WEB-DHM with advanced energy balance based snow-melt scheme and glacier melt component

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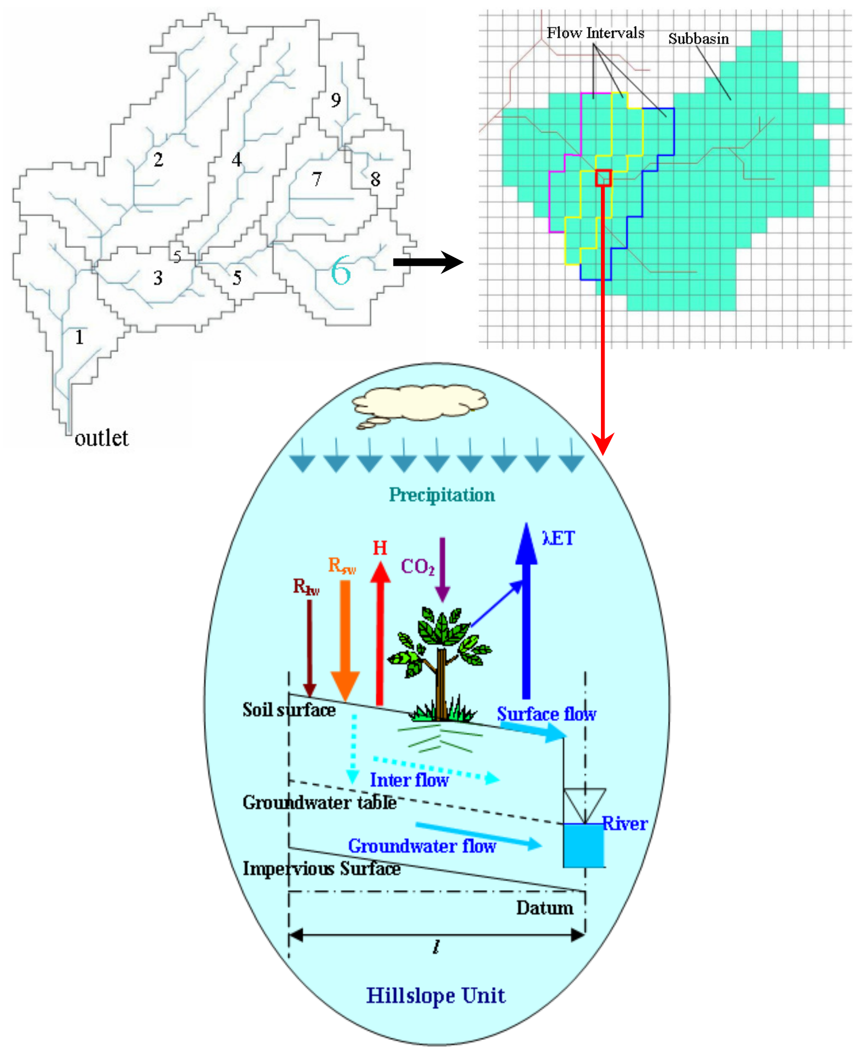
Snow scheme in WEB-DHM



Description	WEB-DHM
Snow layer	Single bulk layer
Snow density	Set as constant (200 kgm^{-3})
Snow depth	5 times snow water equivalent
Snow thermal conductivity	Same as that of soil
Shortwave radiation transmission	Not transmitted to snow
Snow water/ice content	Not calculated
Surface energy fluxes	Applied to whole bulk layer
Snow albedo	Set as constant but decreases while melting empirically
Snow surface temperature	Snow and ground surface have same temperature. Snow surface temperature is the average temperature of bulk snow layer

No Glacier Component at ALL

Snow scheme in existing Models

Name of the Model	Layers	Compaction/ Density evolution	Albedo	Cold content/ Refreezing	Canopy snow process	Solar radiation penetration	Snow tempr.	Soil tempr.	Soil moisture	Glacier processes	Runoff routing	References
Distributed Hydrology Soils Vegetation Model (DHSVM)	2	Prognostic (Empirical)	Prognostic (Empirical)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Wigmosta et al. (1994); Storck (1999)
Variable Infiltration Capacity (VIC)	2	Prognostic (Empirical)	Prognostic (Empirical)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Liang et al. (1994), Cherkauer et al. (2003)
Utah Energy Balance (UEB) – distributed snow model	1	Constant	Prognostic (Physical)	Yes	No	Yes	Yes (Bulk)	Yes (Bulk)	No	No	No	Tarboton and Luce (1999)
ISNOBAL	2	Prognostic (Empirical)	Prognostic (Physical)	Yes	No	Yes	Yes	No	No	No	No	Garen and Marks (2005)
WATCLASS	1	Prognostic (Empirical)	Prognostic (Empirical)	Yes	Yes	Yes	Yes (Bulk)	Yes (Bulk)	Yes	No	Yes	Soulis et al. (2000, 2002)
SnowMOD	1	Prognostic (Physical)	Prognostic (Empirical)	Yes	Yes	Yes	Yes (Bulk)	No	No	No	No	Liston et al. (2006)
Cold Region Hydrological Model (CRHM)	1	Not accounted	Prognostic (Empirical)	Yes	Yes	Yes	Yes (Bulk)	Yes (Bulk)	Yes	No	Yes	Pomeroy et al. (2007)
Geo-TOP	5	Prognostic (Physical)	Prognostic (Physical)	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Endrizzi (2007)
Distributed Biosphere Hydrological Model (DBHM)	1	Constant	Empirically constant	Yes	Yes	No	Yes (Bulk)	Yes (Bulk)	Yes	No	Yes	Tang (2006)
Water and Energy Budget based Distributed Hydrological Model (WEB-DHM)	1	Constant	Empirically constant	Yes	Yes	No	Yes (Bulk)	Yes (Bulk)	Yes	No	Yes	Wang et al. (2007; 2009a,b)
WEB-DHM with improved snow and glacier physics (WEB-DHM-S)	3	Prognostic (Physical)	Prognostic (Physical)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	This Study

Model Development

1. Single layer Energy Balance

- Constant Density (200 kg/m^3)
- Surface temperature is averaged snowpack temperature .

SSiB3 model [Simplified Simple Biosphere 3]
[Sun and Xue, 2001]

- 3 layer energy balance snow scheme with prognostic density evolution.
- Albedo is same as in WEB-DHM.

2. Snow Albedo

- Constant dry snow albedo:
  0.8 for Visible (VIS) and
  0.4 for Near infrared (NIR) band.
- For melting snow, albedo is set to 60% of the dry snow albedo.

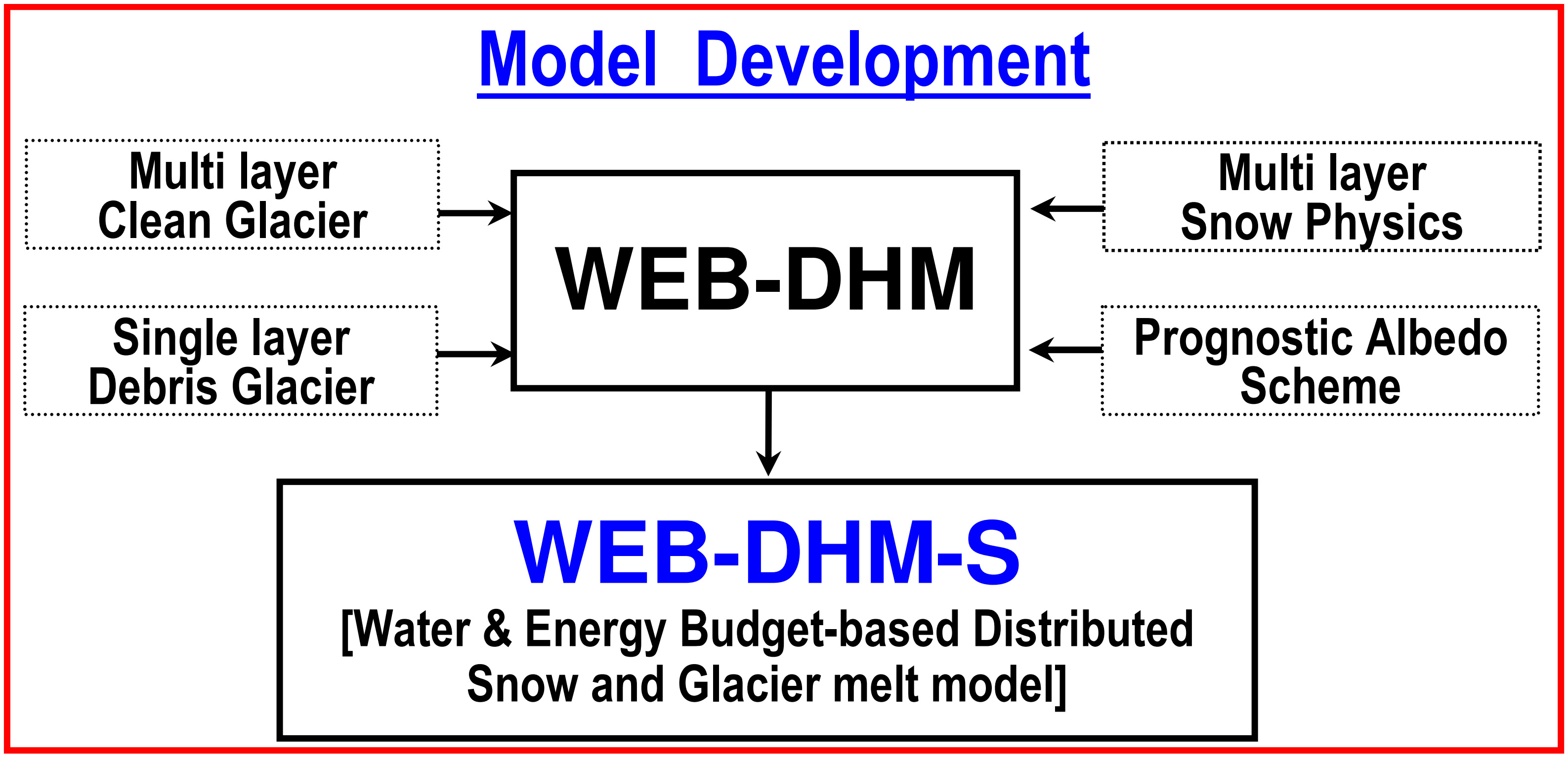
BATS [Biosphere-Atmosphere-Transfer-Scheme]
[Dickinson et al., 1993]

- Single layer energy balance snow scheme.
- Albedo is physically updated accounting the aging effect, grain size and zenith.

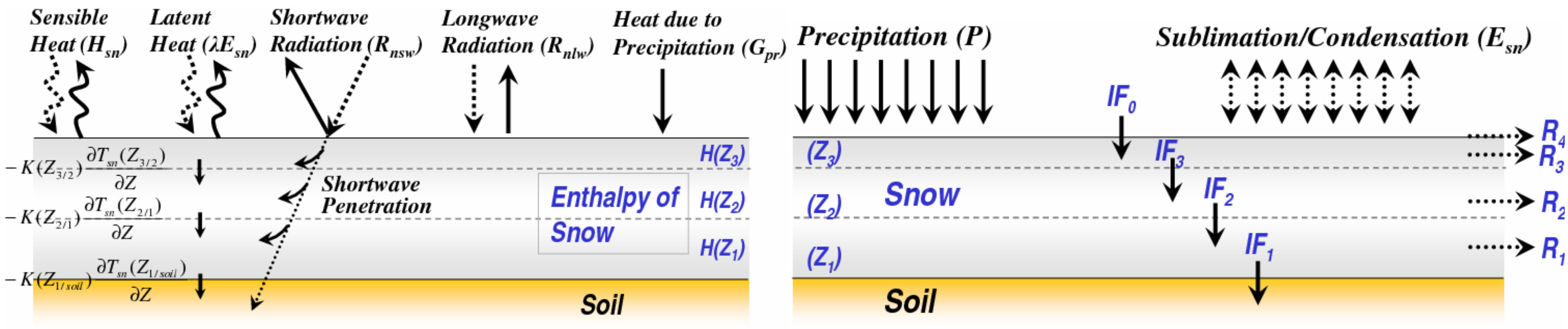
3. No Glacier Physics

Development of Energy balance-based 3 Layer model for Clean Glacier & 1 layer model for Debris covered Glacier

WEB-DHM-S Model



Snow accumulation and Melting Process



Energy Balance

Mass Balance

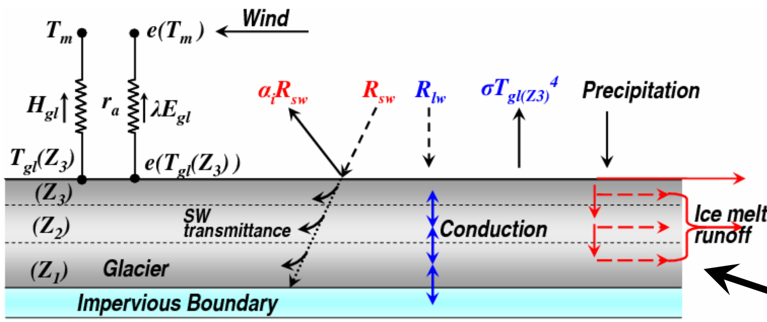
- Surface energy balance – Top layer
- Conductive flux – Underlying layer
- Enthalpy – Cold content
- Phase Change – Refreezing/ Melting

- Ice and Water content
- Compaction
  - Destructive metamorphism
  - Overburden and melt
- Density of fresh snow
- Snow Albedo – BATS albedo
  - VIS and NIR albedo

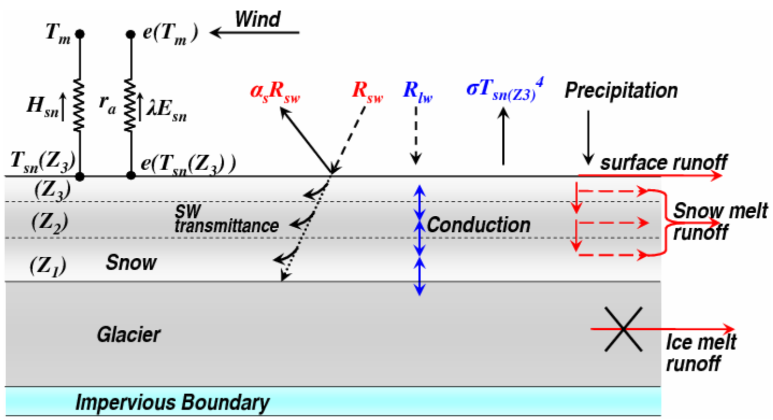
Glacier Scheme

Clean Glacier

- ✓ 3 Layer scheme
- ✓ Ice albedo = 0.4 (Time invariant)



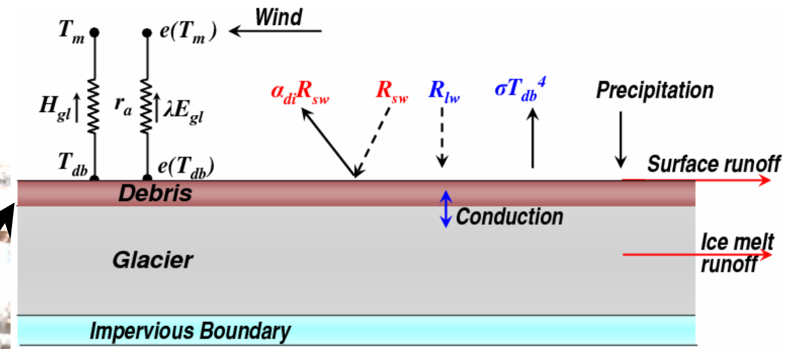
After snowfall



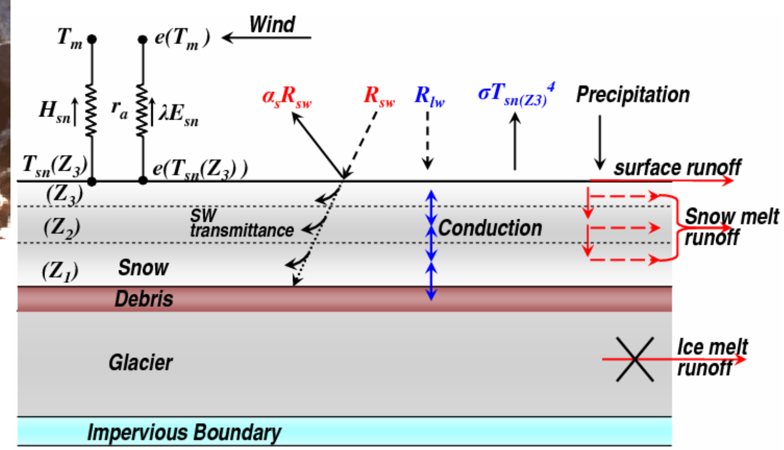
Clean Glacier covered with fresh snow

Debris covered glacier

- ✓ 1 Layer scheme
- ✓ Debris albedo = 0.15 (Time invariant)

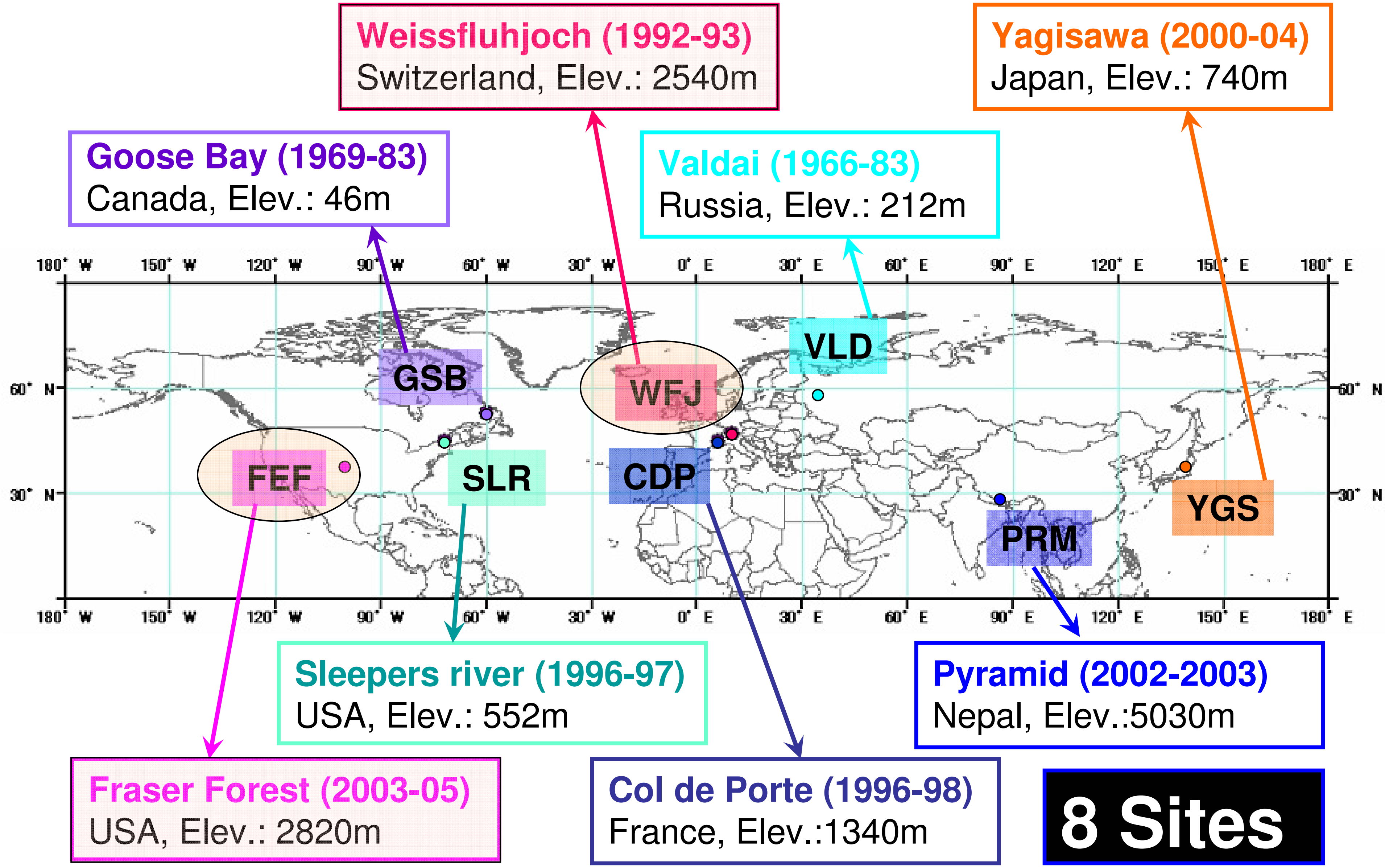


After snowfall

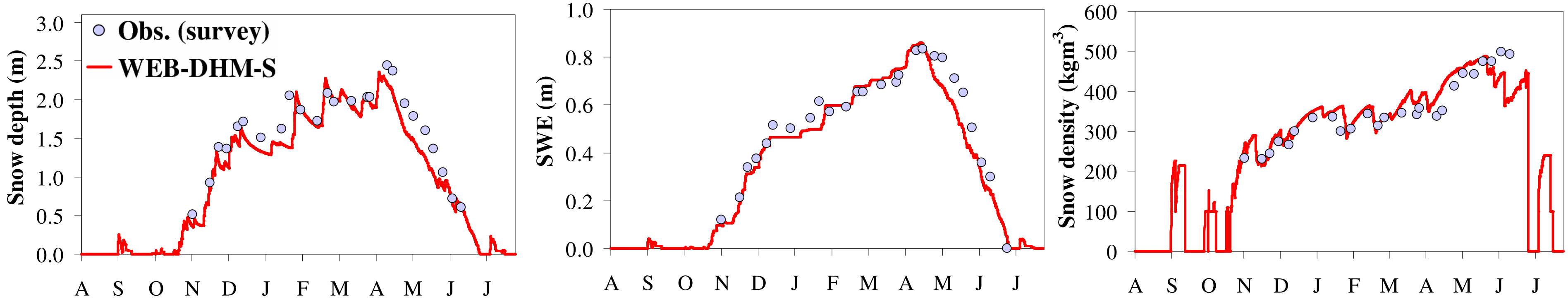


Debris covered with fresh snow

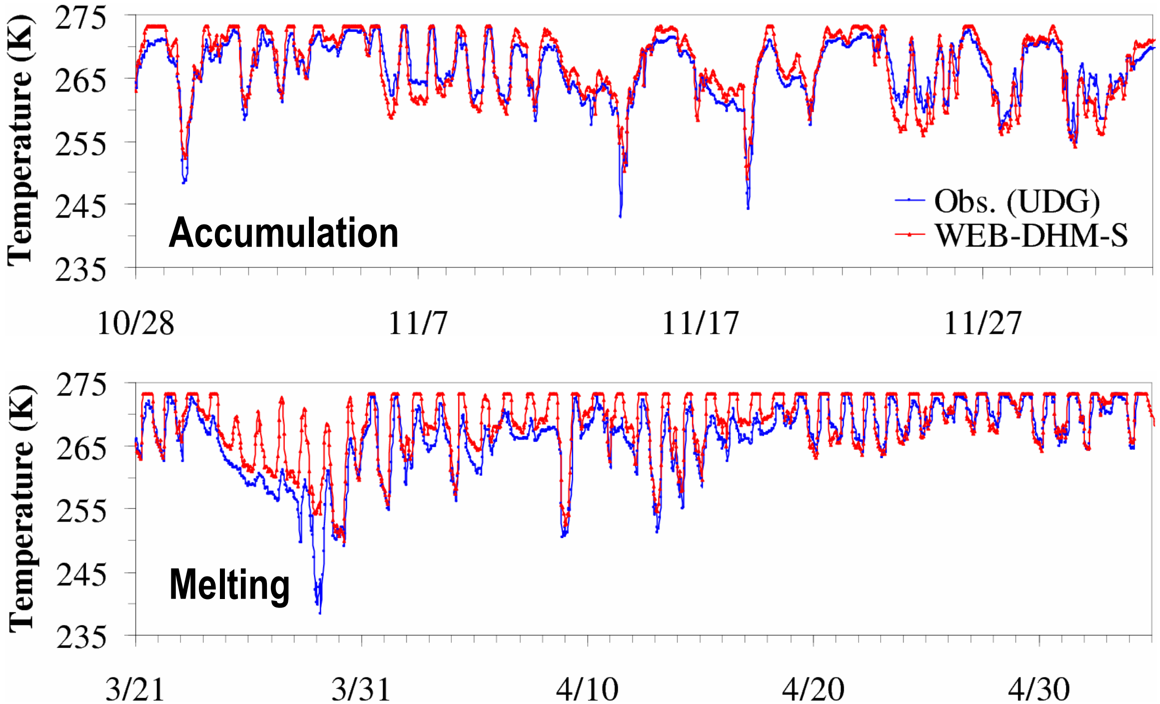
Point-scale Evaluation



Point – simulation results



Snow Surface Temperature



Basin-wide Model development & Validation

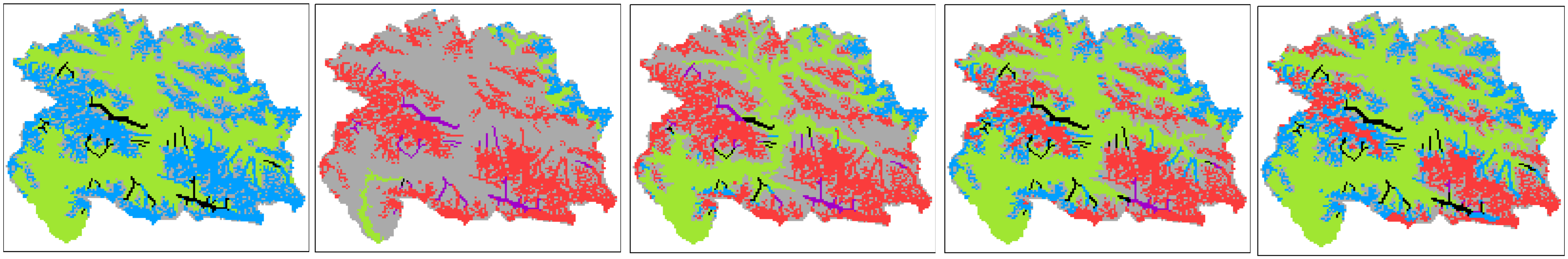
Snow & Glaciermelt Dominant

Snow+Glacier But Monsoon Dominant

Seasonal Snow cover

Snow and Glacier Cover @ Hunza Basin, Upper Indus

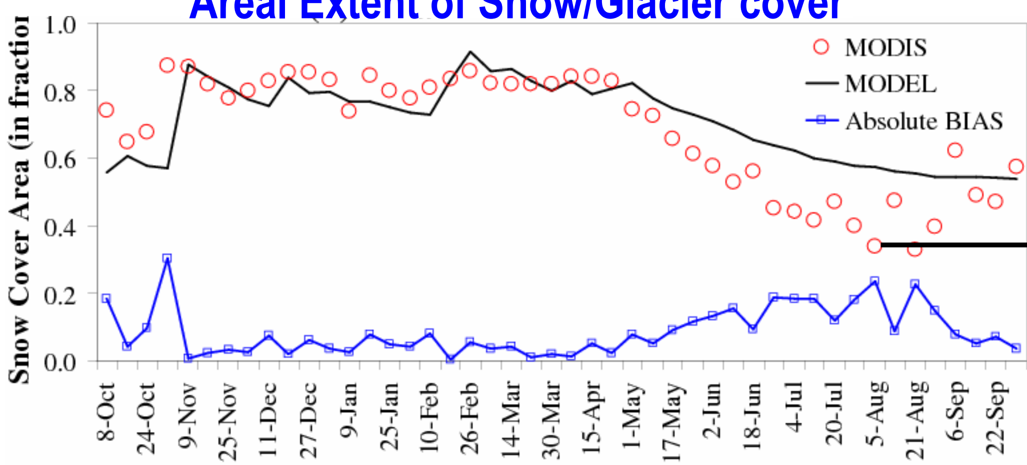
Model Output (Year 2002)



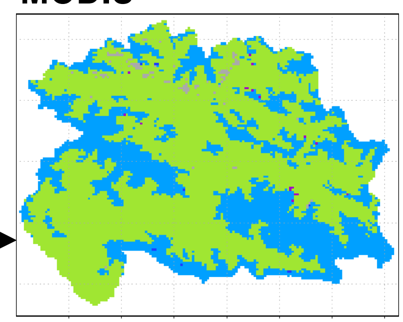
Initial Condition (Inventory-ICIMOD) | **Feb. 24** | **May 18** | **Jul. 12** | **Sep. 30**

Land
Snow over Land
Clean glacier
Snow over clean glacier
Debris covered glacier
Snow over debris glacier

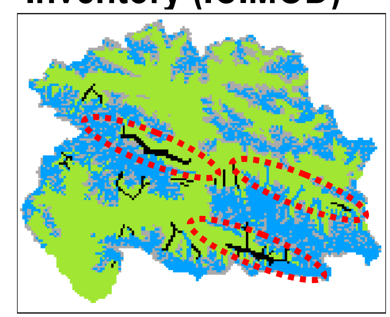
Areal Extent of Snow/Glacier cover



MODIS

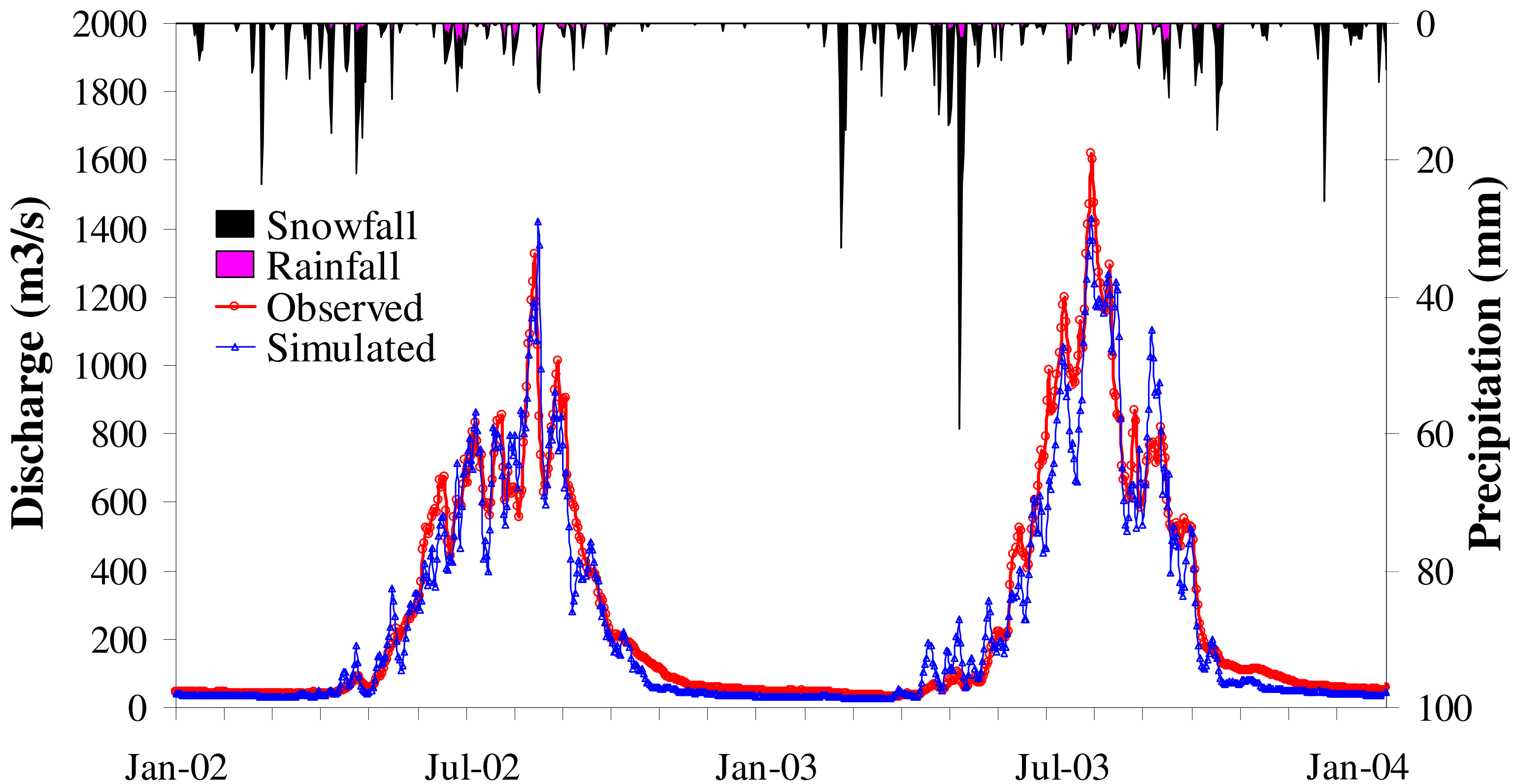


Inventory (ICIMOD)



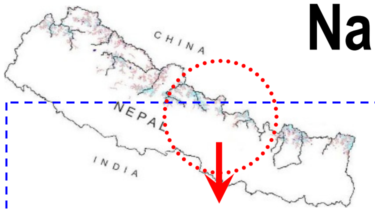
MODIS was unable to capture debris covered glaciers and low altitude clean glaciers.

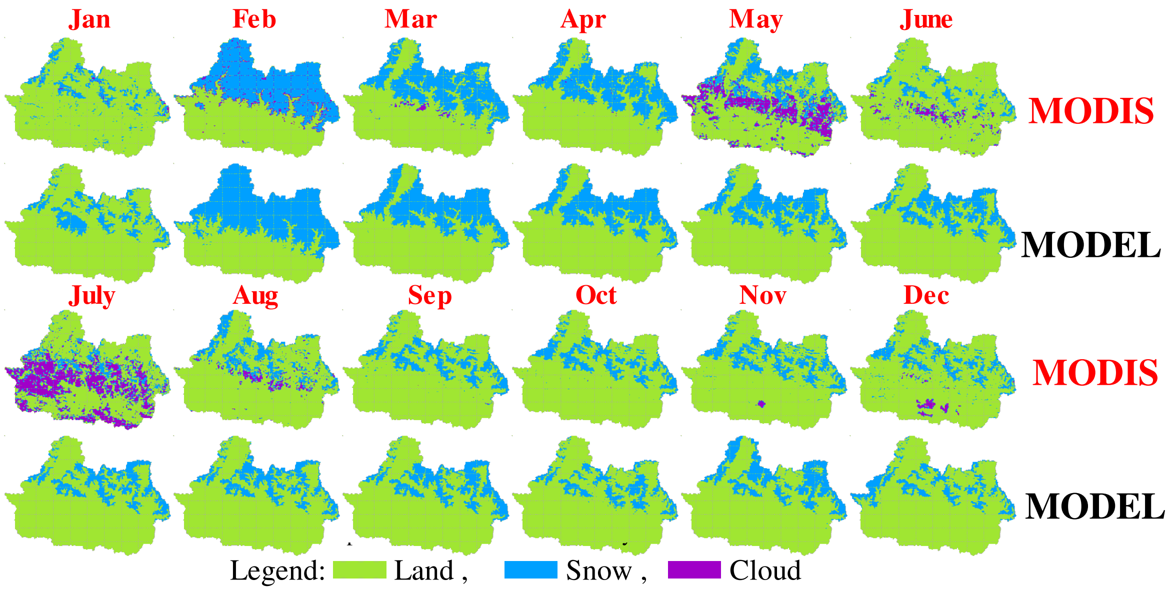
Discharge at basin outlet

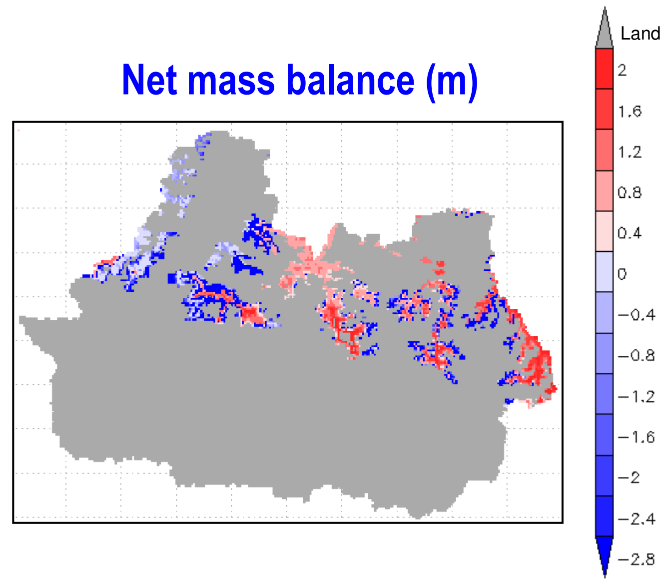


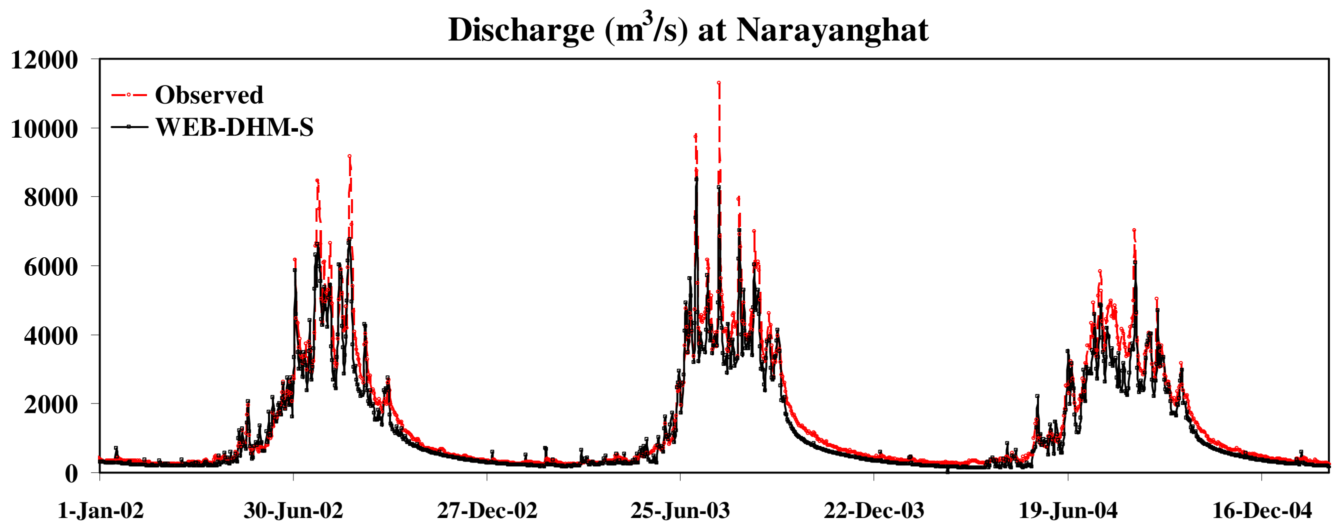
	Contribution to Discharge			Statistics		
Year	Rainfall	Snow melt	Glacier melt	NSE	MBE	R^2
2002	12%	35%	53%	0.92	+4.56%	0.97
2003	10%	40%	50%	0.94	+3.65%	0.97

Narayani River Basin at Nepal (Monsoon Dominant)



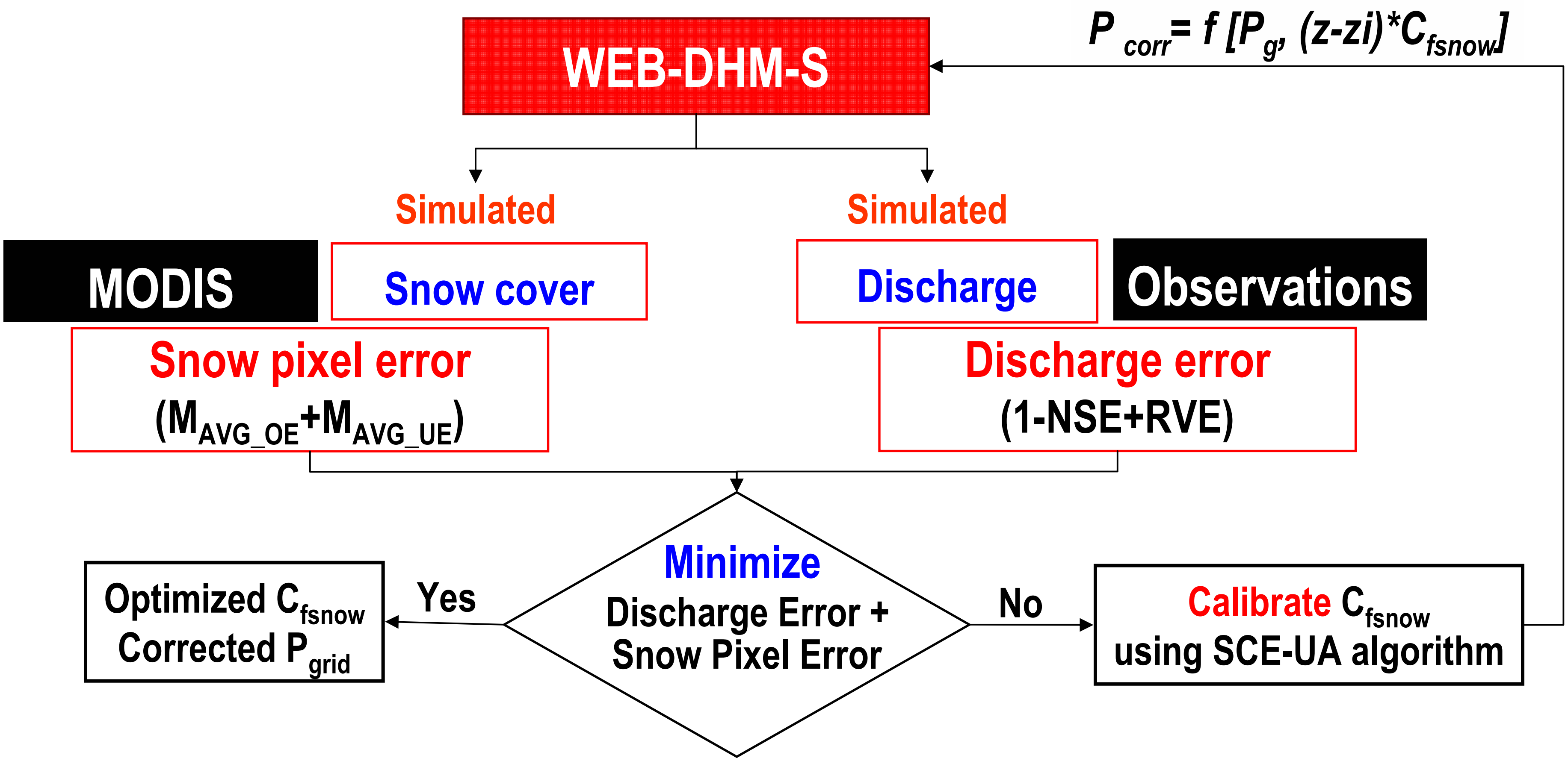






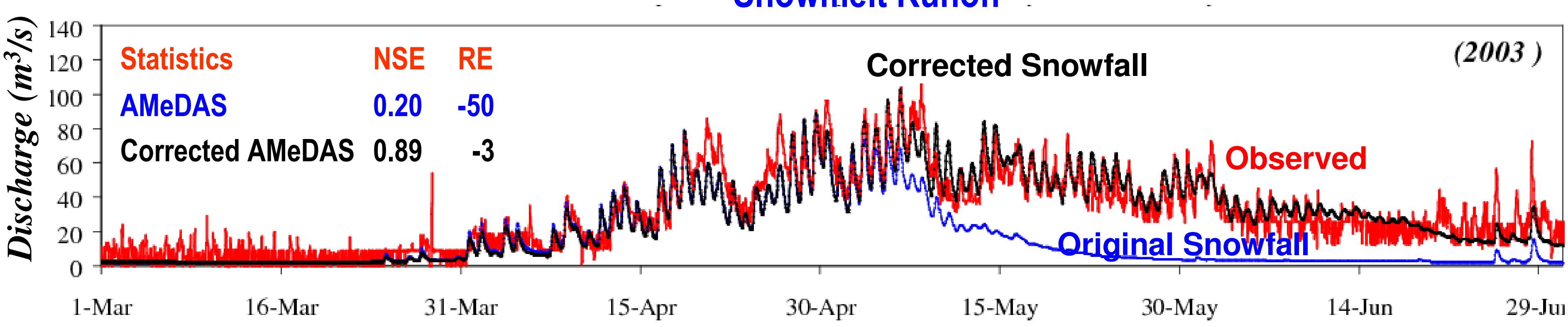
In many cases, basin scale winter precipitation (Snowfall) variability is utmost important – Systematic and Unsystematic BIASES

How the snowfall biases can be improved ?

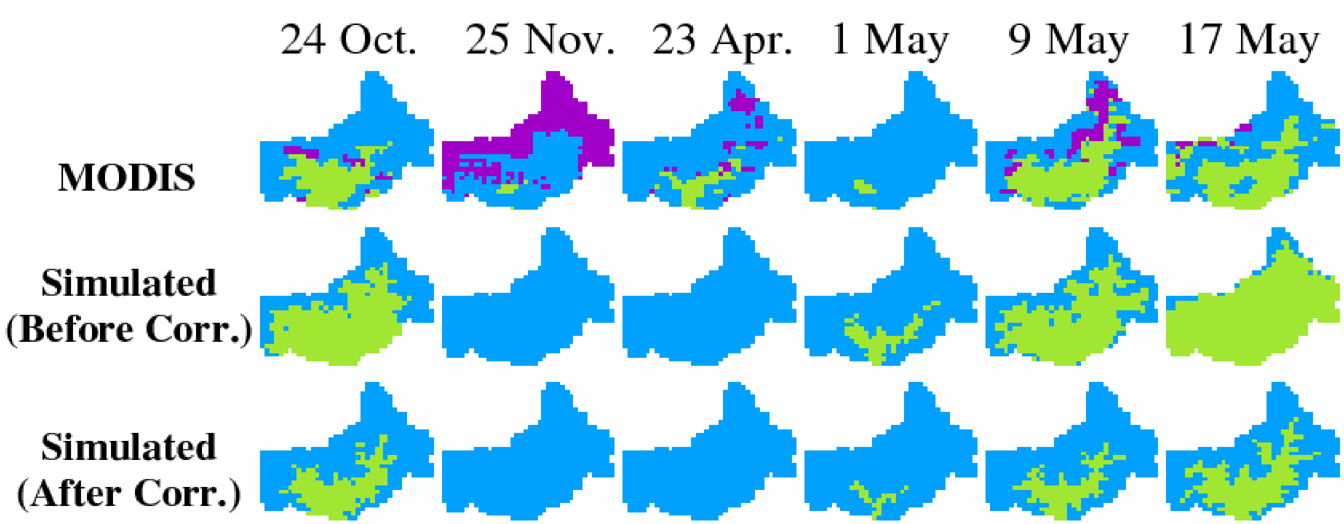


Application at Yagisawa Basin, Japan

Snowmelt Runoff



Snow Cover Area



These Corrected Snowfall values can be used to correct Reanalysis dataset for Long-term simulation.

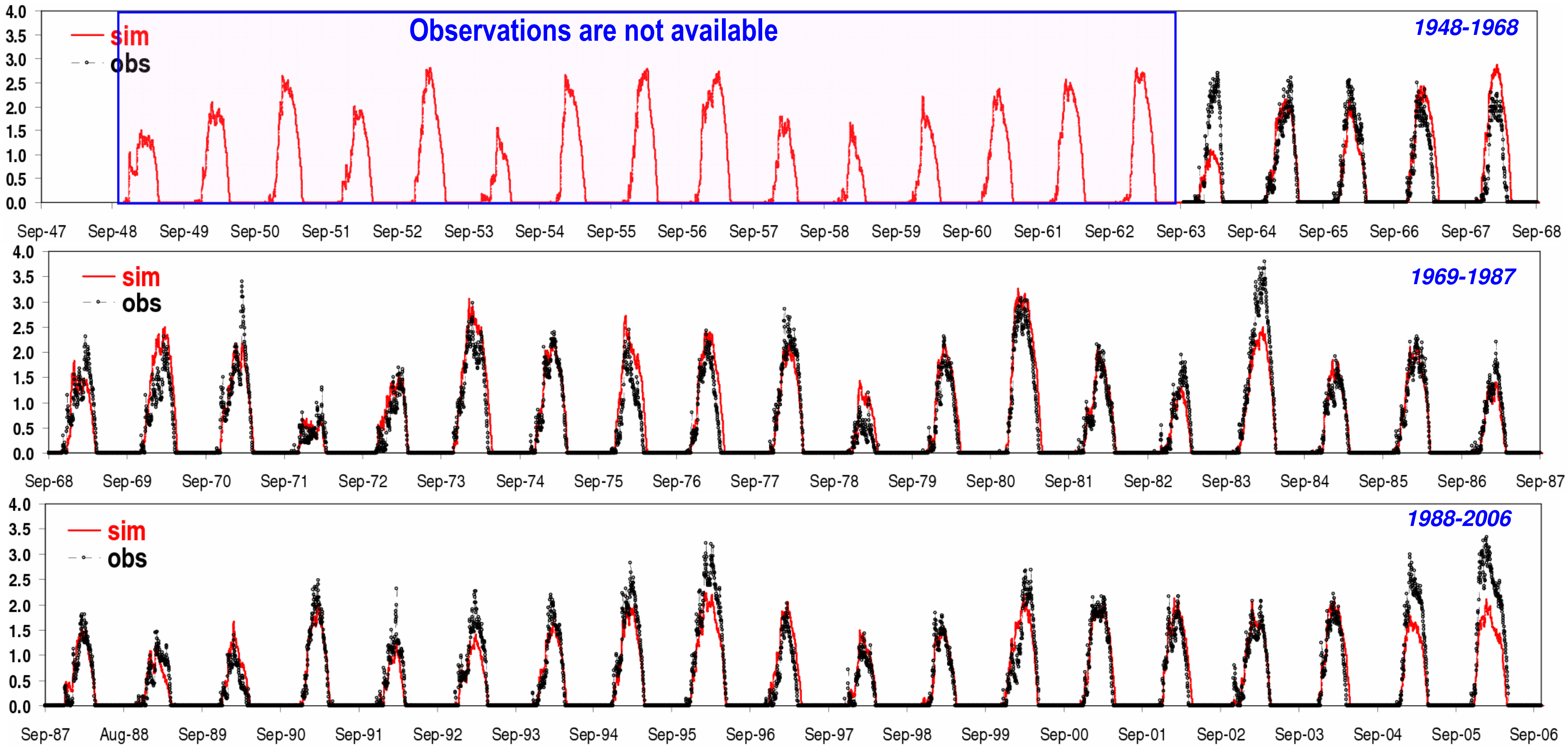
JP10 Reanalysis data (1948-12006) at Yagisawa

Monthly Correction Factor

$$\frac{\text{JP10 raw}}{\text{AMeDAS-Corr}} \rightarrow$$

Correction Factor for JP10 (4 year Average)

Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1.32.	1.01	0.92	1.40	1.51	2.12	1.30

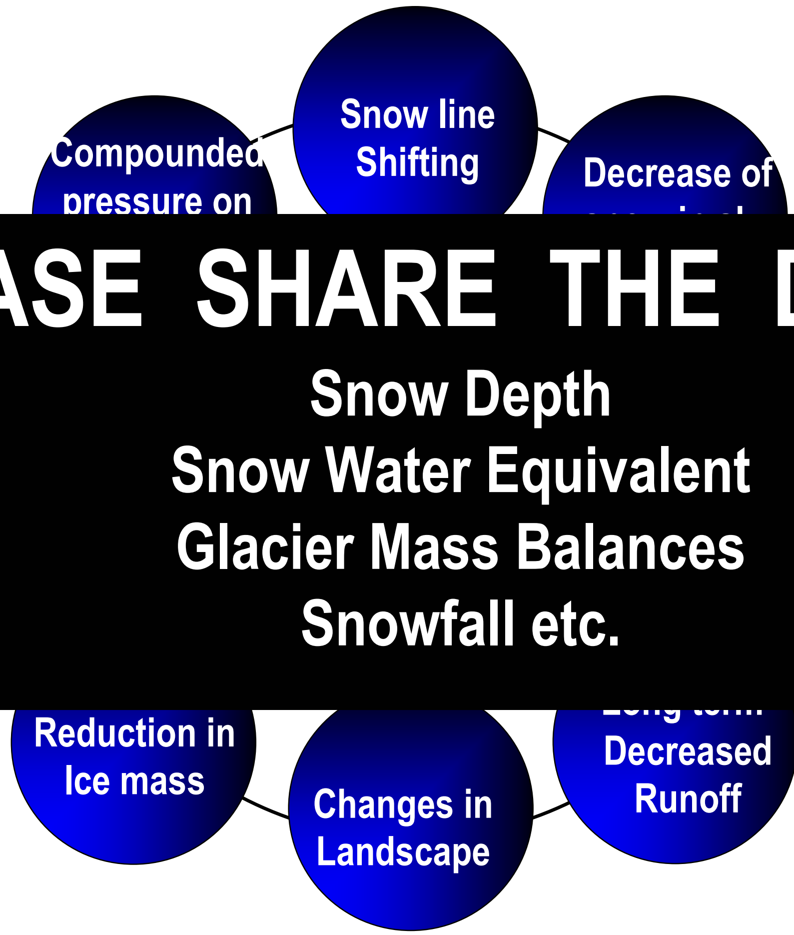


Interannual Variation of Snow Depth was simulated fairly well

Research Implication in AWCI basins

a) The complete snow/glacier Model – **Need More Validation**

b) Method for correction of snowfall – **Need More Validation**



PLEASE SHARE THE DATA !!!

Snow Depth
Snow Water Equivalent
Glacier Mass Balances
Snowfall etc.

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