Distributed Hydrologic Modeling in cold region and high elevation watersheds in an integrated approach

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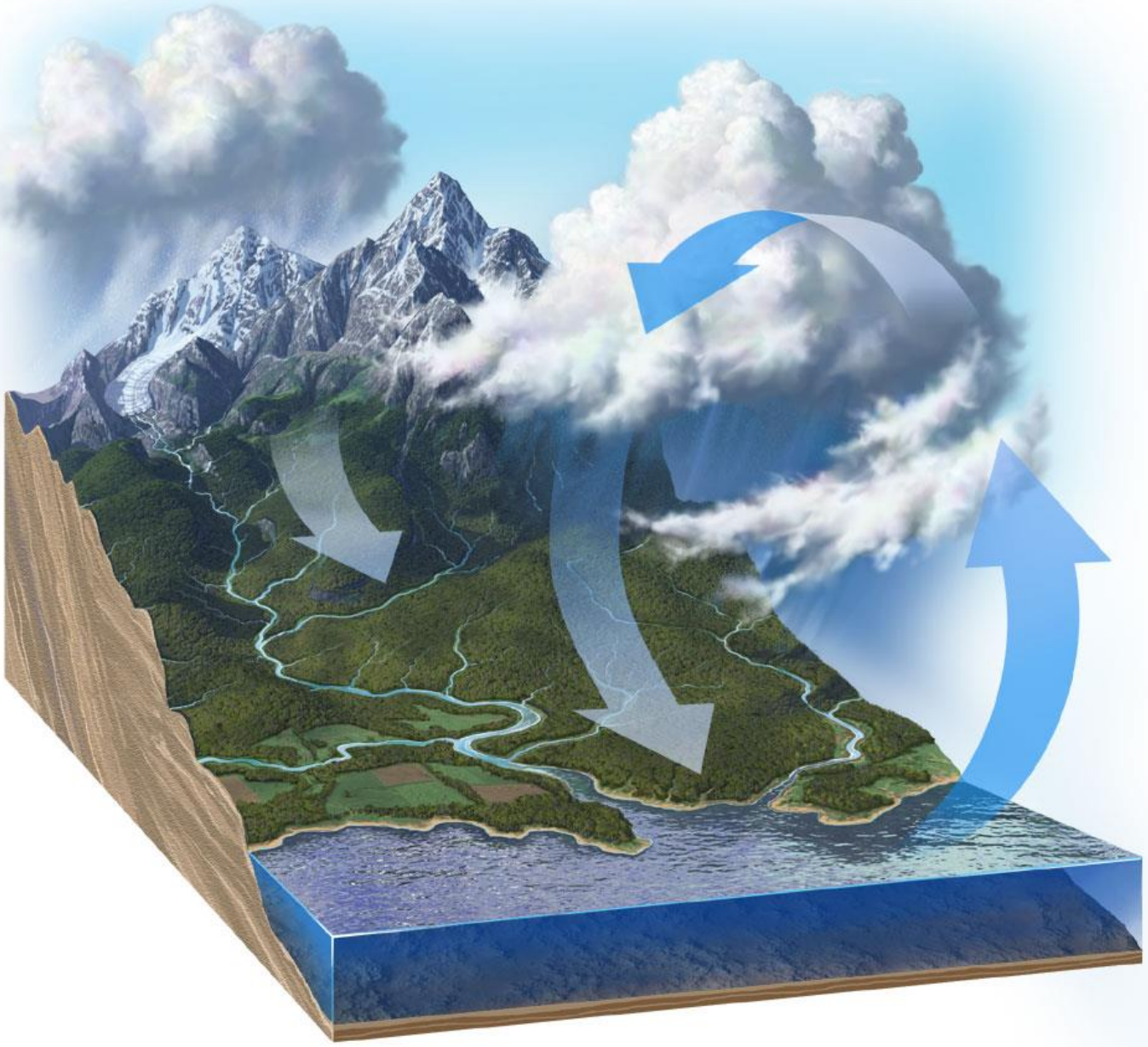
Mainly 2 ISSUES

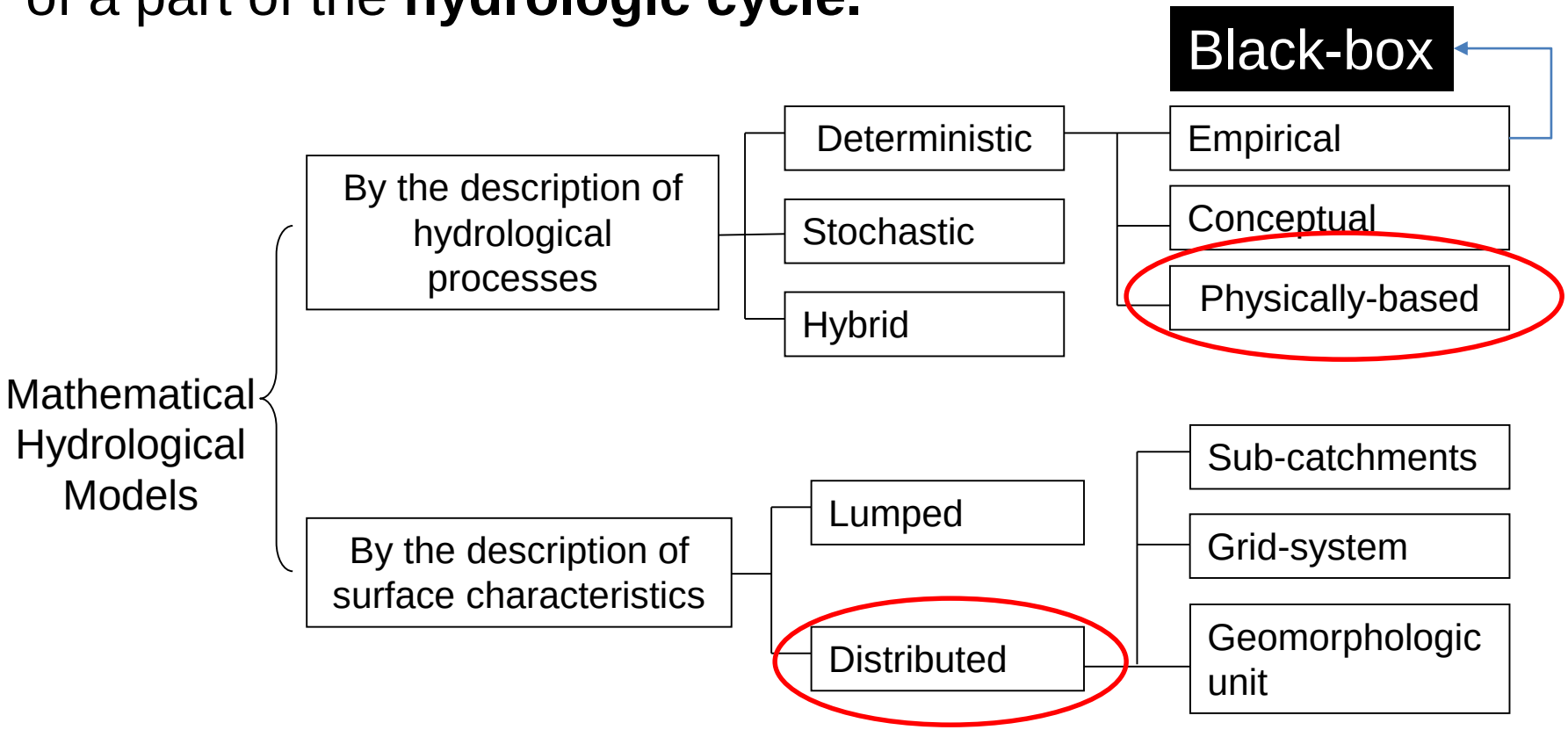
1. Accuracy and Capability of a Hydrological Model
2. Reliability of Precipitation, (especially snowfall)

Hydrologic Cycle



Hydrological Modeling

Hydrologic models are simplified, conceptual representations of a part of the **hydrologic cycle.**



‘Basic Truths’ in Modeling Natural Systems

- Models are approximations of reality; they cannot precisely represent natural systems
- Both the graphical comparisons and statistical tests are required in both model calibration and validation
- Models cannot be expected to be more accurate than the errors (confidence intervals) in the input and observed data

Water Balance

Rainfall/Snowfall

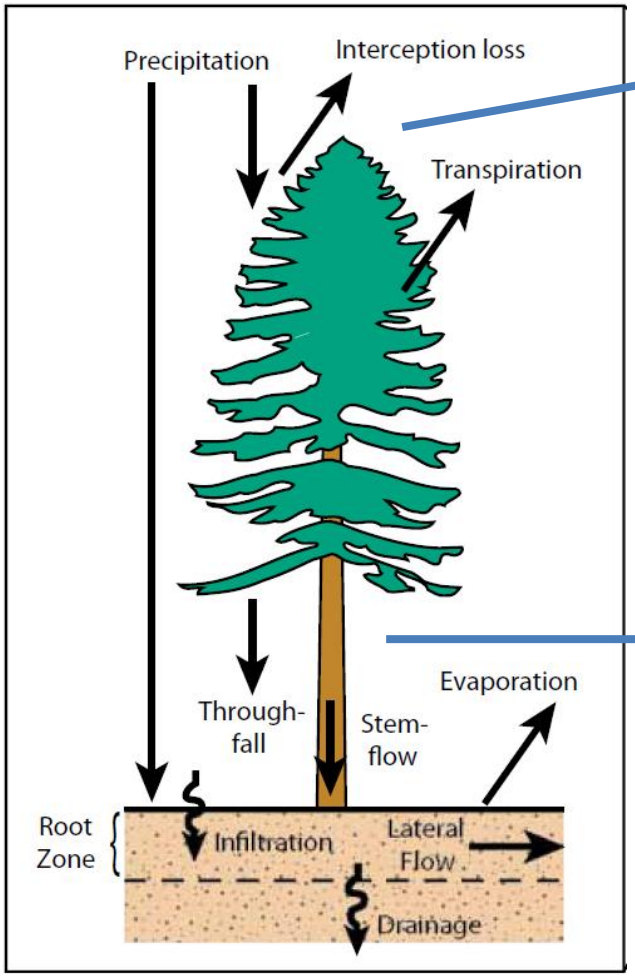
Evaporation/
Sublimation

Interception
Detention
Infiltration
Percolation
Groundwater

Runoff
(Snowmelt, glaciermelt, rainfed)

How well these processes are represented in hydrological model ?

Forested region



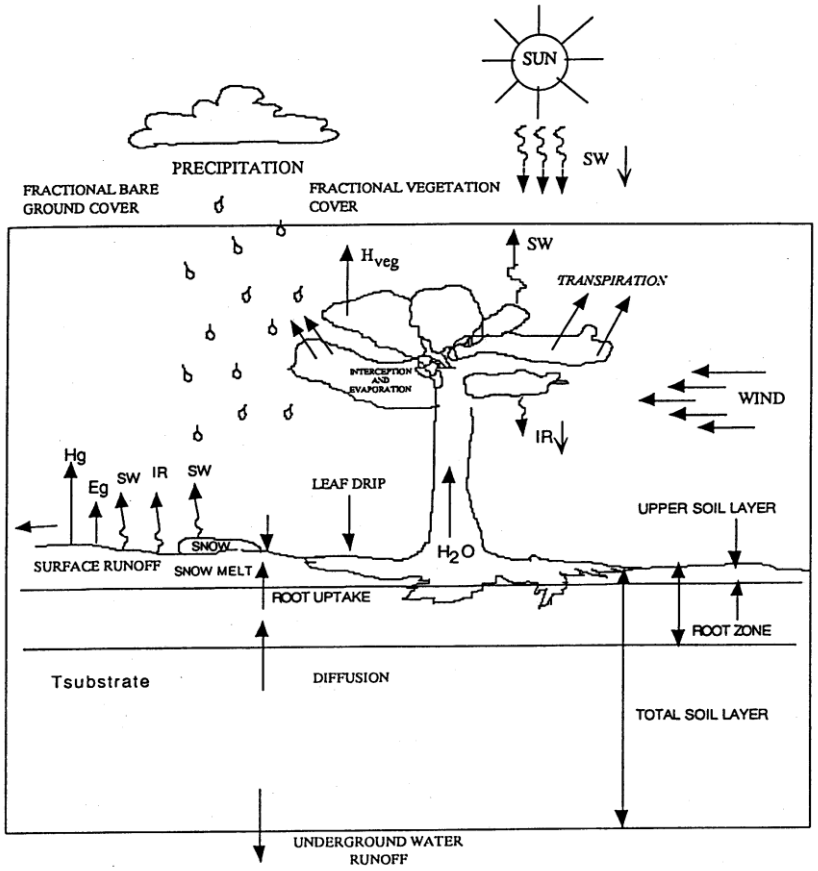
What if snow falls

Energy balance

No energy balance in Traditional hydrological models:
Lack of credible descriptions for land-atmosphere interactions

❑Flux:

- ➢Radiation
- ➢Heat
- ➢Water vapor
- ➢Momentum
- ➢Carbon Exchange



Simple Biosphere Model 2 (SiB2)

Better estimate of
Evapotranspiration
surface temperature
soil moisture

Regarding Snow & Glacier melt Models

Temperature index method

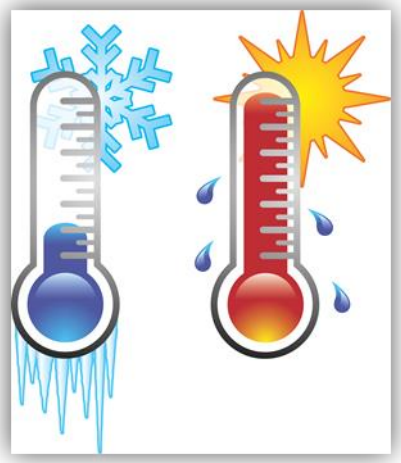
Simple, Empirical

$$MELT = \alpha * T_{air}$$

α = parameter

α_{snow}, α_{ice}, α_{debris}

Region specific



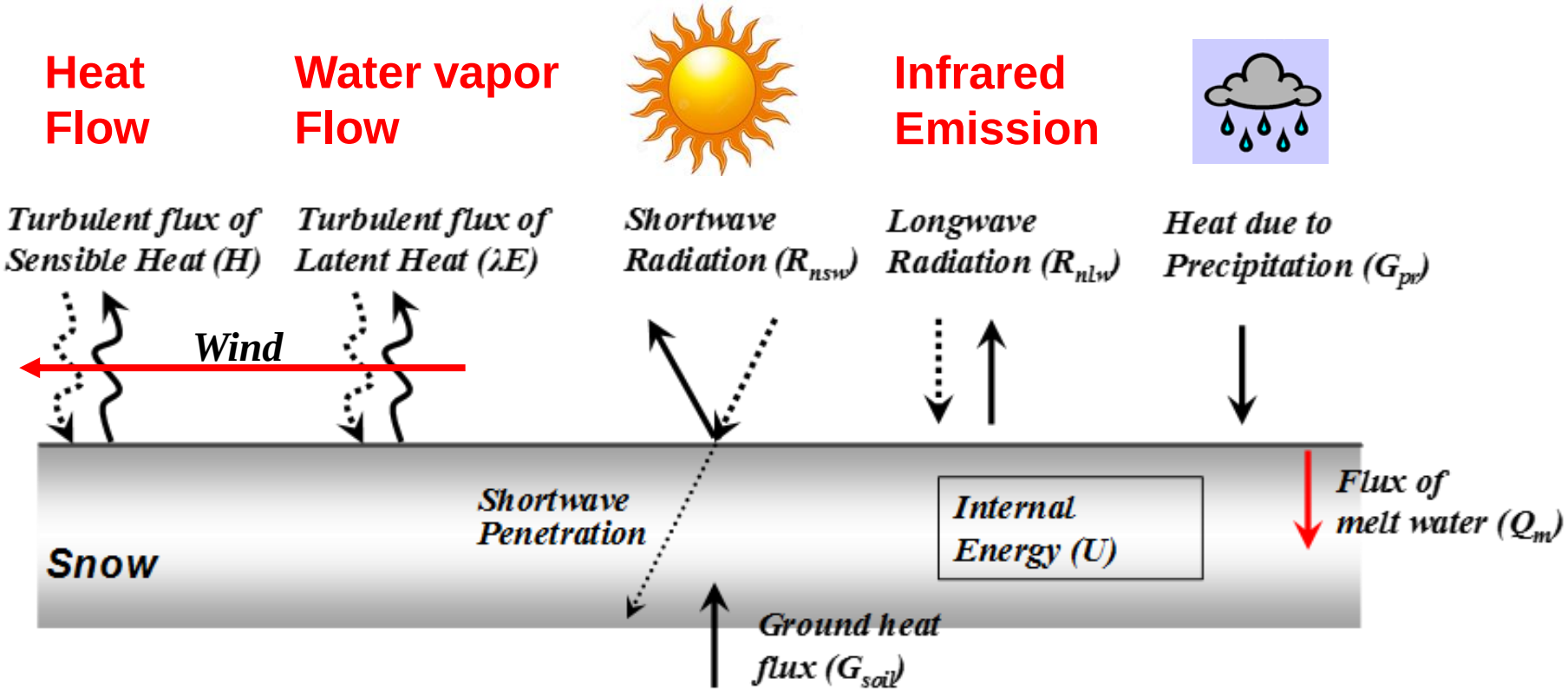
Lumped model: SRM, HBV, HEC

Distributed hydrological model

SWAT, MIKE-SHE, VIC,GBHM ….

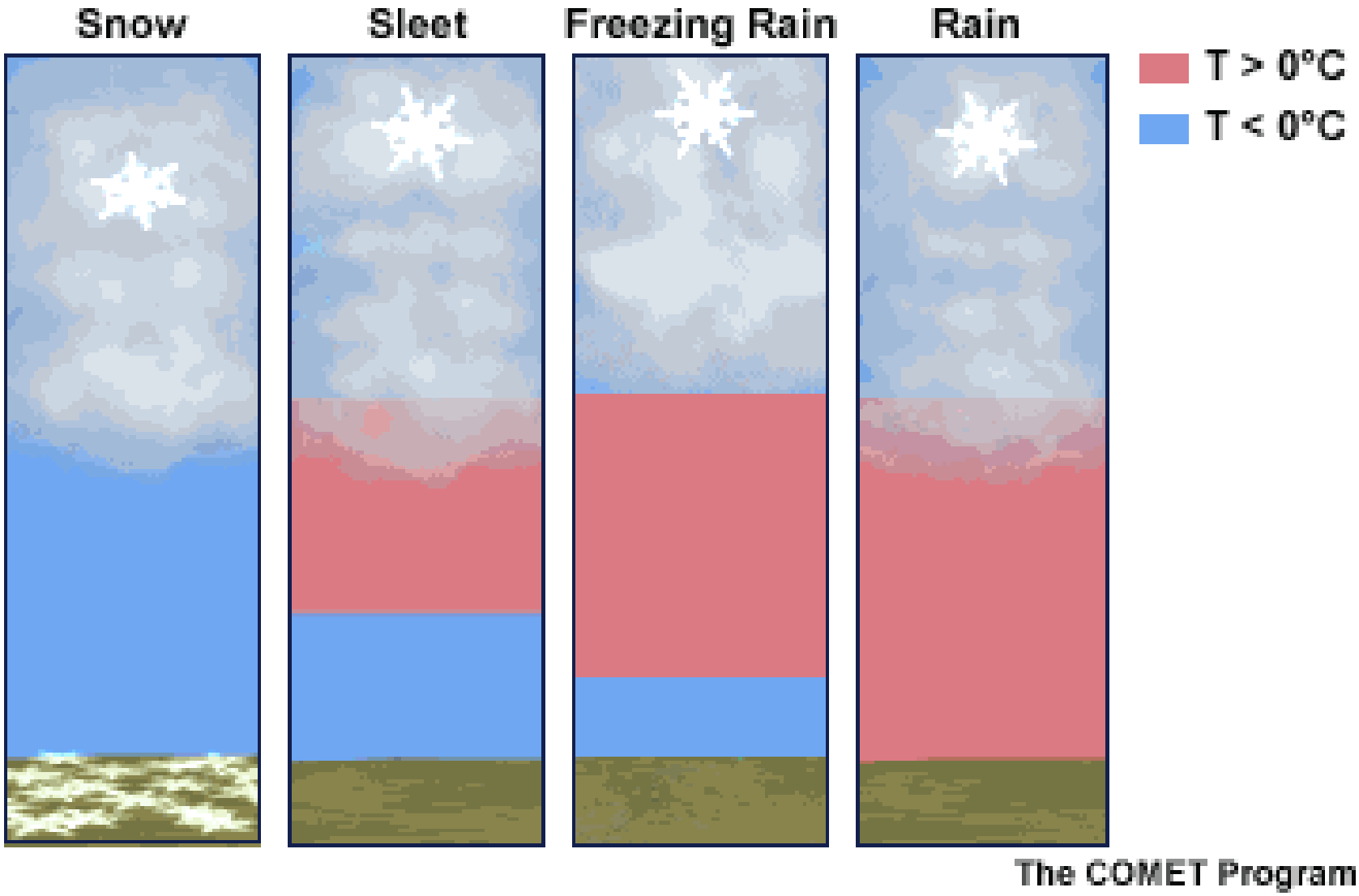
Energy balance method

Complex, Physics based

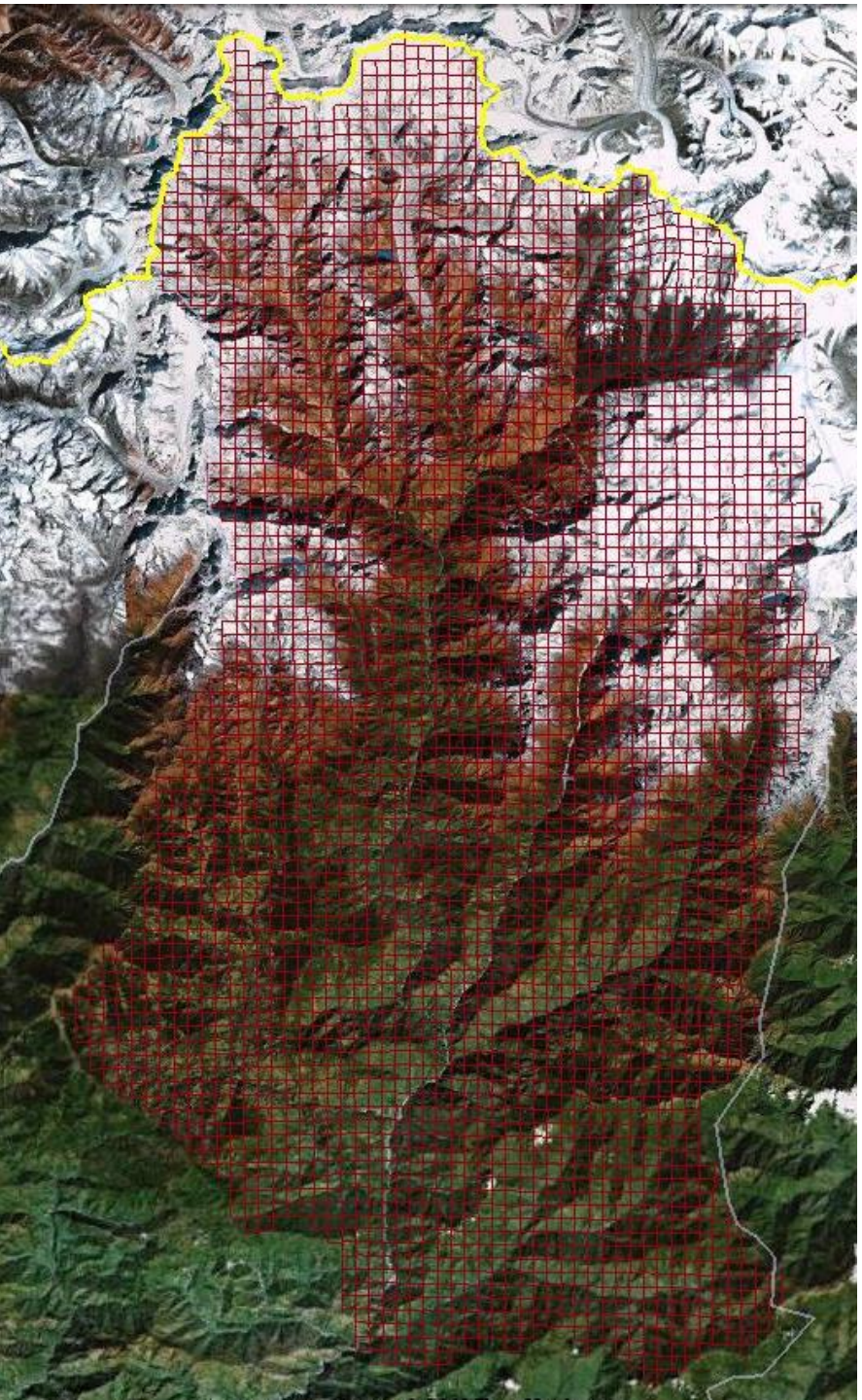


Compaction ; Variability in Density

Threshold Air Temperature - Snow/Rain



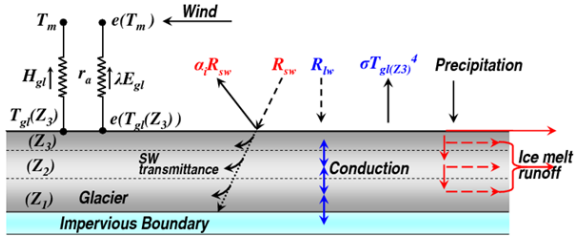
Snow/Glacier state evolution



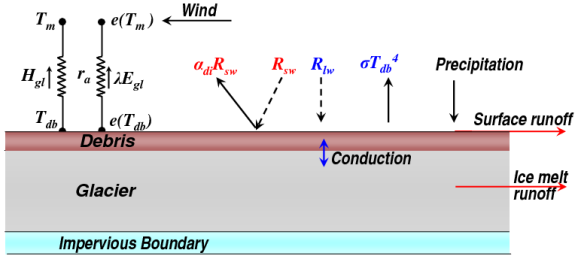
Spatial Representation

- Snowfall/Snowmelt in Forest/Baresoil
- Glacier melt
- Rainfall interception in bare soil and forest regions
- Infiltration
- Soil moisture
- Ground water
- Surface Runoff
- Subsurface Runoff
- River flow
- Elevation effect

Integrated modeling System : WEB-DHM-S



Clean Glacier



Debris covered glacier

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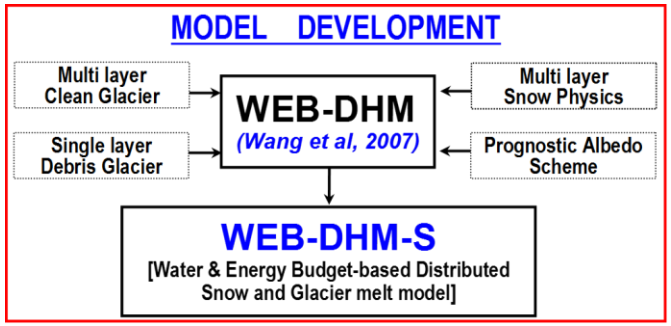
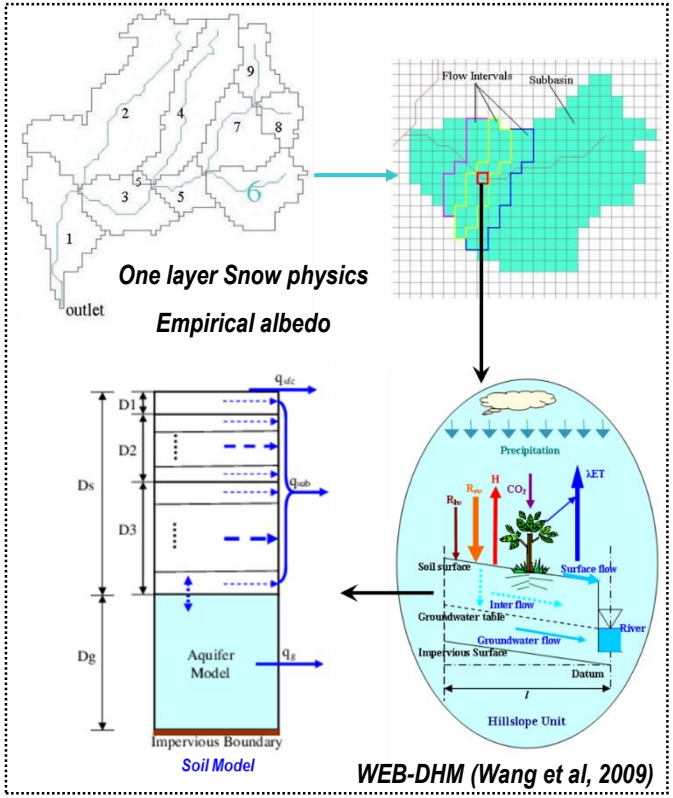
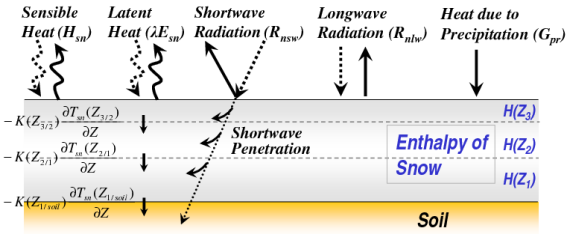
Seasonal Snow over these glaciers

Shrestha et al., 2010, 2012, 2014





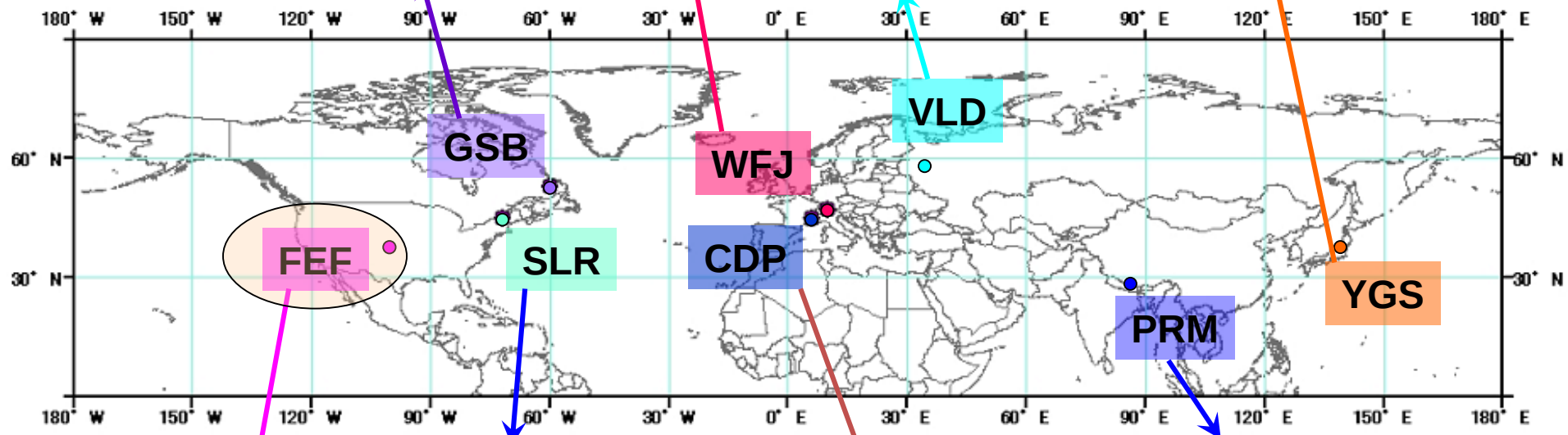


Snow over Bare Land

Snow over forest

Point scale model evaluation

Shrestha, Wang, Koike 2010 (HESS)



Weissfluhjoch (1992-93)
Switzerland, Elev.: 2540m

Yagisawa (1948-2006)
Japan, Elev.: 740m

Goose Bay (1969-83)
Canada, Elev.: **46m**

Valdai (1966-83)
Russia, Elev.: 212m

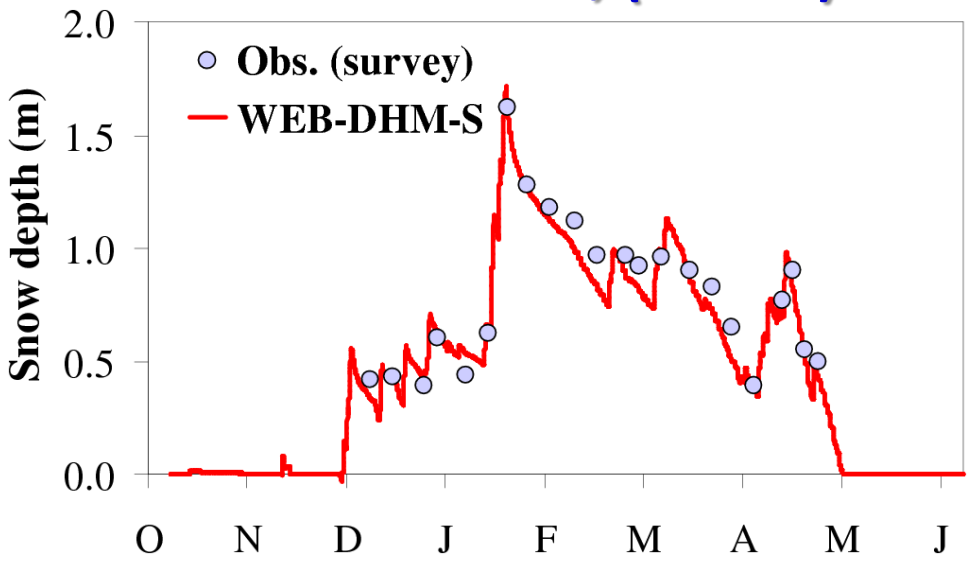
Sleepers river (1996-97)
USA, Elev.: 552m

Pyramid (2002-2003)
Nepal, Elev.:**5030m**

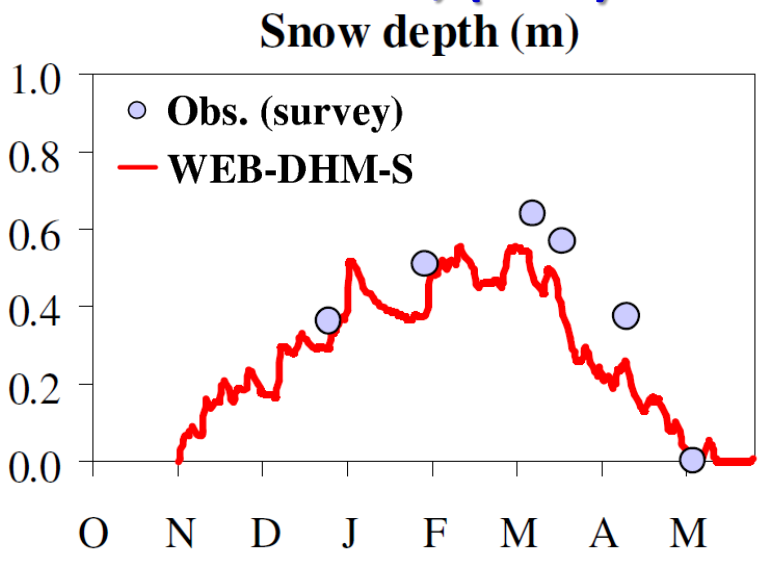
Fraser Forest (2003-05)
USA, Elev.: 2820m

Col de Porte (1996-98)
France, Elev.:1340m

Col De Porte, (France)



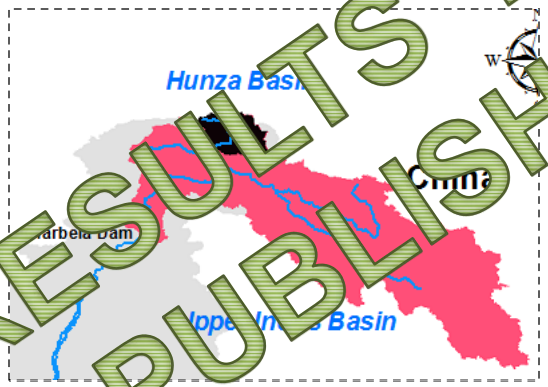
Fraser Forest, (USA)

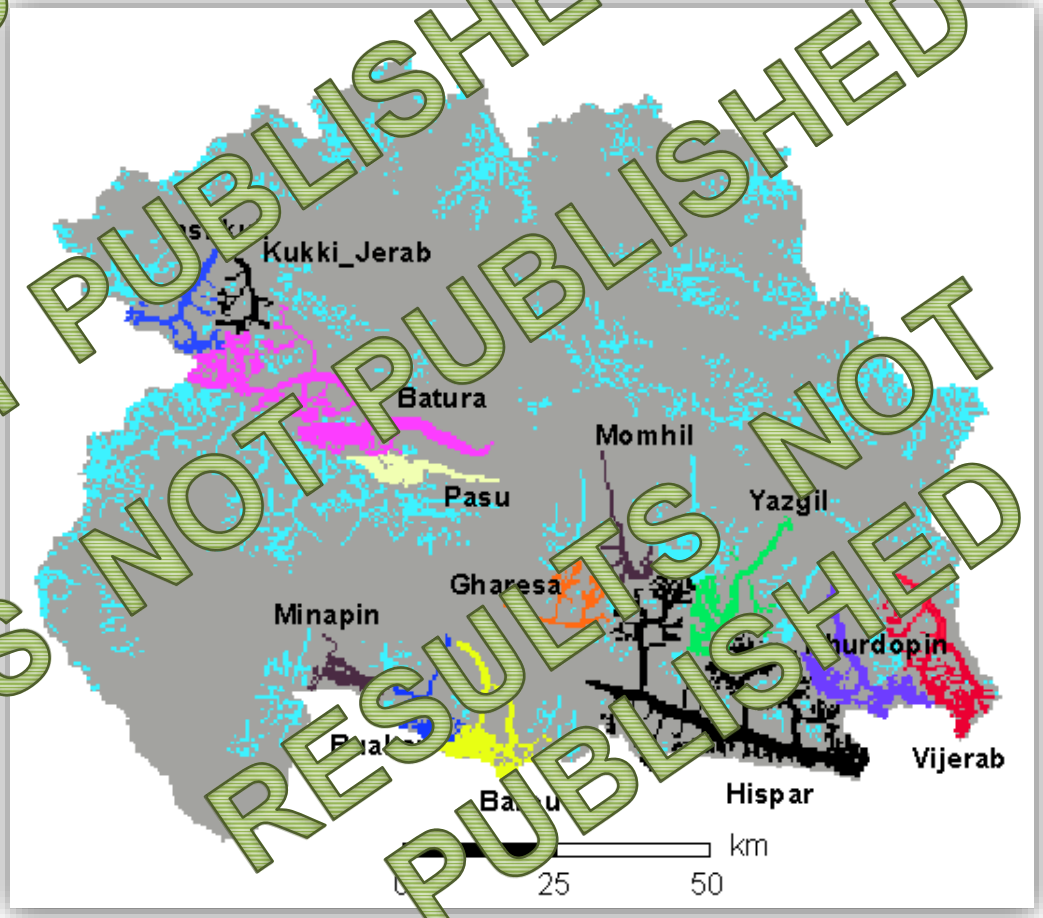


Basin wide model development

HUNZA Basin

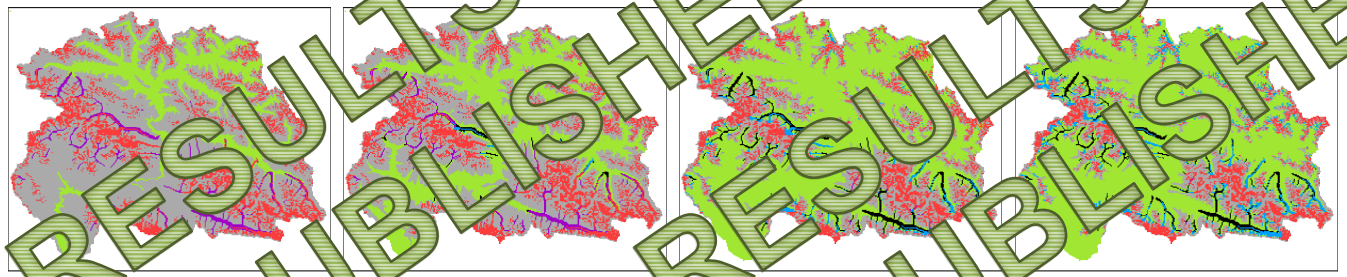
Shrestha, Kooke, and coauthors 2014 (JGR in submission)

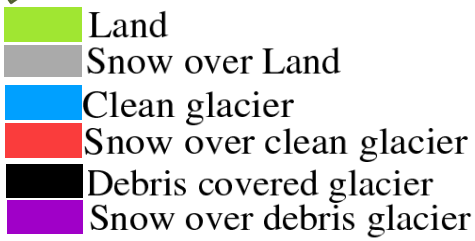




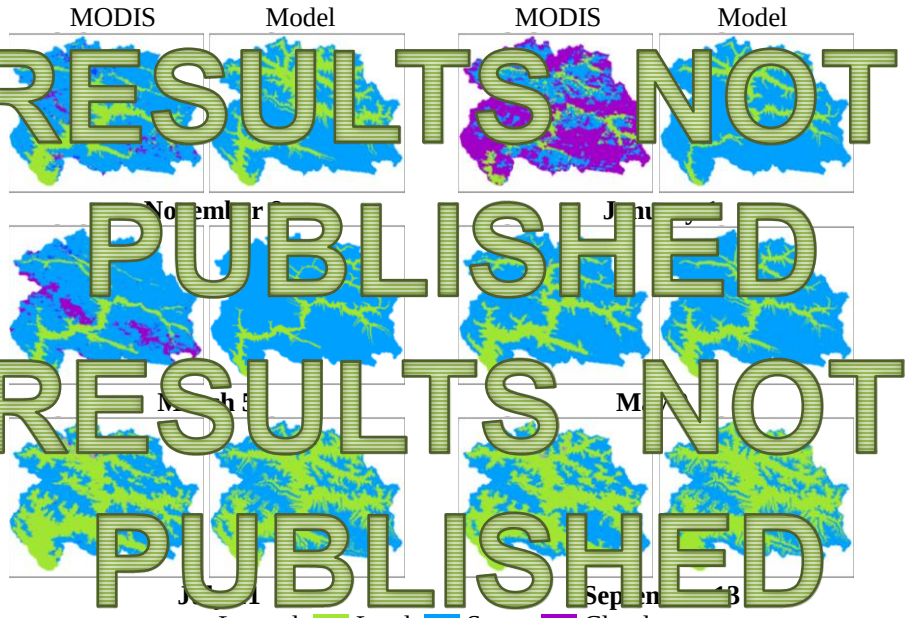
HUNZA Basin – Snow/glacier cover area

Snow/Glacier State simulation (2001-2002)

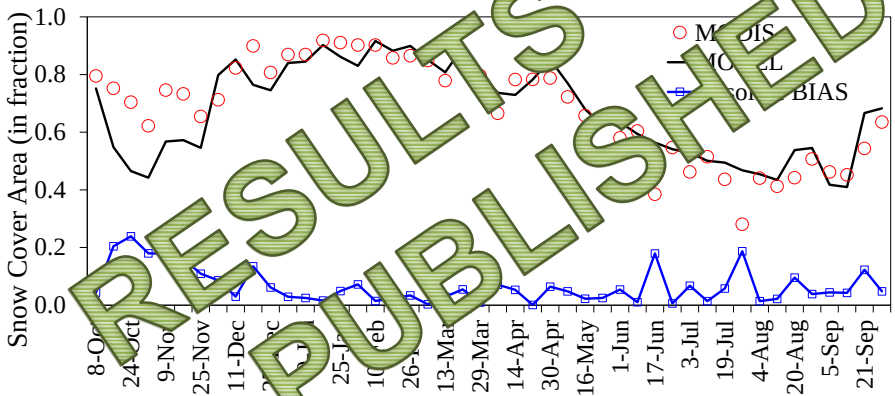




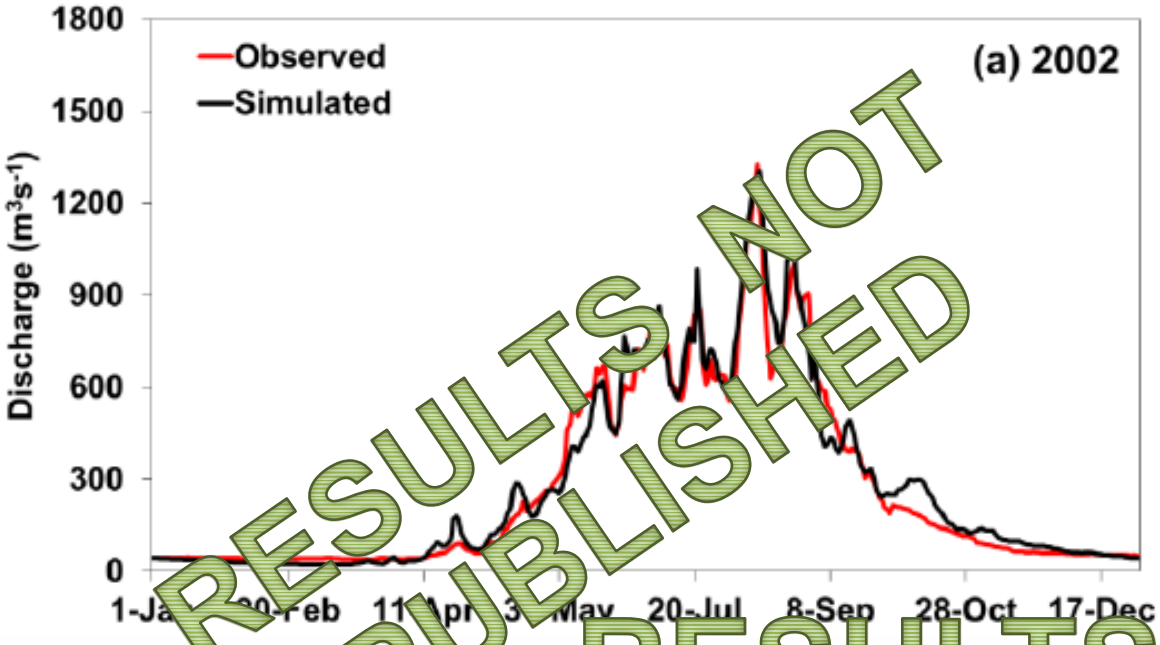
(a) Spatial distribution of snow cover area (2003-2004)

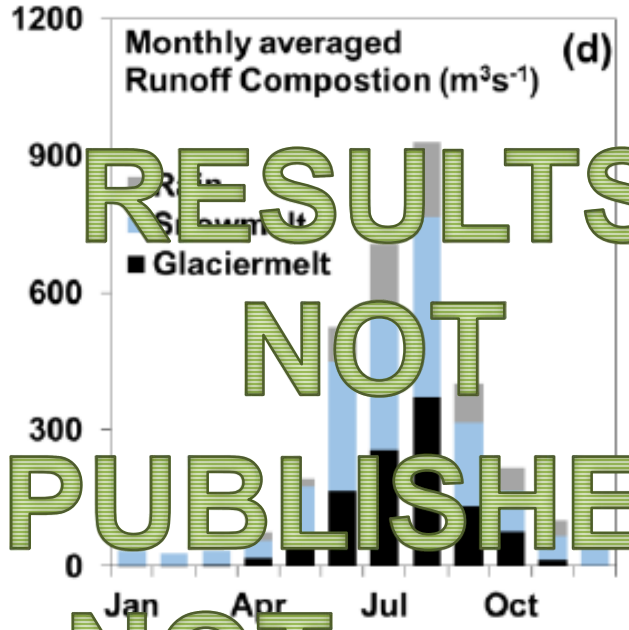


(b) Areal extent of snow cove



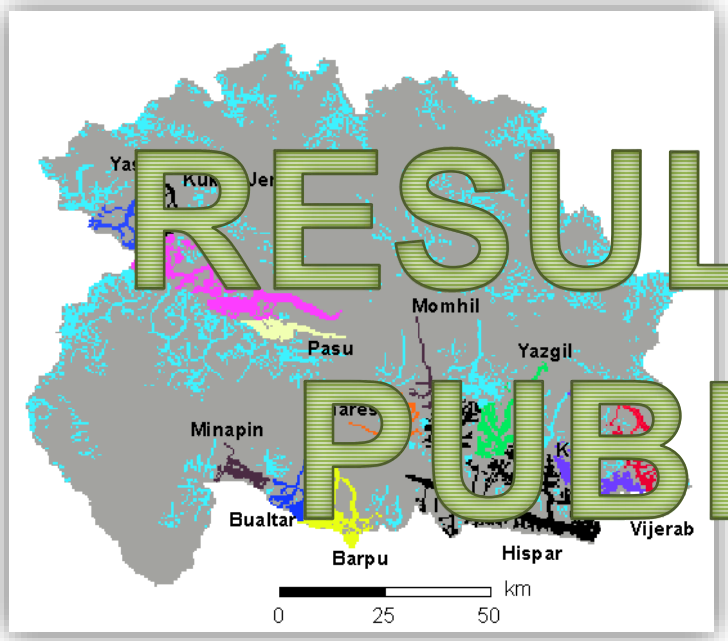
HUNZA Basin – Discharge

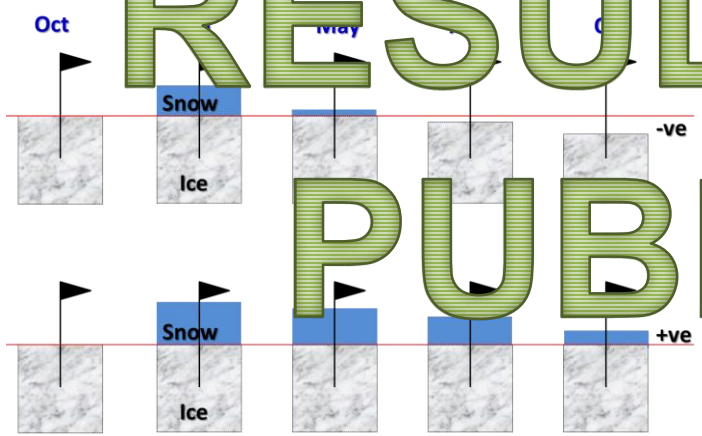




Snow & glacier melt contribution = 80-85% (60-65% snowmelt)
Rainfall contribution = 15-20%

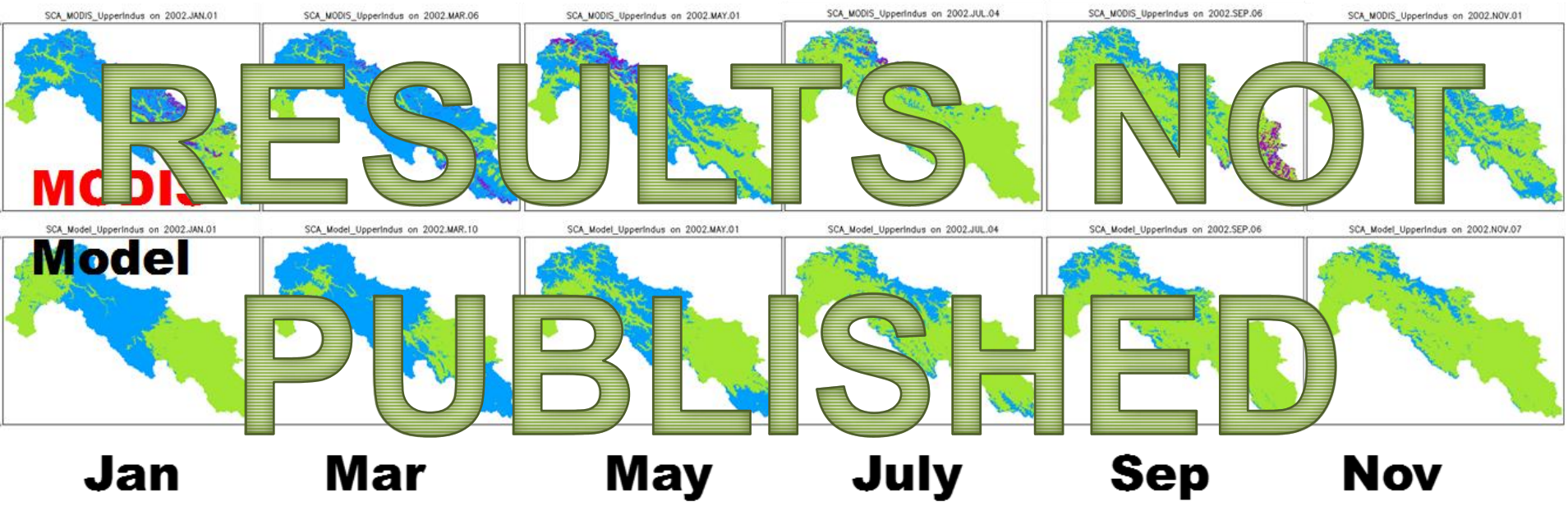
HUNZA Basin – Glacier mass balance





Upper Indus Basin

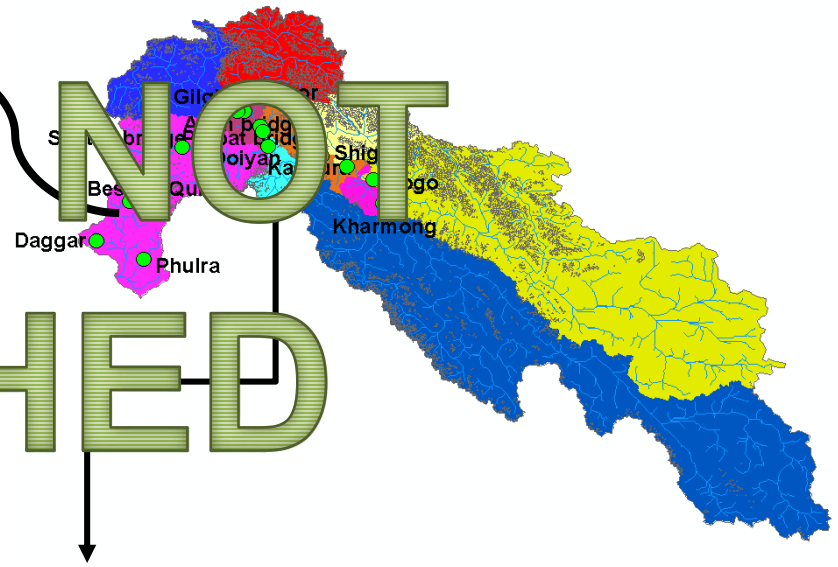
Upper Indus Basin – snow cover



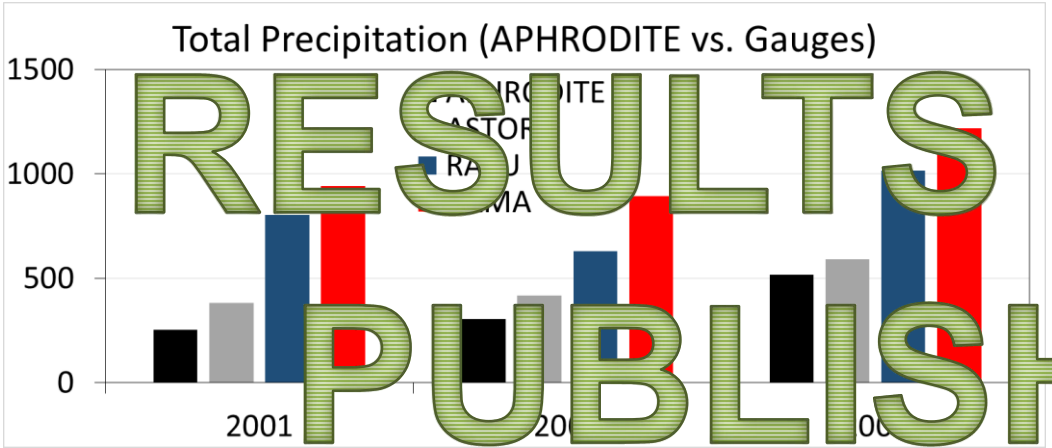
- Simulation results follows the seasonal variation of snow cover represented by the MODIS
- However, large discrepancies were observed while performing pixel-pixel analysis, mainly due to the uncertainty in spatial distribution of APHRODITE precipitation.

Upper Indus Basin – Simulation

Discharge at Besham Quila



However, large discrepancies in small basins due to uncertainty in precipitation



Correction of snowfall in basin scale

Shrestha, Wang, Koike 2014 (HESS)

Model Input
Meteorological data
Precipitation (PPT)

$$P_{grid}(z) = \frac{1}{\sum_{i=1}^{ng} W_i} \left\{ \sum_{i=1}^{ng} P_{gauge}(z_i) * W_i * [1 + (z - z_i) * C_{f(snow/rain)}] \right\}$$

Distributed Snow Model
(WEB-DHM-S)

Model Output
Discharge | **Snow cover**

Observed Discharge

MODIS snow cover

Discharge Error Q_{Err}

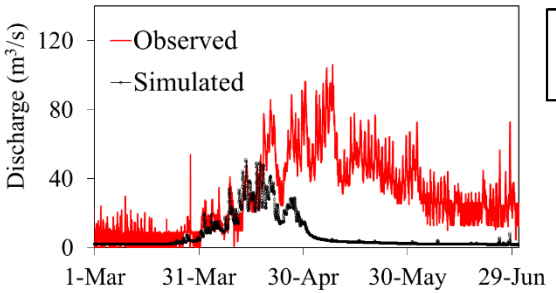
Snow pixel Error S_{Err}

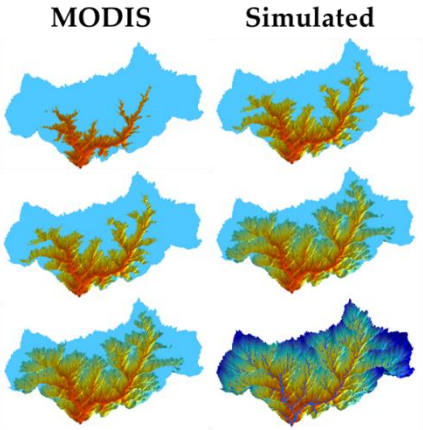
Objective Function
Total Error : $\alpha.Q_{Err}+(1-\alpha).S_{Err}$

Is Total Error Minimized ?

No → **Adjust SCF using SCE-UA method**

Yes → **Optimized** C_{fsnow}

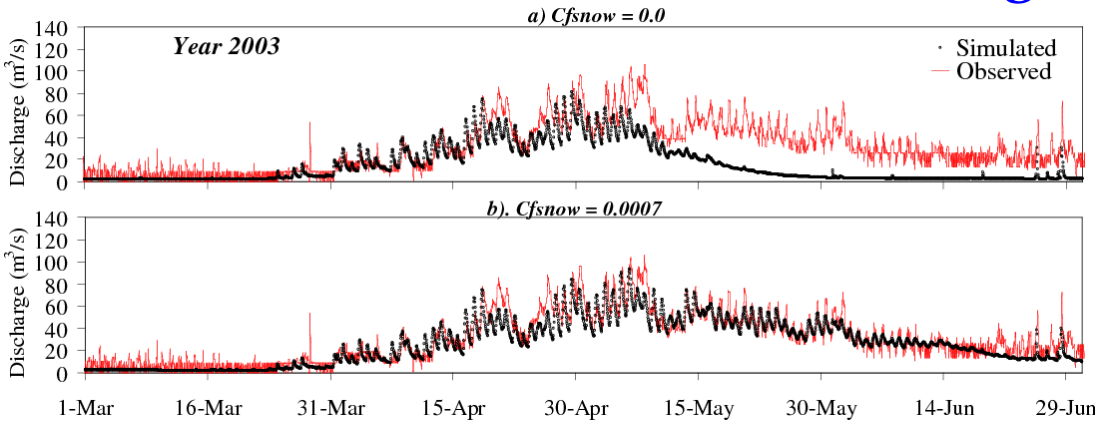




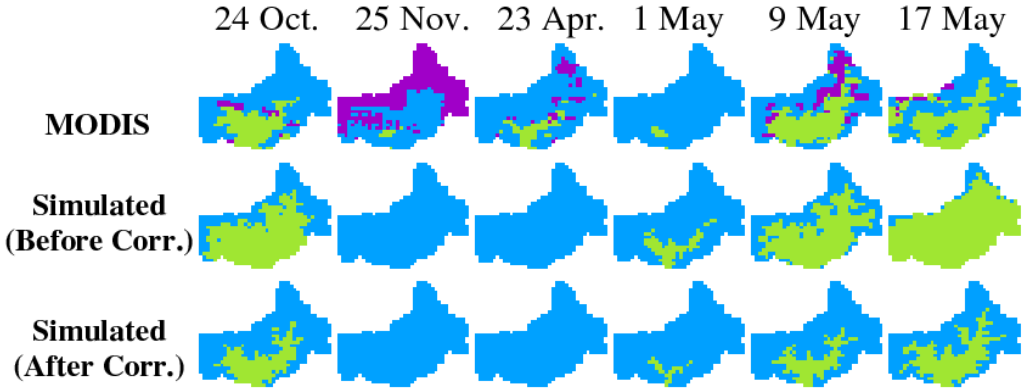
MODIS = Spectro-Radiometer onboard Terra Satellite

Correction of snowfall in basin scalec

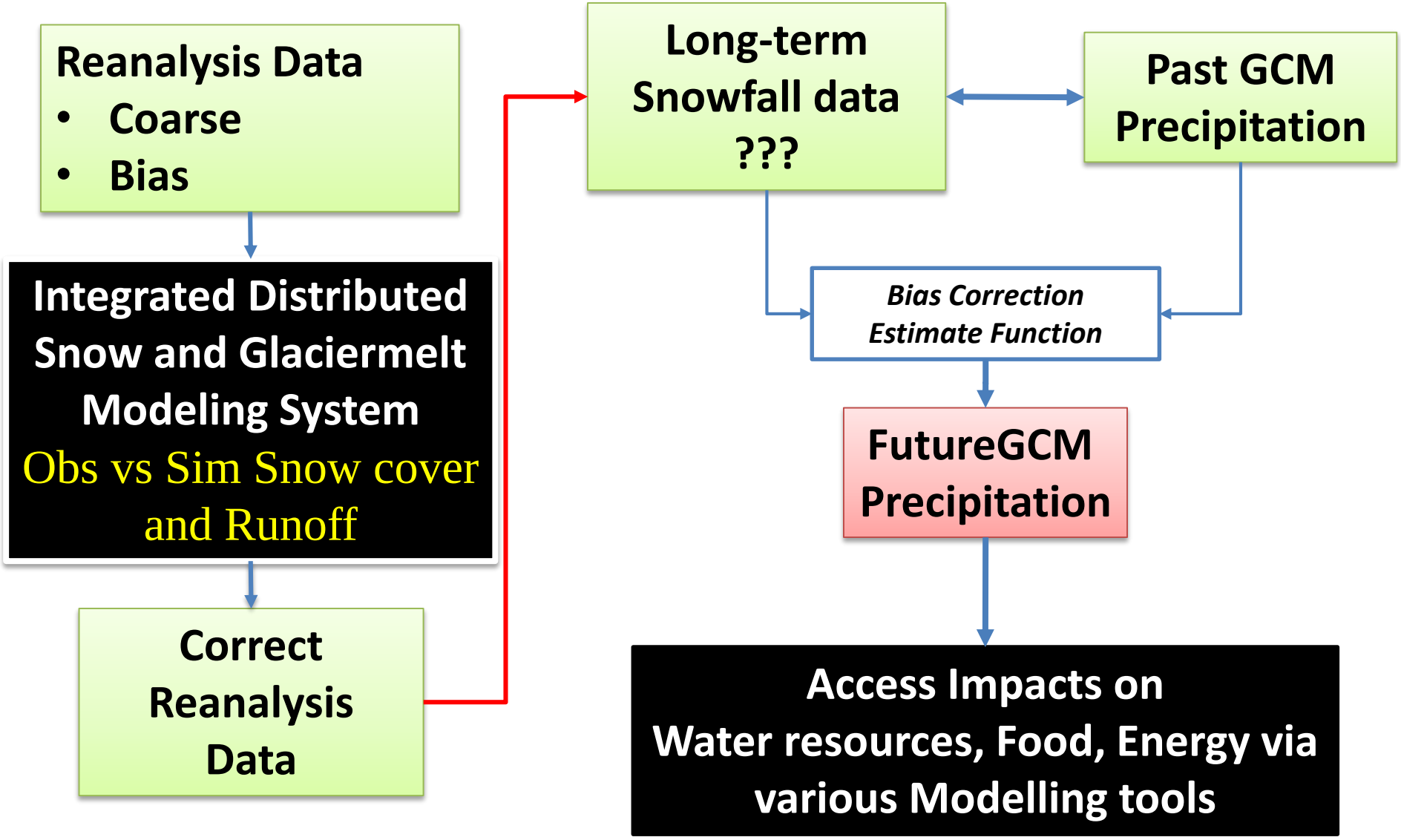
Simulated vs. Observed Discharge



Simulated vs. MODIS snow



Contribution to Climate change impact studies



Summary

- A Comprehensive Modeling system has been established which can simulate the Snow processes and Glacier processes and Forest snow processes simultaneously in a basin scale. The model has been well implemented in HKH river basins.

- Snowfall correction is the key issue for simulation of snow/glaciermelt in Upper Indus basin.

- Inter-linkage of variability in flow of upper Indus basin to the lower region will be studied after successful implementation of the model for past 30 years.