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Observation and modeling of the eco-hydrological changes in Northern China

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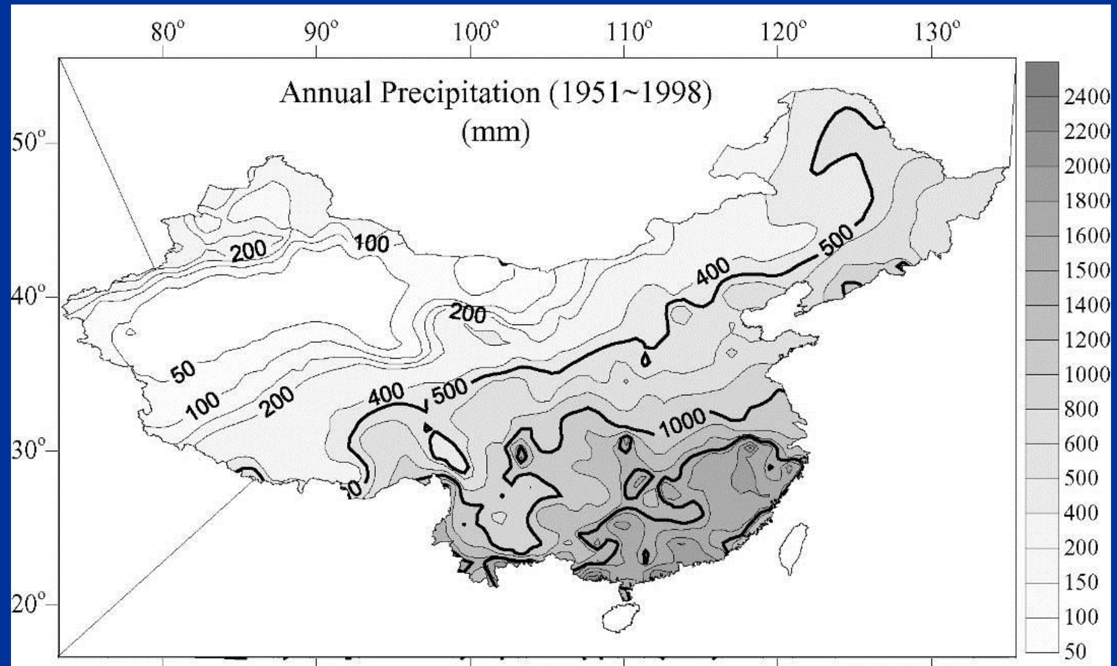
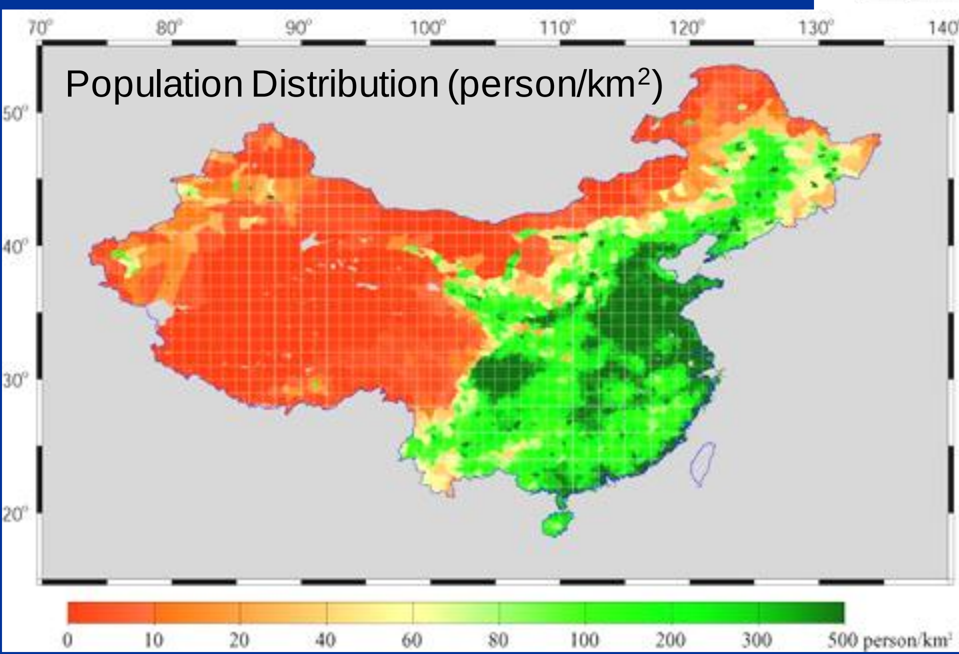
Outlines

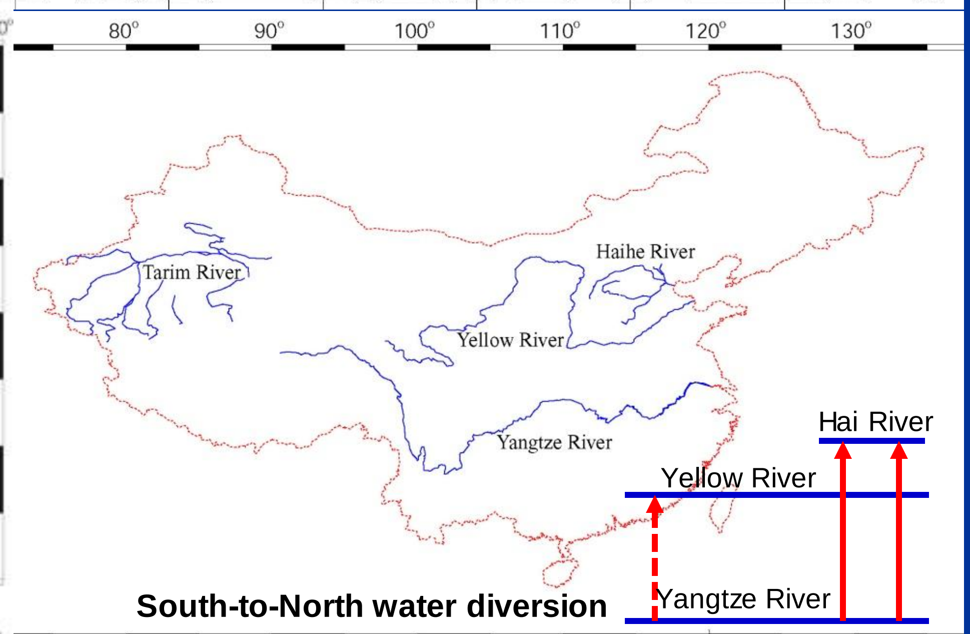
1. Background
2. Eco-hydrological observations in Northern China
3. Eco-hydrological simulation in the Haihe River basin
4. Conclusion

1. Background

Northern China is facing a severe water shortage due to the climate condition and population distribution.







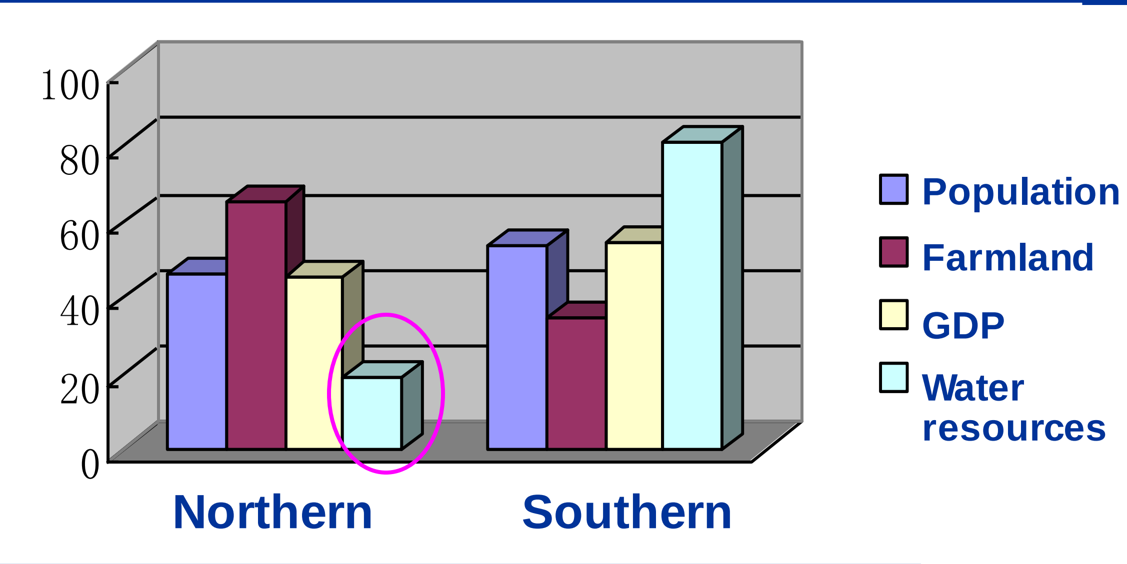
Uneven Distributions of Water and Farmland

Spatial distribution

Northern: Southern

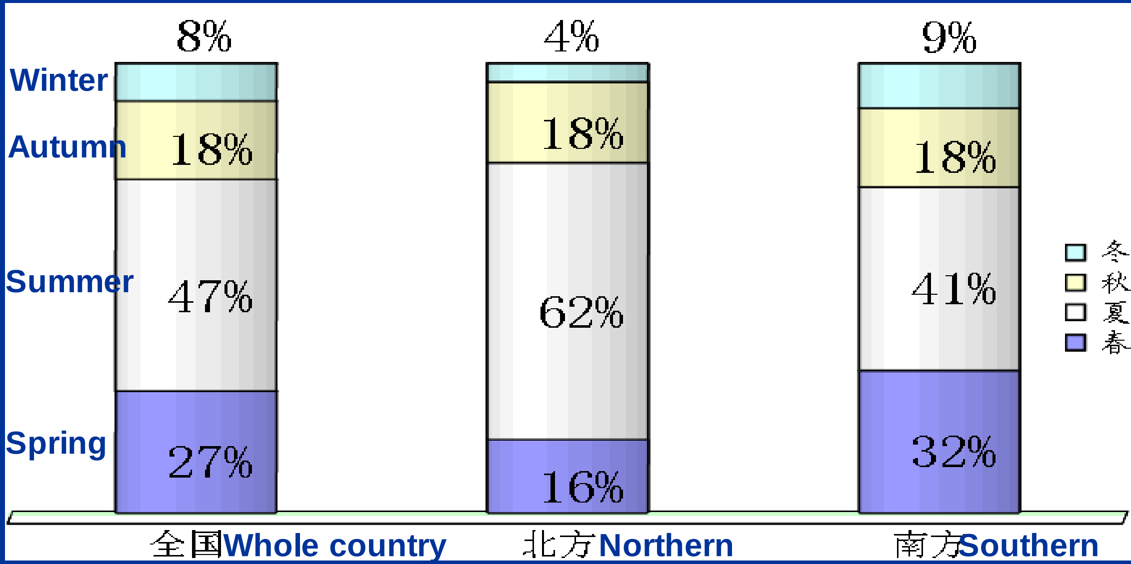
Water: **16% : 84%**

Farmland: **69% : 31%**



Seasonal distribution of water

50% in the summer



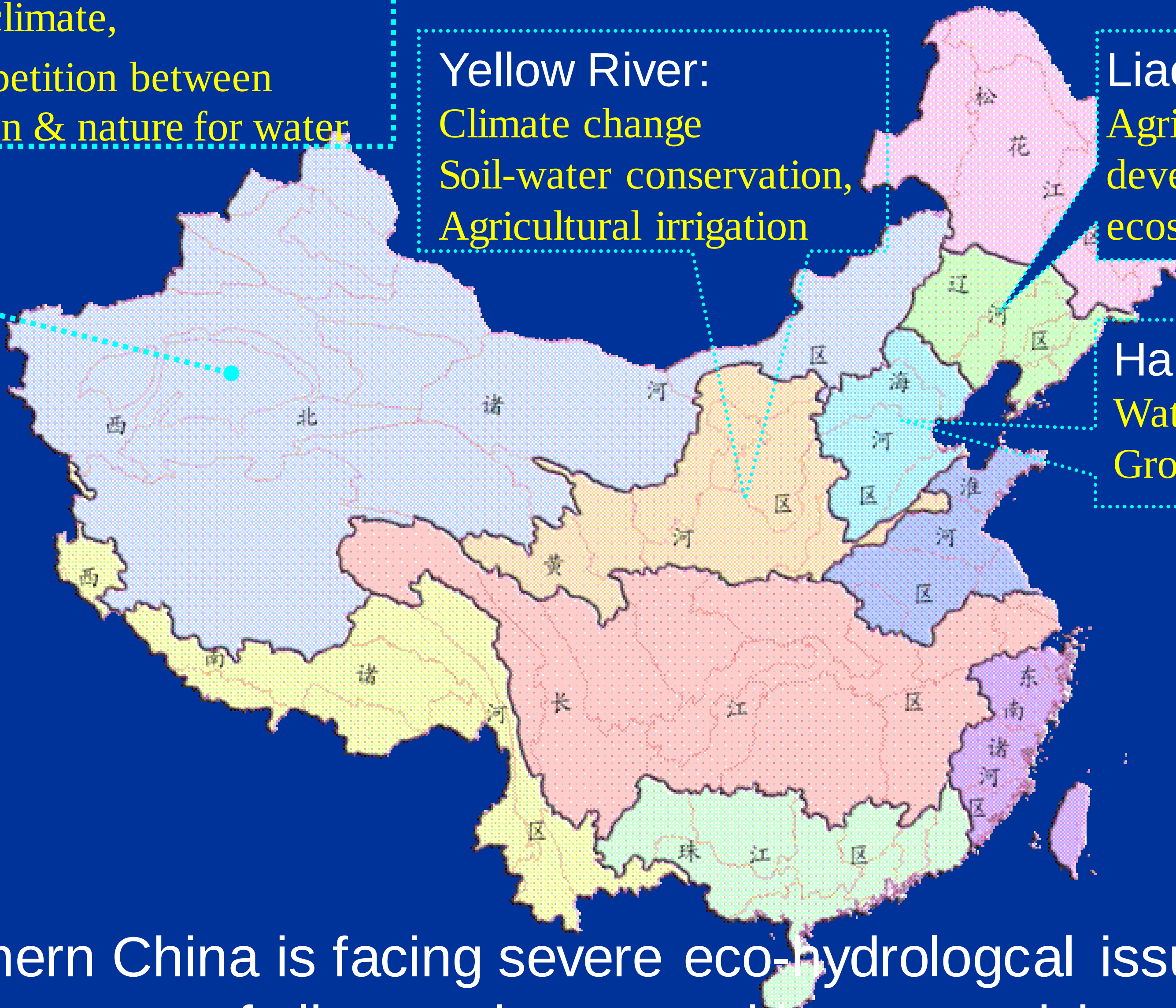
Major Water Issues in Northern China

Northwest Region:
Dry climate,
Competition between human & nature for water

Yellow River:
Climate change
Soil-water conservation,
Agricultural irrigation

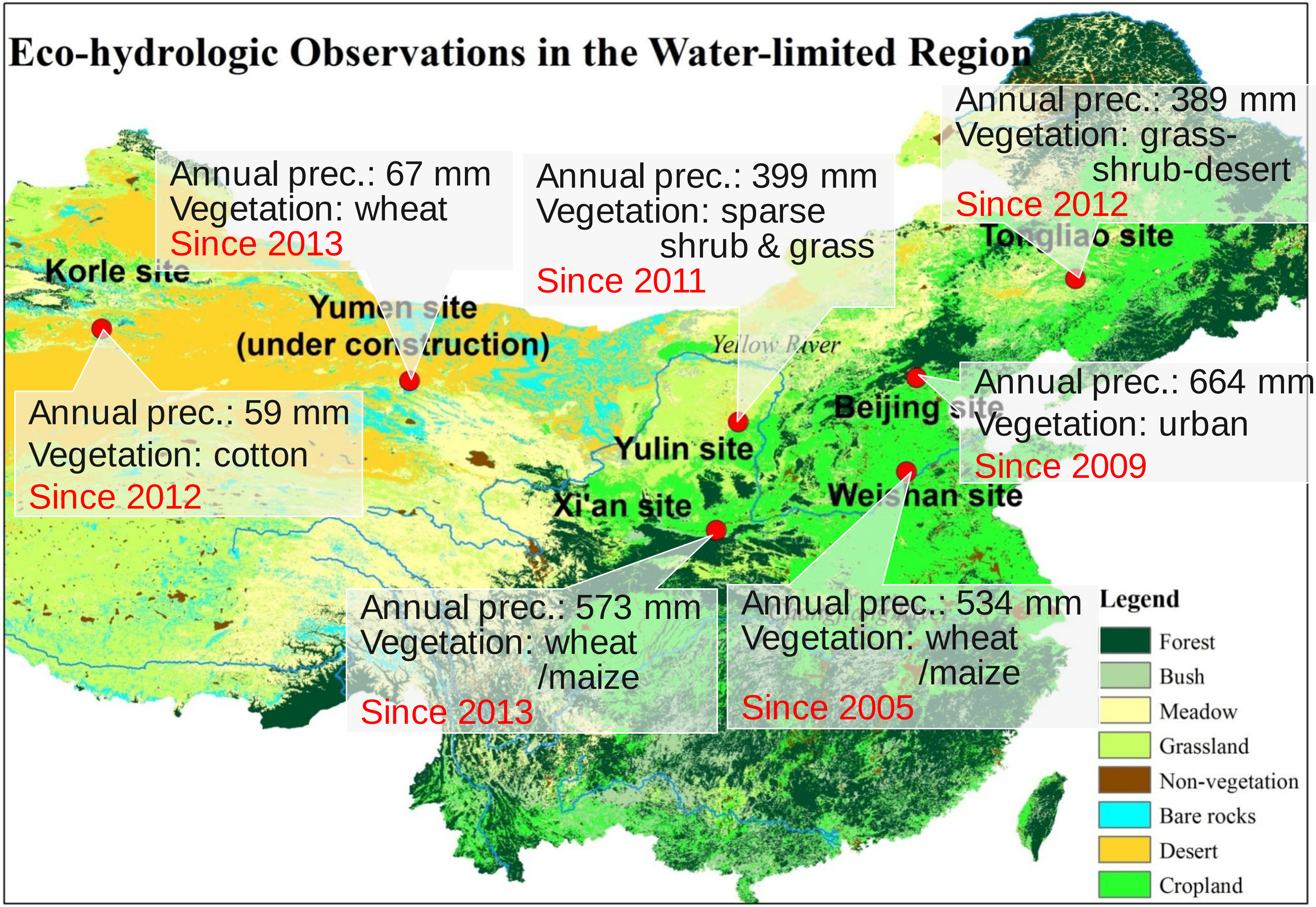
Liao River:
Agriculture development & ecosystem protection

Hai River:
Water shortage,
Groundwater decline



- Northern China is facing severe eco-hydrologcal issues under the pressure of climate change and human activity.

2. Eco-hydrological observations in Northern China

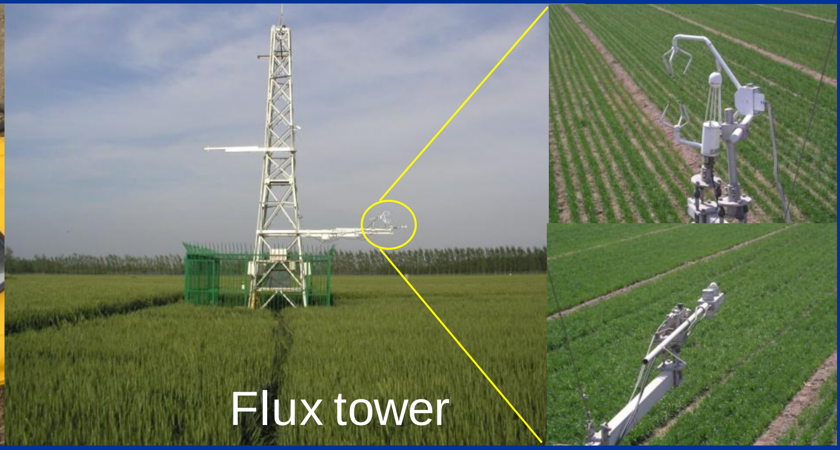


Instruments and Experiment
(e.g. Weishan site, since 2005)

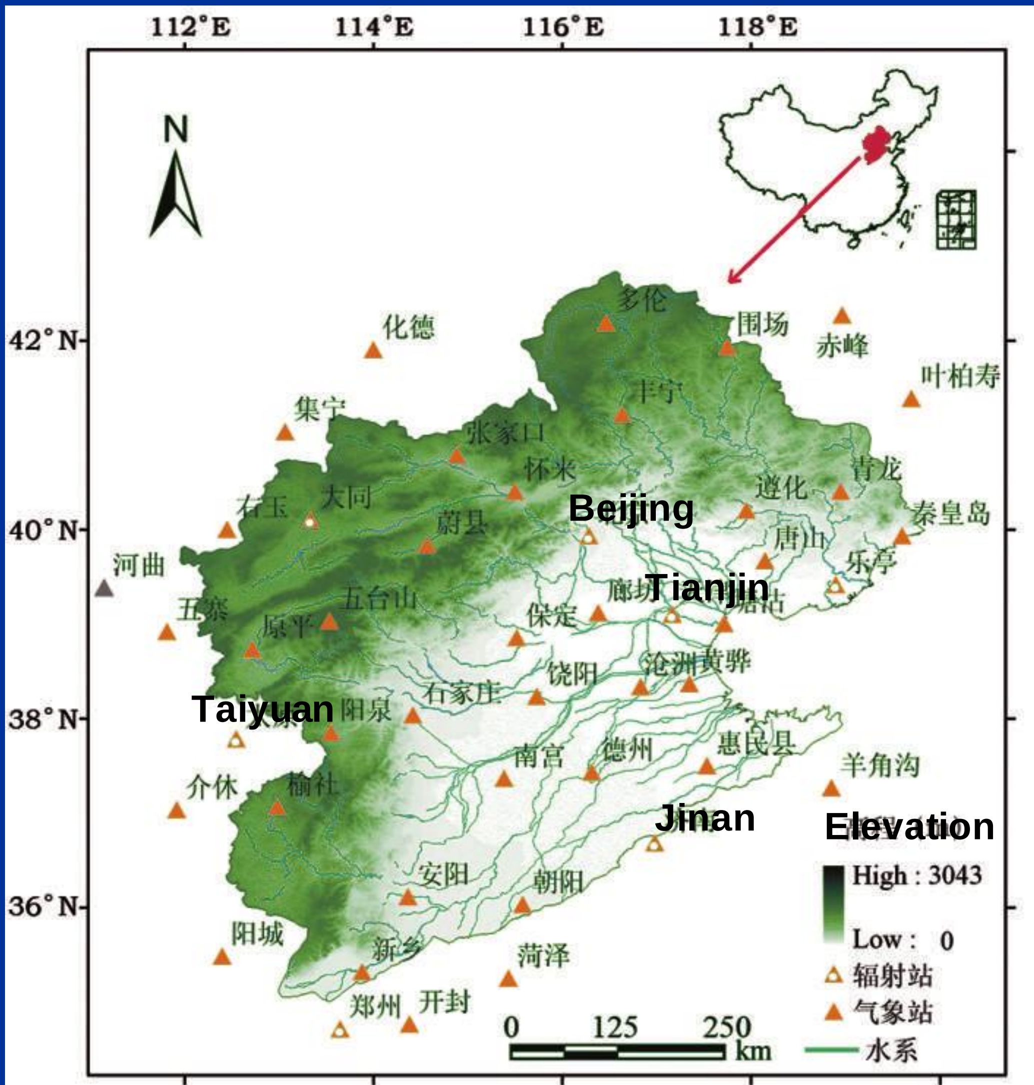
(1) Instruments: meteorological system, eddy covariance system, soil profiles, crop growth status, leaf-level gas exchange, water quality.

(2) Observations:

a. Meteorological observation: wind speed/direction, air temperature/humidity, air pressure, surface temperature, precipitation, radiation
b. Flux observation: latent/sensible heat flux, soil heat flux, carbon dioxide flux, soil evaporation, soil respiration
c. Ecological observation: stomatal conductance, photosynthesis rate, transpiration; leaf area index, dry biomass, crop yield
d. Soil hydrology observation: Soil temperature, soil moisture, soil water potential, groundwater table
e. Soil nitrogen observation: N-NO_3 and N-NH_4 concentrations in groundwater and soil water



3. Eco-hydrological simulation in the Haihe River Basin

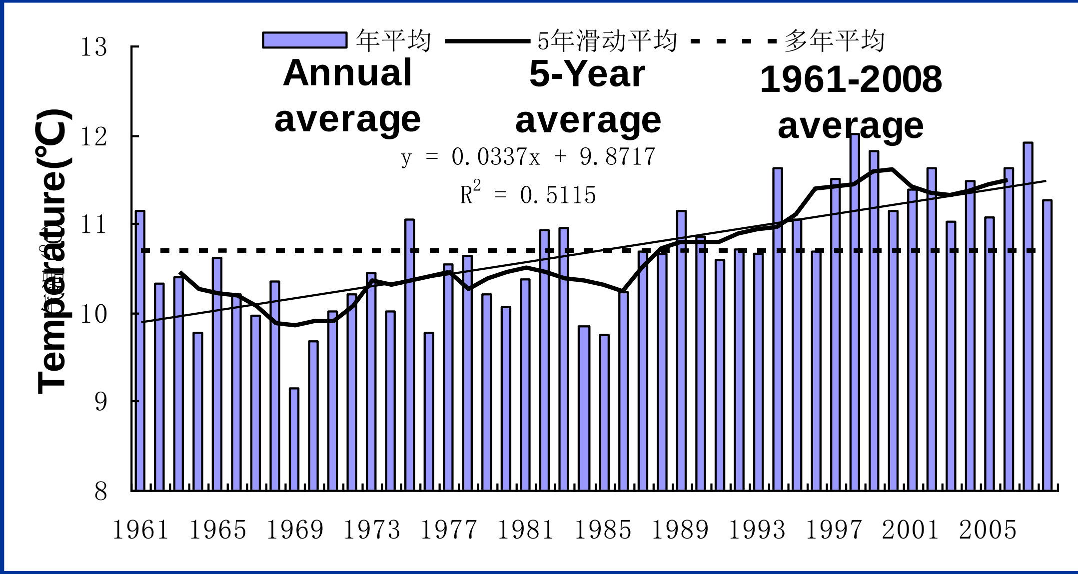


General Situation：

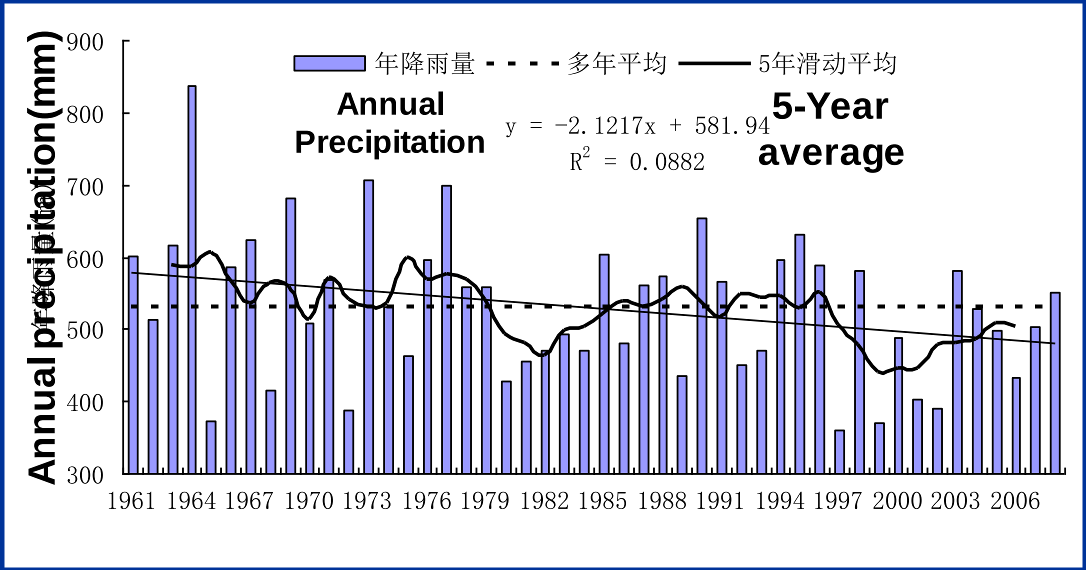
- The most dense population, 70 million in total
- Large area of farmland, 10% of the country total
- Precipitation: 548 mm/year
- Near 60% hilly areas
- Serious decrease of river discharge in recent 20 years

3.1 Changes in climate and land-use/land-cover

- A significant rising trend in air temperature: 0.3℃/10a.

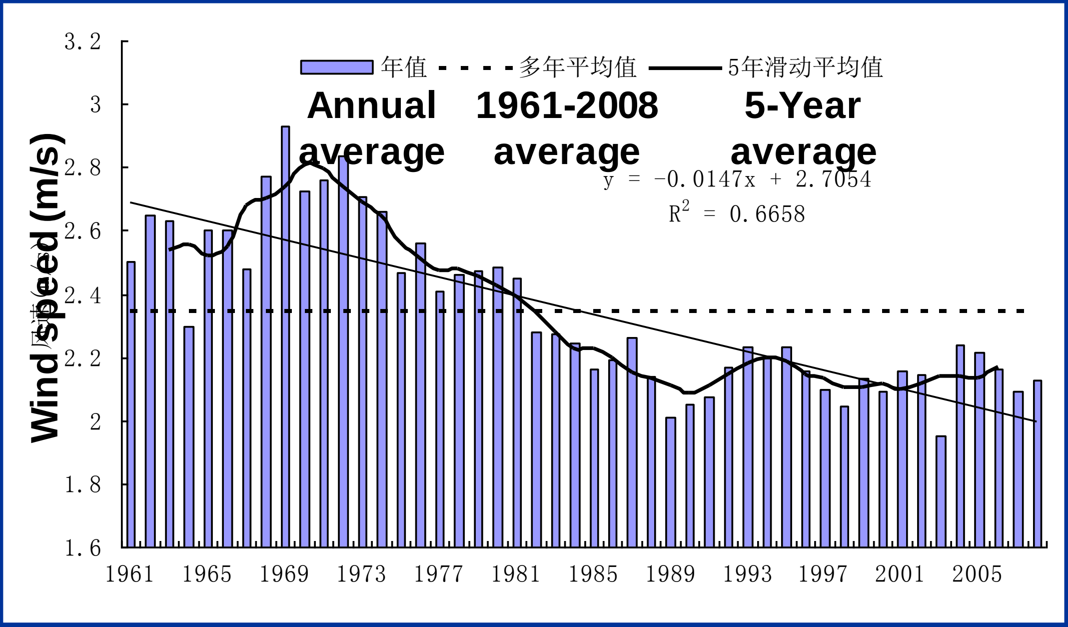


- A non-significant decreasing trend in precipitation: 21mm/10a.

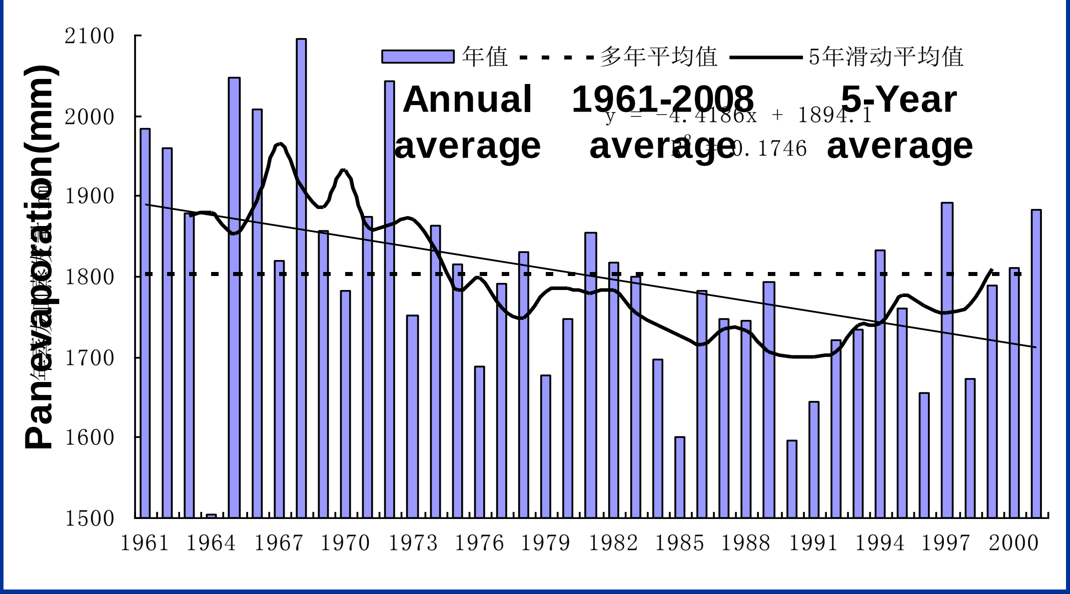


3.1 Changes in climate and land-use/land-cover

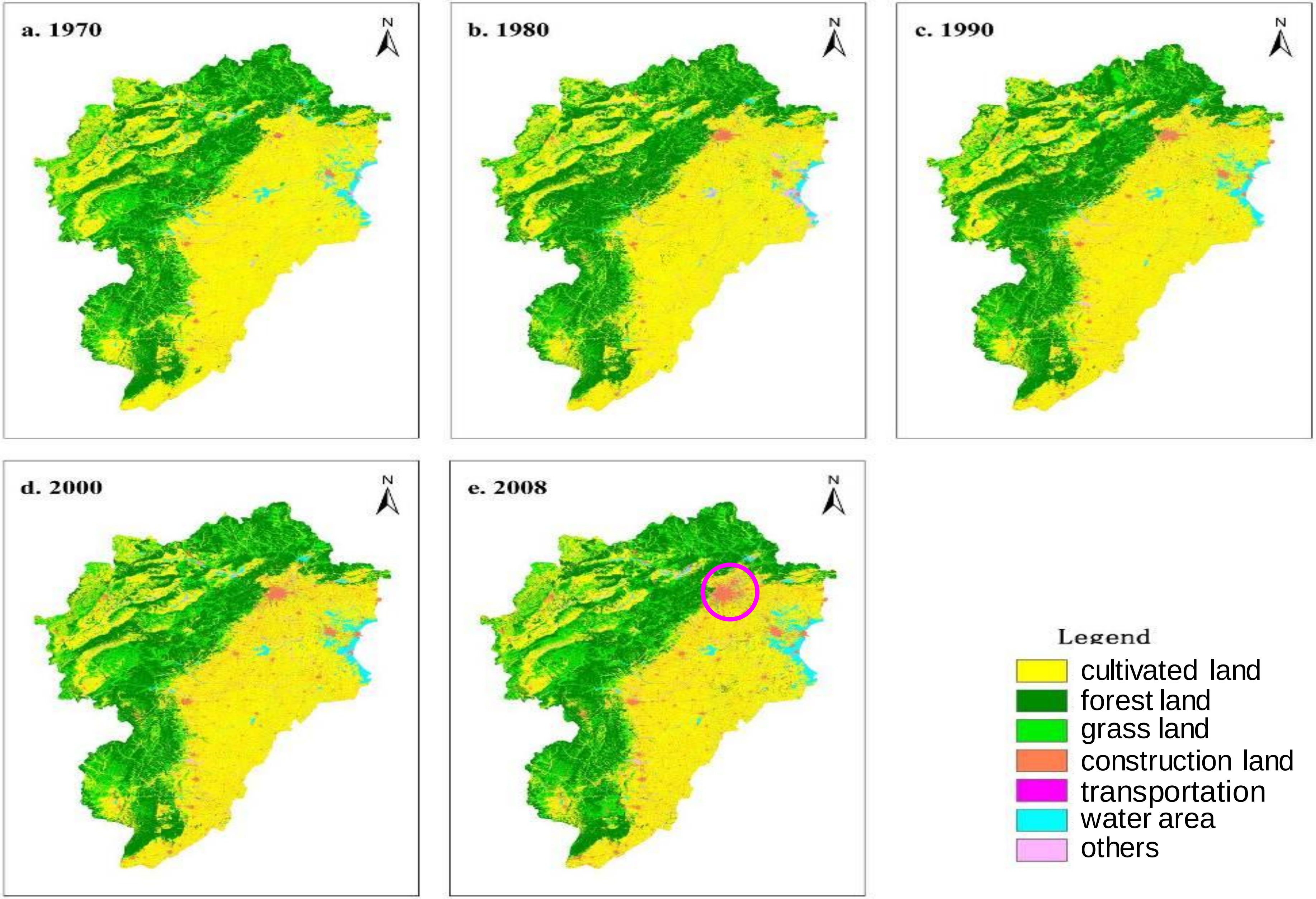
- A significant decreasing trend in wind speed: 0.15ms^{-1}/10a.



- A significant decreasing trend in pan evaporation: -44mm/10a.

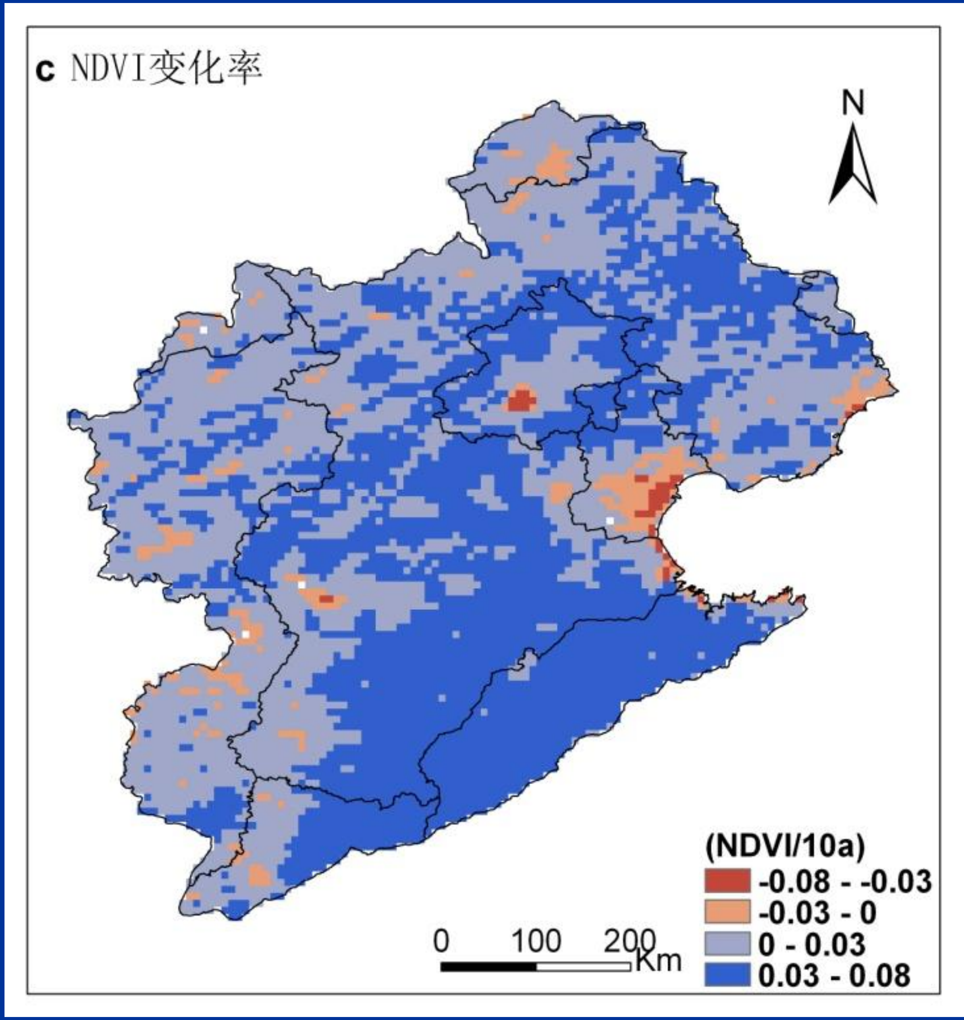


3.1 Changes in climate and land-use/land-cover



3.1 Changes in climate and land-use/land-cover

- During the recent 30 years, NDVI increased especially in the plain areas, where the croplands were irrigated.



3.2 Changes in river discharge

Panjiakou Reservoir:

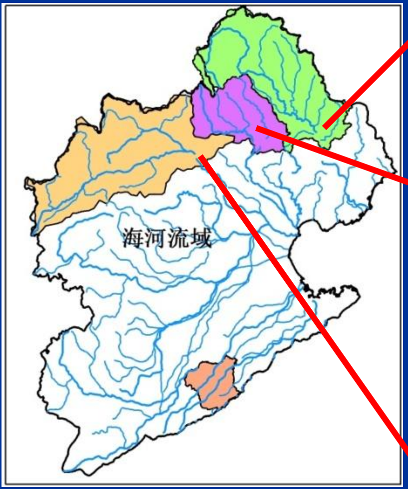
- catchment area: 33,700km^2
- annual precipitation: 455mm
- annual temperature: 3.8℃
- runoff coefficient: 0.13

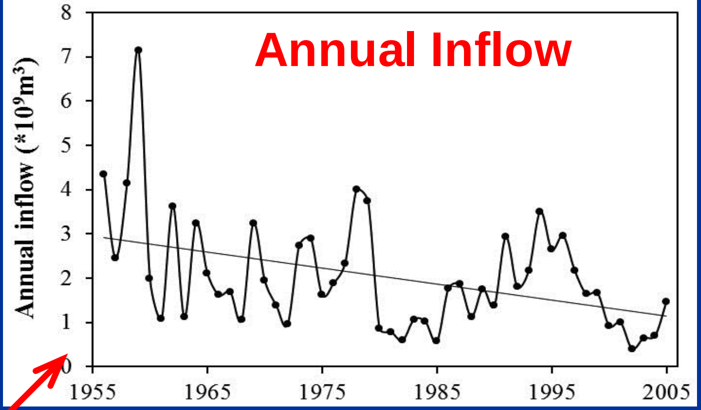
Miyun Reservoir:

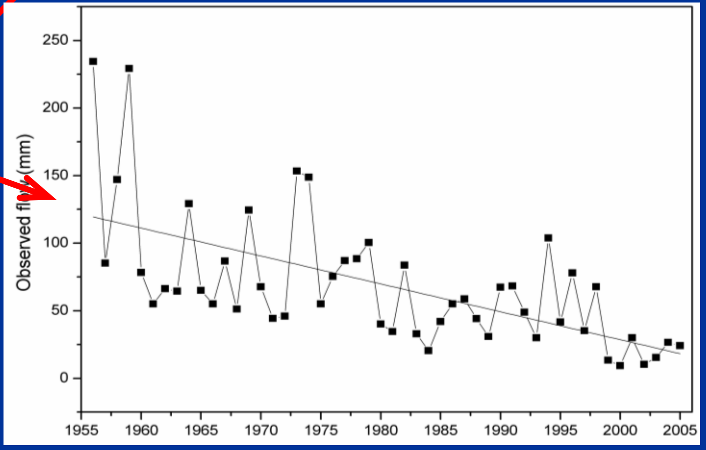
- catchment area: 15,800km^2
- annual precipitation: 490mm
- annual temperature: 5.8℃
- runoff coefficient: 0.13

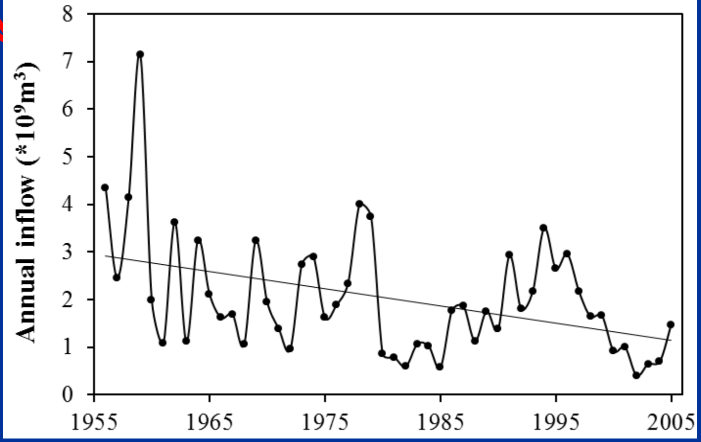
Guanting Reservoir:

- catchment area: 41,692km^2
- annual precipitation: about 400mm
- annual temperature: 5.2℃
- runoff coefficient: 0.049

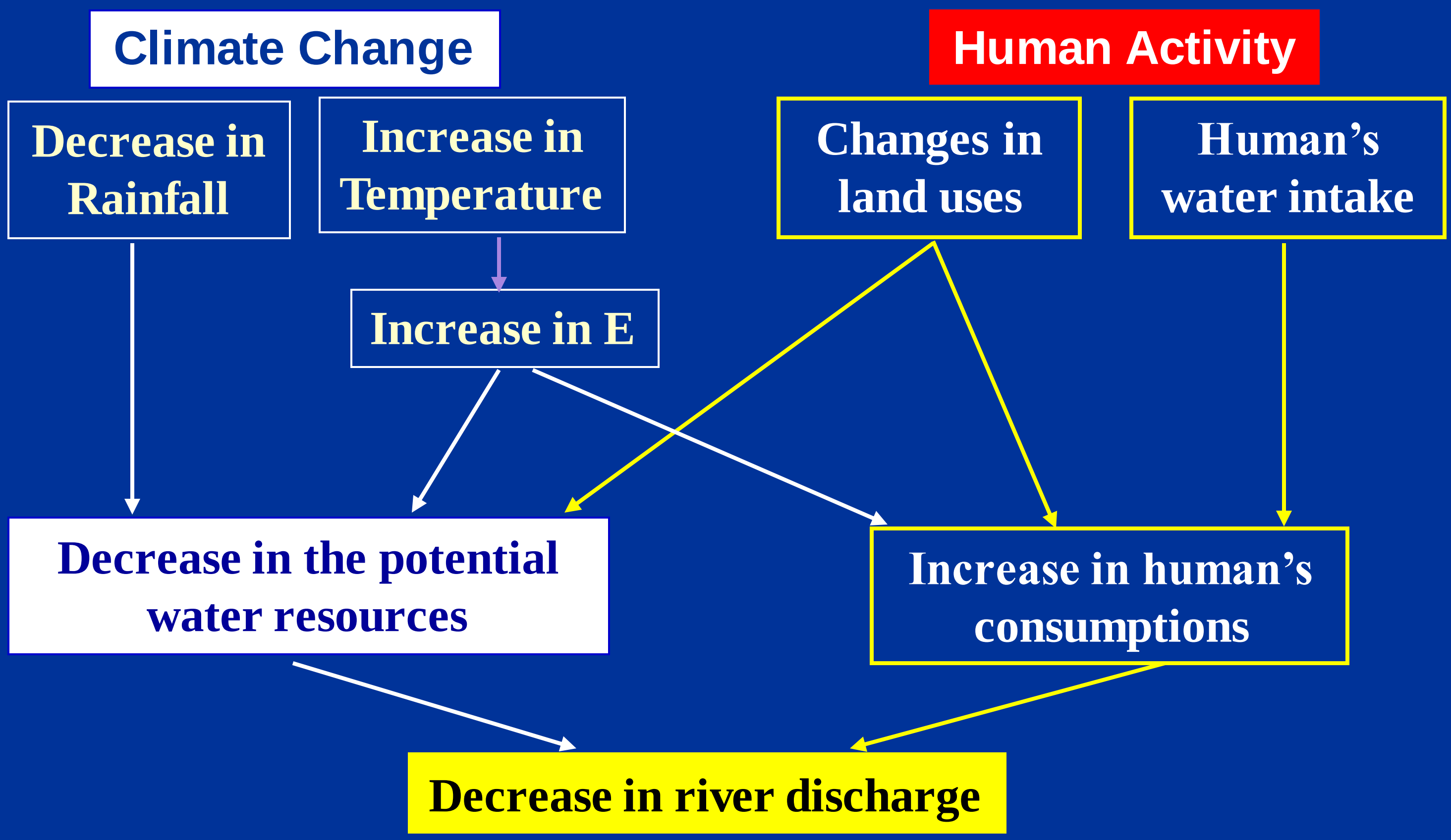








3.3 Attribution analysis of the streamflow decrease



- **A "fixing-changing" approach based on the hydrological model**

  - **Fixing the land use and land cover (LULC) condition, changing the climate data (L: C1, C2)**
  - **Fixing the climate condition, changing the land use and land cover data (C: L1, L2)**

Fixing LULC,
Changing climate

↓

Effect of climate change:
R(L2, C) - R(L1, C)

Fixing climate,
Changing LULC

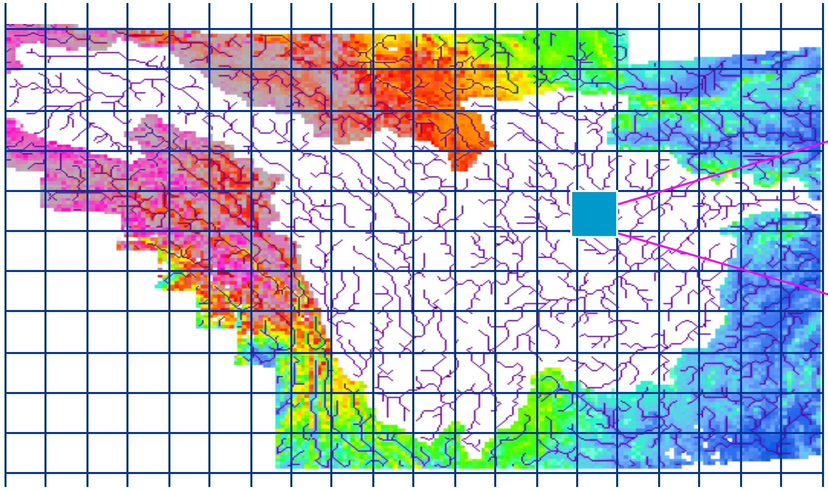
↓

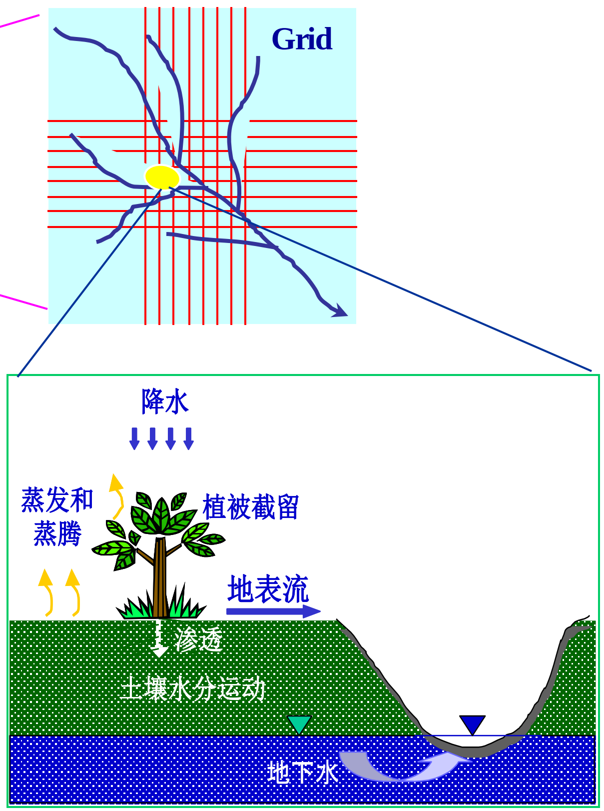
Effect of LULC change:
R(L, C2) - R(L, C2)

Based on physically-based distributed Hydrological model

An example of physically-based distributed hydrologic model

GBHM (Geomorphology- Based Hydrological Model, since 1998)





Representing the catchment using:

- **Basin → sub-basin → flow interval → grid → hillslope**
- **Sub-grid parameterization:** topographical and land use heterogeneity

An example of physically-based distributed hydrologic model

Physically-based representation of the hydrological processes

Potential evaporation (water surface):

$$E_p = \frac{\Delta}{\Delta+\gamma}(R_n + A_h) + \frac{\gamma}{\Delta+\gamma}\frac{6.43(1+0.536U_2)D}{\lambda}$$

Crop reference evaporation:

$$E_{rc} = \frac{\Delta}{\Delta+\gamma^*}(R_n - G) + \frac{\gamma}{\Delta+\gamma^*}\frac{900U_2 D}{T+275}$$

Actual evapotranspiration:

$$E_{\text{canopy}} = K_c E_p \quad \text{(Canopy evaporation)}$$

$$E_{\text{tr}}(z_j) = K_c E_p f_1(z_j) f_2(\theta_j)\frac{LAI}{LAI_0} \quad \text{(Transpiration)}$$

$$E_s = K_c E_p f_2(\theta) \quad \text{(soil evaporation)}$$

Canopy interception:

$$S_{C0} = 0.1 \ LAI \quad \text{(Interception capacity)}$$

Soil water movement:

$$\frac{\partial\theta(z,t)}{\partial t} = -\frac{\partial q_v}{\partial z} + s(z,t) \quad q_v = -K(\theta)\left[\frac{\partial\psi(\theta)}{\partial z} - 1\right]$$

Sub-surface flow:

$$q_{sub} = K(\theta)\sin\beta$$

● The “elasticity” approach based on the regression analysis

Climate elasticity:

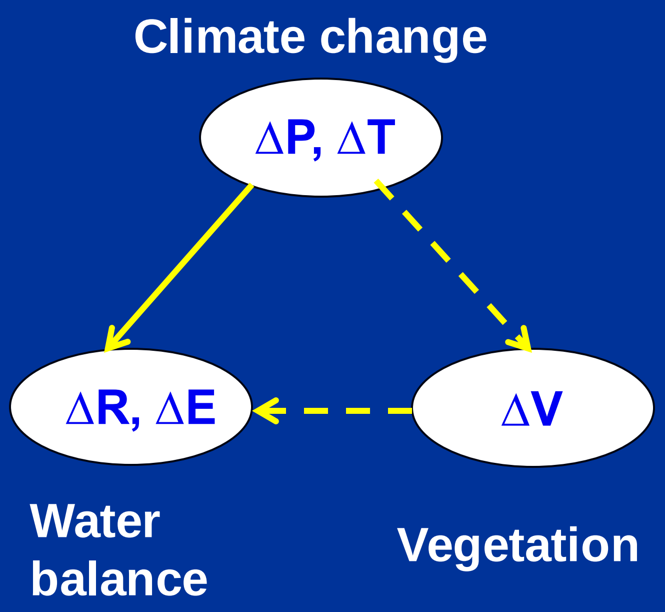
-- for runoff (Schaake, 1990):

$$\frac{\Delta R}{\overline{R}} = \varepsilon_P \frac{\Delta P}{\overline{P}}$$

$$\frac{\Delta R}{\overline{R}} = \varepsilon_1 \frac{\Delta P}{\overline{P}} + \varepsilon_2 \frac{\Delta T}{\overline{T}}$$

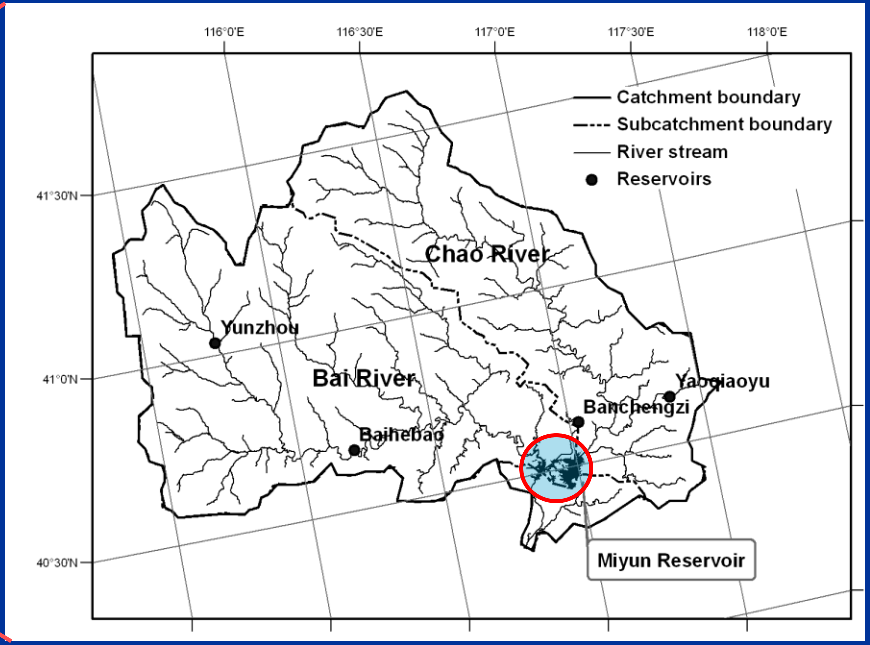
-- for evapotranspiration:

$$\frac{\Delta E}{\overline{E}} = \varepsilon_1 \frac{\Delta P}{\overline{P}} + \varepsilon_2 \frac{\Delta T}{\overline{T}}$$



- Divide the study period into two sub-periods, the elasticity parameters are simulated by regression analysis;
- Estimating the parameters in period 1, validating the model in period 2.

➢ A case study in the Miyun Reservoir catchment



Basic Characteristics:

Location： 100km north of Beijing

Drainage area： 15,800km^2

Annual Precipitation： 490mm

Annual mean temperature： 5.8℃

Mean runoff coefficient： 13%

Reservoir capacity: 4.4 billion m^3

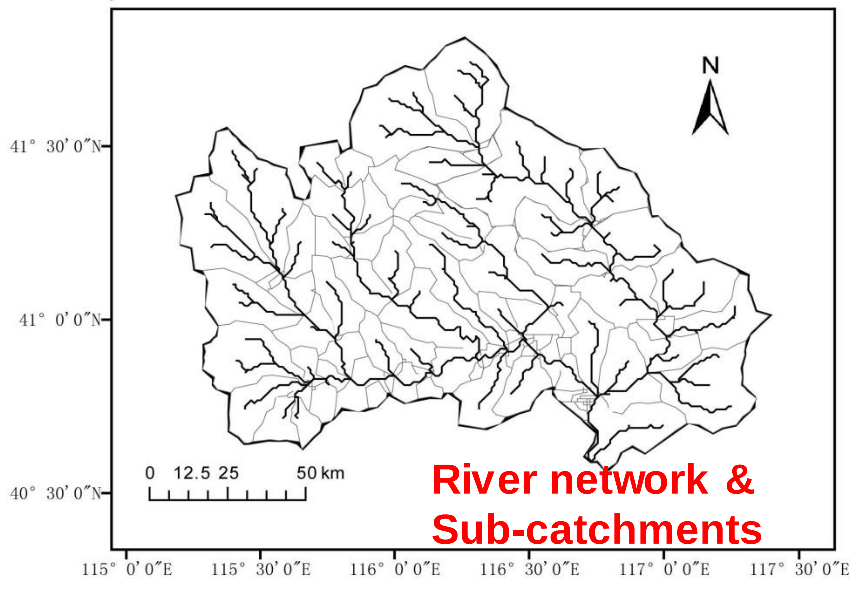
Construction year: 1960

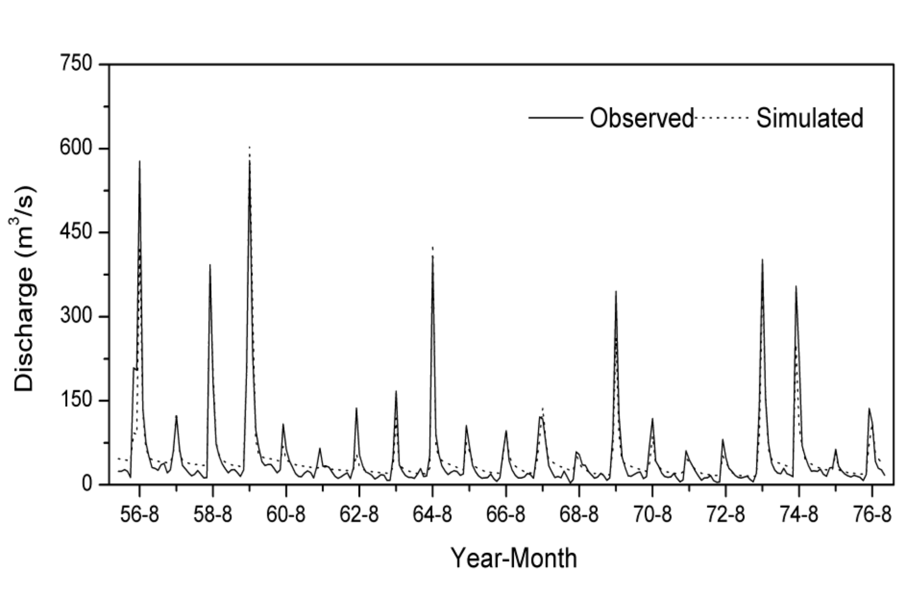
Changes in annual inflow, climate, land use and "direct abstraction"

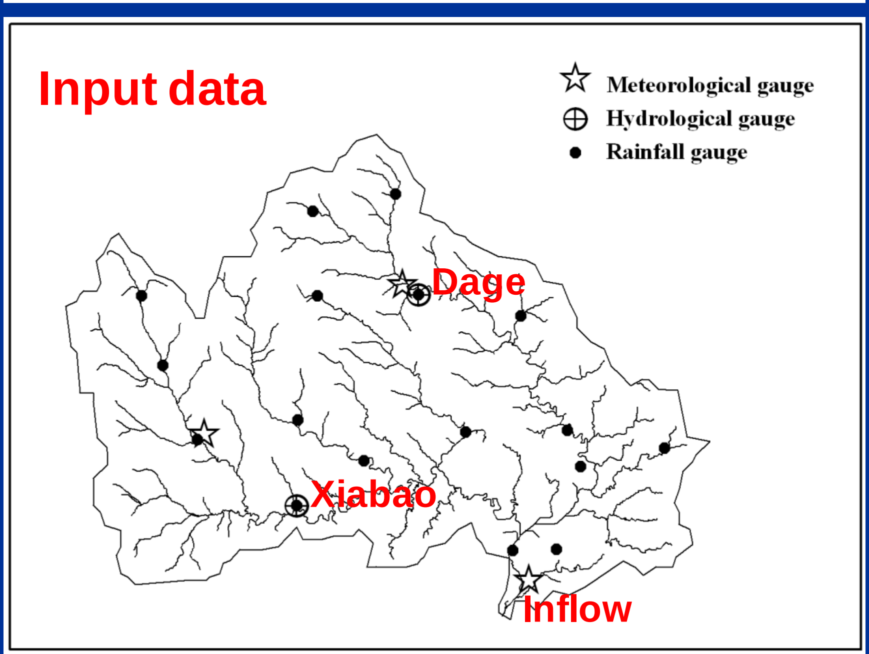
Observed inflow into the Miyun Reservoir (mm/a)		Climate variability		Direct abstraction (mm/a)	Major land use type (area ratio) *	
		Annual precipitation (mm/a)	Mean temperature (℃)		Forest & Shrub	Grassland
1956~1983	90.3	**506.2**	**5.5**	**2.2**	**49%**	**27%**
1984~2005	41.8	**475.7**	**6.4**	**13.4**	**65%**	**16%**
Change between two periods	-48.5	**-30.5**	**0.9**	**11.2**	**16%**	**-11%**

* Land use maps in 1980s and 1996 were used to calculate the area ratio for the two periods, respectively.

Validation of the GBHM model







	Calibration			Validation		
	Inflow	Dage	Xiabao	Inflow	Dage	Xiabao
R2	0.86	0.86	0.79	0.83	0.87	0.77
RE	4.4%	9.3%	-5.1%	-1.9%	-0.5%	6.3%

R2: the Nash efficiency coefficient;

RE: the relative error.

Attribution of the decrease in annual inflow to the Miyun Reservoir

Units: mm

Time	Annual measured runoff	Annual human water abstraction	Annual simulated runoff		
			Climate elasticity method	GBHM	
1956~1983	90.3	2.2	92.5	94.9	
1984~2005	41.8	13.4	67.5	68.3（A）	59.6（B）
Change	-48.5	11.2	-24.9	-26.6	-8.7（A-B）
Attribution		23%	51%	55%	18%

Water abstraction

Influence of climate change

Influence of land use change

➢**Conclusion：** human activities (water abstraction and land use change) and climate change have similar effects on annual inflow decrease of Miyun Reservoir.

Attribution of the decrease in annual inflow to the Panjiakou Reservoir

Units: mm

Time	Annual measured runoff	Annual human water abstraction	Annual simulated runoff		
			Climate elasticity method	GBHM	
1956~1979	65.7	3.6	66.1	64.5	
1980~2005	46.2	26.1	74.0	72.3（A）	67.8（B）
Change	-19.5	22.5	7.9	7.8	-4.5（A-B）
Attribution		115%	-41%	-40%	23%
		Water abstraction	Influence of climate change		Influence of land use change

➢**Conclusion：** human activities(water abstraction and land use change) is the main reason for the annual inflow decrease of Panjiakou Reservoir.

Attribution of the decrease in annual inflow to the Guanting Reservoir

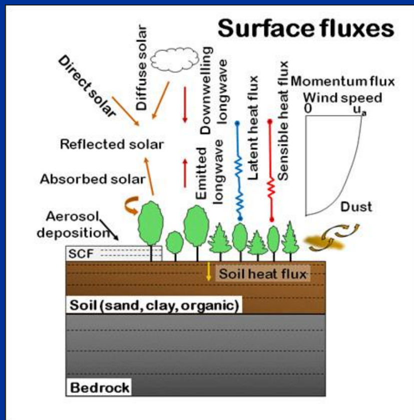
Units: mm

Time	Annual measured runoff	Annual human water abstraction	Annual simulated runoff		
			Climate elasticity method	GBHM	
1956~1979年	29.9	16.3	46.1	48.6	
1980~2005年	10.6	17.7	36.3	34.6（A）	32.3（B）
Change	-19.3	1.4	-9.8	-14.0	-2.3（A-B）
Attribution		7%	51%	73%	12%
		Water abstraction	Influence of climate change		Influence of land use change

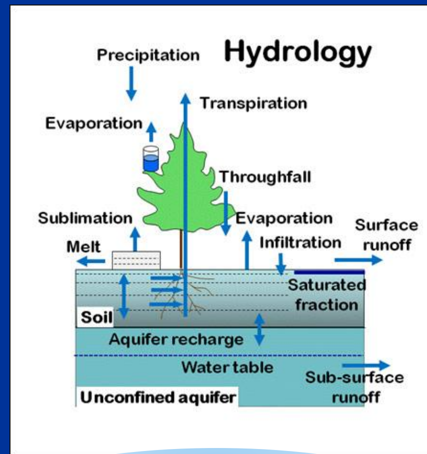
- **Conclusion：** Climate change is the main reason for the annual inflow decrease of Guanting Reservoir.

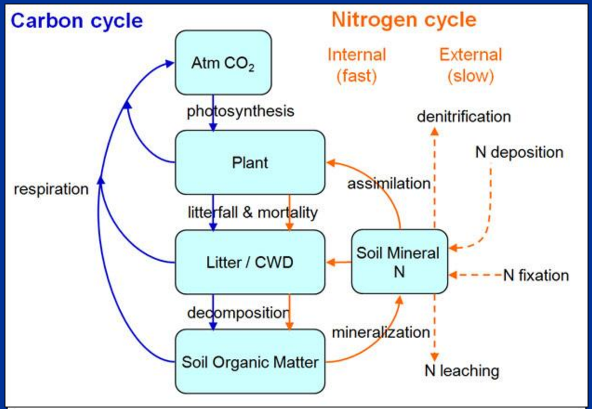
3.4 Eco-hydrological simulation using CLM 4.0

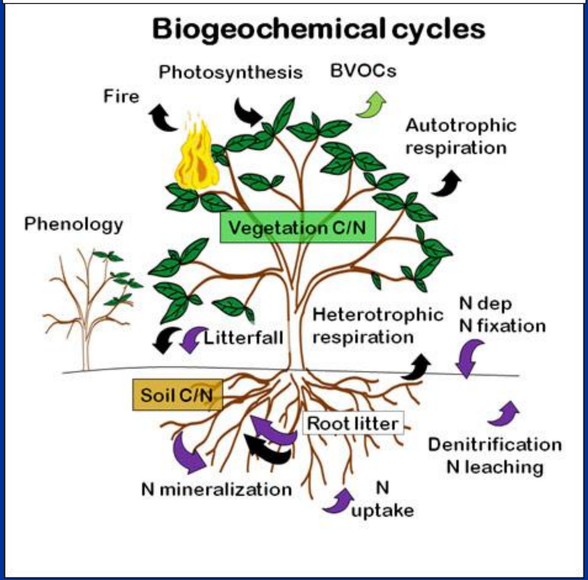
Community Land Model 4.0 (NCAR)



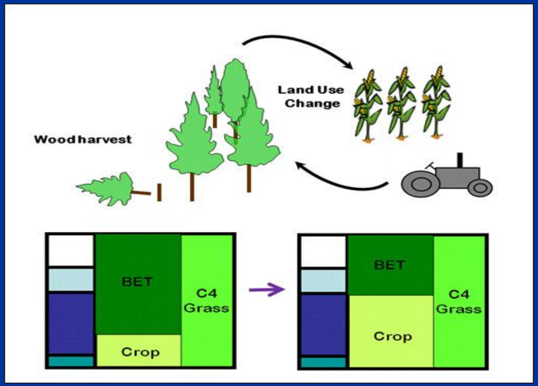
Energy flux

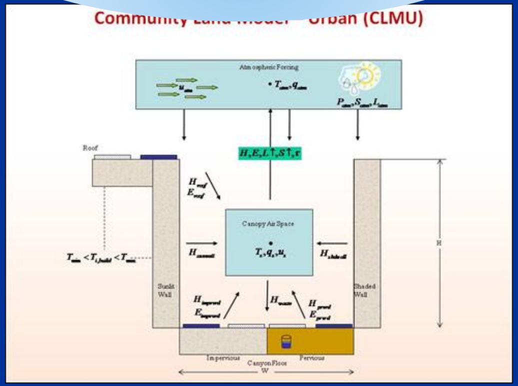






Hydrology





Land use change

Urban heat-water cycle

Carbon-nitrogen cycle

3.4 Eco-hydrological simulation using CLM 4.0

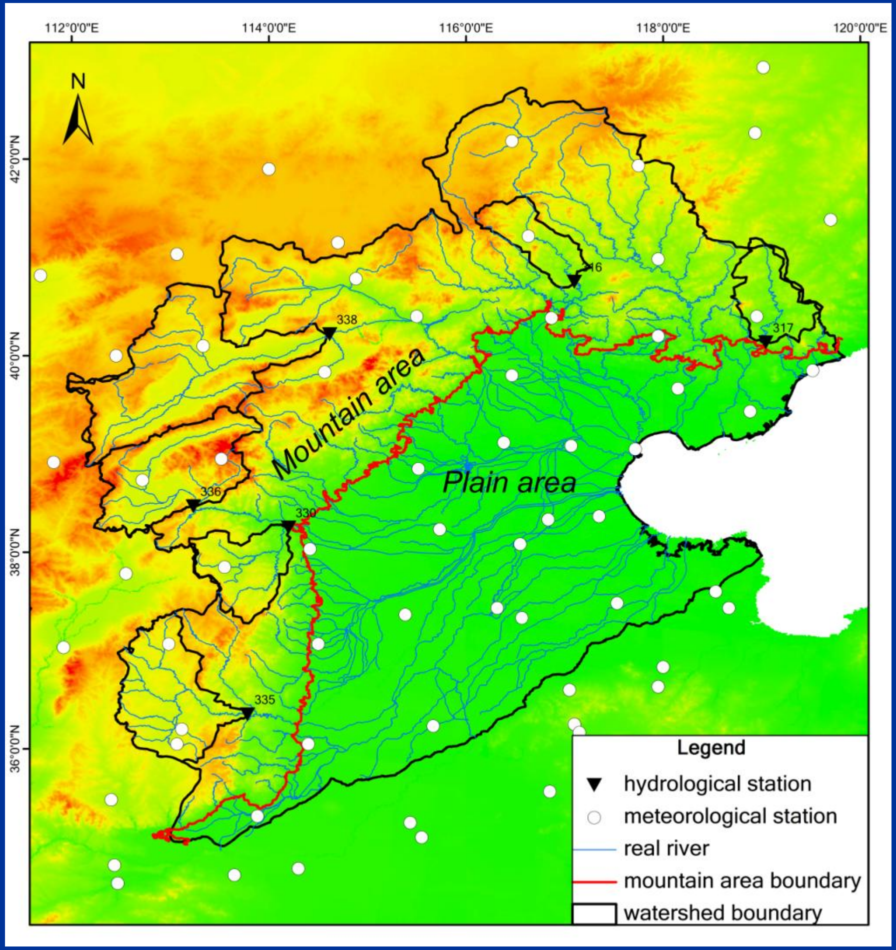
Trends in climate factors during the past 50 years

Climate factor	Annual Mean value	Trend (P-value)
Precipitation	483 mm	-1.27 mm yr^{-1} (0.0836)
Air temperature	7.325 ° C	**+0.038** ° C yr^{-1} (6.06E-10)
Solar incident radiation	181.9 W m^{-2}	**-0.3** W m^{-2} yr^{-1} (1.53E-10)
Relative humidity	66%	-0.0057 yr^{-1} (0.81)
10m wind speed	2.0 m s^{-1}	**-0.014** m s^{-1} yr^{-1} (2.72E-14)
CO_2 concentration	324 ppm	**+1.3** ppm yr^{-1} (2.74E-45)

- Air temperature, radiation, wind speed, and CO_2 concentration changed significantly
- Precipitation decreased slightly
- Relative humidity had no significant trend

3.4 Eco-hydrological simulation using CLM 4.0

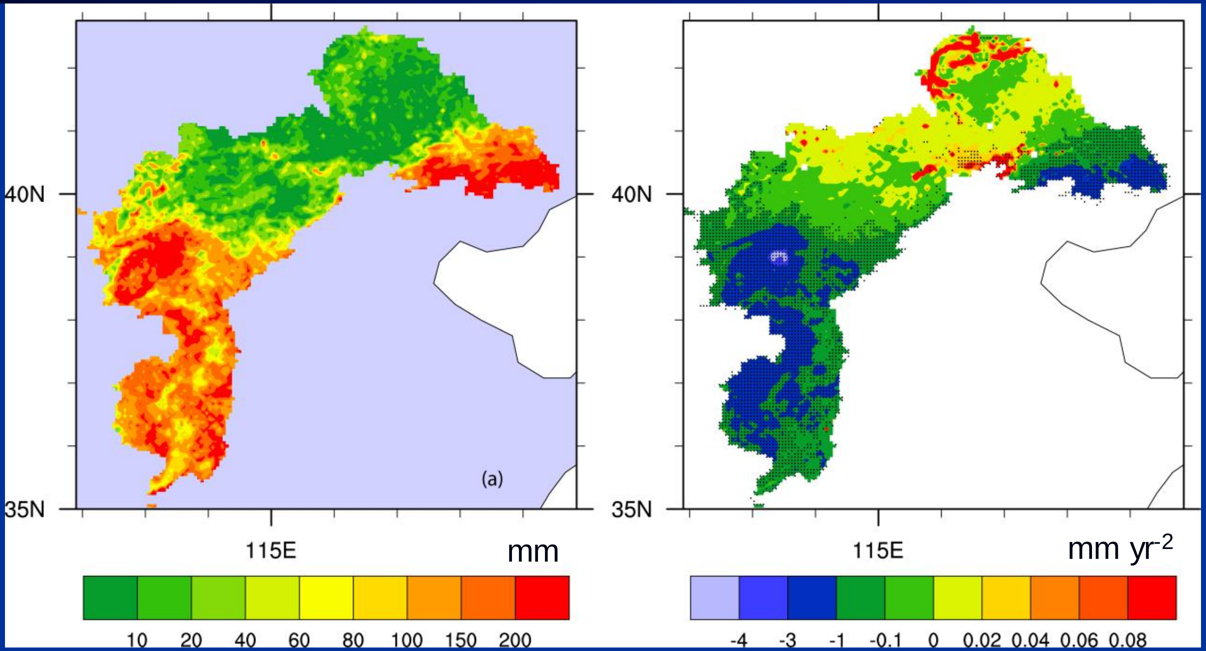
■ Focus on the hilly areas and the effect of dynamic vegetation



- The hilly area of the Haihe River basin: 18.9*10^4 km^2.
- Change in climate was significant.
- Runoff generated in the hilly area is the water source of the irrigation in plain area.

3.3 Eco-hydrological simulation using CLM 4.0

Annual mean runoff

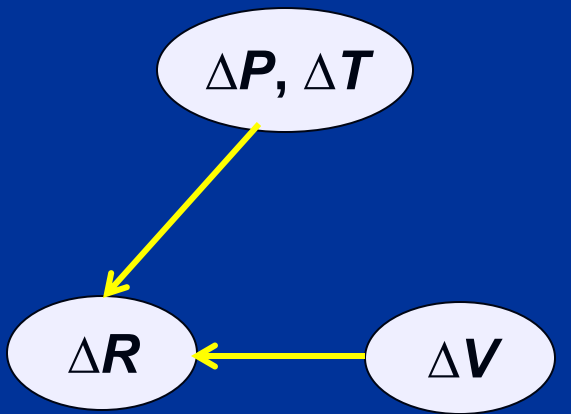


Trend in annual runoff

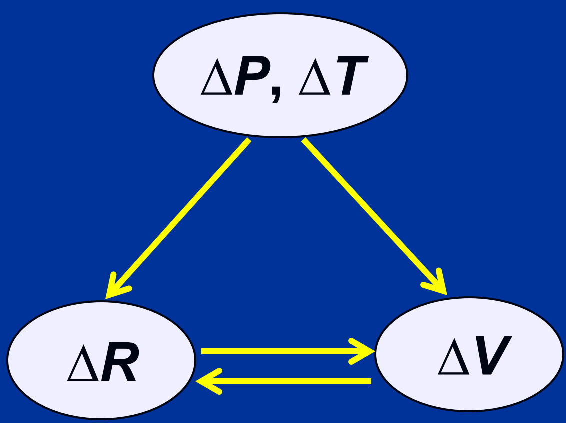
Summary of the effects of climate change on annual runoff

Climate factor	Change rate **(mm yr^{-2}) (P-value)**	Contribution ratio
Precipitation	-0.52 (0.0064)	**+44.3%**
Solar radiation	0.14 (0.0000)	**-11.7%**
Air temperature	-0.09 (0.0002)	**+7.7%**
10m wind speed	0.04 (0.0000)	**-3.0%**
CO_2 concentration	**0.01 (0.0000)**	**-1.1%**
Relative humidity	0.001 (0.8536)	-0.1%

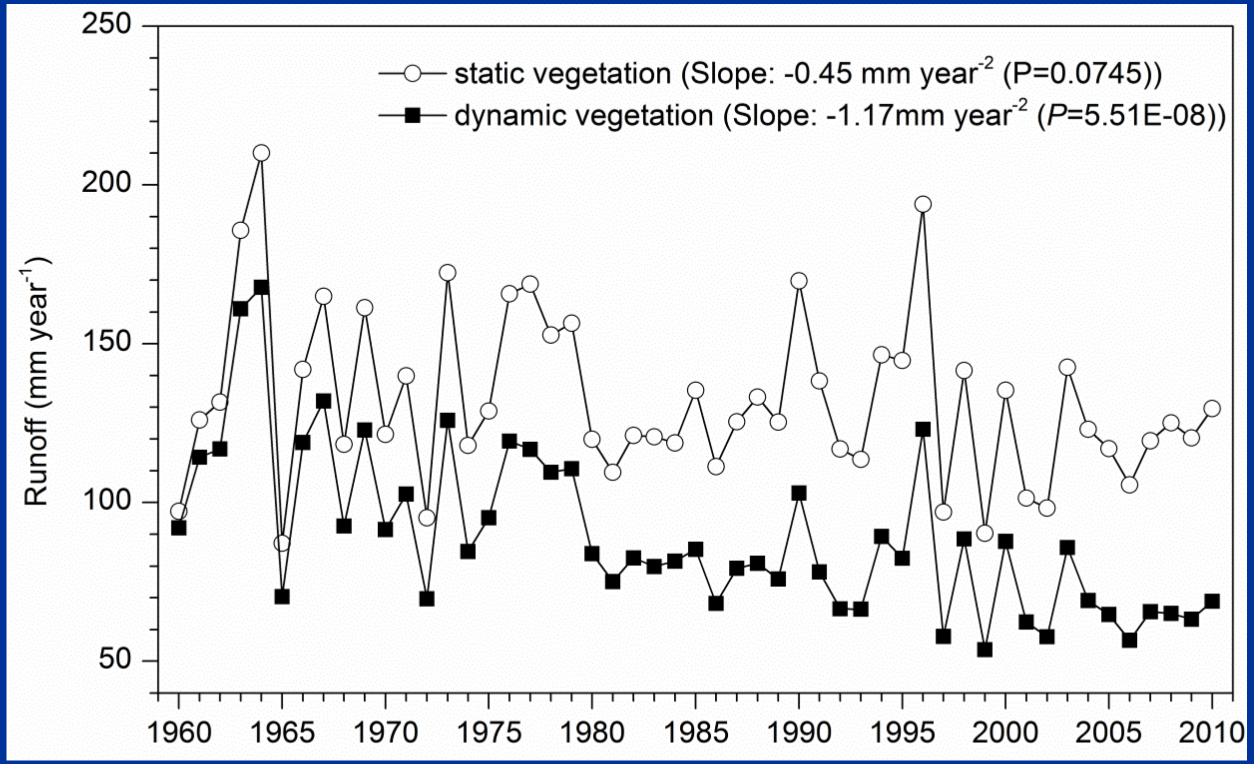
3.3 Eco-hydrological simulation using CLM 4.0



Static vegetation phenology



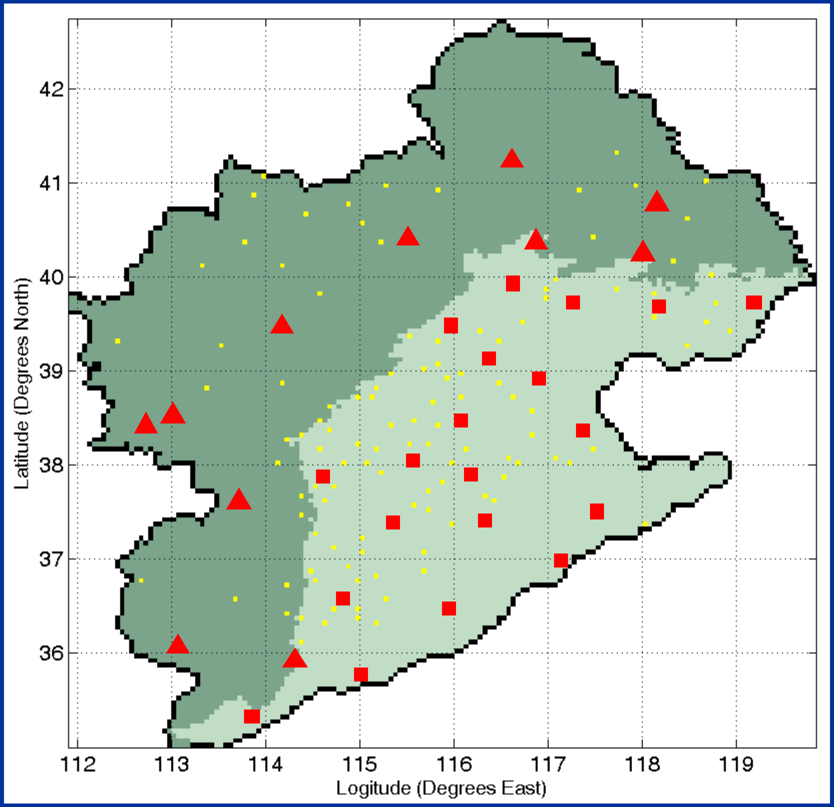
Dynamic vegetation phenology



- The trend in runoff would be greatly underestimated if dynamic vegetation phenology was not included.

3.4 Drought analysis based on simulated soil moisture by CLM4.0

- Validation of the simulated soil moisture using the measured soil moisture data during1991-2007



- Observations

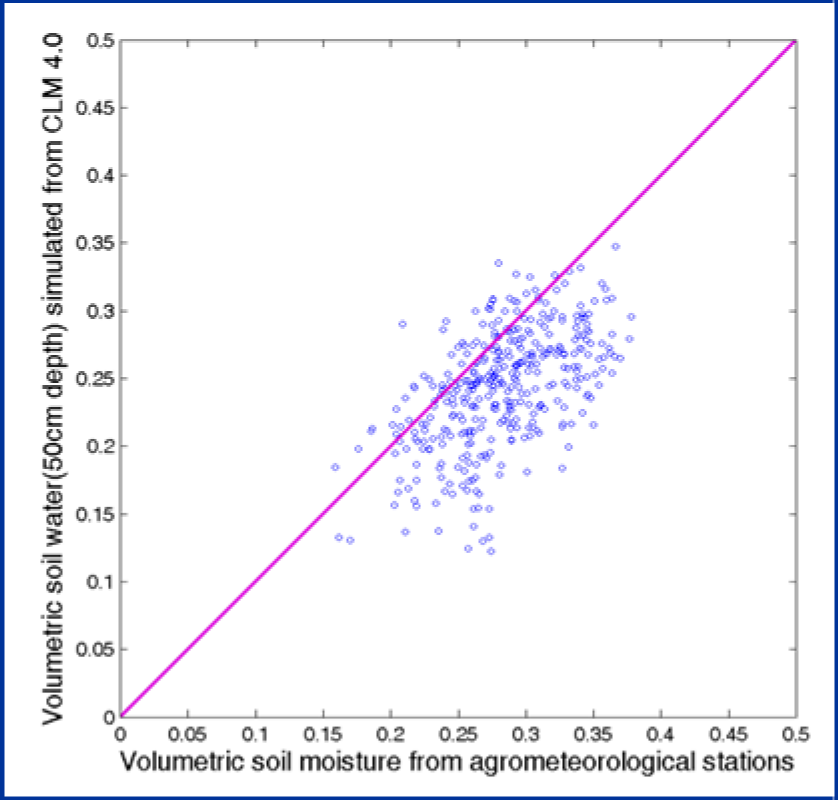
  Plain area: 20 sites

  Mount. area: 11 sites

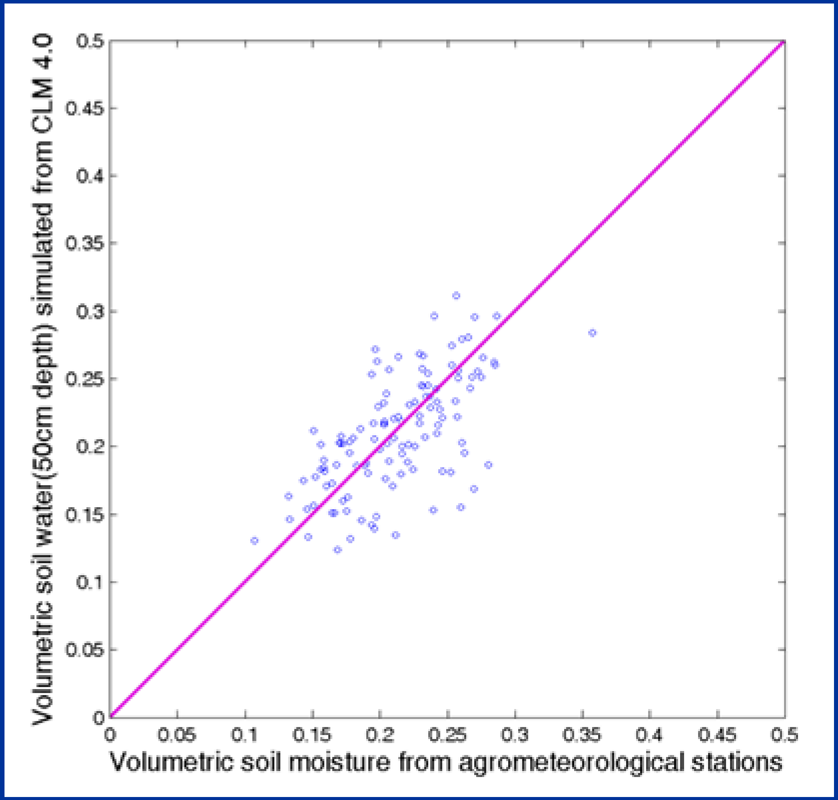
3.4 Drought analysis based on simulated soil moisture by CLM4.0

- Validation of the simulated soil moisture using the measured soil moisture data during1991-2007

Simulated soil moisture from CLM



Measured soil moisture in Plain area



Measured soil moisture in Mount. area

- CLM4.0 underestimated the soil moisture in the plain areas because it didn't consider the irrigation.

3.4 Drought analysis based on simulated soil moisture

- Drought identification based on the probability distribution of soil moisture (Andreadis et al, 2005)

1. Cumulative probability distribution

$$P = m / (n + 1) * 100\%$$

where m is the rank number(low to high), and n is total sample amount.

2. Drought severity, S

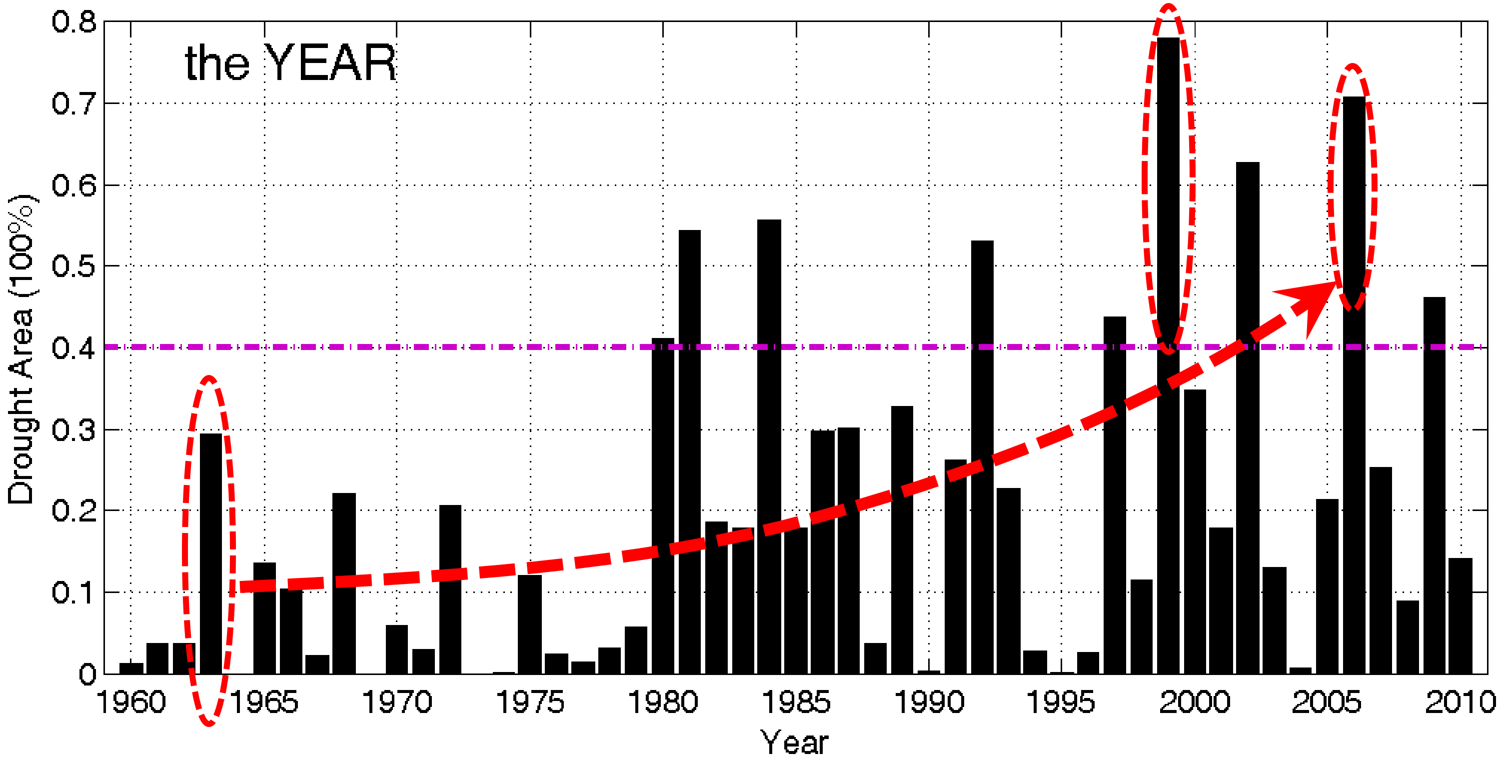
$$S = (1 - \Sigma P / t) * 100\%$$

3. Threshold of S = 80%

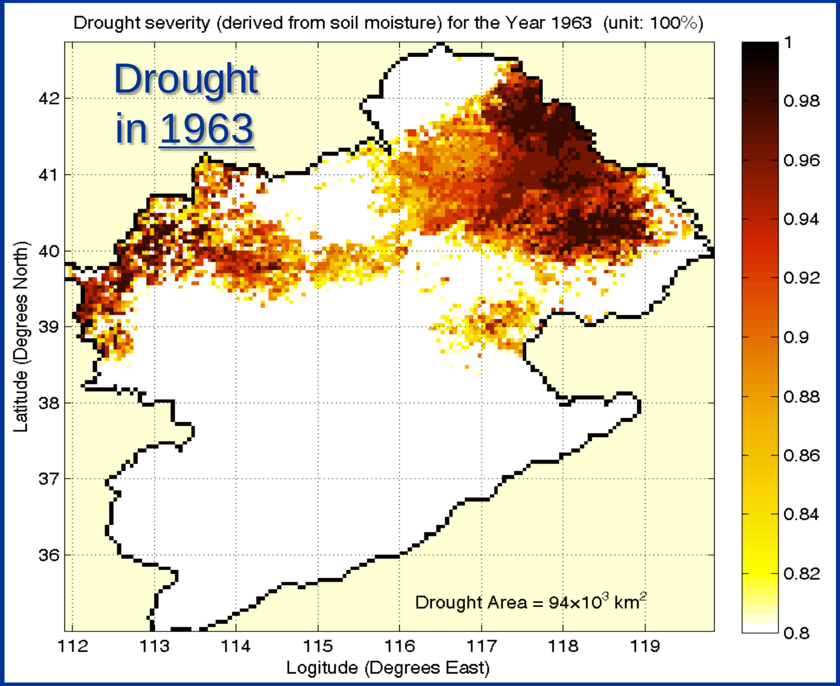
When S<80%, the grid is not identified as a drought event.

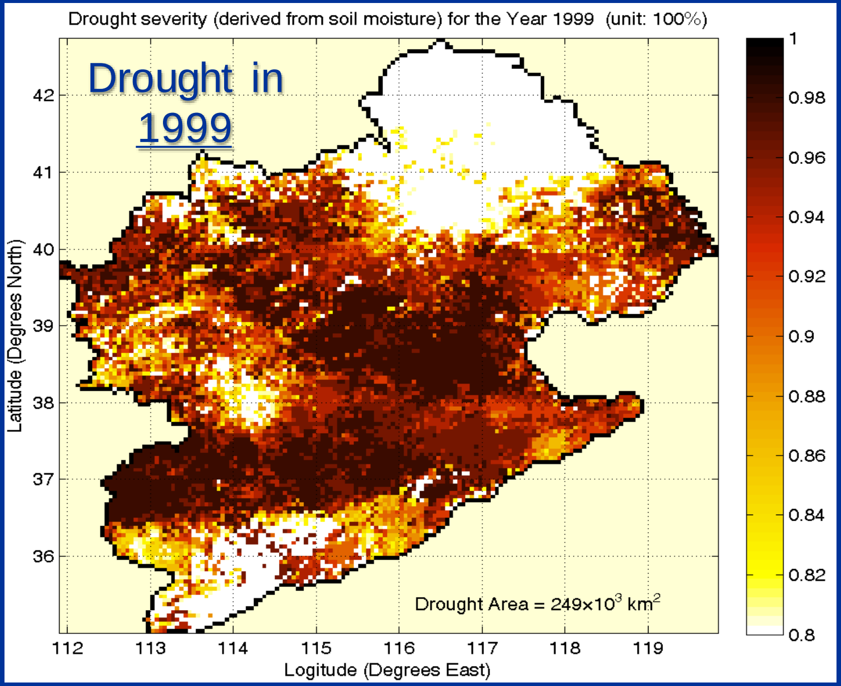
Andreadis et al, 2005. Twentieth-Century Drought in the Conterminous United States, Journal of Hydrometeorology.

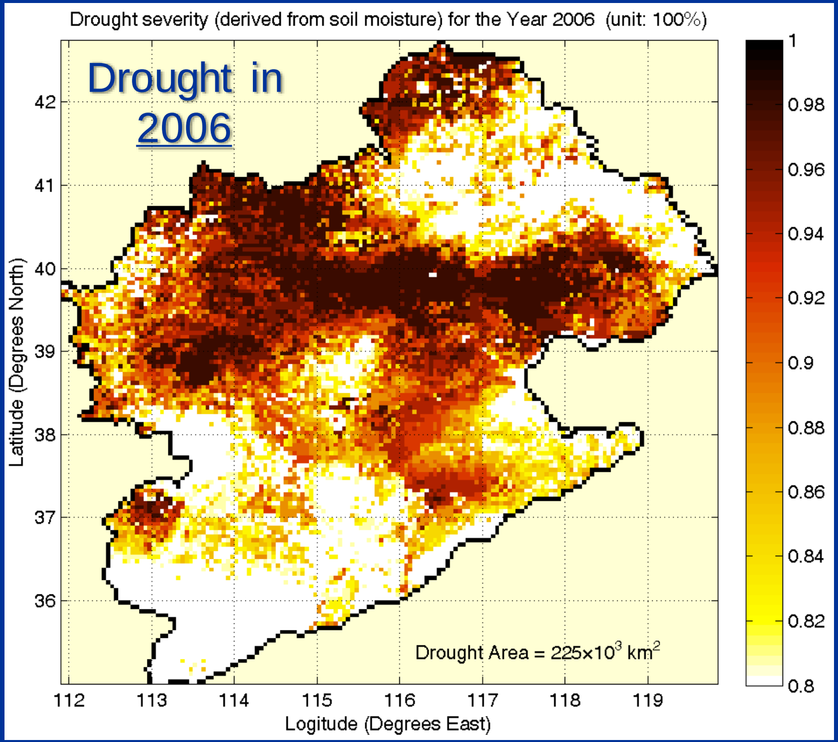
■ Inter-annual variability of the drought during 1960-2010



Drought area percentage of Haihe River Basin (1960-2010)







- Land surface model (CLM4.0) is a useful tool for predicting the impact of climate change.
- Dynamic vegetation phenology is important for simulating runoff under the climate change.

4. Conclusion

- The northern China is facing serious water shortage due to its relatively dry climate and dense population, where the ecohydrological processes are important for understanding the changes in water resources.
- The Haihe basin is a typical nature-human coupled system in which water is the control factor for the balance between the nature and human.
- The eco-hydrological modeling/prediction is the first step towards the better management of the water resources in this region.

Thanks for your kind attention

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