Modelling the Impact of Black Carbon on a Nepalese Glacier Catchment Using CRHM and Bias-corrected Reanalysis Data

Prasanna Dhakal[1], Dhiraj Pradhananga[2,3] and John Pomeroy[3]

[1]Institute of Engineering & [2]Department of Meteorology, Tribhuvan University, Kathmandu, Nepal

[3]Centre for Hydrology, University of Saskatchewan

Canmore, Canada

Issues

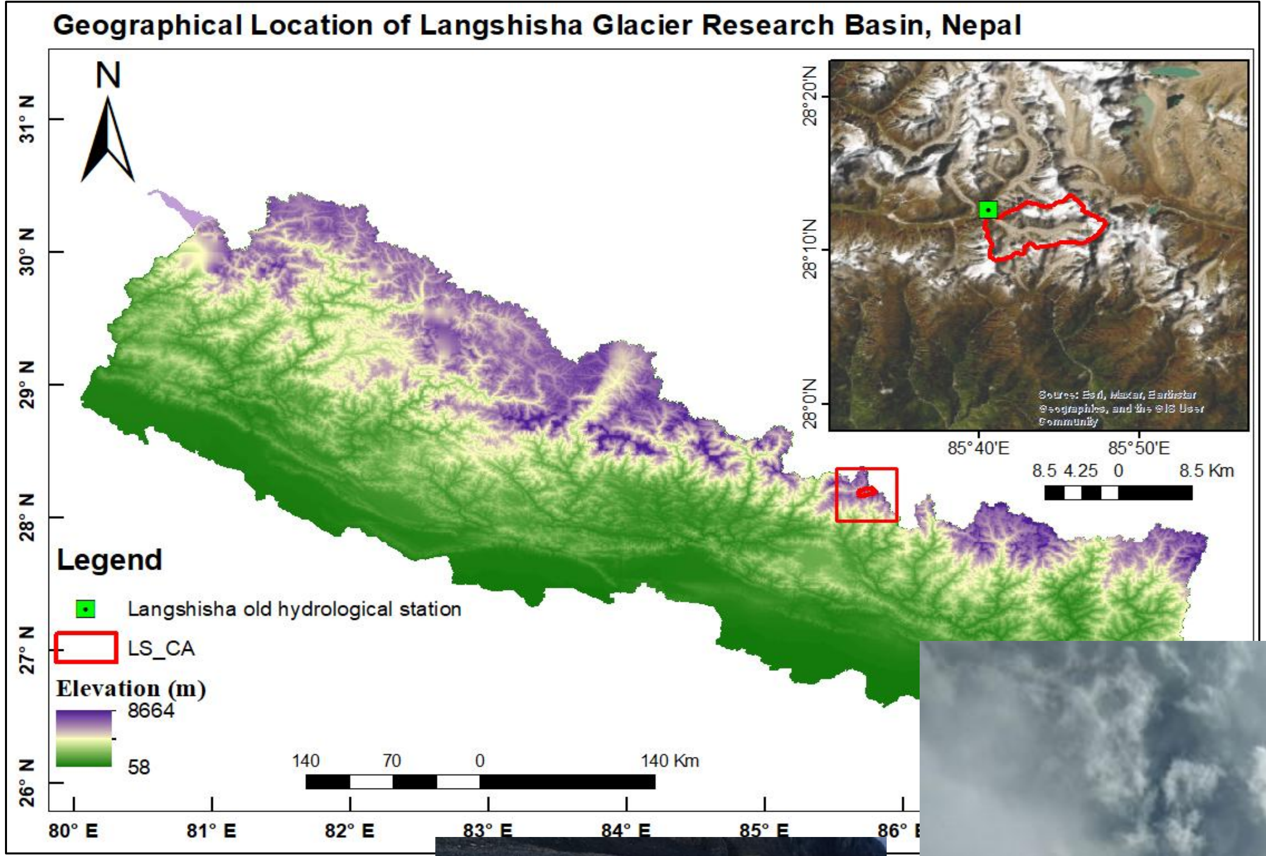
- HKH: large pollution source in the form of black carbon (BC), dust and other shortwave radiation absorbing impurities
- Black Carbon (BC) has positive feedback effect on glacier melt
- Need to apply a cold region specific, process based hydrological model to diagnose and assess the hydrological and glaciological impacts of BC deposition.

Source: Basanta Pratap Singh

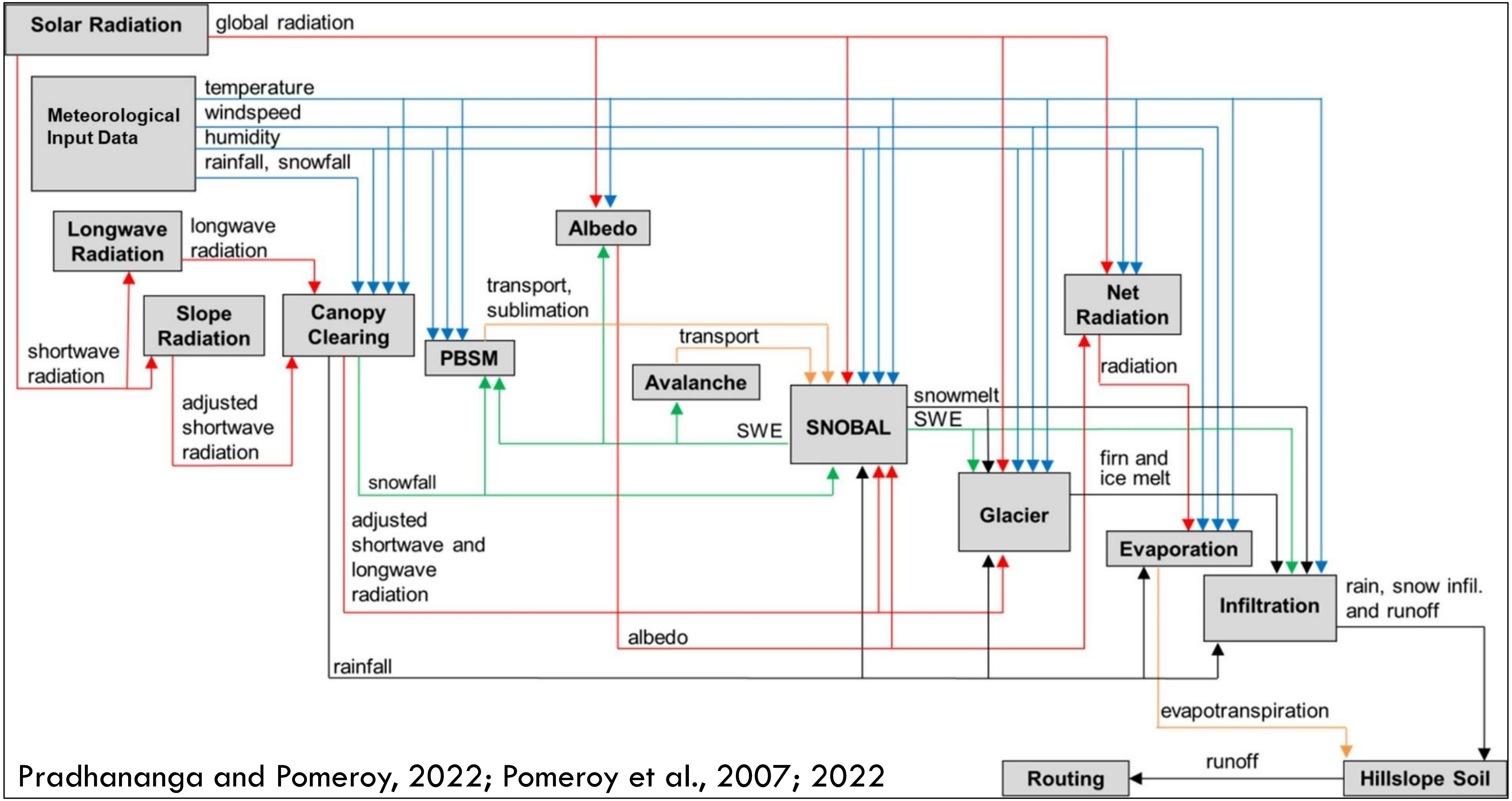
Study Basin

- Langshisha Glacier Research Basin (LGRB) of Langtang valley
- Elevation 4180 to 6820 m
- Monsoon dominant climate circulation

Langshisha Glacier Research Basin		
Land cover type	**Area (km²)**	**% cover**
Firn	12.0	22
Ice	3.7	7
Debris covered glacier	4.7	9
Pasture	13.9	25
Barren	20.5	37
Total	54.8	

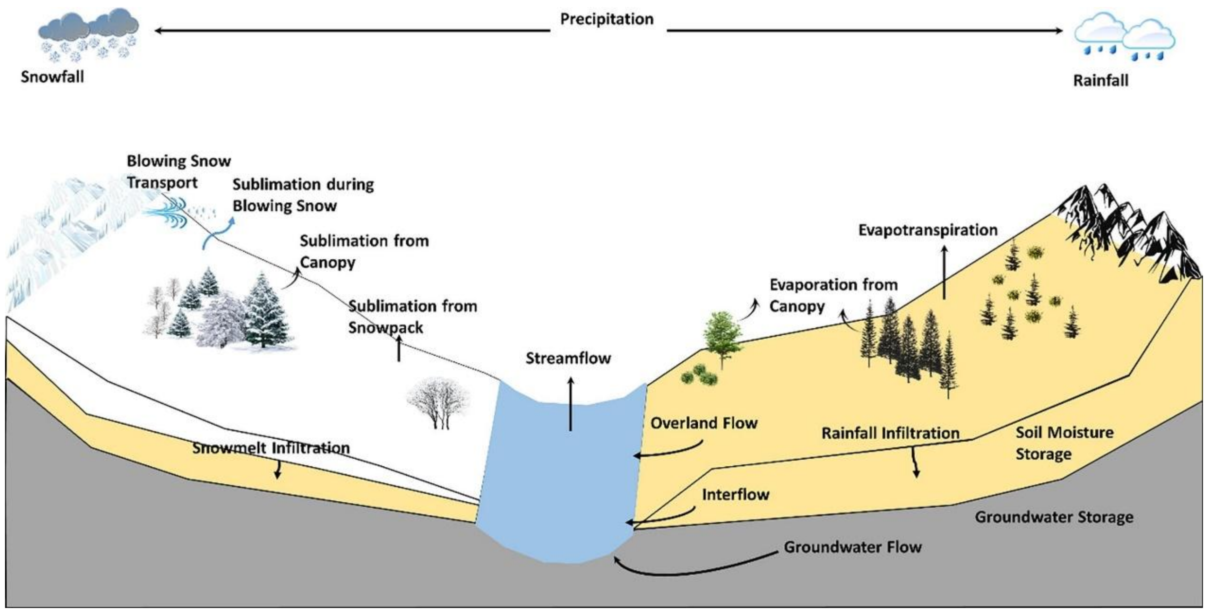


Cold Regions Hydrological Modelling Platform (CRHM)

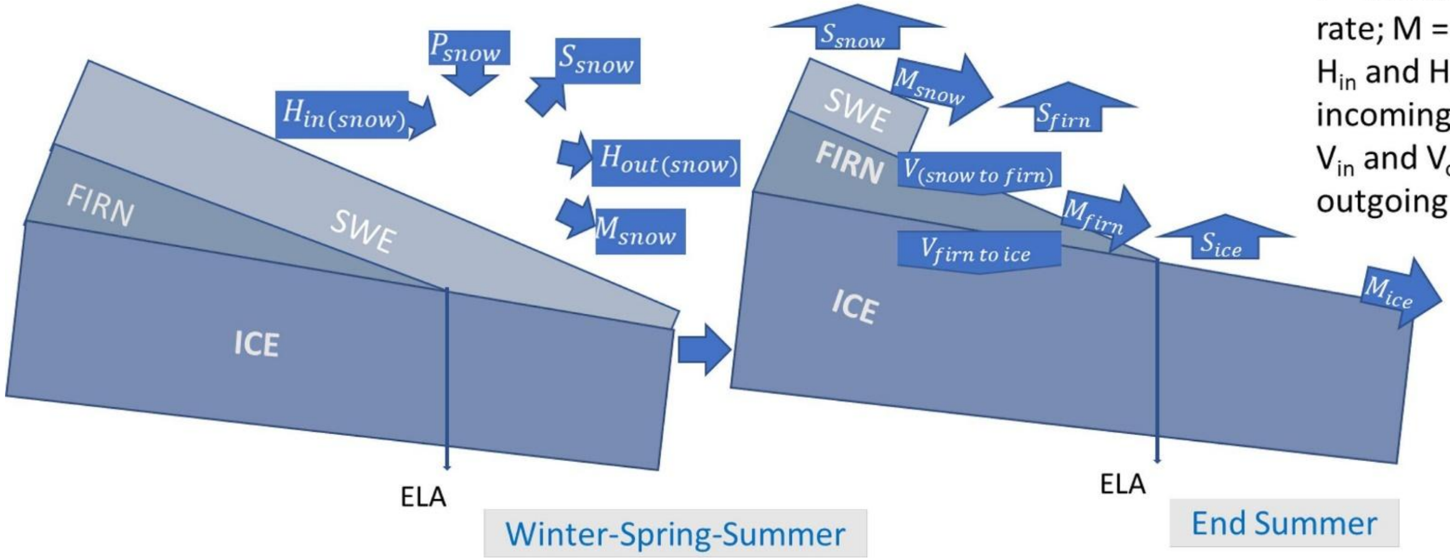


Pradhananga and Pomeroy, 2022; Pomeroy et al., 2007; 2022

CRHM Conceptual Setup



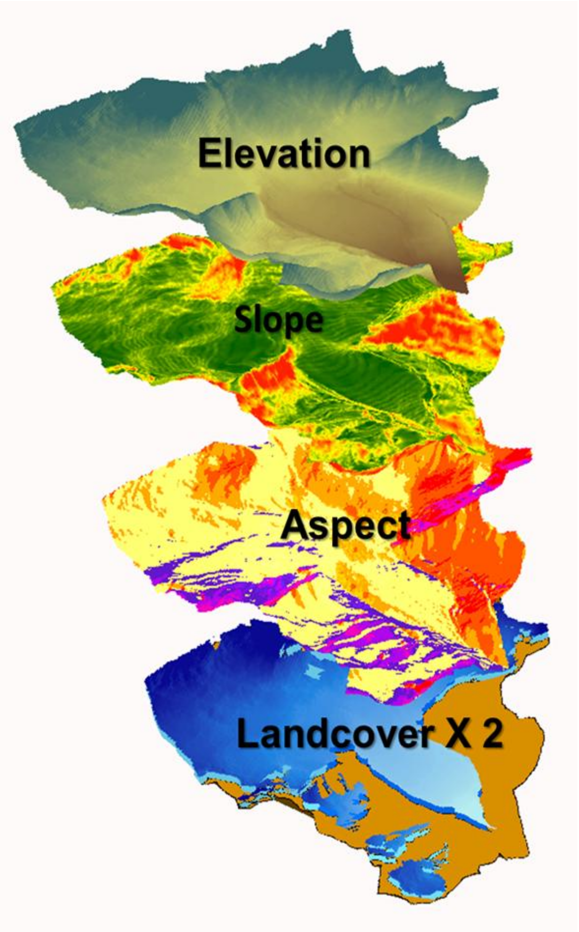
Canadian Rockies conceptual model (Fang and Pomeroy, 2020)

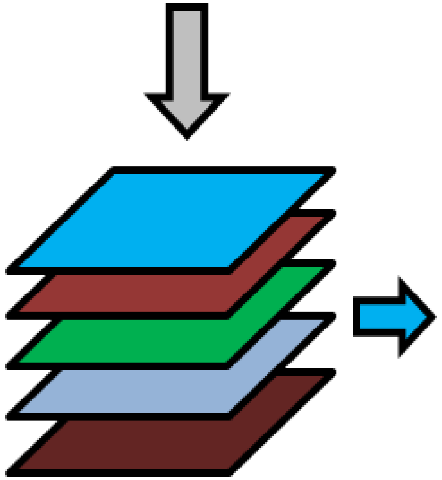


P = snowfall rate; S = sublimation rate; M = melting rate
H_{in} and H_{out} are horizontal incoming and outgoing mass flows.
V_{in} and V_{out} are incoming and outgoing vertical mass flows.

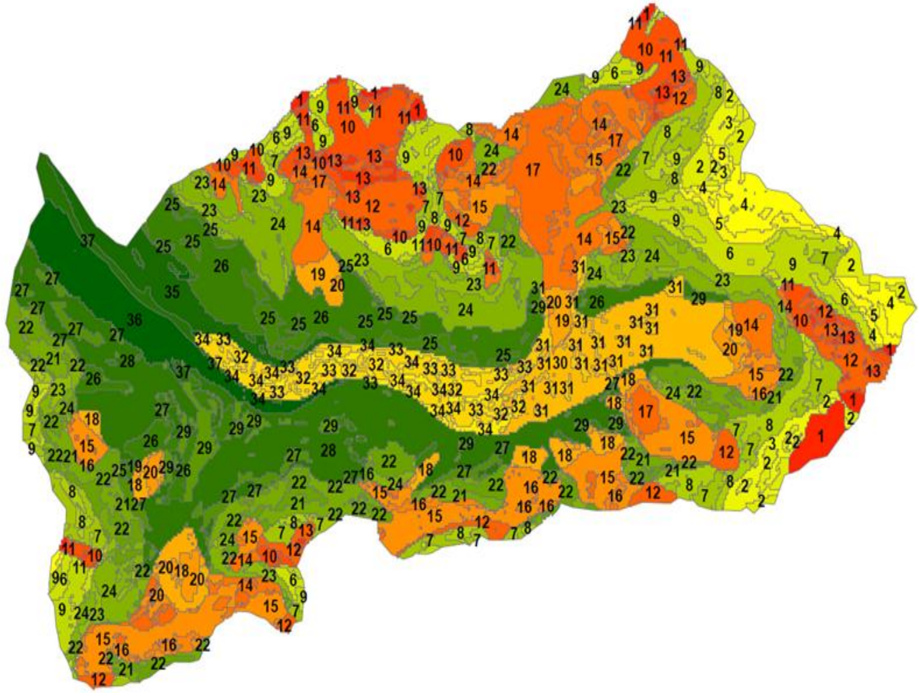
Mass balance simulation in CRHM-Glacier module
(Pradhananga and Pomeroy, 2022)

Discretisation of Langisha Glacier Research Basin into Hydrological Response Units





Intersect of 3+2 (LULC+RGI 6.0)
layers in ArcGIS interface

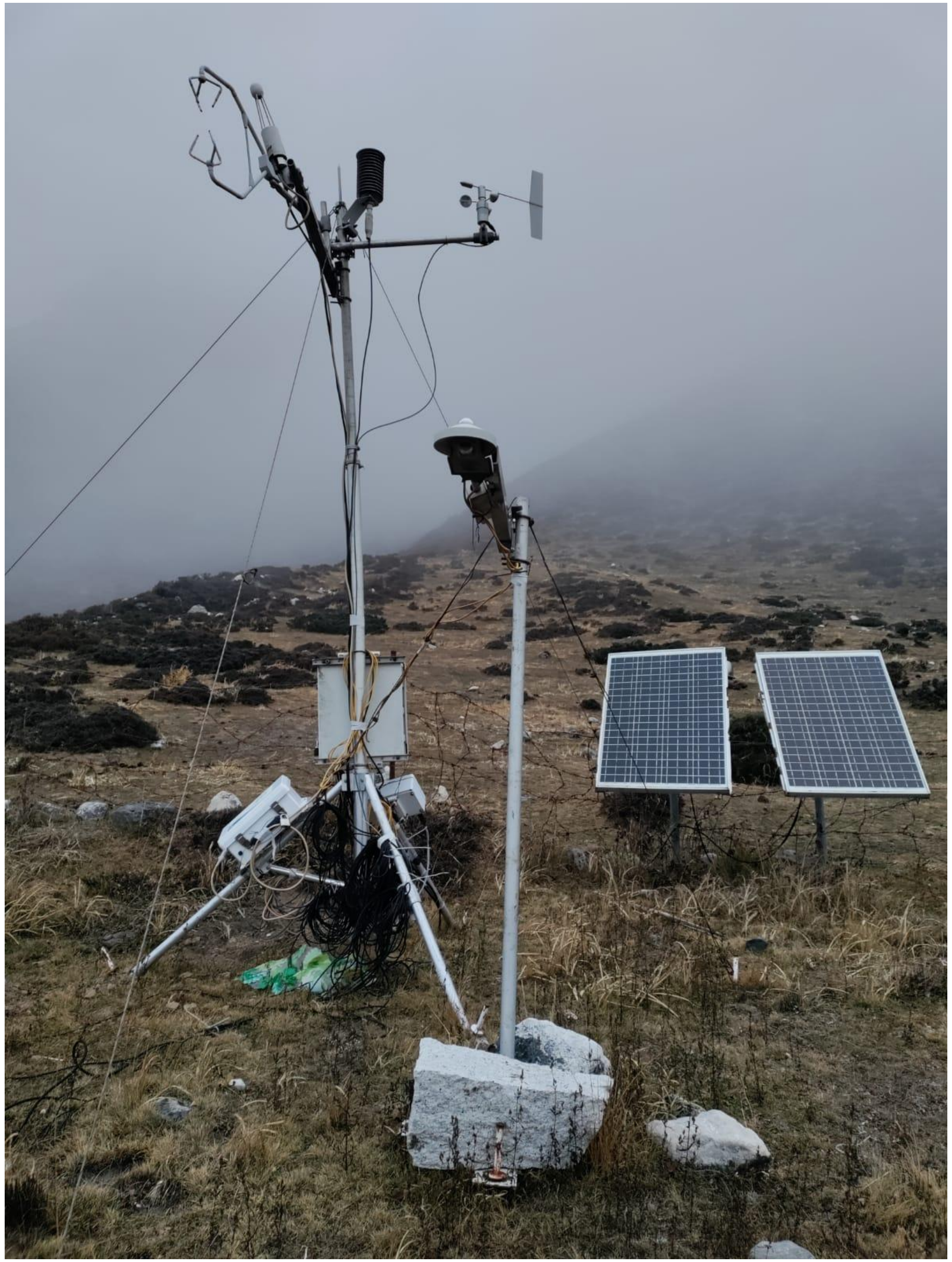


37 HRU types, 10 firn/ice layers

FABDEM; Landsat 2016; Randolph Glacier Inventory 6.0.

FORCING DATA

- WFDEI bias-corrected (Pradhananga et al., 2024) using Kyanging AWS (ICIMOD, 2016)
- Hourly resolution climate data used to force model:
  - Temperature (°C)
  - Precipitation (mm)
  - Wind Speed (m/s)
  - Incoming Shortwave Radiation (W/m^2)
  - Incoming Longwave Radiation (W/m^2)
  - Relative Humidity (%)



Kyanging Automatic Weather Station

OBSERVATION DATA

Station Name	Elevation (m)	Variables	Station type	Use in study	Data use date
Kyanging AWS	3862	t, rh, u, p, Qsi, Qli	AWS	WFDEI bias correction	2012 to 2019
Yala Glacier	5291	Tair, ppt, snow depth, Qsi, Qli	AWS	Ice albedo	2013 to 2014
Yala Base Camp	5090	Tair, ppt, snow depth, Qsi, Qli	AWS	Fresh snow albedo	2013 to 2014
Pluviometer Langshisha Glacier Station	4452	t, rh, u, p, snow depth	AWS	Verify forcing data	2016 to 2019
Langshisha old	4069	Q	Hydrological	Evaluate model Performance	2014 to 2019

BC AND ALBEDO CHANGE : SNOW

- Gul et al. (2021): 5.08% albedo reduction for 0.73 μg/m^3 atmospheric BC concentration during the pre-monsoon season.
- Albedo change for other seasons was interpolated using the pre-monsoon albedo change and atmospheric BC concentration.
- The approach assumes that atmospheric BC deposits on snow affect the snow albedo in similar ways in all seasons.

Season	Atmospheric BC (ug/m3)	Albedo reduction (%)
pre-monsoon	0.73	5.08
monsoon	0.23	1.6
post-monsoon	0.29	2.02
winter	0.46	3.2

BC AND ALBEDO CHANGE: FIRN AND ICE

Average BC deposition of 266 µg/m^2 for Yala Glacier (Gul et al., 2021), was input into Yasunari et al.'s (2012) equation to calculate the change in albedo due to BC deposition on firn and ice.

Firn

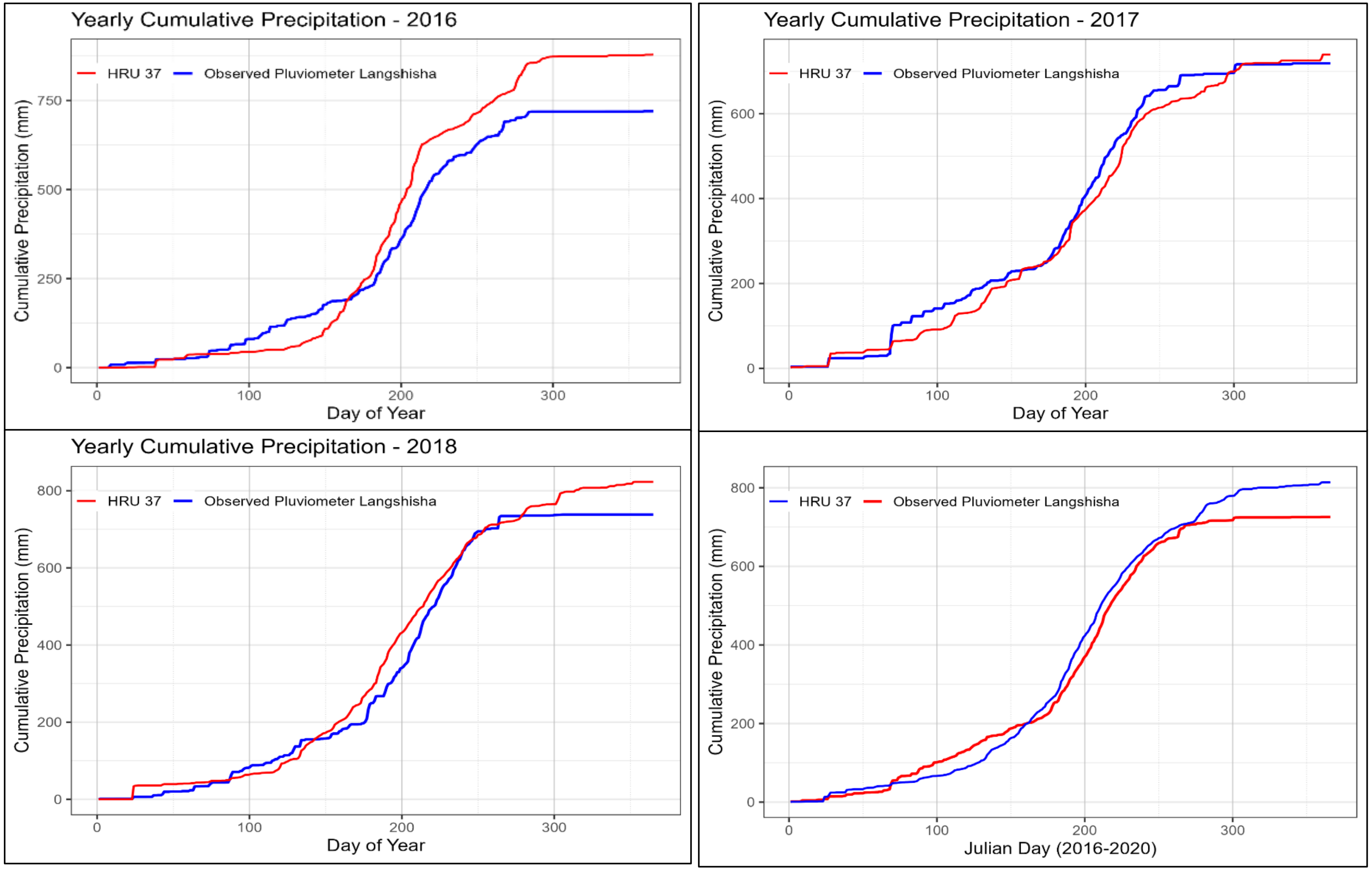
BCD amount (µg m^{-2})	Firn density (kg/m^3)	BC deposition snow depth (m)	BCC (µg kg^{-1})	Albedo reduction (%)
266	450	0.02	29.6	8.0
266	780	0.02	17.1	5.3

Glacier Ice

BCD amount (µg m^{-2})	Ice density (kg/m^3)	BC deposition snow depth (m)	BCC (µg kg^{-1})	Albedo reduction (%)
266	915	0.02	14.5	4.7

Forcing Data Evaluation: Precipitation

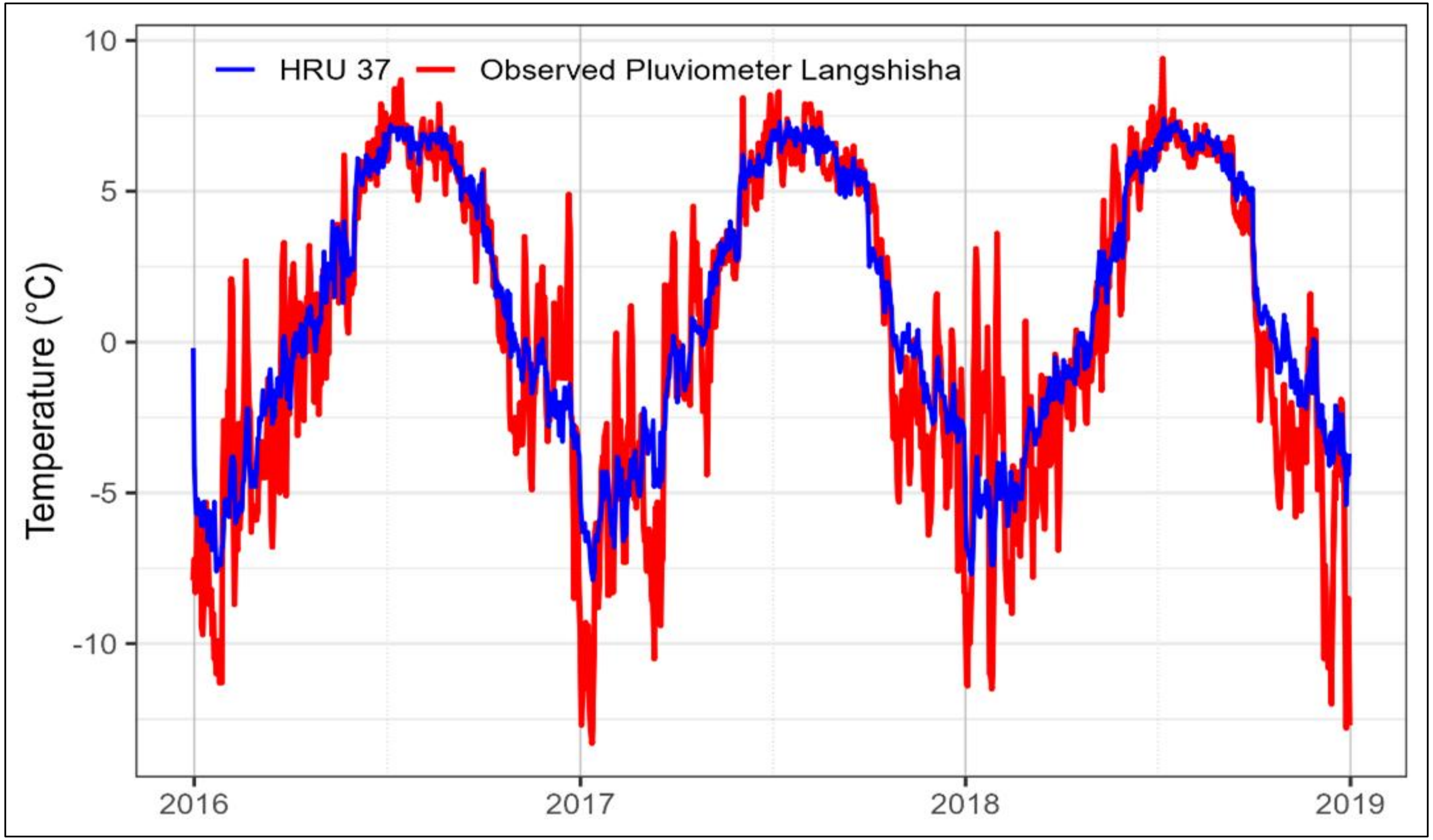
- Kyanging AWS Obs + WFDEI
- Precipitation elevation adjustment



Evaluation of elevation adjusted cumulative precipitation forcing data (HRU 37) with observations.

Forcing Data Evaluation: Temperature

- Kyanging AWS Obs + WFDEI
- Temperature Lapse rate of 0.54°C/100 m



Evaluation of lapse rate-adjusted average temperature forcing data (HRU 37) with observations.

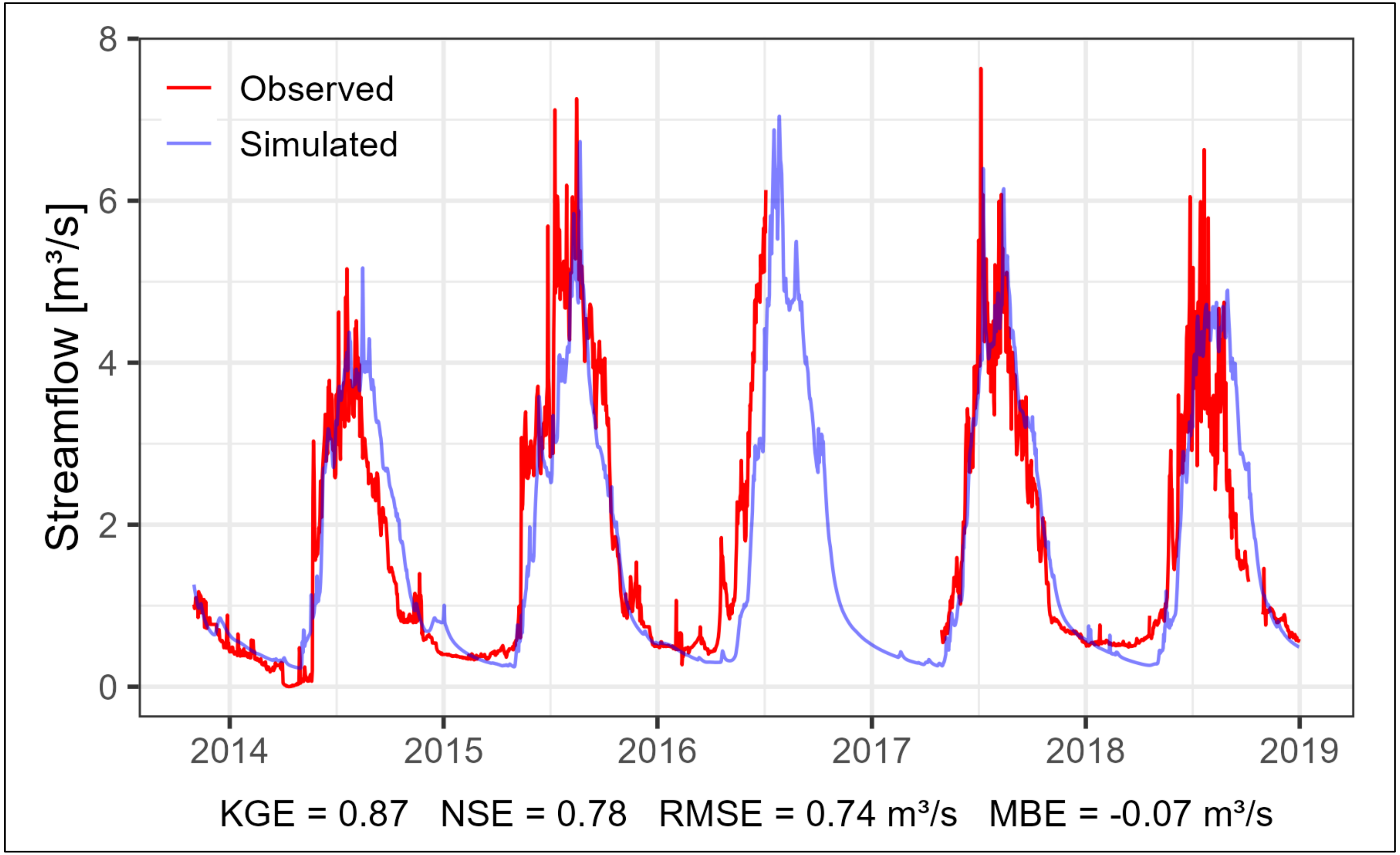
CRHM Streamflow Simulation Evaluation

Nash-Sutcliffe Efficiency (NSE) 0.87,

Kling Gupta Efficiency (KGE) 0.78,

RMSE 0.74 m^3/s

Mean Bias Error -0.07 m^3/s.



Evaluation of simulated and observed daily mean streamflow discharge at Old Langshisha discharge station.

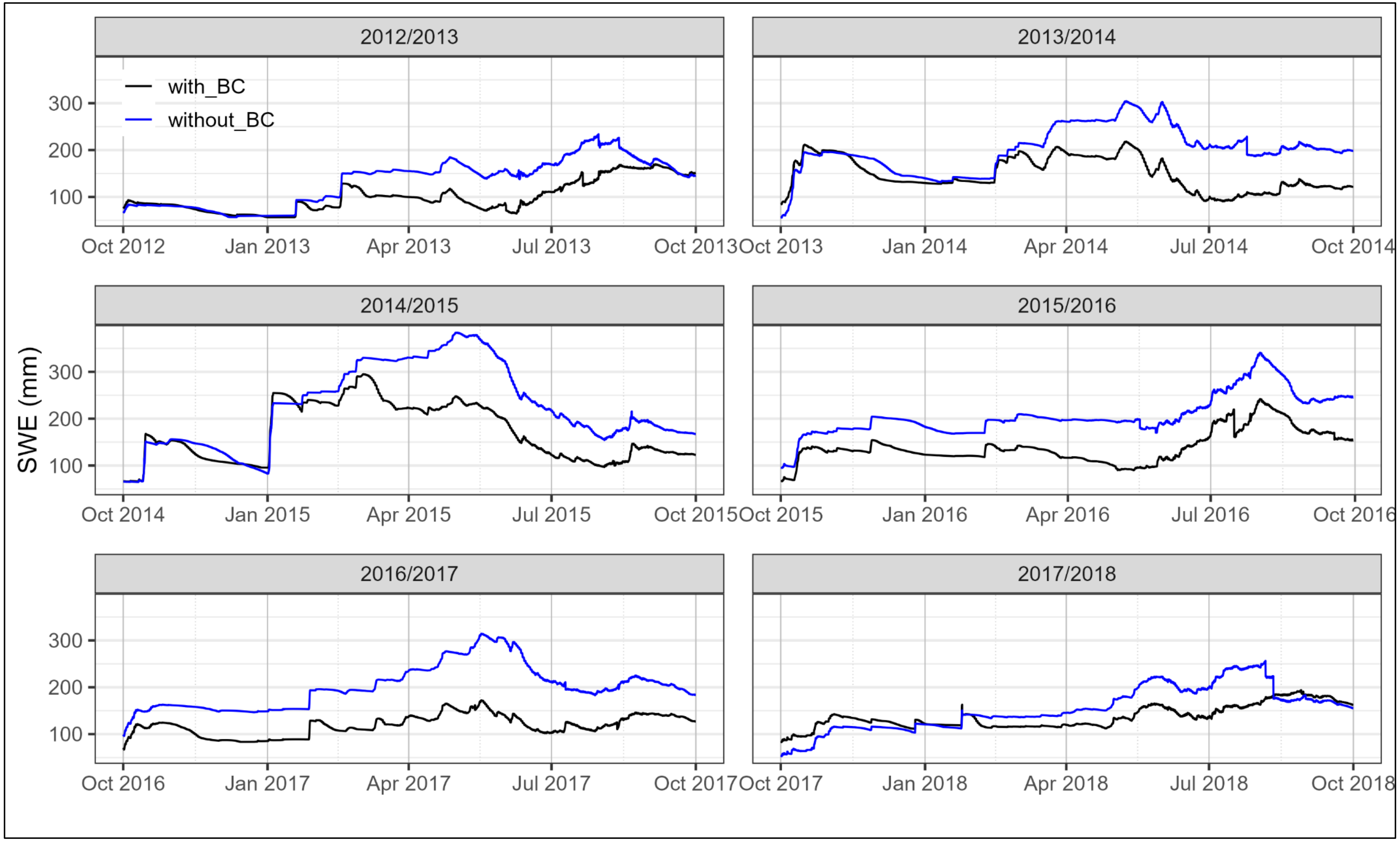
Langisha Glacier Mass Balance Results

2012-2018.

- Glacier-wide average mass balance -0.56 m w.e./year.
- Clean ice : -0.62 m w.e./year.
- Debris-covered ice : -0.023 m w.e./year.

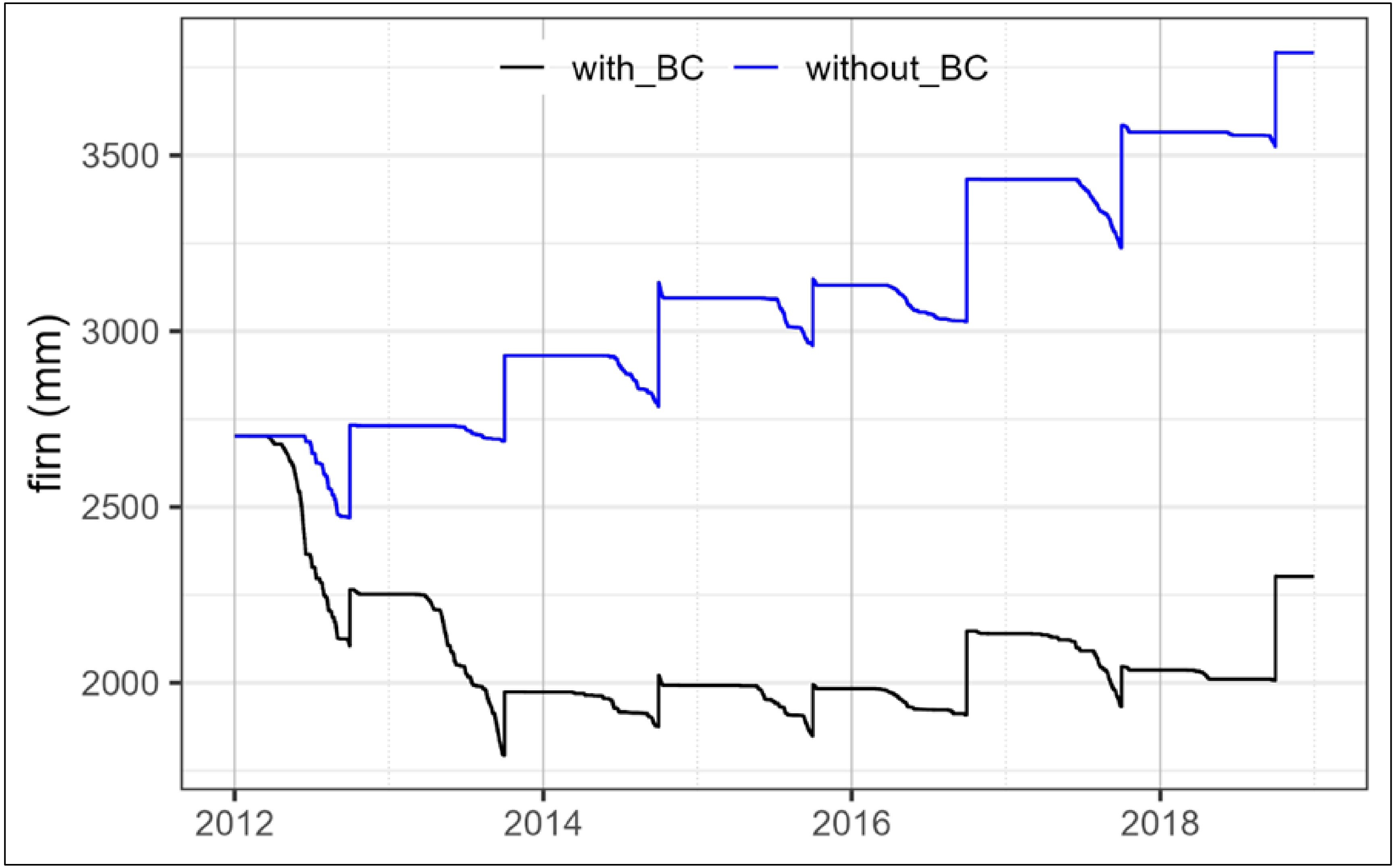
Simulated BC Impact on SWE

- SWE converted to firn at end of hydrological year (September 30).
- Decline in SWE of ~100 mm in pre-monsoon and monsoon seasons.



Simulated BC Impact on Firn

- Average firn formation decreased by 0.145 m w.e./year.
- BC stops firn accumulation.



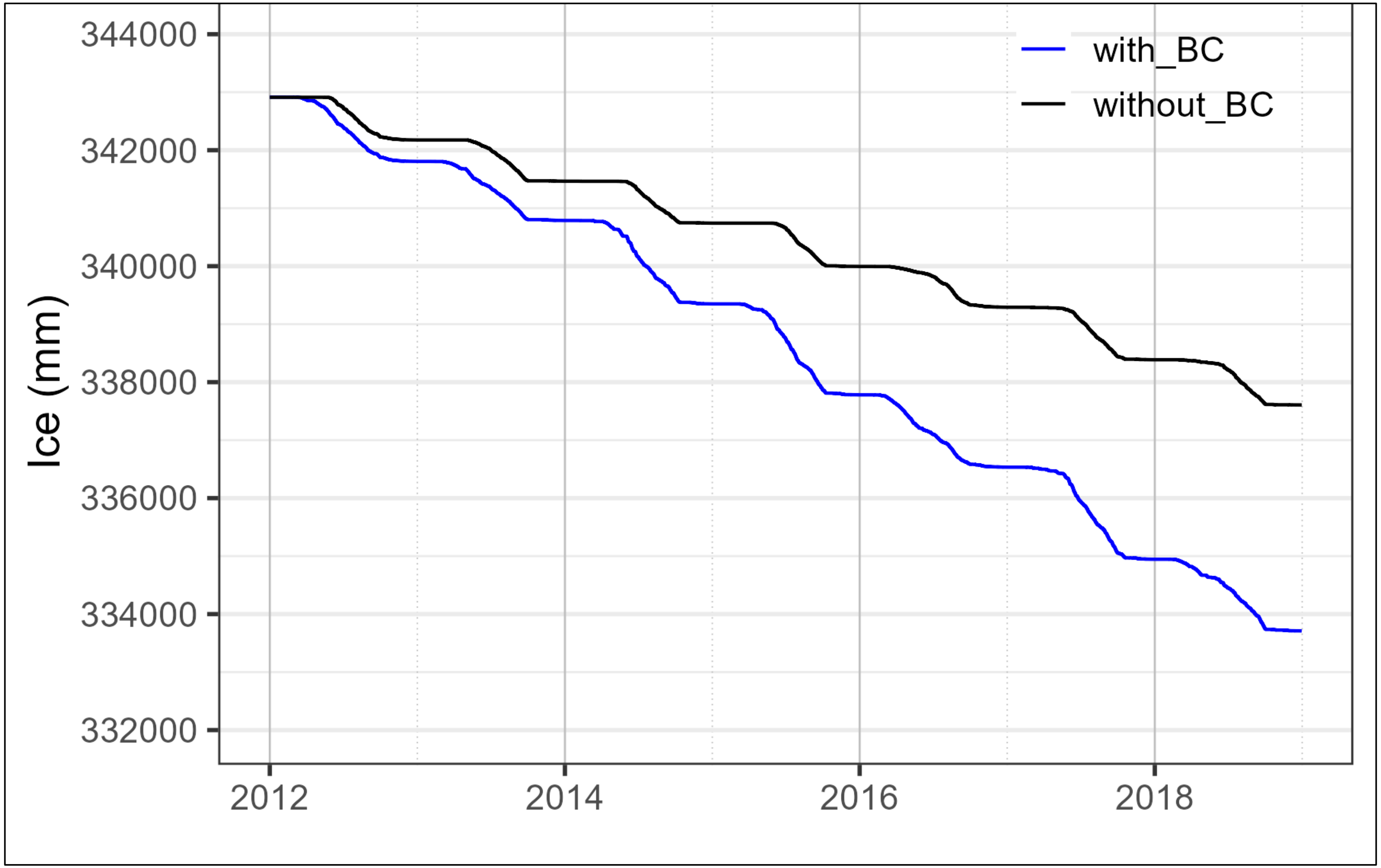
Glacier-wide average firn condition with and without the impact of BC.

Simulated BC Impact on Glacier Ice

Annual ice ablation without BC 0.75 m/yr

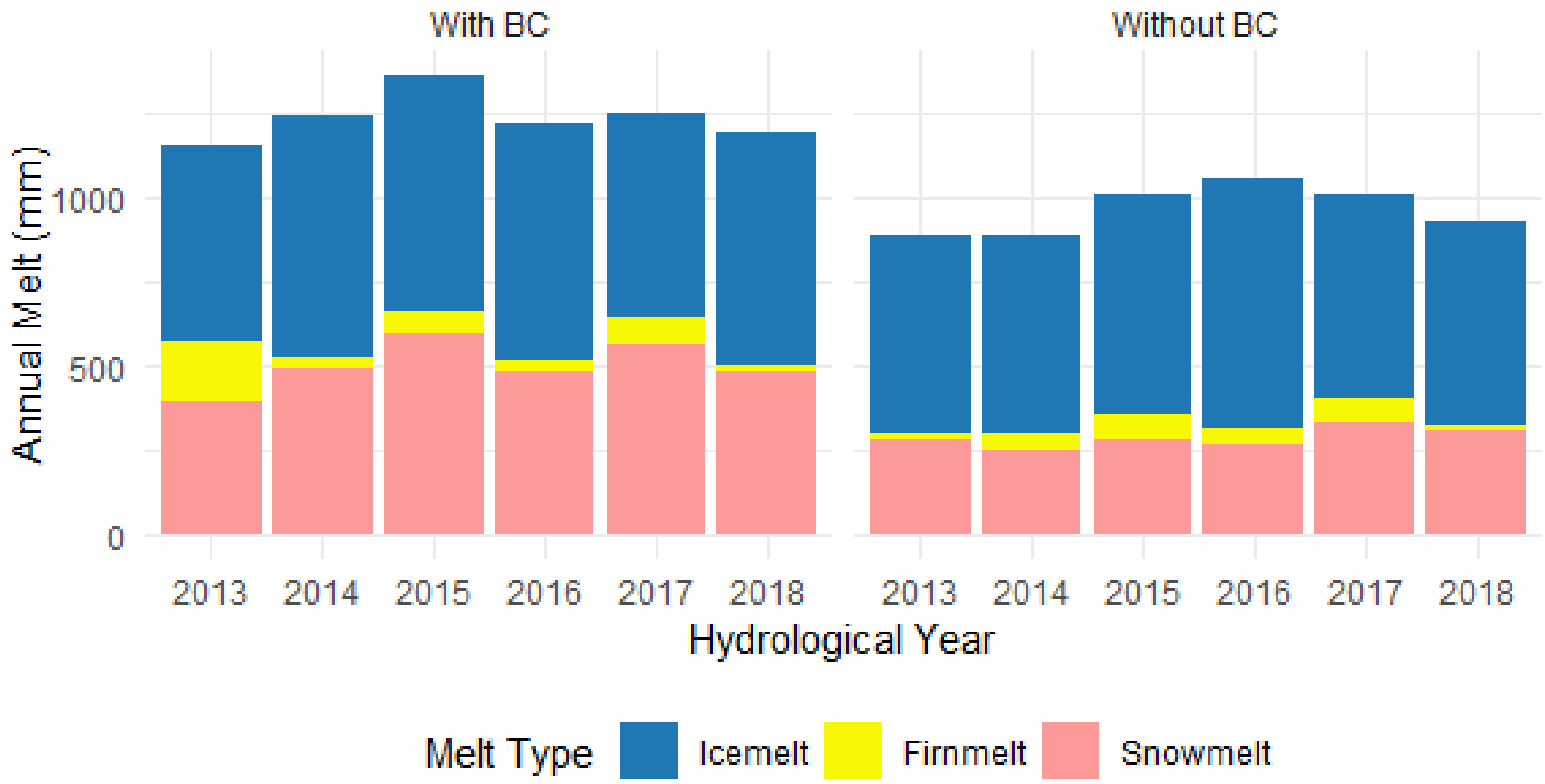
with BC 1.31m/yr

75% increase in ice ablation due to BC

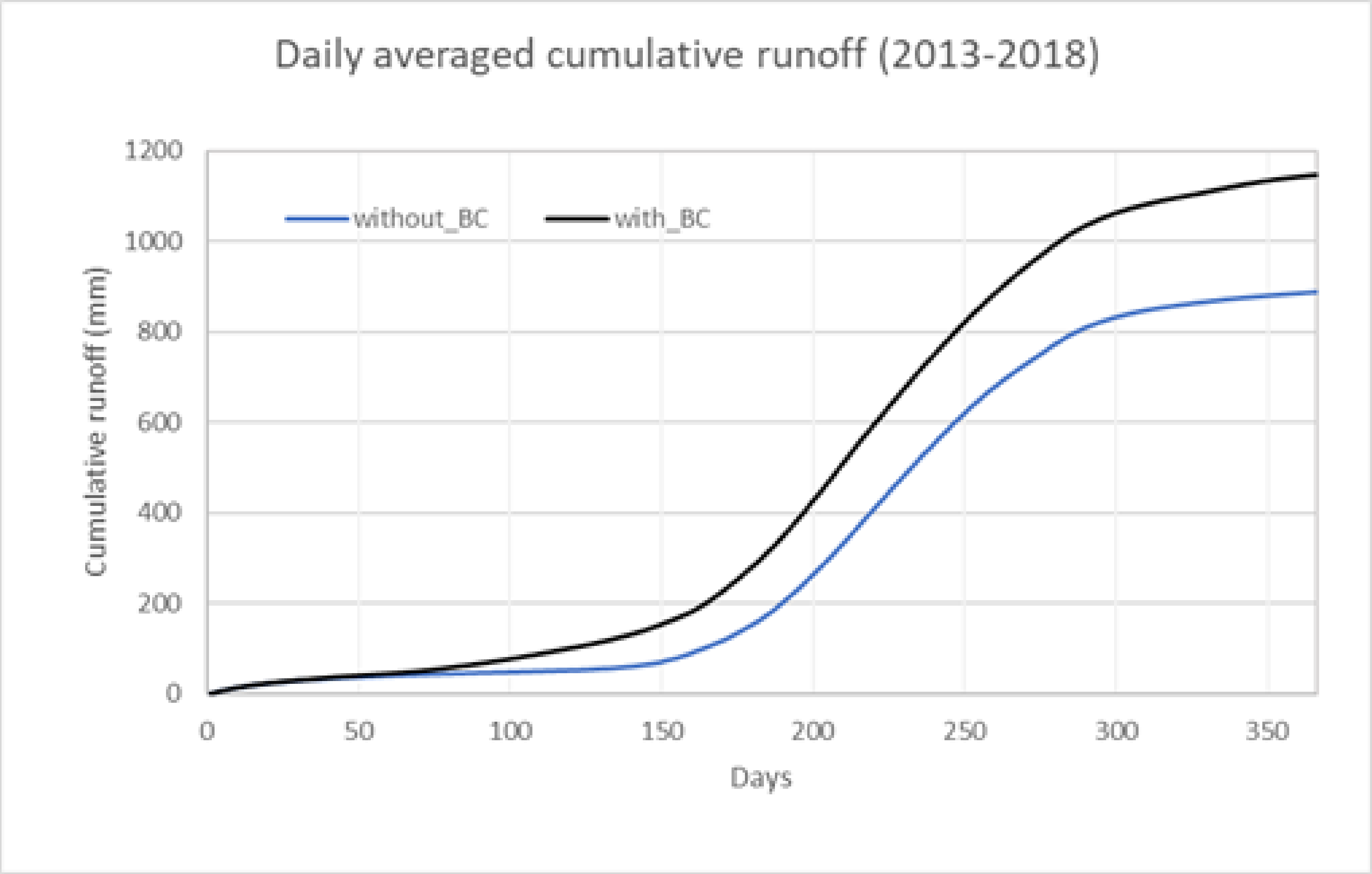


Glacier-wide average ice condition with and without the impact of BC.

BC impacted melting



Basin Runoff Change



29% increase in discharge volume due to BC

Conclusions

- An object-oriented, physical process-based CRHM glaciohydrological model was successfully applied to LGRB, the Nepal Himalayas with minimum calibration.
- The Langshisha glacier is melting rapidly with a 30% increase in snow and ice melt due to BC. BC is causing the depletion of firn on the glacier. Glacier ice melting increased 75% due to BC.
- This result in an increase in streamflow discharge volume of 29% due to BC.
- Climate warming and BC are causing deglaciation of the Langshisha Research Basin, with BC pushing the system past its tipping point. This is resulting in greater discharge, and will, until deglaciation reduces flows.