China was 13.1 Pg with a clear spatial pattern. The highest biomass values occurred in the Da Hinggan, Xiao Xing'an and Changbai mountains of the northeast, and the Hengduan mountains of the southwest; while relatively high values were widely distributed in mountain areas in Sichuan and Yunan provinces of the southwest, and Fujian province of the southeast.

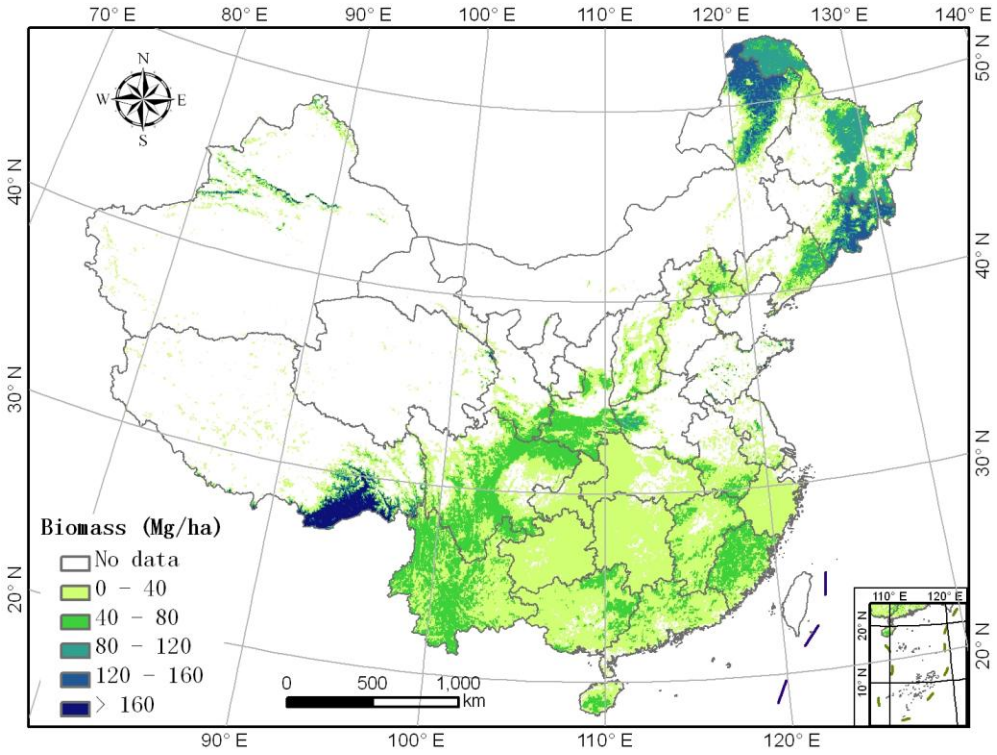

Fig. 2. Spatial distribution of forest biomass in China during 2009-2013.

5. ACKNOWLEDGEMENT

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