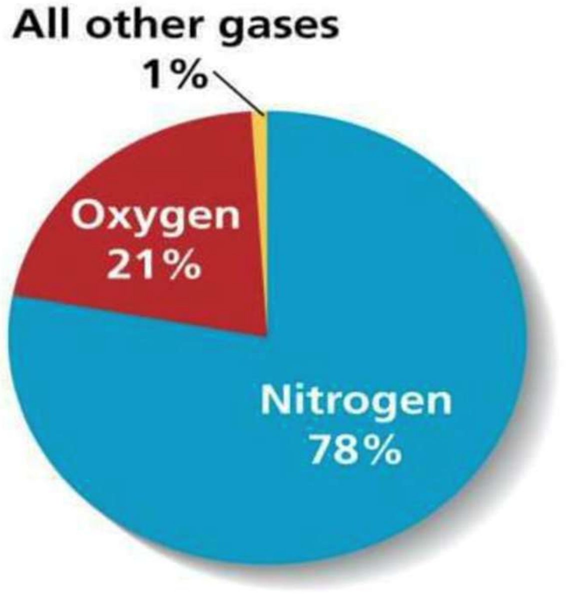
Review: Global Warming by Prof. Zhen Liu

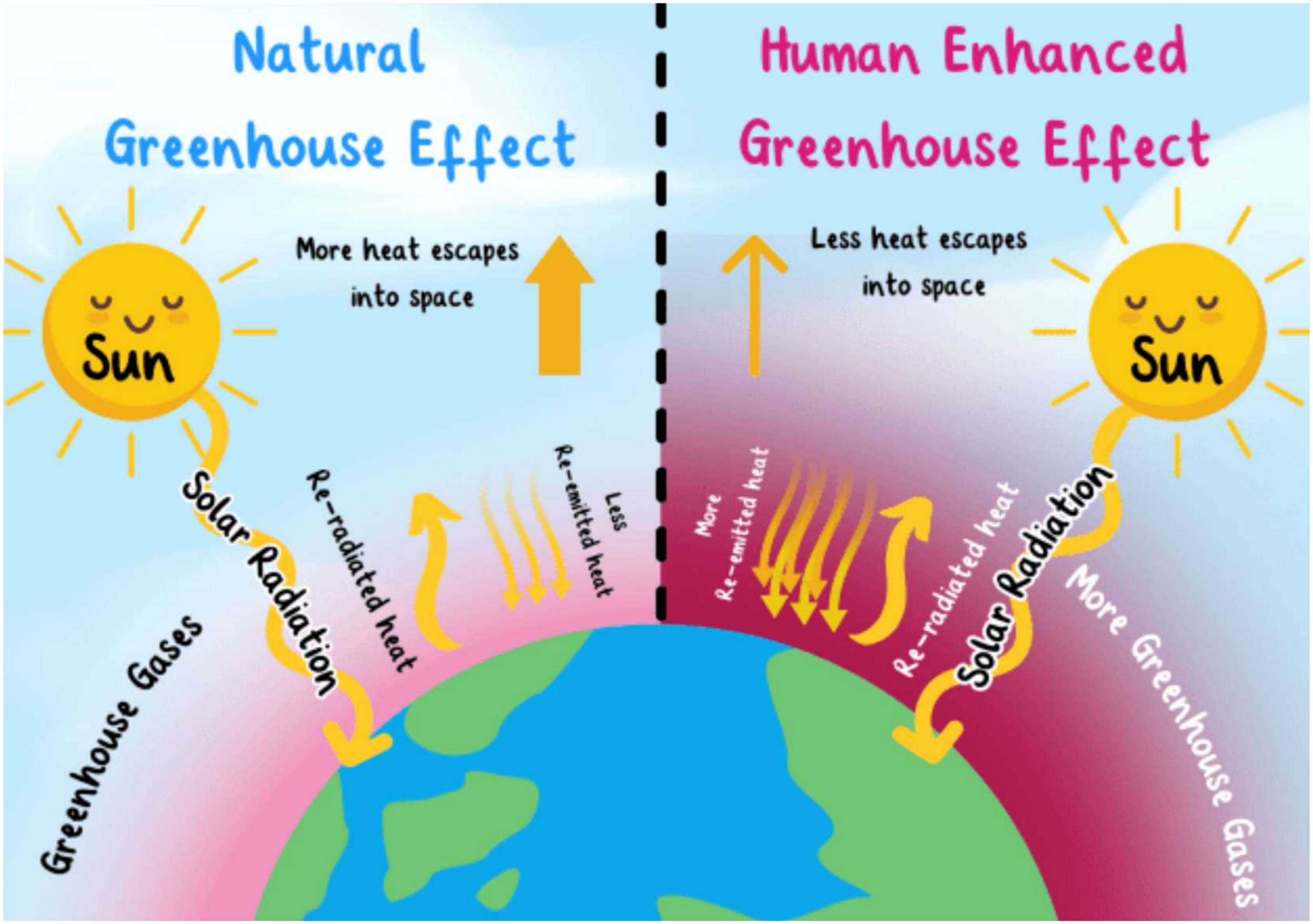
Atmospheric Composition

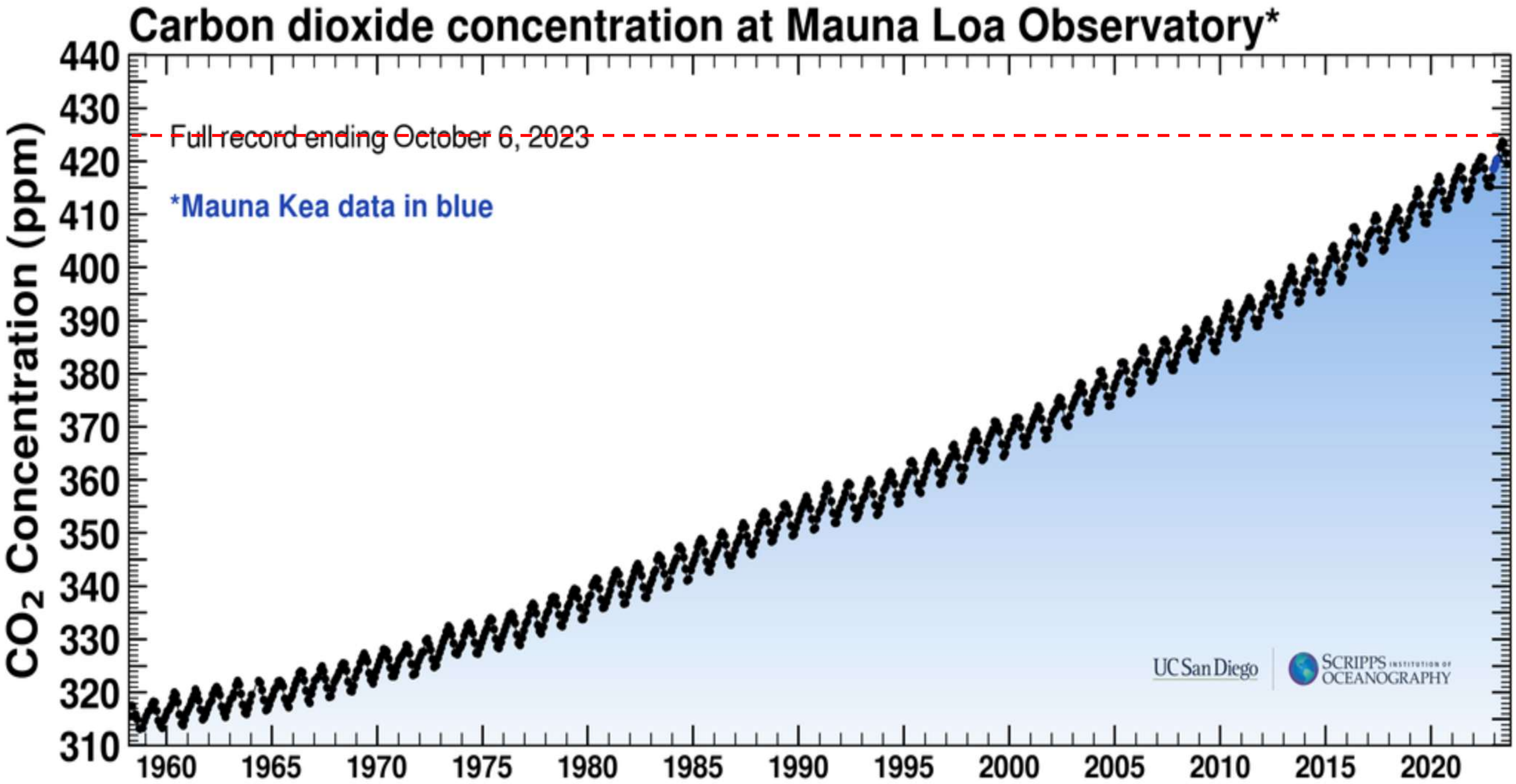


Gas	Percentage by Volume
Nitrogen (N_2)	78.084
Oxygen (O_2)	20.946
Argon (Ar)	0.934
Carbon dioxide (CO_2)	0.037
Neon (Ne)	0.00182
Helium (He)	0.00052
Methane (CH_4)	0.00015
Krypton (Kr)	0.00011

370 ppm

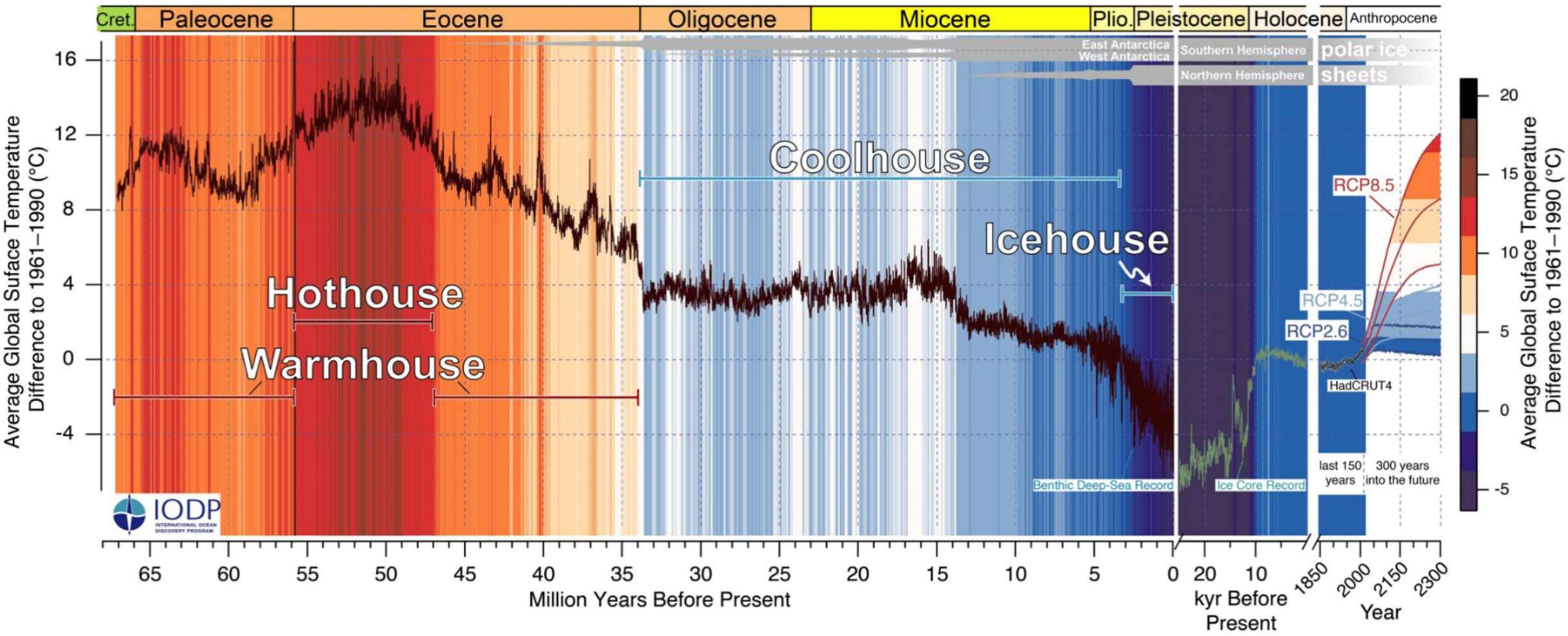
Too Much Greenhouse Gas

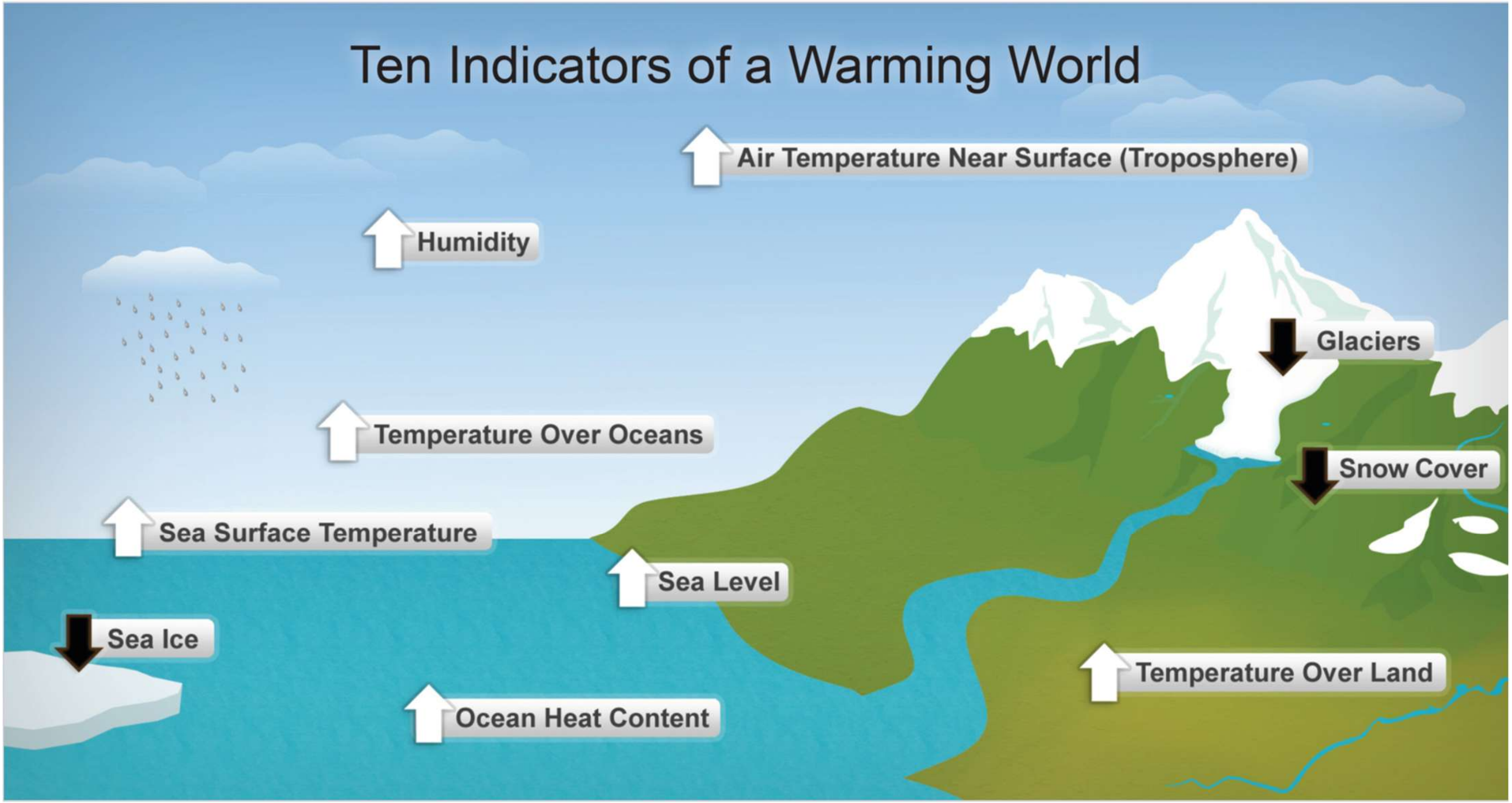


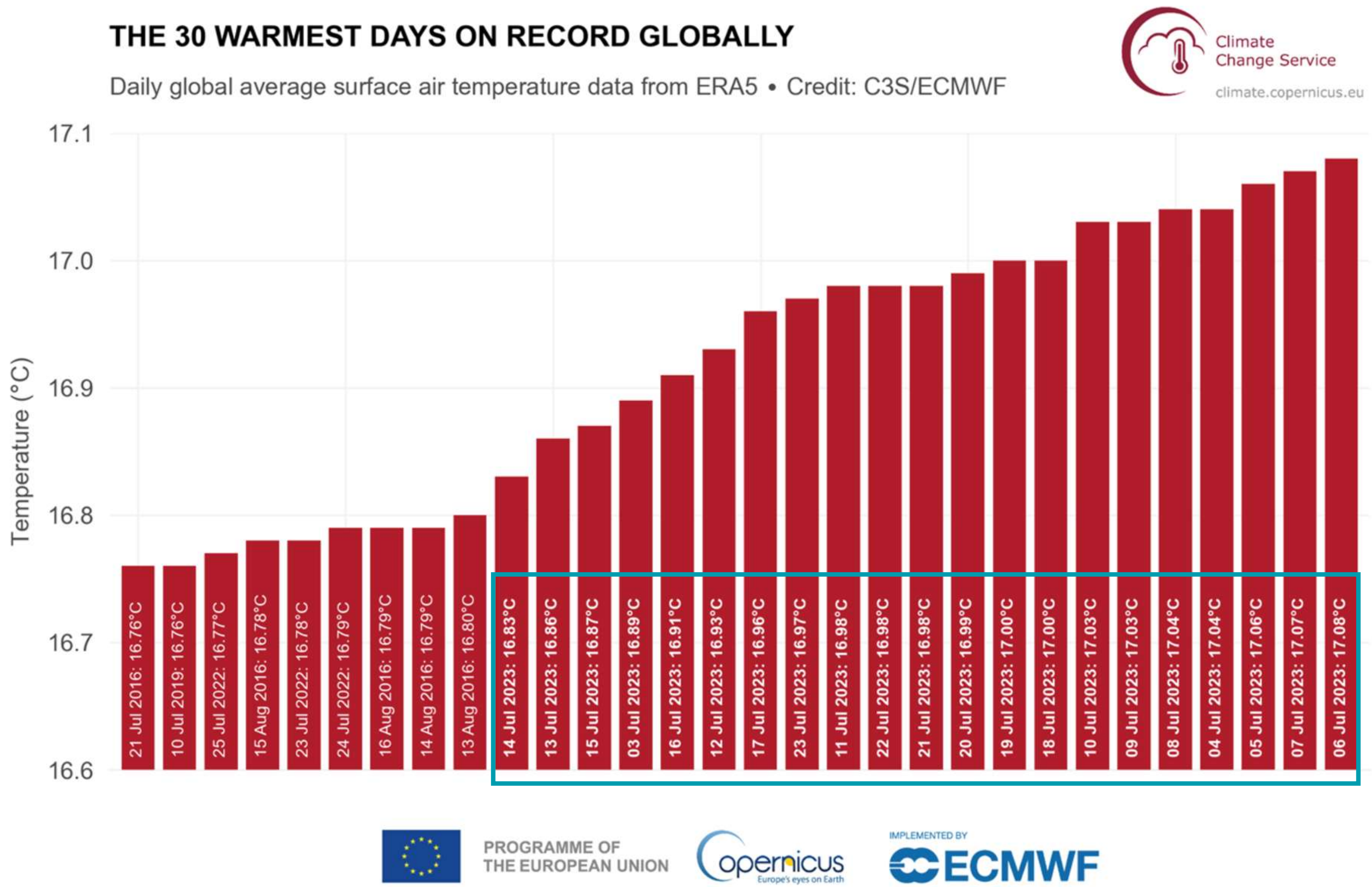


Pre-industrial (~1750) atmospheric CO_2 concentration ~ 280 ppm
Now increasing by ~ 2 ppm per year

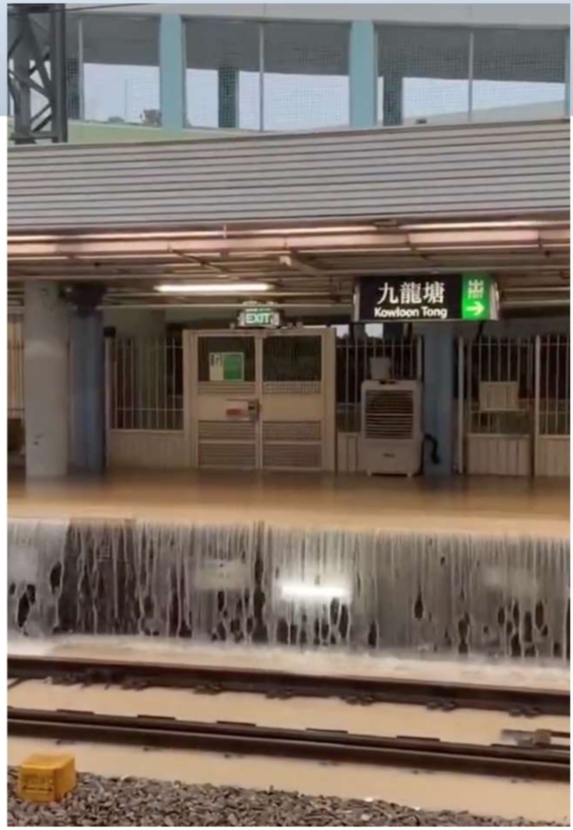
Global Mean Surface Temperature across the Last 66 Million Years




Ten Indicators of a Warming World
Air Temperature Near Surface (Troposphere)
Humidity
Glaciers
Temperature Over Oceans
Snow Cover
Sea Surface Temperature
Sea Level
Sea Ice
Temperature Over Land
Ocean Heat Content

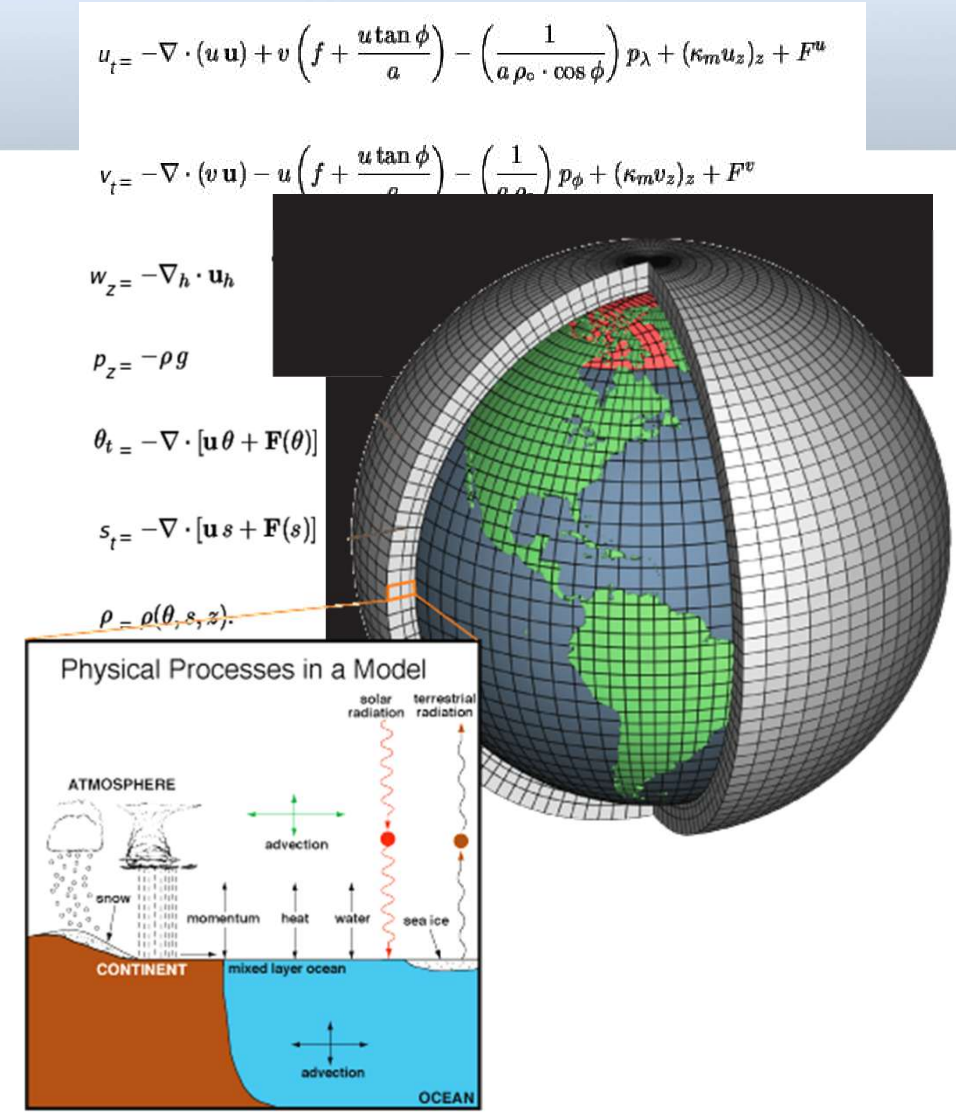


21 out of 30 occurs in 2023



Hong Kong’s heaviest rain since records began 140 years ago (**1884**) has left **two** people dead. **158.1** mm within one hour from **11 pm** on Sep 7.

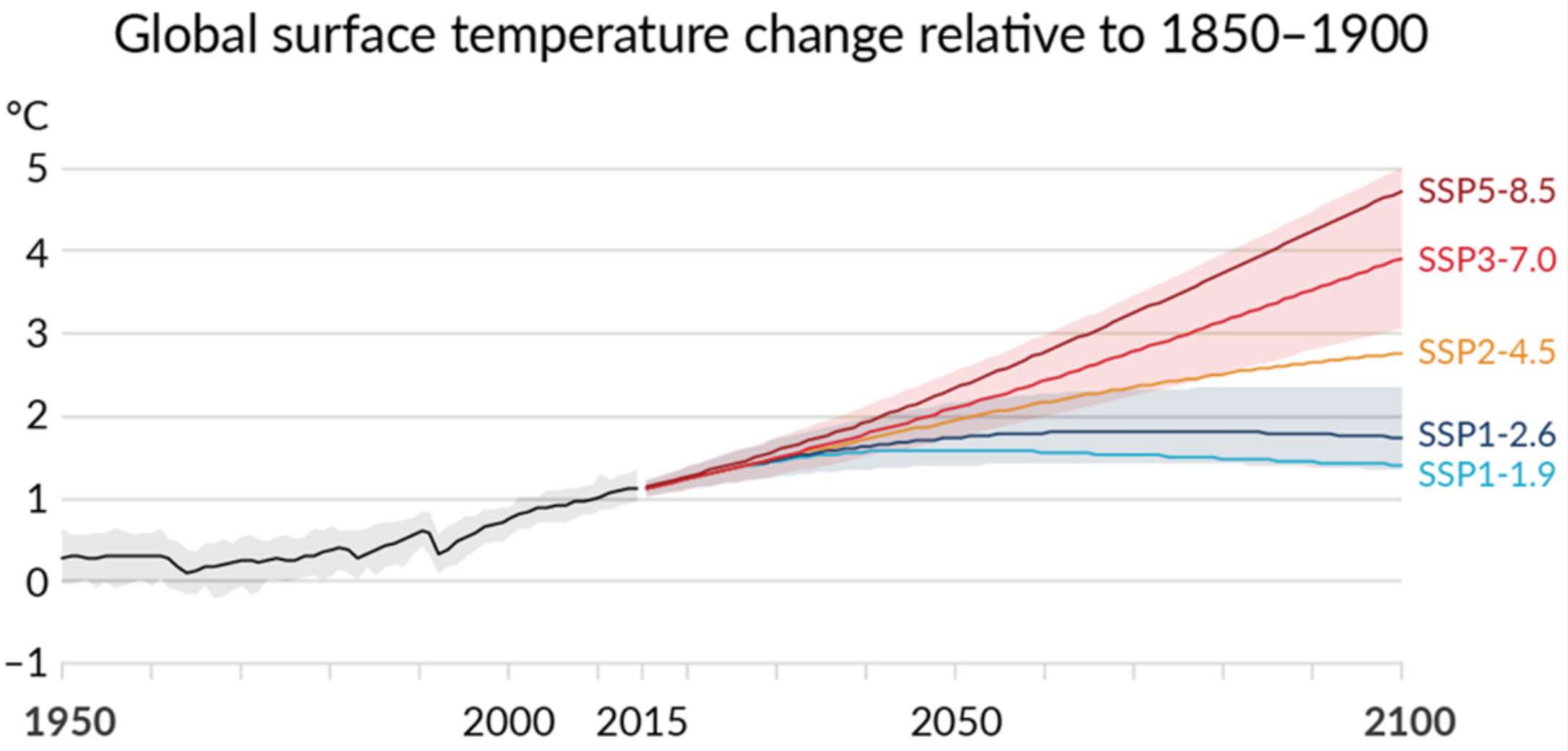
Global Climate Models



Our “workhorse” models have more than 300,000 atmospheric grid cells and a couple million ocean grid cells.

And there’s thousands more grid cells for the land and sea ice model components.

Future Temperature Changes



(IPCC AR6, 2021)

Precipitation in Guangzhou

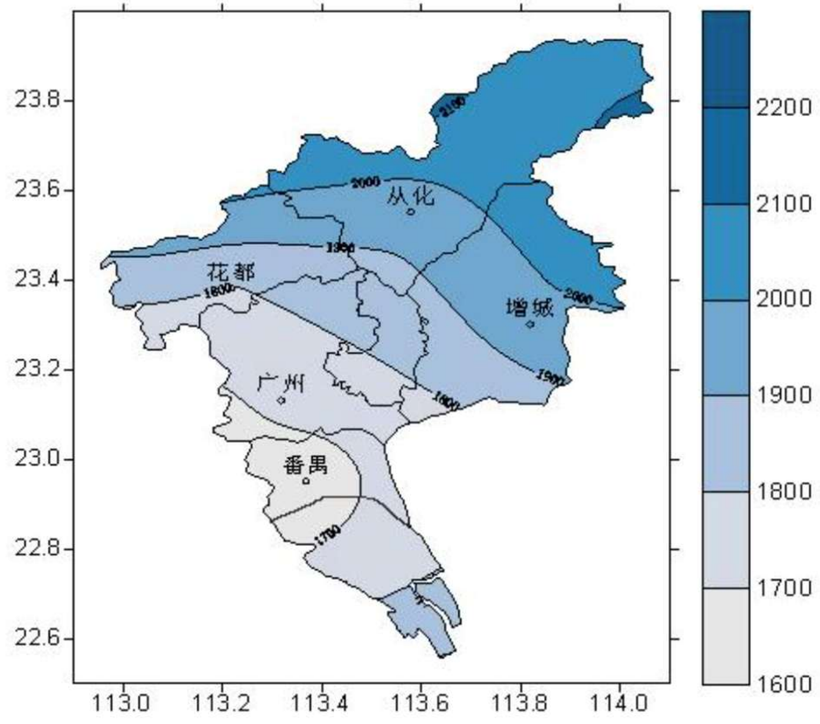
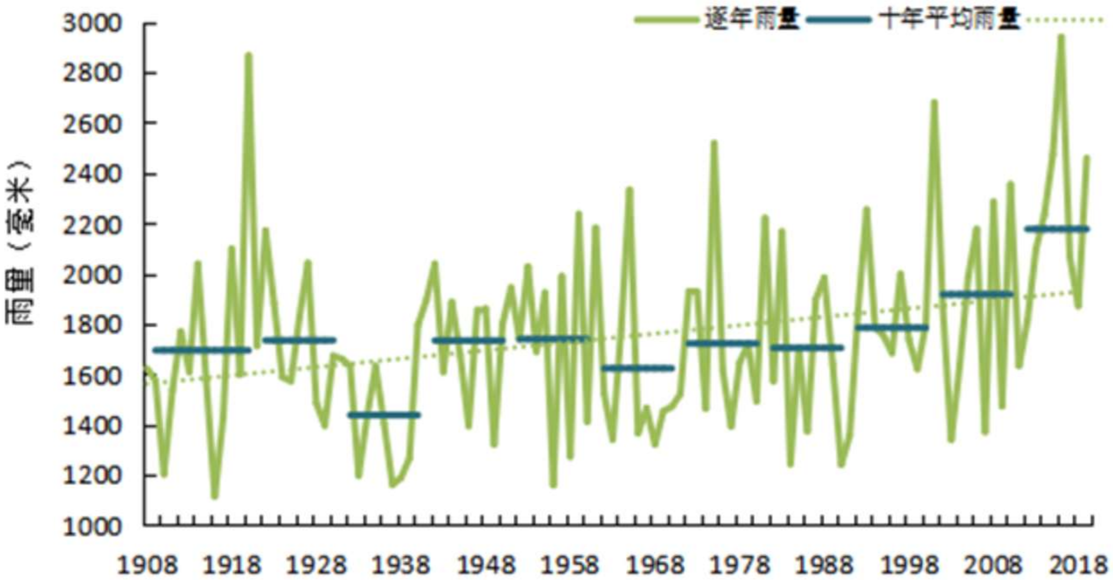


图4 广州市年平均降水量分布图（单位：毫米）



Temperature

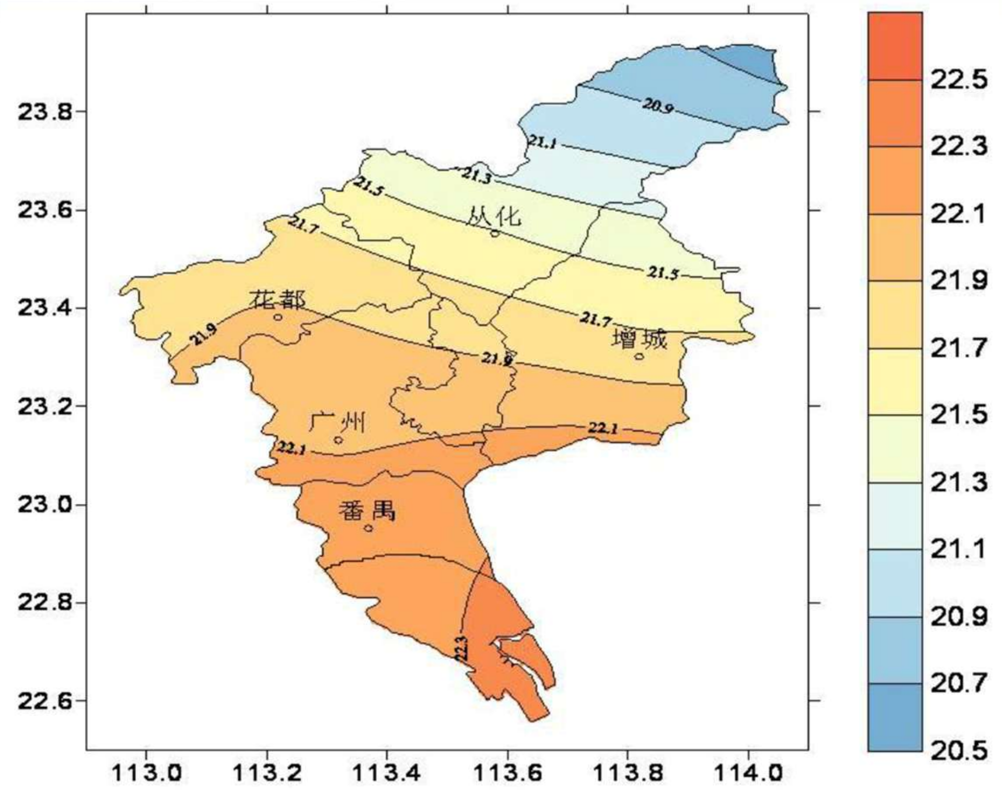
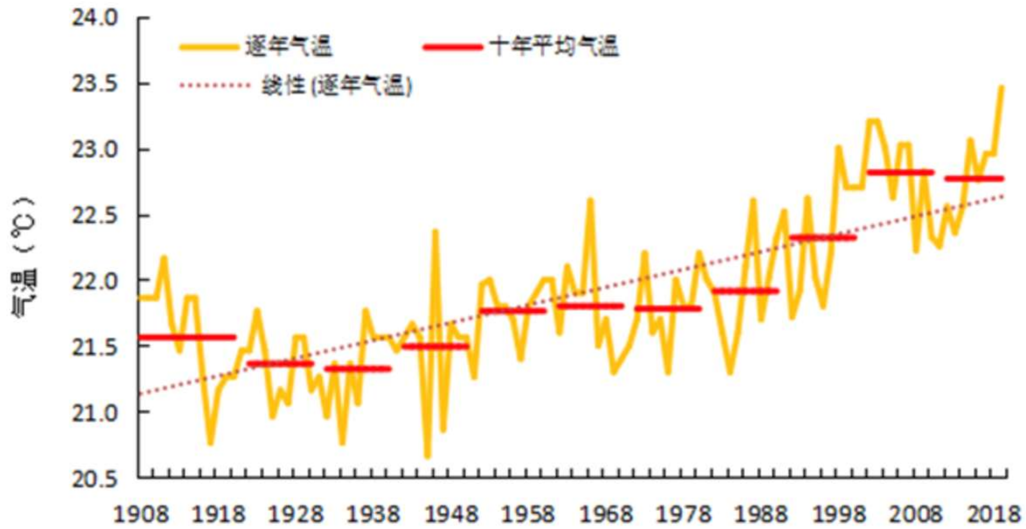


图2 广州市年平均气温分布图（单位：°C）



What is our national anthem?

What is our ‘second’ national anthem?

My Motherland

Introduction to Function Hub For Sustainable Future

Lecture 3： Hydrology in the Context of Climate Change

Qichun Yang

2024-10-14

香港科技大学（广州）
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY (GUANGZHOU)

Vocabulary of this lecture

- Hydrology: 水文学
- River basin: 流域 （面积较大）
- Watershed:流域 （面积较小）
- Water vapor：水汽
- Soil moisture: 土壤水
- Drainage divide: 分水岭
- Topography: 地貌
- Nitrogen: 氮
- Phosphorus: 磷
- Humidity: 湿度
- Precipitation: 降水
- Evapotranspiration：蒸散发
-

Outline

- History of Hydrology
- River basin
- Key components and processes
- Environmental challenges associated with Hydrology
- Solutions through innovative research

Outline

- **History of Hydrology**
- River basin
- Key components and processes
- Environmental challenges associated with Hydrology
- Solutions through innovative research

Rivers

- Drinking water supply
- Transportation

vs.

- **Floods vs. Droughts**
- **Water pollution**

https://depts.washington.edu/chinaciv/geo/proper.htm

History of hydrology

Long, long ago….

- **Yu the Great Harnesses the Flood (大禹治水)**

- **Noah's ark and the Flood**

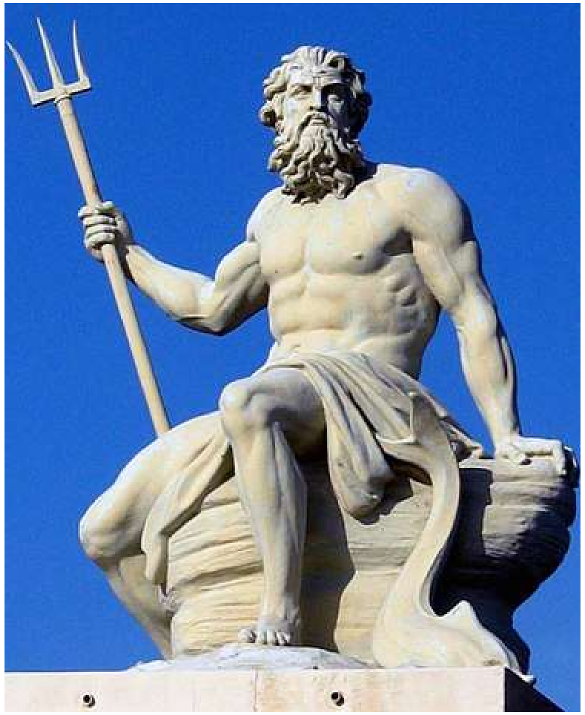
https://inews.gtimg.com/newsapp_bt/0/13618806230/641 https://view.inews.qq.com/k/20210315A088UC00?web_channel=wap&openApp=false&f=newdc

History of Hydrology

- **From ancient times many speculated about the circulation of water.**
  - **Where is the water coming from?**
  - **Where is it going?**
  - **Why it varies?**
  - **What should we do when we have too much or too little**

https://w[illegible]oh.com/fenxiang/56811.html
https://zh.wikipedia.org/zh-hans/File:Poseidon_sculpture_Copenhagen_2005.jpg

Dragon king



Poseidon

History of Hydrology

- **Limited knowledge of different forms of water.**
  - **Water vapor**
  - **Soil moisture**

- **Early thinkers and philosophers did not understand the basic hydrologic principles.**
  - **Conservation of mass**
  - **Evaporation and condensation**
  - **Infiltration**

https://cn.dreamstime.com/%E5%BA%93%E5%AD%98%E4%BE%8B%E8%AF%81-%E8%83%8C%E6%99%AF%E7%9C%BC%E8%A7%81%E4%B8%BA%E5%AE%9E-image84056283

History of Hydrology

- Vitrivius (a Roman engineer 1st century BC) first recognized the infiltration processes

- Leonardo da Vinci made the first systematic studies of velocity distributions in streams. He likely was the first to provide a complete description of the hydrologic cycle

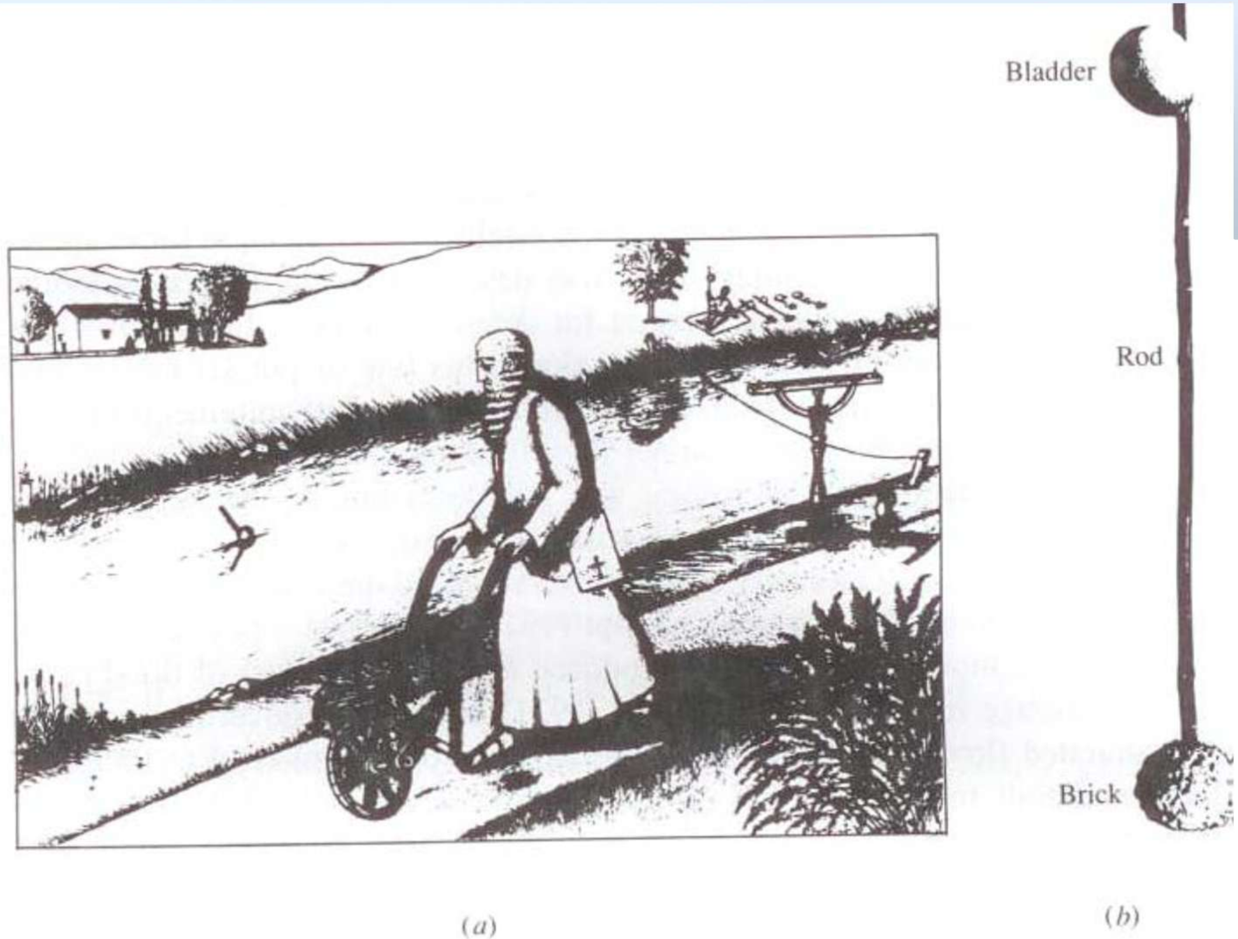
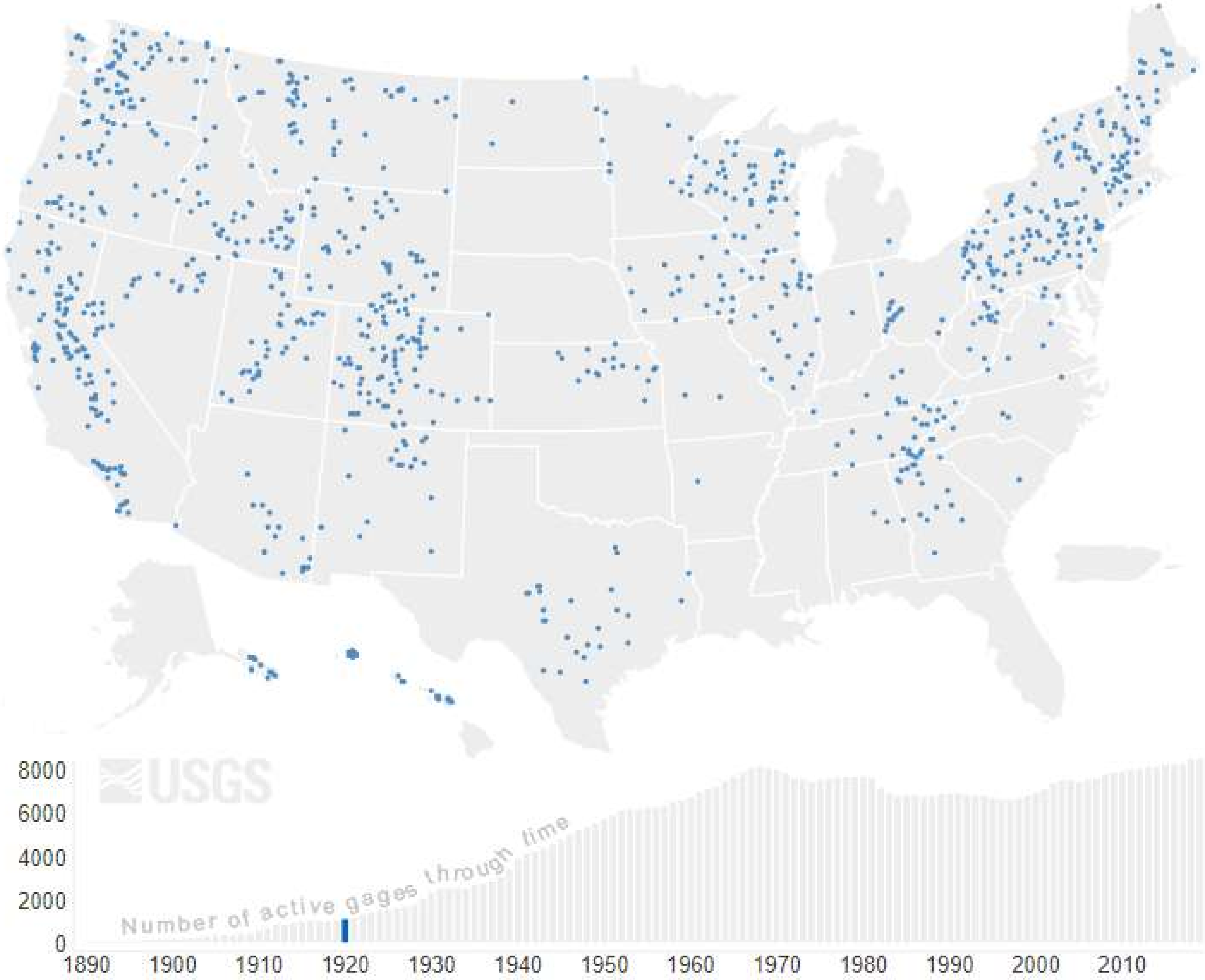


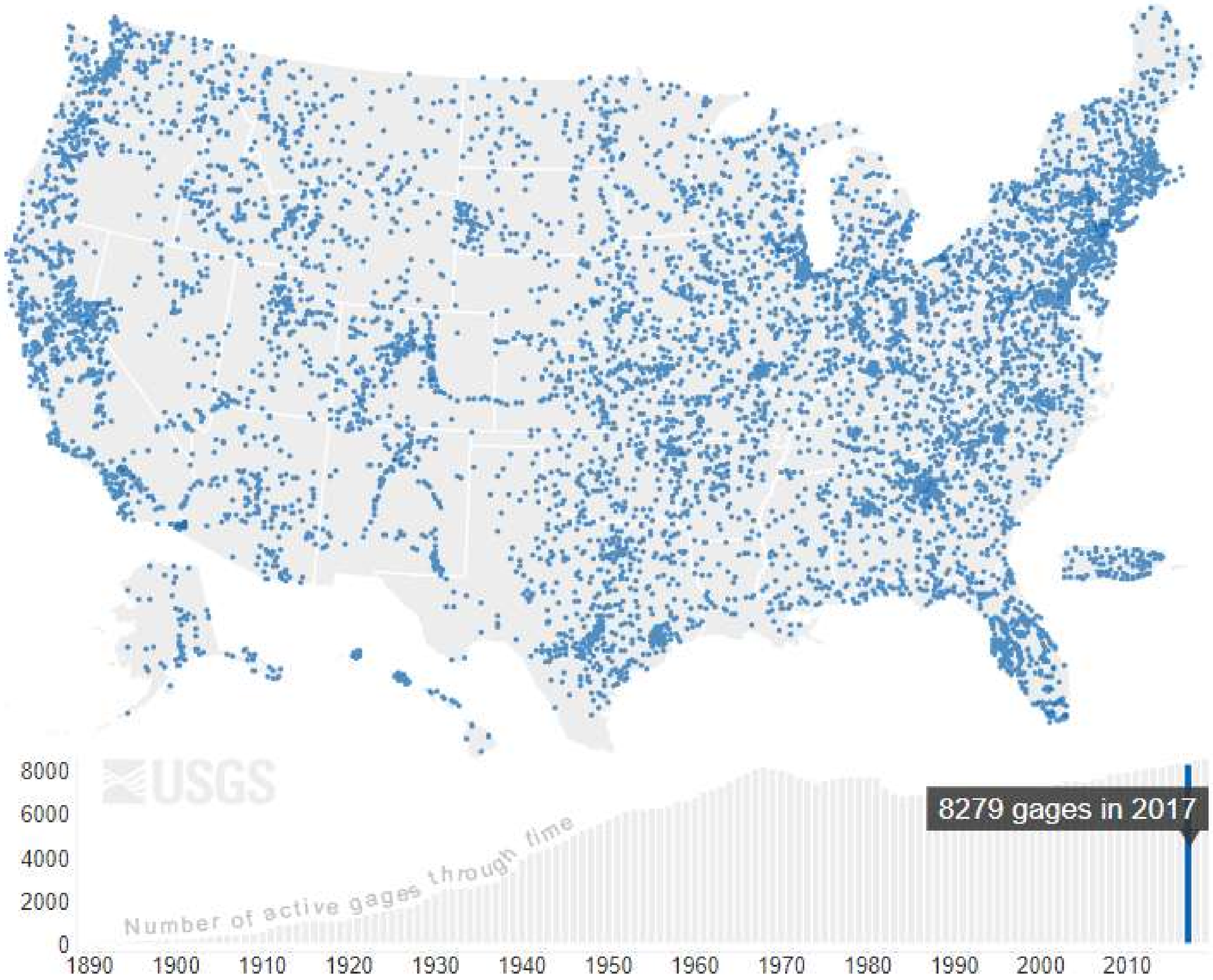
FIGURE 1.5.1
Leonardo da Vinci measured the velocity distribution across a stream section by repeated experimen of the type shown in (*a*). He would release a weighted rod (*b*) held afloat by an inflated blad and follow its progress downstream, measuring distance with the odometer and time by rhythm chanting. (*Source:* Frazier, 1974, Figs. 6 and 7. Used with permission.)

History of Hydrology

- 18th and 19th centuries: hydraulic experiments flourished
- Until the 1930s, hydrology remained a science full of empiricism, qualitative descriptions and little understanding of physical processes
- All these experience and study have converged to form the concept of “hydrologic cycle”



https://labs.waterdata.usgs.gov/visualizations/gages-through-the-ages/index.html#/



https://labs.waterdata.usgs.gov/visualizations/gages-through-the-ages/index.html#/

Hydrology in China

- China has a long history of hydrological engineering

https://sichuan.scol.com.cn/sczh/202008/57874660.html

Dujiangyan （都江堰）

The largest hydropower dam of the world： Three Gorges

- World largest installed capacity (22,500 MW)
- Plays an important role in flood control

Le Grand Portage Derivative work

The second largest hydropower dam: Baihetan

https://sichuan.scol.com.cn/sczh/202008/57874660.html

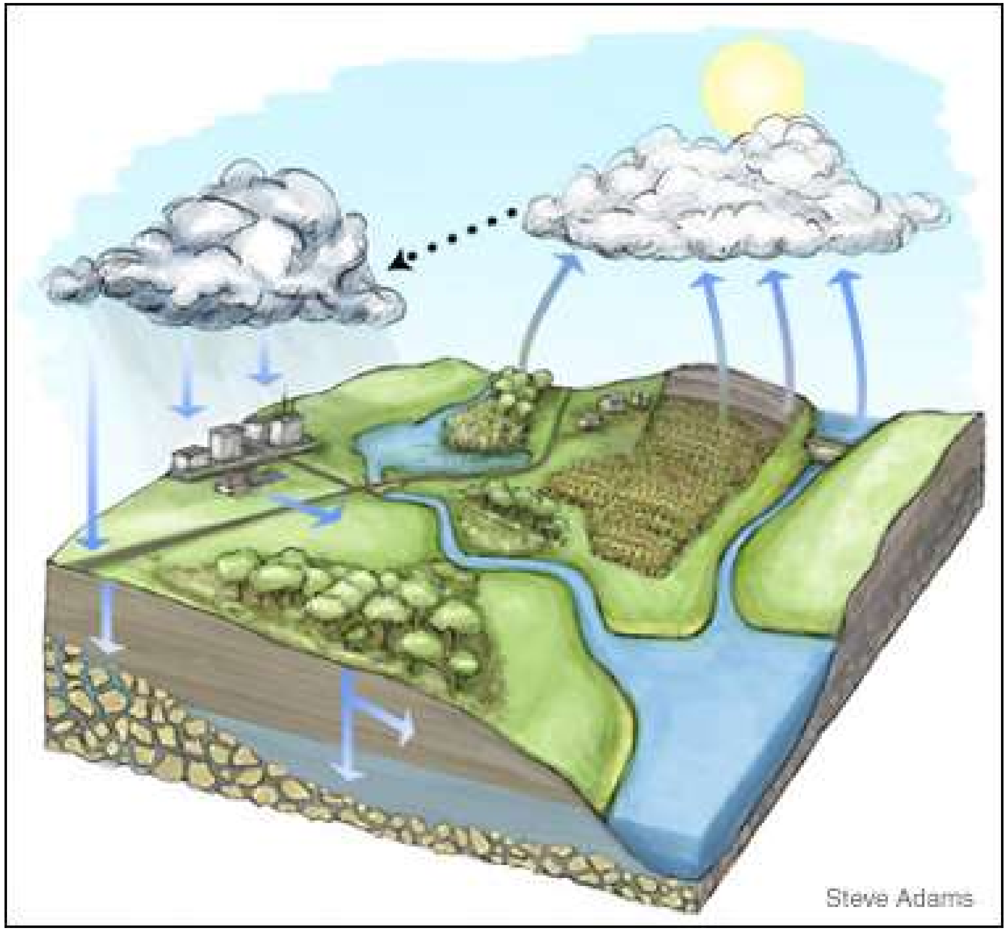

T-00:00:25
STARSHIP FLIGHT TEST

Outline

- History of Hydrology
- River basin
- **Key components and processes**
- Environmental challenges associated with Hydrology
- Solutions through innovative research

River basin

- Fundamental hydrological unit
- Boundary are defined by drainage divide
- All locations within a basin are hydrologically connected.
- Important for management
- Open and dynamic system



https://files.dnr.state.mn.us/assistance/backyard/healthyrivers/course/200/201_10.htm

River basins

- River basins are different in climate condition, size, shape, land use types, topography, and soils

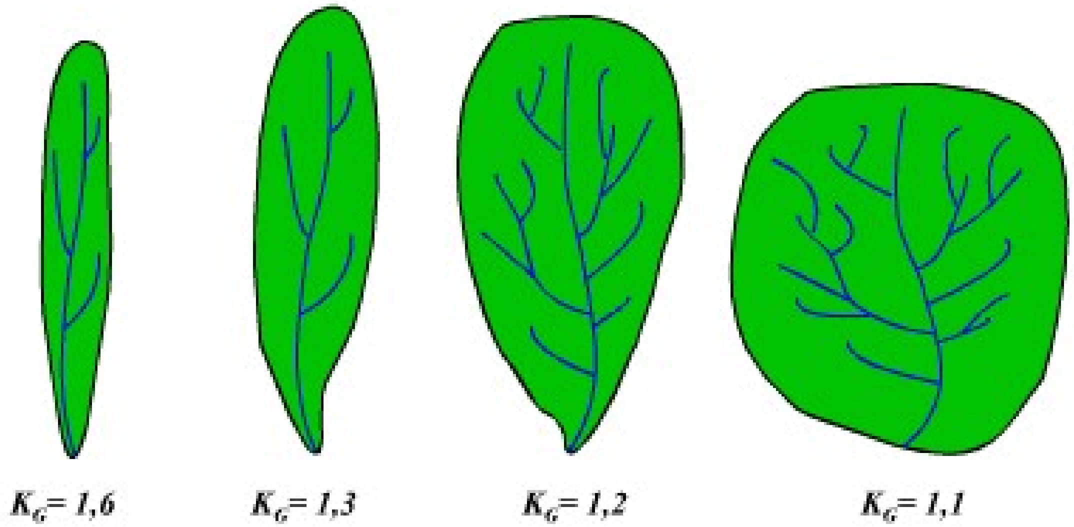
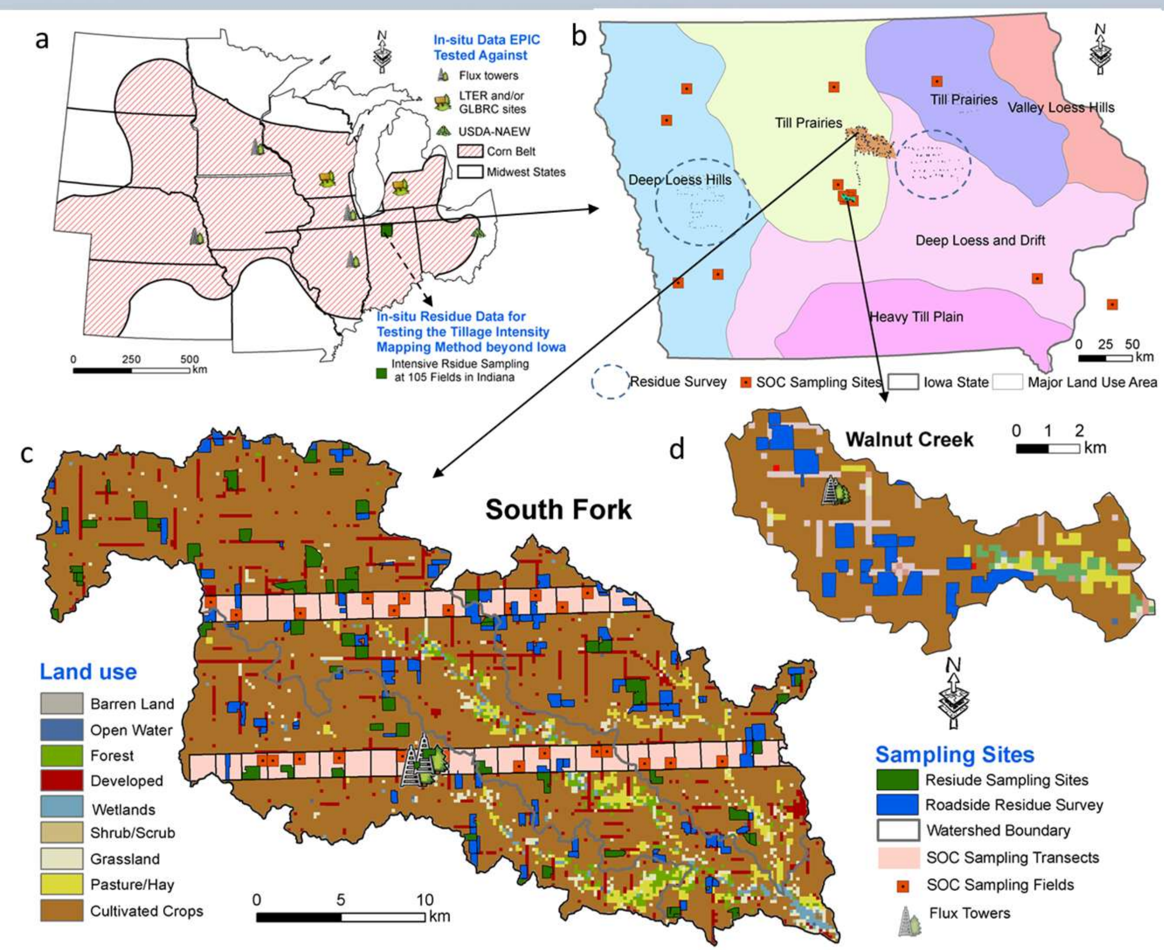


Figure 2.5. Some K_G values for different watershed shapes [Musy, 2001]

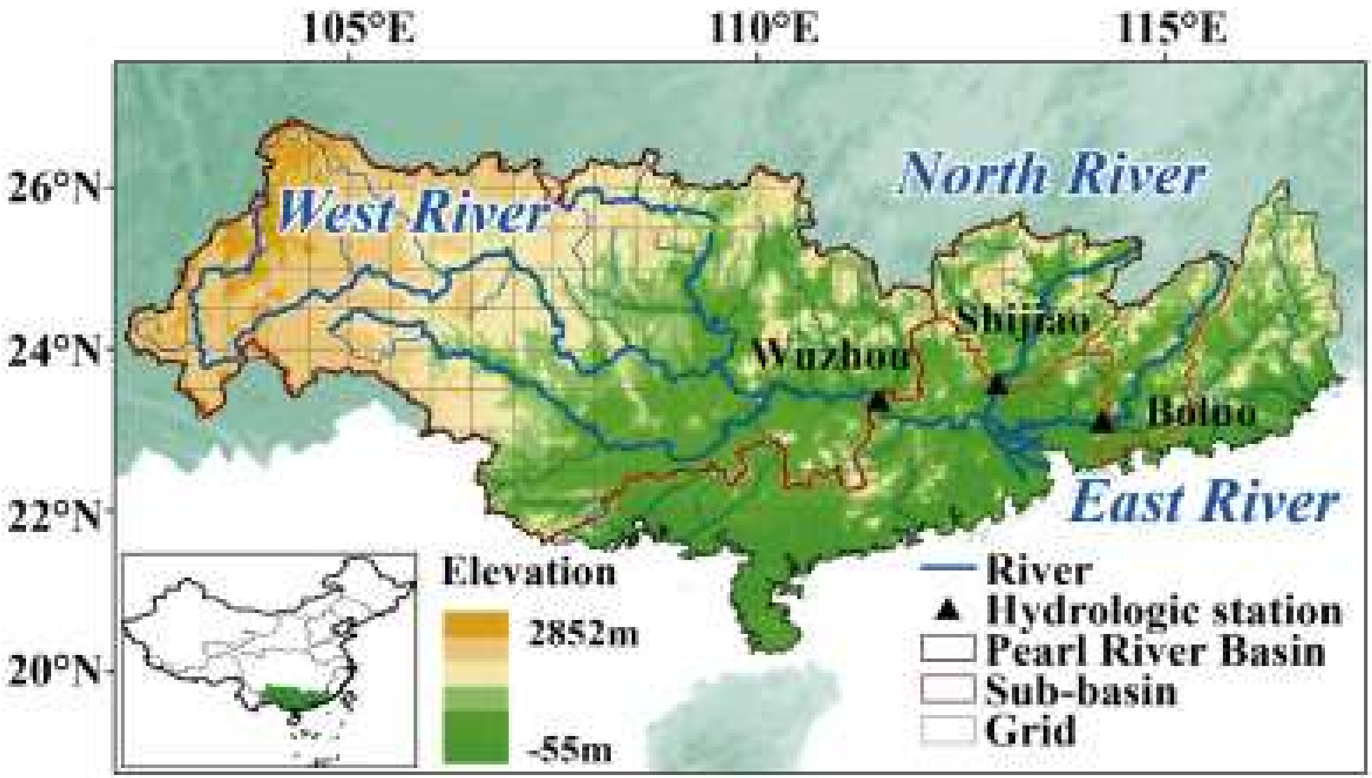
https://echo2.epfl.ch/VICAIRE/mod_1a/chapt_2/text.htm

River basins



River basins

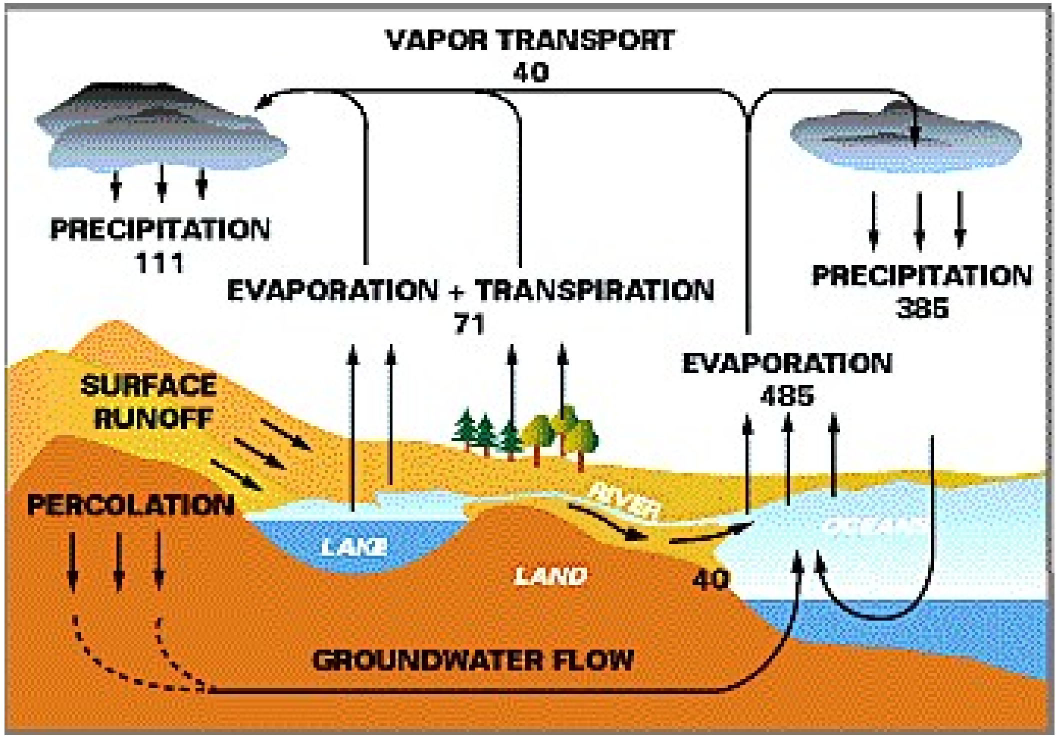
Pearl River Basin



Pools and fluxes in water cycle

water in $km^3 \times 10^6$

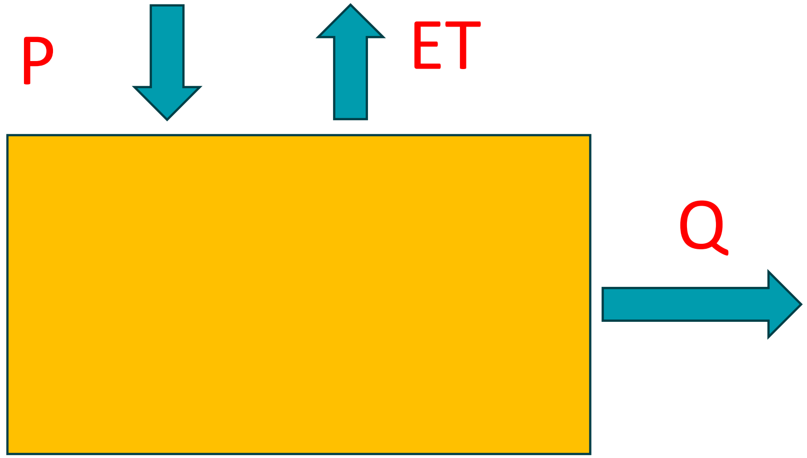
- Ocean, atmosphere, lakes, rivers, ice, groundwater
- Precipitation, evapotranspiration, river discharge



https://globalchange.umich.edu/globalchange1/current/lectures/kling/water_cycle/water_cycle.html

Water fluxes and water balance

$$Q = P - ET$$



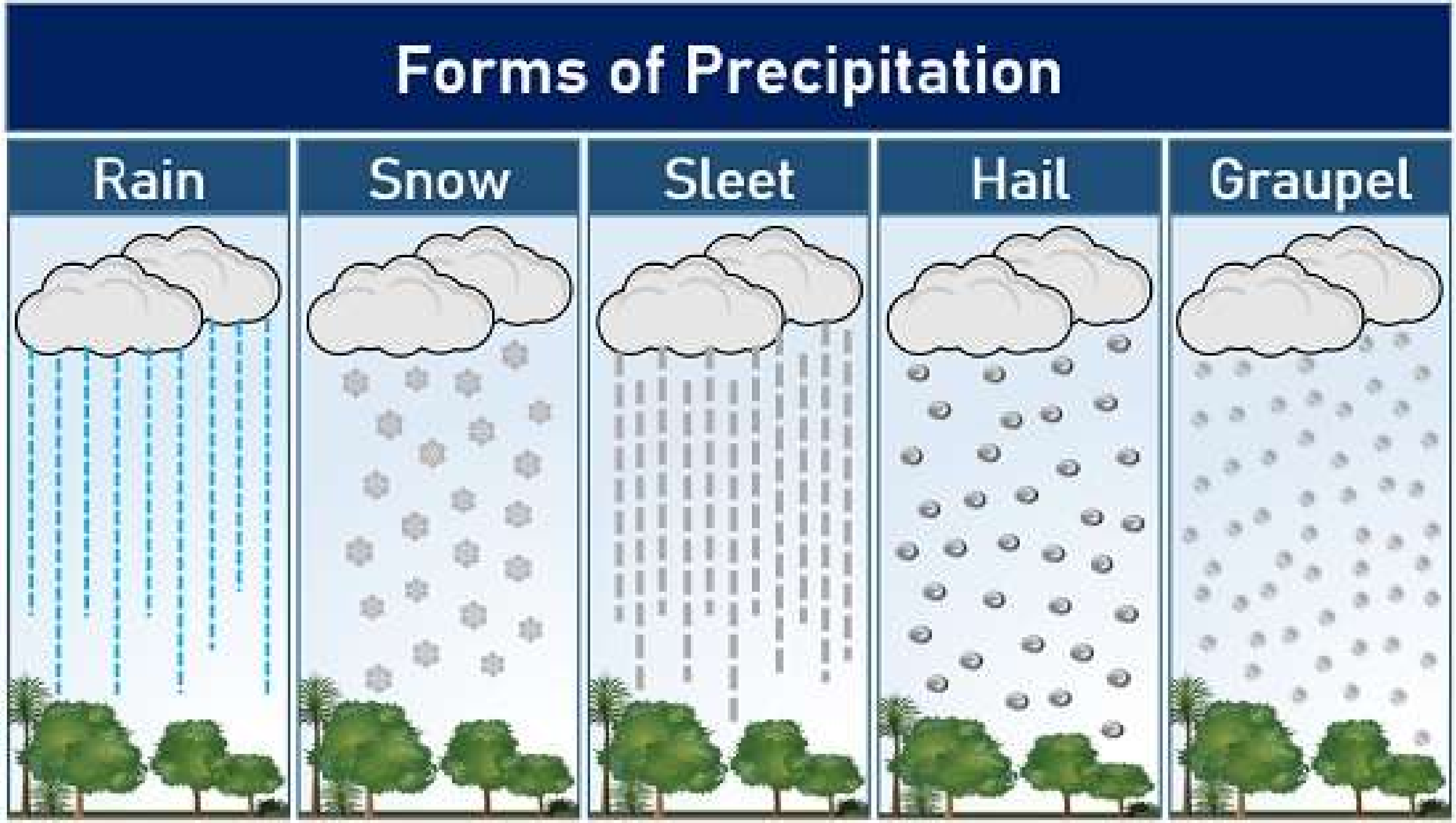
P = Precipitation (mm)

Q = Stream flow (mm)

ET = evaporation and transpiration (mm)

Arnold 2010

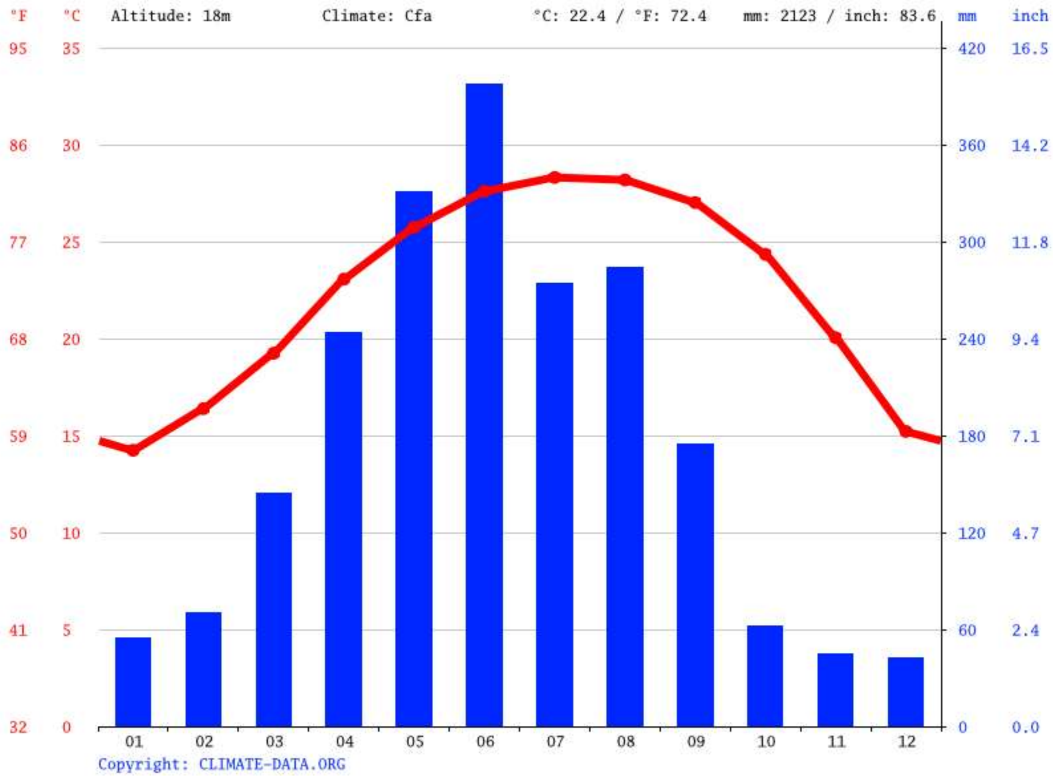
Precipitation



https://biologyreader.com/types-of-precipitation-in-hydrology.html
https://en.climate-data.org/asia/china/guangdong/guangzhou-2309/

Precipitation

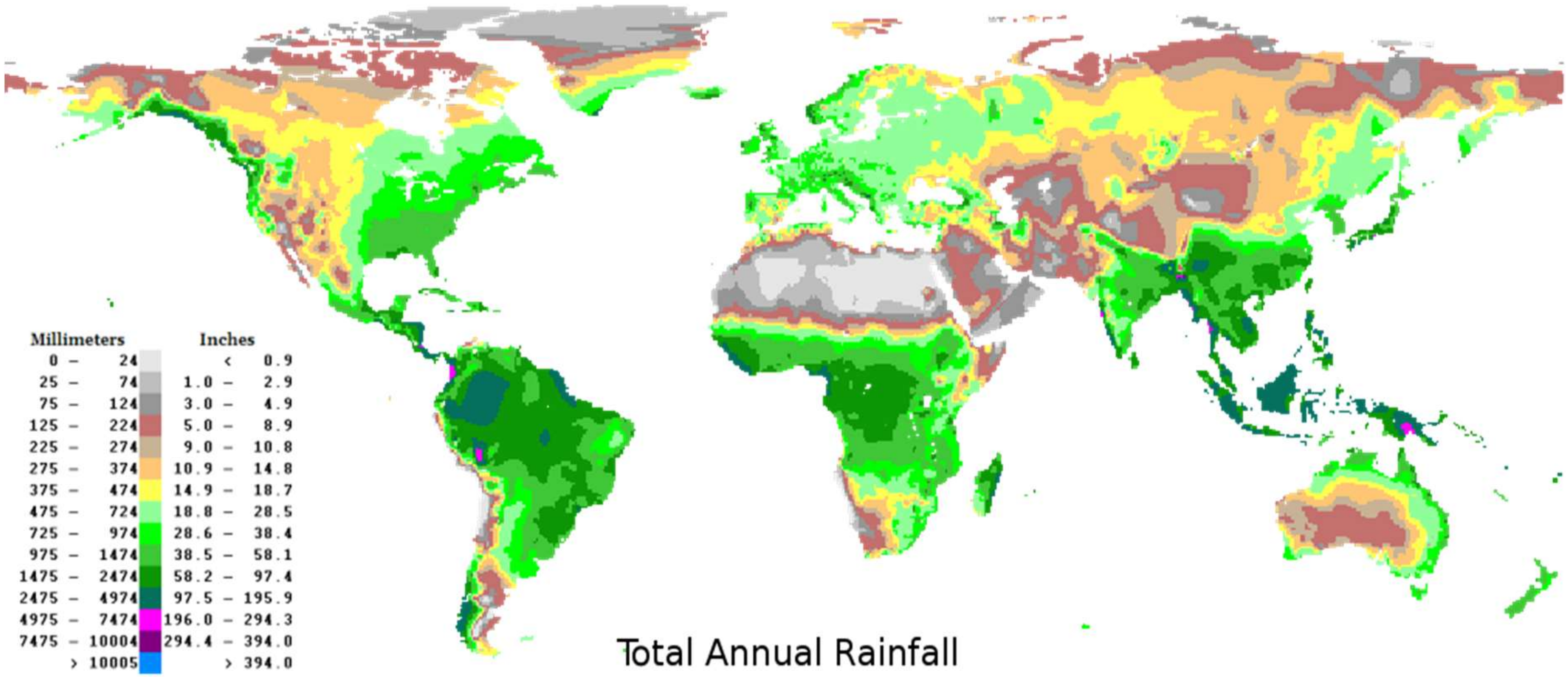
- **Strong seasonality**
- **Play the dominant role in hydrology**
- **Critical to many human activities**
- **Heavy rainfall could lead to floods**



https://biologyreader.com/types-of-precipitation-in-hydrology.html
https://en.climate-data.org/asia/china/guangdong/guangzhou-2309/

Precipitation

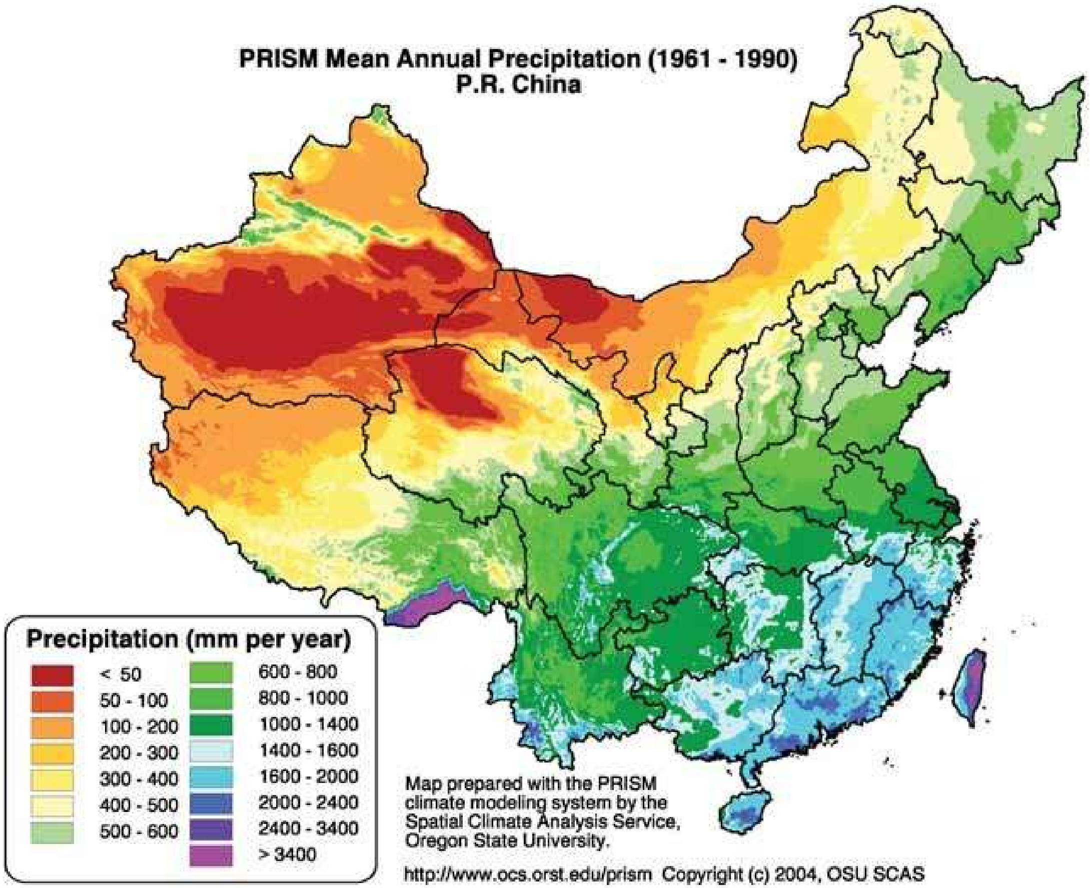
- **Highly variable**
- **Cherrapunji–India gets on average 10.82 meters of rain**
- **Atacama Desert in Chili gets < 1mm/yr**



https://www.eldoradoweather.com/climate/world-maps/world-annual-precip-map.html

Precipitation

- **Highly variable**
- **Guangzhou 2123 mm/yr; Beijing 600mm/yr**
- **Similar to distribution of agricultural activities, and population, economic prosperity, etc**



OSU SCAS 2004

Water vapor

- Water vapor is water in gaseous instead of liquid form.

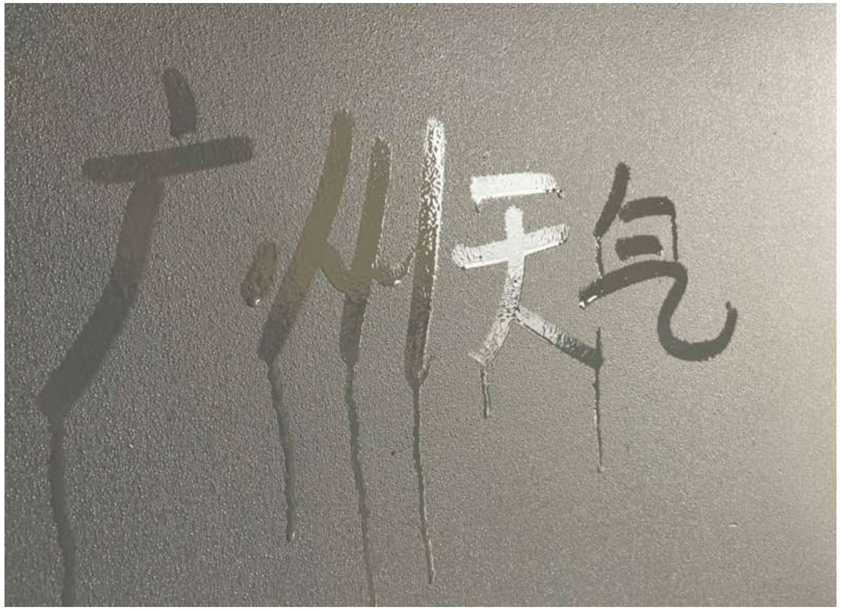
- For a given temperature, there is a maximum moisture content air can hold. The corresponding vapor pressure is saturation vapor pressure (e_s).

- Addition of more water vapor or lowering of the temperature results in condensation via formation of liquid droplets or ice crystals in the air

Arnold 2010

Extremely humid weather

- ➢ **Why here?**
- ➢ **Why this time?**

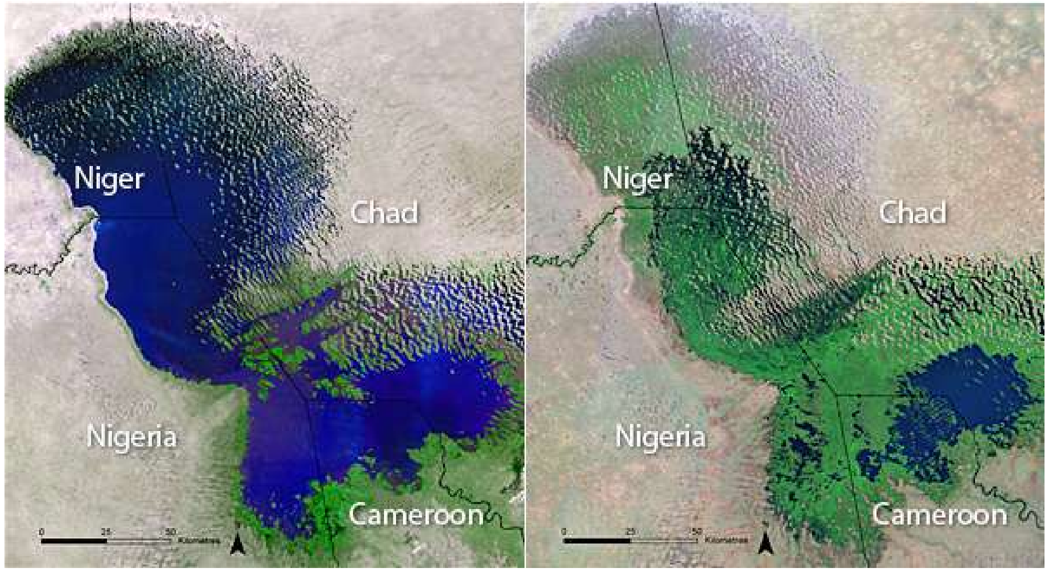


https://www.sohu.com/a/532884369_100116740

Evapotranspiration

- ET is total amount of water loss from land surface to the atmosphere. It include water used by the plants in transpiration and evaporation from adjacent soils
- Returns more than 60% of energy and water falling on land surface back to the air
- One of the most critical process in watershed hydrology

Lake Chad 1972 / 2007



https://ourworld.unu.edu/en/sucking-dry-an-african-giant

Outline

- History of Hydrology
- River basin
- Key components and processes
- **Environmental challenges associated with Hydrology**
- Solutions through innovative research

Challenges associated with water

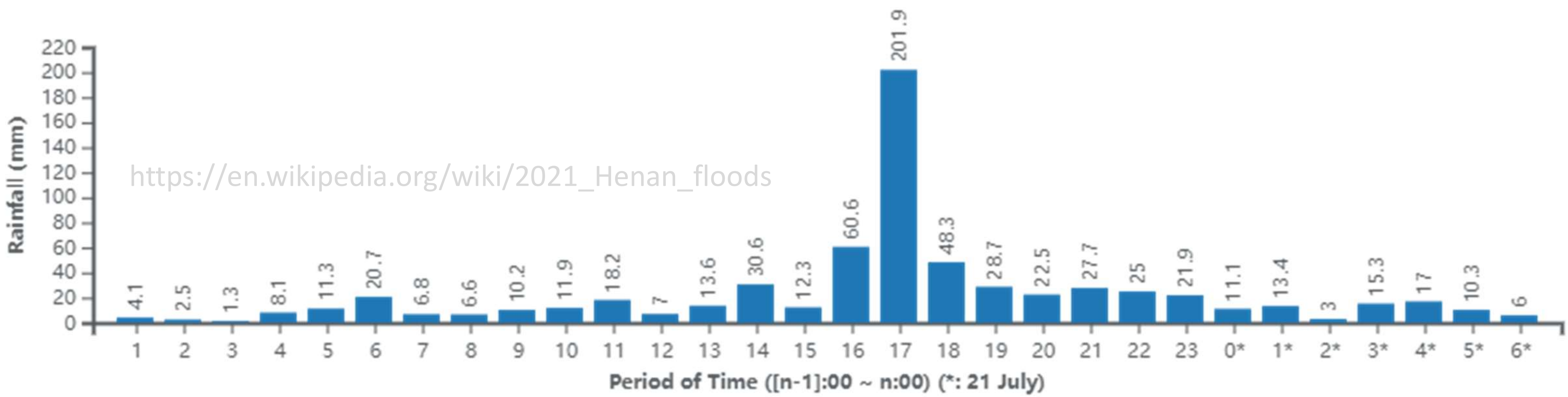
- **Rain in spring is as precious as oil.** 春雨贵如油。
- **Rain after long drought is especially relieving.** 久旱逢甘霖。
- **A good rain knows its appointed time, right in spring it brings things to life.** 好雨知时节，当春乃发生。

- **Misfortunes never come alone(Leaky house in a continuous rain)** 屋漏偏逢连阴雨.

- **It never rains, but it pours.**

Flood in Zhengzhou

Extremely heavy rainfall is a key reason for the flood in Zhengzhou (7.20,2021), but hard to forecast

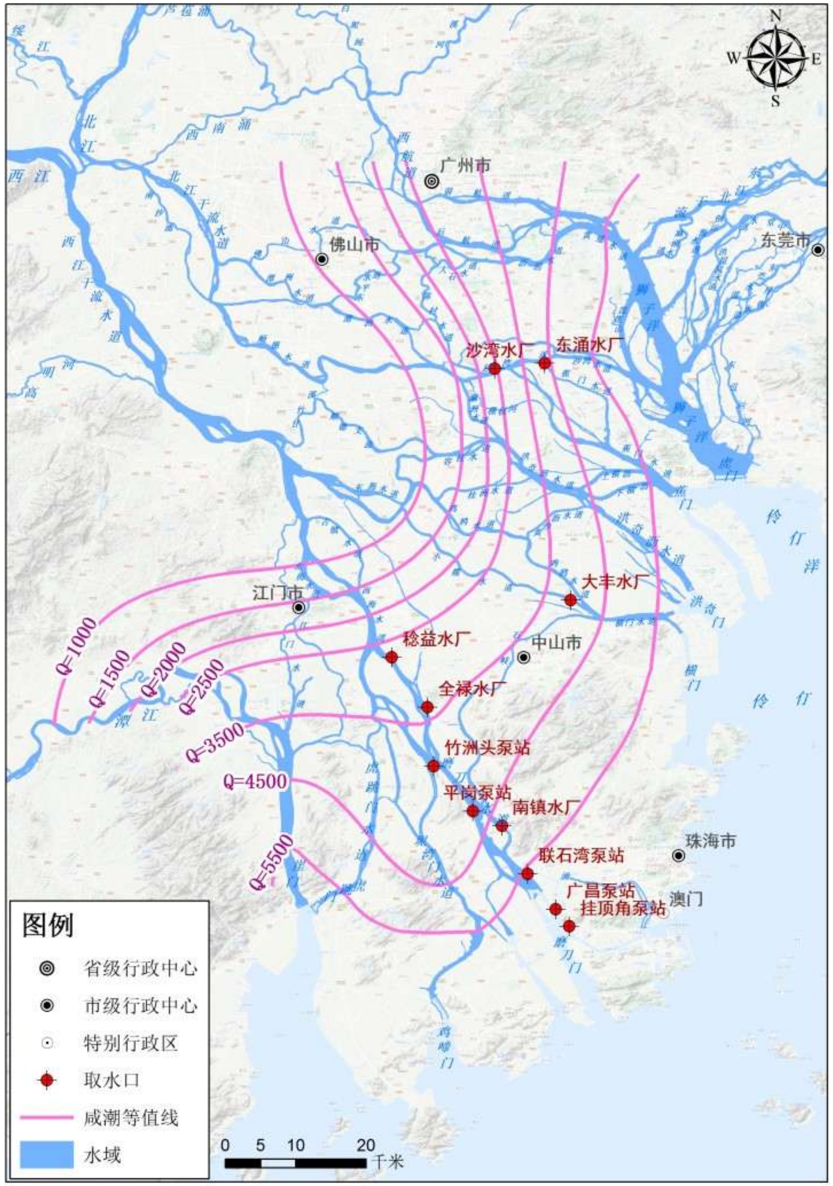


617.1mm in three days vs. the annual average of 640mm

Flood in Guangdong in 2022

Drought

- Saltwater intrusion: movement of saline sea water into freshwater aquifers.



Drought

- **Wildfire in Guangxi in early 2023**

https://baijiahao.baidu.com/s?id=1762701540450755703&wfr=spider&for=pc

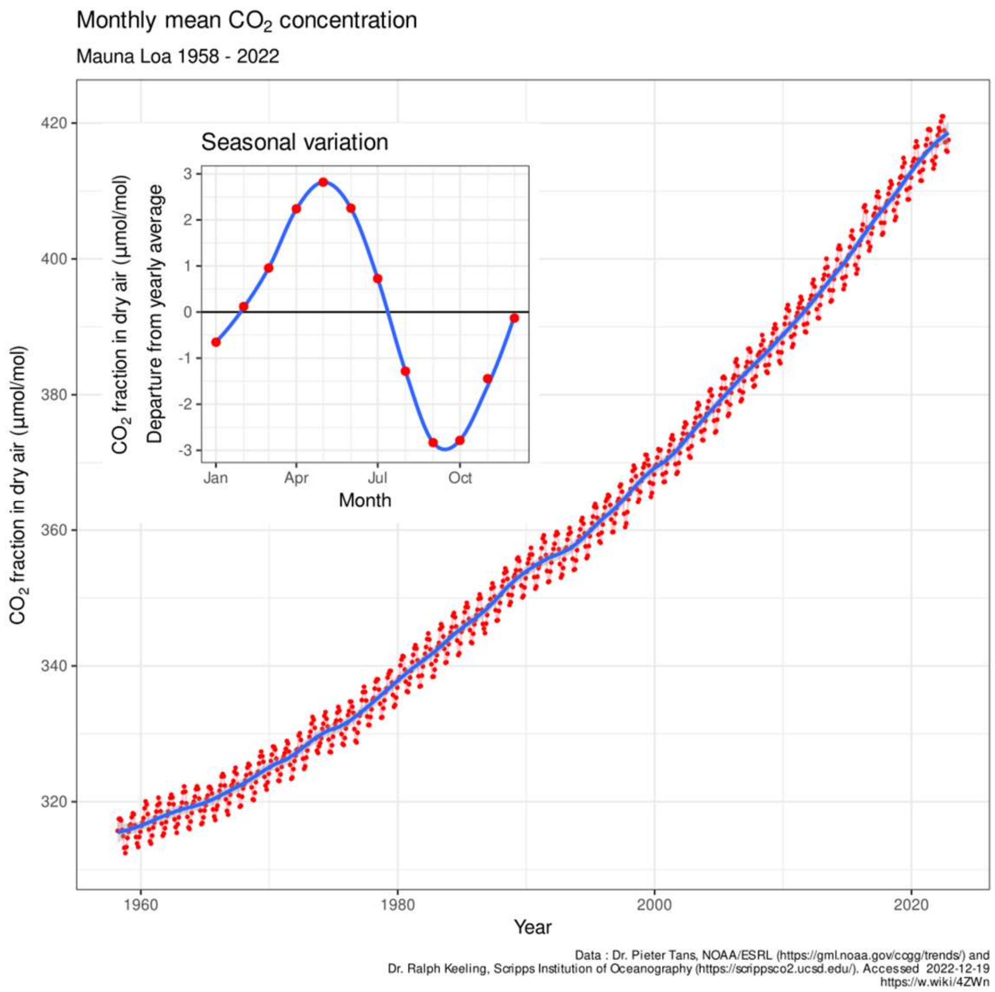
Flood in Zhengzhou （7.20, 2021）

398 people died;
property damage
of 82 billion yuan

https://www.rfa.org/english/news/china/henan-floods-07212021080107.html

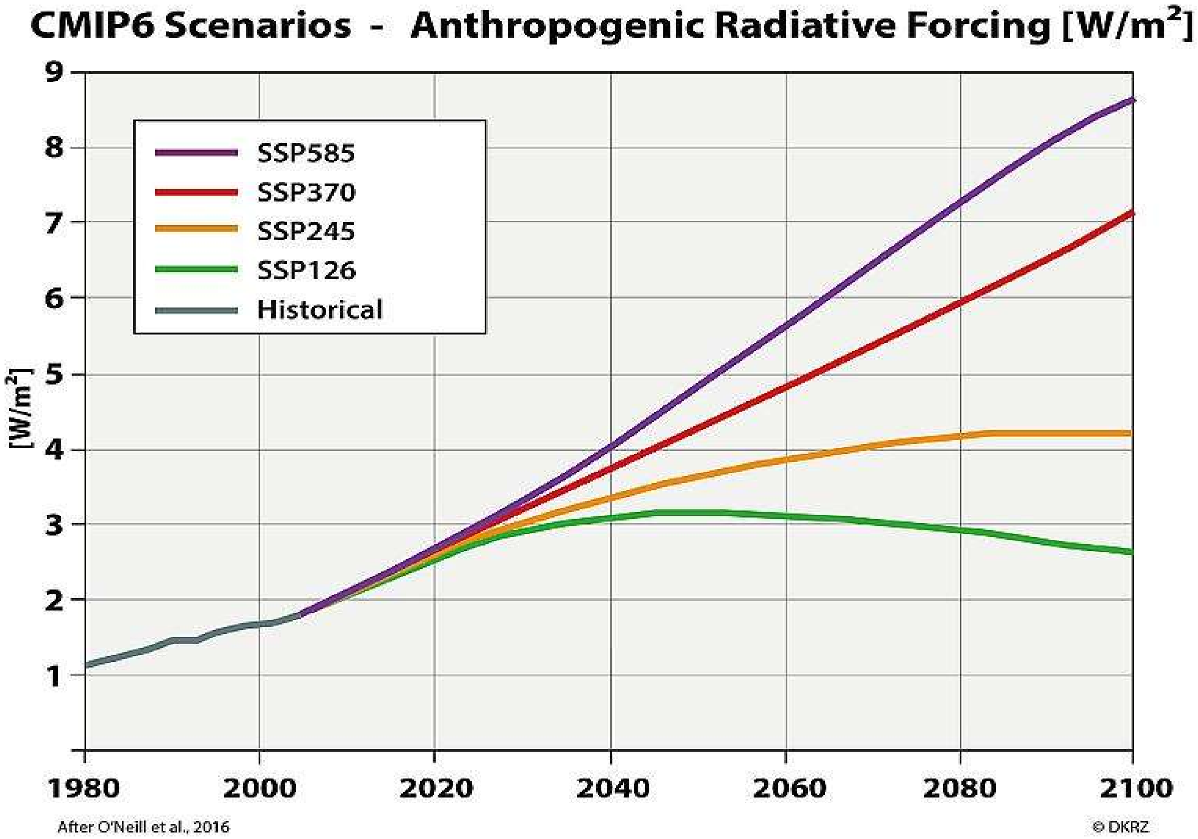
Global warming

- ➢Increasing atmospheric CO_2
- ➢Emission of different Greenhouse gases



Global warming

1. Warming temperatures
2. More extreme rainfall



Outline

- History of Hydrology
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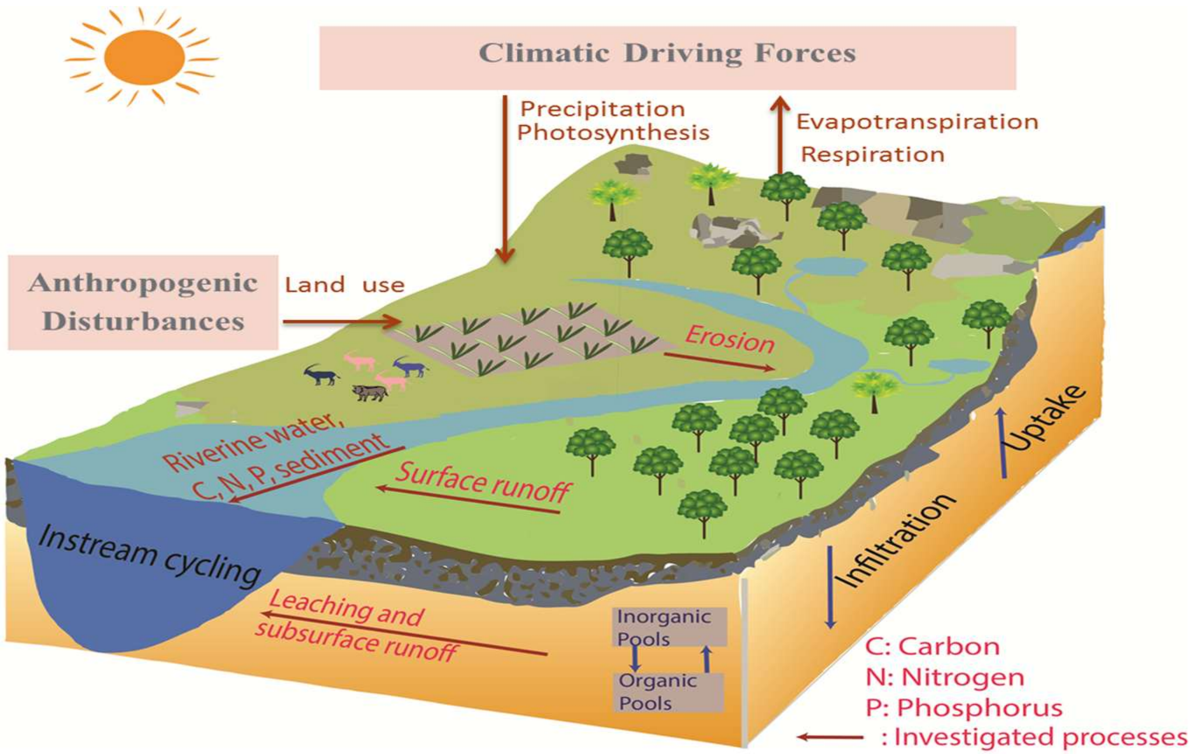
- Environmental challenges associated with Hydrology
- **Solutions through innovative research**

Innovative research

- ➢Hydrological modeling
- ➢Water forecasting
- ➢Flood analysis

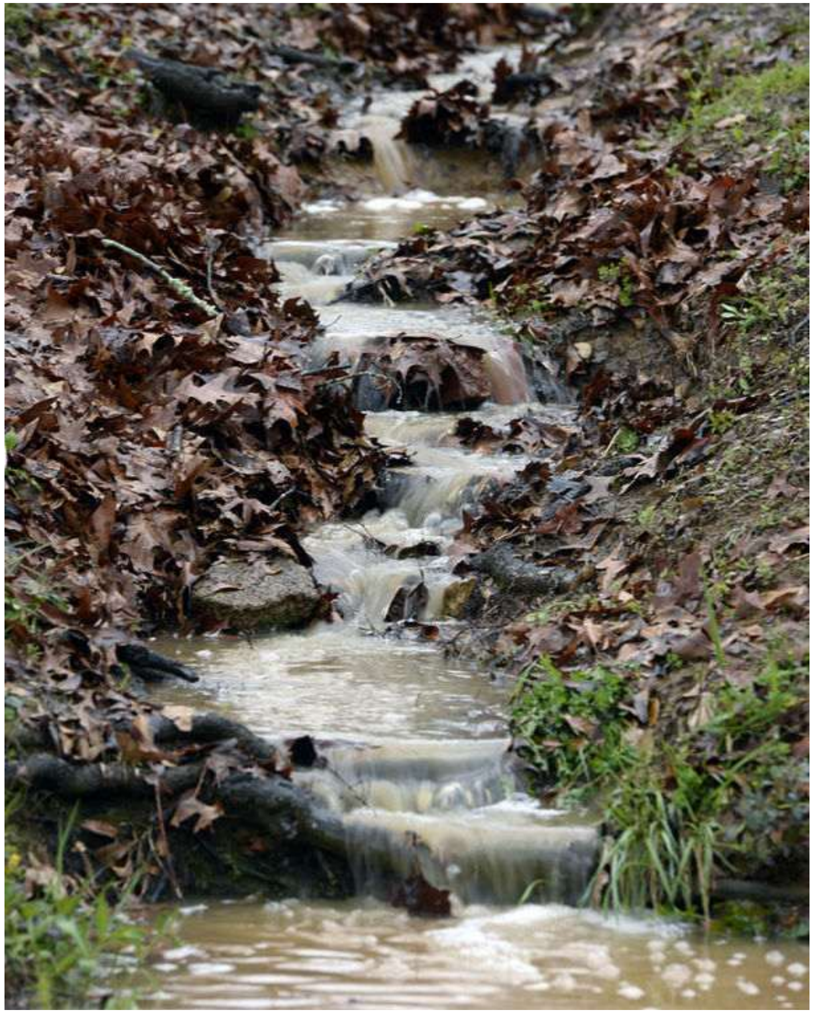


Arnold 2010

Hydrological modeling

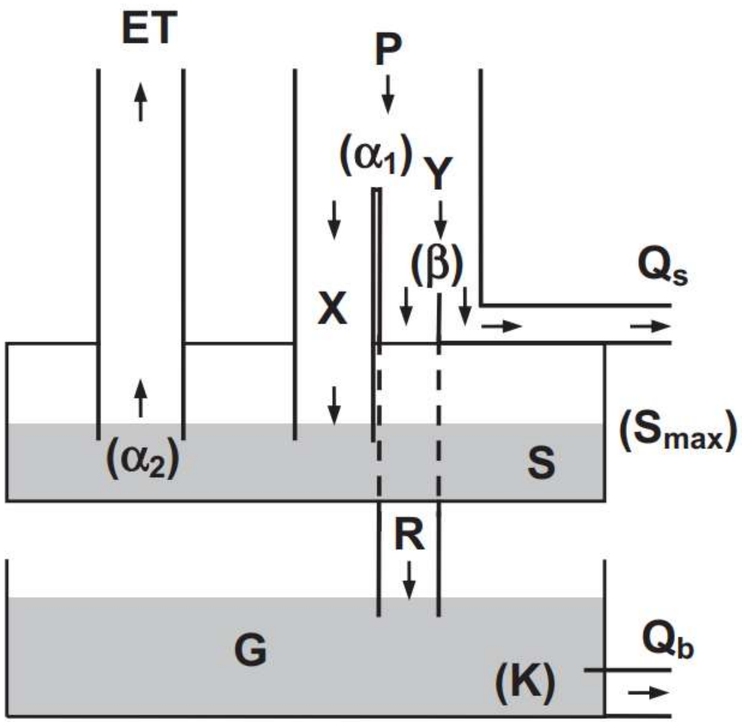
- Understand complex hydrological cycles
- Help understand water quality and biogeochemical processes
- Needed for management purpose: e.g., early warming, project design and planning, mitigation of climate change

https://www.freshwaterinflow.org/runoff/



An example

- WAPABA
- Monthly runoff model
- 5 parameters to optimize



Wang et al, 2011

Model variables:

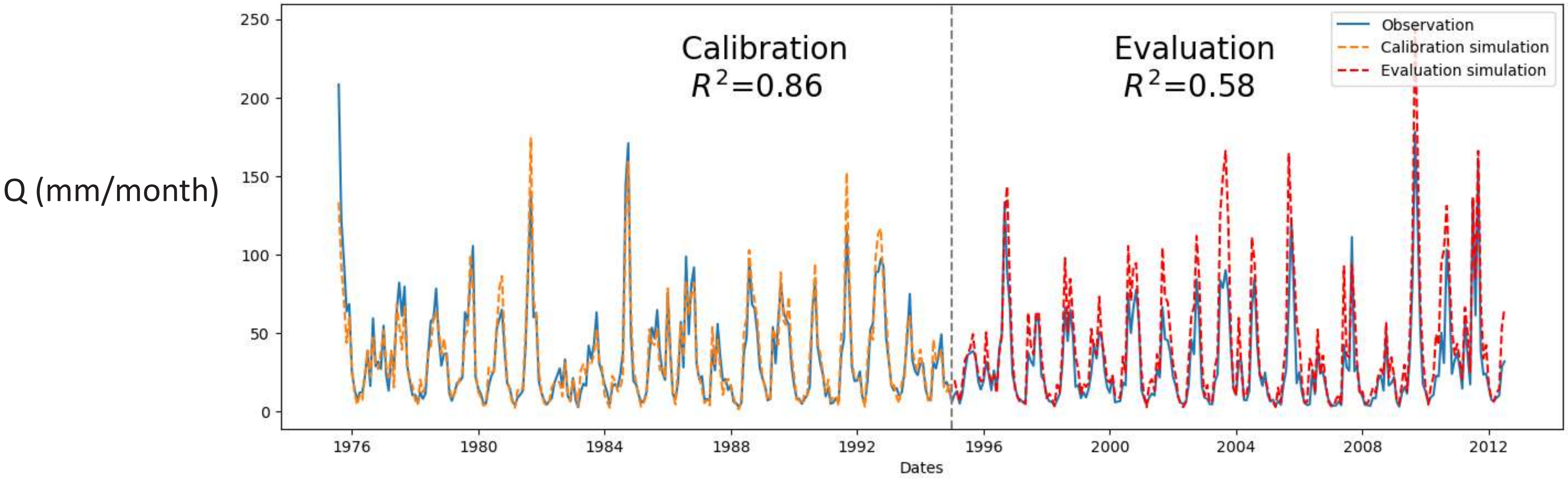
- ET - evapotranspiration
- G - groundwater storage
- P - rainfall
- Q_b - base flow
- Q_s - surface runoff
- R - recharge to groundwater
- S - soil water storage
- X - catchment water consumption
- Y - catchment water yield

Model parameters

- α_1 - catchment consumption curve parameter
- α_2 - evapotranspiration curve parameter
- β - proportion of catchment yield as groundwater
- K - groundwater store time constant
- S_{max} - maximum water holding capacity of soil store

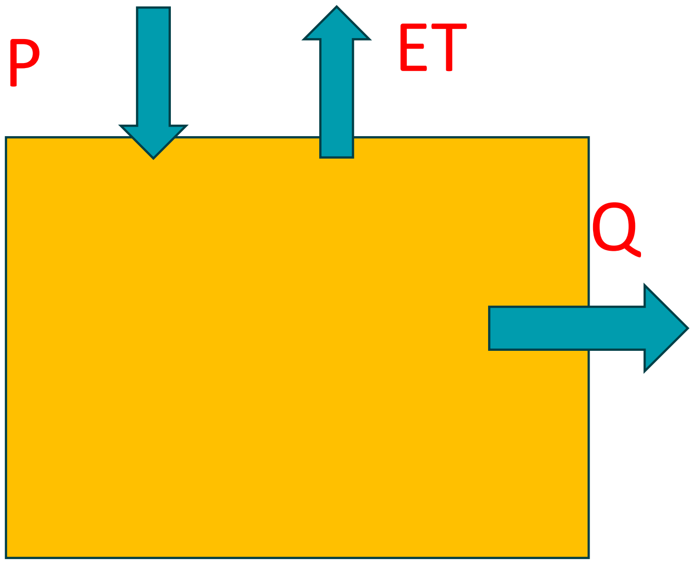
An example

- The model simulates seasonal variability and magnitude of streamflow well



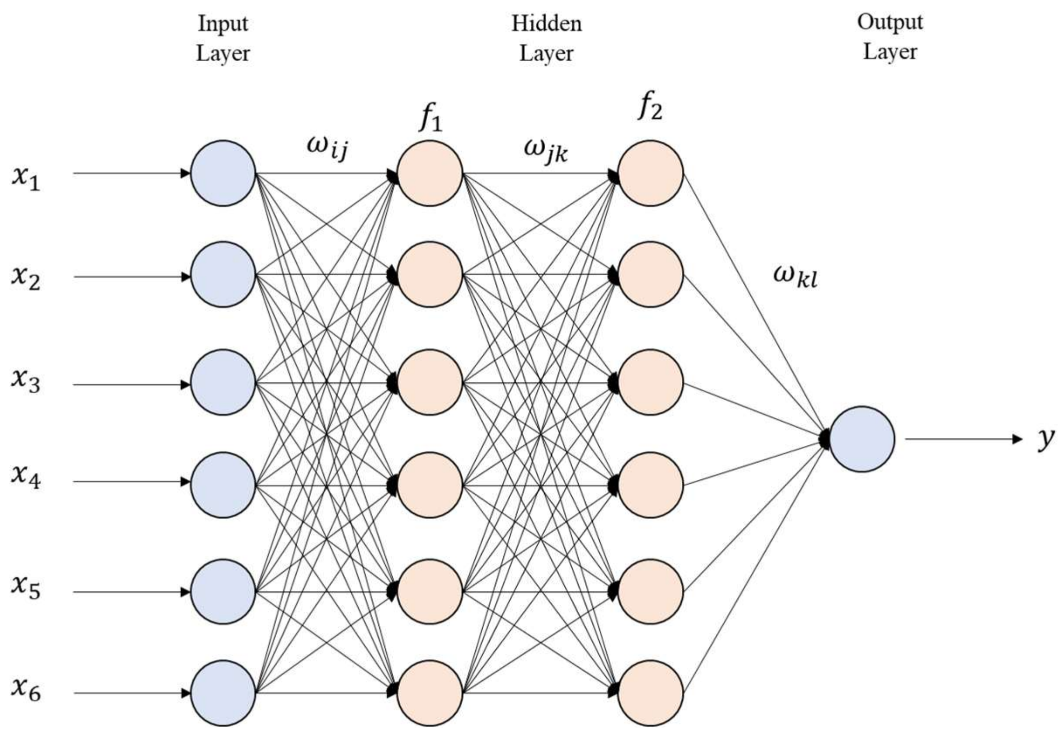
Credit to Zhouxiao Liu

Machine learning Models



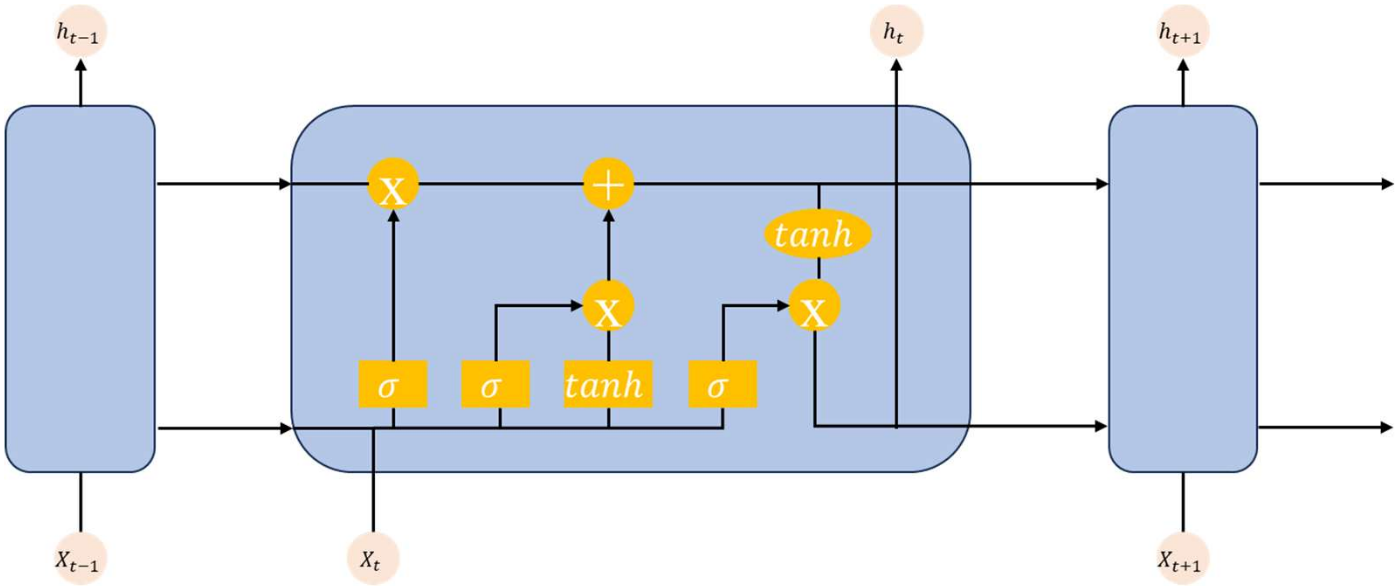
Models	Strengths	Limitations
DNN	Capture complex and non-linear relationships. Handle large datasets.	Structural complexity. Computationally expensive.
LSTM	Handle time series data. Capture complex and non-linear relationships.	Structural complexity. Computationally expensive.
SVM	Handle high dimensional data. Memory efficient.	Not suitable for larger datasets. Require careful parameter tuning.
GPR	Provide uncertainty estimates. Less prone to overfitting.	Need to assume Gaussian noise. Relatively computationally intensive.
LR	Capture linear relationships. Less prone to overfitting.	Weak ability to capture non-linear relationships. Sensitive to noise.
XGB	High efficiency and fast speed. Good performance with large datasets.	Prone to overfitting. Larger data requirements.
LGBM	High efficiency and fast speed. Good performance with large datasets.	Prone to overfitting. Larger data requirements.

Models



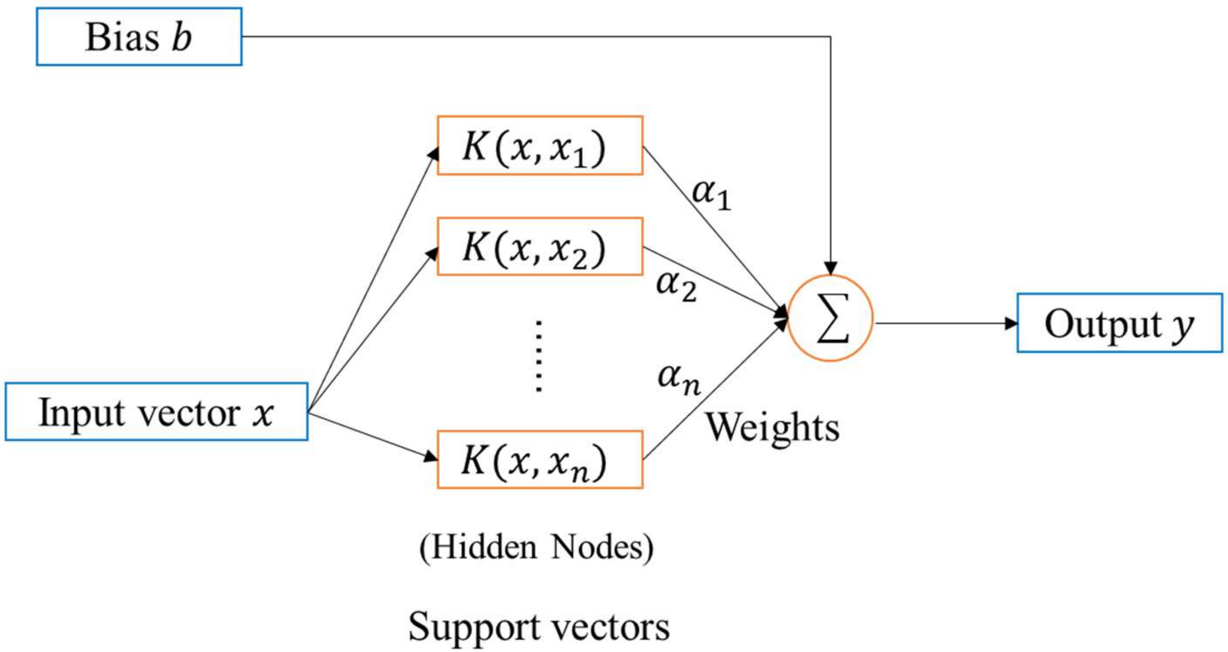
Schematic diagram of the Deep Neural Networks.

Models



Long Short-Term Memory Network

Models



Support Vector Machine.

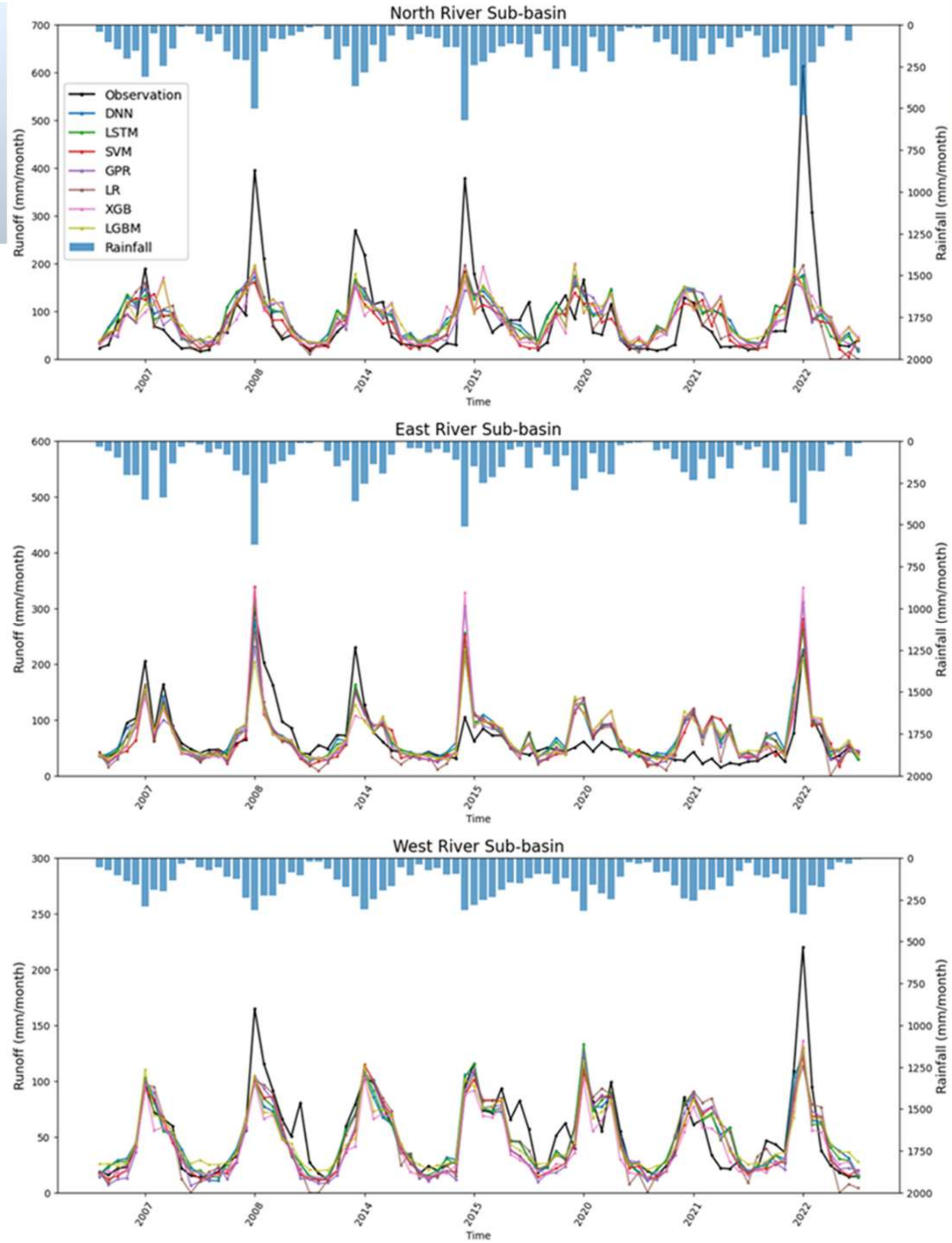
Input data

Table 1. Variables used for model simulations in each sub-basin.

Variables	North River	East River	West River	Unit
Runoff (R)	89.05	75.46	50.46	mm/month
Precipitation (P)	161.04	145.90	150.11	mm/month
Vapor pressure (e_a)	1.81	1.91	1.71	kPa
Wind speed at 2m (u_2)	0.66	0.81	0.63	m/s
Surface net radiation (R_n)	11.62	12.39	11.25	MJ/ (m^2 day)
Daily maximum temperature (T_{max})	22.40	23.74	21.72	°C
Daily minimum temperature (T_{min})	12.22	12.92	12.60	°C

https://www.freshwaterinflow.org/runoff/

Results: Machine learning



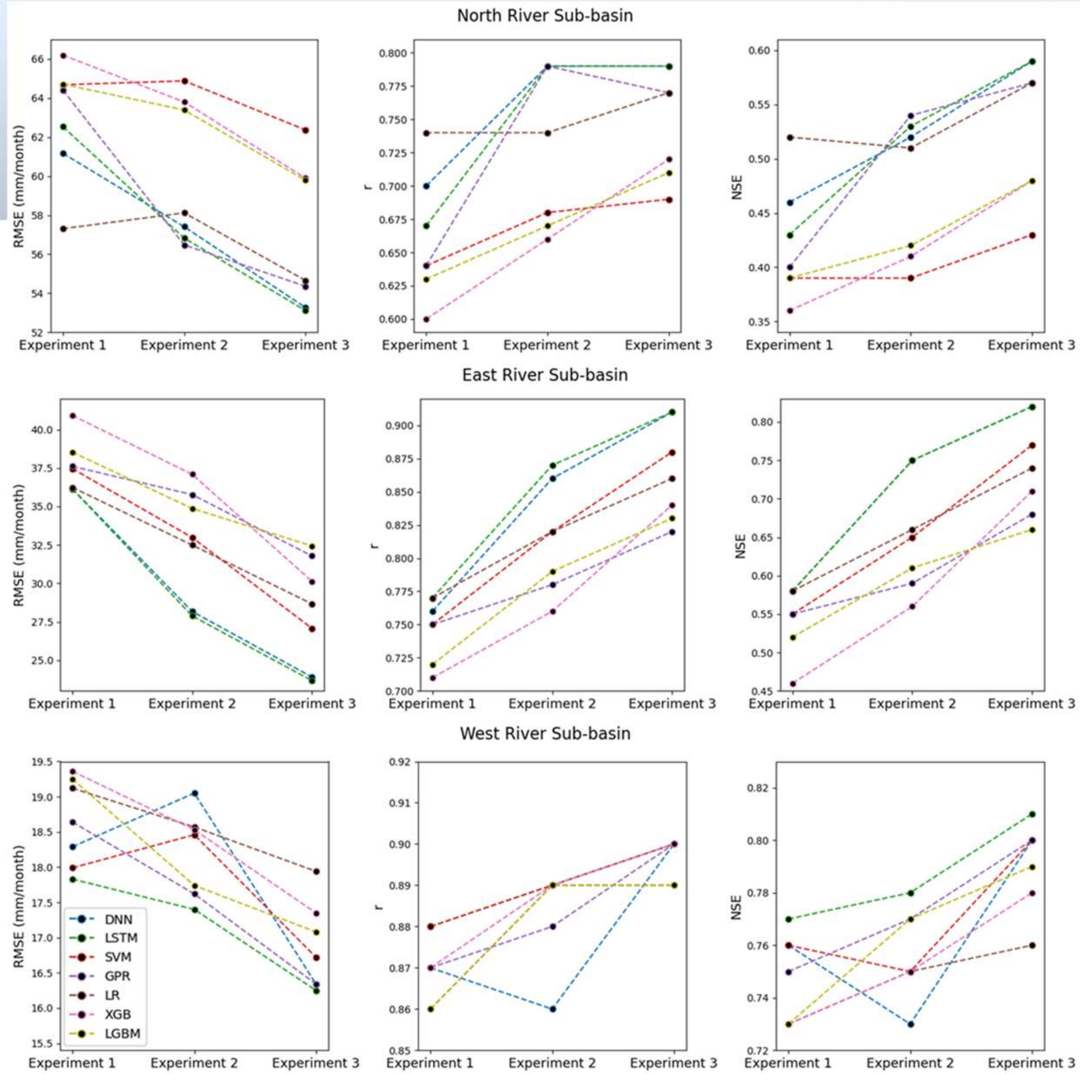
Results: Machine learning

- With OK performance, but generally worse than WAPABA

	DNN	LSTM	SVM	GPR	LR	XGB	LGBM
North River sub-basin							
Training Period							
Bias	1.91	1.33	-7.46	-0.10	0.00	-4.86	0.96
RMSE	61.22	59.12	59.31	58.72	62.37	47.62	52.01
r	0.67	0.70	0.70	0.70	0.65	0.83	0.79
NSE	0.44	0.48	0.48	0.49	0.42	0.66	0.60
Validation Period							
Bias	3.92	2.45	-8.23	-1.04	-4.26	-2.34	3.59
RMSE	61.17	62.53	64.68	64.41	57.31	66.2	64.71
r	0.70	0.67	0.64	0.64	0.74	0.60	0.63
NSE	0.46	0.43	0.39	0.40	0.52	0.36	0.39
East River sub-basin							
Training Period							
Bias	1.54	1.34	-4.84	0.00	0.01	-2.58	1.24
RMSE	36.84	33.85	32.18	31.20	35.80	25.01	31.20
r	0.80	0.84	0.86	0.86	0.81	0.92	0.87
NSE	0.64	0.70	0.73	0.74	0.66	0.83	0.74
Validation Period							
Bias	3.38	2.21	-3.77	-2.16	-2.52	0.56	0.92
RMSE	36.15	36.14	37.46	37.61	36.24	40.92	38.53
r	0.76	0.77	0.75	0.75	0.77	0.71	0.72
NSE	0.58	0.58	0.55	0.55	0.58	0.46	0.52
West River sub-basin							
Training Period							
Bias	-0.10	0.77	-2.12	0.00	0.22	-5.75	0.22
RMSE	23.30	22.25	20.55	20.60	22.83	19.64	21.04
r	0.85	0.86	0.89	0.88	0.85	0.91	0.89
NSE	0.72	0.74	0.78	0.78	0.73	0.80	0.77
Validation Period							
Bias	0.27	0.49	-3.25	-2.83	-2.41	-6.26	1.10
RMSE	18.29	17.83	17.99	18.64	19.12	19.36	19.25
r	0.87	0.88	0.88	0.87	0.86	0.87	0.86
NSE	0.76	0.77	0.76	0.75	0.73	0.73	0.73

Results: Machine learning

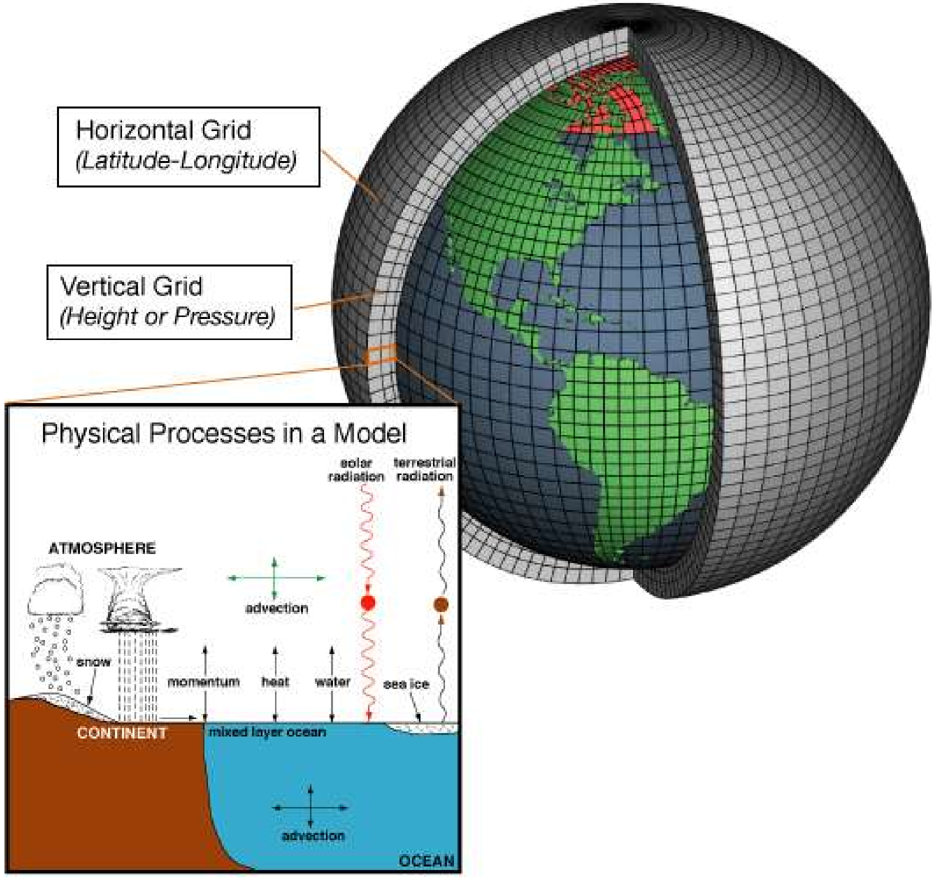
- Using runoff of last month as input improve model performance



Water forecasting

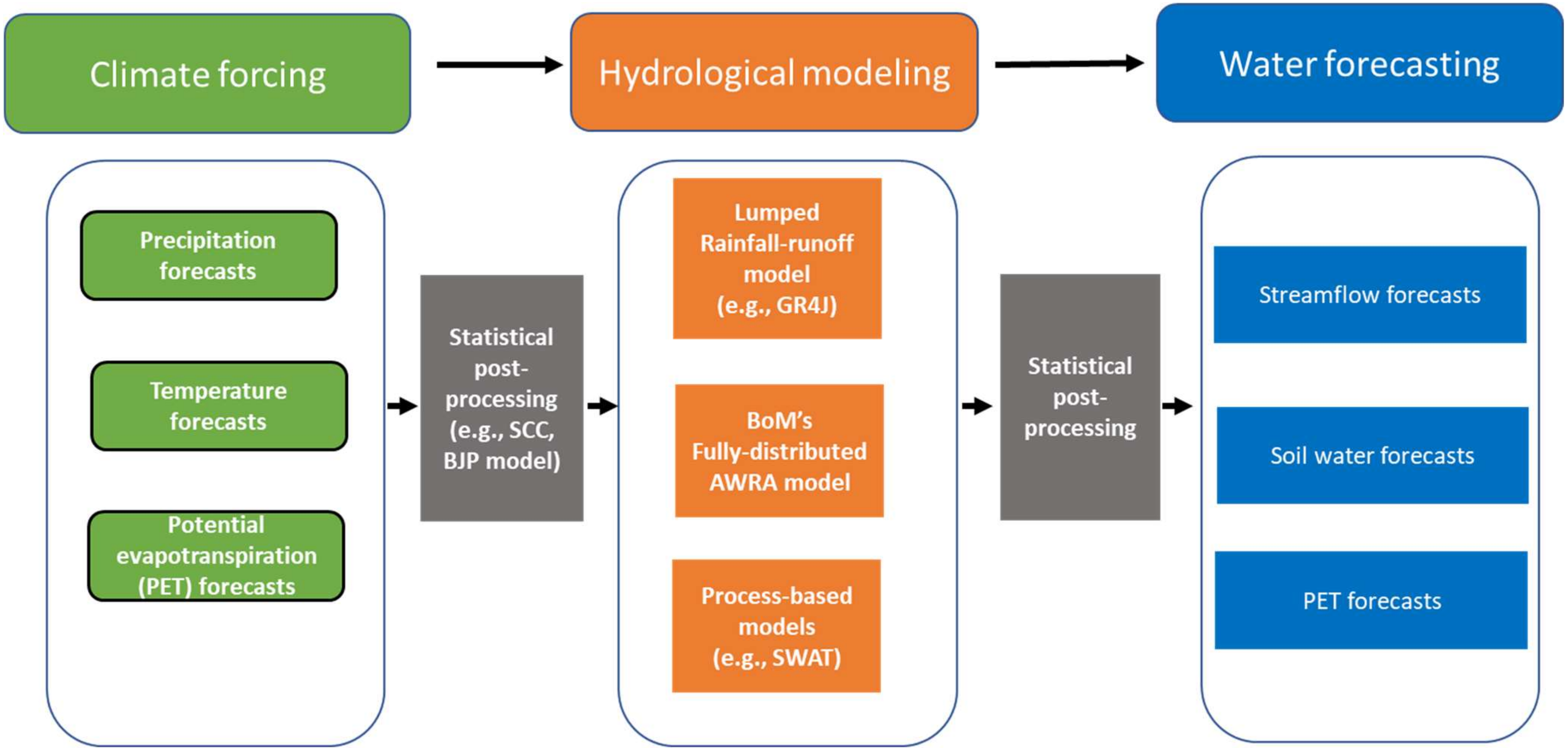
- Numerical weather prediction (NWP) uses mathematical models to predict the weather based on current weather conditions

- Connect NWP forecasts with hydrological models for water forecasting

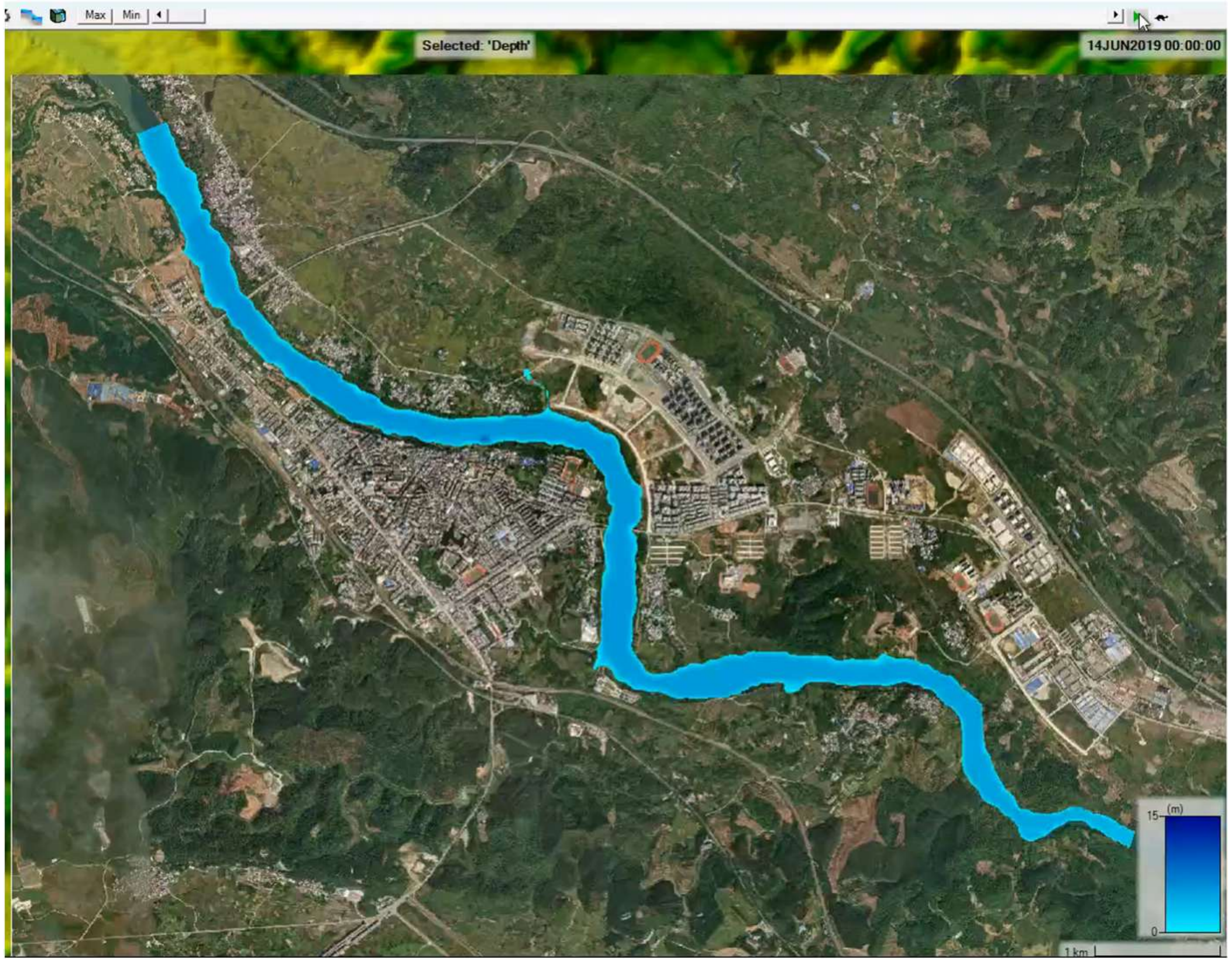


https://en.wikipedia.org/wiki/Numerical_weather_prediction

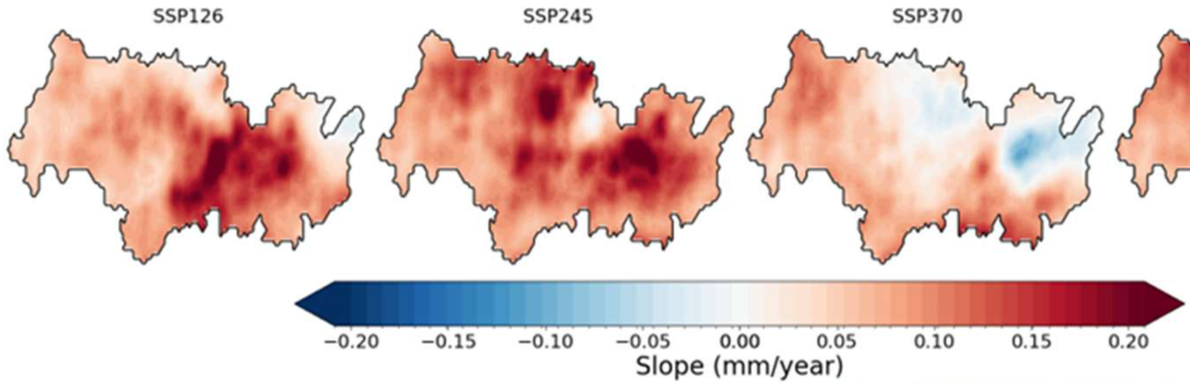
Water forecasting



Flood analysis

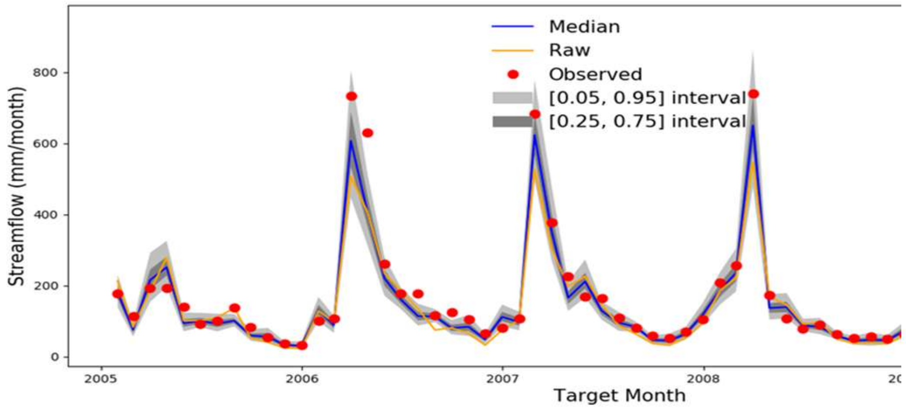


Hydrology Research in the EOAS thrust



Qichun Yang（杨其纯）

Email: qichunyang@hkust-gz.edu.cn



Essay2 Topic

- **Why climate change is a global crisis?**
- **What are the challenges for solving this problem?**
- **Any thoughts on the solutions?**

Essay2 requirements

- **Deadline: Oct 27th**
- **Length: 750 words**
- **Statement of whether AI is used**

Essay2 Please pay attention!!

- **Generating your essay directly with AI is not allowed!**
- **Late submission will result in a 10-point reduction**
- **No submission will get ZERO point**

Your feedback is highly appreciated!