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2.8 RETROSPECTIVE ANALYSIS OF WATER BUDGET FOR THE MISSISSIPPI RIVER BASIN

John C. Schaake*, Qingyun Duan, Shuzheng Cong
NOAA/NWS, 1325 East-West Highway, Silver Spring, MD 20910

1. INTRODUCTION

One of the principal scientific objectives of the GEWEX Continental-Scale International Project (GCIP) is to determine the time/space variability of the hydrological and energy budgets over a continental scale. Mississippi River basin, the third largest river basin in the world, is regarded as an ideal study area for this purpose because of the abundance of historical hydrometeorologic data, and the existence of a vast array of hydrometeorologic observation networks in the basin. There are many approaches to studying water and energy budgets over Mississippi River basin. One approach is to compute the atmospheric water budget over the area (Roads et al., 1998; Yarosh et al., 1999). This approach generally works well for large scale areas.

An alternative approach is to conduct diagnostic surface water budget study on the land surface using retrospective hydrometeorologic data. The main advantage of a diagnostic surface water budget approach is the availability of abundant retrospective hydrometeorologic data for both precipitation and streamflow. These variables substantially constrain the surface water budget. A few assumptions are needed to determine the budget, but monthly statistical properties of the budget are insensitive to a reasonable range of these assumptions. This approach works well from small scale areas (SSAs) to continental scale areas (CSAs). The latter approach was taken in this paper to study the surface water budget of Mississippi River basin.

The paper is organized as follows. Section 2 describes the diagnostic water balance methodology. Section 3 discusses the data used for the study and some preliminary results. Section 4 offers discussion and summaries.

2. DIAGNOSTIC WATER BALANCE EQUATION

The diagnostic water budget study is based on a water balance equation. The time step used in this study is a month. Transfers of groundwater across basin boundaries are assumed to be negligible. It is further assumed that evaporation is proportional to potential evaporation, but the proportion depends on the state of the water balance. Annual potential evaporation does not change from year-to-year, but monthly potential evaporation varies seasonally according to a sinusoidal function. (Note in the United States the annual coefficient of variation of pan evaporation is less than 10 per cent so this is not a major factor in the overall dynamics of the surface water budget).

Accordingly, the water balance equation can be expressed as:

$$S_{t+1} = S_t + P_t - f(S_t, P_t, \Phi) \cdot E_{p,avg} \cdot \left(1 + \epsilon \cdot \sin(\omega t + \theta)\right) - Q_t \qquad (1)$$

where t denotes month, P_t, and Q_t are mean areal precipitation and total streamflow from the basin during the tth month, S_{t+1} and S_t are total water stored within the basin at the beginning and the end of tth month, $E_{p,avg}$ is the long term average monthly potential evaporation, and $f(S_t, P_t, \Phi)$ is the evaporation function which defines how actual evaporation occurs according to total water storage, precipitation, and a user-specified parameter vector Φ. Assuming that $f(S_t,P_t,\Phi)$ is given, parameters $E_{p,avg}$, ϵ and θ are prescribed, the initial water storage, S_0, is known, and P_t and Q_t are obtained from historical records; the values of S_t can then be determined recursively.

Values of $E_{p,avg}$ for the conterminous U.S. can be determined from the NOAA annual freewater evaporation map [Farnsworth, et al., 1982]. Based on the same NOAA annual freewater evaporation map and the May-October freewater evaporation, Schaake [1997] has also created maps of ϵ as well as θ .

Five different formulations of $f(S_t,P_t,\Phi)$ are tested in this study. For details, see Duan et al. (1999).

* *Corresponding author address:* John Schaake, OH/NWS/NOAA, 1325 East-West Highway, Silver Spring, MD 20910

3. DATA USED AND PRELIMINARY RESULTS

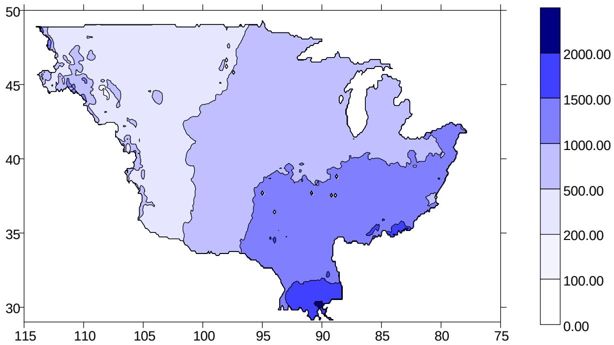

Figure 1. Mean Annual precipitation as estimated by the PRISM project for period 1961-1990

Monthly precipitation and streamflow discharge data from 1948 to 1997 were collected for more than 200 unregulated intermediate scale area (ISA) catchments in the Mississippi River basin. Also collected was the corresponding long term monthly potential evaporation.

The Mississippi river basin has a total drainage area of 3.224×10^6 km^2. It encompasses a wide variety of climate, ranging from an arid/semi-arid region in the West to a very humid region in the Southeast (see Figures 1 & 2). One interesting way to look at the climatology of a region is to examine the relationships between the ratios of long term water balance components. One such empirical relationship is the Turc-Pike equation:

$$\frac{AE}{PE} = \frac{P/PE}{\sqrt{1 + \left(P/PE\right)^2}} \qquad (2)$$

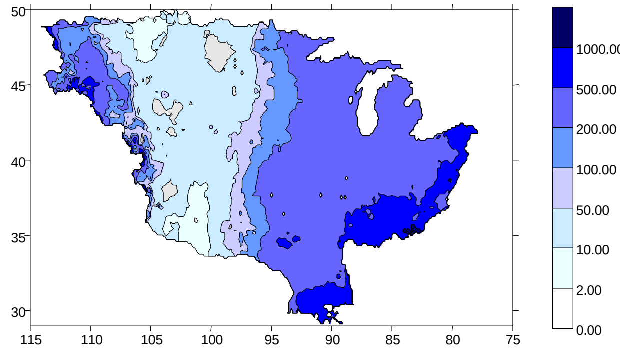

Figure 2. Mean annual runoff constructed using spatial analysis of mean annual streamflow data from the USGS HCDN network

where *AE* is the actual climatic annual evaporation, *PE* is the climatic annual potential evapotranspiration, and *P* is the climatic annual precipitation. Depending on the values of ratio, *P/PE*, a region can classified into *desert, steppe, forest* and *tundra*, respectively.

Figure 3a displays the theoretical Turc-Pike curve along with the observed data from all the basins. Note that the basins fall into three categories: desert, steppe and forest. Figure 3b shows an alternative form of the Turc-Pike curve where the vertical axis is the climatic annual runoff/ precipitation ratio, *Q/P*, also known as the climatic runoff coefficient.

Figures 4a-d show the long term monthly average precipitation, streamflow discharge, evaporation and total water storage deficit for the four Large-Scale-Areas (LSA): Arkansas/Red, Missouri, Upper Mississippi and Ohio river basins. Note that monthly variations of hydrologic statistics for different LSAs are slightly different, with precipitation peaking in May for the Arkansas/ Red river basin and in July for the Ohio river basin. In Upper Mississippi and Ohio basins,

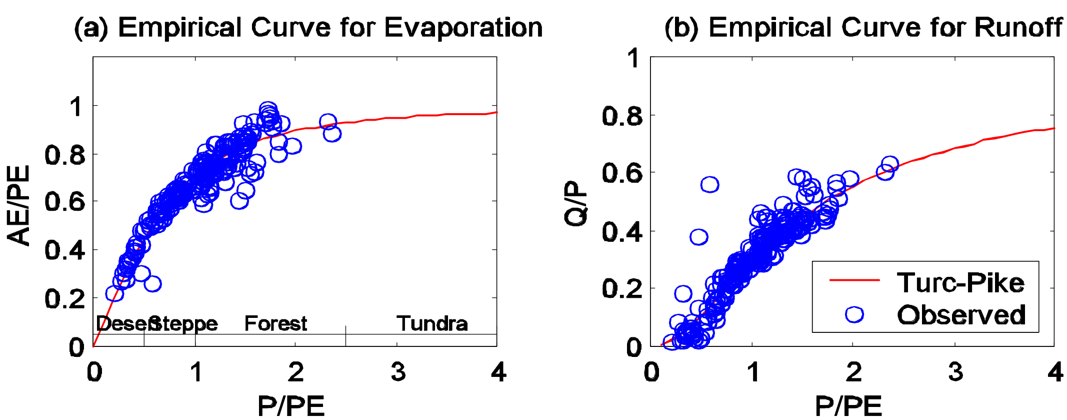

Figure 3. Empirical relationships between long term water balance components

runoff peaks in March.

The estimated evaporation for the Arkansas-

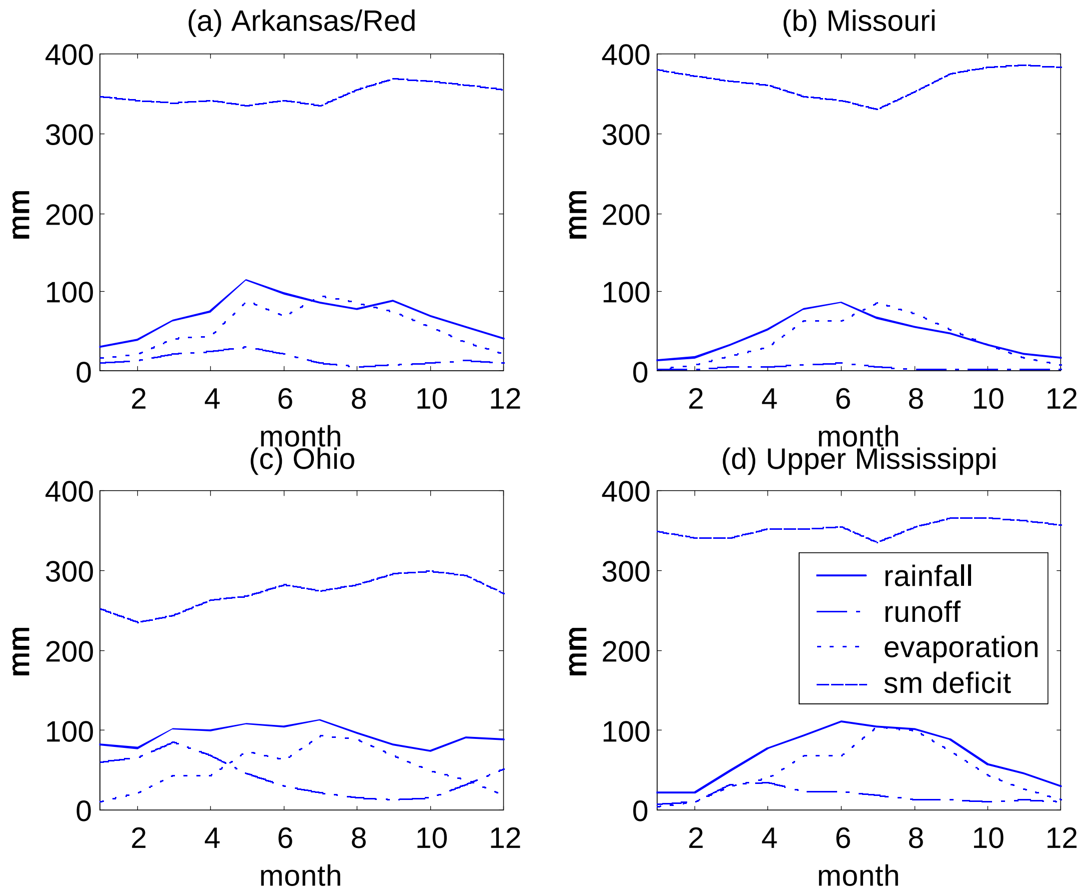

Figure 4. Long term monthly average of hydrologic statistics for the Mississippi river basin

Red river basins from the diagnostic water budget was compared to the estimated evaporation from the atmospheric water budget for the period between 1979-1988 (Figure 5). Mean monthly estimates of atmospheric water vapor flux

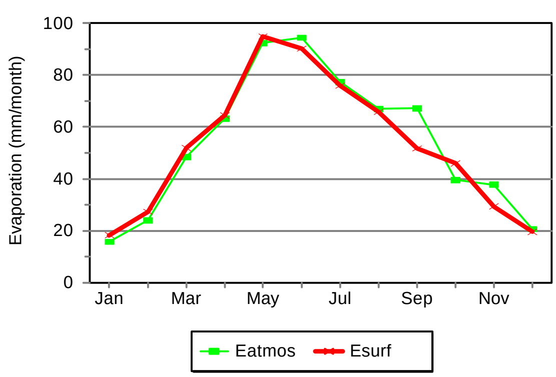

Figure 5. Comparison of evaporation estimated using diagnostic surface water budget and atmospheric water budget

divergence were made for the PILPS2c experiment (Liang, et al., 1998). Mean monthly evaporation was estimated as the sum of mean monthly precipitation and mean monthly water vapor flux divergence. Because the mean annual total flux divergence was not equal to the mean annual runoff from the basin, adjustments to the atmospheric budget-based monthly evaporation estimates were made to close the annual atmospheric water budget. The evaporation estimates from the monthly surface water budget and from the atmospheric water budget agree very well, with $R^2 = 0.82$. In terms of how well atmospheric divergence data can close the water budget, our study shows that the mean flux divergence error (~ 5.3 mm/month) is about 10 percent of mean evaporation and 50 percent of mean runoff.

4. SUMMARIES AND DISCUSSIONS

This paper presents a diagnostic approach to study the surface water budget of Mississippi river basin. The study shows that the water budget of the Mississippi river basin is diverse in response to climate. This is true not only spatially, but also seasonally. The results from this study demonstrate that a diagnostic surface water budget approach is a very useful tool to complement the results obtained using atmospheric water budget approach, especially because it can be applied at a much finer spatial scale.

The work presented so far represents preliminary work. Future study will examine the space/time variability of water budget at ISA scale. The effect of assumptions on evaporation should be investigated further for other large scale areas beyond the Arkansas/Red basin. The implication of the results on surface water modeling will be explored.

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