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2.9 TOTAL WATER STORAGE RANGE OF THE MISSISSIPPI RIVER BASIN

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1. INTRODUCTION

Total water storage (TWS) in the land surface includes water in the soil zone, subsurface aquifers and in streams and surface reservoirs. Land surface water storage controls the partitioning of precipitation into evaporation and runoff, the partitioning of net radiation energy into latent and sensible heat fluxes and the occurrence of base streamflow. Water storage properties are important at both short and long time scales, and have important effects on weather and climate.

A clear understanding of TWS variability of a basin is very important in modeling land surface hydrologic processes. It has special relevance to the estimation of model parameters such as those related to total water storage capacity (TWSC) and to the role of water storage in regulating water and heat fluxes.

The TWSC of a particular basin is highly uncertain. Although the range of water holding capacity of soils is reasonably well known, there is uncertainty in the actual water holding capacity of the soils in a given basin. An estimate of the plant-available water holding capacity equal to 15 cm has been widely used in some atmospheric models for lack of a better estimate. This estimate is equivalent to assuming that the water holding capacity of the soil is about 15 percent of its volume and that the maximum root depth is about one meter. Past research has indicated that a universal value of 15 cm for TWSC leads to poor model performance by a bucket model (Chen et al., 1996; Schaake et al, 1996).

This study considers how the TWS and monthly changes in TWS vary in time and space and how TWS relates to the actual total water storage capacity (TWSC).

This paper is organized as follows. Section 2 give a brief discussion of the methodology used. Section 3 demonstrates the use of the methodology in a Large-Scale-Area in Mississippi river basin - the Arkansas/Red river basin (i.e, LSA-SW). Section 4 summarizes the results and outlines further research.

2. METHODOLOGY

A diagnostic approach is used to investigate TWS over the range of climate regimes in the Mississippi river basin. Water storage changes are estimated using observed precipitation and observed streamflow together with an estimate of evaporation that depends on potential evaporation and the current estimated water storage deficit. The range of TWS variability depends on the period of time and the events during the period.

Previous studies of water storage have used hydrologic models to simulate water storage changes in response to observed precipitation and energy (e.g. potential evaporation) forcing. In this study, observed runoff is used in the analysis so the partitioning between runoff and precipitation is not model dependent. But the month by month partitioning of the sum of storage change and evaporation is dependent on the rule used to estimate monthly evaporation. Accordingly, five different evaporation schemes are considered in this study to investigate the sensitivity of the conclusions to this assumption. The assumptions range from a simple scheme in which evaporation is equal to a fixed fraction of potential evaporation to complicated ones, where evaporation is not only dependent on potential evaporation, but also on soil moisture content, precipitation, vegetative activity and user specified parameters. For detailed description of the evaporation schemes, please refer to Duan et al. (1999).

Before we describe the results, the following definition is given. During a period, T, beginning at time, t, the maximum and minimum of soil moisture deficit, D_t, are:

$$M_T = \max(D_t, D_{t+1}, D_{t+2}, \ldots, D_{t+T}) \tag{1a}$$

$$m_T = \min(D_t, D_{t+1}, D_{t+2}, \ldots, D_{t+T}) \tag{1b}$$

The variability range of water storage, R_T , can be expressed as follows:

$$R_T = M_T - m_T \tag{2}$$

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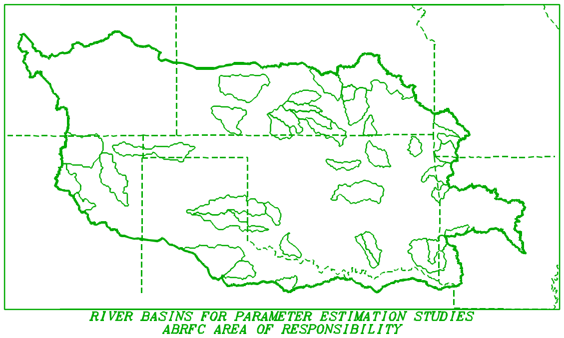

Figure 1. Location of study basins

3. PRELIMINARY TESTING RESULTS

Monthly hydrometeorologic observations of precipitation and streamflow discharge were collected for the period 1948-1997 from more than 200 unregulated catchments in the Mississippi River basin. A simple water balance equation based on the physical law of mass conservation was applied to each of the catchments. For illustration purpose, results from the Arkansas/Red river basin are presented here.

The Arkansas-Red river basin (see Figure 1), is located in the southwestern part of Mississippi river basin. With a total area of 538,382 km^2, it encompasses part or all of eight Southwestern states. Within LSA-SW are a number of smaller river basins termed Intermediate Scale Areas (ISA's) by GCIP. Thirty-six years (from 1950 to 1986) of monthly mean areal precipitation and streamflow discharge data were assembled for 27 ISA basins.

3.1 Temporal Analysis of R_T

Figures 2 a-c show estimates of the average values of R_T for three typical basins. The solid lines in Figure 2 are the sample average values of R_T. The averages are taken over all T-year periods in the total 36 year data period. The dotted lines represent the average values plus/minus the sample standard deviation, while the dashed lines represent the sample maximum and minimum. The figure shows that R_T increases monotonically as the study period T increases from one year to 36 years. It is also clear that the wet basin has the larger variability range while the dry one has the smaller variability range. In each case there appears to be an upper limit to the total storage capacity, but this is approached asymptotically. A further observation from the figures is that the values of R_T rise faster for the wet basin than for the dry one, implying that it takes longer to observe the full range of storage variability for dry basins.

3.2 Sensitivity of R_t to Evaporation Assumptions

Figure 3 indicates that TWS ranges, R_T, are different for different evapotranspiration functions. Differences are expected since evapotranspiration is computed differently. Three of the functions (e.g., 1, 2 and 4) produce similar results. Function 5 has the smallest range for R_T, while Function 3 has the greatest. Function 3 has the greatest range because it assumes that water evaporates and transpires at a constant fraction of potential evaporation throughout the entire analysis period. This constant fraction produces the correct total volume of evaporation over the long run but evaporation by this function is unrealistic because it is insensitive to the temporal variation of precipitation or water storage. Accordingly, more evapotranspiration takes place in dry years and less in wet years than actually occurs. Since storage is the only water balance component that can absorb the error in calculating evapotranspiration, the amplitude of storage variability is unreasonably enlarged as a result. Function 5 has the lowest range because part of

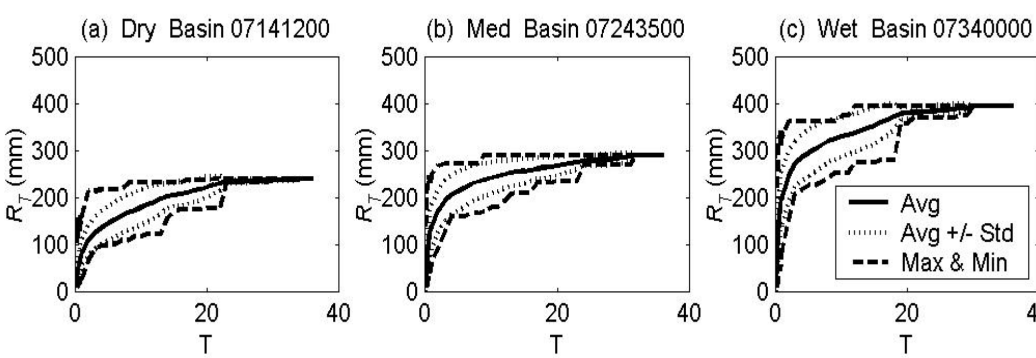

Figure 2. TWS range for selected basins

the precipitation may evaporate in the same month as it occurred so less storage is required.

3.3 Spatial Analysis of R_T

Figures 4a-d plot, respectively, the gridded fields of R_T for T = 1, 5, 10, and 36 years. The figures show that R_T increases from the West to the East. The spatial differences are greater for smaller values of T.

An analysis was done to see if differences in R_T among the 27 basins could be explained by basin characteristics. Figure 5 is a scattergram of sample maximum range R_{10} vs P/PE. The correlation between R_{10} and P/PE is relatively high, with R^2 =0.806. R_{10} increases with P/PE ratio, echoing previous findings that wetter basins have larger storage variability than drier basins.

3.4 Comparison of R_T for ISA Basins and LSA-SW

Basin average estimates for the entire LSA-SW were made using a spatial analysis of the data for the 27 basins used in the study. Figure 6 presents the resulting function of R_T vs T. Also shown in this figure is the average ISA basin value of R_T vs T which lies above the composite LSA-SW function. This means that R_T is scale dependent. The water storage range is much higher for ISA basins than for LSA basin (300 vs 200 mm). This scale-dependency may be expected to apply for scales smaller than the ISA scale as well. But that is not possible to measure except for a few experimental watersheds

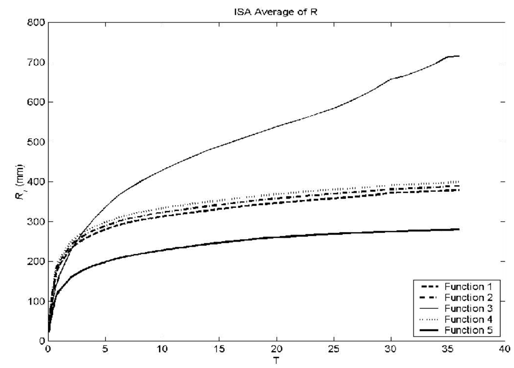

Figure 3. Comparison of TWS range for different evaporation schemes

because sufficiently accurate measurements of precipitation do not exist for very small stream basins.

4. SUMMARIES AND DISCUSSIONS

Results show that water storage range is sensitive to assumptions on how water evaporates. Wetter regions exhibit larger variability in water storage range than dry regions. Dry regions have very small intra annual variability in water storage range, compared to year-to-year variability, suggesting that longer data sets are needed to model dry region water balance. Water storage range shows strong

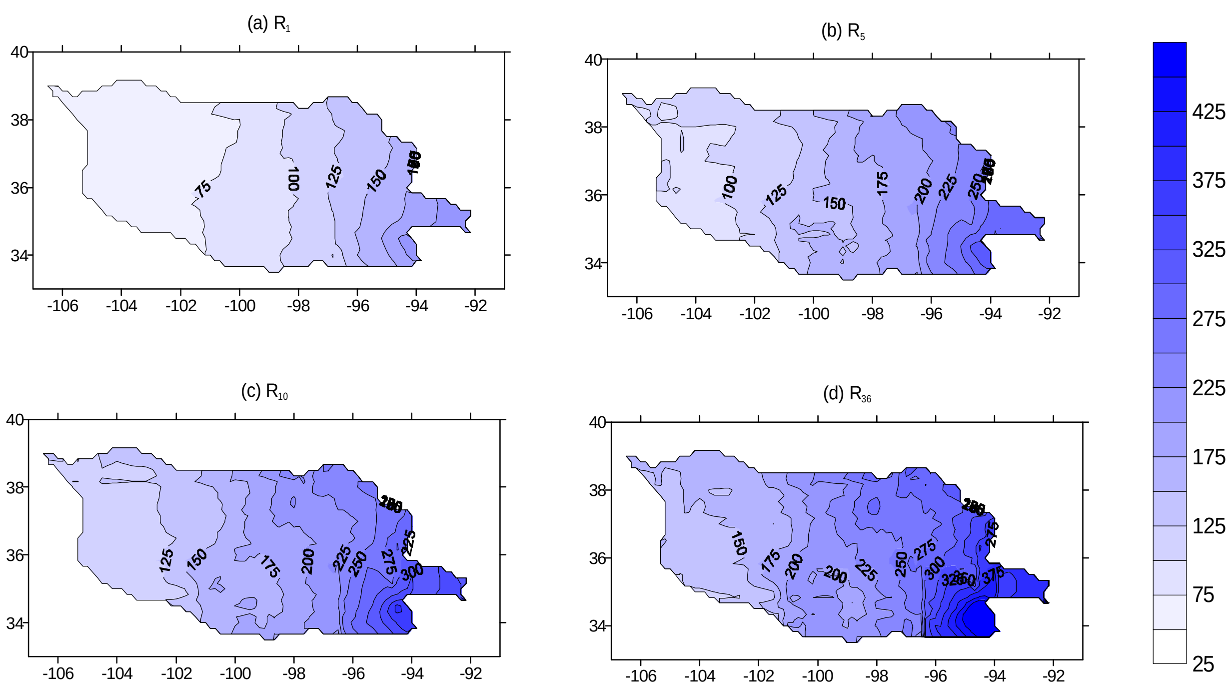

Figure 4. Spatial plots of TWS ranges for different analysis periods

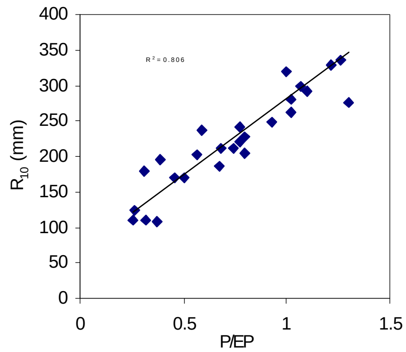

Figure 5. Scattergram of R_{10} vs P/EP

correlation with climatological factors such as P/PE ratios. Water storage range is scale dependent, with ISA scale displaying larger ranges than larger LSA scale.

We are proceeding to complete the study for the entire Mississippi river basin. The relevance to the estimation of hydrologic model parameters will be a key focus.

5. REFERENCES

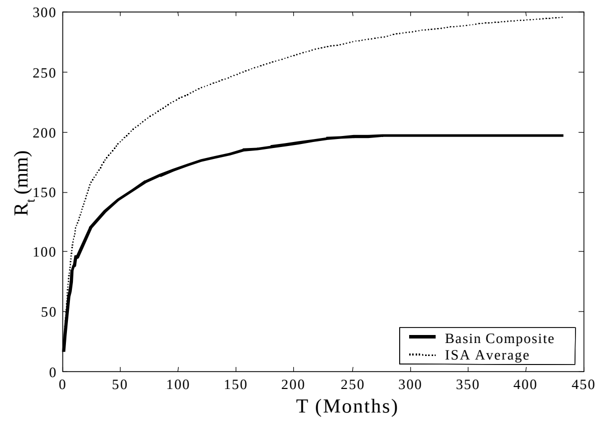

Figure 6. Comparison of TWS range for average ISA basins and LSA-SW

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