J4.12 REGIONAL HYDROLOGICAL CYCLE AND WEATHER AND CLIMATE IN THE CONTIGUOUS UNITED STATES

Qi Hu[1] and Song Feng
Climate and Bio-Atmospheric Sciences Program
School of Natural Resource Sciences
University of Nebraska-Lincoln
Lincoln, Nebraska 68583-0728

1. INTRODUCTION

Hydrological cycle in the Earth-atmosphere system is not only a manifestation of the weather and climate but also a driving force for changes of the climate, particularly when the cycle is disturbed by anthropogenic changes of land surface conditions. Understanding the hydrological cycle and its variability and relation to weather and climate on various time scales will assist us to understand both regional and global climate and how anthropogenic effects may alter the water cycle and the current climate. In this study, we address the relationship between properties of regional hydrological cycle and weather and climate and emphasize the equilibrium of the hydrological cycle and its corresponding statistical features of precipitation in the regional climate. Hydrological cycles for different regions in the contiguous United States were first analyzed using NCEP-NCAR Reanalysis data of 1948-2000. Then, the relationship of the hydrological cycle intensity and other components in the cycle are examined with regional precipitation and temperature. The data and methods used in this study are discussed in the next section followed in section 3 by presentations and discussions of the major results. Some issues related to change of the hydrological cycle and weather and climate are highlighted in section 4.

2. DATA AND METHODS

The components in regional hydrological cycle, e.g., surface evaporation, local water recycling, atmospheric moisture fluxes and convergence, and precipitation, were obtained and calculated from several data sources. Specifically, the moisture fluxes and convergence were computed using 6-hourly NCEP-NCAR Reanalysis Model data on sigma levels and then transformed to the physical domain. The surface evaporation was obtained from 2.5º×2.5º NCEP-NCAR Reanalysis Model. Although the evaporation data may contain bias in some isolated spots and cause spurious local land moisture sources, effects of such biases on calculated hydrological cycle could be minimized using regional average and for temporal scales longer than a month (Trenberth and Guillemot 1998; Dirmeyer and Brubaker 1999; Bosilovich and Schubert 2001). Accordingly, we calculated the monthly and annual hydrological cycle in large-scale regions (L>1000km) in the contiguous U.S. The precipitation data used in examining the hydrological cycle were 1949-2000 land precipitation data on a 2.5º×2.5º grid (Chen et al. 2002). In addition, daily precipitation data from 1062 stations in the U.S. (Easterling et al. 1999) also were used to derive precipitation properties that were used in evaluations of relationship between precipitation climate and local hydrological cycle.

To calculate the hydrological cycle, we used the method described in Brubaker et al. (1993), which is based on the conceptual framework of Budyko (1974). The model has two major assumptions: 1) variations in evaporation and precipitation are linear across the study region, and 2) the atmosphere efficiently mixes the evaporated water (P_m) with advected moisture (P_a) and the ratio of P_a vs. P_m in the total precipitation is a constant. These assumptions have been examined and shown to cause about 10% error in regional water budget for the conditions in the central U.S. and using long-term time average values in the calculations (Brubaker et al. 1993; Burde and Zangvil 2001). Based on these assumptions, the total moisture content in the atmospheric column of a region is composed of an advection portion, W_a, and a portion from local evaporation, W_m, thus, $W= W_a + W_m$. Consequently, the total precipitation, P, is made from two sources: advection, Pa, and local evaporation, P_m, i.e., $P= P_a + P_m$. The two components in P play different roles in regional hydrological cycle and characterize regional climate. In particular, in

[1] Corresponding author address: Dr. Qi Hu, 237 L.W. Chase Hall, University of Nebraska-Lincoln, Lincoln, NE 68583-0728. E-mail: QHU2@unl.edu. Internet: http://snrs.unl.edu/climate.

the local water recycle, a “water recycling ratio” has been used to define “the contribution of local evaporation to the total precipitation” (Elfaith and Bras 1996), and is recognized as a major character of a region’s climate (Brubaker et al. 1993; Trenberth 1999). A larger recycling ratio describes a more significant role of local evaporation in the regional precipitation and climate. A smaller recycling ratio, on the other hand, indicates a weaker role of evaporation in rainfall development but a dominant role of moisture flux in the region’s rainfall and climate.

If we define the inward flux of moisture to a region as the integral of the atmospheric moisture inflow across all the boundaries of the region, i.e., $F^{+} = -\int_{\Gamma_{in}} w_{\gamma} V_{\gamma} d\gamma$, where, w_{γ} and $V_{\gamma} = (u_{\gamma}, v_{\lambda})$ are the moisture content and the velocity perpendicular to the boundary surface, respectively, and Γ_{in} is the boundaries of the domain with inward moisture flux, then the total moisture input to the region is $Q = F^{+} + \frac{(E-P)A}{2}$, where A is the area of the region and the second term on the rhs includes the net moisture input from the surface (Brubaker et al. 1993; Burde and Zangvil 2001). In *Q*, the moisture advected into the region is calculated from: $Q_a = F^{+} - \frac{P_a A}{2}$. For time scales of month and longer, the atmosphere can be assumed to be well mixed, meaning that at a given region the water molecules of advective origin and those of local evaporative origin are well mixed and have equal probabilities to be precipitated, i.e., $\frac{P_a}{P} = \frac{Q_a}{Q}$. So, the local water recycling ratio, *r*, can be calculated in terms of *Q* and Q_a from $r = \frac{P_m}{P} = \frac{P-P_a}{P} = \frac{Q-Q_a}{Q}$.

Because “the water cycle has different equilibria in the different climate” (Elfaith and Bras 1996), we divided the continental U.S. into 11 regions with similar climate conditions and calculated the hydrological cycle and its relationship with precipitation and temperature climate in those regions.

3. MAJOR RESULTS

In discussing the results, we focus on the relationship of the regional hydrological cycle and precipitation events of different characteristics, e.g., intensity and duration, and elaborate the differences in hydrological cycles corresponding to different precipitation climate. In Fig. 1, we show the coefficients of correlation of local water recycling ratio vs. precipitation in different categories of intensity and duration. We should remind that these correlations were calculated using 52-year data from 1949-2000. A general feature in Fig. 1 is the negative correlation between the recycling ratio and precipitation in regions along the west coast, in southeastern and eastern U.S., and in the Great Lakes area. Positive but small correlations are found in the west central and mountainous regions in the west. Consistently, the relationship between the recycling ratio and the drought event has a reversed sign in the regions. With regard to the definition of the recycling ratio, a negative correlation between recycling ratio and precipitation in a particular category, for example, the largest or most intense precipitation events in a year, would indicate a large P_a in the total precipitation, *P*, so that P-P_a is always much smaller than *P*, which then, based on the definition of the recycling ratio, dominates the change in the ratio. This creates an inverse relationship and results in a negative correlation between *r* and *P*. Thus, in Fig. 1 the regions with large negative correlations (<-0.3) indicate advection of moisture into the regions as an essential process affecting the regions’ precipitation and water cycle. On the other hand, the regions with a positive correlation have smaller contributions from P_a to *P* and, thus, weaker dependence of their precipitation and water cycle on advected moisture. In these regions, surface evaporation plays an important role in regional precipitation and water cycle.

This difference in dependence of the precipitation on advected moisture and local evaporation among the regions is further described in the result of Fig. 2 showing the relationship between surface evaporation and regional precipitation. The correlation coefficients are large in the regions of the central U.S. where the advection effect is weak, and small in the western and eastern U.S. where the advected moisture played a major role in local precipitation and local water cycle. This role of the moisture advection in precipitation is explicitly shown in Fig. 3; the high correlations in the regions along the west coasts, southeastern U.S., and the Great Lakes area depict a significant effect of moisture flux on precipitation development and low correlations in the central and particularly north-central U.S. show a rather weak influence of moisture advection on precipitation and water cycle in those regions. Such weak effect in the central U.S. could be a result of lacking mechanisms transporting moisture to the central portions of the continent.

Similar results also have been obtained from analyses for the northern summer.

4. DISCUSSION

These mutually consistent results differentiate hydrological or water cycle in different climates across the contiguous U.S. and associated characteristics of regional precipitation. These characteristics reveal not only the processes unique to the regional precipitation development but also the different sources that could cause the precipitation variations in various regions. For example, in the central U.S., regional land surface change could have a substantial effect on precipitation, water cycle, and climate because of a strong dependence of the water cycle on the surface evaporation. However, a similar magnitude of land surface change may have a much weaker effect on local precipitation and climate in the coastal regions because of the weak dependence of local water cycle on the surface evaporation in those regions. Therefore, land surface change effects on and vegetation feedbacks to regional climate could be more significant in the in-land regions, whereas flow anomalies and associated changes in circulation dynamics should be major concerns of water cycle, precipitation, and climate variations in regions in the west and east coastal regions in the contiguous U.S.

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Annual recycling ratio vs. precipitation indexes

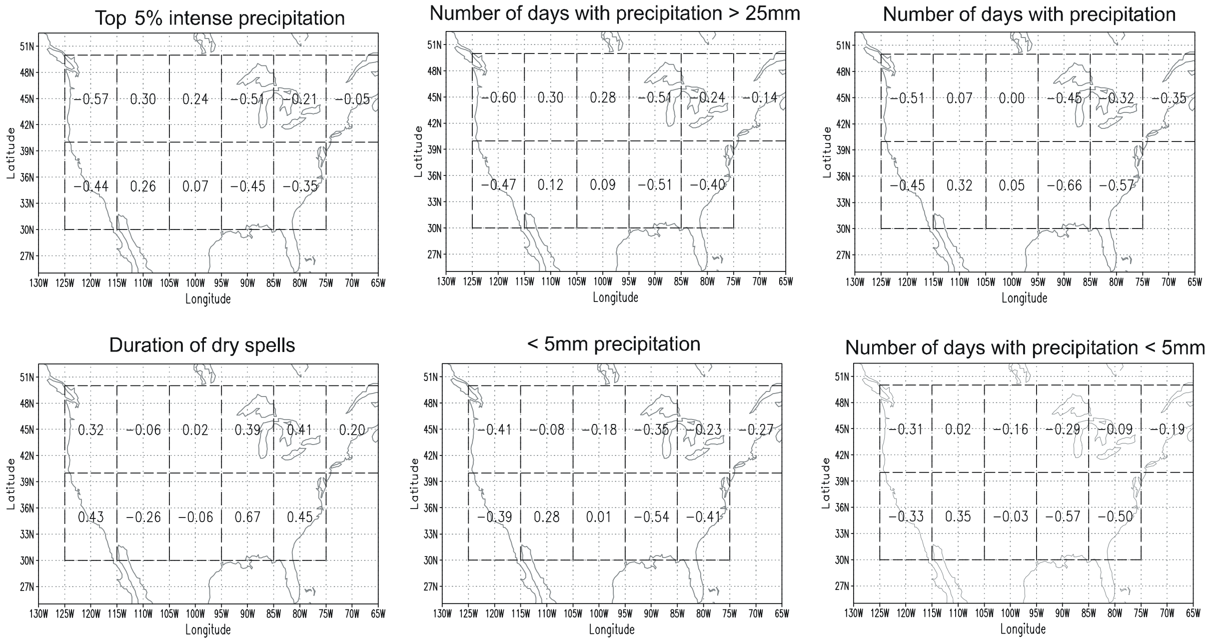

Figure 1: Correlation coefficients of local water recycling ratio vs. precipitation and drought.

Annual evaporation vs. precipitation indexes

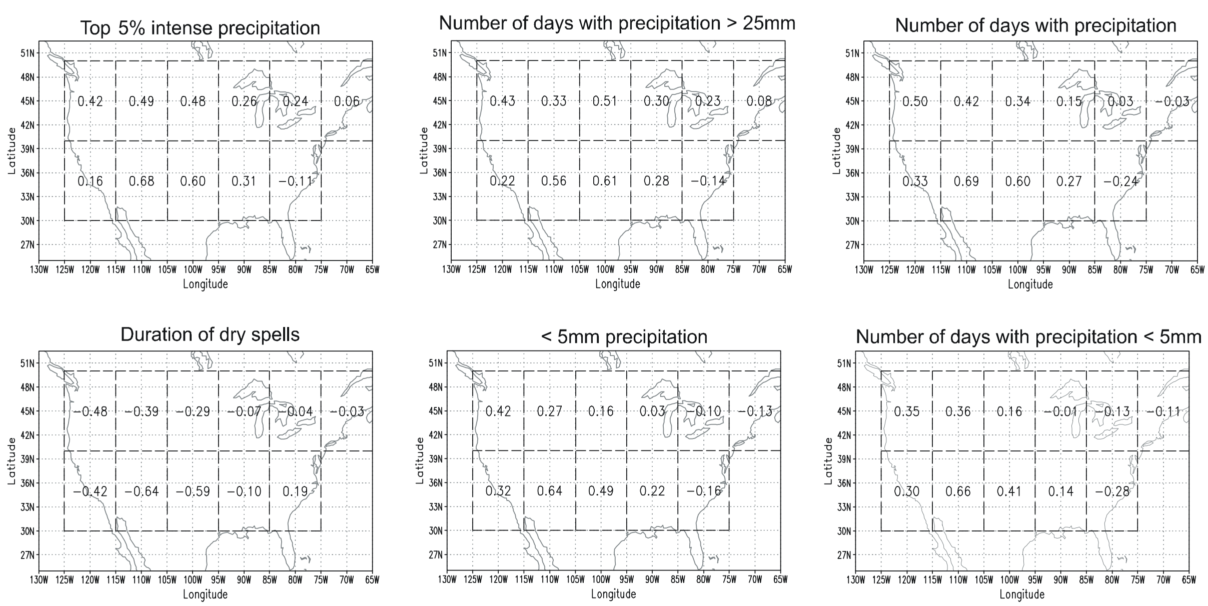

Figure 2: Correlation coefficients of local surface evaporation vs. precipitation and drought.

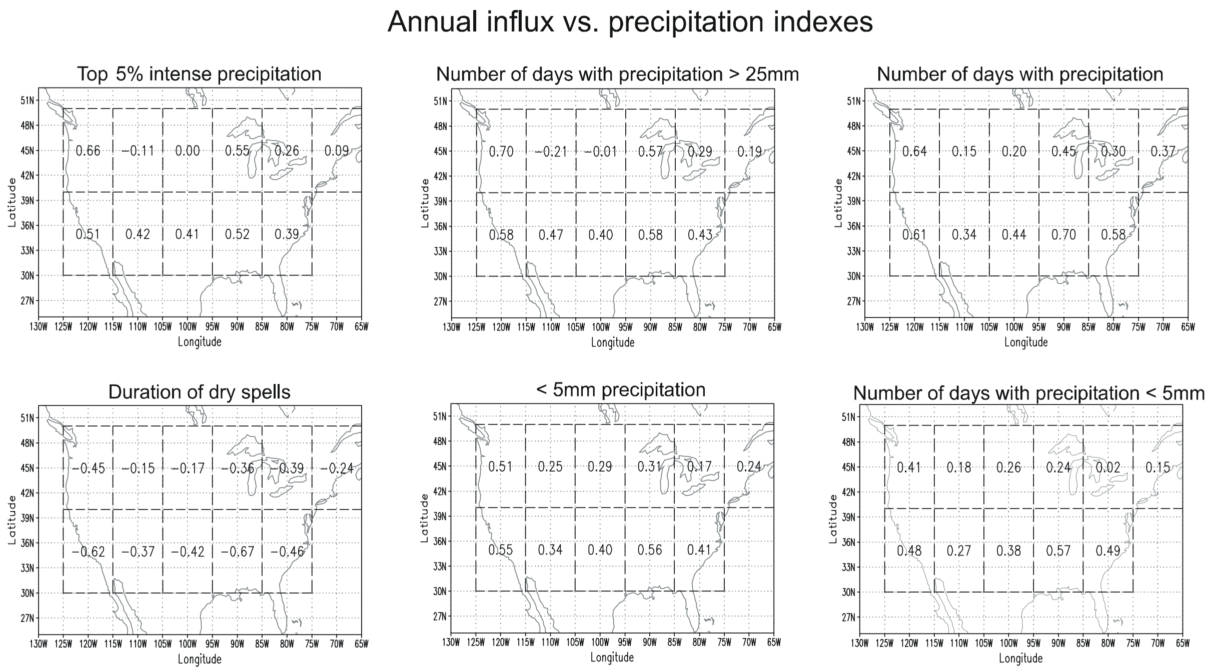

Figure 3: Correlation coefficients of moisture flux vs. precipitation and drought.