Improving Hydrological Process Representations in GWF Models

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WHY MORE PROCESSES?

HYDROLOGICAL PROCESSES
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An evaluation of snow accumulation and ablation processes for land surface modelling

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Abstract:

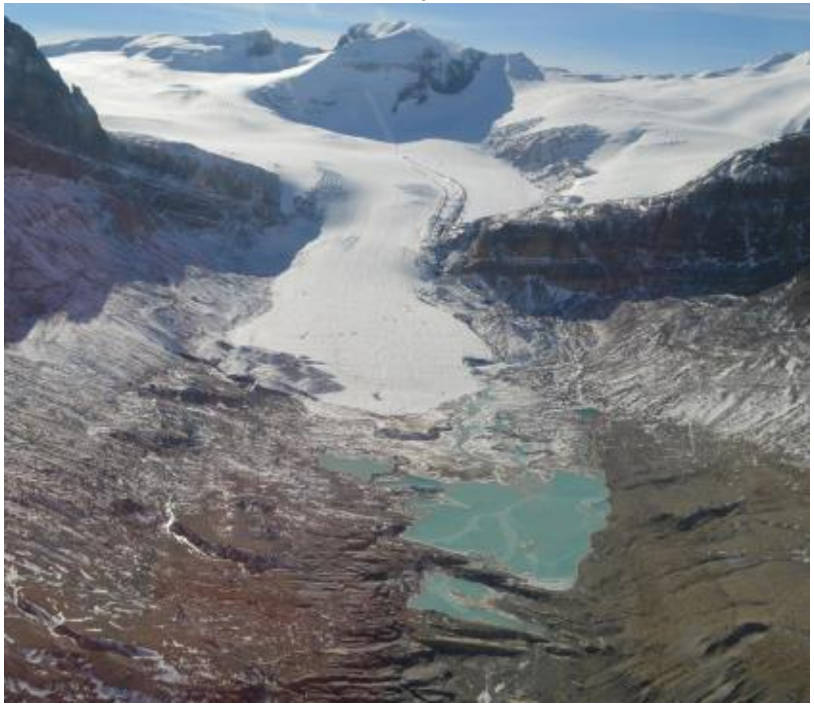
This paper discusses the development and testing of snow algorithms with specific reference to their use and application in land surface models. New algorithms, developed by the authors, for estimating snow interception in forest canopies, blowing snow transport and sublimation, snow cover depletion and open environment snowmelt are compared with field measurements. Existing algorithms are discussed and compared with field observations. Recommendations are made with respect to: (a) density of new and aged snow in open and forest environments; (b) interception of snow by evergreen canopies; (c) redistribution and sublimation of snow water equivalent by blowing snow; (d) depletion in snow-covered area during snowmelt; (e) albedo decay during snowmelt; (f) turbulent transfer during snowmelt; and (g) soil heat flux during meltwater infiltration into frozen soils.

Preliminary evidence is presented, suggesting that one relatively advanced land surface model, CLASS, significantly underestimates the timing of snowmelt and snowmelt rates in open environments despite overestimating radiation and turbulent contributions to melt. The cause(s) may be due to overestimation of ground heat loss and other factors. It is recommended that further studies of snow energetics and soil heat transfer in frozen soils be undertaken to provide improvements for land surface models such as CLASS, with particular attention paid to establishing the reliability of the models in invoking closure of the energy equation.

KEY WORDS snow hydrology; general circulation models: CLASS; land surface schemes; energy balance

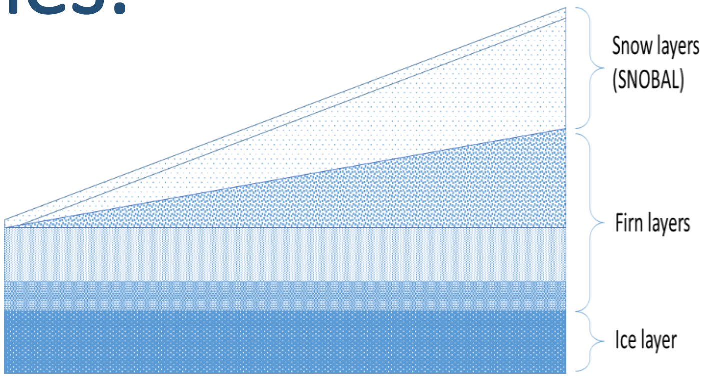
Context:

- Mountain glaciers and perennial snowpacks, and lowland (prairie/boreal/tundra) ponds are neglected components of Earth system models.
  - The mountain cryosphere can have important implications for sustaining river flows during droughts and delivering runoff in excess of precipitation in floods.
  - In lowland environments, ponds control the variable contributing area for streamflow generation through contributing area – surface storage relationships.

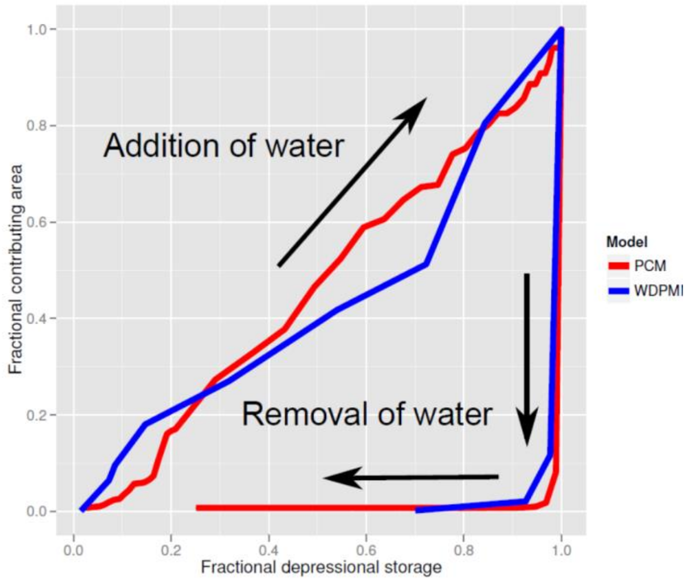


Objectives, Methods, Deliverables:

Develop a dynamical glacier component in MESH by porting algorithms from the Cold Regions Hydrological Model that modify current snowpack algorithms, accounting for topography and changes as perennial snow turns into firn and glacier ice.



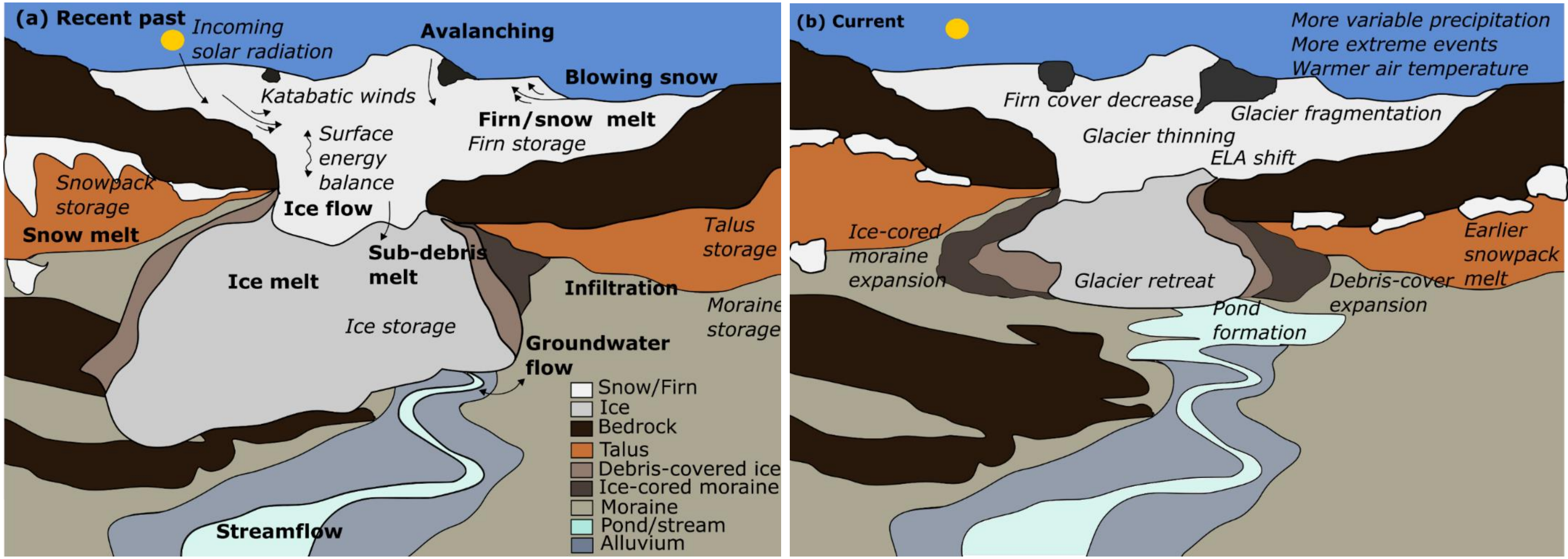
Pond effects on runoff generation in lowland areas will be parameterised using a simplified algorithm that describes the non-linear network behaviour of large numbers of ponds that fill by blowing snow and overland flow and spill by overland flow



Parameterize in CRHM => Port to MESH

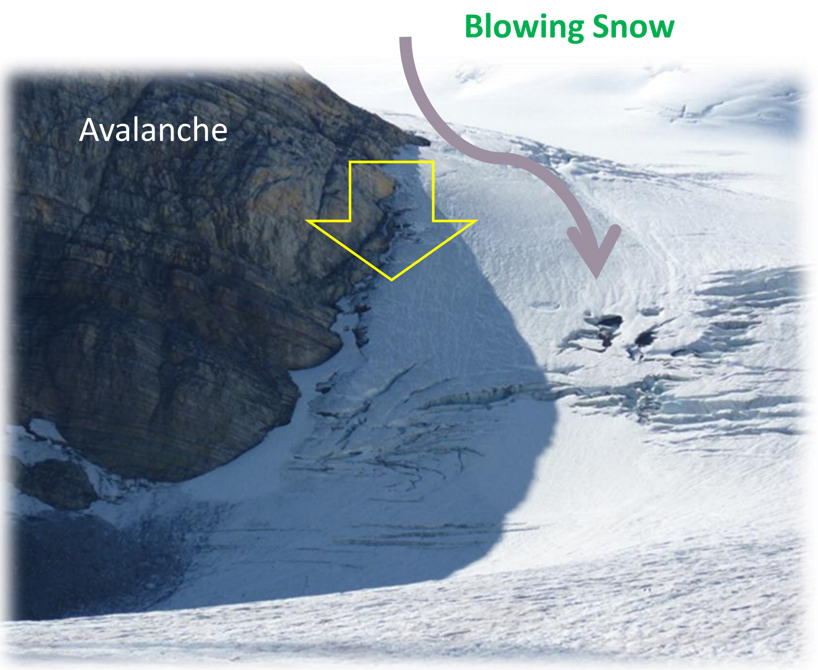
Deliverables: Glacier, perennial snow and lowland pond components added to MESH. Impacts of glaciers on runoff and depressional storage on runoff under climate change.

Glacierized catchments are complex & dynamic



Glacier Modelling Needs

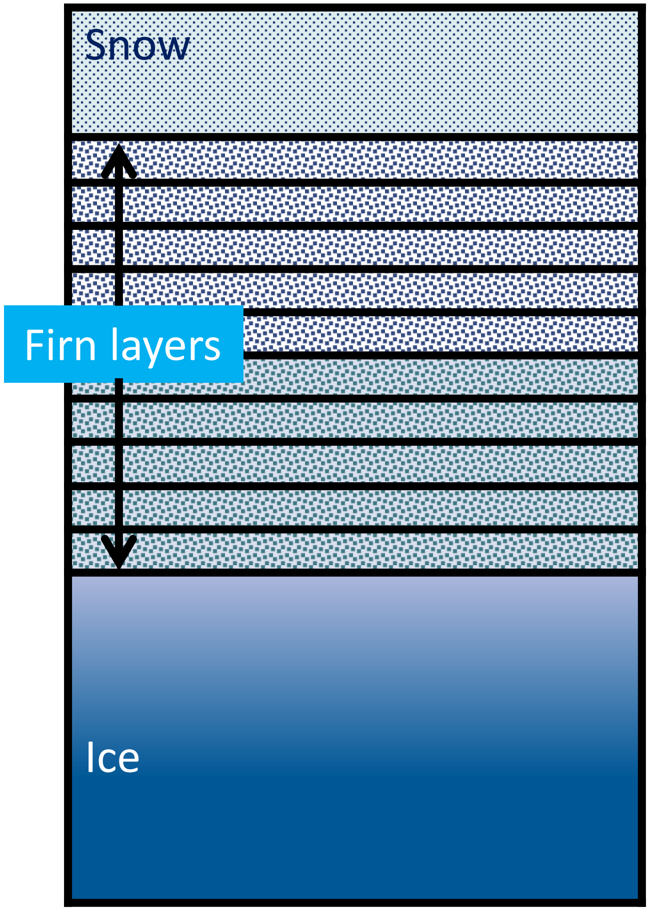
- **Blowing snow coupled to avalanche snow redistribution**
- **Distributed radiation**
- **Energy budget snow, firn and ice melt**
- **Meltwater routing through supra and sub-glacier reservoirs**
- **Ice flow**



Glacier Modelling approach

- **Wind and avalanche snow redistribution**
  - Snow transport, sublimation and redistribution by wind (Pomeroy and Li, 2000) and avalanche transport (Bernhardt and Schulz, 2010)
- **Radiation**
  - Direct and diffuse solar radiation to slopes (Pomeroy et al., 2007), terrain-view and cloud effects on longwave radiation (Sicart et al., 2006)
- **Snowpack and glacier melt**
  - CLASS snowpack
  - Energy Budget Glacier Model (Pradhananga and Pomeroy, 2018 - modified from Gray & Landine, 1988; Ellis et al., 2010) using turbulent fluxes from Radic et al., (2017)
  - Debris-covered Ice Melt Model (modified from Reid and Brock, 2010)
- **Firn densification and Ice Dynamics**
  - Multilayer snow and firn densification (Pomeroy et al., 1998; Herron and Langway, 1980)
  - Ice flow (Clarke et al., 2015)
- **Meltwater routing through three linear reservoirs**
  - snow, firn and ice
- **Groundwater storage and routing (McClymont et al., 2010)**
- **GRU based on slope, aspect, elevation, and glacier cover**
  - Elevation adjustment (Ice depth)
  - Change in glacier cover (Firn, Ice, Ice-free)

Firnification and the densification process



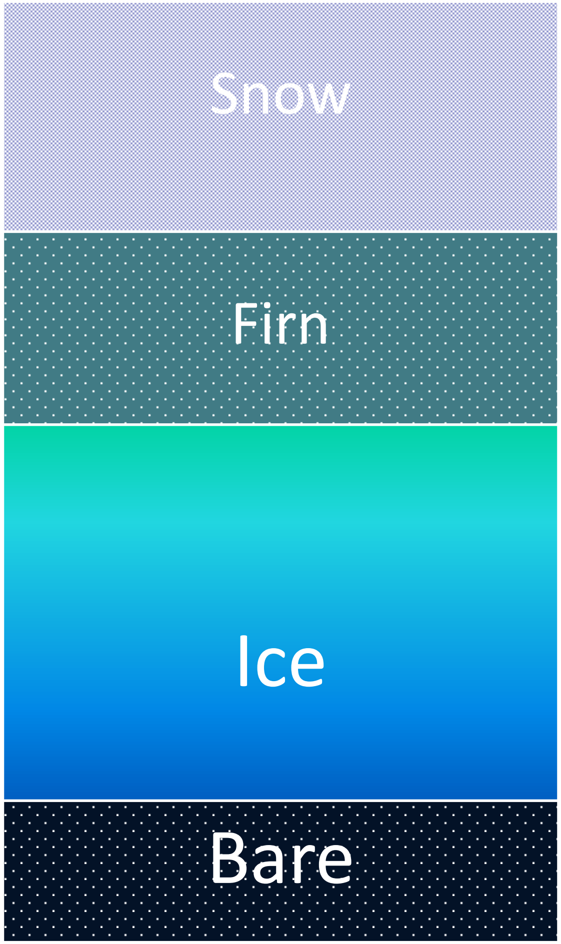
Episodic and fast densification

Slower densification

Very slow densification

Fixed density

Albedo, α



Snow albedo decay [Verseghy, 1991; Essery & Etchevers, 2004]:

a) for cold snow:

$$\alpha_t = \alpha_{o.snow} - \frac{dt}{a_1}$$

b) for melting snow:

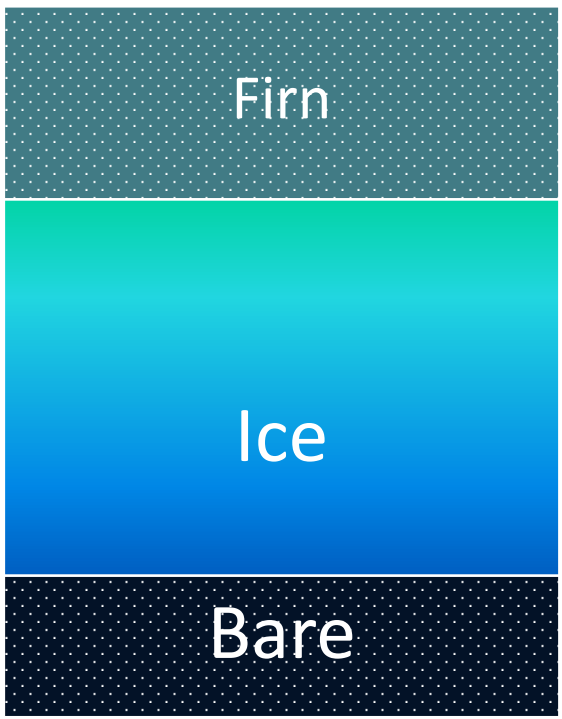
$$\alpha_t = (\alpha_{o.snow} - \alpha_{min})e^{-\frac{dt}{a_2}} + \alpha_{min}$$

<u>Albedo updated at each timestep:</u>

$$\alpha_{t+dt} = \alpha_t + (\alpha_{max} - \alpha_t)\frac{snow}{S_{min}}$$

a_1 and a_2 are albedo decay time constants for cold snow and melting snow, respectively.
$\alpha_{o.snow}$ is initial snow cover albedo.
S_{min} is minimum snowfall to refresh snow cover albedo

Albedo, α



α = 0.5

Albedo, $\boldsymbol{\alpha}$

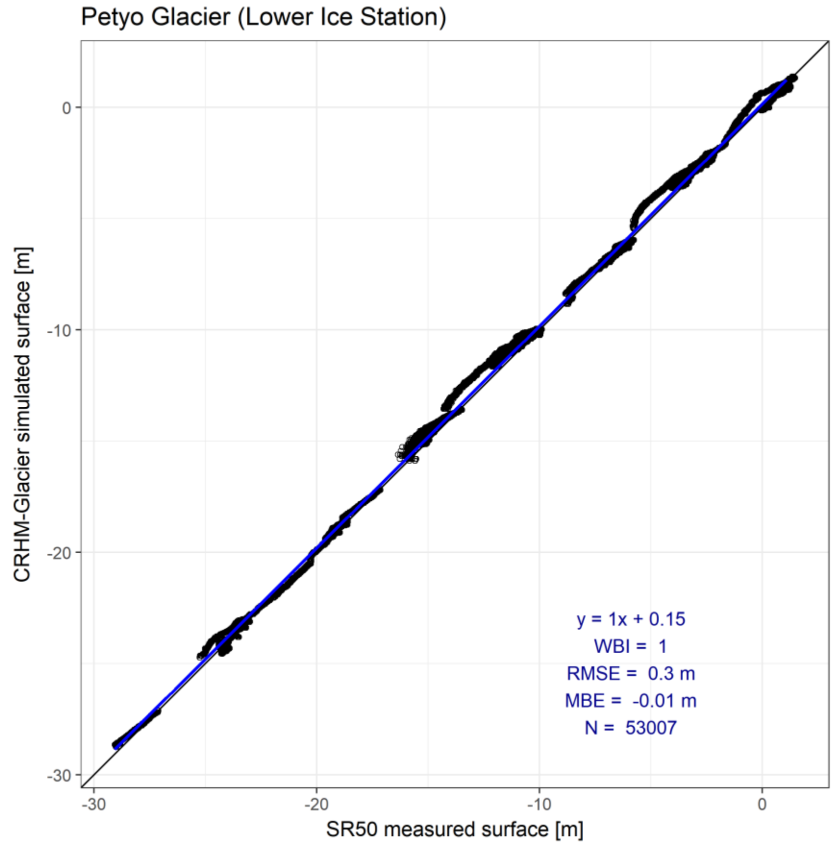
$\boldsymbol{\alpha} = 0.25 - 0.35$

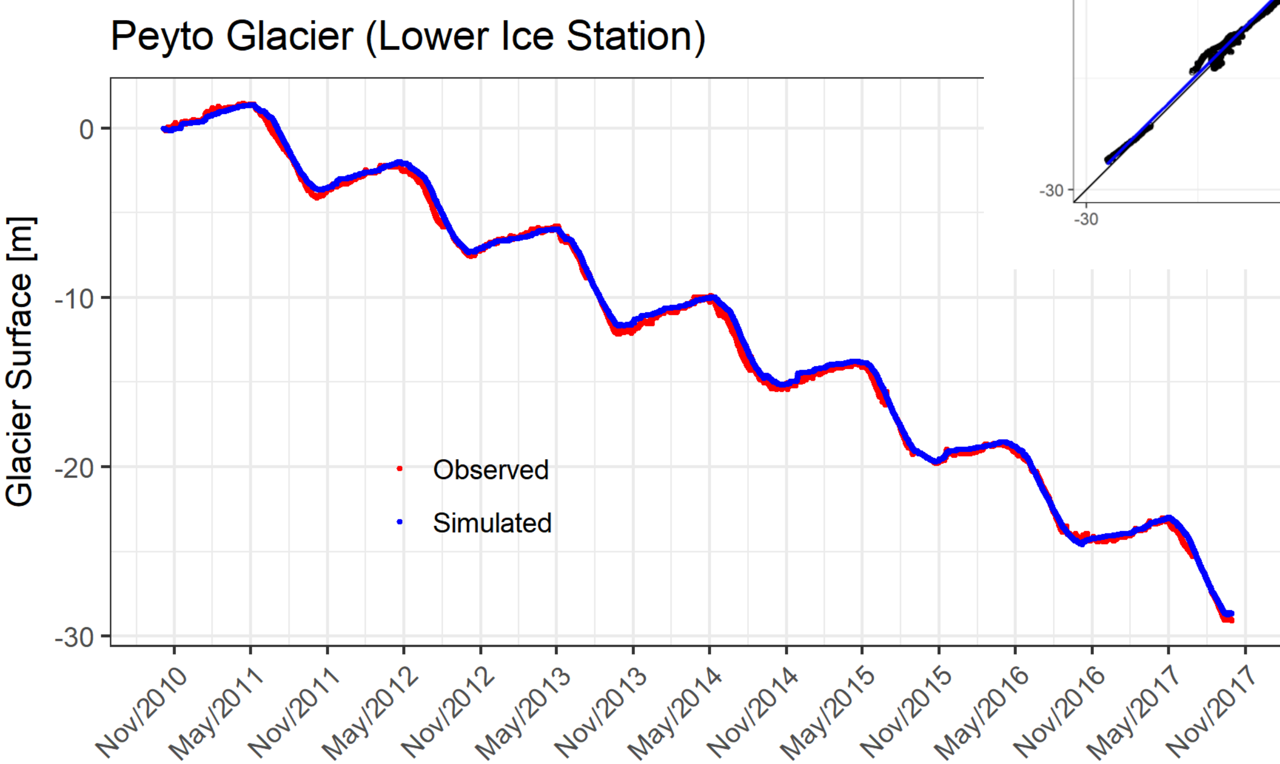
Albedo, α

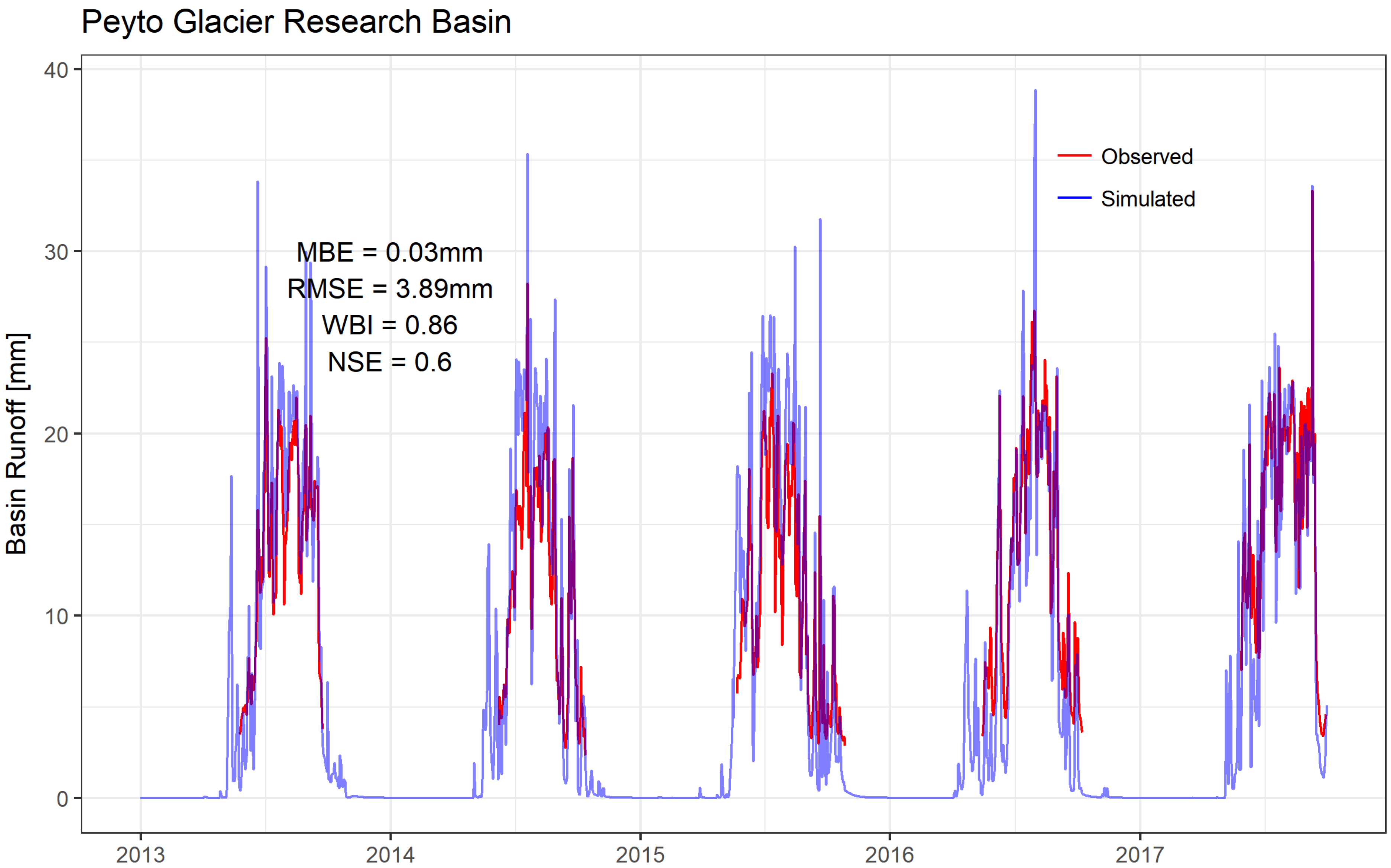
Bare

$\alpha = 0.17$

Glacier surface elevation:
Peyto Lower Ice 2010-2017

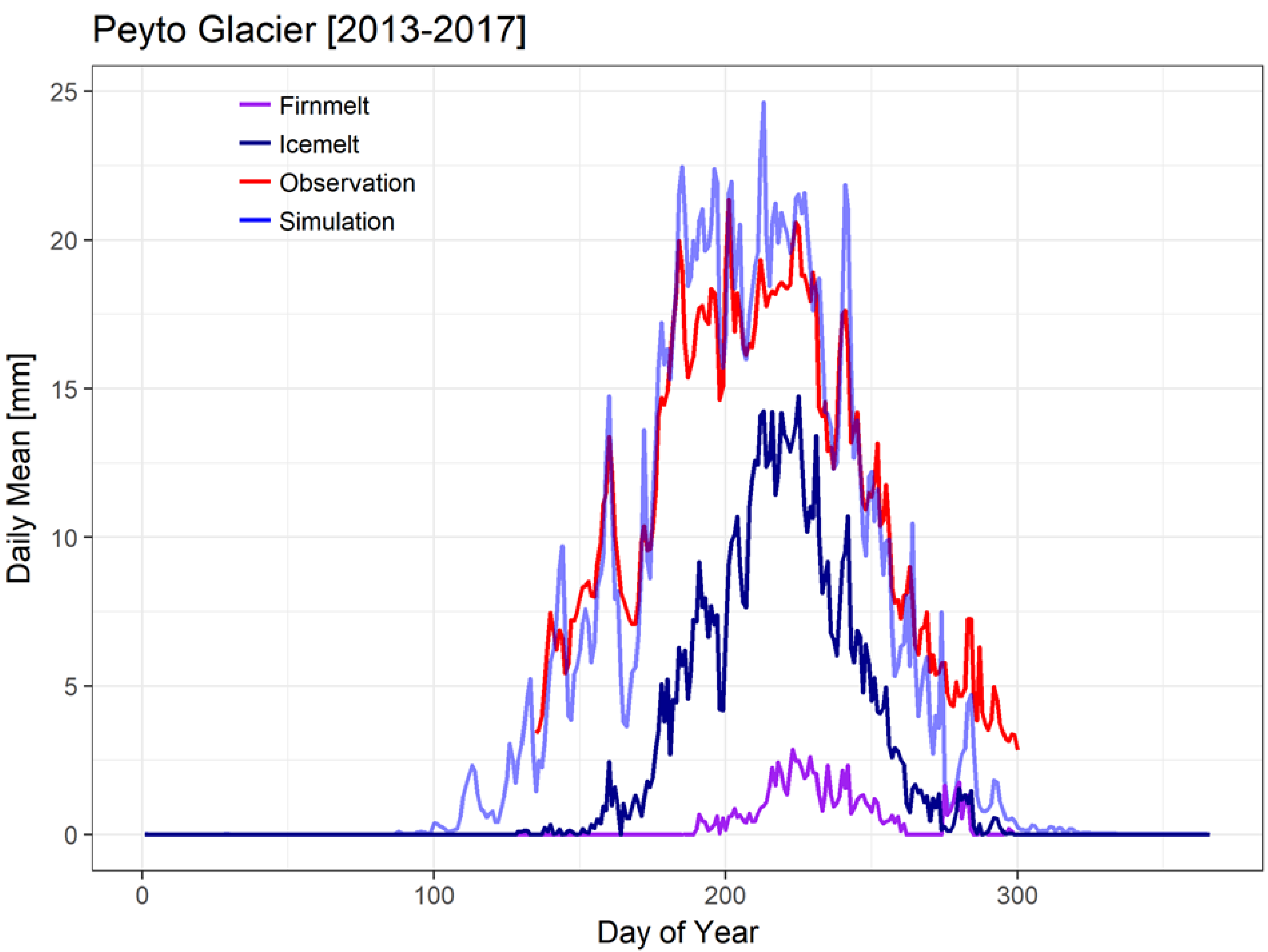




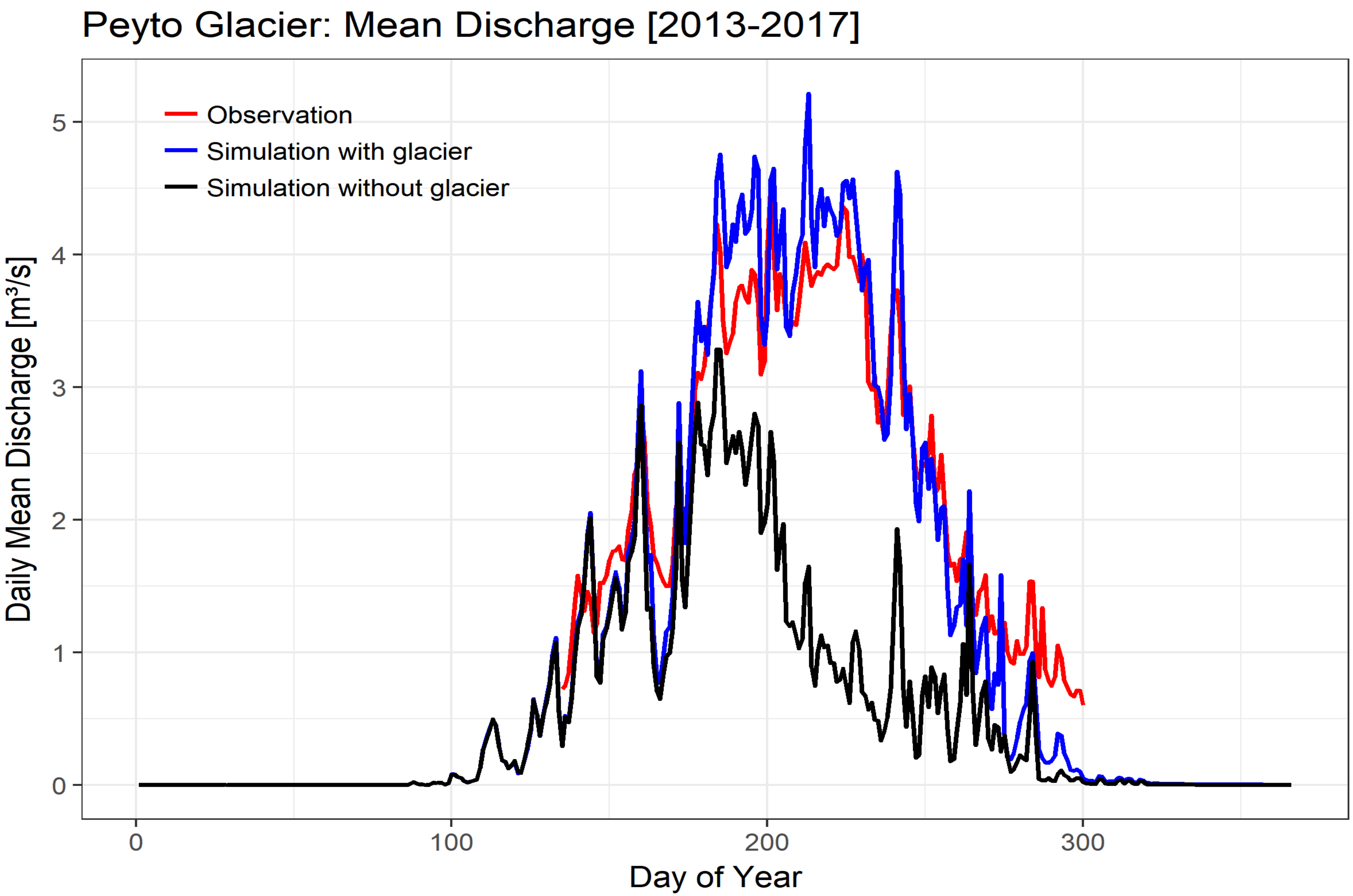


Peyto Glacier Research Basin
Basin Runoff [mm]
40
30
20
10
0
2013
2014
2015
2016
2017
MBE = 0.03mm
RMSE = 3.89mm
WBI = 0.86
NSE = 0.6
Observed
Simulated

Components of Runoff



Peyto Creek: with and without the glacier



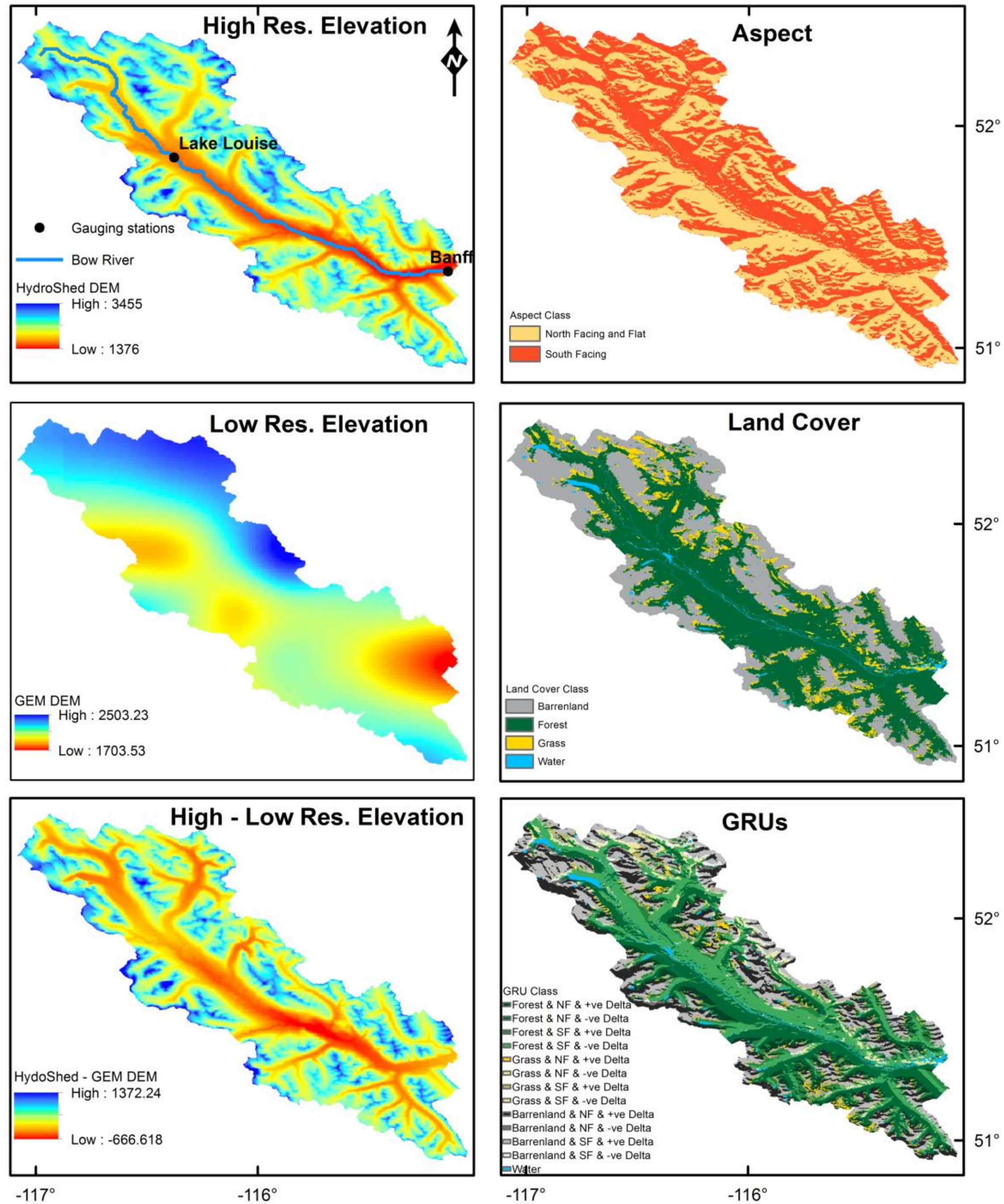
Progress with "Mountain MESH"

- Incoming shortwave radiation was calculated for slope and aspect and corrected for cloud cover by taking the ratio of GEM with the theoretical flat surface radiation (Garnier and Ohmura, 1968)
- Longwave radiation was adjusted by lapse rate (Marty et al., 2002)
- Temperature was adjusted by lapse rate (Bernier et al., 2011)
- Pressure was adjusted for change in both elevation and temperature
- Specific humidity was adjusted for changes in temperature and pressure

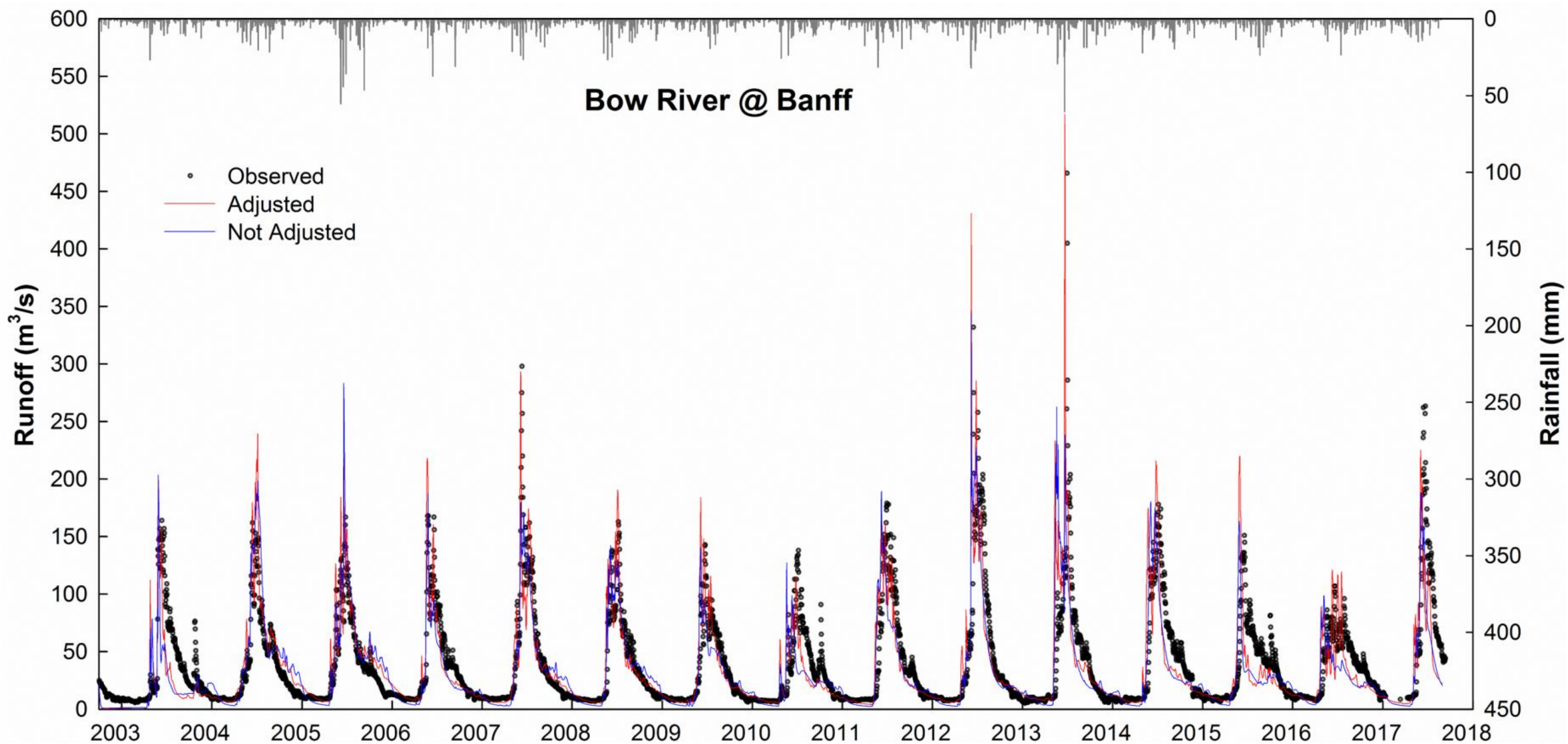
Mountain – slope, aspect and topography, 17 GRU

FLAT – flat, 5 GRU.

0.125^{o} resolution



Bow River @ Banff



	NSE, %Bias	
Calibration	Mountain = 0.88, 0.25	FLAT = 0.79, -3.50
Validation	Mountain = 0.79, -15	FLAT = 0.73, -24

Next Steps

- Evaluate existing CLASS glacier algorithm in MESH
- Code in some GLACIER components into MESH – stepwise approach
- Test MESH-GLACIER configurations

- Dr. Abbas Fayad starts August 2018