Evolution characteristics of global land surface water resources

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Outline

01 Background

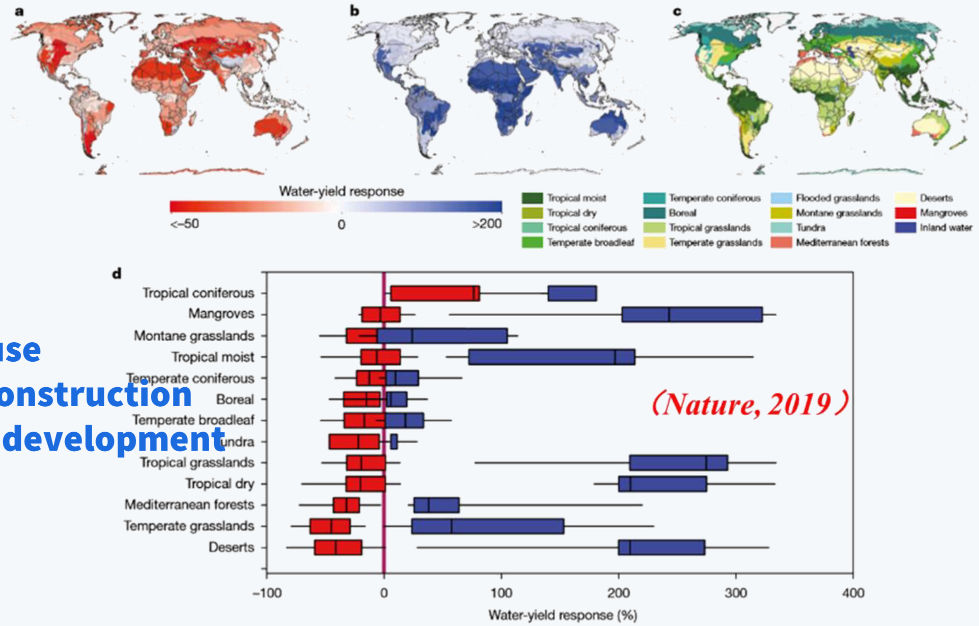
02 Basic Data

03 Water resource simulator

04 Evolution mechanism

05 Data quality evaluation

1 Background



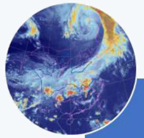
(Nature, 2019)

- **Land use**
- **Dam construction**
- **Water development**
- **……**

- **Climate change**
- **Human activities**

Evolution mechanism of global terrestrial water resources

Generalized Water Resources Evaluation and Prediction



Future trends

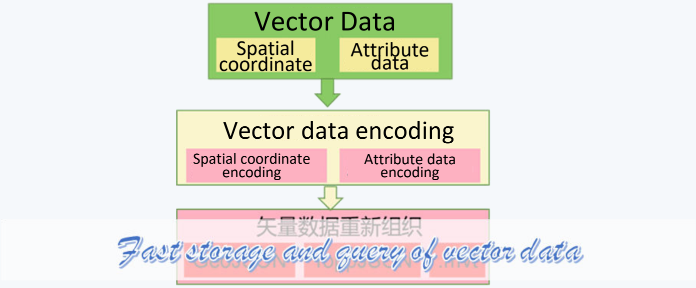
Clarify the situation

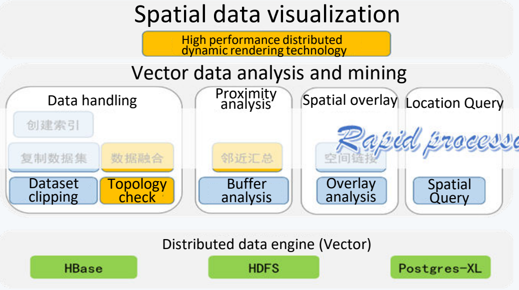
1 Responding to global climate change

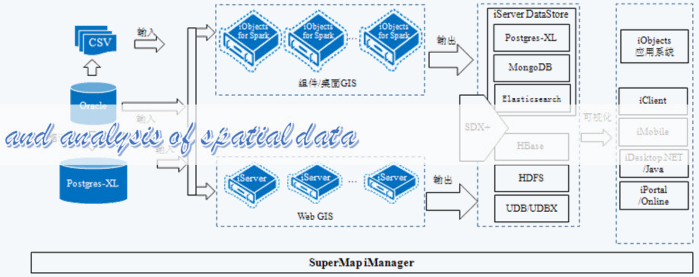
2 Optimizing of socio-economic layout

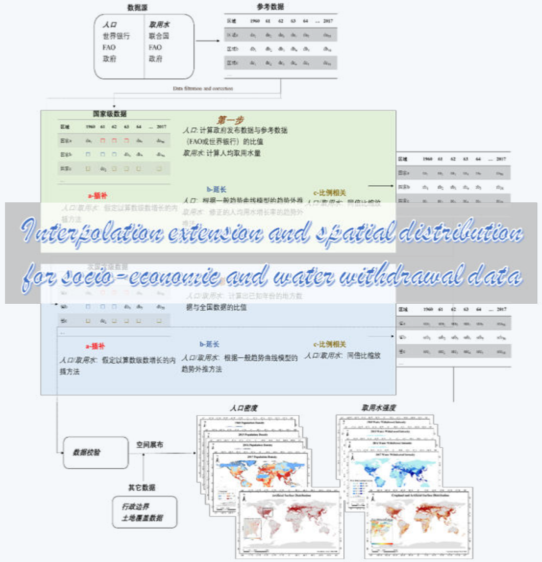
3 Adjusting the eco-environmental protection strategy

2 Basic data *Collection and standardized processing*

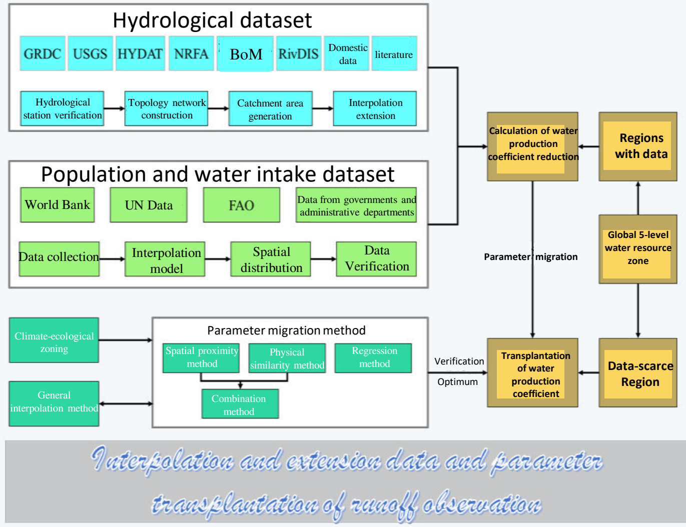


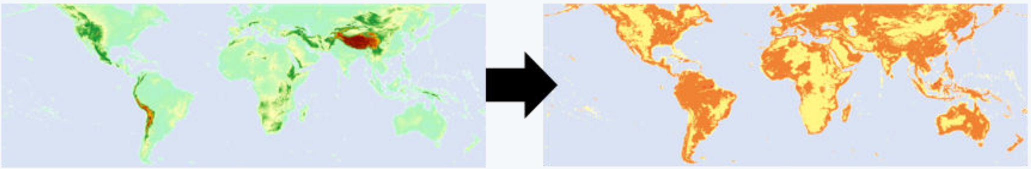






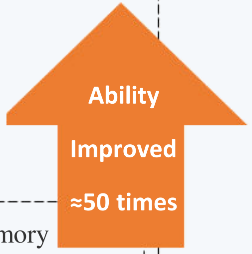
Figshare data platform（https://doi.org/10.6084/m9.figshare.10012559.v1）





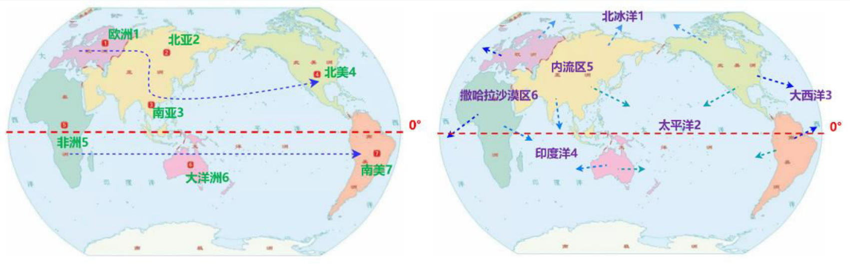
52 hours
Traditional computing mode
Generate a large amount of intermediate temporary data in the process
CPU 4 core 16 GB memory

1.1 hours
Distributed computing mode
Function chain Intermediate data does not require storage
8-node: CPU 4 core 16 GB memory

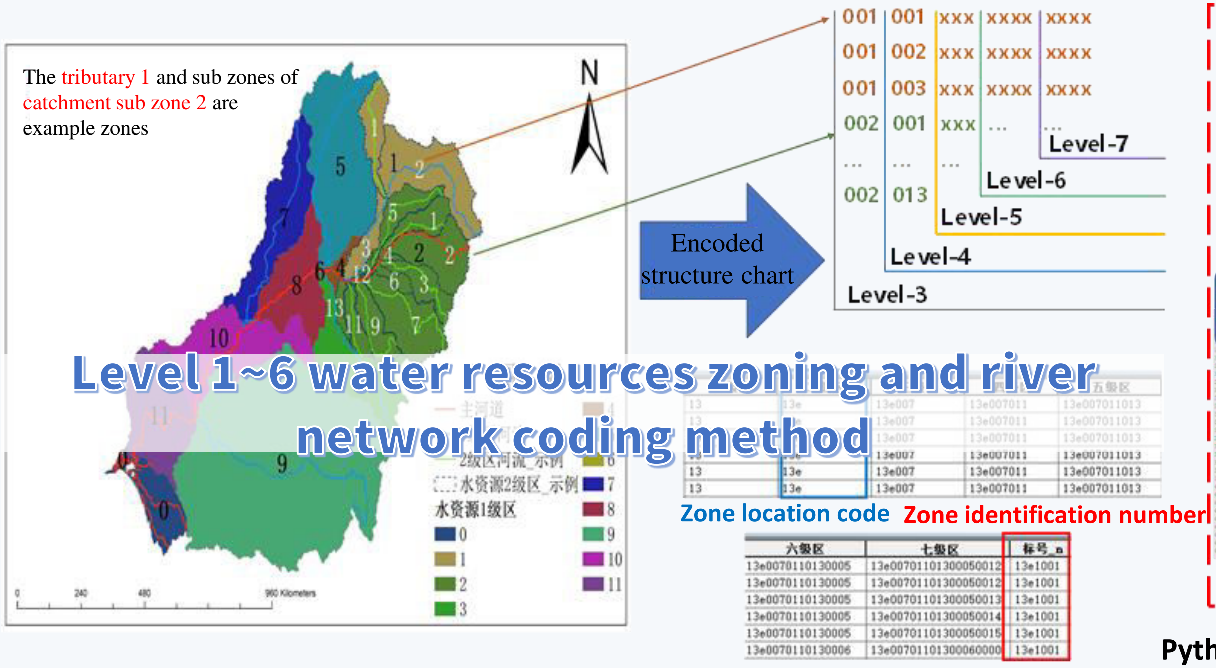


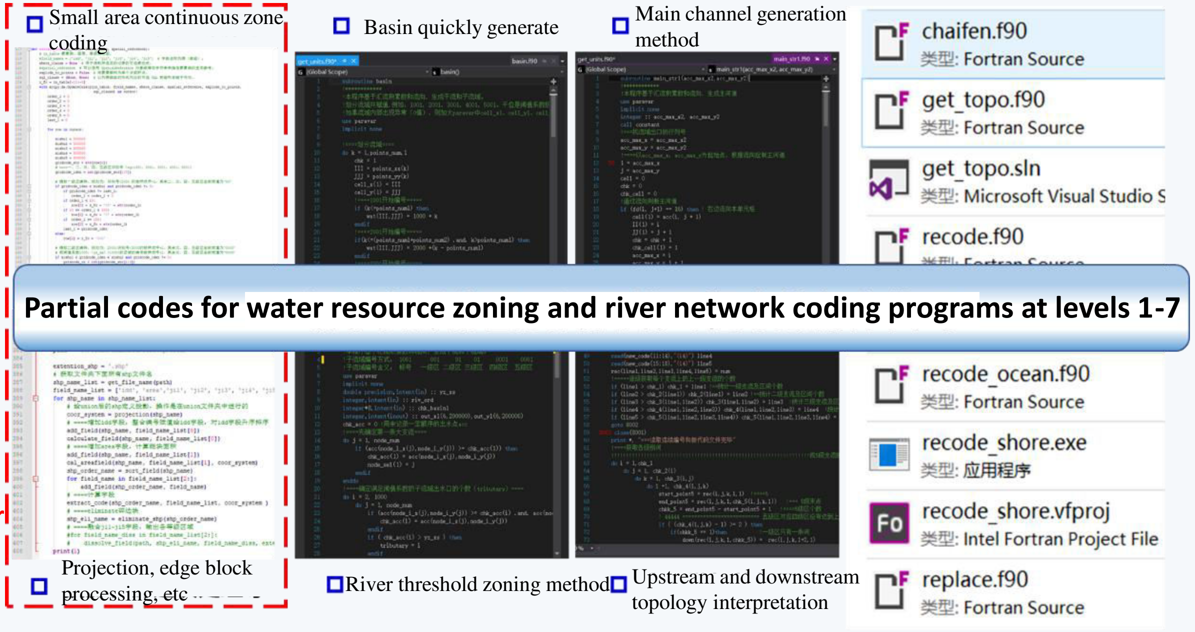
2 Basic data *Global 1-7 river network and 1-7 water resources zoning*

◆ Technology



- **Level 1-2 water resources zoning** 21a： **Asia** (2) **into Arctic Ocean** (
- **Level 3-7 water resources zoning** 001 001 001 0001 0001





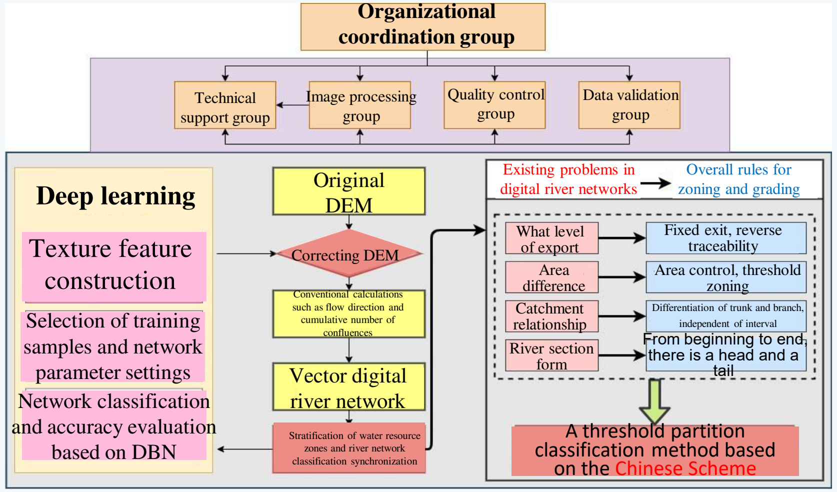
Python development program

Fortran development program

2 Basic data

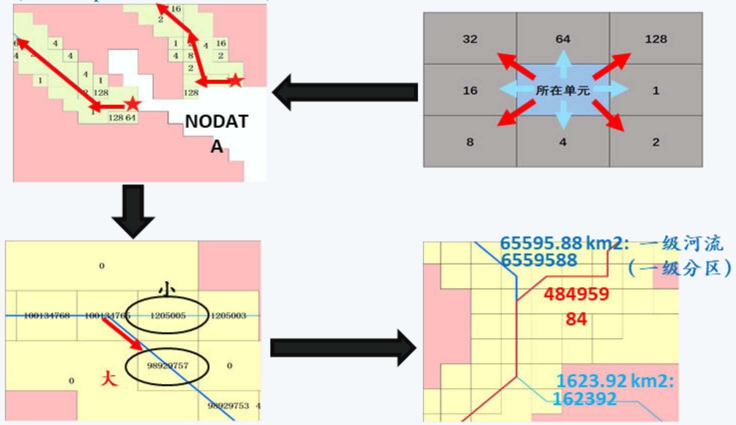
Global 1-7 river network and 1-7 water resources zoning

◆ Technology



Exit location
(Cells imported into NODAT)

D8 flow direction

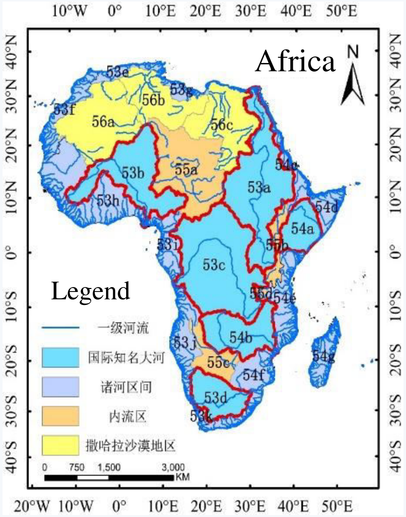


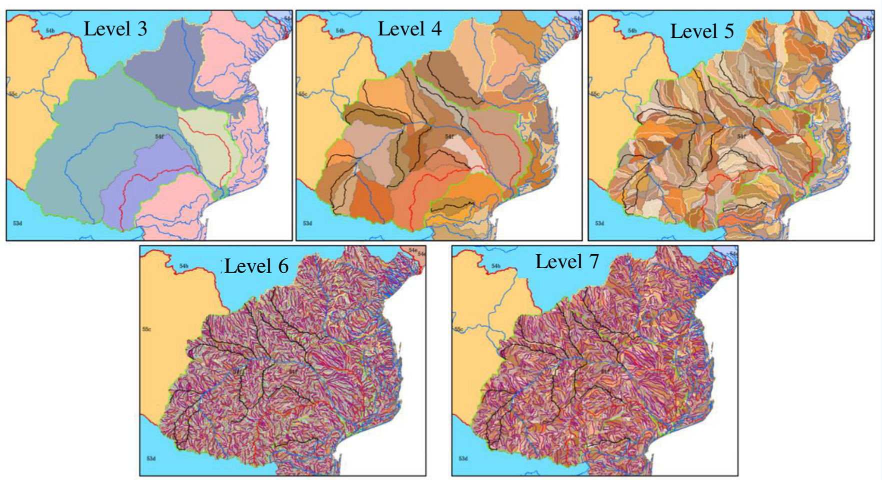
Tracing where the cumulative number of confluences is relatively large

Threshold partition classification (Grid size 0.01 Km^2)

Level 1~7 river network division standard

- **Level 1**: The rivers flow into the same ocean or the same endorheic basin (excluding Greenland and Antarctica)
- **Level 2**: The independent and world-famous large exorheic rivers, the rivers that flow into the sea alone in coastal areas or the same endorheic basin
- **Level 3**: The rivers that flow into the L2 RN with confluence area larger than 50000 km^2 or flow into the ocean alone
- **Level 4**: The rivers that flow into the L3 RN with confluence area larger than 10000 km^2 or flow into the ocean alone
- **Level 5**: The rivers that flow into the L4 RN with confluence area larger than 1000 km^2 or flow into the ocean alone
- **Level 6**: The rivers that flow into the L5 RN with confluence area larger than 100 km^2 or flow into the ocean alone
- **Level 7**: The rivers that flow into the L6 RN with confluence area larger than 50 km^2 or flow into the ocean alone

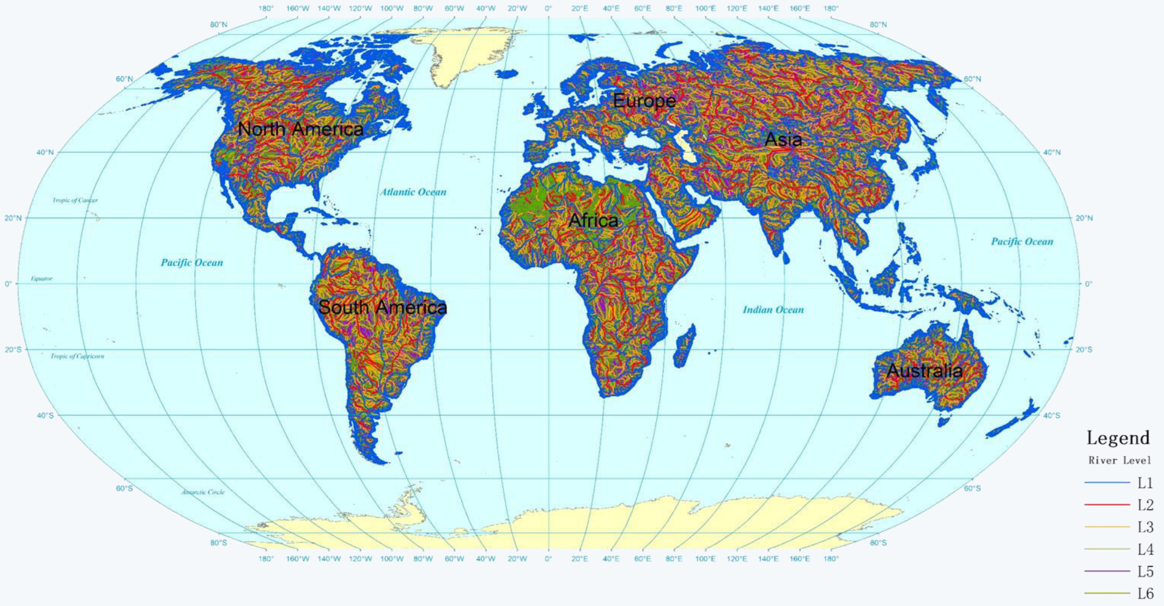


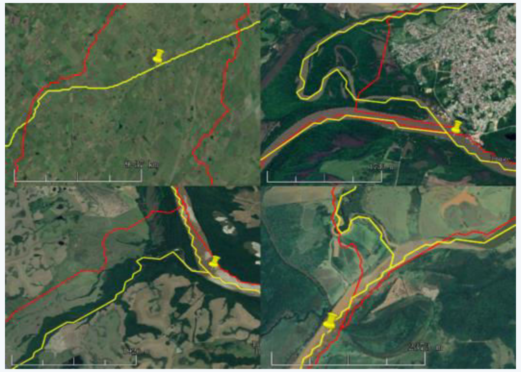


2 Basic data

Global 1-6 river network and 1-7 water resources zoning

◆ Technology





Accuracy comparison between rivers obtained by our technology and HDMA

（Red lines ：HDMA ；Yellow lines ：our technology）

Area	Global average	This study	HDMA	Offset distance	Percentage reduction in deviation distance
Global average	1	176.73	570.58	393.85	69%
	2	119.07	515.97	396.89	77%
	3	108.13	450.24	342.12	76%
	4	125.18	490.52	365.34	74%
	Average value	132.28	506.83	374.55	74%
South America	1	65.93	866.14	800.21	92%
	2	71.41	670.75	599.34	89%
	3	55.13	326.11	270.98	83%
	4	63.86	420.24	356.38	85%
North America	1	234.33	377.33	142.99	38%
	2	106.68	411.08	304.39	74%
	3	135.54	198.22	62.67	32%
	4	98.58	243.90	145.32	60%
Europe	1	128.90	305.78	176.88	58%
	2	110.79	539.31	428.53	79%
	3	117.06	735.84	618.78	84%
	4	95.10	655.71	560.61	85%
Africa	1	364.93	935.81	570.88	61%
	2	184.89	610.68	425.79	70%
	3	102.32	668.20	565.88	85%
	4	217.21	661.89	444.68	67%
Asia	1	228.73	850.46	621.72	73%
	2	112.63	590.73	478.10	81%
	3	130.62	569.97	439.35	77%
	4	196.17	750.87	554.69	74%
Oceania	1	37.58	87.96	50.38	57%
	2	128.04	273.24	145.20	53%
	3	108.10	203.13	95.04	47%
	4	80.16	210.50	130.34	62%

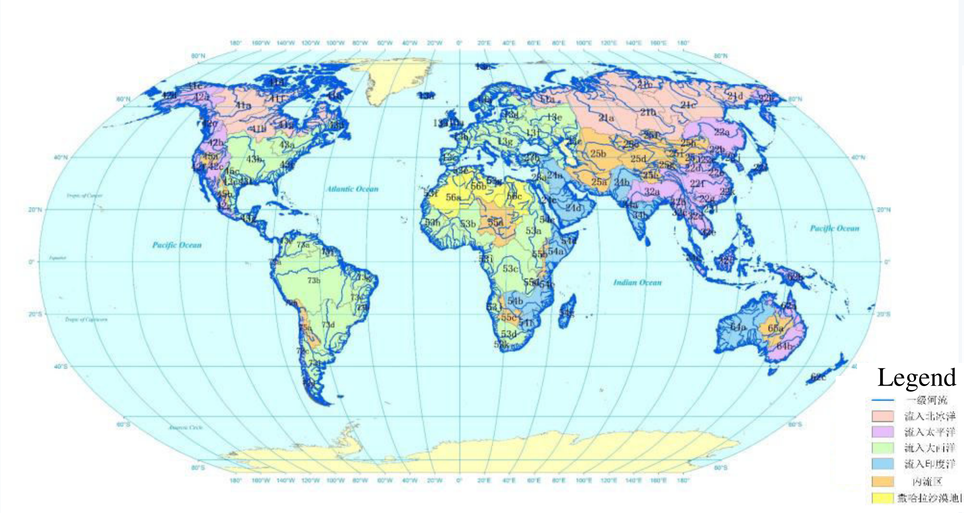
Characteristics

- ➢ **Achieved the full, continuous and automatic extraction from the origin of the ridge line to the estuary**
- ➢ **Realized the one-time automatic extraction of the clear hierarchical river network**
- ➢ **Realized the automatic extraction of rivers in the inner flow area**
- ➢ **Each river/section has a unique code, the topological and hierarchical**

2 Basic data

Global 1-6 river network and 1-7 water resources zoning

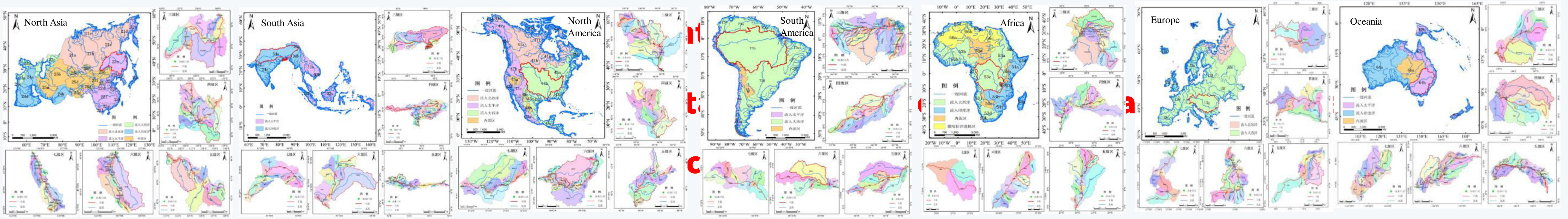
◆ Results



Global terrestrial water resources area of Level 1-2

Water resources zones	Asia	Europe	Oceania	South America	North America	Africa	Global
Level 1	7	2	3	3	4	4	23
Level 2	[illegible]	[illegible]	6	14	24	25	120
Level 3	333	71	73	133	166	236	1012
Level 4	1060	402	[illegible]	818	863	1289	[illegible]
Level 5	18797	4066	3756	7417	9260	12924	56220
Level 6	[illegible]	[illegible]	37201	74599	93524	126146	558595
Level 7	467632	103000	93264	187213	231081	314970	1397160

- ➢ **Realized 7 levels of refined water resources zoning based on the Chinese plan**
- ➢ **Realized the unique code of water resources area with clear topological relationship**
- ➢ **Obtained the boundaries of internal flow zones on all**



2 Basic data

Global climate-ecology-hydrological zoning

◆ Technology

Köppen climate zone

Indicator type	zoning indicators
Precipitation	Annual total precipitation
	Summer total precipitation
	Winter total precipitation
	Maximum monthly average precipitation in summer
	Maximum monthly average precipitation in winter
	Minimum monthly average precipitation in summer
	Minimum monthly average precipitation in winter
	Minimum monthly average
	Precipitation threshold
Temperature	Annual average temperature
	Average temperature of the warmest month
	Average temperature of the coldest month

Climatic zone	Prerequisite	Climate Type	Partition conditions
A Tropical climate	The average temperature of the coldest month is≥18℃	Af Tropical rainforest climate	Minimum monthly average precipitation≥60mm
		Am Tropical monsoon climate	100 year total precipitation/25≤Minimum monthly average precipitation<60mm
		Aw Tropical savanna climate	Minimum monthly average precipitation<60mm Minimum monthly average precipitation<100-Annual total precipitation/25
B Arid climate	The annual total precipitation is < the annual precipitation threshold	Bw Desert climate	Annual total precipitation/Annual precipitation threshold<0.5
		Bs Grassland climate	0.5≤Annual total precipitation/Annual precipitation threshold<1
C Warm climate	0℃≤Average temperature of the coldest month<18℃ Average temperature of the warmest month≥10℃	Cs Warm summer dry climate	Maximum monthly average precipitation in winter>3×Minimum monthly average precipitation in summer Minimum monthly average precipitation>30mm
		Cw Warm winter dry climate	Maximum monthly average precipitation in summer>10×Minimum monthly average precipitation in winter
		Cf Warm and humid climate	The proportion of rainfall with uneven distribution of global precipitation that cannot reach Cs and Cw
D Cold climate	Average temperature of the coldest month<0℃ Average temperature of the warmest month≥10℃	Ds Cold summer dry climate	Maximum monthly average precipitation in winter>3×Minimum monthly average precipitation in summer Minimum monthly average precipitation>30mm
		Dw Cold winter dry climate	Maximum monthly average precipitation in summer>10×Minimum monthly average precipitation in winter
		Df Cold and humid climate	The proportion of rainfall with uneven distribution of global precipitation that cannot reach Ds and Dw
E Polar climate	Average temperature of the warmest month<10℃	ET Tundra climate	0℃≤Monthly average temperature<10℃
		EF Ice field climate	Monthly average temperature<0℃

Climate-ecology zoning based on K-Means unsupervised classification

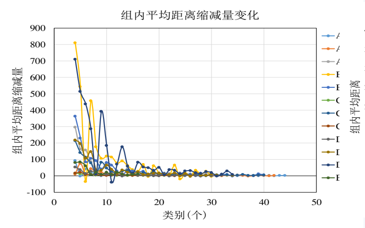
Classification function

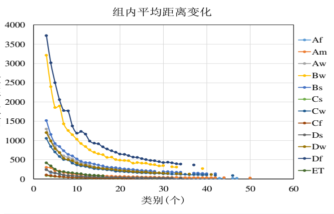
$$\begin{cases} E = \sum_{i=1}^{k} \sum_{x \in A_i} \left\| x - \mu_i \right\|_2^2 \\ \mu_i = \frac{1}{|A_i|} \sum_{x \in A_i} x \\ d_{ij} = \left\| x_i - \mu_j \right\|_2^2 \end{cases}$$

Constraint function

$$\begin{cases} \left| d_k - d_{k+1} \right| \le m \\ \left| d_{k+2} - d_{k+1} \right| \le m \\ \left| d_{k+3} - d_{k+2} \right| \le m \end{cases}$$

Indicator type	Indicator selection
Topographic features	Elevation(m)
	Surface undulation(m)
Land cover	Cultivated area(%)
	Wetland area(%)
	Water area(%)
	Tundra area(%)
	Artificial surface area(%)
	Bare land area(%)
	Glacier area(%)
Vegetation type	Forest area(%)
	Grassland area(%)
	Shrub area(%)
Soil	Soil type





Climate-ecology-hydrology zoning considering water production and water resources development

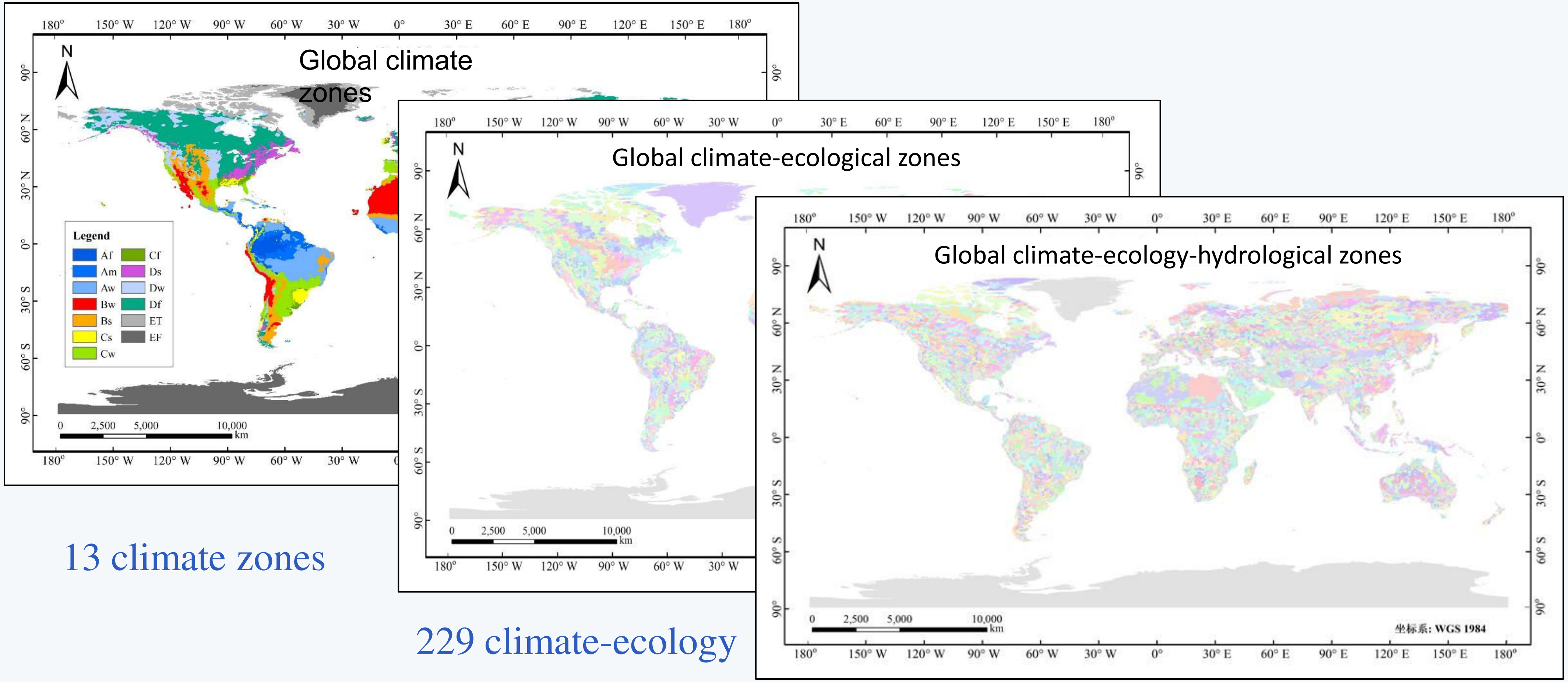
Physical feature type	Physical feature parameters	Hydrological process
Climatic characteristics	Annual precipitation(mm)	Precipitation
	Precipitation concentration degree	
	Annual average temperature(℃)	Evapotranspiration
	Maximum monthly average temperature	
	Minimum monthly average temperature	
	Annual total evaporation	
	Sensitivity	Meteorological element fluctuations
Topographic features	Elevation(m)	Precipitation
	Surface undulation(m)	Surface interception, slope convergence, and soil flow
	Slope(°)	
River network features	River network density	River network division
Land cover	Cultivated area(%)	Surface runoff and evapotranspiration
	Wetland area(%)	
	Water area(%)	
	Tundra area(%)	
	Artificial surface area(%)	
	Bare land area(%)	
	Glacier area(%)	
Vegetation	Forest area(%)	Surface runoff and evapotranspiration
	Grassland area(%)	
	Shrub area(%)	
	NDVI index	Evapotranspiration
Soil	Soil type	Soil water movement, infiltration process
	Soil thickness(cm)	
Social economy	Population density	Social water cycle
	Water intensity	

Classification	Classification of water production coefficient					
	1	2	3	4	5	6
Water production coefficient conditions	<0.2	0.2~0.4	0.4~0.6	0.6~0.8	0.8~1.0	>1
Number of Level 4 water resource zones	20866	21796	105247	4369	1660	1349

Classification	Classification of surface water resource development and utilization rate				
	1	2	3	4	5
Development utilization conditions	<0.1	0.1~0.2	0.2~0.4	0.4~0.8	>1
Number of Level 4 water resource zones	45158	3775	3907	3535	4189

2 Basic data *Global climate-ecology-hydrological zoning*

◆ Results



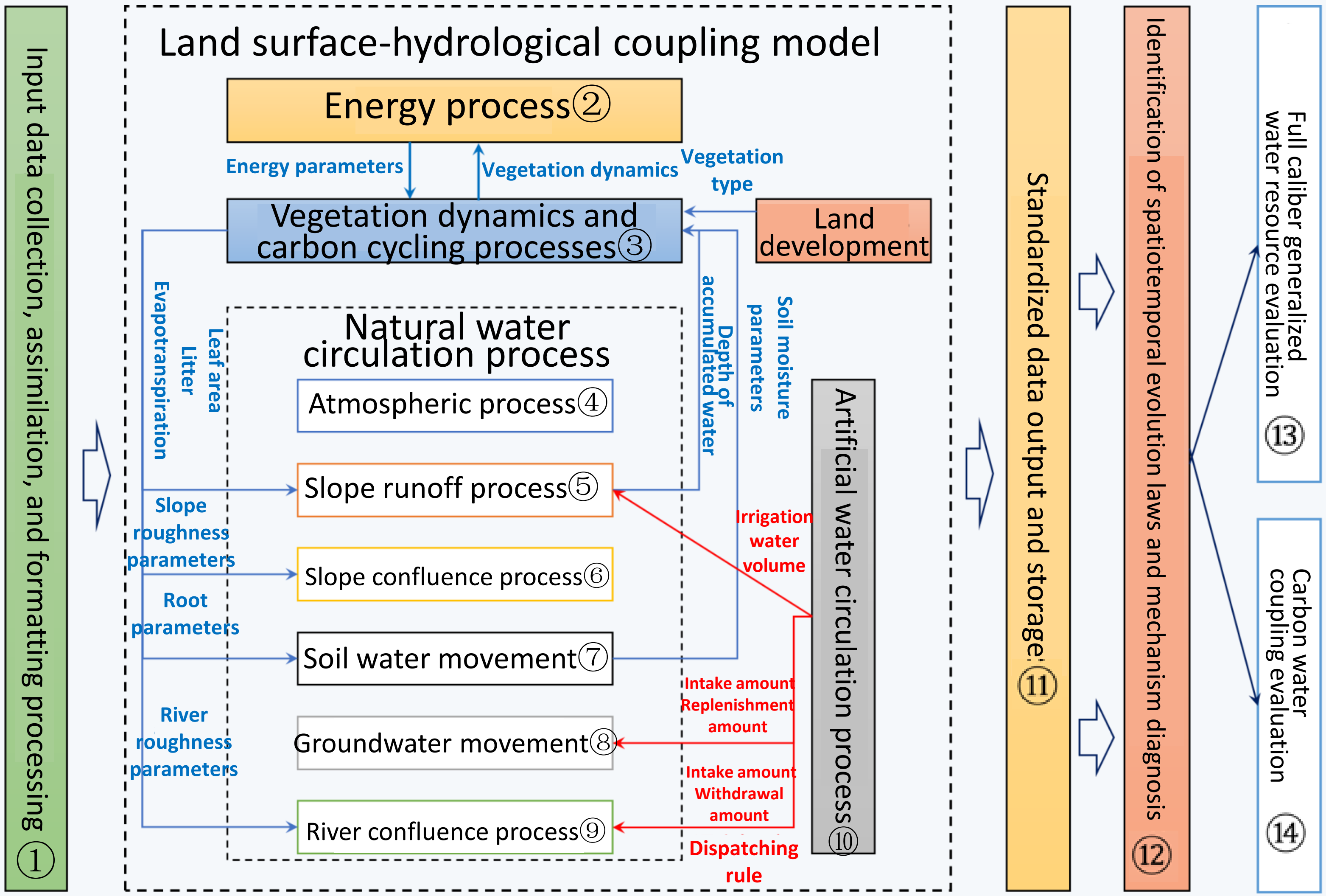
13 climate zones

229 climate-ecology zones

2561 climate-ecology-hydrological zones

3 Water resource simulator

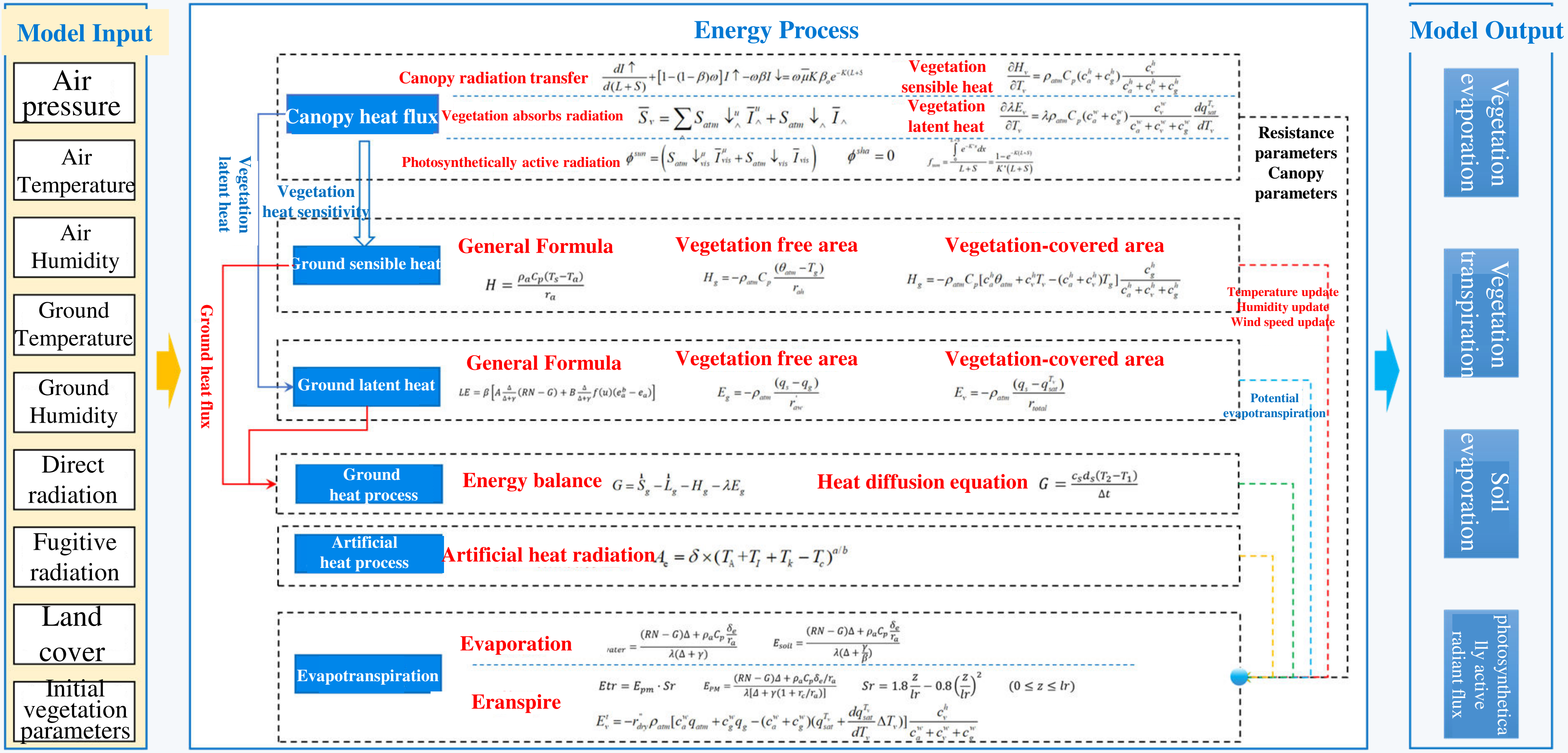
Coupling simulation framework



3 Water resource simulator

Factor simulation method

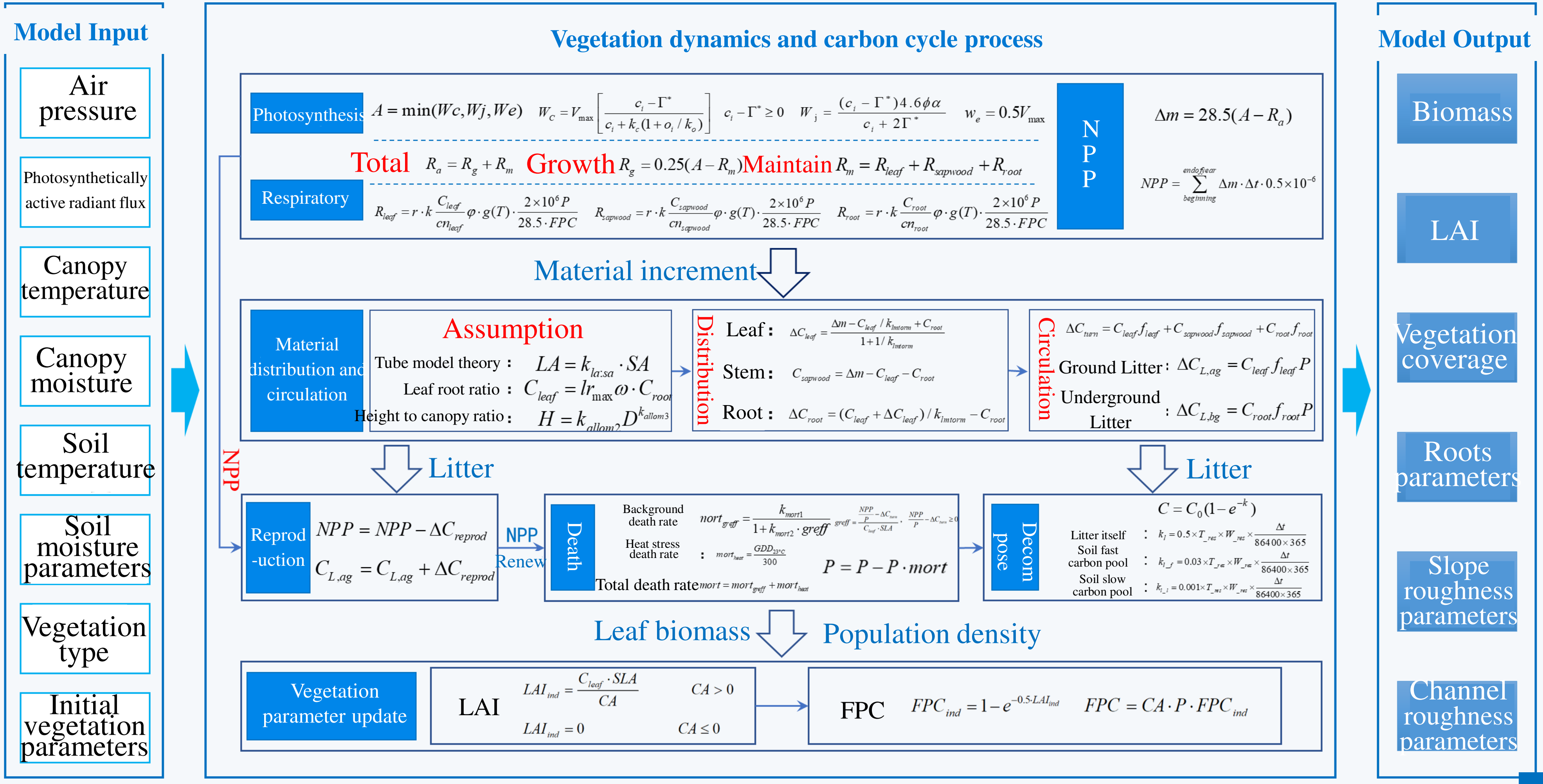
◆ Energy process



3 Water resource simulator

Factor simulation method

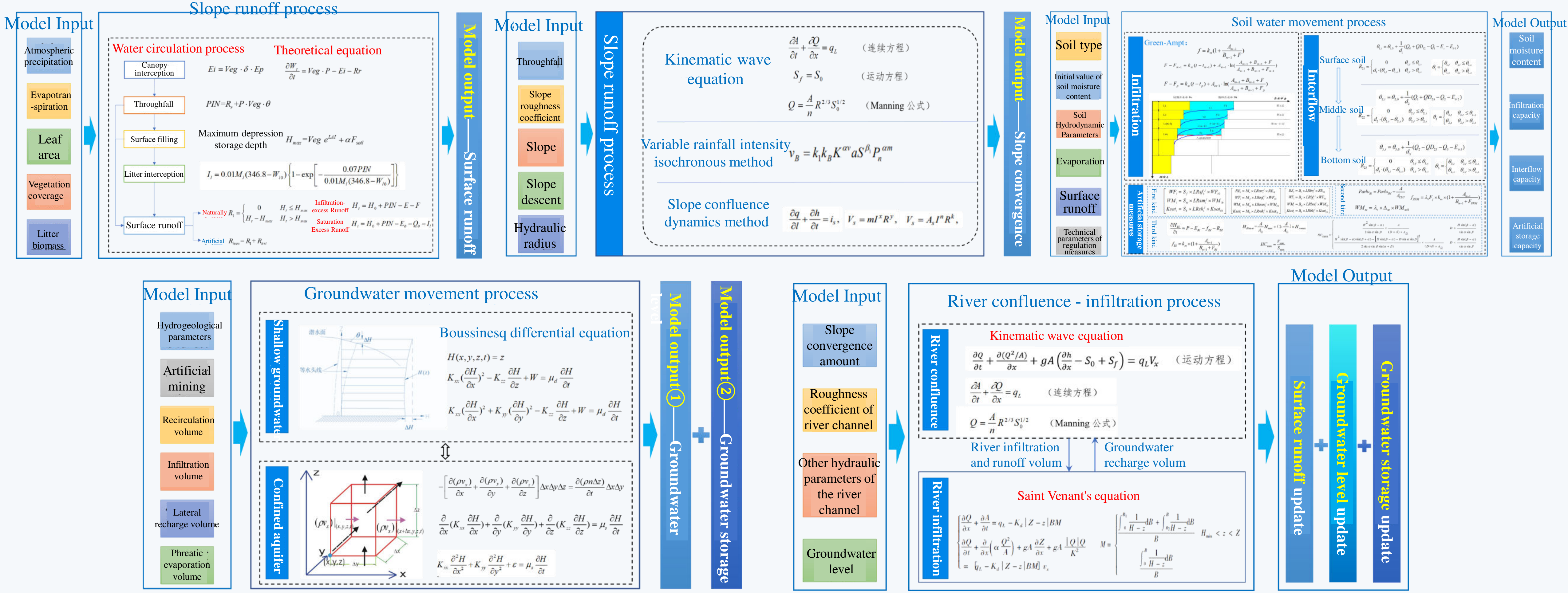
◆ Carbon cycle



3 Water resource simulator

Factor simulation method

◆ Water cycle

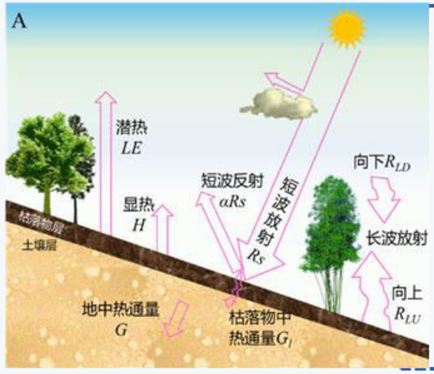


3 Water resource simulator

Factor simulation method

◆ Litter

Key Element Mechanism Equation ⇨ Slope Unit scale ⇨ Basin scale



Energy Process

- Energy balance $R_N = LE + H + G_l + G$
- ⚠ The blocking effect of litter on shortwave radiation
- Net shortwave radiation absorbed by litter

$$R_{SNL} = R_s(1-\alpha_l)(\tau_v F_{veg} + F_{soil}) - R_s(1-\alpha_s)(\tau_v F_{veg} + F_{soil})\tau_l$$

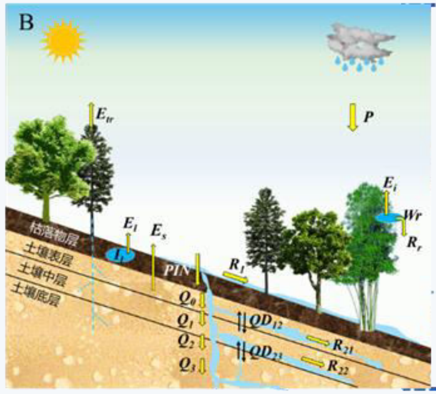
- Net shortwave radiation reaching the soil surface

$$R_{SNS} = R_s(1-\alpha_s)(\tau_v F_{veg} + F_{soil})\tau_l$$

Through litter

- Litter heat flux G_l根据Park et al.（1998）的公式计算

$$G_l = \lambda_l (T_{ls} - T_{ss})/THK$$



Water Cycle

Runoff

- Litter interception formula

$$I_l = 0.01M_l(346.8 - W_{l0})\left\{1 - \exp\left[-\frac{0.07PIN}{0.01M_l(346.8 - W_{l0})}\right]\right\}$$

- Litter evaporation formula

$$E_l = (\rho_{vl} - \rho_{va})/r_l \Rightarrow E_l = \frac{\Delta R_{NL} + \rho_a C_p \delta_e / r_a}{\lambda(\Delta + 0.622^2 \gamma r_l / r_a)}$$

- Formula for soil evaporation under litter cover

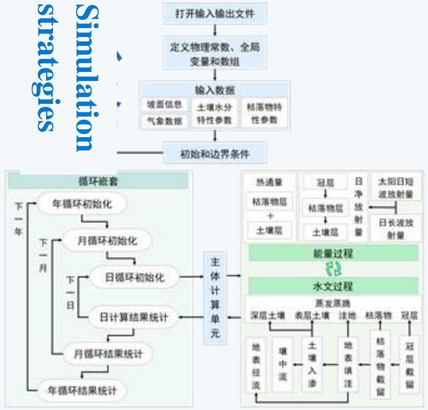
$$E_s = (\rho_{vs} - \rho_{vl})/(r_l + r_s) \Rightarrow E_s = \frac{\Delta R_{NS} + \rho_a C_p \delta_e / r_a}{\lambda\left(\Delta + 0.622^2 \gamma \frac{r_l + r_s}{r_a}\right)}$$

Confluence

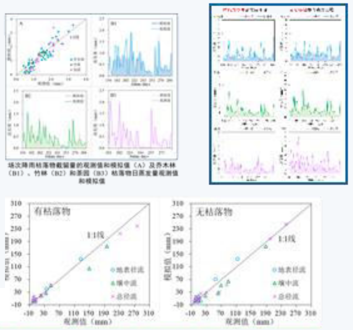
- Surface roughness parameters considering litter

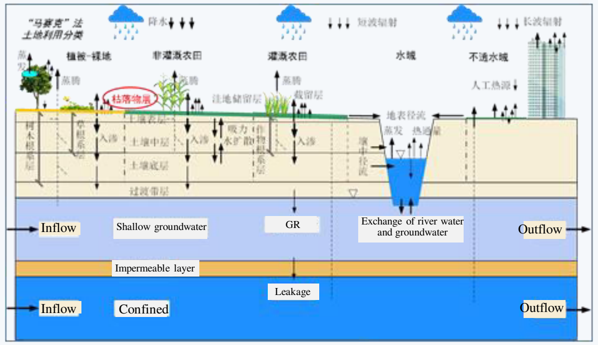
$$y = 0.006 + 1.047LI\_p + 0.003LI\_t - 0.002x_3LI\_c$$

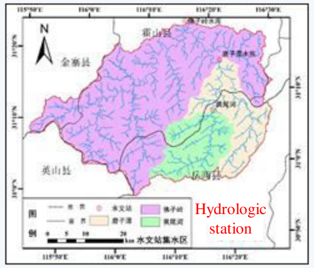
Simulation strategies

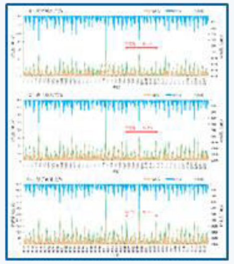


Calibration







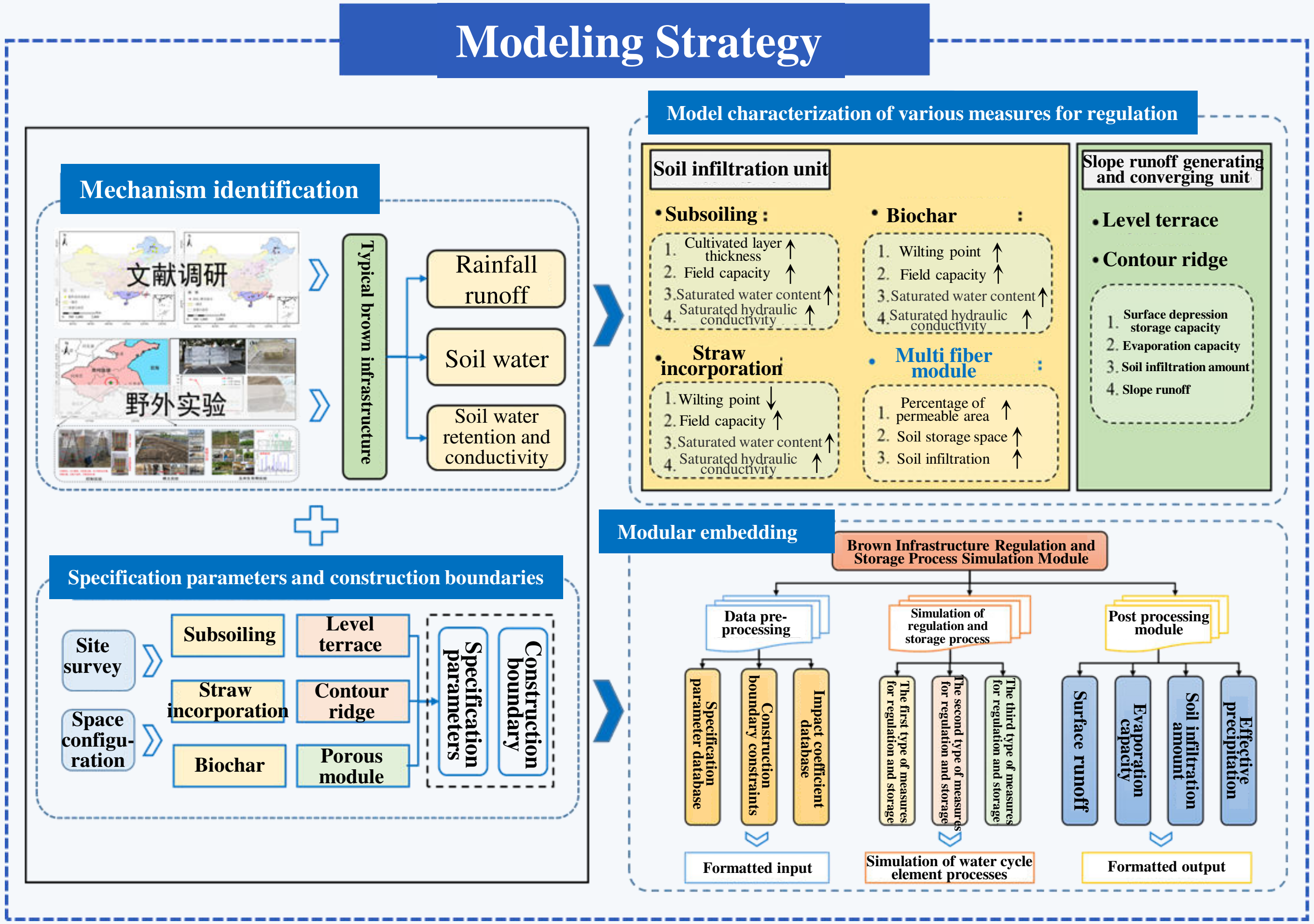


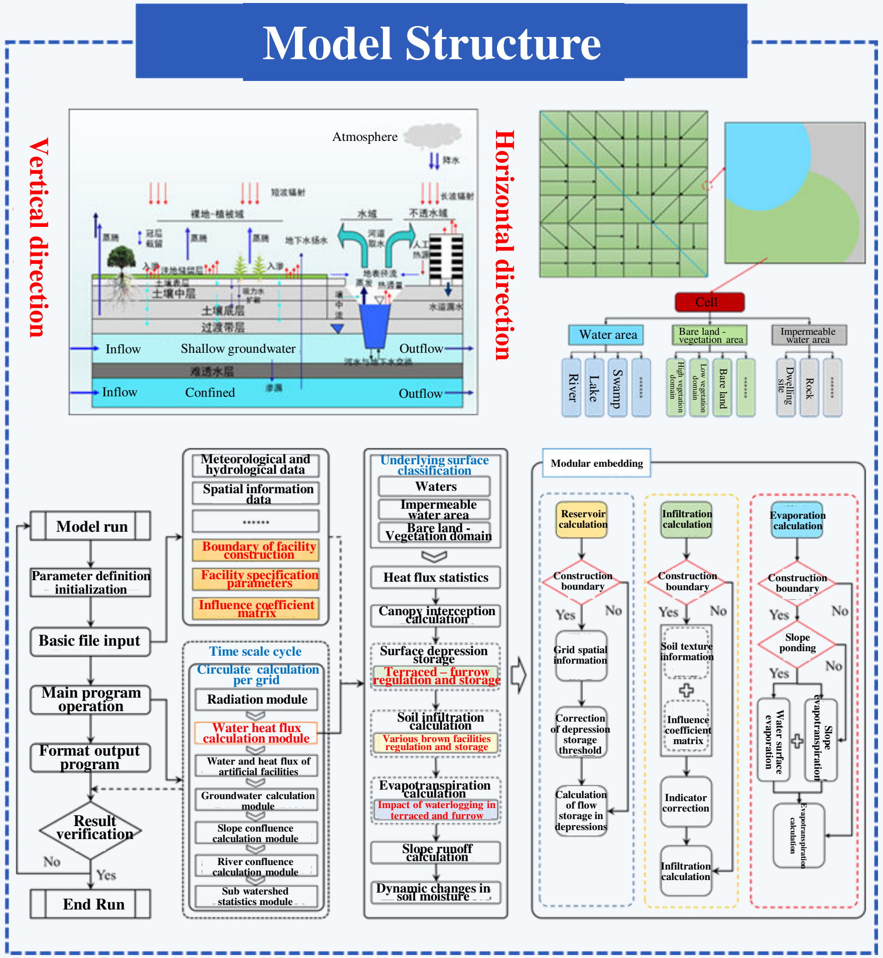
Hydrologic station	Calibration period（1972-2000年）			Verification period（2001-2015年）		
	NSE	RE	R^2	NSE	RE	R^2
黄尾河	0.76	-7.30	0.91	0.72	-4.77	0.87
磨子潭	0.69	-8.57	0.87	0.77	-0.14	0.89
佛子岭	0.67	-6.75	0.87	0.75	1.64	0.89

3 Water resource simulator

Factor simulation method

Regulation measures on slope





3 Water resource simulator

Factor simulation method

◆ Regulation measures on slope

First Class Facility

- The key adjustment coefficient is the effect value of different environmental conditions and facility construction on soil water retention and conductivity characteristic indicators

• Subsoiling

$$\begin{bmatrix} WF_i = S_f \times LRsf_i^j \times WF_{i0} \\ WM_i = S_m \times LRsm_i^j \times WM_{i0} \\ Ksat_i = S_k \times LRsk_i^j \times Ksat_{i0} \end{bmatrix}$$

→ Field capacity
→ Saturated water content
→ Saturated hydraulic conductivity

• Biochar addition

$$\begin{bmatrix} RE_i = M_r \times LRmr_i^j \times RE_{i0} \\ WF_i = M_f \times LRmf_i^j \times WF_{i0} \\ WM_i = M_m \times LRmm_i^j \times WM_{i0} \\ Ksat_i = M_k \times LRmk_i^j \times Ksat_{i0} \end{bmatrix}$$

→ Wilting point
→ Field capacity
→ Saturated water content
→ Saturated hydraulic conductivity

• Returning straw to the field

$$\begin{bmatrix} RE_i = B_r \times LRbr_i^j \times RE_{i0} \\ WF_i = B_f \times LRbf_i^j \times WF_{i0} \\ WM_i = B_m \times LRbm_i^j \times WM_{i0} \\ Ksat_i = B_k \times LRbk_i^j \times Ksat_{i0} \end{bmatrix}$$

→ Wilting point
→ Field capacity
→ Saturated water content
→ Saturated hydraulic conductivity

Second Class Facility

- Changing the micro geomorphic structure and affecting the processes of depression storage, runoff production, evaporation, and infiltration

Correction of depression storage process

• Terrace construction

$$HT_{max} = \frac{V_{max}}{A_{\text{总}}} \approx \frac{b \times [h \times (\cot\alpha - \cot\theta) - B]}{h} \times \frac{A\sin}{A_{\text{总}}}$$

Maximum interception depth

$$ST_{max} \approx [h \times (\cot\alpha - \cot\theta) - B] \times \frac{A\sin\alpha}{h}$$

Accumulated water surface area

• Ridge layout

Maximum interception depth

$$VC_{max} = \begin{cases} \frac{H^2 \sin(\beta - \alpha)}{2\sin\alpha\sin\beta} \times \frac{A}{D+d} & D \ge \frac{H\sin(\beta-\alpha)}{\sin\alpha\sin\beta} \\ \frac{H^2 \sin(\beta-\alpha)\sin(\beta+\alpha) - [H\sin(\beta-\alpha) - D\sin\alpha\sin\beta]^2}{2\sin\alpha\sin\beta\sin(\alpha+\beta)} \times \frac{A}{D+d} & D < \frac{H\sin(\beta-\alpha)}{\sin\alpha\sin\beta} \end{cases}$$

$$SC_{max} = \begin{cases} \frac{H}{\sin\alpha} \times \frac{A}{D+d} & D \ge \frac{H\sin(\beta-\alpha)}{\sin\alpha\sin\beta} \\ \frac{2H\cos\beta + D\sin B}{\sin(\alpha+\beta)} \times \frac{A}{D+d} & D < \frac{H\sin(\beta-\alpha)}{\sin\alpha\sin\beta} \end{cases}$$

Accumulated water surface area

Correction of infiltration process

$$f_{BI} = k_m \times (1 + \frac{A_{m-1}}{B_{m-1} + F_{BI}})$$

Calculation of soil infiltration capacity in different soil layers

Correction of runoff process

Correction of evaporation process

$$\frac{\partial H_{BI}}{\partial t} = P - E_{BI} - f_{BI} - R_{BI}$$

Water balance

$$E_{BI} = E_i + E_{tr} + \frac{S_{BI}}{A_{\text{总}}} \times E_0 + (1 - \frac{S_{BI}}{A_{\text{总}}}) \times E_S$$

E_0: Water surface evaporation; E_S: Bare ground evaporation

$$R_{BI} = \begin{cases} 0 & H_{BI} \le H_{BImax} \\ H_{BI} - H_{BImax} & H_{BI} > H_{BImax} \end{cases}$$

Runoff yield calculation

$$H_{BImax} = \frac{A}{A_{\text{总}}} H_{max} + (1 - \frac{A}{A_{\text{总}}}) \times H_{svmax}$$

Maximum detention depth

Third Class Facility

- Reduce the proportion of impermeable area in the construction area
- Increase the effective storage space of soil units and enhance soil infiltration

• Porous fiber module landfill

$$Parlu_{BI} = Parlu_{IM} - \frac{A}{A_{CLU}}$$

→ Correction of impermeable area

$$WM_m = \lambda_v \times \Delta_m \times WM_{m0}$$

→ Correction of storage space

$$f_{PFM} = \lambda F_j \times k_m \times (1 + \frac{A_{m-1}}{B_{m-1} + F_{PFM}})$$

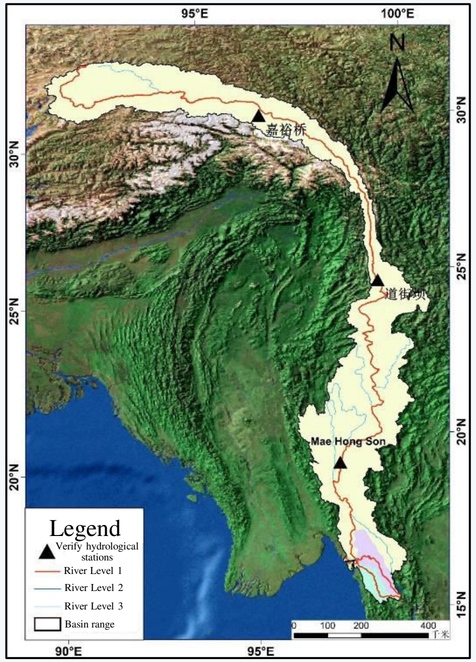
→ Correction of soil infiltration

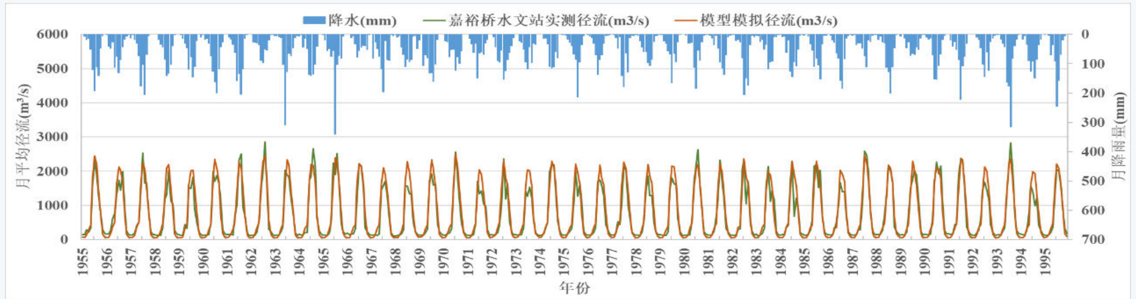
F_j: Theoretical impact of module landfill on soil infiltration

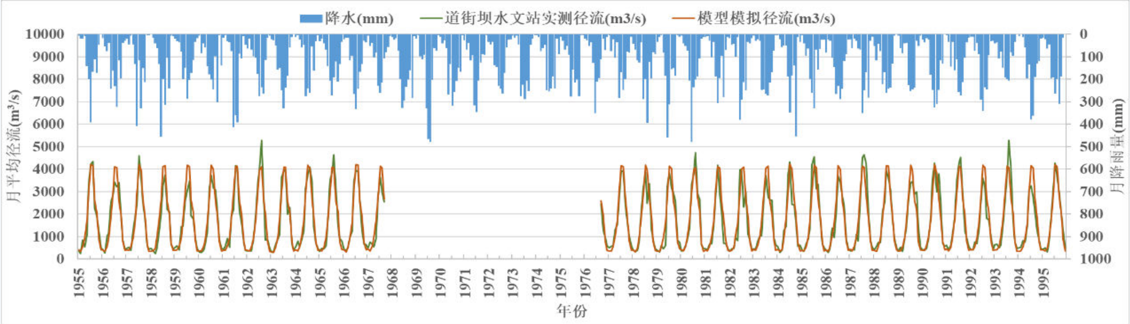
3 Water resource simulator

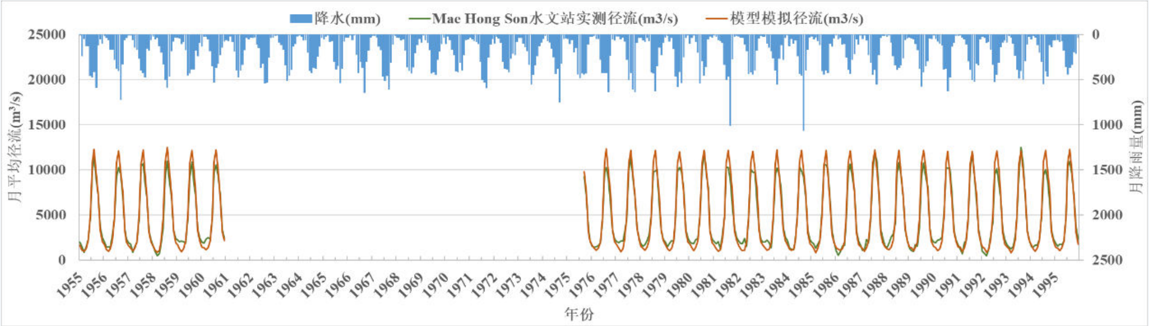
Calibration of typical watersheds

◆ Asia--Nujiang River







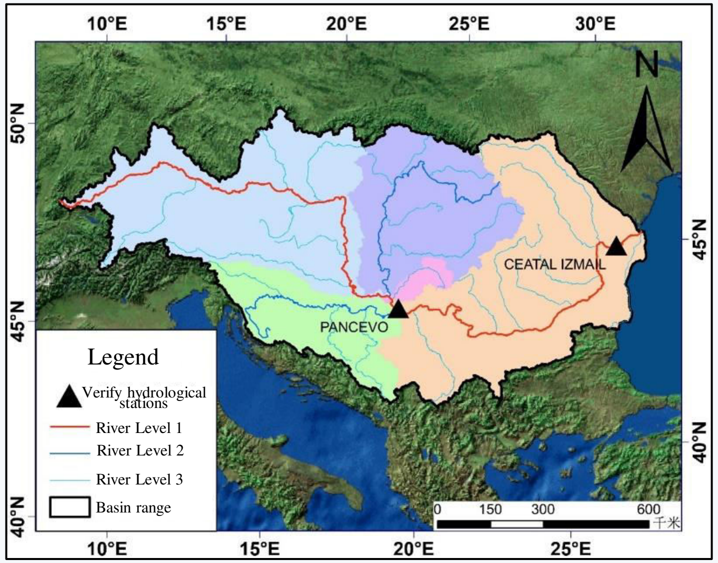


Hydrological station	R^2	NSE	RE (%)
Jiayuqiao	0.931	0.899	5.549
Daojieba	0.921	0.892	2.839
Mae Hong Son	0.987	0.955	2.346

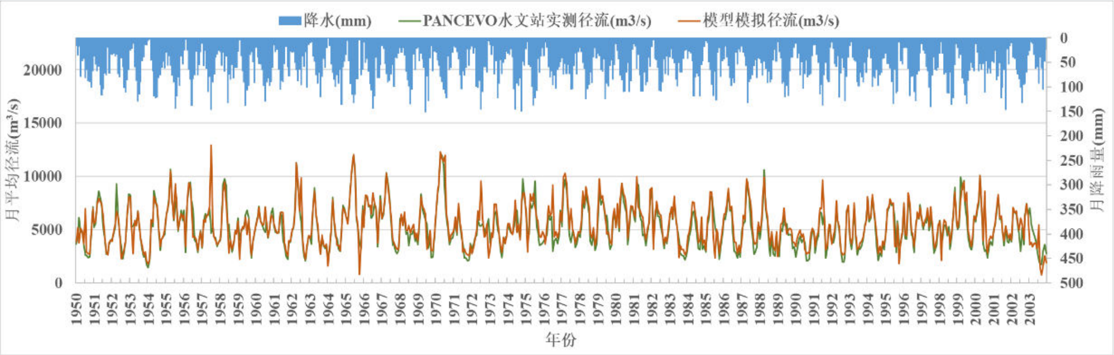
3 Water resource simulator

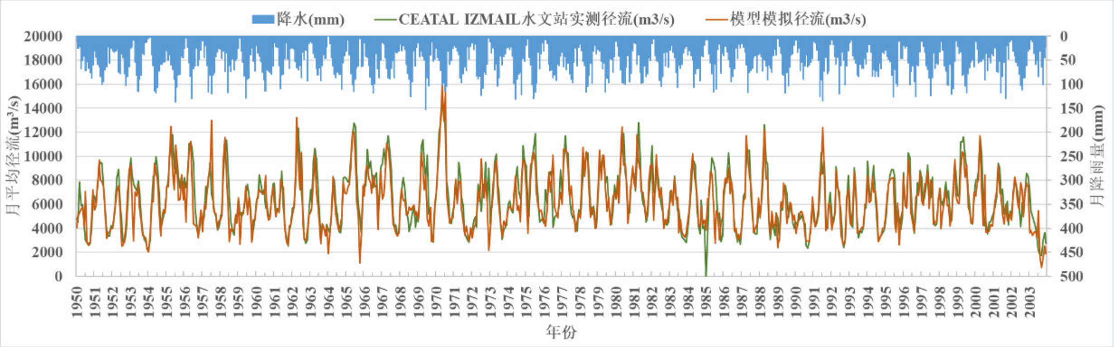
Calibration of typical watersheds

◆ Europe--Danube



Hydrological station	R^2	NSE	RE (%)
PANCEVO	0.898	0.766	4.397
CEATAL IZMAIL	0.862	0.704	4.097

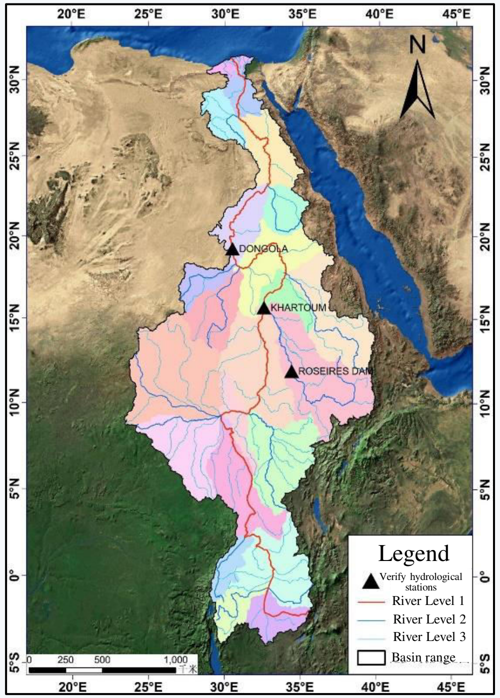


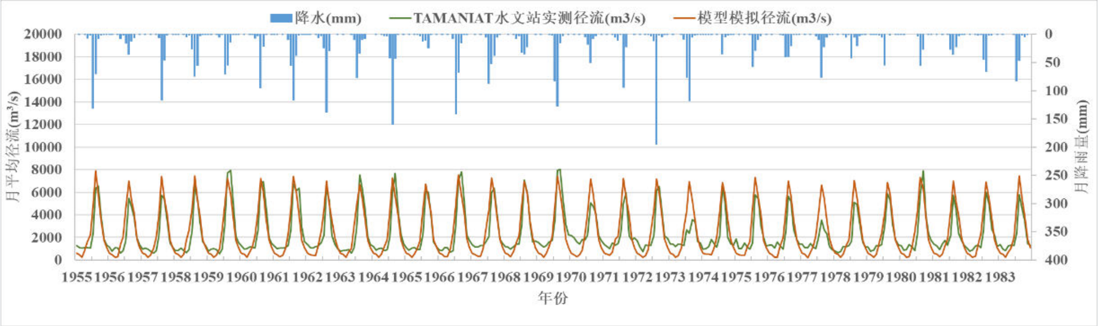


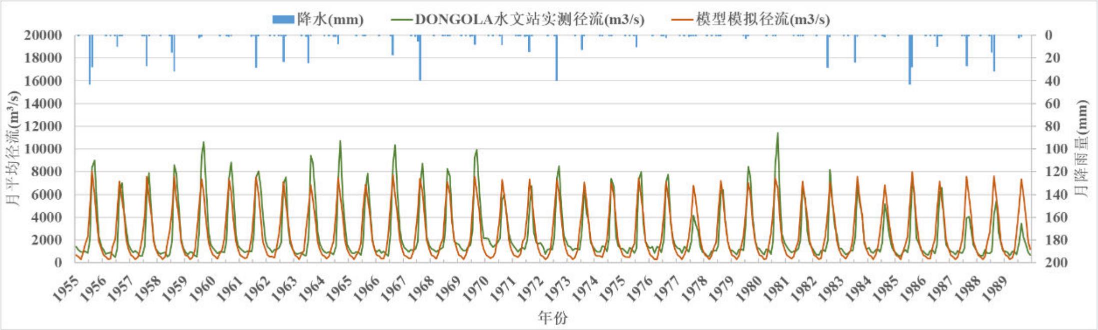
3 Water resource simulator

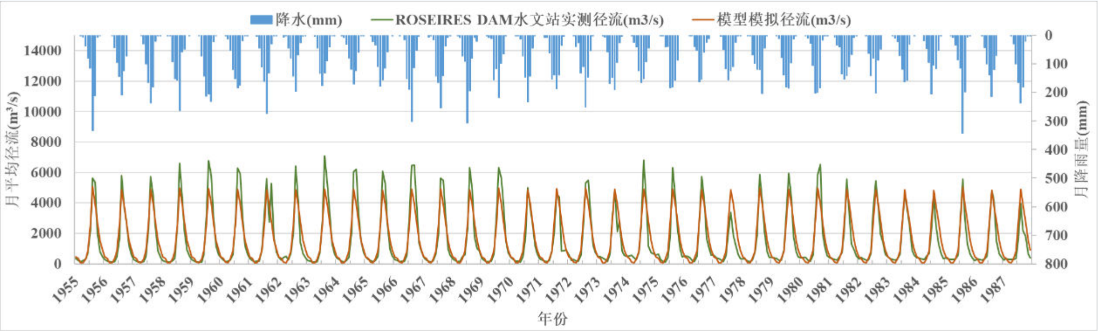
Calibration of typical watersheds

◆ Africa--Nile







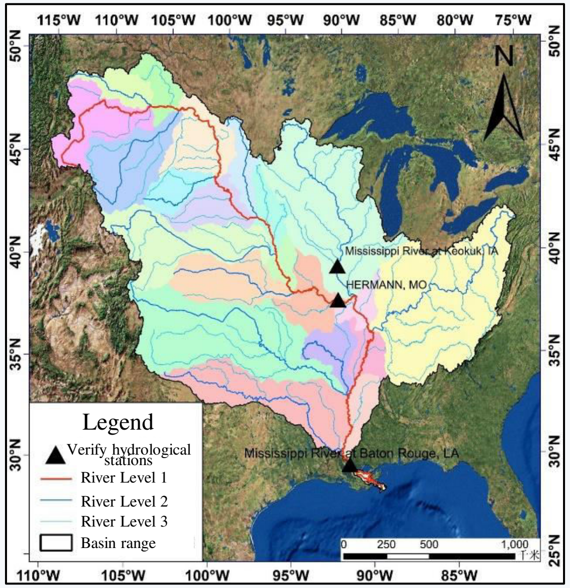


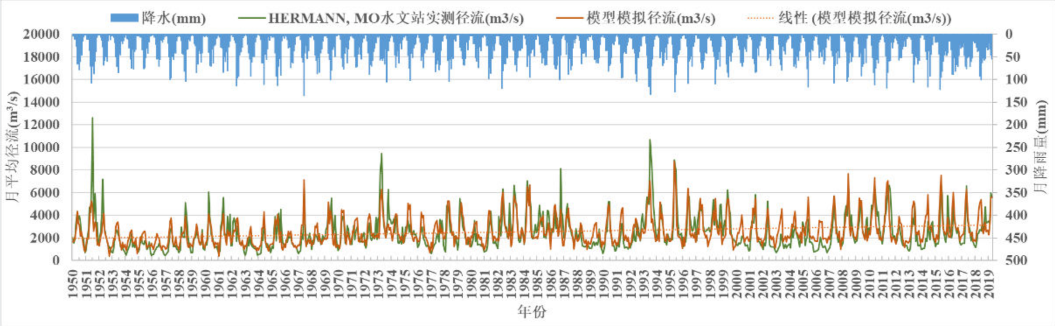
Hydrological station	R^2	NSE	RE (%)
TAMANIAT	0.806	0.645	6.982
DONGOLA	0.721	0.690	1.112
ROSEIRES DAM	0.943	0.873	2.820

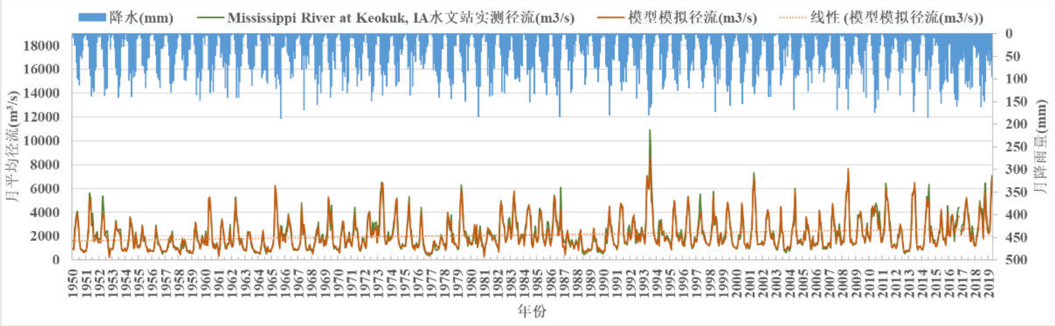
3 Water resource simulator

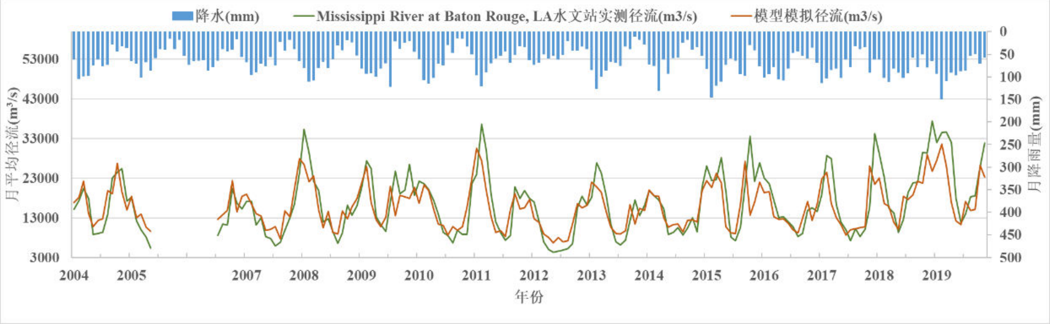
Calibration of typical watersheds

◆ North America--Mississippi River







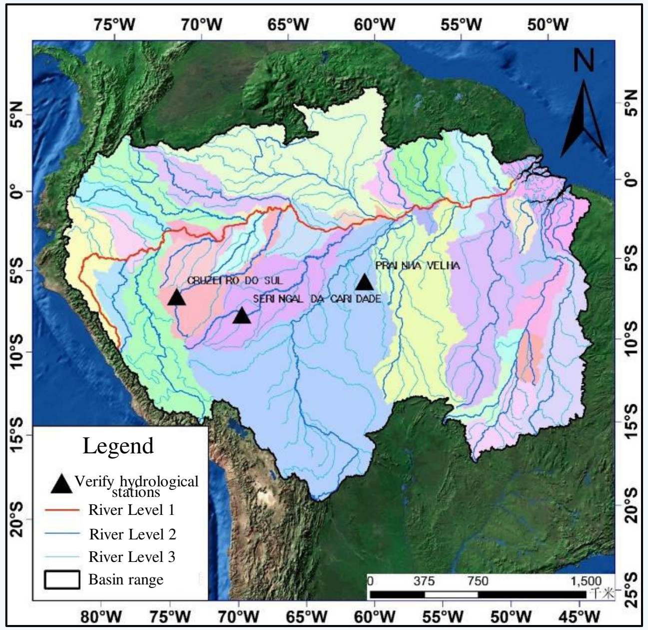


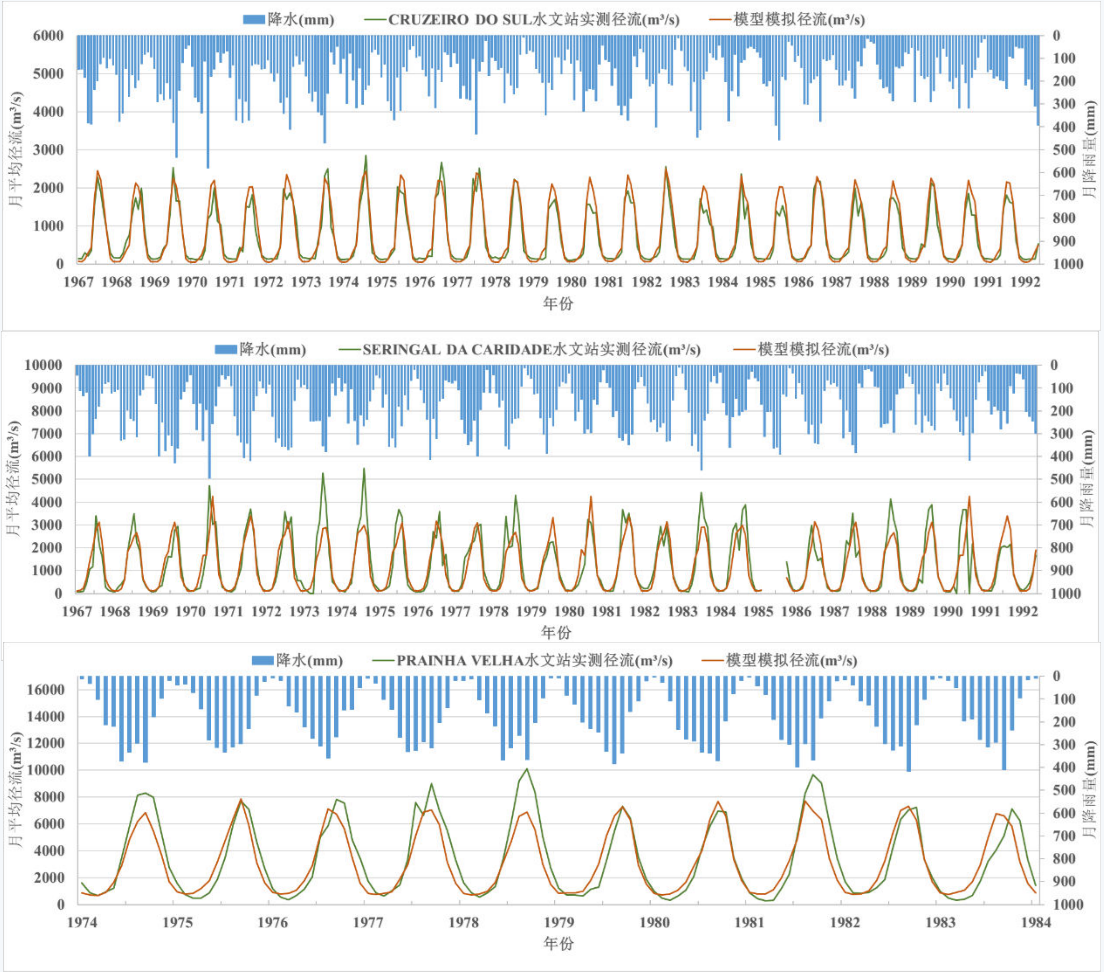
Hydrological station	R^2	NSE	RE (%)
HERMANN, MO	0.787	0.615	4.504
Mississippi River at Keokuk, IA	0.970	0.947	3.846
Mississippi River at Baton Rouge, LA	0.867	0.653	3.976

3 Water resource simulator

Calibration of typical watersheds

◆ South America--Amazon River



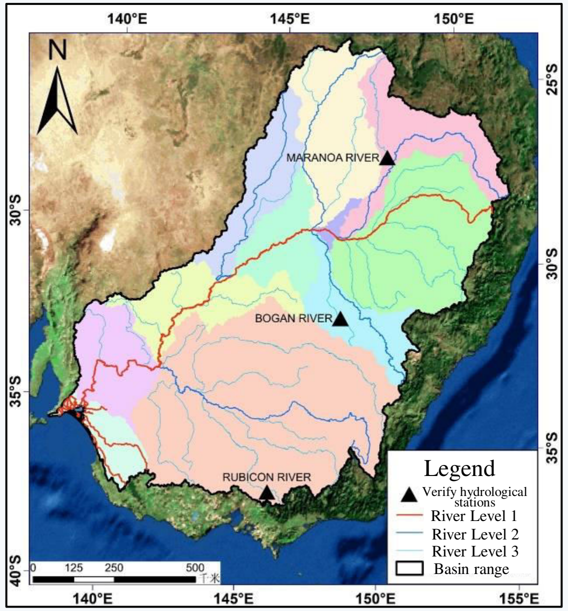


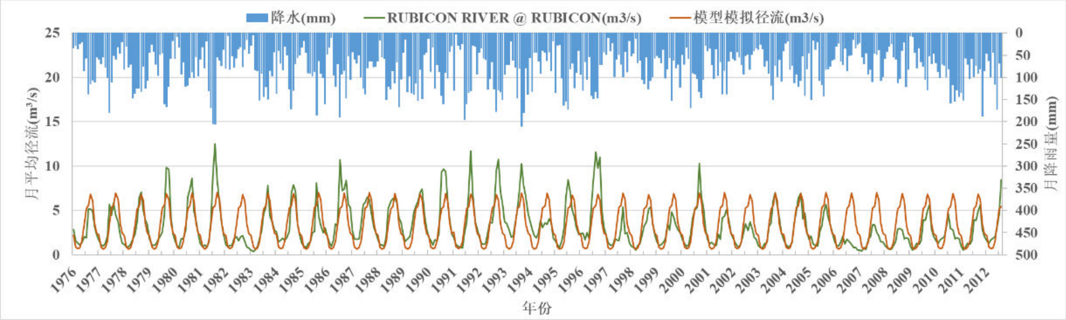
Hydrological station	R^2	NSE	RE (%)
CRUZEIRO DO SUL	0.853	0.712	7.13
SERINGAL DA CARIDADE	0.917	0.749	4.725
PRAINHA VELHA	0.936	0.817	7.728

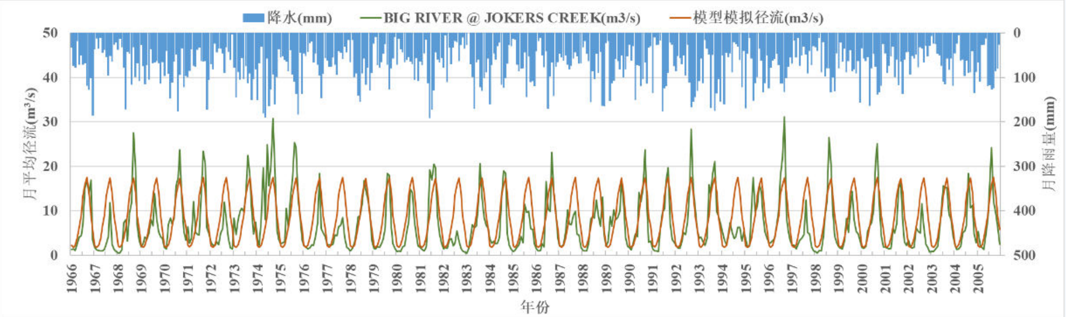
3 Water resource simulator

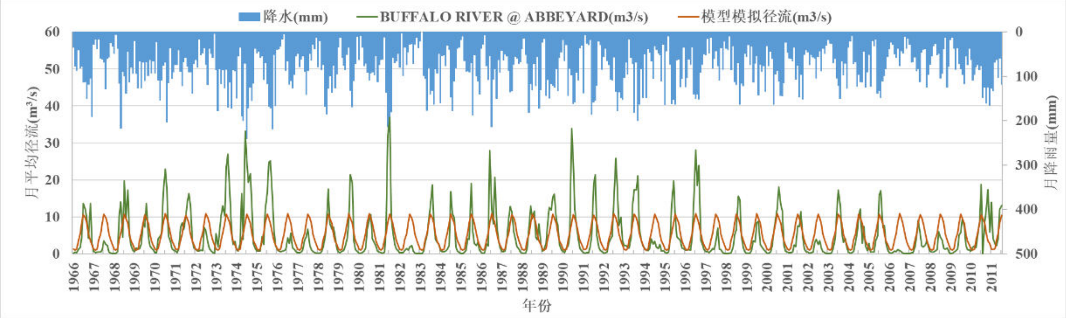
Calibration of typical watersheds

◆ Oceania--Murray-Darling River









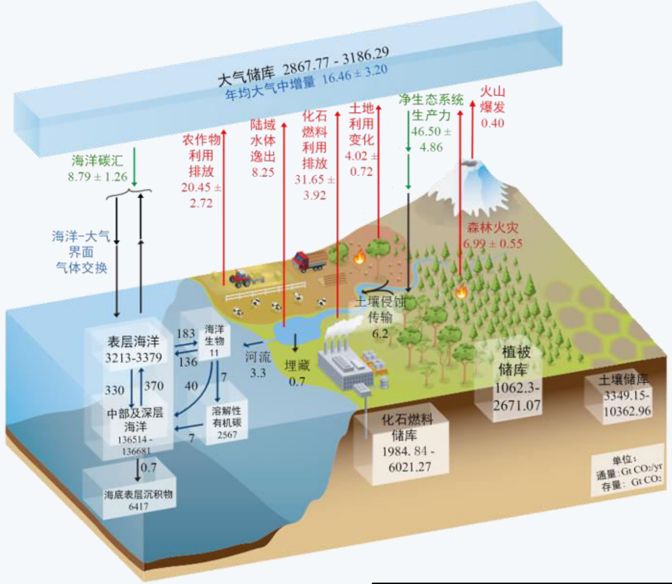
Hydrological station	R^2	NSE	RE (%)
RUBICON RIVER	0.733	0.654	1.903
BIG RIVER	0.720	0.695	15.205
BUFFALO RIVER	0.639	0.524	0.524

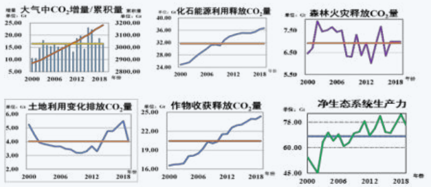
4 Evolution mechanism

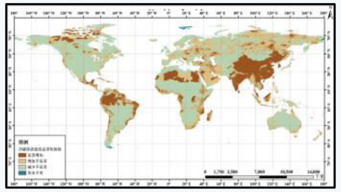
Impact of global changes on water cycle system

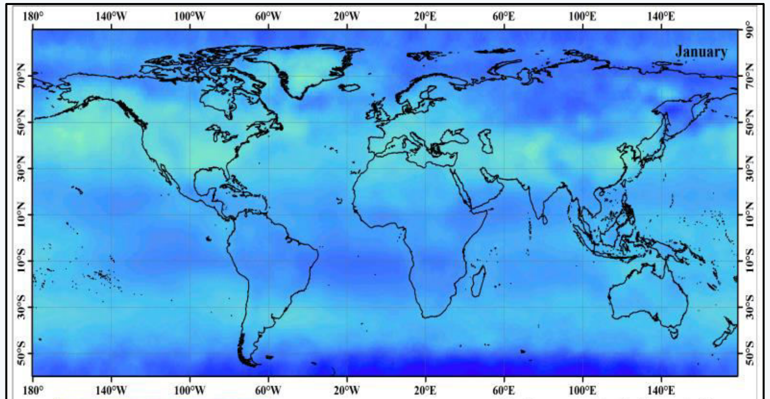
◆ Climate change

Global carbon balance → CO_2 in free troposphere → Temperature rise

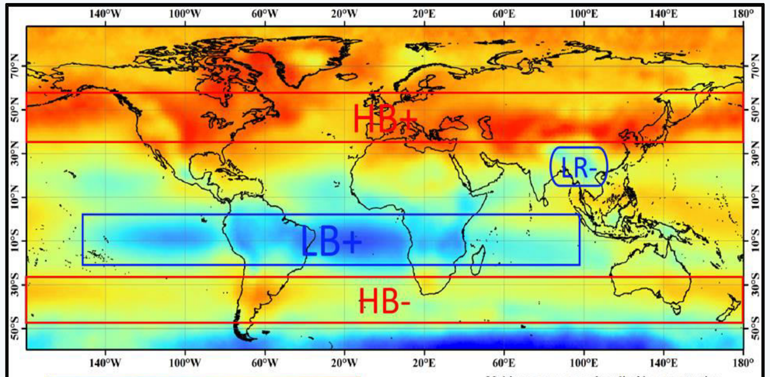




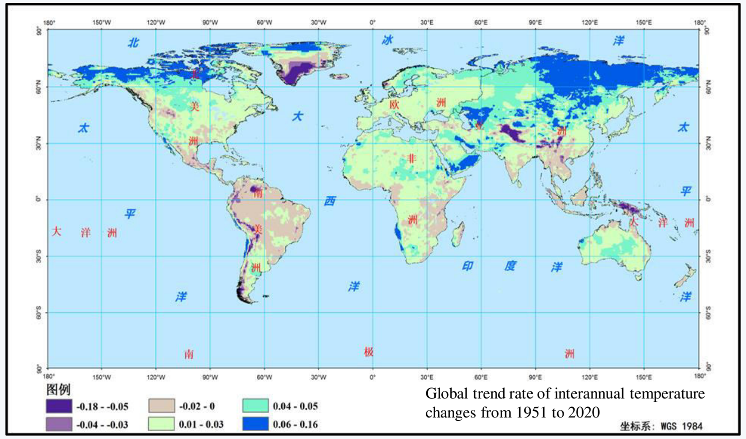




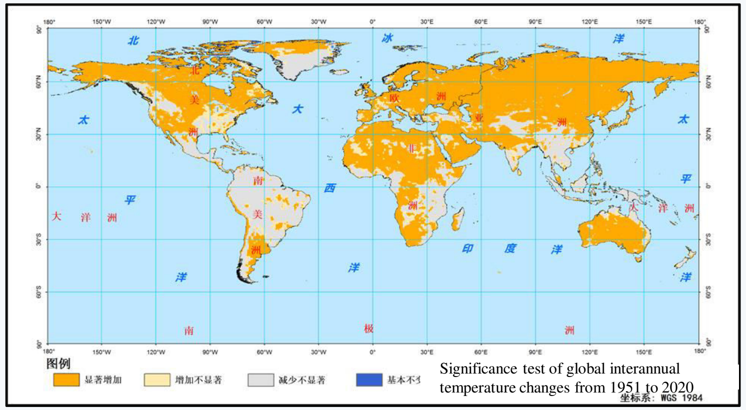
Monthly average carbon dioxide concentration in free troposphere in January from 2003 to 2016 (ppmv)



Multi-year average carbon dioxide concentration in free troposphere from 2003 to 2016 (ppmv)



Global trend rate of interannual temperature changes from 1951 to 2020



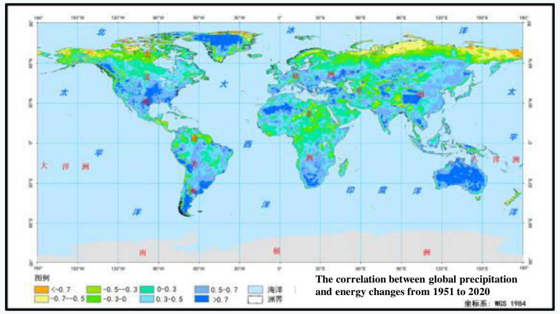
Significance test of global interannual temperature changes from 1951 to 2020

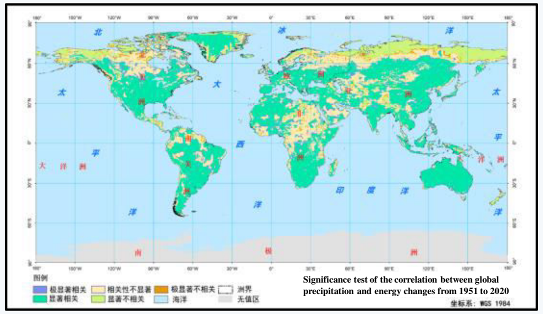
- From 2000-2019, the annual average net emission is 25.25 Gt/a, with average annual growth rate of 0.46 Gt/a

Impact of global changes on water cycle system

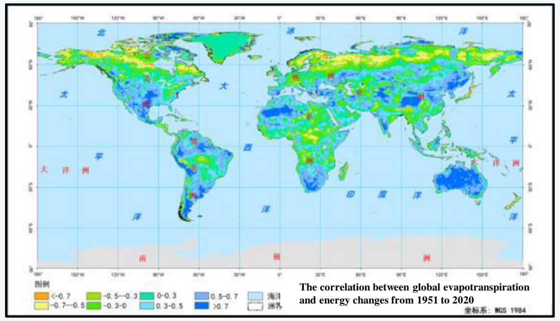
Climate change

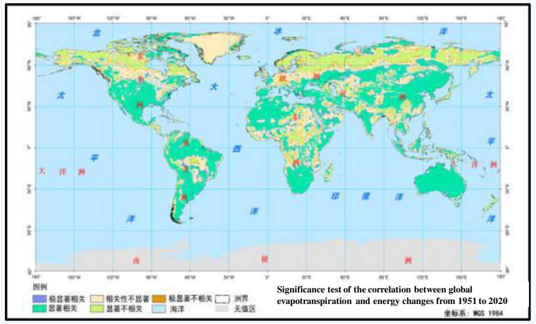
CO_2 → Energy → Temperature → Precipitation



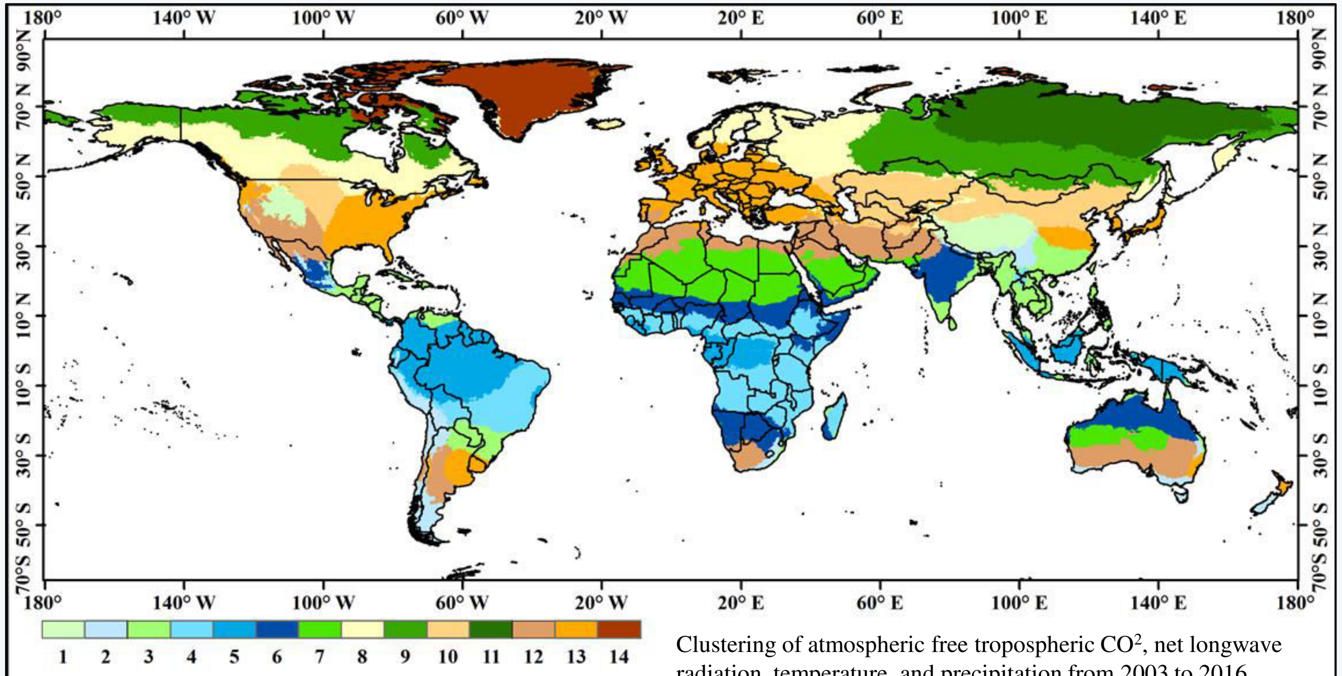


Terrestrial energy → Precipitation





Terrestrial energy → Evapotranspiration



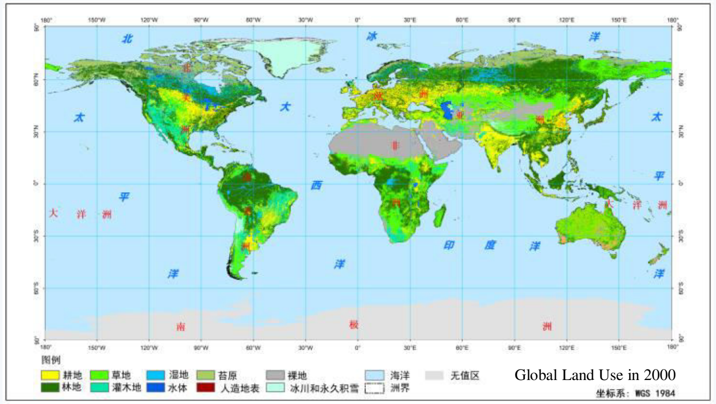
Clustering of atmospheric free tropospheric CO^2, net longwave radiation, temperature, and precipitation from 2003 to 2016

4 Evolution mechanism *Impact of global changes on water cycle system*

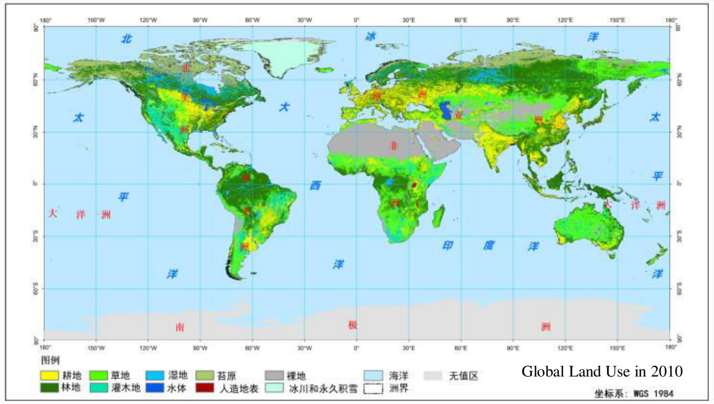
◆ Human activities

Land cover changes

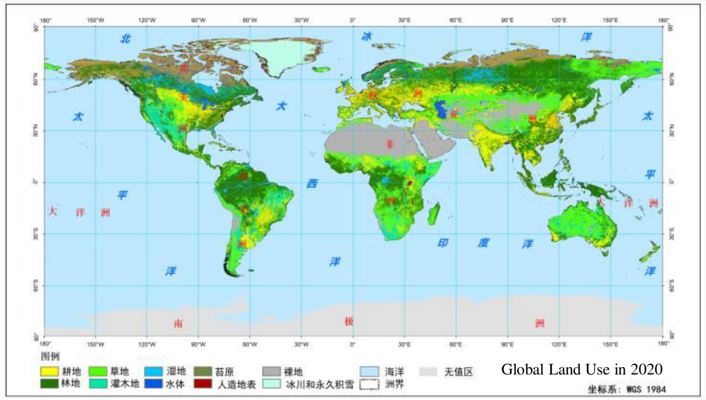
2000



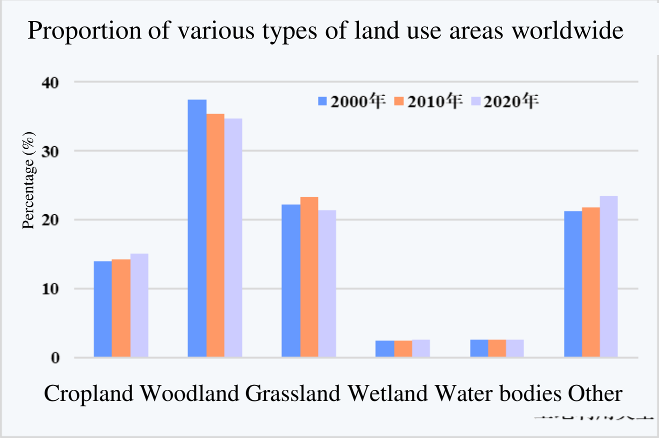
2010

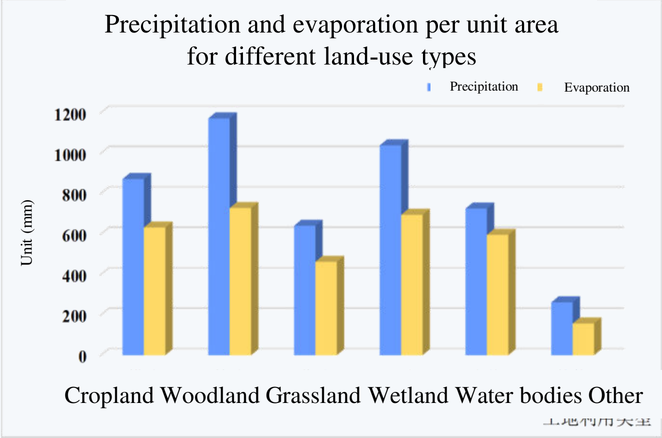


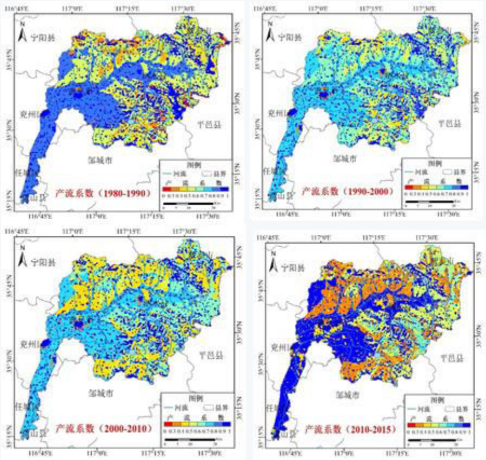
2020



Code	Type	Content
10	Cultivated land	Land used for planting crops, including paddy fields, irrigated drylands, rain fed drylands, vegetable fields, pasture planting areas, greenhouse land, land mainly used for planting fruit trees and other economic trees, as well as shrubby economic crop planting areas such as tea gardens and coffee plantations
20	Forest	Land with tree cover and canopy coverage exceeding 30%, including deciduous broad-leaved forest, evergreen broad-leaved forest, deciduous coniferous forest, evergreen coniferous forest, mixed forest, and sparse forest with canopy coverage of 10-30%
30	Grass	Land covered by natural herbaceous vegetation with a coverage rate greater than 10%, including grasslands, meadows, sparse tree grasslands, desert grasslands, and urban artificial grasslands
40	Shrubland	Land covered with shrubs and a canopy coverage of over 30%, including mountainous shrubs, deciduous and evergreen shrubs, as well as desert shrubs with a coverage of over 10% in desert areas
50	Wetland	Land located at the junction of land and water, with shallow accumulated water or excessively wet soil, often containing marsh or wet plants
60	Water body	The area covered by liquid water within the land, including rivers, lakes, reservoirs, ponds, etc
70	Tundra	Land covered by lichens, moss, perennial cold tolerant herbaceous plants, and shrub vegetation in a cold zone environment, including shrub tundra, tree tundra, etc
80	Artificial surface	The surface formed by artificial construction activities, including various residential areas such as towns, industrial and mining areas, transportation facilities, etc., does not include the internal contiguous green spaces and water bodies of the construction land
90	Bare land	Natural cover land with vegetation coverage less than 10%, including deserts, sandy land, gravel land, bare rock, saline alkali land, etc
100	Glaciers and permanent snow cover	Land covered by permanent snow, glaciers, and ice sheets, including permanent snow, glaciers, and polar ice sheets in high mountain areas



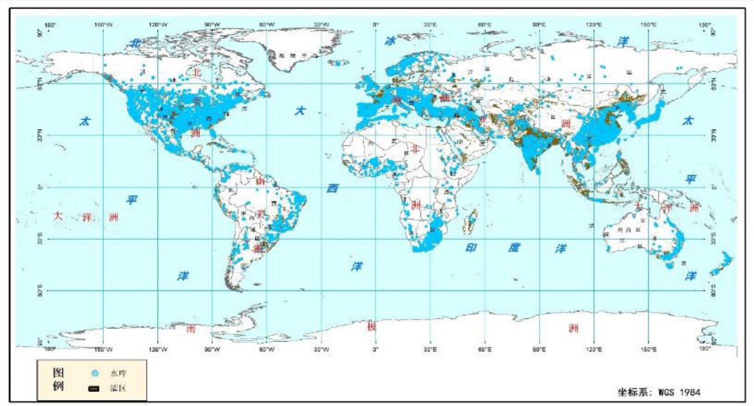


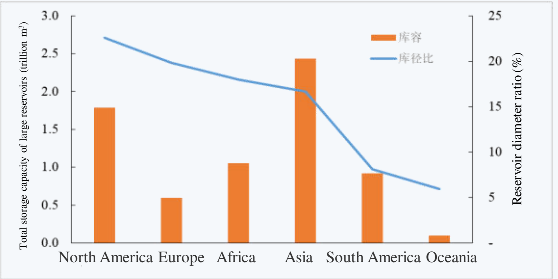


4 Evolution mechanism *Impact of global changes on water cycle system*

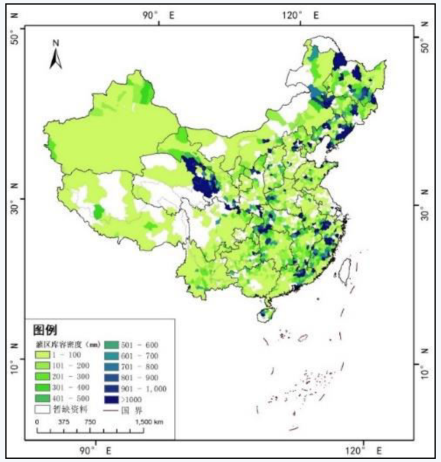
◆ Human activities

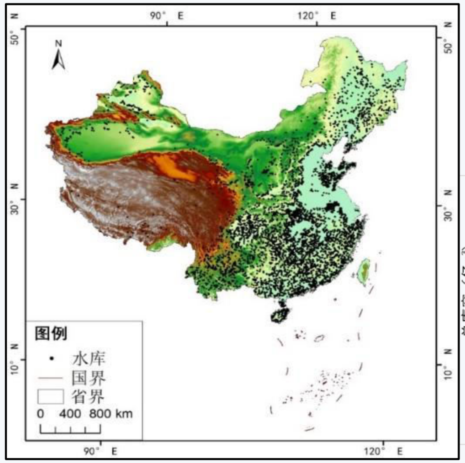
Hydraulic engineering

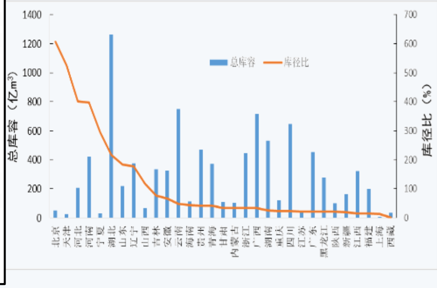




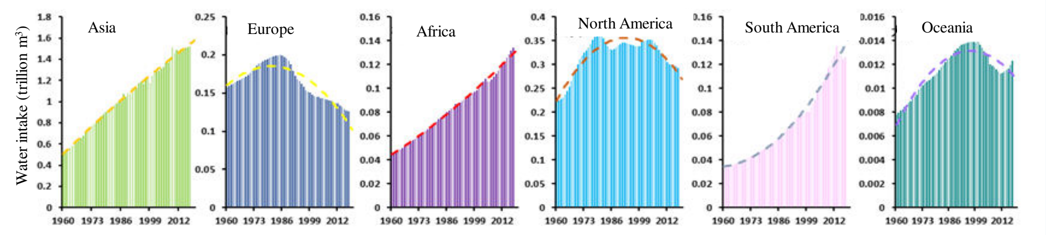
- More than 160,000 reservoirs in the world, including 7,320 large-scale reservoirs

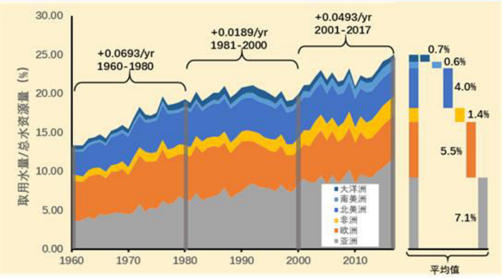


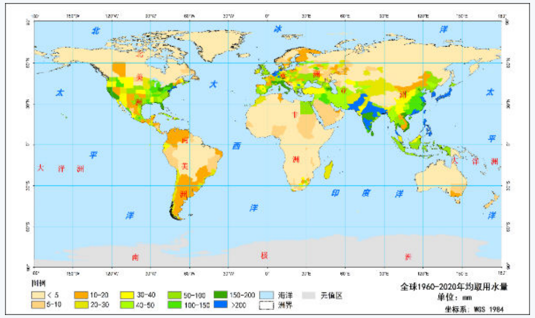


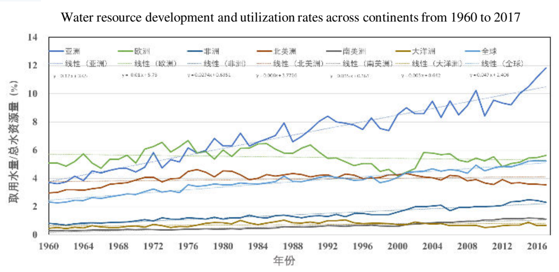


Artificial water withdrawal







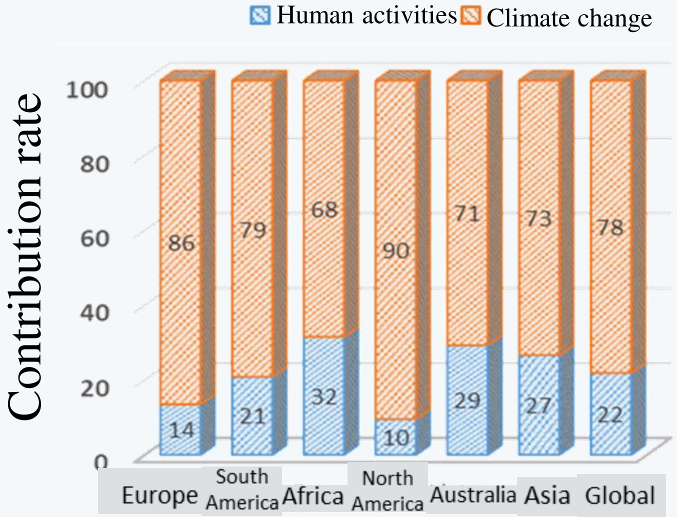


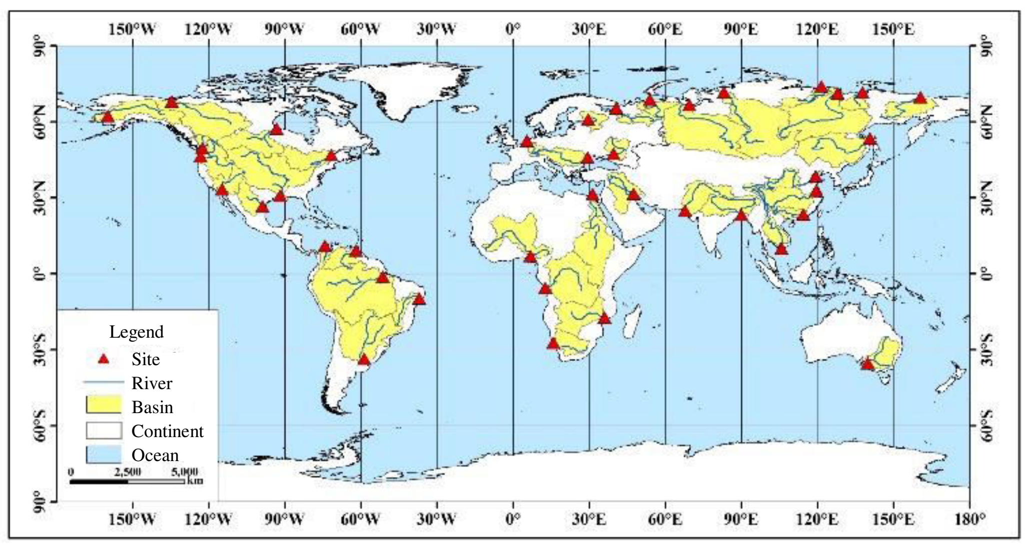
- From 1951-2020, the global average annual water consumption is 3.39 trillion m³, showing an overall increase trend

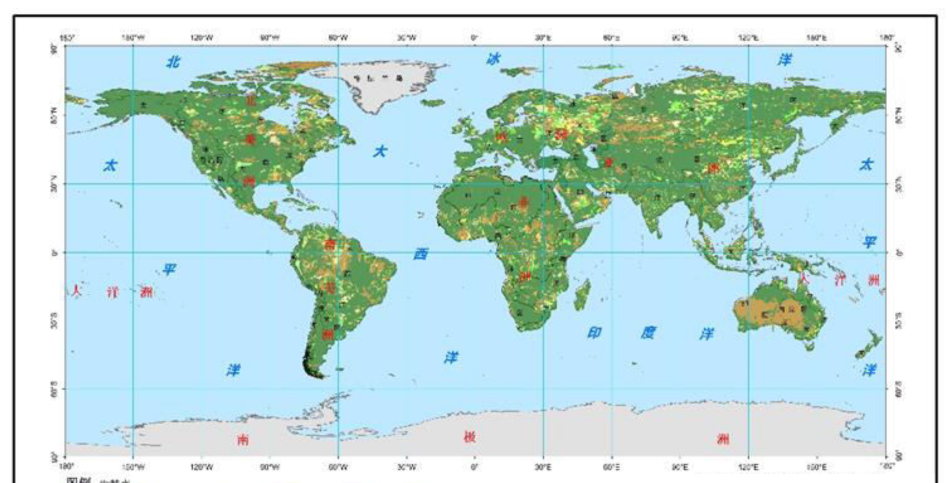
4 Evolution mechanism

Impact of global changes on water cycle system

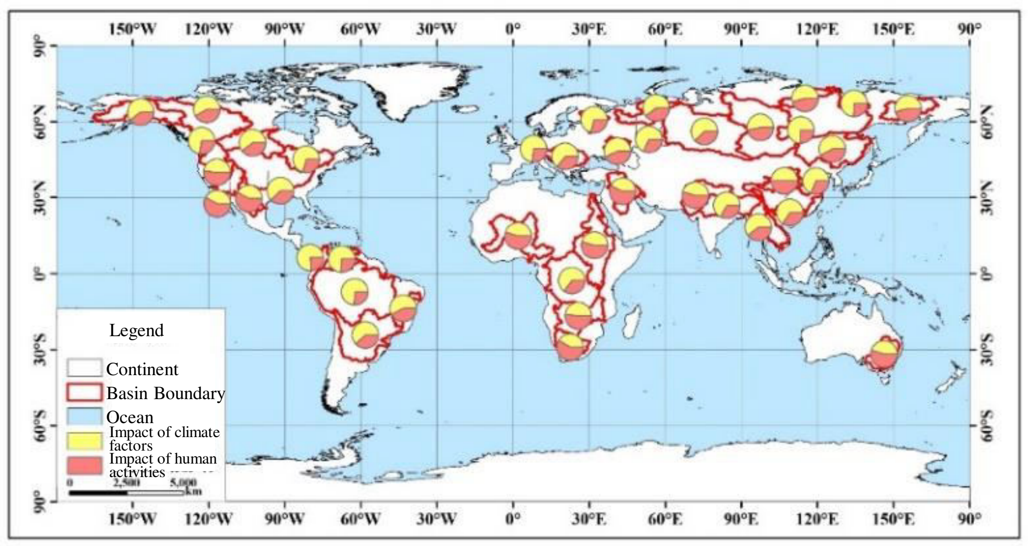
◆ Climate change & Human activities





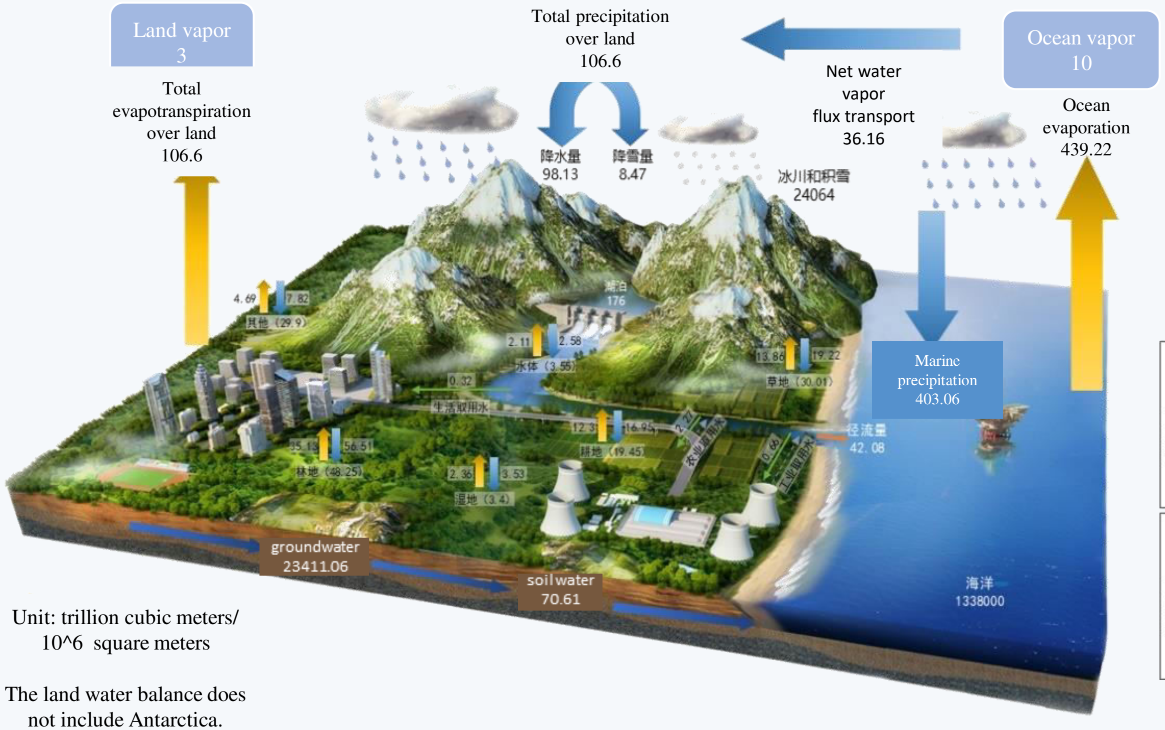


Contribution rate of global climate change to changes in surface water resources from 1961 to 2020



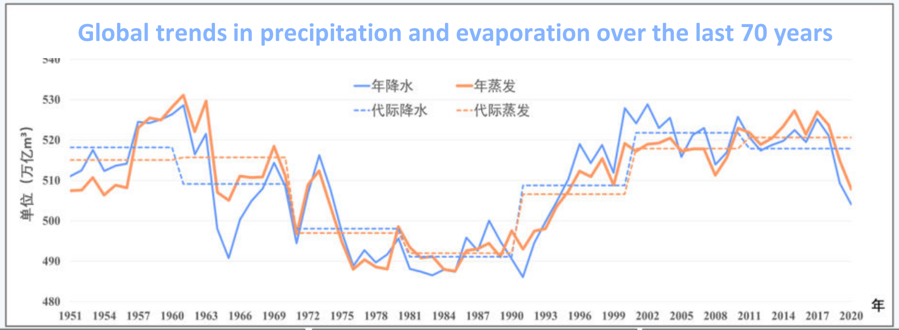
4 Evolution mechanism *Global water balance and key elements*

◆ Global water balance



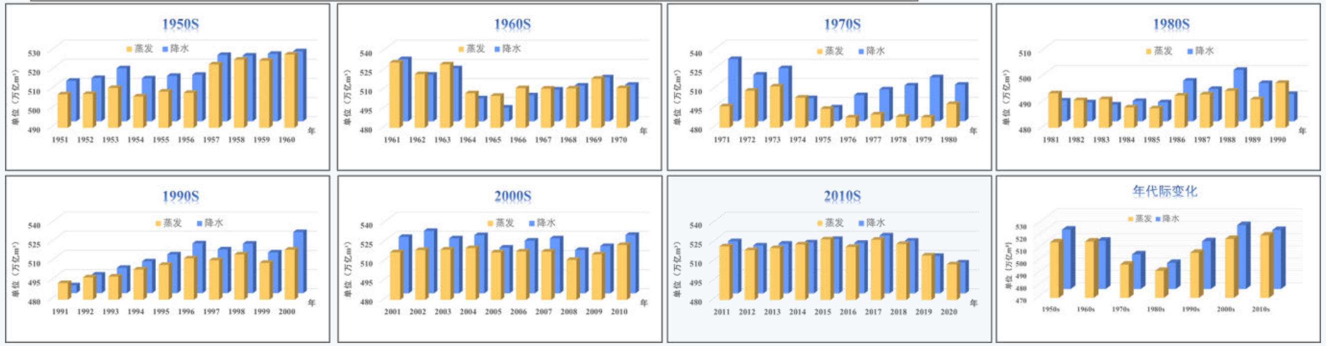
Unit: trillion cubic meters/ 10^6 square meters

The land water balance does not include Antarctica.



Change rate (trillion m^3/yr)

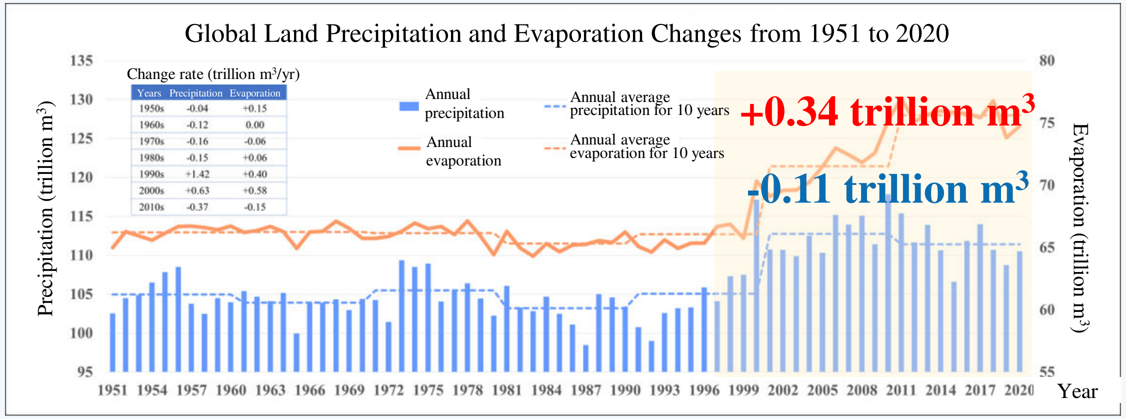
Years	Precipitation	Evaporation
1950s	+2.61	+1.79
1960s	-1.41	-1.71
1970s	-1.41	-1.79
1980s	+1.00	+0.46
1990s	+3.82	+2.60
2000s	-0.71	-0.12
2010s	-1.10	-0.81



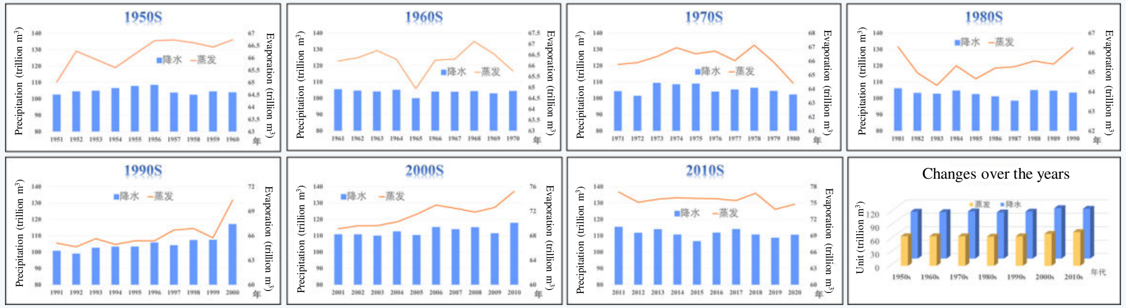
4 Evolution mechanism *Global water balance and key elements*

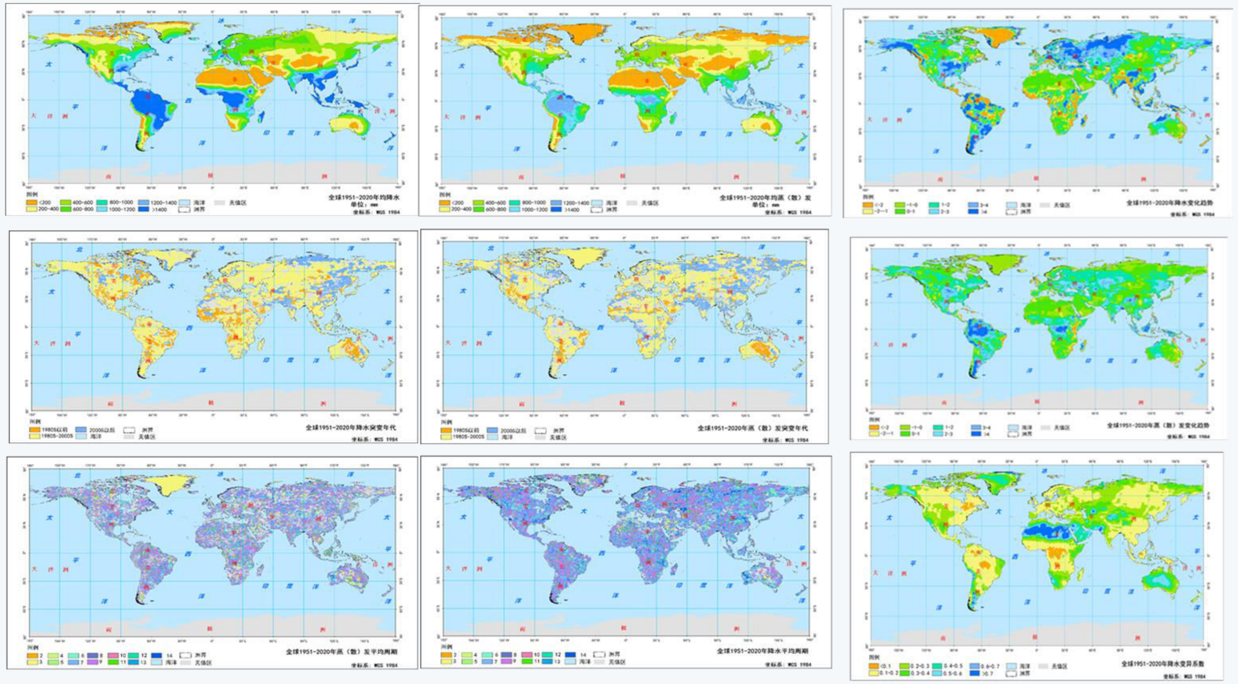
◆ Land

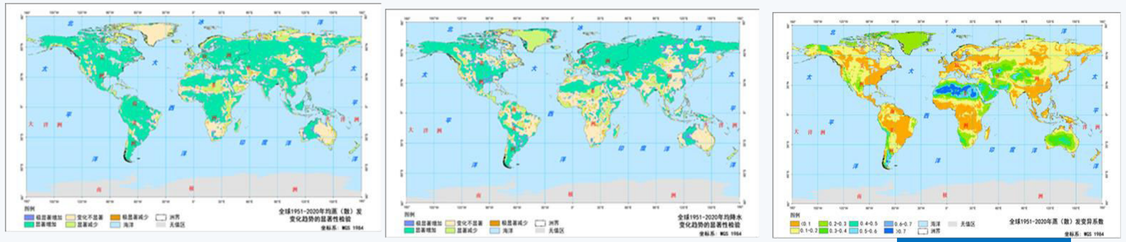
- ➢ **Global terrestrial precipitation:** 106.6 trillion m^3, 0.13 trillion m^3/a
- ➢ **Global terrestrial evapotranspiration:** 70.44 trillion m^3, 0.14 trillion m^3/a



Years	Precipitation	Evaporation
1950s	-0.04	+0.15
1960s	-0.12	0.00
1970s	-0.16	-0.06
1980s	-0.15	+0.06
1990s	+1.42	+0.40
2000s	+0.63	+0.58
2010s	-0.37	-0.15

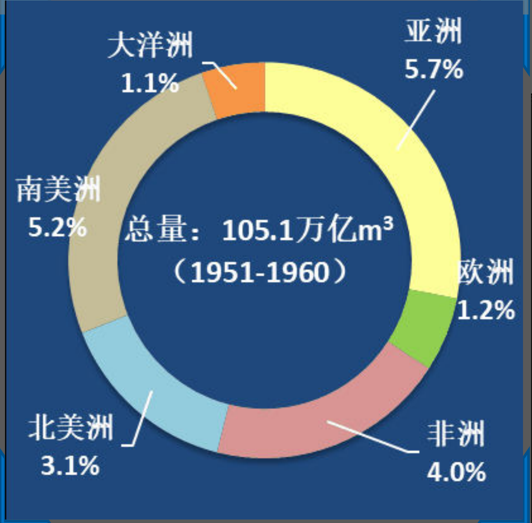




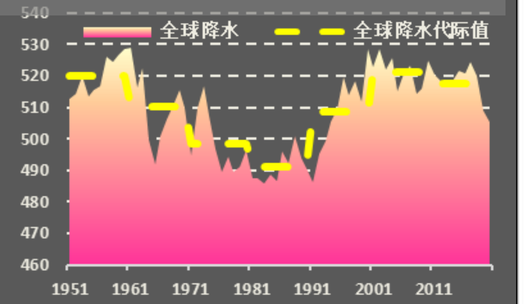


Temporal and Spatial Characteristics of Precipitation in all Continents

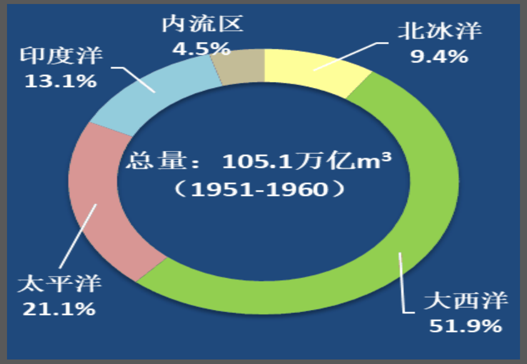
Precipitation in every decade from 1951-2020

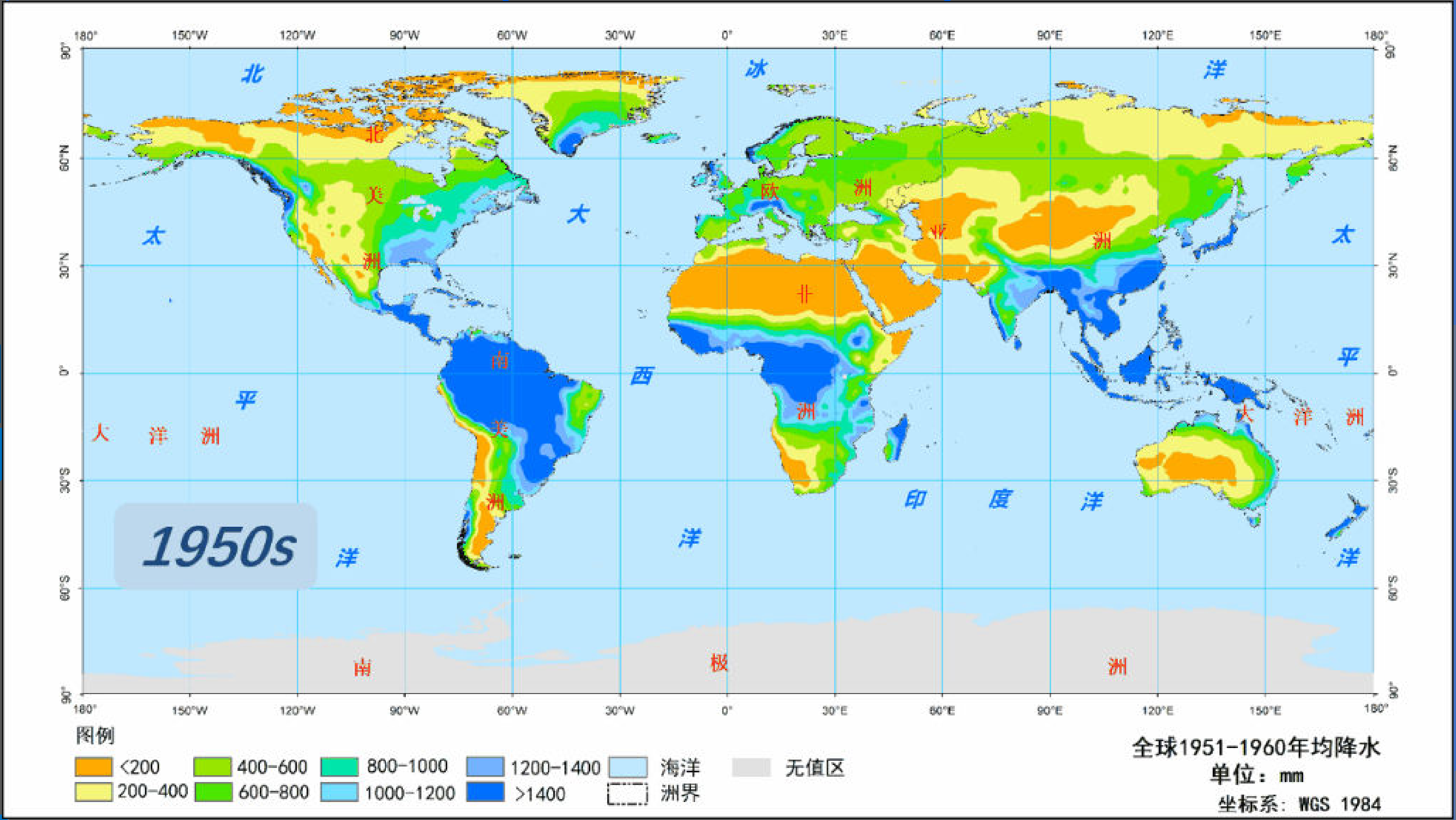


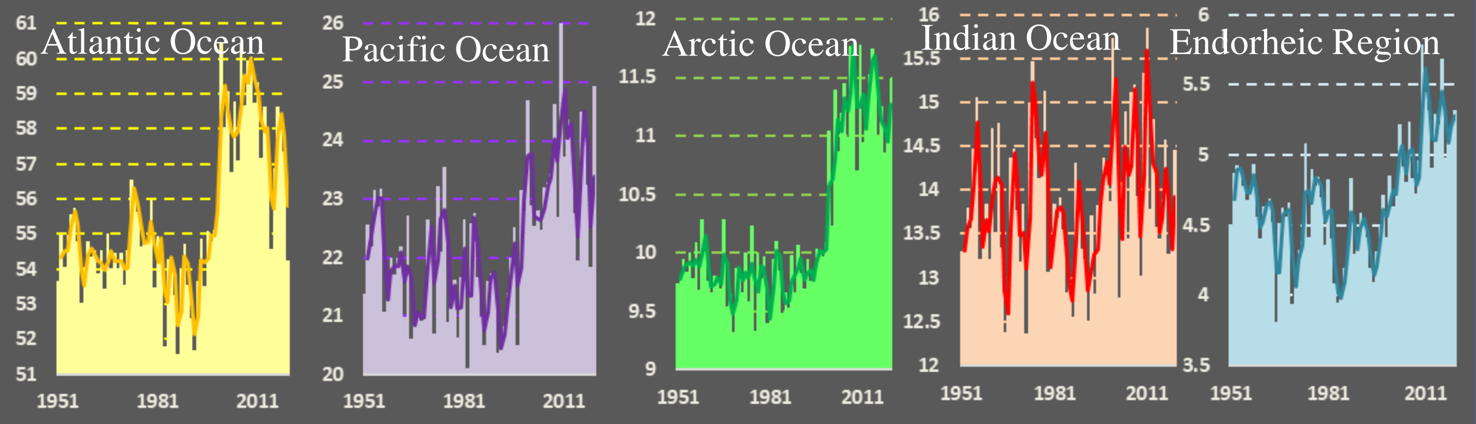
Global precipitation amount during 1951-2020



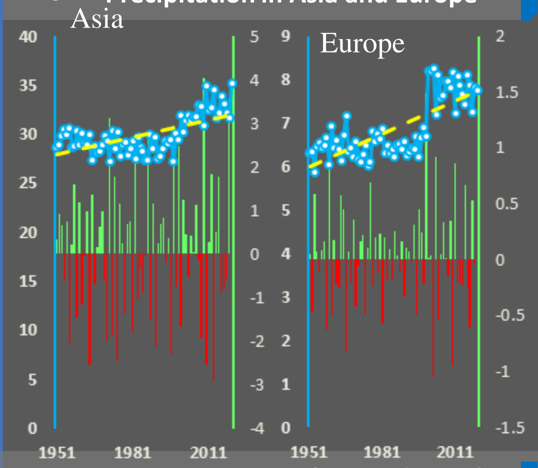
Ocean precipitation during 1951-2020



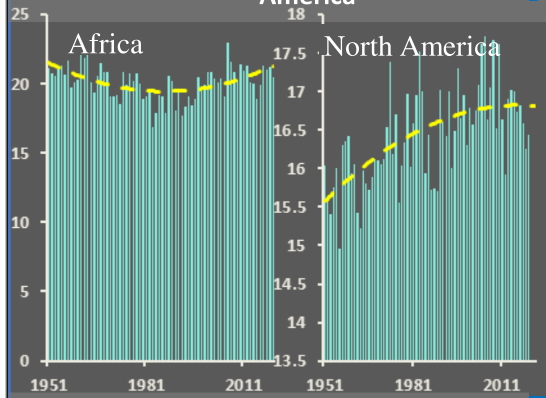




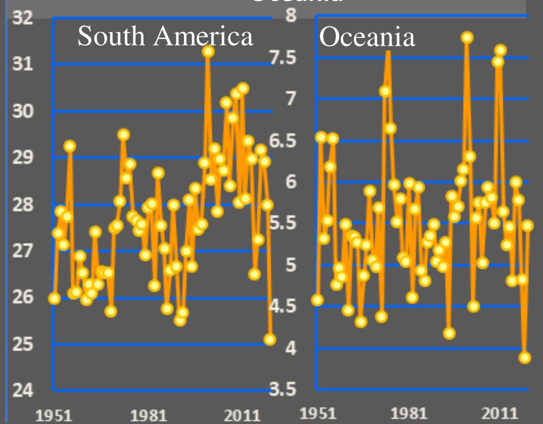
Precipitation in Asia and Europe



Precipitation in Africa and North America

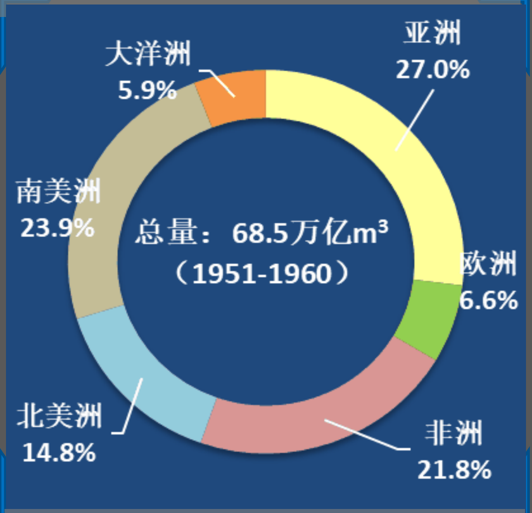


Precipitation in South America and Oceania

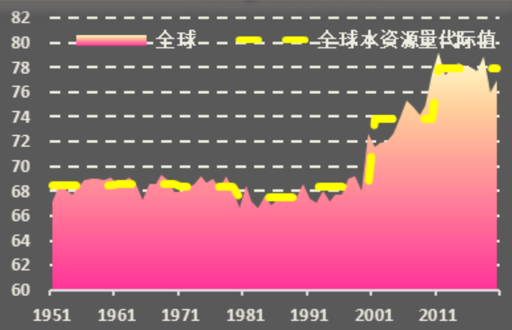


Temporal and Spatial Characteristics of evapotranspiration in all Continents

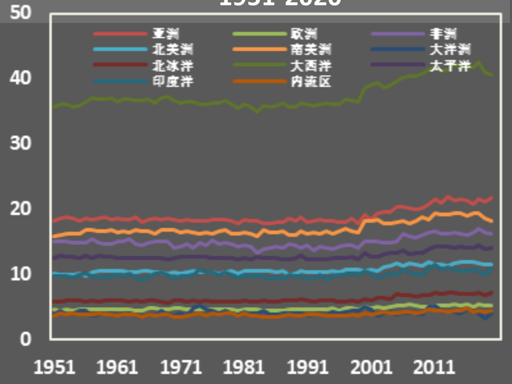
Evapotranspiration in every decade from 1951-2020

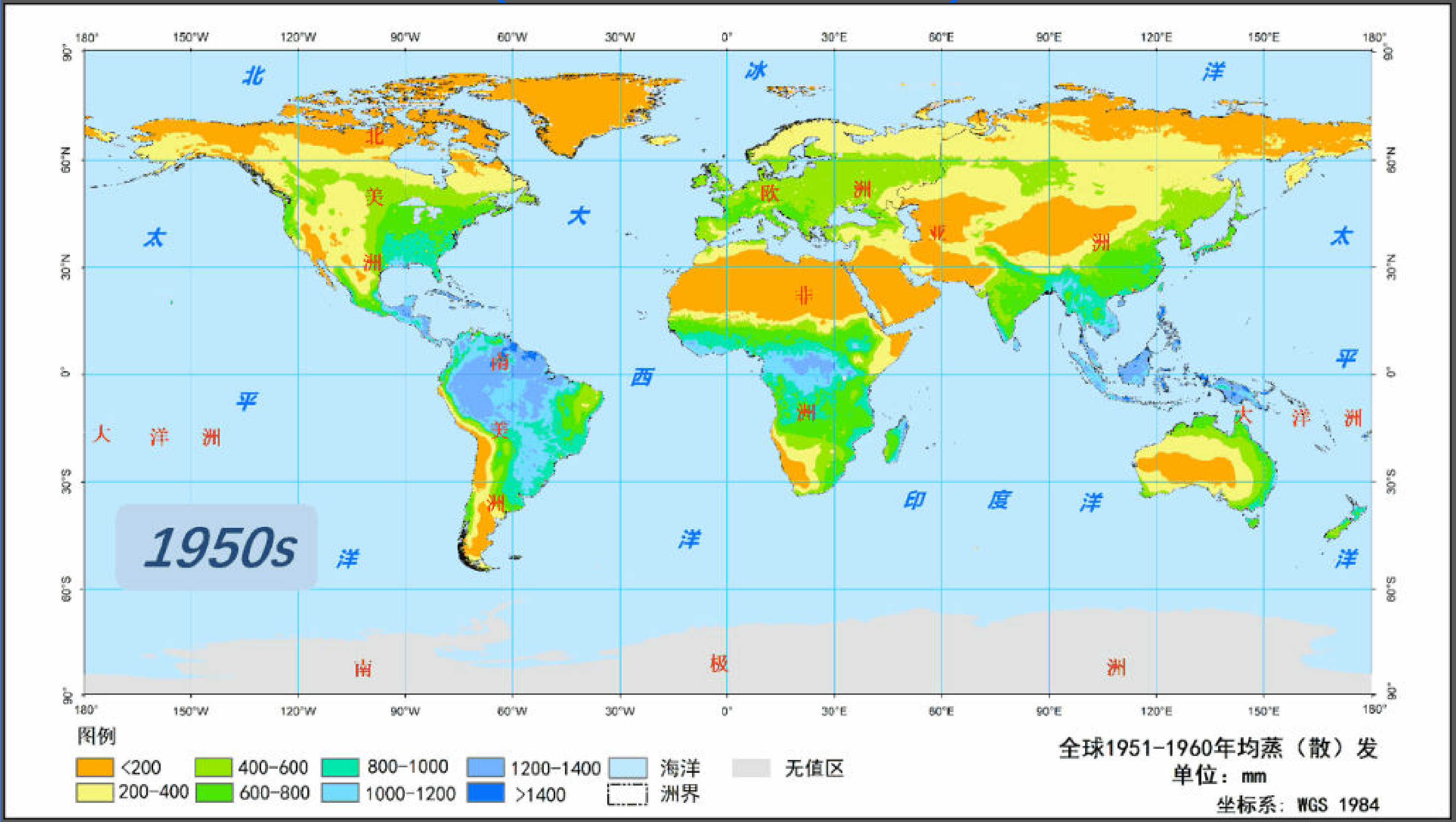


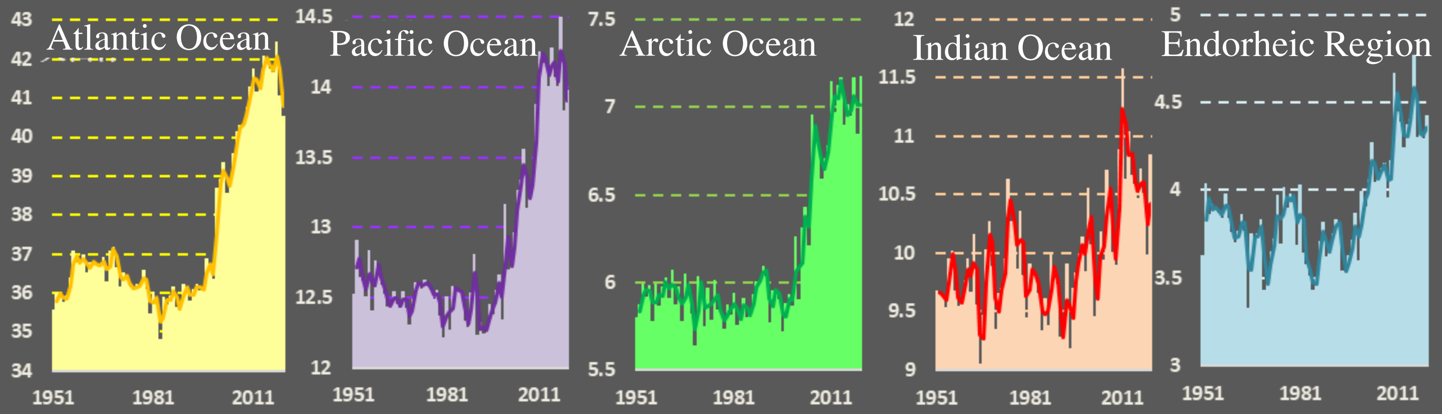
Global evapotranspiration amount during 1951-2020



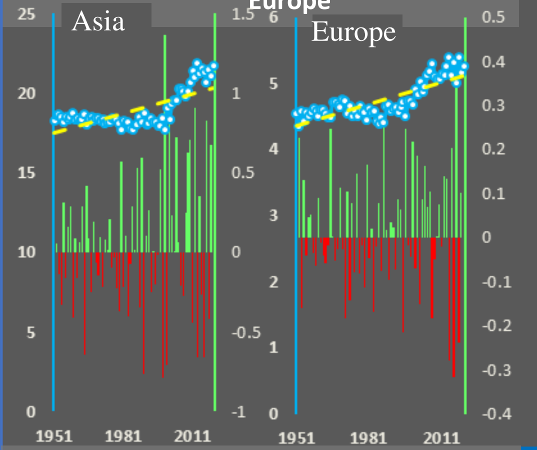
Ocean evapotranspiration during 1951-2020



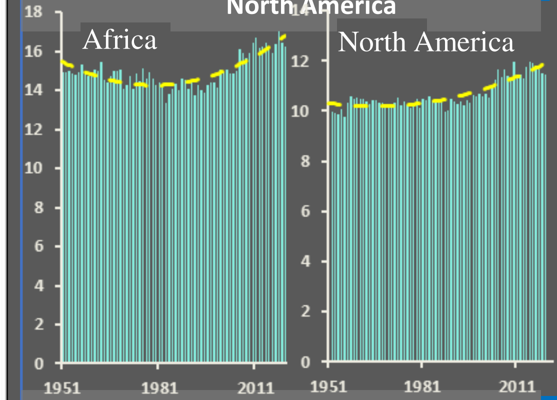




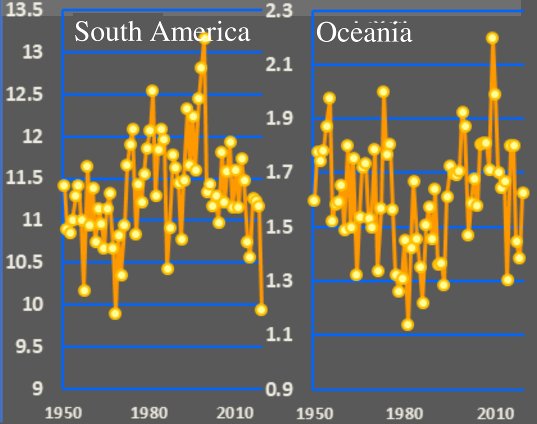
Evapotranspiration in Asia and Europe



Evapotranspiration in Africa and North America



Evapotranspiration in South America and Oceania

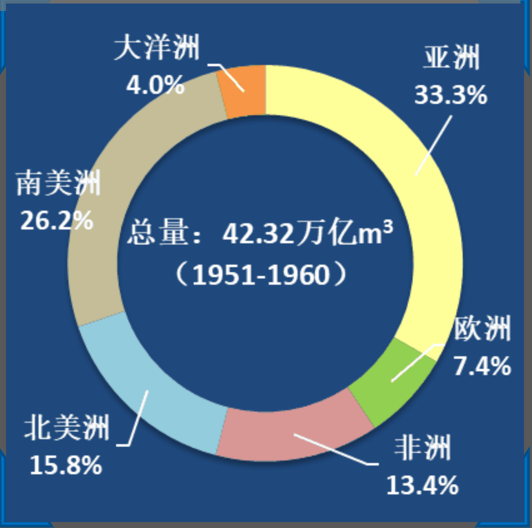


Temporal and Spatial Characteristics of surface water amount in each Continent

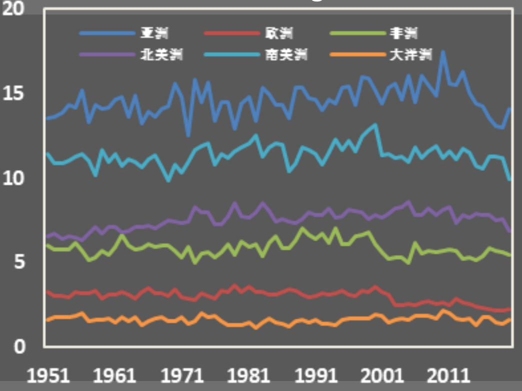
44.32 trillion m³

2010s：-2.09 trillion m³

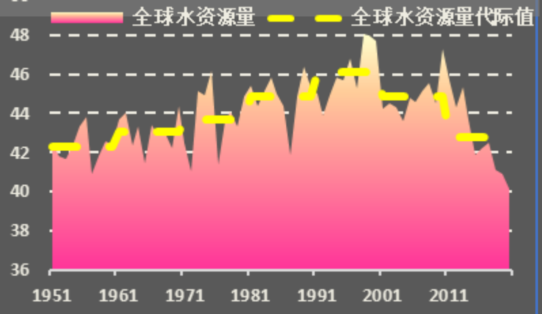
● Surface water amount in every decade from 1951-2020

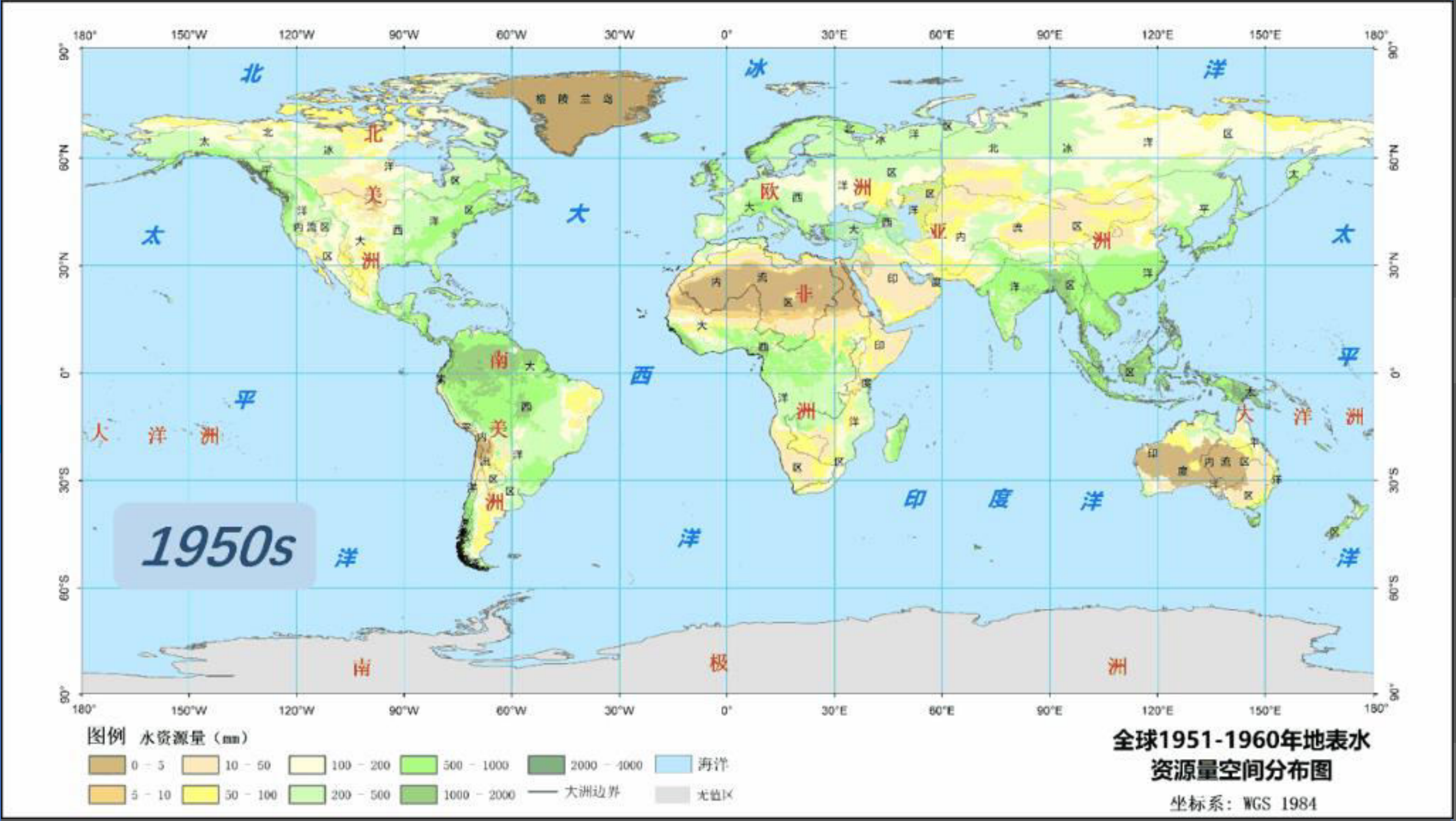


● Surface water amount in each continent during 1951-2020

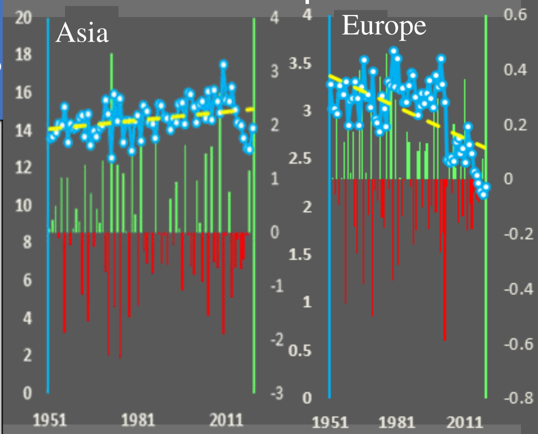


● Global surface water amount during 1951-2020

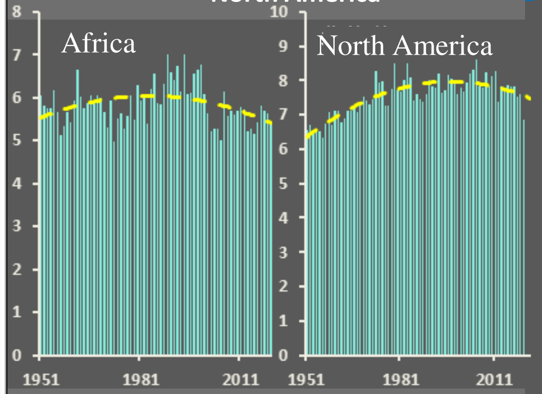




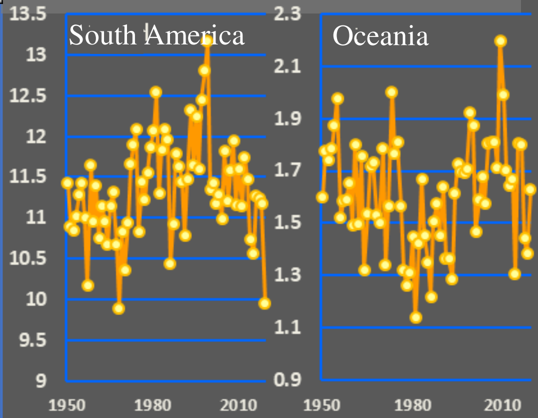
● Surface water amount in Asia and Europe



● Surface water amount in Africa and North America



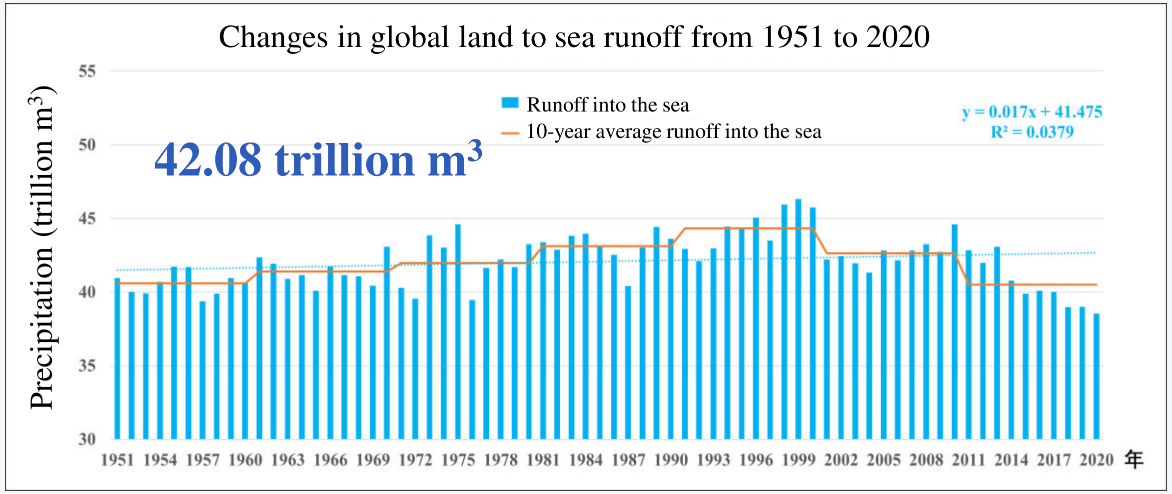
● Suface water amount in South America and Oceania

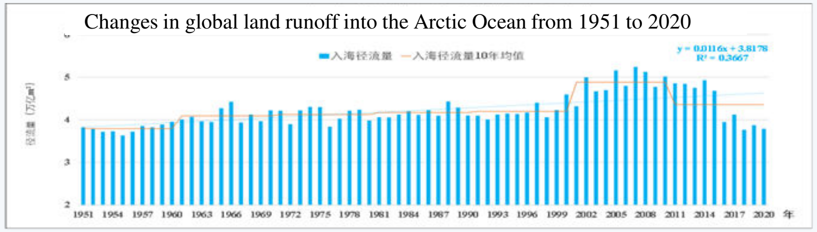


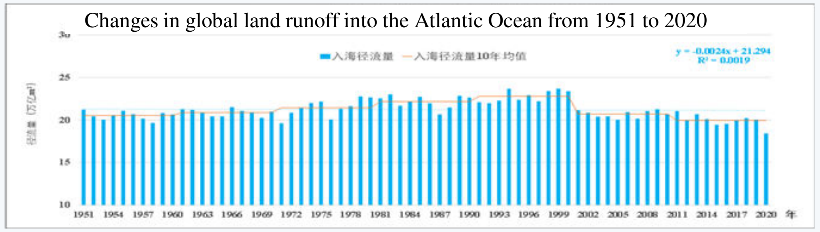
	Asia	Europe	Africa	North America	South America	Oceania	Global
1951-1960	14.08	3.11	5.67	6.67	11.07	1.71	42.32
1961-1970	14.27	3.20	5.99	7.15	10.88	1.59	43.07
1971-1980	14.31	3.10	5.60	7.74	11.39	1.57	43.71
1981-1990	14.61	3.23	6.18	7.77	11.66	1.42	44.87
1991-2000	15.00	3.21	6.45	7.87	12.00	1.60	46.13
2001-2010	15.47	2.68	5.51	8.05	11.39	1.75	44.86
2011-2020	14.48	2.39	5.51	7.66	11.09	1.64	42.77

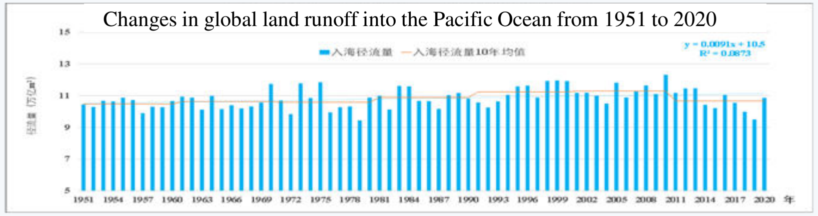
4 Evolution mechanism *Global water balance and key elements*

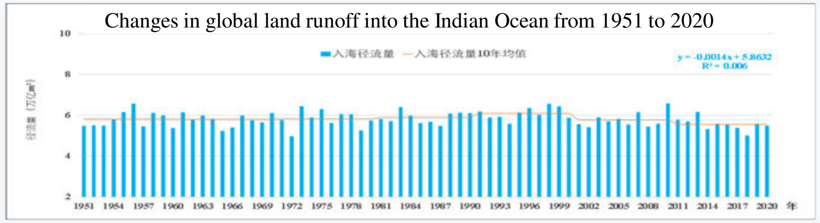
◆ Runoff from land to ocean







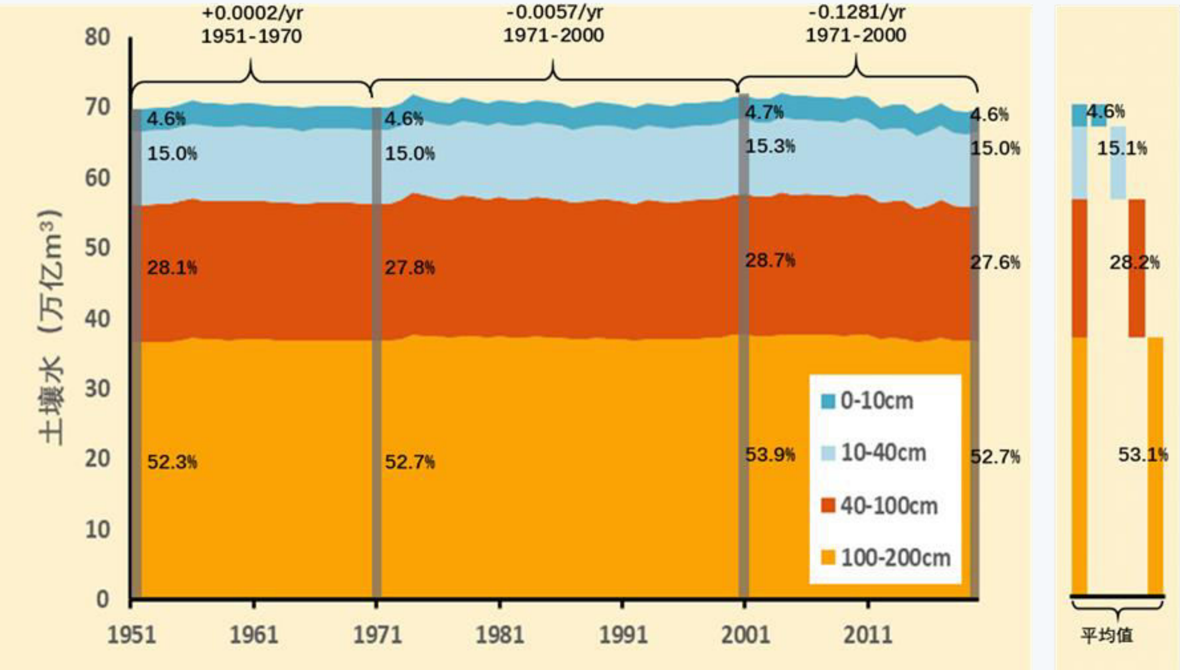


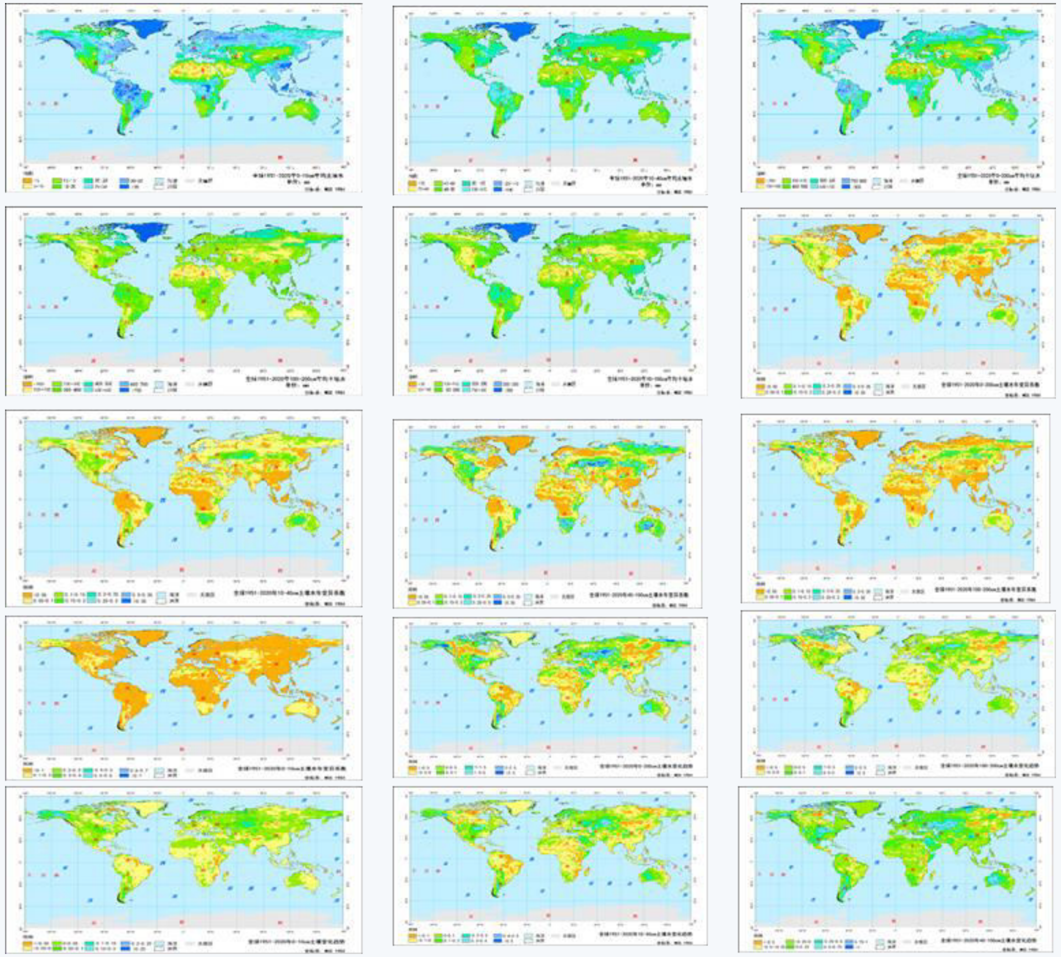


Ocean name	Average annual inflow (trillion m³)	CV	Rate of change (10^8 m³/a)	Change rate in recent 10 years (10^8 m³/a)	Annual average volume for 2011-2020 /1951-2000
Arctic	4.23	9.23%	+116	-1482	3%
Atlantic	21.21	5.32%	-24	-546	-7%
Pacific	10.82	5.81%	+91	-1384	-2%
Indian	5.81	6.24%	-14	-546	-4%

Soil water content

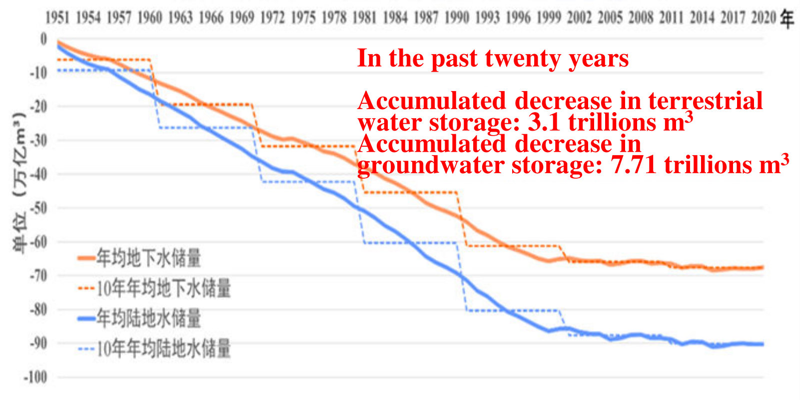
- In the past 70 years, the global soil water content has shown an overall increasing trend
- While it has decreased significantly in the past 10 years, and the soil water content of 40-100 cm has changed the most drastically



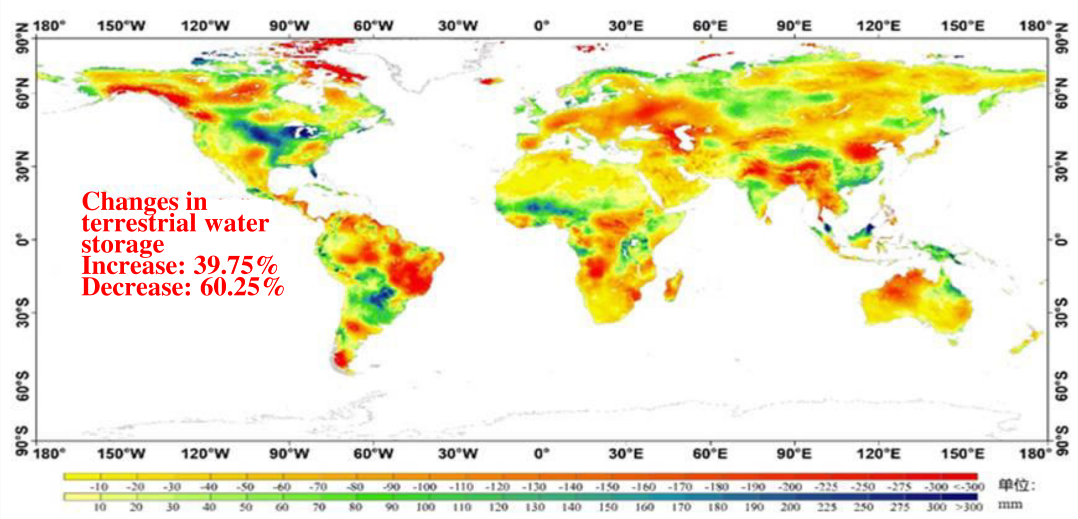


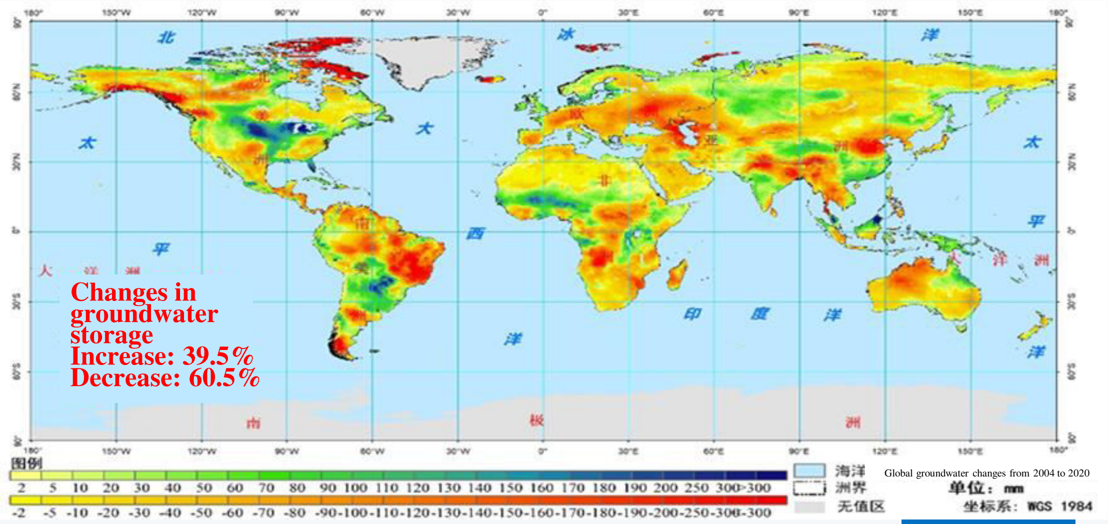
◆ Terrestrial water reserves & Groundwater reserves

Decade	Cumulative change in terrestrial water reserves	Cumulative change in groundwater reserves
1950s	-9.2	-6.1
1960s	-26.3	-19.3
1970s	-42.3	-31.7
1980s	-60.4	-45.3
1990s	-80.4	-61.2
2000s	-87.6	-65.9
2010s	-90.1	-67.7



- ☐ From 1951 to 2020, the global terrestrial water reserves reduced by 91.45 trillion m³, of which the groundwater reserves reduced by 67.88 trillion m³

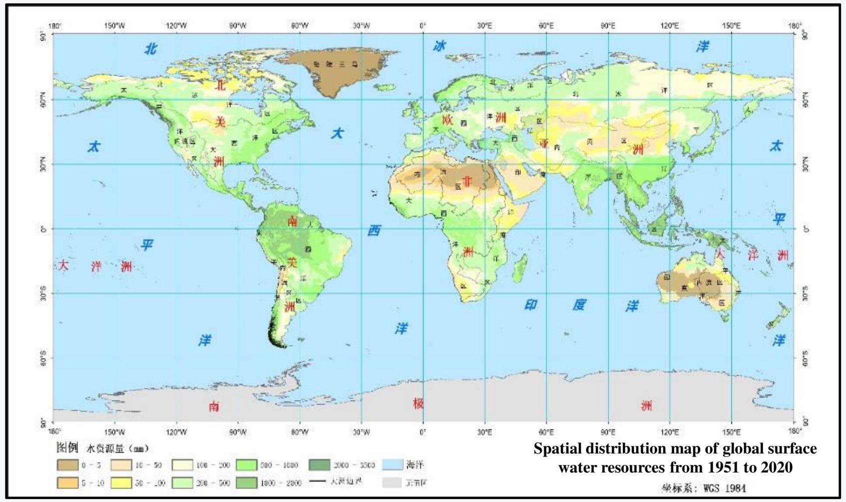




4 Evolution mechanism *Evaluation and prediction*

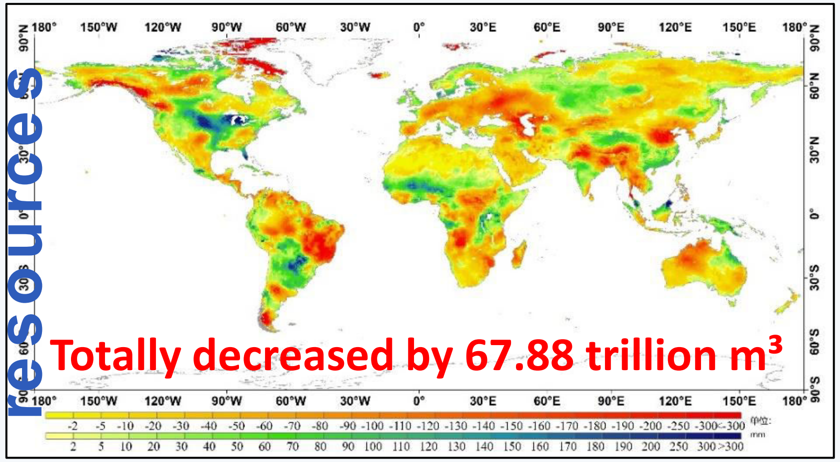
◆ Global terrestrial water resources assessment

Surface water

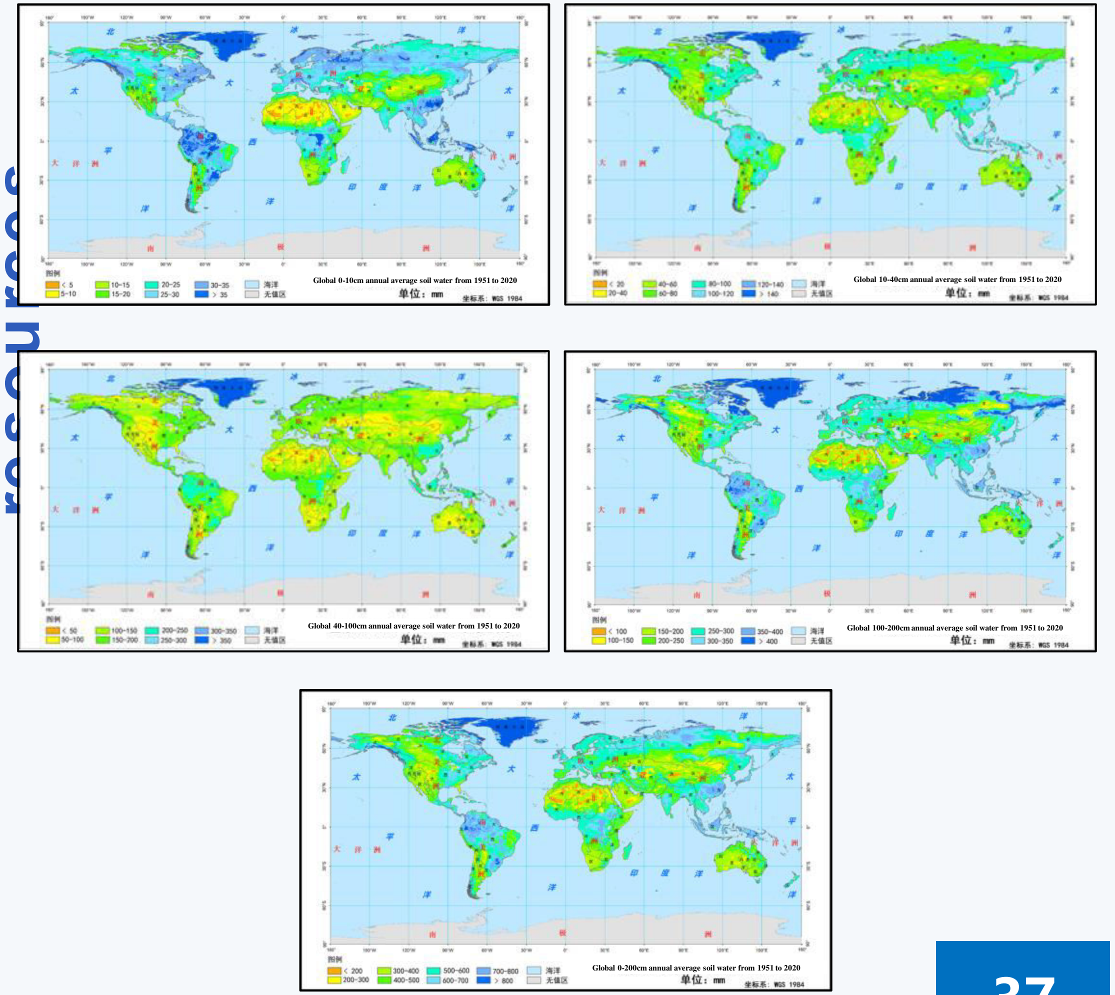


Spatial distribution map of global surface water resources from 1951 to 2020

Groundwater resources



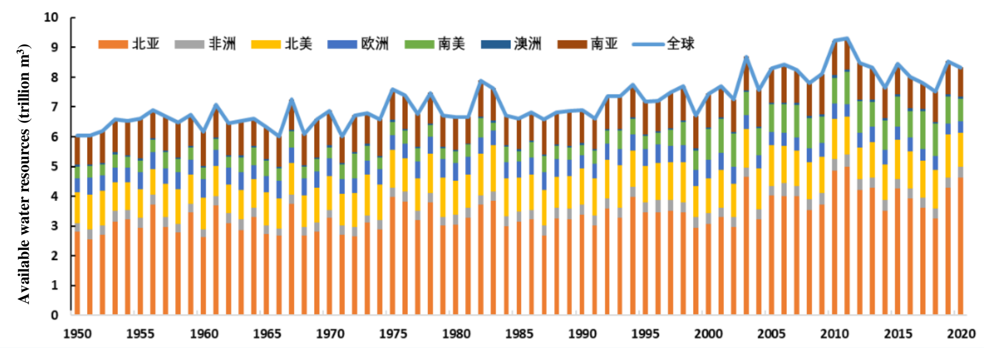
Soil water resources

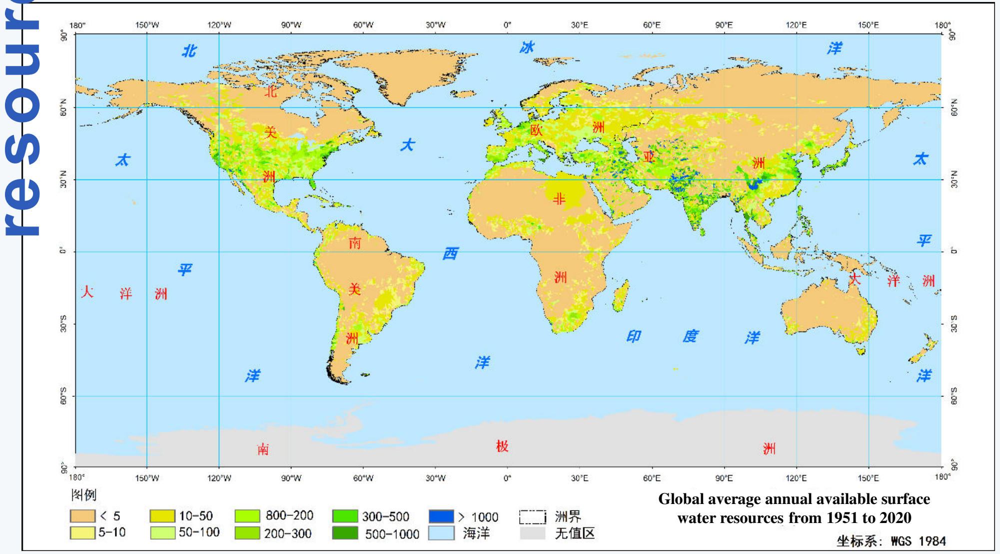


4 Evolution mechanism *Evaluation and prediction*

◆ Global terrestrial water resources assessment

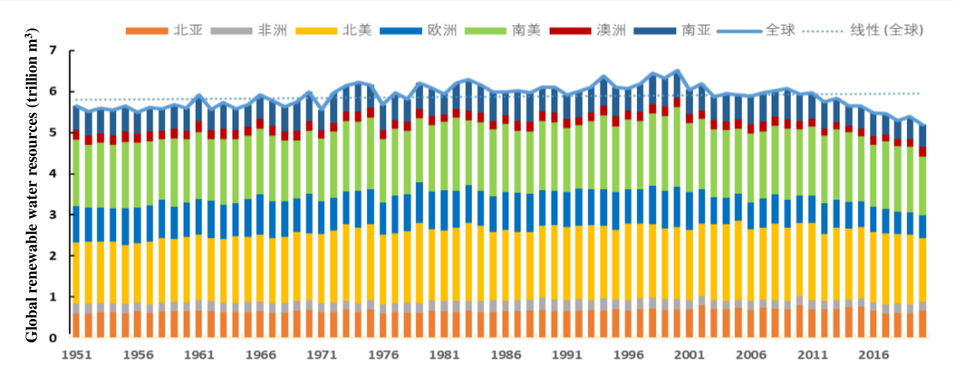
Available water resource

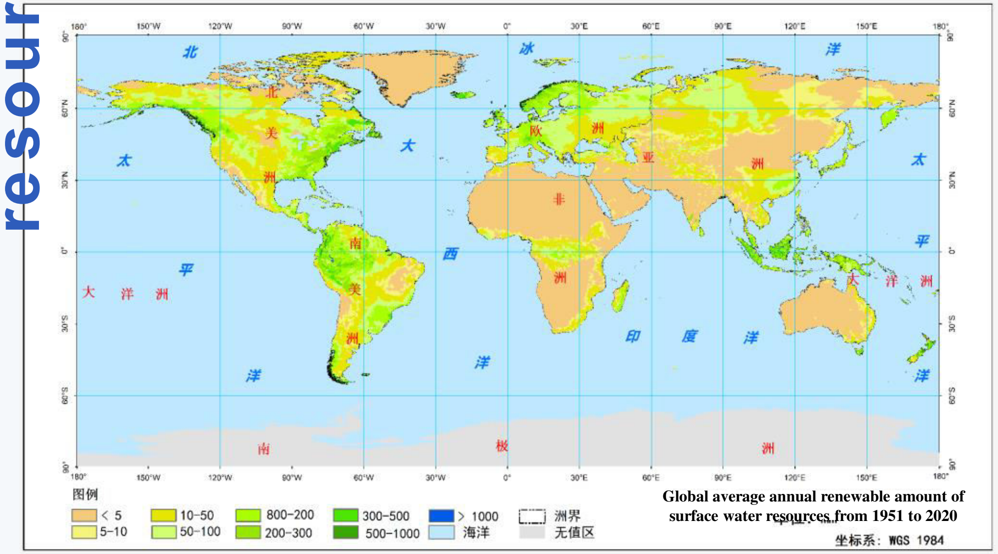




Global average annual available surface water resources from 1951 to 2020

Renewable water resource





Global average annual renewable amount of surface water resources from 1951 to 2020

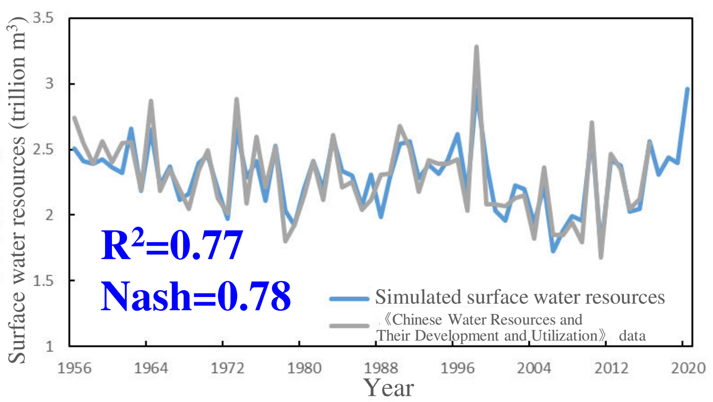
5 Data quality evaluation *Main technical indicators*

◆ Results and accuracy comparison of terrestrial water resources evaluation

Comparison of calculated values of surface water resources in the world and on all continents with FAO

Continent	FAO	Calculated value	Relative error
Asia	16017	14775	-7.76%
Europe	2491	2894	16.18%
Africa	3905	5706	46.11%
North America	7278	7562	3.91%
South America	12865	11222	-12.77%
Oceania	1703	1657	-2.73%
Global	44259	43816	-1.00%
China	22784	22861	0.34%

Calculation results of surface water resources in China



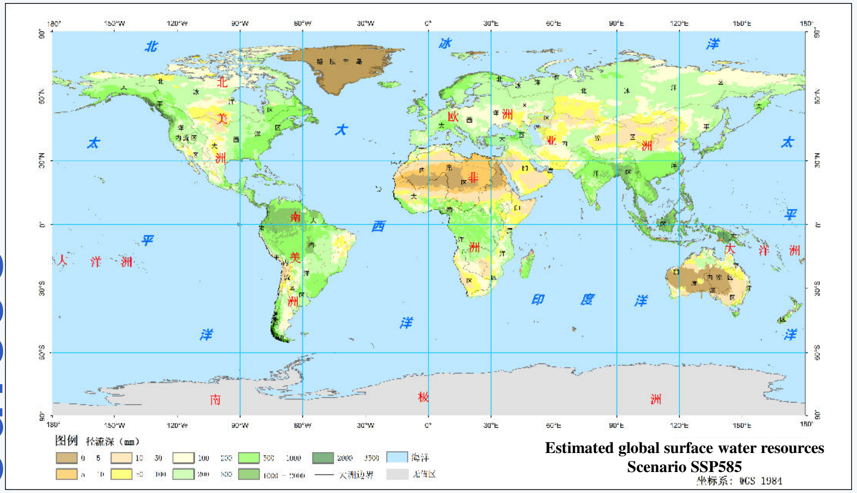
Comparison of calculation results and literature of surface water resources in the world and on all continents

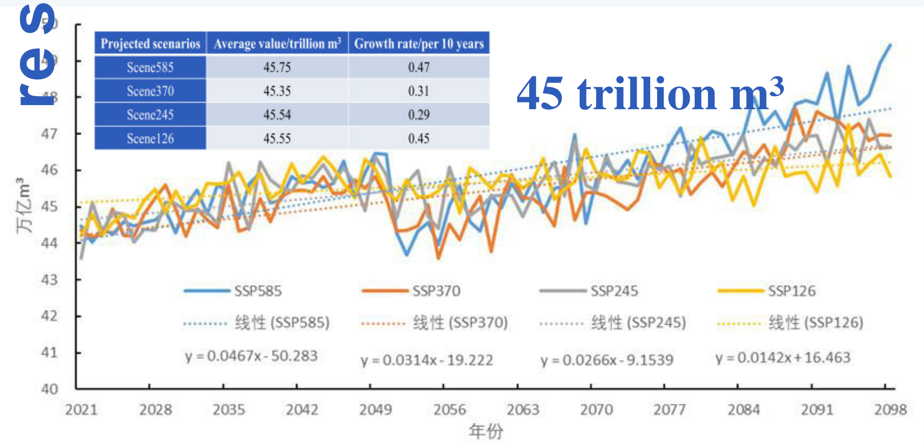
Source literature	Time	Africa	Asia	South America	North America	Oceania	Europe	Global
Liang (2018)	1956-1979	6.94	13.57	13.90	7.54	3.03	2.91	47.88[2*]
This study		5.70	14.27	11.08	7.30	1.61	3.14	43.10
Döll P,(2003)	1961-1990	3.53	11.23	11.38	5.54	2.24	2.76	36.69[3*]
This study		5.92	14.40	11.31	7.55	1.53	3.18	43.89
Shiklomanov,(1996,1997)	1921-1985	4.04	13.51	12.03	7.77	2.40	2.90	42.65[4*]
This study	1950-1985	5.78	14.24	11.24	7.27	1.61	3.14	43.28
Global Runoff Data Centre（2004）	1960-1990	3.69	13.85	11.90	6.29	1.72	3.08	40.53[8*]
This study		5.91	14.39	11.30	7.54	1.53	3.17	43.84
Nijssen, B,(2001)	1980-1993	3.62		10.18	6.22	1.71	0.00	36.01
This study		6.24		11.58	7.80	1.42	3.21	44.81
Sirajul I M,(2007)	1986-1995	4.47	15.90	10.71	9.80	1.94	9.83	52.66
Sirajul I M,(2007)	1986-1995	4.53	10.80	10.18	6.46	1.88	5.09	38.94
This study		6.40	14.64	11.44	7.71	1.44	3.19	44.83
Widen-Nilsson E,(2007)	1961-1990	3.74	13.61	9.45	7.01	1.13	3.67	38.61
This study		5.92	14.40	11.31	7.55	1.53	3.18	43.89
mundi	1962-2014	3.91	15.37	12.72	6.68	1.70	2.49	42.88[10*]
This study		5.91	14.80	11.47	7.73	1.60	3.05	44.56
Shen Y J(2014)	1970-1999	5.20	9.10	11.40	8.00	1.60	3.80	39.10[11*]
This study		6.06	14.65	11.60	7.78	1.52	3.18	44.79

5 Data quality evaluation *Main technical indicators*

◆ Results and rationality of terrestrial water resources prediction

Surface water resources

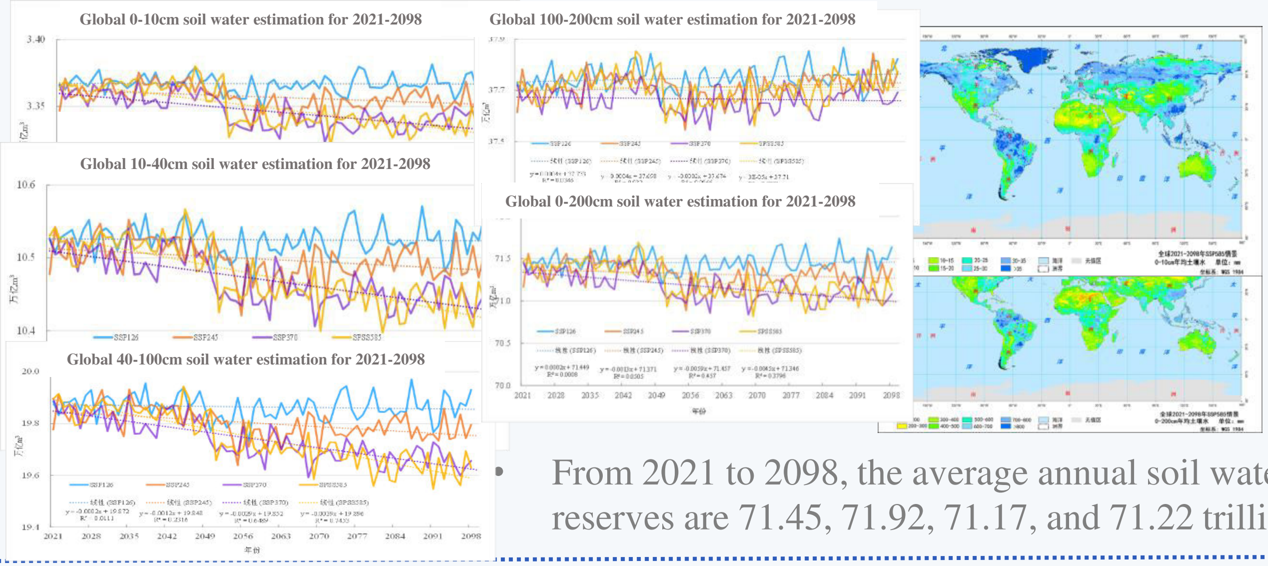




Projected scenarios	Average value/trillion m³	Growth rate/per 10 years
Scene585	45.75	0.47
Scene370	45.35	0.31
Scene245	45.54	0.29
Scene126	45.55	0.45

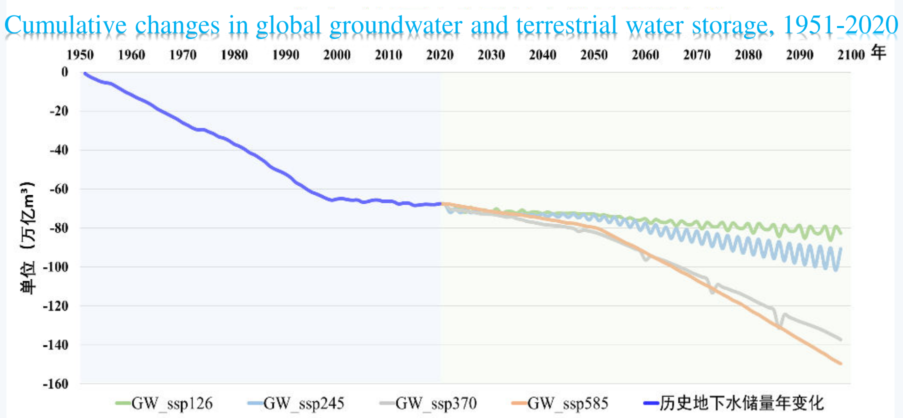
□ **Available**：7.5 trillion m³ □ **Renewable**：6.15 trillion m³

Soil water resources



- From 2021 to 2098, the average annual soil water reserves are 71.45, 71.92, 71.17, and 71.22 trillion m³

Groundwater resources



- Compared with 2020, groundwater reserves have decreased by 19.50, 45.92, 45.56, and 82.26 trillion m³, respectively.

Thank you for your attention!

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