Improving mountain hydrological predictions by better representing mountain topography in a hydrological land surface model

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Introduction

- Realistic simulation of streamflow derived from mountains is crucial for mitigation of flood damage and better water resources management for communities and irrigation under a changing climate.
- Simulating the mountain hydrological cycle including the cryosphere is critical for predicting climate impacts on these world heritage ecosystems. However, most hydrological models have insufficient representation of complex terrain topography and cold regions processes to accurately simulate hydrology in high mountain basins (Pomeroy et al., 2016).
- Problems include poor representation of cold regions physical processes such as snow redistribution, snowmelt on slopes, and glacier melt in models, and low resolution atmospheric inputs.
- Dornes et al., (2008) suggested model performance can be improved by downscaling climate forcing using high resolution topography and permitting snow redistribution.

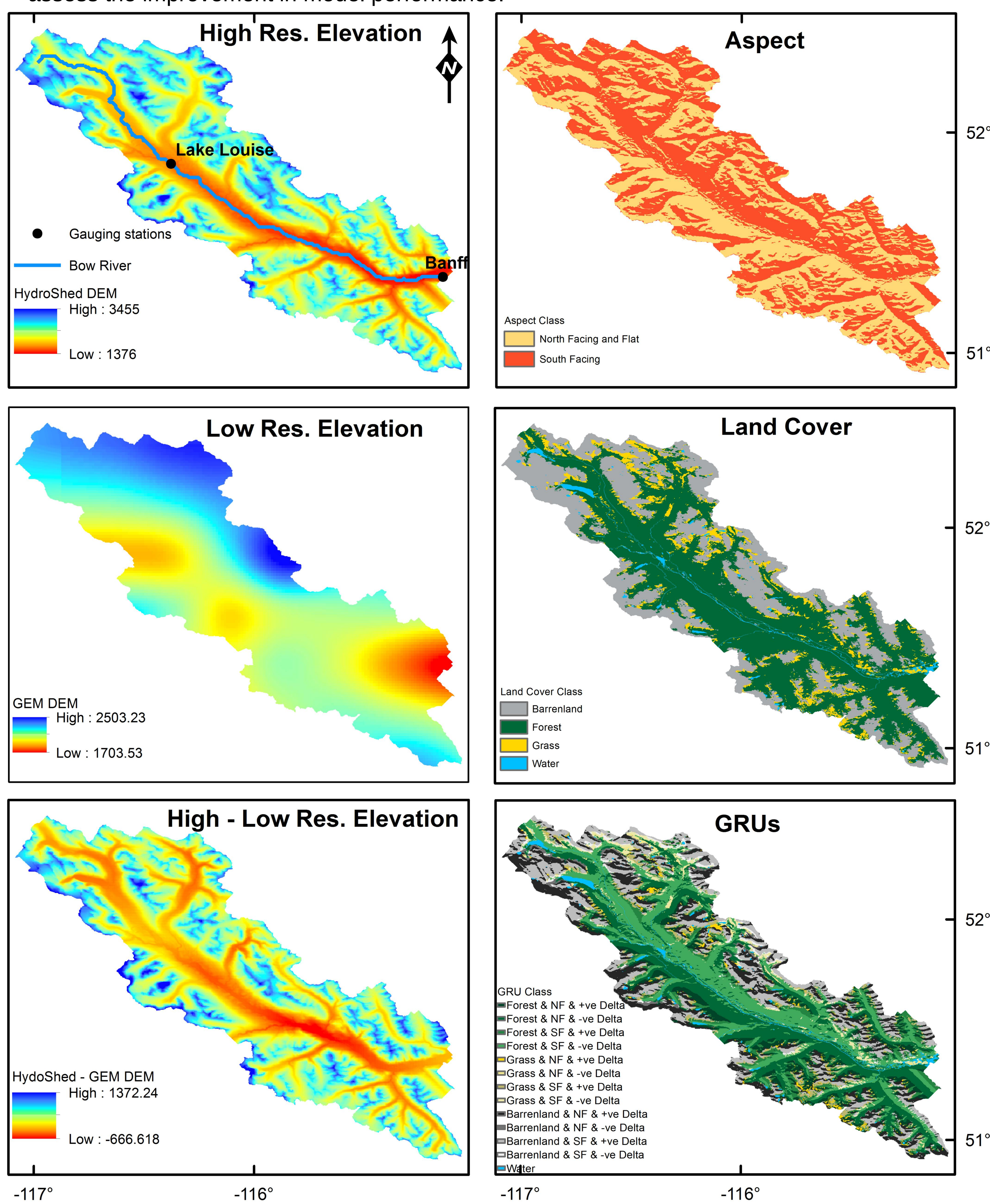
Objectives

- This study aims to make improvements to the GWF-ECCC hydrological land surface model, MESH (Modélisation Environmentale Communautaire - Surface and Hydrology), driven by the atmospheric Global Environmental Multi-scale model (GEM), in order to make the coupled GEM-MESH more suitable for mountain predictions.

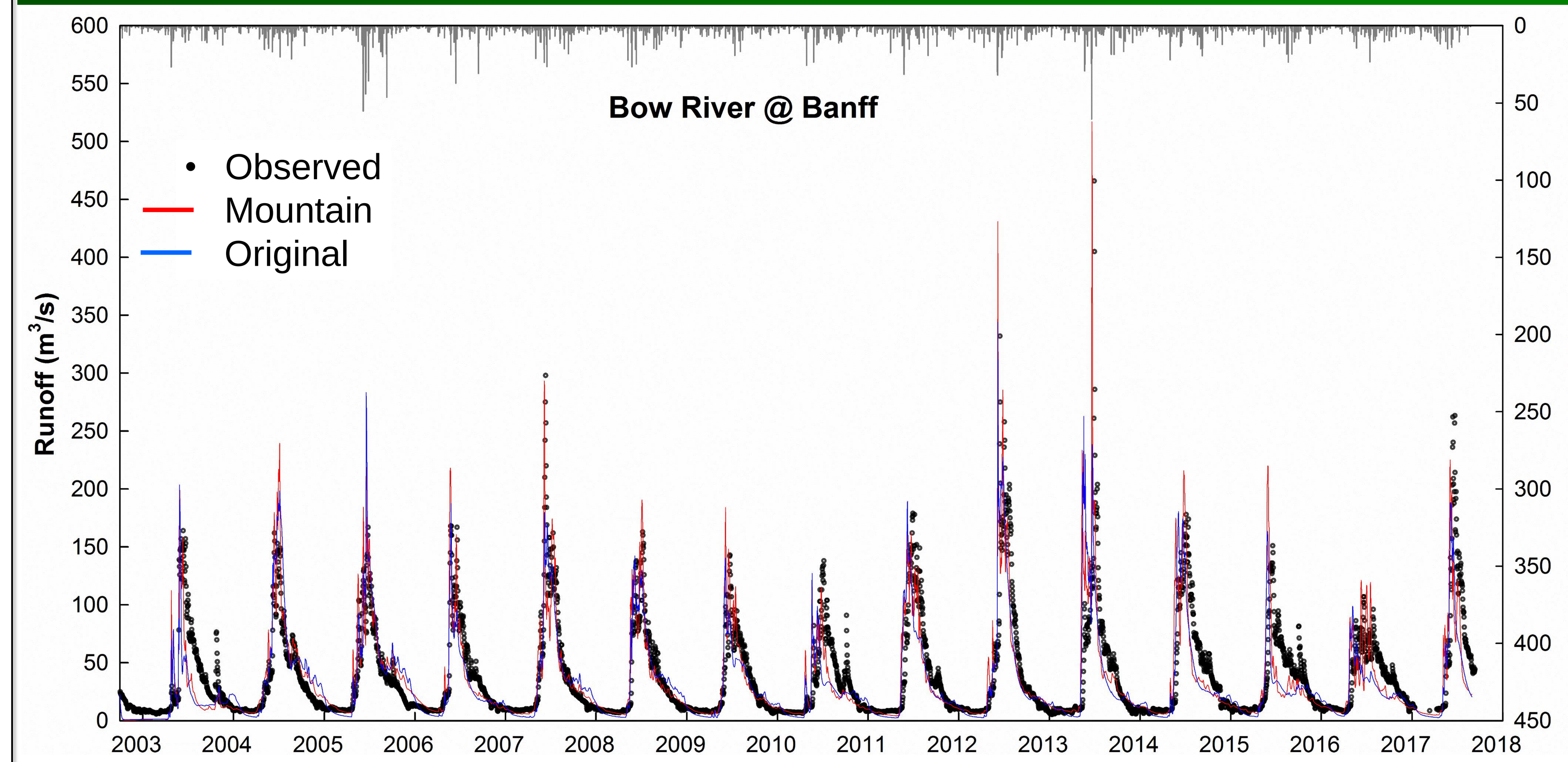
Study Site and Methods

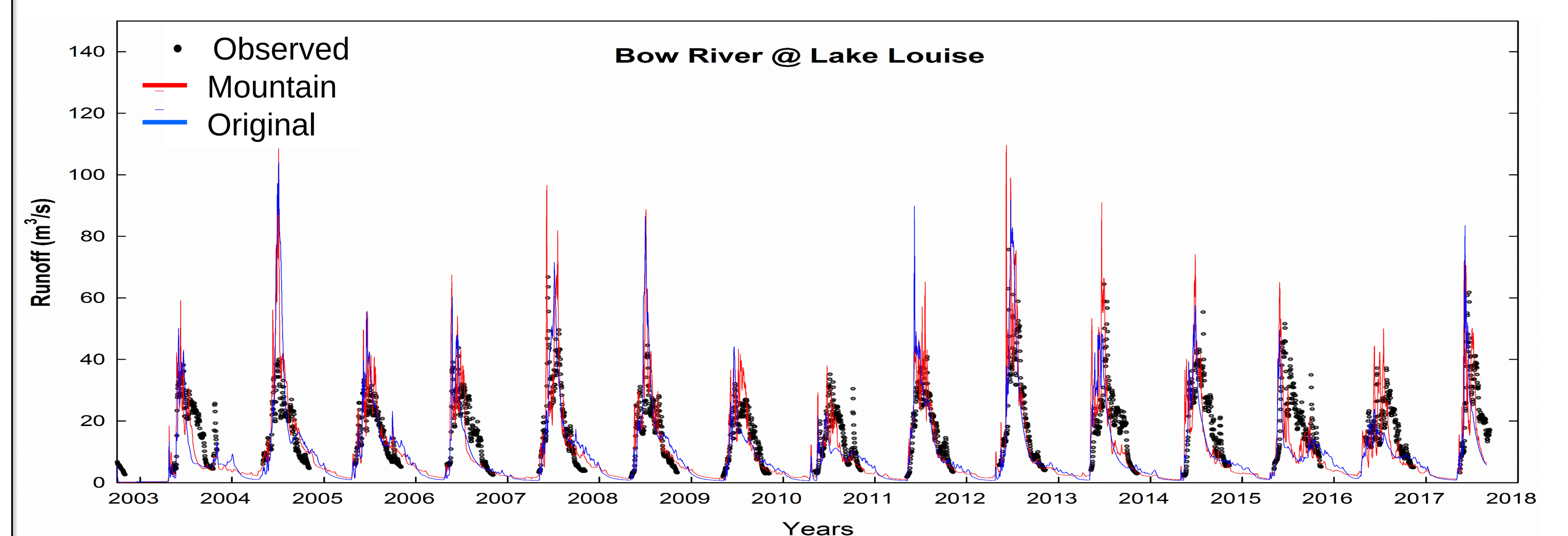
- The Bow River Basin at Banff covers an area of 2207 km^2 with elevation ranging from 1376 to 3455 m.a.s.l.
- MESH that couples the Canadian Land Surface Scheme (CLASS) and flow routing (WATROUTE) was used.
- MESH was set-up for the Bow River using topographic, land use and soil data at 0.125° spatial resolution and included elevation, slope and aspect in grid-cell discretization to Grouped Response Units (GRU or tiles).
- A module that downscaled and adjusted forcing data from GEM - CaPA to GRU was integrated into 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

- Original: Without improved representation of slope, aspect and topography with only 5 GRUs: Forest, Grass, Cropland, Barren land and Water.
- Mountain: With improved representation of slope, aspect and topography 17 GRUs (Land cover (Forest, Grass, Cropland, Barrenland) combined with aspect (North and South Facing) combined with elevation difference between model high resolution elevation and GEM elevation (located above or below GEM elevation level) and water.
- MESH calibrated for both cases separately using pseudo multi-objective optimization framework (NSE, logNSE, PBIA) for the period Oct, 2002 to Oct, 2012.
- Validated at the same stream gauging station for the period Oct, 2012 to Oct, 2017 and another stream gauging station: Lake Louise for the period from Oct, 2002 to Oct, 2017 to assess the improvement in model performance.



Results





Stations	MESH	Calibration (Oct, 2003 – 2012)			Validation (Oct, 2012 – 2017)		
		NSE	LogNSE	%BIAS	NSE	LogNSE	%BIAS
Banff	Mountain	0.88	0.88	0.25	0.79	0.82	-15
	Original	0.79	0.66	-3.50	0.73	0.62	-24
Lake Louise	Mountain	Spatial Validation (Oct, 2002 – 2017)			0.45	0.64	0.77
	Original				0.04	0.30	-6

Conclusions

- The modelling experiment showed improved predictive performance with more realistic representation of mountain topography, slope and aspect in GEM-MESH.
- The mountain-version GEM-MESH model can be used for forecasts and predictions for mountain river basins where rigorous consideration of topography heterogeneity, slope and aspect is necessary to forecast floods and assess the impact of future climate change on water resources availability.

References

- Bernier, N.B., S. Bélair, B. Bilodeau, and L. Tong, 2011: Near-Surface and Land Surface Forecast System of the Vancouver 2010 Winter Olympic and Paralympic Games. J. Hydrometeor., 12, 508–530
- Garnier BJ and Ohmura A. 1968. A method of calculating the direct shortwave radiation income of slopes. Journal of Applied Meteorology 7(5): 796–800.
- Marty, Christoph & Philipona, R & Fröhlich, Claus & Ohmura, Atsumu. (2002). Altitude dependence of surface radiation fluxes and cloud forcing in the alps:Theoretical and Applied Climatology. 72. 137-155.

Acknowledgements

The University of Saskatchewan and CFREF Global Water Futures Programme