Effects of Paddy Field conversion to urban use on watershed hydrology in Southern China

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Background

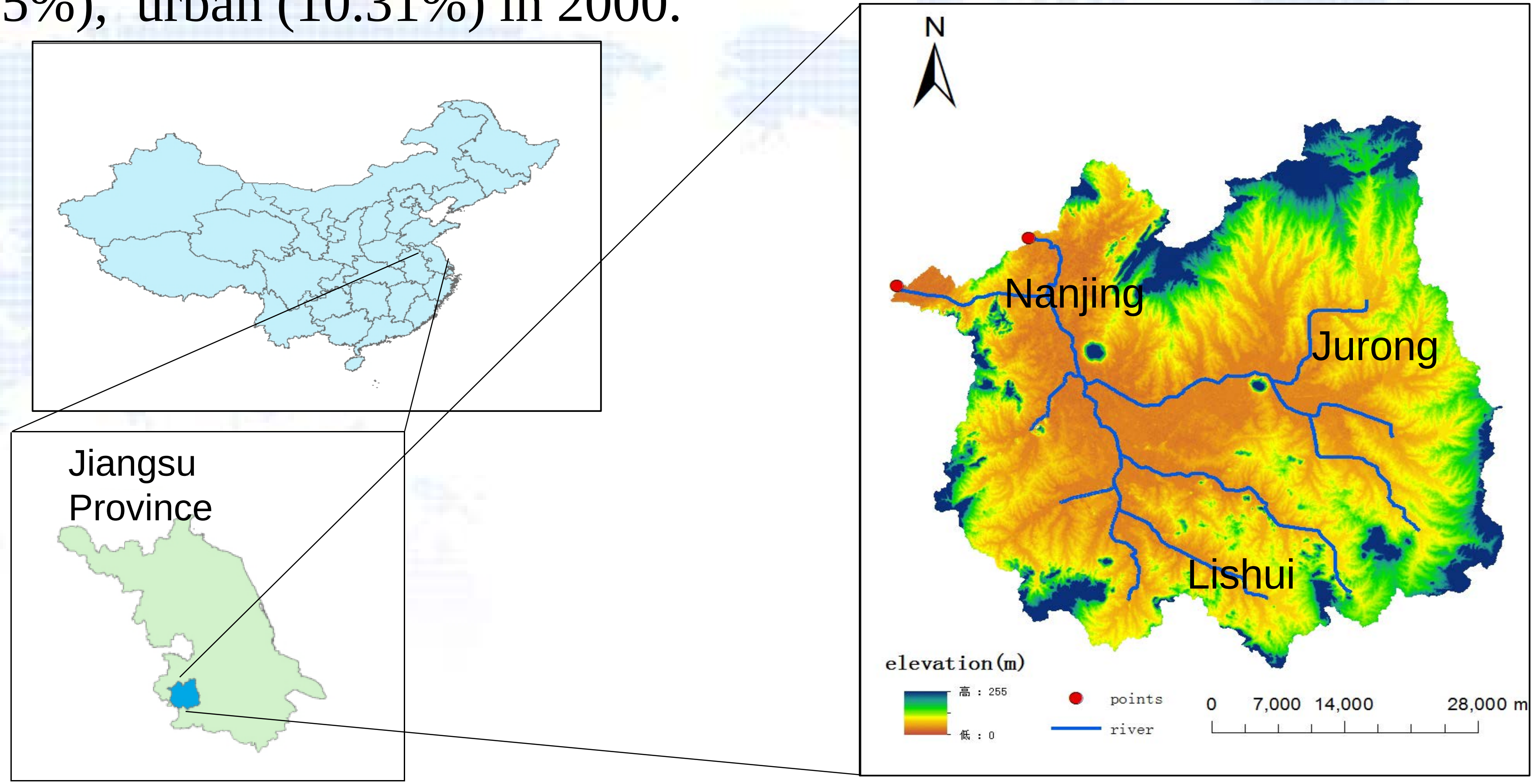
- The most obvious direct consequence of urbanization is the altered hydrology and water balances that control the flows of energy and matter in watershed ecosystems.
- However, the hydrologic response to urbanization is extremely variable due to climatic differences and land use change patterns across a watershed.
- Rice paddy fields provide important ecosystem services (e.g., food production, water retention, carbon sequestration) to a large population globally.
- These benefits are diminishing as a result of population growth, urbanization, and climate change in many Asian countries

Waterlogging due to urbanization in Nanjing

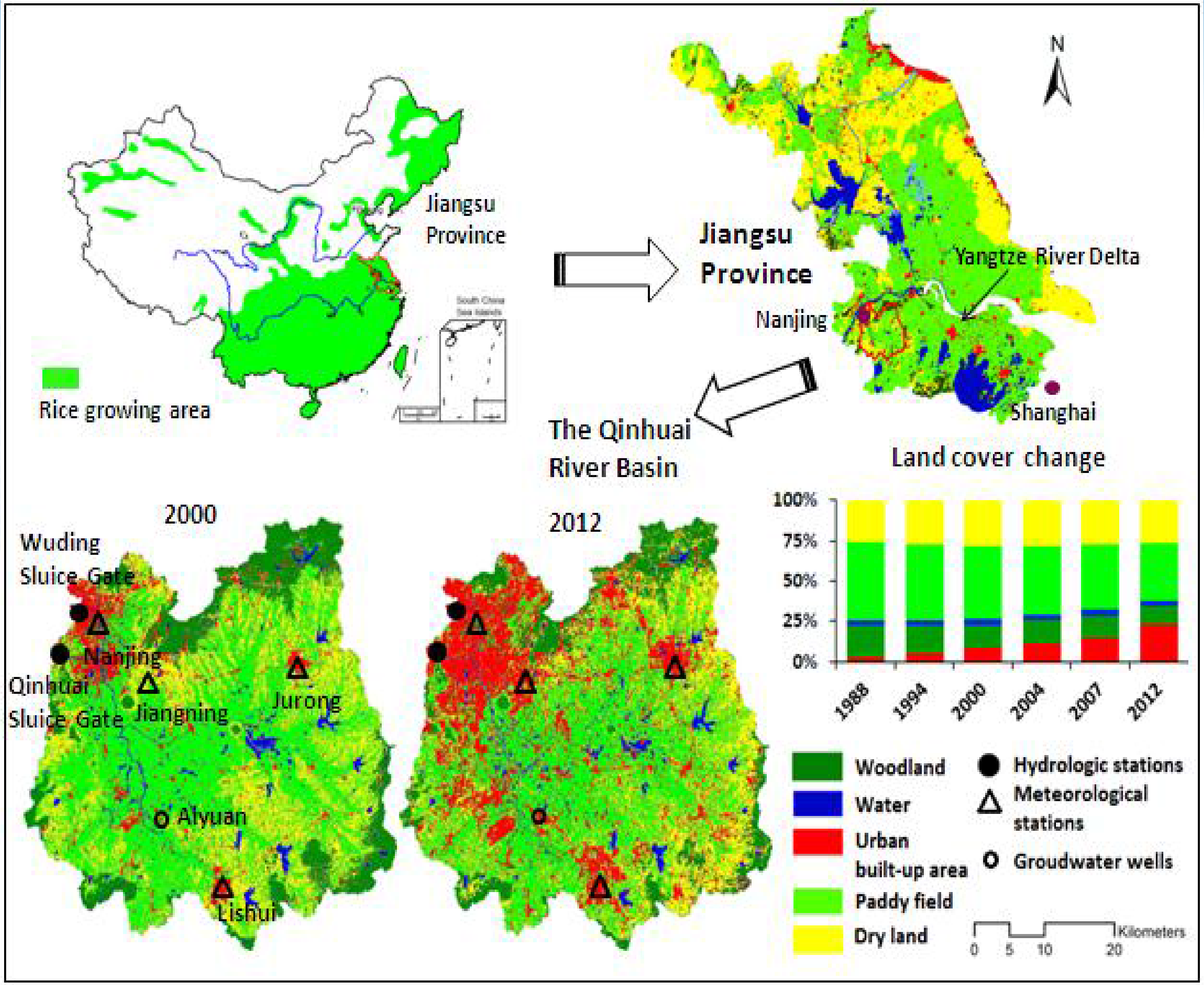
occurred in NUIST on July 13, 2016

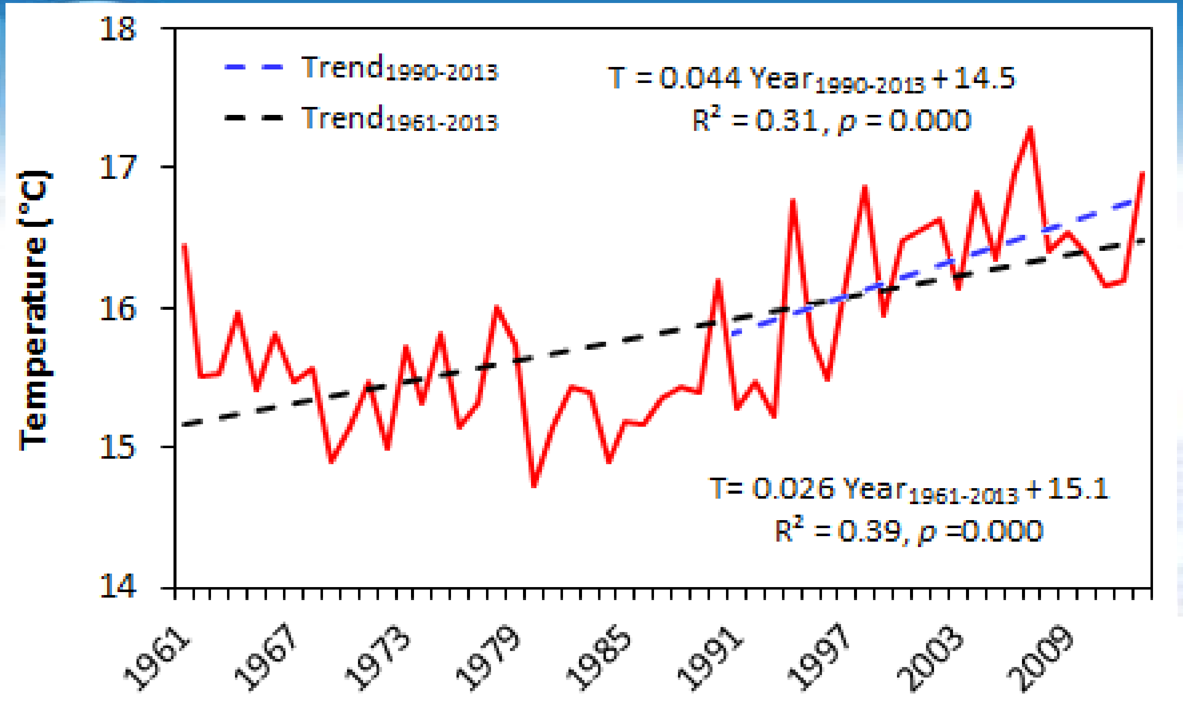
Study area

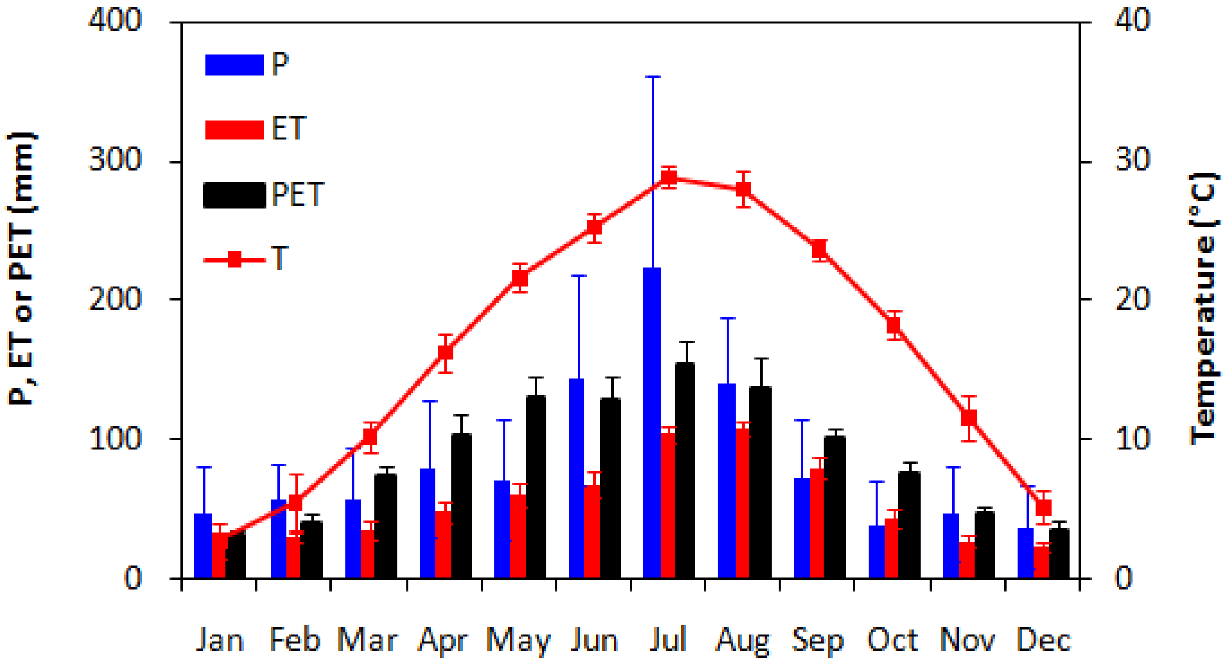
The study area, the Qinghuai River Basin (QRB), a subbasin of Yangtze River (YRD), is located in the Southwest of Jiangsu province. The area comprises approximately 2613km^2 and two outlets, of which the paddy rice accounts for 42.4%, followed by Agricultural Land (30.08%), Forest (12.5%), urban (10.31%) in 2000.



- The QRB has seen rapid urbanization during the past decade.
- The urban built-up areas increased from 9% (222km2) to 12% (301 km2) from 2000 to 2004, but jumped to 23% (612 km2) in 2012
- The area of rice paddy fields decreased from 45% of the total land area in 2000 to 43% in 2004, and dramatically dropped to 36% in 2012.







- The local climate is controlled by the East Asia summer monsoon
- The multi-year mean air temperature is 15.4°C.
- Mean air temperature (1961-2013) across the study basin has increased drastically at rate of 0.44 oC/decade from 1990 to 2013, suggesting an increasing trend in evaporative potential during the past two decades.
- The mean annual P is 1,116 mm with 75% rainfall falling during Apr.-Oct.
- The observed long-term mean annual streamflow is about 430 mm

Hypotheses

- Converting rice paddy fields to urban areas represents the maximum ET reduction possible among all common land cover change scenarios, potentially resulting in disproportionally higher impacts on water balances than other land conversion scenarios.

Specific objectives

- Examine how urbanization in the past decade (2000-13) has affected the water balances and hydrologic characteristics of the QRB, a typical landscape of the YRD
- Test the hypothesis that urbanization in a paddy field-dominated watershed dramatically reduced ET, thus altered water balances
- Explore the implications of urbanization for regional environmental change in southern China.

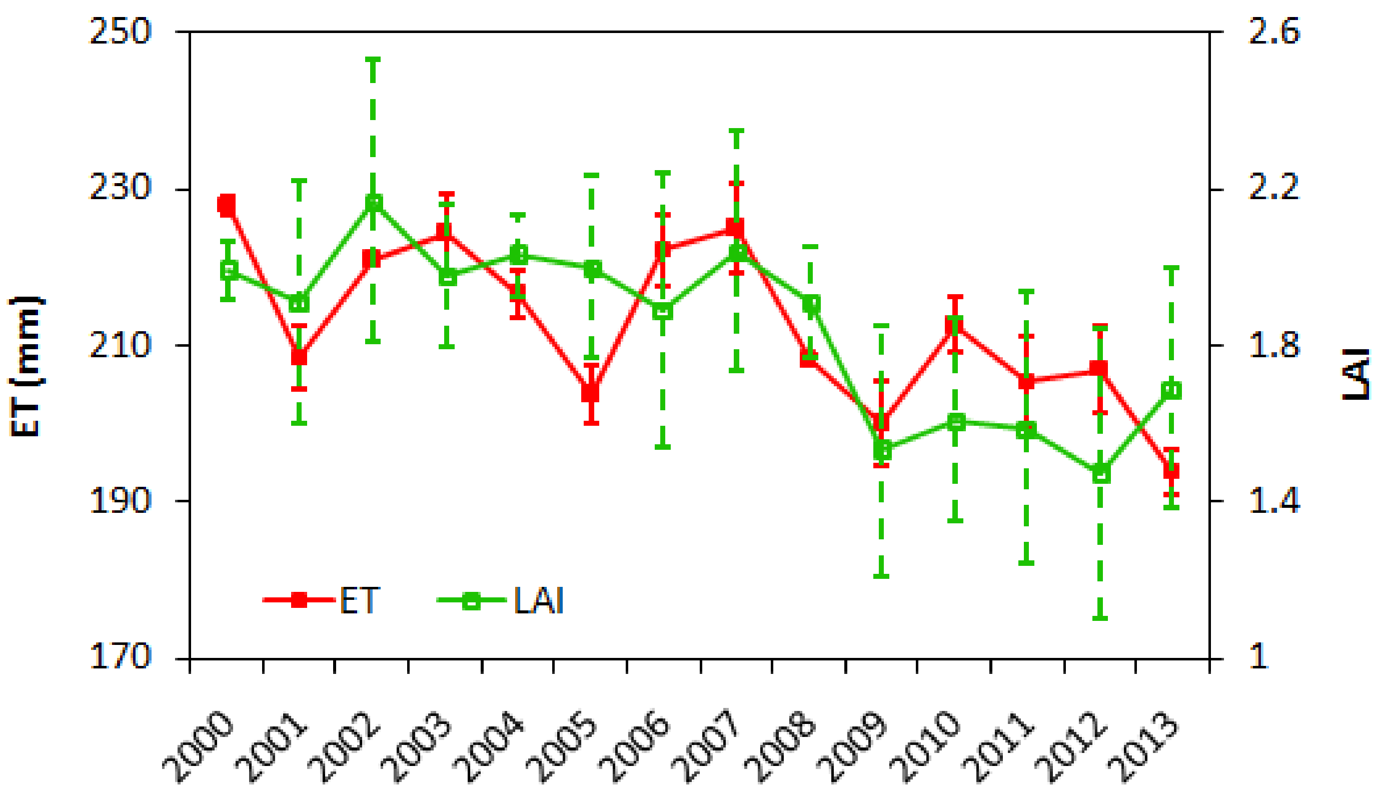
Methodology

- Integrated long-term hydro-meteorological monitoring data and remote sensing-based ET and vegetation products.
- Multiple advanced detection techniques were used to examine trends of climate and streamflow overtime and their associations with biophysical variables such as vegetation leaf area index and land use dynamics.
- Simulating evapotranspiration (ET) using SWAT.

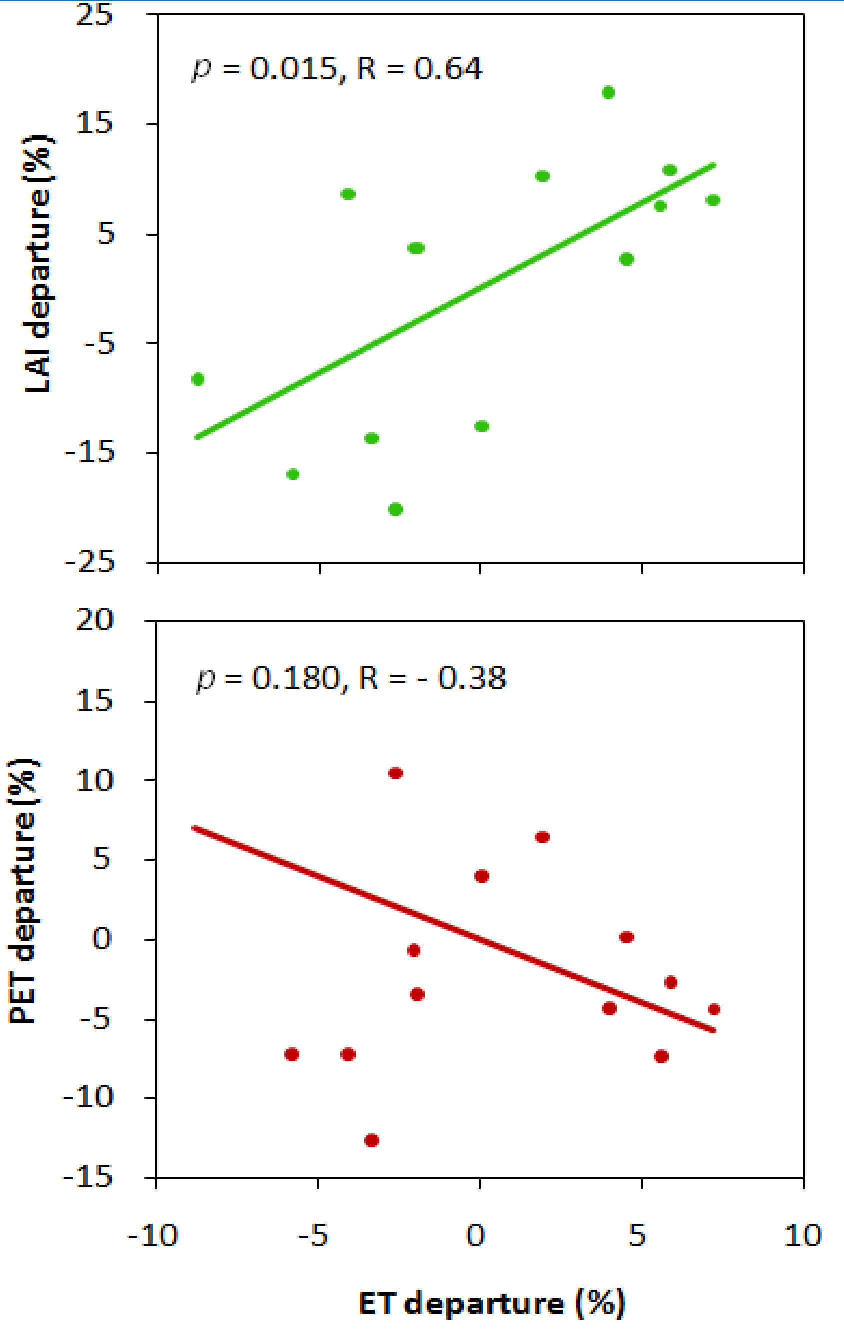
Results

- Land conversion and change in LAI
- Trend in Climate and MODIS ET
- Changes in streamflow characteristics
- Changes in Annual Watershed Water Balances
- Contributions of LULC change and climate change and variability
- Simulation results using SWAT

MODIS ET and LAI during 2000-2013 (Jul-Aug)



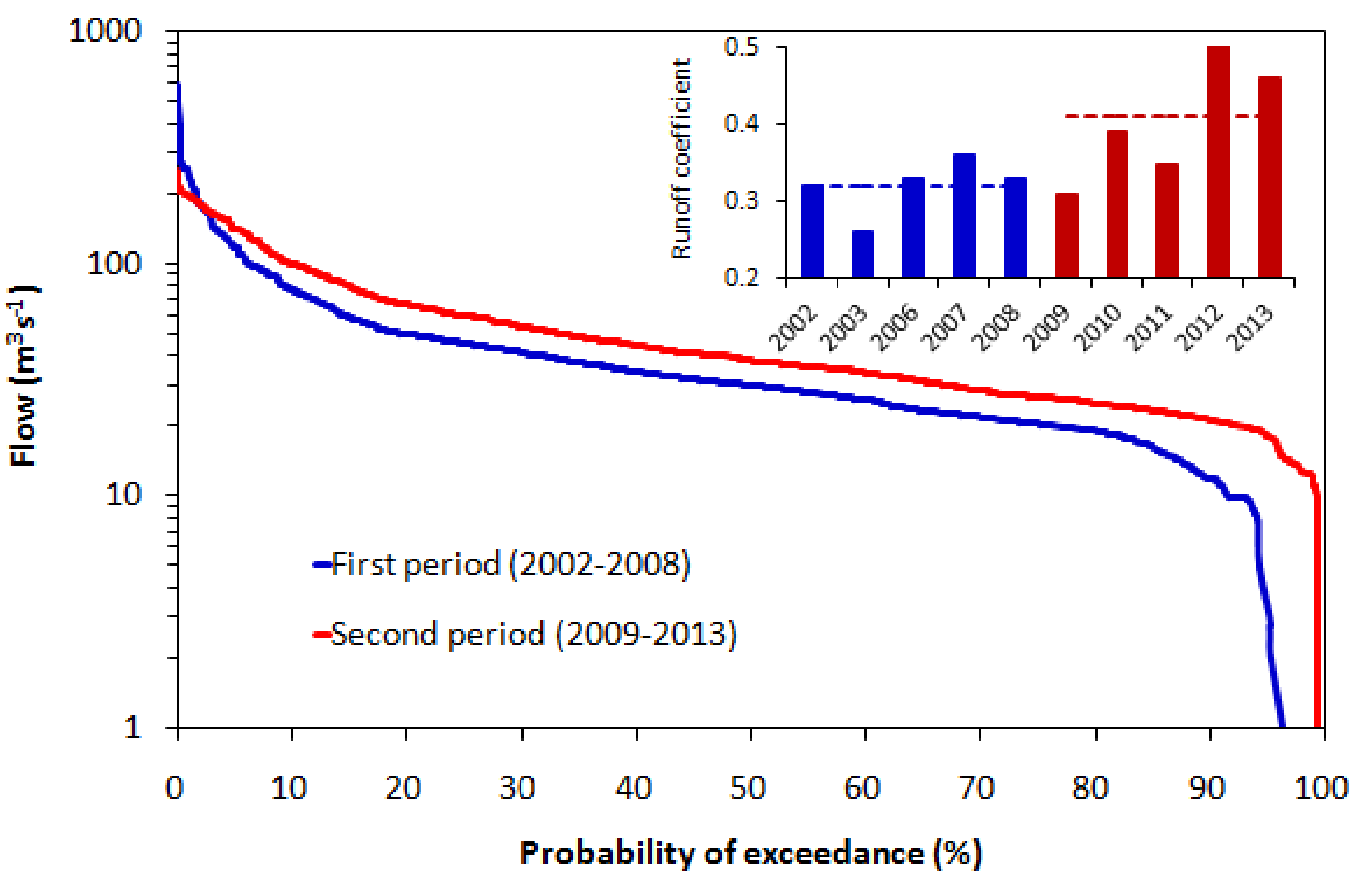
- The decrease trend of LAI followed a similar pattern as ET
- Since the major decrease in land use was paddy rice, we believe that the decline of LAI was mainly caused by land conversion of paddy field to urban uses.



Periods	Z statistic				
	LAI	ET	PET	PPT	T
Jul-Aug	-2.41*	-2.30*	1.31	1.31	1.31
Apr-Oct	-2.30*	-1.20	2.41*	0.11	0.77
Annual	-2.08*	-1.53	2.52*	-0.55	0.00

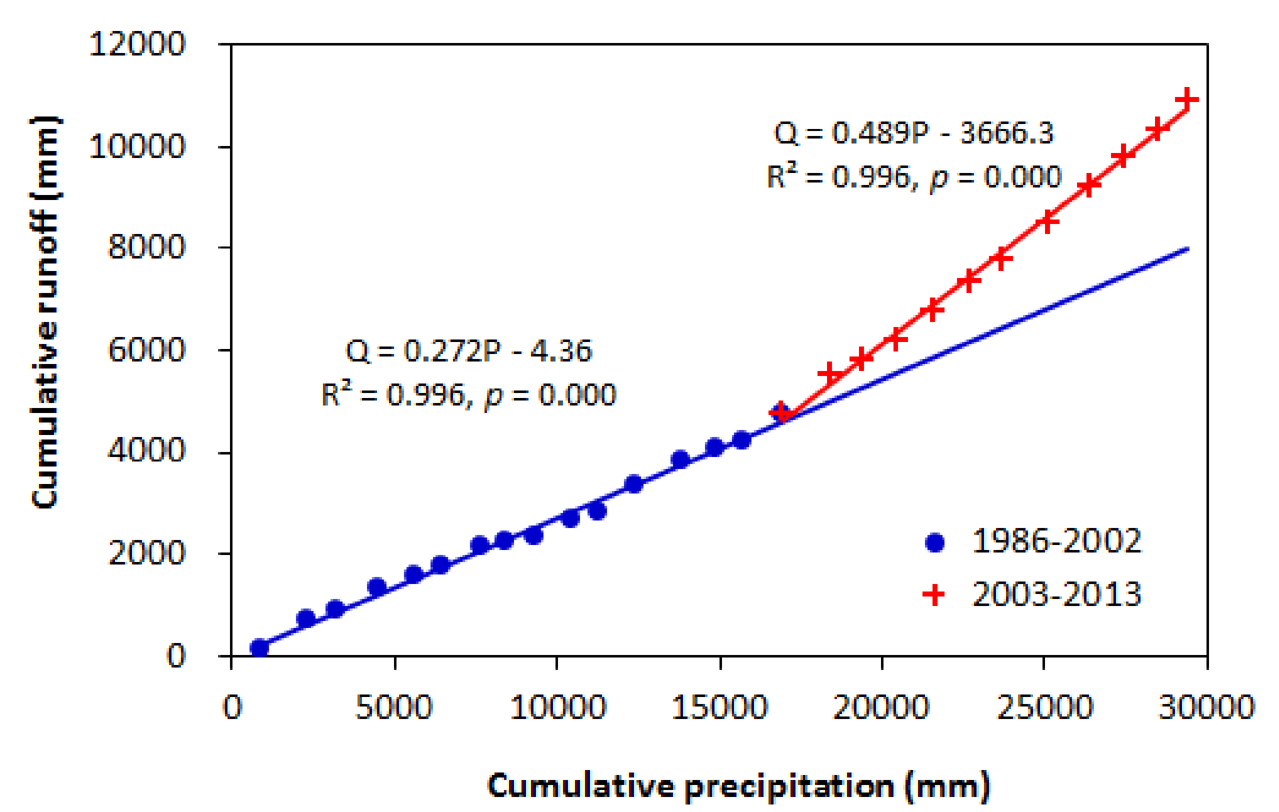
- Annual ET and the peak growing season ET departures from the long-term means had significantly positive correlations with LAI departures, but weak negative correlations with PET departures

Changes in streamflow characteristics



- Flow Duration Curve showed that both daily highflows and lowflows were elevated during 2009-13 compared to 2002-08
- The runoff coefficient during May-October increased significantly from 0.32 to 0.41, or 28%, during 2002-2013

Changes in Annual Watershed Water Balances



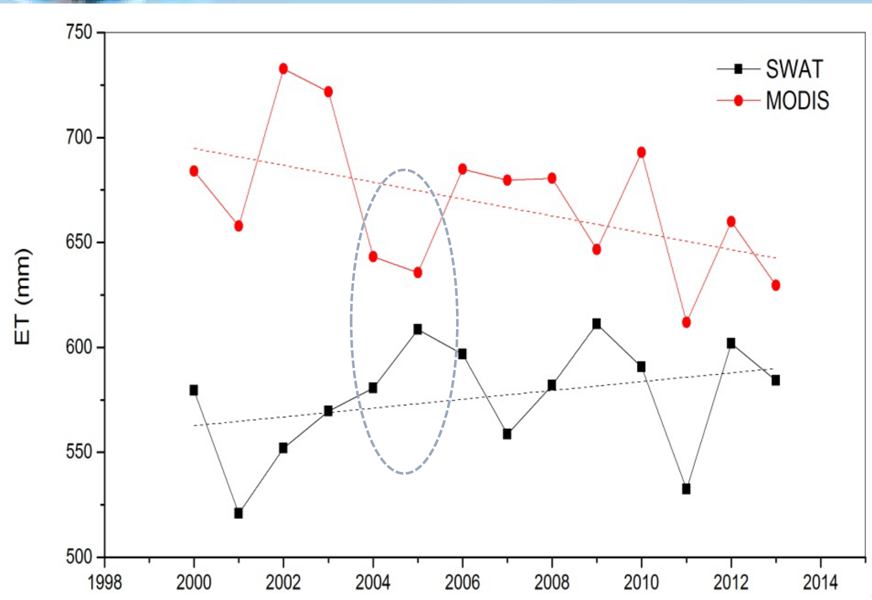
- The DMC identified a clear 'break point' of total annual streamflow around 2003
- Mean annual streamflow significantly increased from 353 mm to 556 mm from period 1 to period 2 , representing an increase of runoff coefficient (Q/P) from 0.32 to 0.49, a 53% increase.

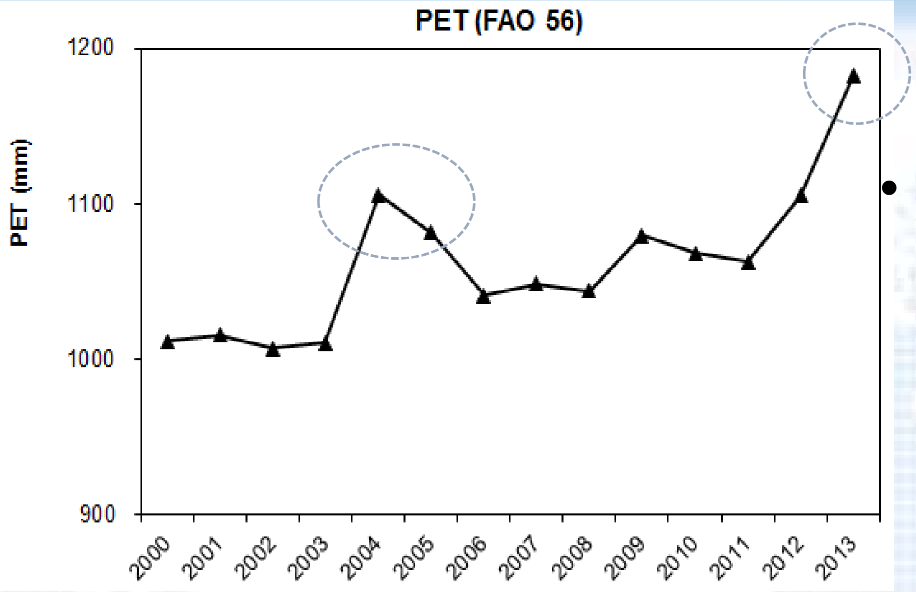
Contributions of LULC change and climate change and variability

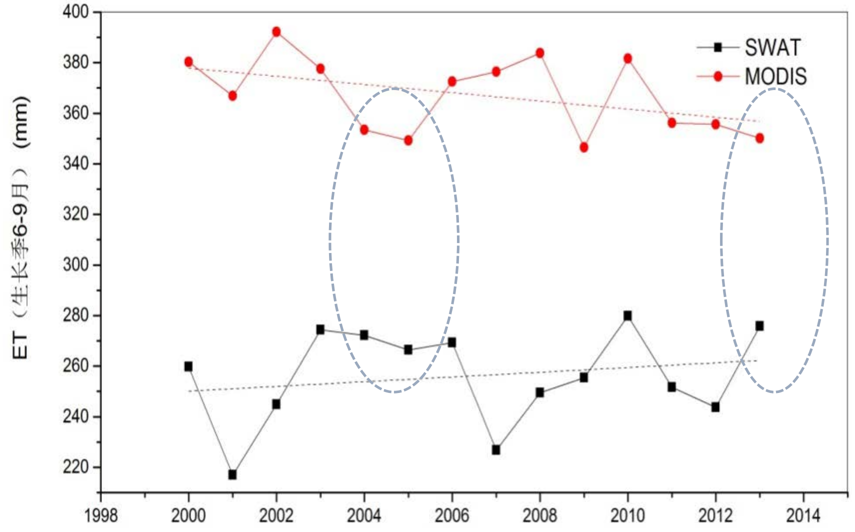
Period	$\bar{P}$	$\overline{PET}$	$\bar{Q}$	ΔQ_o	CEM (a=0.27; β=-0.65)		RRM (a=-509; b=0.45; c=0.064)	
					$\Delta\bar{Q}_{clim}$	$\Delta\bar{Q}_{lulc}$	$\Delta\bar{Q}_{clim}$	$\Delta\bar{Q}_{lulc}$
1986-2002 (reference)	1105±291	998±82	353±287	--				
2003-2013	1134±178	1075±45	556±145	203	−15±23(-8%)	218±131(108%)	36±169(18%)	167±100(82%)

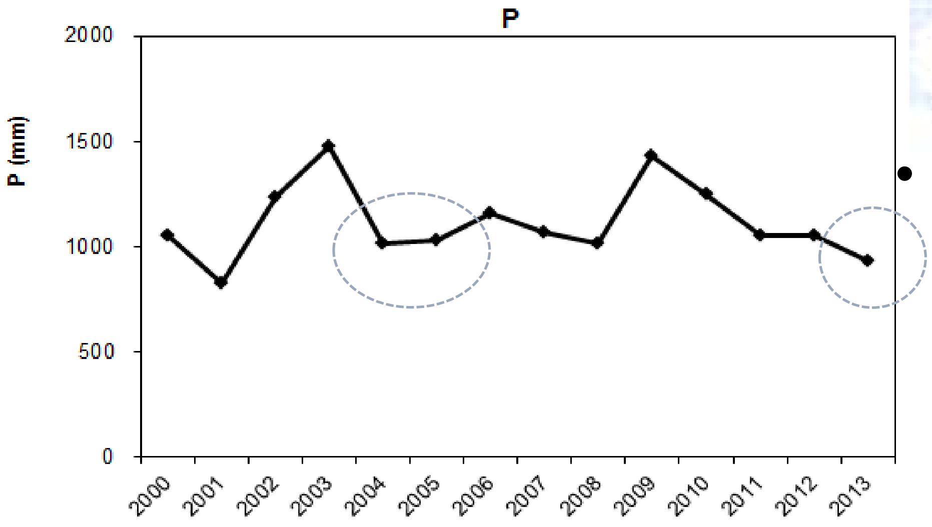
- Land use/land cover change contributed about 82-108% of the observed increase in streamflow from 353±287 mm yr-1 during 1986-2002 to 556±145 during 2003-2013.
- PET is an important factor in evaluating the impacts of climate and LULC change. The effects of PET on streamflow (reducing flow) exceeded the influence of P (increasing flow).
- Without considering the long-term change in air temperature, the contribution of LULC might have been underestimated in this study.

- Comparison of the simulated yearly ET graph using SWAT and MODIS.
- Assumption: Land use remains unchanged in 2000



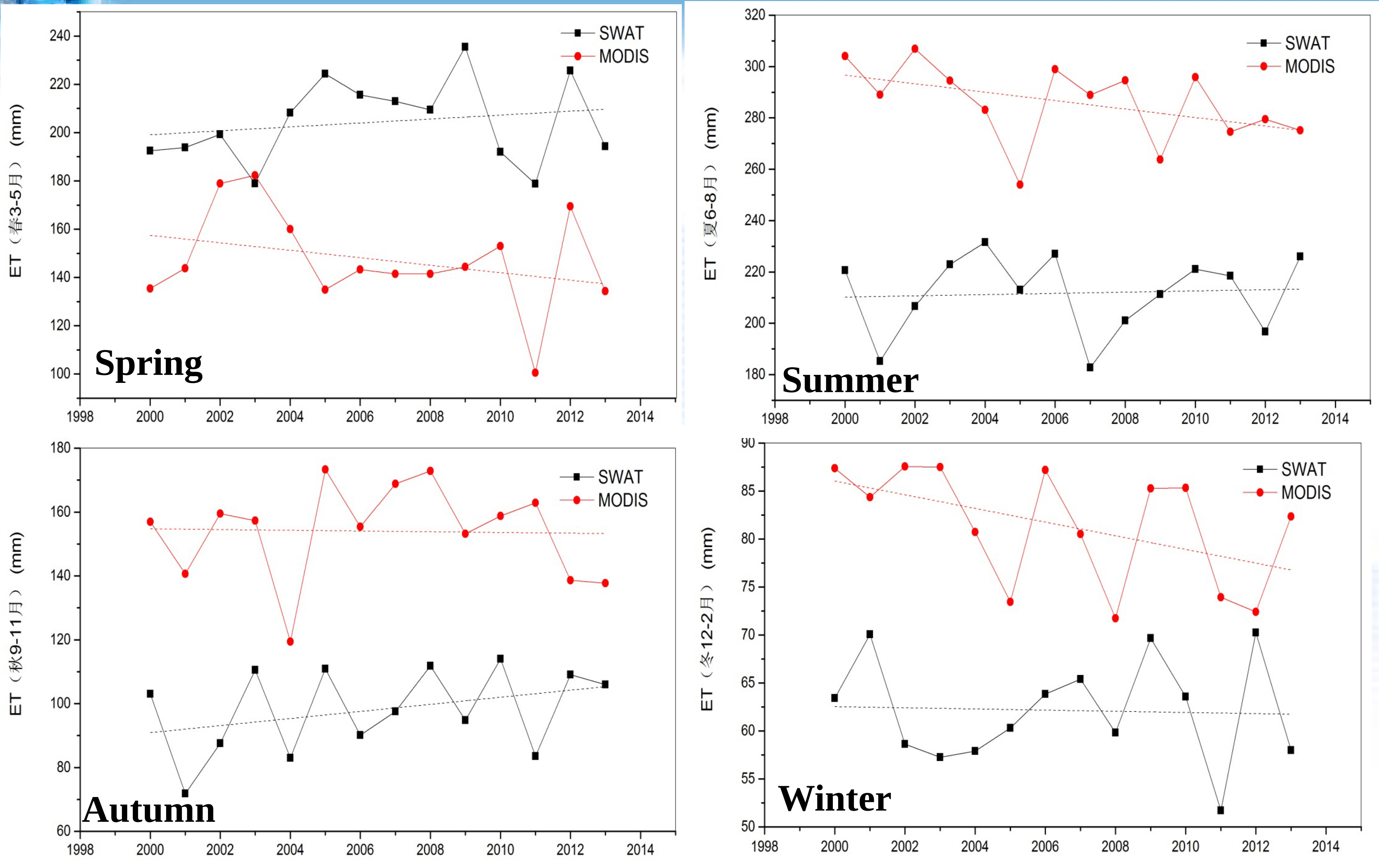






- The ET curve of SWAT shows an upward trend which is opposite to the trend of ET calculated by MODIS during 2000-12. Nevertheless, it is also consistent with the trend of PET, as well as in the peak growing season.
- In some drought years of less rainfall and high temperature, ET diversity becomes diminished

Seasonal change: ET_MODIS16 VS

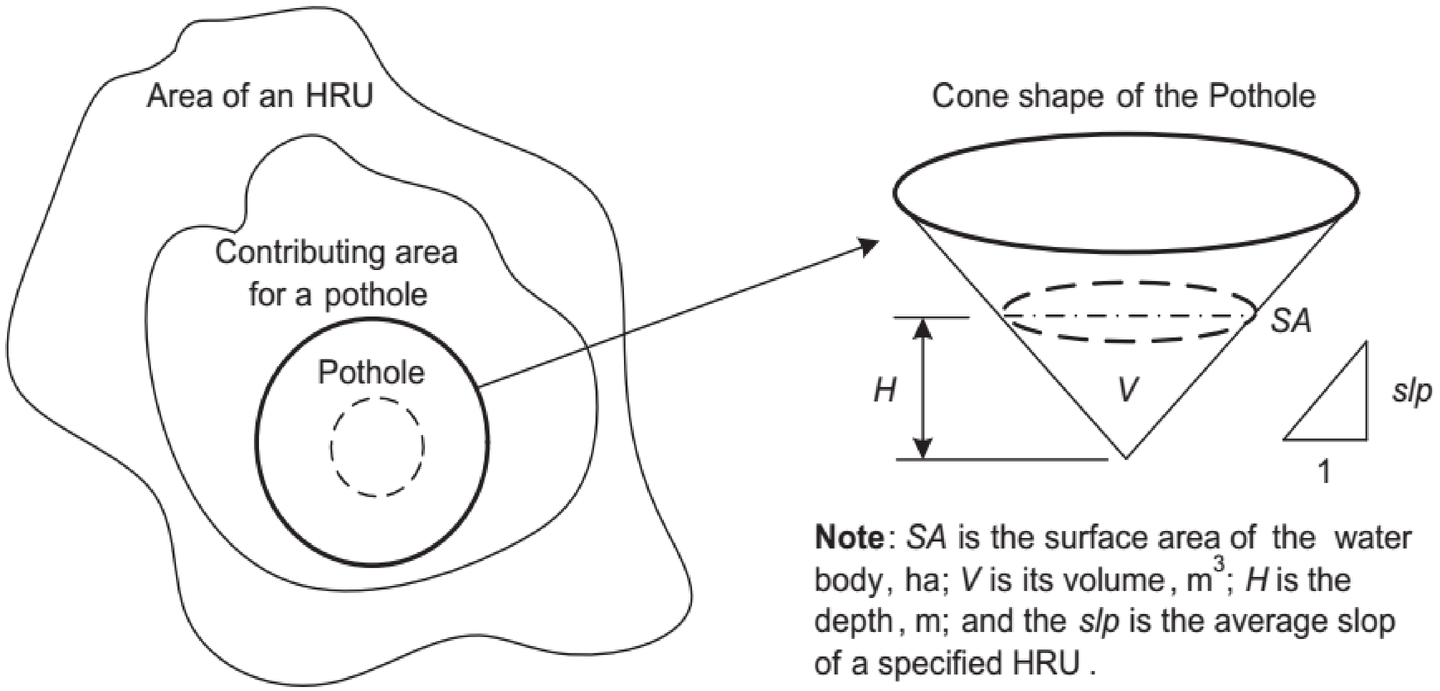


- Except in spring, MODIS ET are all higher than SWAT ET.
- MODIS ET has declined except in autumn；
- SWAT ET showed an increasing trend in spring and autumn.
- The average climatic conditions are not enough to explain the dynamic change of the annual water balance, and then the land use change must be considered.

SWAT model for hydrologic processes in paddy fields: Review and Discussion

- Obviously, one of the typical features in LUCC classification of QRB is that the paddy rice accounts for almost half of the total area. However, there are a few models could simulate the hydrology process of evapotranspiration detailedly in China and overseas.
- While paddy field in a subbasin are aggregated and simply treated as a pothole under imponded conditions, some studies have been focused on developing the model:
  - Houxi Zhang et al.(2011) modified the source code in order to simulate nitrogen and phosphor change in Lianshui River.
  - Xianhong Xie et al.(2011) developed the SWAT model by incorporating new process for irrigation and drainage.
  - A. Sakaguchi et al (2014) developed a paddy module by modifying an alogorithm designed for pothole landscapes in SWAT.

Schematic diagram of the area of an HRU (left) and its related pothole with the cone shape (right)



Note: *SA* is the surface area of the water body, ha; *V* is its volume, m^3; *H* is the depth, m; and the *slp* is the average slop of a specified HRU .

SWAT assumes the paddy rice could grow in a pothole. So, the paddy field in this kind of HRU is assumed to be a cone shape, and its surface area of water body is varied with the depth or the volume of water storages.

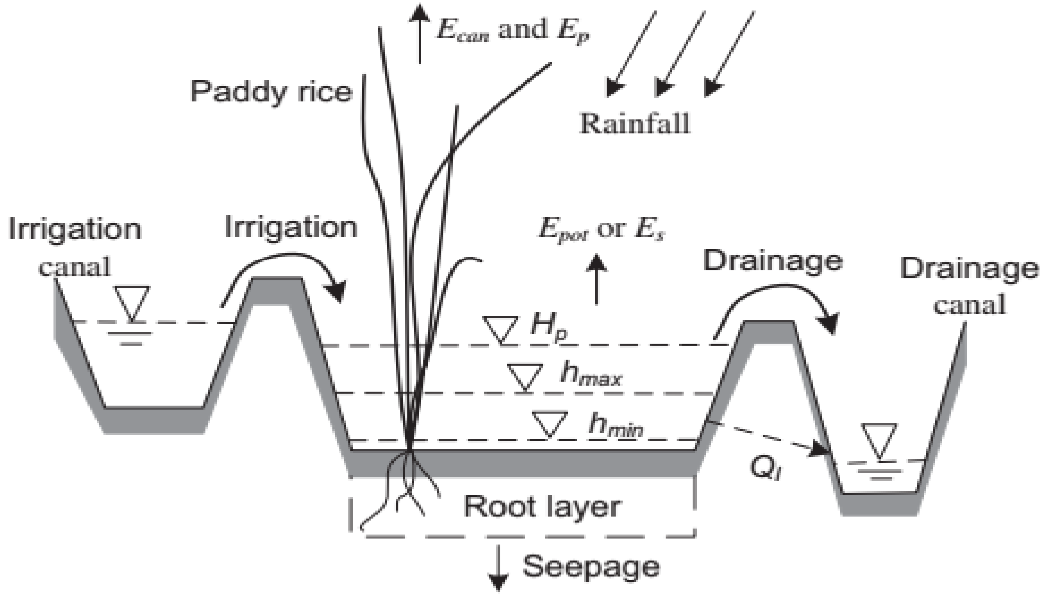


Fig. 3. Schematic diagram of a paddy field. (h_{min}, h_{max} and H_p denote the three critical depths; E_{can}, E_{pot} and E_s denote the three kinds of evaporation from the free water in canopies, the water body surface and the soil water respectively; E_p denotes the crop transpiration.

Gou(1997) introduced a technique with three critical depths, namely the minimum fitting depth (h_{min}), the maximum fitting depth (h_{max}) and the maximum ponding depth (H_p)

If the HRU is not an impounded area:

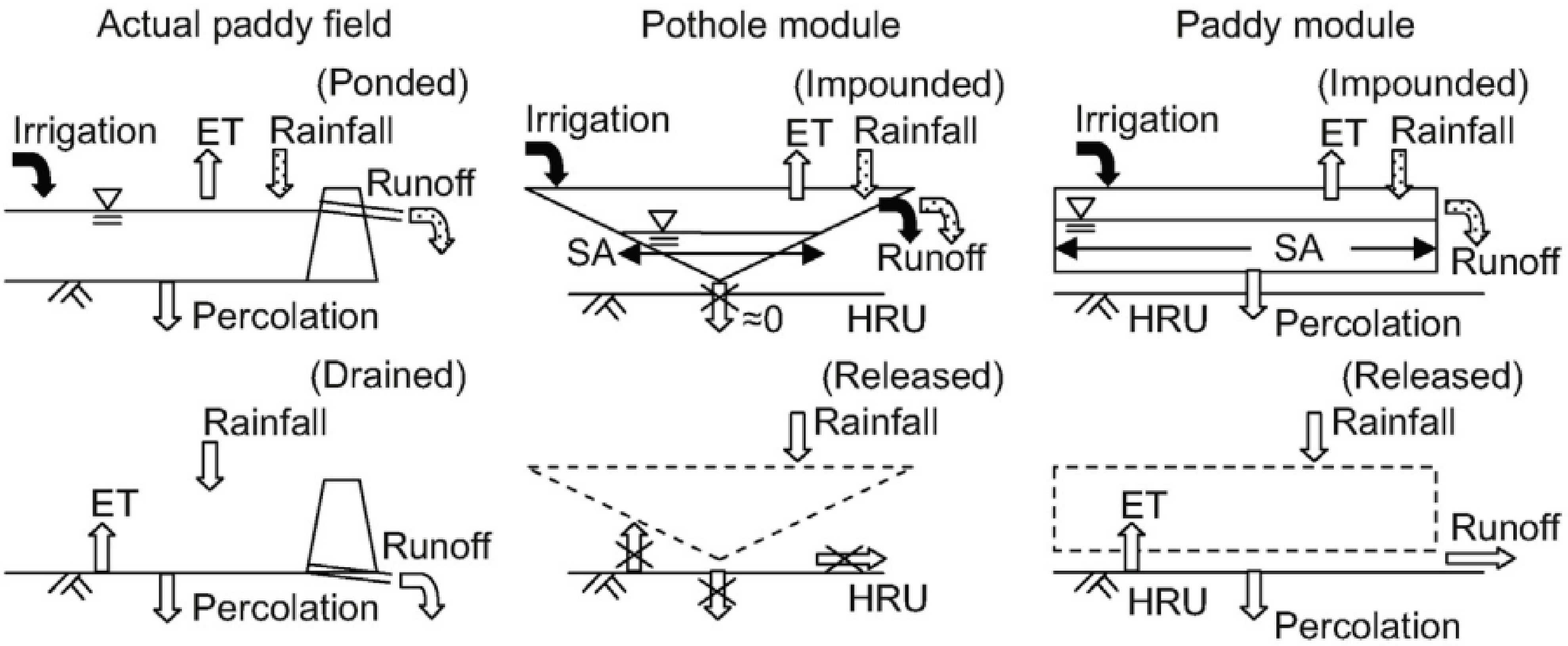
$$ET_{act} = E_{can} + E_p + E_s$$

If the HRU is impounded:

$$ET_{act} = E_{can} + E_p + E_{pot}$$

where ETact is the actual amount of ET (mm); Ecan is the amount of ET from free water in the canopy; Ep is the amount of plant transpiration on a given day; Es, Epot are the water ET from the soil profile and the water body surface respectively.

A. Sakaguchi et al.(2014) developed a paddy model by modifying an algorithm desighed for pothole landscapes in SWAT.



Schmatic diagram of the water balance of an actual paddy field, pothole module, and paddy module. and paddy module under ponded(impounded) and drained (released) conditions. SA is the surface of the water body

Conclusions

- ✓ The streamflow increased by 58% and ET decreased by 23% during 1986-2013 as a result of an increase in urban areas of three folds and reduction of rice paddy field by 21%.
- ✓ Both highflows and lowflows increased significantly by about 28% from 2002 to 2013. The increases in streamflow were consistent with the decreases in ET and LAI monitored by independent MODIS data.
- ✓ The reduction in ET and increase in streamflow were attributed to the large cropland conversion that overwhelmed the effects of regional climate change and variability.

Conclusions

- ✓ Converting traditional rice paddy fields to urban use dramatically altered land surface conditions from a water-dominated to human-dominated landscape, and thus was considered as one of the extreme types of contemporary hydrologic disturbances.
- ✓ The ongoing large-scale urbanization in the rice paddy-dominated regions in China, and East Asia, will likely elevate streamflow volume, aggravate flood risks, and intensify urban heat island effects.
- ✓ The water movement in irrigation districts, especially for paddy rice cultivation, is characterized by complicated factors. The SWAT model needs to be improved and adapted for the paddy field-dominated basin.

Thank you!