GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L14403, doi:10.1029/2006GL026550, 2006

Changes in moisture and energy fluxes due to agricultural land use and irrigation in the Indian Monsoon Belt

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Received 10 April 2006; revised 22 May 2006; accepted 25 May 2006; published 21 July 2006.

[1] We present a conceptual synthesis of the impact that agricultural activity in India can have on land-atmosphere interactions through irrigation. We illustrate a ‘‘bottom up’’ approach to evaluate the effects of land use change on both physical processes and human vulnerability. We compared vapor fluxes (estimated evaporation and transpiration) from a pre-agricultural and a contemporary land cover and found that mean annual vapor fluxes have increased by 17% (340 km^3) with a 7% increase (117 km^3) in the wet season and a 55% increase (223 km^3) in the dry season. Two thirds of this increase was attributed to irrigation, with groundwater-based irrigation contributing 14% and 35% of the vapor fluxes in the wet and dry seasons, respectively. The area averaged change in latent heat flux across India was estimated to be 9 Wm^{-2}. The largest increases occurred where both cropland and irrigated lands were the predominant contemporary land uses. **Citation:** Douglas, E. M., D. Niyogi, S. Frolking, J. B. Yeluripati, R. A. Pielke Sr., N. Niyogi, C. J. Vörösmarty, and U. C. Mohanty (2006), Changes in moisture and energy fluxes due to agricultural land use and irrigation in the Indian Monsoon Belt, *Geophys. Res. Lett.*, *33*, L14403, doi:10.1029/2006GL026550.

1. Introduction

[2] Globally, agricultural water use (in the form of crop irrigation) comprises 70% of all human water withdrawals. Irrigation water use can alter the hydrologic cycle in several ways: by reducing base flow to rivers, by increasing physical evaporation (from soils and standing water) and transpiration (from vegetation), by adding to the greenhouse effect (since water vapor is also a greenhouse gas), by changing cloud coverage and depth, through changes in vegetation distributions and surface albedo and roughness, and by subsequent feedbacks to precipitation, and runoff and contributions to the soil moisture and ground water storage. India leads the world in total irrigated land where irrigation withdrawals represent 80–90% of all water use in India. Approximately 60% of irrigated food production depends on irrigation from groundwater [*Shah et al.*, 2000]. Between 1950 and 1985, groundwater withdrawals increased 113-fold [*Sampat*, 2000], resulting in rapidly declining groundwater levels in as many as 15 states [*Bansil*, 2004]. An important question is whether such hydrologic alteration results in a collection of localized impacts or do they produce feedbacks that are significant at regional scales. Recent research [*National Research Council*, 2005; *Kabat et al.*, 2004; *Adegoke et al.*, 2003] has identified dramatic changes to local and regional hydrology and weather patterns due to agricultural conversion and expanded cropland irrigation. Traditionally, the effects of such changes have been investigated with regional to global general circulation models, a so-called ‘‘top down’’ approach that does not always sufficiently simulate the linkages and non-linear responses inherent in land-atmosphere interactions [*Niyogi et al.*, 2002a]. *Pielke and Bravo de Guenni* [2004] proposed a new vulnerability paradigm that has a ‘‘bottom-up’’ perspective, and focuses on the resource of interest (in our case, freshwater resources). Figure 1 (modified from *Pielke* [2004]) illustrates water resource vulnerability on human and natural systems in India. Changes in seasonal weather patterns, such as the Indian monsoon, could dramatically affect not only the water resources but also the economic and social factors that depend on these resources.

[3] Only a few studies have investigated the influence of intensive irrigation on terrestrial and atmospheric moisture fluxes and the consequences of groundwater mining on these processes. *Gordon et al.* [2005] note that increases in water vapor flows are correlated with intensive food production on the Indian subcontinent and suggest that expanding irrigation in this area will increase the risk for changes in the Asian monsoon system and possibly impact food production capacities in other regions (such as sub-Saharan Africa) as well. *Chase et al.* [2003] and *Pielke et al.* [2003] have documented changes of the global and Indian monsoon system. *de Rosnay et al.* [2003] reported a 9.5% increase in latent heat fluxes due to irrigated agriculture in India. In this paper we estimate changes in vapor fluxes due to conversion of the natural landscape to agricultural land use and then simulate representative feedbacks of these changes in the atmosphere. The purpose of this paper is to illustrate a ‘‘bottom up’’ approach to evaluating the impacts of land use change on land-atmosphere interactions in India and to highlight the effects of these changes on human vulnerability.

2. Methodology

[4] Vapor fluxes were estimated from the output of a terrestrial water balance model applied to India at a monthly

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0094-8276/06/2006GL026550$05.00