HYDROLOGICAL MODELING OF HIGHLY GLACIERIZED RIVER BASINS

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Problem statement

- **Glaciers help to keep the earth cool**

High solar radiation reflection with albedo 0.8 (albedo ranges 0-1)

- **Glaciers as reservoirs of fresh water**

Only 2% glacier cover provides more than 30% of total annual discharge in Indus river basin (Immerzeel et al., 2010).

- **Glacier compensation effect**

In European Alps during dry summer 2003, glacier contribution was 12 times greater than normal, permitting normal hydroelectric production, whereas power production was significantly reduced elsewhere (Koboltschnig et al., 2008).

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Background

- Spatial variation of melt rates is affected by: topography (aspect, slope), ice or snow cover, climate type etc.
- SWAT model snow routing has been modified (SWAT2012), so that the snow melt/accumulation parameters are allowed to be spatially **variable** in **sub basins** and **elevation band** scale
- Distributed temperature-index, allowing for spatially variable melt estimates (Cazorzi and Fontana, 1996; Hock, 1999; Daly et al., 2000).

Objectives

1) Evaluation of SWAT's distributed snow algorithm in simulation of monthly runoff in glaciered basins

2) Extending the applied method to other river basins that are vary in climatic condition

Major steps

1) Identifying the vulnerable areas
2) Data collection
3) Modeling the glacierized area in SWAT
4) Model calibration and validation for pilot study areas
    - vs. streamflow only
    - vs. streamflow and glacier measurements
5) Extending the methodology to the other regions

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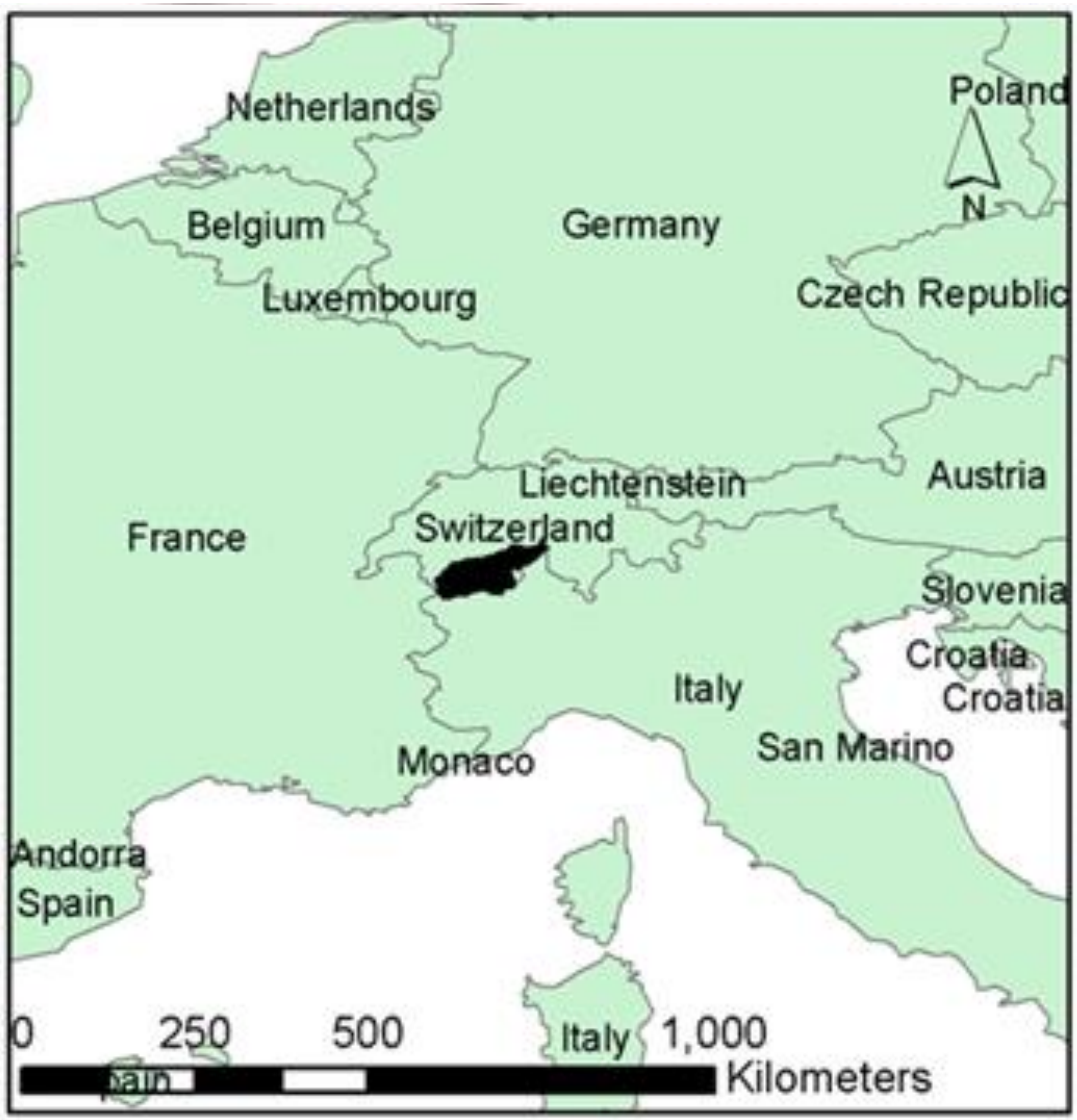
Study Area



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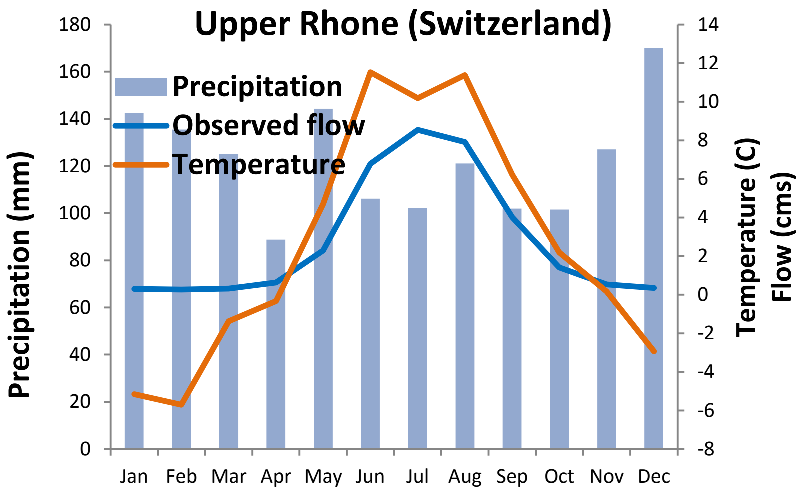
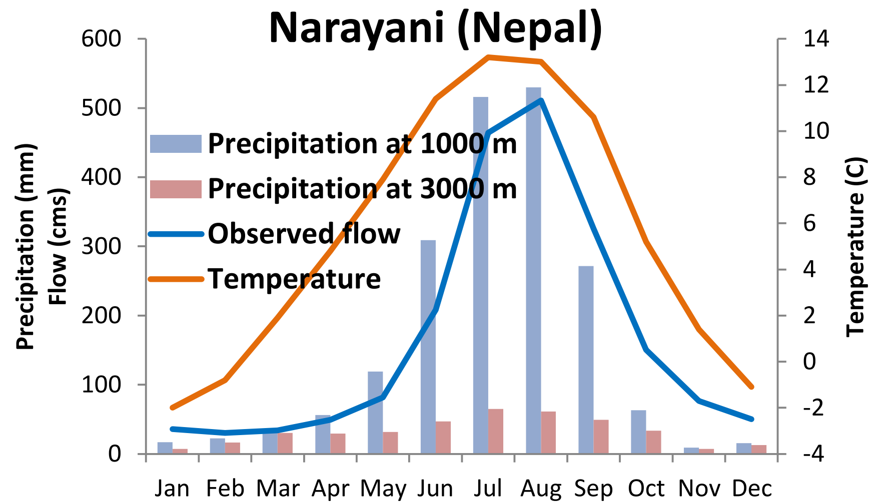
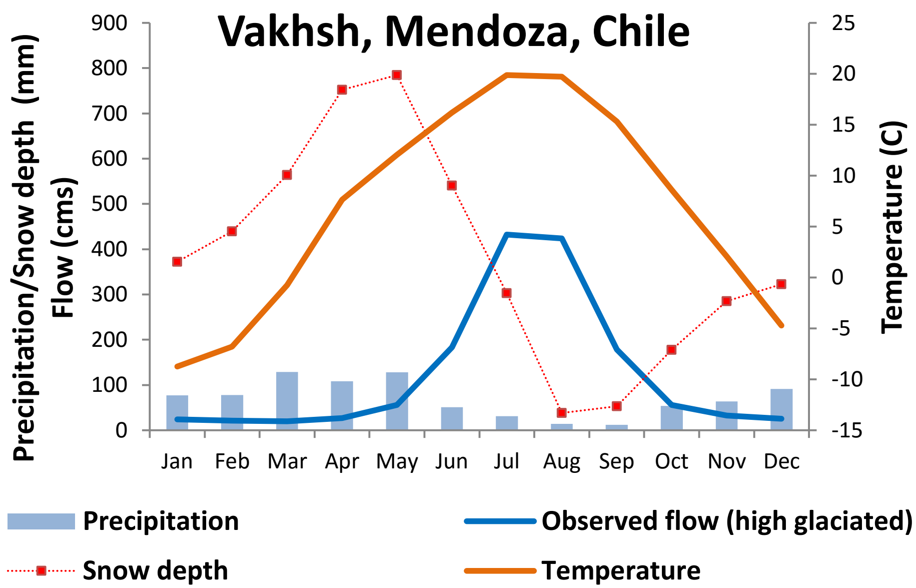
Runoff regime of the basins







Setting the climatic glacier boundary

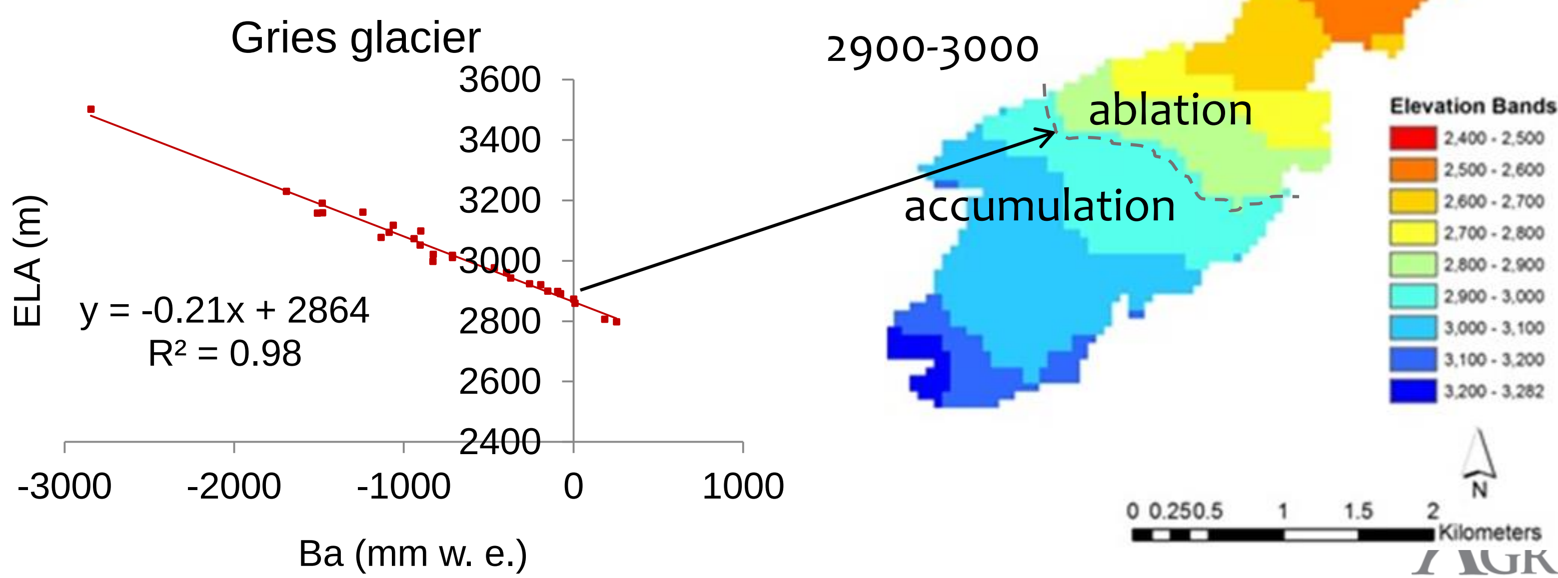
The climatic glacier boundary was set at some randomly selected subbasins

Glacier climatic boundary is a synthetic line where accumulation = ablation

Mass budget (Ba) is zero.

Parameter setting:

- Precipitation laps rate: controls accumulation
- Temperature laps late: controls melt
- Snow melt temperature: controls melt



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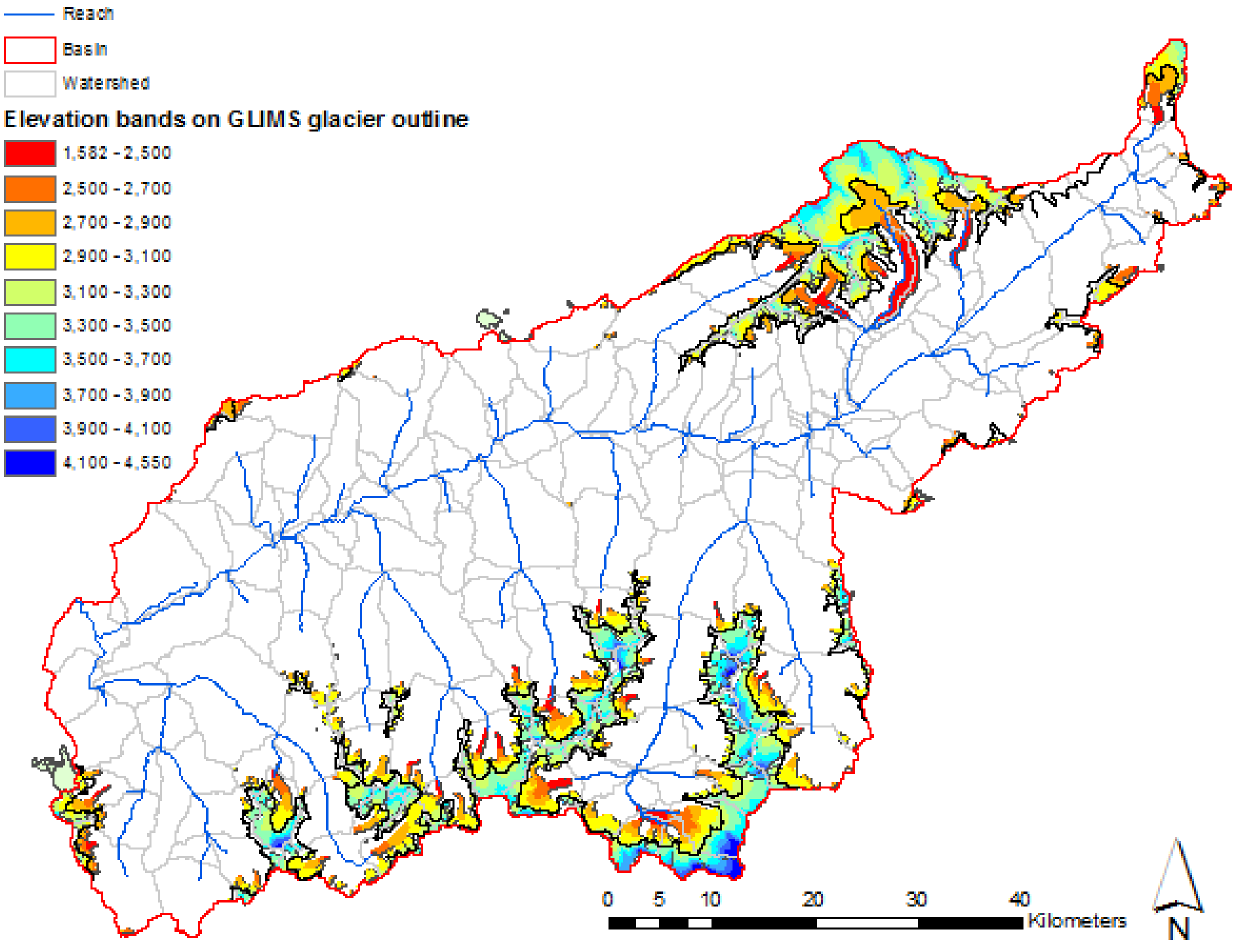
Glacier modeling in SWAT

- 10 elevation bands with 100m to 250m intervals
- Glaciers accumulation boundary: Lowest boundary of climatic glaciation
- Infinite depth (1 km)

	GLIMS %	Modeled Area%
Narayani	10	11
Vakhsh	10	12
Upper Rhone	14	14
Mendoza	-	4
Central Chile	-	4



Model Calibration and Validation

A calibrated model can give good runoff predictions for the wrong reasons.

On glaciers there are extra possibilities:

mass balance and equilibrium-line altitude, besides the discharge can help constrain the values of parameters.

1) streamflow only

2) streamflow and glacier measurements

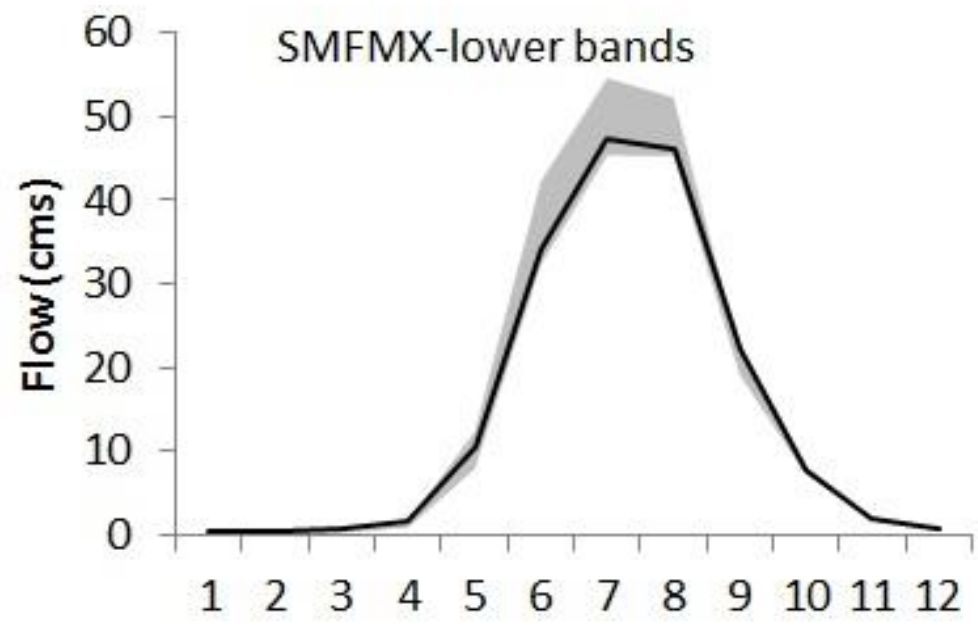
Monthly flow data at 35 gauging stations.

Automatic calibration tool: SWAT-CUP (Abbaspour, 2002)

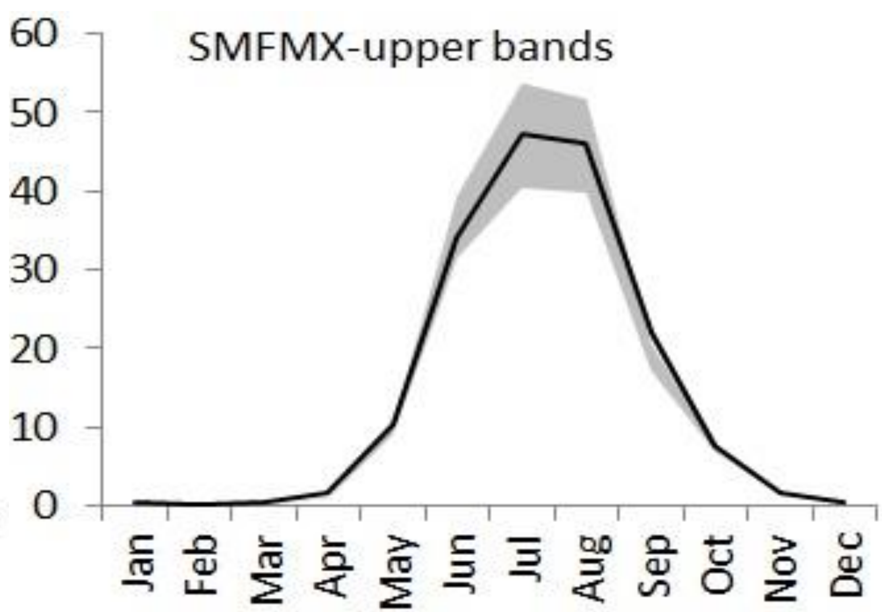
Effect of melt parameter distribution on simulated flow (Massa-Blatten in Rhone)

SMFMX varies between 2 to 8 mm d^{-1} $^{o}C^{-1}$ thorough elevation bands

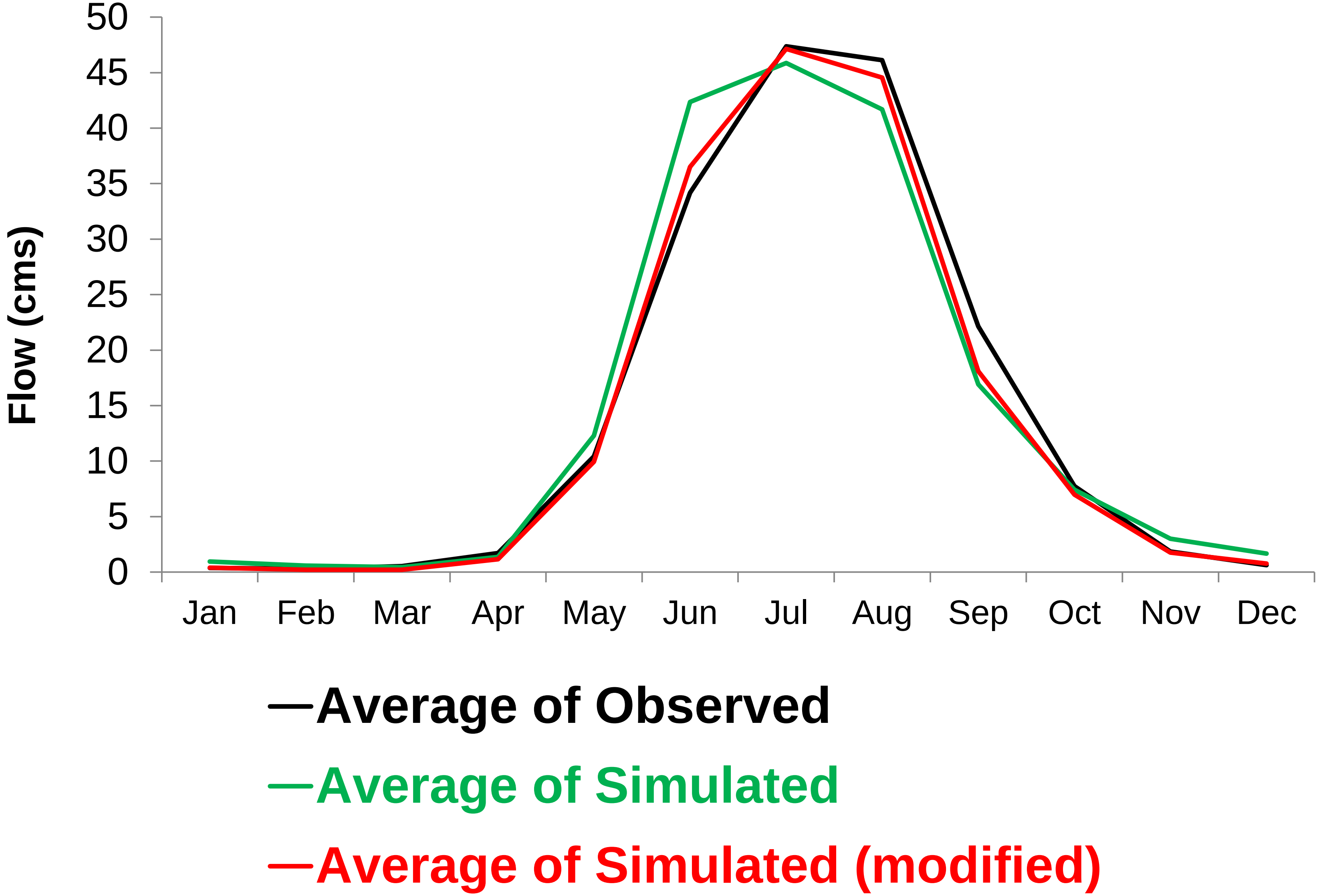
Glacier free bands
Below 2900 m



Glacierized bands
Over 2900 m



Massa-Blatten in Rhone



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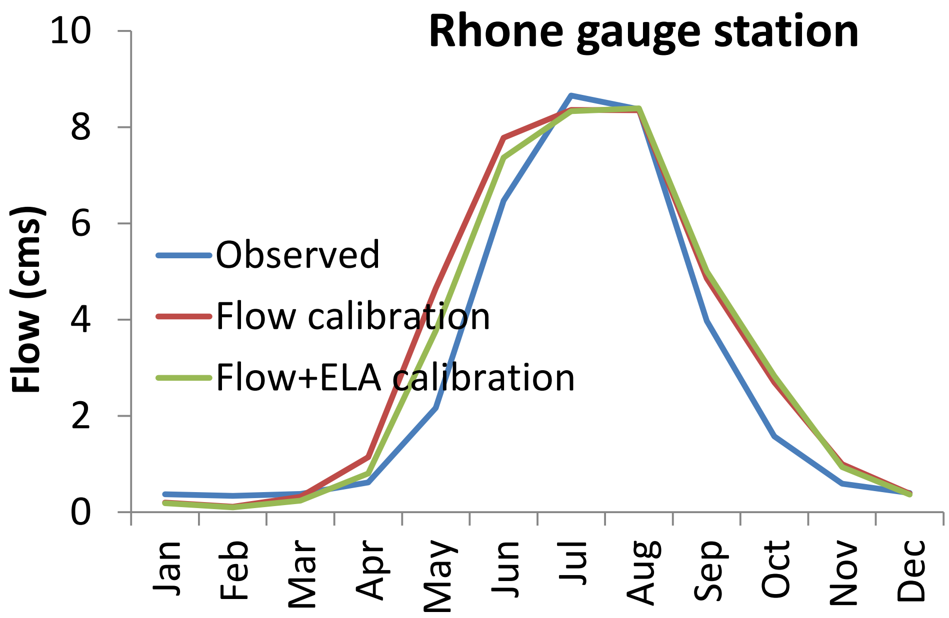
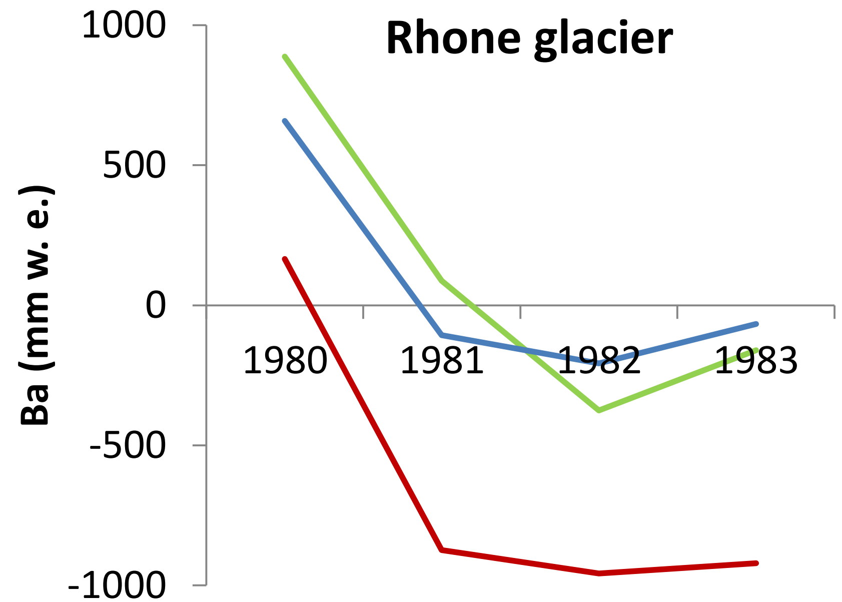
Rhone glacier (Gauged)

Calibration 1: monthly flow (automatic calibration)

Calibration 2: monthly flow + annual ELAs (1980-1983) (manual parameter adjustments)



Specific net mass balance



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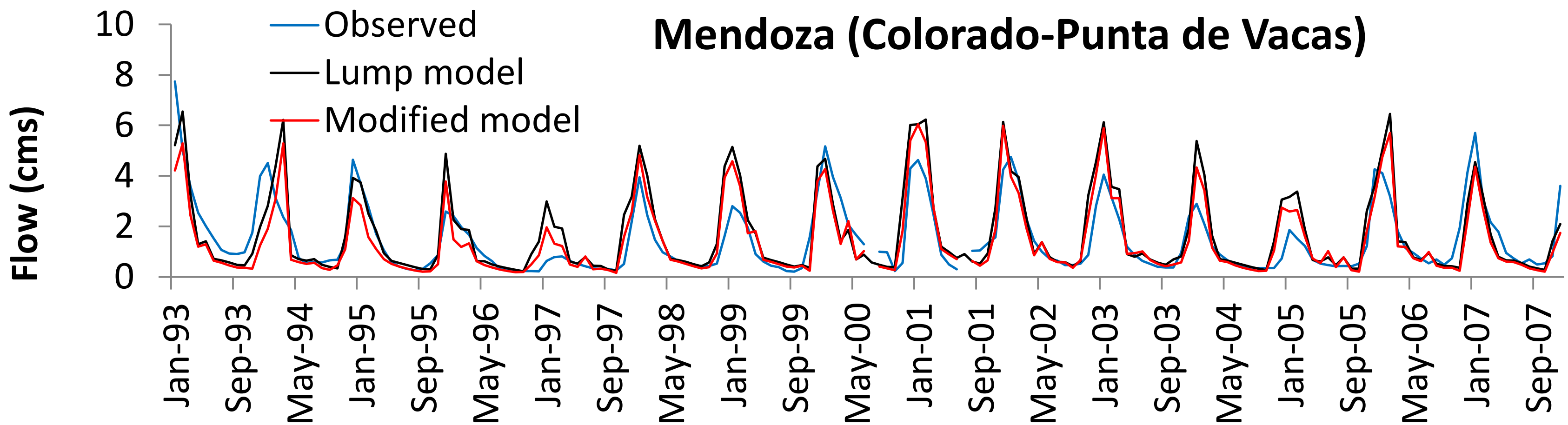
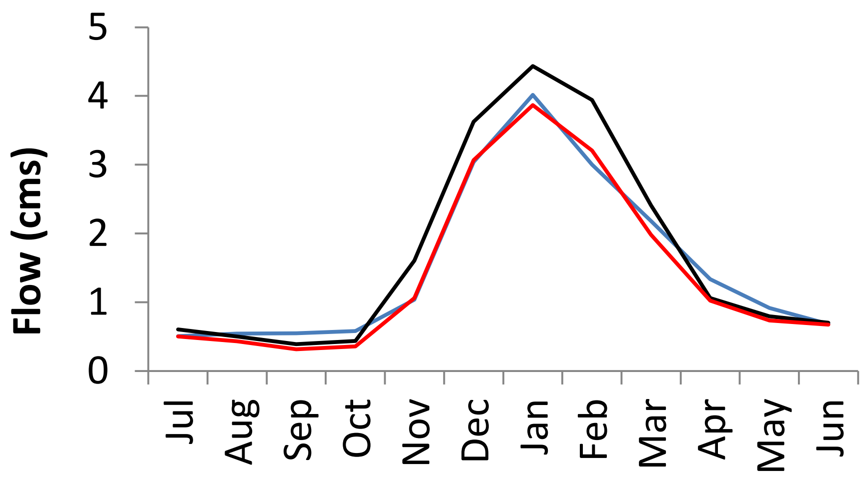
Model accuracy in simulation of seasonal runoff was enhanced by setting the melt parameters for glaciers (high altitude elevation bands) and seasonal snow (low altitude elevation bands) separately.





	Calibration						Validation	
	R^2		NSE		PBIAS			
	lumped	distributed	lumped	distributed	lumped	distributed	R^2	NSE
Narayani	0.81	0.83	0.81	0.83	-6.6	+0.5	-	-
	0.85	0.83	0.77	0.73	+10.5	+25.7	-	-
	0.88	0.88	0.85	0.87	+2.1	+8.6	0.79	0.78
	0.91	0.89	0.69	0.70	**+39.5**	**+33.8**	0.78	0.70
Mendoza	0.76	0.78	0.70	0.77	**+22.5**	**+5.0**	0.80	0.71
	0.66	**0.65**	**0.32**	**0.59**	**-15.8**	**+3.6**	0.43	-0.24
	0.60	0.62	0.52	0.58	+7.2	+7.9	0.61	0.59
	0.45	**0.54**	**0.28**	**0.50**	**-17.9**	**+5.5**	0.57	0.46
Rhone	**0.82**	**0.85**	**0.76**	**0.83**	**-24.7**	**-13.2**	0.86	0.81
	0.81	0.81	0.75	0.74	+2.7	+5.5	0.76	0.61
	0.86	**0.91**	**0.85**	**0.91**	**-7.3**	**-1.5**	0.86	0.82
	0.95	0.95	**0.86**	**0.95**	**+25.9**	**+2.2**	0.95	0.89

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Conclusions

- Treating the glacierized and glacier free areas separately, significantly improved the SWAT model performance in simulation of volume and seasonality of runoff in glacierized areas.
- Significance of meltwater is negligible where the melt season is coincidence with monsoon precipitation, so there was no significance different in the results by distributed model. This is due to dominance of rainfall-runoff model rather than the snow melt model.
- The results emphasized on the importance of combining even few information about the glaciers along with measured discharge data in model calibration.

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Thank you