Simulation of Future Hydrologic Process by a Distributed Model and Climate Projections

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Outlines

- Research Background
- Assessment of climate change impacts on the hydrologic processes in Mekong river
  - Distributed hydrological model in basin scale
  - Jointed impacts of climate change and dam operation (human activities)
- Projection of future water resources in China
  - Improved land surface model CLM-MOSART in regional and global scale
  - Scenarios analysis for various temperature raise targets
- Remarks

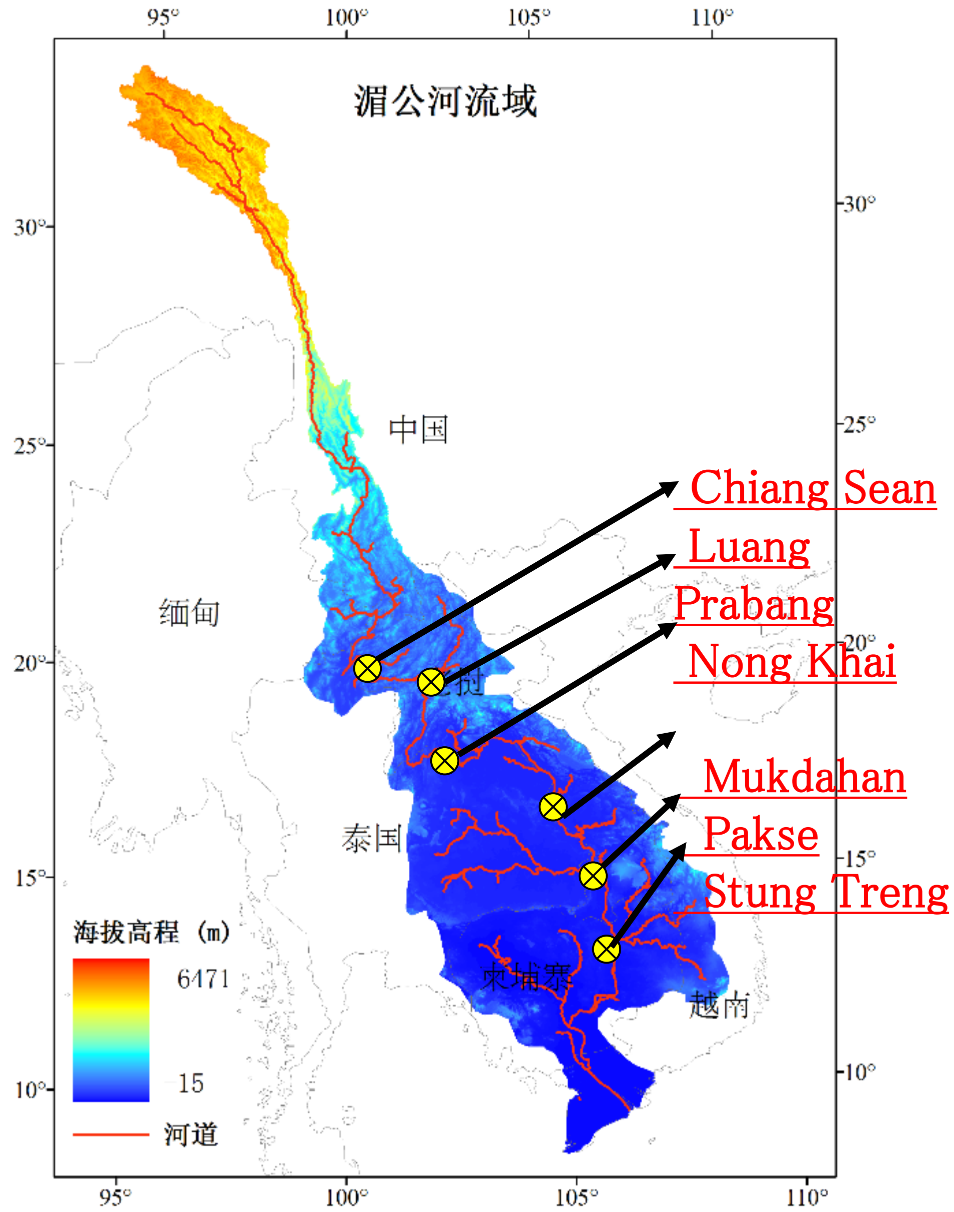
Research background of my group

- Targets: Observation and simulation of global water cycle
  - Observation of essential variables of water cycle through remote sensing and data fusion
  - Simulation and projection of water cycle processes
  - Data assimilation and parameter optimization
- Tools
  - Remote sensing
    - Quantitative remote sensing:Precipitation, Soil moisture, Snow, Evapotranspiration
  - Models
    - Distributed hydrologic model in basin scale: flood forecast, dam operation
    - Land surface model in global and regional scale: land-atmosphere interaction, climate projection
  - Earth System Model: Tsinghua CIESM
    - Global land atmosphere coupled simulation: AMIP
    - Projection of future climate and its impacts on hydrologic processes

Study Region

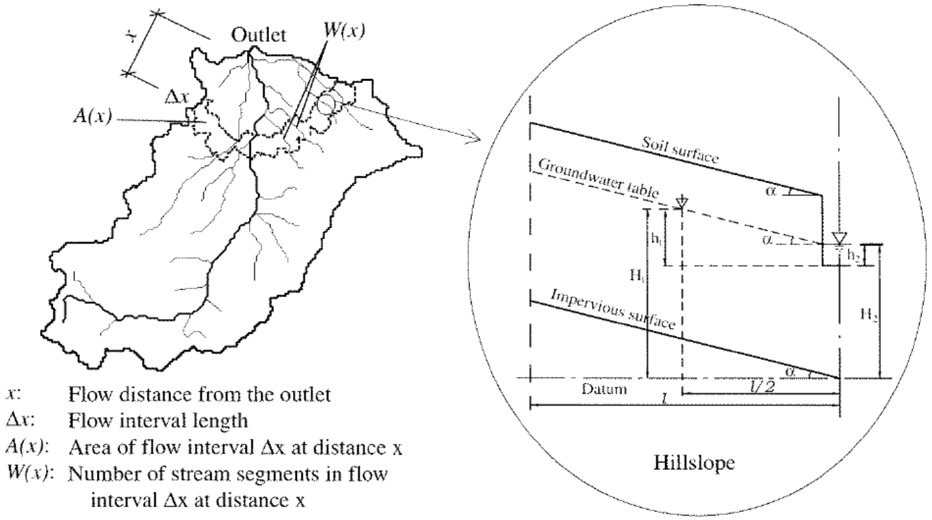
- Mekong river
  - Lancang-Mekong
- Six streamflow gauging stations

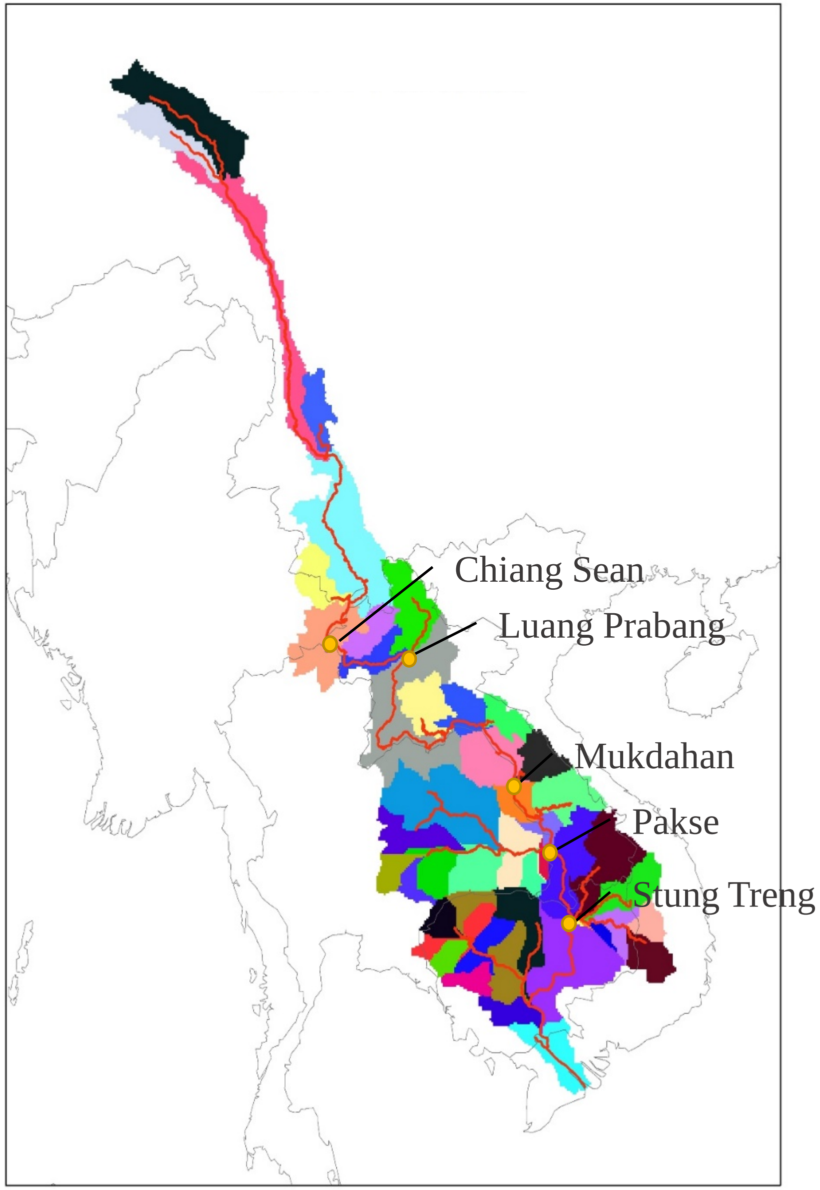
Station	Drainage area 10^4 km^2(ratio,%)	Average runoff m3/s (ratio,%)
Chiang Sean	18.9(23.8)	2688(18.6)
Luang Prabang	26.8(33.7)	3913(27.0)
Nong Khai	30.2(39.7)	4422(30.3)
Mukdahan	39.1(49.2)	7782(53.7)
Pakse	54.5(68.6)	9880(68.2)
Stung Treng	63.5(79.9)	13133(90.1)



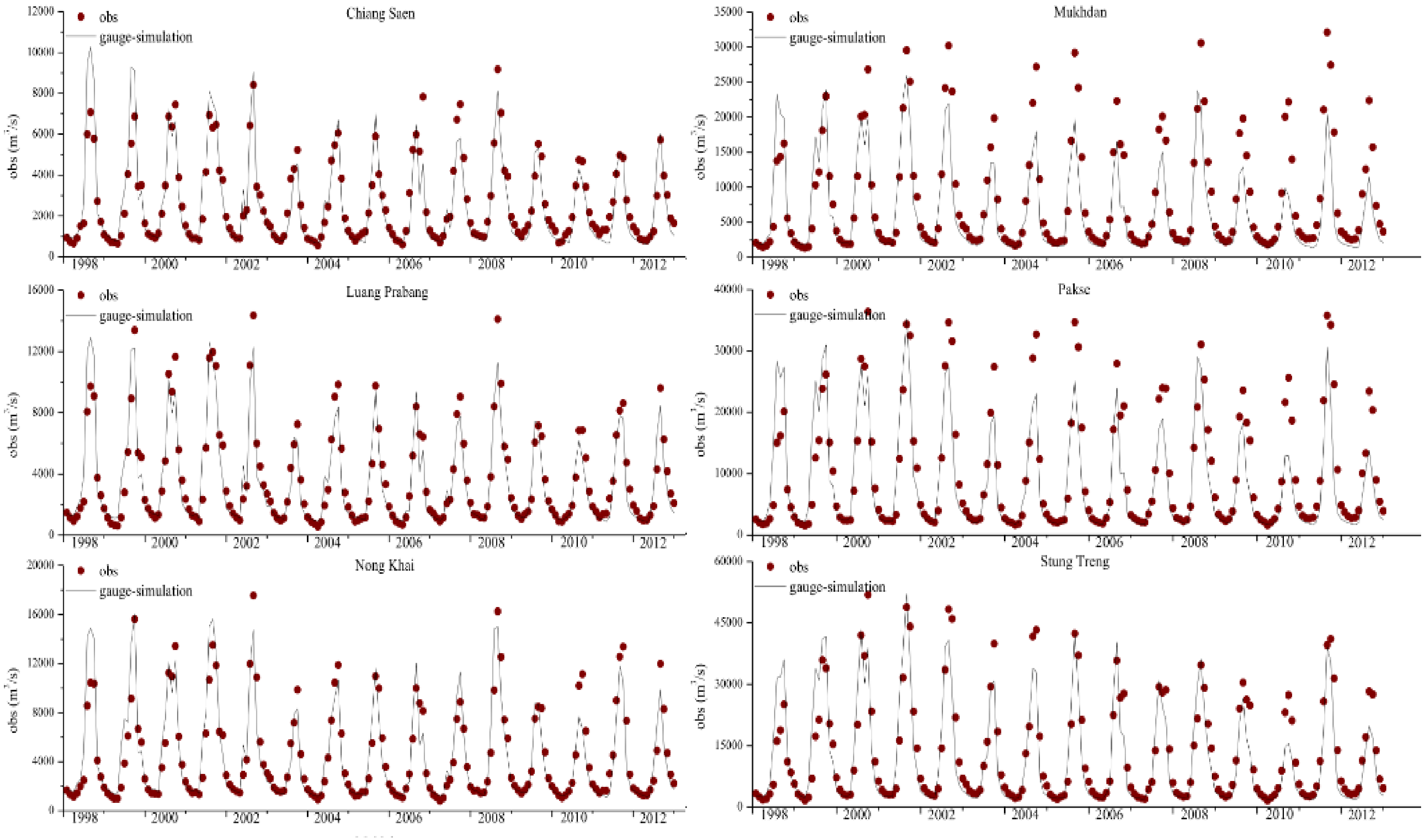
Distributed Hydrologic Model

- Geomorphology Based Hydrological Model (GBHM)
  - hillslope hydrology
- The GBHM is constructed in MRB using a grid size of 5 km;
- The model is well calibrated and validated at six stations
  - Calibration during 1998-2001
  - Validation in the period of 2002-2012
  - using gauge data and remote sensing (TRMM) data, separately.

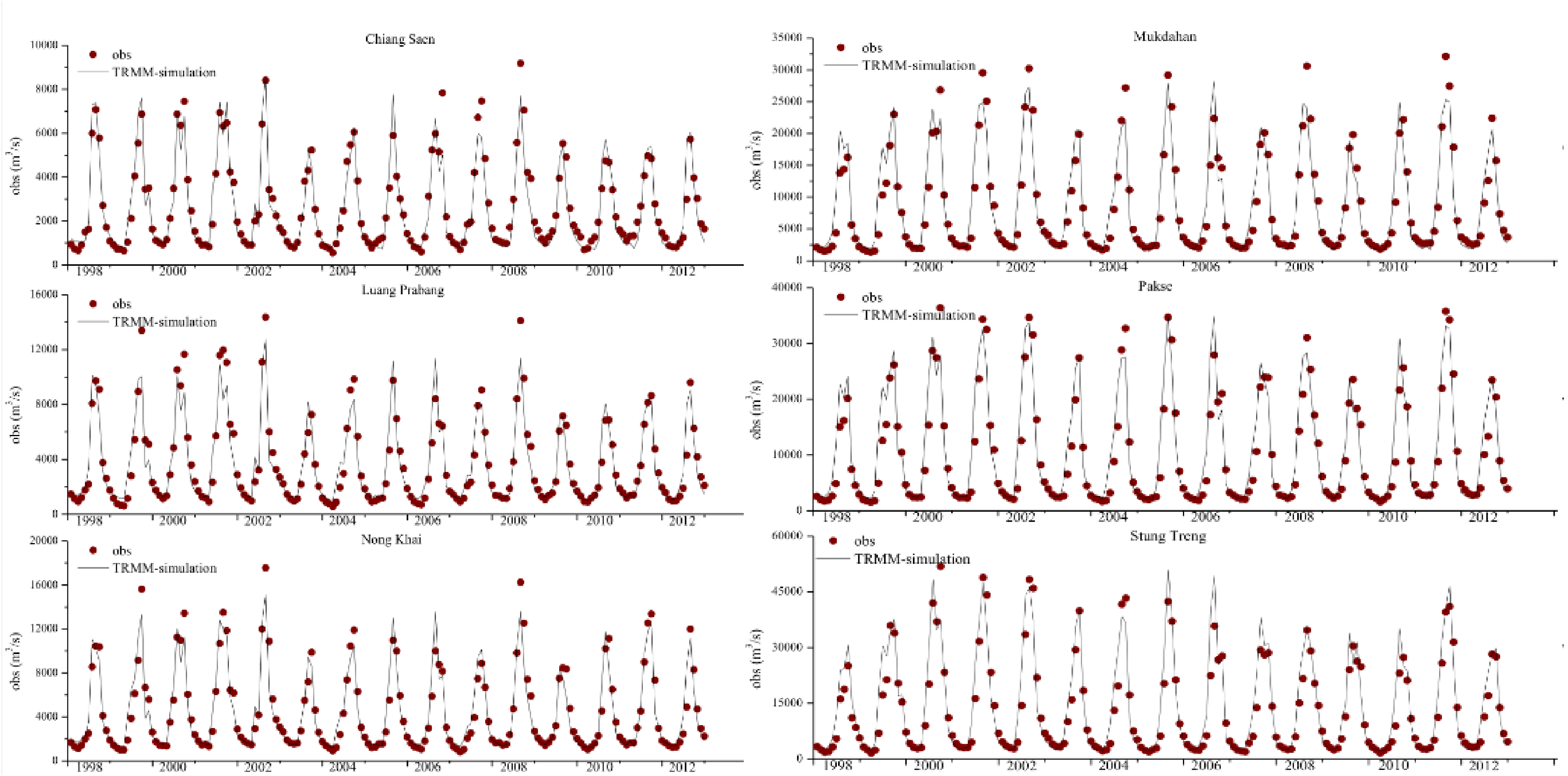




Simulation of hydrologic process by gauge data



Simulation of hydrologic process by TRMM



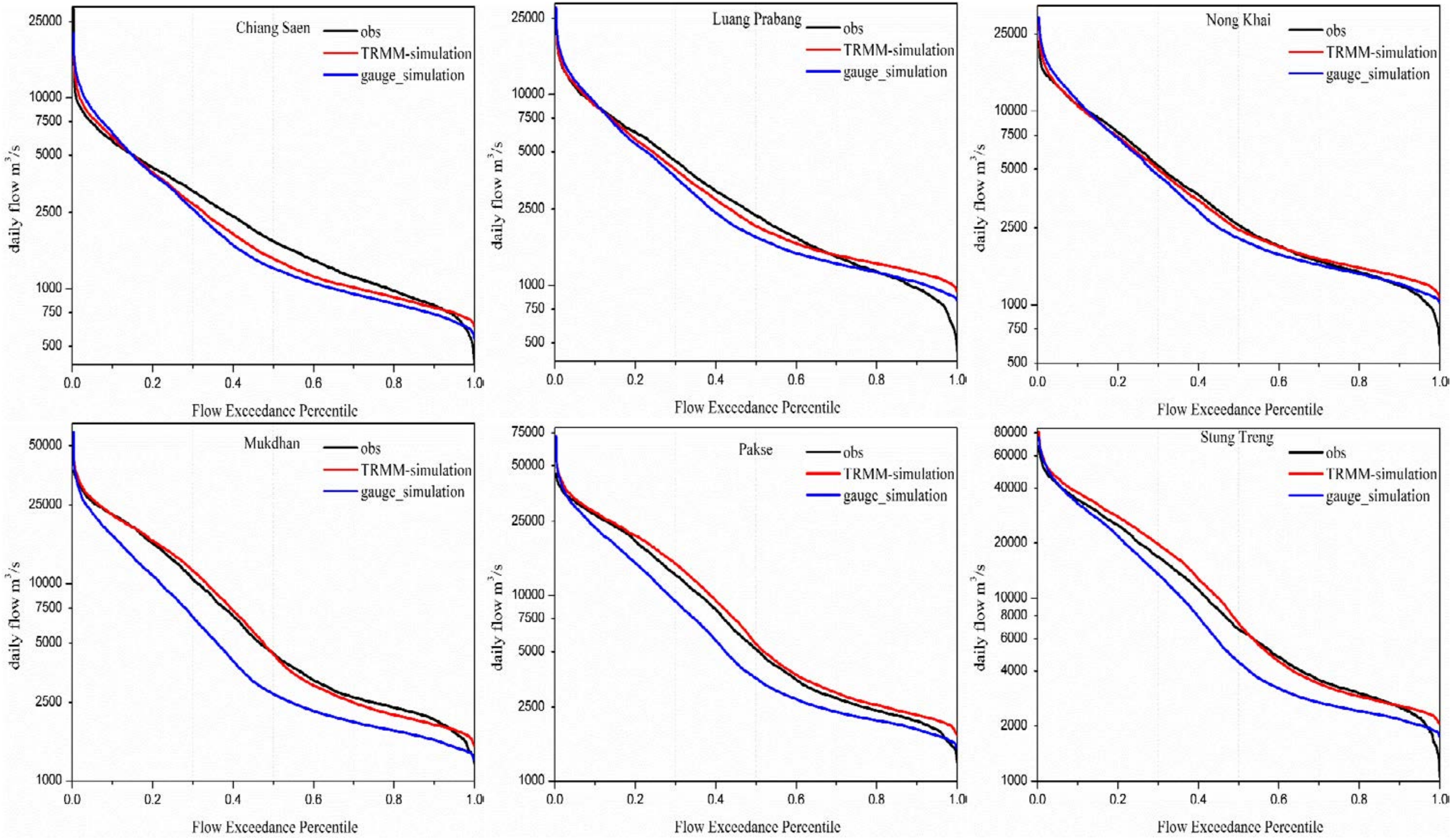
Statistic results

清華大学 Tsinghua University

Forcing data	Gauge	Calib. (1998-2001) RE	NASH	RMSE	Valid. (2002-2012) RE	NASH	RMSE
In situ station	Chiang Sean	8.3%	0.508	1679	-19.8%	0.588	1190
	Luang Prabang	-1.9%	0.722	2216	-16.1%	0.655	1557
	Nong Khai	7.5%	0.620	2860	-12.8%	0.621	2036
	Mukdahan	-9.2%	0.688	4995	-17.2%	0.693	3927
	Pakse	-2.8%	0.670	6479	-20.1%	0.669	4917
	Stung Treng	-2.6%	0.722	8419	-15.8%	0.741	5536
TRMM	Chiang Sean	2.3%	0.656	1402	-7.5%	0.644	1106
	Luang Prabang	-8.5%	0.684	2250	-0.8%	0.679	1504
	Nong Khai	2.1%	0.679	2418	-1.2%	0.673	1890
	Mukdahan	12.8%	0.642	4853	-1.0%	0.747	3565
	Pakse	12.6%	0.675	5870	6.2%	0.738	4375
	Stung Treng	9.7%	0.724	7617	10.2%	0.754	5398

(Wang, Lu, et al., PLOS ONE, 2016)

Simulated flow duration curves



Simulation driven by TRMM is closer to observation than gauge simulation.

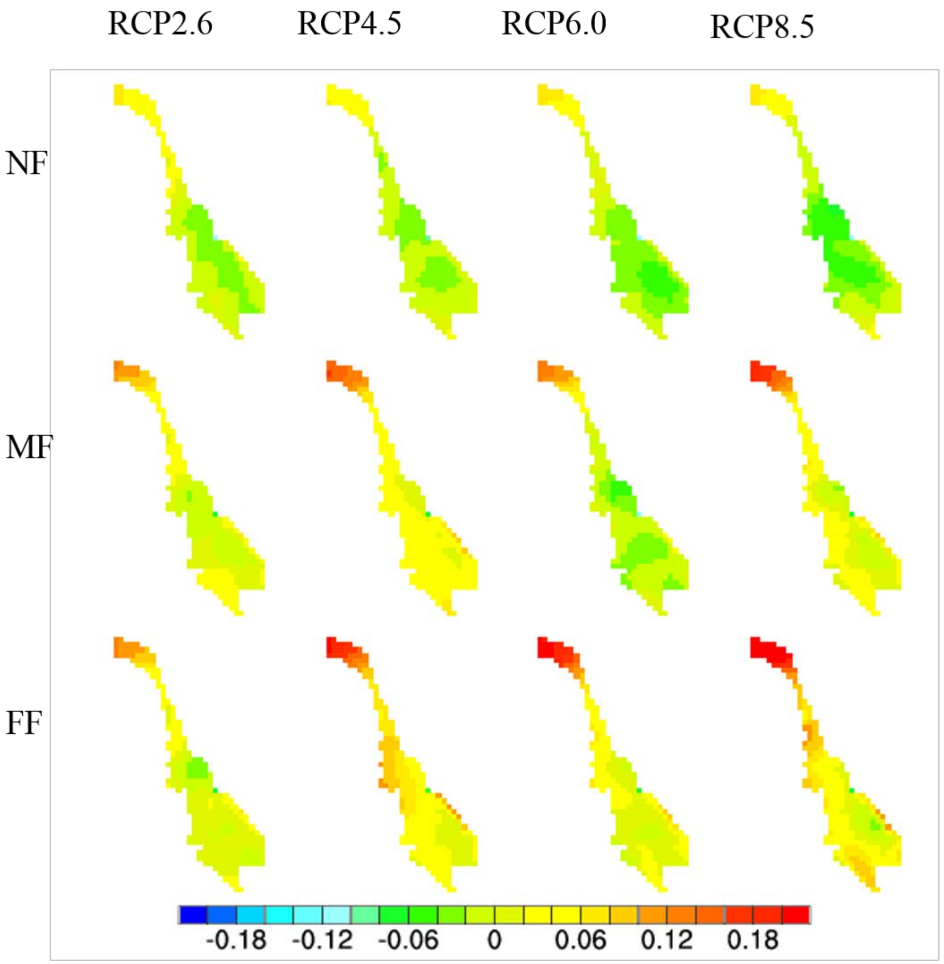
Climate changes in Mekong: projection data

- ISI–MIP downscaling data of five GCMs ：
  - ✓GFDL–ESM2M
  - ✓HadGEM2–ES
  - ✓IPSL–CM5a–LR
  - ✓MIROC–ESM–CHEM
  - ✓NorESM1–M

  → Ensemble Mean
- Four RCP：RCP2.6, RCP4.5, RCP6.0, RCP8.5
- Reference period: three decades of 1975–2004
- Projection: three period in 2010–2099
  - ✓Near Future (NF):2010–2039,
  - ✓ MF: 2040–2069;
  - ✓ FF: 2070–2099

Projection of future rainfall by ISIMIP

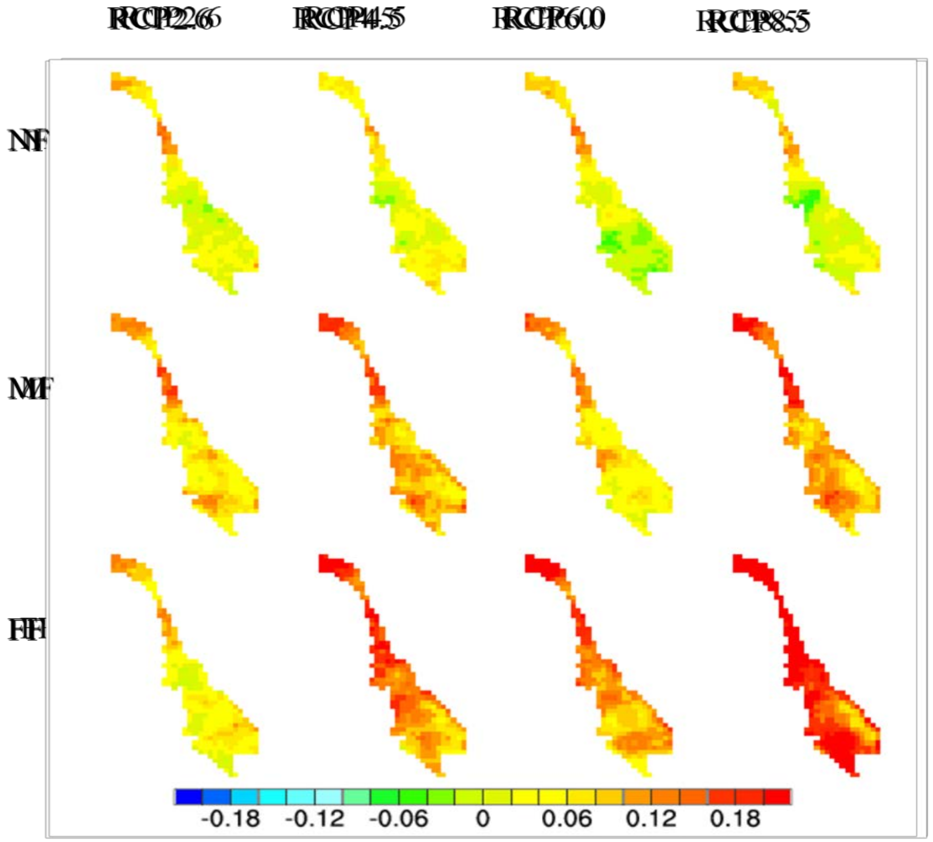
- Relative change of annual mean rainfall
  - (future minus reference)/reference
  - In general, rainfall increases in MRB as climate changes, especially in MF and FF;
  - More obvious change from NF to MF and then to FF;
  - Lager RCP with bigger increase;
  - Upstream is impacted more seriously than downstream;



Relative change of annual mean rainfall

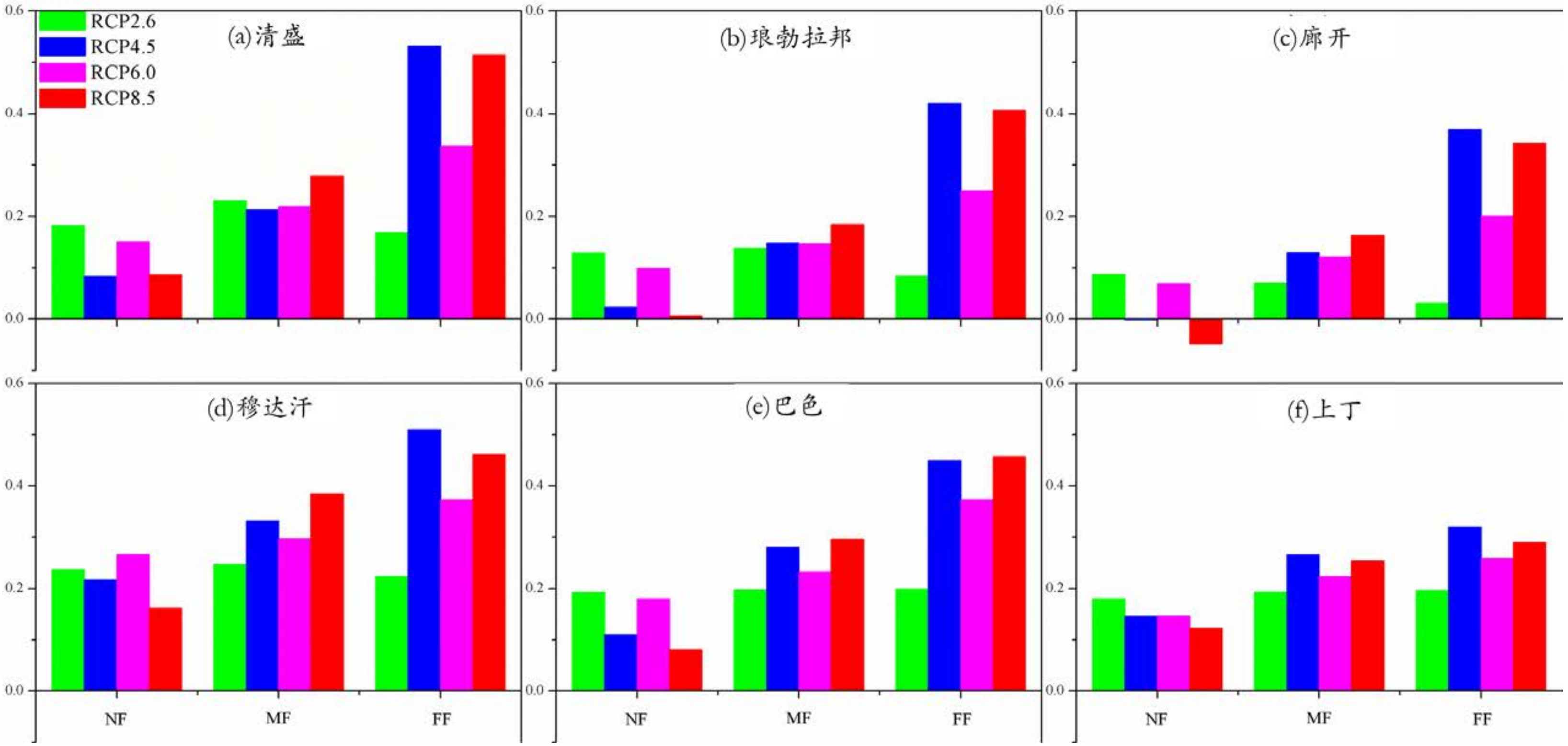
Projection of Extreme Rainfall in future

- Relative change of extreme rainfall:
  - Daily rainfall amount with exceedance percentile > 90%
  - In general, **all extreme rainfall increase in MF and FF;**
  - Big increase in FF;
  - Larger RCP with Bigger increase;
  - **More extreme events with bigger increase;**



99% exceedance rainfall

Impacts of climate change on -- future flood volume



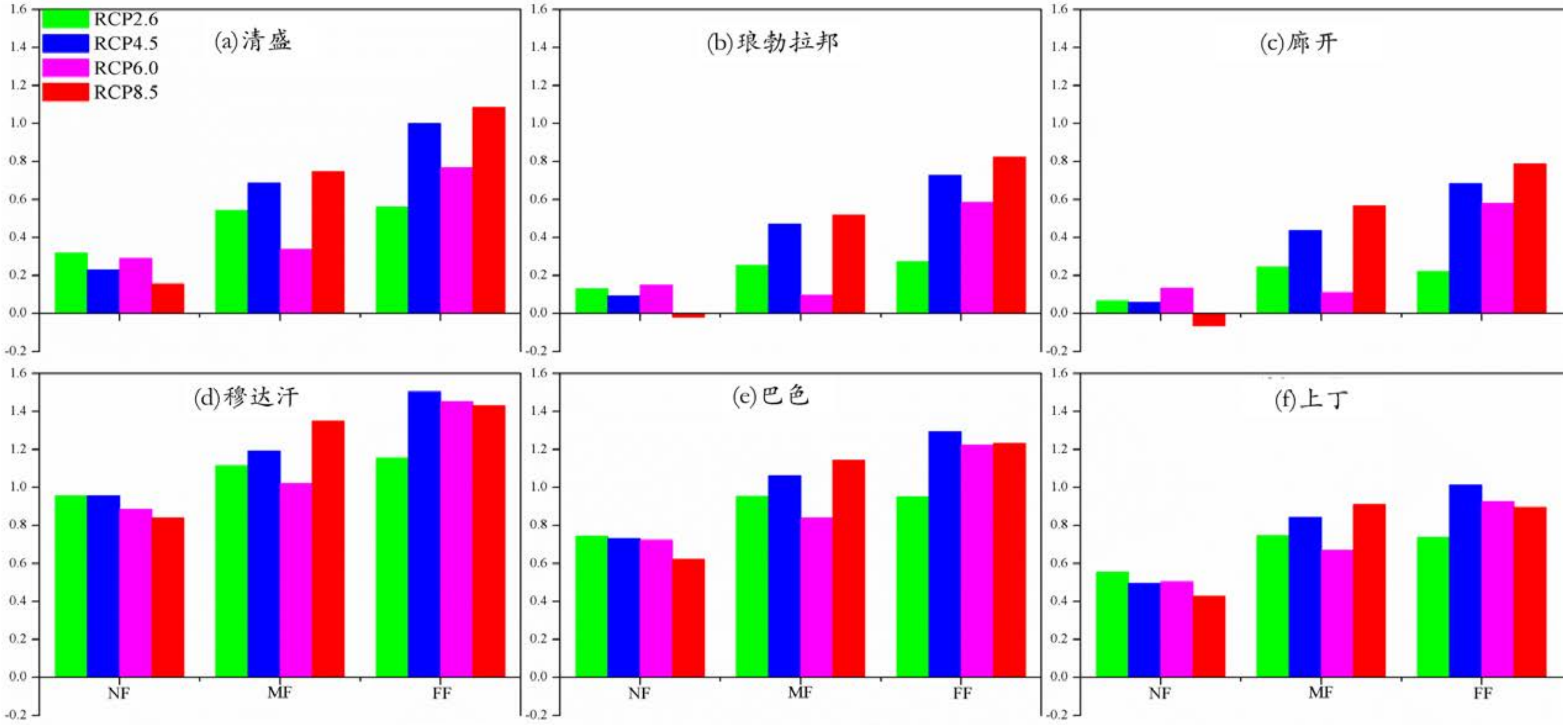
- Relative change of mean flood volume

✓Flood volume increase from NF→MF→FF

✓Big RCPs generally have larger increase, RCP 4.5 increase more in FF

✓CS and MK increase obviously, by 0.2~0.6 times

Impacts of climate change on ---future flood frequency



- Relative change of flood frequency

✓Increases as time goes by

✓Big RCPs have big increase

✓Stations in downstream increase more obvious；

  ✓ MK: increase by more than one time

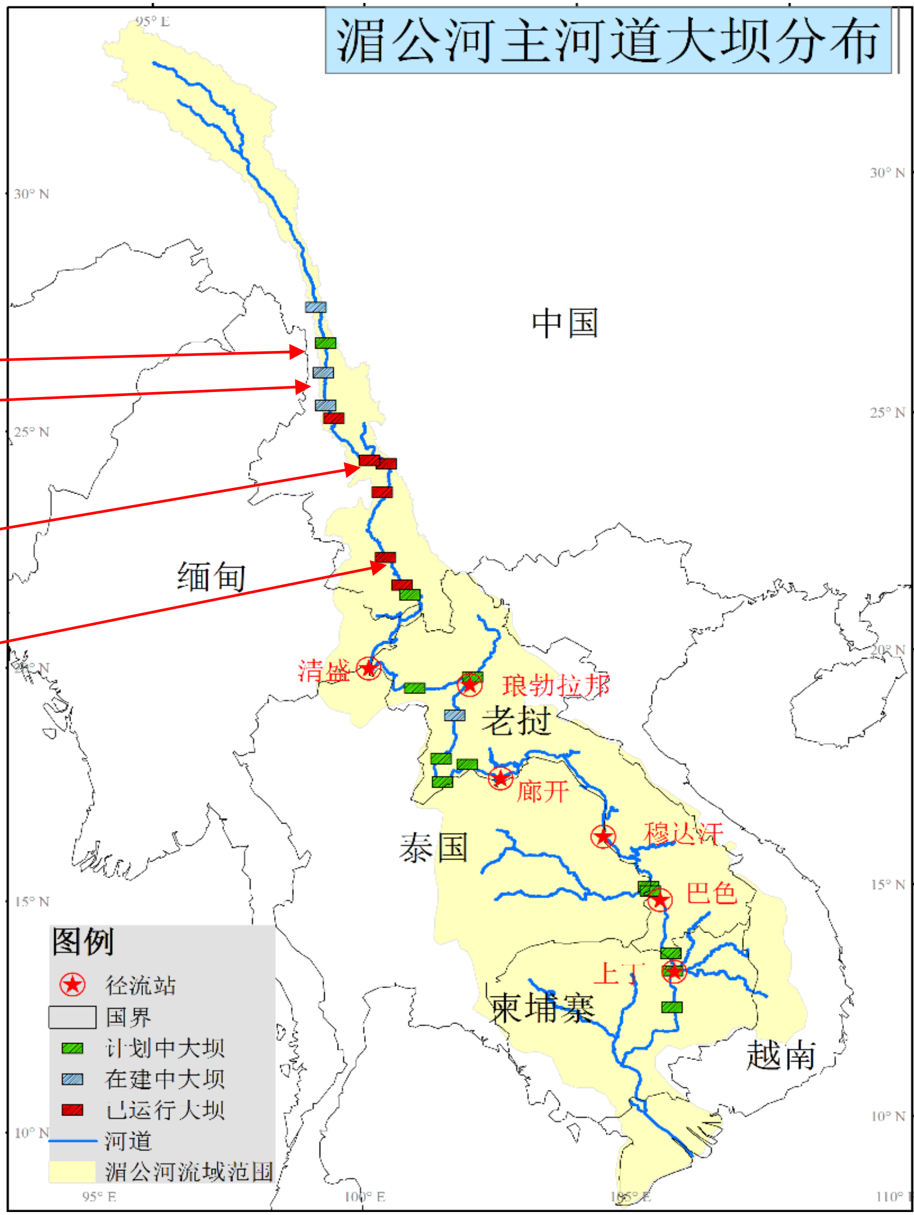
Reservoirs in Mekong Basin

- 22 reservoirs in the main channel of Mekong river are constructed and planned

大坝	国家	纬度(° N)	经度(° E)	状态	类型	有效调节库容 (10^6m^3)
Pakchom	老挝	18.20	102.05	规划中	径流式	12
Ban Koum	老挝	15.42	105.59	规划中	径流式	15
Lat Sua	老挝	15.32	105.62	规划中	径流式	649
Don Sahong	老挝	13.96	105.96	规划中	径流式	115
Stung Treng	柬埔寨	13.58	105.98	规划中	径流式	70
Sambor	柬埔寨	12.79	105.94	规划中	径流式	463

Stations	Volume(10^6m^3)	Ann. Discharge (m^3/s)	RII
Chiang Sean	30452.3	2688	0.359
Luang Prabang	31629.3	3913	0.256
Nong Khai	32356.3	4422	0.232
Mukdahan	32356.3	7782	0.132
Pakse	33020.3	9880	0.106
Stung Treng	33205.3	13133	0.080

Impacting decreases



Dam operation with a standard operation policy

- **Standard Operation Policy(SOP)** :

Priority decreasing

✓$S(t+1) = S(t) + Qin * T - Qout * T$

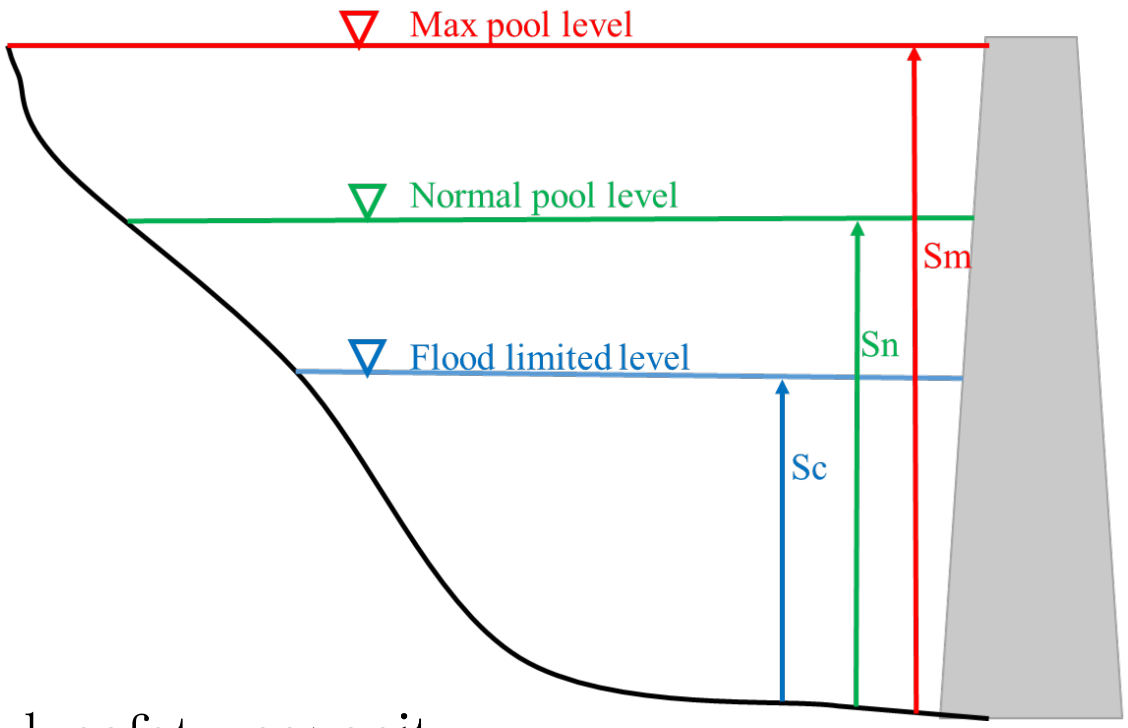
✓$0 \leq S(t) \leq S_m$

✓$Q_e \leq Qout \leq Q_s$

✓Flood season: target: $S(t) < S_c$

✓$Qout \geq Q_d$

✓Non-flood season: $S(t) \leq S_n$



Where,
$S(t+1), S(t)$ water storage in reservoirs
$Qin, Qout$ inflow and outflow
S_m, S_n, S_c total capacity, normal capacity, flood-safety capacity
Q_e, Q_d, Q_s ecological flow、domestic flow , and safe flow

(Wang et al., WRR, 2017)

Future flood in Mekong

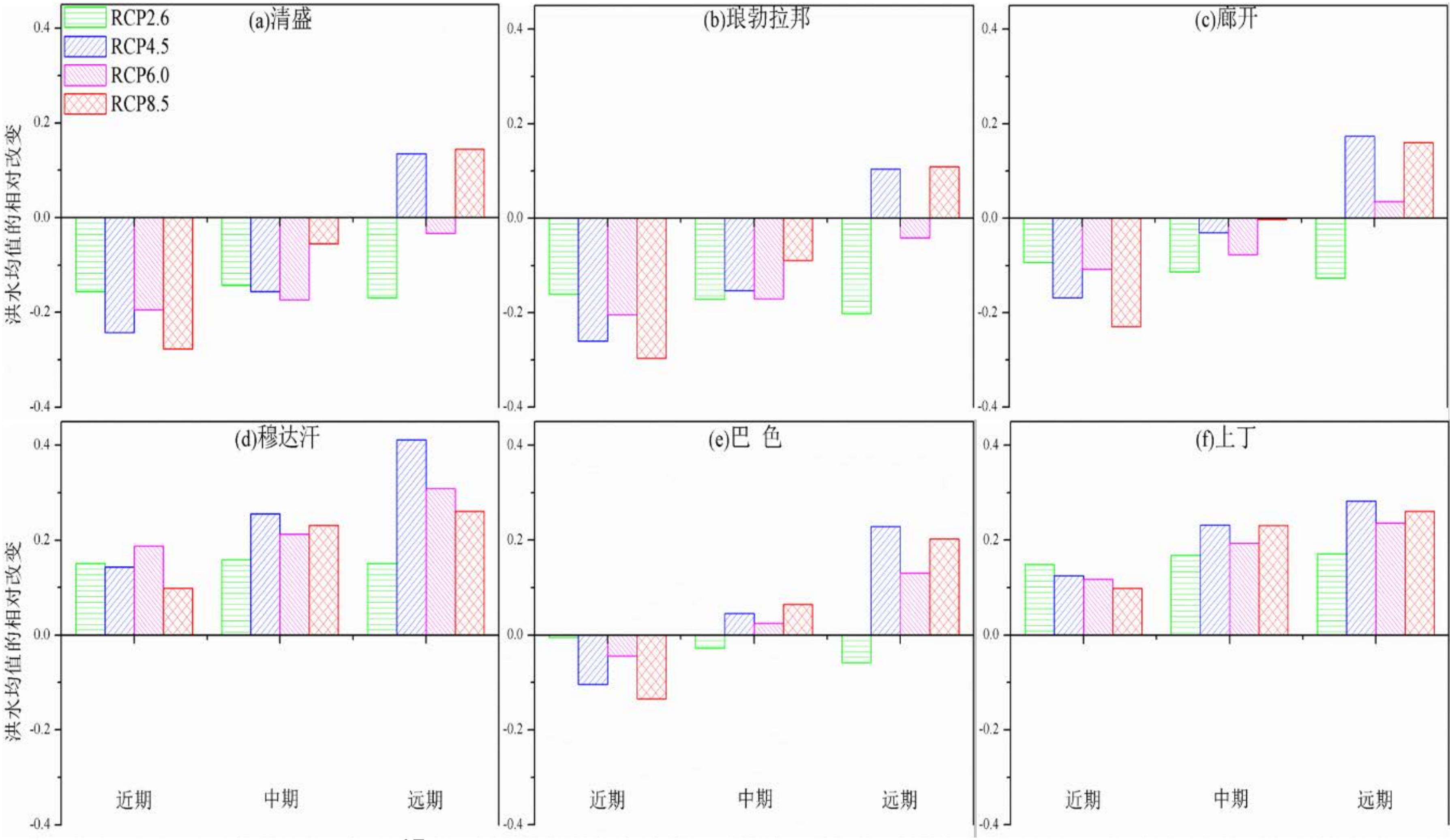
–jointed impacts of climate changes and dam operation on flood volume

- Relative changes of Flood volume:

✓Decreasing in NF and MF, for upstream

✓Keep increasing for downstream for next 100 year

✓Farer future, increasing more seriously.



Future flood in Mekong

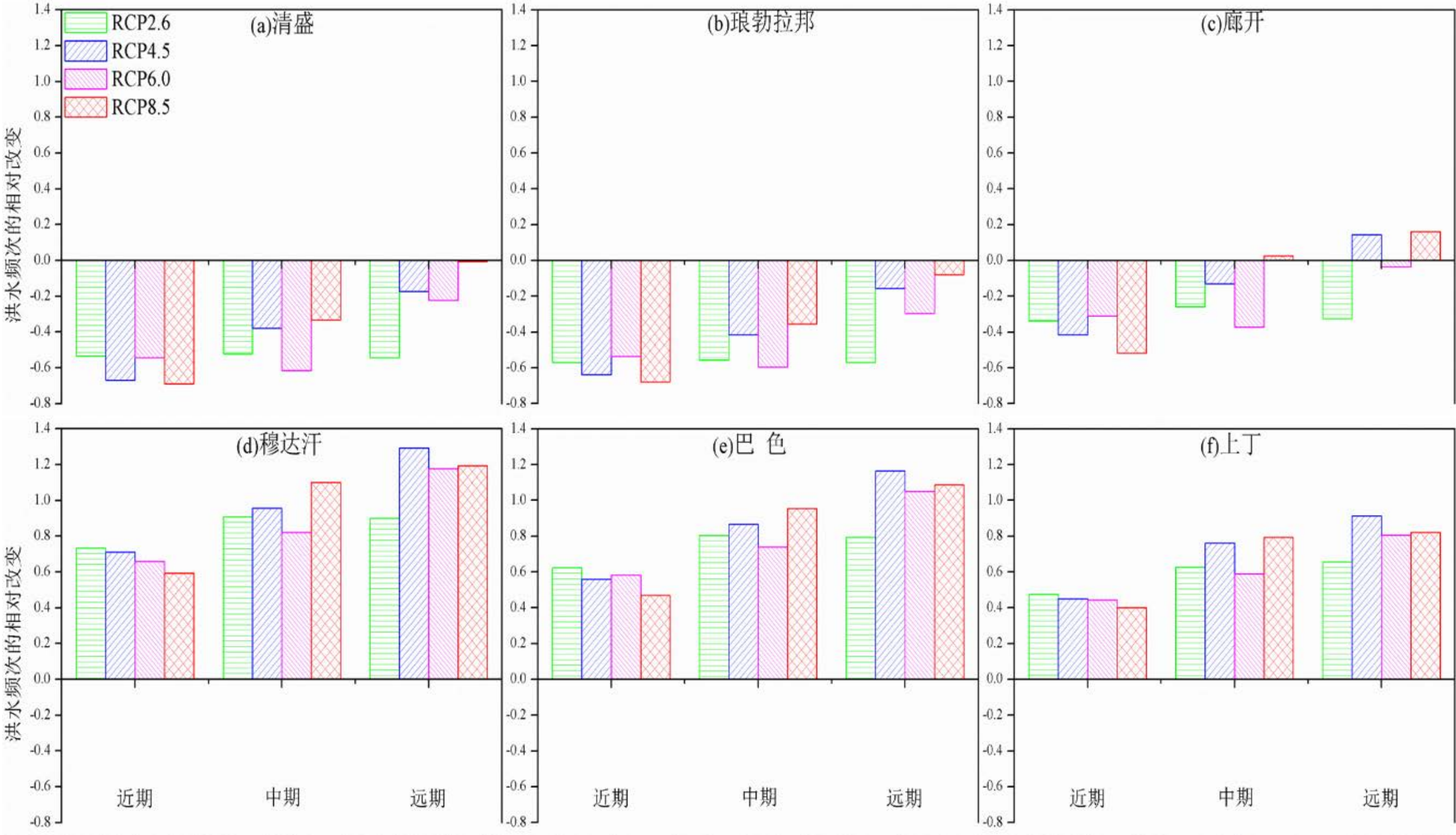
–jointed impacts of climate changes and dam operation on flood frequency

- Relative changes in flood frequency:

✓In future, upstream flood frequency keeps decreasing

✓While downstream keeps increasing

✓NF<MF<FF



Remarks

- We developed a GBHM based distributed hydrologic model over MRB;
- The distributed model is well calibrated and validated
- ISI-MIP forcing data were used to drive the model
- Impacts of climate change on future flood in MRB
  - both flood volume and frequency will increase, as time goes by
  - The relative change of frequency is more obvious than volume
    - <u>More flood events in future, with small increase of flood volume</u>
  - More flood risk in downstream, especially at MK station.
- With consideration of dam operation
  - Flood risk can be reduced by dam operation, especially for upstream and NF
  - Impacts of climate change overwhelm the mitigation effects of reservoirs in downstream and FF

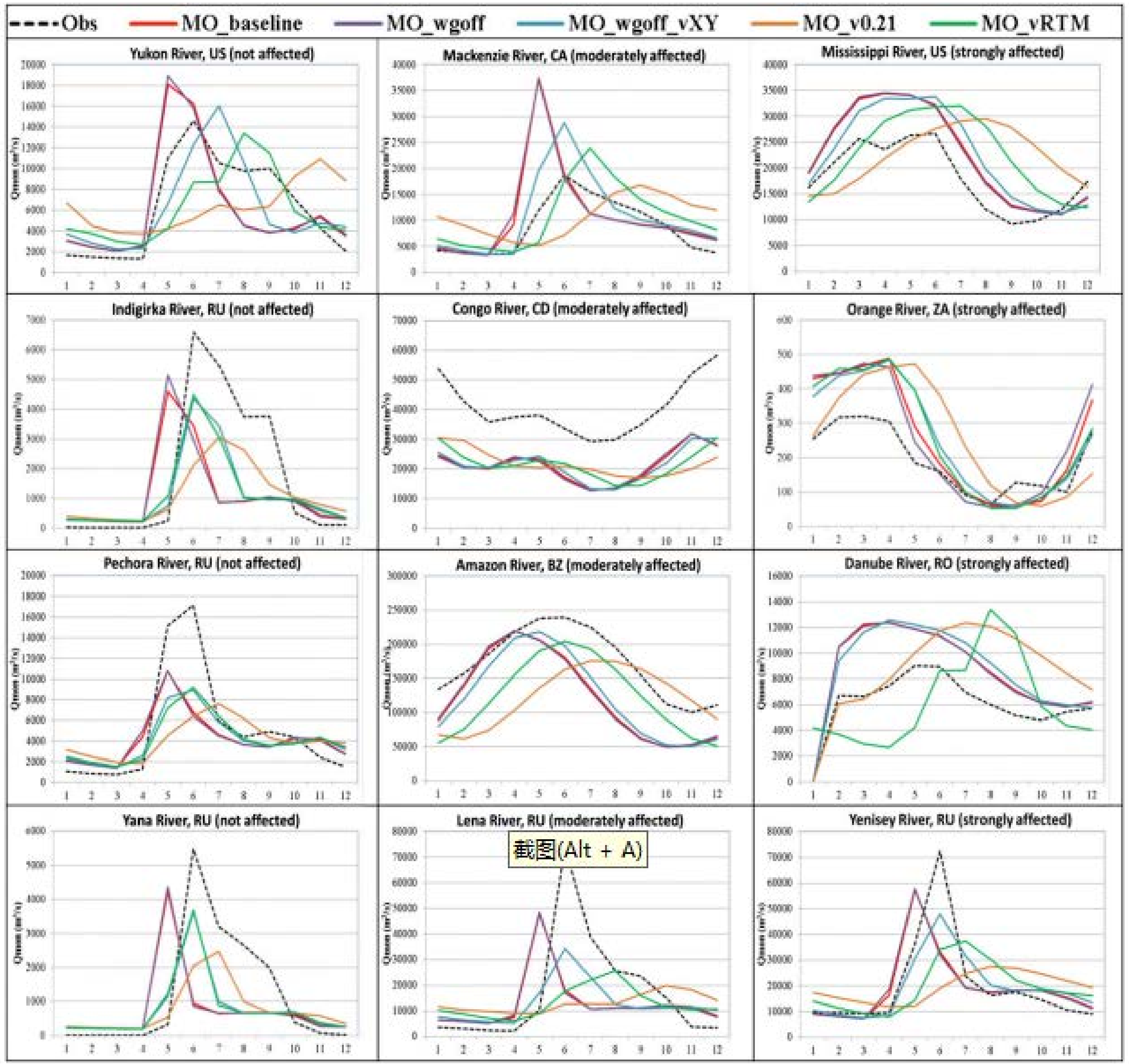
(Wang, Lu, et al., GRL, 2017)

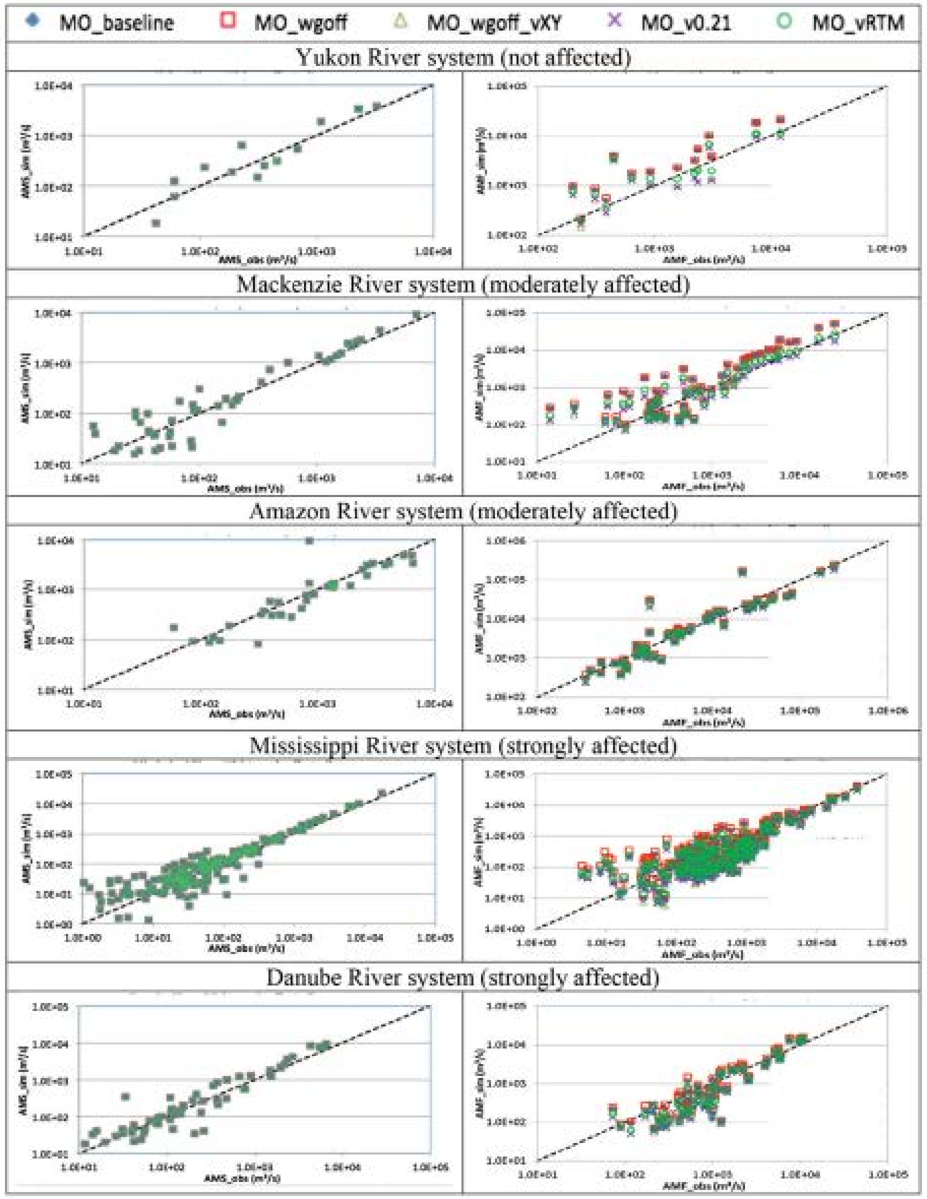
Projecting climate change impacts on water resource in China under various temperature raise targets

- Model: CLM-MOSART
  - CLM(Community Land Model, Dai et al. 2003), Community Land Surface Model
  - Updated hydrological component：
    - Model for Scale Adaptive River Transport (MOSART，Li et al. 2013) , Based on the GBHM
- Forcing: Ensemble mean of 36 GCM projections
  - by NCAR（http://www2.cesm.ucar.edu/models/experiments/LME, Otto-Bliesner et al. 2015）
  - Reference decade: 1986–2015
  - The decade Temperature raise to various control targets（by RCP 4.5 and 8.5）：
  - （1）1.5℃：2020–2030；（2）2 ℃ ：2035–2045；（3）2.5 ℃ ：2047–2057；（4）3 ℃ ：2057–2067；（5）3.5 ℃ :2062–2072；（6）4 ℃： 2065–2075；（7）4.5 ℃： 2072–2082；（8）5 ℃： 2079–2089。
  - Comparing the target decade with reference decade

Model validation at big basins

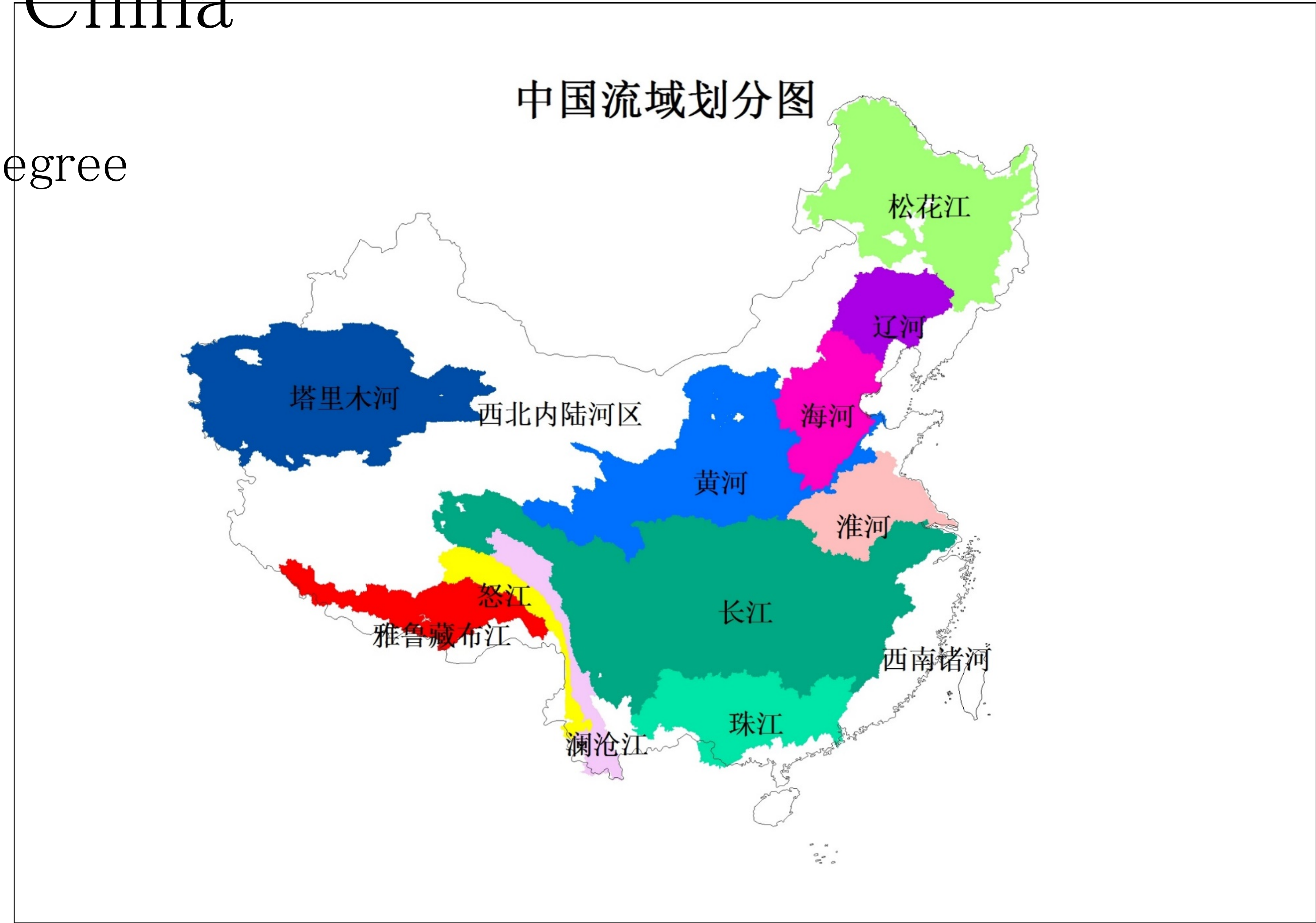
Li et al. 2015





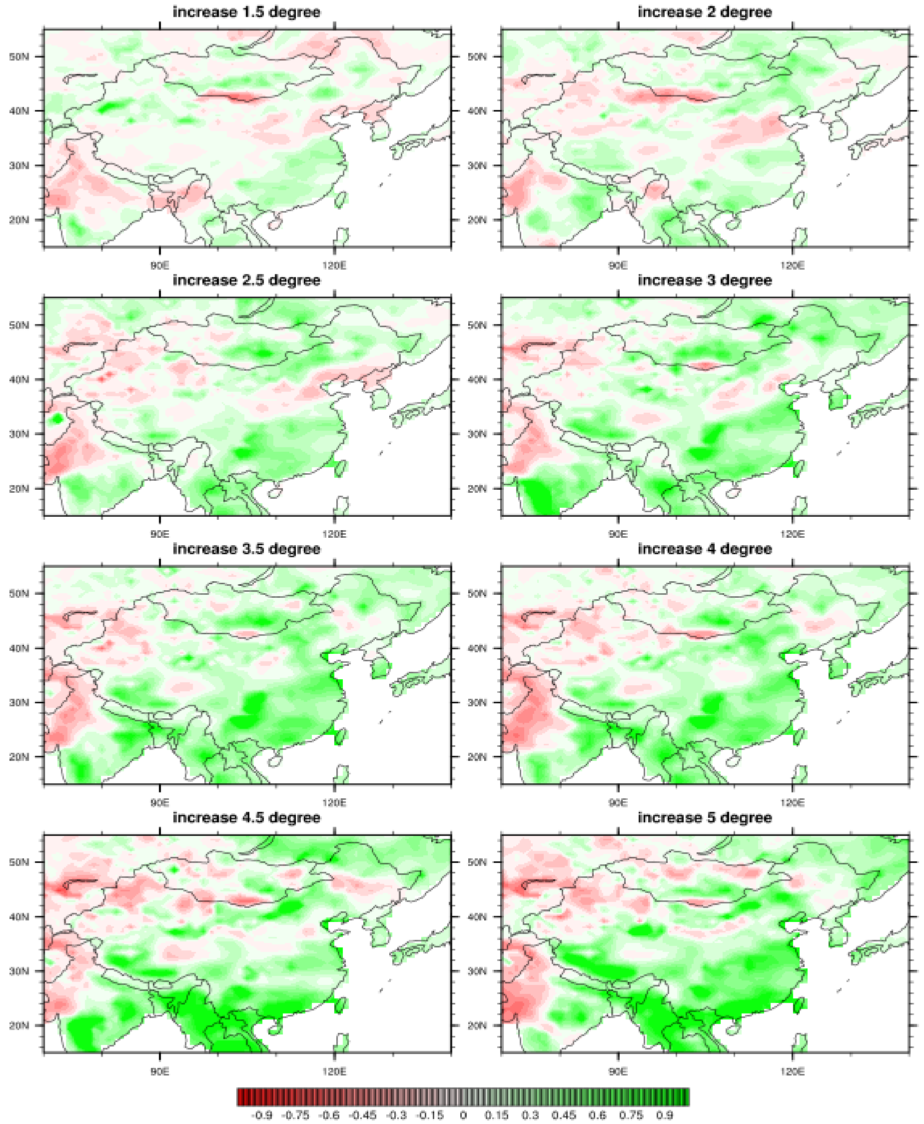
Simulation in China

- Resolution of 0.5 degree
- Eleven Basins

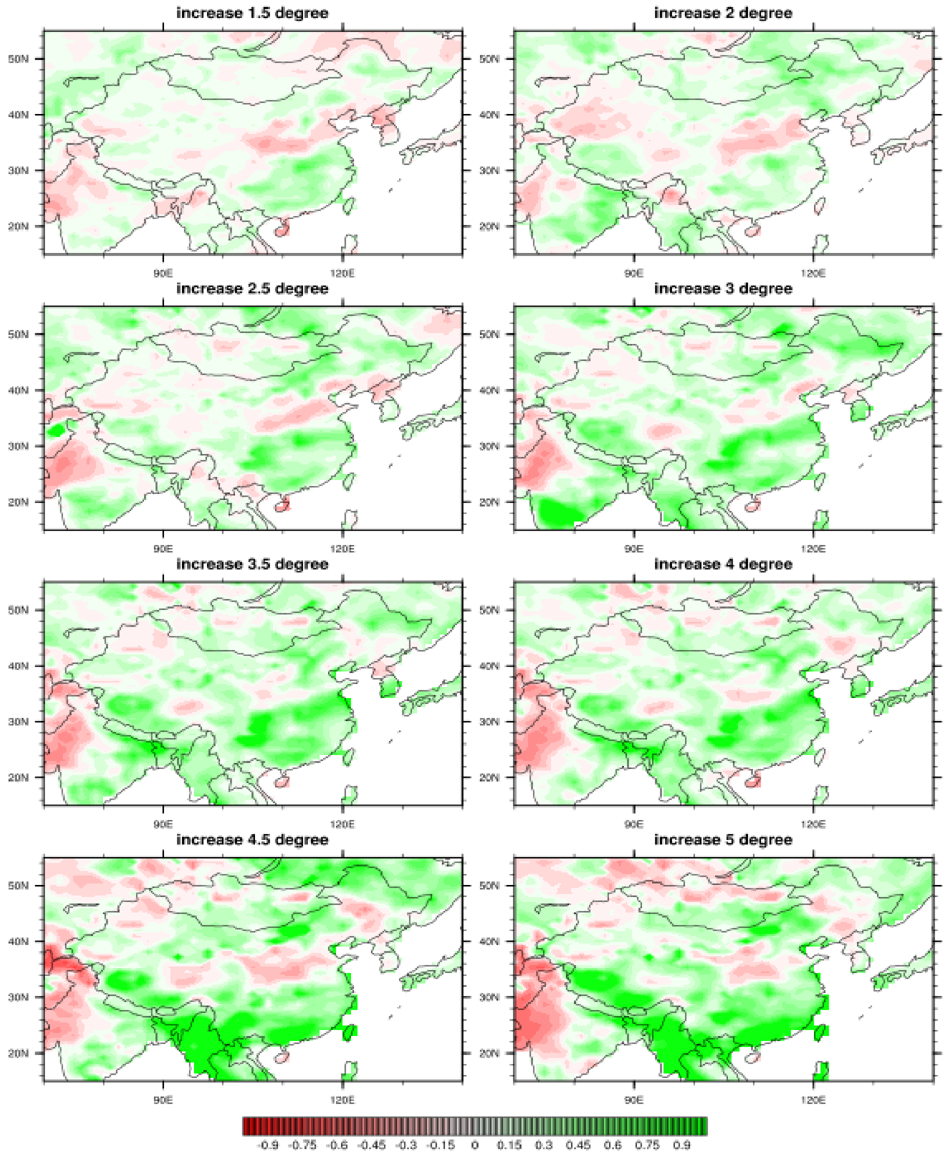


Runoff changes in different scenarios

Annual runoff change

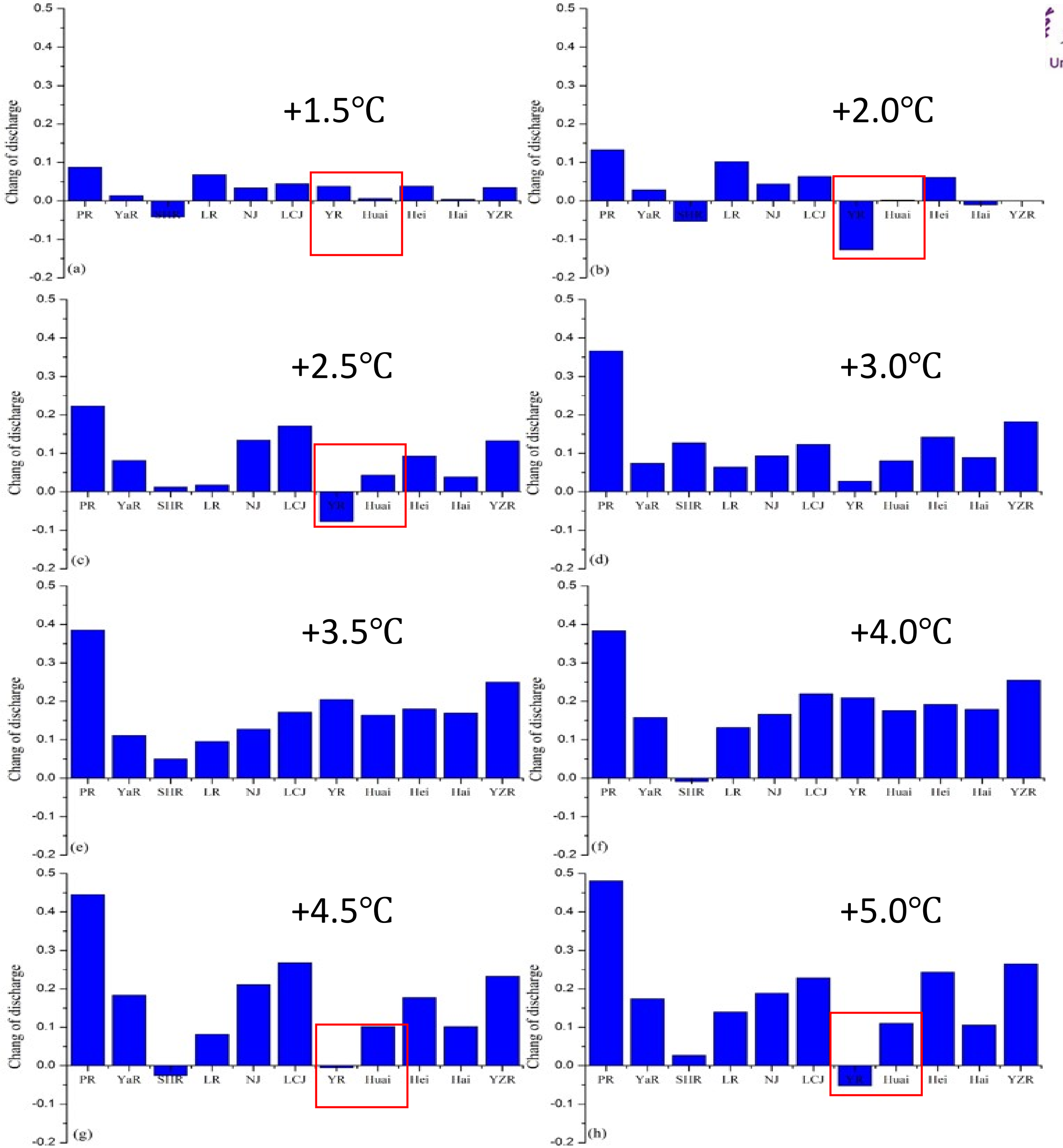


runoff change during JJA



Changes of discharges

PR–Pearl River
YaR–Yarlunzangbo
SHR–Song Hua
LR–Liaohe
NJ–Nu
LCJ–Lancang
YR–Yellow River
Huai–Huai
Hei–Hei He
Hai–Hai He
YZR–Yangze River



Remarks

- Projecting future water resource in China by CLM-MOSART
  - 1986-2099, ensemble of multiply GCM climate projections
  - Analysis under various temperature raise targets
- Different patterns of surface runoff in north and south China;
  - In North China (Yellow river and Hai river), discharge decreases obviously
  - In South China (Yangtze River and Pearl river), discharge increases obviously
- Projected hydrological data were used to project the vulnerability of energy production in the Yangtze River
  - Yue Zhang, **Alun Gu, Hui Lu**, Wei Wang. Hydropower Generation Vulnerability in the Yangtze River in China under Climate Change Scenarios: Analysis Based on the WEAP Model, Sustainability 2017, 9(11), 2085; doi:10.3390/su9112085

Thanks!

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Looking forward to sharing model, data, and knowledge to FEWS