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Research paper

Terrestrial hydrological features of the Pearl River basin in South China

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Abstract

This paper presents the terrestrial hydrological features of the Pearl River basin in South China by using a macro-scale hydrological model, the Variable Infiltration Capacity (VIC) model, and a routing scheme. Without calibration, the VIC model is used to simulate streamflow, evapotranspiration and soil moisture change at a daily time step for the period 1951−2000. After aggregation of daily output, it is observed that the VIC streamflow simulation is comparable to the observation at a month step. Moreover, from the model simulation, the study reveals that the monthly soil moisture change varies dynamically for maintaining the basin water balance, and both of the streamflow and evapotranspiration are dominant hydrological processes over the basin. With the routing scheme, the hydrological simulation from the VIC model is investigated at a daily step. It is observed that the scheme can improve the simulation of the timings and magnitudes of the daily streamflow peaks significantly, and the temporal scale of the influence of the routing on the streamflow simulation is less than 2−3 weeks in the Pearl River basin.

Keywords: Hydrological features; Streamflow simulation; VIC; Routing; Pearl River

1. Introduction

Floods and droughts are natural hazards that occur frequently over the Pearl River basin in South China (Pearl River Water Resource Commission, 2005; Cui et al., 2007). In order to develop mitigation measures to attenuate the damages of these hazards, it is important to know the features of hydrological processes in the basin, which would provide a sound basis for a variety of water resource diagnostic studies.

Since the 1980s, in order to study hydrological processes at basin and continental scales, macro-scale hydrological models (MHMs) have been developed to simulate the land surface hydrology through modeling physical processes of the terrestrial water cycle (e.g. Sellers et al., 1986; Dickinson et al., 1986; Russell and Miller, 1990; Chen and Kumar, 2001; Nijssen et al., 2001a). The advancement of MHMs was closely related to the development of land surface parameterization schemes (LSPs) for general circulation models (GCMs) (e.g. Sellers et al., 1986; Dickinson et al., 1986), but focused more on modeling soil moisture change, evapotranspiration and runoff generation (Chen and Kumar, 2001; Nijssen et al., 2001b). Subsequently, MHMs can be useful for exploring the hydrological features through assessing the terrestrial hydrological responses to topography, vegetation covers and soil characteristics at basin and continental spatial scales.

This study applies the Variable Infiltration Capacity (VIC) model (Liang et al., 1994), one of the MHMs, to the Pearl River basin in South China to study the hydrological features. The VIC model has been used for a number of modeling studies over large-scale river basins (e.g., Abdulla et al., 1996; Nijssen et al., 1997, 2001b; Su and Xie, 2003; Chen and Wu, 2008). Nijssen et al. (2001b) reported the study of discharge simulation for 26 continental river basins over the globe, which include one tributary of the Pearl River, the West River, by using the VIC model at a spatial resolution of $2^\circ \times 2^\circ$ grids. Su and Xie (2003) studied runoff simulation for the regions over Mainland China, especially over the Huaihe River and the Yellow River, at a spatial resolution of 60 km × 60 km by using the VIC model. In addition, the hydrological processes

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of the East River, one tributary of the Pearl River basin, were investigated by using the VIC model (Chen and Wu, 2008).

However, the VIC model has not been specifically applied to the whole Pearl River basin for studying its terrestrial hydrological features, which is imperative to mitigate water-related natural hazards in the basin. Furthermore, the studies of Su and Xie (2003) and Chen and Wu (2008) did not use the routing scheme (Lohmann et al., 1996, 1998a,b), which was developed specifically for routing the runoff simulated by the VIC model, to study the effects of routing on the timings and magnitudes of peak flows, which is critical for studying floods. It is worth noting that the VIC model developed by Liang et al. (1994) does not include any river channel routing schemes. Generally, a proper flow routing can effectively improve the accuracy of streamflow simulation (Lian et al., 2007), especially for daily flow simulation. Nijssen et al. (2001b) used the routing scheme of Lohmann et al. (1996, 1998a,b) to simulate river discharges; however, the spatial resolution ($2^\circ \times 2^\circ$, i.e. one grid cell with the area of about 40,000 km^2) used in the study might be too coarse to model hydrological processes for the West River properly.

Therefore, the objectives of this paper are to apply the VIC model and the routing scheme to the whole Pearl River basin with $1^\circ \times 1^\circ$ spatial resolution, and to explore the terrestrial hydrological features over the basin. The paper is organized as follows. Section 2 introduces the models and objective functions. The description of the study area and data is given in Section 3. The study results are presented in Section 4.

2. Models and objective functions

2.1. Variable infiltration capacity (VIC) model

The VIC macro-scale model (Liang et al., 1994, 1996) is used to simulate surface and subsurface hydrological processes on a spatially distributed (grid cell) basis. The land surface in the model is grouped into different land cover types, and the soil column in a grid cell is specified by using averaged soil characteristics with a number of soil layers (Liang et al., 1994). Compared to other MHMs, the main feature of the VIC model is the application of the variable infiltration curve developed by Zhao et al. (1980) and Zhao (1984, 1992), which can scale the infiltration by a non-linear function of the fractional grid cell area.

The variable infiltration curve in the VIC model is defined over a grid cell as follows (Liang et al., 1994):

$$i = i_m\left[1 - (1 - A)^{1/B}\right] \tag{1}$$

where i and i_m are the infiltration rate and maximum infiltration rate within the grid cell, respectively. A represents the fraction of a grid cell for which the infiltration rate is equal to i, and B is an infiltration rate shape parameter, which is a measure of the spatial variability of the infiltration rate (Liang et al., 1994). Using Eq. (1), the direct runoff (i.e., overland flow) is computed from the areas where precipitation exceeds the storage capacity of the soil column.

The soil moisture transport mechanism of the soil column in the VIC model consists of gravity drainage in each soil layer, which is a function of the soil moisture storage and the hydraulic conductivity. The ARNO baseflow model (Todini, 1996) is used to represent subsurface runoff generation from the deepest soil layer (Liang et al., 1994). Basically, the baseflow is specified as a function of soil moisture in the lowest soil layer, which is non-linearly related to high soil moisture content and linearly related to low soil moisture content (Liang et al., 1994) of the deepest soil layer. The total runoff is the sum of direct runoff and baseflow for each grid cell.

2.2. Flow routing for VIC

The VIC model provides the simulation of overland flow and baseflow, but the scheme for routing the runoff from the upstream to downstream over a basin is not available (Liang et al., 1994). Thereafter, a stand-alone routing scheme was developed by Lohmann et al. (1996, 1998a,b). The flowchart of simulation procedure for VIC and the routing scheme is shown in Fig. 1. The main task of this routing scheme is to simulate the lateral travel time of water within each grid cell as well as the transport time in river channels.

The routing scheme consists of two impulse response functions. One is for river channels, and the other for grid cells (Lohmann et al., 1996, 1998a,b). The river channel impulse response function (Lohmann et al., 1996, 1998b) can be represented as follows:

$$h(x,t) = \frac{x}{2t\sqrt{\pi t D}}\exp\left(-\frac{(Ct - x)^2}{4Dt}\right) \tag{2}$$

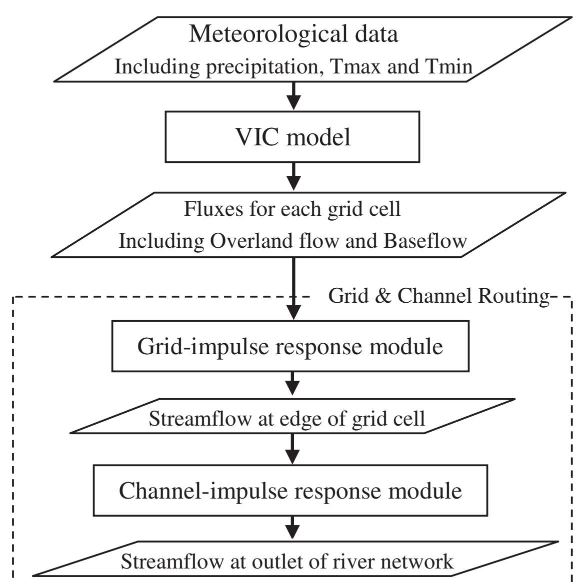

Fig. 1. Flowchart of simulation procedure for VIC and the routing scheme.