Hydrol. Earth Syst. Sci. Discuss., 10, 11293–11310, 2013
www.hydrol-earth-syst-sci-discuss.net/10/11293/2013/
doi:10.5194/hessd-10-11293-2013

Hydrology and Earth System Sciences Discussions
Open Access

Effects of surface wind speed decline on hydrology in China

X. Liu[1], X. Zhang[1,2], Q. Tang[1], and X. Zhang[1]

[1]Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China

Received: 23 July 2013 – Accepted: 25 August 2013 – Published: 29 August 2013

Correspondence to: Q. Tang (tangqh@igsnrr.ac.cn)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Surface wind speed decline in China has been widely reported, but its effects on hydrology have not been fully evaluated to date. In this study, the effects of wind speed change on hydrology are investigated using the Variable Infiltration Capacity (VIC) hydrological model for China during 1966–2011. Two model experiments, i.e. VIC simulations with the observed (EXP1) and detrended wind speed (EXP2), are performed over the major river basins in China. The differences between the two experiments are analyzed to assess the effects of wind speed decline on hydrology. Results show that wind speed has decreased by 29 % in China. The wind speed decline have resulted in a decrease of evapotranspiration by 1–3 % of mean annual evapotranspiration and an increase of runoff by 1–6 % of mean annual runoff at most basins in China. The effect of wind speed on runoff and soil moisture is large in the northern basins where small change in hydrological conditions would have significant implications for water management. In addition, Wind speed decline has offset the expansion of the drought area in China. It has contributed to a reduction of drought areas by 8.8 % of the mean drought area (i.e. approximate 10.6×10^4 km^2 out of 1.2×10^6 km^2) over China. The effect of wind speed decline on soil moisture drought is large in most basins in China expect for the Southwest and Pearl River basins.

1 Introduction

Drying trends have been detected in several regions of China during the past half century (Dai et al., 2004; Zou et al., 2005). Soil moisture based on land surface models is widely used to assess hydrological drought condition (Sheffield and Wood, 2008; Wu et al., 2011; Li and Ma, 2012). Soil moisture drought in China shows roughly the similar increasing trend in the last several decades as other drought indices (Wang et al., 2011). The reduction of precipitation and increase of temperature may have contributed to the drying trend in China (Ma et al., 2000; Ma and Fu, 2006; Xin et al., 2006; Tang et al., 2008b; Dai, 2011). However, few studies have addressed the effects of surface wind speed decline (i.e. atmospheric stilling) which may alleviate the drying of soil moisture by reducing atmospheric evaporative demand (McVicar et al., 2012b). Wind speed decline has been observed in the last several decades over many countries of the world (Pryor et al., 2009; Vautard et al., 2010; Wan et al., 2010). The wind speed has declined as well over most areas in China (Jiang et al., 2010; Guo et al., 2011). The change in wind speed may have affected the surface hydrological cycle.

The hydrological consequence of wind speed decline has attracted great interest in recent years. The previous studies have tried to assess the effects of the wind speed decline on evaporation and suggested that the wind speed decline was a major or even the primary factor contributing to the decrease of evaporative demand (McVicar et al., 2012a). For example, Rayner (2007) and Roderick et al. (2007) suggested that wind speed change was the dominant factor causing the decreasing trends in pan evaporation in Australia. Zheng et al. (2009) and Tang et al. (2011) pointed out that wind speed decline was the main reason that caused the decrease in pan evaporation in the Hai River basin in China. Liu et al. (2011) also suggested that wind speed decline has dominated the decrease in pan evaporation before 1990s in the northern and central regions of China. Yang and Yang (2012) further confirmed that wind speed decline caused the decrease in pan evaporation for most regions of China except the southwest China. Therefore, it is interesting to further investigate the hydrological effect of wind speed decline in China. In this paper, the off-line hydrological simulations with different wind speed changes are used to evaluate the hydrological effects of wind speed decline over the major river basins in China.

2 Method

The Variable Infiltration Capacity (VIC) hydrological model (Liang et al., 1994) is used to simulate the hydrologic conditions in the major rivers of China. The VIC model can enclose both water and surface energy within each model grid cell and it can statistically capture sub-grid variability in land surface vegetation classes and soil moisture storage capacity. The key characteristics of VIC are the representation of vegetation heterogeneity, multiple soil layers (three layers are used in this study) with variable infiltration, and non-linear base flow (Gao et al., 2010b). The VIC model has been widely used for hydrologic simulation in China (e.g. Xie et al., 2007; Wang et al, 2012) and the world (Tang and Lettenmaier, 2010; Gao et al., 2010a; Sheffield et al., 2012). The observed daily meteorological data (maximum and minimum temperature, precipitation, and wind speed) from 1952–2011 are obtained from the China Meteorological Administration (CMA). Total 756 stations data are used (Fig. 1), it should be noted that there are missing records at some stations in the western China. There are only a few stations available in the Tibetan Plateau and Northwest China. The analysis and results in these regions should be treated with considerable caution. The station data are interpolated to 0.25° grids using the synergraphic mapping system (SYMAP) (Shepard, 1984) as implemented in the VIC model applications (Maurer et al., 2006; Tang et al., 2009). The model is run off-line at a daily time step forced by the gridded meteorological data, and is calibrated against the naturalized streamflow data at the major basins of China.

The VIC model is run with a long model spin-up period from 1952, producing an initial model state from which the experiments were started. Two VIC experiments are performed over China for the period of 1966–2011. One experiment is forced with the observed wind speed (EXP1), and the other experiment is forced with the detrended wind speed (EXP2). The linear trends in annual wind speed over the study period are removed at each grid cell, and the mean of the detrended time series of annual wind speed is fixed to the mean of the first decade (1966–1975) in EXP2 (Tang et al., 2008b). Using the detrending method, the original time series of annual wind speed is adjusted to a time series without linear trend. The daily wind speed of each year is then adjusted using the proportion of the adjusted to the original annual value.

Three hydrological variables, evapotranspiration, runoff and total soil moisture of the three soil layers produced by the VIC model are used for analyses. Differences in the annual means of the three hydrological variables between EXP1 and EXP2 are calculated to assess the wind speed decline effects. The change trends are calculated using the linear least-squares regression. The statistical significance of trend is evaluated by the Student's t test at the 95 % confidence level (Santer et al., 2000). The change magnitude during the study period is computed as the slope of the linear regression times the length of the study period. The relative change magnitude is then calculated as the percentage of change magnitude relative to the mean value (Tang et al., 2008a).

Monthly soil moisture is transformed to percentiles by fitting it with an empirical cumulative probability distribution (Weibull distribution) for each grid cell and each month (Andreadis et al., 2005). The transformed soil moisture index is used in the soil moisture comparisons between EXP1 and EXP2. Drought is identified if the monthly soil moisture index is less than 20 % in a grid cell. The area sum of the drought grid cells is calculated for each month. Annual mean drought area is computed in the major river basins and in China (Fig. 1). The Northwest, Yellow River, Hai River, Liao River and Songhuajiang River basins are referred as the northern basins and the rest basins are referred as the southern basins.

3 Results

Surface wind speed in China kept at a relative high level in the 1960s and significantly declined after the 1970s (Jiang et al., 2010; Guo et al., 2011). The relative change magnitude of wind speed during 1966–2011 in China is shown in Fig. 1. Annual wind speed has decreased by more than 20 % during the study period in most areas of China. Wind speed has decreased up to 80 % at some regions in the Northwest, Songhuajiang, Liao River, Hai River, Huai River, and Southeast River basins. Only a few regions, mainly in the middle Yangtze River and Pearl River basins, show increasing trends in wind speed. Figure 2 shows the areal annual wind speed before and after removing tendency at the major river basins in China. The observed wind speed shows a significant decreasing trend for all the basins. The trend is generally linear in China during the study period

HESSD
10, 11293–11310, 2013

although the decreasing rate seems more rapid in the 1970s and 1980s than other period in some river basins such as the Northwest basin. The non-linearity of the change is not considered and the linear trend is adopted as a first step to assess the effect of wind speed decline on hydrologic cycle. The largest and smallest decreasing magnitude is found in the Southeast (−40 %) and Pearl River basin (−11 %), respectively. In China, the wind speed has decreased by about 29 % during the study period.

Table 1 shows the relative change magnitudes in evapotranspiration and runoff and change magnitude in soil moisture from EXP1 and EXP2 during the study period for the major river basins. The hydrological variables from EXP1 show decreasing trend for most basins, but the trends in evapotranspiration and runoff are seldom significant. The relative change magnitude in evapotranspiration from EXP1 is smaller than that from EXP2 at all the river basins, indicating that wind speed decline would have caused a decrease in evapotranspiration. Consequently, the relative change magnitude in runoff from EXP1 is greater than that from EXP2, suggesting that more runoff would have been generated due to wind speed decline. Although the effect of wind speed decline is relative small comparing with the runoff change caused by other climatic factors, it may be important for the northern dry river basins such as the Northwest, Yellow River, and Hai River where small change in hydrology and water resources would have significant implications for water management. Soil moisture has decreased in most of the river basins, with significant decrease in the Northwest, Yellow River, Hai River, Southwest and Yangtze River basins. The decreasing soil moisture in the Northwest river basins is interesting, especially in the context of increases in evapotranspiration and runoff. It implies a general increase in soil moisture drought in the arid and semi-arid areas. The change magnitude in soil moisture from EXP1 is greater than that from EXP2 at all the river basins, suggesting that wind speed decline would have alleviated the soil moisture drought although it could not reverse the general drying trend.

Figure 3 shows the EXP1 and EXP2 differences (EXP1 minus EXP2) of annual evapotranspiration, runoff, and soil moisture index from 1966 to 2011. The differences are generally small in the 1960s because the wind speed in EXP2 is set to the 1960s'

HESSD
10, 11293–11310, 2013

conditions in EXP1. The differences become large at present (i.e. the end of the study period) when the wind speed difference becomes large. The relative change magnitude of the difference provides an assessment of the effect of wind speed decline to the hydrological condition at present. At all the river basin, evapotranspiration decreased and runoff and soil moisture increased along with wind speed decline. The annual evapotranspiration at present would be more than 5 mm higher in most basins in the eastern and southern China and about 2 mm higher in the northern dry basins if the present wind speed was as high as that in 1966–1975. The wind speed decline would have resulted in a decrease of evapotranspiration by 1–3 % of mean annual evapotranspiration at most basins. Meanwhile, the wind speed decline would have led to an increase of runoff by 1–6 % of mean annual runoff at most basins. The relative change magnitude associated with wind speed decline is generally large (3–6 %) in the northern basins and small (1–2 %) in the southern basins. The soil moisture index at present is higher than the simulated soil moisture index when the wind speed at present was assumed to be as high as that in 1966–1975. The relative change magnitude of soil moisture index is 3 % in China, and is generally large in the northern basins (3–6 %) and small in the southern basins (mostly less than 3 %). It suggests that wind speed decline may play a role in regulating soil moisture drought.

Figure 4 shows the relative change magnitude of the differences (EXP1 minus EXP2) of annual runoff and soil moisture index from 1966 to 2011 at the model grid cells. Runoff and soil moisture from EXP1 is generally more positive than those from EXP2. The relative change of runoff difference is negative in some areas such as the middle Yangtze River and Pearl River basins where correspond well to the areas with increasing wind speed (Fig. 1). The relative change magnitude of the runoff difference is large (2–10 %) in Northeast and Northwest China, while it is small (less than 2 %) in the southern China. It should be noted that the change magnitude in the southern China is comparable to that in the northern China because the mean annual runoff is larger in the southern China. The relative change magnitude of the soil moisture index difference is large in the northern Northwest China and eastern China where the wind

HESSD
10, 11293–11310, 2013

speed decline is large. It suggests that the declined wind speed may have alleviated the soil moisture drought over these areas. The negative relative changes of the soil moisture difference are found at some areas in the Southwest and Pearl River basins.

Figure 5 shows the drought area and the effect of wind speed decline on the drought area change during the study period. The estimated mean drought area is about 120×10^4 km^2 over China. The drought area in China has increased with a rate of 2.16×10^4 km^2 yr^{-1} during the study period. Increases in drought area are found in six river basins, namely the Northwest, Yellow River, Hai River, Southwest, Yangtze River and Pearl River basins. The Northwest basin shows the largest significant increasing trend in drought area (8900 km^2 yr^{-1}) and followed by the Yangtze River basin (5100 km^2 yr^{-1}). The Liao River, Songhuajiang River, and Southeast basins show non-significant increasing trend, while the Huai River basin shows non-significant decreasing trend in drought area. Wu et al. (2011) used the VIC model to estimate soil moisture drought in the nine regions in China during 1951–2009. Wang et al. (2011) used the ensemble of soil moisture from four land surface models to estimate soil moisture drought in China during 1950–2006. They have also reported a general increasing trend of drought area in most parts of China.

The drought area has been reduced by the wind speed decline. The estimated drought area with the observed wind speed is generally smaller than the estimates that assume the wind speed is at the high condition in the 1960s. Wind speed decline has contributed to a reduction of drought area by 21.1 %, 17.4 %, 14.7 % and 12.2 % of the mean drought area in the Songhuajiang River, Hai River, Liao River and Yellow River basins, respectively. The effect of wind speed change on drought area is small at the Southwest and Pearl River basins where wind speed effect on soil moisture is small (Fig. 4). Over China, wind speed decline has contributed to a reduction of drought areas by 8.8 % of the mean drought area at the end of the study period. In other words, drought area at present could be 10.6×10^4 km^2 larger if the wind speed at present is at the high condition in the 1960s.

HESSD
10, 11293–11310, 2013

4 Conclusions

Effects of wind speed decline (atmospheric stilling) on hydrology in China during 1966–2011 are investigated using the VIC model. Two VIC experiments, one using the observed (EXP1) and the other using the detrended wind speed (EXP2), are implemented. The differences in hydrological variables and soil moisture drought between the two experiments are compared to assess the wind speed decline effects. Results show that wind speed decline has somewhat offset the land surface drying trend in China.

Surface wind speed in China has decreased by 29 % of its mean during the study period. The decline of wind speed has resulted in a reduction in evapotranspiration and an increment in runoff and soil moisture in all the river basins. That suggests wind speed decline would offset the drying trend and favor a wet condition. The results show that land surface would be even dryer without wind speed decline. The wind speed decline has resulted in an increase of runoff by 1–6 % of mean annual runoff at most basins. The effect of wind speed on runoff and soil moisture is large in the northern basins and relative smaller in the southern basins.

The area of soil moisture drought has significantly increased in most basins, and has increased with a rate of $2.16 \times 10^4\,km^2\,yr^{-1}$ in China during the study period. Although the drought area has increased rapidly, the increasing rate could be even larger without wind speed decline. Our results show that wind speed decline has contributed to a reduction of drought areas by 8.8 % of the mean drought area over China. Wind speed decline has alleviated the soil moisture drought over $10.6 \times 10^4\,km^2$ area comparing with the experiments in which wind speed is assumed to be at the high condition in the 1960s. The effect of wind speed decline on soil moisture drought is large in most basins in China expect for the Southwest and Pearl River basins.

Acknowledgements. This work was supported by the National Basic Research Program of China (Grant No. 2012CB955403), the National Sciences Foundation of China Project (No. 41201201 and 41171031), and Hundred Talents Program of the Chinese Academy of Sciences.

References

Andreadis, K. M., Clark, E. A., Wood, A. W., Hamlet, A. F., and Lettenmaier, D. P.: Twentieth-century drought in the conterminous United States, J. Hydrometeorol., 6, 985–1001, 2005.

Dai, A.: Drought under global warming: a review, Wiley Interdisciplinary Reviews: Climate Change, 2, 45–65, 2011.

Dai, A., Trenberth, K. E., and Qian, T.: A global dataset of Palmer Drought Severity Index for 1870–2002: Relationship with soil Moisture and effects of surface warming, J. Hydrometeorol., 5, 1117–1130, 2004.

Gao, H., Tang, Q., Ferguson, C. R., Wood, E. F., and Lettenmaier, D. P.: Estimating the water budget of major US river basins via remote sensing, Int. J. Remote Sens., 31, 3955–3978, 2010a.

Gao, H., Tang, Q., Shi, X., Zhu, C., Bohn, T. J., Su, F., Sheffield, J., Pan, M., Lettenmaier, D. P., and Wood, E. F.: Water budget record from Variable Infiltration Capacity (VIC) model, available at: http://www.hydro.washington.edu/SurfaceWaterGroup/Publications/Water_Cycle_MEaSUREs_ATBD_VICmodel_submit.doc (last access: 28 August 2013),in: Algorithm Theoretical Basis Document for Terrestrial Water Cycle Data Records, 2010b.

Guo, H., Xu, M., and Hu, Q.: Changes in near-surface wind speed in China: 1969–2005, Int. J. Climatol., 31, 349–358, 2011.

Jiang, Y., Luo, Y., Zhao, Z., and Tao, S.: Changes in wind speed over China during 1956–2004, Theor. Appl. Climatol., 99, 421–430, 2010.

Li, M. and Ma, Z.: Soil moisture-based study of the variability of dry-wet climate and climate zones in China, Chinese Sci. Bull., 58, 531–544, 2012.

Liu, X., Luo, Y., Zhang, D., Zhang, M., and Liu, C.: Recent changes in pan-evaporation dynamics in China, Geophys. Res. Lett., 38, L13404, doi:10.1029/2011GL047929, 2011.

HESSD
10, 11293–11310, 2013

Effects of surface wind speed decline on hydrology

X. Liu et al.

Ma, Z. and Fu, C.: Some evidence of drying trend over northern China from 1951 to 2004, Chinese Sci. Bull., 51, 2913–2925, 2006.
Ma, Z., Wei, H., and Fu, C.: Relationship between regional soil moisture variation and climatic variability over East China, Acta. Meteorol. Sin., 58, 278–287, 2000 (in Chinese).
McVicar, T. R., Roderick, M. L., Donohue, R. J., Li, L. T., Van Niel, T. G., Thomas, A., Grieser, J., Jhajharia, D., Himri, Y., Mahowald, N. M., Mescherskaya, A. V., Kruger, A. C., Rehman, S., and Dinpashoh, Y.: Global review and synthesis of trends in observed terrestrial near-surface wind speeds: Implications for evaporation, J. Hydrol., 416–417, 182–205, 2012a.
McVicar, T. R., Roderick, M. L., Donohue, R. J., and Van Niel, T. G.: Less bluster ahead? Ecohydrological implications of global trends of terrestrial near-surface wind speeds, Ecohydrology, 5, 381–388, 2012b.
Pryor, S. C., Barthelmie, R. J., Young, D. T., Takle, E. S., Arritt, R. W., Flory, D., Gutowski, W. J., Nunes, A., and Roads, J.: Wind speed trends over the contiguous United States, J. Geophys. Res.-Atmos., 114, D14105, doi:10.1029/2008JD011416, 2009.
Rayner, D. P.: Wind run changes: The dominant ractor affecting pan evaporation trends in Australia, J. Climate, 20, 3379–3394, 2007.
Roderick, M. L., Rotstayn, L. D., Farquhar, G. D., and Hobbins, M. T.: On the attribution of changing pan evaporation, Geophys. Res. Lett., 34, L17403, doi:10.1029/2007GL031166, 2007.
Santer, B. D., Wigley, T. M. L., Boyle, J. S., Gaffen, D. J., Hnilo, J. J., Nychka, D., Parker, D. E., and Taylor, K. E.: Statistical significance of trends and trend differences in layer-average atmospheric temperature time series, J. Geophys. Res.-Atmos., 105, 7337–7356, 2000.
Sheffield, J. and Wood, E. F.: Global trends and variability in soil moisture and drought characteristics, 1950–2000, from observation-driven simulations of the terrestrial hydrologic cycle, J. Climate, 21, 432–458, 2008.
Sheffield, J., Livneh, B., and Wood E. F.: Representation of terrestrial hydrology and large scale drought of the Continental U.S. from the North American Regional Reanalysis, J. Hydrometeorol., 13, 856–876, 2012.
Tang, B., Tong, L., Kang, S., and Zhang, L.: Impacts of climate variability on reference evapotranspiration over 58 years in the Haihe river basin of north China, Agr. Water Manage., 98, 1660–1670, 2011.
Tang, Q. and Lettenmaier, D. P.: Use of satellite snow-cover data for streamflow prediction in the Feather River Basin, California, Int. J. Remote Sens., 31, 3745–3762, 2010.

Tang, Q., Oki, T., Kanae, S., and Hu, H.: A spatial analysis of hydro-climatic and vegetation condition trends in the Yellow River basin, Hydrol. Process., 22, 451–458, 2008a.
Tang, Q., Oki, T., Kanae, S., and Hu, H.: Hydrological cycles change in the Yellow River Basin during the last half of the twentieth century, J. Climate, 21, 1790–1806, 2008b.
Tang, Q., Wood, A. W., and Lettenmaier, D. P.: Real-time precipitation estimation based on index station percentiles, J. Hydrometeorol., 10, 266–277, 2009.
Vautard, R., Cattiaux, J., Yiou, P., Thepaut, J.-N., and Ciais, P.: Northern Hemisphere atmospheric stilling partly attributed to an increase in surface roughness, Nat. Geosci., 3, 756–761, 2010.
Wan, H., Wang, X. L., and Swail, V. R.: Homogenization and trend analysis of Canadian near-surface wind speeds, J. Climate, 23, 1209–1225, 2010.
Wang, A., Lettenmaier, D. P., and Sheffield, J.: Soil moisture drought in China, 1950–2006, J. Climate, 24, 3257–3271, 2011.
Wang, G. Q., Zhang, J. Y., Jin, J. L., Pagano, T. C., Calow, R., Bao, Z. X., Liu, C. S., Liu, Y. L., and Yan, X. L.: Assessing water resources in China using PRECIS projections and a VIC model, Hydrol. Earth Syst. Sci., 16, 231–240, doi:10.5194/hess-16-231-2012, 2012.
Wu, Z., Lu, G., Wen, L., and Lin, C.: Reconstructing and analyzing China's fifty-nine year (1951–2009) drought history using hydrological model simulation, Hydrol. Earth Syst. Sci., 15, 2881–2894, 2011, http://www.hydrol-earth-syst-sci.net/15/2881/2011/.
Xie, Z., Yuan, F., Duan, Q., Zheng, J., Liang, M., and Chen, F.: Regional parameter estimation of the VIC land surface model: methodology and application to river basins in China, J. Hydrometeorol., 8, 447–468, 2007.
Xin, X., Yu, R., Zhou, T., and Wang, B.: Drought in late spring of South China in recent decades, J. Climate, 19, 3197–3206, 2006.
Yang, H. and Yang, D.: Climatic factors influencing changing pan evaporation across China from 1961 to 2001, J. Hydrol., 414–415, 184–193, 2012.
Zheng, H., Liu, X., Liu, C., Dai, X., and Zhu, R.: Assessing contributions to panevaporation trends in Haihe River Basin, China, J. Geophys. Res.-Atmos., 114, D24105, doi:10.1029/2009JD012203, 2009.
Zou, X., Zhai, P., and Zhang, Q.: Variations in droughts over China: 1951–2003, Geophys. Res. Lett., 32, L04707, doi:10.1029/2004gl021853, 2005.

Table 1. Relative change magnitude (%) of evapotranspiration and runoff and change magnitude of soil moisture index for major river basins during 1966–2011. E1 and E2 are evapotranspiration from EXP1 and EXP2, respectively; likewise, R1 and R2 are for runoff, and S1 and S2 are for soil moisture index. Bold number means the trend is statistically significant.

Basin	E1	E2	R1	R2	S1	S2
NW	6.9	**8.0**	**20.5**	14.9	**−14.6**	**−16.3**
YR	−5.2	−4.4	−14.3	−16.4	**−18.1**	**−19.4**
HAI	−8.6	−8.0	−25.5	−27.6	**−20.3**	**−22.0**
LR	**−10.4**	−8.8	−4.0	−7.4	−6.1	−7.8
SHJ	−6.2	−3.6	7.8	1.5	−6.8	**−9.9**
SW	0.4	1.7	−5.7	−6.9	**−15.7**	**−15.8**
CJ	−2.3	−1.2	−2.2	−3.4	**−12.6**	**−13.3**
HUAI	0.4	1.7	13.5	11.8	10.9	8.2
PR	−3.7	−3.2	−3.8	−4.2	−7.3	−7.5
SE	0.4	1.6	13.1	12.0	3.3	2.0
China	−3.0	−1.8	1.5	0.1	−8.7	−10.2

HESSD
10, 11293–11310, 2013

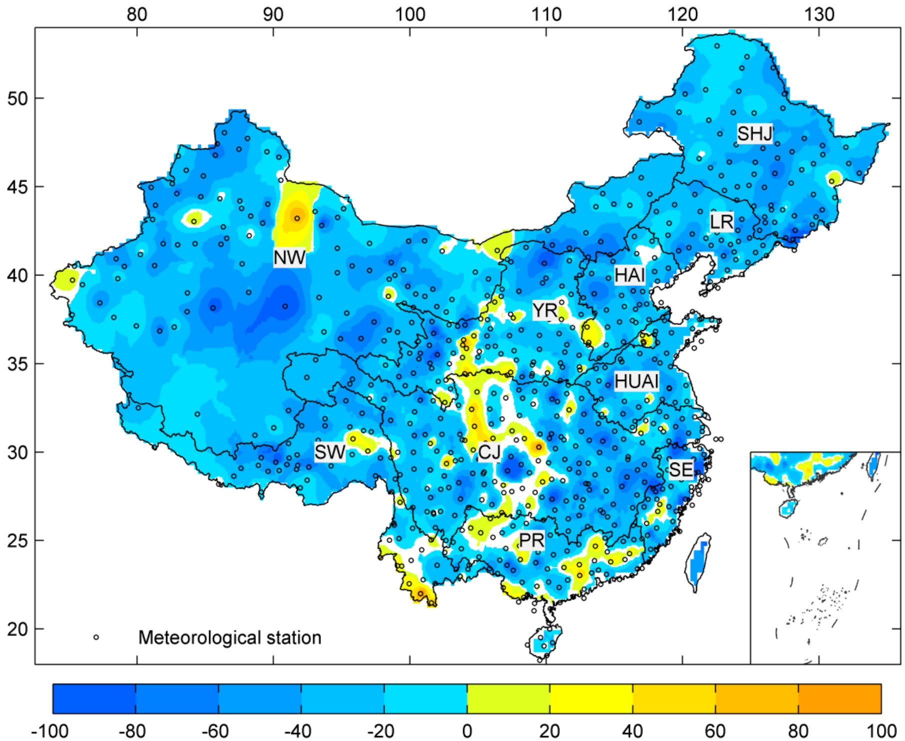

Fig. 1. Relative change magnitude (%) of annual wind speed during 1966–2011 in China. Only significant trends are shown. The major river basins (NW: Northwest, YR: Yellow River, HAI: Hai River, LR: Liao River, SHJ: Songhuajiang, SW: Southwest, CJ: Yangtze River, HUAI: Huai River, PR: Pearl River, SE: Southeast) in China are shown.

HESSD
10, 11293–11310, 2013

Effects of surface wind speed decline on hydrology

X. Liu et al.

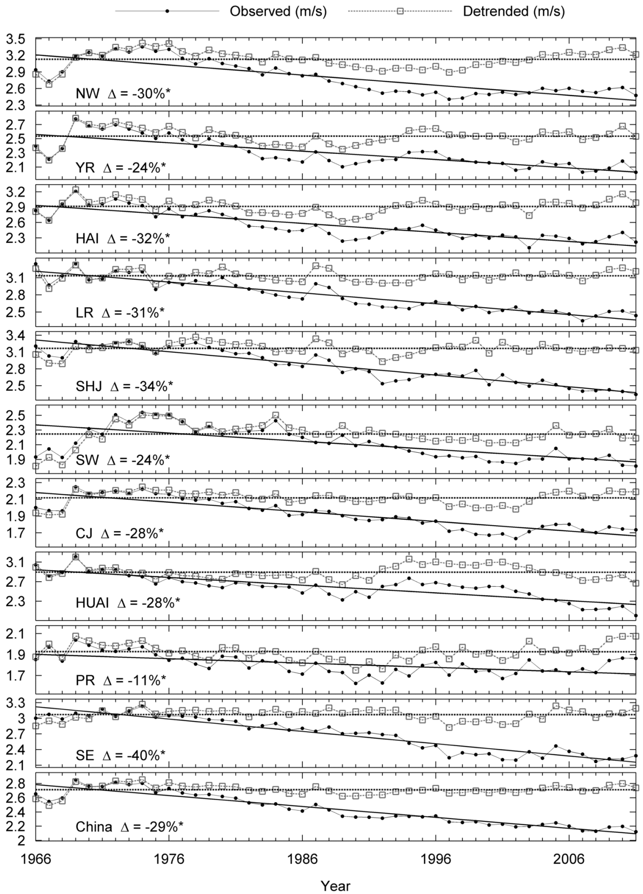

Fig. 2. The observed and detrended time series of annual wind speed at the major river basins in China. The straight solid and dashed lines are trends for EXP1 and EXP2, respectively. Relative change magnitudes (Δ) of the observed annual wind speed during the study period are shown. The "*" symbol indicates the observed trend is significant.

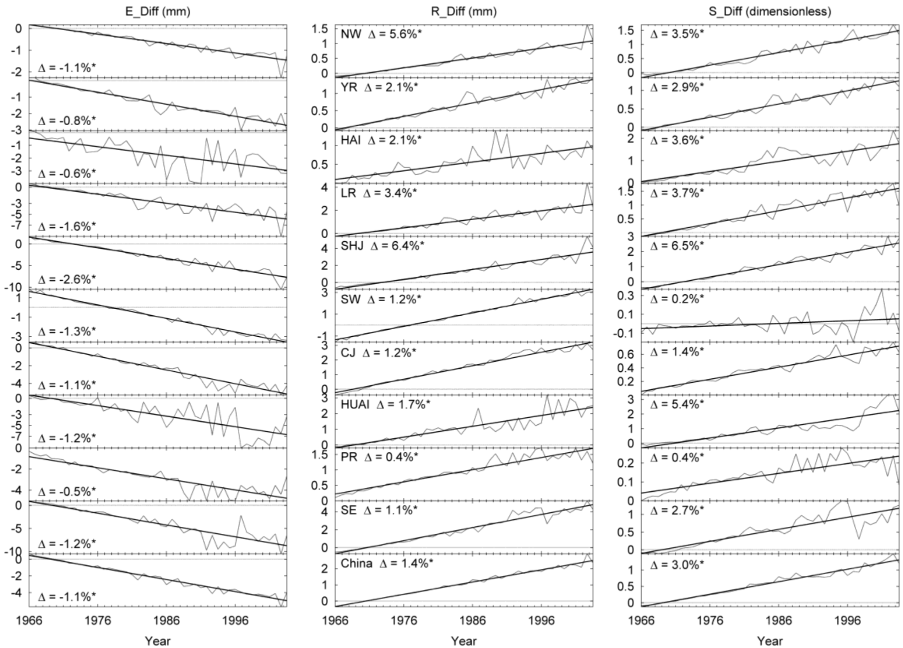

Fig. 3. Differences of annual evapotranspiration (E_{Diff}), runoff (R_{Diff}) and soil moisture index (S_{Diff}) between EXP1 and EXP2 for major river basins and the whole China. . is relative change magnitude. The “*” symbol indicates the trend is significant.

HESSD

10, 11293–11310, 2013

Effects of surface wind speed decline on hydrology

X. Liu et al.

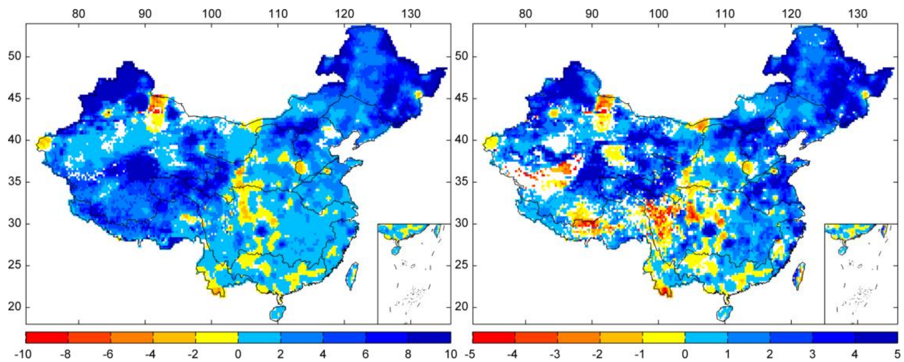

Fig. 4. Relative change magnitude of the differences of runoff (left) and soil moisture index (right) between EXP1 and EXP2. Grid cells with non-significant trends are not shown.

HESSD
10, 11293–11310, 2013

Effects of surface wind speed decline on hydrology

X. Liu et al.

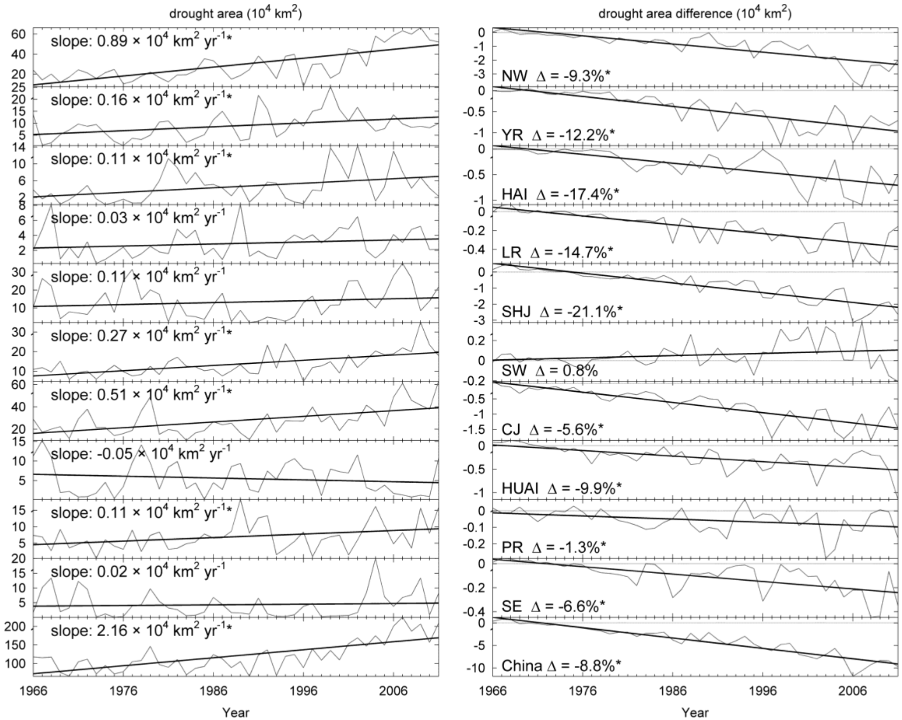

Fig. 5. Annual drought area from EXP1 (left) and the drought area differences (EXP1 minus EXP2) (right). Δ is relative change magnitude. The "*" symbol indicates the trend is significant.

HESSD
10, 11293–11310, 2013

Effects of surface wind speed decline on hydrology

X. Liu et al.