Changes in moisture and energy fluxes due to ground-water based irrigation in the Indian Monsoon Belt.

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Abstract

The Indian monsoon belt is home to a large part of the world's population and agriculture is the major land-use activity in the region. In this poster we present a conceptual synthesis of the impact that agricultural activity can have on the atmosphere and regional climate through irrigation and its feedback on the atmospheric moisture flux and water cycles. The analysis builds on estimating the potential impact that irrigation and related agricultural activities have for modifying the atmospheric conditions within the Indian monsoon belt. These modified atmospheric conditions could potentially lead to changes in the interannual variability in the monsoon rainfall, and perhaps more directly to changes in the intensity of inland rain events. We found that 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 Two-thirds of this increase is attributed to irrigation; at least half of irrigation water is withdrawn from groundwater stores which may be introducing additional water to the hydrologic cycle. The area-averaged change in latent heat flux across India was estimated to be 9 Wm^{-2}. The largest increases in vapor and latent heat fluxes occurred where both cropland and irrigated lands were the predominant contemporary land cover classes (particularly northwest and north-central India). The largest decreases in vapor and energy fluxes occurred where the original moist tropical forests were replaced by agriculture (particularly southern India). The impacts of these changes and other societal factors affecting the water resource vulnerability and economic, societal and water feedbacks are also highlighted.

Introduction

Human modifications to the hydrologic cycle are in few places felt as acutely and urgently as in India. India leads the world in total irrigated land and irrigation withdrawals represent 92% of all water use. Furthermore, more than 50% of total irrigated area is dependent on groundwater in India (CWC, 2000) and approximately 60% of irrigated food production depends on irrigation from groundwater (Shah et al., 2000). Between 1950 and 1985, surface water withdrawals for irrigation doubled, while **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 alteration of the hydrologic cycle simply results in a collection of localized impacts or do these alterations produce feedbacks that are significant at regional scales. There is increasing evidence that the latter is true. For example, Figure 1 illustrates potential changes in weather patterns due the conversion of a natural landscape to irrigated cropland in the midwestern U.S.

Traditionally, the effects of changes in atmospheric composition (i.e., increased CO_2 concentrations) on land processes 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 of land-atmosphere interactions (Niyogi et al. 2002). Pielke and de Guenni (2004) proposed a new ***vulnerability*** paradigm that is place-based, has a "bottom-up" perspective, and focuses on the resource of interest (in our case, freshwater). Figure 2 (adapted from Pielke, 2004) illustrates the impacts of water resource vulnerability on human and natural systems in India.

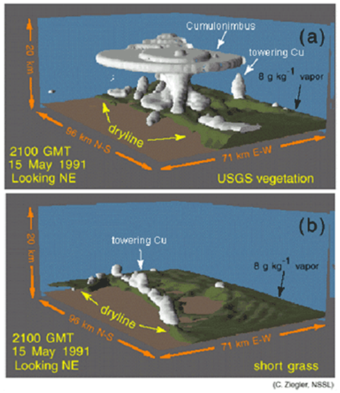
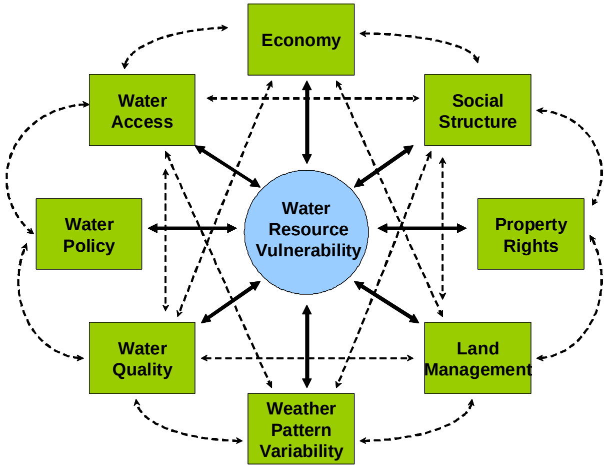


Figure 1: Effect of Agricultural Expansion on Regional Weather Patterns
Simulation of cloud and water vapor mixing ratio fields at 21 GMT on May 15, 1991 obtained with a) contemporary (USGS-derived) landcover comprised of irrigated crops, shrubs and short-grass prairie and b) natural vegetation (short-grass prairie only). Clouds are depicted by white surfaces, with the sun illuminating the clouds from the west. The vapor mixing ratio in the planetary boundary layer is depicted by the green surface. The tan surface is the ground. The vertical axis is height, and the blue backplanes are the north and east sides of the grid domain (from Pielke et al, 1997).

Figure 2: The Impacts of Water Resource Vulnerability in India
Schematic of linkages (solid arrows) and interactions (dashed arrows) related to changes in the vulnerability of water resources in India due changes in the Indian Monsoon (modified from Pielke, 2004). Even though the availability of water is a key critical factor, the economy, which determines the ability of a community to maintain its livelihood in unpredictable conditions, becomes an equally important factor. The influence of social structure is related to the rigid caste and class system that determines each individual's access to water supply; it is not uncommon in some villages that members from different castes draw water from different sources. Water access is influenced by rainwater harvesting and other local solutions that can be implemented to insure a constant supply of water during droughts. Water quality is often degraded by industrial waste, improper sanitation facilities and natural disasters, as well as over population leading to over utilization of available resources. Changes in seasonal weather pattern, such as the Indian monsoon, would dramatically affect water resource availability and the economic and social factors that depend on it. These issues are not only directly related to the state of water resources, but are also linked to each other.



Methodology

Two landcover scenarios were used in this study: estimated physical evaporation and transpiration from a potential (pre-agricultural) landcover and estimated physical evaporation and transpiration from a contemporary landcover. The potential vegetation simulation used the landcover dataset prepared by Melillo et al. (1993). Contemporary (agricultural) landcover was simulated by overlaying estimated percentages of rainfed, irrigated and fallow cropland onto the potential landcover. The crop area dataset developed by Ramankutty and Foley (1999) was used to represent the spatial distribution of contemporary cultivated area, which matched well with published crop area when summarized at the country-level. State-level, seasonal rainfed, irrigated and fallow cropland areas for 1999-2000 were developed to be as consistent as possible with several state-wise datasets (Chanda et al., 2003; Frolking and Yeluripati, 2005). The gridded cropland areas from Ramankutty and Foley (1999) were then assigned fractional areas of seasonal cropping systems (irrigated, rainfed, fallow) based on the appropriate state-level values.

Vapor fluxes from irrigated cropland were set equal to "potential evapotranspiration" (PET), which represents crop water demand in the absence of water limitations. Vapor fluxes from rainfed cropland were set equal to actual evapotranspiration (AET), which is limited by the available soil moisture. Vapor fluxes from fallow land was set equal to 20% of cropland AET (J. Jacobs, persn. comm., 2005), which approximates the proportion of AET attributable to soil (physical) evaporation alone. PET was estimated using the Shuttleworth and Wallace (1985) modification of the Penman-Monteith PET function, a physically-based method recommended by the Food and Agricultural Organization. AET was computed by the Water Balance Model (WBM; Vörösmarty et al., 1998), a physically-based, one-dimensional water balance model. For more details and results, see Douglas et al. (2005).

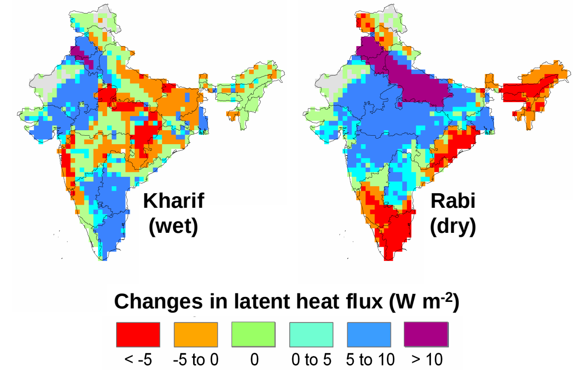


Figure 3: Geospatial changes in latent heat fluxes (in W m^{-2}) for kharif (wet season) and rabi (dry season) at resolution of 30-min (latitude by longitude). Negative changes denote decreases in vapor fluxes due to agricultural conversion of original forests; positive changes denote increases due to irrigation and the agricultural conversion of other landcover types. In Kharif, the largest flux increases occur in the northwest and the southeast portions of the continent where both cropland and irrigated areas are high. In Rabi, a large portion of northern India is subject to high vapor flux increases indicating that intensive irrigation is the dominant component of change, while fluxes have decreased in the southern and eastern extremes of the country indicating that landcover conversion (tropical forest to agriculture) is the dominant component of change.

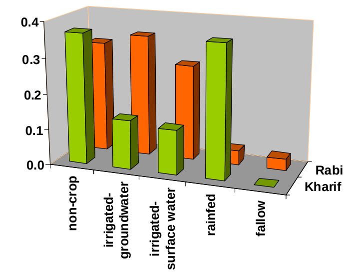


Figure 4: Percentage of ET flux difference attributable to different land uses. Vapor fluxes increased by 17% (340 km^3) annually between the potential and the contemporary land cover scenarios, with a 7% increase (117 km^3) in the wet season (kharif) and a 55% increase (223 km^3) in the dry season (rabi). Although there was not much seasonal difference in non-crop areas, irrigated croplands showed an increase in vapor fluxes of nearly 250% between the kharif and rabi seasons. Groundwater-based irrigation contributed 14% of the vapor fluxes in kharif and 35% in rabi.

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