Application of Macro-scale Hydrologic Model for Drought Identification in Cold Climate Regions

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Introduction

As one of the major hydrologic extremes, drought affects water resources, agriculture, and environment. To identify drought and mitigate its destructive impact, drought indices are employed. Hydrologic drought indices take into account the lag between meteorological and hydrologic processes. For instance, the standardized runoff index (SRI) is based on surface runoff and considers snow accumulation and snowmelt as essential hydrologic processes in cold climates. The objective of this study is to identify drought in the Red River basin (RRB) based on SRI. Specifically, the macro-scale grid-based hydrologic model (GHM) is used to provide high-resolution surface runoff outputs, which are further utilized for quantifying spatial and temporal distributions of drought in the RRB.

Methodology

Input Data

GHM provides surface runoff with a 4-km resolution. Unique hydrologic processes under cold climate such as snowmelt and frozen soil are simulated in this model. The gridded surface runoff data simulated by GHM for a period of 2003-2007 are used for computation of SRI .

SRI Calculation

The procedure for calculation of SRI is as follows:

1) Fit a probability distribution function (PDF) to the runoff time series
2) Calculate the cumulative distribution function (CDF) of the fitted PDF
3) Calculate SRI values (i.e., normal inverse of CDF)

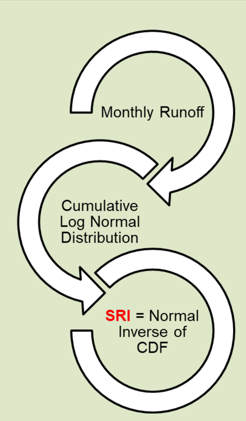

Figure 1 SRI computation procedure

Study Area

The annual mean precipitation and temperature in RRB are 500 mm and 4.3 °C, respectively. It drains parts of North Dakota, Minnesota, and South Dakota and the river flows northward. 60% of the basin area is covered by cultivated croplands. Thus, information on drought in this area is crucial in decision making for stakeholders.

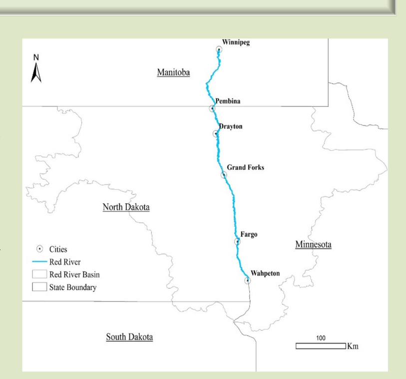

Figure 2 Red River basin

Results

Drought Coverage Area

According to the USDM drought classification, drought area coverage is estimated for D1: Moderate (-0.8≥SRI>-1.2), D2: Severe (-1.2≥SRI>-1.5), D3: Extreme (-1.5≥SRI>-1.8), and D4: Exceptional (-1.8≥SRI) droughts.

Based on the modeling results, a larger area was covered by extreme/exceptional drought in 2006. In contrast, a small percentage of the area was covered by drought in 2005.

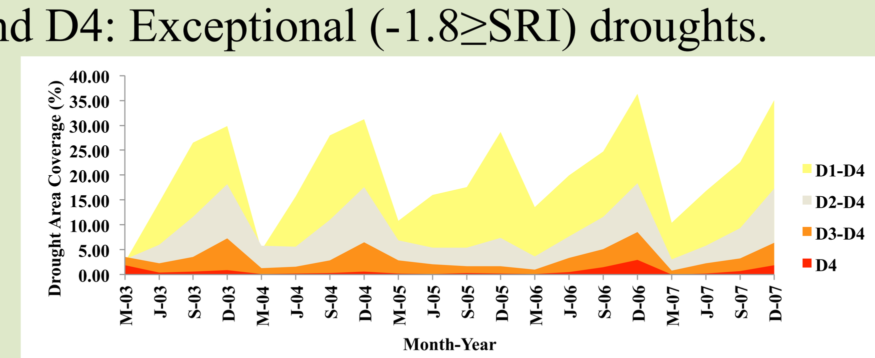

Figure 3 Drought coverage area in RRB

Seasonal SRI

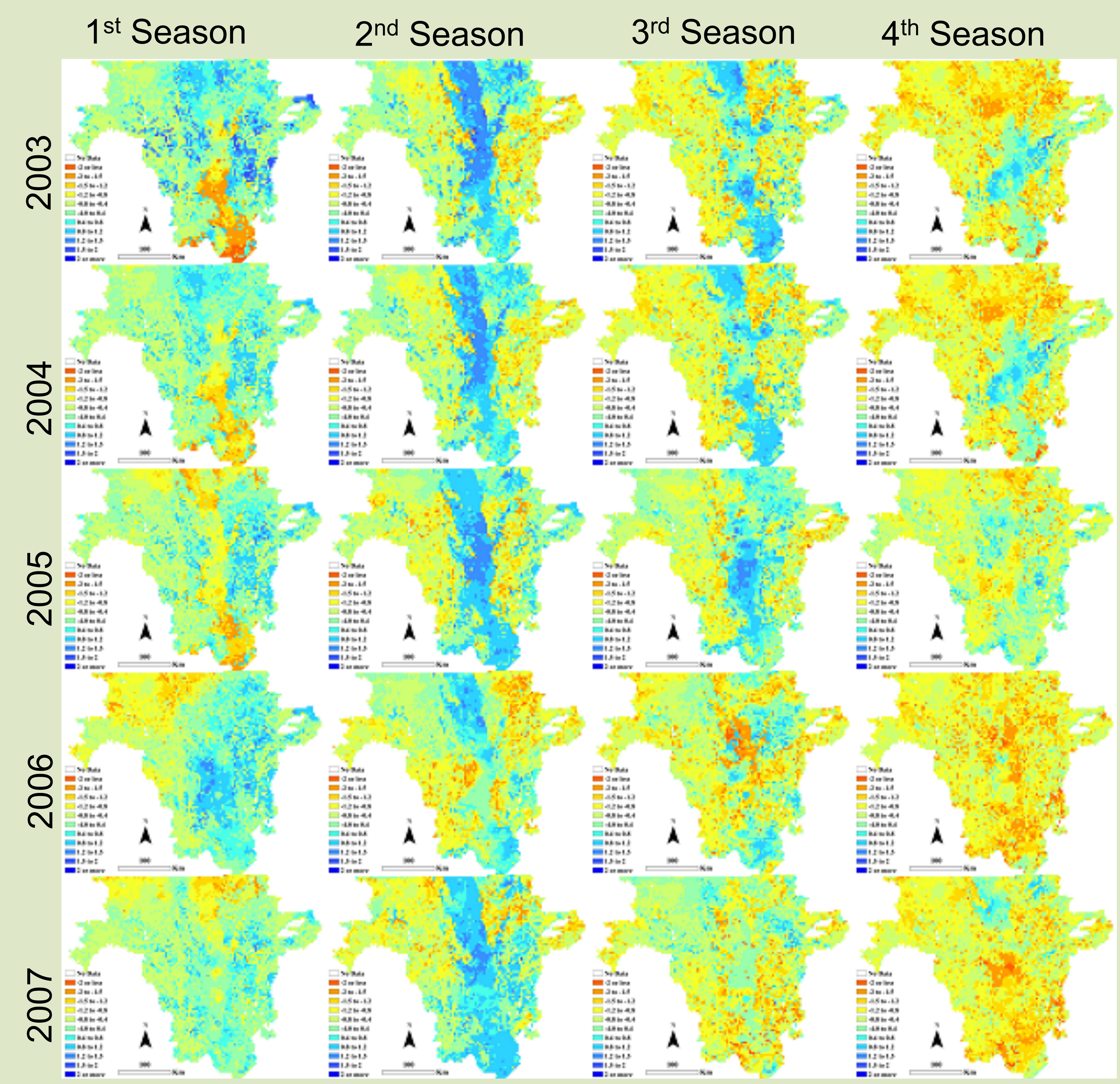

Figure 4 Spatial and temporal distributions of seasonal SRI values in RRB

Figure 4 shows the spatial and temporal distributions of drought of seasonal SRI values in RRB.

- ❖ The results indicate that there is a seasonal trend in drought variations. Generally, fall and summer are the driest seasons and winter and spring are the wettest seasons.
- ❖ Comparing with other years, 2006 has the driest condition throughout all seasons.
- ❖ The winter of 2007 is the wettest winter in the entire simulation period.
- ❖ In 2005, RRB has wet spring, summer, and fall, in spite of a dry winter.

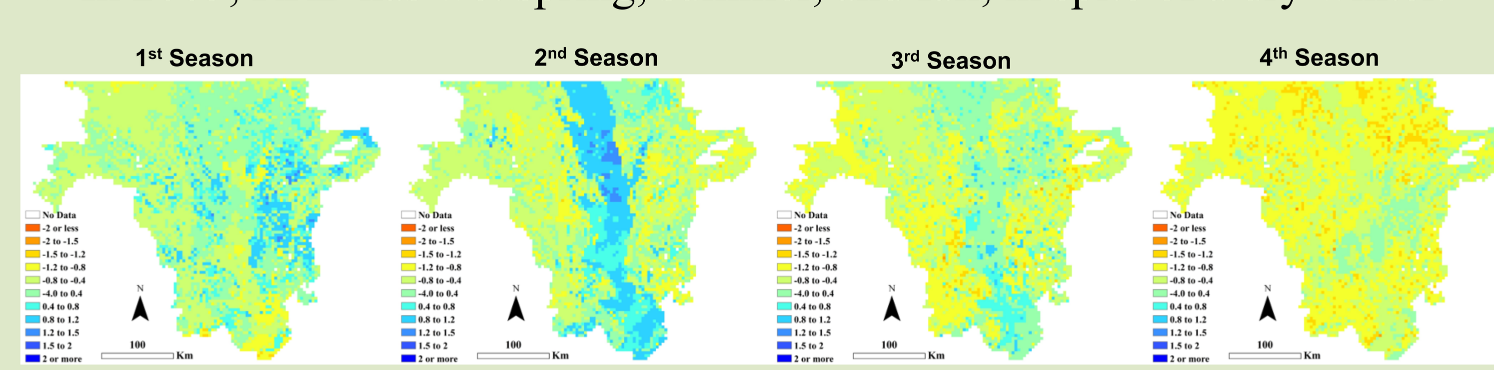

Figure 5 Spatial distributions of mean seasonal SRI values in RRB

To examine the spatial distribution of drought in different seasons, mean seasonal SRI values are estimated and mapped.

- ❖ In the 1st season (Jan-Mar), the upstream area is drier than other parts.
- ❖ In the 2nd season (Apr-Jun), a wet condition is prevalent in the central area of the basin (along the Red River).
- ❖ In the 3rd season (Jul-Sep), the upstream area is relatively wet, but both west and east sides of the basin have a dry condition.
- ❖ In the 4th season (Oct-Dec), drought is dominant throughout the entire basin.

Monthly SRI

Comparison of the monthly SRI values for 2005 (wet year) and 2006 (dry year)

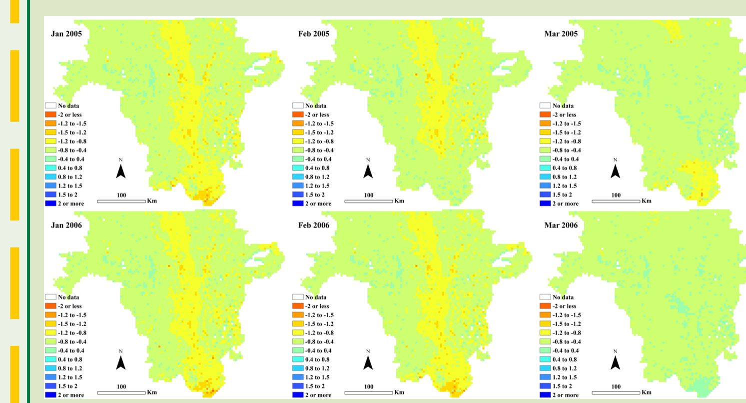

Figure 6 Monthly SRI in January-March of 2005 and 2006

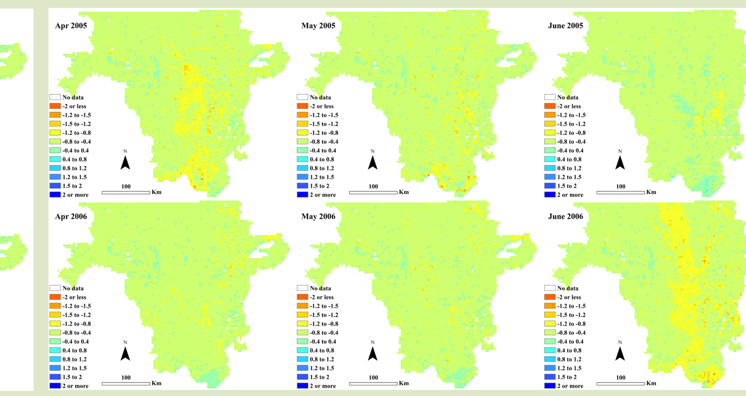

Figure 7 Monthly SRI in April-June of 2005 and 2006

The upstream area of RRB in March 2005 is drier than 2006 (Figure 6). This situation continues until June 2005 when it is wetter than 2006 (Figure 7).

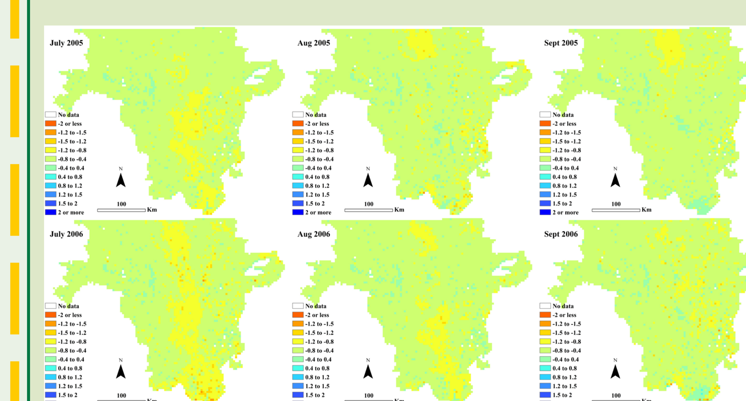

Figure 8 Monthly SRI in July-September of 2005 and 2006

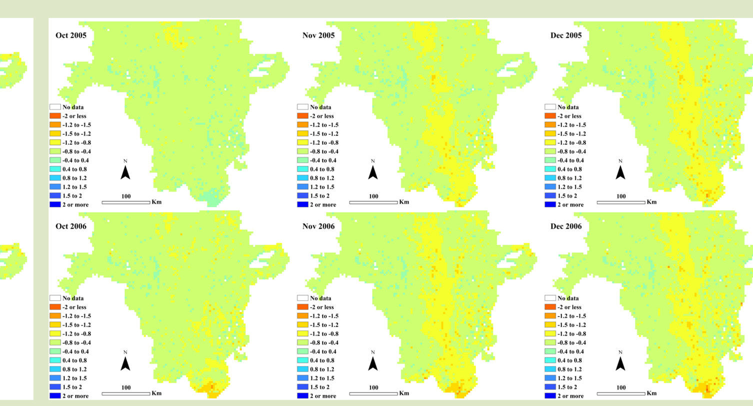

Figure 9 Monthly SRI in October-December of 2005 and 2006

- ❖ The summer months of 2006 are drier than 2005 (Figure 8).
- ❖ The fall months are dry for both 2006 and 2005.
- ❖ Although the average temperature is high in both years, 2006 is drier due to lower precipitation (and hence surface runoff).

Conclusions

The focus of this research was on identification of regional drought in RRB by employing the SRI index method. The major conclusions can be summarized as follows:

- ❖ The capability of GHM in simulation of cold-climate hydrology makes it applicable to the identification of drought.
- ❖ 2006 and 2005 are the driest and wettest years, respectively, in the simulation period. In addition, fall is the driest season in RRB.
- ❖ The seasonal SRI is less influenced by individual short events and presents a better overall drought condition over a longer period than the monthly SRI. In the future, longer time series and time scales will be analyzed.

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