



Trend of estimated actual evapotranspiration over China during 1960–2002

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[1] In this study, the water balance methodology introduced by Thornthwaite and Mather (1955) is modified to estimate monthly actual evapotranspiration for 686 stations over China during 1960–2002. The modification is done by replacing the Thornthwaite potential evapotranspiration estimation with the Penman-Monteith method. Temporal trend and spatial distribution of the estimated annual actual evapotranspiration during the past 43 years are analyzed. The results show that (1) the actual evapotranspiration had a decreasing trend in most areas east of 100°E, and there was an increasing trend in the west and the north parts of northeast China; (2) the spatial distribution of the trend for the actual evapotranspiration is similar to that of the potential evapotranspiration in south China, while the trends are opposite in north China; (3) for most parts of China, the change in precipitation played a key role for the change of estimated actual evapotranspiration, while in southeast China, the change of potential evapotranspiration appeared to be the major factor; and (4) in general, the hydrological cycle was intensified in western China, whereas it was weakened from the Yellow River basin northward.

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1. Introduction

[2] Along with the increasing global temperature, much evidence from the changes of precipitation, runoff, and soil moisture suggests that the hydrological cycle has been intensified in many parts of the world during the past century [e.g., Alan *et al.*, 2003; Huntington, 2006]. As the only connecting term between water balance and energy balance and because of complex interactions in the land-plant-atmosphere system, actual evapotranspiration is perhaps the most difficult and complicated component of the hydrological cycle [Xu and Singh, 2005]. Contrary to the expectation that a warmer climate will bring about an increase in evaporation, many studies have shown that pan evaporation and potential evapotranspiration had decreased over the past decades in many places of the world [Peterson *et al.*, 1995; Chattopadhyay and Hulme, 1997; Brutsaert and Parlange, 1998; Lawrimore and Peterson, 2000; Thomas, 2000; Roderick and Farquhar, 2002, 2004; B.-H. Liu *et al.*, 2004a; Chen *et al.*, 2005; Xu *et al.*, 2006a, 2006b]. Some of these studies have attempted to identify what meteorological factors have caused this trend [e.g.,

Gong *et al.*, 2006], which is useful to explain the evaporation paradox. A number of studies have shown that the trend is not determined by temperature alone [e.g., Ohmura and Wild, 2002; Xu *et al.*, 2006a, 2006b]. Roderick and Farquhar [2002] suggest that the decrease in observed potential evaporation by pan in the Northern Hemisphere was consistent with what one would expect from the observed large and widespread decreases in sunlight resulting from increasing cloud coverage and aerosol concentration. For China, B.-H. Liu *et al.* [2004a] find that the decrease in solar irradiance, attributed to increased concentrations of aerosols, was the most likely driving force for the reduced pan evaporation. More recently, Ren and Guo [2006], Gao *et al.* [2006] and Xu *et al.* [2006a, 2006b] further demonstrate that solar radiation and wind speed were the major contributors to the changes in pan evaporation as well as potential evapotranspiration estimated by the Penman-Monteith method in China and the Yangtze River basin, respectively.

[3] Because of a varying degree of access to water, actual evapotranspiration can be much less than potential evapotranspiration. It is one of the most important variables in determining the water use efficiency in agriculture [Zhang *et al.*, 2007]. Actual evapotranspiration is more complicated and driven essentially by climatic factors, mediated by the vegetation and soil characteristics, and constrained by the amount of available water [Arnell and Liu, 2001]. Climate change has the potential to affect all of these factors in a combined way.

[4] There are a number of methods to evaluate actual evapotranspiration. Rana and Katerji [2000] summarize 10 methods for measuring and estimating actual evapotranspiration. Depending on purpose, the methods can be divided into hydrological, micrometeorological, and plant physio-

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logical. All methods have their advantages and disadvantages. For example, a weighing lysimeter can provide detailed information about the water balance; however, it is practically and economically impossible to measure evapotranspiration over widespread areas for a considerably long time period [Xu and Chen, 2005]. Therefore actual evapotranspiration is usually estimated through less complex physically based or empirical approaches.

[5] Linacre [2004] proposes that actual evapotranspiration can be evaluated through a relationship between available water content in the soil and evaporation rate. Xu and Chen [2005] compare two different approaches in estimating actual evapotranspiration: the complementary evapotranspiration models derived by Bouchet [1963] and a model based on a soil water balance where the actual evapotranspiration is considered as a fraction of the potential evapotranspiration and the fraction is an increasing function of the soil water content.

[6] Until now, studies on changes in actual evapotranspiration have been few and limited. From a hydrological cycle point of view, Brutsaert and Parlange [1998] explain the evaporation paradox as a reaction to the decrease in pan evaporation over a significant portion of the extratropical land area in the Northern Hemisphere and argue that decreasing pan evaporation actually provided a strong indication of increasing actual evapotranspiration in many situations. Milly and Dunne [2001] relate an upward trend in actual evapotranspiration over the Mississippi River basin between 1949 and 1997 primarily to increased precipitation and secondly to increased human water use. Using large weighing lysimeters, Golubev et al. [2001] find that the actual evapotranspiration during the warm seasons of 1950–1990 tend to increase in some relatively dry parts of southern Russia and Ohio, while, there is a decreasing trend of actual evaporation in two wetter places of the taiga. Similarly, Linacre [2004] points out that declining pan evaporation did not necessarily mean declining actual evapotranspiration.

[7] Trends for potential evapotranspiration of major basins in China from 1951 to 2000 have been established recently [e.g., Chen et al., 2005], while the trend of actual evapotranspiration during the past 50 years remains to be determined. Zhan et al. [2005] calculate monthly and annual actual evapotranspiration using a water balance model, and the result shows that the actual evapotranspiration increased during 1991 and 2000 in most parts of China, especially in the arid and semiarid regions. These results are interesting; however, the relatively short time period makes it difficult to put them into a climate change perspective. In this study, we use a similar but improved water balance model to estimate actual evapotranspiration and other components of the water balance on a monthly scale over China during 1960 and 2002. The improvement is done by replacing the Thornthwaite potential evapotranspiration estimation with the Penman-Monteith method in the water balance model. Furthermore, we analyze the trend of actual evapotranspiration in relation to changes of other components of the water balance in China.

2. Method and Data

2.1. Water Balance Model

[8] The water balance model used in this study is based on the Thornthwaite-Mather approach [Thornthwaite and

Mather, 1955]. Considering the deficiencies of potential evapotranspiration estimated by the Thornthwaite method in China, i.e., temperature and latitude only considered in the Thornthwaite method and unreliable results given under dry conditions [Chen et al., 2005], the potential evapotranspiration estimated in the Thornthwaite-Mather water balance approach is replaced by the Penman-Monteith method [Allen et al., 1998]. However, since there is practically no active vegetation cover during winter in northern China, the reference evapotranspiration will be overestimated, which asks for a correction of the estimated reference evapotranspiration in northern China. In this study, the reference evapotranspiration is simply assumed to be 0 mm when the monthly air temperature is less than or equal to 0°C. This assumption is held realistic since cold months with freezing temperatures in China are often associated with snow cover which prevents effective evapotranspiration from vegetation cover and soil surfaces. This treatment should be considered as an improvement of the previous estimates by Chen et al. [2005]. To maintain the simplicity of the model, other hydrological processes such as snowpack and melting are not taken into account. Further, irrigation is not included in the model.

[9] The governing equation of the water balance model can be described as follows:

$$S = P - E_a - \Delta W / \Delta t \quad (1)$$

where S is water surplus, P is precipitation, E_a is actual evapotranspiration, W is soil water content ($W_0 \leq W \leq W_{fc}$), where W_{fc} represents soil water holding capacity (field capacity), W_0 is the lower limit of evaporable soil water which is assumed to be equal to the moisture at wilting point W_p , and t is time. E_a is calculated as follows:

$$E_a = \begin{cases} P + \beta(W - W_p, W_{fc} - W_p)(E_p - P) & P < E_p \\ E_p & P \geq E_p \end{cases} \quad (2)$$

where E_p is the potential evapotranspiration, calculated by the Penman-Monteith method for a reference surface. The soil moisture retention function β depends on the ratio of available soil water content and maximum available soil water content expressed as $\frac{W - W_p}{W_{fc} - W_p}$, namely soil water retention curve C [Mather, 1974]. In this way, β will decrease linearly until all available water is used up. In order to estimate the monthly change of W , the W is calculated on a daily time step assuming equal values of $(P - E_p)$ for each day of the month. The soil moisture contents at the beginning and end of each month are used to calculate the monthly change of W .

[10] If $P < E_p$, the soil water will be depleted to compensate the water supply. At the same time, $E_a < E_p$ and $S = 0$. If $P \geq E_p$, then $E_a = E_p$, W is initially estimated with $S = 0$. If $W > W_{fc}$, then $S = W - W_{fc}$, and if $W \leq W_{fc}$, then $S = 0$.

[11] Typically, the initial soil water content is unknown; therefore a balancing routine (spin-up period) is used to force the net change in soil moisture from the beginning to the end of a specified balancing period to zero. The spin-up period is set to 60 months. When the change of the soil water content at the end of the balancing period is less than

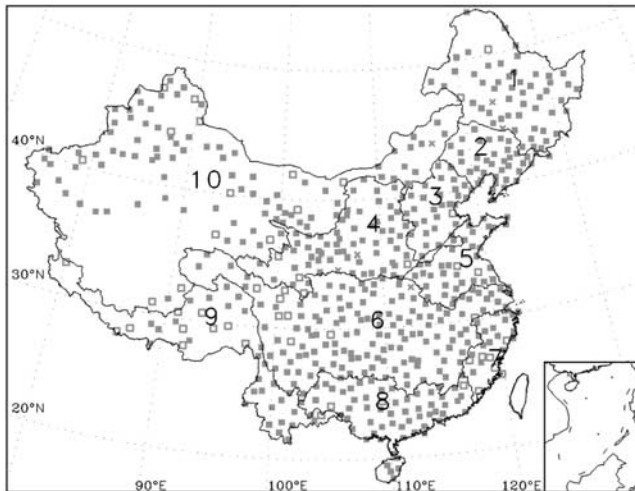


Figure 1. Locations of the 686 meteorological stations used in the creation of water balance climatology shown in Figures 3 and 4 (solid and open squares). The solid squares indicate the 546 stations used in the trend analysis shown in Figures 2, 5, 6, and 7. The cross symbols indicate the stations listed in Table 1. The boundaries to the 10 major drainage basins in China are the Songhua River (1), Liao River (2), Hai River (3), Yellow River (4), Huai River (5), Yangtze River (6), rivers in the southeast (7), Pearl River (8), rivers in the southwest (9), and rivers in the northwest (10).

1.0 mm, the spin-up process is over. The soil depth of the model is set to 1 m.

[12] A dominant merit of the water balance model for actual evapotranspiration estimation is that it can reflect the influence of soil water content dynamically in addition to climatic factors. The change of soil water content is important for actual evapotranspiration, especially in arid regions and during the dry season in other climatic regions.

2.2. Trend Analysis and Associated Significance Test

[13] Simple linear regression method and the Mann-Kendall trend test, which is highly recommended for general use by the World Meteorological Organization [Mitchell *et al.*, 1966], are used to determine the trends for the annual potential and actual evapotranspiration as well as other meteorological elements and to test their significance. The rank-based Mann-Kendall method [Mann,

1945; Kendall, 1975] is a nonparametric and commonly used method to assess the significance of monotonic trends in hydrometeorological time series [e.g., Alan *et al.*, 2003; Yue and Pilon, 2004]. This test has the advantage of not assuming any distribution form for the data and has similar power as its parametric competitors [Serrano *et al.*, 1999]. The significance level used in this study is 0.05.

2.3. Data

[14] Inputs to the water balance model consist of observed climatic data and gridded soil characteristics.

2.3.1. Climate Data

[15] The climate data include the observed monthly mean temperature and precipitation (from National Data Center of China Meteorological Administration) as well as monthly potential evapotranspiration calculated by the Penman-Monteith equation [Chen *et al.*, 2005] from 743 stations in China. The longest time series are from 1951 to 2002. However, not all the stations have complete records and acceptable quality during 1951 and 2002. Only 686 stations are chosen to calculate the averaged water balance components including actual evapotranspiration for 1971–2000 (see Figure 1). For annual trend analysis, we use data from 1960 to 2002 and require that a station is used in the analysis only if it has data in the start and end of the period, that the total missing data in between is less than 5%, and that it does not have a serious inhomogeneity problem. Only 546 stations meet the requirements and are used in this trend analysis. Missing data of the stations are replaced with long-term means for the whole study period.

2.3.2. Soil Parameters

[16] To our knowledge, soil water holding capacity (W_{fc}) and wilting point (W_p) data are observed at few and scattered agrometeorological stations in China. Thus the two soil parameters from the IGBP-DIS Global Gridded Surfaces of Selected Soil Characteristics database [Global Soil Data Task Group, 2000] are used for the water balance model, although there are several limitations to using this kind of inferred and coarse spatial resolution data [see Tempel *et al.*, 1996; Batjes, 2002a, 2002b]. Originally, this data set was derived from the soil physical attributes in the 1995 digital 1:5 million-scale FAO Soil Map of the World and the Global Pedon Database (for further description see Tempel *et al.* [1996], Global Soil Data Task Group [2000], Batjes [2002b]). Each station's value is extracted from the 5×5 arc-minutes gridded soil parameters for the 0–1 m topsoil layer in ArcMap. In this study the soil parameters are

Table 1. Calculated Water Balance Model Components Based on Two Sources of the Soil Parameters, IGBP Soil Global Database (IGBP) and Observations (OB) as a Long-Term Average (1981–2002) for Six Agricultural Stations in China^a

Stations	ASM (IGBP)	ASM (OB)	RE1	AE (IGBP)	AE (OB)	RE2	Runoff (IGBP)	Runoff (OB)	Prec	PE
Tailai	45.2	23.0	0.95	400.5	389.7	0.95	2.1	12.9	402.8	804.4
Xifengzhen	71.4	58.3	0.99	522.4	520.2	1.00	0.4	2.8	523.4	804.8
Xilinhaote	11.1	10.8	0.99	270.7	270.7	1.00	0.0	0.0	271.0	829.6
Changling	62.1	54.4	0.99	436.7	435.2	1.00	2.2	3.5	437.8	761.4
Tianshui	78.1	72.6	0.99	488.7	487.6	1.00	1.6	2.6	488.9	718.1
Nanyang	125.0	134.3	0.99	688.7	691.8	1.00	84.6	81.5	772.9	863.0

^aASM is annual mean available soil moisture (mm); RE1 and RE2 are correlation coefficients of annual available soil moistures and annual evapotranspirations (AE: mm) between the two estimates using different soil parameters respectively; Runoff is annual runoff (mm); Prec is annual precipitation (mm); PE is potential evapotranspiration (mm). The locations of the stations are indicated with cross symbols in Figure 1.

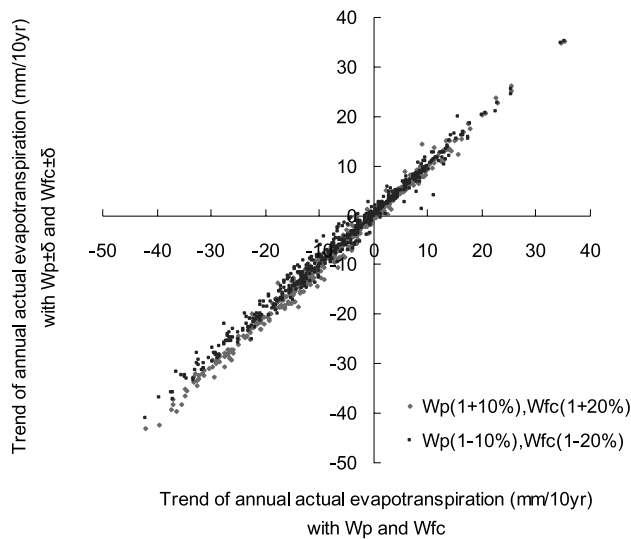


Figure 2. Trends for actual evapotranspiration calculated from the linear regression method under different soil parameters conditions. Values in the figure show the increase/decrease of evapotranspiration (mm/10 years). The trend of actual evapotranspiration using the original values of W_p and W_{fc} is given on the X axis, and the trend when W_p and W_{fc} are increased (gray) and decreased (black) by 10% and 20%, respectively, is given on the Y axis.

assumed static, hence land use changes and their impact on soil physical characteristics and indirectly on evapotranspiration are not considered.

3. Results

3.1. Sensitivity of Water Balance to Soil Parameters

[17] To determine the impact of the accuracy of soil parameters, W_{fc} and W_p , on the estimated water balance, the observed soil moistures at six nonirrigated stations for 1981 –

2002 are compared with those estimated by the model using soil parameters from the IGBP-DIS (Table 1). This test indicates that the estimated actual evapotranspiration is insensitive to the choices of the soil parameters (results are not shown here). Although remarkable differences exist in absolute magnitudes of the available soil moisture and runoff, the annual values covary well as reflected by a high correlation.

[18] Figure 2 compares trends of actual evapotranspiration under different soil parameters for all the 546 meteorological stations used in this study. The calculated trends of actual evapotranspiration display only minor differences for most stations under these conditions. This further confirms that the estimated trend for actual evapotranspiration from the water balance model is generally insensitive to the selected soil parameter values and that use of the soil parameters taken from IGBP database will bring about a minor effect on the estimated trend of actual evapotranspiration.

3.2. Annual Actual Evapotranspiration and Precipitation

[19] The spatial patterns of the annual actual evapotranspiration and precipitation averaged over 1971–2000 in China are shown in Figures 3a and 3b, respectively. The southward increase in annual actual evapotranspiration from 20 mm in the northwest to 1000 mm in the southeast resembled the pattern of precipitation. The 200, 400, and 800 mm contour lines of annual precipitation roughly divided China into arid, semiarid, semihumid, and humid climates from northwest to southeast. Areas where precipitation exceeds 400 mm are mainly affected by the summer monsoon and constitute major agricultural regions. In arid and semiarid areas the actual evapotranspiration and annual precipitation display similar distribution and magnitudes. Similarly, in semihumid areas with annual precipitation varying between 400 and 800 mm, the annual evapotranspiration and annual precipitation are analogous except for the eastern Liao River basin where precipitation is higher.

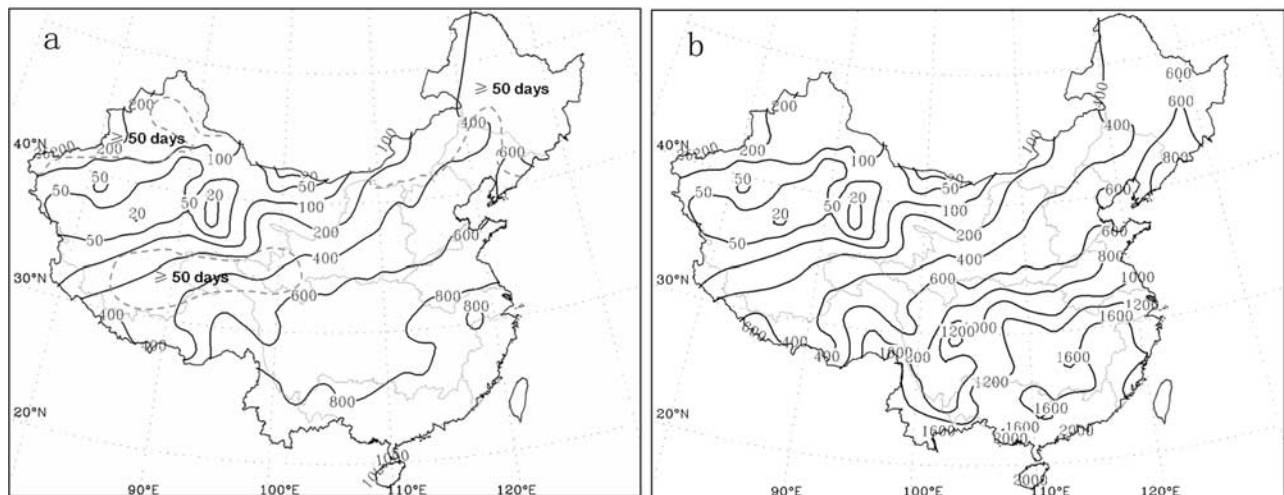


Figure 3. Averages of annual actual evapotranspiration (mm) (a) and annual precipitation (mm) (b) for 1971–2000. Drainage basin boundaries are the same as in Figure 1. The dashed lines in Figure 3a show the areas where the mean number of snow cover days are longer than or equal to 50 [see Domrös and Peng, 1988].

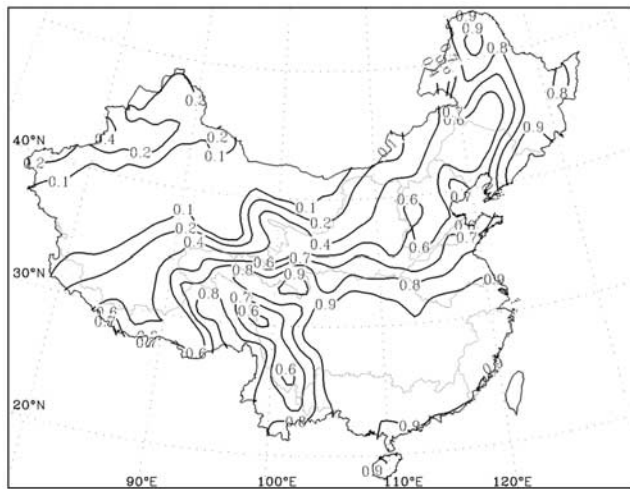


Figure 4. Ratio of annual actual evapotranspiration to annual potential evapotranspiration averaged over 1971–2000.

For humid areas the annual actual evapotranspiration is clearly lower than the annual precipitation. In northeast China, north parts of Xinjiang, and the Tibetan plateau the mean number of days with snow cover is greater than or equal to 50 days (Figure 3a). The present calculation does not explicitly treat snow accumulation and melting processes, which may cause a bias in the estimated potential evapotranspiration, actual evapotranspiration, and the ratio of them in areas which are covered by snow for a long time. However, this bias is considered of minor importance since these areas are very cold with air temperatures far below zero in winter.

[20] Another factor reflecting the wetness of the soil is the ratio of actual to potential evapotranspiration, where a ratio approaching 1 signifies increasing humidity. The average ratios of 1971–2000 are shown in Figure 4. The actual evapotranspiration is close to the potential evapotranspiration with ratios between 0.8 and 1 in the Pearl River, the middle and eastern parts of the Yangtze River, as well as the river basins in southeastern China, southeastern Tibetan Plateau, northern and eastern Songhua River basin, and eastern Liao River basin. These are the humid regions in China where the actual evapotranspiration is close to the upper limit. For the arid desert regions in northwestern China, however, the difference between actual and potential evapotranspiration is comparatively large and the actual evapotranspiration occupies less than 10% of the potential evapotranspiration. For the semiarid and semihumid areas the ratios vary from 0.2 in the northwest to 0.7 in the southeast which coincides with spatial distribution of precipitation.

[21] The above results clearly reveal that in the arid northwest part of China most incoming precipitation evaporates back to the atmosphere and the actual evapotranspiration is controlled by the amount of precipitation, regardless of the potential evapotranspiration amounts. Thus this can be referred to as a “water limited” system. However, in the more humid southeast part of China the actual evapotranspiration is restricted by the evaporative

demand (or energy available for evaporation as reflected by potential evapotranspiration), hence an “energy limited” system. In other regions the intra-annual and interannual variations in precipitation and potential evapotranspiration are manifested in the soil moisture content, and consequently, an actual evapotranspiration varies between the two limiting systems.

[22] These spatial distribution maps provide valuable information for water resources planning and management in China, which will also supply an important background and physical interpretation for climate change studies in the region. Changing a meteorological variable in different seasons or areas will have a different effect on the reference evapotranspiration, and in turn, on the actual evapotranspiration and the hydrological cycle.

3.3. Temporal Trends of Annual Actual and Potential Evapotranspiration

[23] Previous studies [e.g., *Chen et al.*, 2005] have shown that the potential evapotranspiration decreased during 1951–2000 in most parts of China. However, for water balance studies the spatial and temporal variations of actual evapotranspiration are more important. The spatial distributions of temporal trends for potential and actual evapotranspiration during 1960–2002 are compared in Figures 5 and 6. Figure 5 illustrates a widespread decreasing trend of potential evapotranspiration in most parts of China during 1960–2002, which is consistent with previous studies [e.g., *Chen et al.*, 2005]. The trends are particularly significant in south and northwest China. The belt from northeastern China through the middle and upper Yellow River basin and southwestward toward the east Tibetan plateau has a slight increasing trend. Most of these areas belong to semiarid/semihumid regions or lie in the transition zone from animal husbandry to grain agriculture with high climatic sensitivity. If precipitation is constant, an increase in potential evapotranspiration would result in increasing water demands for agriculture.

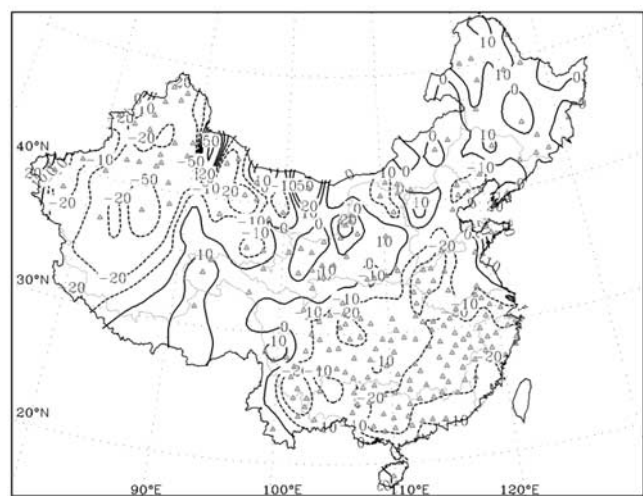


Figure 5. Trends for annual potential evapotranspiration during 1960–2002 calculated using linear regression method (mm/10 years). Triangles indicate stations with a significant trend at the 0.05 significance level tested by Mann-Kendall method.

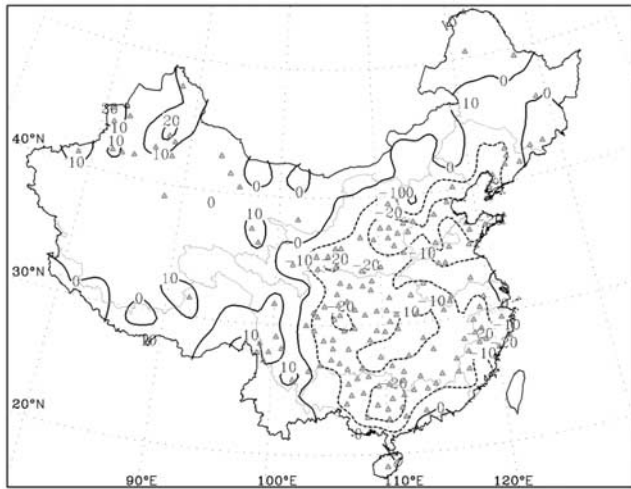


Figure 6. Trends for annual actual evapotranspiration during 1960–2002 calculated using the linear regression method (mm/10 years). Triangles indicate stations with a significant trend at the 0.05 significance level tested by Mann-Kendall method.

[24] The estimated annual actual evapotranspiration tends to decrease in most areas east of 100°E and increase in areas west of it between 1960 and 2002 (see Figure 6). The negative trends range from about -30 mm/10 years to -10 mm/10 years and are significant for most parts of the Hai River basin, low and middle reaches of the Yellow River basin, middle part of the Yangtze River basin, middle and north part of the Pearl River basin, and the rivers in southeast China. Contrarily, in the west and adjacent areas of the 100°E longitude and in northern Songhua River basin, the annual actual evapotranspiration tended to increase. Particularly in southeast Tibetan, north of Xinjiang, and north of the Songhua River basin, the trends vary between 5 mm/10 years and 20 mm/10 years. However, the increasing trends are insignificant with a few exceptions.

[25] Generally speaking, the spatial patterns of the temporal trends for annual potential and actual evapotranspiration are similar in southern China, but are contrary to each other in northern China during 1960–2002. This means that in the arid and semiarid regions the variation of actual evapotranspiration is to a large extent controlled by factors other than potential evapotranspiration. The result resembles that of *Linacre* [2004]; that is, under wet conditions actual evapotranspiration equals the potential evapotranspiration, while under arid conditions soil dryness or precipitation governs the evaporation losses. The result is also consistent with the widespread Budyko type interpretation [see *Roderick and Farquhar*, 2004; *Milly and Dunne*, 2001]. The role played by precipitation will be discussed further in section 4.

4. Discussion

[26] As the largest component of the water balance, changes in precipitation are expected to affect the amounts and redistribution of the other components in the water

balance. Figure 7 shows the spatial distribution of the trend for annual precipitation during 1960–2002. The pattern is generally similar to the results of *Zhai et al.* [2005] for 1951–2000. The annual precipitation has decreased over parts of the Songhua River basin, the Liao River basin, the Hai River basin, the Yellow River basin, the Huai River basin, and the middle part of the Yangtze River basin. For northern China the general decreasing trend in precipitation is partly explained by a weakening of the Asian summer monsoon during the past decades [e.g., *Wang et al.*, 2004]. Similarly, the annual actual evapotranspiration in these areas shows negative trends even though the surface air temperatures have increased significantly in northern China during 1955–2000 [*B.-H. Liu et al.*, 2004b]. In the above mentioned areas, reduced amounts of precipitation have played an important role for the decreasing trend in the estimated actual evapotranspiration, which is further strengthened by decreasing potential evapotranspiration. Decreases in precipitation and actual evapotranspiration denote a weakening of the hydrological cycle in these areas. Much evidence points to the conclusion that the streamflows in the Hai River and the Yellow River decreased remarkably in the recent 20 years as a result of less precipitation and increasing human activities [e.g., *C.-Z. Liu et al.*, 2004; *Li and Yang*, 2004; *Ma*, 2005]. Droughts became more frequent and serious [*Zhai et al.*, 2005]. North China in particular suffered from continuous and serious droughts in the late 1990s and early 2000s.

[27] In western China the increasing annual precipitation trend drives the increasing trend of actual evapotranspiration, accompanied by increasing air temperature. Accordingly, the hydrological cycle was intensified between 1960 and 2002. In some parts of the source areas of the Yangtze River and the Yellow River (Qinghai-Tibet plateau), the actual evapotranspiration increased, whereas the annual precipitation decreased which had brought about a drier climate.

[28] In southeastern China, including the river basins in southeast China, eastern Yangtze River basin, and the

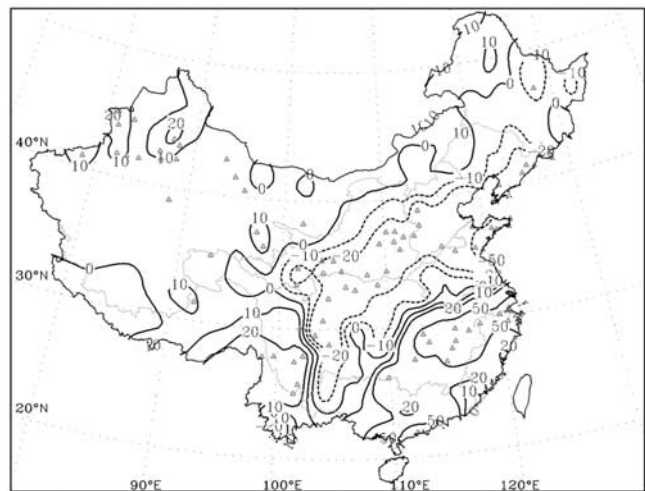


Figure 7. Trends for annual precipitation during 1960–2002 calculated using the linear regression method (mm/10 years). Triangles indicate stations with a significant trend at the 0.05 significance level tested by Mann-Kendall method.

middle of Pearl River basin, the annual precipitation has increased significantly along with increasing air temperatures [B.-H. Liu et al., 2004b] and decreasing potential evapotranspiration during 1960–2002. In the humid areas the changes of actual evapotranspiration are unrestricted by water supply because of relatively abundant precipitation. Thus the potential evapotranspiration is mainly controlled by climatic factors and sets the upper limits for actual evapotranspiration. Hence the decreasing potential evapotranspiration largely influences the decreasing trends of actual evapotranspiration in these regions. Moreover, the combination of increased precipitation and decreased actual evapotranspiration has amplified runoff in the lower reaches of the Yangtze River [Qin et al., 2005].

[29] It should be kept in mind that the water balance model used in this study is highly simplified. For example, different vegetation covers across China in reality is replaced with the reference vegetation. Furthermore, a number of choices regarding the potential evapotranspiration and soil parameters (e.g., soil depth) used in the water balance model have been made, which certainly have impacts on the estimated water balance, including the actual evapotranspiration. Future studies are needed to further identify the roles played by these choices and by processes that are unaccounted for in the water balance model.

5. Conclusions

[30] From the above results and discussions the following conclusions may be drawn:

[31] 1. The estimated annual actual evapotranspiration in China shows a decreasing trend in most areas east of the 100°E longitude during 1960 and 2002, except for the northeastern Songhua River basin in the northeast. Areas west of 100°E have an increasing trend for the actual evapotranspiration over the same period.

[32] 2. The trends for the estimated actual and potential evapotranspiration are distributed similarly in humid southern China, while they have opposite signs in the north and northwest, where the estimated actual evapotranspiration simply followed the precipitation changes.

[33] 3. In most parts of China, the trend in precipitation played a key role for the long-term change of the actual evapotranspiration except for the southeast where changes in the potential evapotranspiration was the major factor.

[34] 4. The hydrological cycle has intensified in western China and weakened from the Yellow River basin northward between 1960 and 2002.

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