Assessment of Climate Change Impact on Summer Low Flows in Mountainous Regions using a Coupled Hydrology-Glacier Model

Arelia T. Schoeneberg (née Werner)[1], Markus A. Schnorbus[1] and Mohammad Reza Najafi[1]

[1]**Pacific Climate Impacts Consortium**

With Special Thanks to Mike Fischer (formerly) of PCIC's Computational Support Group and Faron Anslow , PCIC Climatologist, developer of the Regional Glacier Model while at UBC.

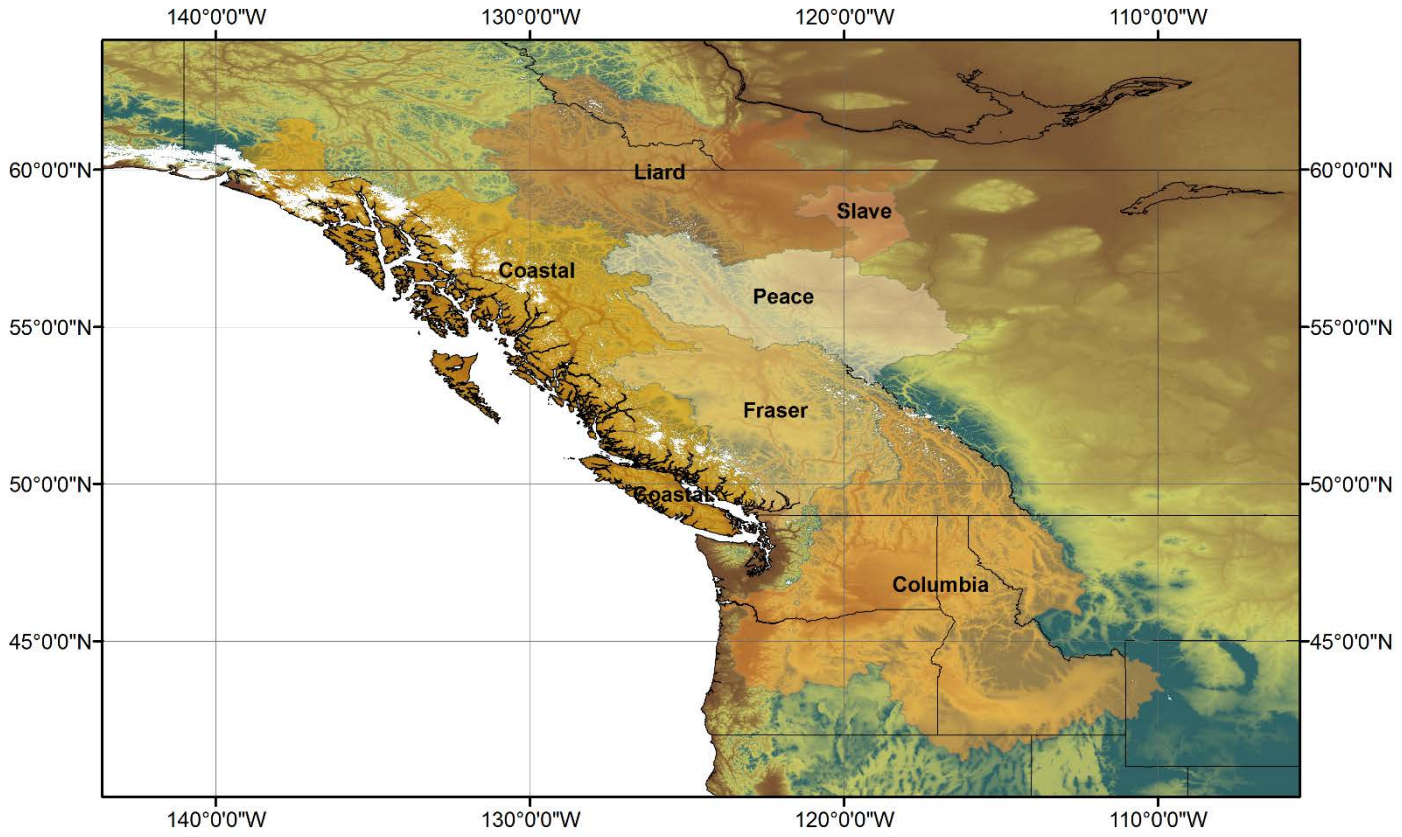
AGU 2016 – Fall Conference – San Francisco

H54A: Advances in Process-Based Hydrologic Modeling III

Friday, December 16th 2016

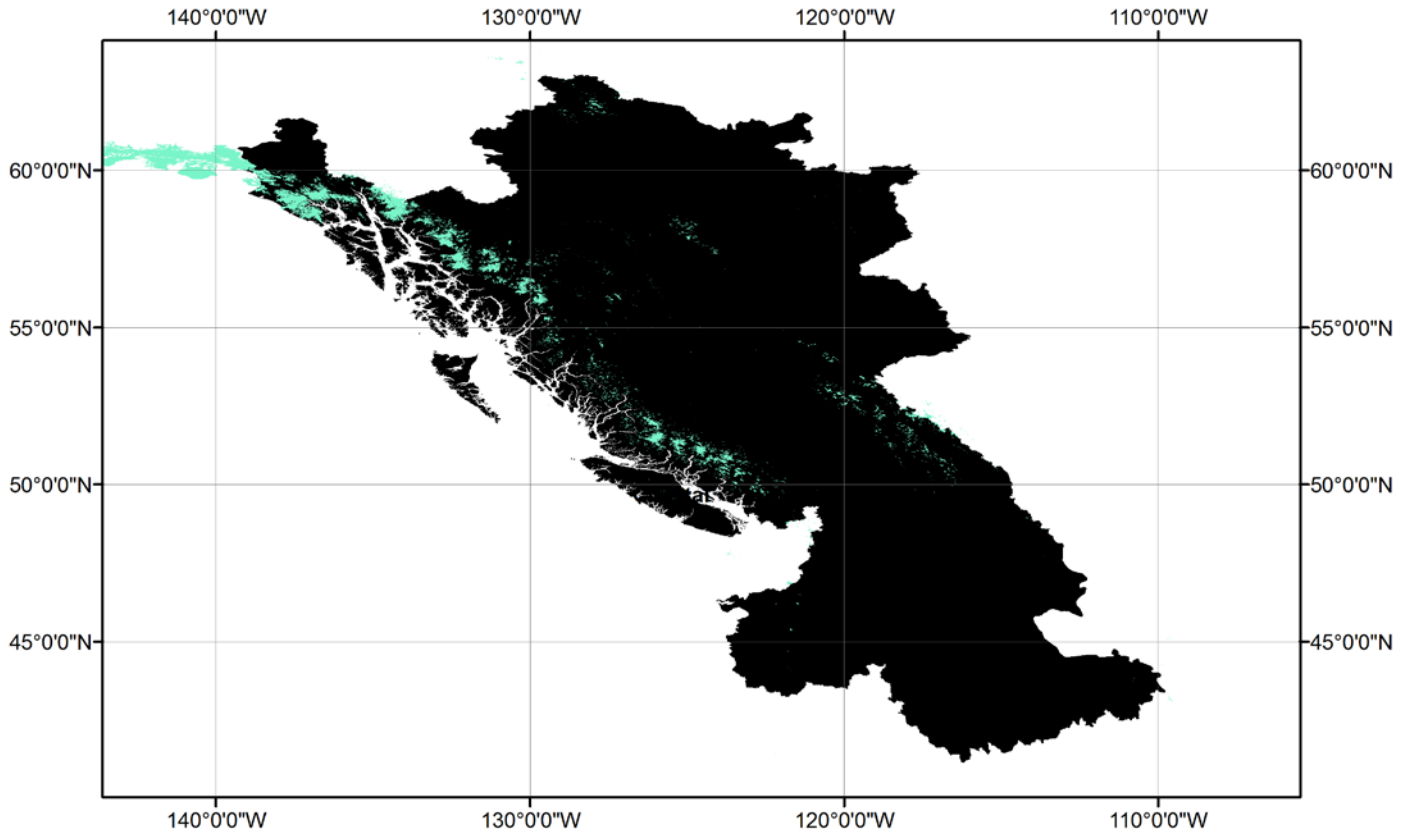
"Left to Parker Ridge" ~ Randy Hayashi Paintings

Applying the Variable Infiltration Capacity model



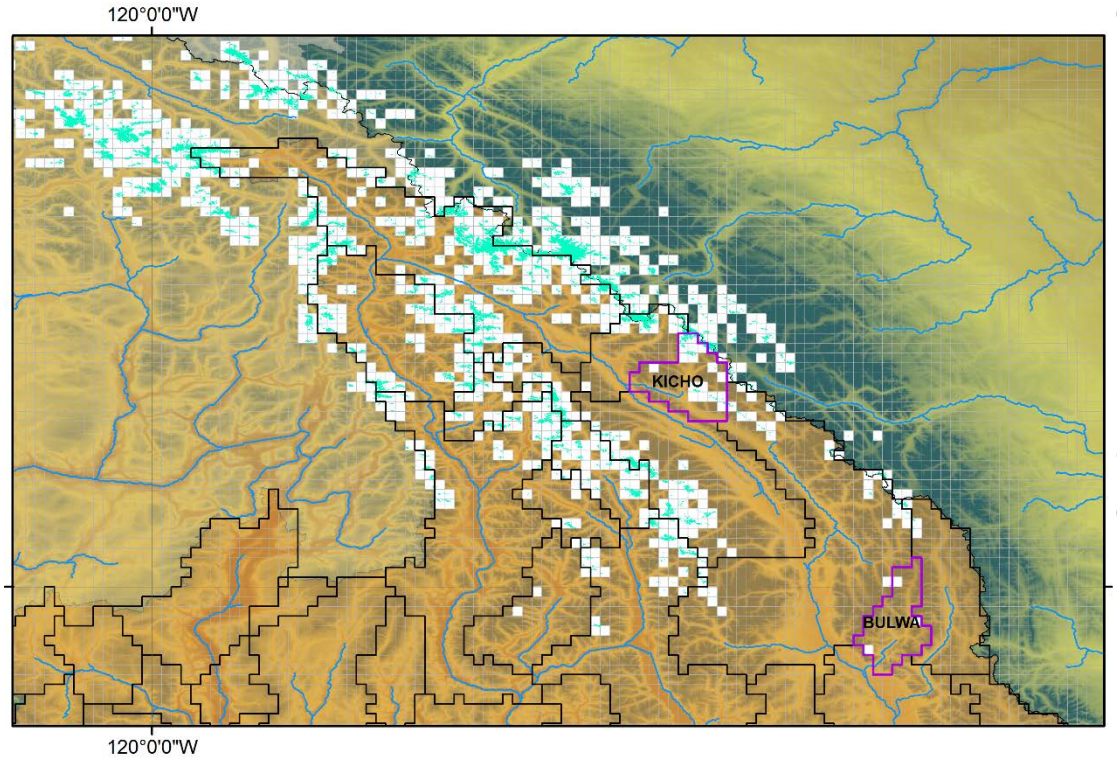
- ✓ Large Spatial Scales
- ✓ Physical Representation of *Most* Major Processes
- X Not Glaciers

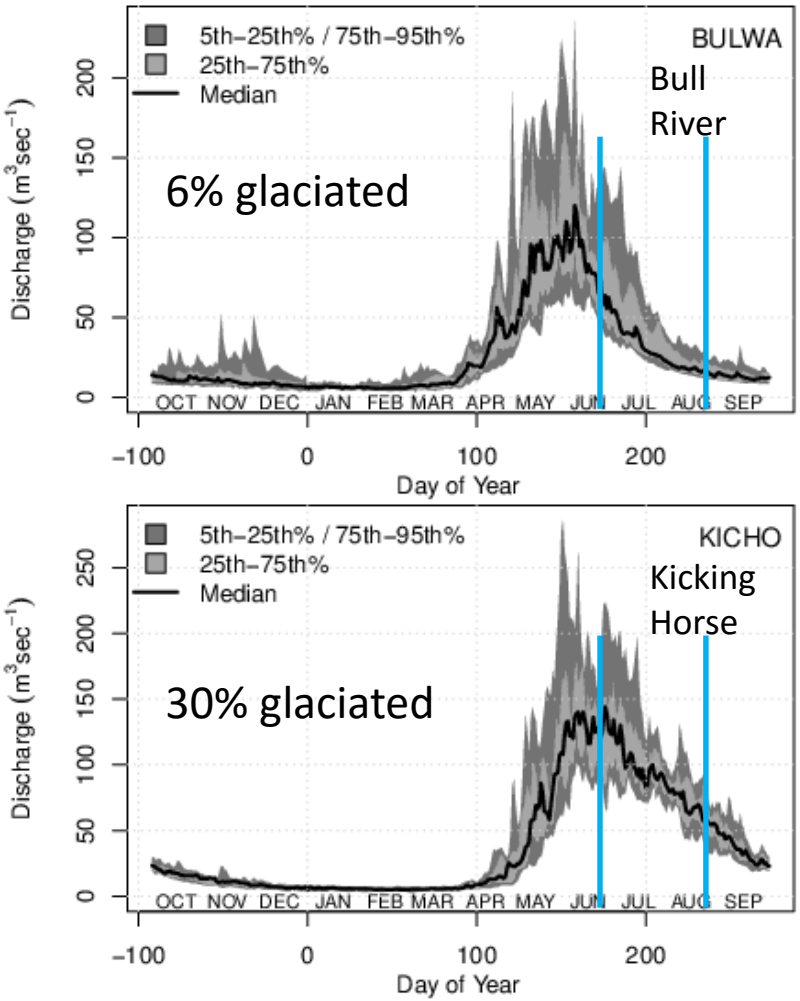
Location of Glaciers in the Study Area



~ Randolph Glacier Inventory (RGI; Pfeffer et al. 2014)

Modelling in Mountainous-Glaciated Basins





Observed Streamflow 1985-1995

VIC Limitations

1. No explicit treatment of glacier mass or glacier energy balance.
2. Naïve representation of sub-grid land cover and topographic variability.
3. No lateral fluxes between grid cells.

Adapted from
Schnorbus et al. 2016

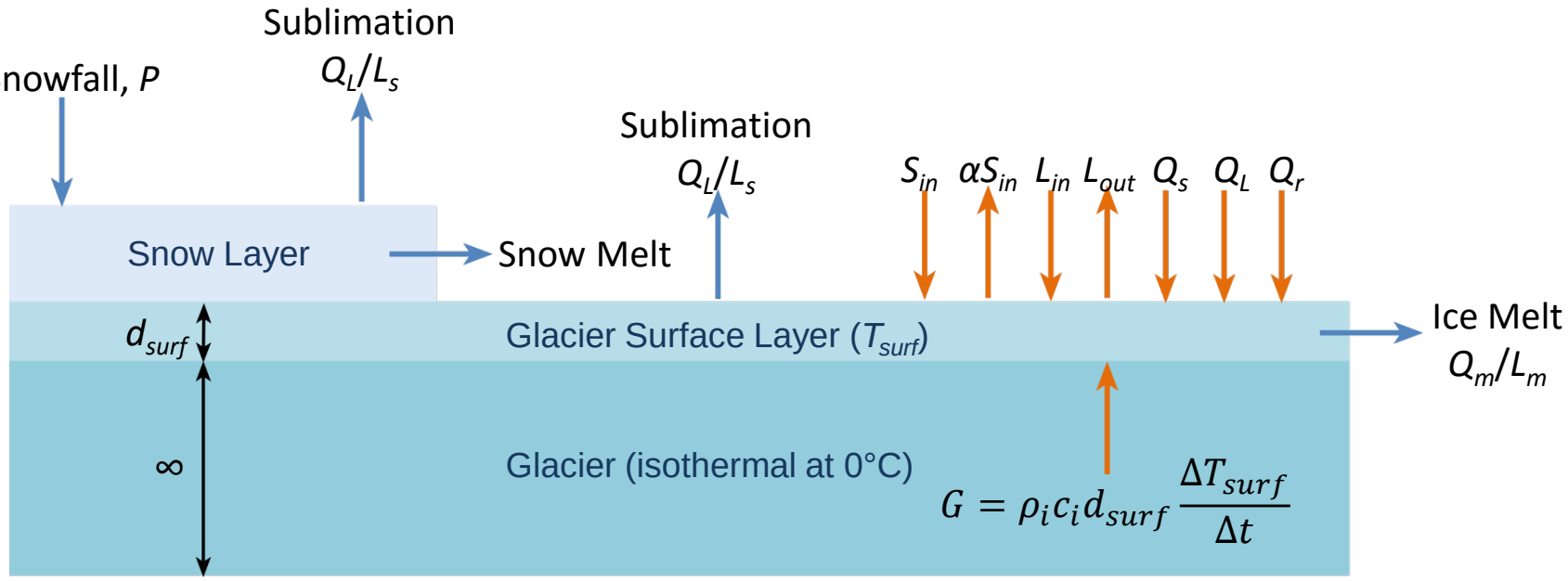
Implementing a Glacier Mass Balance Model in VICGL

The model estimates the rate of accumulation and ablation of glaciers, or mass balance, which serves two purposes:

1. To directly calculate ice melt contribution to runoff in VIC.
2. To act as a forcing to the (offline) dynamics model.

Adapted from
Schnorbus et al. 2016

Glacier Mass and Glacier Energy Balance Model in VICGL



Predominantly based on model of *Klok and Oerlemans* (2002):

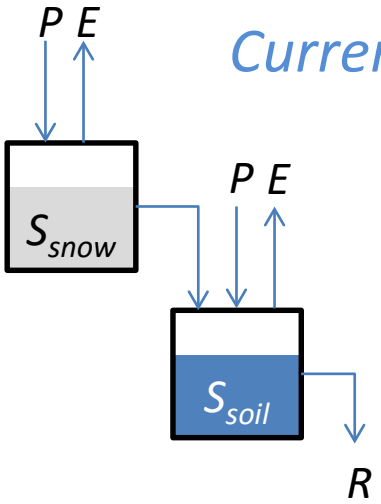
$$F = S_{in}(1-\alpha) + L_{in} + L_{out} + Q_s + Q_L + Q_r = Q_m + G$$

where:

S_{in} = incoming solar radiation
L_{in} = incoming longwave radiation
L_{out} = outgoing longwave radiation
Q_s = sensible heat
Q_L = latent heat
Q_r = heat advected from rainfall
Q_m = energy for ice melt
G = glacier heat flux
L_s = latent heat of sublimation
L_m = latent heat of melt
d_{surf} = thickness of glacier surface layer
T_{surf} = glacier surface temperature
p_i = density of ice
c_i = heat capacity of ice
α = glacier albedo

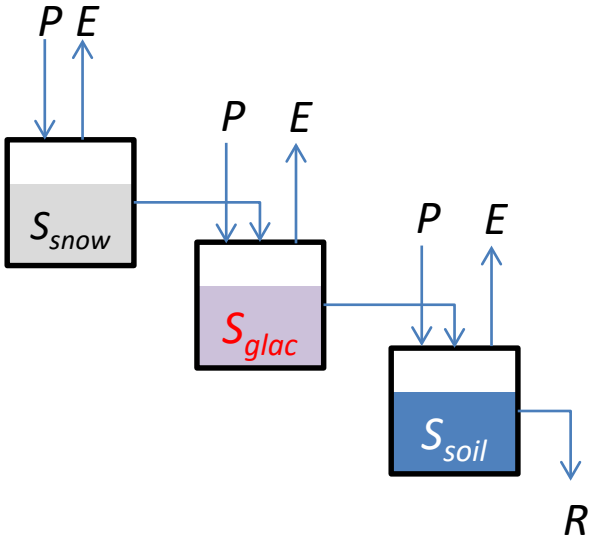
Adapted from Schnorbus et al. 2016

VIC versus VICGL Water Balance



Current Water Balance (e.g. VIC 4.1.2g)

$$R = P - E - \Delta S_{soil} - \Delta S_{snow}$$



Revised Water Balance (VICGL)

$$R = P - E - \Delta S_{soil} - \Delta S_{snow} - \Delta S_{glacier}$$

Adapted from
Schnorbus et al. 2016

VIC → VICGL

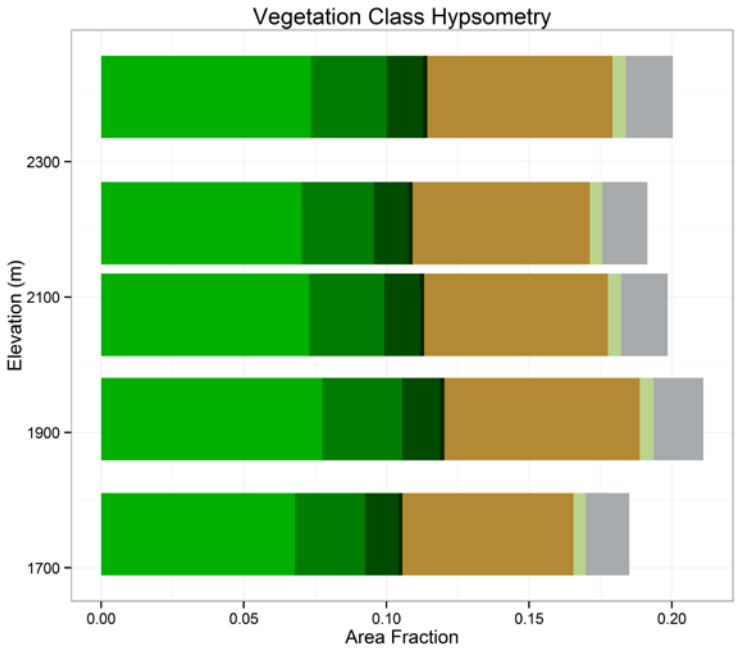
1. ~~No~~ Explicit treatment of glacier mass or glacier energy balance.
2. Naïve representation of sub-grid land cover and topographic variability.
3. No lateral fluxes between grid cells.

Adapted from
Schnorbus et al. 2016

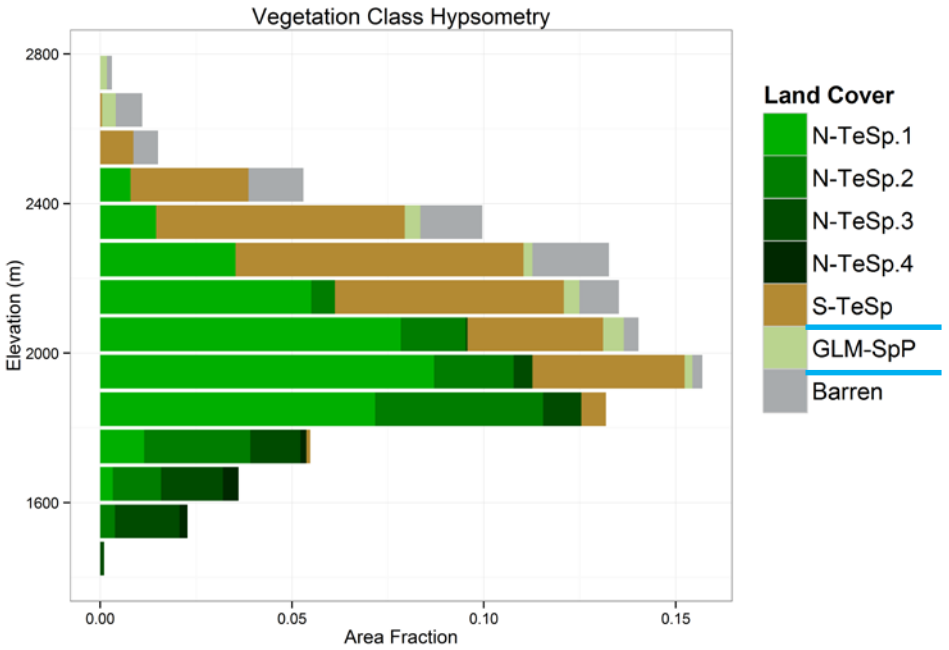
Refactoring VIC to VICGL: from Bands to HRUs

Bull River near Wardner, BC

Original w/ Tiles
500-m Bands



Updated w/ HRUs
100-m Bands



Adapted from
Schnorbus et al. 2016

VIC → VICGL

1. ~~No~~ Explicit treatment of glacier mass or glacier energy balance.
2. ~~Naïve~~ Reasonable representation of sub-grid land cover and topographic variability.
3. No lateral fluxes between grid cells.

Adapted from
Schnorbus et al. 2016

The Regional Glaciation Model – Clark et al. 2016

NATURE GEOSCIENCE DOI: 10.1038/NGEO2407 LETTERS

Figure 1 | Study region and subregions in the Canadian Cordillera of western Canada. Present-day (2005) glacier extent is indicated in white. The yellow rectangle indicates the location of Columbia Reach drainage basin. Inset: Study region (black rectangle) within northwestern North America.

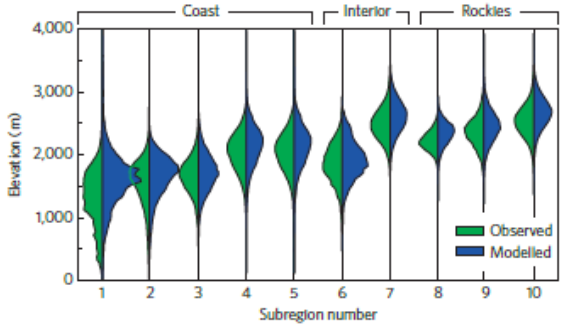


Figure 2 | Comparisons of observed and modelled ice hypsometry for reference year 2005. For each of the ten subregions, pairs of bell-shaped curves show the distribution of ice area (normalized to the largest observed area) with elevation for the observed (green) and modelled (blue) ice extent.

LETTERS
PUBLISHED ONLINE: 6 APRIL 2015 | DOI: 10.1038/NGEO2407
nature geoscience

Projected deglaciation of western Canada in the twenty-first century

Garry K. C. Clarke[1]*, Alexander H. Jarosch[2], Faron S. Anslow[3], Valentina Radić[1] and Brian Menounos[4]

Retreat of mountain glaciers is a significant contributor to sea-level rise and a potential threat to human populations through impacts on water availability and regional hydrology. Like most of Earth's mountain glaciers, those in western North America are experiencing rapid mass loss[1,2]. Projections of future large-scale mass change are based on surface mass balance models that are open to criticism, because they ignore or greatly simplify glacier physics. Here we use a high-resolution regional glaciation model, developed by coupling physics-based ice dynamics with a surface mass balance model, to project the fate of glaciers in western Canada. We use twenty-first-century climate scenarios from

and global scales[5,6,8,15]. A common feature of these models is that they lack a physics-based treatment of glacier dynamics. The central contribution of our study is thus to simulate the changes in ice thickness and extent over a large region using a high-resolution model of glacier dynamics, which yields year-to-year changes in ice area and volume for the entire study region.

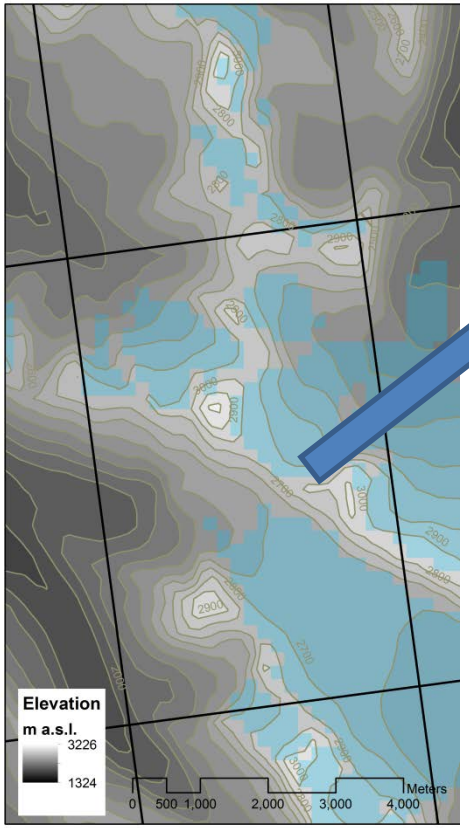
Our study area is Alberta and British Columbia (BC) in western North America (Fig. 1), where glaciers account for an estimated area of 26,700 km² (ref. 18) and volume of 2,980 km³ (ref. 19). The geographical scale is comparable to that of other glacierized mountain regions, such as South America (~31,900 km²; ref. 7), the Himalaya and Karakoram (~22,800 km² and ~18,000 km²;

The Regional Glaciation Model – Clark et al. 2016

Clarke, G. K. C., Jarosch, A. H., Anslow, F. S., Radic, V., and Menounos, B.: Projected deglaciation of western Canada in the twenty-first century, Nat. Geosci., 8, 372–377, 2015.

VICGL ↔ HydroConductor ↔ RGM

VICGL



Run 3 Hourly with Daily Output

HydroConductor from VICGL to RGM

- VIC grid cell to RGM grid cell remapping

RGM requires

- Surface DEM
- Bed DEM
- Mass balance

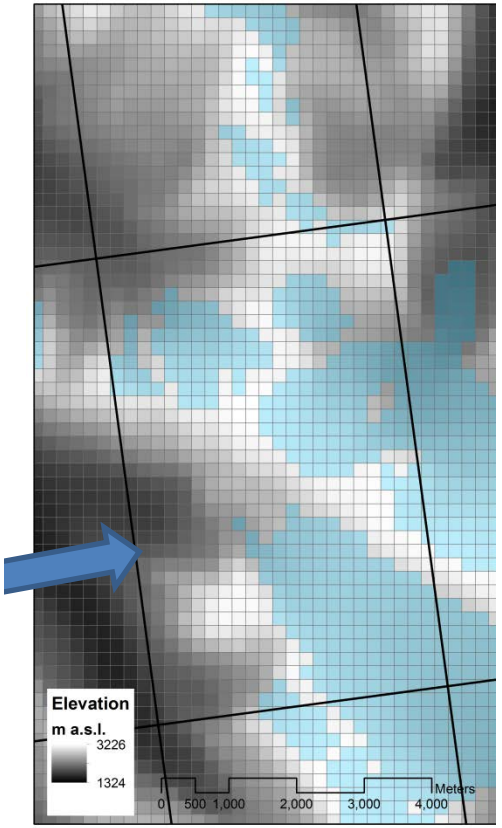
RGM produces

- An updated surface DEM

HydroConductor from RGM to VICGL

- Turns this updated glacier mask into updated HRUs for VICGL by modifying the:
  - State file
  - Vegetation Parameter file
  - Snow Band file

RGM



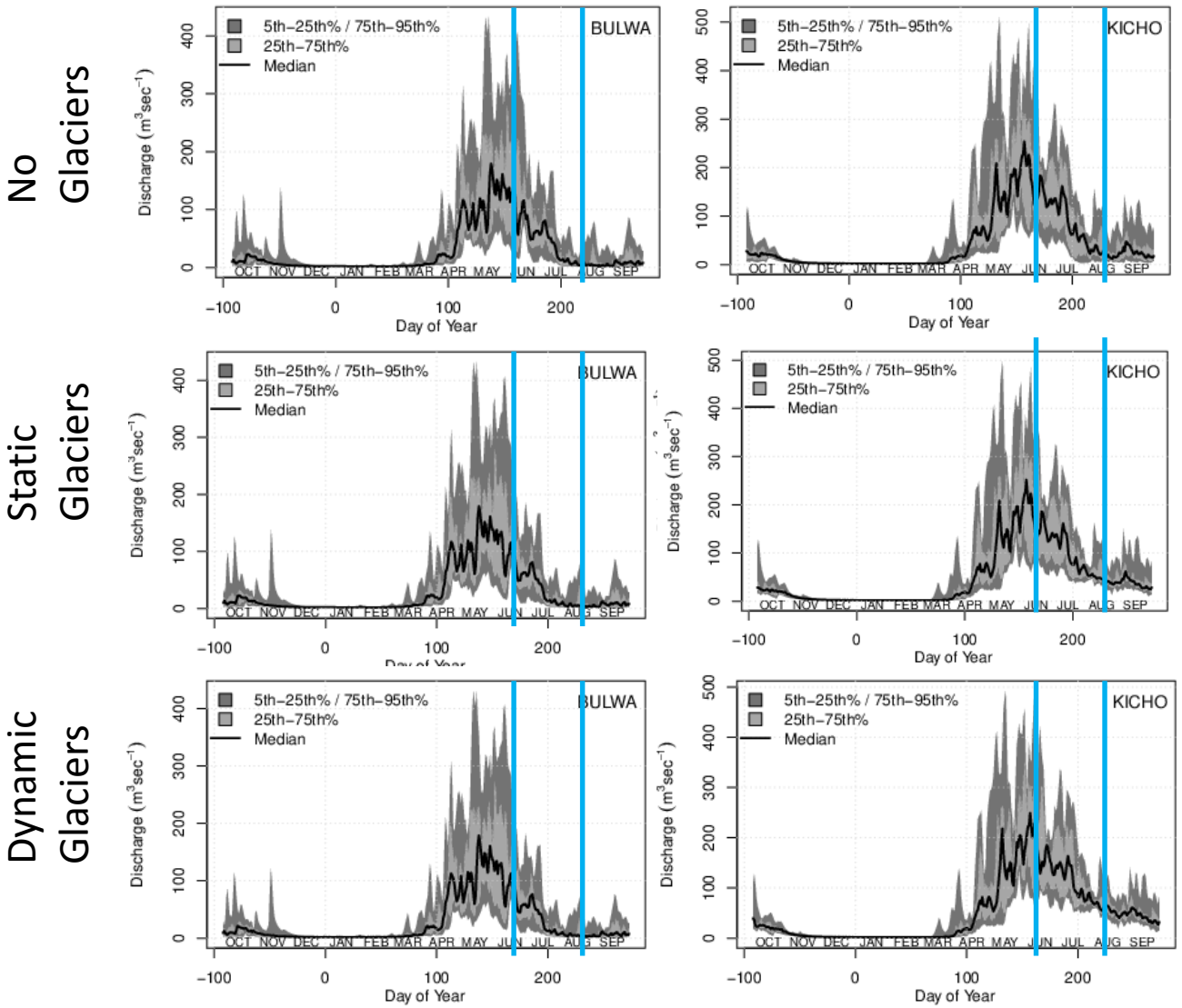
Run Monthly with Annual Output

VIC → VICGL

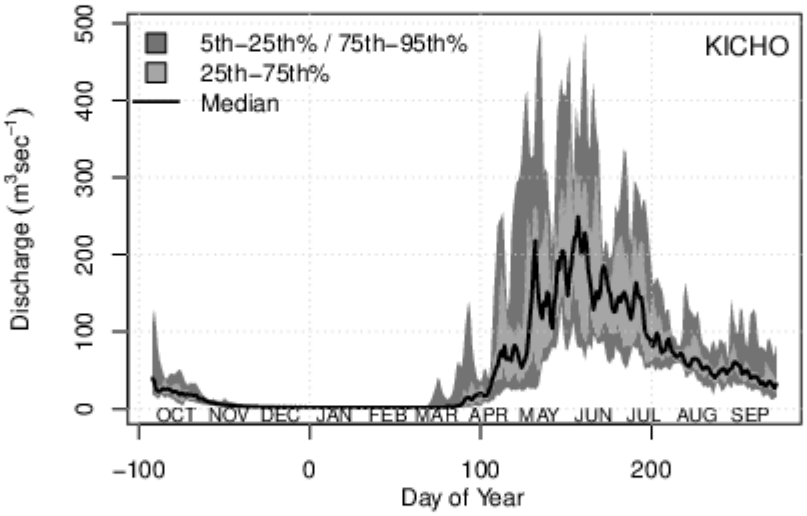
1. **Explicit treatment of glacier mass or glacier energy balance.**
2. **Reasonable representation of sub-grid land cover and topographic variability.**
3. **Lateral ice fluxes between grid cells.**

Adapted from
Schnorbus et al. 2016

RESULTS



Modelled Streamflow 1991-2000


5th–25th% / 75th–95th%
25th–75th%
Median
KICHO
Discharge (m^3sec^{-1})
0
100
200
300
400
500
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
−100
0
100
200
Day of Year

Thank you

https://github.com/pacificclimate

www.pacificclimate.org

wernera@uvic.ca

"Left to Parker Ridge" ~ Randy Hayashi Paintings

PACIFIC CLIMATE IMPACTS CONSORTIUM

University of Victoria
British Columbia • Canada

BC hydro

BRITISH COLUMBIA
Ministry of Environment