Variable-lag Channel Flow Routing Algorithm for climate models

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1. Introduction

In the climate modeling community, there is a need for models that can route runoff generated by the land surface component of Global Circulation Models (GCMs) and Regional Climate Models (RCMs) to the ocean cells of the ocean-modeling component as the fresh water influx is an important buoyancy source for coastal ocean circulation. Routing models are also required to fully evaluate the impact of climate change on water resources. A simple cell-to-cell routing scheme based on Askew's formula (1970) and the findings of Boyd (1981) and Kumar *et al.* (1997) for computing time-evolving channel lags is implemented.

2. Model

The control volume in cell-to-cell routing is the grid cell. Each grid cell is conceptualized as a watershed with two reservoirs, the surface and groundwater reservoirs, as in the variable-velocity scheme of Arora and Boer (1999). The water balance within each grid cell for the surface and groundwater stores are given by continuity equation as

$$\frac{dS}{dt} = I - Q;$$
$$\frac{dG}{dt} = f_p - f_g, \qquad (1a, 1b)$$

where S and G are the surface water and groundwater stores respectively. I and Q are the inflow and outflow respectively for the surface water store. I is the sum total of the surface runoff generated within the grid cell (f_s), the flow from neighboring cells (f_n) and the contribution from the ground water store (f_g) of the same grid cell, i.e.

$$I = (f_s + \sum_n f_n + f_g). \qquad (2)$$

f_p is the inflow into the groundwater store. Both surface water and groundwater stores are modeled as linear reservoirs, i.e. the surface water and groundwater stores are assumed to be related linearly to their outflows as

$$S = kQ;\ G = k_g f_g. \qquad (3a, 3b)$$

The channel lag k is the travel time between the grid cell under consideration and its downstream neighbor. Based on the findings of Boyd (1981) and Kumar *et al.* (1997), the channel lag k in hours can be approximated by

$$k = 0.6 \times K, \qquad (4)$$

where K, the basin lag (in hours), is given by Askew's formula,

$$K = \alpha A^{\beta} Q^{\gamma}. \qquad (5)$$

In Eq. (5), A is the basin area (in km^2), Q is the flow rate in (m^{3}s^{-1}), and α, β and γ are constants ($\alpha = 2.12$, $\beta = 0.57$ and $\gamma = -0.23$). The residence time associated with the groundwater reservoir, k_g, is assumed to be related to the major soil type of the grid cell as in Arora and Boer (1999).

Basin discretization and flow directions for the routing scheme are adapted from global data sets of continental watersheds and river networks of Graham *et al.* (1999). In the absence of gridded estimates of observed daily runoff, the runoff fields from the Variable Infiltration Capaciy (VIC) hydrological model (Lohmann *et al.* 1998) is used.

3. Results

Routing is performed for Mississippi and Fraser basins at 5 min resolution. The choice of the routing time interval is very critical and varies with spatial resolution as in any hydrological model. Knowing the area of the cell at the basin outlet and the range of flows expected, channel lags corresponding to the range of flows for that particular cell can be computed using Eqs. (4) and (5). Cells located at the mouth have maximum flows and hence the smallest channel lag of all cells in the basin. A suitable choice for the routing interval for the basin would be a value close to the smallest channel lag or response time. The channel lags for the cell at the outlet of the Mississippi and Fraser basins are as in Fig. 1.

As per the scatter plot the channel lag for Mississippi is between one and two hours and that of Fraser between one and three hours at 5 min spatial resolution. Choice of higher routing interval at 5 min spatial resolution will result in delays, with the time to peak of the hydrograph at the mouth of the basin lagged and the peak attenuated as in Fig. 2. The difference in volume between the observed and simulated flows for the Fraser basin (Fig. 2) can be

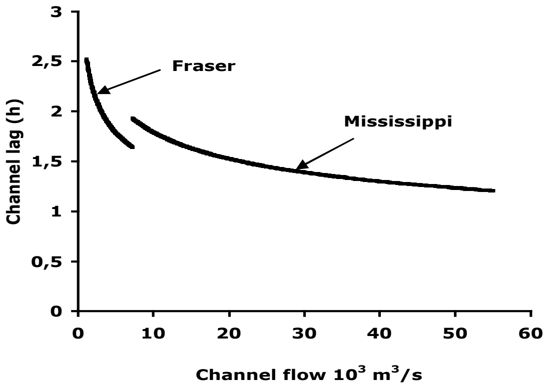

Figure 1. Scatter plot of Channel lag vs. Channel flow for Mississippi and Fraser, at 5 min spatial resolution.

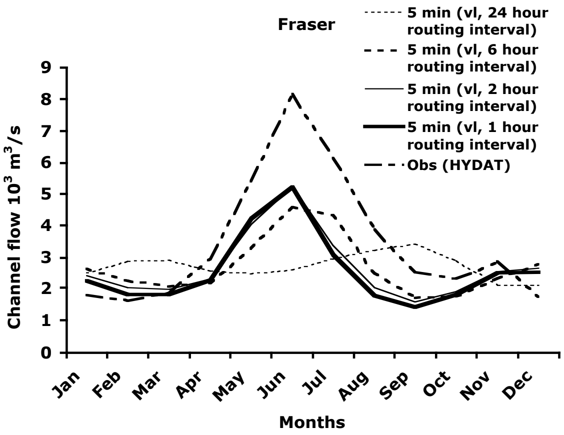

Figure 2. Mean annual hydrographs for Fraser basin at 5 min spatial resolution, for various routing intervals.

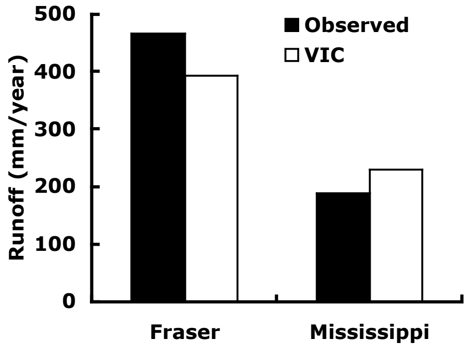

Figure 3. Basin-wide average runoff from observation and VIC data.

partially attributed to the underestimation of runoff (Fig. 3) by the VIC model over Fraser along with the lack of representation of cold region processes.

For the Mississippi basin, the model does a good job in capturing the seasonality (Fig. 4) and the efficiency of the model is quite good. The VIC model overestimates runoff over Mississippi (Fig. 3) and accounts for the difference between the observed and simulated hydrographs.

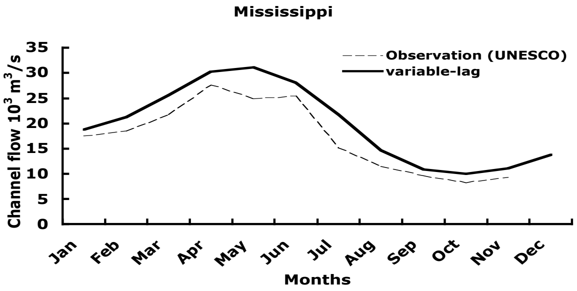

Figure 4. Observed and simulated mean annual hydrograph for the Mississippi basin.

4. Conclusions

The variable-lag routing scheme does a good job in capturing not only the seasonality, but also in simulating the time to peak and volumes. The scheme could be very useful at fine resolution, where the uncertainity associated with parameters can be quite large. The computational efficiency of the scheme is also higher than other routing schemes.

References

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