Monitoring and Modelling of Hydrological Extremes in the Mekong River Basin

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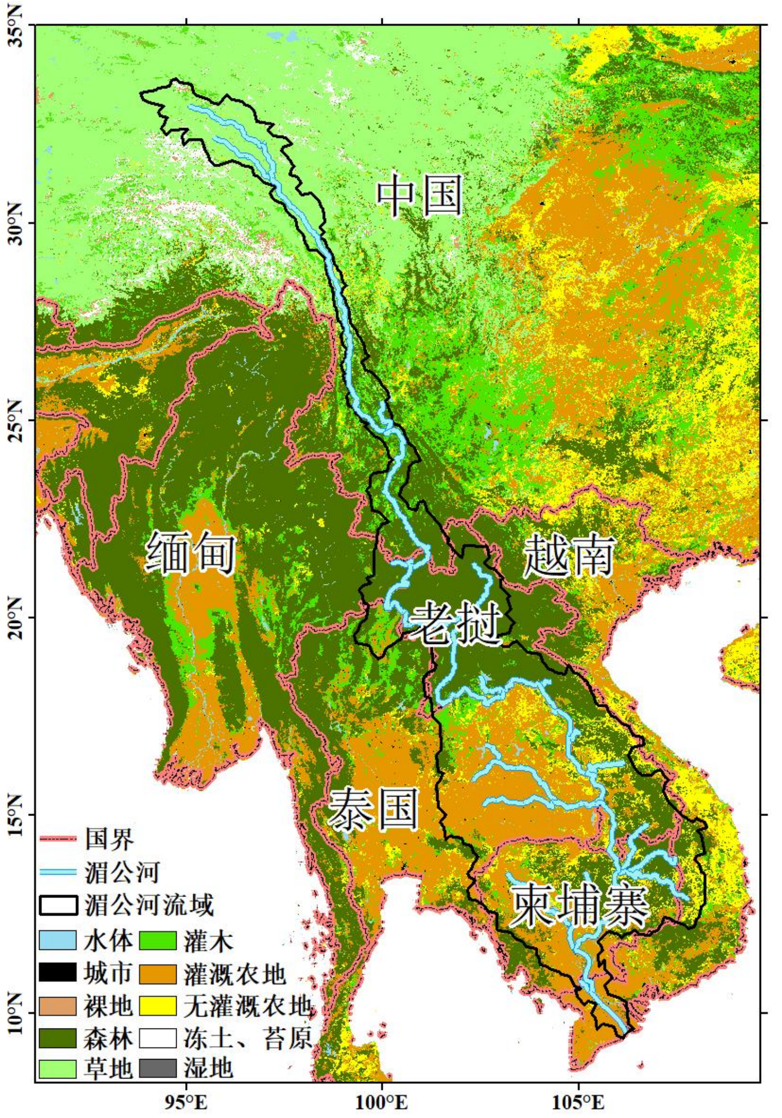
Outline

- Background
- Used data and model
  - A remote sensing based distributed hydrological model
- Flood simulation driven by TRMM and GPM
- Drought monitoring and simulating
  - Soil moisture drought monitored by remote sensing
  - Hydrological drought simulation
- Final remarks

Background

- Mekong River
  - One of the most important rivers in southwest China, originated from Tibetan Plateau
  - The most important trans-boundary river in Southeast Asia, bringing an ongoing debate about equitable sharing of the river's resources
- Climate change and socio-economic development will place additional pressure on Mekong water resource.
- Reliable simulation of Mekong river is the basis for climate change impact studies.



Background

- Complicate topography and land cover, various climate condition

➔ physically based distributed hydrological model

- Ungauged/ poor gauged basin; Data sharing problems due to international politic issues

➔ Using remote sensing data as much as possible during model development and simulation

- Impacts of future climate change

➔multi-GCM ensemble, future flood and drought

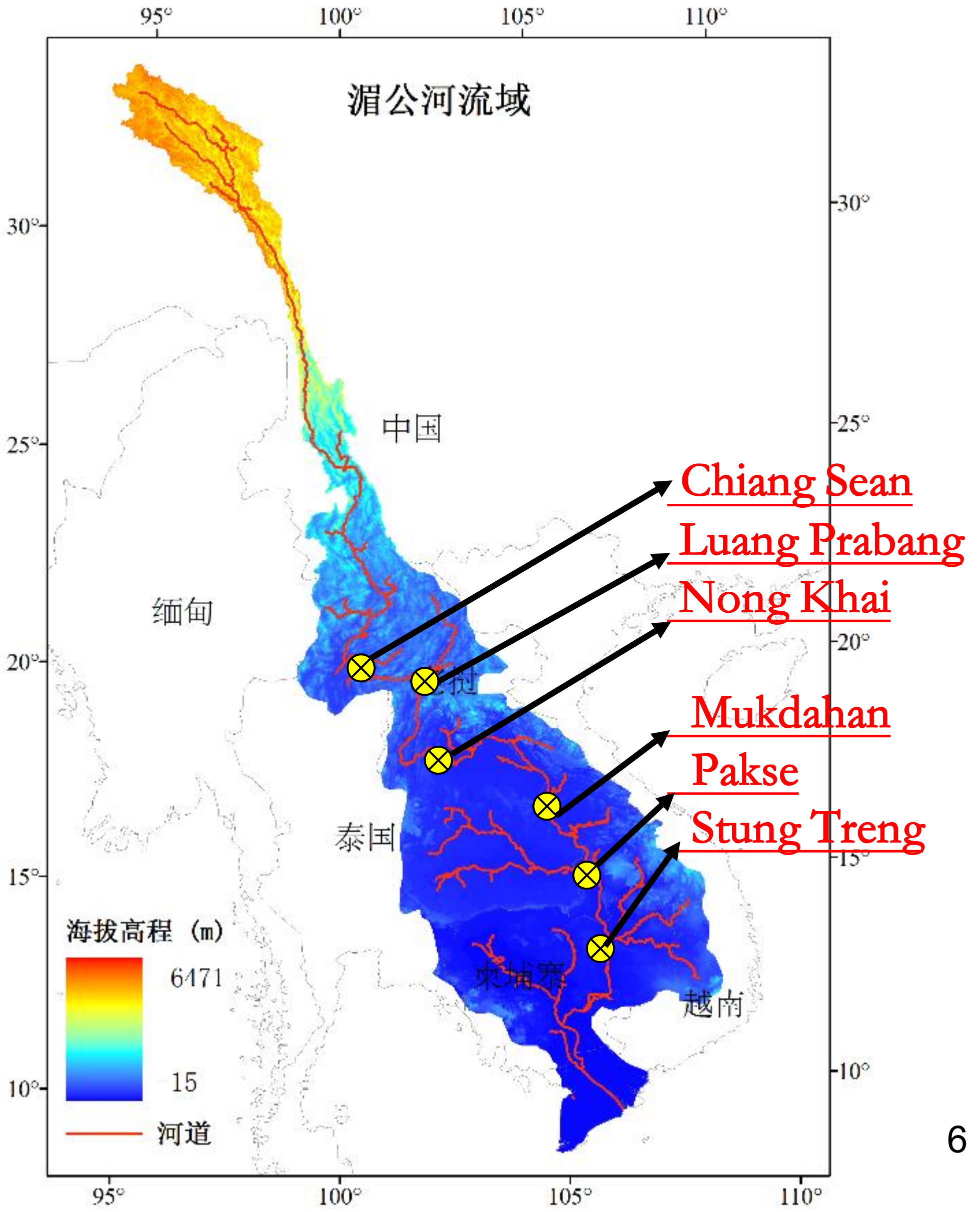
Used data

- Data for building distributed hydrologic model
  - Remote Sensing data
    - River networks: DEM
    - Vegetation (ET, interception): NDVI
    - Hydrological and hydraulics parameter: LULC
  - Soil data from FAO
- Data for running DHM
  - Rain gauge data from MRC, CMA ➔ traditional case
  - Remote sensing rainfall from TRMM 3B42 V7 ➔RS-based
  - Reanalysis data set: Temperature, radiation, ……
- Data for calibration and validation DHM
  - River discharge observation at six gauges from MRC

Discharge Data

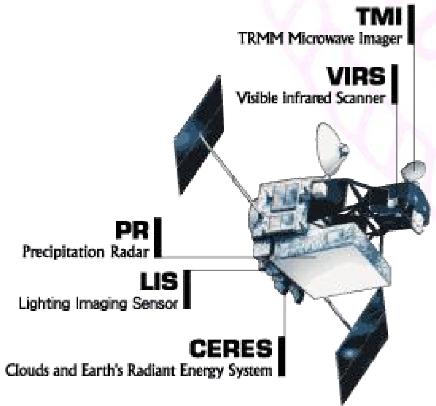
- Mekong river
  - Lancang-Mekong
- Six discharge gauges

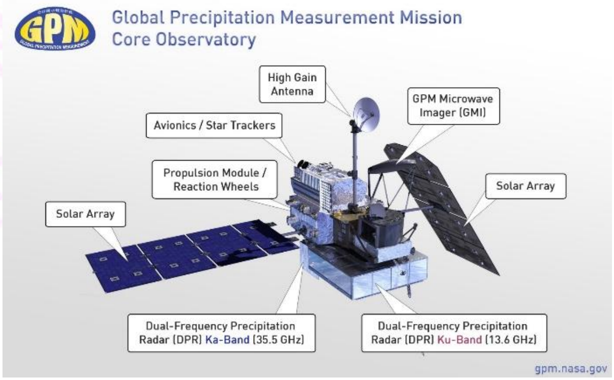
Station	Drainage area 10^4 km^2(ratio,%)	Average runoff m3/s (ratio,%)
Chiang Sean	18.9(23.8)	2688(18.6)
Luang Prabang	26.8(33.7)	3913(27.0)
Nong Khai	30.2(39.7)	4422(30.3)
Mukdahan	39.1(49.2)	7782(53.7)
Pakse	54.5(68.6)	9880(68.2)
Stung Treng	63.5(79.9)	13133(90.1)



Satellite-based precipitation Data

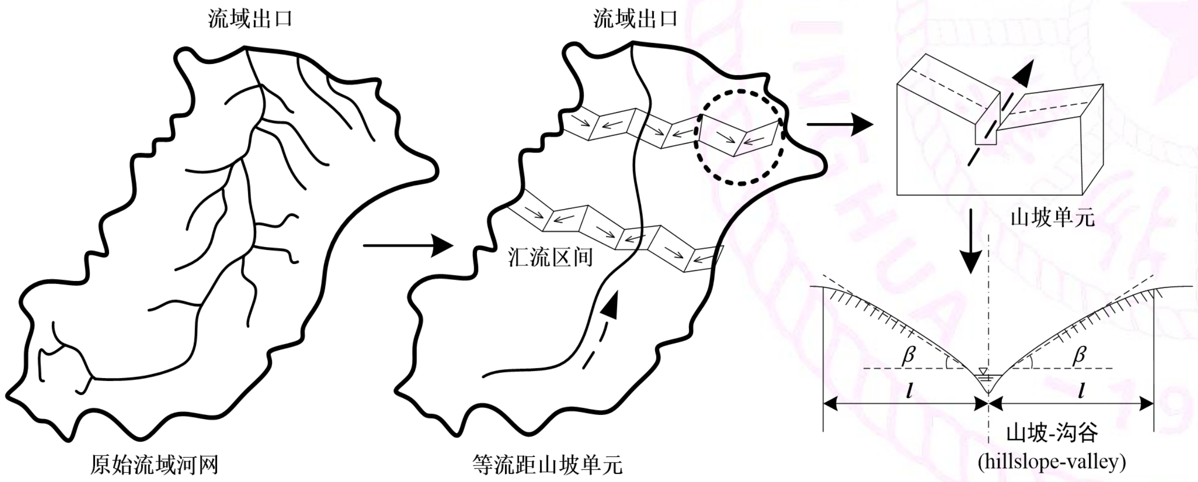
- Precipitation is one of the most important variables in hydrological processes
- TRMM: Tropical Rainfall Measuring Mission
  - ✓ Lunched by NASA and JAXA at November 1997;
  - ✓ 0.25° ×0.25° spatial resolution & 3-hourly temporal resolution;
  - ✓ 50° N to 50° S and covered from November 1997 to June 2015;
- GPM: Global Precipitation Measurement Mission
  - ✓ Lunched by NASA and JAXA at March 2014;
  - ✓ 0.1° ×0.1° spatial resolution & 30mins temporal resolution;
  - ✓ Global data and covered from March 2014 to present;

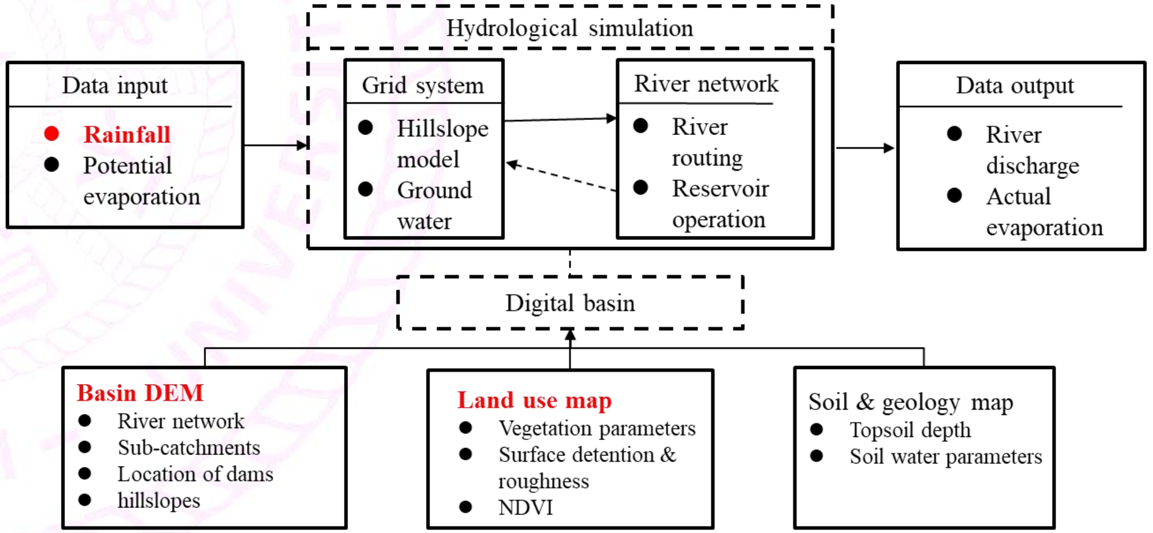




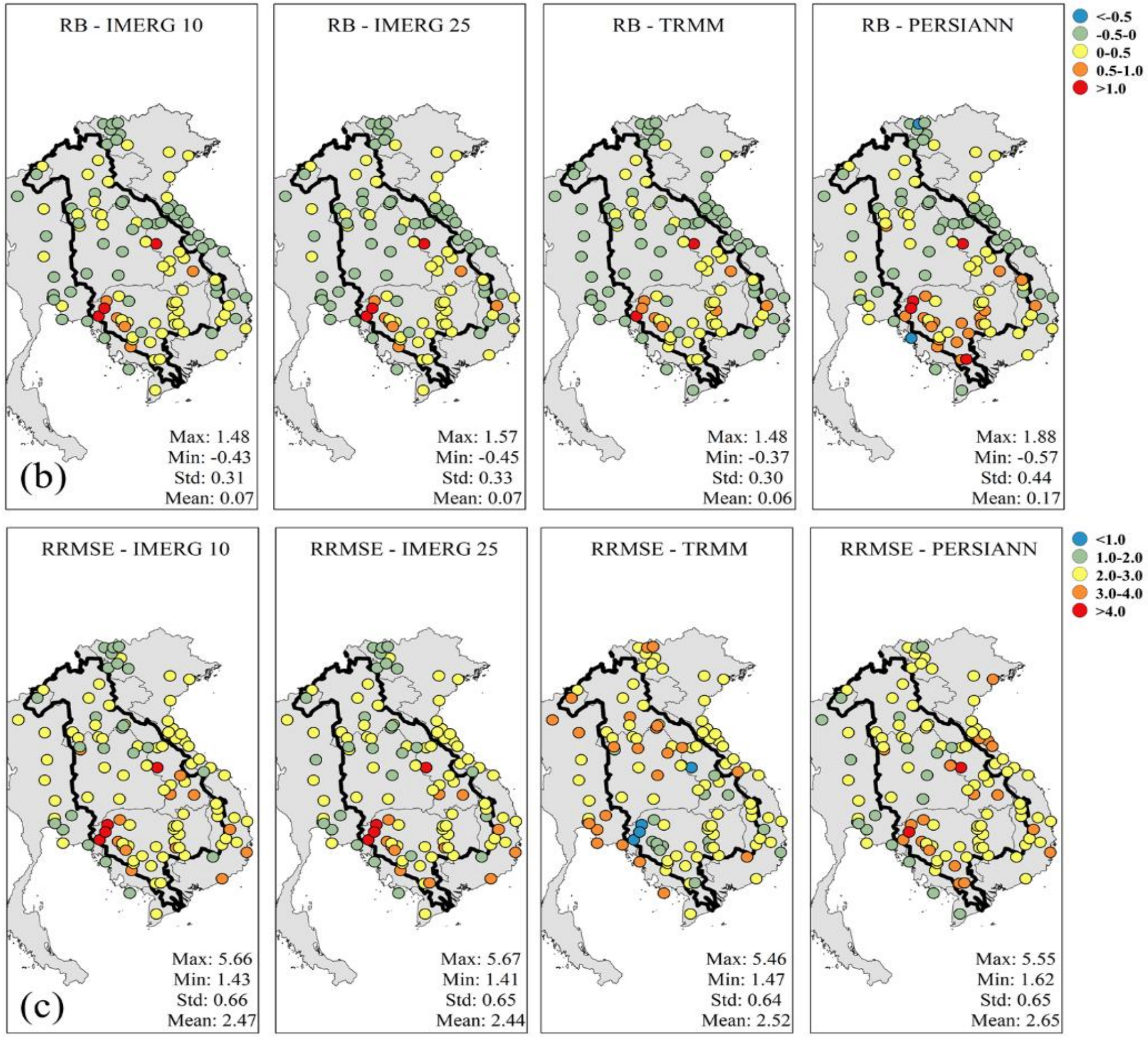
Used Model

- Geomorphology Based Hydrological Model (GBHM)
  - A flow-interval hillslope scheme is applied to subdivide the catchment into a number of cascade-connected flow intervals
  - The hillslopes in the flow interval are hydrologically similar without regard to spatial variation
  - All hillslopes are assumed to rush directly to the same main stream





Evaluation of satellite rainfall

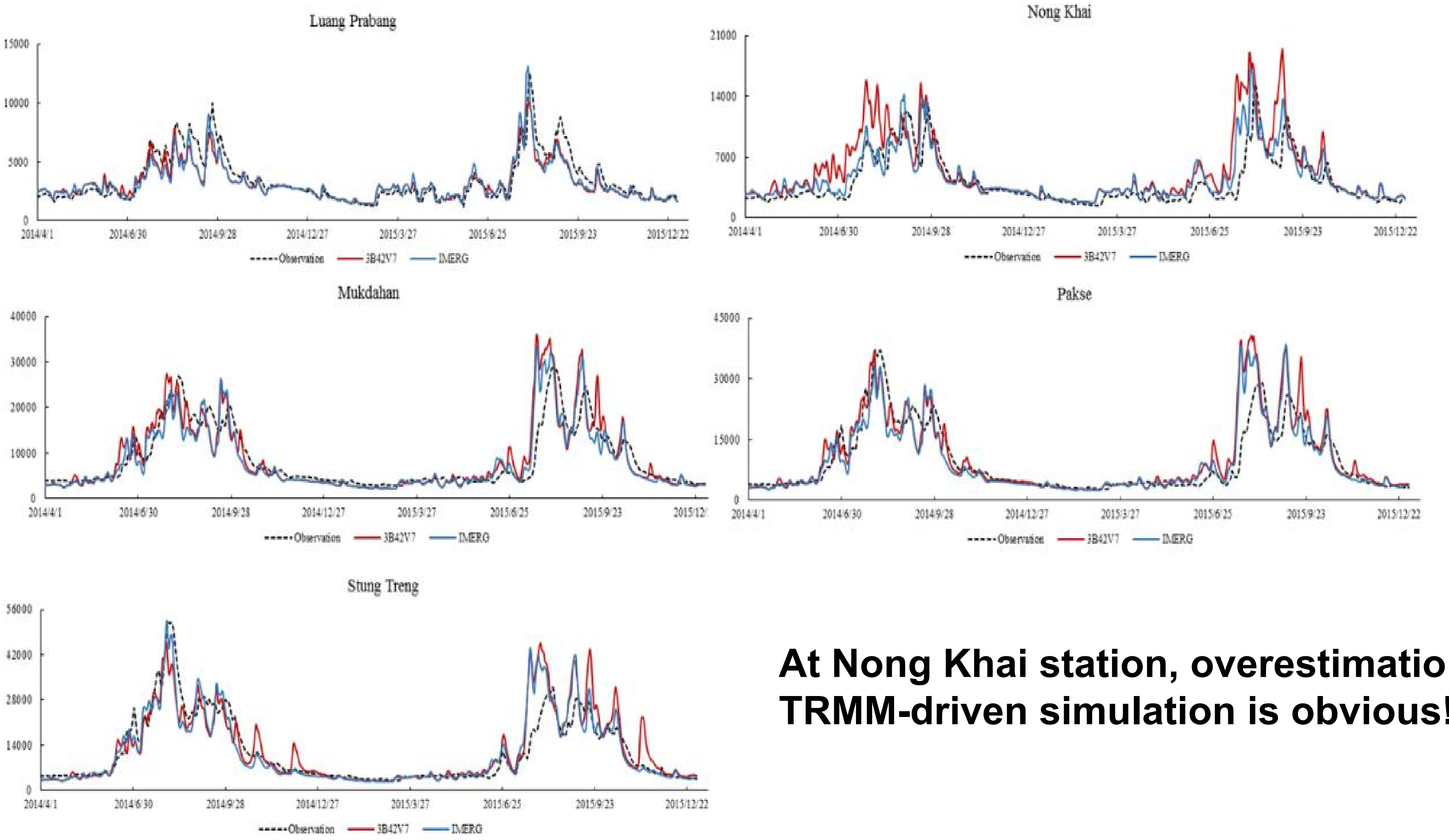


	POD	FAR	CSI	RB	RRMSE	CC
IMERG 10	0.89	0.30	0.64	0.07	2.47	0.54
IMERG 25	0.91	0.32	0.63	0.07	2.44	0.53
TRMM	0.81	0.25	0.64	0.06	2.52	0.51
PERSIANN-CDR	0.89	0.35	0.60	0.17	2.65	0.40

- High accuracy for identifying precipitation events;
- PERSIANN-CDR has the longest coverage but the highest false alarm rate and poorer accuracy;
- TRMM has better precipitation event identification and higher accuracy;
- GPM the highest accuracy;

(Li, Wang, Lu*, et al., JSTARS, 2019)

Flood simulated by TRRM & GPM



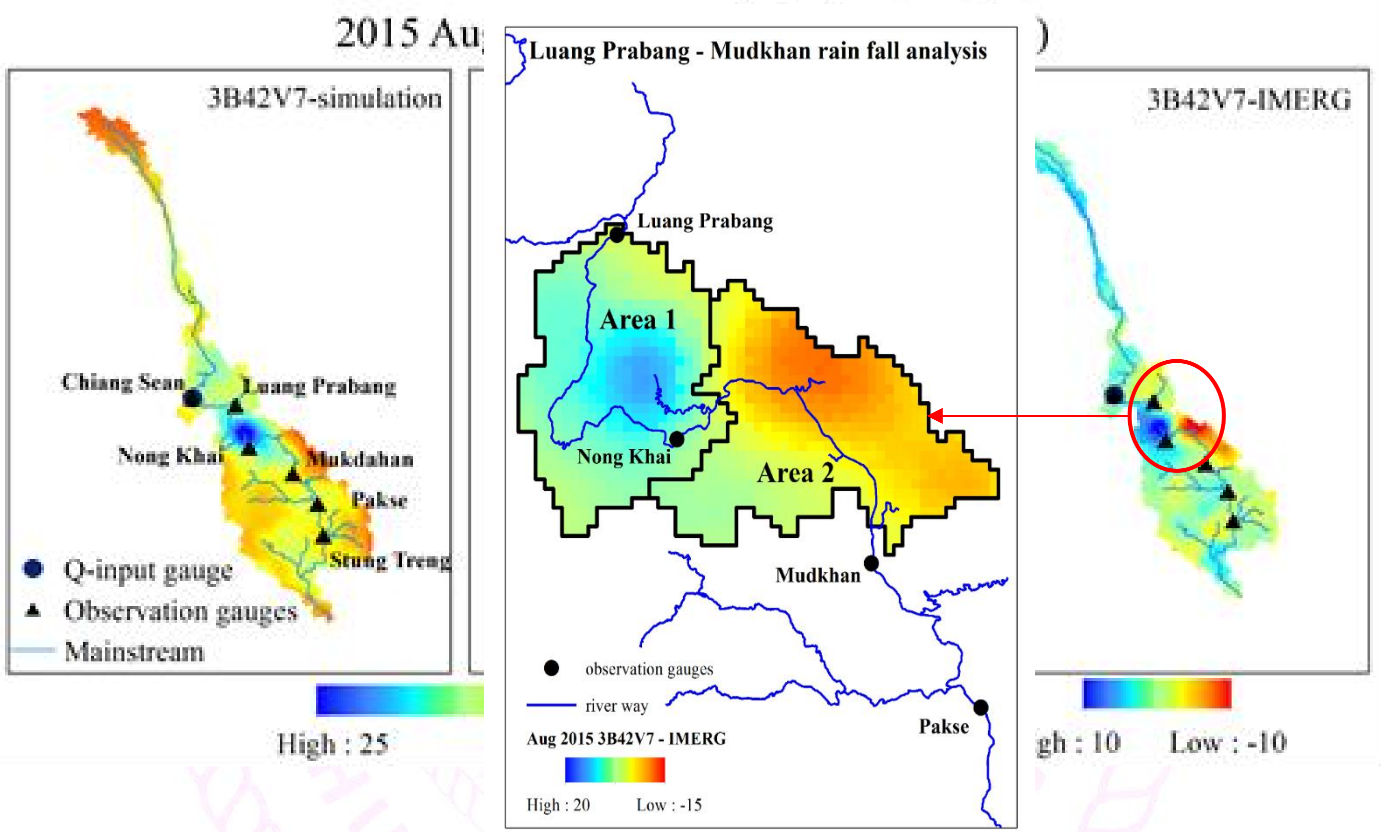
At Nong Khai station, overestimation of TRMM-driven simulation is obvious!

Flood simulation

Input data	Stations	Evaluation Index				
		RB	NASH-daily	NASH-monthly	RRMSE-daily	RRMSE-monthly
IMERG	Luang Prabang	-6.5%	0.77	0.85	0.27	0.20
	Nong Khai	12.4%	0.64	0.87	0.41	0.22
	Mukdahan	-4.3%	0.74	0.90	0.40	0.22
	Pakse	-1.0%	0.73	0.88	0.43	0.26
	Stung Treng	0.1%	0.79	0.90	0.40	0.25
TRMM	Luang Prabang	-7.0%	0.79	0.84	0.28	0.20
	Nong Khai	31.4%	0.01	0.36	0.69	0.62
	Mukdahan	-4.5%	0.65	0.85	0.46	0.28
	Pakse	9.1%	0.66	0.83	0.48	0.31
	Stung Treng	7.1%	0.70	0.86	0.47	0.30

- ✓ IMERG has more stable and accurate result when forcing hydrological model than TRMM does;
- ✓ TRMM performs not good at Nong Khai, why?

Flood simulation



- TRMM overestimates rainfall in the upstream of Nong Khai, and underestimates rainfall in the region from Nong Khai to Mukdahan.
  - The underestimation and overestimation of TRMM along the river may compensate and then generates acceptable simulation in downstream.

✓ GPM is more reliable than TRMM

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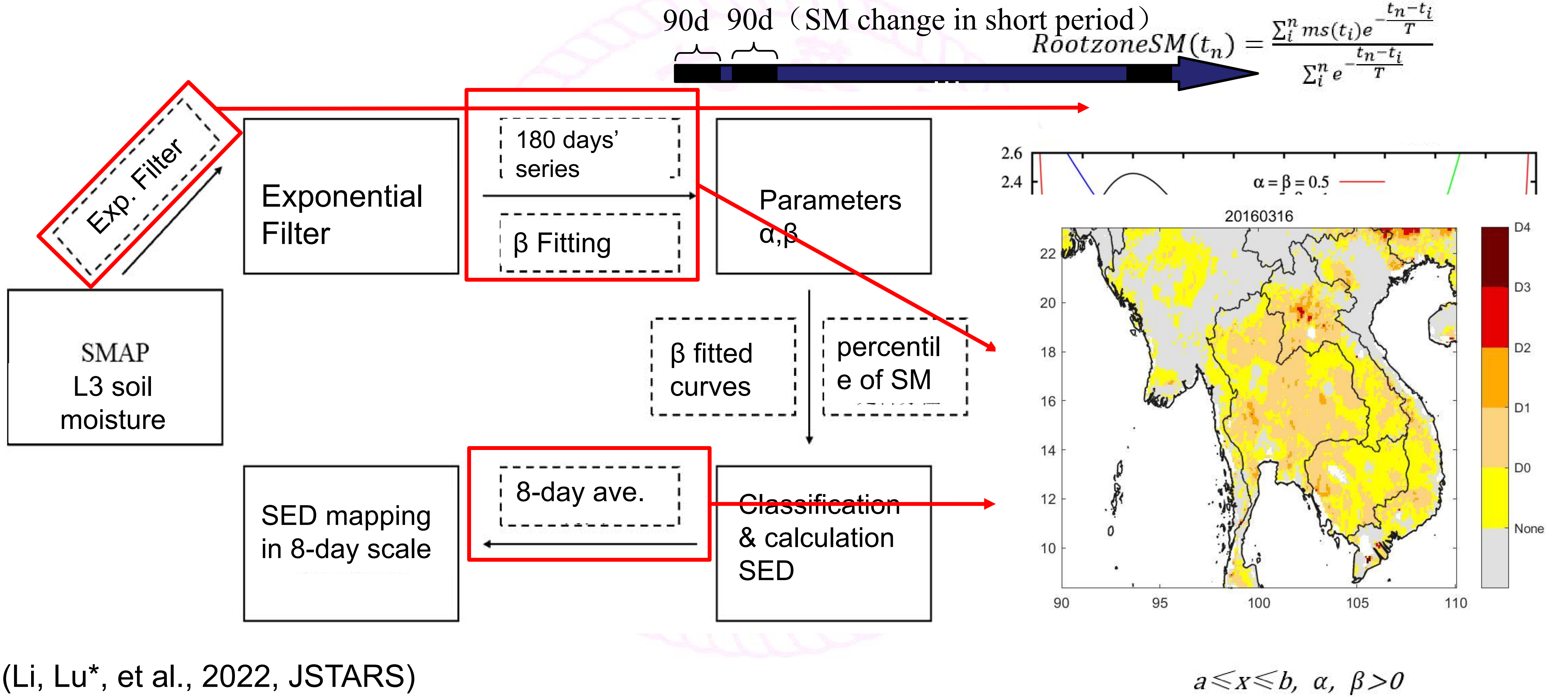
2016 drought in LMR

- The Lower Mekong River experienced a severe drought in spring 2016
  - Saltwater intrusion in the lower delta two months earlier than usual, threatening over 30% of winter and spring crops.
- Emergency Water Supply to mitigate drought
  - from the Lancang River reservoirs to the Mekong River by increasing the water discharge of the Jinghong Dam in Yunnan Province.
  - increased the overall water level along the Mekong main stream by 0.18 to 1.53 meters and increased the runoff by 602 to 1010 m^3/s.
  - reduced the maximum salinity of the Mekong Delta by 15% to 74% and the minimum salinity by 9% to 78%
  - making a great contribution to alleviating the drought and reducing salinity intrusion along the Mekong Delta.

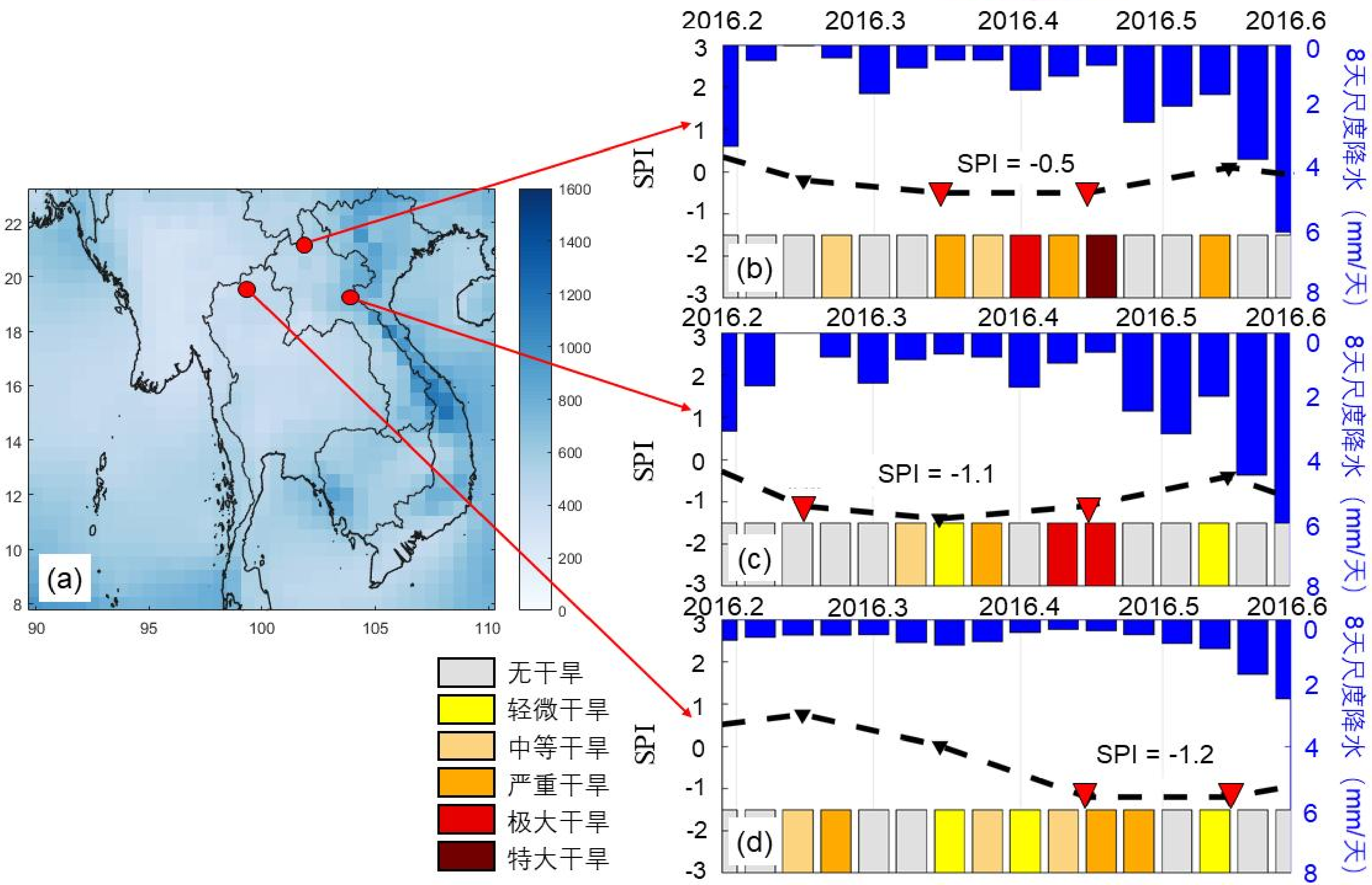
Soil moisture drought monitoring by SED

- The Soil moisture Eight Day drought Index (SED) has been developed using SMAP remotely sensed soil water data and is capable of monitoring agricultural drought conditions at a higher temporal resolution.



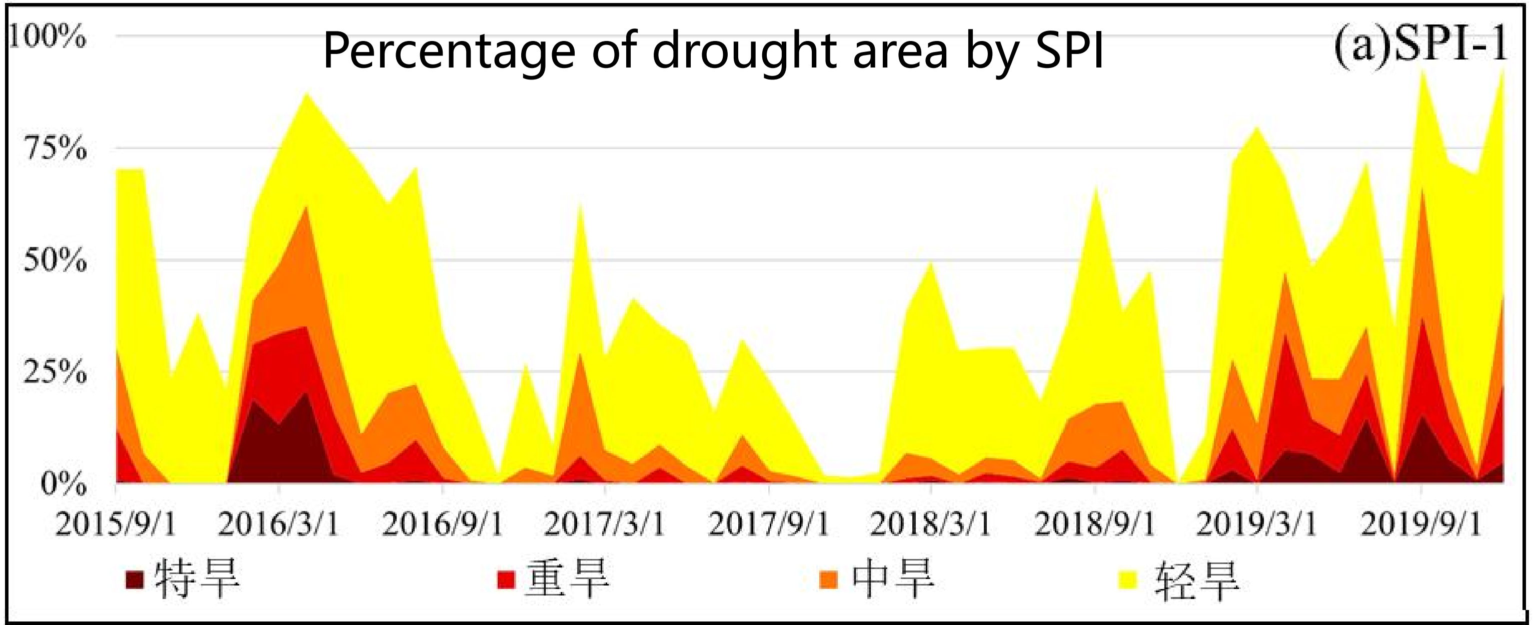
(Li, Lu*, et al., 2022, JSTARS)

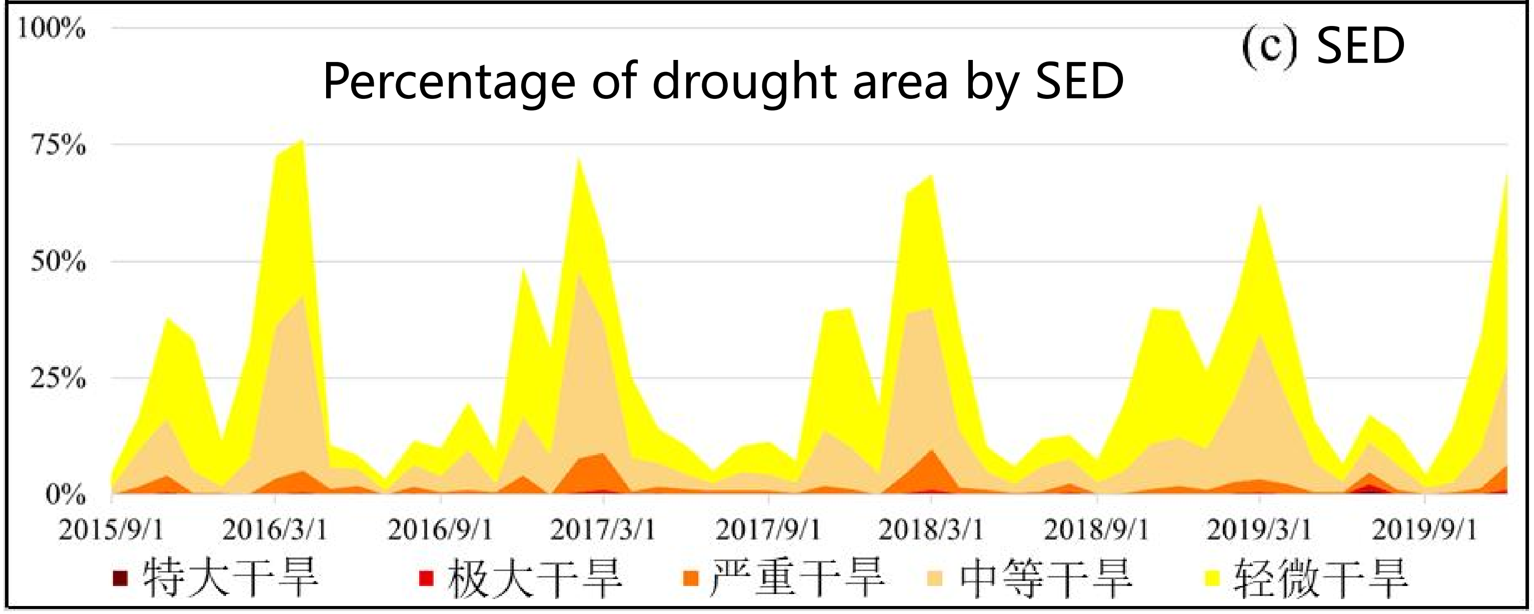
Difference between SPI & SED



- The same SPI (red triangle in the graph), but with its corresponding 8-day scale SED shows a large difference;
- SED can reflect the influence of surface features on drought

Drought monitoring by SPI & SED

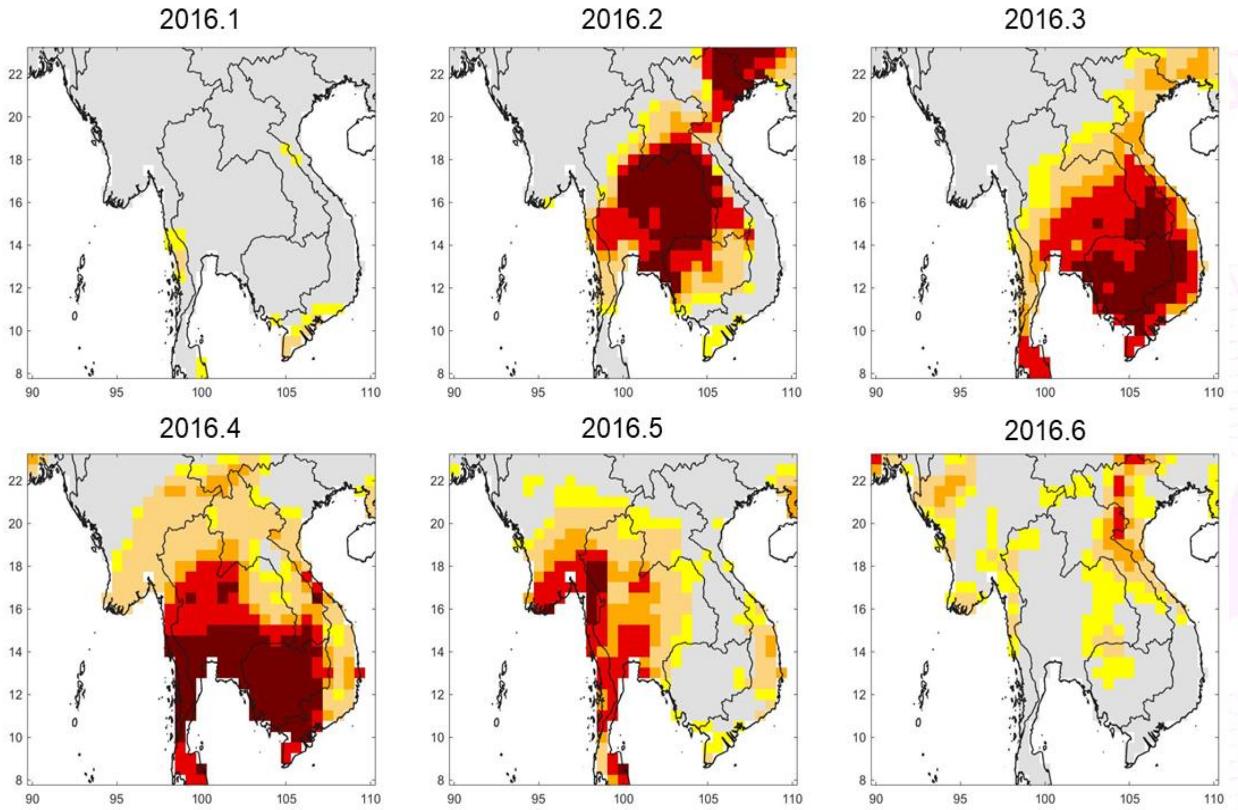




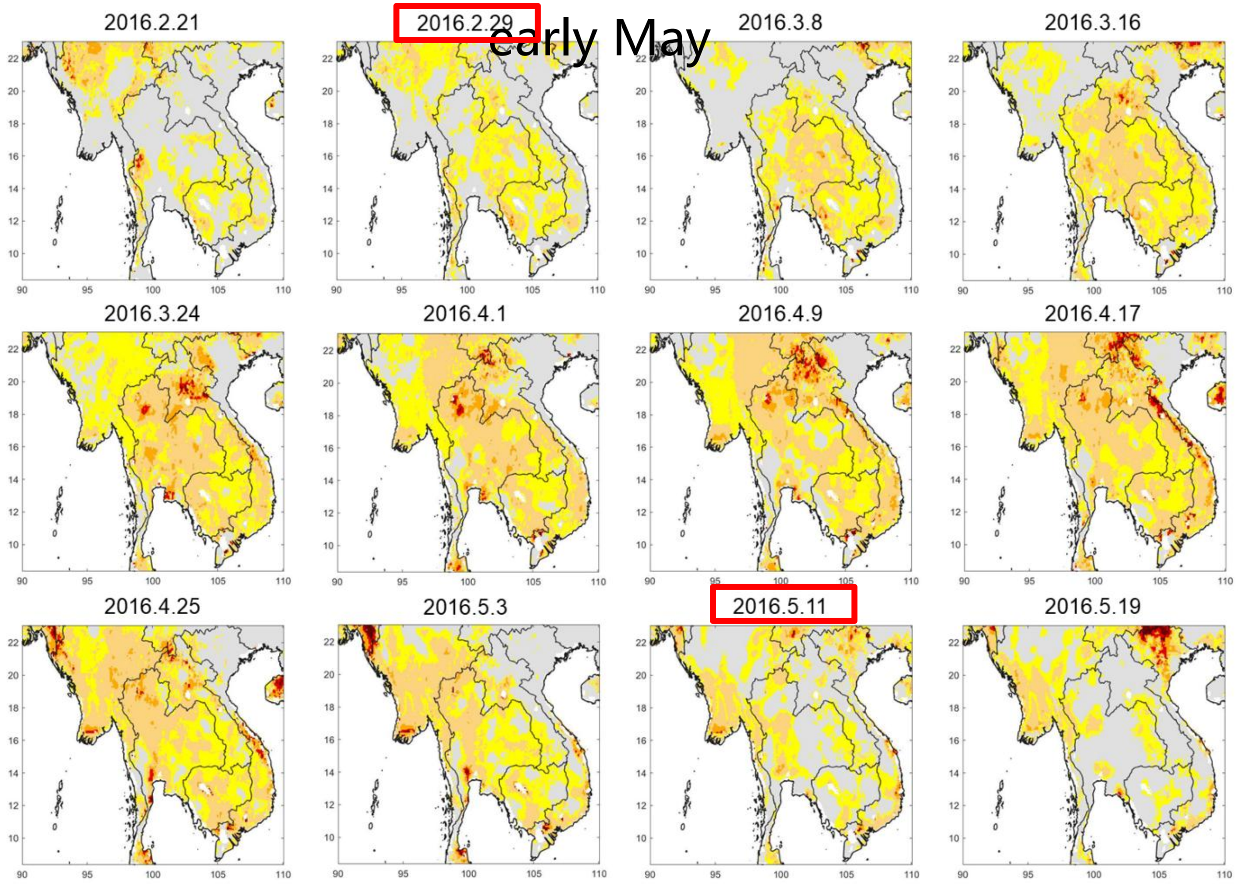
- Meteorology drought by SPI-1
  - Drought from early 2016 to Sep.
  - Drought throughout 2019
- Soil moisture drought by SED
  - Early 2016 to June drought
  - Early 2019 to June drought
- Soil moisture droughts are shorter than meteorology drought

2016 Drought

SPI: Occurs in Feb., recedes in May



SED: Occurs at the end of Feb. and recedes in early May

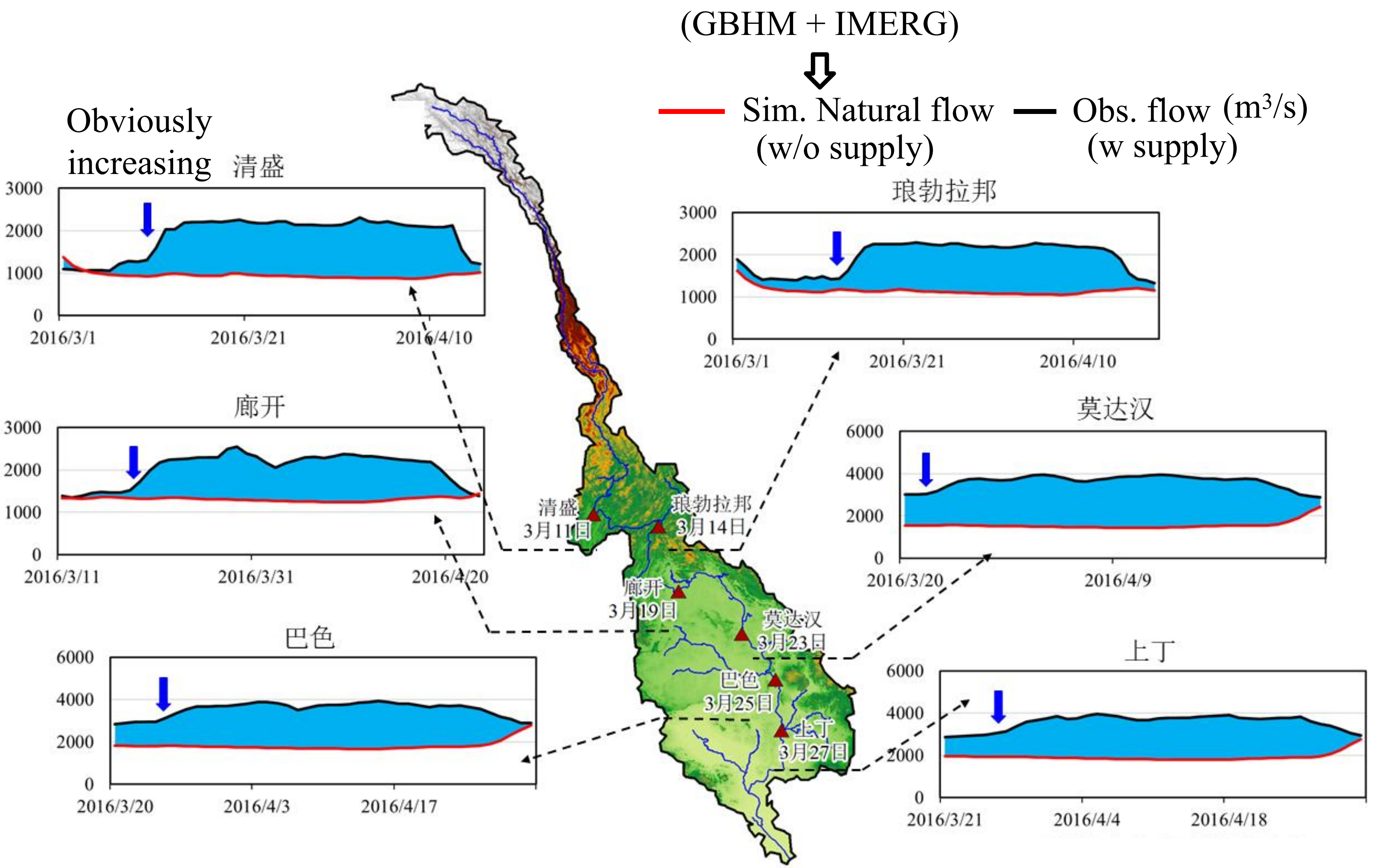


- Meteorological drought occurs from Feb. and is most severe in the lower region in Mar. and Apr.;
- During the same period, soil water drought occurred throughout the region, being most severe basin-wide in late Mar. and Apr.;
- The 2016 downstream drought was primarily due to meteorological factors.

Drought Mitigation in 2016

- Three steps of emergency water supply in 2016:
  - 1） The first phase, from 9 March to 10 April, recharged approximately 6.1 billion cubic metres of water downstream and had an average daily runoff of over 2,000 m^3/s;
  - 2） The second phase, from 11 April to 20 April, recharged approximately 1.1 billion cubic metres of water downstream, with an average daily runoff of over 1200 m^3/s;
  - 3） The third phase lasted longer, from 21 April until 31 May, with a total of nearly 5.5 billion cubic metres of water replenishment and an average daily runoff of over 1,500 m^3/s。
- Using hydrological models and GPM data, natural flow simulations are carried out to compare with actual measured flows and to analyze the drought mitigation effect of emergency water supply.

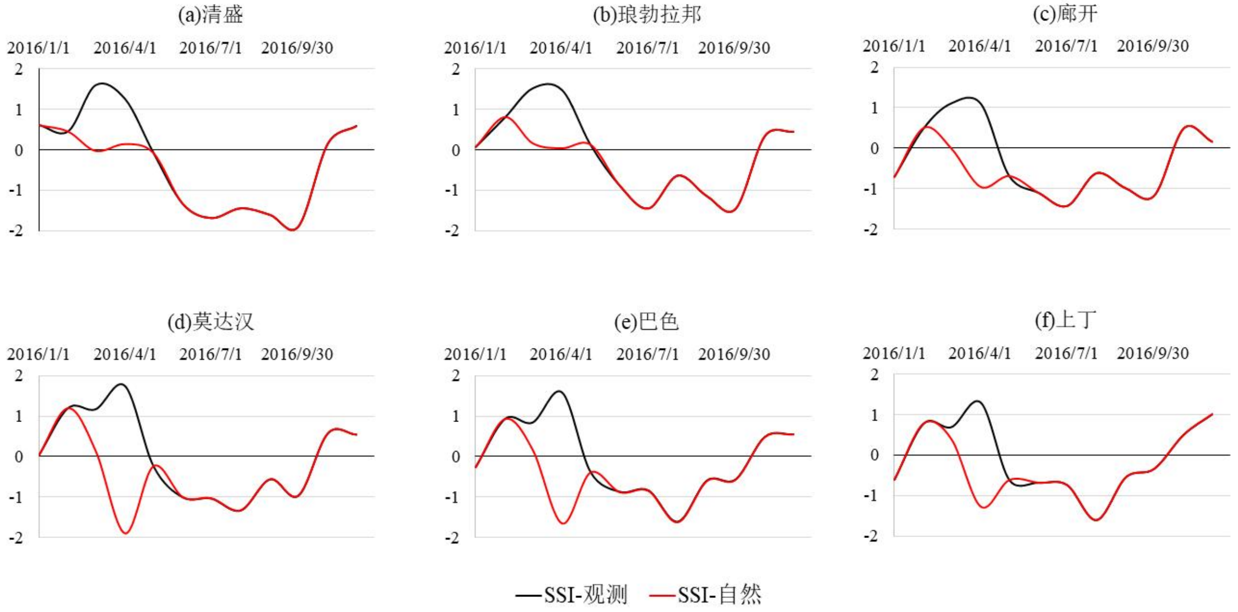
Simulating 2016 hydrological drought



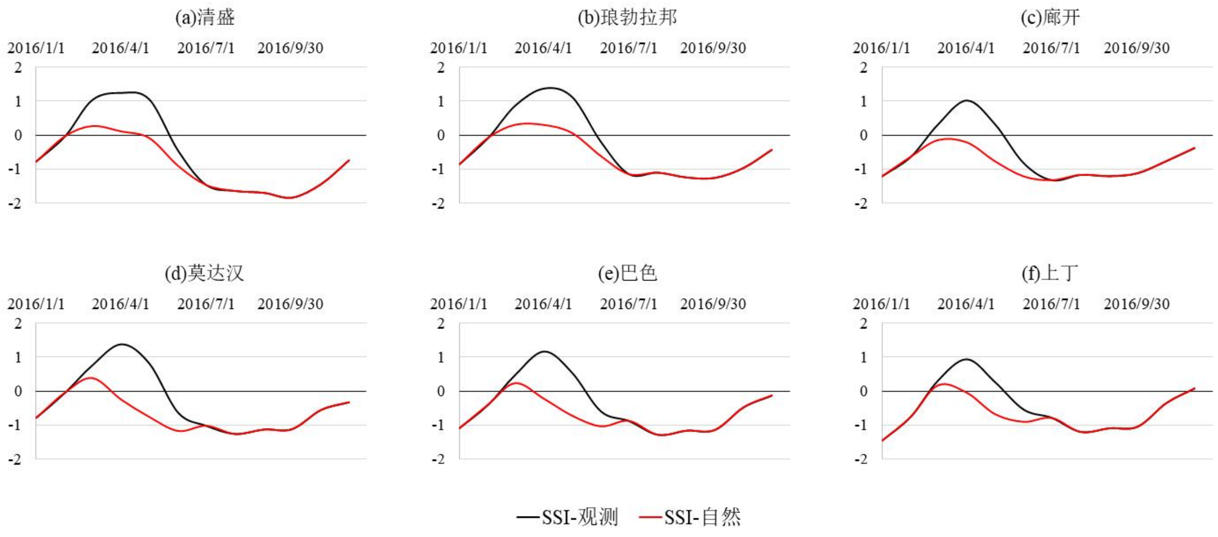
- Driven by GPM, the natural flows (red line) were simulated and compared with observed ones(blue);
- Clearly quantifies the amount of extra water at each station due to emergency water supply;
- To quantify the hydrological drought by standard stream index (SSI)

Drought mitigation by emergency water supply

Monthly SSI-1



Seasonal SSI-3



- Observed SSI>Nature flow SSI, →Water release alleviates hydrological drought
- For monthly hydrological droughts, the basin-wide drought is largely mitigated in Mar., but continues after Apr.,
- For seasonal hydrological droughts, in Mar.-Apr., there was a noticeable relief;
- The effect of drought mitigation on longer time scales gradually reduces.

Drought mitigation

	One month SSI			3 months SSI		
	SSI-Obs.	SSI-Nat.	Change	SSI-Obs.	SSI-Nat.	Change
CS	/	/	/	/	-0.16	-100.0%
LP	/	/	/	/	/	/
NK	/	-0.96	-100.0%	/	-0.59	-100.0%
MK	/	-0.88	-100.0%	/	-0.46	-100.0%
BS	/	-0.73	-100.0%	/	-0.44	-100.0%
ST	/	-0.44	-100.0%	/	-0.36	-100.0%
	6 months SSI			12 months SSI		
	SSI-Obs.	SSI-Nat.	Change	SSI-Obs.	SSI-Nat.	Change
CS	-0.51	-1.00	-49.0%	-1.42	-1.60	-11.3%
LP	-0.36	-0.74	-51.4%	-1.15	-1.27	-9.4%
NK	-0.83	-1.14	-27.2%	-1.46	-1.55	-5.8%
MK	-0.49	-0.90	-45.6%	-1.14	-1.24	-8.1%
BS	-0.64	-0.95	-32.6%	-1.31	-1.39	-5.8%
ST	-0.75	-0.99	-24.2%	-1.46	-1.52	-3.9%

To alleviate drought on longer time scales downstream, greater water supply capacity is needed

The capacity of the reservoir to release water? The capacity of the river bed?

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• Op-Ed Contributors

Trust key to Lancang-Mekong cooperation

By Tian Fuqiang, Liu Hui and Lu Hui | chinadaily.com.cn | Updated: 2020-08-24 14:55

The drought that hit the Lancang-Mekong River basin in 2019 caused the water in this great river to drop to one of its lowest levels in more than 100 years, inflicting substantial damage to both upstream and downstream water users.

The unprecedented low level of the water in the river attracted much attention from Lancang-Mekong riparian countries and beyond, including a study by researchers from Eyes on Earth and Global Environmental Satellite Applications (EoE) that said the drought was caused because China's dams upstream withheld water. But a subsequent commentary by Mekong River Commission raised serious doubts about the data and methodology used by the EoE study.

Final Remarks

Tsinghua University 清華大學

- Earth observation data provides great help in water research in Mekong
  – Simulate flood with RS rainfall driven hydrological model
  – Simulate hydrological drought
  – Monitoring soil moisture drought
- The experiences of the 2016 drought and all previous droughts call for more collaborative actions among the multiple stakeholders to alleviate drought and other extreme hydrological hazards.
- Share water, share knowledge, share the future!

Related publications

1. Wang, W., H. Lu*, et al. : Modelling Hydrologic Processes in the Mekong River Basin Using a Distributed Model Driven by Satellite Precipitation and Rain Gauge Observations, PoLS One,   DOI: 10.1371/journal.pone.0152229, 2016
2. Wei Wang, H. Lu*, et al., Evaluation and Comparison of Latest GPM and TRMM Products over Mekong River Basin, IEEE JSTARS, 10(6), 2540-2549, DOI:10.1109/JSTARS.2017.2672786, 2017
3. Wei Wang, H. Lu*, et al, Dam construction in Lancang-Mekong River Basin could mitigate future flood risk from warming-induced intensified rainfall, GRL,44(20), 10378-10386. DOI: 10.1002/2017GL075037， 2017
4. Wei Wang,…, H. Lu, et al. , Nonlinear filter effects of reservoirs on the flood frequency curves at the regional scale, WRR, 10.1002/2017WR020871, 2017
5. Li D.N., D. Long, J.S. Zhao, H. Lu, Y. Hong, Observed changes in flow regimes in the Mekong River basin, Journal of Hydrology, Volume 551, p. 217-232, 2017
6. Li Y., Wang W., H. Lu*, et al. Evaluation and Application of the Latest Satellite-Based Precipitation Products with a Distributed Hydrological Model in the Lower Mekong River Basin. In: Huang G., Shen Z. (eds) Urban Planning and Water-related Disaster Management. Strategies for Sustainability. Springer, Cham, DOI: 10.1007/978-3-319-90173-2_5, 2019
7. Li Y., W. Wang, H. Lu*, et al., “Evaluation of Three Satellite-Based Precipitation Products Over the Lower Mekong River Basin Using Rain Gauge Observations and Hydrological Modeling,” IEEE JSTARS. doi: 10.1109/JSTARS.2019.2915840, 2019
8. Li Y., H. Lu*, et al., “Meteorological and hydrological droughts in Mekong River Basin and surrounding areas under climate change”, Journal of Hydrology: regional studies, 36, 100873, 2021
9. Li Y., H. Lu*, et al, “Satellite-Based Assessment of Meteorological and Agricultural Drought in Mainland Southeast Asia”, IEEE JSTARS. DOI: 10.1109/JSTARS.2022.3190438,2022

Thank you for your attention!

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