THE UNIVERSITY OF TOKYO

RIEEL

Modeling of snow and glacier melt runoff simulations

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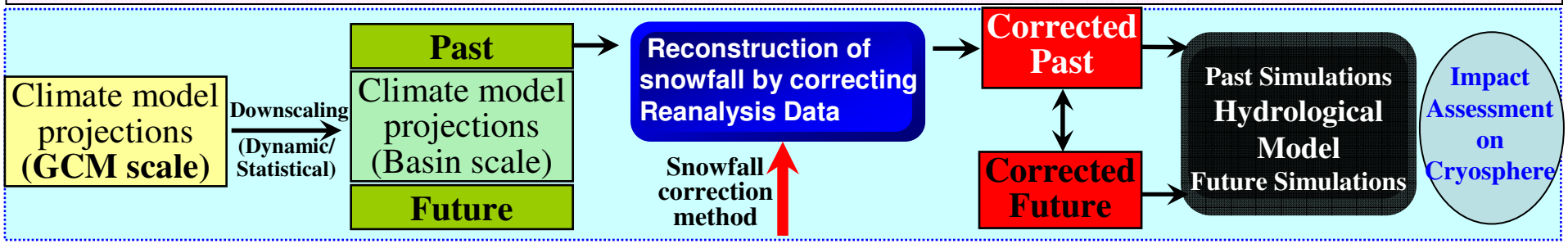
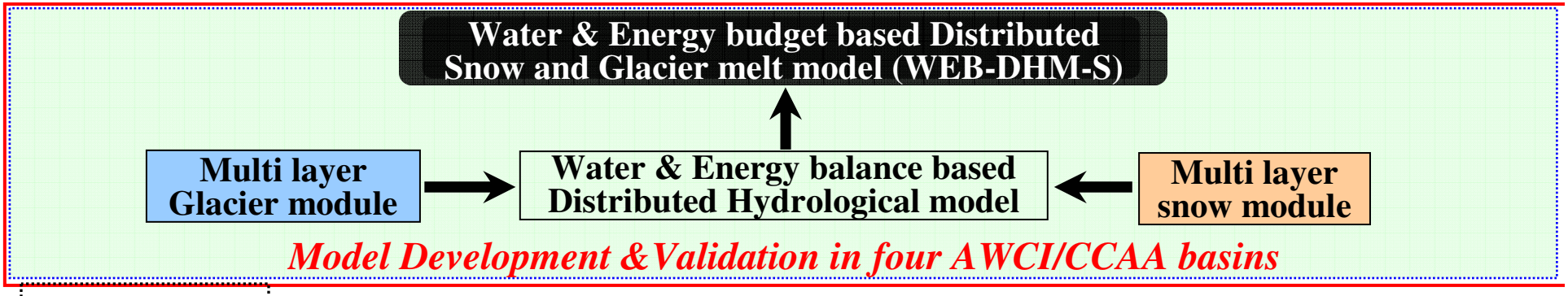
Motivation for AWCI/CCAA Study-Snow & Glacier

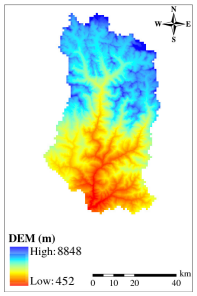
- *Long term snowfall dataset is needed for bias correction of climate projections, which is currently unavailable in many poorly gauged/ungauged basins.*
- *Reanalysis dataset can be used as baseline data but they should be corrected in prior to application.*
- *A method has to be established for snowfall correction, based on analysis of simulated discharge with observed one and simulated snow cover with satellite snow cover, through physically based hydrological modeling. Thus, firstly, we need to develop "the physically based snow & glacier-melt model"*



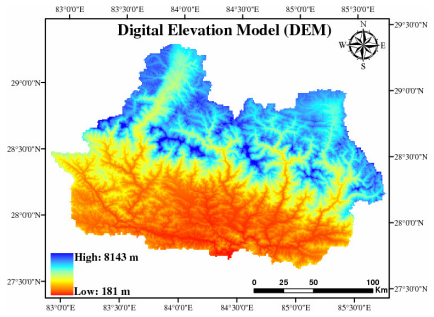


Model Development &Validation in four AWCI/CCAA basins

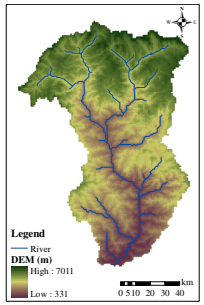
Dudhkoshi (Nepal)



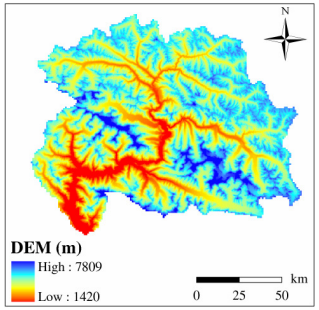
Narayani (Nepal)



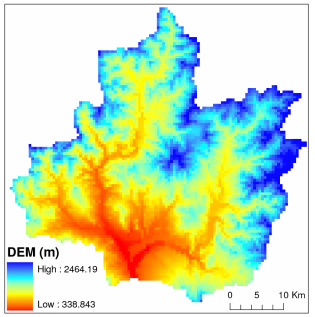
Punatsangchu (Bhutan)



Hunza (Pakistan)

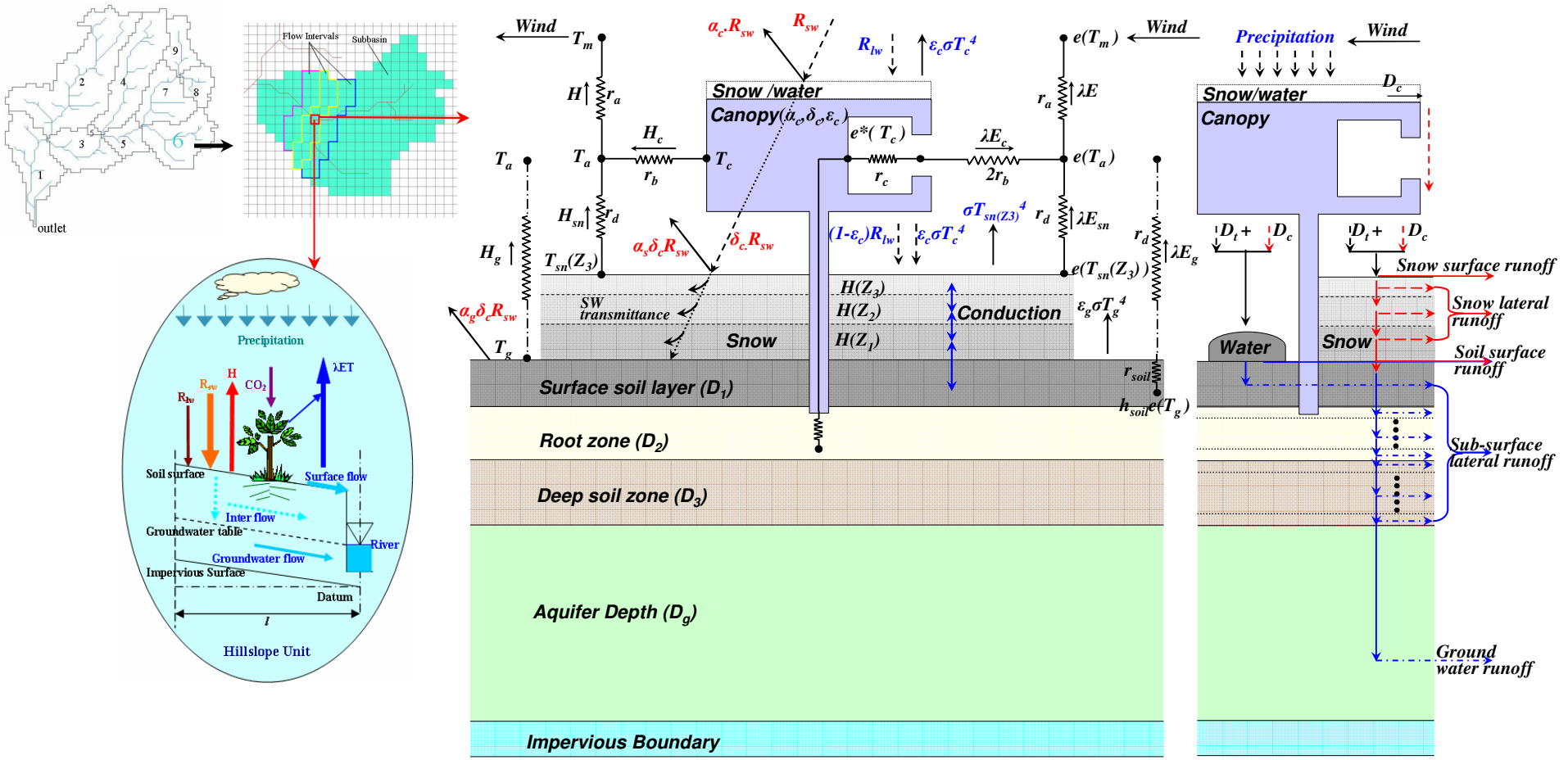


Upper Tone (Japan)



Model Development (WEB-DHM-S)

WEB-DHM with improved **S**now physics (**WEB-DHM-S**) has been developed by incorporating the 3 layer energy balance snow scheme of SSiB3 and prognostic BATS albedo scheme to WEB-DHM.



T_m: Reference height air temperature
T_a: Canopy Air Space temperature
T_g: Ground(snow free) surface temperature
$T_{sn}(Z_j)$: Snow temperature
SSiB: Simplified Simple Biosphere Model 3

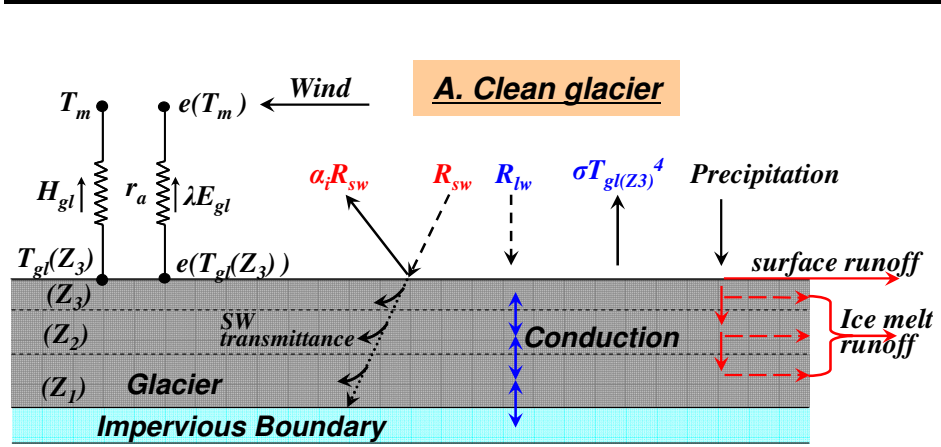
R_{sw}: Downward shortwave radiation
R_{lw}: Downward longwave radiation
H_c: Canopy sensible heat flux
H_{sn}: Snow sensible heat flux
BATS: Biosphere-Atmosphere Transfer Scheme

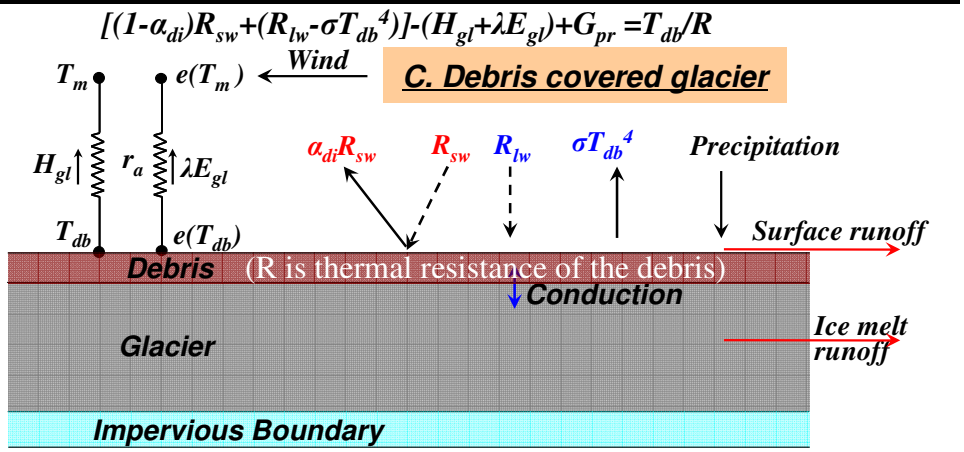
H_g: Ground sensible heat flux
E_c: Canopy latent heat flux
E_{sn}: Snow latent heat flux
E_g: Ground latent heat flux

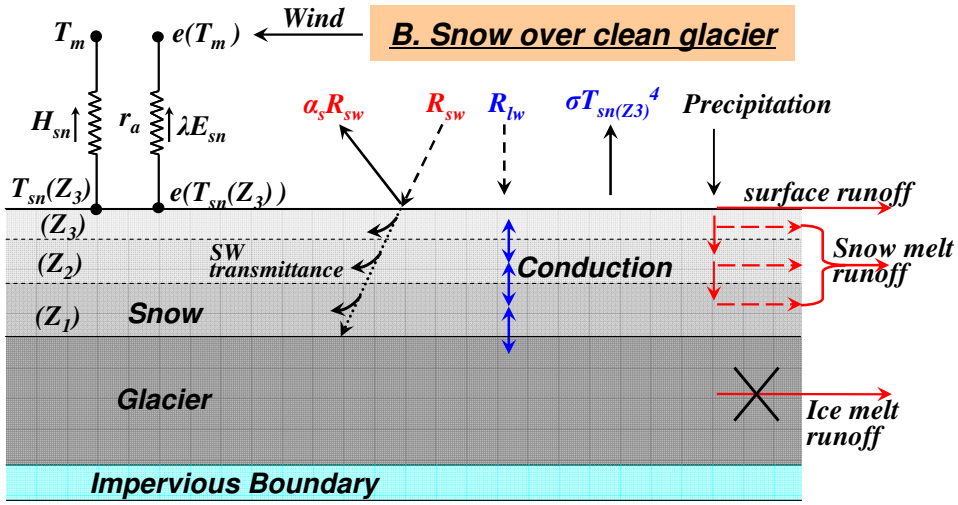
$H(Z_j)$: Snow enthalpy
δ: Transmissivity
ε: Emissivity
α: Reflectivity(albedo)

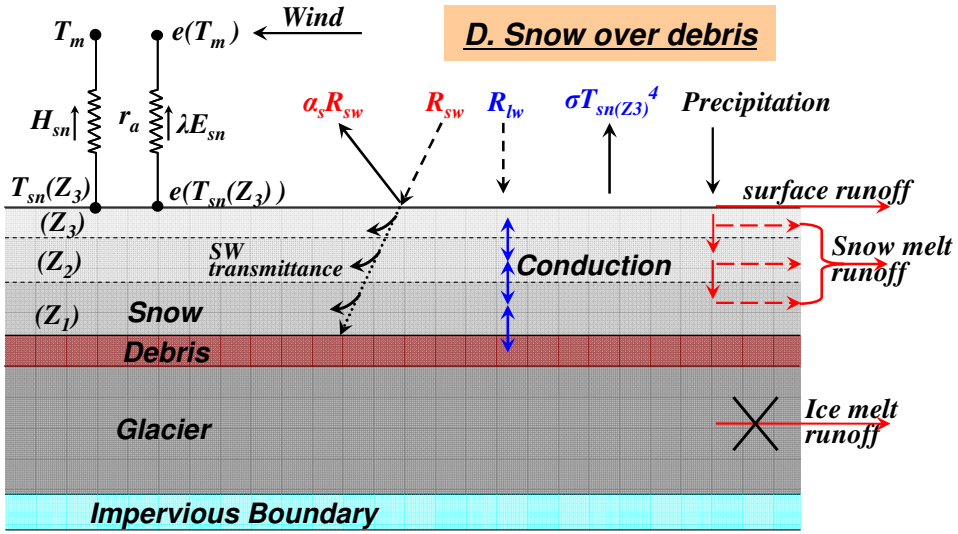
D_c: Drainage from canopy
D_t: Canopy throughfall
$r_a, r_b, r_c, r_d, r_{soil}$: Aerodyamic resistances
$e(T_m), e(T_a), e(Tsn(Z3)), e(T_g)$-vapor pressures at $T_m, T_a, T_{sn}(Z_3)$and T_g

Model Development (Glacier physics)









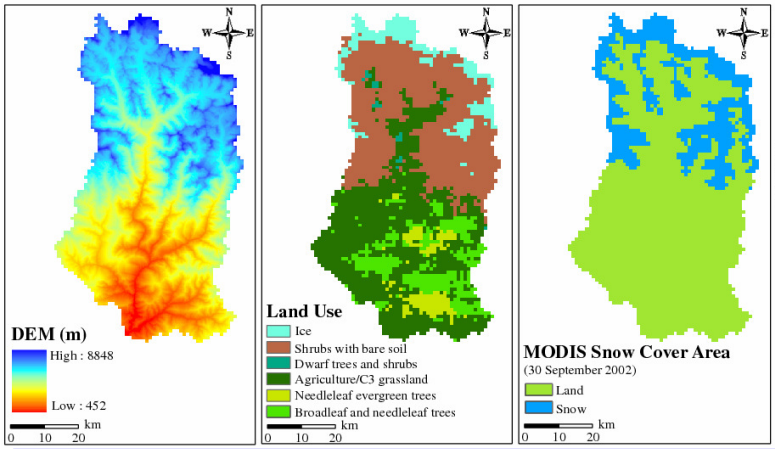
WEB-DHM-S can simulate 11 land use types with 6 different types of snow states

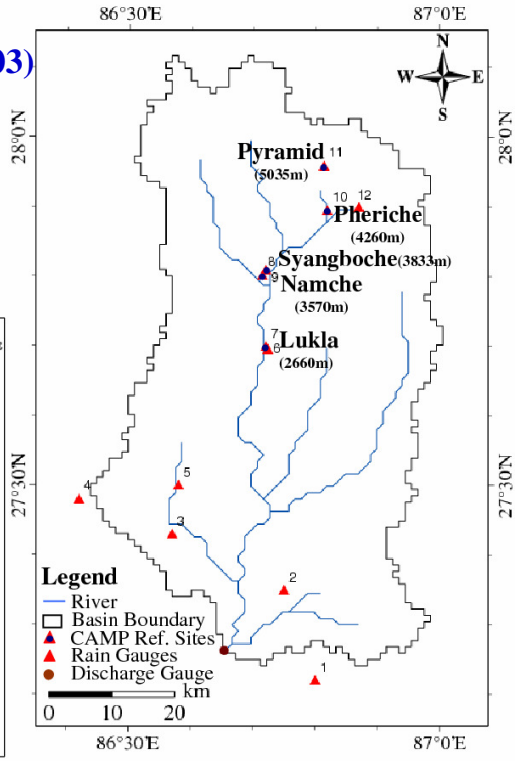
Type	Land Use Name	Grid code	Snow/Glacier type	Albedo
1-9	SiB2 type (Bare soil and Forest)	0 1	Snow No Snow	Snow (0.85~0.95)
10	Water	1	No Snow	
11	Glacier	2 3 20 30	Debris Free/Clean Glacier Debris covered Glacier Snow over clean glacier Snow over debris	Clean Glacier (0.4) Debris (0.2) Snow over clean glacier and debris (0.85~0.95)

Application to Dudhkoshi river basin (Nepal)

CEOP - 3
(2 Oct. 2002 to 25 June 2003)

(3700 km^2)

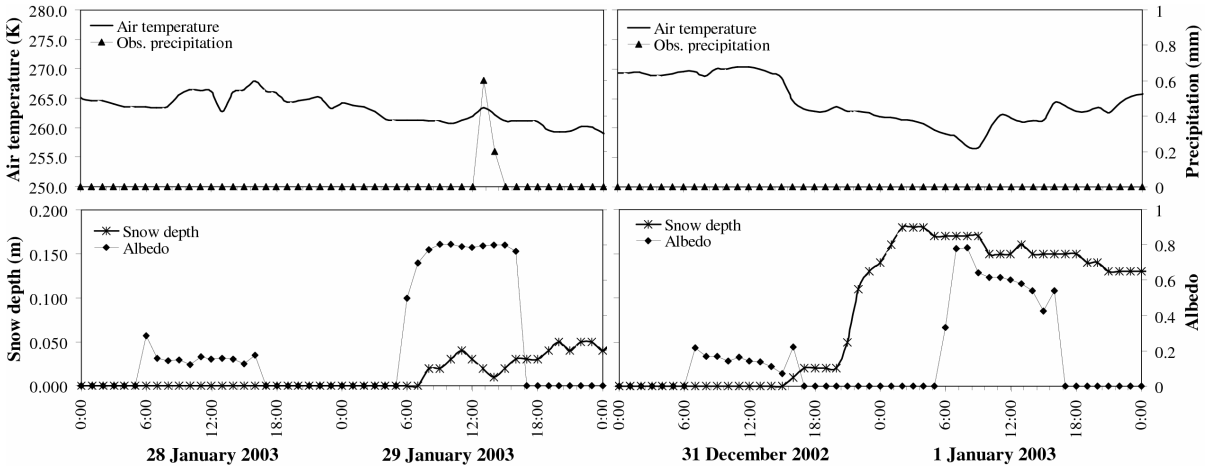


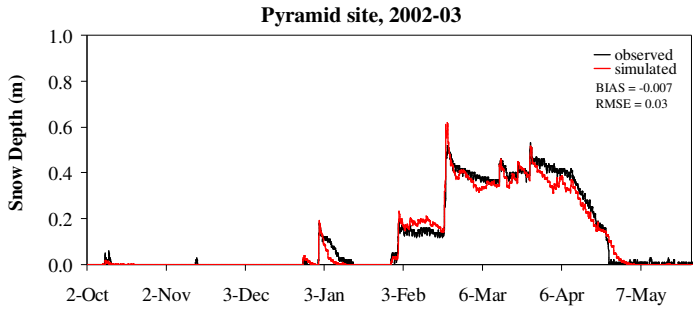


Grid Size : 1 km^2 **Time step: Hourly**

Dataset	*Resolution*
DEM	Grid (90 m)-SRTM
Meteorological data (Shortwave, longwave, wind speed, humidity, pressure, air temperature)	Hourly - Coordinated Enhanced Observing Period (CEOP)
Precipitation	CEOP-corrected hourly, Department of Hydrology and Meteorology (DHM-daily)
Soil type	Grid (9 km) – FAO
Land use	Grid (1 km) – USGS
LAI	8-day averge Grid (1 km)
FPAR	8-day averge Grid (1 km)
Snow cover	8-day max. Grid (500 m)
Land surface Temp.	8-day averge Grid (1 km)
Snow depth, upward Shortwave, longwave	CEOP-hourly

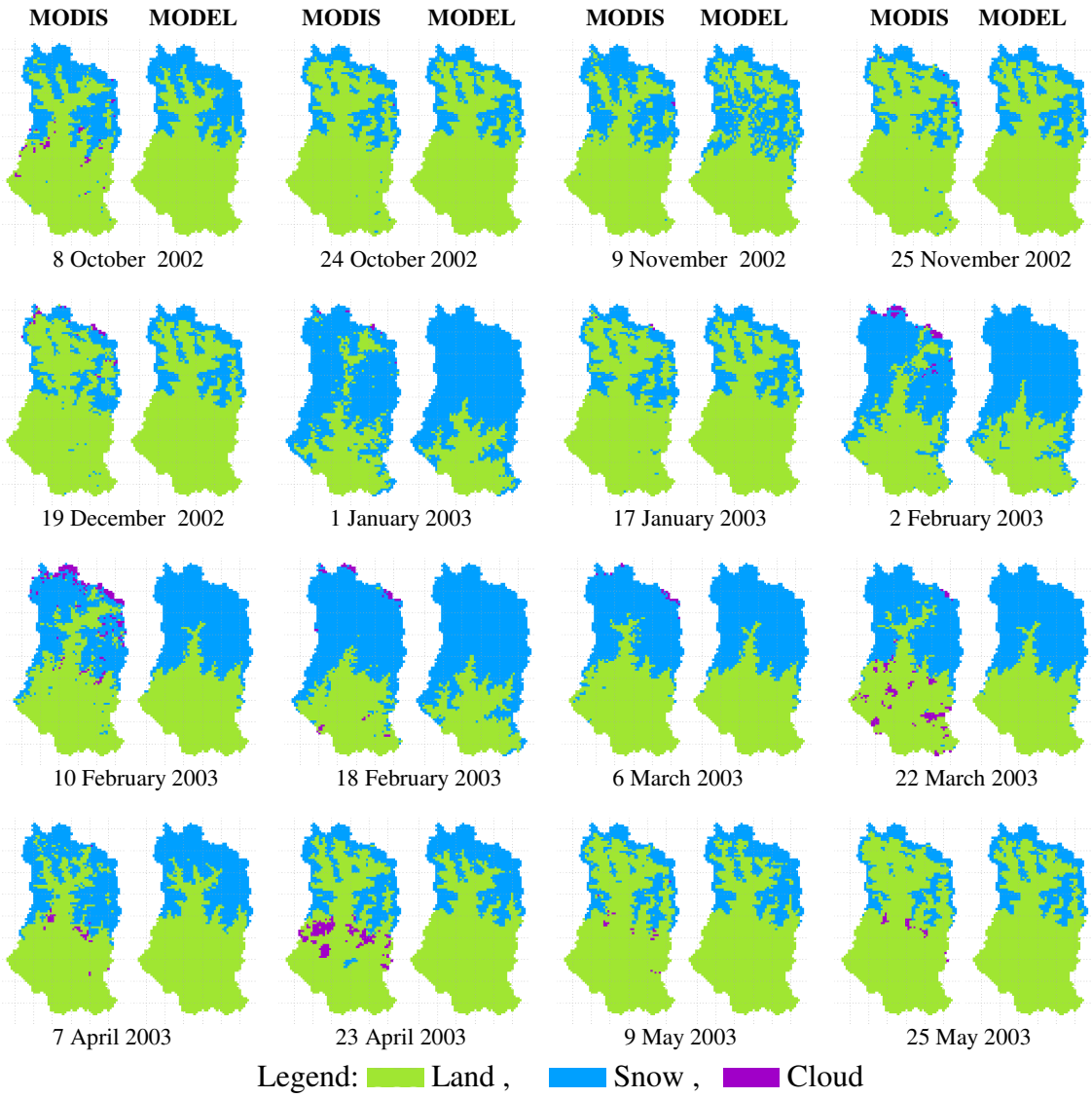
Rain gauges are not heated – Snowfall need to be corrected based on albedo/snow depth/temperature



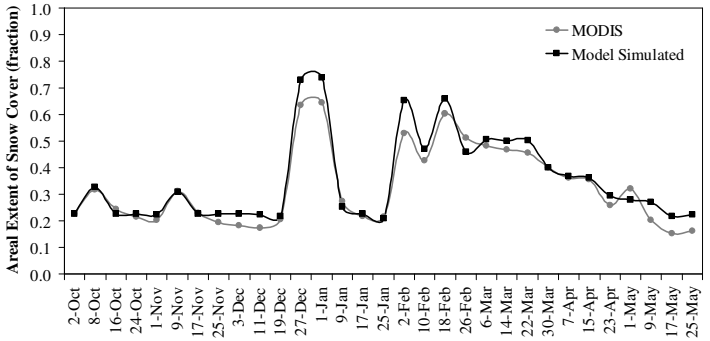


Application to Dudhkoshi river basin (Nepal)

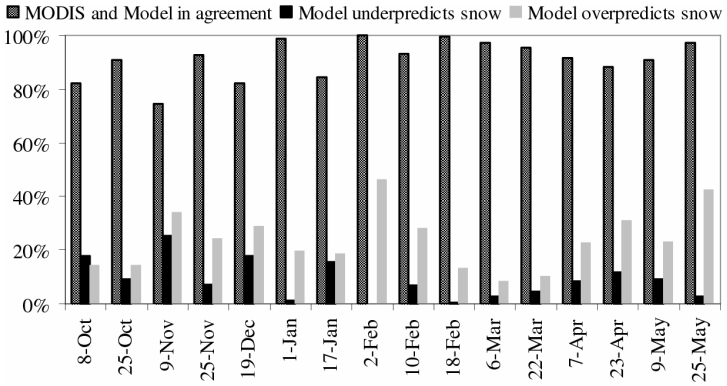
Snow Cover Area Simulation (MODIS Vs Model)



Areal Extent of snow cover



Grid to Grid comparison

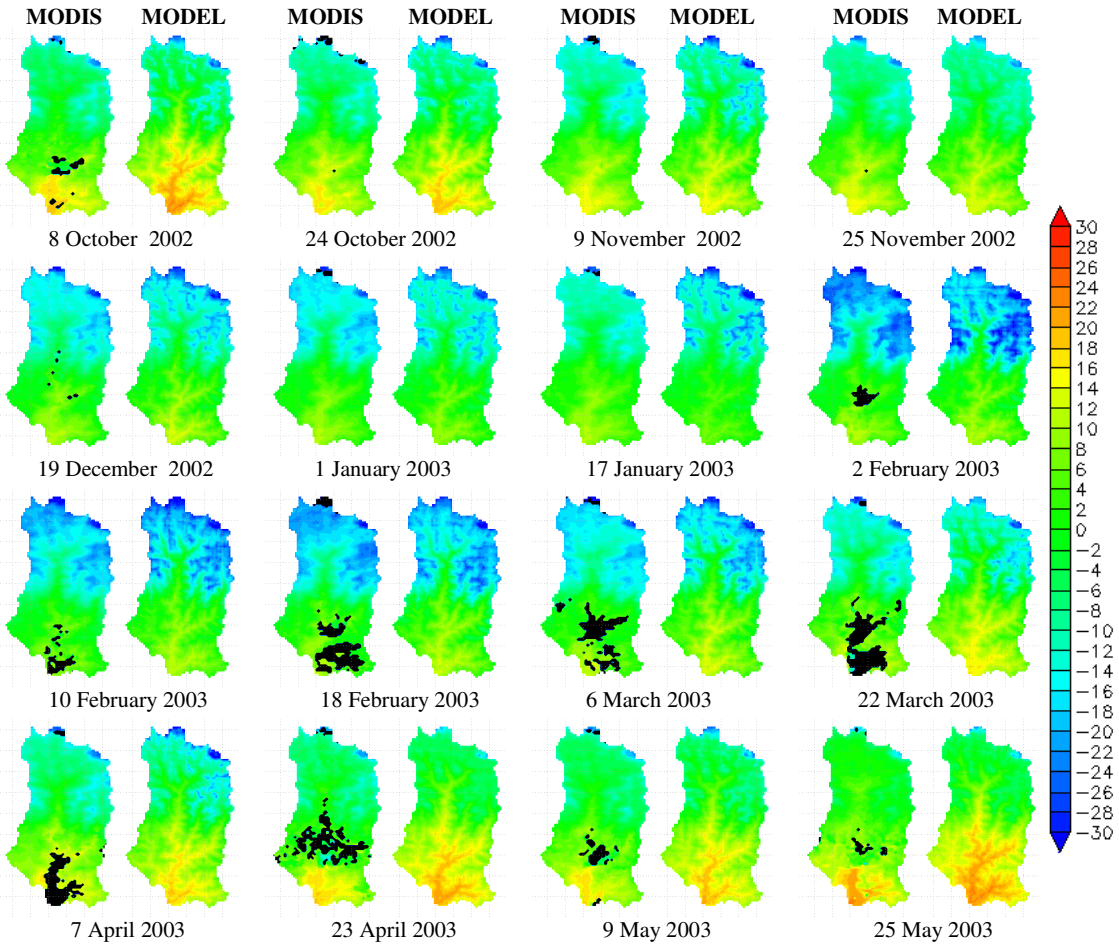


Overall Accuracy = 92%

[Shrestha et al.,2011, JHM]

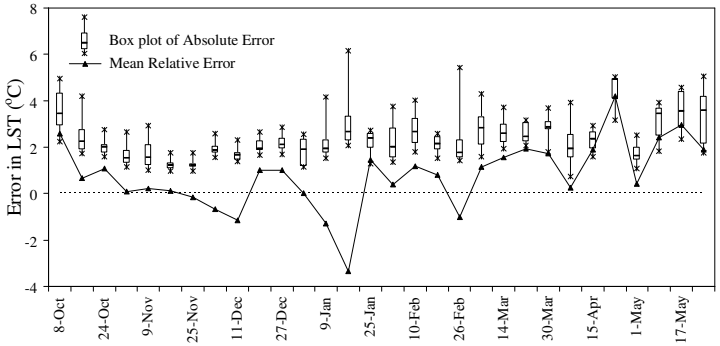
Application to Dudhkoshi river basin (Nepal)

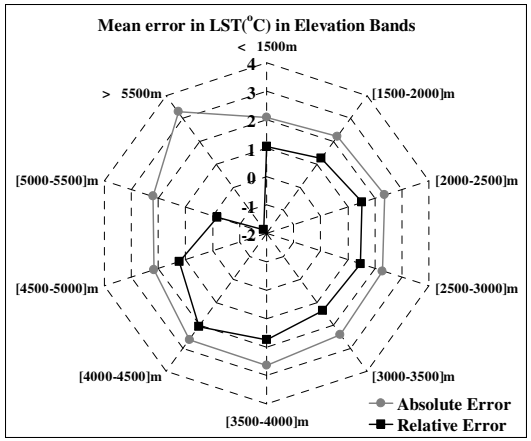
Land Surface Temperature Simulation (MODIS Vs Model)



(Black in MODIS images indicates that the grids having problems in reproducing LST due to cloud effect)

Bias in land surface Temperature

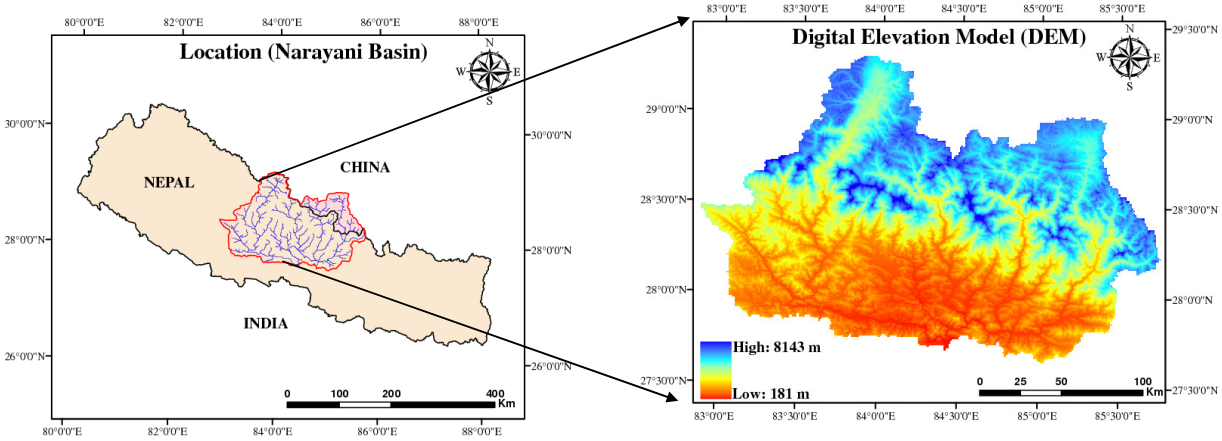


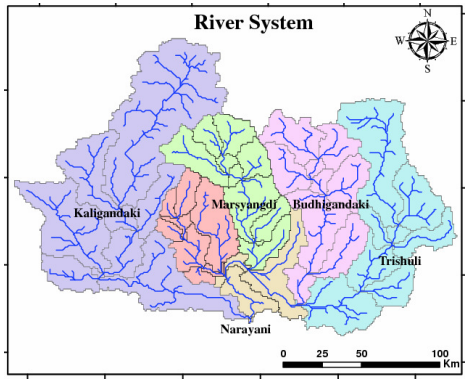


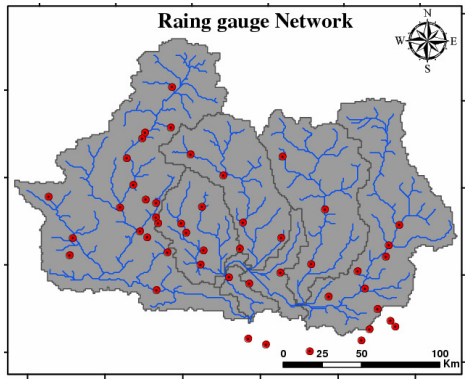
mean absolute bias = 2.42°C
mean relative bias = 0.77°C.

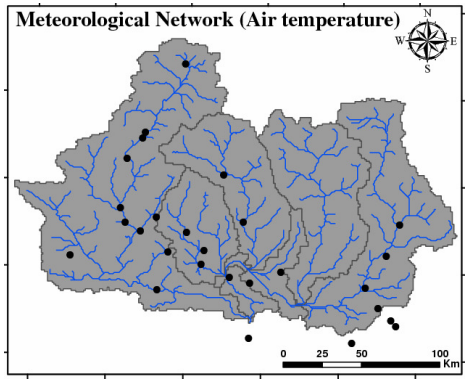
AWCI/CCAA-Narayani river basin (Nepal)

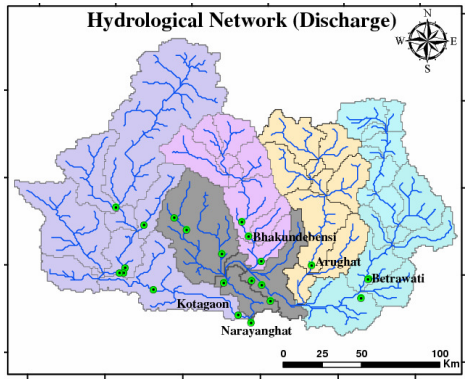
- Narayani basin, one of the major river basin of Nepal, occupy about 32000 km^2 (Narayanghat outlet).
- This river originates from the Himalayas and carries snow fed flows with significant discharge even in the dry season.
- Highly affected by summer monsoon, about 80% of the precipitation occurs in summer season.







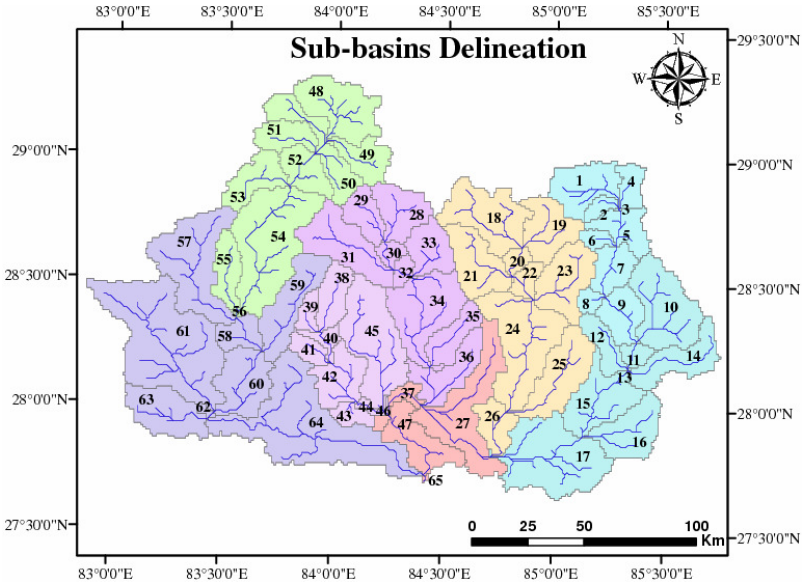


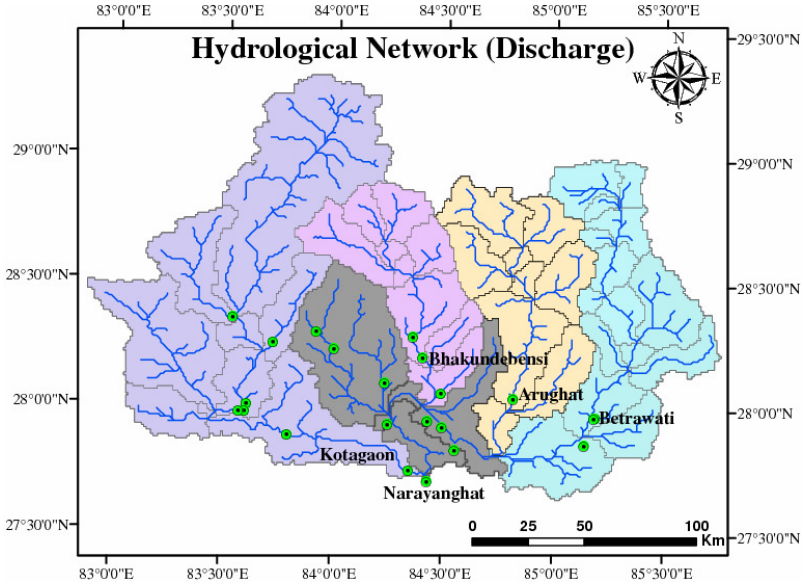


- 48 rain gauges. (long term data since 1966 or from 2000 to 2009 depending on sites)
- 27 meteorological gauges which has air temperature data (long term as stated above)
- 25 discharge gauges (long term)

Submitted to AWCI/DIAS

AWCI/CCAA-Narayani river basin (Nepal)

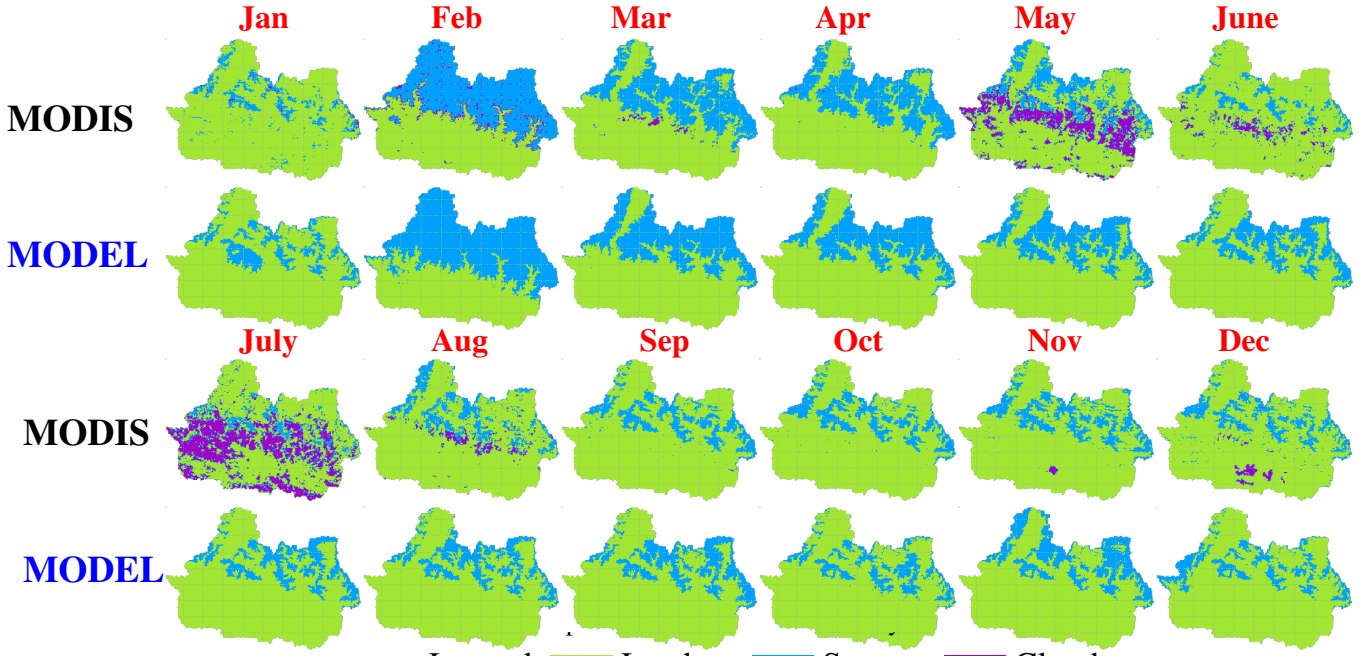




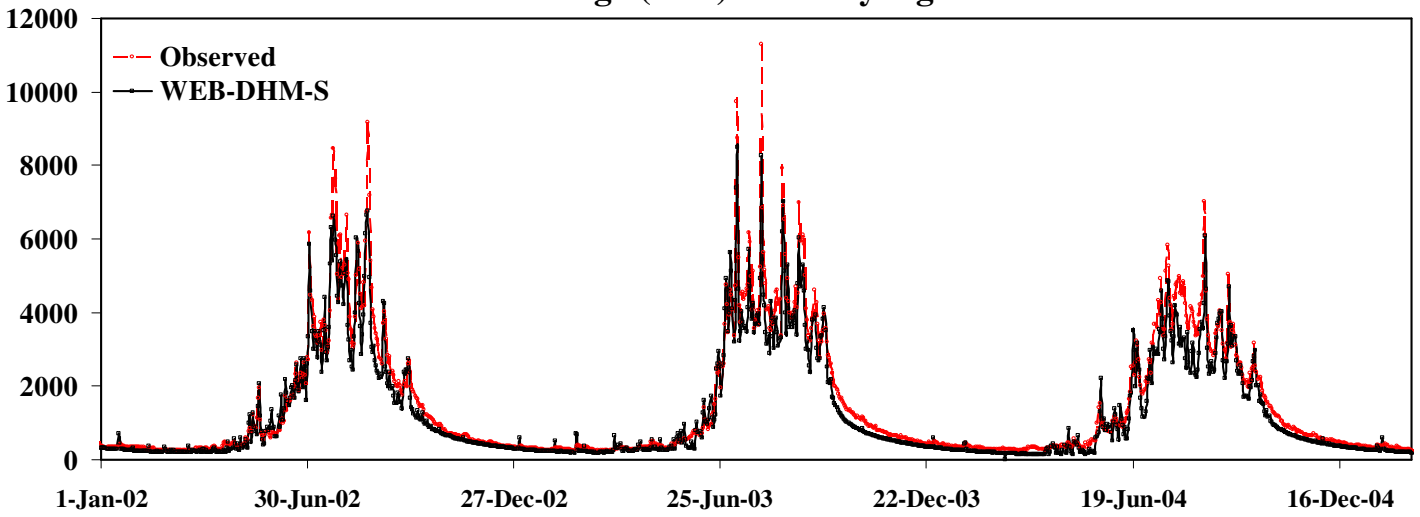
- 65 sub basins have been created during basin delineation.
- Meteorological Forcing are taken from – Global land data assimilation system (GLDAS).
- Observed air temperature is used in stead of GLDAS. Detrended Inverse Distance Weigt (IDW) interpolation method is used. IDW is used for interpolation of the precipitation.
- Model is set up for 2002-2003 (3 years continous setup) – Hourly simulation at 1 km grid size.
- MODIS snow cover area is used as intitializing the snow cover area.
- **Data in snow covered area almost nil.**

AWCI/CCAA-Narayani river basin (Nepal)

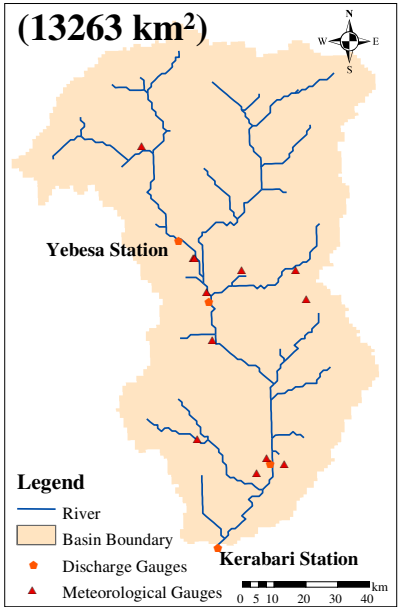
Snow Cover Area Simulation (MODIS Vs Model) in 2002 (Overall Accuracy = 91%)

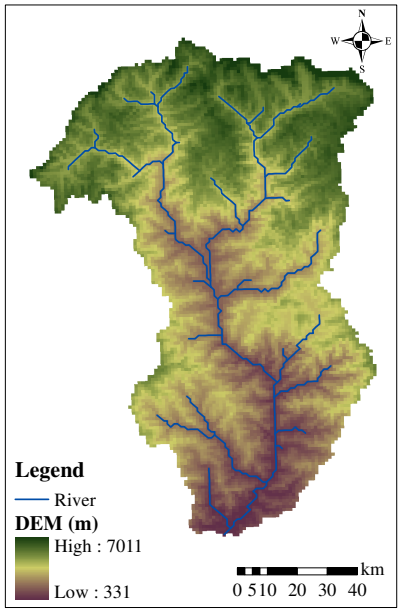


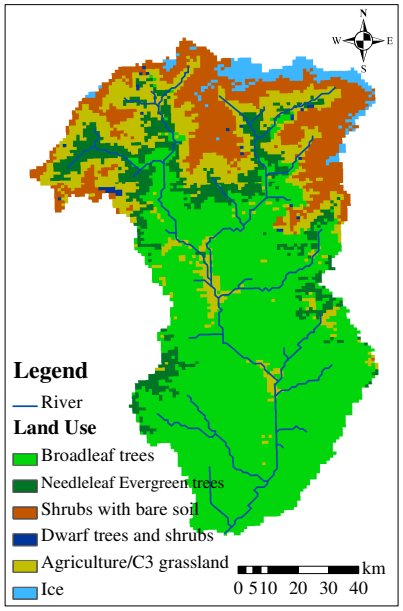
Discharge (m^3/s) at Narayanghat



AWCI/CCAA-Punatsangchu basin (Bhutan)

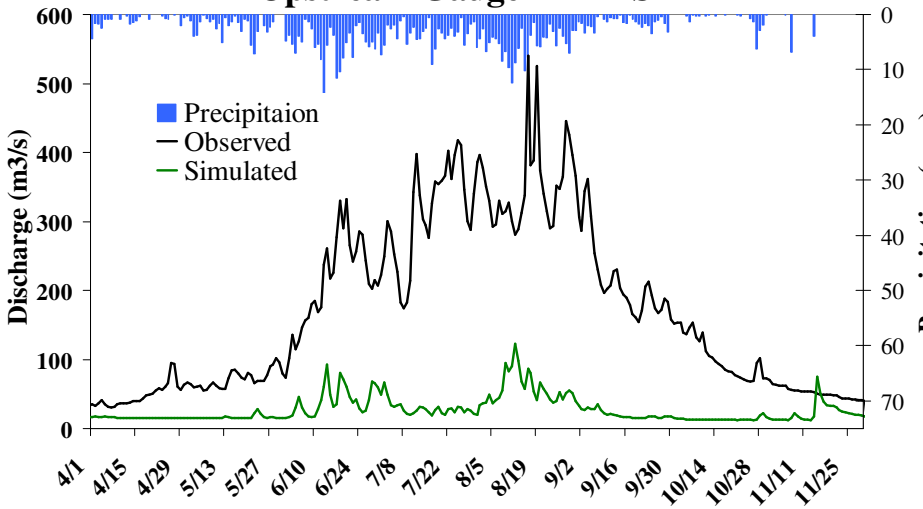


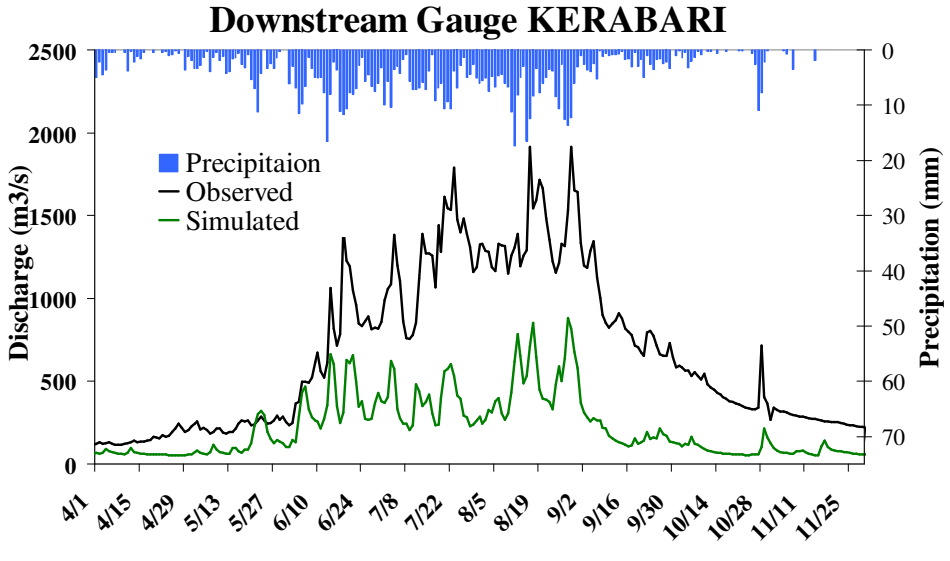




Grid Size : 1 km² Time step: Hourly

Dataset	*Resolution*
DEM	Grid (90 m)-SRTM
Meteorological data (Shortwave, longwave, wind speed, humidity, pressure, air temperature)	6-Hourly – Japan Reanalysis Dataset (JRA25)
Precipitation	Hydrometeorological Services Division (HSD), Department of Energy
Soil type	Grid (9 km) – FAO
Land use	Grid (1 km) – USGS
LAI	8-day averge Grid (1 km)
FPAR	8-day averge Grid (1 km)
Snow cover	8-day max. Grid (500 m)
Discharge	HSD, Bhutan





Underestimation of discharge is mainly due to the bias in JRA-25 air temperature

AWCI/CCAA-Punatsangchu basin (Bhutan)

Duran et al (2011) Submitted (JSCE)

Snow Cover Area Simulation (MODIS Vs Model)

Land , Snow , Cloud

Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sept

MODIS

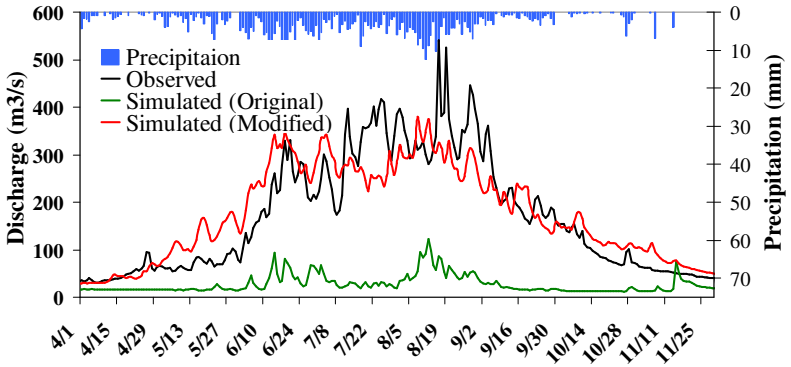
MODEL (Original JRA25 temperature)

Correction of JRA25 air temperature taking account of elevation effect

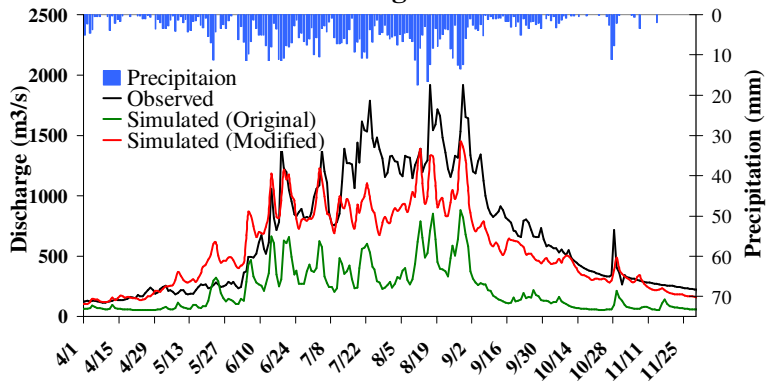
$$T_{corr} = T_{JRA} - \left(\frac{0.65}{100}\right)\left(Elev_{i,j} - 2000\right)$$

MODEL (Modified JRA25 temperature)

Upstream Gauge YEBESA



Downstream Gauge KERABARI

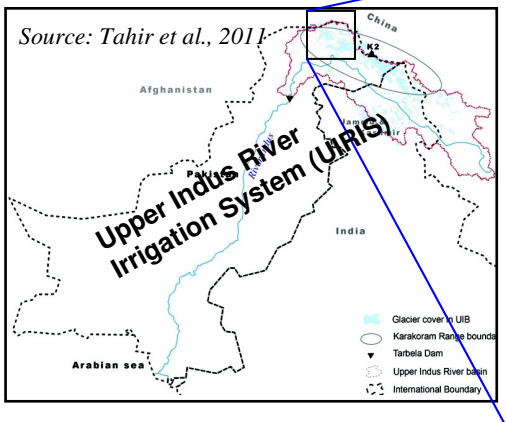


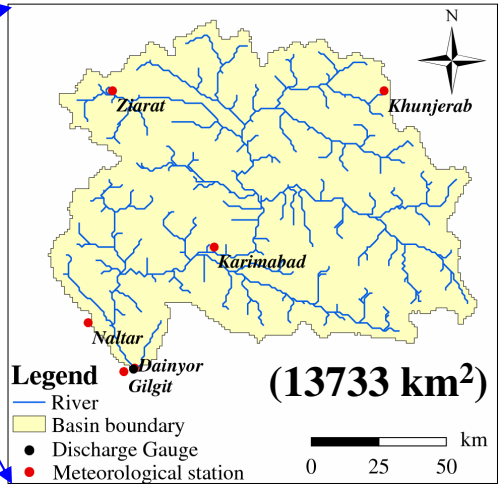
Observed Daily Maximum and minimum temperature at meteorological stations are requested.

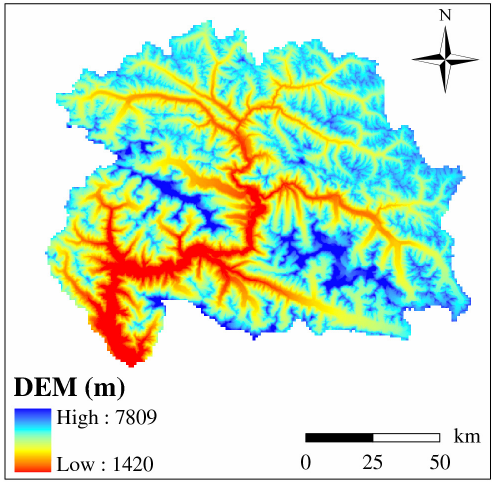
AWCI/CCAA - Hunza basin (Pakistan)

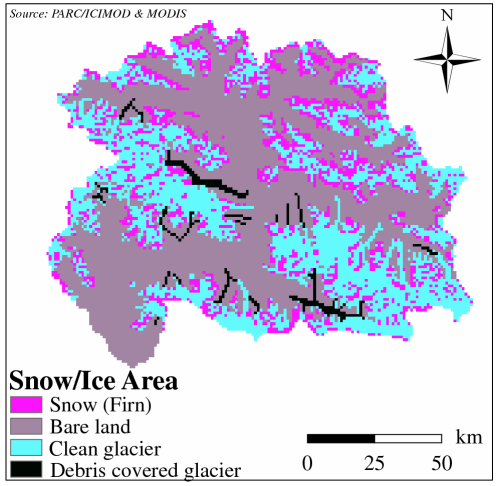
- **Snow and glacier melt fresh water contribute more than half of the inflow to the Tarbela reservoir (Upper Indus River Catchment)**

- **The Hunza River contributes nearly one-fifth of the Upper Indus flow. 34% of the basin is glaciated.**





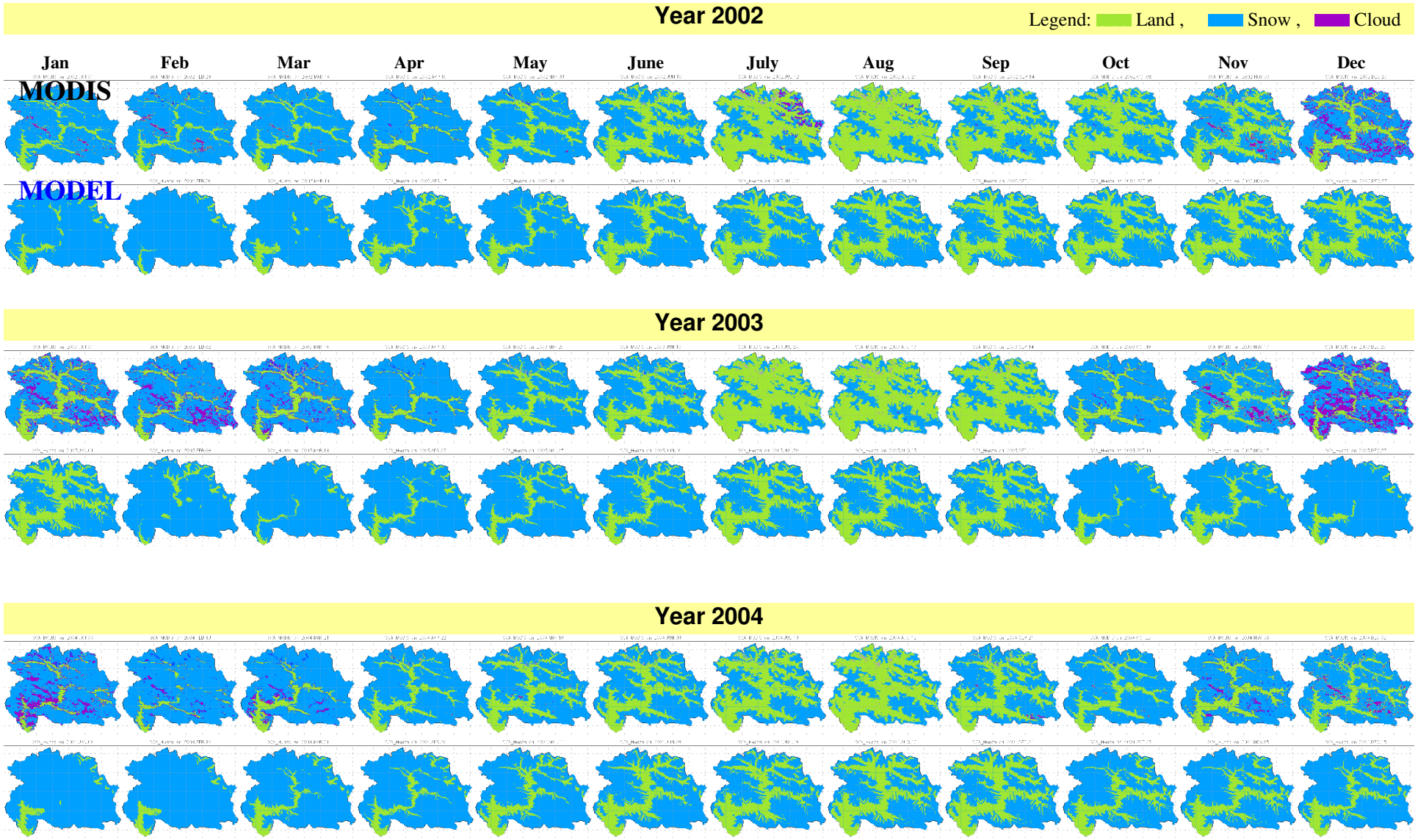




Dataset	Resolution
Digital Elevation Model (DEM)	Grid (90 m) - SRTM
Meteorological data (Shortwave, longwave, wind speed, humidity, pressure)	Grid (25km) – 3 hourly [Global Land Data Assimilation System (GLDAS)]
Precipitation	Grid (5km) – Daily Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE)
Air temperature (Max,min)	Point-Daily(Pakistan Met. Department)
Soil type	Grid (9 km) - FAO
Land use	Grid (1 km) - USGS
LAI	8-day averge Grid (1 km) - MODIS
FPAR	8-day averge Grid (1 km) - MODIS
Snow/Ice cover	Coverage-Pakistan Agr. Res. Council
Snow cover	8-day max. Grid (500 m) - MODIS
Discharge at Dainyor	Basin outlet at Dainyor-Daily

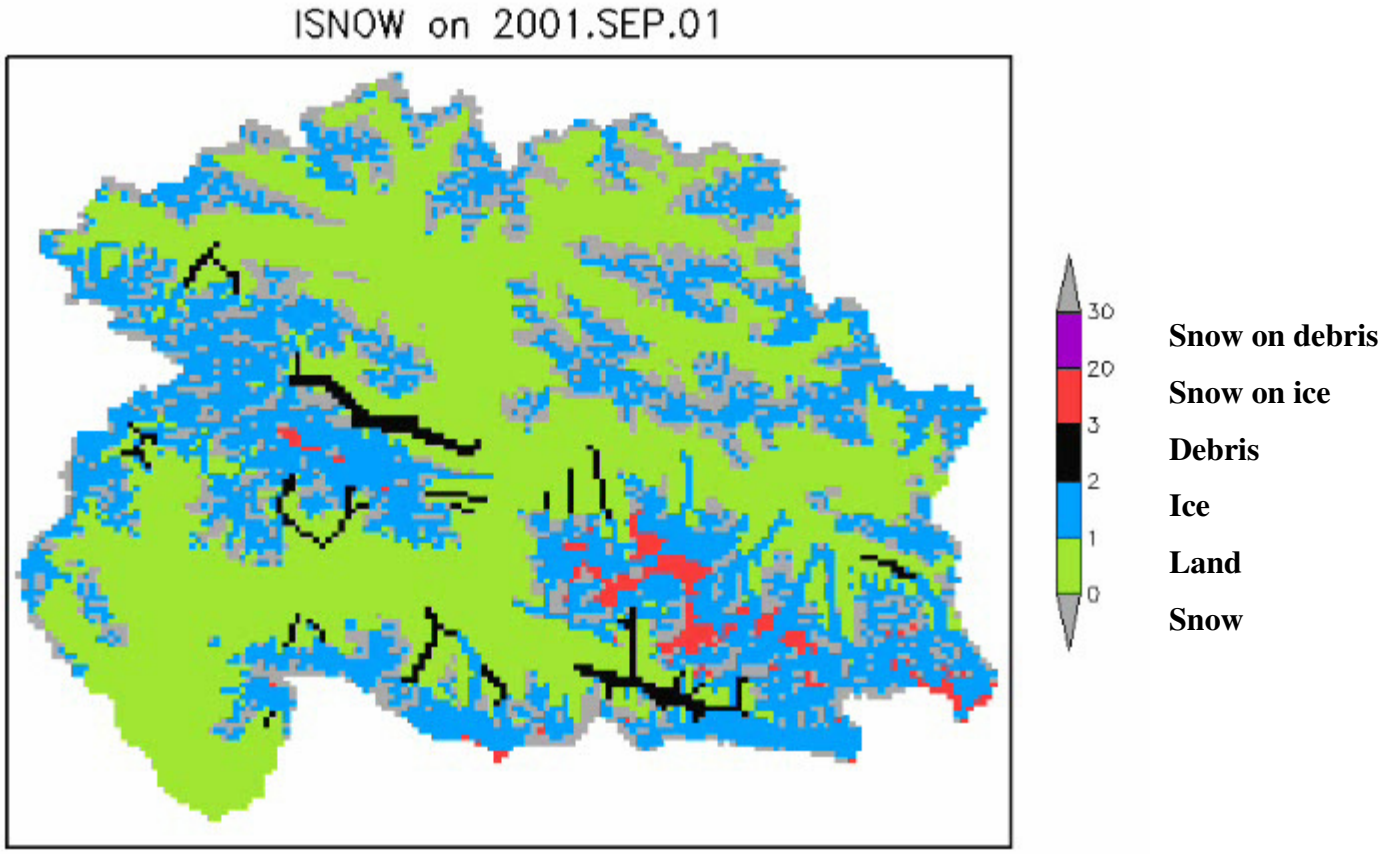
AWCI/CCAA - Hunza basin (Pakistan)

Snow Cover Area Simulation (MODIS Vs Model)



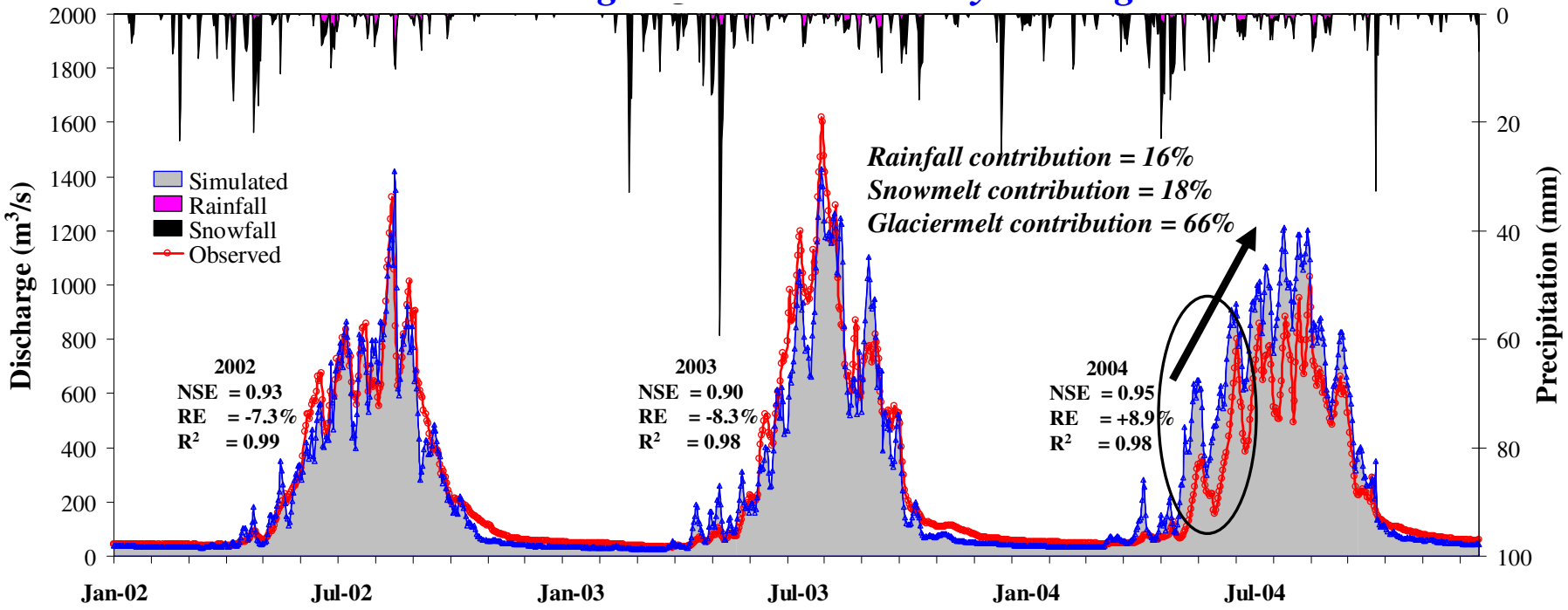
AWCI/CCAA - Hunza basin (Pakistan)

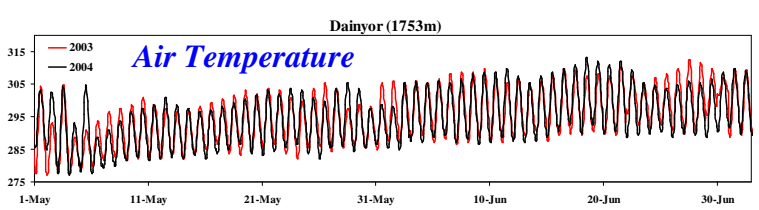
Snow/Glacier State Simulation

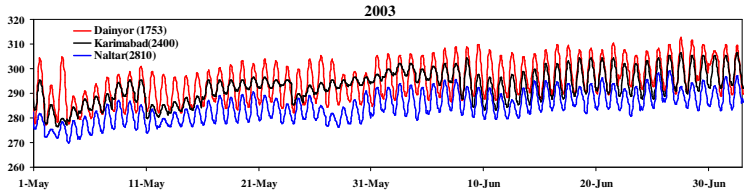


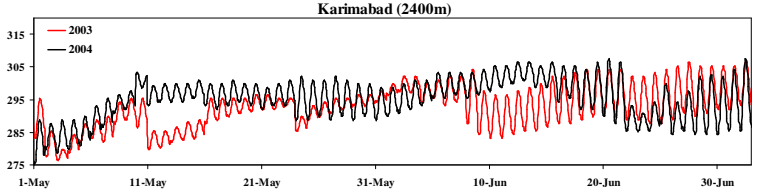
AWCI/CCAA - Hunza basin (Pakistan)

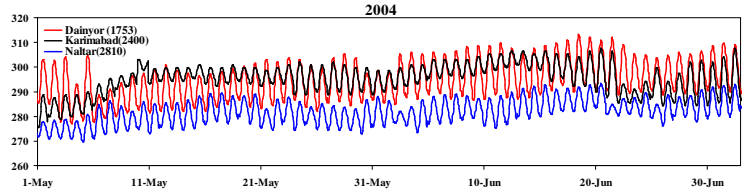
Discharge simulation at Dainyor Bridge







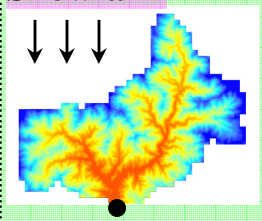




•Air temperature in 2004 has wide variations which causes the substantial uncertainty in air temperature interpolation. Consequently, large absolute BIAS in discharge in May and June are simulated.

Correcting snowfall in basin scale – Upper Tone, Japan (AWCI/CCAA)

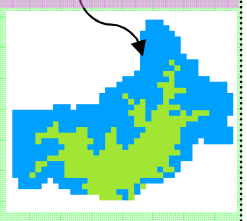
Snowfall



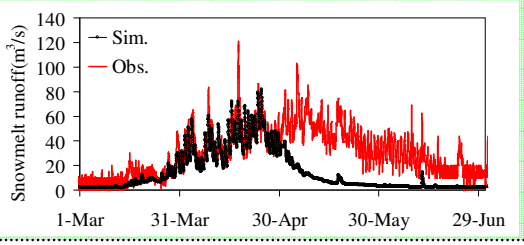
A large inconsistency between observed snowfall and snowmelt runoff

Is *winter precipitation (snowfall)* reliable?
Need Adjustment/Correction

Snow cover area

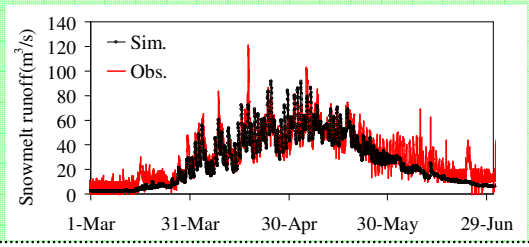


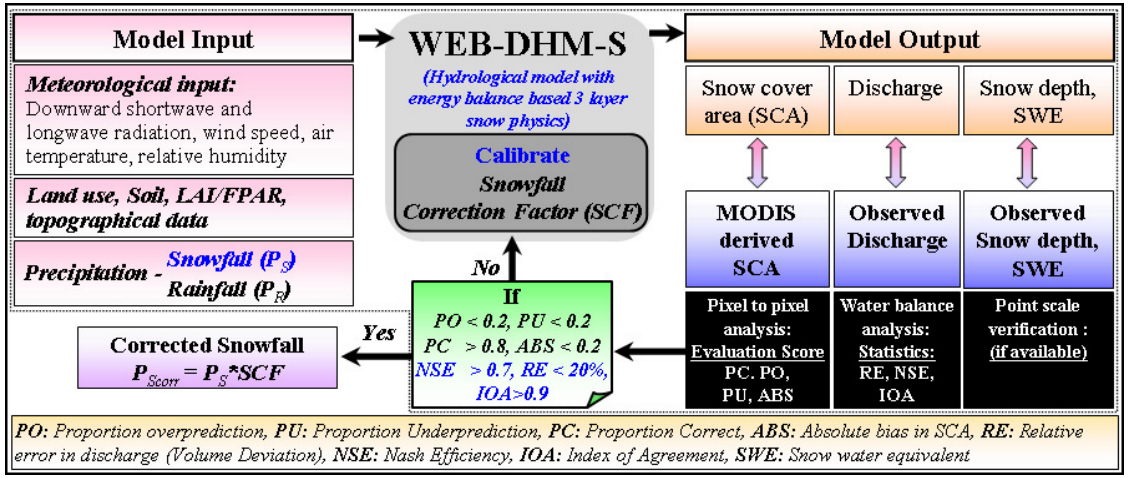
How to correct ?



Establish a method to correct snowfall (in point/basin scale)

$$SCF(z) = \{1 + (z - z_a) * C_f\}$$





Contingency Table

Model Simulated	MODIS		
	Snow	*No Snow*	*Marginal Total*
Snow	**A** (Hit)	**B** (False Alarm)	**A+B**
No Snow	**C** (Miss)	**D** (Negative Correlation)	**C+D**
Marginal Total	**A+C**	**B+D**	**A+B+C+D**

$$PO = \frac{B}{A+B+C+D}, \quad PU = \frac{C}{A+B+C+D}, \quad PC = \frac{A+D}{A+B+C+D}$$

$$ABS = \frac{\sum_{i=1}^{N}(SCA_{MODEL} - SCA_{MODIS})}{N}$$

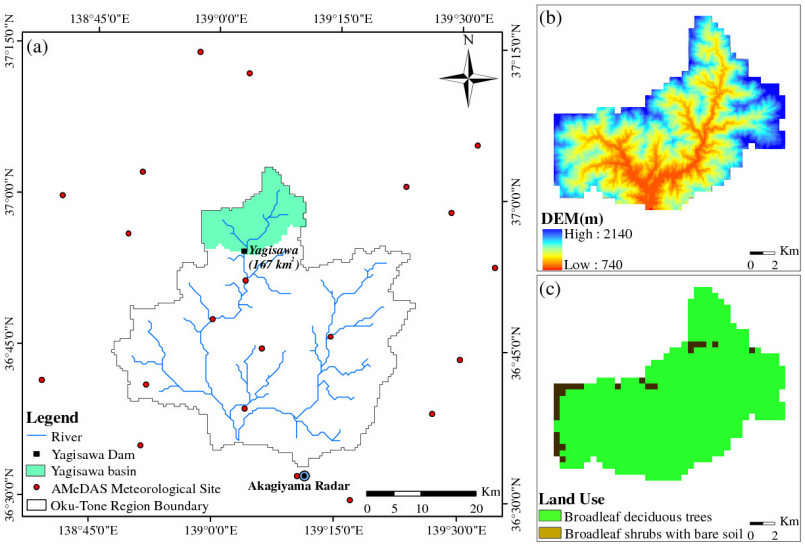
Discharge evaluation

$$NSE = 1 - \frac{\sum_{i=1}^{N}(Q_{oi} - Q_{si})^2}{\sum_{i=1}^{N}(Q_{oi} - \overline{Q}_o)^2} \qquad RE = \frac{\sum_{i=1}^{N}(Q_{si} - Q_{oi})}{\sum_{i=1}^{N} Q_{oi}}$$

$$IOA = 1 - \frac{\sum_{i=1}^{N}(Q_{oi} - Q_{si})^2}{\sum_{i=1}^{N}\left(|Q_{si} - \overline{Q}_o| + |Q_{oi} - \overline{Q}_o|\right)^2}$$

Correcting snowfall in basin scale – Upper Tone, Japan (AWCI/CCAA)

Yagisawa basin, Upper Tone, JAPAN



Two types of precipitation are corrected.

Rain gauge (AMeDAS), ⟹ *AMeDAS - Corr*

Radar data (Radar-AMeDAS), ⟹ ***Radar-AMeDAS-Corr***

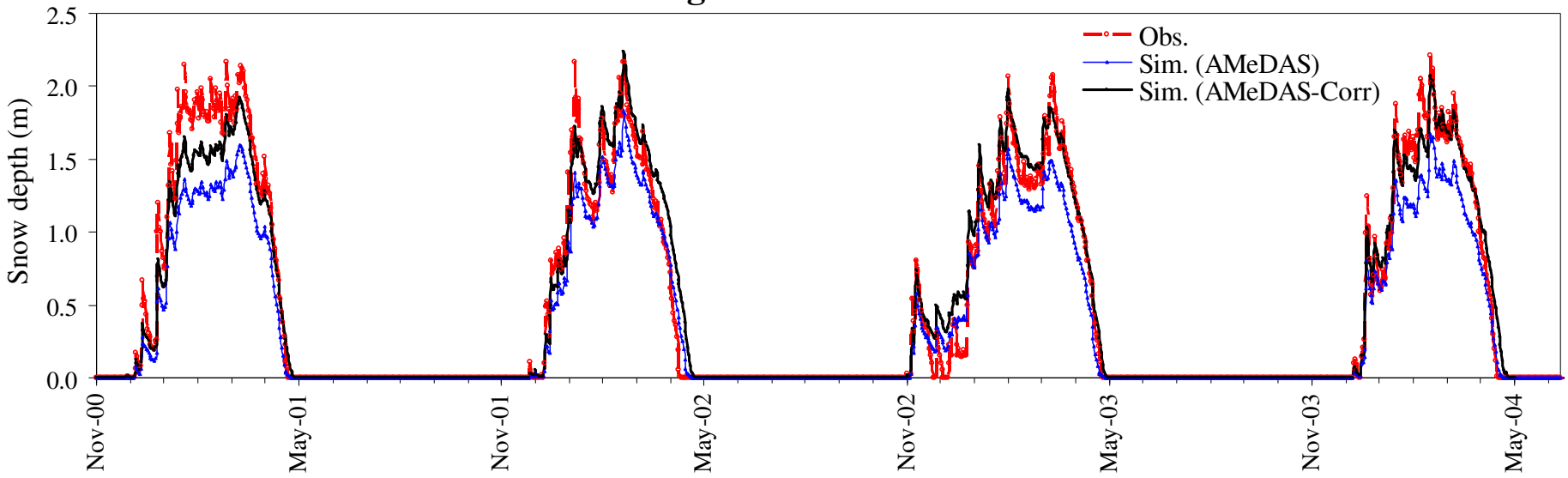
Inverse distance Weight (IDW) – Interpolation for meteorological forcing data

Detrended IDW for temperature interpolation using a lapse rate of 6.5°C/1000m

Grid : *500 m* , ***Time step*** : *Hourly*

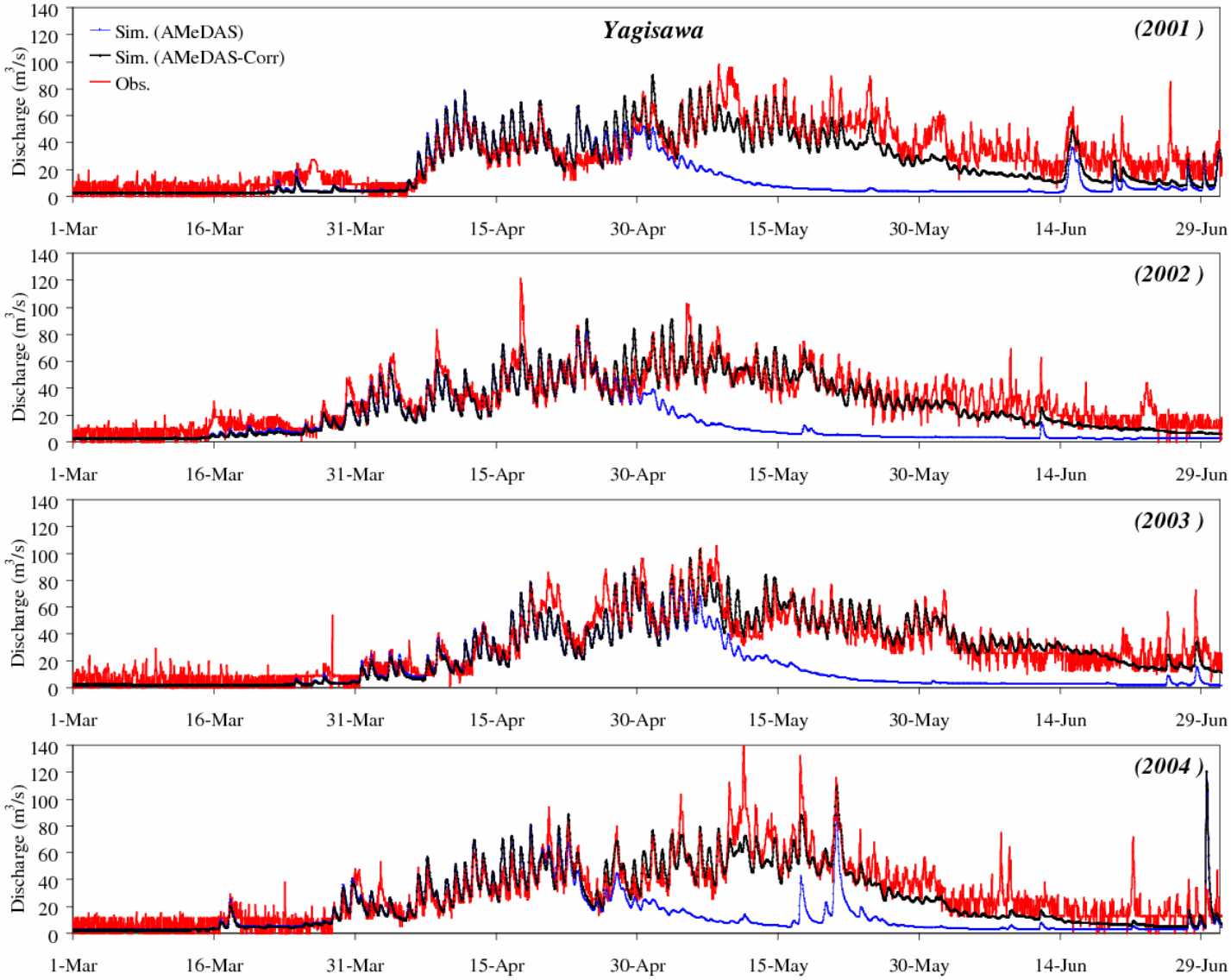
Period : *2001-2004*

Yagisawa Dam site



Correcting snowfall in basin scale – Upper Tone, Japan (AWCI/CCAA)

Correction of Rain gauge precipitation, $C_f = 0.001$



	AMeDAS	AMeDAS -Corr
NSE	-0.46	0.78
RE	-56	-10
IOA	0.4	0.93

	AMeDAS	AMeDAS -Corr
NSE	-0.14	0.88
RE	-53	-8
IOA	0.57	0.97

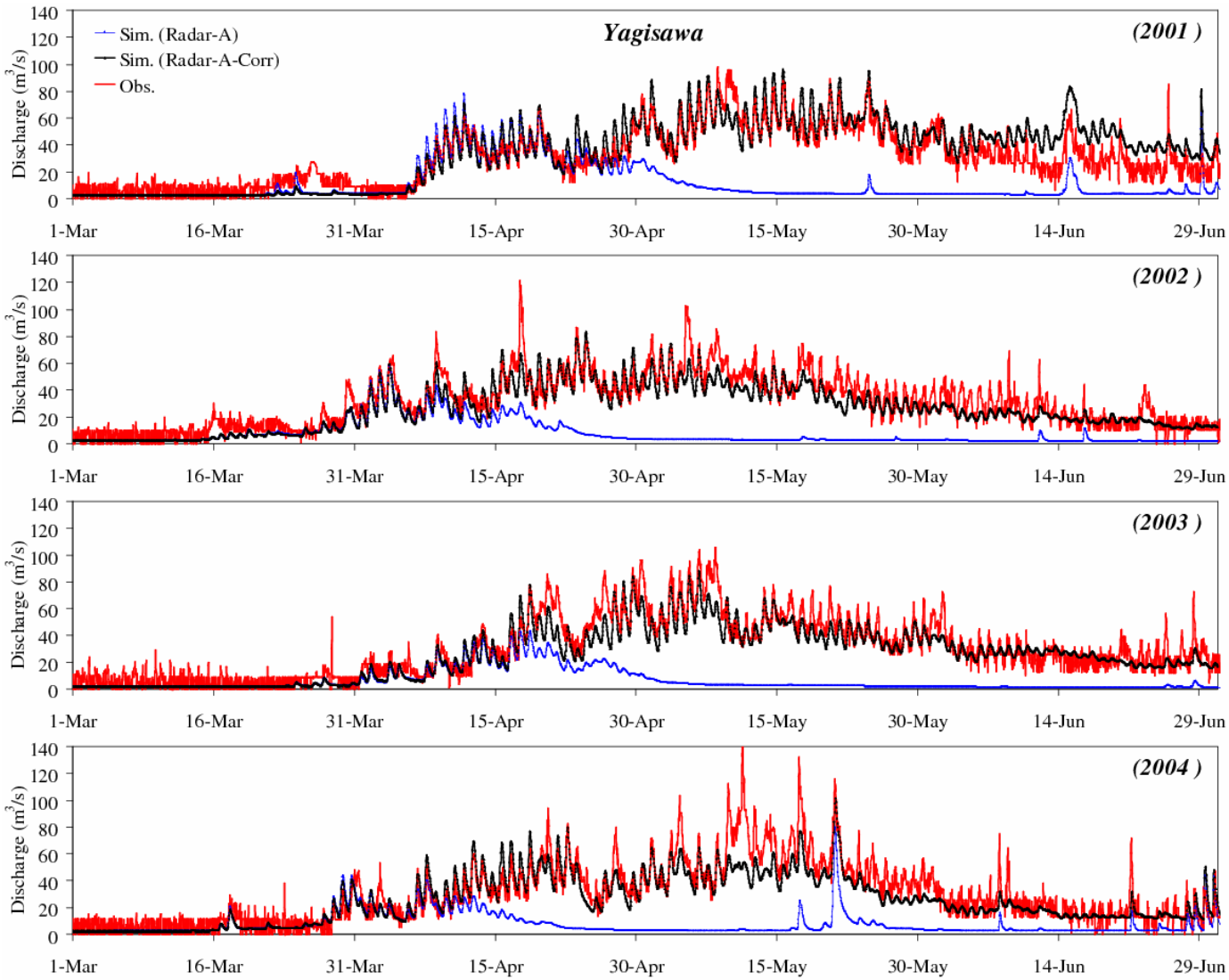
	AMeDAS	AMeDAS -Corr
NSE	0.2	0.89
RE	-50	-3
IOA	0.71	0.98

	AMeDAS	AMeDAS -Corr
NSE	-0.2	0.85
RE	-52	-8
IOA	0.45	0.96

4 year average SCF = 1.87

Correcting snowfall in basin scale – Upper Tone, Japan (AWCI/CCAA)

Correction of Radar precipitation, $C_f = 0.007$



	Radar	Radar -Corr
NSE	-0.29	0.8
RE	-65	14
IOA	0.28	0.95

	Radar	Radar -Corr
NSE	-0.4	0.89
RE	-80	-14
IOA	0.14	0.97

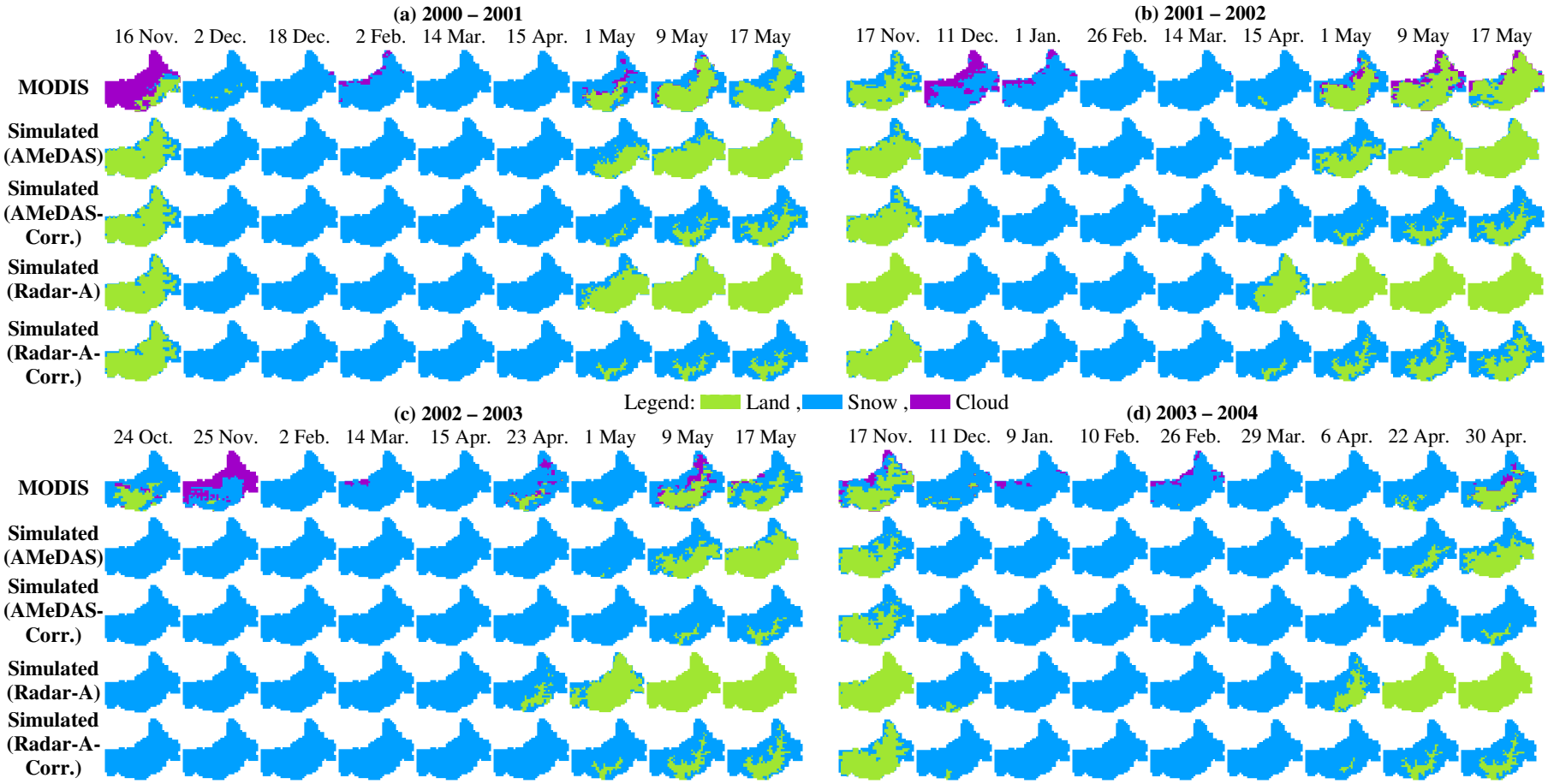
	Radar	Radar -Corr
NSE	-0.4	0.89
RE	-80	-14
IOA	0.14	0.97

	Radar	Radar -Corr
NSE	-0.42	0.82
RE	-76	-13
IOA	0.14	0.94

4 year average SCF = 3.87

Correcting snowfall in basin scale – Upper Tone, Japan (AWCI/CCAA)

Snow Cover Area Simulation (MODIS Vs Model)



Overall Accuracy = 91 %

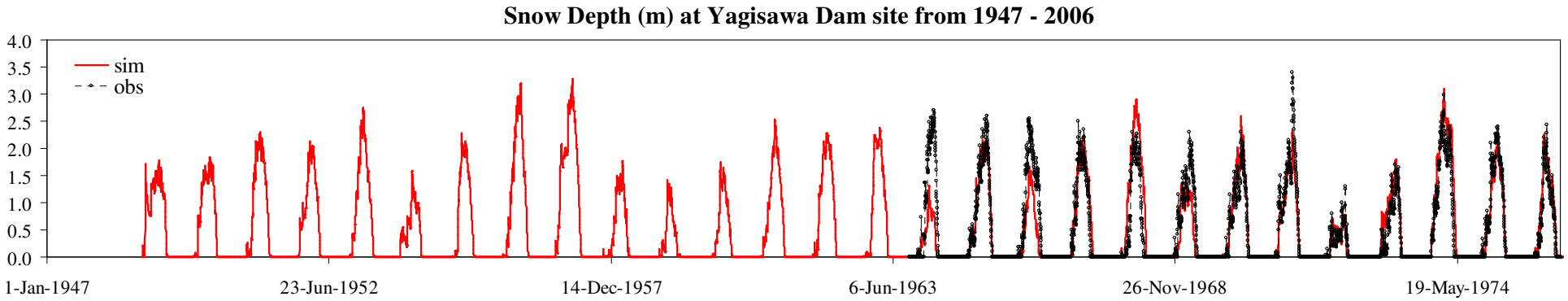
	AMeDAS-Corr.				Radar-A-Corr.			
Year	PC	PO	PU	ABS	PC	PO	PU	ABS
2001	0.92	0.07	0.01	0.04	0.91	0.08	0.01	0.07
2002	0.87	0.11	0.02	0.11	0.88	0.08	0.04	0.10
2003	0.94	0.05	0.01	0.03	0.95	0.04	0.01	0.03
2004	0.92	0.06	0.02	0.07	0.92	0.05	0.03	0.06

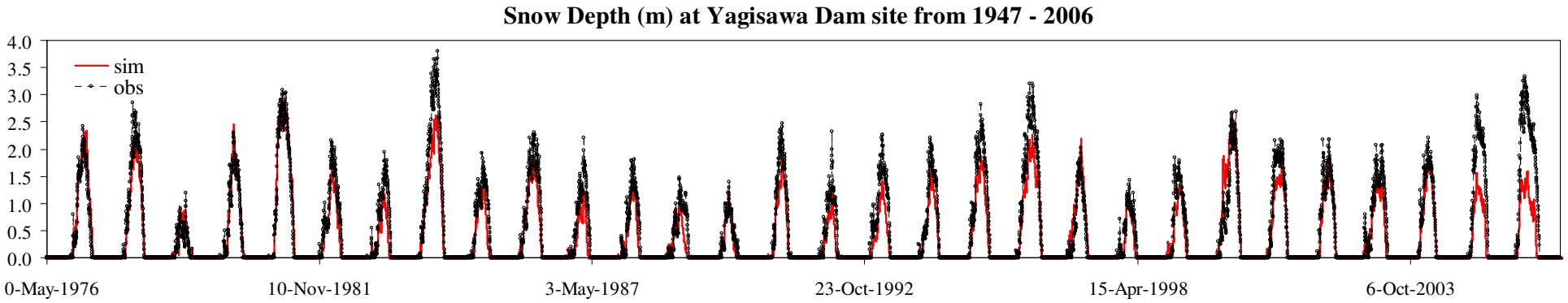
Long term simulation (59 years) of snow depth
Upper Tone, Japan (AWCI/CCAA)

Atmospheric Forcing: JP10 data over Japan for 1948-2006

A 10-km and hourly dynamically downscaling simulation dataset from NCEP/NCAR Reanalysis

(Experimental Climate Prediction Center in Scripps Institution of Oceanography)





9. Concluding remarks

1. *A detailed energy balance based multilayered snow and glacier melt model in a distributed hydrological framework has been developed.*
2. *Basin scale evaluation of WEB-DHM-S was performed at Dudhkoshi region of Nepal Himalaya for snow cover and land surface temperature simulations. Snow cover simulation is comparable to the MODIS 8 day snow cover product (MOD10A2) with overall accuracy of 92%.*
3. *WEB-DHM-S model has been developed for four AWCI/CCAA study basins- Narayani (Nepal), Punatsangchu (Bhutan), Hunza (Pakistan) and Upper Tone (Japan).*
4. *Spatial distribution of snow/glacier cover and snow/glacier melt runoff has been simulated well as compared to the MODIS satellite snow cover and the observed discharge, respectively.*
5. *A method has been established to correct the snowfall at the Yagisawa basin of Upper Tone river. The method can be applied at any river basin. In addition, long term simulation (59 years) of snow depth have been simulated well with the use of JP10 reanalysis dataset..*

Application of WEB-DHM-S in other AWCI/CCAA snowy basins has been planned in near future.

Thanks for your kind attention

Queries ??? / Comments !!

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