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Effect of irrigation in simulating long-term evapotranspiration climatology in a human-dominated river basin system

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ABSTRACT

Evapotranspiration (ET) is highly variable in space and time and its quantification using observations or land surface models aids in irrigation and water management. Using the Noah land surface model, long-term trends of ET and surface energy balance were studied within the Snake River basin for the past 30 years spanning between 1980 and 2010. In this study, changes only due to meteorological factors were considered to capture the patterns of change in surface energy balance components. We employed an irrigation scheme in this simulation study since the agricultural lands in the river basin is irrigated almost entirely. This investigation has implications for water management, hydrology, and sustainability of this ecosystem. Uncoupled land surface modeling showed that the energy budget was altered due to anthropogenic activities in the basin with increased latent heat flux and reduced sensible heat flux. ET generally increased over a thirty year period due to warming climate and boundary layer meteorological variables indicated cooling induced by irrigation.

1. Introduction

Climate change and related impacts on basin hydrology and water resources have drawn considerable attention in many sensitive basins in the Pacific Northwest (Hoekema and Sridhar, 2011; Hoekema and Sridhar, 2013) Numerous studies have reported that in the Columbia River basin, increased temperature due to climate warming can potentially reduce the snowpack, increase the winter runoff, early snowmelt and increased evapotranspiration (ET) in the summer (Hamlet and Lettenmaier, 1999; Mote, 2006; Jin and Sridhar, 2012; Sridhar et al., 2012). From the analysis of historical stream flow records, Clark (2010) showed that there is a trend in earlier snowmelt runoff over many locations in Idaho. Nonetheless, there is a general reduction in pan evaporation in most regions in the U.S. including the Pacific Northwest (Lawrimore and Peterson, 2000) which can be an indication of increasing actual evaporation as explained by Brutsaert and Parlange (1998) due to complementarity of potential and actual ET (Huntington et al., 2011; Jaksa et al., 2013; Sridhar et al., 2012; Sridhar and Jaksa, 2013).

ET is a key process in the earth system and land-atmospheric interactions which links both energy and water budgets. About 60% of the precipitation is returned to the atmosphere through ET (Oki and Kanae, 2006). Nearly 30% of the precipitation for extratropical cyclones comes from ET (Trenberth, 1999). With possible increases in ET due to climate warming, atmospheric moisture will rise, affecting storms (Trenberth et al., 2005). Moreover, water vapor is the most important greenhouse gas (Kiehl and Trenberth, 1997). ET is the main phenomenon related to the presence of atmospheric water vapor over the continental land mass. The amount of ET is mainly affected by the energy partitioning at the earth's surface (i.e., partitioning of available energy into sensible and latent heat flux). In semiarid regions, soil moisture is one of the major variables that can influence energy partitioning (Sridhar and Wedin, 2009; Sridhar et al., 2006).

Historical observations of ET are generally used for retrospective analysis and also in the future planning of water resources for agriculture. When observational data are scarce, hydrological or land surface models have been widely used to estimate hydrological and atmospheric states in assessing the impacts due to climate change (Chen et al., 2007; Hamlet et al., 2007; Qian et al., 2004). Using the Variable Infiltration Capacity model, Hamlet et al. (2007) showed positive ET trends from April to June and shift in timing of peak ET from mid-summer to early summer and late spring due to the early snowmelt in the Western US.

Inclusion of irrigation in land surface models deserves attention as it is one of the significant human-induced changes to the landscape which adds considerable amount of water to the soil column and in turn adding water vapor through ET to the boundary

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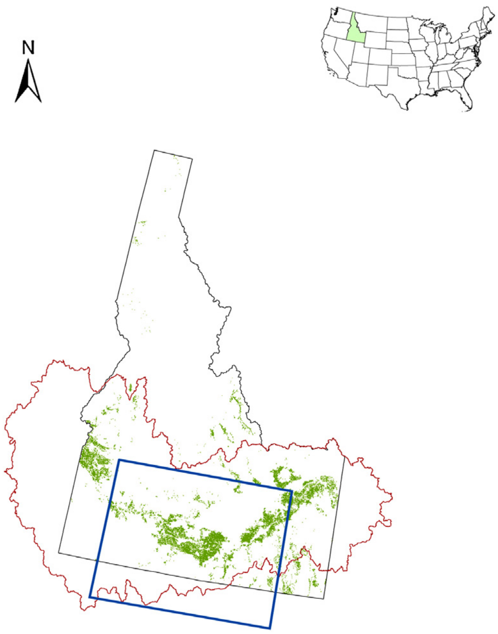

Fig. 1. The Snake River basin (in red line) which is mostly in Idaho and some areas extending to Oregon, Nevada, Wyoming, Montana and Washington. The irrigated croplands in the Snake River basin are shown in green (Pervez et al., 2008). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

layer. Increased ET, enhanced precipitation, surface cooling (Cook et al., 2010) and change in runoff are some of the direct effects of irrigation. It also changes the energy partitioning at the surface, favoring the energy to be partitioned to latent heat. Several studies have shown that incorporating irrigation can improve model simulations (Evans and Zaitchik, 2008; Ozdogan et al., 2010). In addition, other observational and modeling studies have showed irrigation-induced cooling (Adegoke et al., 2003; Haddeland et al., 2006), sensible heat advection from surrounding drier areas (Lei and Yang, 2010) and difference in initiation and evolution of summertime cloud patterns (Adegoke et al., 2007) due to irrigation.

The Snake River basin, a semiarid region in Idaho, consists of natural vegetation such as grasslands, shrubland, forests and irrigated agricultural lands. Irrigation water demand is supplied from the Snake River and Eastern Snake River Plain aquifer. Winter precipitation is the main source of water during the growing season. Therefore, the timing of snowmelt resulting in streamflow is important for agriculture. Long-term climatology is crucial for understanding climate impacts, and also to solve the stress impacted on water resources, agriculture, fisheries, recreational and land management in the basin. This study employs the uncoupled Noah Land Surface Model (LSM) with an irrigation scheme implemented in the model by Sridhar (2013) in order to model the long-term climatology of surface fluxes, ET and relative soil moisture storage change in the Snake River basin due to climate change and variability over the past 30 years. The objectives of the study are (1) to assess irrigation effects in agricultural areas, (2) to study the temporal pattern in ET for different land cover types, (3) to analyze the atmospheric factors most sensitive to ET in the area and (4) to assess the long-term climatology of surface energy balance.

2. Study area

The Snake River basin is situated in a semiarid region covering most of Idaho and extending to Oregon, Nevada, Wyoming, Montana and Washington (Fig. 1). The Snake River, the largest tributary to the Columbia River, flows through the Snake River plains, an area that is heavily irrigated. Cold winters and hot, dry summers are common in the area. While most of the precipitation during the summer is evaporated, precipitation in the winter and early spring is the main source for recharge of the ground water (Kjelstrom, 1995). Runoff from snowmelt events from the mountains are the main source of water for irrigation diversions during the growing season. Average annual precipitation ranges from 200 to 250 mm and the mean annual air temperature range is 5–10.9 °C, with July being the warmest month with highest evaporation (Kjelstrom, 1995). The main land cover types in the watershed are grasslands, shrublands, agricultural lands and forests. Due to semi-arid conditions in this region, extensive irrigation takes place during the growing season in the cropland area to provide required water for crop growth. Sprinkler irrigation and surface irrigation (furrow) are the two methods that are commonly adopted in use in the area (USGS, 2005).

3. Methodology

The Noah LSM in the High Resolution Land Data Assimilation System (HRLDAS; Chen et al., 2007) platform was used to simulate the surface fluxes, ET, soil moisture, and soil temperature. The Noah LSM has four soil layers with layer thicknesses of 10, 30, 60 and 100 cm from ground surface to bottom, one canopy layer and one snow layer. More details on physical processes in the Noah LSM can be found in Chen et al. (1996) and Ek et al. (2003). This LSM was chosen for this study due to its promising performance in other studies (Chen et al., 2003; Hogue et al., 2005; Radell and Rowe, 2008; Sridhar et al., 2002) and its wide use in the surface energy balance and water budget modeling research.

The HRLDAS platform runs the Noah LSM in the uncoupled mode. Input parameters required for HRLDAS are soil data, land cover types, green vegetation fraction and time invariant deep soil temperature. Soil data were obtained from 1 km State Soil Geographic (STATSGO) database and MODIS-based land surface characterization provided the land cover types for this study. All meteorological forcing fields and initialization data were obtained from 3 hourly North American Regional Reanalysis (NARR) data of 32 km resolution. Irrigation water is a main source of water input in agricultural regions especially in semiarid regions. An irrigation algorithm (Sridhar, in review), which highlights the need for accounting irrigation in energy balance studies to better represent the agricultural lands in the Snake River basin, is also explained in the following section.

3.1. Irrigation method

Due to aridity and the absence of summer rainfall during the growing season over agricultural lands, irrigation water was required to replenish soil moisture periodically to the first soil layer (0–10 cm). This was done by adding water through surface irrigation throughout the growing season (April to October for Snake River basin). Only the cells classified as cropland in the land use categories were subjected to irrigation in the model. Since our model domain, which mainly consists of irrigated lands in the south central Idaho, an arid region with minimal or no rain during the crop growing season between April and September, we treated all the croplands as irrigated lands. Sridhar (2013) presents a detailed description on the irrigation function added to the model. The irrigation algorithm is briefly presented in this article for continuity. The formulation contained three adjustable parameters: (1) minimum percentage of soil moisture (MinPCT), which served as an irrigation trigger, (2) the start date of the irrigation season, and (3) the end date. The available soil moisture of the second soil layer (10–40 cm) was used to trigger irrigation by comparing with