Anthropogenic impacts on regional surface water fluxes

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1. Introduction

The global water cycle reflects both natural and anthropogenic variability and changes on the land surface. Seasonal and long-term climate variability obviously impact runoff and evapotranspiration, and in the post-industrial era management of the world's rivers has changed the dynamics of the water cycle. Here we present results from a hydrologic modeling study of anthropogenic impact on surface water and energy fluxes.

2. Approach

Hydrologic model: The Variable Infiltration Capacity (VIC) macroscale hydrologic model.

Irrigation module: Based on the VIC model's predicted soil moisture, irrigation water (if available) is added to crops. Information on irrigated areas is taken from FAO's global map of areas equipped for irrigation.

Reservoir model: A simple reservoir model is included in the river routing scheme. Operating rules are based on the purpose of the dam. Dam information (storage capacity, purpose) is obtained from ICOLD (International Commission on Large Dams), and the University of New Hampshire (location).

Simulation period: 1980 - 1999

Table 1: Model setups

Model setup	*Irrigation*	*Reservoirs*
Irr_false	FALSE	FALSE
Irr_true	TRUE	FALSE
Irr_false_res	FALSE	TRUE
Irr_true_res	TRUE	TRUE

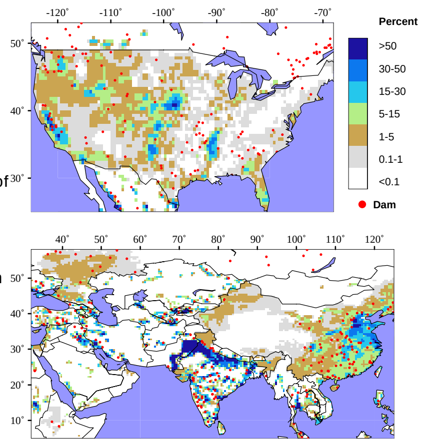

Figure 1: Map showing areas equipped for irrigation (FAO), and dam sites (ICOLD/UNH).

Model setups:
The model setups are listed in Table 1. In addition, simulations assuming water is freely available (**irr_free**) are performed.

3. Model validation

Irrigation water requirements

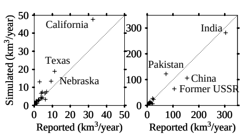

Figure 2: Simulated irrigation water requirements compared to reported consumptive water use (USA), and irrigation water requirements (Asia).

Streamflow

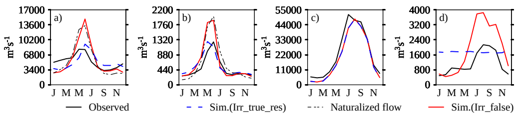

Figure 3: Observed and simulated streamflow in a) The Columbia River, b) The Upper Colorado River, c) The Brahmaputra River, and d) The Huang He River (the location of the river basins is shown in Figure 4).

When irrigation and reservoirs are not taken into account, simulated streamflow (irr_false) is close to naturalized streamflow (only available for the Columbia and Colorado River basins). Simulated actual streamflow (irr_true_res) is fairly close to observed streamflow in the Upper Colorado River, but the results from the Columbia and Huang He Rivers demonstrate that the assumptions included in the reservoir model need to be modified.

4. Results: North America and Asia

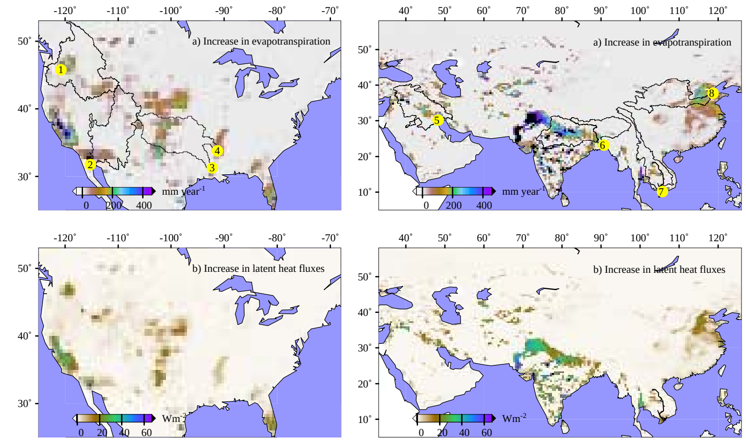

Figure 4: a) Increase in evapotranspiration because of irrigation (= irrigation water requirements), and b) Corresponding increase in latent heat fluxes. All numbers are averaged over the grid cell and simulation period, and water for irrigation is assumed freely available. The numbers (1-8) show the outlet locations of the basins analyzed (Figure 5).

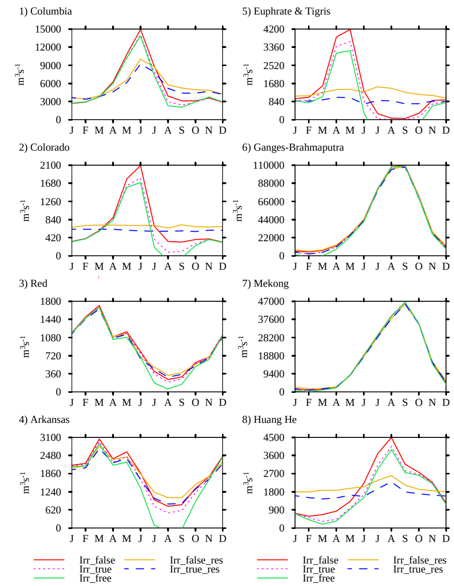

Figure 5: Anthropogenic impact on streamflow in North American and Asian river basins. Line labels are explained in Table 1.

The most pronounced increases in evapotranspiration/latent heat fluxes caused by irrigation practices, can be found in California, Pakistan, India, and Northeastern China, see Figure 4. Averaged over the years and continents, the mean increase in evapotranspiration for North America and Asia (bounding boxes as in Figure 4, land areas only) are 15 and 25 mm $year^{-1}$, respectively, while the corresponding numbers for latent heat fluxes are 1.2 and 1.7 Wm^{-2}.

Figure 5 shows simulated streamflow at the outlet of 8 large river basins, resulting from the various model setups. Anthropogenic impact on streamflow is of course dependent on the level of disturbance, either because of irrigation (e.g. the Arkansas River basin), and/or the presence of reservoirs (e.g. the Euphrate & Tigris River basin).

5. Results: Colorado River basin

Results from the Colorado River basin show that the locally significant increases in evapotranspiration (or latent heat) results in lower surface temperatures, and hence decreased sensible heat flux. The 20-year simulations indicate irrigation water requirements of 10 $km^3 year^{-1}$, corresponding to streamflow decreases of 37 percent. The increase in latent heat flux is accompanied by a decrease in annual averaged surface temperatures of 0.04 ºC.

The maximum simulated increase in latent heat flux averaged over the three peak irrigation months for one grid cell is 63 Wm^{-2}, where surface temperature decreases 2.1 ºC, see also Figure 6.

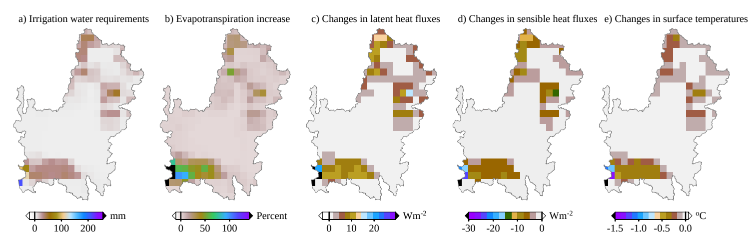

Figure 6: Spatial effects of irrigation on water and energy balance components in the Colorado River basin. All numbers are averaged over the grid cell and the three peak irrigation months (Jun, Jul, Aug).

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