National Remote Sensing Centre
Indian Space Research Organisation
Dept. of Space, Govt. of India

National Hydrology Project

Water Resources Group, RSAA, NRSC
www.nrsc.gov.in

Development of Snowmelt model for Himalayan region using energy balance approach

Principal Investigator: Shri B. Simhadri Rao (Scientist-SG)

Project Director: Dr V.V. Rao (Scientist-H)

Presented by:

Dr Shivam

Research Scientist

www.isro.gov.in

Date: 25.04.2019

Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Organisation of Presentation

1. Introduction
2. Methodology
3. Input data
4. Preliminary Results
5. Assumptions & Limitations

Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Introduction

- Snow and glaciers play major role in the hydrology, as it is the major source of water for the many perineal river systems of India.
- Hydropower projects established in the Himalayan region requires necessary assessment of snowmelt for proper reservoir operations.
- Snowfall in the Himalayan region starts from month of October and continues till late March and snowmelt starts from the beginning of the month of April and continues till June-July month.

Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Snowmelt Runoff modelling approaches

- **Energy Balance approach**
  - Energy exchange at Snow surface through exchange of Short Wave & Long Wave Radiation and Energy Fluxes due to Sensible Heat, Latent Heat, Soil Heat and Rainfall
- **Temperature Index approach**
  - Air Temperature or Degree days are used to approximate snowpack energy exchange in lieu of Energy Balance approach.
  - Snow melt rate and changes in snowpack are estimated using Degree day approach which is based on the assumption of Linear relationship between snow melt rate and mean daily air temperature

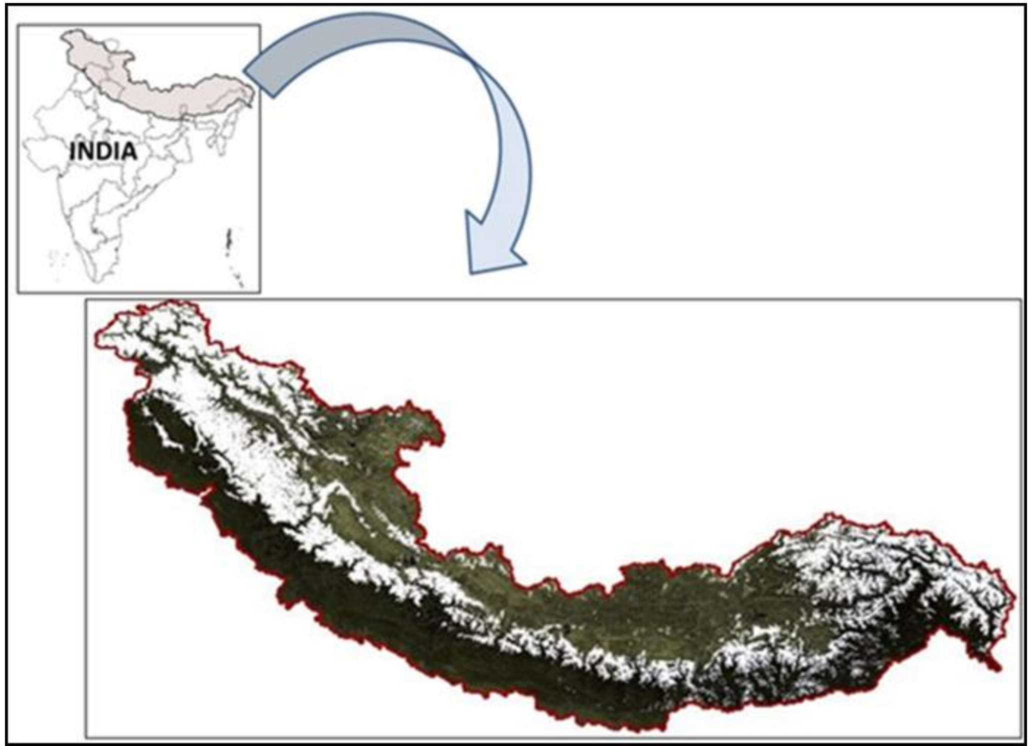
Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Study Objectives

- To develop a short-term snowmelt runoff forecasting model using satellite derived products and field data
- To generate a spatial daily gridded snowmelt product
- To generate a spatial 3-day snowmelt forecast gridded product
- To provide short term snowmelt runoff forecast at selected basin outlets during snowmelt season

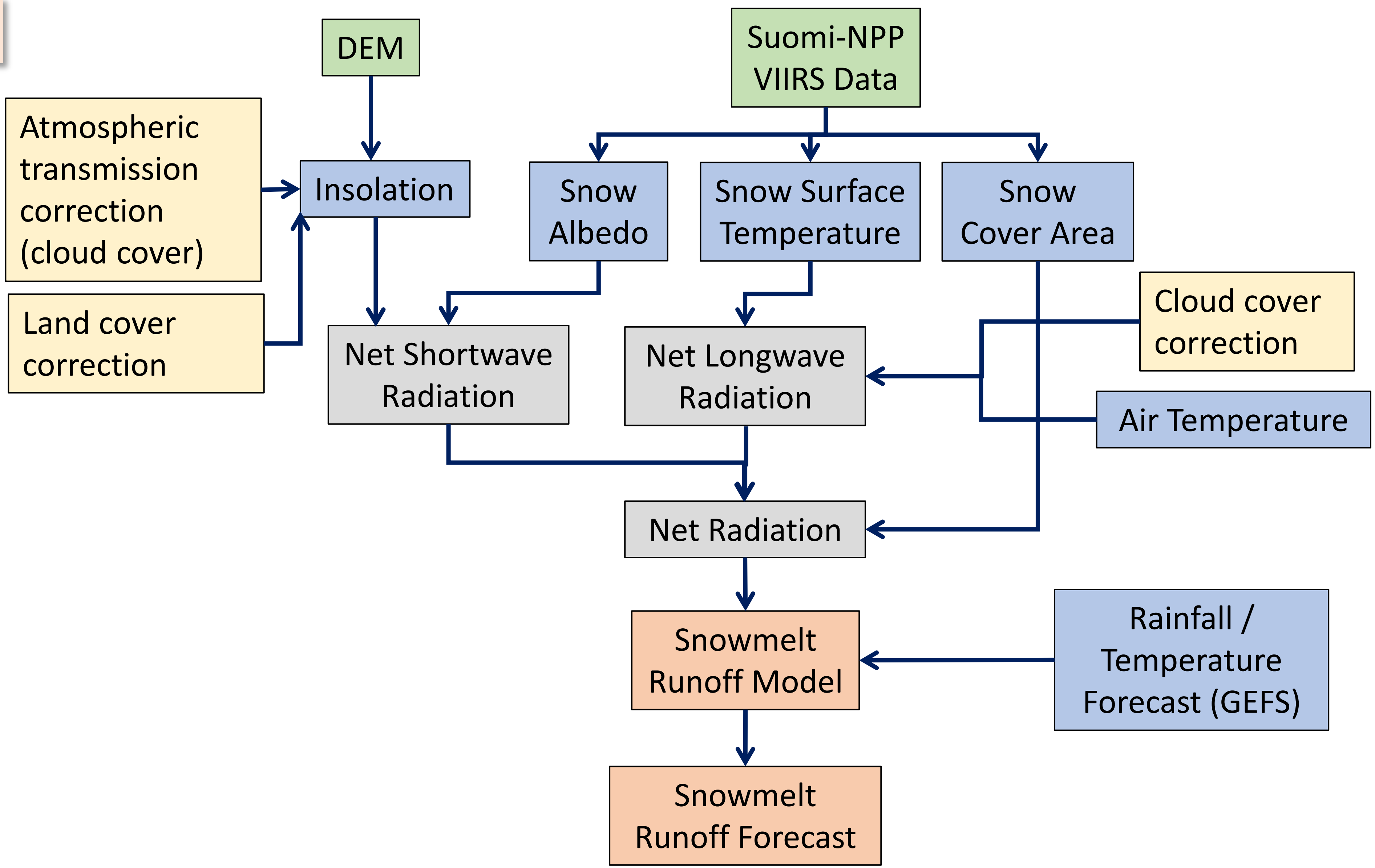
Study Area

- Indian Himalayas covering Major river systems (Indus, Ganga and Brahmaputra) including outside Indian boundary



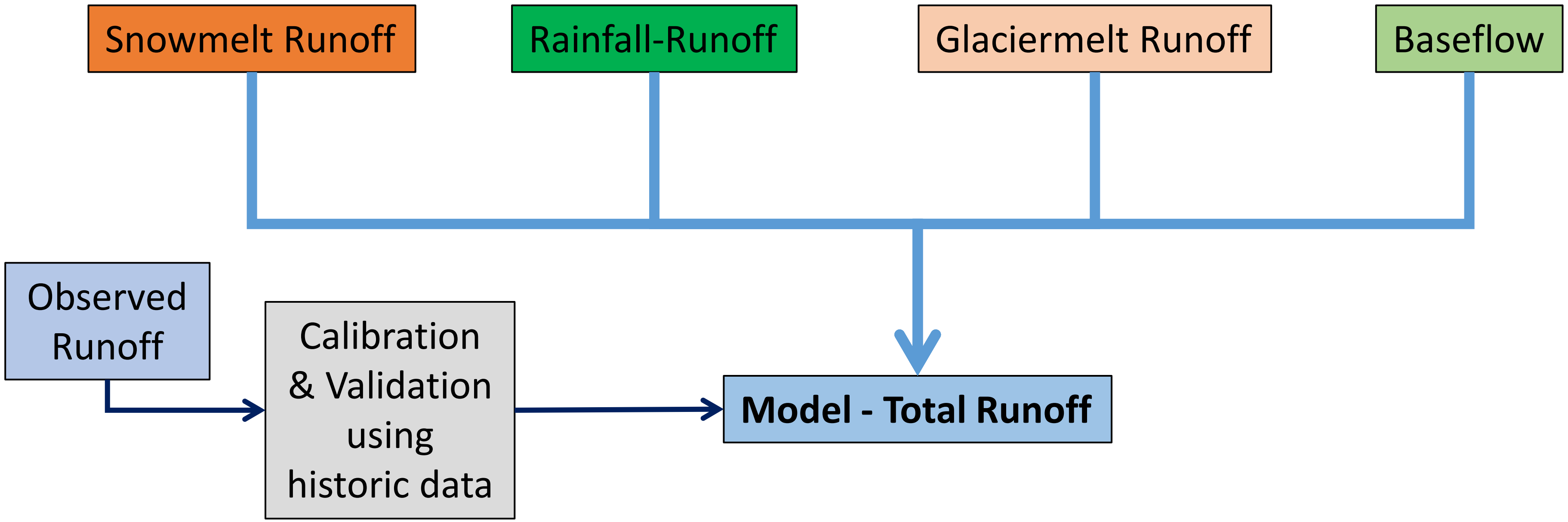
Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Methodology



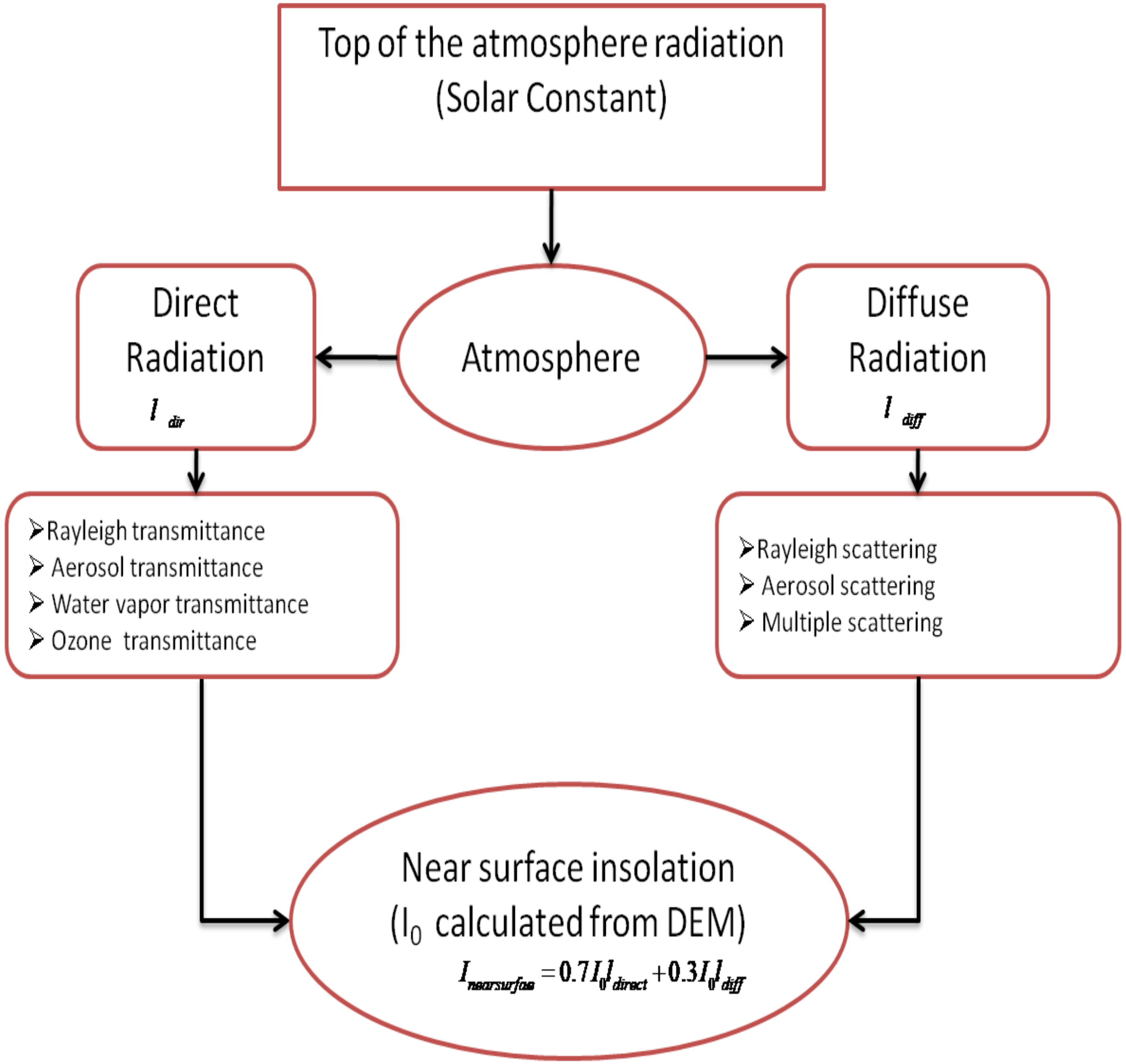
Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Total Runoff



Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Shortwave Radiation



Direct Radiation Losses $I_{dir} = \tau_R \times \tau_{oz} \times \tau_w \times \tau_g \times \tau_A$

τ_R Rayleigh Transmittance

τ_{oz} Ozone Transmittance

τ_w Water vapor Transmittance

τ_g Gas Transmittance

τ_A Aerosol Transmittance

Diffuse Radiation Losses $I_{diff} = S_R + S_A + S_M$

S_R Rayleigh Scattering

S_A Aerosol Scattering

S_M Multiple Scattering

Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Transmission Losses Through Direct and Diffuse Radiation

➢Water vapor, Ozone, Aerosol Transmittance

$$\tau(x) = \exp[-x(a + bx + cx^{d})]$$

Component	x	Variables		Source
For ozone	x=ml	l is ozone content in atmosphere in cm		INSAT Sounder-Atmospheric Profile Product (11X11Km, Half hourly)
For water vapor	x=mw	W is atmospheric perceptible water or columnar water vapor in gcm-2		INSAT 3D Sounder-Atmospheric Profile Product (11X11Km, Half hourly)
For aerosol	x=mb	Atmospheric visibility of haziness based on given aerosol type and size distribution		INSAT 3D Imager AOD product (11X11 Km, Half hourly)
For Other Gases	x=m	Relative optical air mass value		Kasten and Young (1989)
Atmospheric variable	Ozone (*l*)	Water vapor (*w*)	Aerosol (*b*)	Other gases
a	0.0184	0.002	1.053	-5.4×10^(-5)
b	0.0004	1.67 × 10^(-5)	0.083	-3.8×10^(-6)
c	0.022	0.094	0.3345	0.0099
d	-0.66	-0.693	-0.668	-0.62
				Paulescu and Schlett (2003)

Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Diffuse Radiation $l_{diff} = S_R + S_A + S_M$

1. S_R Rayleigh Scattering
2. S_A Aerosol scattering
3. S_M Multiple scattering

- **Rayleigh Scattering**

$$S_R = 0.79 I_0 \tau_{oz} \tau_g \tau_w (1-(1-w_0)(1-m+m^{1.06})(1-\tau_A)) \frac{0.5(1-\tau_R)}{1-m+m^{1.06}}$$

- **Aerosol scattering**

$$S_A = 0.79 s_0 \tau_{oz} \tau_g \tau_w \left(\frac{\tau_A}{1-(1-w_0)(1-m+m^{1.06})(1-\tau_A)}\right) \times \frac{f_c}{1-m+m^{10.6}} \left(1 - \frac{\tau_A}{(1-(1-w_0)(1-m+m^{1.06})(1-\tau_A)\tau_R}\right)$$

- **Multiple scattering**

$$S_M = (S_{dir} + S_R + S_A) \frac{\rho_g \rho_a}{1-\rho_g \rho_a}$$

ρ_g is ground albedo and ρ_a atmospheric albedo respectively

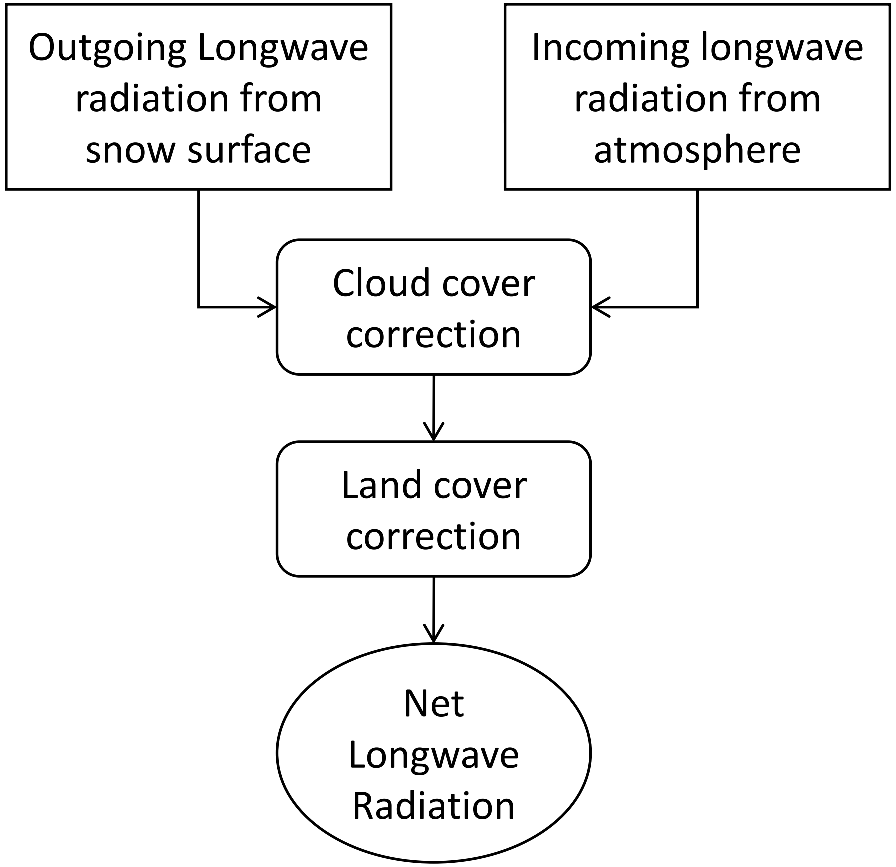
$$\rho_a = 0.0685 + (1 - f_c)(1 - \frac{\tau_A}{1-(1-w_0)(1-m+m^{1.06})})$$

w_0 *is single scattering albedo assumed as 1*

f_c *is ratio of forward to backward scattering calculated as* $f_c = 0.9302 \cos(\theta_s)^2$

Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Longwave Radiation



Incoming Longwave Radiation

$$LW_{in} = \sigma * \varepsilon_{air} * T_{air}^{4}$$

σ Stefan Boltzmann Constant ($5.67 \times 10^{-8} Wm^{-2}K^{-4}$)

ε_{air} Emissivity of air

T_{air} Air Temperature

Outgoing Longwave Radiation

$$LW_{out} = \sigma * \varepsilon_{snow} * T_{lst}^{4} + (1-\varepsilon_s) LW_{in}$$

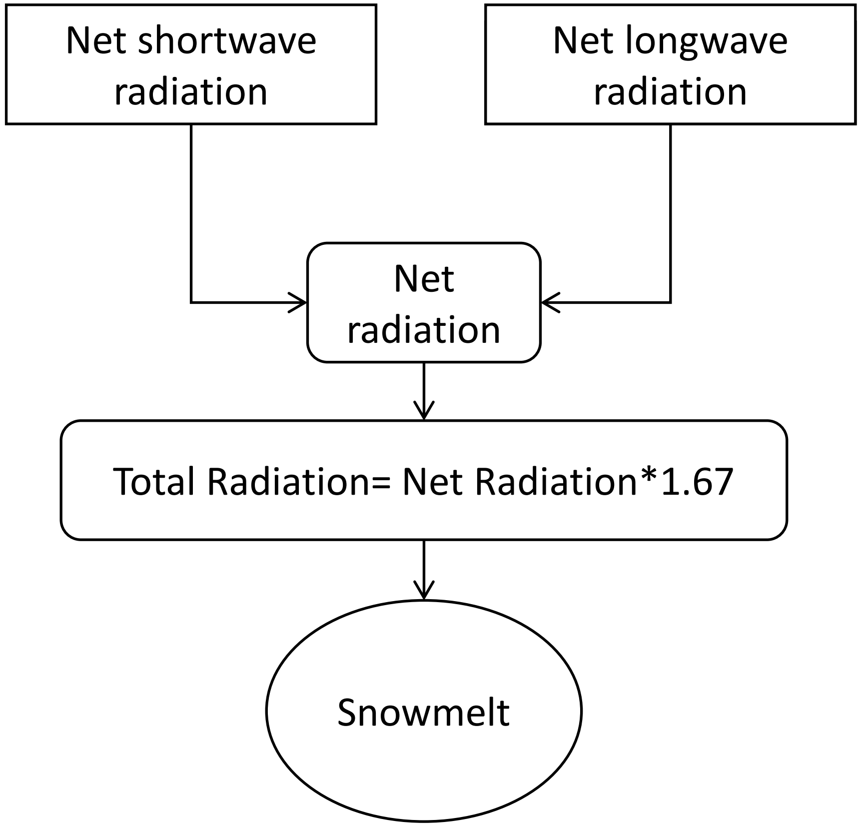
σ Stefan Boltzmann Constant ($5.67 \times 10^{-8} Wm^{-2}K^{-4}$)

ε_{snow} Emissivity of snow

T_{lst} Snow Surface Temperature

Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Methodology for Snowmelt Calculation



$$M = \frac{Q_m}{334.9 * \rho_w * B}$$

M	Depth of Snowmelt (mm)
Q_m	Total Energy available at snowpack for snowmelt (kJ/m2)
B	thermal quality of the snow (ratio of heat required to melt a unit weight of the snow to that of ice at 0 degree Celsius).
ρ_w	Density of water kg/m3.
334.9	Latent heat of fusion of ice kJ/Kg

Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Input Data

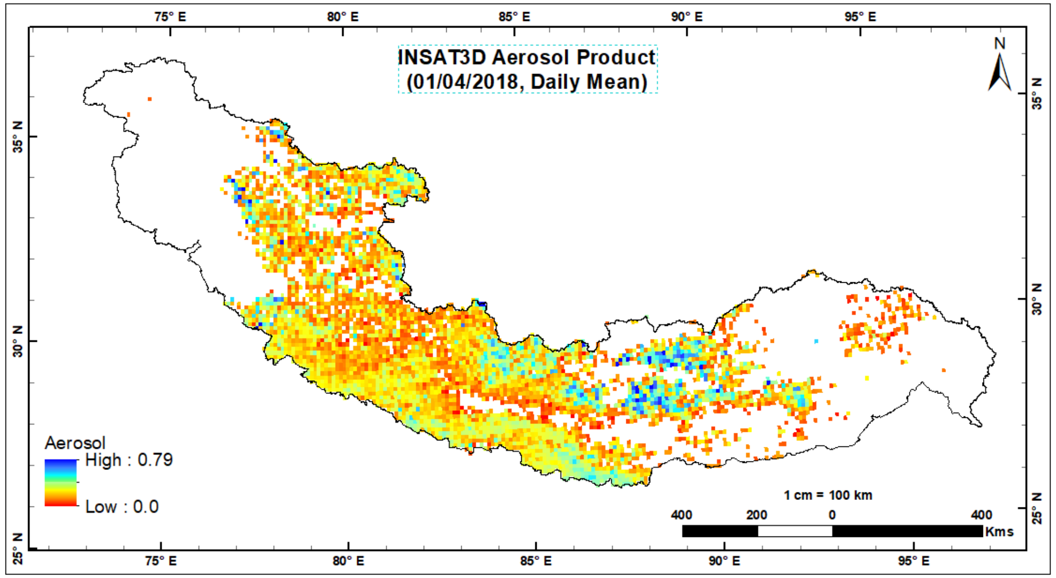
- AOD, WV & Ozone - INSAT-3D
- Snow Cover Area (SCA) - Suomi-NPP satellite data
- Snow Albedo (α) - Suomi-NPP satellite data
- Land Surface Temperature (LST) - Suomi-NPP satellite data
- Glacier Cover Area (GCA) - ICIMOD, RGI and GLIMS
- Incoming Solar Radiation (SR) - SRTM DEM - f(elevation,slope,aspect,Julian day, lat.)
- Land Cover - Mapped with AWiFS satellite data

- Field measured discharge, Rainfall data

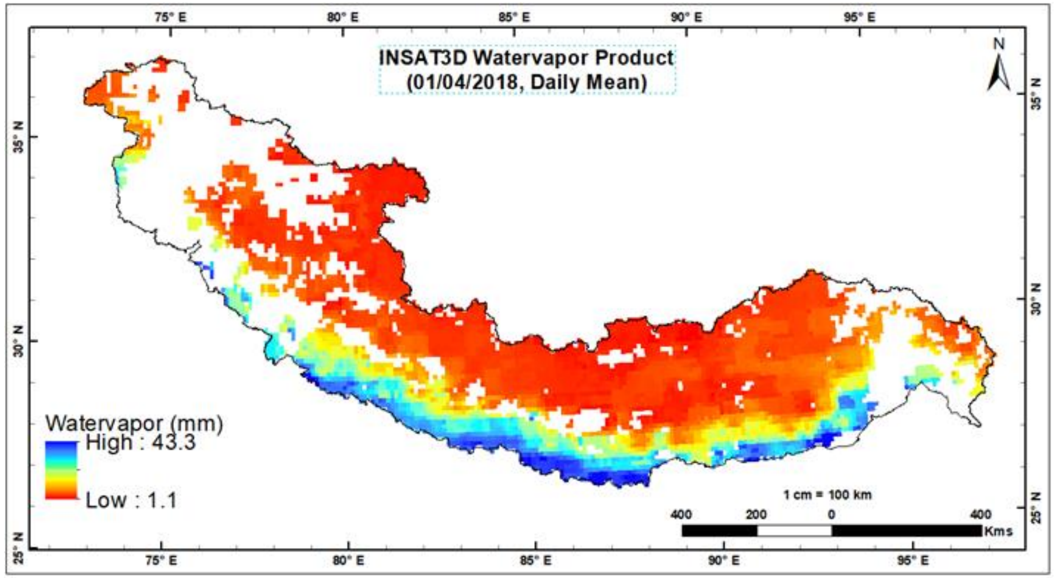
Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Input Data

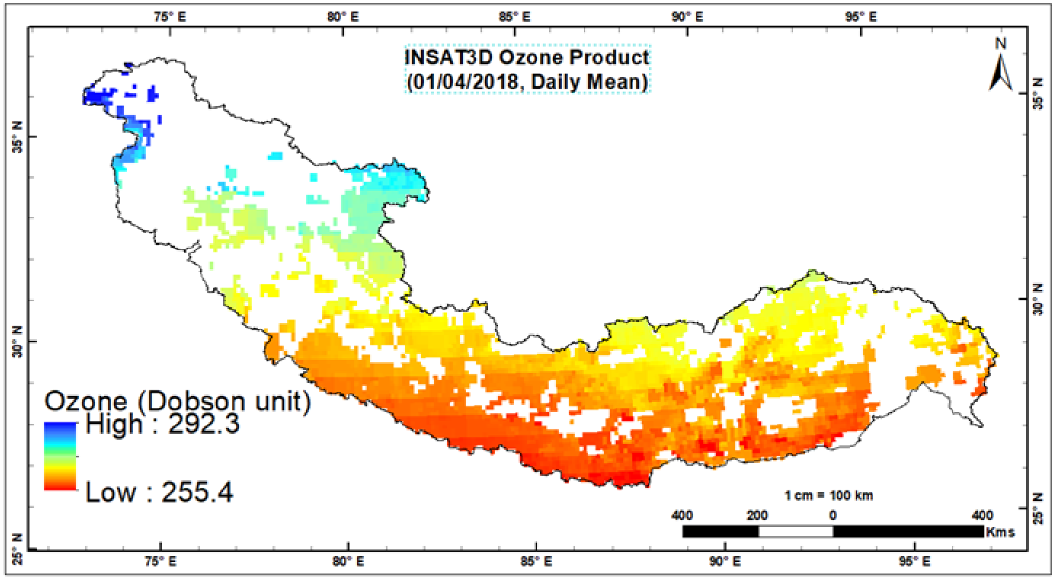
INSAT 3D Aerosol Optical Depth
(April 1, 2018)



INSAT 3D Water Vapor column
(April 1, 2018)



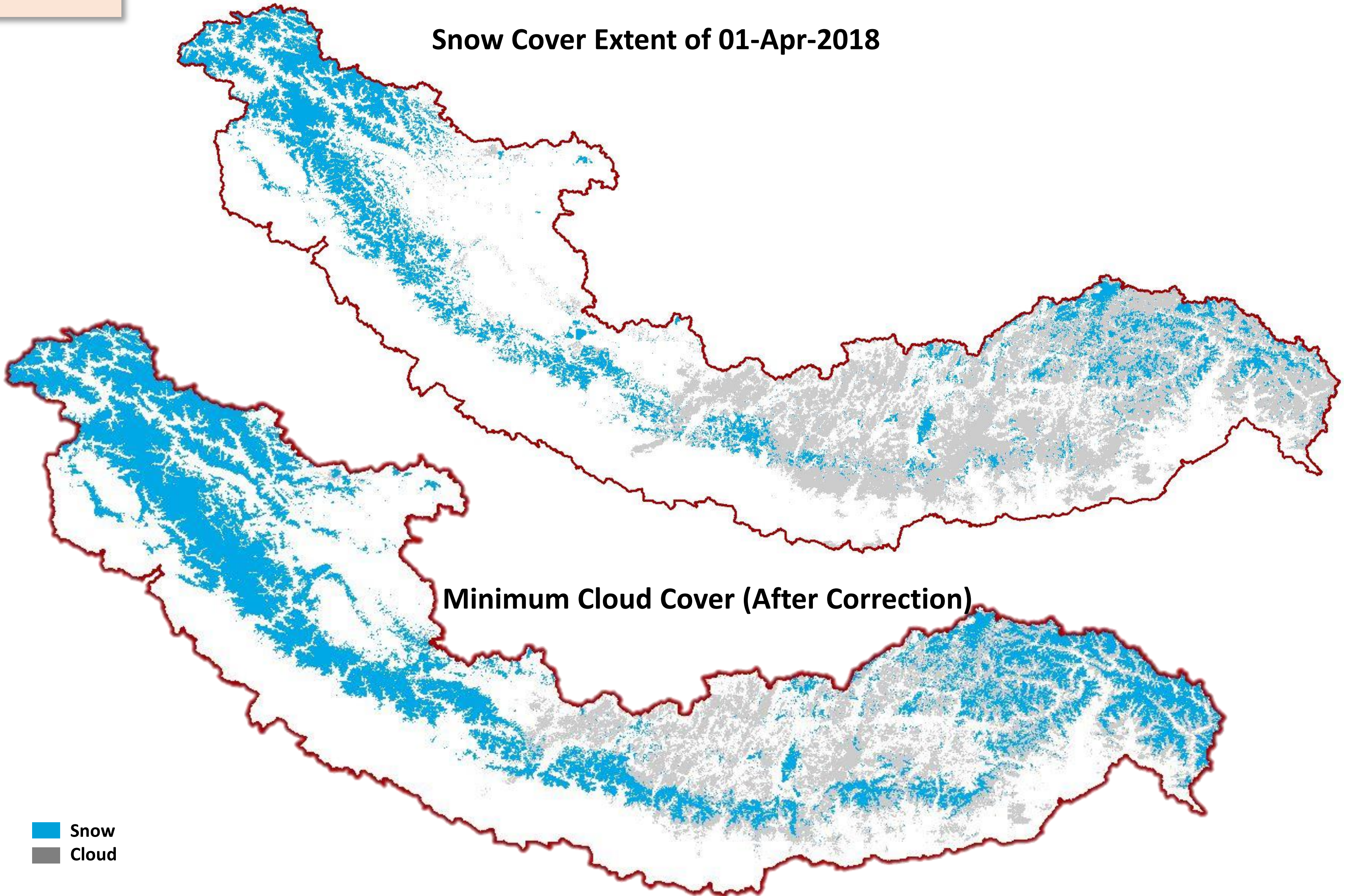
INSAT 3D Ozone
(April 1, 2018)



Data	Specifications
AOD, WV, O	11 Km X 11Km Half Hourly

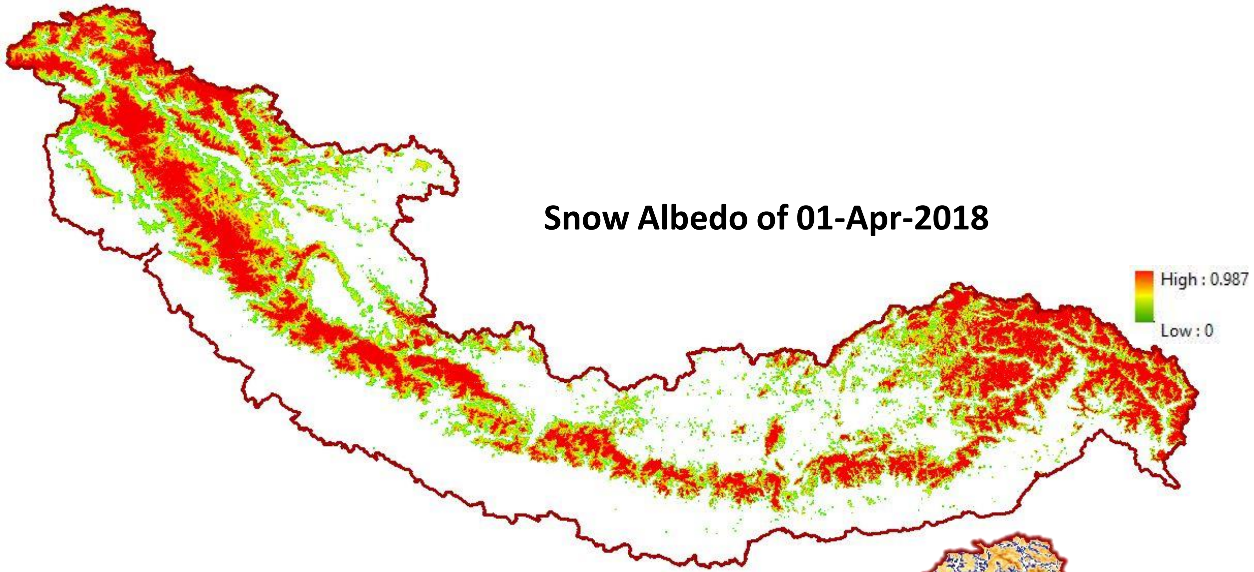
Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Snow Cover Extent

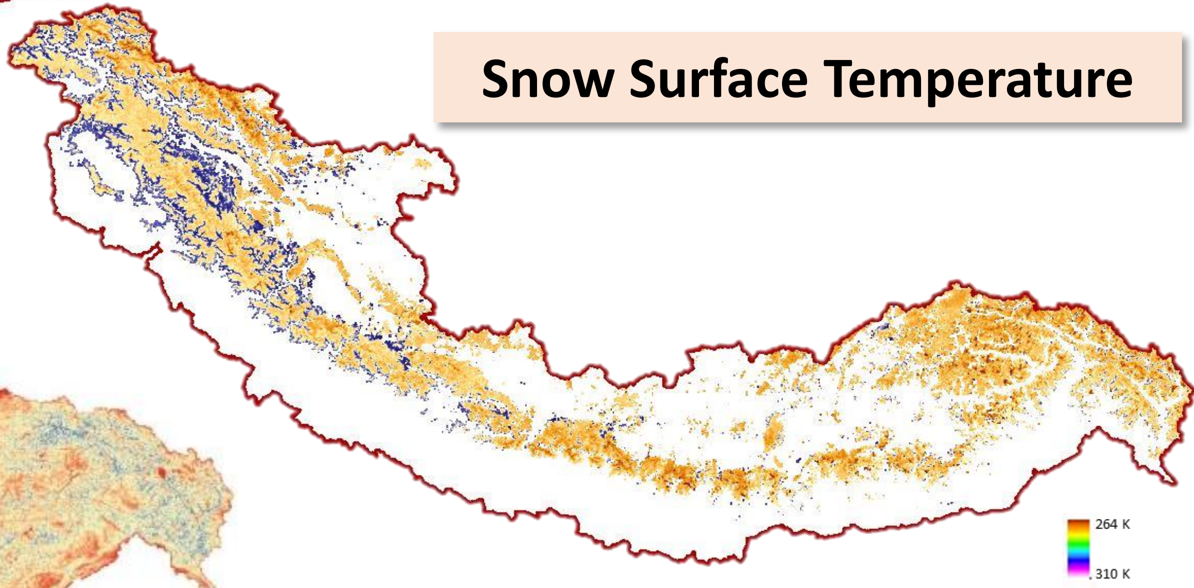


Development of Snowmelt Model for Himalayan region using Energy Balance Approach

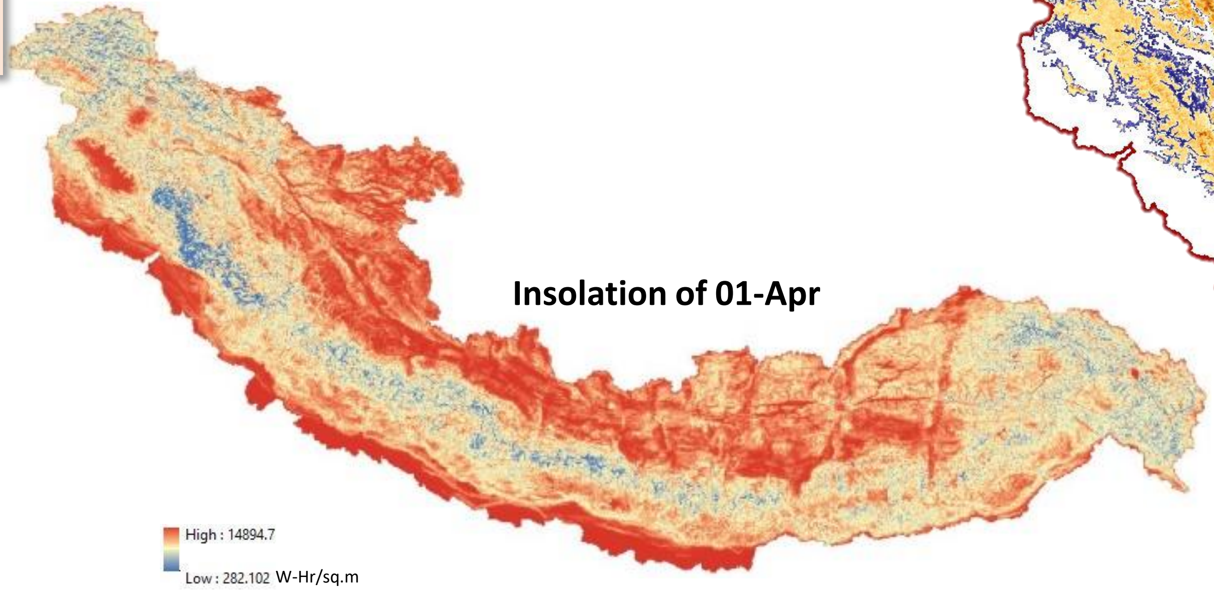
Snow Albedo



Snow Surface Temperature



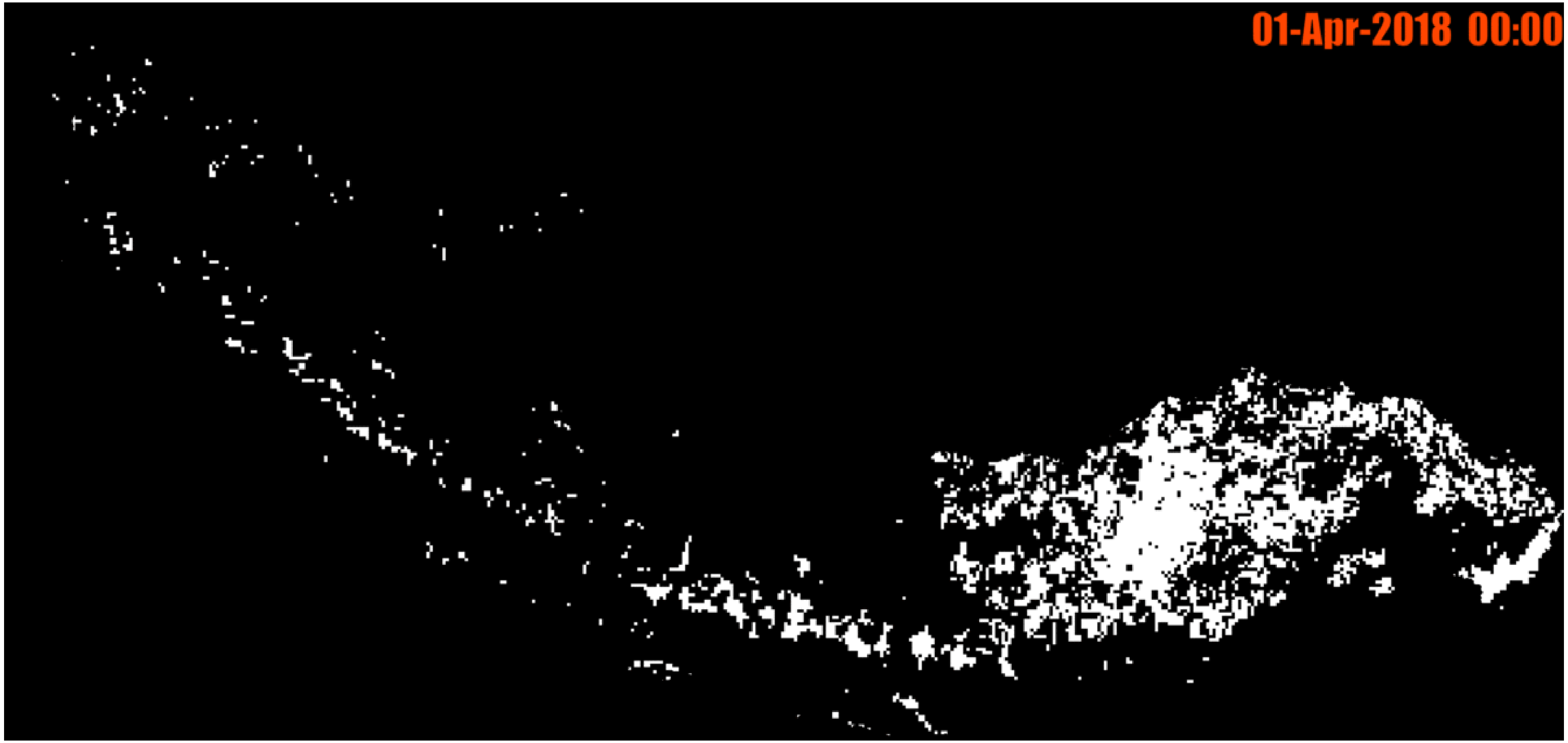
Insolation



Development of Snowmelt Model for Himalayan region using Energy Balance Approach

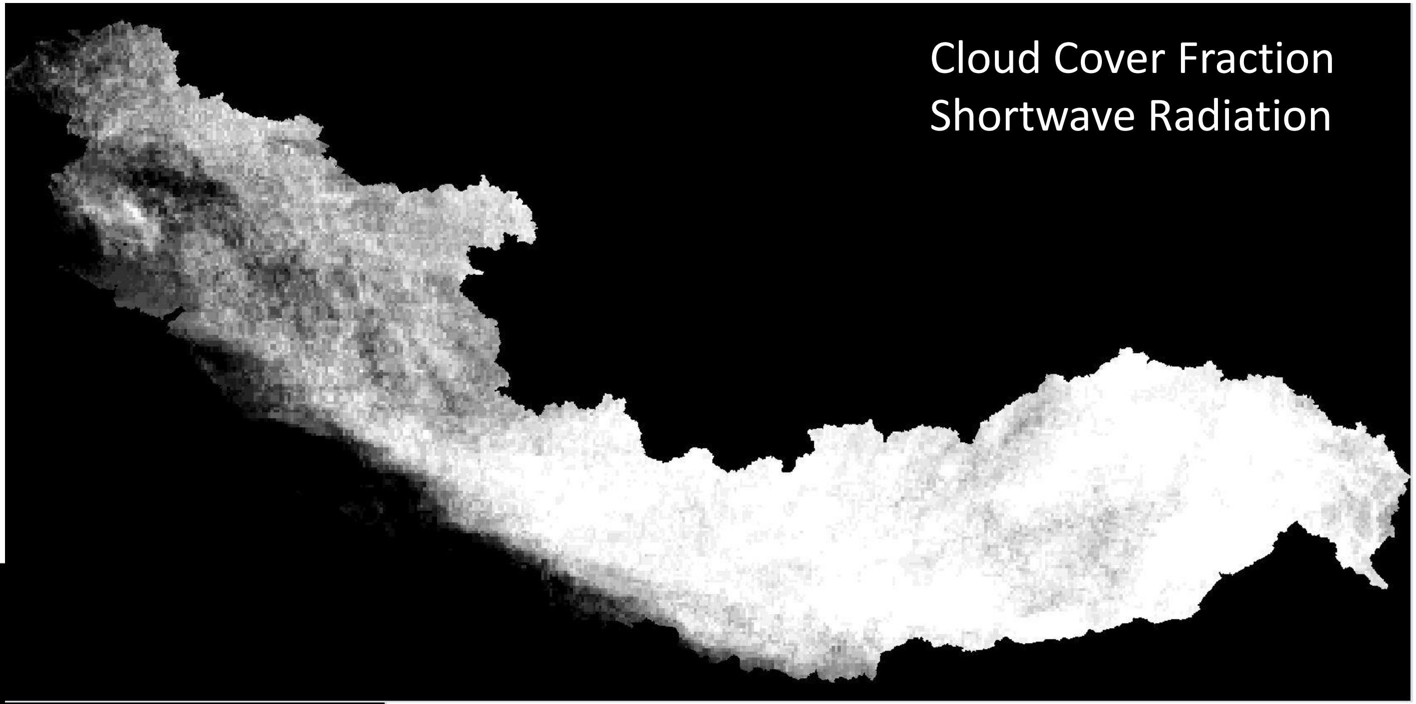
Cloud Cover

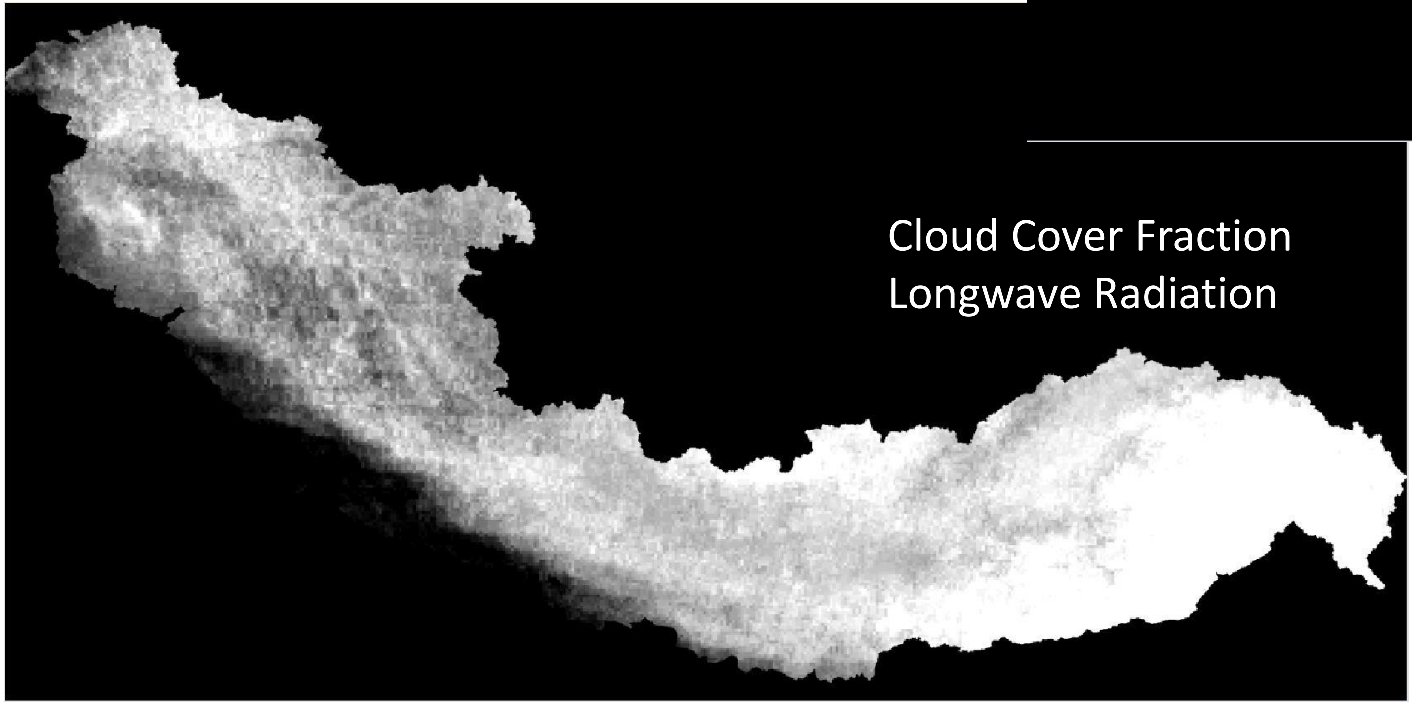
Half-hourly INSAT-3D cloud cover images of 01-Apr-2018



Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Cloud cover

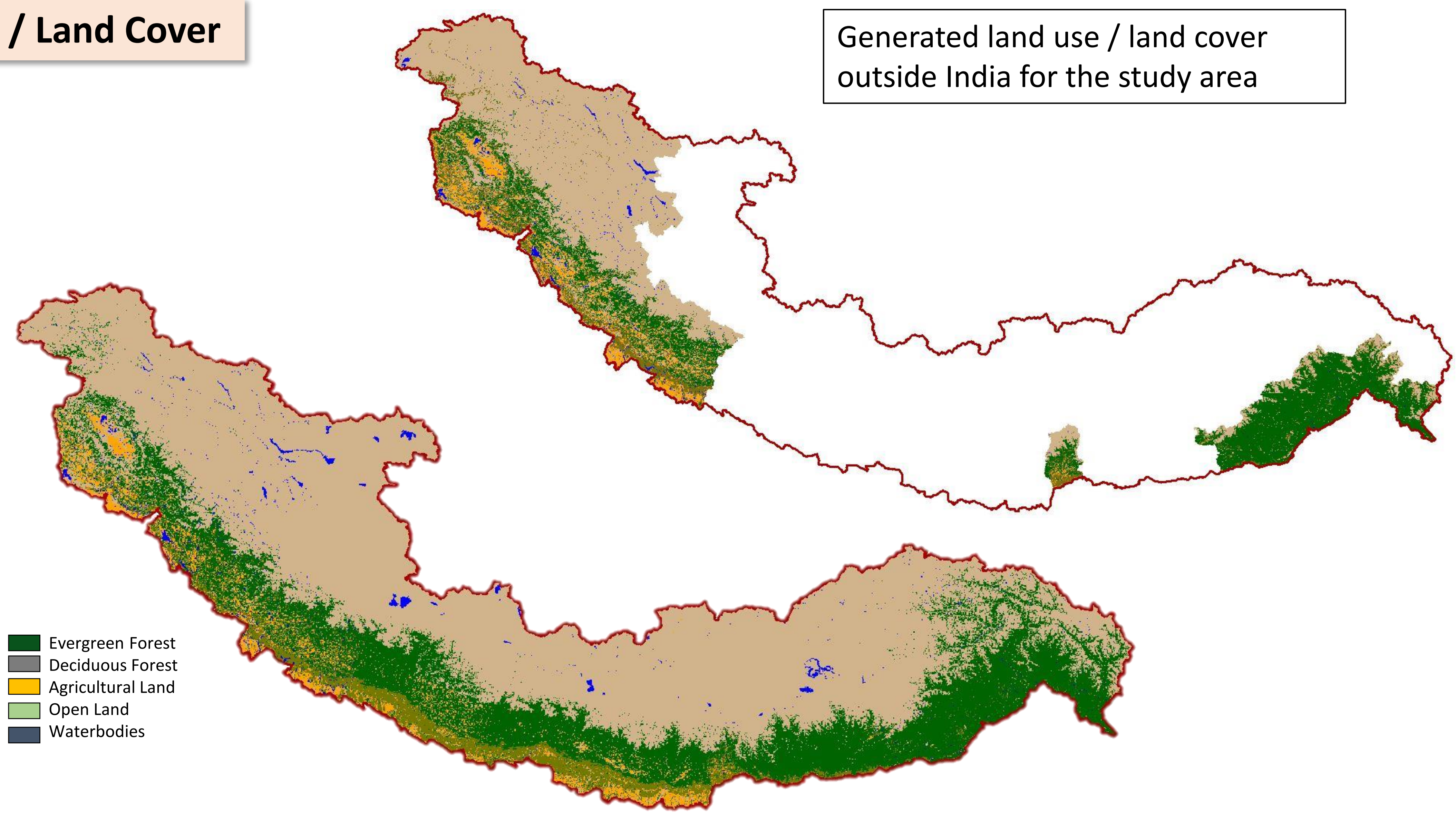




Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Land Use / Land Cover

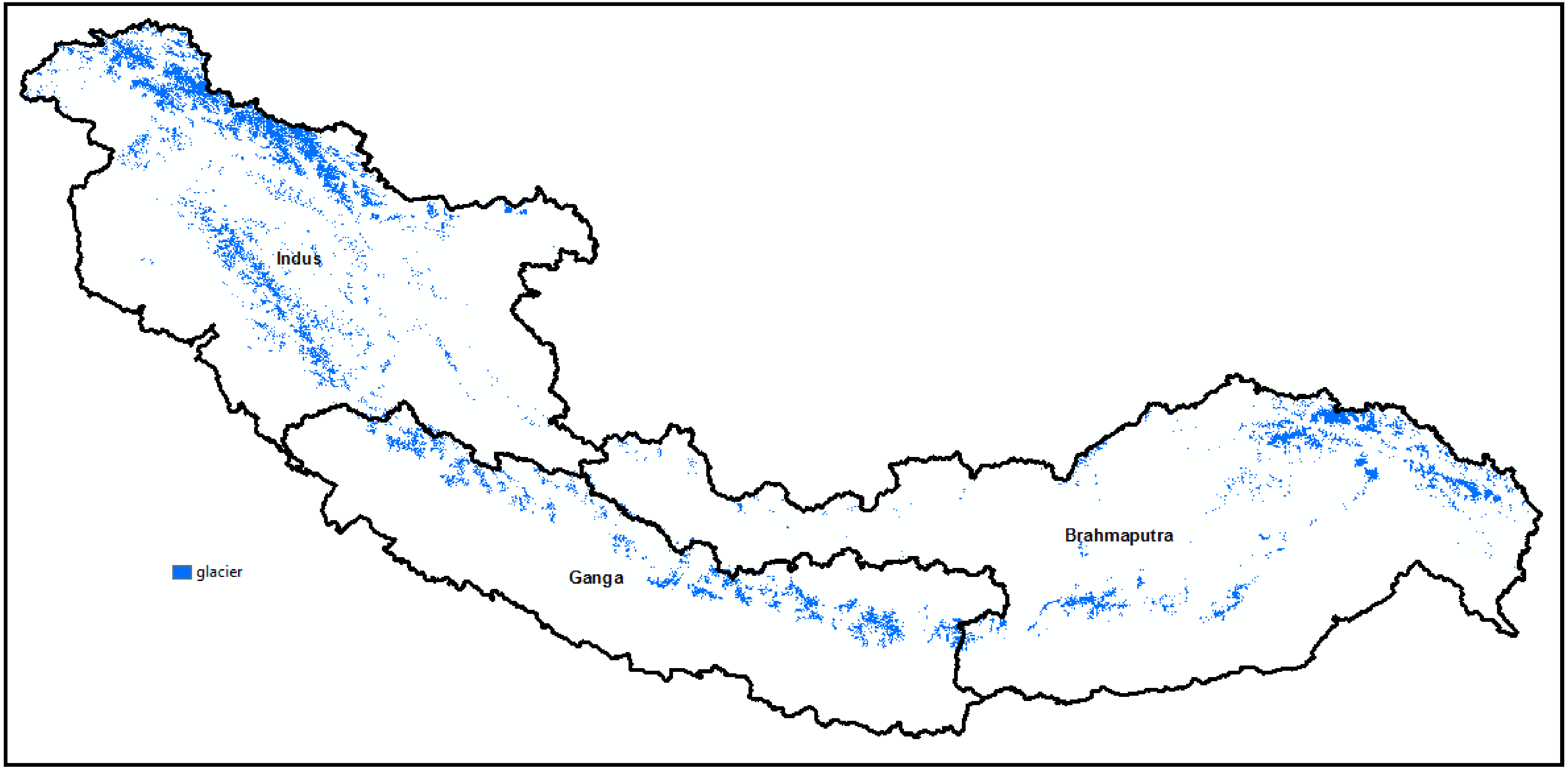
Generated land use / land cover outside India for the study area



Development of Snowmelt Model for Himalayan region using Energy Balance Approach

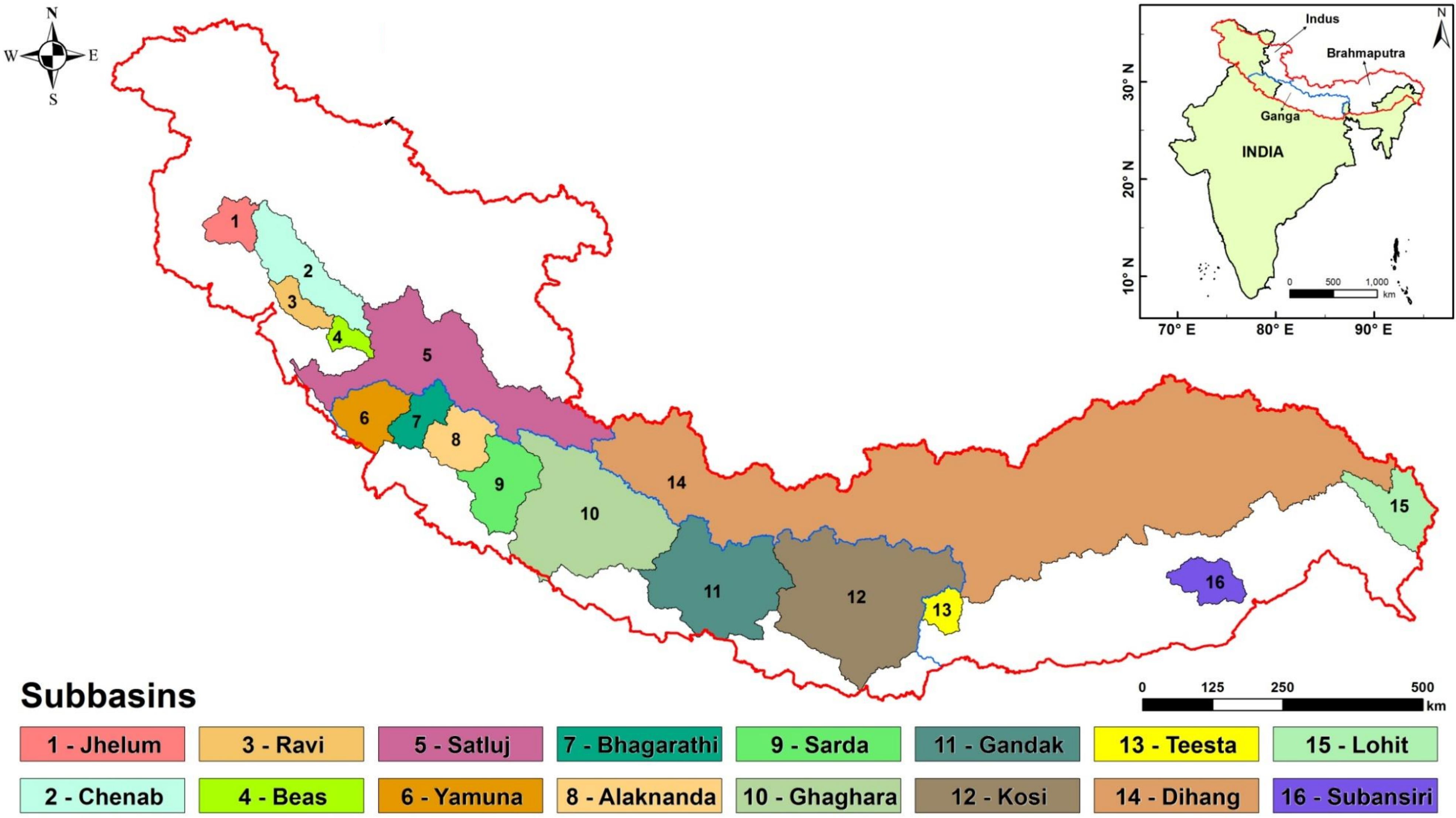
Glaciers

Glaciers mapped from ICIMOD, RGI and GLIMS for Indian Himalayas region



Development of Snowmelt Model for Himalayan region using Energy Balance Approach

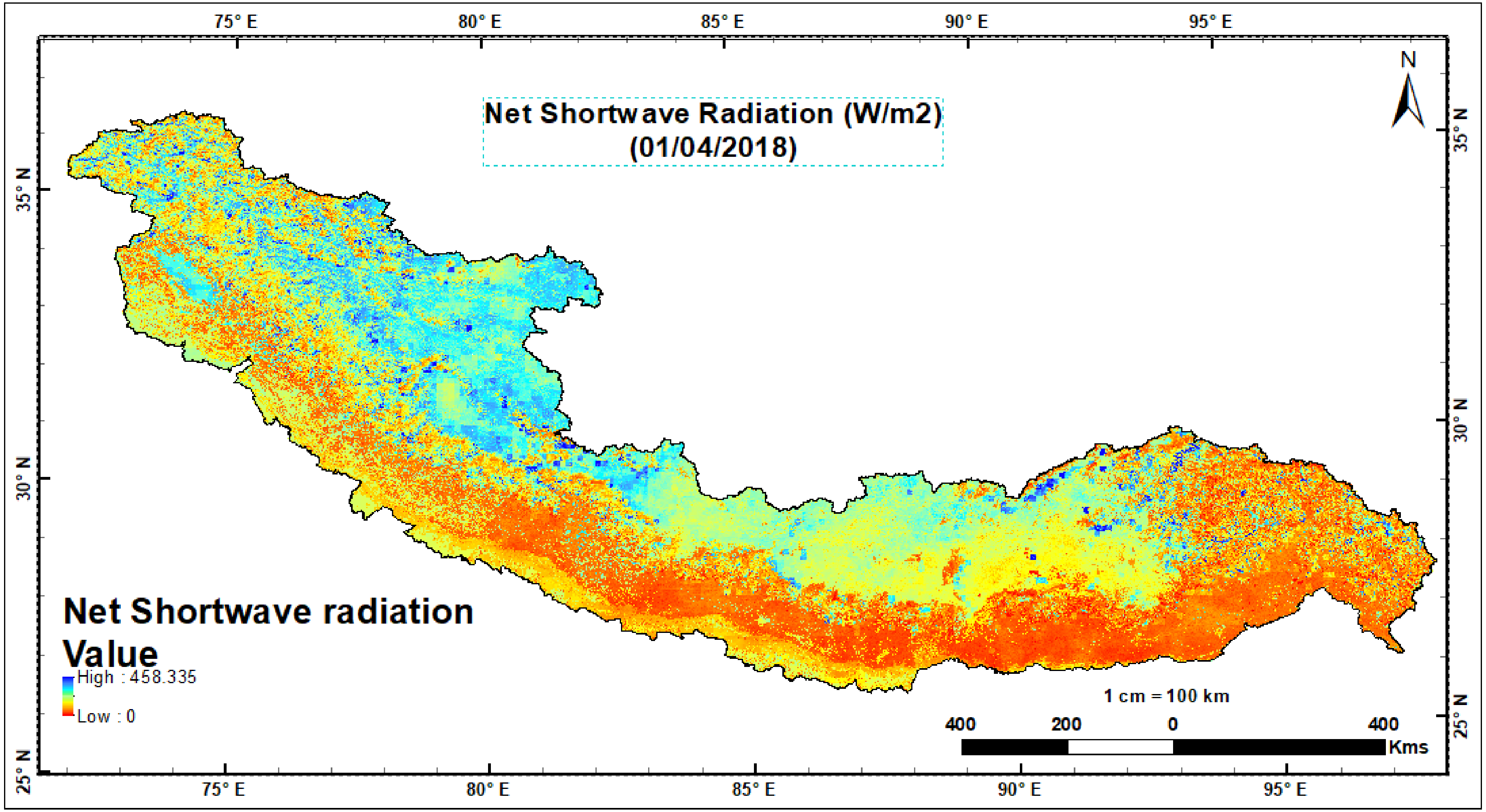
S.No	River	River Basin outlet
1	Jhelum	Sangam
2	Chenab	Premnagar
3	Ravi	Chamera Dam
4	Beas	Bhuntar
5	Satlej	Bakra
6	Yamuna	Hatnikund
7	Bhagarathi	Uttarkashi
8	Alaknanda	Rudraprayag
9	Sarda	Banbasa barrage
10	Ghaghara	Girija barrage
11	Gandak barrage	Gandak barrage
12	Kosi	Kosi barrage
13	Teesta	Teesta barrage
14	Dihang	Tuting
15	Lohit	Kibithu
16	Subansiri	Tamen



Development of Snowmelt Model for Himalayan region using Energy Balance Approach

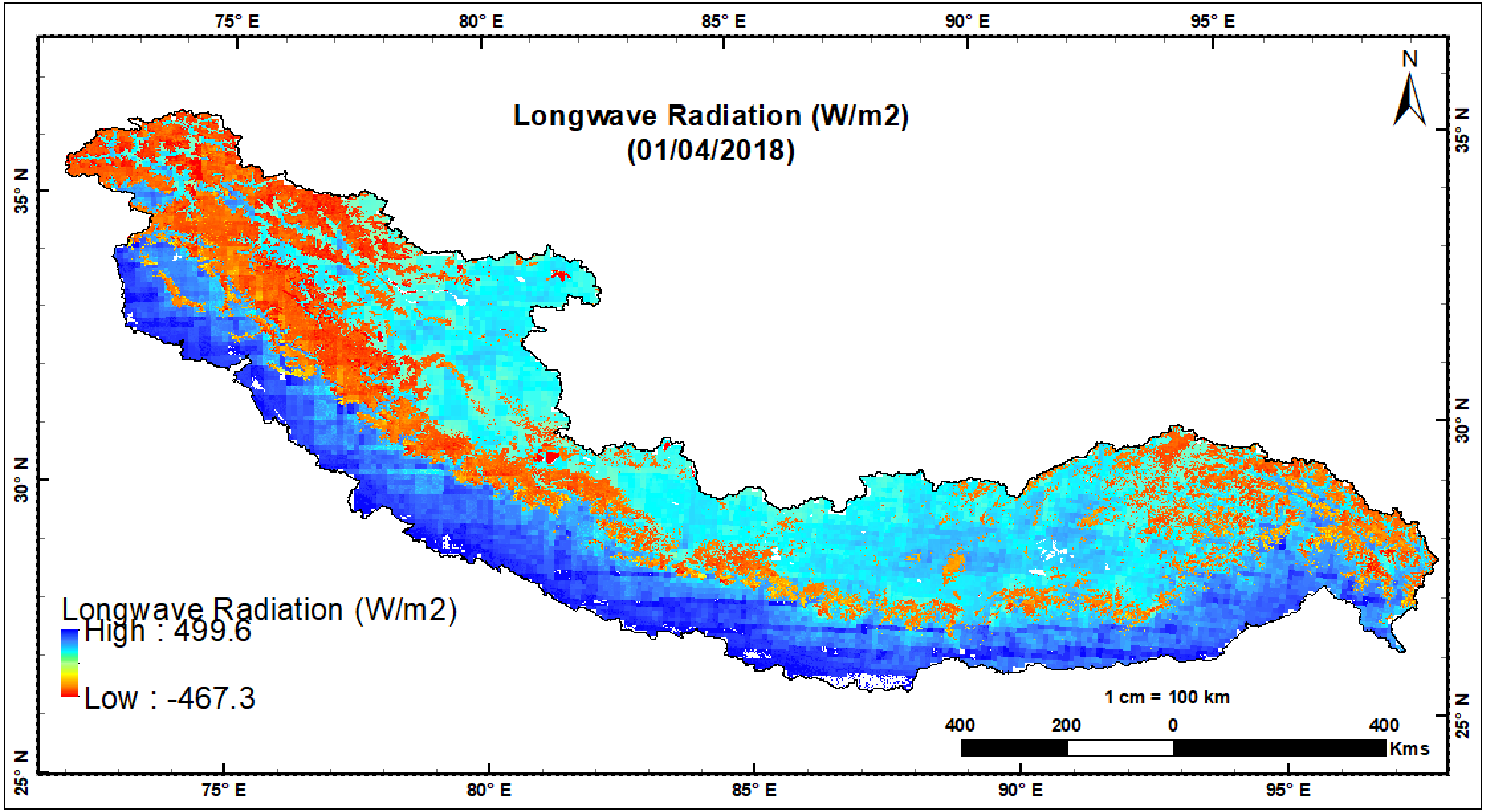
Results

Net Shortwave Radiation



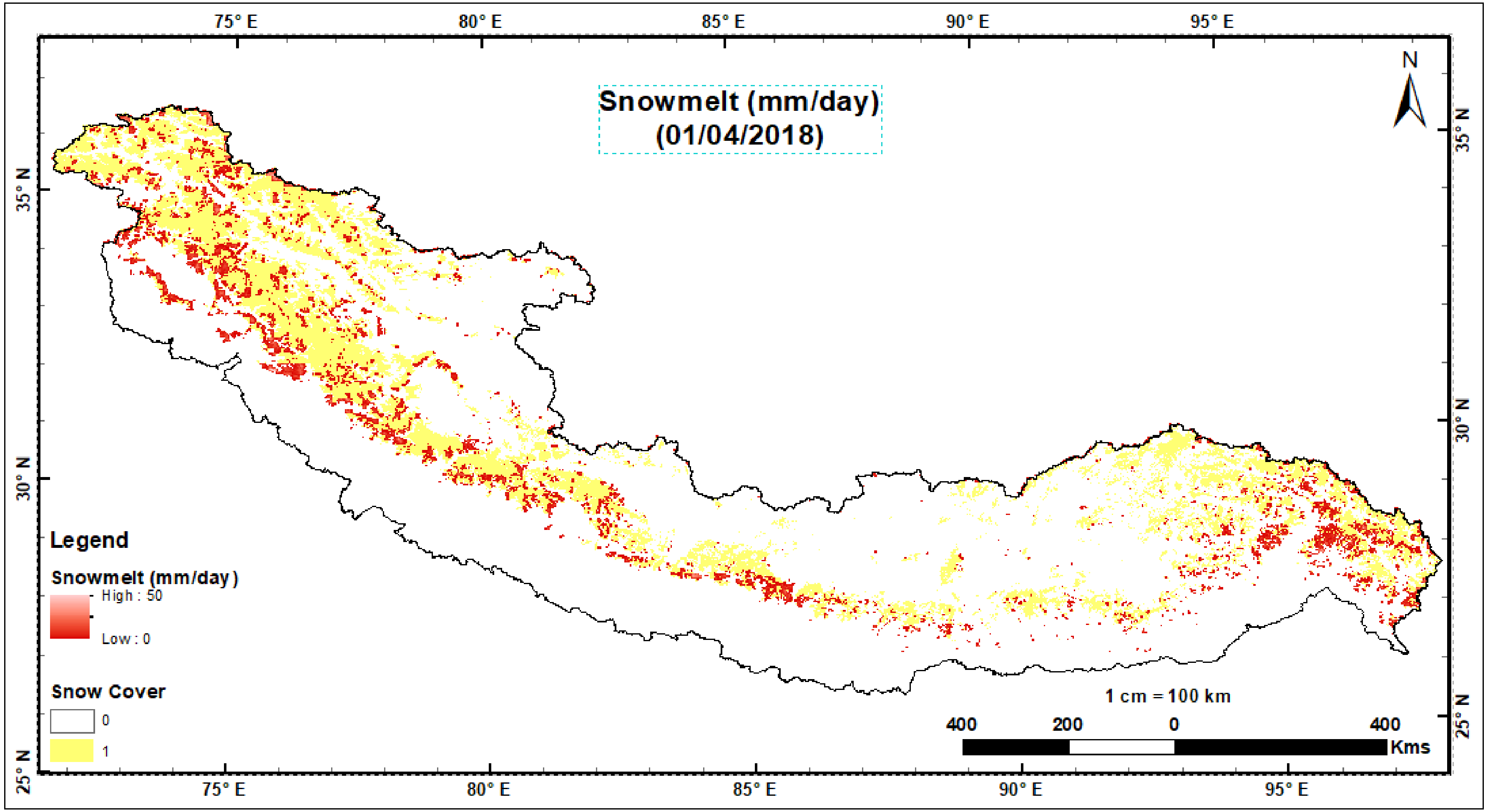
Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Net longwave Radiation



Development of Snowmelt Model for Himalayan region using Energy Balance Approach

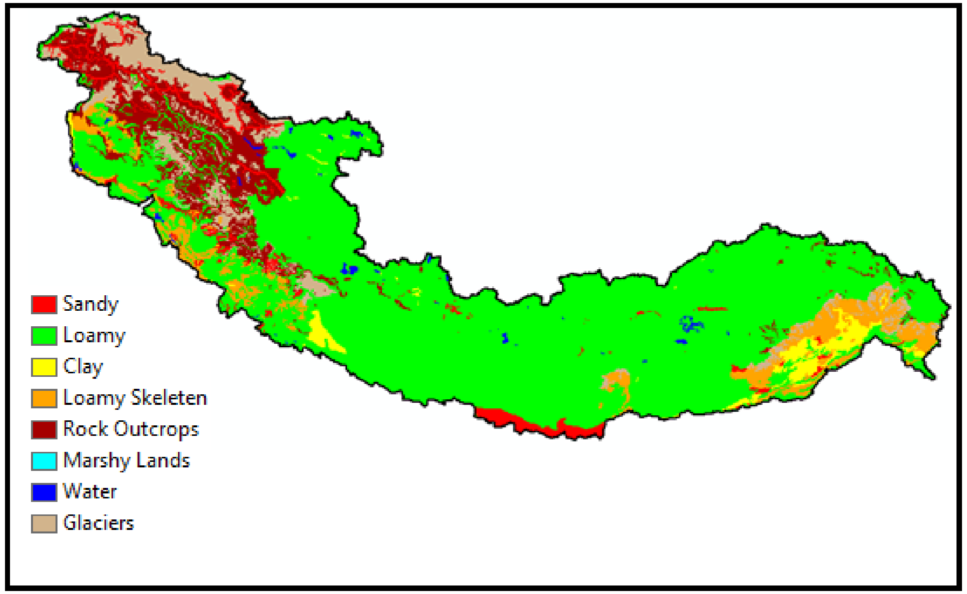
Snowmelt Product

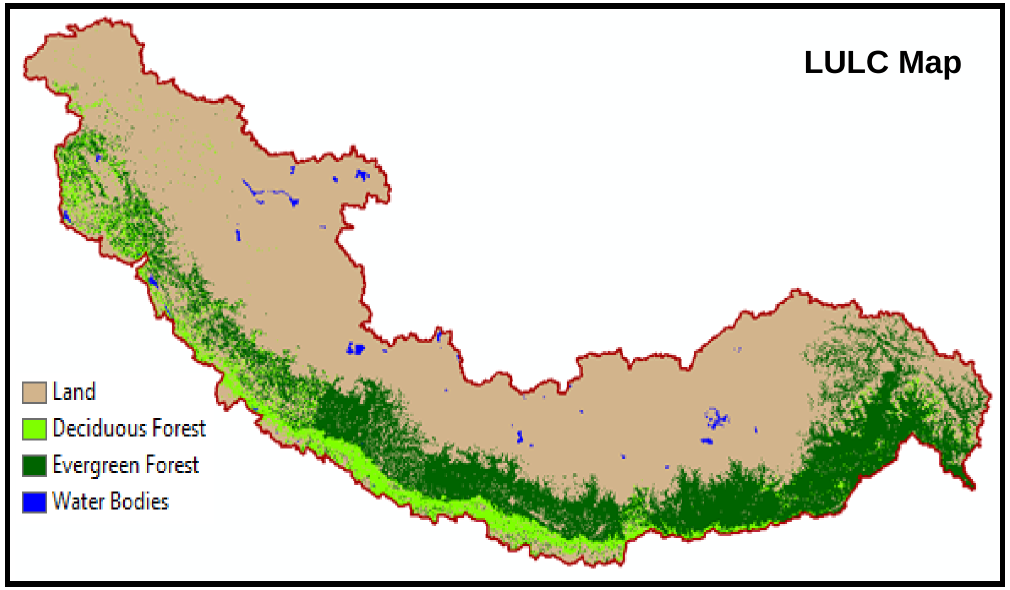


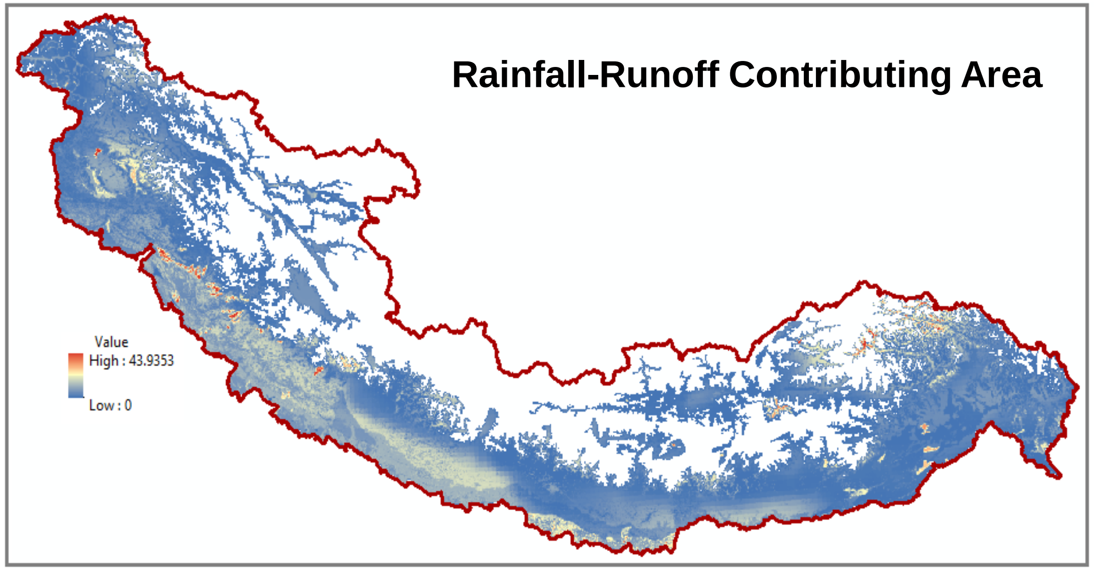
Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Rainfall-Runoff

Slope corrected SCS CN Method



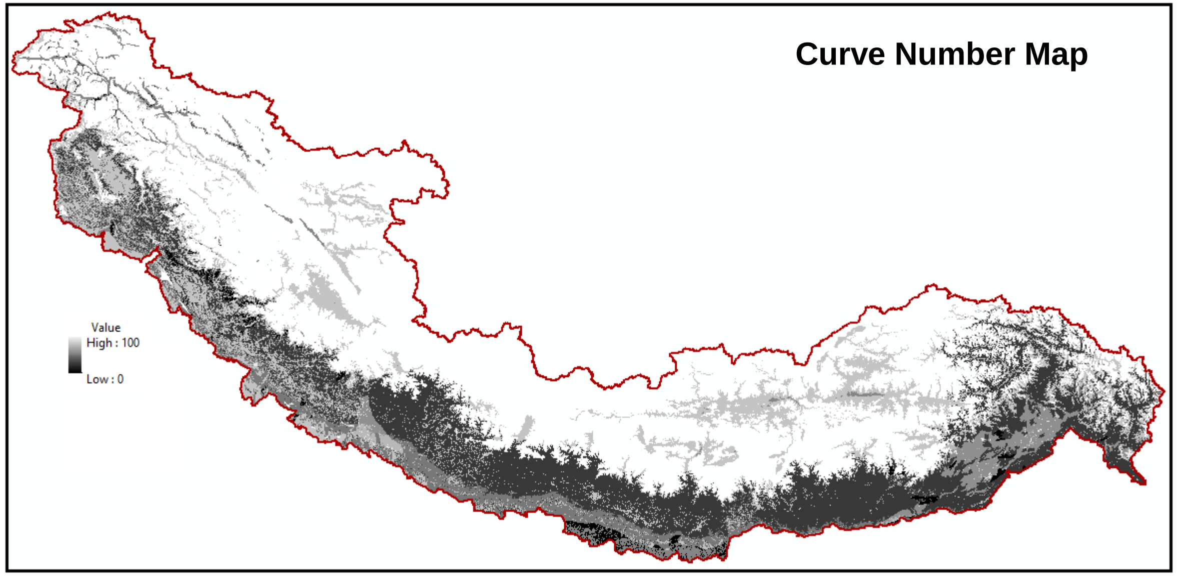


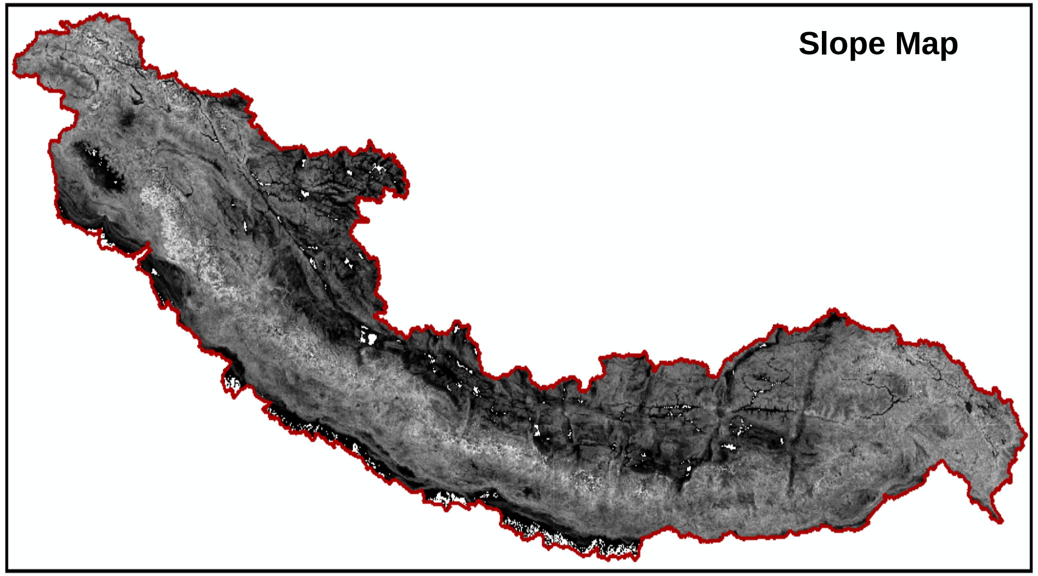


Development of Snowmelt Model for Himalayan region using Energy Balance Approach

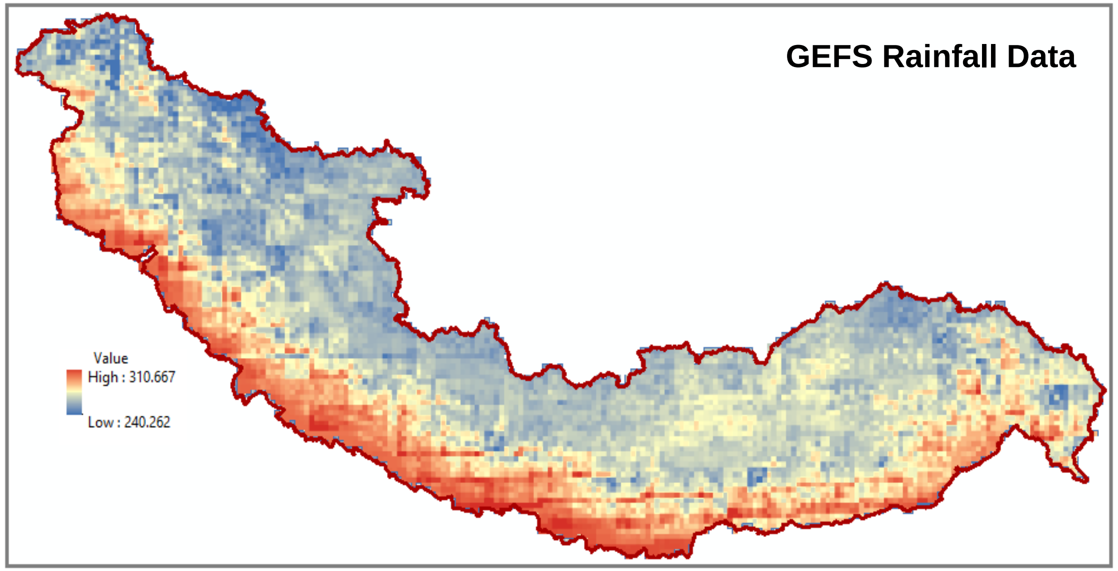
Rainfall-Runoff

Slope corrected SCS CN Method





Rainfall-Runoff Contributing Area



Development of Snowmelt Model for Himalayan region using Energy Balance Approach

Assumptions & Limitations

- SW Radiation and LW Radiation could be estimated and other fluxes could not be estimated.
  For other Energy components, since input data is not available, an assumption was made.
  It is estimated that other components constitute about 40% of total energy input – based on literature
- All components for Atmospheric Transmission effects on SW Radiation is not considered
- Cloud cover type is assumed to be cumulus for its effect on SW radiation
- Assumed suitable coefficients for Land cover classes for estimation of surface Solar radiation
- Assumed suitable relationship between LST and air temperature as a function of elevation.
- Empirical relationship was used to estimate air emissivity as a function of air temperature.
- It is assumed that rain fed area in Himalayan basins is generally below 4500m in elevation.
  The elevation range of the actual rain fed area may be marginally different.
- Glacier melt is assumed to occur from middle of May. However, the level of exposure of glaciers
  may vary temporally and spatially. Year to year this exposure may differ.

Thank You