2024 Noah-MP International Workshop

Influence of glacier retreat on streamflow in East Asia using the constrained WRF-Hydro/Glacier with LSTM

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Contents

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Introduction

Climate Change and Glacier

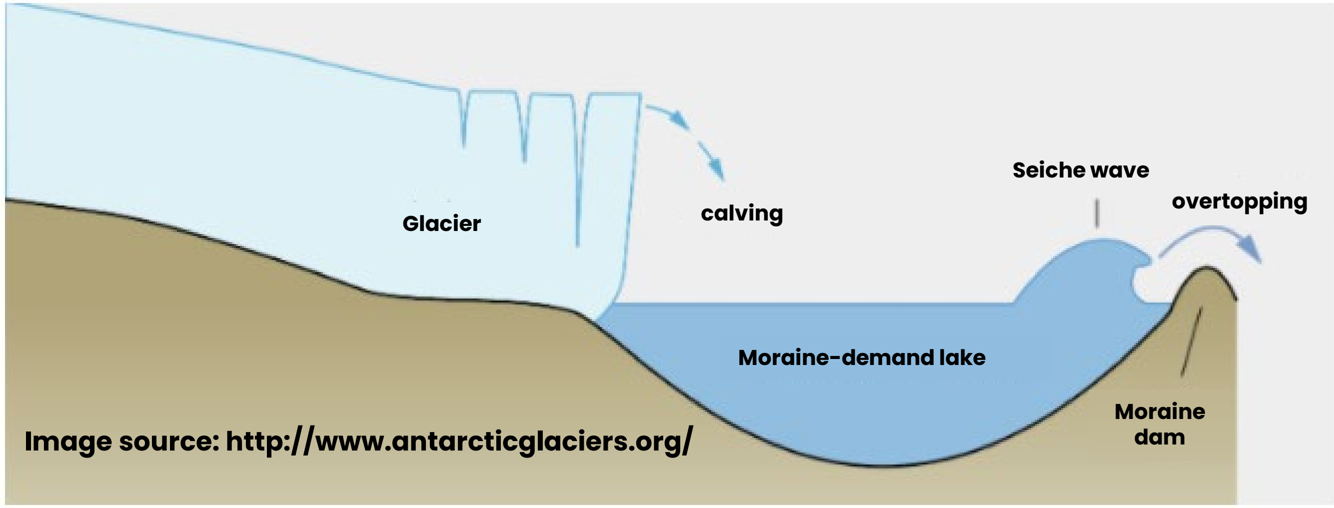
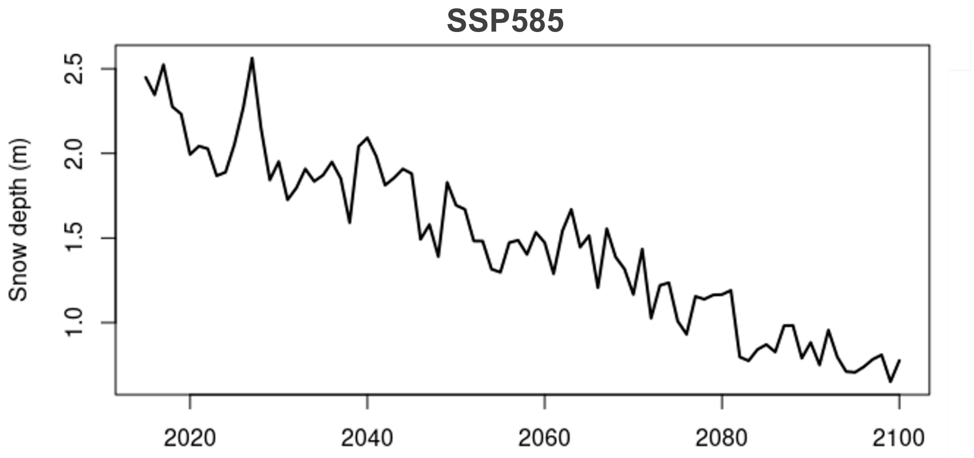


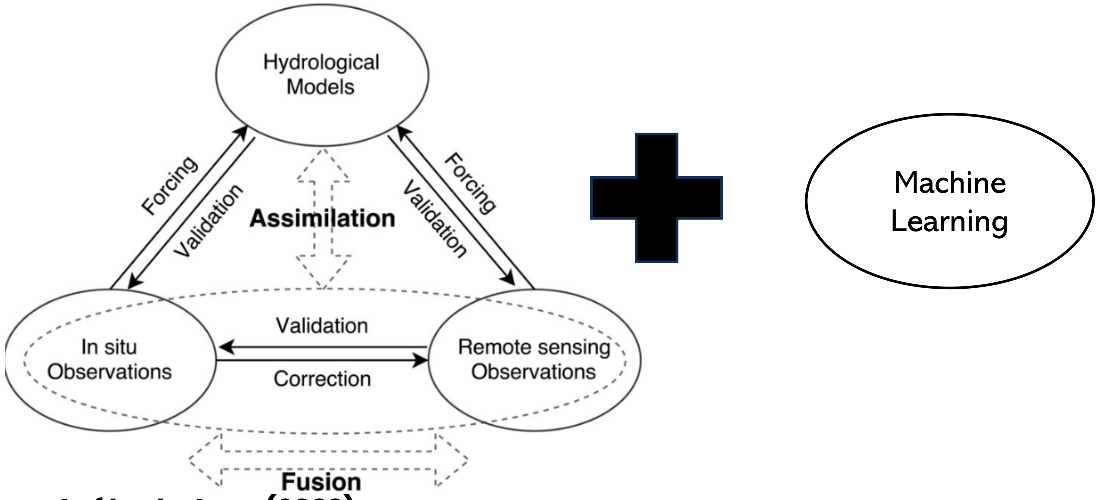
Image source: http://www.antarcticglaciers.org/



- With the ongoing climate change, glaciers are melting more rapidly. If the trend continues, major river basins across East Asia, including those with Tibetan glaciers, are expected to experience flooding.
- Furthermore, by approximately 2050, substantial droughts are projected due to the deficit of glacier melting (Huss and Hock, 2018).

Data sources

- To understand and even to predict the hydrological processes and their extremes, hydrological models, observation, and remote sensing data are widely applied.
- Machine learning is actively implemented to assess the hydrological cycle and its extremes.
- This new framework has its own merits and limitations, and researchers must select the most suitable method for their purpose.
- Neither method could be solely preferable, but incorporating methods may be more suitable for representing complex and heterogeneous dynamics.

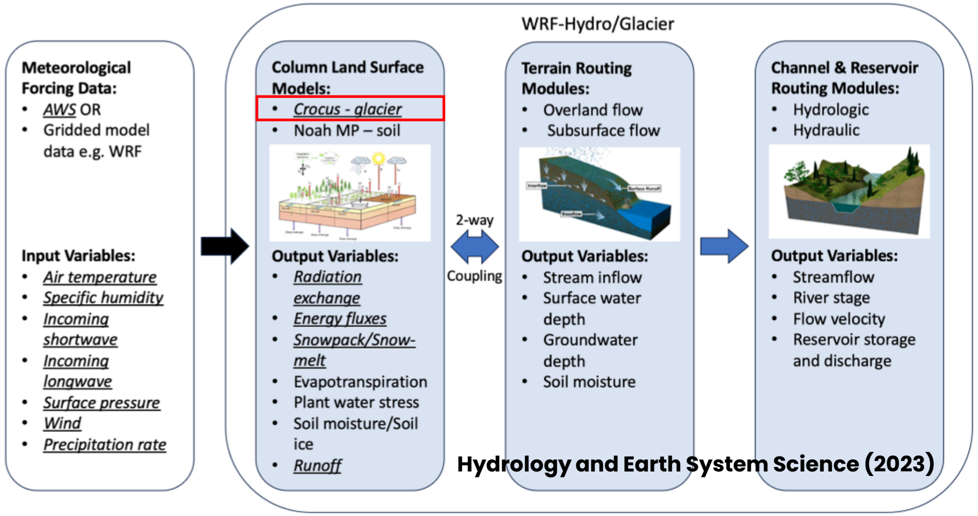


Journal of hydrology (2022)

Tools	Merits	Limitations
In sit observation	- High accuracy	- No data in future and before observe - Coarse resolution
Remote sensing	- Accuracy - Fine spatial resolution	- No data in future and before remote sense - Temporal limitation
Hydrological Model	- User control temporal and spatial resolution	- Computational time
Machine learning	- High efficiency	- Not consider physic process

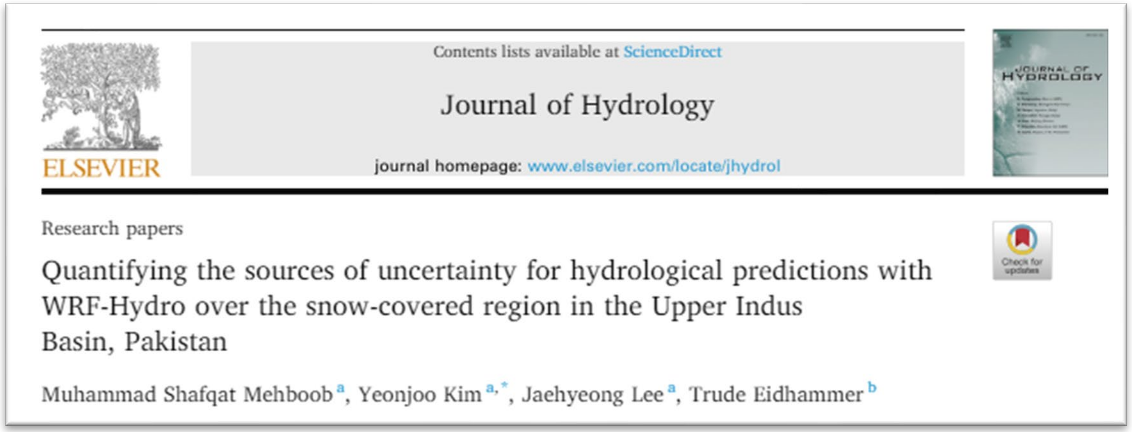
Literature review

- Selection of base-framework



Hydrology and Earth System Science (2023)

- Eidhammer et al. (2021) developed WRF-Hydro/Glacier to improve the hydrological dynamics in glaciated and snow-covered areas.
- Mehboob et al . (2022) showed that the WRF-Hydro/Glacier model performed well in the Himalaya area than WRF-Hydro.


Contents lists available at ScienceDirect

Journal of Hydrology

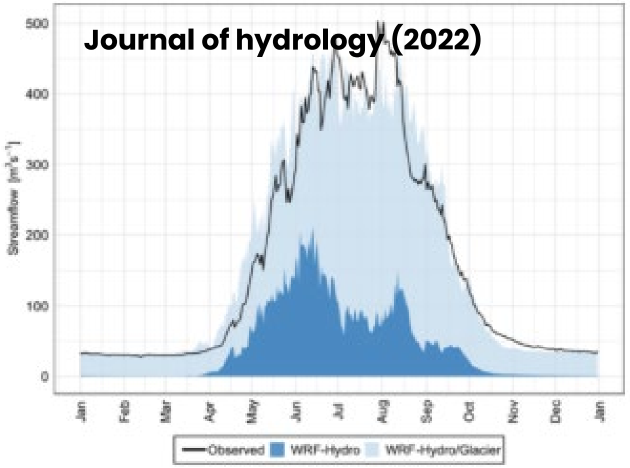
journal homepage: www.elsevier.com/locate/jhydrol

ELSEVIER

Research papers

Quantifying the sources of uncertainty for hydrological predictions with WRF-Hydro over the snow-covered region in the Upper Indus Basin, Pakistan

Muhammad Shafqat Mehboob[a], Yeonjoo Kim[a,*], Jaehyeong Lee[a], Trude Eidhammer[b]



Literature review

- How to use machine learning to adapt physic-based model

ARTICLE

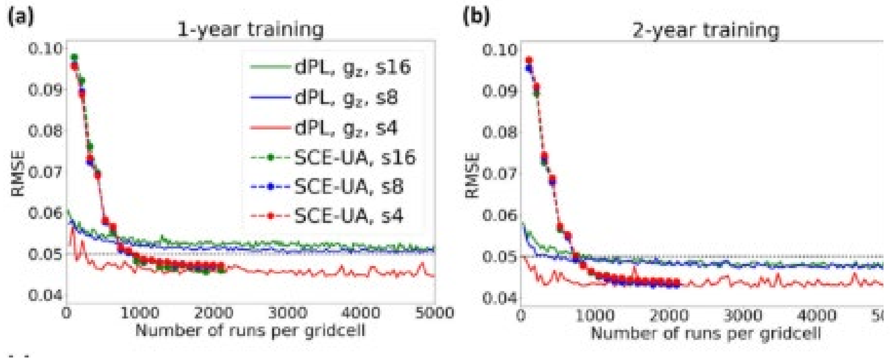
Check for updates

https://doi.org/10.1038/s41467-021-26107-z OPEN

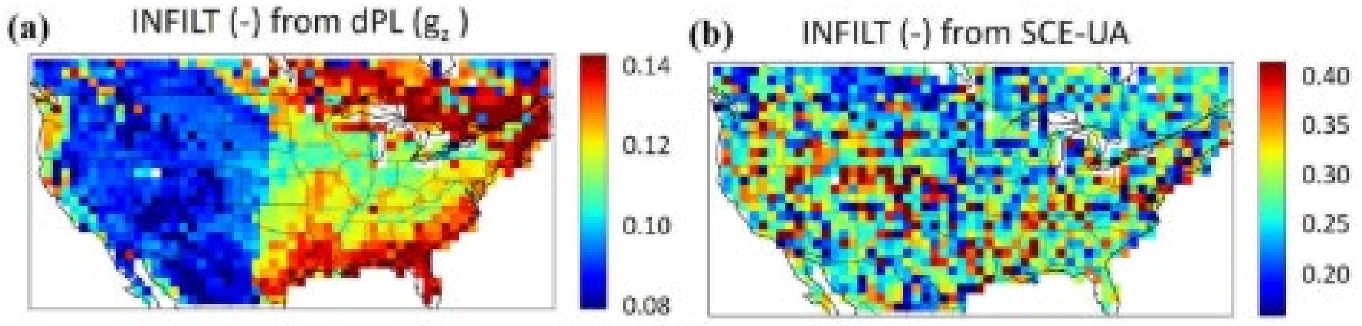
From calibration to parameter learning: Harnessing the scaling effects of big data in geoscientific modeling

Wen-Ping Tsai[1], Dapeng Feng[1], Ming Pan[2,3], Hylke Beck[4], Kathryn Lawson[1,5], Yuan Yang[6,7], Jiangtao Liu[1] & Chaopeng Shen[1,5]

- Tsai et al. (2020) proposed machine learning methods to calibrate the a geoscientific model with a generated surrogate model of the geoscientific model.
- The surrogate model reduces computational time and generates regionalized parameters.



Reduce computational time



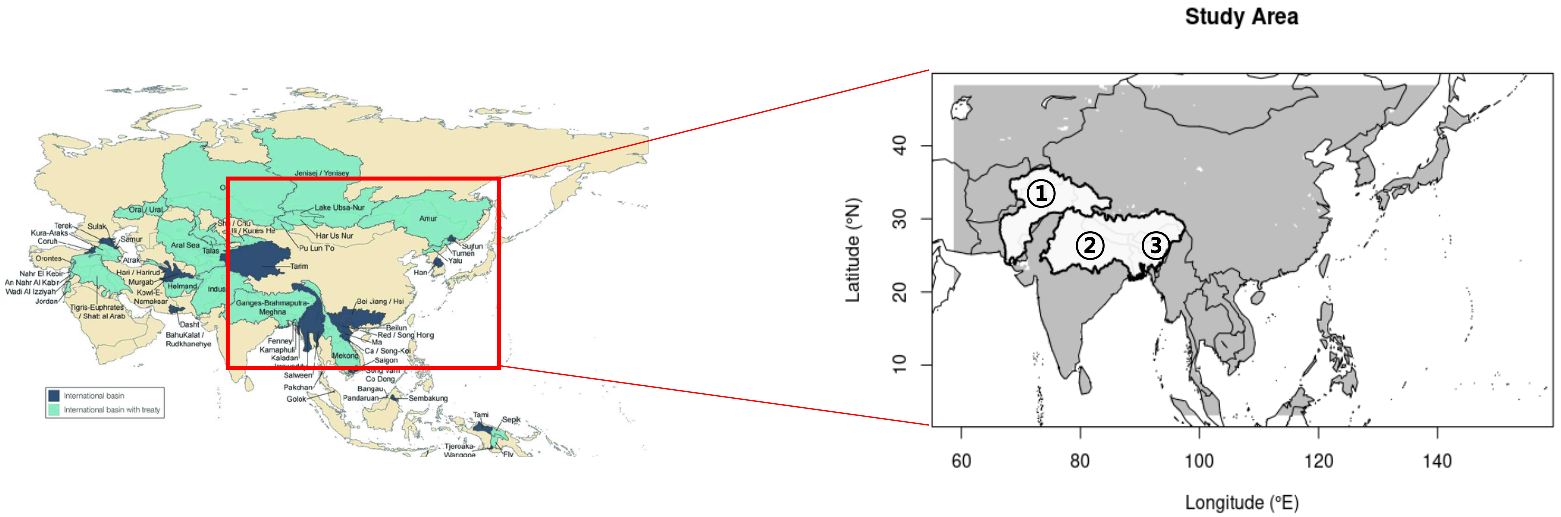
Regionalized parameters

Research Objectives

- To build a hydrological model appropriate for East Asia, with glaciers as the major water source
- To apply machine learning algorithm to build a more efficient and improved model with constrained parameters
- To use the constrained model to assess changes in streamflow and its contribution from glacier-melting

Methods

Study Sites

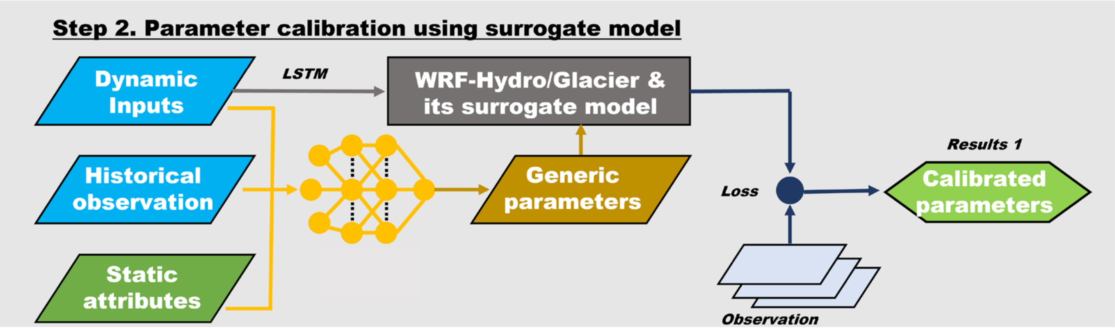


Basin	① Indus	②Ganges	③Brahmaputra
Total Area (km²)	1,005,789	990,316	525,797
P (mm)	423	1,035	1,071
Upstream area (%)	40	14	68
Glaciated area (%)	2.2	1.0	3.1

Experimental design

Contents		Description
Model		WRF-Hydro-Glacier
Domain Resolution	Land	0.25° (about 25 km)
Meteorological	Historical	GLDAS, GFDL-ESM4
	SSP585	CMIP6 SSP585 (GFDL-ESM4)
Calibration	Soil moisture	ESA-CCI (satellite)
	Surface Runoff	GLDAS (model reanalysis)
	ET	MODIS (satellite)
Time periods	Historical	2011 - 2020
	Mid future	2041 – 2050
	Far future	2091 - 2100
Study area	Latitude	9.6N – 47.7N
	Longitude	80.0W – 140.0W
	Surface area	East Asia
Land surface option		Noah-Multiparameterization Land Surface Model (Noal-MP LSM)
Landuse type		USGS

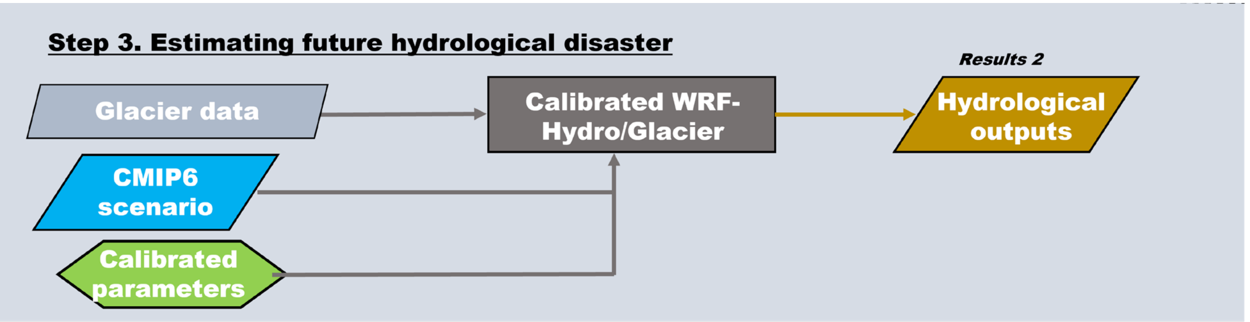
Surrogate model



Parameter	Explanation	Default value	Range
LKSAT	Lateral saturated conductivity for each soil type	3.38e-6	3.38e-7 - 3.38e-5
SLOPE	Linear reservoir coefficient	0.1	0.01-10
REFDK	Surface runoff parameterization	2.00e-6	1e-7 – 1e-5
REFKDT	Surface runoff parameterization	3	0.1-10

- In step 1, a generative surrogate model to calibrate parameters using the input and output of WRF-Hydro/Glacier
- Estimate parameters from the surrogate model using observed and satellite data (soil moisture, surface runoff and ET)
- Evaluate streamflow from the constrained WRF-Hydro/glacier with calibrated parameters

Effects of glacier melting



- (a) Changes in streamflow

  = future streamflow – historical streamflow

- (b) Changes in glacier-melting water

  = future melting water – historical melting water

- (c) Contribution of melting water in future

$$*\text{Contribution} = \frac{\text{(b) Increased melting water}}{\text{(a) Increased total streamflow}}$$

Results

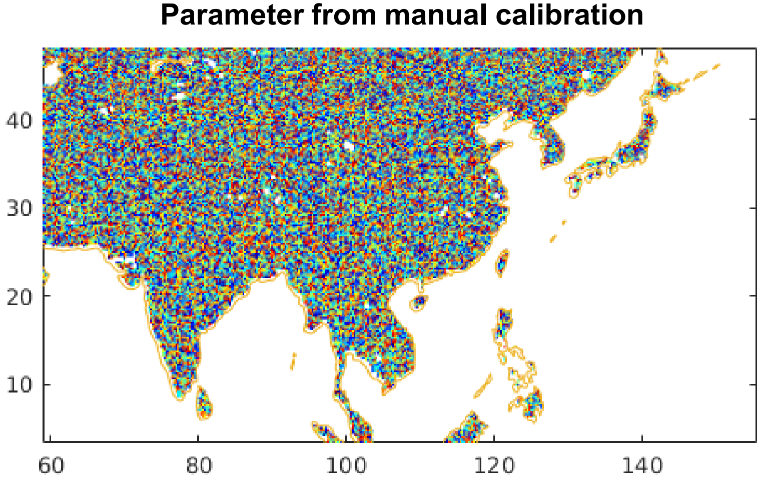
Surrogate model evaluation

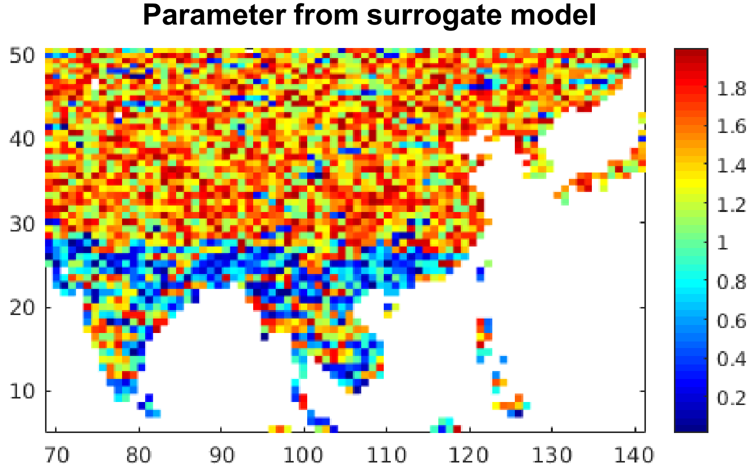
- Computational time

Computation time	
Manual	2 hours (1 time)
Surrogate	1 hour (2,000 times)

- The computation time is greatly reduced with the surrogate model → the surrogate model shows efficient methods.

- Regionalized parameter

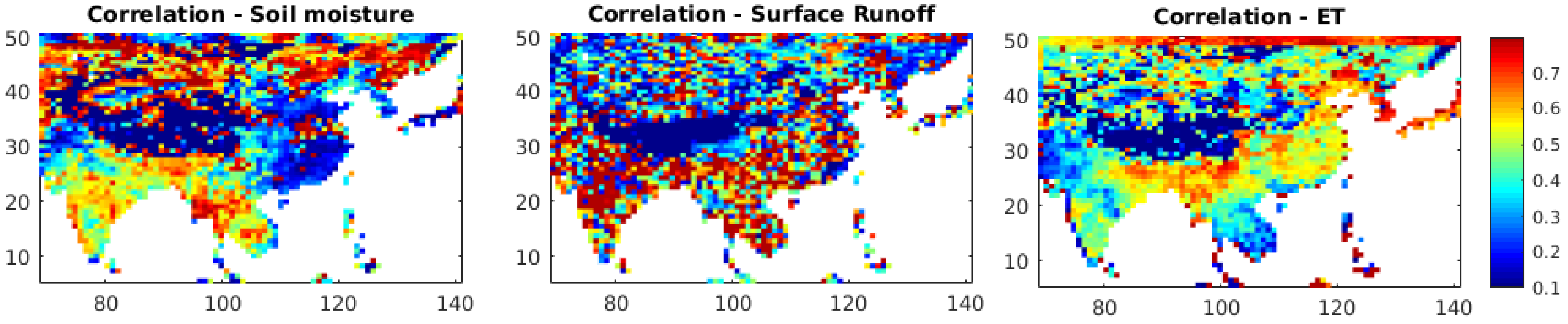




- The parameters of the surrogate model appeared to represent regional, especially latitudinal, characteristics.

Surrogate model evaluation

- Surrogate model of WRF-Hydro/glacier

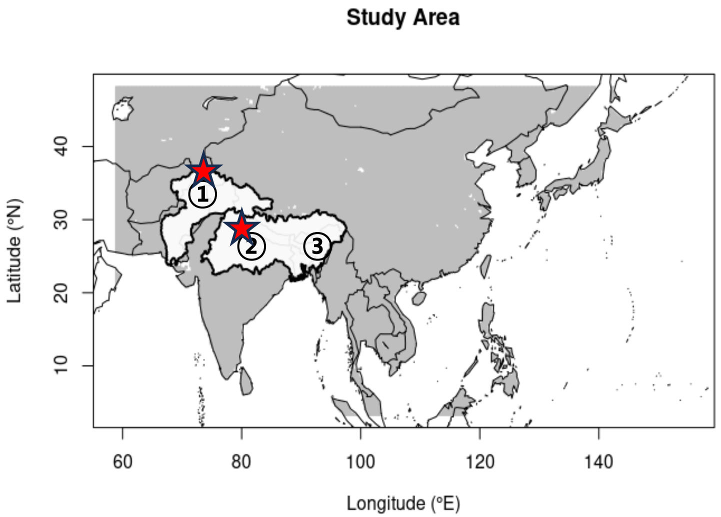


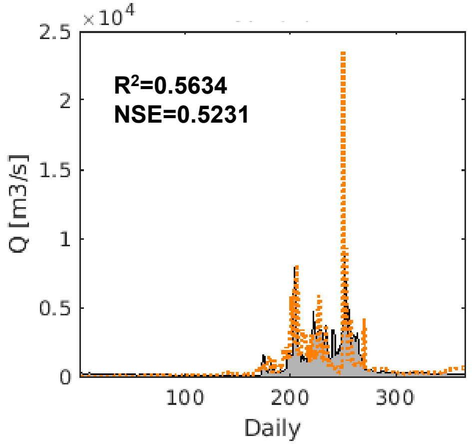
- The constrained results of soil moisture, Q, and ET generally agreed with the observed values, with a correlation value of about 0.5 and even up to 0.9.
- Yet, the low performance as low as 0.2 over the glaciated-area indicates that the dynamic of glacier-dominating areas are not yet properly represented.

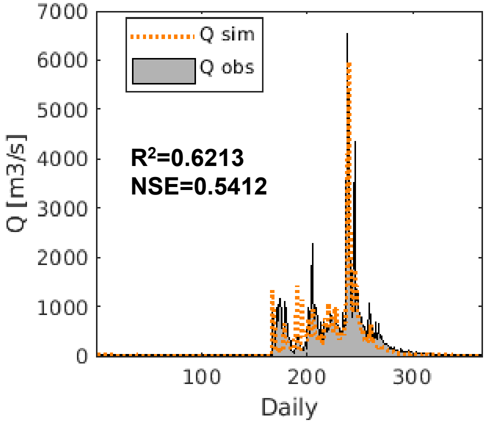
	SM	SF	ET
Max	0.9215	0.9852	0.8752
Median	0.3244	0.4118	0.4917

Model evaluation

- Constrained WRF-Hydro/Glacier

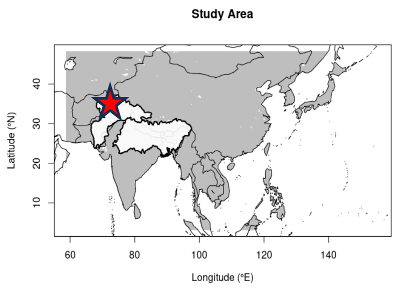




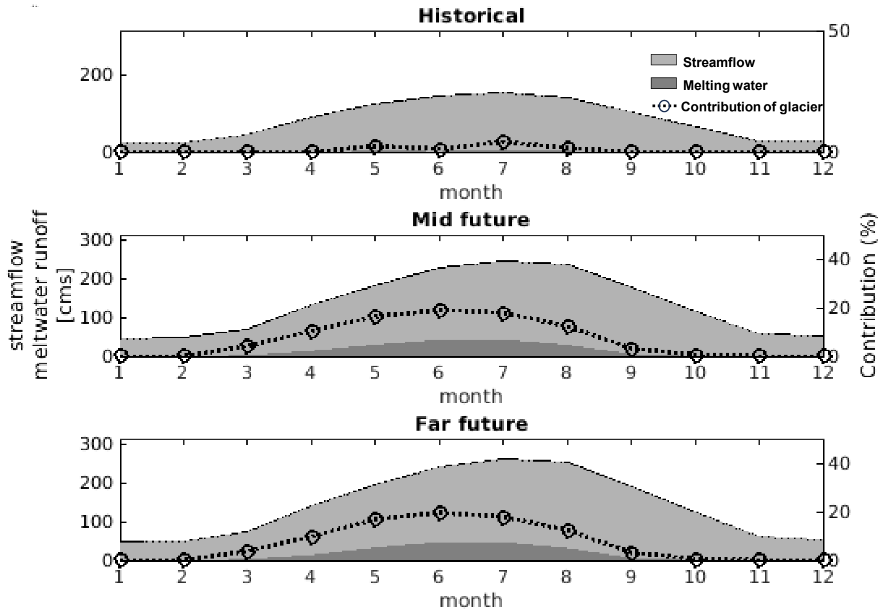


- The constrained results of streamflow (outputs of the WRF-Hydro/Glacier model with surrogate model) were satisfactory, r^2>0.5 and NSE > 0.5 (Moriasi et al., 2007)

Effects of glacier



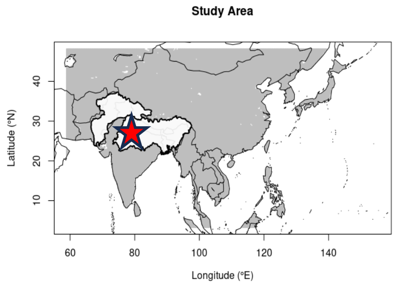
- Indus basin



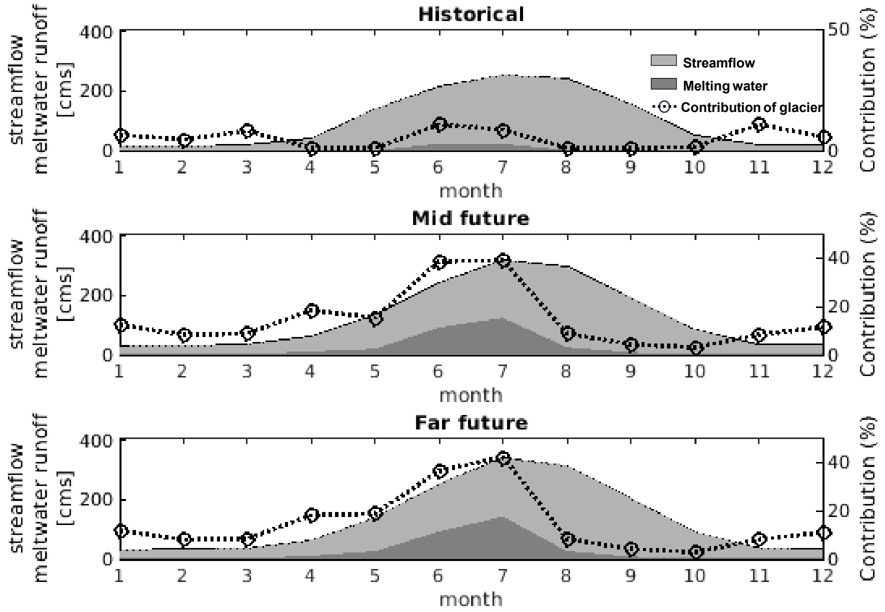
	Annual Streamflow (cms)	Annual melting water (cms)	Contribution (%)
Historical	963	121.9	-
Mid-future	1577	301.8	
Changes	(a) 614	(b) 179.9	29.1
Far future	1687	326.1	
Changes	(a) 724	(b) 205.2	28.34

- In both the mid and far futures, streamflow has increased by 50% and 60%, respectively. In addition, the amount of glacier melting water has more than doubled in both futures.
- The contribution of glaciers to future streamflow growth is expected to be 29.1% and 28.3%, respectively.

Effects of glacier



- Ganges basin

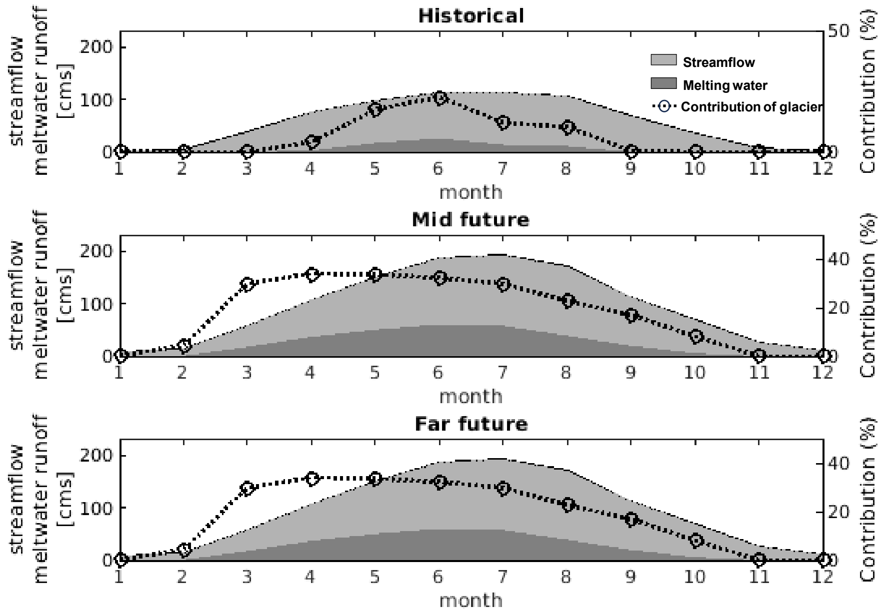


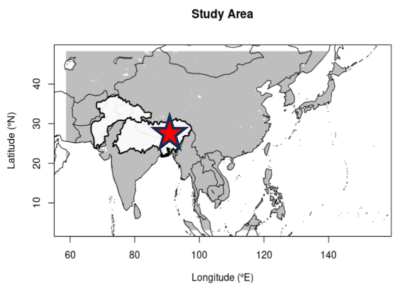
	Total Streamflow (cms)	Total melting water (cms)	Contribution (%)
Historical	1183.1	172.3	-
Mid-future	1496.3	301.5	
	(a) 313.2	(b) 129.2	41.2
Far future	1591.3	328.47	
	(a) 408.2	(b) 156.2	38.3

- In both the mid and far futures, streamflow has increased by 26% and 34%, respectively. In addition, the amount of glacier melting water has increased by approximately 75% and 90%, respectively.
- The contribution of glaciers to future streamflow growth is expected to be 41.2% and 38.3%, respectively.

Effects of glacier

- Brahmaputra basin





	Total Streamflow (cms)	Total melting water (cms)	Contribution (%)
Historical	660.3	70.7	-
Mid-future	1106.9	285.4	
	(a) 446.6	(b) 214.7	48.0
Far future	1107.0	285.5	
	(a) 446.7	(b) 214.8	48.1

- In both the mid and far futures, streamflow has increased by 67%. In addition, glacier melting water has increased by approximately 300%, respectively.
- The contribution of glaciers to future streamflow growth is 48%, which is the greatest among the three basins.

Conclusions

Conclusions

- WRF-Hydro/Glacier

  : well simulated streamflow with melting water in the glaciated area

- Surrogate model

  : showed efficiency with a much shorter time

  : can take regional characteristics into account when calibrating parameters

- Under the future scenario,

  : streamflow will increase in both future

  : contribution of glaciers appeared to be different among the basins therefore critical for water resource management in East Asia

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Thank you!

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Training Workshop: The community WRF-Hydro Modeling System in 2017