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The impact of agricultural intensification and irrigation on land–atmosphere interactions and Indian monsoon precipitation — A mesoscale modeling perspective

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A B S T R A C T

Using the Regional Atmospheric Modeling System (RAMS) we show that agricultural intensification and irrigation can modify the surface moisture and energy distribution, which alters the boundary layer and regional convergence, mesoscale convection, and precipitation patterns over the Indian monsoon region. Four experiments were conducted to simulate a rain event from 16 to 20 July 2002 over the Indian region: (i) a control with Global Land Cover land use and observed Normalized Difference Vegetation Index, (ii) an irrigated crop scenario, (iii) a non-irrigated crop scenario, and (iv) a scenario for potential (natural) vegetation. Results indicate that even under active monsoon conditions, the simulated surface energy and moisture flux over the Indian monsoon region are sensitive to the irrigation intensity and this effect is more pronounced than the impact of land use change from the potential vegetation to the agricultural landscape. When model outputs were averaged over the south Asia model domain, a statistically significant decrease in mean sensible heat flux between the potential vegetation and the irrigated agriculture scenarios of 11.7 Wm^{-2} was found. Changes in latent heat fluxes ranging from −20.6 to +37.2 Wm^{-2} (−26% to +24%) and sensible heat fluxes ranging −87.5 to +4.4 Wm^{-2} (−77% to +8%) fluxes were found when model outputs were averaged over Indian states. Decreases in sensible heat in the states of Punjab (87.5 Wm^{-2} or 77%) and Haryana (65.3 Wm^{-2} or 85%) were found to be statistically significant at the 95% confidence level. Irrigation increased the regional moisture flux which in turn modified the convective available potential energy. This caused a reduction in the surface temperature and led to a modified regional circulation pattern and changes in mesoscale precipitation. These agricultural changes, including irrigation modify the mesoscale convection and rain patterns in the Indian monsoon region. These regional changes in land use need to be considered in improved weather forecasting as well as multi-decadal climate variability and change assessments.

1. Introduction

Individuals and societies have always been vulnerable to weather extremes and rapid shifts in climate. But over the last few decades, evidence is growing that weather patterns and climate stability are vulnerable to humans as well. For instance, there is a growing consensus within the scientific community that human activities have played a key role in causing, or at least altering, the pace at which climate is changing. Although much of the current research focus has been on the direct effects of human activities on atmospheric composition, there is also mounting evidence that human-induced landscape changes can affect atmospheric processes from local to regional weather patterns (Cotton and Pielke, 2007; Pielke et al., 2002; Alpert et al., 2006) and climate variability (National Research Council, 2005; Kabat et al., 2004; Pielke et al., 2007a,b). Feddema et al. (2005) showed that the transient climate modeling based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) lead to different regional climates when the impact of land cover changes are considered in addition to the SRES forcing alone. Gordon et al. (2005) evaluated the effects of land cover change on water vapor flows globally. They report that irrigated agriculture has increased global vapor flows by about 2600 $km^3\ yr^{-1}$, which is more than twice that of estimated global consumptive irrigation water losses (~1200 $km^3\ yr^{-1}$; Vörösmarty et al., 2005). Irrigation has been shown to significantly affect local and regional climate in the United States (e.g. Barnston and Schickedanz, 1984; Adegoke et al., 2003; Pielke, 2001). In the U.S., land cover change over the last 290 years has lead to a weak warming along the Atlantic coast and a strong cooling of more than 1 K over the Midwest and Great Plains region (Roy et al., 2003). Some reduction in precipitation due to changes in large-scale moisture advection has also occurred over the

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