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The climatic impacts of land use and land cover change compared among countries

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Abstract: Land use and land cover change (LULCC) strongly influence regional and global climate by combining both biochemical and biophysical processes. However, the biophysical process was often ignored, which may offset the biogeochemical effects, so measures to address climate change could not reach the target. Thus, the biophysical influence of LULCC is critical for understanding observed climate changes in the past and potential scenarios in the future. Therefore, it is necessary to identify the mechanisms and effects of large-scale LULCC on climate change through changing the underlying surface, and thus the energy balance. The key scientific issues on understanding the impacts of human activities on global climate that must be addressed including: (1) what are the basic scientific facts of spatial and temporal variations of LULCC in China and comparative countries? (2) How to understand the coupling driving mechanisms of human activities and climate change on the LULCC and then to forecasting the future scenarios? (3) What are the scientific mechanisms of LULCC impacts on biophysical processes of land surface, and then the climate? (4) How to estimate the contributions of LULCC to climate change by affecting biophysical processes of land surface? By international comparison, the impacts of LULCC on climate change at the local, regional and global scales were revealed and evaluated. It can provide theoretical basis for the global change, and have great significance to mitigate and adapt to global climate changes.

Keywords: land use and land cover change; climate change; biophysical effects; model simulation

1 Introduction

The impacts of human activities on global climate change are mainly attributed to greenhouse gases, aerosols, and land use activities (IPCC, 2014). Currently, the process to solve global warming is a serious challenge facing the international community, and the core con-

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cern of the intergovernmental negotiations on climate change and "mitigation" is reducing the greenhouse gases and increasing the sinks (Le Quéré *et al*., 2014). Although many studies of climate change considered that greenhouse gas emissions is the main causes for climate change, and ignored the impacts of land use change on climate through changes in land surface biophysical processes, which may overestimate the role of carbon emissions and neglected the scientific regulation of human behaviors on land use (Marland *et al*., 2003; Gibbard *et al*., 2005; Paeth *et al*., 2009).

Land use and land cover change (LULCC) underwent rapid variations at different spatial and temporal scales. It impacts the climate system significantly by changing the land cover violently at different scales (Feddema *et al*., 2005; Mahmood *et al*., 2014), and thus becoming one of the important human activities to influence the climate change (GLP, 2005; IPCC, 2007; Foley *et al*., 2005; Pielke *et al*., 2011). LULCC strongly influence regional climate through both biogeochemical and biophysical processes (Pielke *et al*., 2002; Houghton and Hackler, 2003; Feddema *et al*., 2005; Chapin *et al*., 2008; Diffenbaugh *et al*., 2009). Its impacts are mainly manifested in the two key processes of the radiation/energy exchanges between atmosphere and land surface, and the carbon adjustment.

On the one hand, LULCC impacts the climate system by change the carbon cycles through the emissions or absorptions on the atmospheric greenhouse gases (Pielke *et al*., 2002; Ramankutty *et al*., 2007). On the other hand, LULCC results in the varied surface albedo and roughness, and the urban expansion leads to the enhancement of heat island effect, which then affects the surface heat budget and vertical transport of water vapor, and the changes of temperature, humidity, wind speed, evapotranspiration, etc. (Paeth *et al*., 2009), by a series of biophysical processes to impact the climate change. LULCC alter the surface patterns of sensible and latent heat into the atmosphere (Mahmood *et al*., 2010), whether warming or cooling effects of LULCC depends on factors like temperature, precipitation, soil water content, and surface reflectivity (Betts, 2011), and more or less warming or cooling depends on the local background climate (Pitman *et al*., 2011). Therefore, consideration of the biophysical processes would shift the relative values of some ecoregions, and sometimes even reversing (Betts, 2000; Anderson-Teixeira *et al*., 2012).

However, the existing global LULCC datasets showed lower precision and lack of dynamic changes. Available dynamic models of LULCC have been mostly driven by human activities or climate, but failed to coupling the two factors. The insufficient ability to obtain critical surface parameters resulted in the lack of the knowledges on the influences of LULCC on the spatial and temporal variations of land-atmosphere energy exchange through the radiation energy balance and land surface roughness. Climate model simulations embedded dynamic LULCC is less, and therefore the feasibility to mitigate the climate warming by LULCC has not been fully demonstrated. The key questions need to be addressed including: (1) what are the basic scientific facts of spatial and temporal variations of LULCC in China and comparative countries? (2) How to understand the coupling driving mechanisms of human activities and climate change on the LULCC and then to forecasting the future scenarios? (3) What are the scientific mechanisms of LULCC impacts on biophysical processes of land surface, and then the climate? (4) How to estimate the contributions of LULCC to climate change by affecting biophysical processes of land surface?

Therefore, it is necessary to identify the mechanisms and effects of large-scale LULCC on climate change through changing the underlying surface, and impacting the water and heat distribution patterns and thus the energy balance, and to achieve the quantitative analysis on the climate impact of large-scale LULCC process, which are the key scientific issues on understanding the impacts of human activities on global climate that must be addressed. By international comparison, the climatic impacts of LULCC at the country scale could be revealed and evaluated, which can not only provide scientific theories for the study of global change and earth system models, but is also significant to mitigate and adapt to global climate changes by the scientific regulation of human land use.

2 Methods on the climatic impacts of LULCC

The impacts of land use and land cover change on global climate primarily applied the satellite and ground integration methods coupled LULCC, climate and ecosystem, which focus on multi-scale LULCC process and its climatic effects, to build series of database with mutual evaluation between earth observation from space and ground stations network. And then a relatively completed system with simulation, prediction and validation of land system and surface atmosphere could be developed.

Existing datasets of LULCC, long-term ecosystem flux observation, meteorological observation, model simulation, remote sensing retrieval, transect survey and forest inventory etc. were collected. The classification information on the second-level land cover types and LULCC were extracted based on Landsat images and MODIS/AVHRR data, especially for those typical types of agriculture and cropland abandoned, deforestation and afforestation, grassland degradation and restoration, urbanization. Then the dynamic patterns and driving factors of LULCC were analyzed.

The impacts of land use change on land surface radiation energy balance and hydrothermal exchange were observed comparatively by establishing new flux equipment around existing flux observation stations. The spatial and temporal data of evapotranspiration and land surface biophysical parameters (albedo, roughness, net radiation, etc.) were retrieved. Then the biophysical effects of land use change and its mechanisms were analyzed.

Bayesian ensemble approach integrated multi-model of regional integrated environmental model system (RIEMS), weather research and forecasting model (WRF) and regional climate model (RegCM3) were applied to simulate the impacts of LULCC on climate in China and other comparative countries.

Scientific research platform to simulate the impacts of large-scale land use change on climate were developed, which consists of LULCC dynamic models coupled natural and human factors, climate model, and land surface model. In support of remote sensing retrieval and field observation, the climatic effects of large-scale land use change were simulated.

The past, current and future LULCC patterns and their driving mechanisms in different spatial scales of typical region or country, and global range were analyzed comprehensively. The impacts of LULCC on the climate regulation services of ecosystem through hydrothermal exchange and then on climate were discussed.

Finally, the countermeasures and consulting researches could be suggested on regulation of human land use change, climate adaptation and mitigation, strategies and recommendations for environmental diplomacy.

3 Spatial and temporal patterns of LULCC in different countries

Based on the China's 1:100,000-scale land use and land cover change datasets (Liu *et al*., 2003a; Liu *et al*., 2003b; Liu *et al*., 2010) in the late 1970s, the late 1980s, 1995, 2000 and 2005, LULCC dataset for 2010 was constructed by the human–computer interactive interpretation method based on the 2010 Landsat TM images covering China (Zhang *et al*., 2012). At the same time, a standardized LULCC data of comparative countries were made, and the LULCC data in the 1950s, 1970s and 2005 of the United States of America (USA), LULCC data of the Brazil, India, Mongolia, Russia, and the five Central Asian countries (Kazakhstan, Turkmenistan, Kyrgyzstan, Uzbekistan, Tajikistan) in 1970s and 2005 were produced.

The spatial and temporal characteristics of LULCC and its driving causes in the past 20 years at a national scale were investigated by Liu *et al*. (2014). It is shown that LULCC across China presented large variations in the spatial and temporal patterns in the last 30 years. The total area of cropland was nearly constant, although it decreased in southern regions and increased in northern regions. And the cropland reclamation expanded in northern regions showed a shift from the northeast part to the northwest. The rapid expansion trend of built-up lands in eastern China was spread gradually out to the central and western regions. Woodland area was decreased in the former 10 years, and then increased in the latter 10 years. The desert area was increased before 2000 and decreased after 2000. Grassland area showed a continuous decrease in the 20 years. The main anthropogenic driving factors of land use change patterns in the first decade of the 21st century shifted from land development to both land development and environment conservation.

The dynamic patterns of LULCC in comparative countries were analyzed. From the 1950s to 1970s, urbanization in Eastern USA, agriculture on grassland in Central and Western USA were primary land use change types. From the 1970s to 2005, the continued urbanization presented obvious regional differences. According to comparative analysis on the patterns and rates of urban expansion in China and the USA, Kuang *et al*. (2014) found that the expansion area of impervious surface in three megacities of China showed five times larger than that in USA. From the viewpoint of expansion patterns, impervious surface in China's megacities expanded abruptly outward from the urban center in a cyclic structure, however, impervious surface in USA's megacities expanded constantly and smoothly in the inner cities with patch patterns.

In Brazil, the main characteristics in the past 30 years showed the increasing cropland and urbans, and decreasing forest and grassland. The area of LULCC reached 7.943×10^5 km^2, accounting for 9.33% of the total land area in Brazil. According to Lu *et al*. (2014) and Du *et al*. (2015), the direct driving forces for the LULCC presented as climate change, land use policy, population growth and migration, etc. which are all the same factors in the developing countries.

From the 1970s to 2005 in India, the areas of cropland, urban and waters showed the largest changes, with cropland and forest decreasing by 3.69×10^4 km^2 and 0.46×10^4 km^2, water and urban areas increased by 4.05×10^4 km^2 and 0.86×10^4 km^2, respectively. In the five countries of Central Asia, urban areas in all countries increased in the past 30 years, cropland was decreased in Kazakhstan but increased in other four, water areas decreased in Uzbekistan and Tajikistan but increased in other three.

It is crucial to reconstruct the historical land cover change to assess the human impacts on the climate. Representative global historical land use datasets of HYDE (History Database of the Global Environment) and SAGE were developed by the Center for Sustainability and the Global Environment (SAGE) in University of Wisconsin-Madison and the Netherlands Environmental Assessment Agency. However, due to the differences in reconstruction methods, input data, and model assumptions, we can see large discrepancies and biases of those datasets, especially in China. Based on historical cropland areas, population numbers and the land suitable for agriculture, He *et al*. (2013c) and Li *et al*. (2015) produced a provincial cropland dataset of China from 1661 to 1996, and then allocated it into 10 km×10 km grid cells. The cropland increased from about 55.5×10^4 km^2 in 1661 to 130.0×10^4 km^2 in 1996. To capture the spatial distribution of cropland, land cover maps in 2000 detected from satellite were applied.

In addition, historical forest and cropland cover of China, the USA, India and Brazil in the past 300 years were reconstructed by integrated applying SAGE, HYDE and LULCC datasets in recent decades. The land development process in the past 300 years has obvious differences compared among China, USA, Brazil and India. In one hundred years from the early 18th century to the 20th century, cropland area in USA increased significantly following the implementation of development policy in western and central regions. The large-scale land development was contained till the 1930s. Since 1887, Brazil's cropland began to grow rapidly, and large-scale land development activities expanded to the eastern and southern regions. As two ancient civilizations, China and India both has a long history of agricultural development and earlier cropland expansion. In recent 300 years, cropland area showed a sustained growing trend driven by the pressure of population.

The scenarios of land use patterns of China and comparative countries were analyzed by dynamics model of LULCC. Xu *et al*. (2013) designed three scenarios of baseline, economic development and ecological conservation based on socio-economic development, and explored the possible trends of China's land use change according to the three scenarios with different parameters by applying the Agriculture-Land-Use module and Edmonds-Reilly-Barnes module of global change assessment model (GCAM model). Three future scenarios of global terrestrial ecosystems during the periods of 2010–2039, 2040–2069 and 2070–2099 were developed by Yue *et al*. (2011), based on a high accuracy and speed method (HASM) of surface modelling. Applying observed temperature data of 2766 weather stations scattered over the world, the regression formulations among temperature, elevation and latitude are simulated. And then the mean annual bio-temperature, mean annual precipitation and potential evapotranspiration ratio were simulated by HASM.

4 The impacts of LULCC on climate

4.1 Integrated climatic impacts of LULCC

The impacts of typical LULCC on land surface temperature were analyzed by applying meteorological observation data and remote sensing images. Meteorological observations are influenced by surrounding land cover types. Based on LULCC datasets from the late 1980s to 2005, NCEP/DOE AMIP-2 reanalysis datasets, and observed temperature data of 136 meteorological stations, Gong *et al*. (2012) summarized the impacts of land cover types on climate warming, and showed that the changing trends of annual mean, maximum and minimum air temperatures are most significant in built-up areas, moderate in cropland area, and less significant in forest area in southern China. Forest plays a cooling effect on temperature, while built-up land and cropland have warming effect.

The land use change impacts on land surface radiation energy balance were analyzed mainly based on high spatial and temporal resolution remote sensing retrieved products, to reveal the driving mechanisms of LULCC on land surface albedo change, and then the biophysical mechanisms of LULCC on affecting regional climate change. Zhai *et al*. (2014) showed that the average radiative forcing of LULCC was 0.062 W/m^2 during 1990–2010 in China, and the huge spatial heterogeneity of LULCC radiative forcing indicated warming effects on climate system.

Land surface models were applied to investigate the impact phenomenon and mechanisms of LULCC on land surface energy balance through the land surface thermal-hydrologic exchange, such as NOAH, CLM, SiB2, EASS, etc. Based on the process-based land surface model EASS, Yan *et al*. (2014) investigated that the contributions of climate change and LULCC on surface energy changes were 4:1 or even higher over eastern China in the past 30 years, and the impacts of LULCC on the land surface heat fluxes showed large seasonal variations. For next 40 years, Yan *et al*. (2013) investigated spatial and temporal variation patterns of sensible heat flux (H) and evapotranspiration (ET) under the land cover and climate scenarios across southern China, and showed that H displays a downward trend (10%) and ET presents an increasing trend (15%).

Due to the diversities and uncertainties of LULCC in China, few researches focused on the impacts of LULCC on China's climate system. In northern China, Dong *et al*. (2013) simulated the impact of LULCC on surface air temperature applying RIEMS 2.0, and showed that the effects of deforestation in temperate zones is more like summer deforestation in tropical zones and winter deforestation in boreal zones. Compared to higher latitudes, the net radiation absorption change from forest converted to cropland at lower latitudes has less influence on the air temperature, but the latent heat flux has a stronger influence.

The climate system model of intermediate complexity (MPM-2) was applied to assess the global-scale biophysical climatic effects of land cover change for the past millennium. Due to the changes in albedo and precipitation, the impacts of land cover change was most obvious over Eurasia, with the maximum cooling by about 0.8ºC during summer at middle latitudes, however, the maximum warming by about 0.1ºC during the Northern Hemisphere summer at low latitudes over the Southern Hemisphere. For the climatic impacts of historical deforestation, Wang Y *et al*. (2013a, 2013b) simulated a cooling biophysical effect on global mean annual temperature by about 0.13ºC, in which the maximum cooling over Eurasia by 0.5ºC and the minimum over the Southern Hemisphere by 0.02ºC.

4.2 The climatic impacts of urbanization

Urbanization results in higher land surface temperatures in urban areas than its surrounding rural areas, and it causes several obvious effects on land surface energy balance (Zhao *et al*., 2014). Climatic impacts of urbanization are often estimated by the air temperature differences between meteorological stations located in and out of urban areas. However, it is difficult to rely on those observation data alone due to the sparse density of stations, and the potentially influences from surrounding local conditions. In addition, many studies also applying the satellite derived products to compare the differences of land surface temperature in one or several big cities (Peng *et al*., 2012; Clinton and Gong, 2013). However, a systematic evaluation on the impact phenomenon and mechanism of urbanization on surface temperature is still missing.

The urbanization leads to the effects of urban heat island, especially in the winter. When a meteorological station was forced to 'enter' cities, the observed regional air temperature would be overestimated. The overestimation is relatively higher in eastern regions than in the central and western regions due to its largest urbanization area and rapid rate. By comparing the original observations of urban meteorological stations with the surrounding background temperature, Shao *et al*. (2011) estimated the average intensity of urban heat island in China since 1970, and showed that the mean temperature increased by about 1.58°C in China in the last 40 years, of which about 0.01°C was contributed by urbanization.

Urbanization and cropland irrigation influenced the climate at local and regional scales. Several studies documented the impacts of urbanization or cropland irrigation on temperature separately. However, few studies analyzed the combined effects. Shi *et al*. (2014) analyzed the impacts of irrigation and urbanization on the surface temperatures on the Huang-Huai-Hai Plain in China, and indicated the significant cooling effect of cropland irrigation on maximum temperatures by 0.17–0.20ºC/decade, and a warming effect on minimum temperature by 0.43ºC/decade from 1955 to 2007. In those regions combined with urbanization and cropland irrigation, the warming effects of urbanization on extreme daily maximum temperature seems to be partially offset by the cooling effects of irrigation.

The field observation and model simulation were integrated to analyze the discrepancies of the radiation balance in different underlying surfaces and modeled the radiation balance by changing the land cover type but keeping all other inputs unchanged, then to discuss the impacts of urbanization on climate in typical regions. Cui *et al*. (2012) showed that annual average net radiations for four land use types of forest, grass, roads and buildings ranged of 38.2–53.4 W/m^2, and minimum on the grass surface and maximum on the road surface. The urbanization that transferred from forest or grass to road or from grass to building will lead to increasing net radiation.

Urbanization is an important contribution of human activities to climate change. By coupling the WRF with a single-layer urban canopy model, the impacts of urbanization on climate in the Beijing-Tianjin-Hebei metropolitan area was simulated by Wang *et al*. (2013a, 2013b). It is shown that urbanization can only heat the air inside the urban boundary layer below 850 hPa and has more than 1°C impact on annual mean air temperature in urban areas, with maximum difference of almost 2°C. The heat island effects of urbanization that forcing the underlying surface thermal source enhanced the vertical air movement and formed a convergence zone over the urban areas, and the low-level convergence together with the increasing moisture in layer between 850 and 700 hPa triggered the increasing of convective precipitation. Urbanization in the Beijing-Tianjin-Hebei metropolitan area resulted in intensification and expansion of the regions experiencing extreme heat waves, and the average temperature increased by approximately 0.60°C that is most obvious at night by up to 0.95°C. Therefore, the mitigation strategies to increasing the roof albedo can reduce the urban mean temperature by approximately 0.51°C and offset nearly 80% of the heat wave from urbanization in the last 20 years.

From our comparisons in Figure 1 we can see that urbanization results in the decreased net radiation was less than the decreased latent heat flux, and the heating effects of the land surface to the atmosphere showed the negative values, therefore its net biophysical effect was warming in almost all climate zones. The main difference of the warming effects of urbanization presented as the warming enhancement per unit urban area was lower in arid and semiarid regions than humid and moist regions, and over twice higher in China, India and Brazil than that in the USA, due to significantly variations in patterns and rates of urbanization. Therefore, urban landscape planning based on biophysical mechanism can reduce the urban heat island intensity effectively.

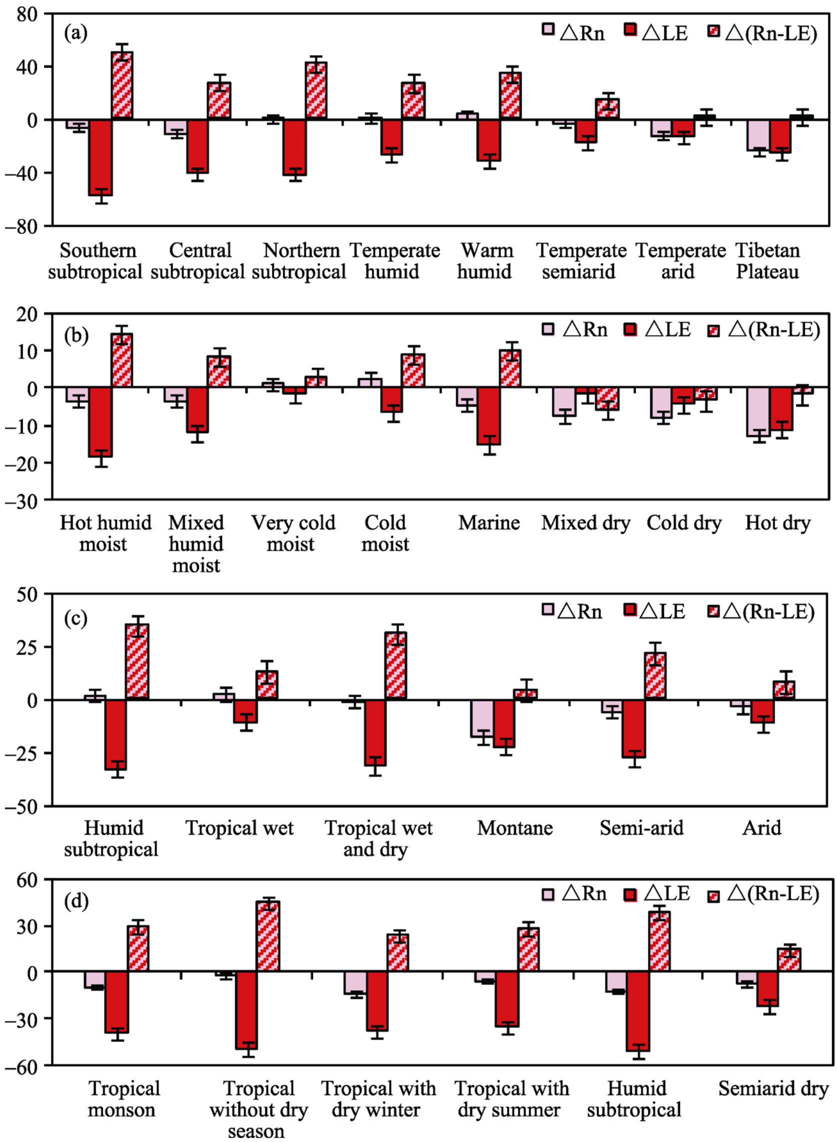

Figure 1 The biophysical forcing of urbanization compared in varied climate zones of China (a), USA (b), India (c) and Brazil (d)

4.3 The climatic impacts of cropland expansion

Due to the surface wind and boundary layer height could be altered by increasing canopy height of crops during the growth processes (Lu *et al*., 2015), the cropland plays a very important role through biophysical processes under the climate change (Feddema *et al*., 2005; Foley *et al*., 2005). Therefore, when LULCC such as conversion of forest to cropland occurs, it generates higher surface albedo and then alters the energy budget obviously (Bonan, 2008). Both field observation and modeling have shown that regional transfer from forest to rain-fed cropland can reduce the evapotranspiration and then the precipitation (Sampaio *et al*., 2007). However, previous studies have mainly focused on the simulation of potential impacts on the mean climate (Davin *et al*., 2014), from the local and regional scale to sub-continental and global scale, whereas the influence mechanisms and variations has never been explored.

The greenness of cropland increased in spring leads to the cooling and wetting effects and conversely substantially decreased in early summer results in warming and drying effects in the North China Plain during 1982–2006, according to the simulation from Zhang *et al*. (2013c). It is shown that the cooling or warming impacts of greenness changes in cropland accounted for about 47% of the spatial variations in spring daily maximum temperature change and 44% in early summer. It also showed that the wetting or drying effects accounted for about 48% of the spatial variations in spring daily minimum humidity change and about 19% in early summer. Therefore, the increased greenness of cropland responds to higher transpiration rate and humidity, less sensible heat flux, and consequently cooling and wetting effects.

The role of cropland irrigation in regulating the regional climate has been widely recognized. Mao *et al*. (2011) simulated the impacts of cropland irrigation on regional climate over India using the RIEMS 2.0. During 1990–2000, the temporal difference of the two regional climate model sensitivity experiments (rain-fed cropland and irrigated cropland) showed that a regional cooling effect exists driving by irrigation with annual averaged 2 m air temperature decreasing 1.4ºC and the precipitation rate increasing 0.35 mm/d at the national scale. The irrigation cooling effect can contribute to the increased latent heat flux and decreased sensible heat flux. The increased precipitation rate depends on the offset between the positive convective rainfall and the negative large-scale none-convective rainfall. The seasonal difference indicated that the climate of pre-monsoon season and June is more sensitive than monsoon season (July to September) to irrigation. The national averaged change in temperature was 3.18ºC in pre-monsoon season and 0.43ºC in monsoon season, respectively.

Conversion of grassland or forest to cropland caused decreased net radiation and increased latent heat flux in China's arid and semiarid regions, so the net biophysical effect was cooling. Whereas it caused increased net radiation and decreased latent heat flux in subtropical regions, therefore warming was the net biophysical effect. In USA, Brazil and India, whatever in arid or humid regions, the net biophysical effects of conversion of grassland or forest to cropland presented as cooling. The net radiation decreased and latent heat flux increased in dry regions in Western USA, and the increased net radiation less than increased latent heat flux in moist regions in Eastern USA. The net radiation and latent heat flux both decreased in Brazil, but the decreased amount of net radiation was less than that of latent heat flux (Figure 2).

4.4 The climatic impacts of afforestation

The promotion of afforestation has often been pointed out as a significant mitigation and adaptation strategy of climate change. The biogeochemical effects of afforestation result in atmosphere carbon dioxide absorption and carbon sequestration, which have a cooling impact on the regional climate (Betts, 2011). In addition, the biophysical effects of afforestation can lead to climate warming by changing the land surface albedo, roughness, evapotranspiration and then surface energy transfer processes (Anderson *et al*., 2010), particularly at high latitudes. Here, the biophysical impacts of afforestation were analyzed for varied climate zones in different countries.

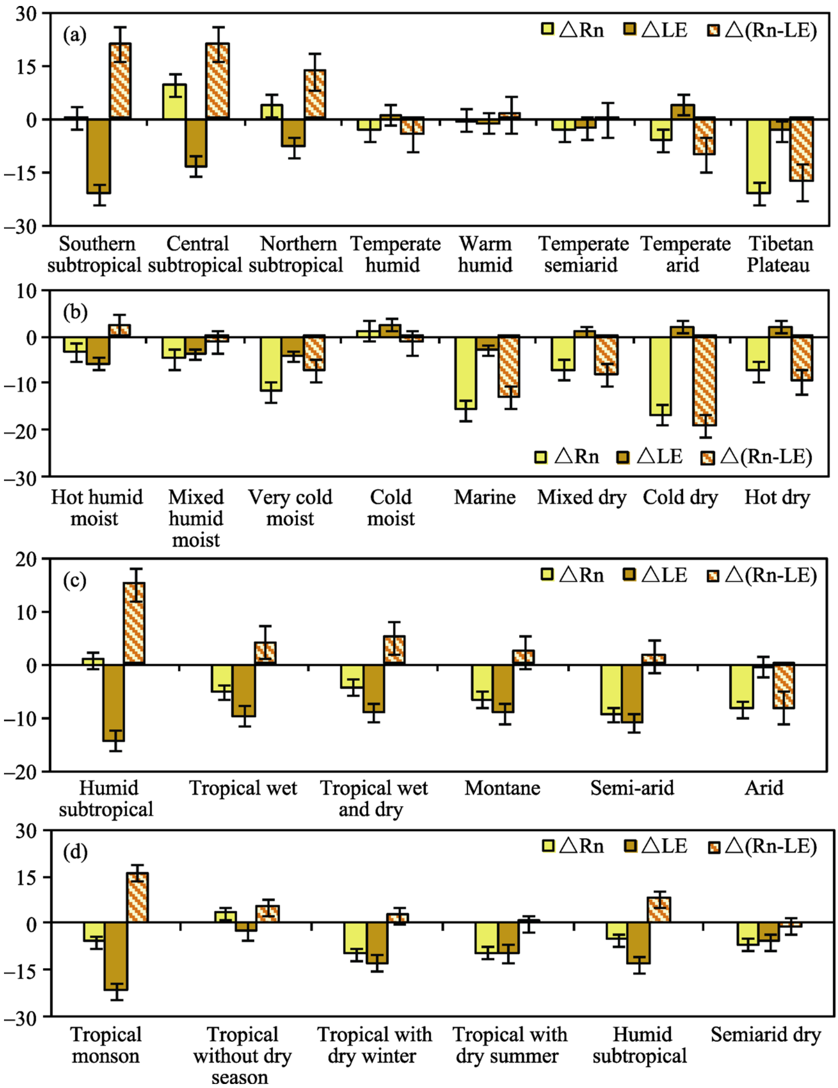

Figure 2 The biophysical forcing of cropland expansion compared in varied climate zones of China (a), USA (b), India (c) and Brazil (d)

From the comparisons in Figure 3, we can see that afforestations in humid subtropical and tropical regions of the four countries have net cooling influences on regional temperature with higher warming reductions per unit area, due to its increased net radiation being less than the increased latent heat flux. However, afforestation in arid and dry regions of China, USA and India have weak cooling or even warming influences, because the increased net radiations are typically overwhelmed the increased latent heat flux, or the cooling carbon effects of afforestation are outweighed the net warming effects related to higher net radiation and lower evapotranspiration. The net biophysical effect of afforestation in whole Brazil showed cooling effects. Therefore, from the climate perspectives, afforestation in the humid, subtropical, tropical regions and the whole Brazil would be obviously beneficial in adapting to and mitigating climate warming, however it would only offer marginal benefits in

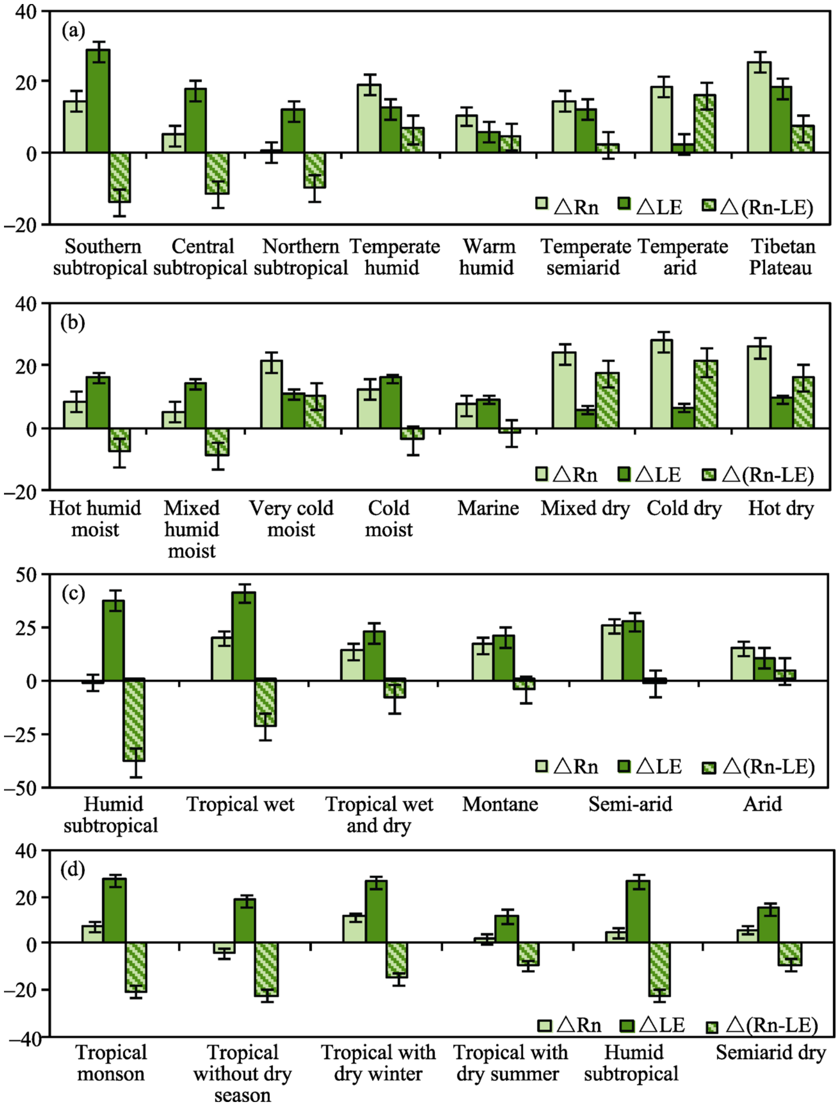

Figure 3 The biophysical forcing of afforestation compared in varied climate zones of China (a), USA (b), India (c) and Brazil (d)

temperate regions, and even counterproductive in arid and semiarid regions.

5 Projecting the potential impacts of LULCC on climate

Most previous studies focused on the relationship and simulation analysis of historical LULCC and climate change, with fewer explorations for the impacts of future LULCC on regional climate. The future scenarios of the LULCC impacts on biophysical processes and then the climate were simulated and analyzed combining EASS and WRF simulation.

Northeast China is one of the regions with the highest intensity of human activities, which have an important role in influencing the regional climate. Shi *et al*. (2013) simulated the climatic effects of cultivated land reclamation by the WRF model, and indicated the increasing temperature and decreasing precipitation during 2030–2040. In the overgrazing regions of northwestern China, Li *et al*. (2013) explored the potential climatic impacts of grassland degradation from 2010 to 2040, which will lead to increasing summer temperature by 0.4–1.2ºC and decreasing winter temperature by 0.2ºC, and decreasing precipitation by 4–20 mm both in summer and winter.

As one of the major types of LULCC, the expansion of cultivated land will impact on regional climate change in the future. By applying the WRF model, Qu *et al*. (2013) forecasted the changes of energy flux and then the temperature based on the future cultivated land reclamation in India, and then the impacts of cultivated land reclamation on climate change were also analyzed. The cultivated land reclamation will lead to the increase in latent heat flux and the decrease in sensible heat flux, and further lead to changes of regional temperature. Furthermore, the cultivated land reclamation mainly leads to a temperature decrease in the summer, while it leads to a temperature increase in the winter.

In Mongolia, the potential climatic impacts of future grassland changes were simulated by WRF model for 2010–2020 and 2040–2050. The baseline underlying surface data in 1993, the atmospheric forcing datasets of RCP 6.0 from CMIP5, and the predicted underlying surface data which can be derived through overlaying the grassland degradation information to the map of baseline underlying surface were applied. Future grassland degradation could result in an increasing temperature in most areas by a range of –0.1ºC to 0.4ºC, and decreasing precipitation by 10–50 mm (Zhang *et al*., 2013a).

In the northeastern megalopolis in the USA, The impacts of future urbanization on regional climate are simulated by Lin *et al*. (2013). It is shown that the future urbanization will result in the increasing mean annual temperature by 2–5ºC in new urban regions and decreasing temperature by 0.4–1.2ºC in southern megalopolis. And the warming will be more obvious in summer than that in winter. For the annual total precipitation, it will respectively decrease by about 5.8, 7.1 and 8.4 mm during the periods of 2010–2020, 2040–2050 and 2090–2100.

In the Brazilian Amazon, the potential climatic impacts of future deforestation was simulated in the 21st century by Zhang *et al*. (2013b), and it is shown that 5.12% of the forests will be transferred to cropland and pasture in the northwestern part and 13.11% to cropland/woodland mosaic in the southeastern part, respectively. And then those LULCC will result in obvious reduction of sensible and latent heat flux, decreasing precipitation and increasing land surface temperature.

6 Conclusions

(1) Based on "global vision", quick information obtained methodology of large-scale LULCC integrated remote sensing and geoscience knowledge was constructed for China and comparative countries. The spatial and temporal datasets in the past 30 to 300 years and future 50 to 100 years of China and comparative countries were produced. The dynamic LULCC processes and its driving mechanism were revealed between China, the United States, Brazil, India, Central Asia and other countries. The absence of high-resolution temporal LULCC data in the global change research was solved. The LULCC dynamic model coupled climate change and human activities were developed to improve the reliability and accuracy of LULCC simulation, and to achieve the scenario simulation and forecasting LULCC process in multiple spatial and temporal scales.

(2) The research frameworks on the biophysical effects of LULCC were developed by integrating the observation, retrievals and simulation to enhance the integration of satellite and ground ability to obtain land surface parameters. In the scale of typical region and country, the impacts of LULCC on land surface biophysical parameters and the spatial variations were quantitatively analyzed and simulated. The mechanisms of LULCC impacts on climate through land surface biophysical processes were obvious, which were not only controled by LULCC types, but also dependent on local climate background.

(3) The impacts of multiple spatial and temporal scale land use change on climate were simulated by applying land surface process model and climate model based on high resolution LULCC dynamic datasets. The contributions of large-scale LULCC impacts on climate by changing the land surface-atmosphere processes were quantitatively assessed. Effects of LULCC on climate were varied by different scales. In local scale, the impacts of LULCC on radiation and energy balance was greater than that of greenhouse gases, which resulted in local temperature change with the similar magnitude of greenhouse gases. However, those impacts were weak in regional scale.

(4) The future scenarios of LULCC and its climatic effects were projected, and accordingly accurate understanding on the scope and extent of the future LUCC process on climate change was simulated. By optimizing human land use activities, the regional climate could be regulated. Therefore, we need to choose the reasonable patterns of land use under future socio-economic development. LUCC can be one of the effective measurements to mitigate climate change, but its negative effects required further assessment.

(5) The climatic impacts of LULCC on regional and global climate change should arouse great concerns by the global change scientific community. In the future, the impacts of LULCC should focus on cloud formation and precipitation change. In addition, due to less research focused on the biophysical consequences of land management changes, such as irrigation, forest thinning, grazing, etc., those anthropogenic activities should modify the land surface without changing the land cover types. Therefore, as suggested by Luyssaert *et al*. (2014), the land management needs to be considered in the earth system science to further study the human impacts on the climate system.

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