

成多源遥感与模型估算森林变化的水热碳影响

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摘要:【目的】森林覆盖变化影响碳汇的时空动态, 并通过改变地表热量、水分和物质循环, 共同影响着区域乃至全球的气候, 为了探究造林与毁林带来的水热碳效应以及生物物理机制在其中起到的作用。【方法】本研究利用 30m 分辨率 2000 年、2010 年、2020 年中国土地覆被数据集 (CLCD)、结合地表温度 (Land Surface Temperature, LST)、气温 (Temperature, Tem)、降水量 (Precipitation, Pre)、碳储量 (Carbon Storage, Carbon) 数据以及蒸散发 (Evapotranspiration, ET)、反照率 (Albedo)、净辐射 (Net Radiation, NR) 数据, 利用移动窗口策略和时空分析法, 定量分析森林变化对水-热-碳 (地表温度、气温、降水、碳储量) 及其生物物理机制 (如蒸散发、反照率和净辐射) 的影响, 并采用线性回归方法和结构方程模型分析森林变化的水热碳效应与生物物理机制之间的关联, 以此构建森林变化及其水热碳变化和生物物理机制变化的时空响应特征及其交互响应关系模型。【结果】杭州市和肇庆市造林与毁林对水-热-碳及生物物理机制的影响具有一致的正负效应。2000 - 2020 年造林和毁林对 LST 的平均降温效应 (-2.59 ± 0.27 °C 和 -1.29 ± 0.2 °C) 和增温效应 (2.42 ± 0.42 °C 和 1.24 ± 0.43 °C) 的变动幅度显著大于对 Tem 的影响 (降温: -0.18 ± 0.07 °C 和 -0.1 ± 0.03 °C; 增温: 0.17 ± 0.04 °C 和 0.09 ± 0.04 °C)。造林和毁林引起了正负碳储量变化, 肇庆市造林导致总碳储量略有增加, 而杭州市毁林则导致总碳储量减少。两市造林的降水量增加显著强于毁林带来的降水量减少 (13.2 ± 4.66 mm 和 2.68 ± 5.09 mm; 2.88 ± 1.24 mm 和 0.62 ± 1.45 mm)。2010 - 2020 年造林对两市的生物物理机制影响为蒸散发增加、反照率降低、净辐射增加, 而毁林则相反。杭州市造林的蒸散发和净辐射效应增加更显著 (0.33 ± 1.12 W/m² 和 0.91 ± 0.79 W/m²), 而肇庆市毁林的蒸散发和净辐射减少更显著 (-2.01 ± 1.69 W/m² 和 -0.03 ± 1.12 W/m²)。对于反照率而言, 造林表现为轻微的负效应而毁林则相反。两市造林与毁林带来的各变量变化及其相关性各自影响趋势基本保持一致。生物物理机制中对 LST 的影响程度为 $ET > NR > Albedo$; 杭州市生物物理机制对降水的作用更强烈而在肇庆市则对气温更具影响; 杭州市气候因子对碳储量的影响大于肇庆市。【结论】森林面积减少是两市碳储量减少的重要原因, 城市化的快速发展导致了总碳储量逐年降低的趋势; 森林变化影响水热碳变化和生物物理过程的动态变化, 但因两市地理位置、海陆位置等因素的不同, 导致两市的分析结果具有差异。总的来说, 合理规划森林面积、科学进行城镇化进程有利于杭州市和肇庆市的固碳增汇, 稳定区域气候, 从而助力于“双碳”政策的实施。

关键词: 森林变化; 遥感与模型; 移动窗口策略; 时空分析法; 水热碳机制

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Integrating multi-source remote sensing and modeling to estimate water-heat-carbon impacts of forest change

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Abstract:【Objective】Forest cover change influences the spatiotemporal dynamics of carbon sinks and impacts regional and global climates by altering surface heat, water, and material cycles. 【Method】This study utilizes the 30-meter resolution China Land Cover Dataset (CLCD) for the years 2000, 2010, and 2020, alongside data on Land

Surface Temperature (LST), temperature, precipitation, carbon storage, evapotranspiration (ET), albedo, and net radiation (NR). By employing moving window strategies and spatiotemporal analysis, the study quantitatively assesses the effects of forest changes on water-heat-carbon dynamics (including surface temperature, air temperature, precipitation, and carbon storage) and their biophysical mechanisms (such as evapotranspiration, albedo, and net radiation). Linear regression and structural equation modeling were used to analyze the relationships between hydrothermal carbon effects and the biophysical mechanisms of forest change, constructing a spatiotemporal response model of forest change and its impacts on hydrothermal carbon and biophysical mechanisms. **【Result】** The results showed that the effects of afforestation and deforestation on water-heat-carbon and biophysical mechanisms in Hangzhou and Zhaoqing had consistent positive and negative effects. The mean cooling effect (-2.59 ± 0.27 °C and -1.29 ± 0.2 °C) and warming effect (2.42 ± 0.42 °C and 1.24 ± 0.43 °C) of afforestation and deforestation on LST from 2000 to 2020 were significantly greater than those on Tem (cooling: -0.18 ± 0.07 °C and -0.1 ± 0.03 °C; Temperature: 0.17 ± 0.04 °C and 0.09 ± 0.04 °C). Afforestation and deforestation led to changes in positive and negative carbon stocks, with afforestation in Zhaoqing leading to a slight increase in total carbon stocks, while deforestation in Hangzhou led to a decrease in total carbon stocks. The increase of precipitation caused by afforestation in the two cities was significantly stronger than that of deforestation (13.2 ± 4.66 mm and 2.68 ± 5.09 mm, 2.88 ± 1.24 mm and 0.62 ± 1.45 mm). From 2010 to 2020, the biophysical mechanism of afforestation on the two cities increased evapotranspiration, decreased albedo and increased net radiation, while deforestation was the opposite. The evapotranspiration and net radiation effects of afforestation in Hangzhou were more significant (0.33 ± 1.12 W/m² and 0.91 ± 0.79 W/m²), while the evapotranspiration and net radiation reductions were more significant in Zhaoqing (-2.01 ± 1.69 W/m² and -0.03 ± 1.12 W/m²). For albedo, afforestation exhibits a slight negative effect, while deforestation does the opposite. The changes and correlations of the variables brought about by afforestation and deforestation in the two cities were basically consistent with the respective impact trends. The degree of influence on LST in the biophysical mechanisms was $ET > NR > Albedo$; The effect of biophysical mechanism on precipitation was stronger in Hangzhou, while it had a stronger effect on temperature in Zhaoqing. The impact of climate factors on carbon storage in Hangzhou is greater than that in Zhaoqing. **【Conclusion】** The decrease of forest area is an important reason for the decrease of carbon storage in the two cities, and the rapid development of urbanization leads to the trend of decreasing total carbon storage year by year. Forest change affects the dynamic changes of hydrothermal carbon changes and biophysical processes, but the analysis results of the two cities are different due to the differences in geographical location, sea and land location and other factors. In general, rational planning of forest area and scientific urbanization process are conducive to carbon sequestration and sequestration in Hangzhou and Zhaoqing, and stabilize the regional climate, thereby contributing to the implementation of the "dual carbon" policy.

Keywords: forest change; remote sensing and modeling; moving window strategy; spatio-temporal analysis methods; water-heat-carbon mechanism