CHILE-CHINA WORKSHOP
ON WATER RECOURSES MANAGEMENT IN CHINA AND CHILE

Hydrological Responses to Rapid Changes of the Earth Surface Environments in China

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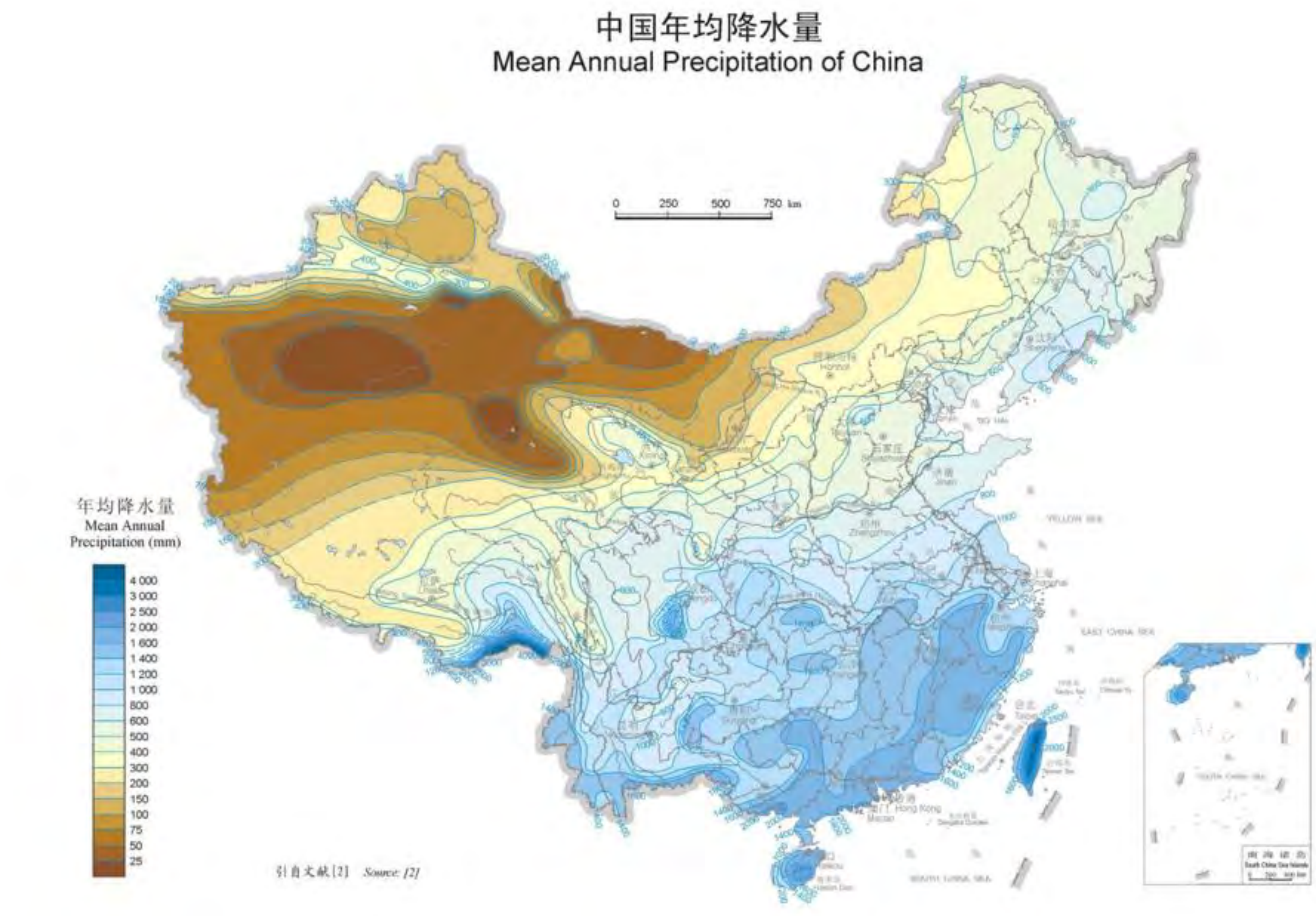
Outline

- **Background:**
  - Climate in China
  - Landscape in China
  - Global Change

- **Hot topics of hydrological researches in China**
  - Effect of Climate Change on Glacier Hydrology
  - Ecohydrology in Ecologically Fragile Areas
  - Effect of Urbanization on Hydrology
  - Earth Critical Zone Hydrology
  - Flash flood forecast
  - Drought monitoring and prediction

- **Comparative studies in hydrology**

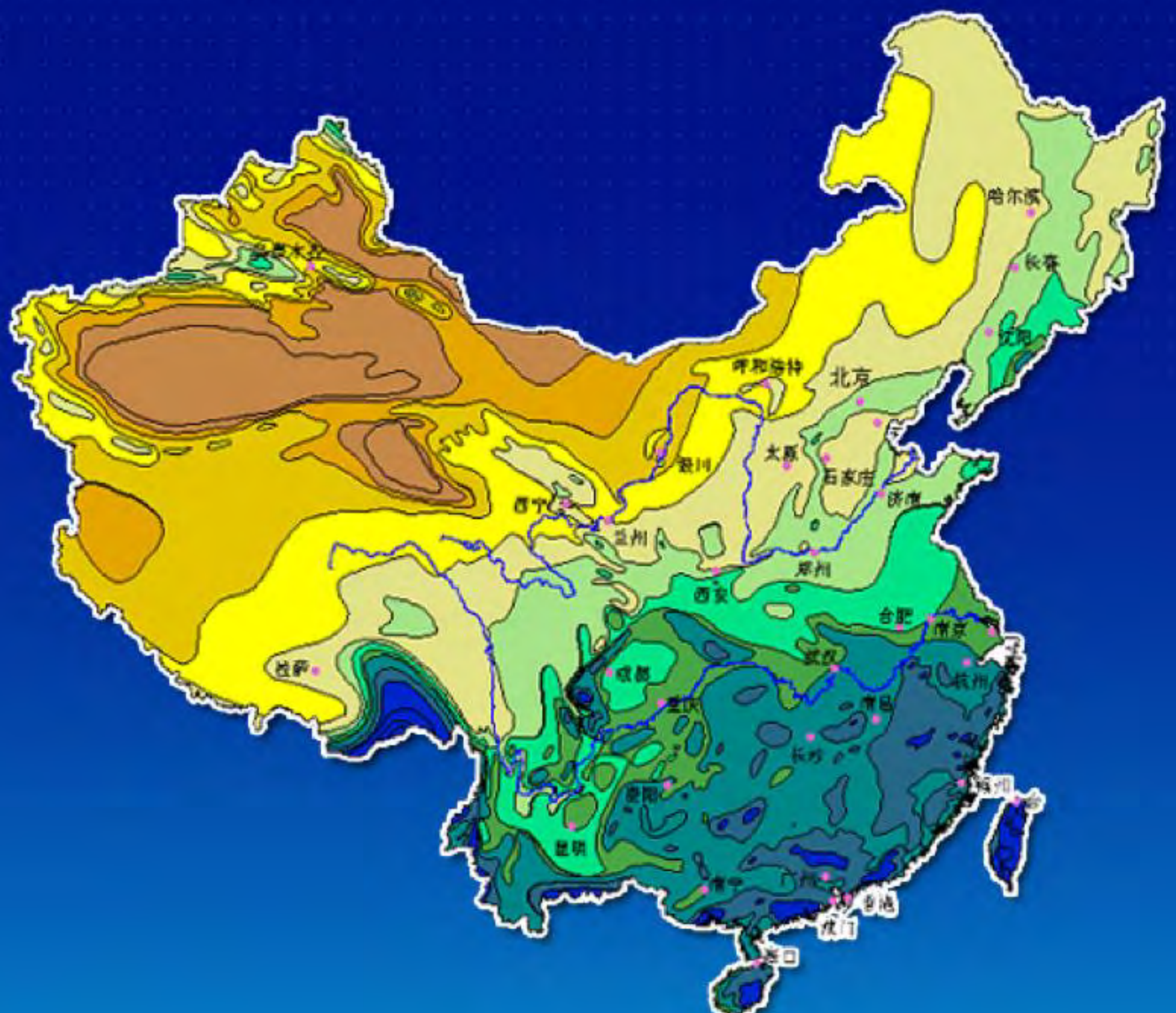
1 Background- Climate in China



- **Monsoon-dominated climate causes very distinctive wet (Apr - Sep) and dry (Oct - Mar) seasons in a *Water Year***
- **From humid to arid: a gradient from SE to NW**

1 Background- Climate in China

Water resources uneven distribution



North:

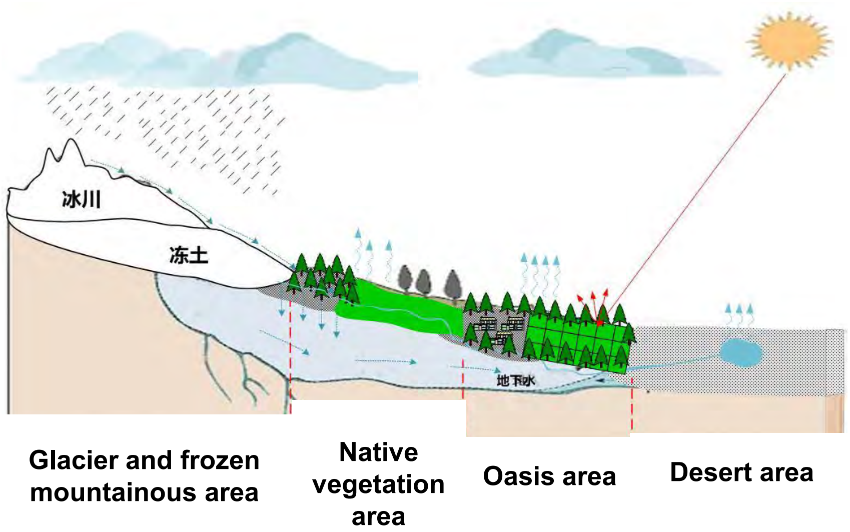
- water resources 19%
- population 47%
- cultivated land 64%
- GDP 45%

South:

- water resources 81%
- population 53%
- cultivated land 35%
- GDP 55%

一、黑河流域生态景观简介

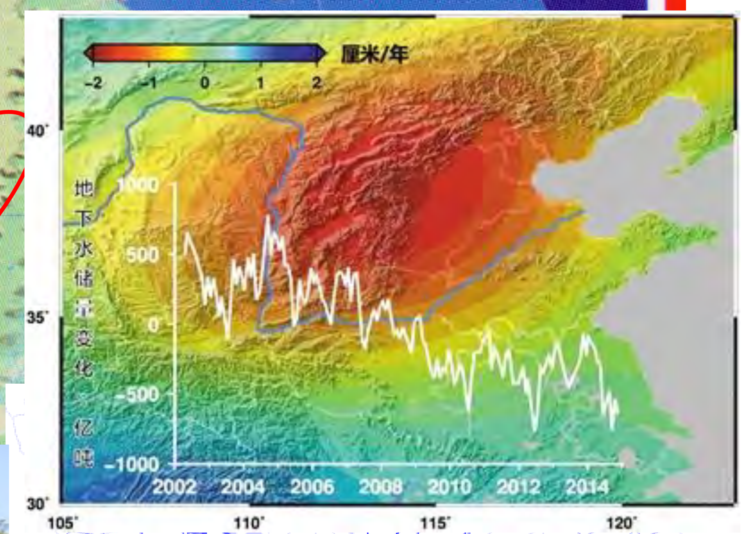
pe in China

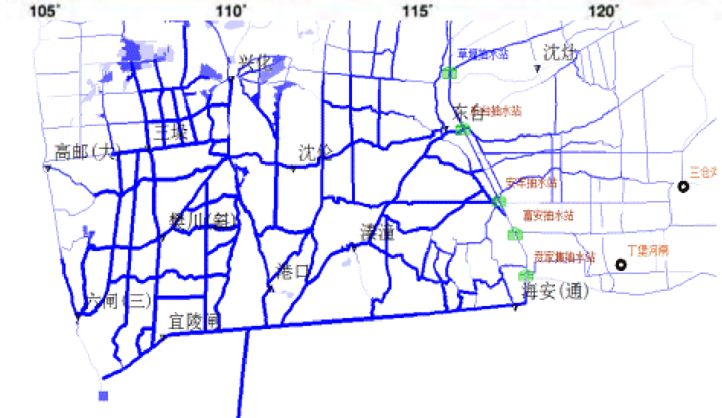


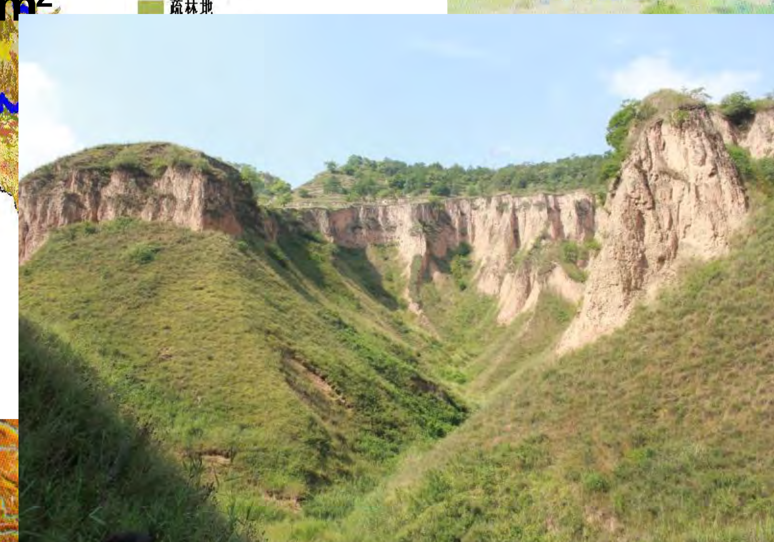
山地 34%

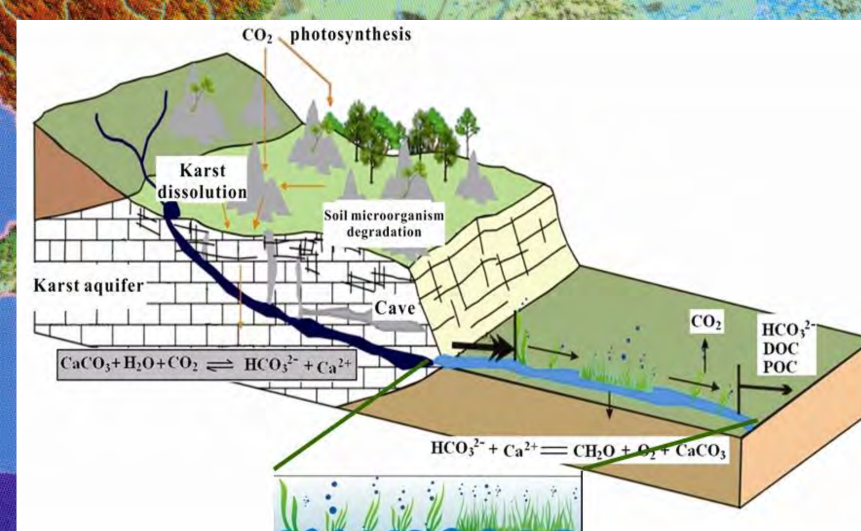
荒漠 57%

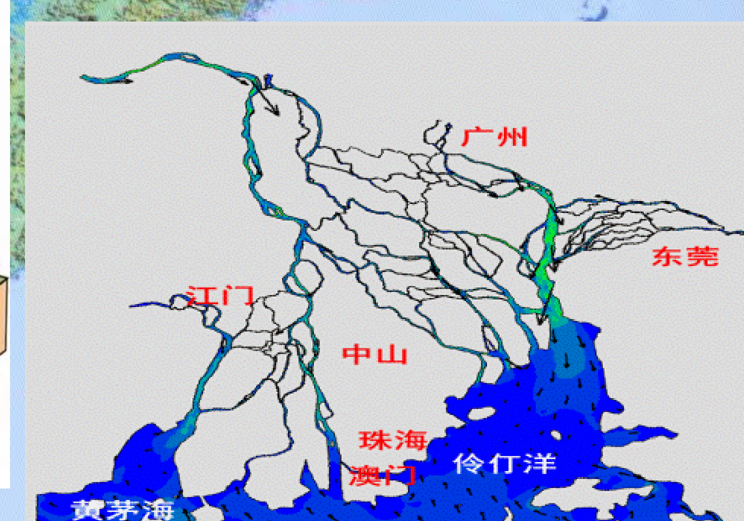
绿洲 9%



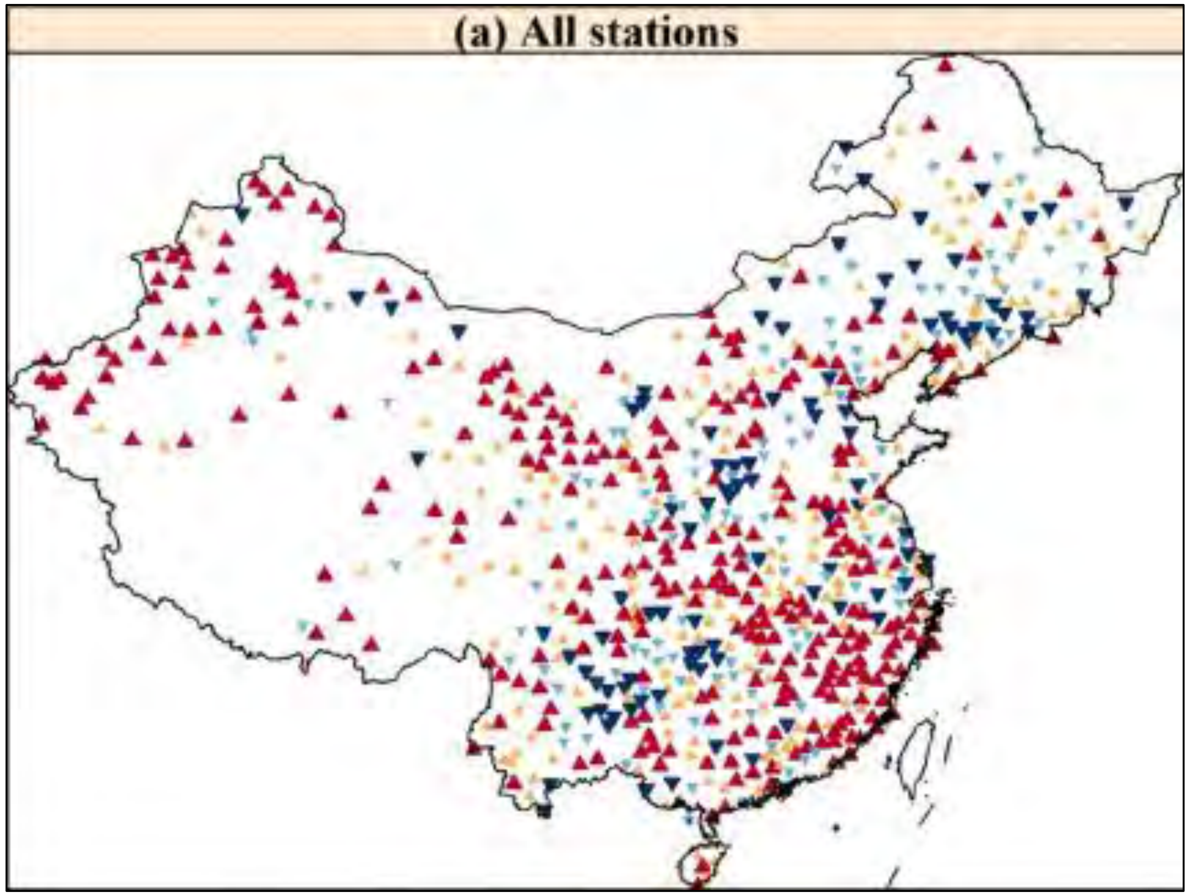


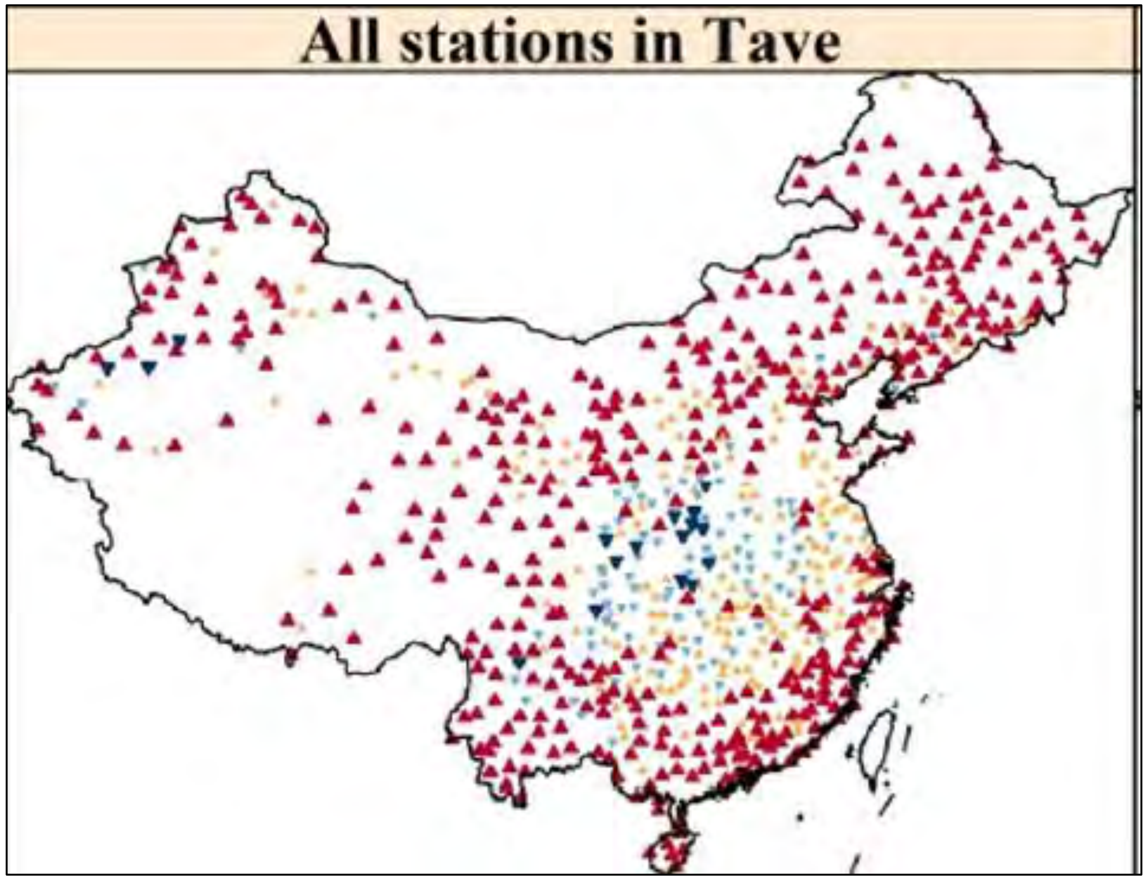




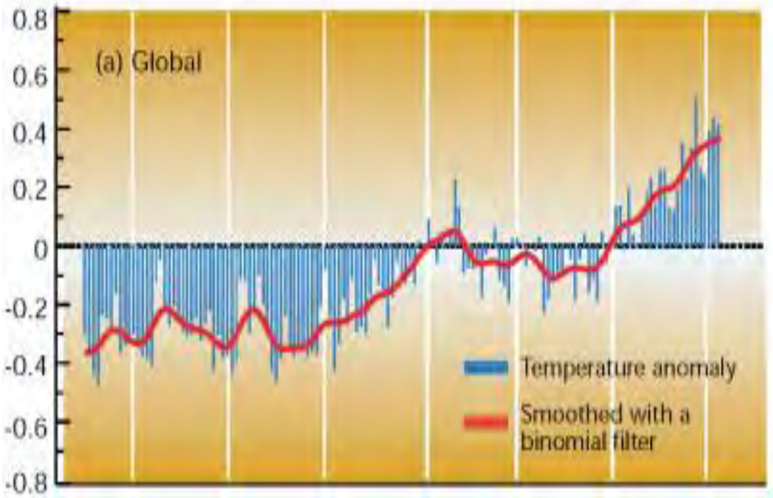


1 Background- Global Change

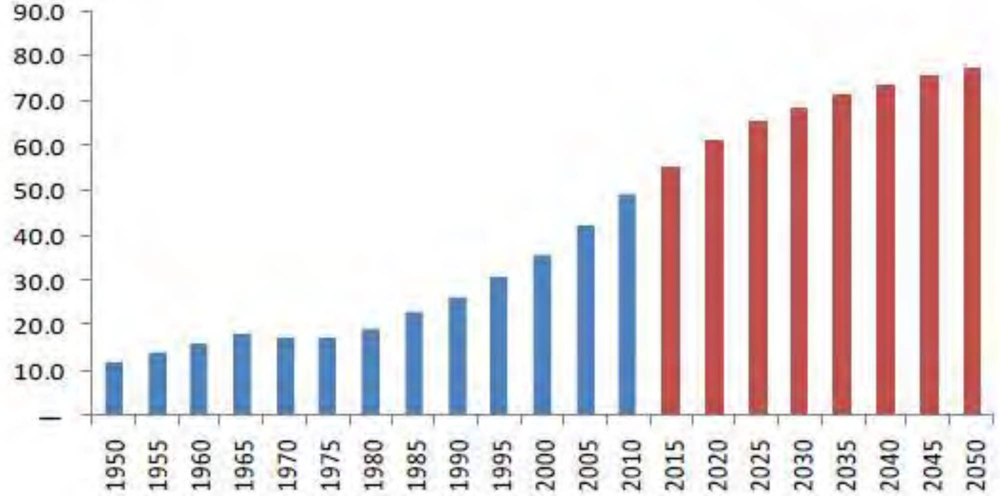




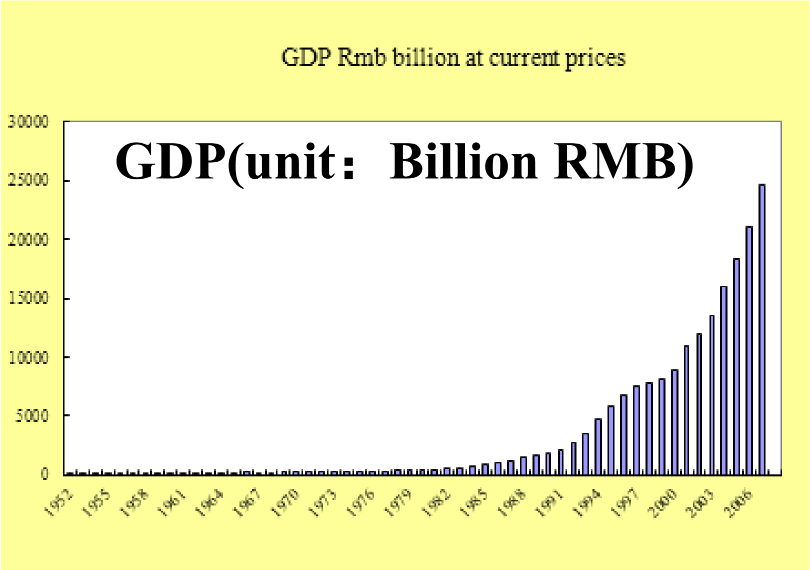
Daily precipitation and temperature data from 728 meteorological stations covering 1951–2014 (Gu and Zhang et al., JH, 2017)



Global warming (0.24 ^{0}C/10a in China)



Urbanization rate in China

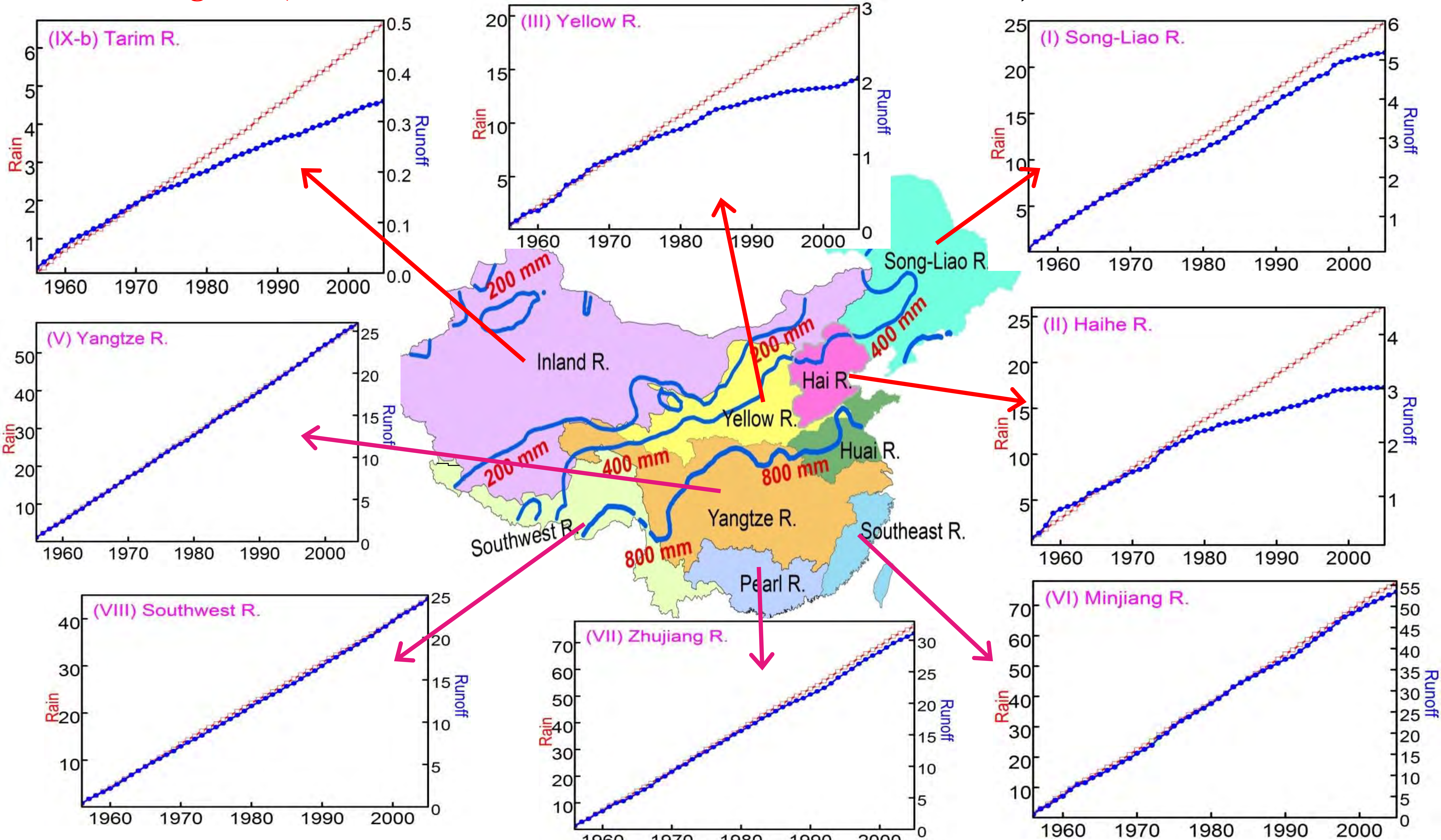


Economic development in China

1 Background- Global Change

Human induced runoff decrease

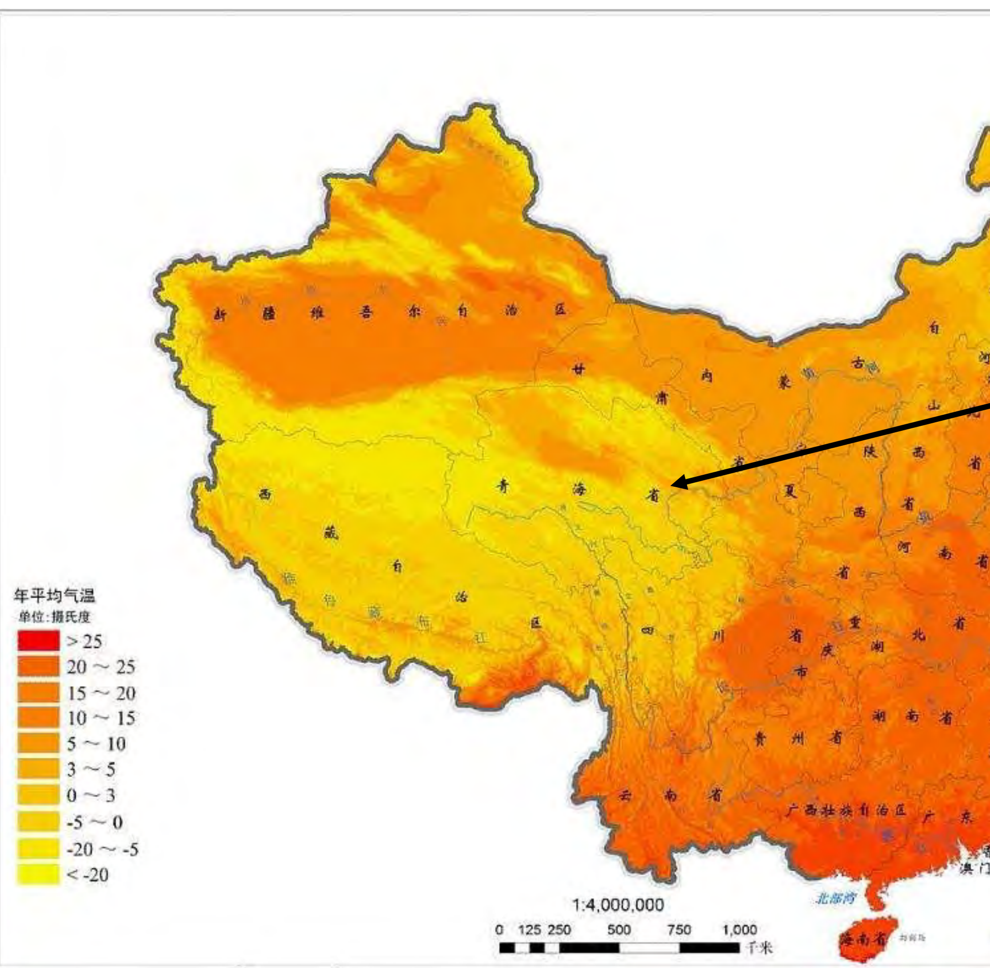
•Annual accumulation series of P and R **: decreasing trend of annual runoff since 1980s in the north regions (ΔR/ ΔP decreases) (Zhang and Chen et al., JH, 2011)**

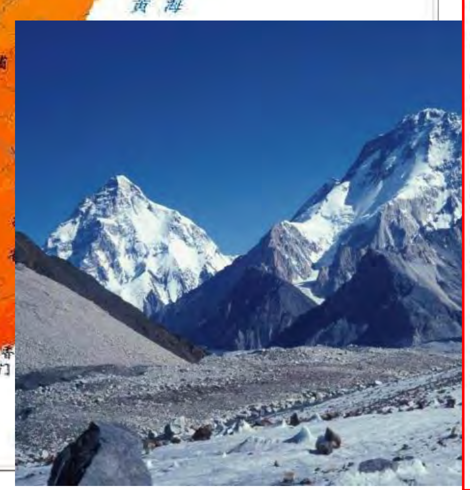


2 Hot topics - Glacier Hydrology

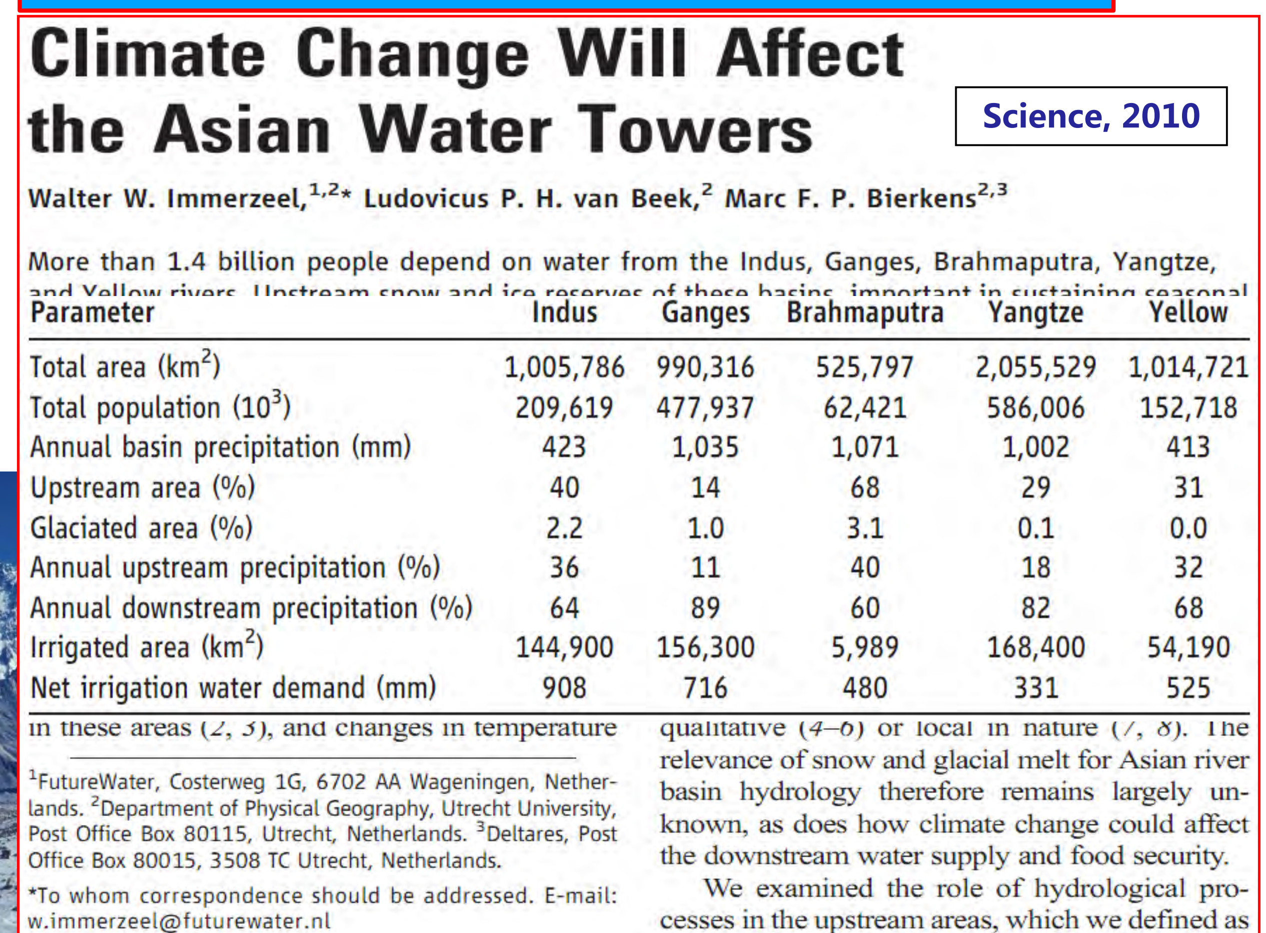
Climate Change (Rapid rise of T)

- Glacier, snow and permafrost melting
- Runoff (stream flow), groundwater storage and lake area change
- Hazard (flood, debris flow and landslide)
- Water utilization and ecological protection





亚洲水塔影响面积近600万km2,人口近10亿



Climate Change Will Affect the Asian Water Towers

Science, 2010

Walter W. Immerzeel,[1,2]* Ludovicus P. H. van Beek,[2] Marc F. P. Bierkens[2,3]

More than 1.4 billion people depend on water from the Indus, Ganges, Brahmaputra, Yangtze,

Parameter	Indus	Ganges	Brahmaputra	Yangtze	Yellow
Total area (km^2)	1,005,786	990,316	525,797	2,055,529	1,014,721
Total population (10^3)	209,619	477,937	62,421	586,006	152,718
Annual basin precipitation (mm)	423	1,035	1,071	1,002	413
Upstream area (%)	40	14	68	29	31
Glaciated area (%)	2.2	1.0	3.1	0.1	0.0
Annual upstream precipitation (%)	36	11	40	18	32
Annual downstream precipitation (%)	64	89	60	82	68
Irrigated area (km^2)	144,900	156,300	5,989	168,400	54,190
Net irrigation water demand (mm)	908	716	480	331	525

in these areas (2, 3), and changes in temperature

[1]FutureWater, Costerweg 1G, 6702 AA Wageningen, Netherlands. [2]Department of Physical Geography, Utrecht University, Post Office Box 80115, Utrecht, Netherlands. [3]Deltares, Post Office Box 80015, 3508 TC Utrecht, Netherlands.

*To whom correspondence should be addressed. E-mail: w.immerzeel@futurewater.nl

qualitative (4–6) or local in nature (7, 8). The relevance of snow and glacial melt for Asian river basin hydrology therefore remains largely unknown, as does how climate change could affect the downstream water supply and food security.

We examined the role of hydrological processes in the upstream areas, which we defined as

2 Hot topics - Glacier Hydrology

Runoff Change and Adaptive Management in the River Source Region of Southwestern China (NSFC Major Research Plan 2016-2024)

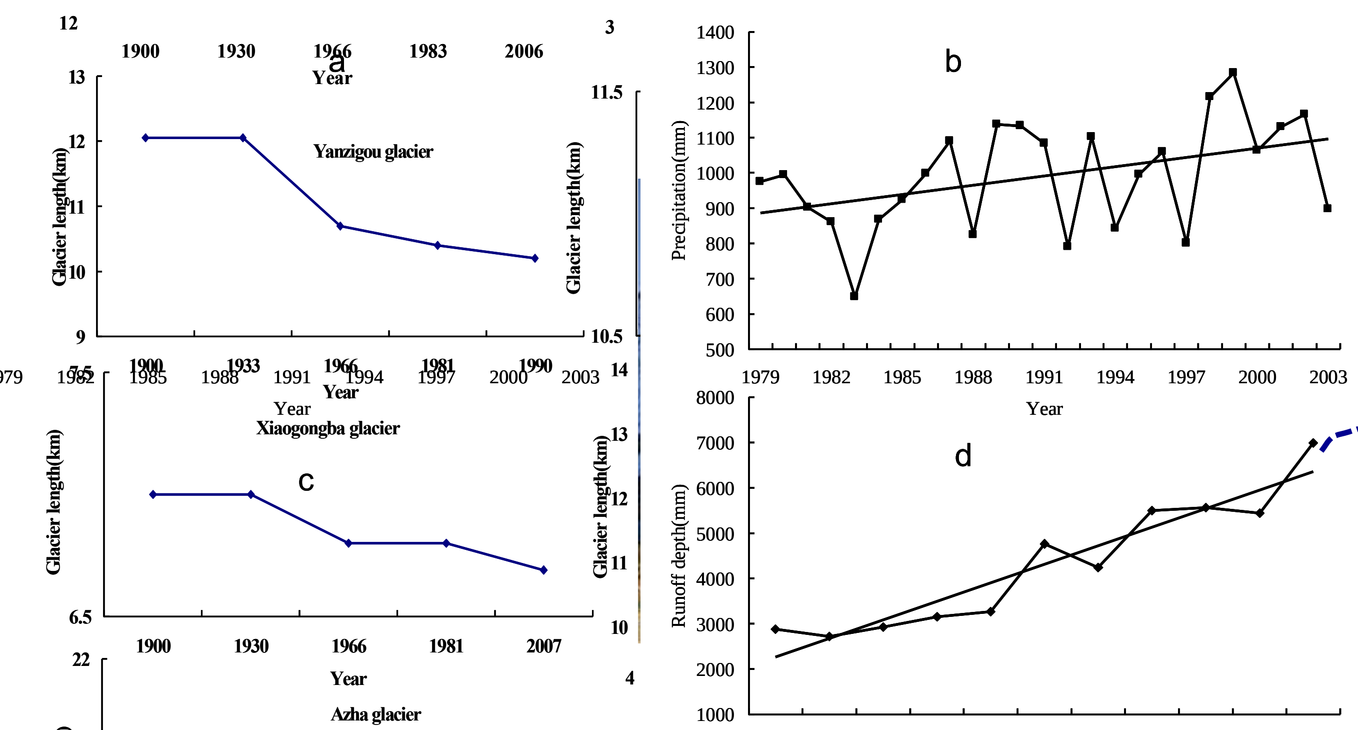
The main objectives of this research:

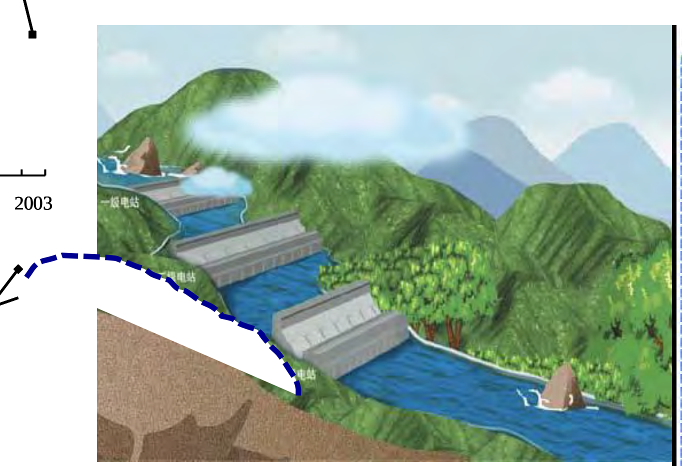
(1) To quantify the runoff variations in response to climate change;

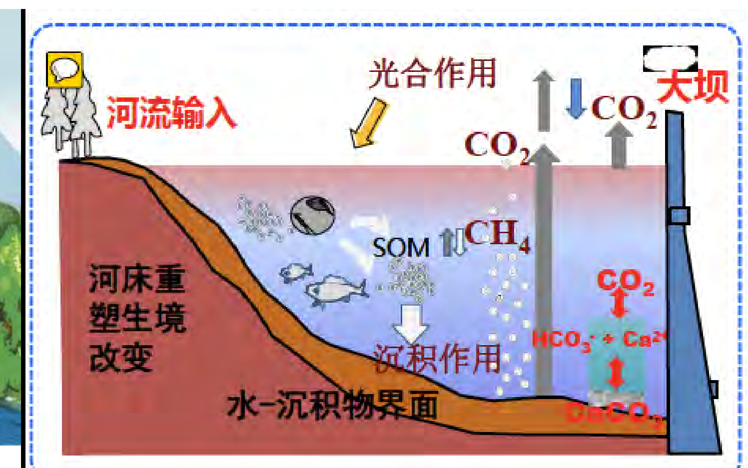
(2) To estimate changes of the biogenic substances in rivers, reservoirs and lakes affected by the runoff variations

(3) To establish the water-energy-environment nexus in the region

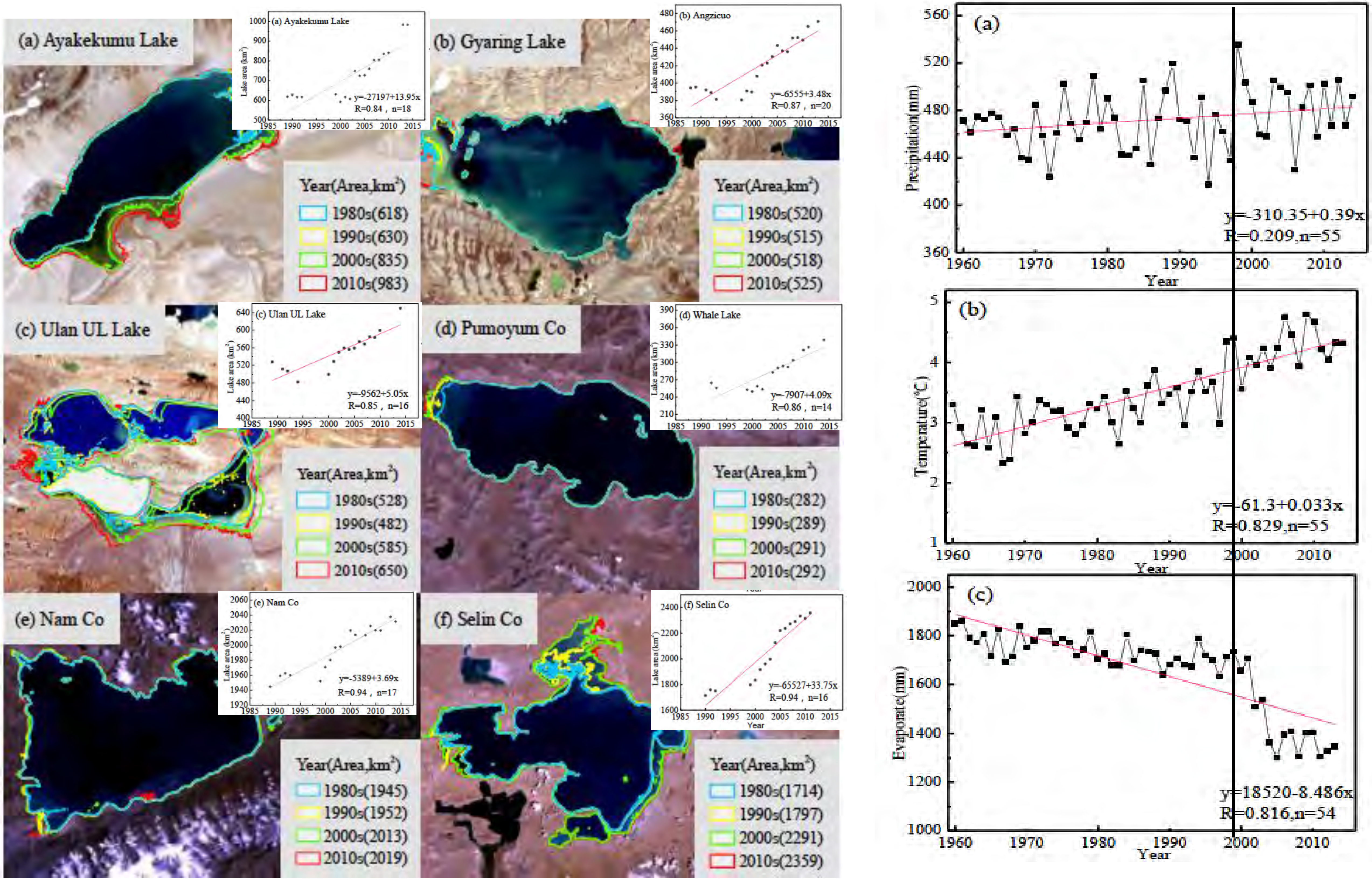
(4) To find the strategies for adaptive utilization of runoff under changing environments







2 Hot topics - Glacier Hydrology



Has the climate shifted from warm-dry period to warm-wet period over Qinghai-Tibetan Plateau during the past 30 years? (Zhang and Chen et al., STE, 2018)

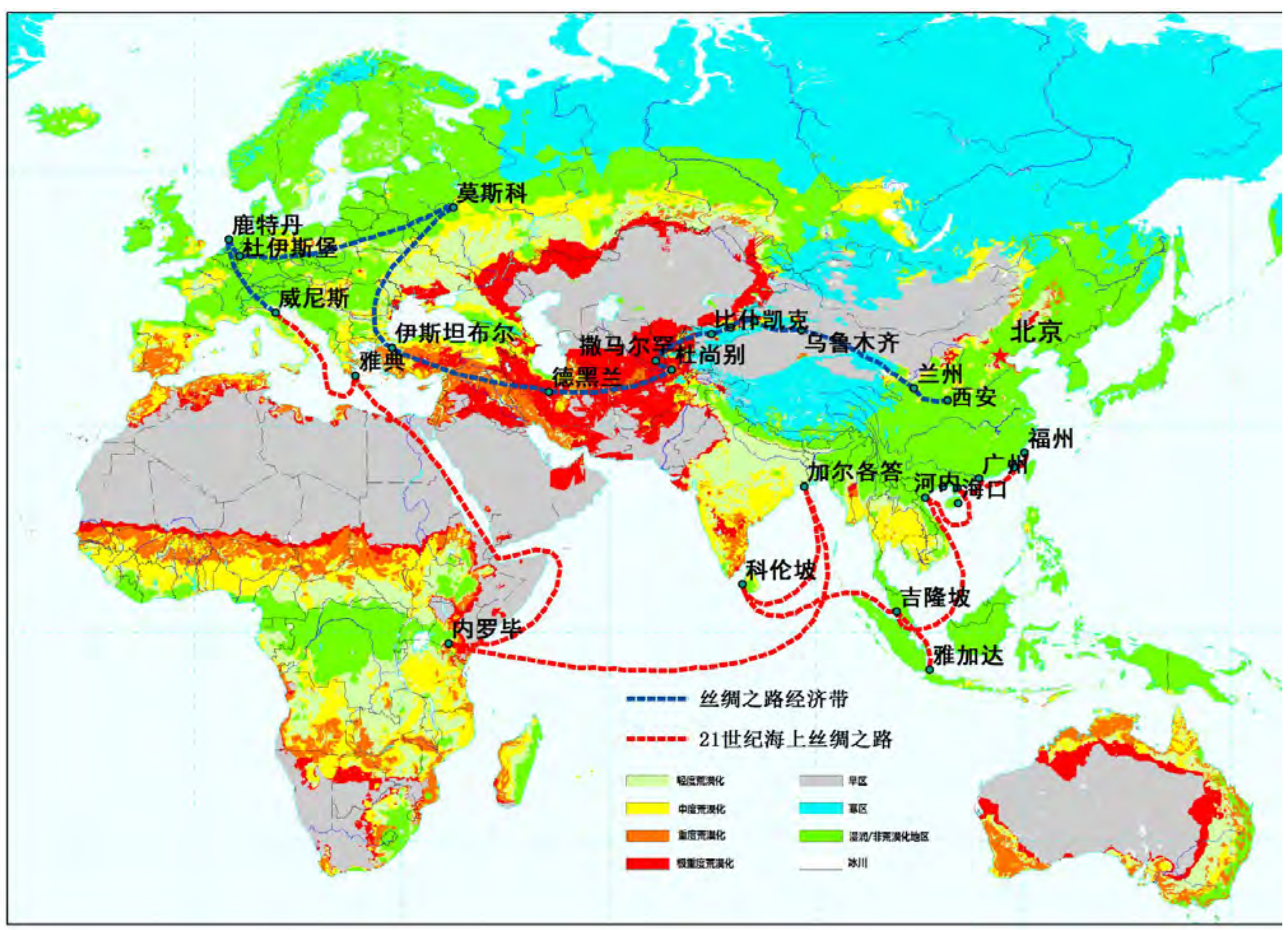
2 Hot topics - Ecohydrology

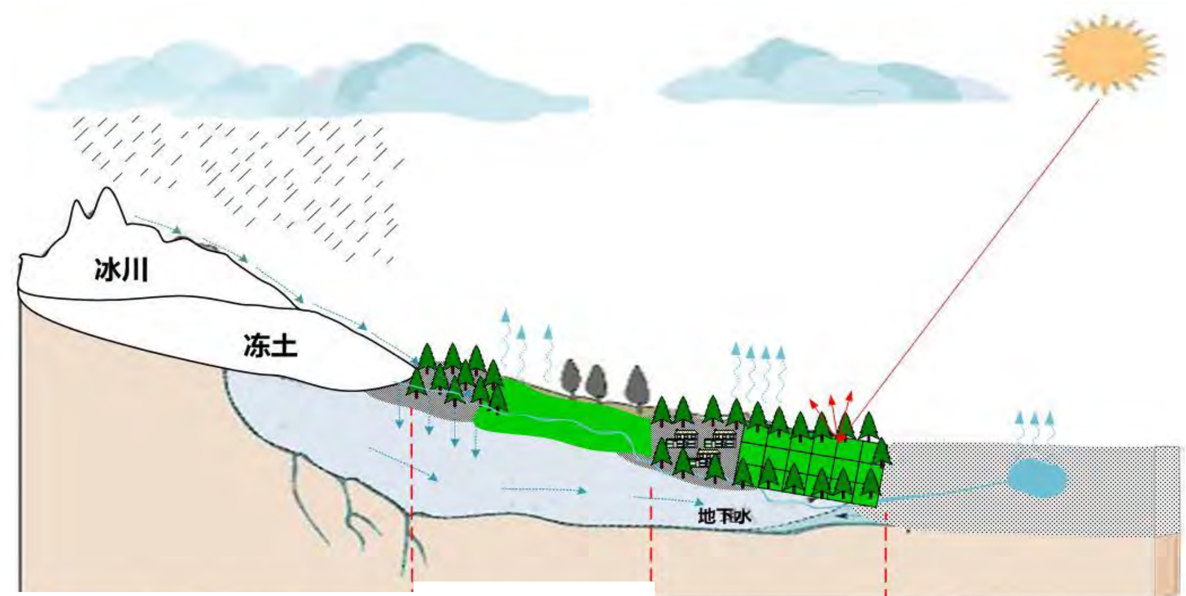
Climate Change and de/reforestation

(The Grain-for-Green Project)

- Mountainous hydrological variability: P, ET, R
- Oasis hydrology: ET, groundwater table, a
- Desert: prevention of desert area expansio
- Connection among mountainous runoff – (

一、黑河流域生态景





山地 34%

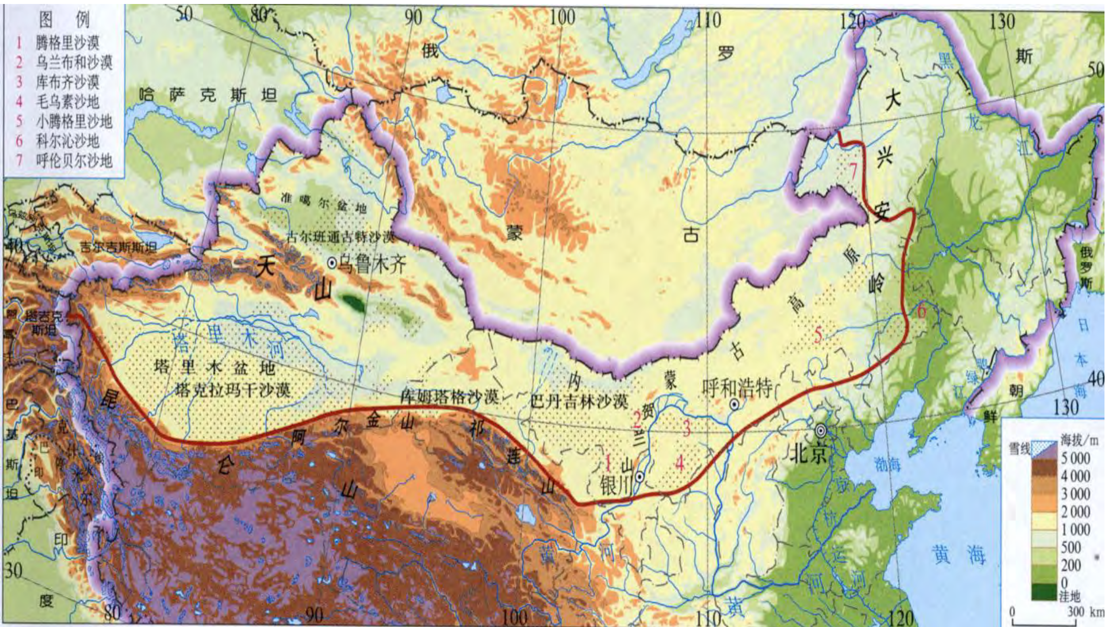
荒漠 57%

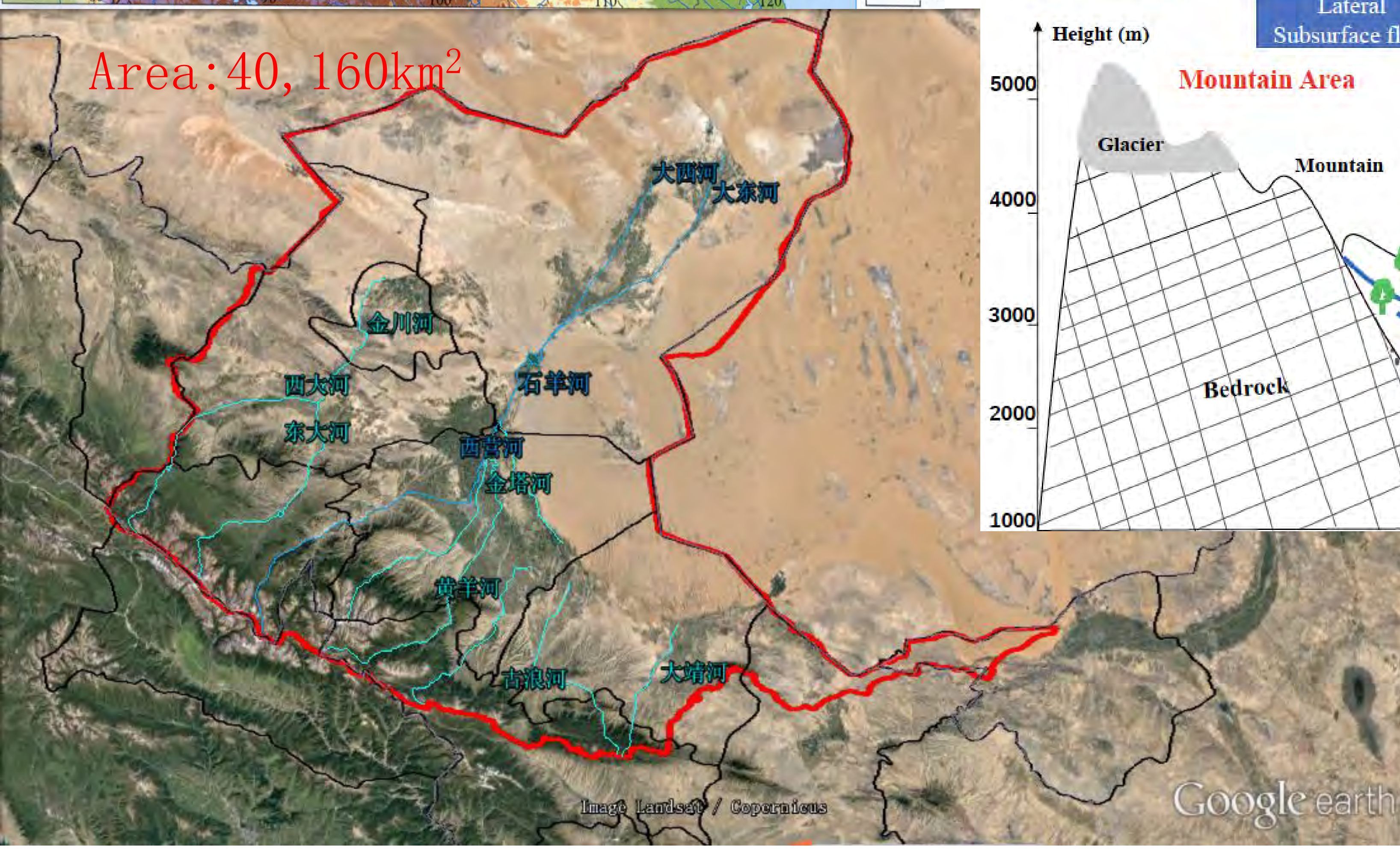
Desertification

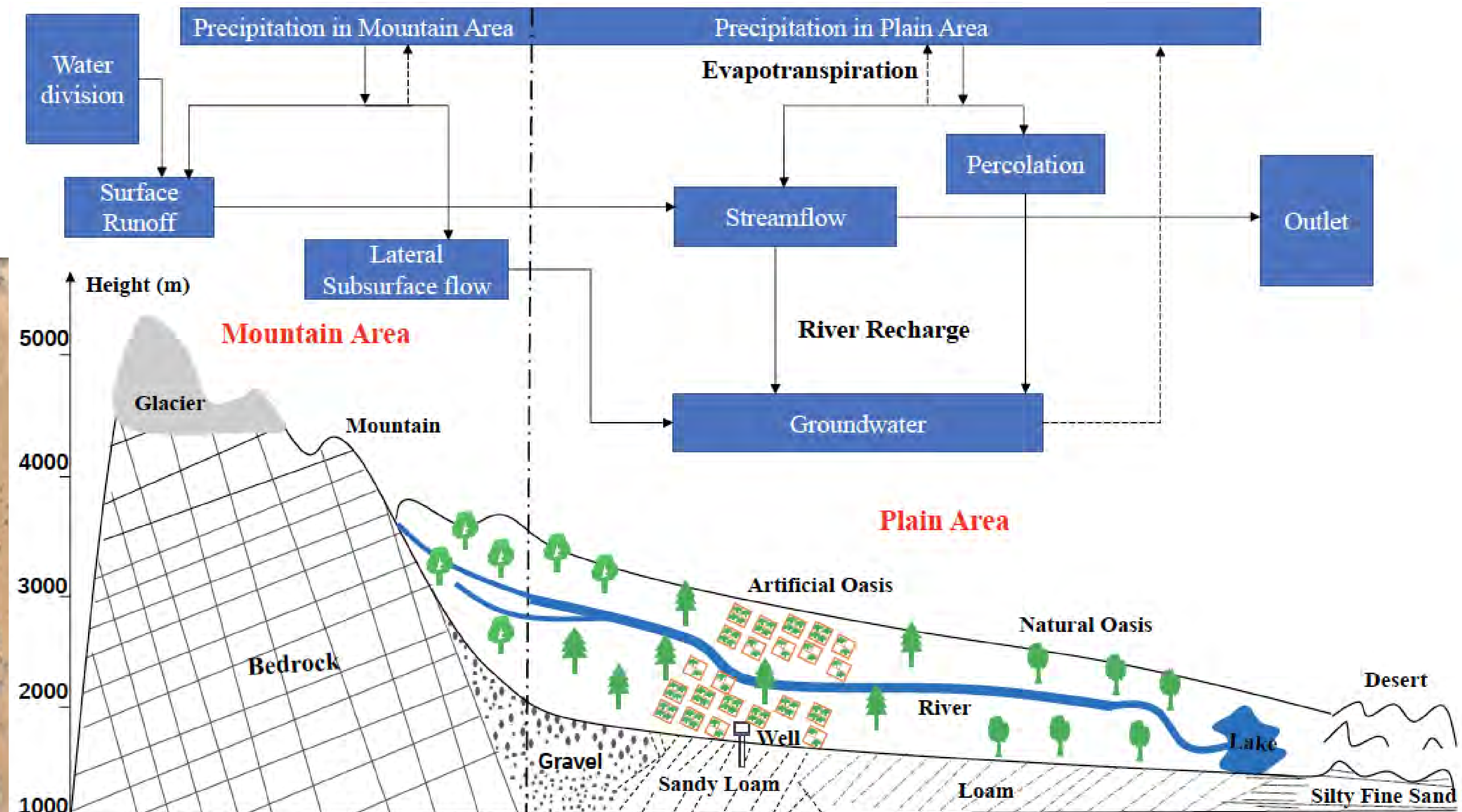
绿洲 9%

2 Hot topics - Ecohydrology

Reasonable groundwater utilization for prevention of ecosystem degradation in the western China (MOST, 2017-2020; PI, Chen)

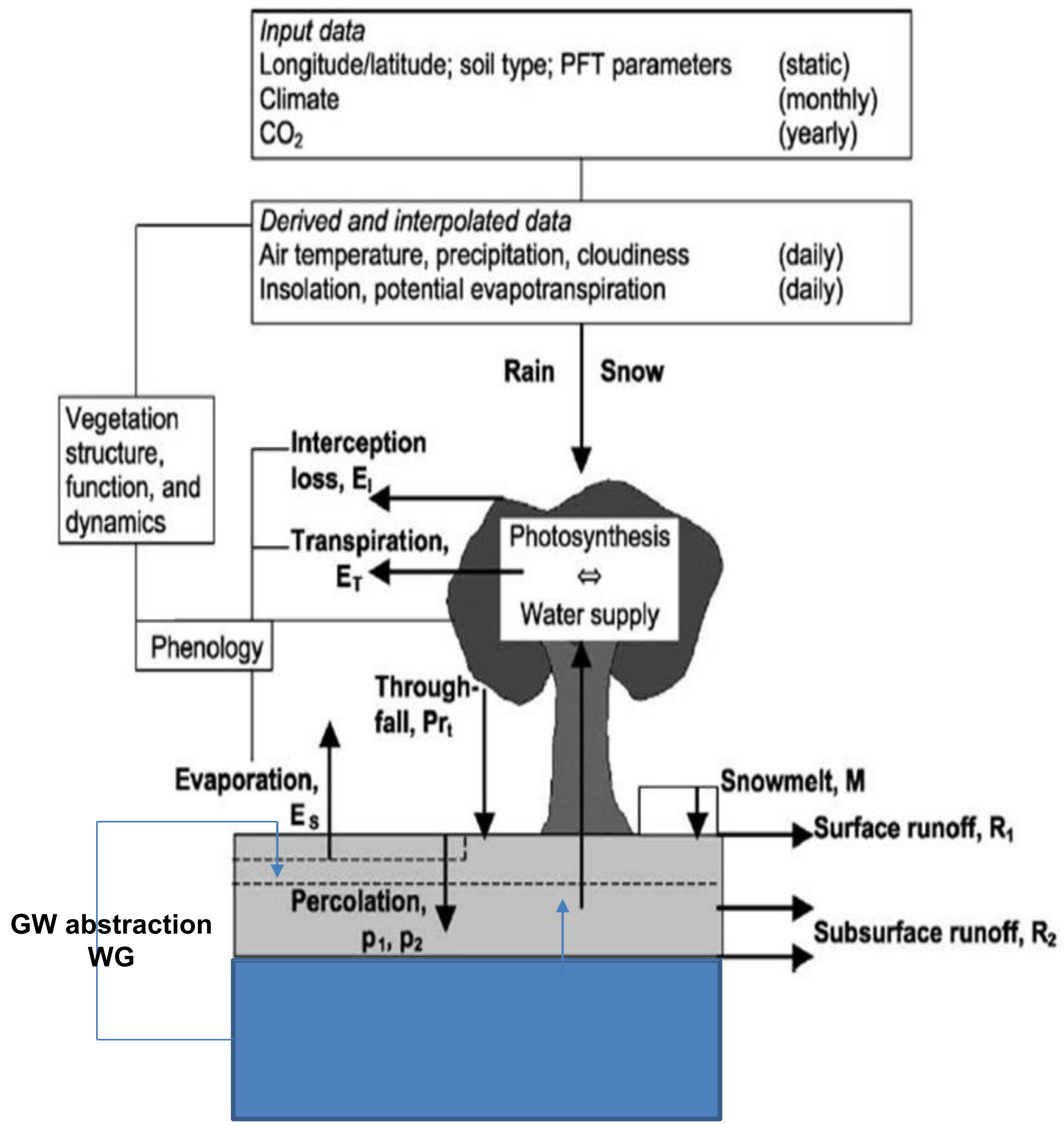






Reasonable groundwater utilization for prevention of ecosystem degradation in the western China (MOST, 2017-2020; PI, Chen)

Observations -> Modeling -> Water utilization strategies



Modified LPJ (according to Gerten D et al ,2004)

Evapotranspiration:

Interception: $E_i=E_q w$

Soil Evap.: $E_s=wr_{20}Ep(1-fv)$

Transpiration: $E_t=Min(S,D)fv$

$S=E_{max}*Wr$ $Wr=f_1* w_1+ f_2* w_2$

$D=(1-w)*（E_q* a_m）*(1+ g_m/g_{pot})$

Runoff:

$R_1= (w_1-1)*fwhc_1*d_1$ $R_2= (w_2-1)*fwhc_2*d_2$

$R= R_1+R_2+P_2$

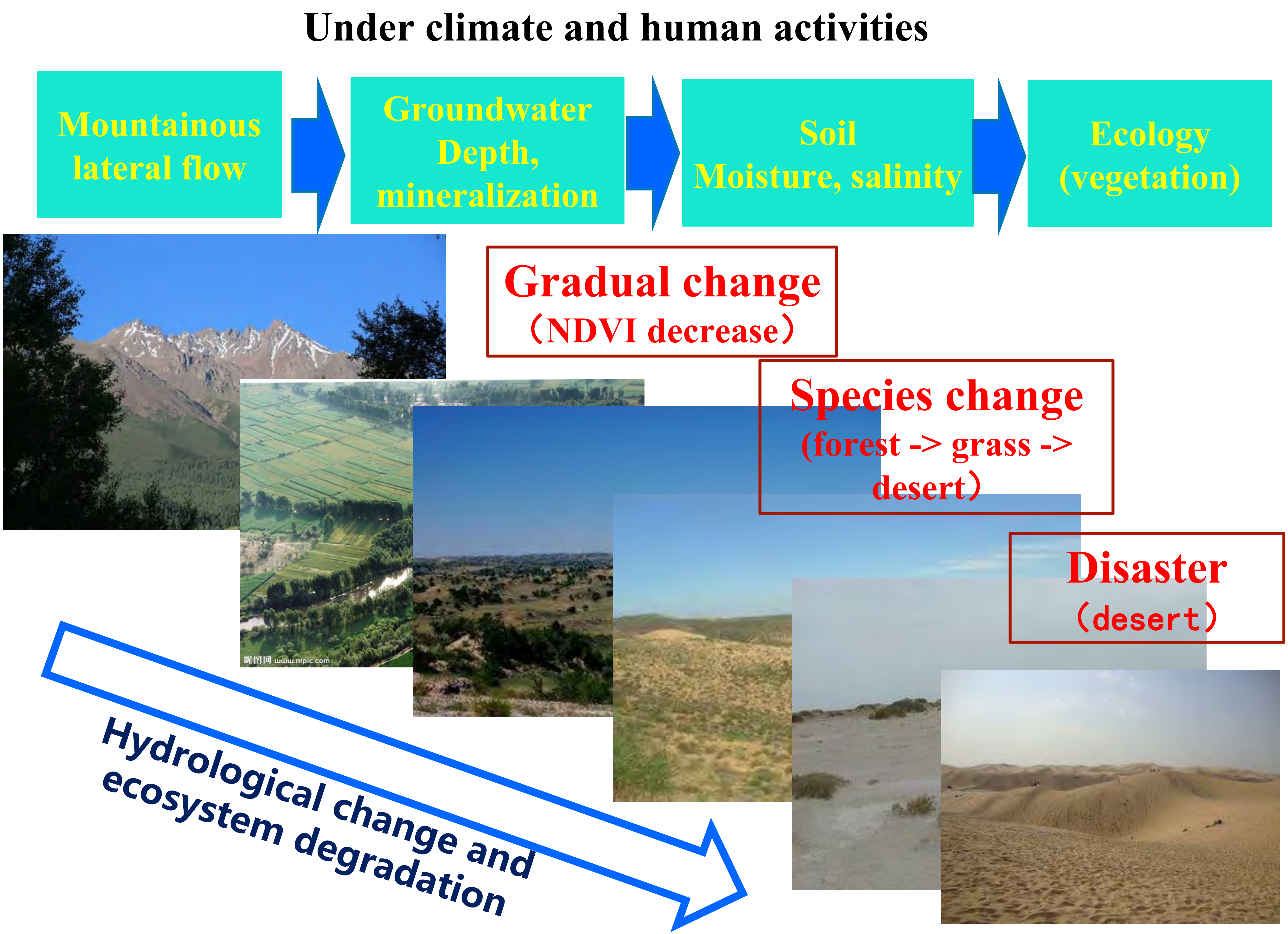
Groundwater flow:

$$\frac{\partial}{\partial x}(K_x\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_y\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_z\frac{\partial h}{\partial z})=S_s\frac{\partial h}{\partial t}-W$$

Net primary production(NPP):

$NPP=GPP-R_m-\max[(GPP-R_m)\times 0.25, 0]$

Leaf Area Index (LAI): $LAI =C_{leaf}*SLA/CA$

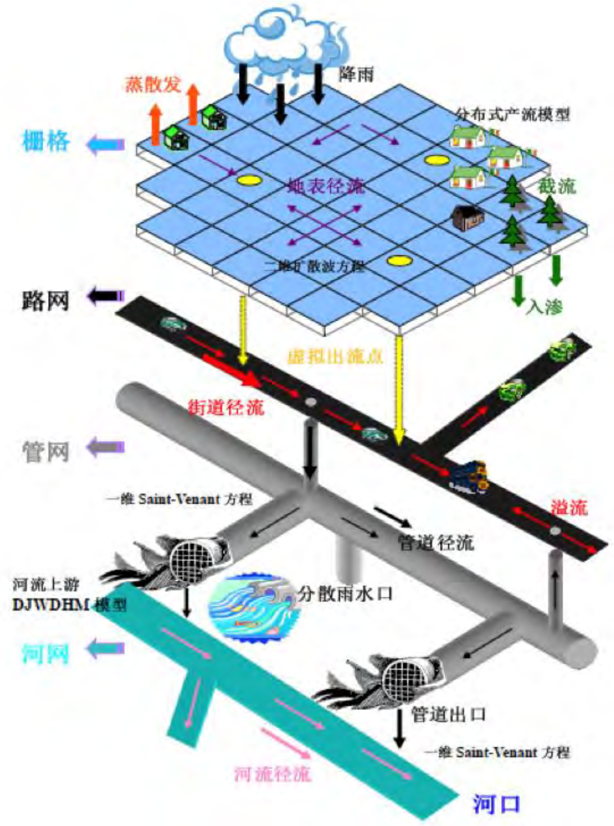

Under climate and human activities
Mountainous lateral flow
Groundwater Depth, mineralization
Soil Moisture, salinity
Ecology (vegetation)
Gradual change
（NDVI decrease）
Species change
(forest -> grass -> desert）
Disaster
（desert）
Hydrological change and ecosystem degradation

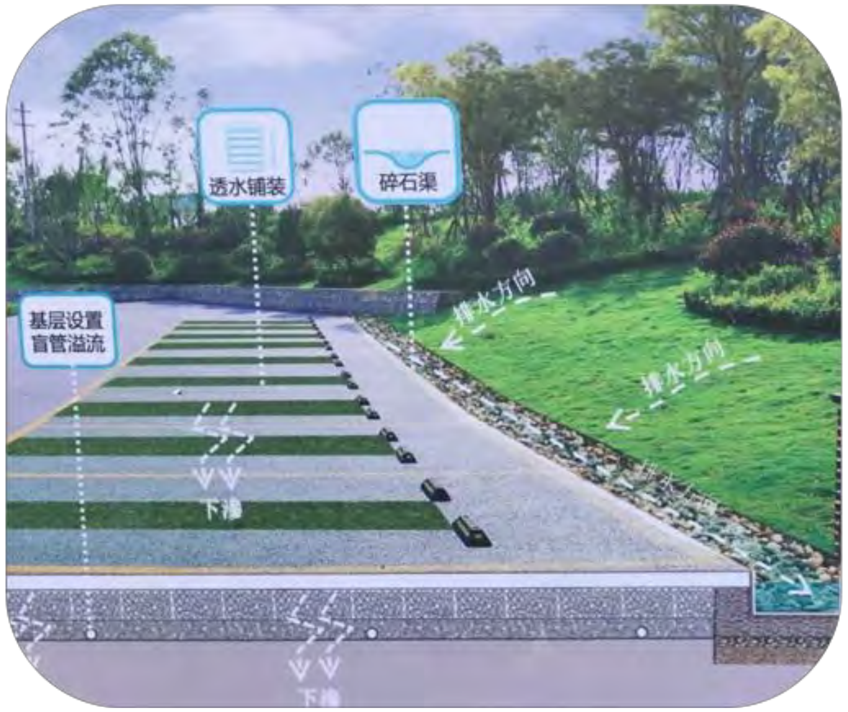
2 Hot topics - Urban hydrology

Climate change and urbanization

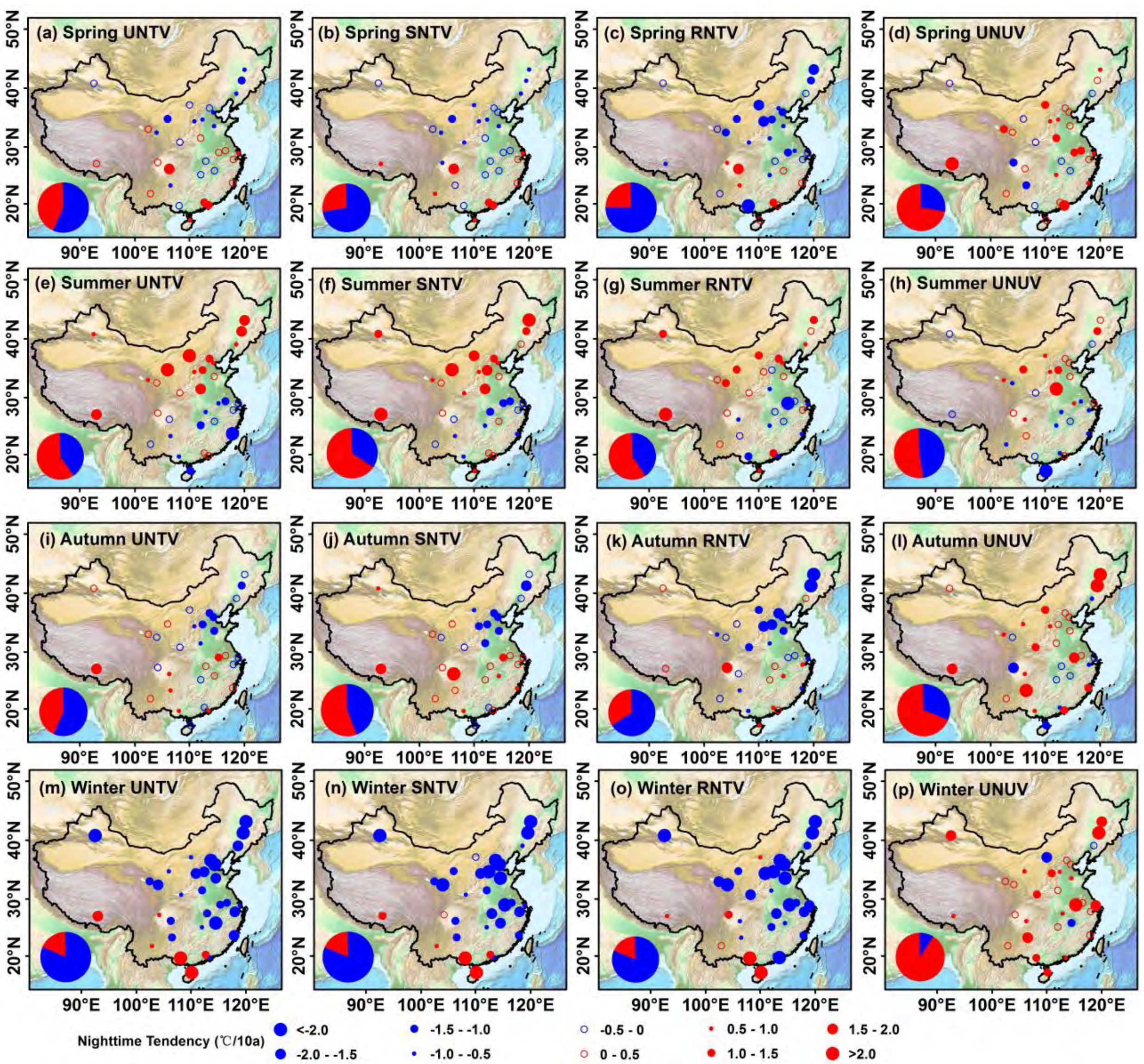
(Sponge City)

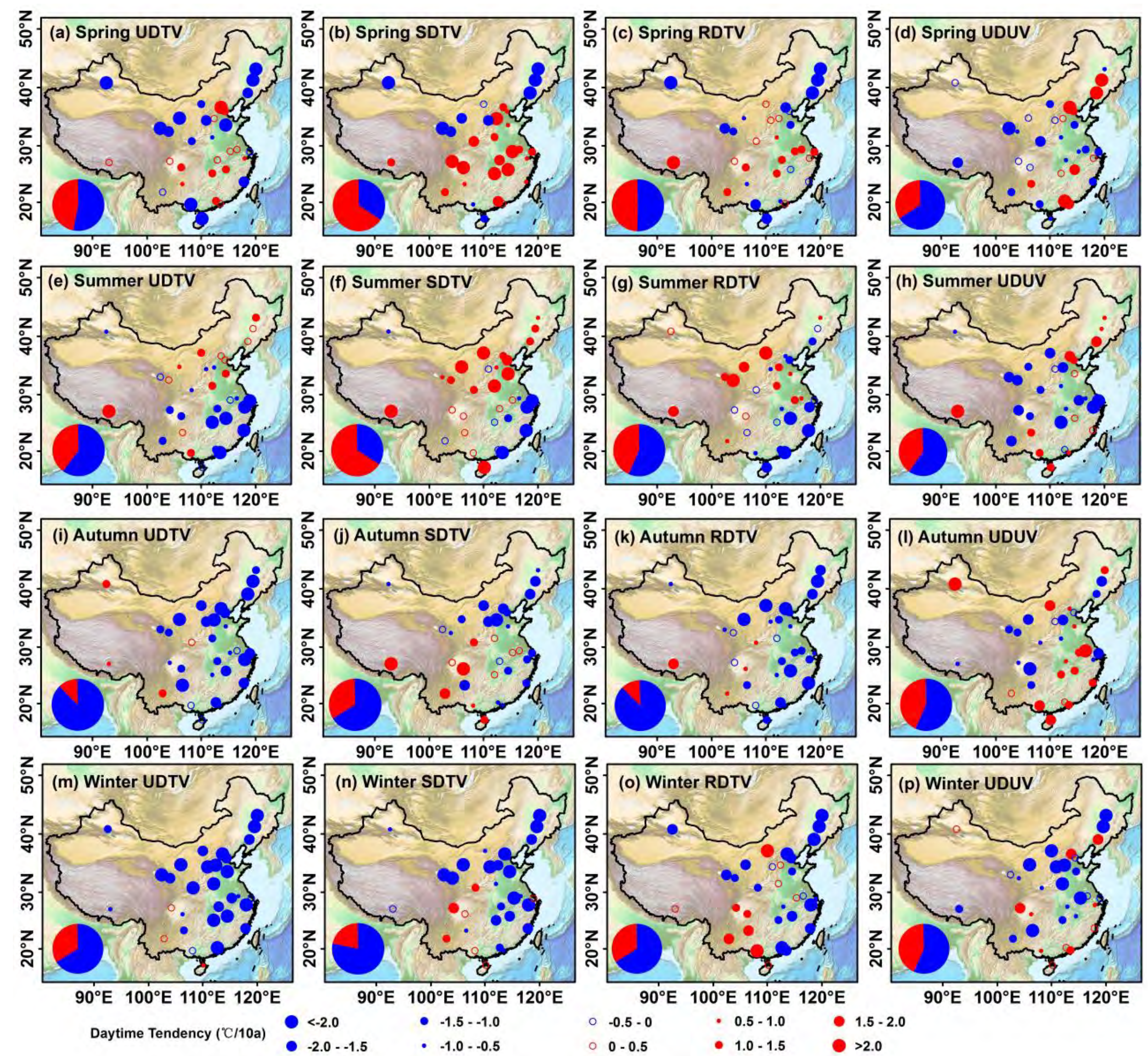
- Effect of Urban heat island on hydrology
- the urban water infrastructure (e.g. storm drains)
- models of the city hydroscape and the urban water balance
- implementation of green infrastructure

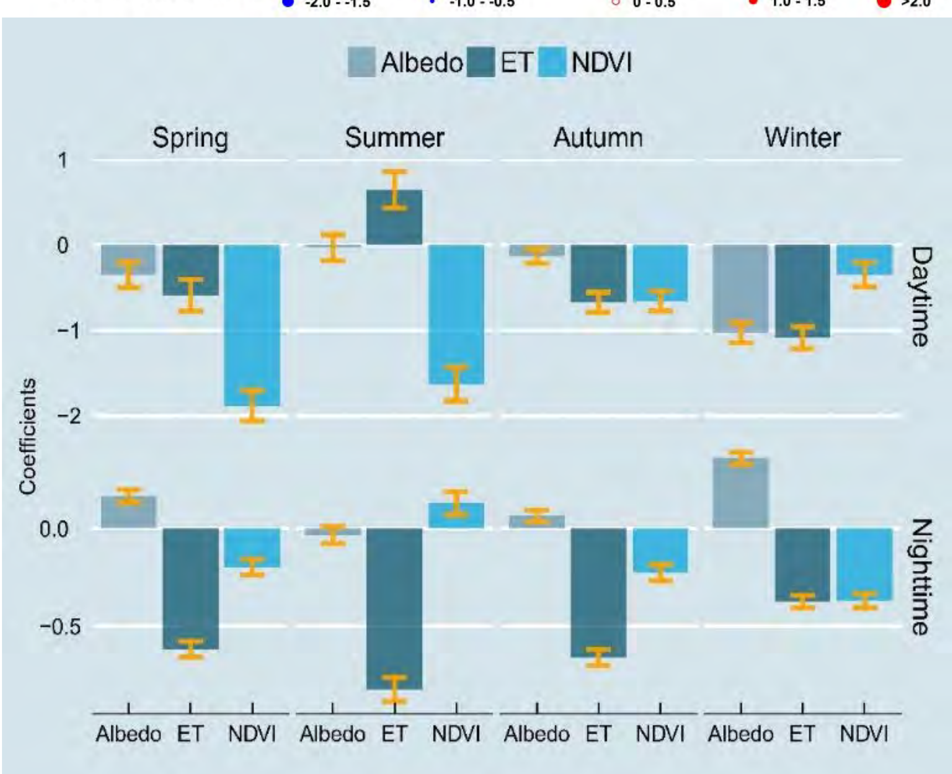


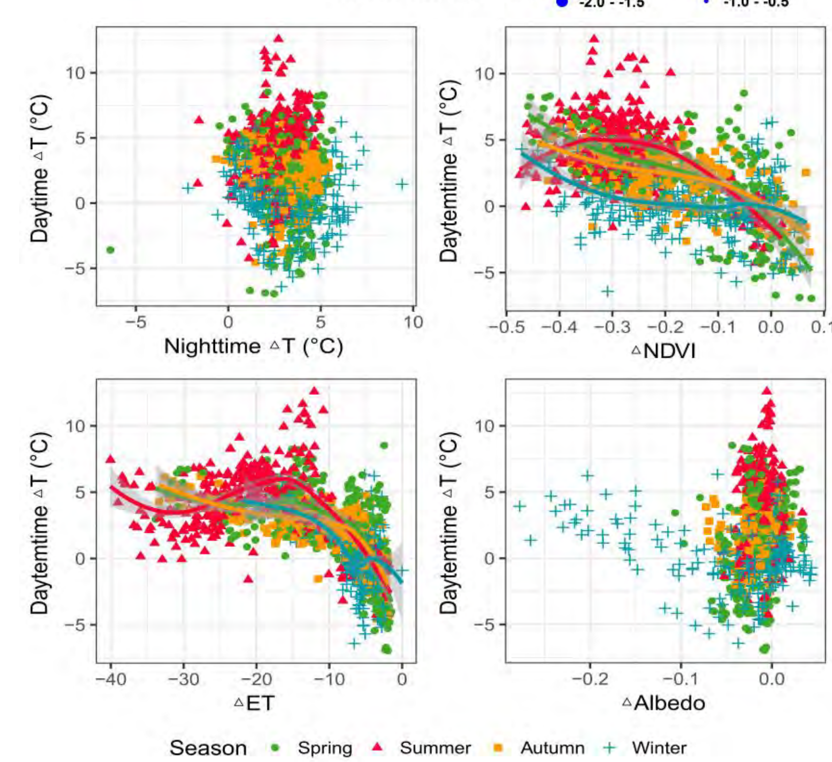


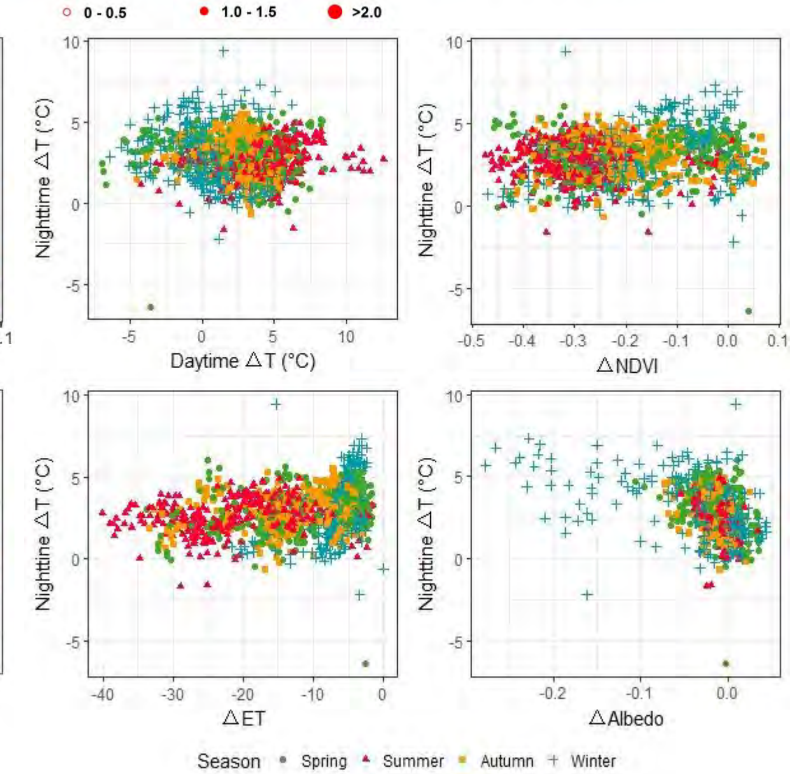
Urbanization-induced regional climate variability (Zhang et al.)



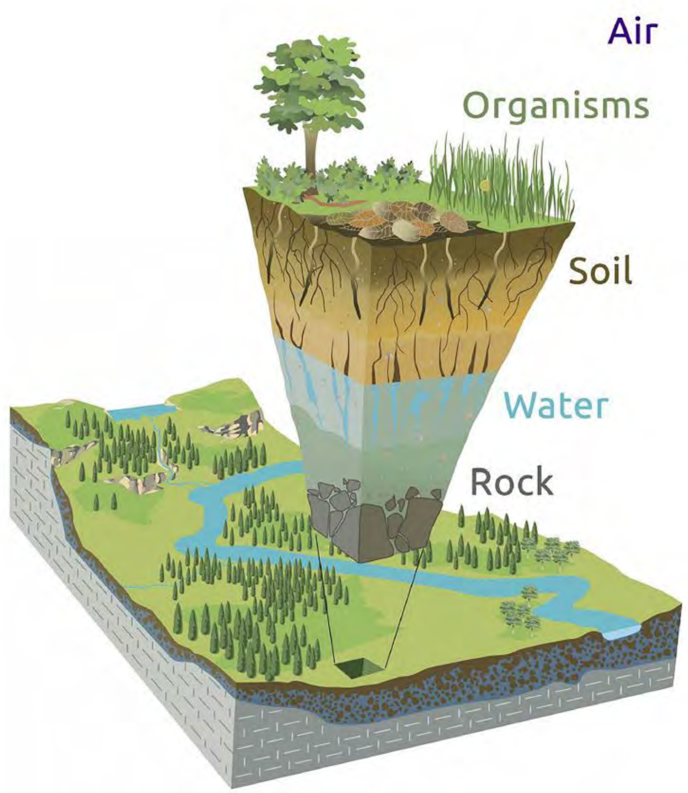


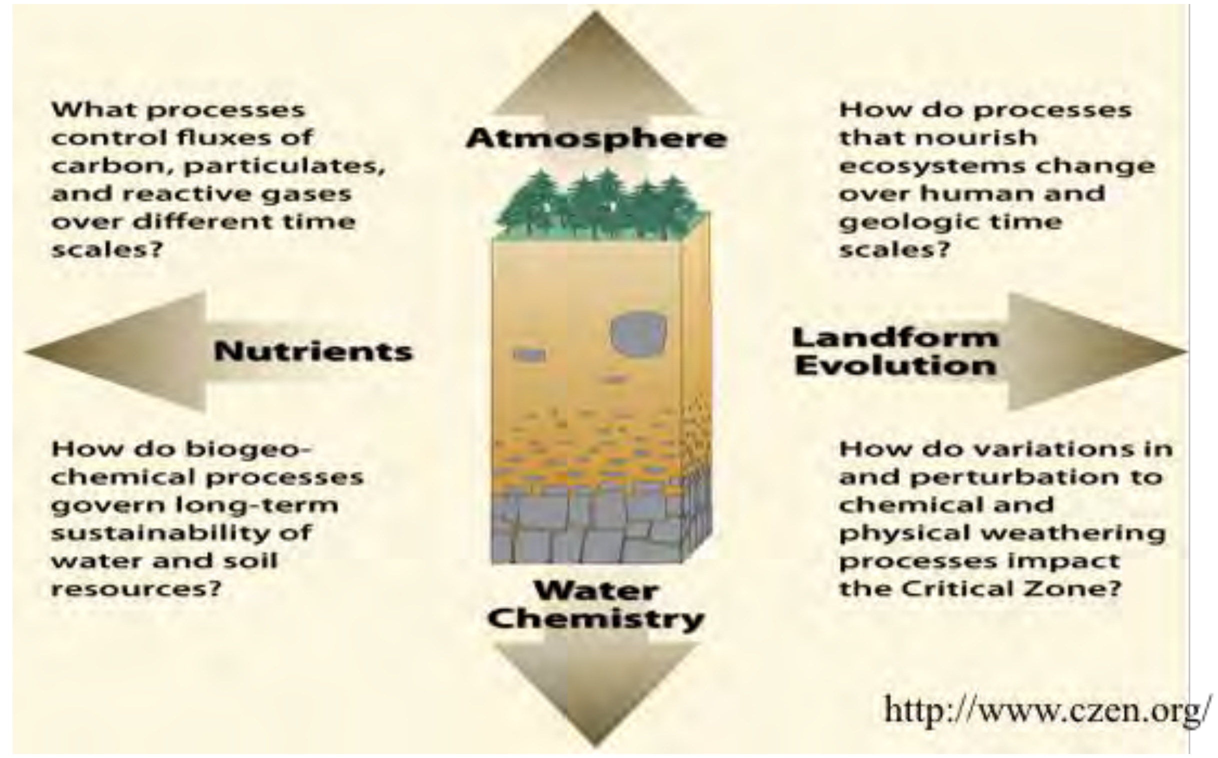






2 Hot topics - Earth Critical Zone Hydrology





2 Hot topics - Earth Critical Zone Hydrology

The 5 Projects

The programme supports 5 UK – China research consortia, each of which is carrying out research to better understand the ecosystem services of soil and water resources in keys sites across China: ranging from the complex and fragile Karst ecosystems of Guizhou; the highly eroded Loess Plateau; the peri-urban agricultural soils of Shanghai; to the unique red soils of the Sunjia Critical Zone Observatory near Yangling. The programme aims to link more closely the 5 projects and establish a coherent research programme that can interface with other UK, China and international research programmes and networks. Together the projects aim to carry out internationally-leading scientific research that also achieves ODA outcomes for soil and water resources in China.

PROJECT 1

The transmissive critical zone: understanding the karst hydrology-biogeochemical interface for sustainable management

PROJECT 2

Using Critical Zone Science to Enhance Soil Fertility and Improve Ecosystem Services for Peri-Urban agriculture in China

PROJECT 3

SPECTRA: Soil Processes and Ecological Services in the Karst Critical Zone of SW China

PROJECT 4

Red Soil CZ: From Natural to Anthropogenic Evolution of Red Soil and its Impact on Ecosystem Function in the Critical Zone

PROJECT 5

Modelling and managing critical zone relationships between soil, water and ecosystem processes across the Loess Plateau

http://www.czo.ac.cn

Using Critical Zone Science to Understand Sustaining the Ecosystem Service of Soil & Water (CZO)- supported by NSFC and NERC

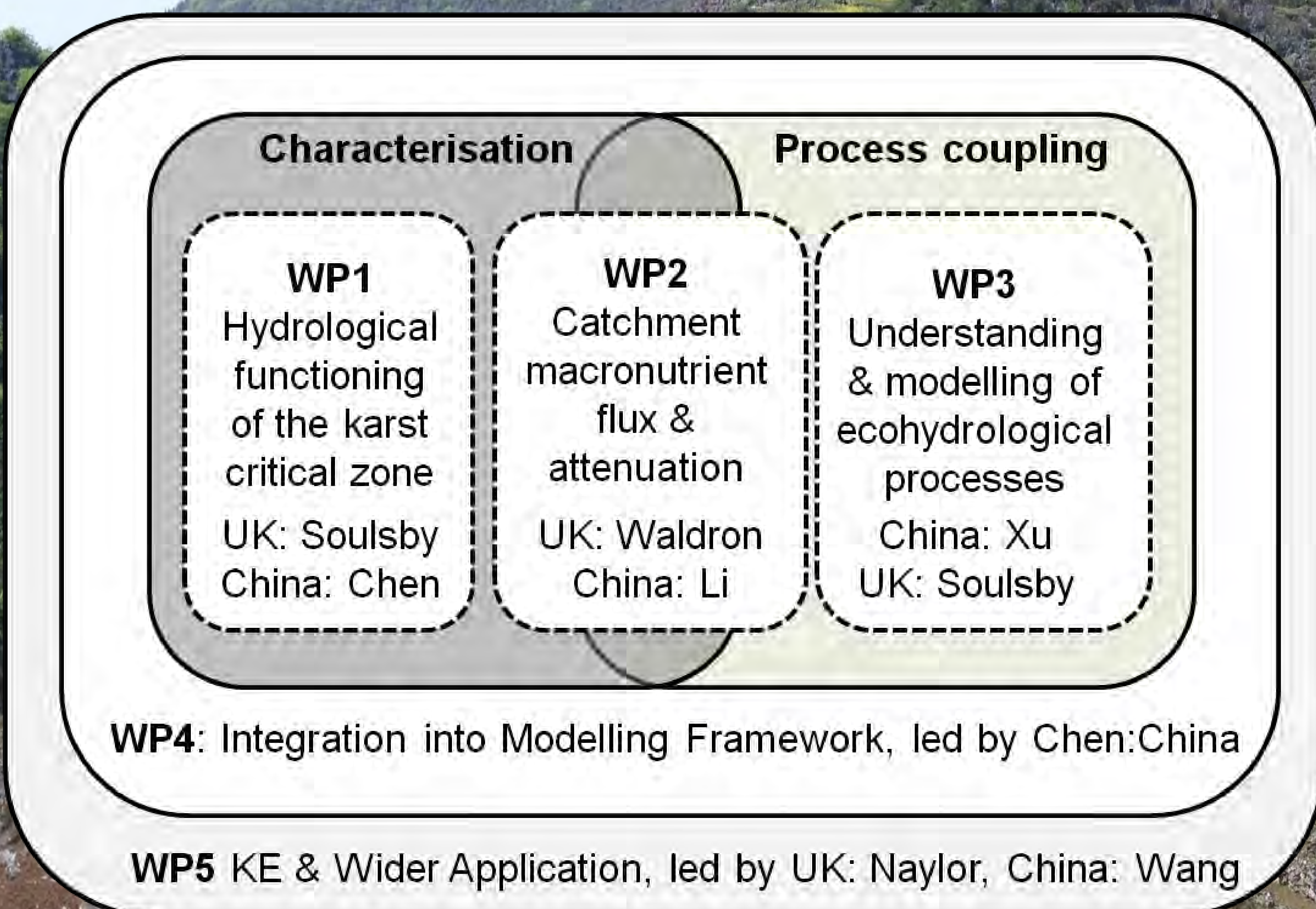
地球关键带中水和土壤的生态服务功能维持机理研究

The transmissive critical zone: understanding the <u>karst hydrology-biogeochemical</u> interface for sustainable management
喀斯特关键带水文-生物地球化学耦合机理及生态系统服务提升机制

Prof. Susan Waldron

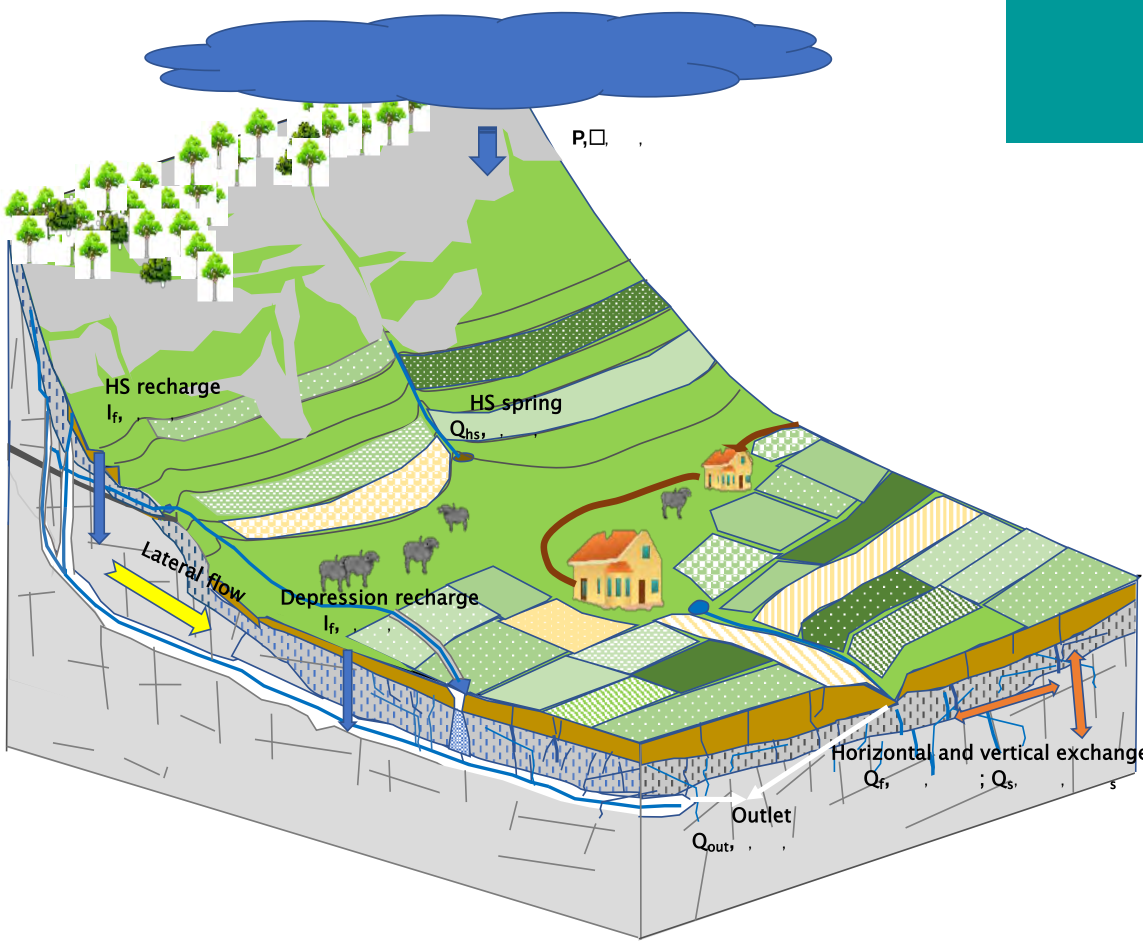
Prof. Xi Chen

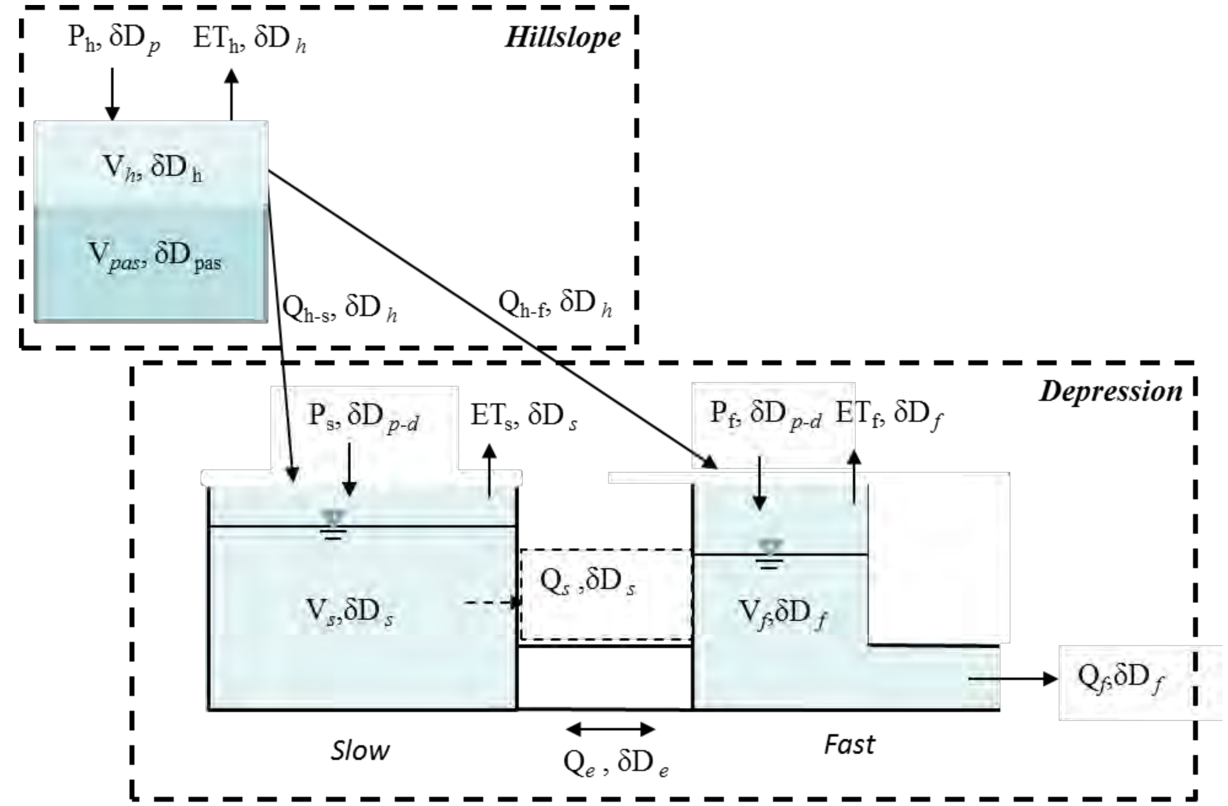
Work Package Management Structure & Interactions



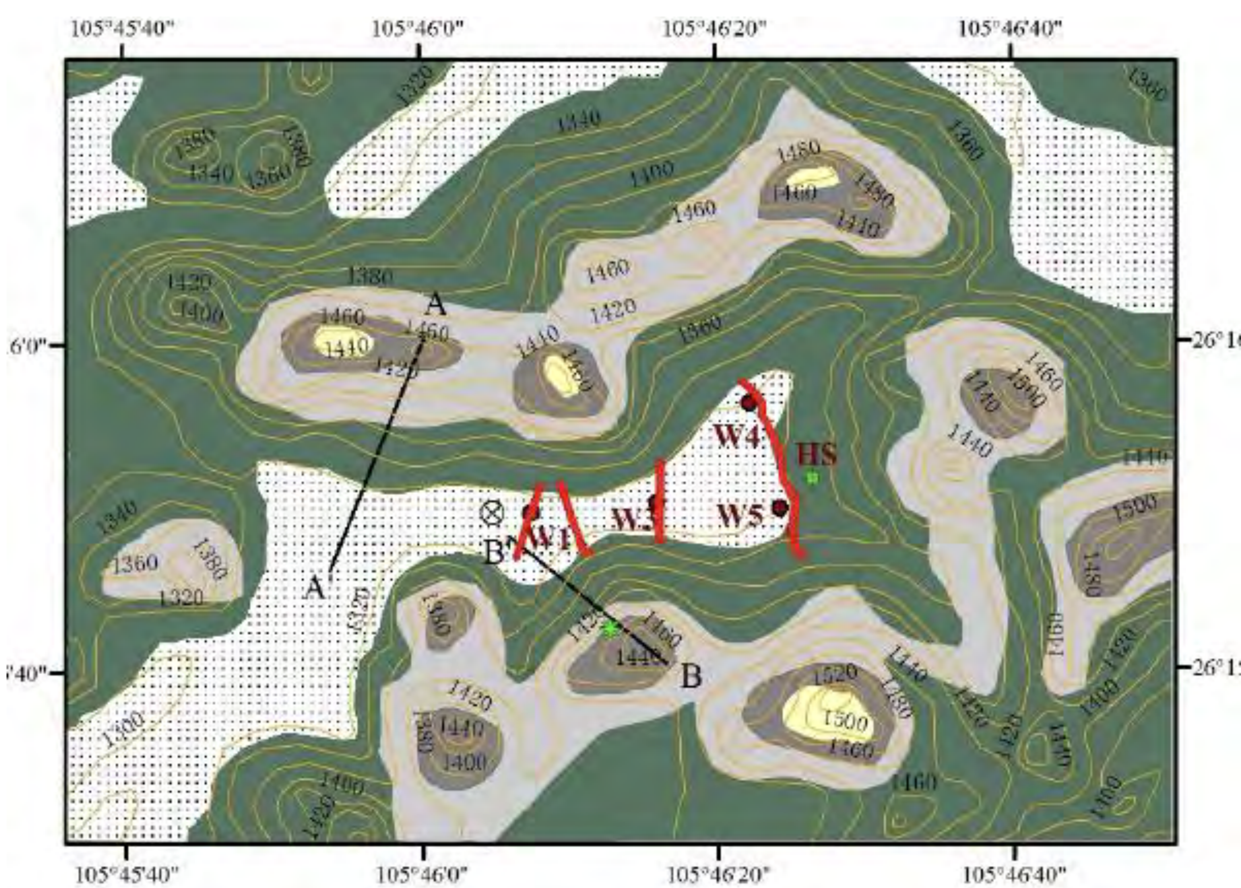
University of Glasgow · University of Aberdeen · SUERC Scottish Universities Environmental Research Centre · University of Stirling

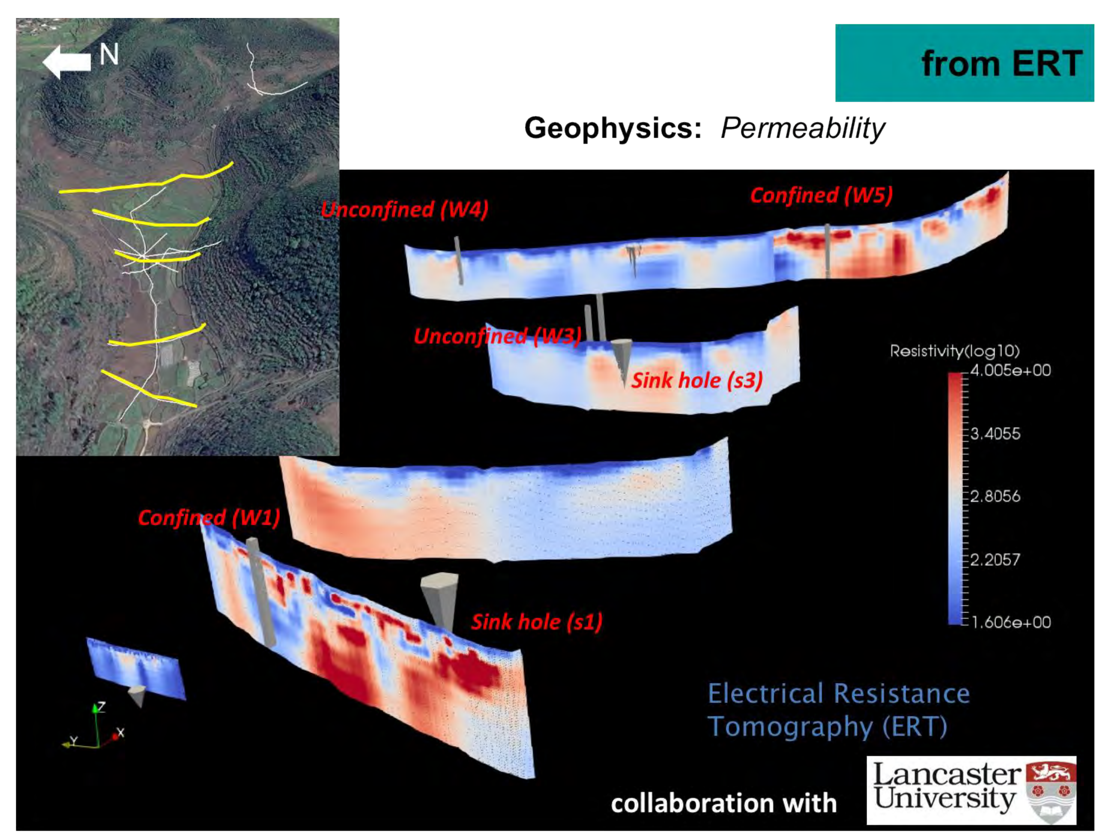
Conceptual Modelling:
Using stable isotopes



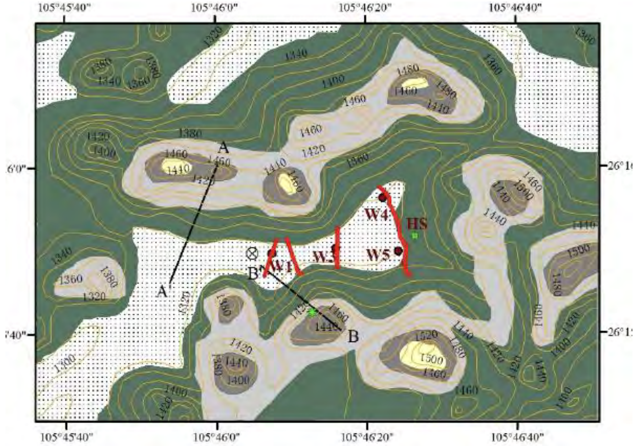


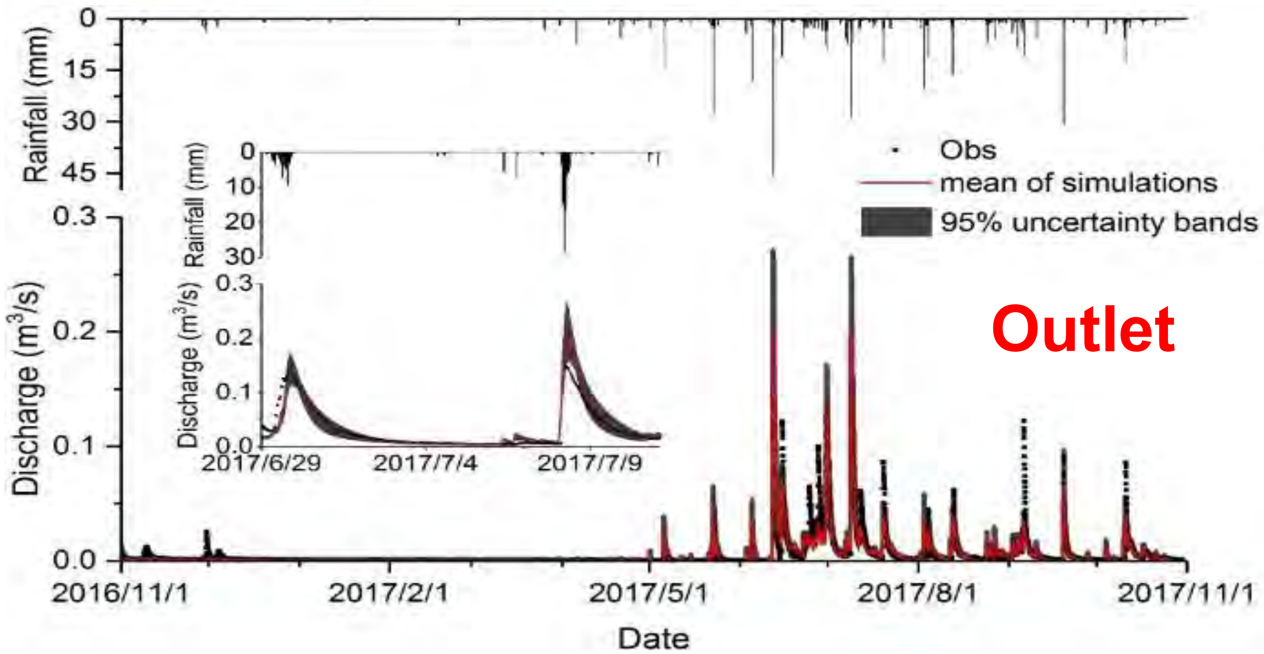
(Zhang, Chen et al. HESS)

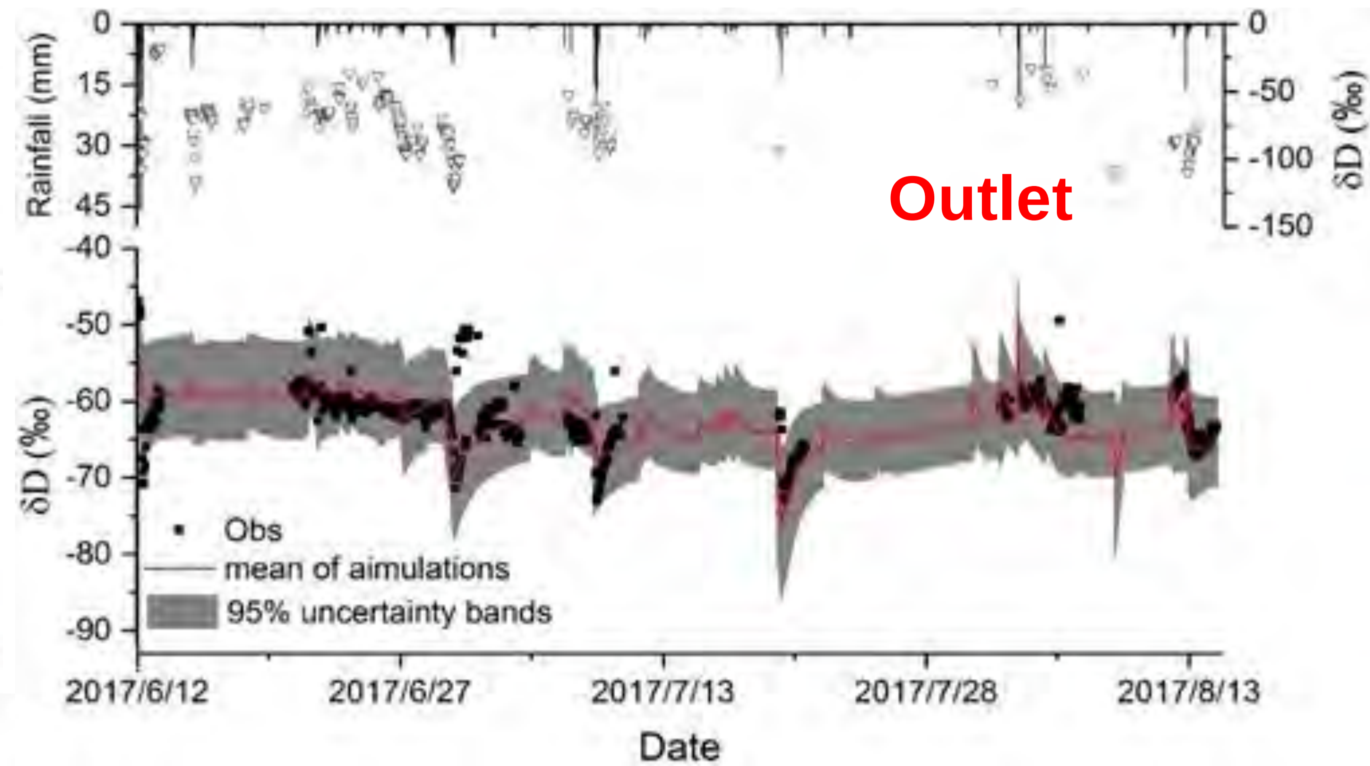


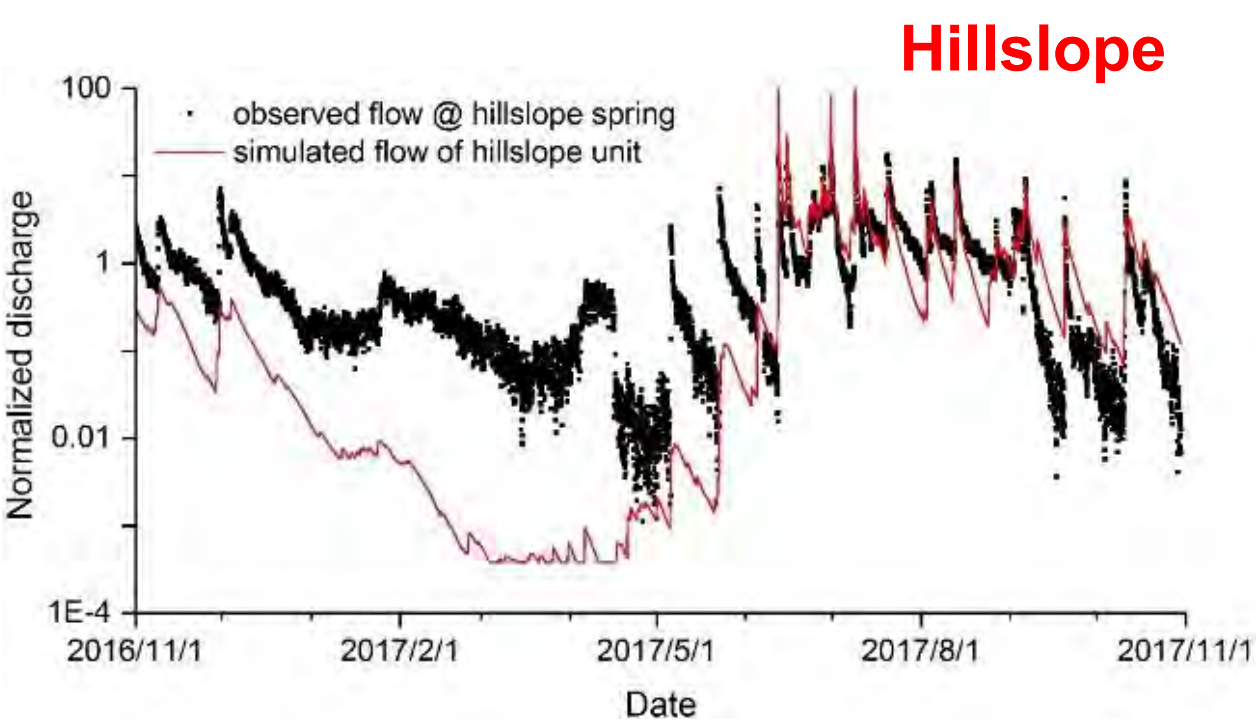


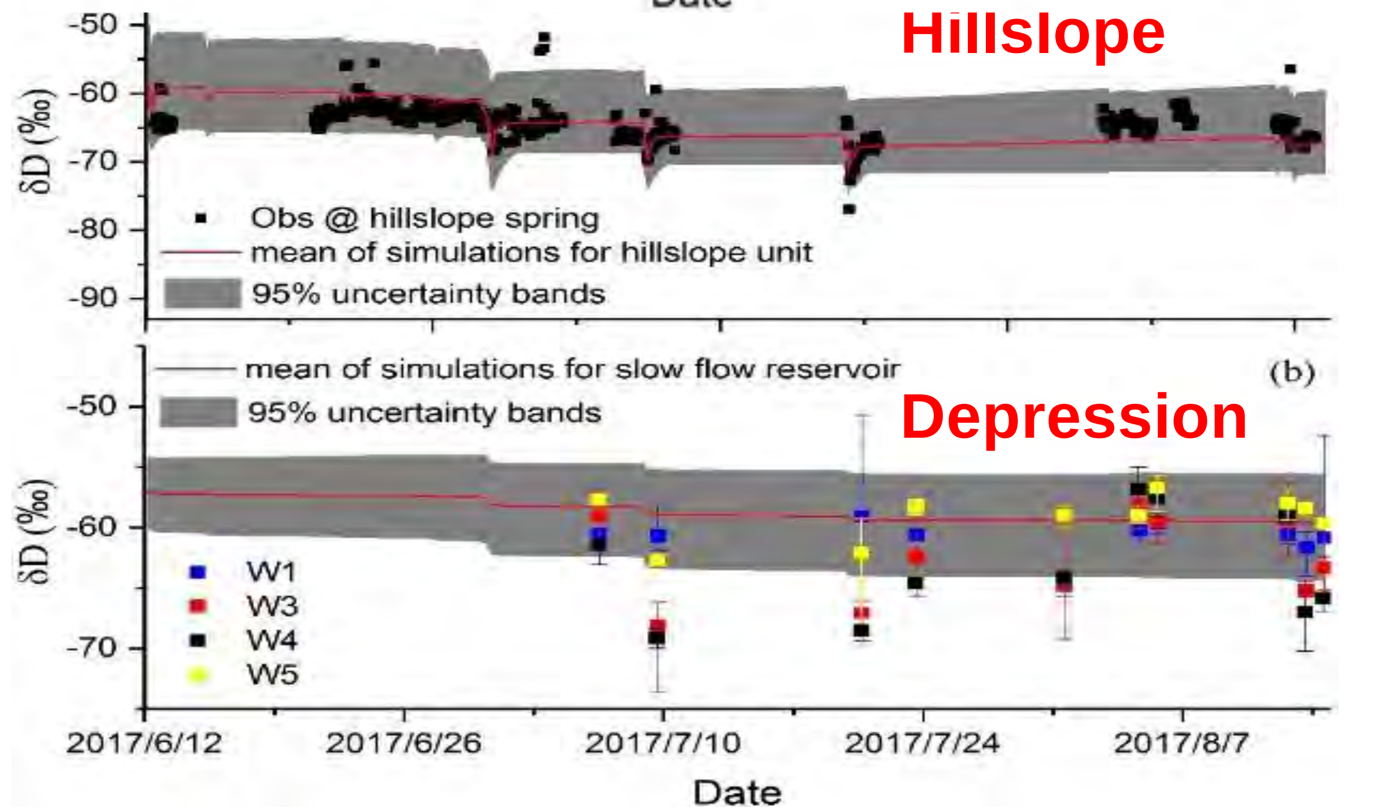
Conceptual Modelling: simulated vs. observed flow at outlet and hillslope





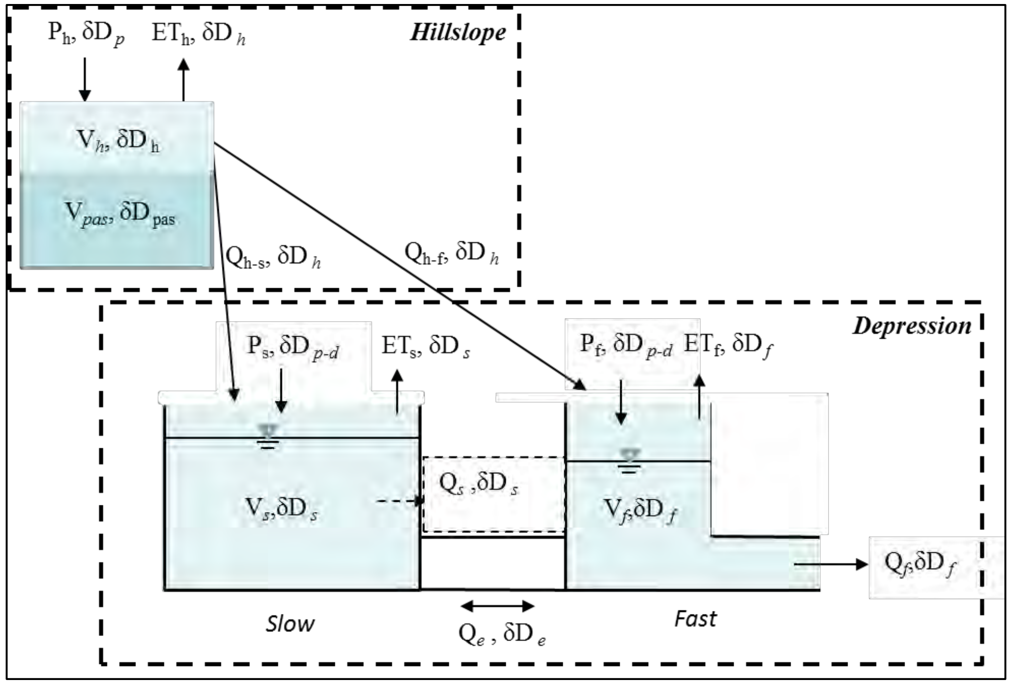


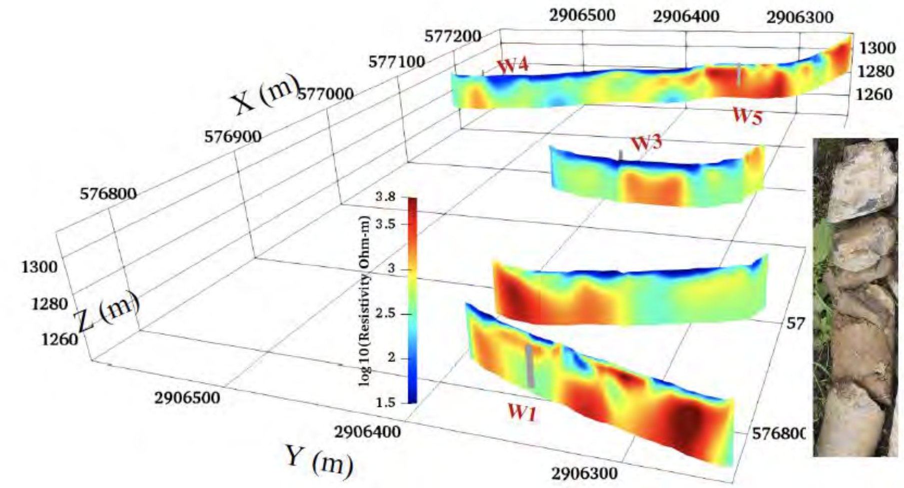


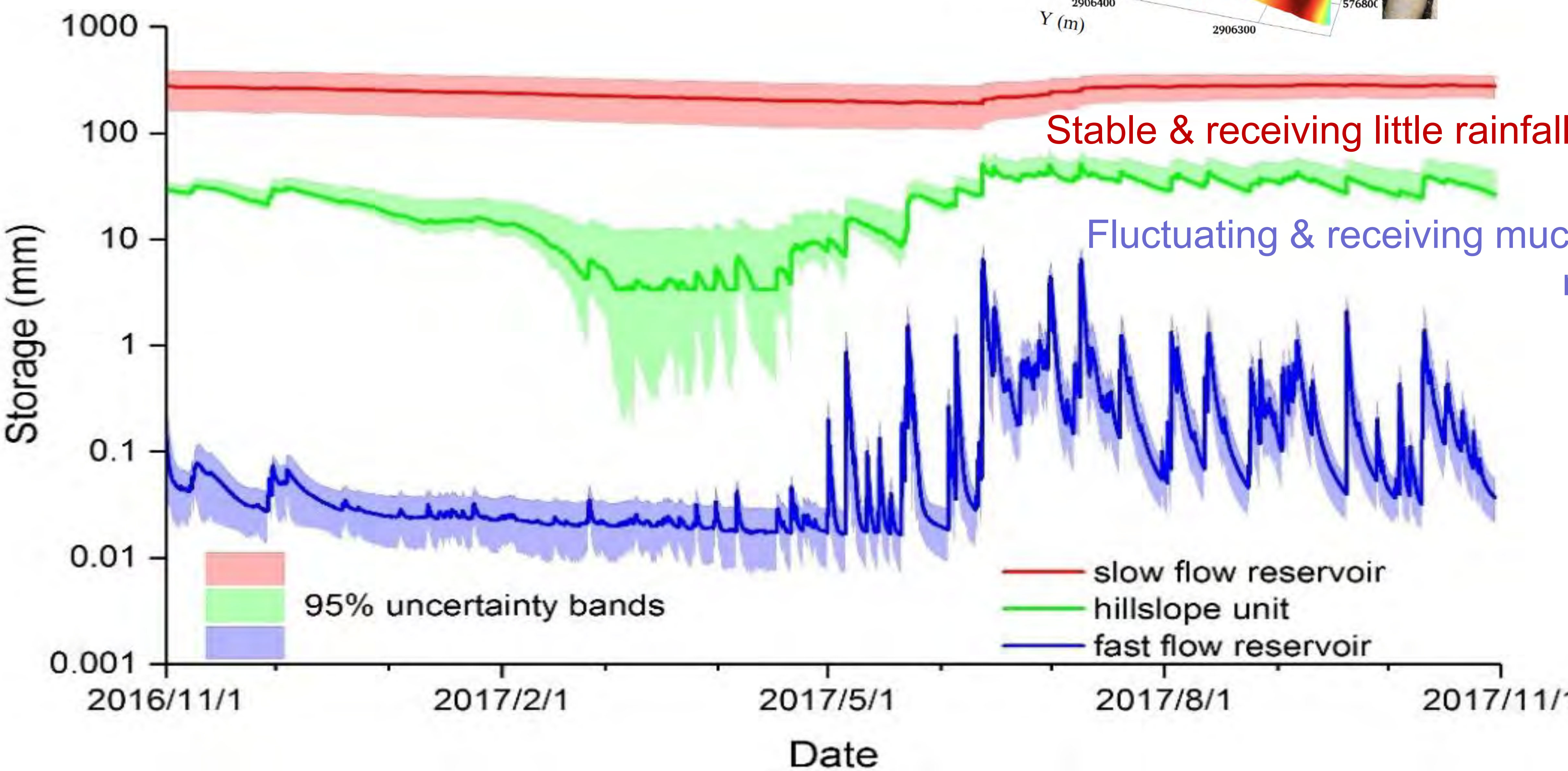


(Zhang, Chen et al. HESS)

Modelling: Quantifying storage dynamics







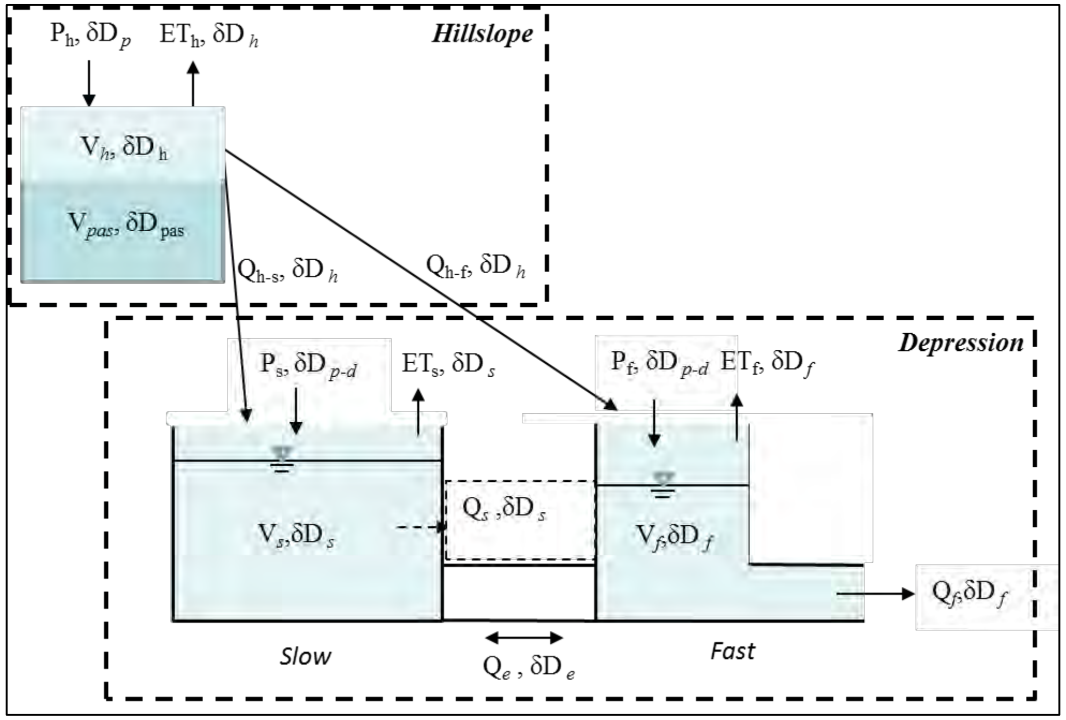
Stable & receiving little rainfall recharge

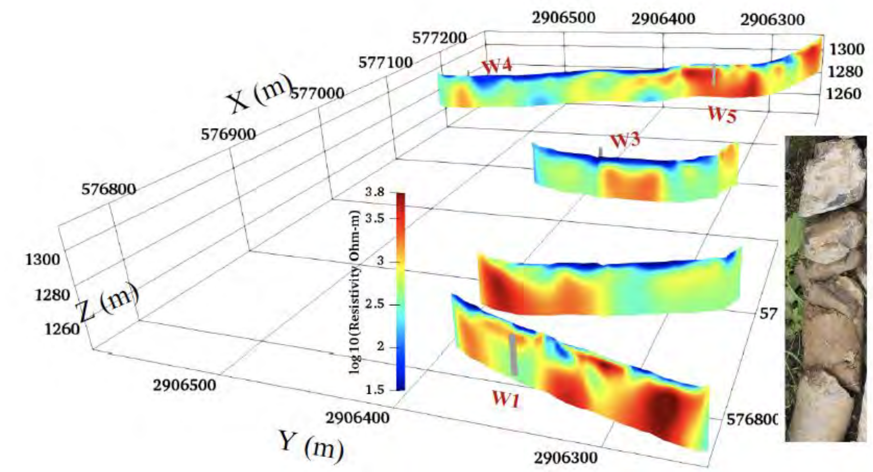
Fluctuating & receiving much rainfall recharge

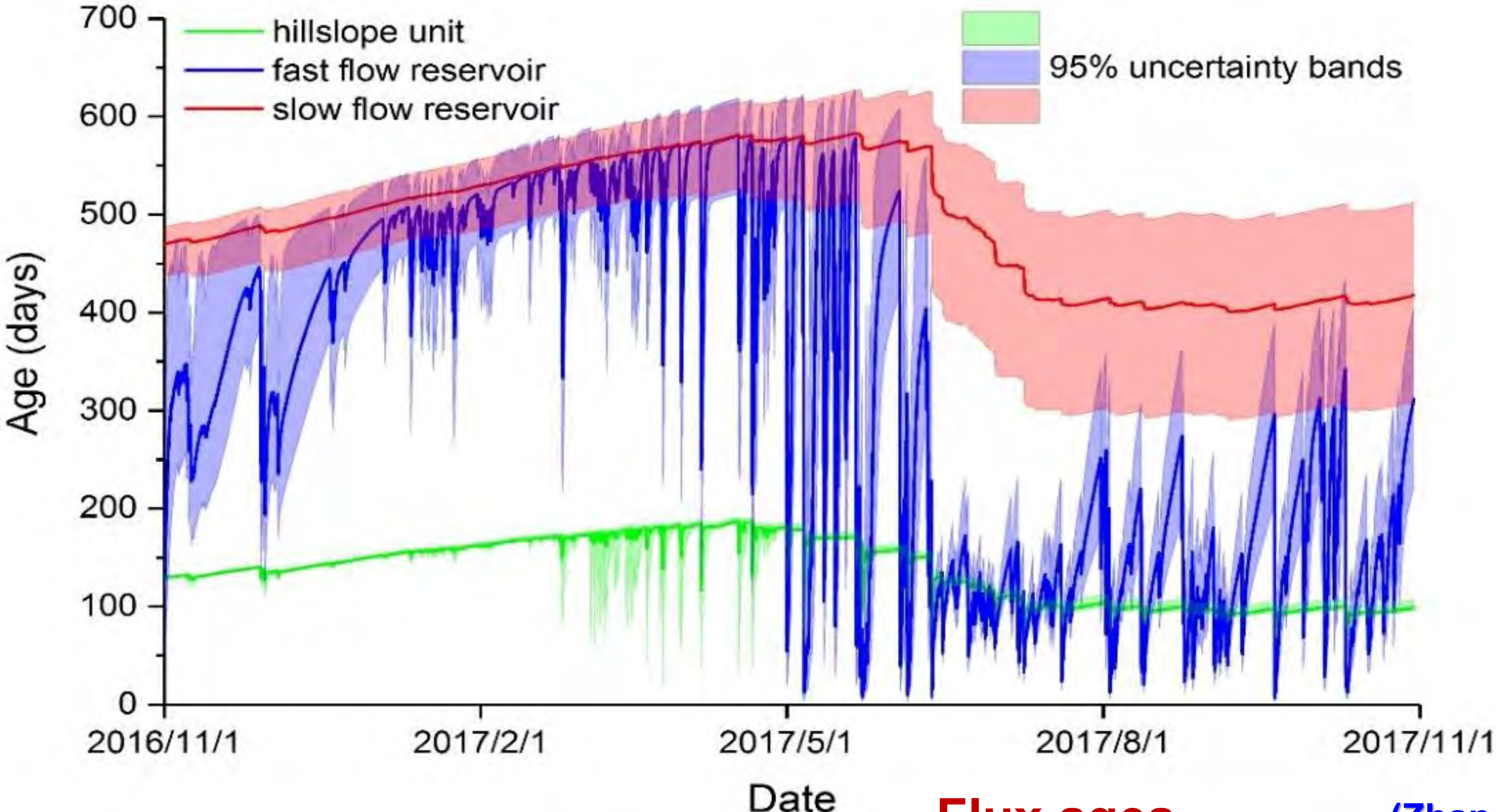
(Zhang, Chen et al. HESS)

Storage dynamics

Modelling:
Profiling flux ages from different units







High capacity & slow response

Low capacity & rapid response

Flux ages

(Zhang, Chen et al. HESS)

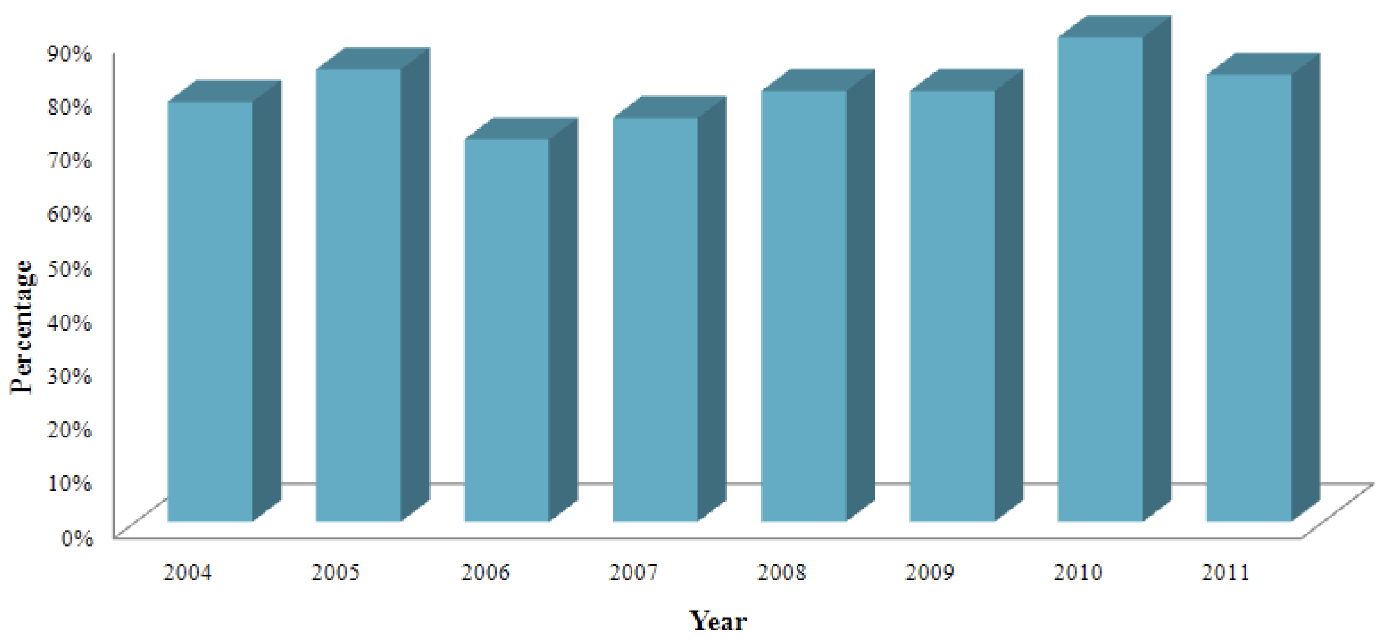
2 Hot topics – Flash flood forecast

Mountainous and hilly areas account for 2/3 of the land area in China, among which the prevention and control area of flash flood disaster reaches to 4.63 million km^2, involving in the population of 560 million.

- **Over 8,600 rivers with areas among 200～3000km^2**
- **Flush flood and mud-rock flow for small catchments are particular severe:**

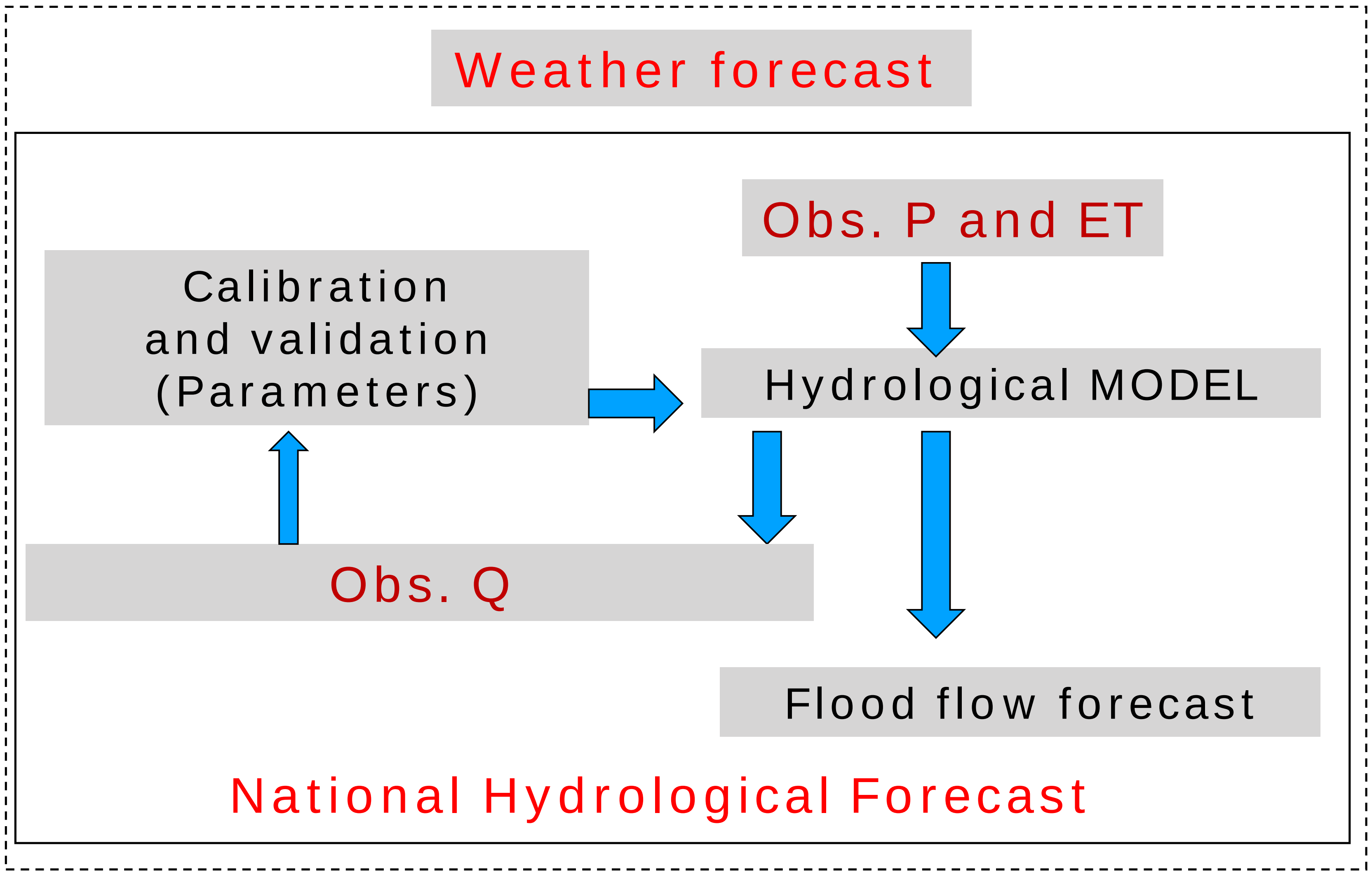
  number of deaths: 158,000people

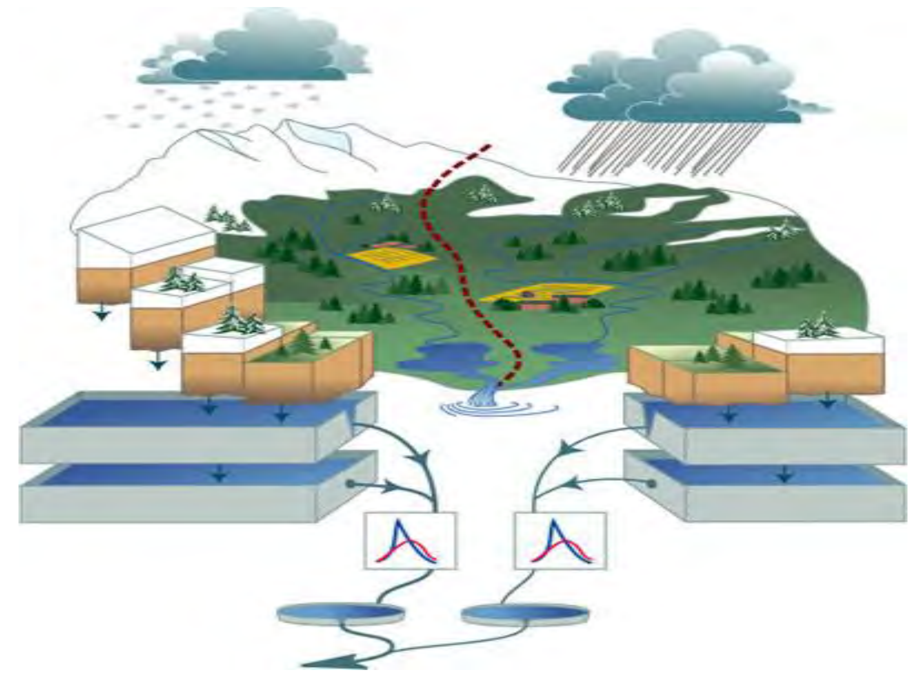
  Economic loss: 131.4billion RMB (2001-2000)

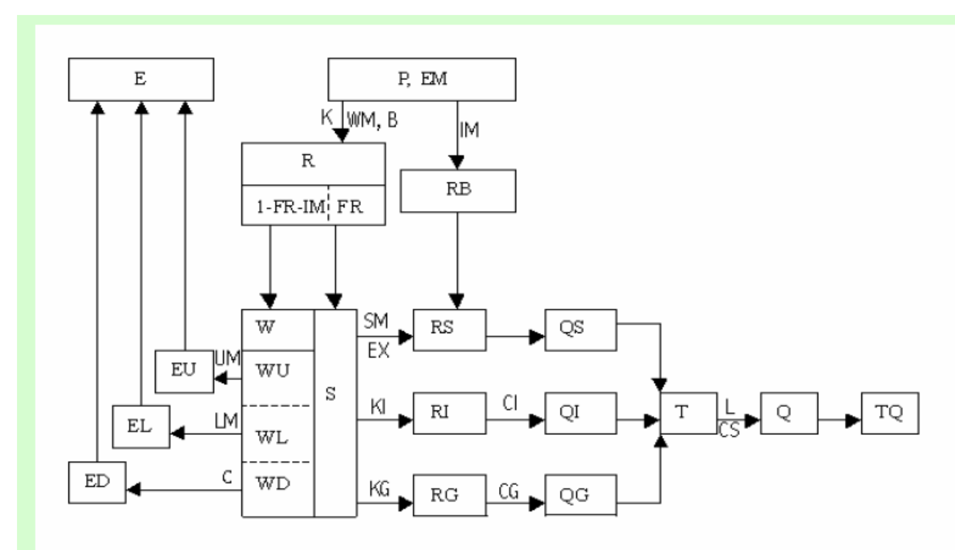


Proportion of deaths caused by flash flood disasters compared to those caused by all flood disasters in China (He et al., 2012)

2 Hot topics – Flash flood forecast



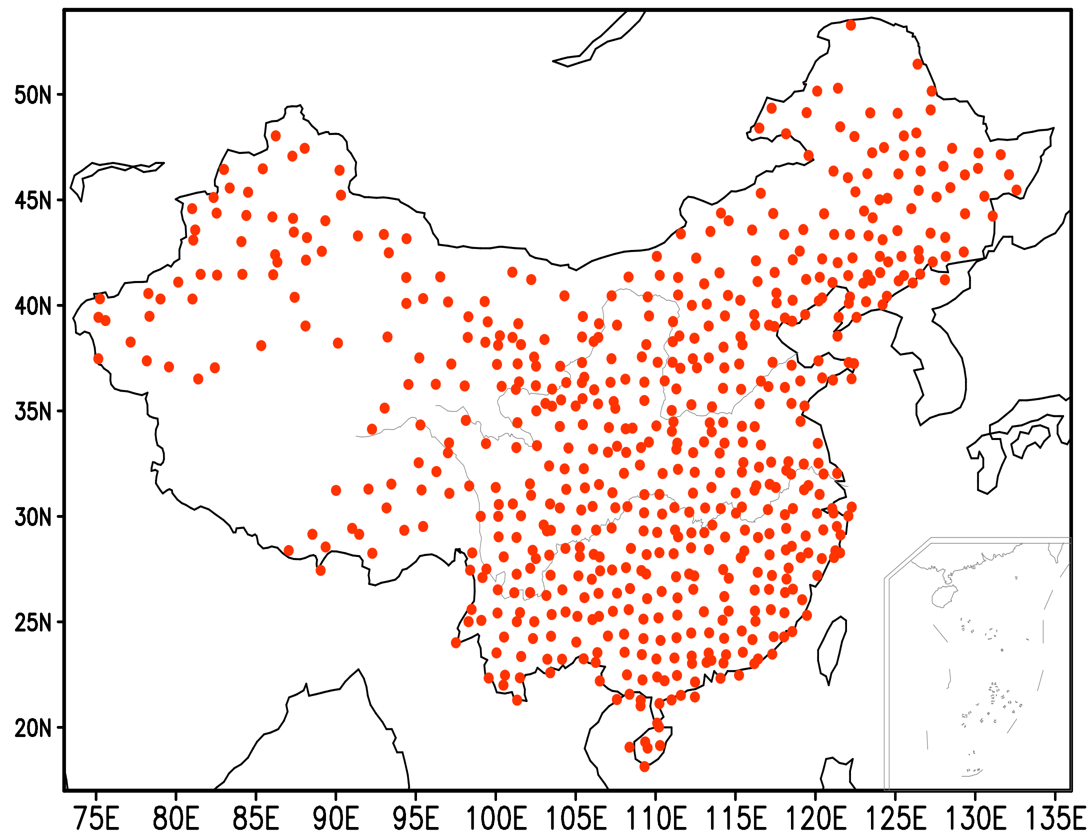




Flowchart of the Xin'anjiang model (after Zhao & Liu, 1995)

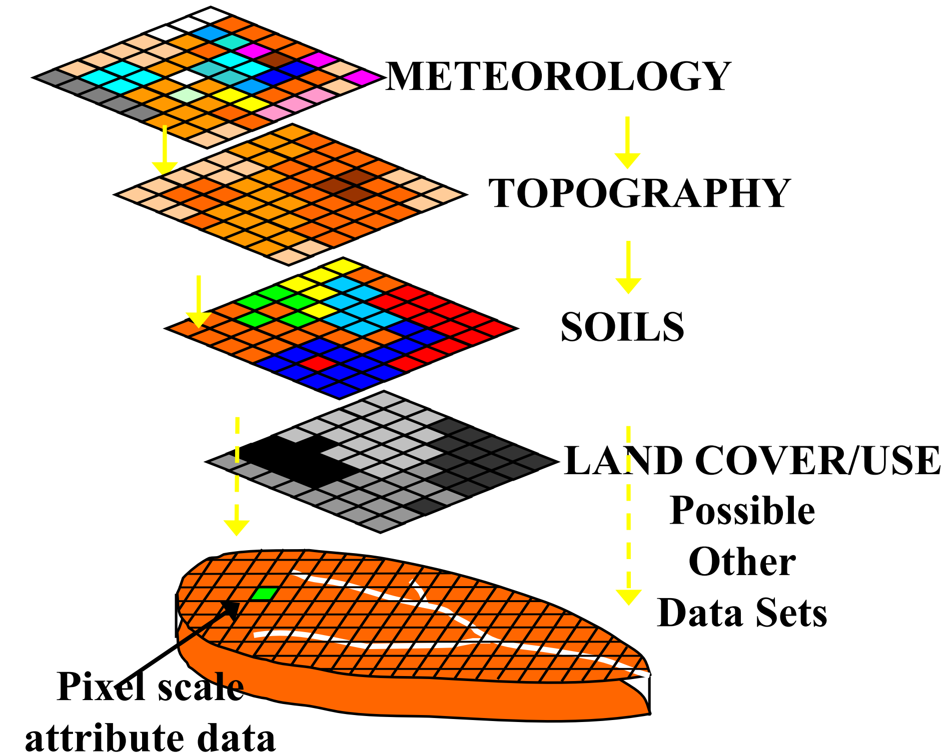
- the short-duration (<12 hrs), short-term (< 3 days), medium- term (4-10 days) and long-term (>10 days) weather forecasting of storms
- flood control departments and meteorological administrations at various levels maintain about 6600 rainfall- observation stations and 2300 rainfall-monitoring stations. 420 meteorological radars are installed for monitoring disastrous weather system, and 4 meteorological satellites have been successfully launched

2 Hot topics – Flash flood forecast



Precipitation stations: 30,000(meteorological dep.) and 20,000 (hydrological dep.) to 100, 000

Data requirement



Parametrization and regionalization

Prediction in Ungauged Basins (PUB)

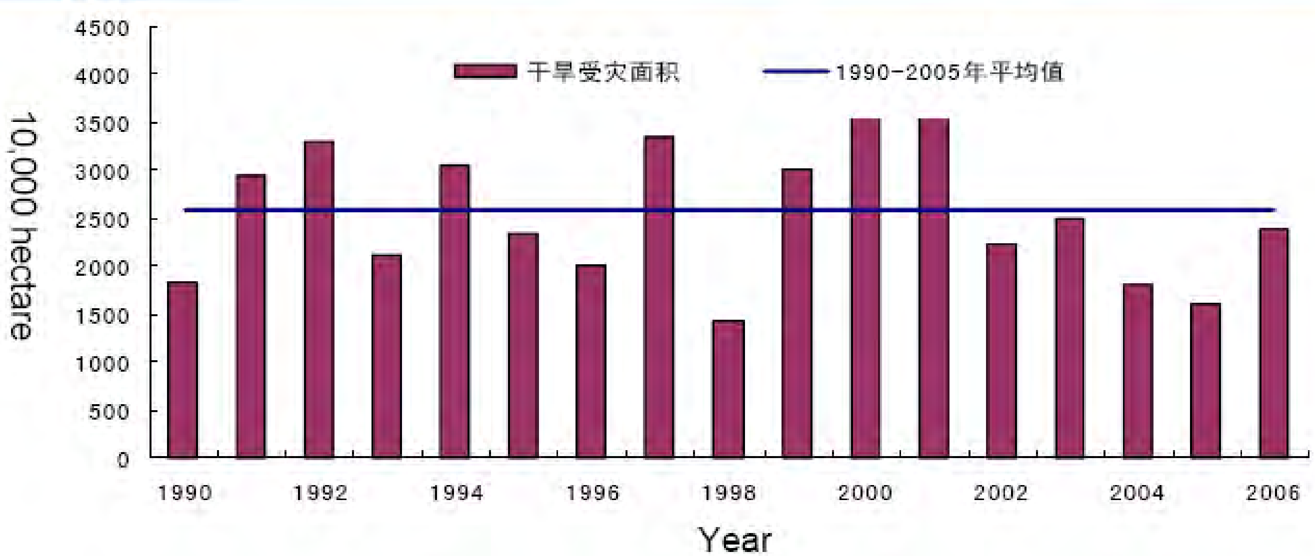
Management of Medium and Small Rivers

2 Hot topics – Drought monitoring and prediction

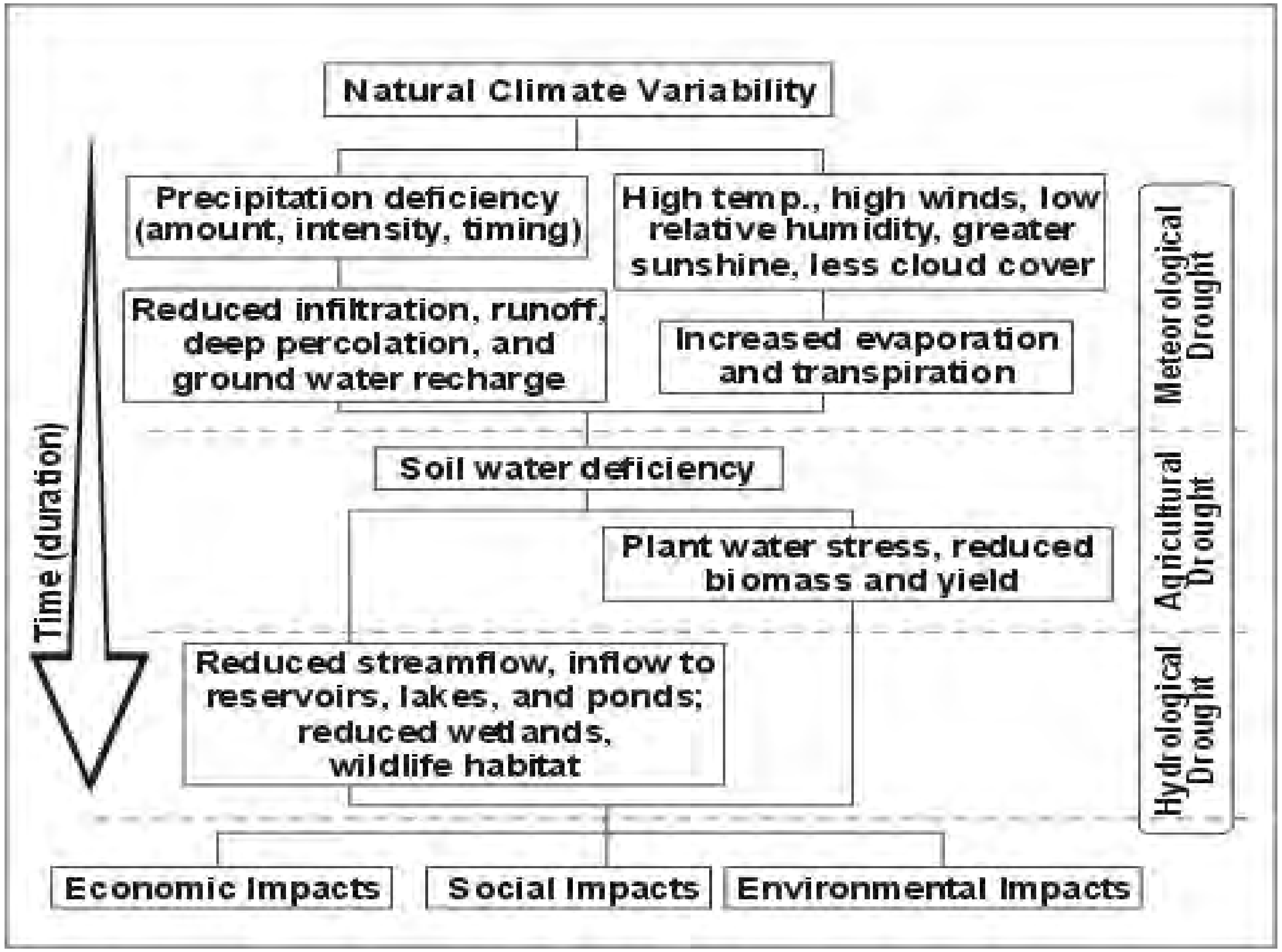
With characteristic of slow development, long duration, wide *stricken* area and severity.

Significant impact on hydrology, agriculture, eco-environment, economy and society

- 26 million hectare crop land affected by drought each year
- Severe drought in the Southwest of China in 2006
- Affected 0.72 million hectare crop , 19 billion RMB economic loss



2 Hot topics – Drought monitoring and prediction



Drought indices and classification

The Standard Precipitation Index (SPI)

The Standard Precipitation-Evapotranspiration Index (SPEI)

Water wetness index (SWI)

Palmer index (PDSI)

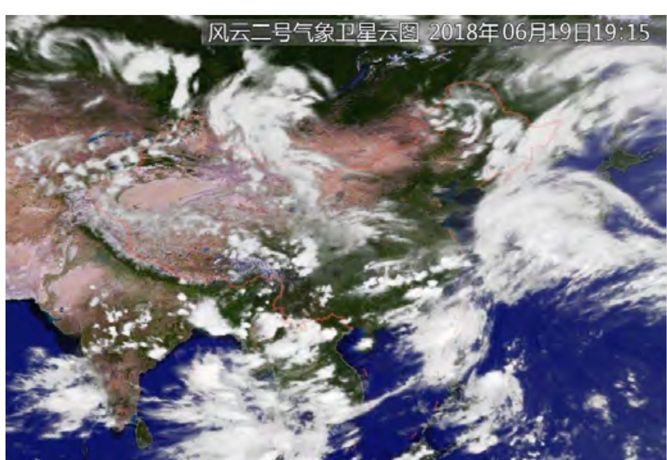
The Standard hydrological Index (SHI)

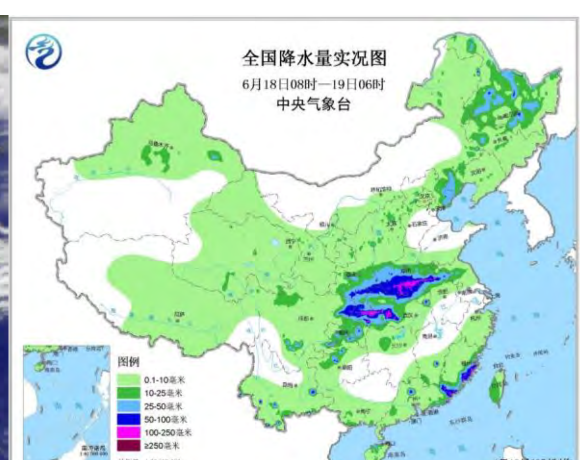
- Reservoir storage
- streamflow discharge
- Groundwater level

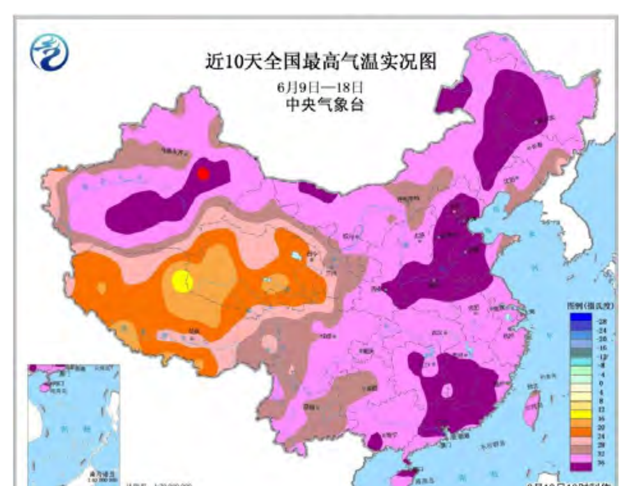
Drought ranks

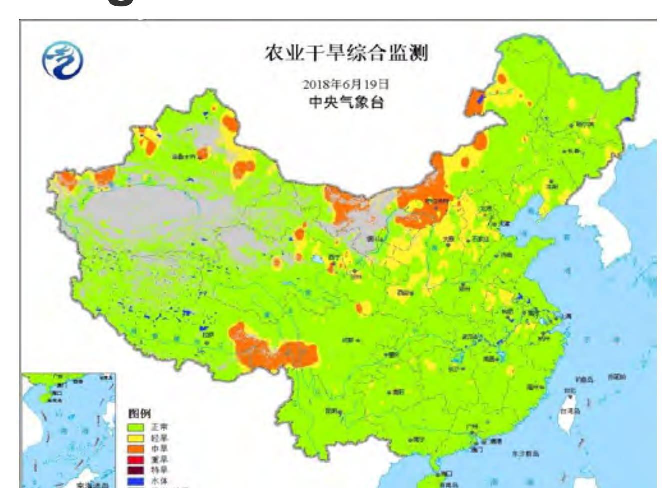
Duration, intensity and magnitude

Their connections and evolution ?



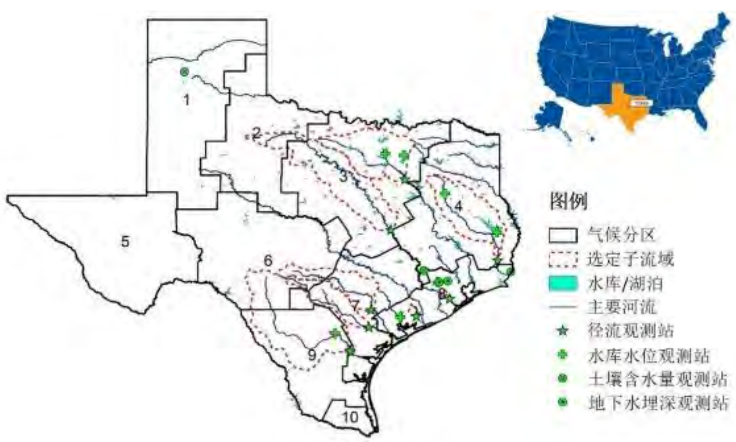






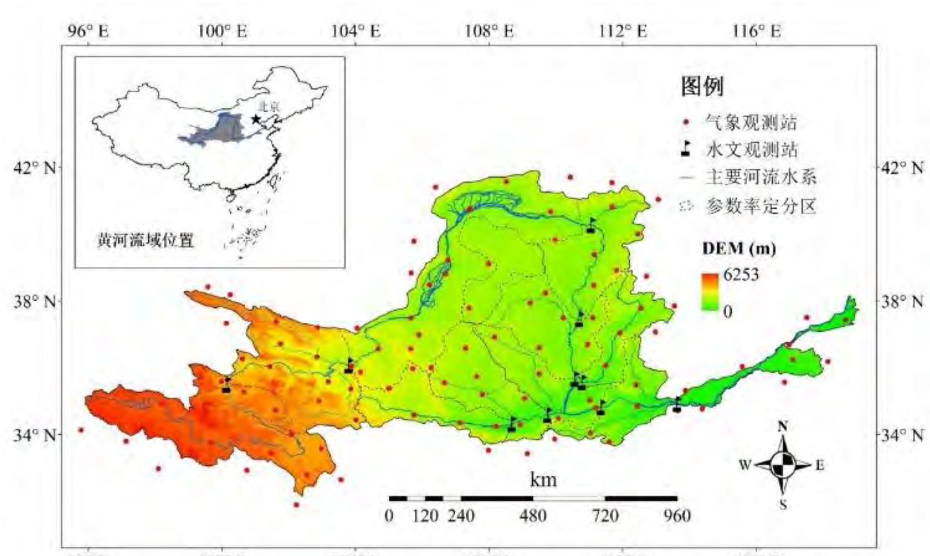
2 Hot topics – Drought monitoring and prediction

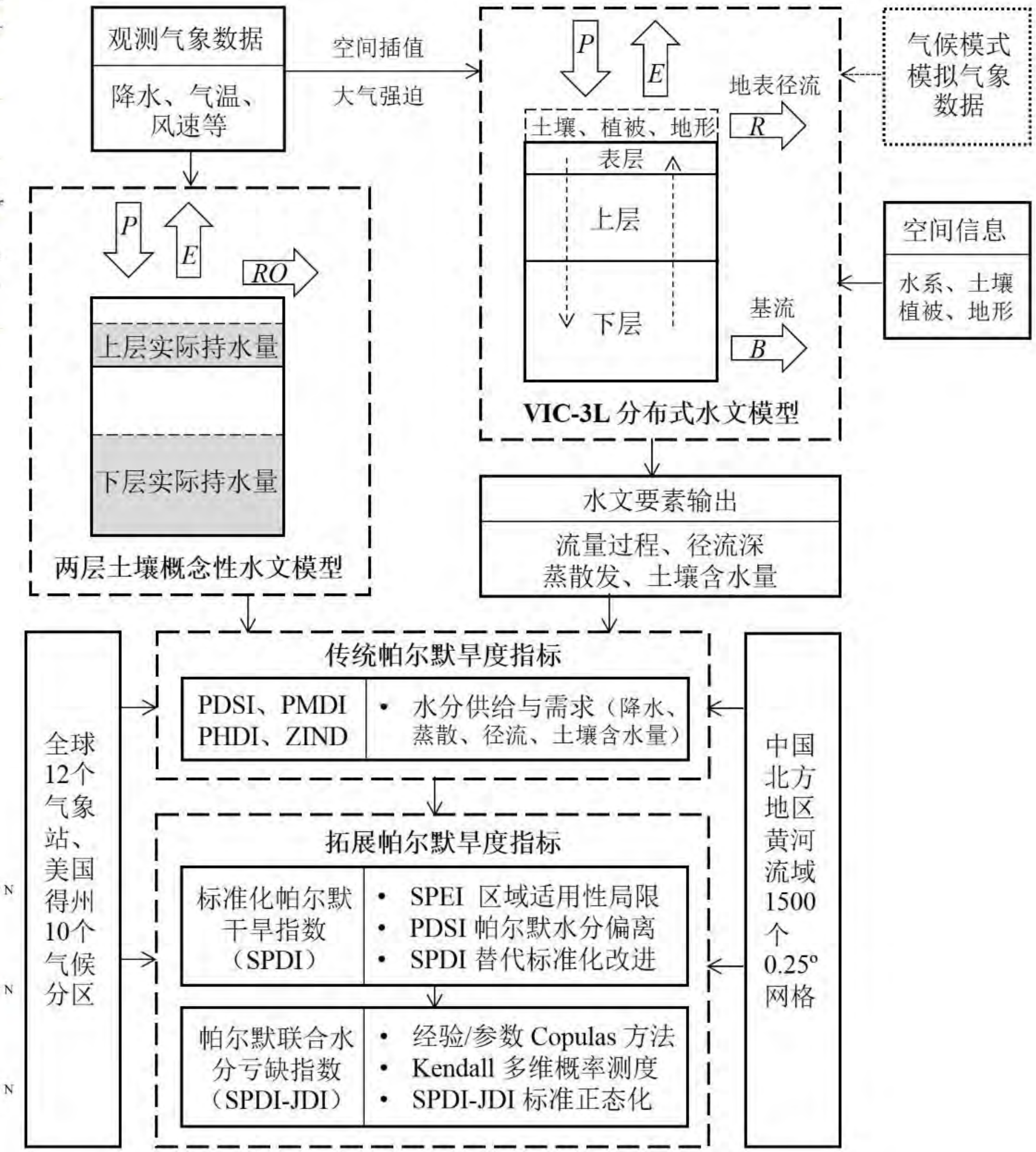
Global



Texas US

Yellow River China

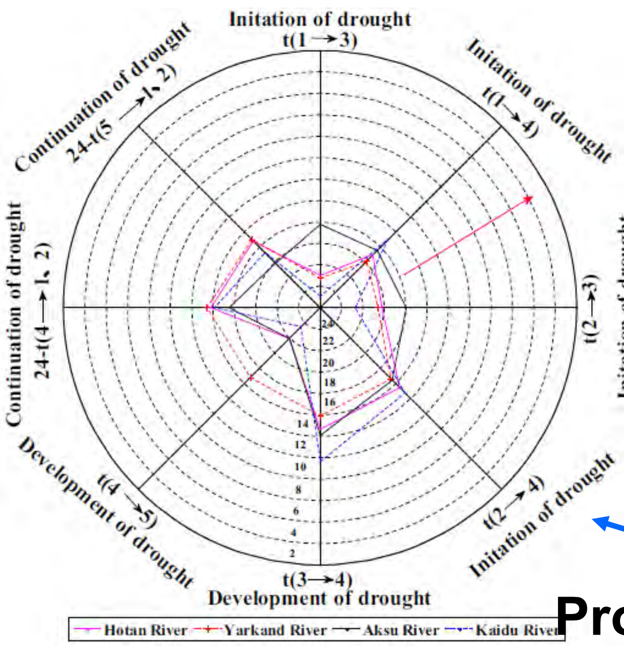


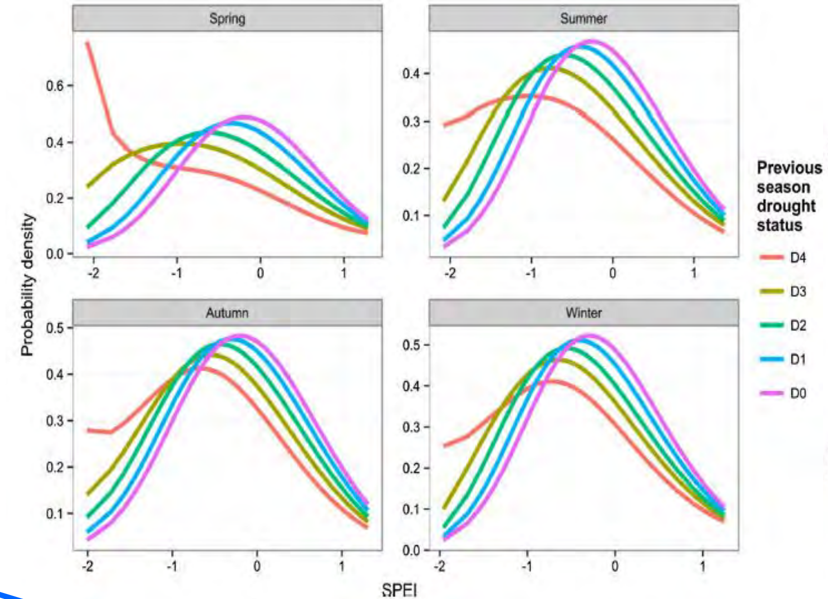


Liu et al. Water Resour Manage (2015)

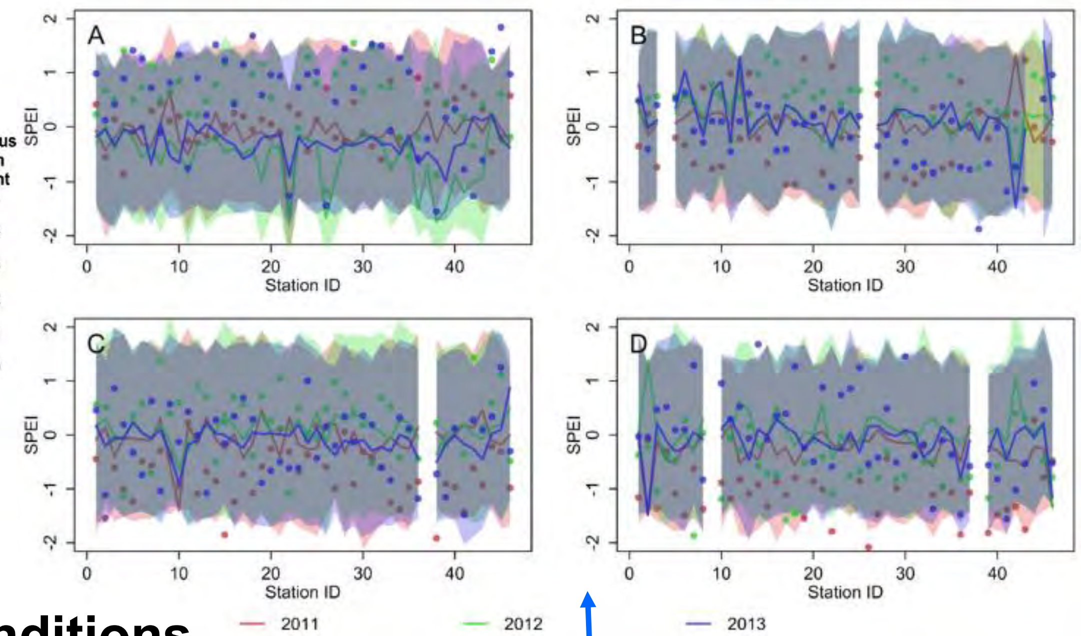
Coupling of Self-Calibrating PDSI with the VIC Model (SCPV)

Drought- and flood-related researches (ZHANG et al)





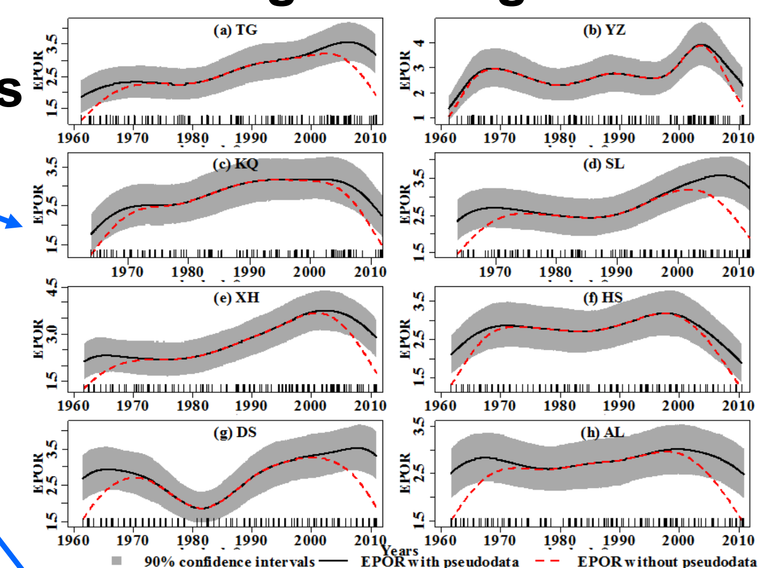
Probabilistic transition of drought conditions



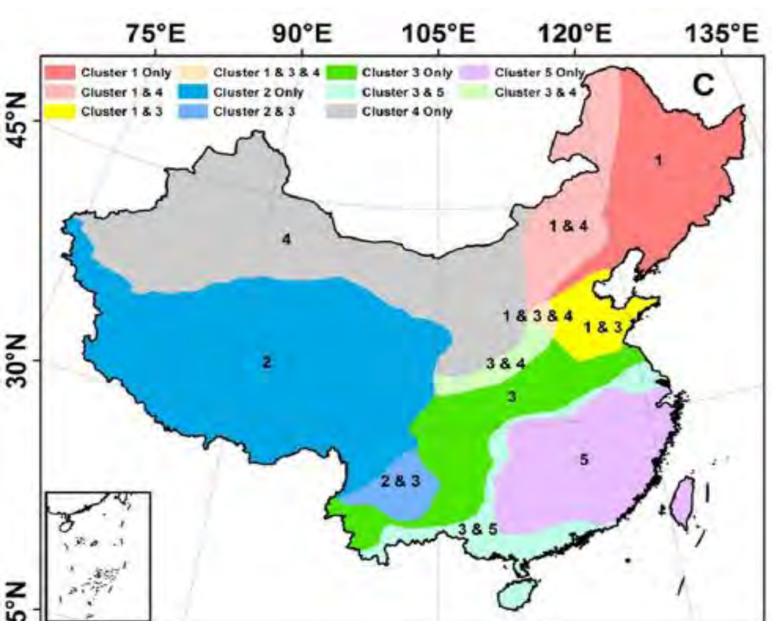
Probabilistic modeling and forecasting of drought conditions

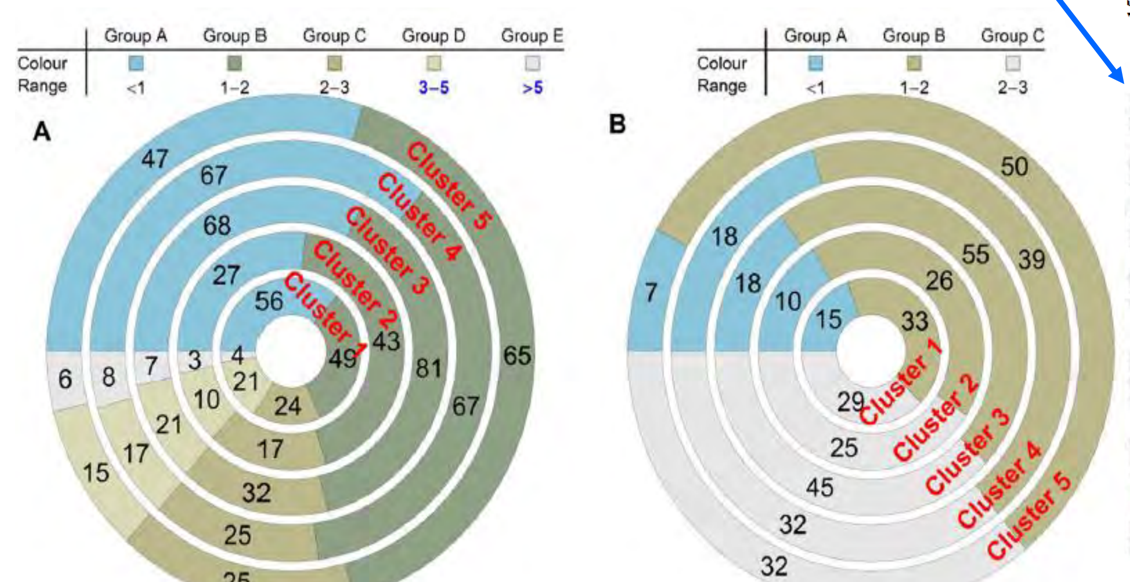
Copula	Function	Support
Gumbel	$C(u_1,u_2)=\exp\{-[(-\ln u_1)^\theta+(-\ln u_2)^\theta]^{1/\theta}\}$	$\theta\in[1,+\infty)$
Clayton	$C(u_1,u_2)=(u_1^{-\theta}+u_2^{-\theta}-1)^{-1/\theta}$	$\theta\in[0,+\infty)$
Frank	$C(u_1,u_2)=-\frac{1}{\theta}\ln\left[1+\frac{(e^{-\theta u_1}-1)(e^{-\theta u_2}-1)}{e^{-\theta}-1}\right]$	$\theta\in R$
Gaussian	$C(u_1,u_2)=\int_{-\infty}^{\varphi^{-1}(u_1)}\int_{-\infty}^{\varphi^{-1}(u_2)}\frac{1}{2\pi(1-\theta^2)^{\frac{1}{2}}}\left[-\frac{x_1^2-2\theta x_1x_2+x_2^2}{2(1-\theta^2)}\right]dx_1dx_2$	$x_1,x_2\in R$; $u_1=\phi(x_1)$; $u_2=\phi(x_2)$
t	$C(u_1,u_2)=\int_{-\infty}^{t_v^{-1}(u_1)}\int_{-\infty}^{t_v^{-1}(u_2)}\frac{1}{2\pi(1-\theta^2)^{\frac{1}{2}}}\left[1+\frac{x_1^2-2\theta x_1x_2+x_2^2}{v(1-\theta^2)}\right]^{-\frac{(v+2)}{2}}dx_1dx_2$	$x_1,x_2\in R$; $u_1=t_v(x_1)$; $u_2=t_v(x_2)$; v: degree of freedom
Plackett	$C(u_1,u_2)=\frac{[1+(\theta-1)(u_1+u_2)]-\sqrt{[1+(\theta-1)(u_1+u_2)]^2-4u_1u_2\theta(\theta-1)}}{2(\theta-1)}$	$\theta\in[0,+\infty)$

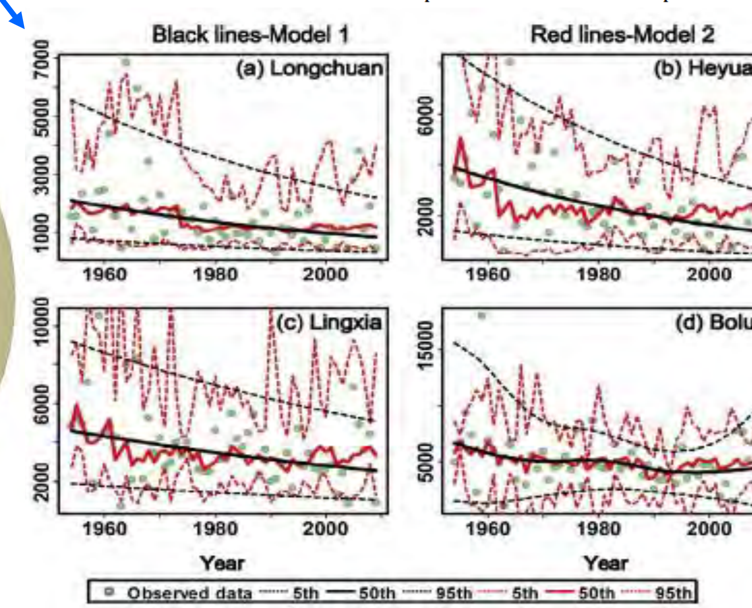
Statistical modelling of flood processes



Regionalization and spatial pattern of drought events







3 Comparative studies in hydrology

Green development

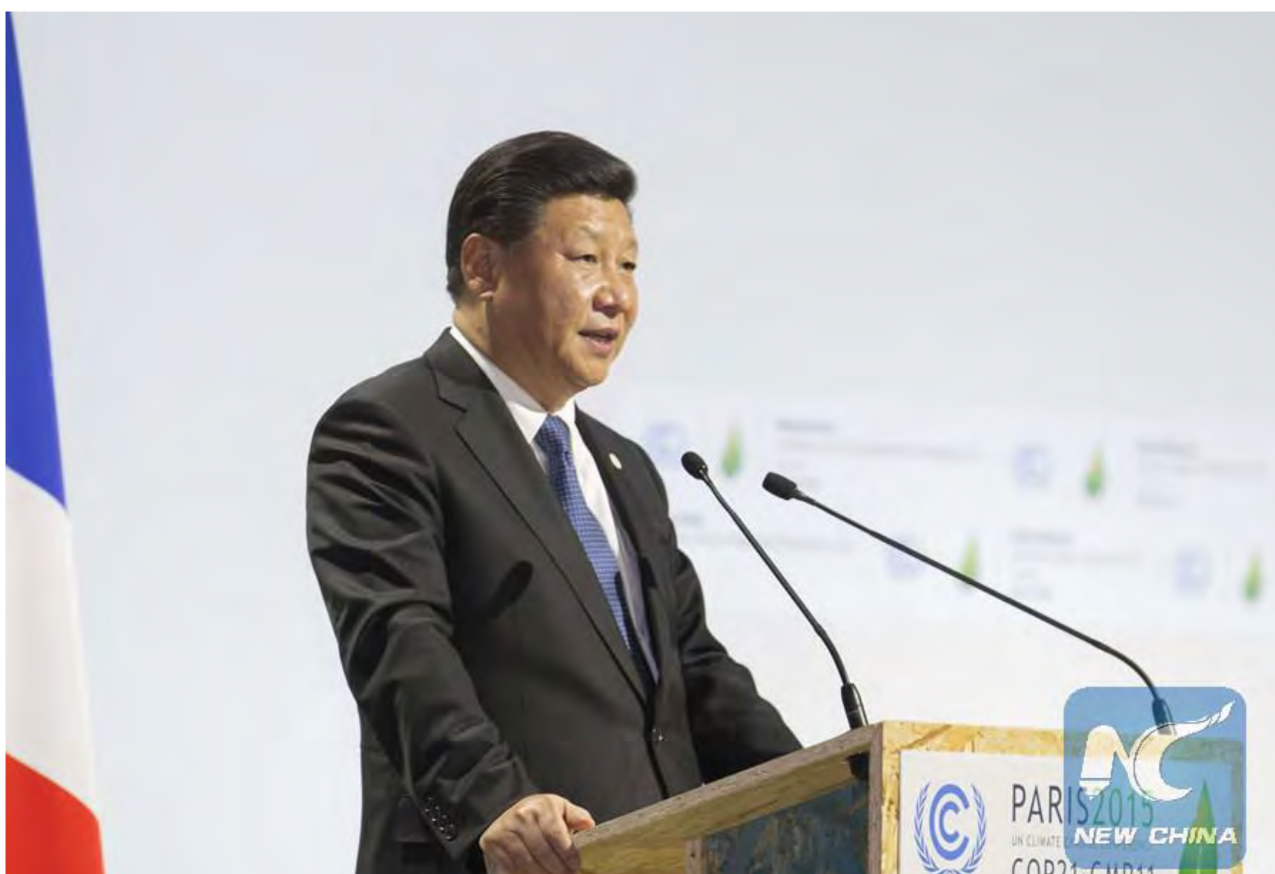
To cut carbon emissions per unit of the GDP by 60-65 percent from 2005 levels by 2030

调整经济结构、提高能源效率、开发利用水电和其他可再生能源、加强生态建设

- transform the economic development pattern
- Improving energy efficiency
- Exploitation and utilization of renewable sources of energy
- carry out systematic ecological control

绿水青山就是金山银山

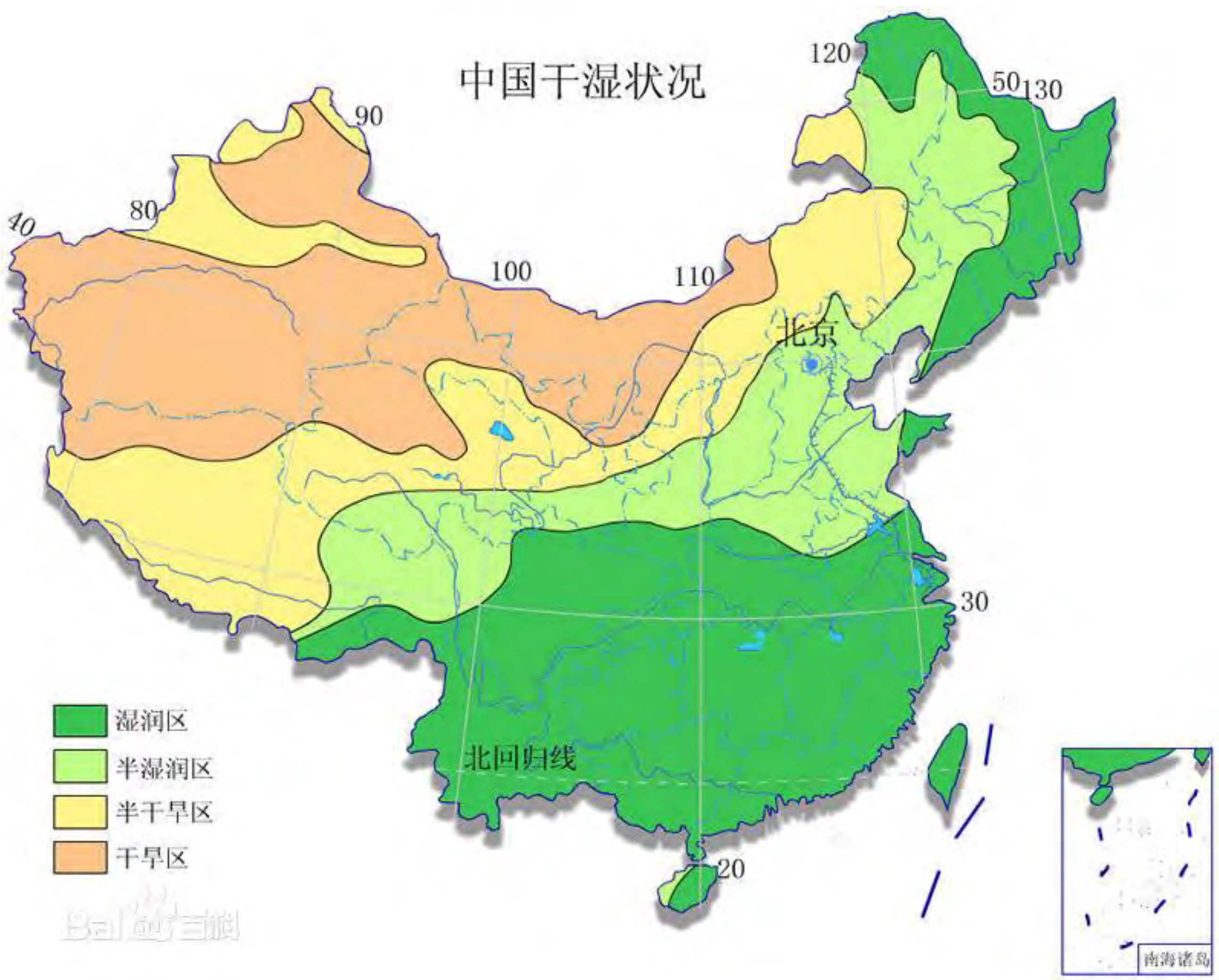
“clear waters and green mountains are as valuable as mountains of gold and silver"



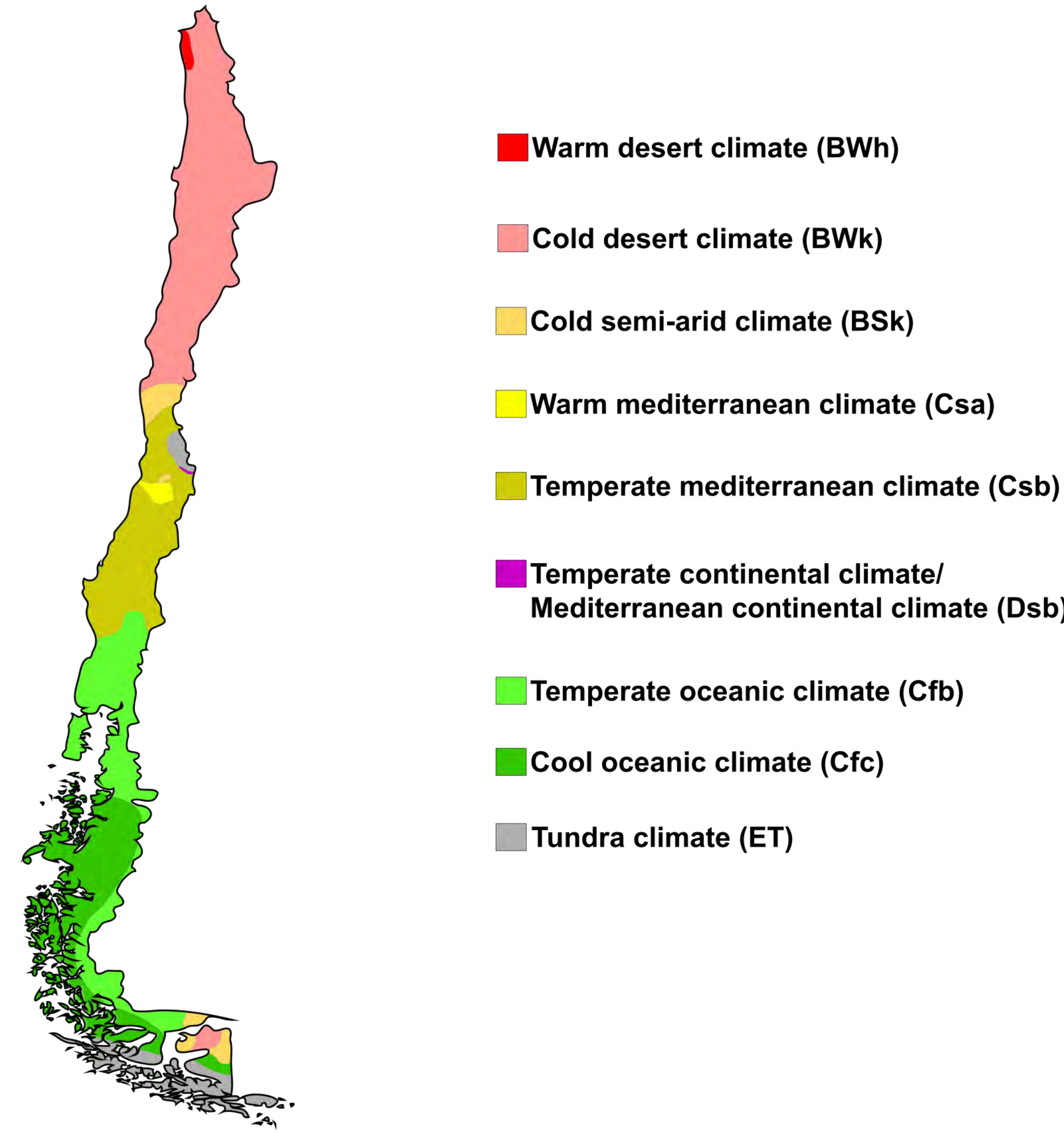
UN 2030 Development Agenda

17项可持续发展目标（SDG）

3 Comparative studies in hydrology



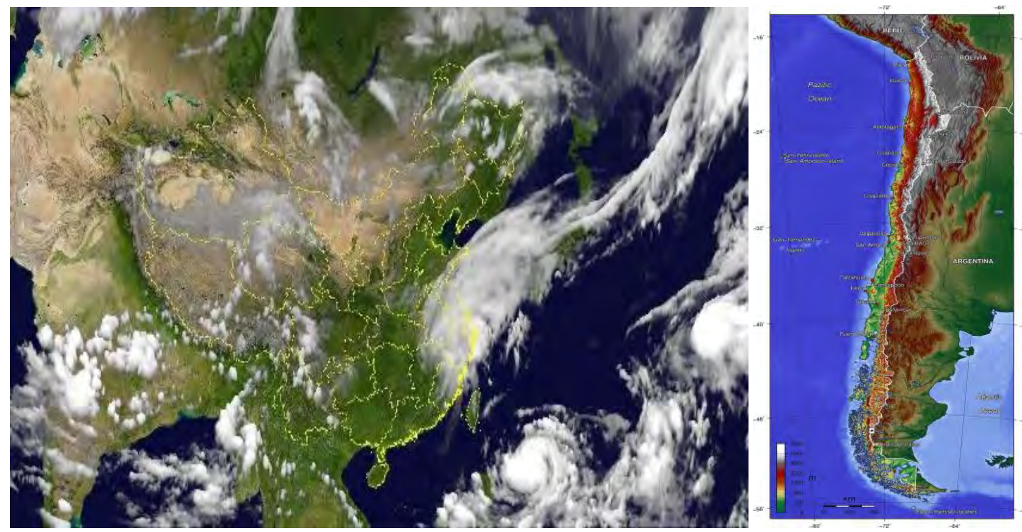
Chile map of Köppen climate classification



Great diversity in Climate and landscape in both countries

3 Comparative studies in hydrology

Climate Change



Impacts and responses

Impacts and responses

Landscape and Human activities

Observation and monitoring

↓

Modeling

↓

Forecast & Prediction

Short- and long- term impacts and responses:

(1) Available water resources (streamflow and groundwater; green and blue water)
(2) Hazard prevention (hydrological extremes)
(3) Evolution of Climate-Landscape-Hydrology

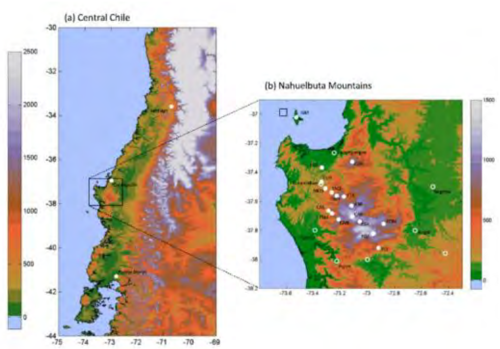
Partial literature review concerning hydrometeorological researches in Chile

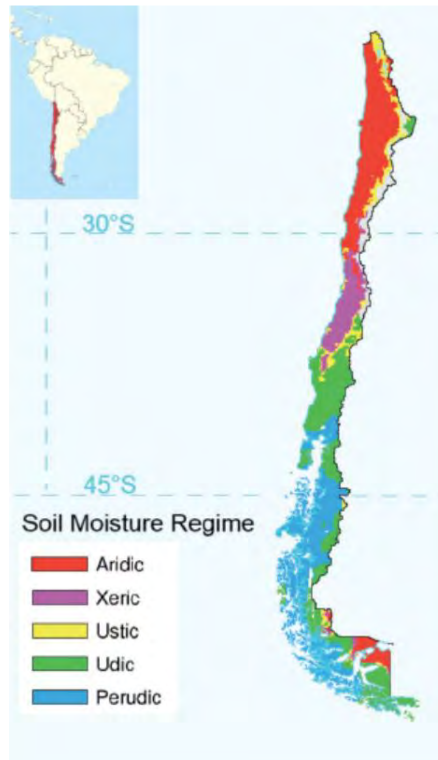
Urban-related climate changes

Cortés, Gonzalo et al. (2012), Assessment of the current climate and expected climate changes in the Metropolitan Region of Santiago de Chile. *UFZ-report*.

Orographic precipitation changes

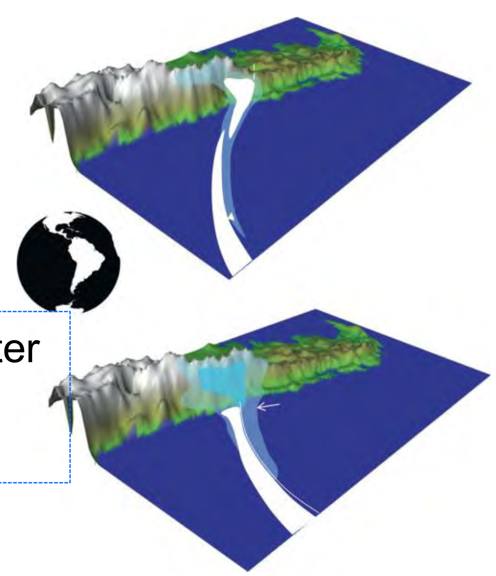
GARREAUD, R. (2016), Orographic Precipitation in Coastal Southern Chile: Mean Distribution, Temporal Variability, and Linear Contribution. *Journal of Hydrometeorology*.





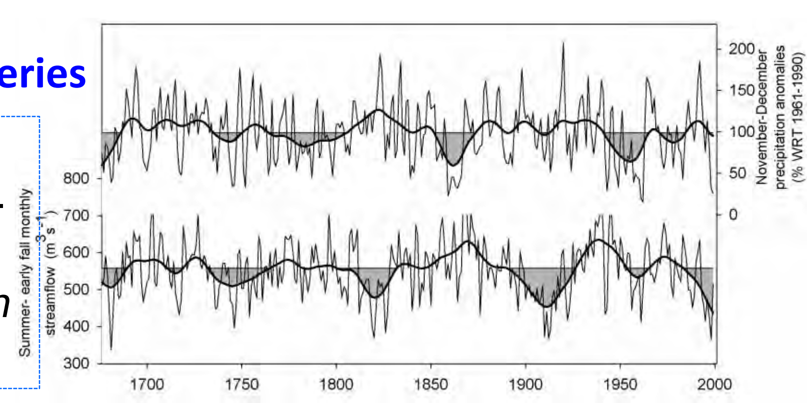
Seasonal precipitation extremes

GARREAUD, R. (2013), Warm Winter Storms in Central Chile. *Journal of Hydrometeorology*.



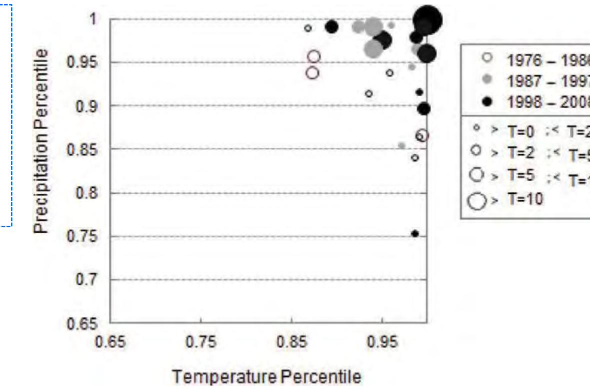
Reconstruction of hydrometeorological series

Rocío Urrutia et al. (2010), Water availability reconstructions using tree-rings in the Valdivian rainforest ecoregion, Chile *IOP Conf. Ser.: Earth Environ. Sci.*



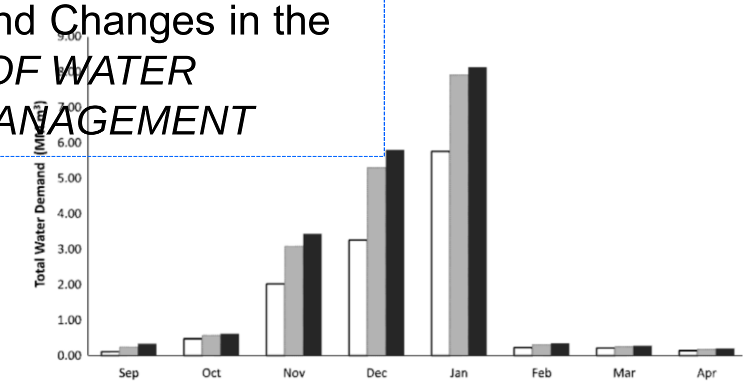
Relations between climate changes and hydrological extremes

Sebastian Vicuña et al. (2013), Exploring possible connections between hydrological extreme events and climate change in central south Chile. HSJ



Impacts of climate on agriculture

Francisco J. Meza, et al. (2013), Impacts of Climate Change on Irrigated Agriculture in the Maipo Basin, Chile: Reliability of Water Rights and Changes in the Demand for Irrigation. *JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT*

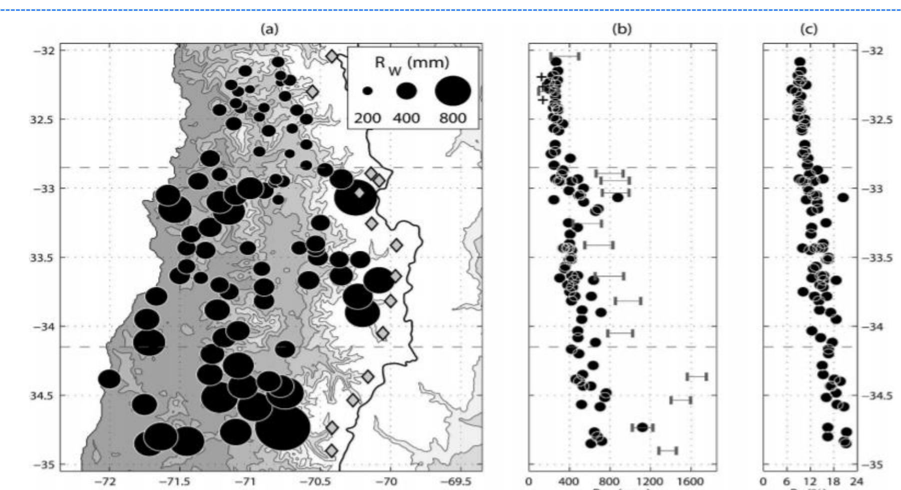


Soil moisture and climate changes

Stolpe, N. and Undurraga, P. (2016), Long term climatic trends in Chile and effects on soil moisture and temperature regimes. *Chillen Journal of Agricultural Research.*

Heavy rain and driving factors

Falvey, M. and Garreaud, R. (2007), Wintertime Precipitation Episodes in Central Chile: Associated Meteorological Conditions and Orographic Influences. *Journal of Hydrometeorology***.**



World Scientific Collaborations 2008-2012

Thank you for your attention!

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