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Impacts of climate change and human activities on vegetation cover in hilly southern China

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ABSTRACT

Vegetation cover is a commonly used indicator to evaluate terrestrial environmental conditions. Changes in the spatiotemporal patterns of vegetation alter the structures and functions of the landscape, thereby affecting ecological processes. Hilly southern China is an important ecological restoration area, in which the vegetation cover and land use has changed significantly. However, very few studies have considered vegetation changes due to multiple factors in this region. We investigated the spatiotemporal variations in vegetation cover using a Normal Difference Vegetation Index (NDVI) time-series data set obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) and climate data from 2000 to 2010. Our results indicate that the NDVI during the growing season had increased by 0.03% during the 11-year period. Patterns of change in vegetation cover differed among locations, with 58.7% of the study area displaying increased NDVI values, and in 7.3% of the study area, within an ecological restoration zone, the increase was significant. Effective ecological restoration programs, such as Grain for Green and hill closure for afforestation, have improved the environmental conditions. The spatiotemporal variations in vegetation cover were likely to be a synergistic impact of climate change (fluctuations in temperature and precipitation) and human activities. A residual analysis of the changes in the NDVI indicated that human activities had either improved or degraded vegetation cover in some parts of southern China. Specifically, the negative effects of extreme weather events in 2009 and 2010 offset the positive benefits of ecological reconstruction programs in the western part of the study area. This indicates that extreme weather events should be considered in the design and planning of future ecological reconstruction. Drought-resistant plant species might be considered for future ecological projects. However, an eco-risk assessment should be conducted when introducing drought-resistant plant species.

1. Introduction

Numerous studies have reported vegetation cover dynamics in various ecosystems in China (Piao et al., 2003; Xin et al., 2008; Yu and Hu, 2013). Climatic factors, land-use change, and the fertilization effect of CO_2 have affected the vegetation cover in different regions (Fabricante et al., 2009). Coarse spatial resolution satellite images (e.g., Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS)) have been widely used to monitor spatial and temporal variations of various ecosystem conditions due to their high temporal resolution. The Normalized Difference Vegetation Index (NDVI) is the difference between the reflectance in the red band (610–680 nm) and the near-infrared band (780–890 nm), and is sensitive to the presence, density, and dynamics of vegetation. Consequently, MODIS NDVI had been applied to quantify vegetation cover, green leaf area index (LAI), vegetation productivity, and green biomass. Over the past 20 years, many studies have examined the inter-annual variation in vegetation cover using multi-temporal NDVI data at regional, continental, and global scales (Tucker et al., 2001; Paruelo et al., 2004; Xin et al., 2008). Recent studies noted an incremental change in vegetation in various ecosystems of the Northern Hemisphere (Slayback et al., 2003). Similarly, vegetation cover has increased throughout China, and the growing season has lengthened due to global climate change (Fang et al., 2004; Li et al., 2011).

Coupled relationships between NDVI and climatic variables have also been reported (Piao et al., 2004; Chen et al., 2005; Li et al., 2011; Liu et al., 2013a; Yu and Hu, 2013). For example, precipitation

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plays an important role in ecosystems of west China; vegetation conditions are positively correlated with precipitation in most dry areas and negatively correlated with heavy rainfall in humid areas. The response of the NDVI to climate variables in southern China is spatially variable. For example, changes in temperature generally affect the NDVI more than precipitation in southwest China (Wang et al., 2008).

Vegetation cover is also significantly impacted by human activities. Changes in land use resulting from human activities such as urbanization and agriculture are important factors influencing the spatial pattern of vegetation. Land degradation is one of the most severe and widespread environmental problems in southwestern China. The expansion of farmland and built-up areas, and excessive deforestation has caused land degradation and soil erosion, and consequently degraded the vegetation cover. Red and karst soils are the main soil types in hilly southern China. The uneven temporal distribution of precipitation in the region, and inappropriate land exploitation has led to soil erosion, degradation, and deterioration of the ecological environment in these areas. Specifically, inappropriate activities (land reclamation and cultivation on steep hillslopes) in the karst region and intensive land use in this extremely fragile geological environment results in serious soil erosion and the extensive exposure of basement rocks (karst rocky desertification, KRD). To mitigate karst rocky desertification and environmental degradation, Chinese governments at various levels have invested considerable human resources and financial resources to improve the conditions for vegetation growth (Yu et al., 2009; Wang et al., 2010; Deng et al., 2012; Sun et al., 2013; Wu et al., 2013; Cai et al., 2014). Specifically, large-scale ecological construction projects such as Grain for Green and karst rocky desertification control programs were implemented from 2000 to 2010 to improve vegetation cover and ecosystem conditions. It is almost time to assess the impacts of these programs on vegetation changes.

However, most research regarding vegetation cover in the study area has focused on the combined impacts of climate and human activities on the inter-annual NDVI variation (Wang et al., 2008; Wang et al., 2014). Few studies have separated the impact of anthropogenic and climatic variations on vegetation conditions. Residual analysis not only identifies human factors but also separately characterizes the influences of climate factors and human activities. This method was used in Syrian dryland and Inner Mongolia to identify the impacts of human activities on vegetation conditions (Evans and Geerken, 2004; Li et al., 2012).

The headwater region of the Yangtze and Pearl rivers in hilly southern China plays an important role in the ecological security of south and southwest China. It had experienced major changes in its environment and landscape due to the implementation of ecological projects, economic development, eco-migration, and climate change (Wang et al., 2014). However, few studies have explored the dynamic changes in vegetation and quantitatively assessed the mechanisms driving these changes. This study used MODIS NDVI and climate data from 2000 to 2010 to examine vegetation distributions and dynamics in hilly southern China and to identify their relationships with climate and land-use changes. Our results will contribute to a better understanding of the interactions among climate, human activities, and vegetation variation, and facilitate the design, planning and implementation of ecological reconstruction projects.

2. Data and methods

2.1. Study site

Our study site in southern China (22°45′–27°14′N, 102°45′–117°08′E) is bounded by Jinping County, Yunnan province; Dapu County, Guangdong province; Hekou County, Yunnan province; and Chengbu Miao Autonomous County, Hunan province. In total, 114 counties (cities or districts) in the provinces of Yunnan, Guizhou, Hunan, Jiangxi, Guangdong, and Guangxi Zhuang are included in our study. The total area of the region is 2.9×10^5 km^2 of land area in China and the main land-use types are forest (1.7×10^5 km^2, 58.80% of the total area), shrubland (4.0×10^4 km^2, 12.07%), grassland (2.0×10^4 km^2, 6.53%), cropland (5.0×10^4 km^2, 17.87%), and other (e.g., wetland, bare land; 2.0×10^4 km^2, 4.93%) in 2010 (Fig. 1). The vegetation cover in the west and northwest of the study area mainly consists of grasses and shrubs. Farmlands are mainly located in the industrial and economic development zones in the central region. The main soil types are red and karst soils. The topography of the study area has a declining slope from the west to the east, with the altitude ranging from −20 to 3040 m. The region has a subtropical monsoon climate and a mean annual precipitation of ~1490 mm. The average annual temperature is 19.3 °C with a minimum average temperature of 10 °C in the winter and a maximum average temperature of 27.5 °C in the summer. The mean annual sunshine duration is 1508 h, with the lowest values in summer.

2.2. Data

To examine large-scale vegetation changes, time-series MODIS Terra NDVI data (MOD 13) were downloaded from the Land Processes Distributed Active Archive Center (LP DAAC), NASA. The spatial resolution of MODIS NDVI data is 250 m, and the time series spans 11 years; from February 18, 2000 to December 19, 2010. The monthly NDVI was a maximum value composite (MVC) data product, where cloud contamination, atmospheric effects, and solar zenith angle effects were minimized. The annual NDVI, the average of the mean monthly NDVI during growing seasons, was used to represent vegetation cover conditions for a year. NDVI images were georeferenced to an Albers equal-area conic projection for further analysis.

Land-cover maps for the study area in 2000 and 2010 were derived from a national land-use map downloaded from the Center for Earth Observation and Digital Earth, China (http://www.ceode.cas.cn/sjyhfw/). The land-use map was created mainly based on visual interpretation of Landsat-5 Thematic Mapper (TM) images and a vegetation map (scale: 1:2.5 million, vector format). The map was resampled to a spatial resolution of 250 m and transformed to the same coordinate system as for the NDVI data.

We obtained climate data (monthly temperature, monthly precipitation, and monthly sunshine duration) for 62 weather stations (29 in the study area and 33 in surrounding areas) between January 2000 and December 2010, from the China Meteorological Data Sharing Service System. Weather stations around the study area were selected to improve the accuracy of spatial interpolation. In addition, for the purpose of analyzing the responses of vegetation to extreme weather events, we extracted daily precipitation from six weather stations (Luodian, Wangmo, Guangna, Yanshan, and Baise). We characterized extreme events using three precipitation indices: consecutive dry days (maximum number of consecutive days with precipitation of <1 mm, CDD), consecutive wet days (maximum number of consecutive days with precipitation of ≥1 mm, CWD), and heavy precipitation days (the number of days with precipitation of ≥25 mm annually, R25). CDD was used to signify extreme dry events, with a longer CDD indicating drought. CWD and R25 were used to represent wet events. Specifically, R25 represents rainfall intensity. A 90 × 90-m digital elevation model (DEM) was downloaded from the CGIAR Consortium for Spatial Information (CGIAR-CSI) (http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp) for the interpolation of climatic variables.