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Research papers

Perturbations in the initial soil moisture conditions: Impacts on hydrologic simulation in a large river basin

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ABSTRACT

Real time hydrologic forecasting requires near accurate initial condition of soil moisture; however, continuous monitoring of soil moisture is not operational in many regions, such as, in Ganga basin, extended in Nepal, India and Bangladesh. Here, we examine the impacts of perturbation/error in the initial soil moisture conditions on simulated soil moisture and streamflow in Ganga basin and its propagation, during the summer monsoon season (June to September). This provides information regarding the required minimum duration of model simulation for attaining the model stability. We use the Variable Infiltration Capacity model for hydrological simulations after validation. Multiple hydrologic simulations are performed, each of 21 days, initialized on every 5th day of the monsoon season for deficit, surplus and normal monsoon years. Each of these simulations is performed with the initial soil moisture condition obtained from long term runs along with positive and negative perturbations. The time required for the convergence of initial errors is obtained for all the cases. We find a quick convergence for the year with high rainfall as well as for the wet spells within a season. We further find high spatial variations in the time required for convergence; the region with high precipitation such as Lower Ganga basin attains convergence at a faster rate. Furthermore, deeper soil layers need more time for convergence. Our analysis is the first attempt on understanding the sensitivity of hydrological simulations of Ganga basin on initial soil moisture conditions. The results obtained here may be useful in understanding the spin-up requirements for operational hydrologic forecasts.

1. Introduction

Hydrologic models are useful for understanding hydrological processes, predictions and managing water resources. As each model is unique in terms of model structures, input requirements and parameterizations, the uncertainties involved in them are persistent and affect the model (Rahman and Lu, 2015). Out of many sources of uncertainties, the initial state is considered to be one of the most sensitive inputs to model outcomes. To eliminate the impacts of initial condition, spin-up runs are required in land surface modeling. In general, a single year forcing is repeated every year and the spin up process is considered to be completed when the model's state in year "n + 1" matches with "n" (Yang et al., 1995). However, such a process needs multi-year simulations and useful for modeling land processes at a climate scale; but cannot be performed in real-time mode for a real-time forecast. Nevertheless, eliminating errors due to initial condition is a very important step for land surface modeling and predictions; though has received little attention in the hydrologic community. While improper spin-up often leads to the loss of true information or may cause erroneous initial outputs (Rahman and Lu, 2015), accurate specification of initial land states is important.

The impacts of initial conditions on model outputs are highlighted by limited number of studies and some of them are listed here. Goodrich et al. (1994) demonstrated the possibility of runoff predictions on small (0.044 km^2) to medium scale catchments (6.31 km^2) through the soil moisture obtained from remote sensing or field measurements. Nikolopoulos et al. (2011) found the role of resolution of precipitation data and contribution of wet soil to the flash flood events in a large basin (632 km^2). With an increase in the basin size, the impacts of initial wetness condition also increase. In addition, the peak discharge and runoff volume are found to be doubled in quantity under the change of soil moisture from drier to saturated conditions, indicating the sensitivity on moisture contents. A similar study demonstrated the impact of antecedent soil moisture on the response of runoff in semiarid regions with the use of a physically distributed model (Castillo et al., 2003). The results showed that for medium and low-

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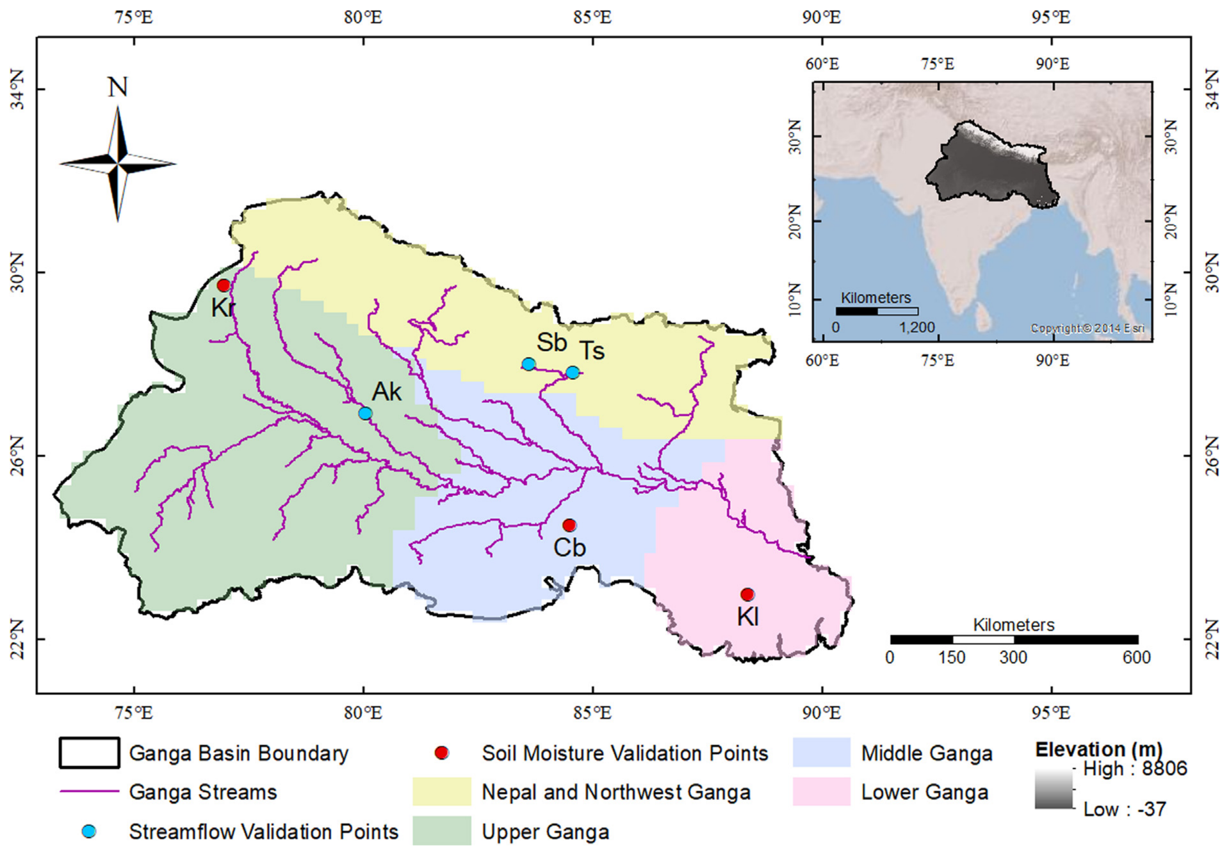

Fig. 1. Extent of Ganga Basin with inlet representing the location of the basin. Points Sb (Seti-Beni), Ts (Trishuli), Ak (Ankinghat) are streamflow calibration and validation points. IMD Station KRL (Kr), IMD Station KLNI (Kl), and Cb (Chhakkharbandha) are the soil moisture validation points. The basin is divided into four subdivisions namely Nepal and Northwest Ganga (North Ganga), Upper Ganga, Middle Ganga and Lower Ganga. Base-Map source (ESRI).

intensity storms (typical in semiarid regions), the pre-existing soil moisture conditions were crucial to control runoff while during high intensity and low-frequency storms, antecedent soil moisture was less impactful. The study also suggested that regions of highly permeable soils with less intense storms are mostly influenced by initial soil water content. However, there is no study available specifically for South Asian river basins, where the water availability is controlled by seasonal summer monsoon rainfall. Initiatives are taken to improve monsoon forecasts and predictions as part of the National Monsoon Mission project of the Government of India; among which accurate land surface initialization for improving the temperature and rainfall forecasts (Halder et al., 2018) is one. However, linking those efforts for initiating accurate hydrologic forecasts at river basin scale is yet to be developed. Under such development process, it is important to understand the impacts of errors in initial condition on the forecast, as well also the forecast error propagation for water resources decision making. This is specifically important for large international rivers such as Ganga basin, which is extended over Tibet, Nepal, India and Bangladesh, but has very limited station level monitoring system for one of the most important variable, soil moisture. It is important to understand the impacts of uncertainty in initial condition of soil moisture on the forecasts of soil moisture and streamflow, as well the propagation of decaying error. Here, we present the first analysis of the same for Ganga basin.

We investigate the impacts of uncertainty in initial soil moisture conditions in the Variable Infiltration Capacity (VIC) model within Ganga Basin. We select monsoon seasons of three different years, namely surplus monsoon (wet) year, normal year and deficit monsoon (drought) year for the hydrologic simulation. A simple and reasonable technique based on the long-term standard deviation of simulated gridded soil moisture is used as the perturbation in the initial conditions. We perform hydrological simulations, initialized on every fifth day of the monsoon season and each of the simulations continues for 3 weeks with original and perturbed initial conditions. This consists of simulating the model for a total of 225 cases spanning the three years. We analyze the data to understand the propagation and convergence of perturbations initiating from the gridded initial conditions. The details of the methods and data are presented in next section.

2. Data and methods

2.1. Study area

The study area consists of Ganga basin extending over Tibet, Nepal, India and Bangladesh with an area of 1,151,740 km^2. The Himalayan lies on the north and the Vindhyas and Chhotanagpur plateau lie in the southern region of the basin. In addition, the basin is surrounded by the Aravalli on the west and the Brahmaputra Ridge on the east. The total length of river Ganga measured from its source at Uttarkashi district of Uttarakhand to the outlet at the Bay of Bengal is 2525 km (http://india-wris.nrsc.gov.in/wrpinfo/index.php?title = Ganga, Access date: 06/07/2017). Along the journey to the Bay of Bengal, the Yamuna and the Sone rivers join Ganga from right whereas the Ramganga, the Karnali, the Narayani, the Koshi, and the Mahananda rivers join the Ganga from left. All the Nepalese rivers drain into Ganga basin and they contribute around 46% of the total flow of Ganga (https://asiafoundation.org/resources/pdfs/ORFIssuebrief61DwarikaN.Dhungelformail.pdf, Access date: 06/07/2017). In the Indian part of the Ganga Basin, the net sown area is around 44 million hectares with 23.41 million hectares of the net irrigated area. The basin mainly constitutes loam, sand and their combinations (http://nihroorkee.gov.in/rbis/basin%20maps/ganga_about.htm, Access date: 07/07/2017). The top 30 cm soil type in the Ganga Basin consists 58% loam and its combination like sandy loam,