INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **30**: 000–000 (2010)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/joc.2157

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Royal Meteorological Society

Editorial

Impacts of land use change on climate

The US National Research Council (NRC, 2005) recommended the expansion of the climate change issue to include land use and land-cover processes as an important climate forcing. These processes have not been a major component of past Intergovernmental Panel on Climate Change (IPCC) reports. The NRC report states that beyond the change in mean atmospheric composition caused by increasing greenhouse gases, landscape variations may have important local, regional and potentially global climatic implications. In some cases, the climate response to land use and land-cover change may even exceed the contribution from increasing greenhouse gases. 'Improving societally relevant projections of regional climate impacts will require a better understanding of the magnitudes of regional forcings and the associated climate responses.' The International Geosphere Biosphere Programme (IGBP) and the Global Energy and Water Cycle Experiment (GEWEX) have also identified the importance of understanding the climate response to land use and land-cover change. As we move forward to the Fifth Assessment Report of the IPCC, there is growing impetus to address this aspect of anthropogenic impacts on the planet's environment. As a matter of fact, the CMIP5 suite of climate simulations that will be run for this report assessment (http://cmip-pcmdi.llnl.gov/cmip5/) now includes a new forcing dataset: the changes in land–surface areas used for agriculture, grazing activities, forestry, etc.

This special issue is inspired by a recent •NSF-sponsored workshop titled 'Detecting the Atmospheric Response to the Changing Face of the Earth: A Focus on Human-Caused Regional Climate Forcings, Land-Cover/Land Use Change, and Data Monitoring' that was held in Boulder, Colorado, USA in August 2007. Workshop presentations are available online from the National Center for Atmospheric Research (NCAR) Joint Office for Science Support (JOSS; http://www.joss.ucar.edu/joss_psg/meetings/Meetings_2007/Detecting/Index.html), and an overview of workshop conclusions is presented by Mahmood *et al*. (2010). Presenters from this workshop and other interested researchers have contributed articles for two special issues. In addition to this special issue of the *International Journal of Climatology*, there is also a special issue of *Boundary Layer Meteorology* (Niyogi *et al*., 2009) focusing on the effects of land use and land-cover change on fluxes to the atmosphere, and subsequent impacts on weather and climate at the synoptic scales and the mesoscale.

This special issue introduces a number of the studies presented at the Boulder workshop. Most of the studies examine regional impacts of land surface states on climate (Costa and Pires, 2010; Fall *et al*., 2010a, 2010b; Ge, 2010; Kishtawal *et al*., 2010; Mishra *et al*., 2010; Moore *et al*., 2010; Petchprayoon *et al*., 2010; Sertel *et al*., 2010; Takahashi *et al*., 2010; Tokairin *et al*., 2010; Xiao *et al*., 2010). However, several studies take a global perspective of land-cover consequences (Anantharaj *et al*., 2010; Kvalevåg *et al*., 2010; Lawrence and Chase, 2010; Strengers *et al*., 2010). Hibbard *et al*. (2010) sums up with a position paper on recommended future directions for research.

Both observational and modelling studies are presented in this study. The observational studies use *in situ* climate data (Petchprayoon *et al*., 2010; Xiao *et al*., 2010), satellite measurements (Ge, 2010; Kishtawal *et al*., 2010) and data from regional reanalyses (Fall *et al*., 2010a, 2010b). The modelling studies use regional atmospheric models (Moore *et al*., 2010; Sertel *et al*., 2010; Takahashi *et al*., 2010; Tokairin *et al*., 2010; Xiao *et al*., 2010), global climate models (Anantharaj *et al*., 2010; Costa and Pires, 2010; Kvalevåg *et al*., 2010; Lawrence and Chase, 2010; Strengers *et al*., 2010) and one uses a land surface model run offline (Mishra *et al*., 2010).

Several studies focus on the impact of urbanization on climate change. Kishtawal *et al*. (2010) look at the evidence of urbanization on precipitation trends and the occurrence of extreme rainfall events over India. Petchprayoon *et al*. (2010) search for evidence that increased runoff and flooding in the Yom River Basin of Thailand is connected to changes in land use, particularly the spread of urban areas. Sertel *et al*. (2010) find evidence that inaccurate specification of land cover in the default configuration of the Weather Research and Forecast (WRF) model, and in particular, poor representation of the extent of urban areas, impairs the simulation of surface temperature as compared to station reports. Tokairin *et al*. (2010) use a mesoscale model to examine the effects of urbanization on circulation over the island of Java, Indonesia.

Other studies examine the consequences of regional vegetation change on climate. Costa and Pires (2010) model the precipitation response to future deforestation scenarios over South America, considering not only the tropical forests but also the cerrado to the south. Mishra *et al*. (2010) look at historic, current and future land use effects on surface fluxes over Wisconsin in offline simulations with the Variable Infiltration Capacity (VIC) land surface model driven by meteorological output from IPCC climate models. Ge (2010) examines the effect of agriculture, specifically the cultivation of winter wheat, compared to native vegetation, on surface temperature over the Southern Great Plains of the United States. Wet and dry soil conditions in a high-resolution model of Southeast Asia are used by Takahashi *et al.* (2010) to investigate the effect of extreme land use change on wet season climate. Xiao *et al.* (2010) appraise whether the flooding caused by construction of the Three Gorges Dam can be linked to changes in rainfall in the vicinity of the resulting reservoir.

A number of studies take a global view of the impacts of land-cover change on climate that may be of great interest to the IPCC. Strengers *et al.* (2010) determine that anthropogenic changes to land cover have climate consequences that far outweigh the secondary feedbacks that vegetation responding to projected climate change will have on climate. Lawrence and Chase (2010) perform a classic global simulation of climate with current vegetation *versus* potential (no anthropogenic land use changes) vegetation in the NCAR climate model. They find the impact of vegetation change on the surface hydrologic cycle to outweigh radiative impacts (changes in albedo). Anantharaj *et al.* (2010) find in the same model significant errors in top-of-the-atmosphere and surface albedo. When surface albedo is corrected, the simulation of the atmospheric radiative budget is improved. Kvalevåg *et al.* (2010) use a climate model to separate the phenological component of land-cover change from the albedo changes, and find that albedo changes are keys in areas where cropland is the main land use change. However, changes in phenology are important contributors to the warming signal in the model. Fall *et al.* (2010a) () corroborate this result examining the North American Regional Reanalysis (NARR), station temperature trends and time-varying satellite land-cover data. Moore *et al.* find that realistic vegetation parameters over East Africa improve simulations of temperature, and to a lesser extend precipitation, in a regional model. Fall *et al.* (2010b) use NARR data to compare variability and trends in equivalent temperature (including the impact of humidity) to conventional temperature, concluding that equivalent temperature trends include the signature of the underlying vegetation and capture more information than just temperature.

These studies provide a sampling of the complexity involved in resolving the role of land use and land-cover change in climate change. These studies show that there can be significant local effects to observed changes in land use, and that models can represent these changes. Unlike the record of warming from increased greenhouse gases, which is most robust at the global scale yet often tenuous locally, impacts from land use change have their strongest signatures at small scales. Even in a controlled modelling framework, uncertainties are large and many questions remain, as shown in some of the studies presented in this study as well as the early results from the project on Land Use and Climate IDentification of robust impacts (LUCID; Pitman *et al.*, 2009). The regional importance of land use induced land-cover changes on surface climate raises the question of the validity of detection/attribution studies in certain areas where Land Use and Land-Cover Changes have been consequent since pre-industrial times.

These studies have shown that globally, land use does not introduce monotonic changes in either the surface energy or water balance, nor do all types of vegetation respond in the same manner to the thermal and radiative trends that are occurring. The broad vegetation categories used in global and regional climate models are often found to need adjustment or tuning at local scales, where we see the largest impacts. A more complete and comprehensive survey of vegetation phenology, radiative properties as well as soil, geomorphology and other properties relevant to surface hydrology and meteorology is required. Such a survey would greatly improve our ability to downscale climate change to useful regional and local projections, and to understand how land use changes alter local and regional climate.

We also see from the results presented in this issue that the observational network monitoring climate change is not sampling, in proportion to their occurrences, the direct responses or feedbacks from vegetation. In many cases, natural variability in climate is sufficiently large to mask the early signs of the consequences of land use change at the global scale. Waiting for unequivocal climatic evidence frustrates if not scuttles the prospects for mitigation. Thus, we turn to models to project the results of land use changes. But we see again that locally models could verify better than they do. Even with high-quality input data and boundary conditions, the models used for simulating both climate change and land-cover change impacts still have much room for improvement.

One way forward might be to focus the scientific community on a small number of pressing questions to which the panoply of observational and modelling potential could be brought to bear. This would provide the impetus to improve both the stream of observational data and the performance of models as each is confronted with the current limitations and needs of the other. These questions are not new. What has been the contribution of land use change to the observed surface temperature record over the last century? How will the partitioning of precipitation between evapotranspiration and runoff be modified with land use change and how will this affect the climate? How, in turn, is climate affected by modifications to the partitioning of precipitation between evapotranspiration and runoff caused by land use change? Are current land use changes exacerbating or ameliorating climate changes from other causes?

Issues of land use and land-cover change in the climate context open what was one strictly a physical science to escalating complexity as many other disciplines are brought into play. As stated by Hibbard *et al.*, 'Process understanding, both from the socioeconomic as well as the natural science's side, will be important considerations.' A concerted multidisciplinary effort is needed to address the issue properly.

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