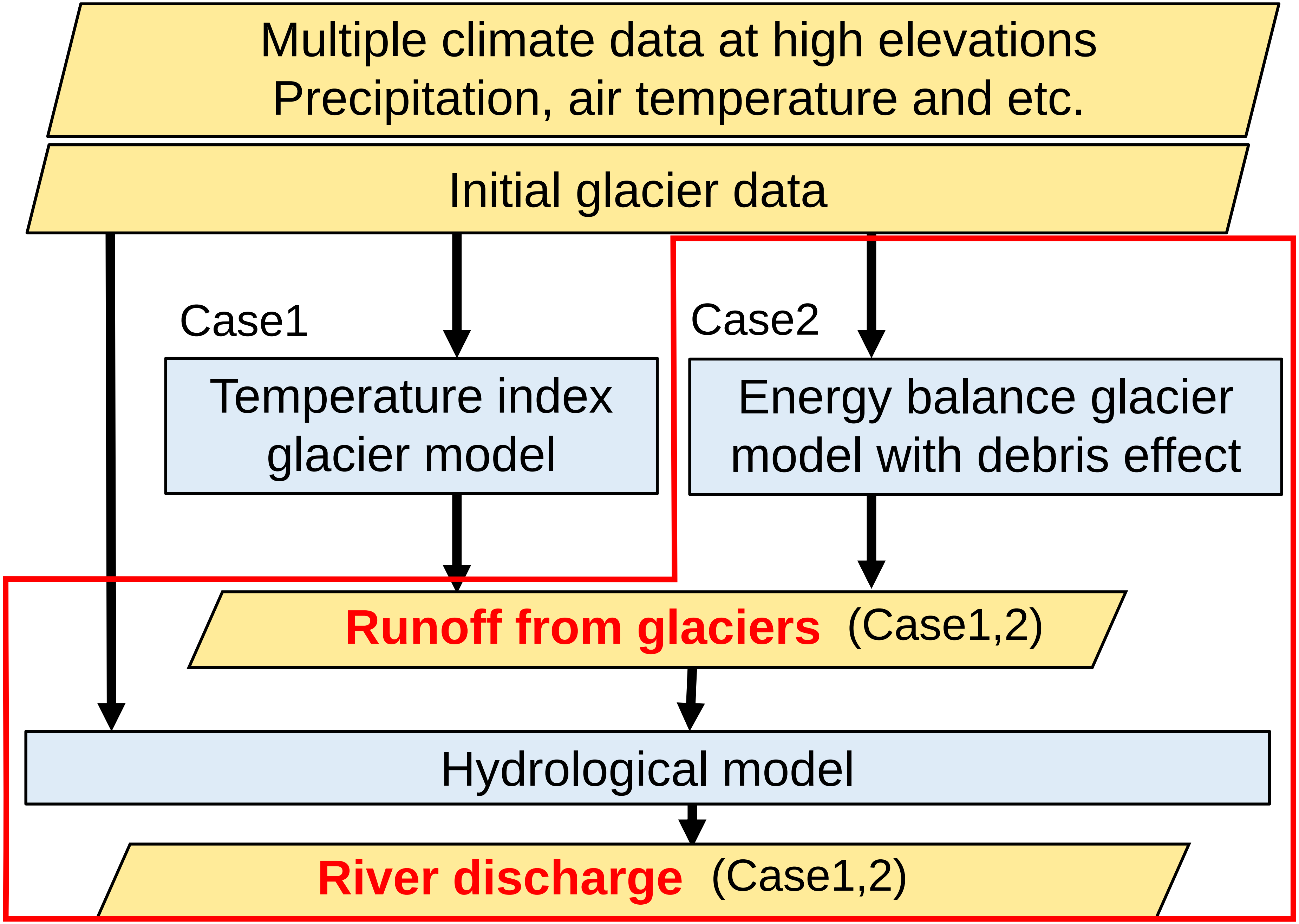
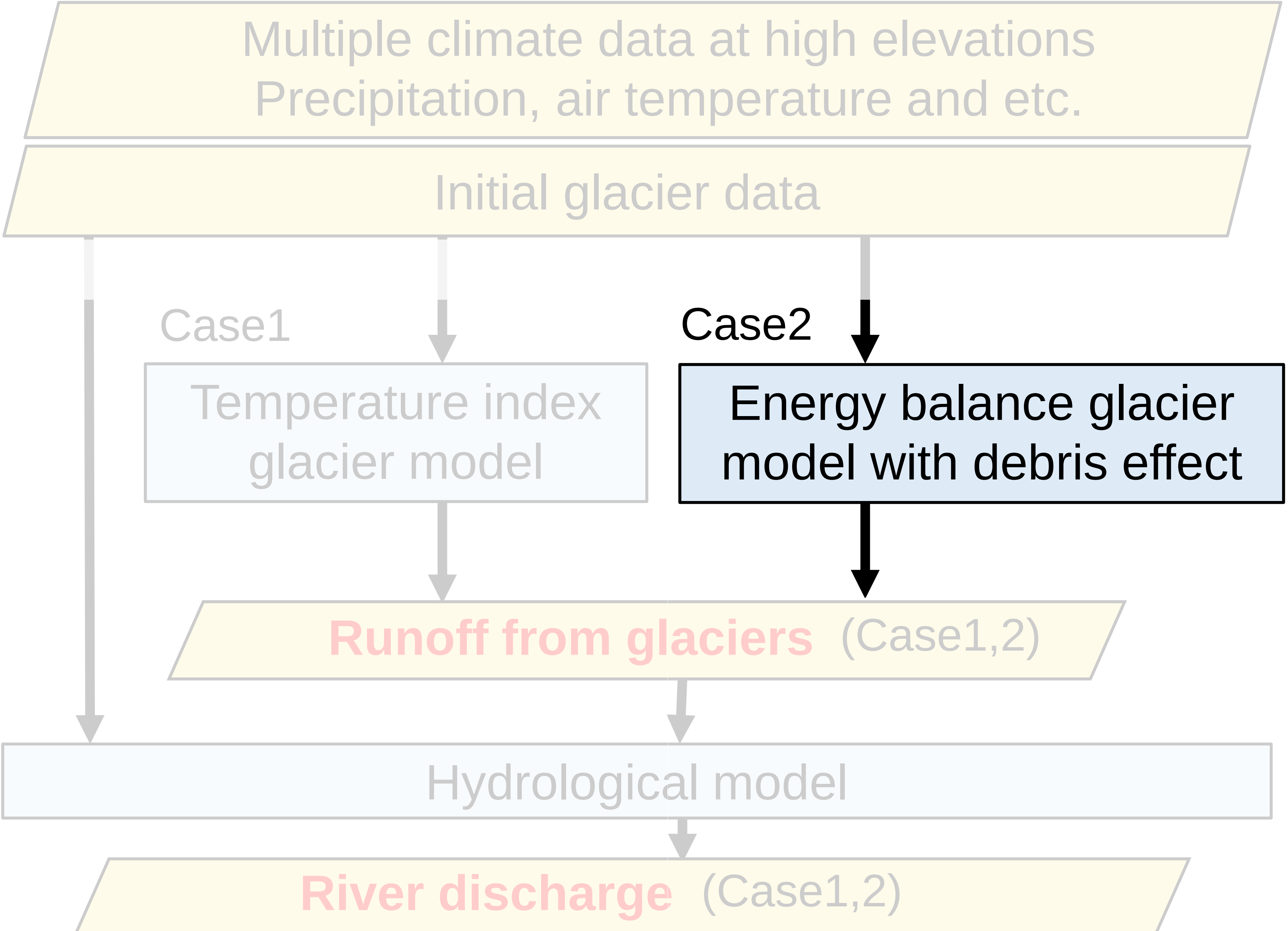
A high resolution glacier model with debris effects in Bhutan Himalaya

Orie SASAKI
Kanae Laboratory
2018/02/08 (Thu)

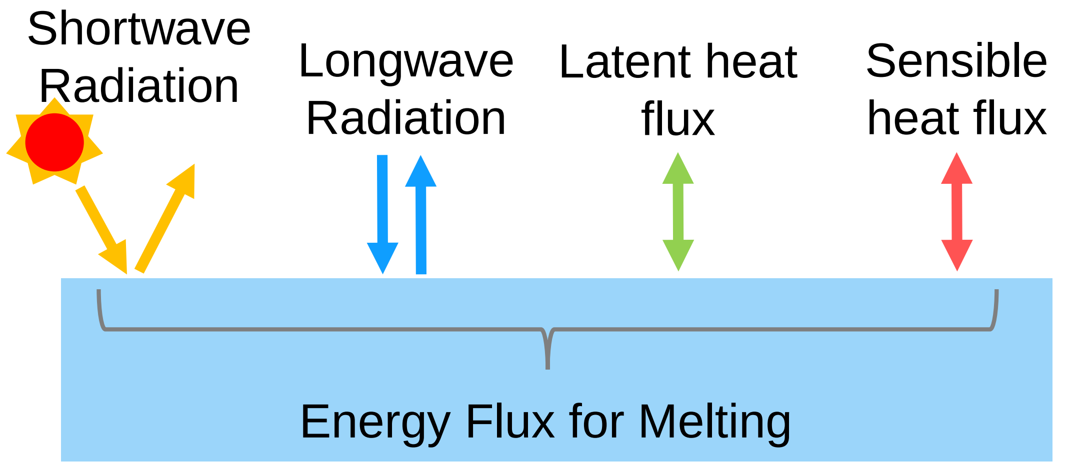
Research flow



Research flow



Energy Balance Model



Debris Effects

Debris on Glaciers

No Debris

Debris covered glacier

Debris
: sand gravel, rocks

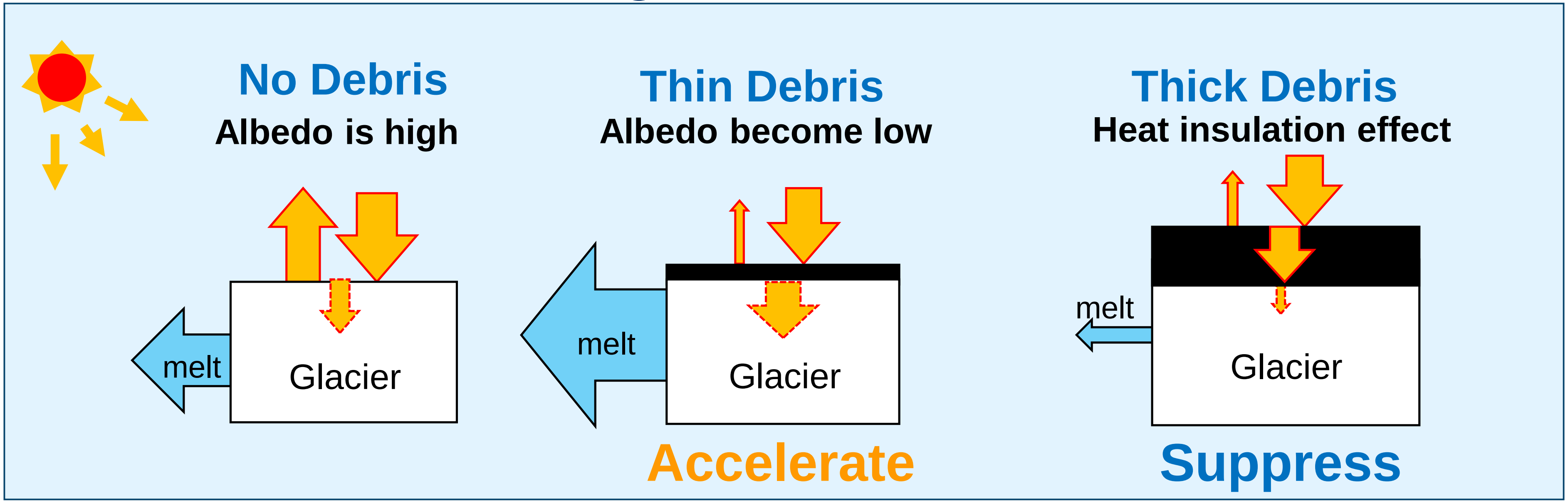
Supraglacial debris affects glacier melting rate significantly.
(e.g. Mattson et al.,1993)

Ex) Rocks inhibits ice melting

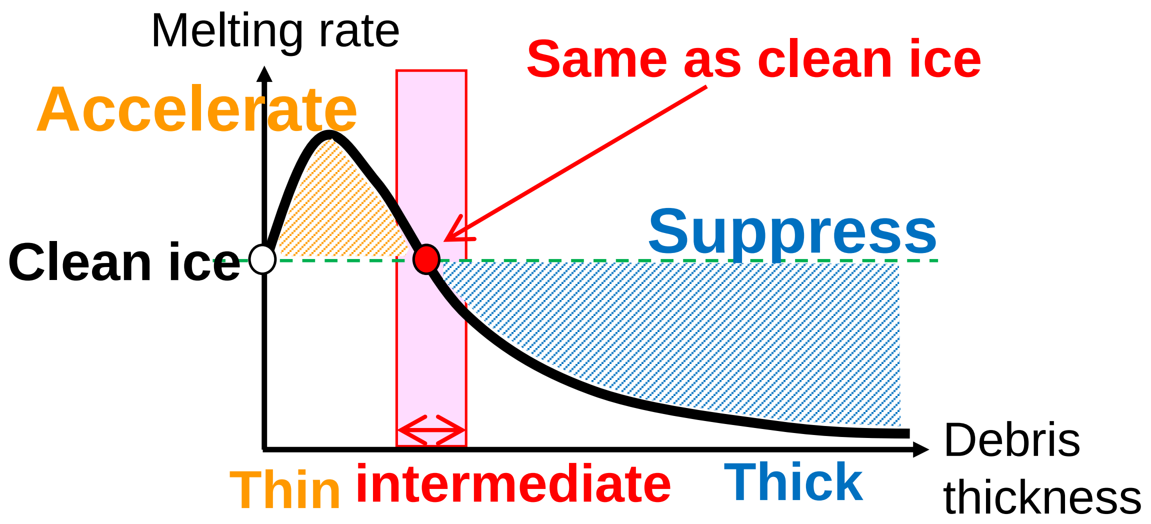
(Photo: ©Florian Mair, 2010)

Debris on Glaciers

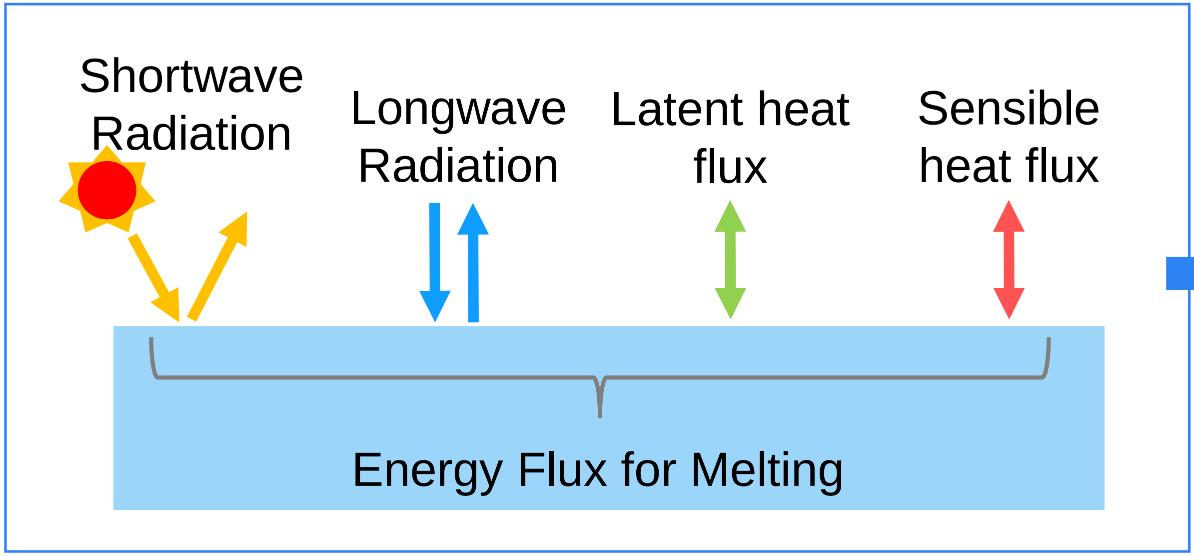
Effects of debris on glacier melts



Debris thickness is important !



Energy Balance Model



+

Debris Effects

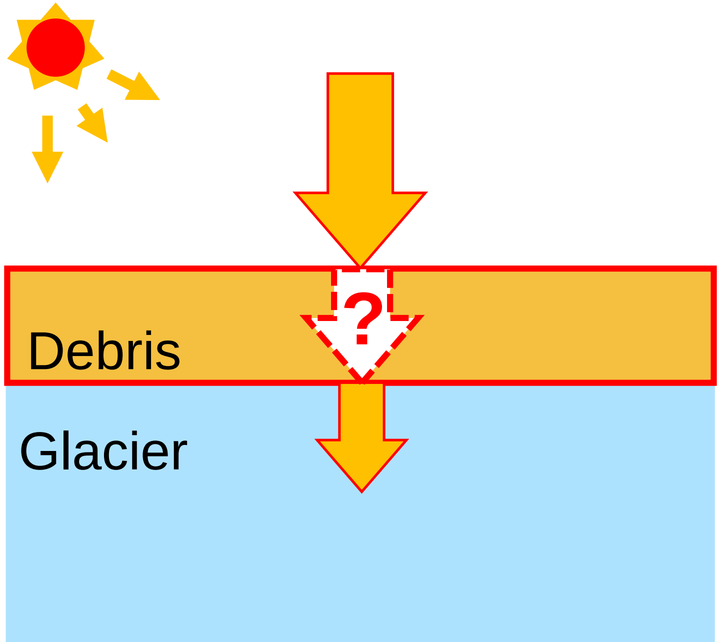
Objective

Estimating glacier melts by a glacier model based on energy balance with debris effects

1. Development of debris information data
2. Model structure

1. Development of debris information data

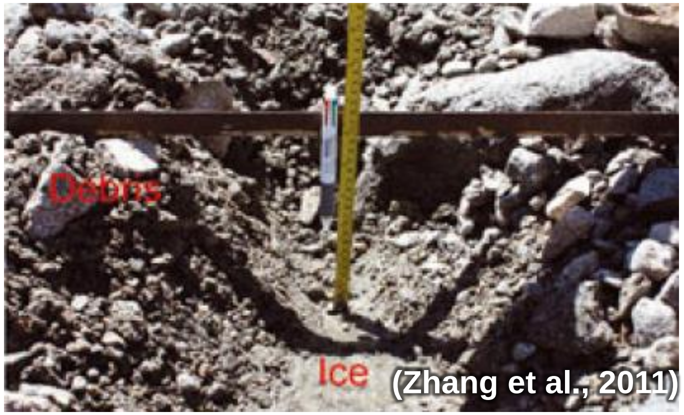
Necessary parameters



To estimate debris effect,

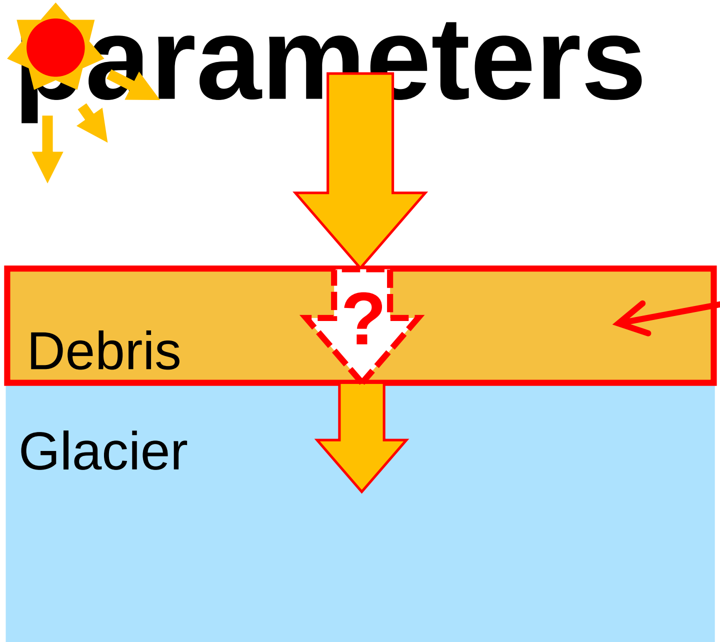
- Thickness [m]
- Thermal conductivity [W m^{-1} K^{-1}]

Ground observation is the only way



It is unrealistic to measure these parameters on a large scale.

How to get necessary parameters

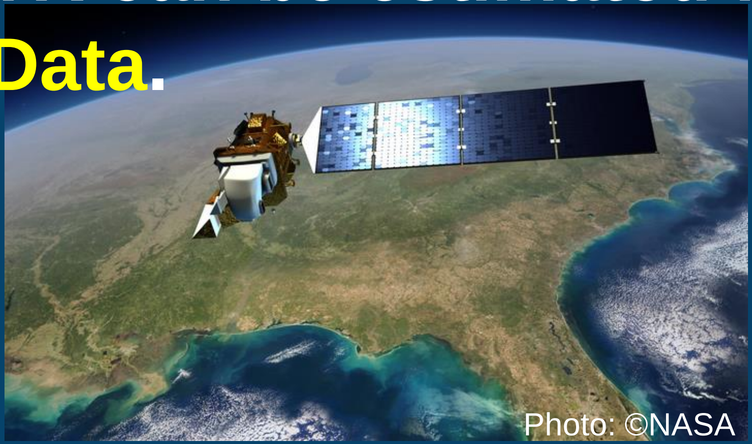


Thermal resistance (TR)
of debris layer [$m^2\ K\ W^{-1}$]

$$TR = \frac{\text{debris thickness}}{\text{thermal conductivity}}$$

（Nakawo and Young, 1981, 1982)

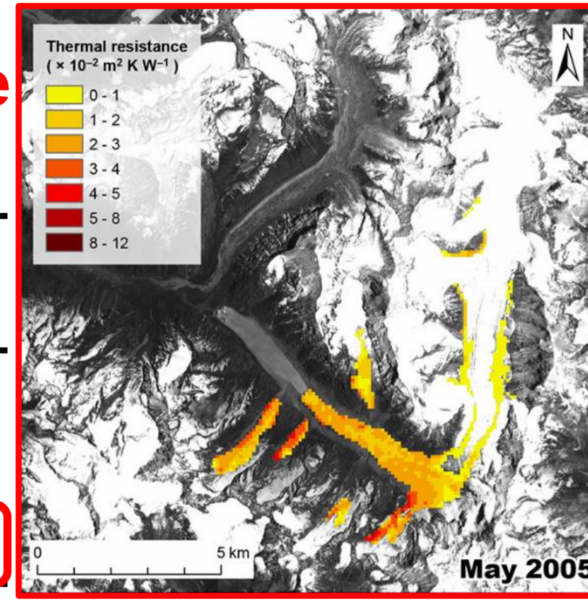
TR can be estimated from Satellite Data.



Previous study

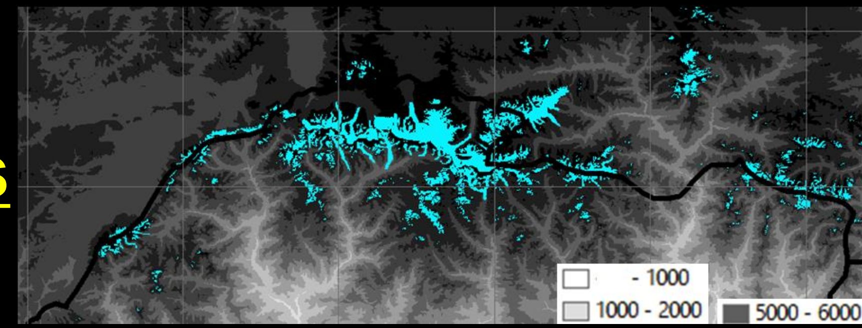
Some studies estimated **thermal resistance** of debris from satellite data.

	Target Region	Number of satellite images
Suzuki et al., 2007	Lunana region	11
Zhang et al., 2011	Hailugou glacier	2
Fujita et al., 2014	Trambau glacier	8



Distribution of thermal resistance on debris at Trambau glacier (Fujita et al., 2014)

Estimate <u>distribution of thermal resistance of debris on Bhutan Glaciers</u>



Data for analysis

Details

Data	Data	Spatial Res.	Time Res.	Period
Landsat 8	**Band 2~7**	30m	16 days	2013-2017
	Band 10 (TIR)	100m	16 days	2013-2017
ERA-Interim	**Reanalysis data (Radiation, Air temp, Humidity, Wind speed)**	0.75°	3hourly	2013-2017
AW3D30	**Elevation data (ALOS PRISM)**	30m	—	—
RGI 6.0	**Glacier Outline data**	Vector	—	—

Data for analysis

Details

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Landsat 8	**Band 2~7**	30m	16 days	2013-2017
	Band 10 (TIR)	100m	16 days	2013-2017
	Reanalysis data			
E				-2017

Multi-temporal 208 data set

Earth Observation Satellite

Landsat 8

Data for analysis

Details

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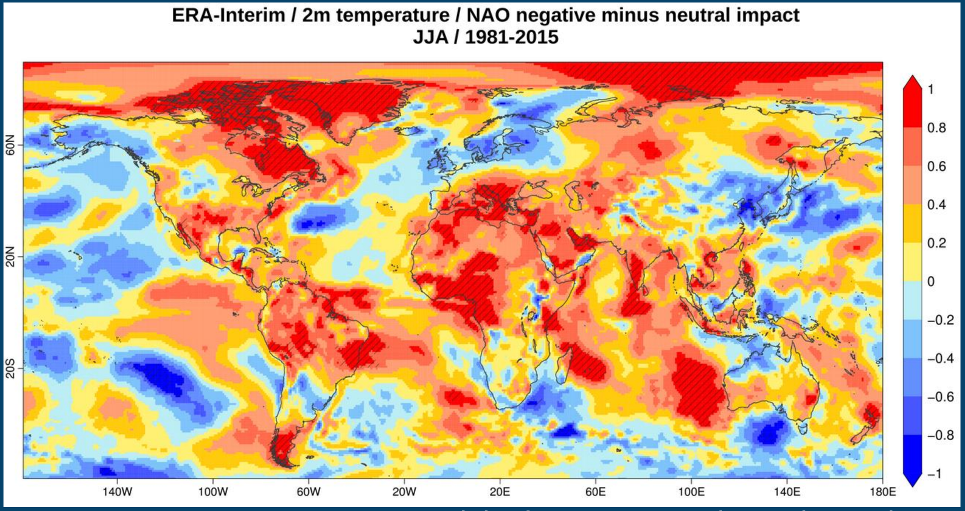
ERA-Interim	**Reanalysis data (Radiation, Air temp, Humidity, Wind speed)**	0.75°	3hourly	2013-2017
A				
F				

ERA-Interim : Reanalysis climate data by ECMWF

- Downward shortwave and longwave radiation
- Air temperature
- Relative humidity
- Wind speed



(Fig. from ERA-Interim Web page)

Data for analysis

Details

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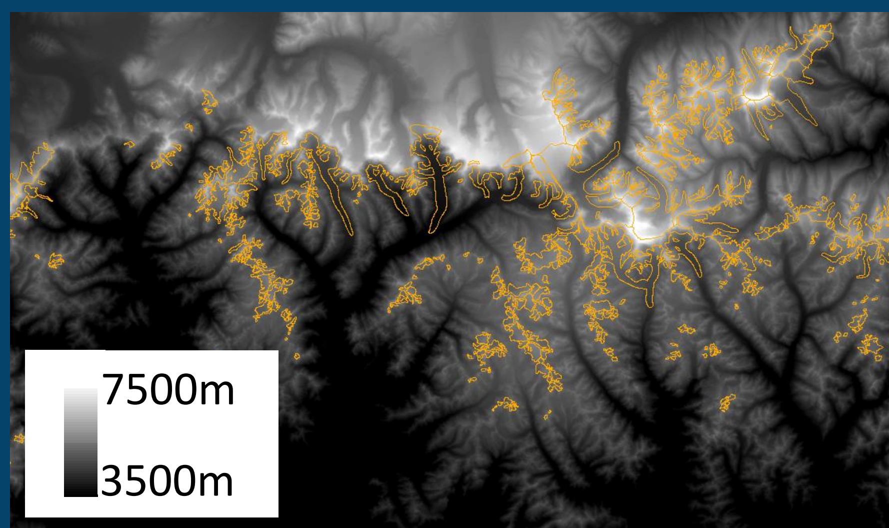
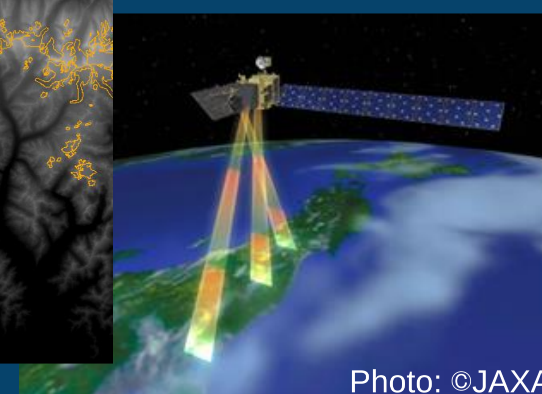
ERA-Interim	Reanalysis data			
AW3D30				
RGI 6.0				

AW3D30: ALOS World 3D - 30m Elevation Data (30m resolution)





ALOS 'PRISM' (JAXA)

Data for analysis

Details

Data	Data	Spatial Res.	Time Res.	Period
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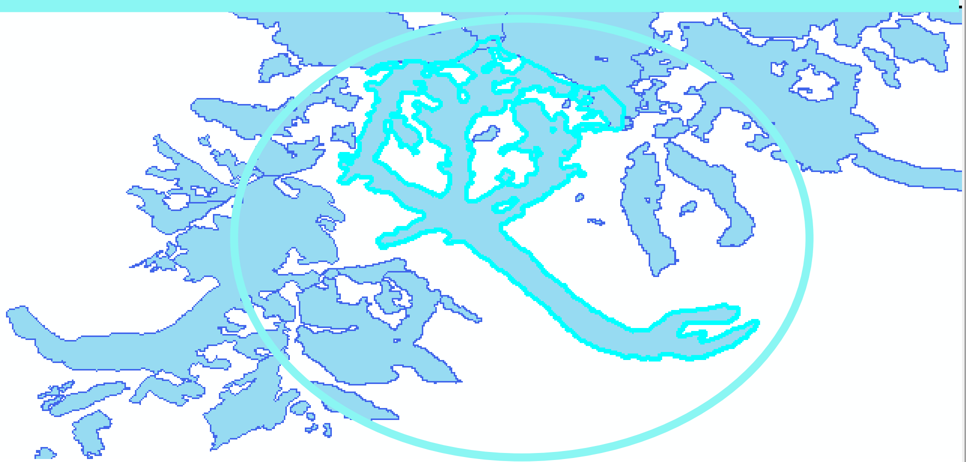
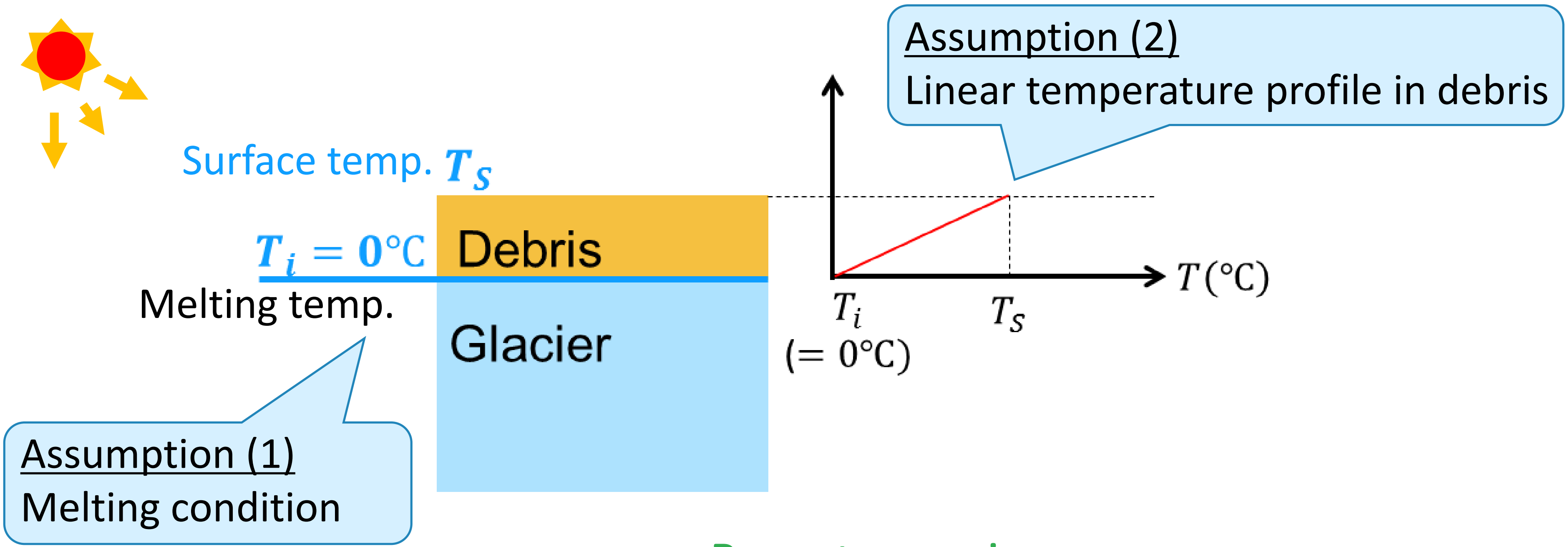
RGI 6.0	**Glacier Outline data**			



フィールド	値
FID	3004
Shape	ポリゴン
RGIId	RGI60-11.03005
GLIMSId	G006846E45813N
BgnDate	20030799
EndDate	20030999
CenLon	6.84583
CenLat	45.8129
O1Region	11
O2Region	1
Area	10.986
Zmin	1736
Zmax	4776
Zmed	2926
Slope	23.7
Aspect	168
Lmax	9042
Status	0
Connect	0
Form	0
TermType	0
Surging	9
Linkages	9

Calculation of TR

Thermal Resistance (TR) [$m^2\,K\,W^{-1}$]



Remote sensing

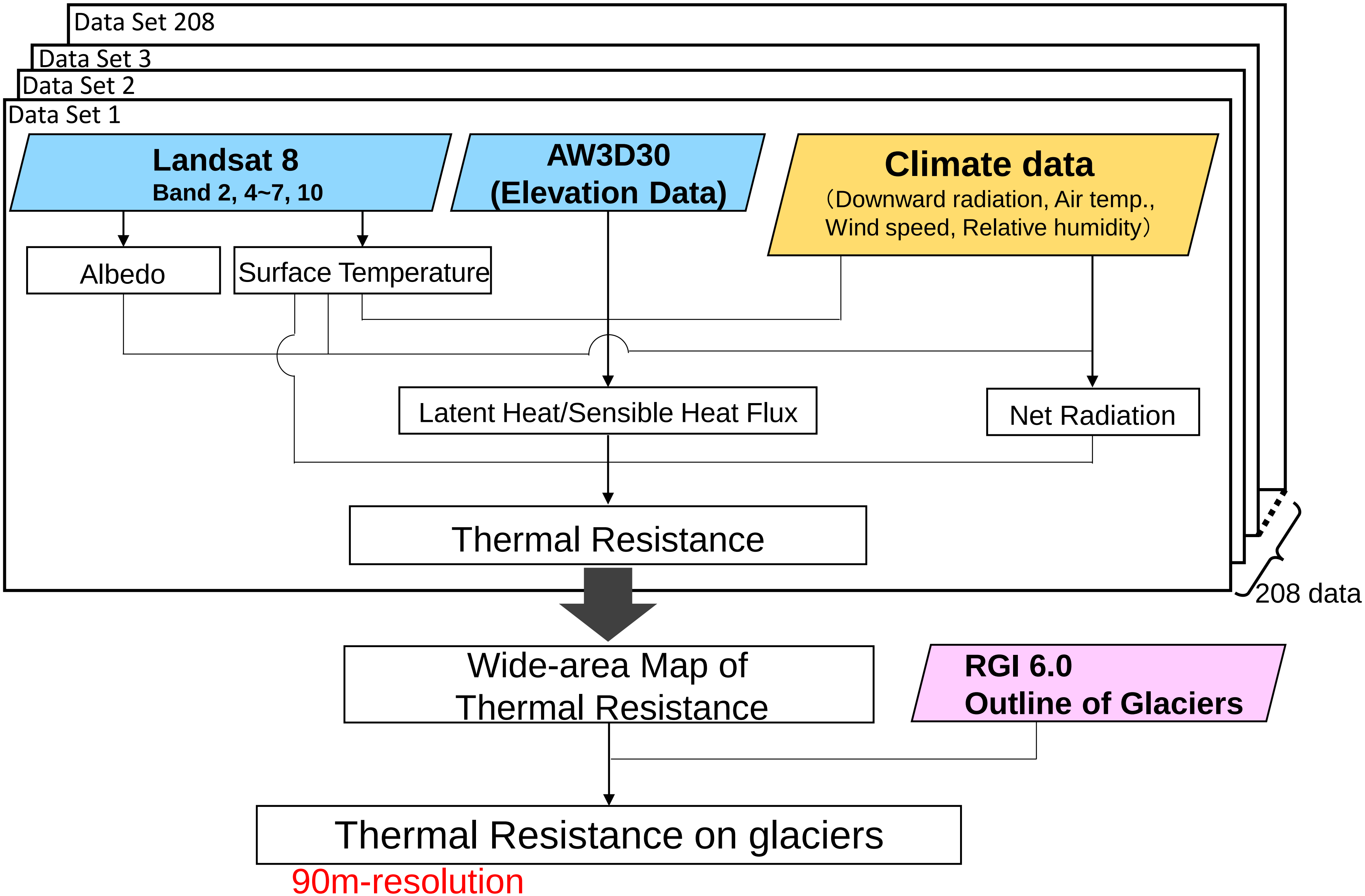
$$\therefore\ TR = \frac{(T_s - T_i)}{Q_g} = \frac{(T_s - T_i)}{R_n + LE + H}$$

Remote sensing

Remote Sensing + Reanalysis data

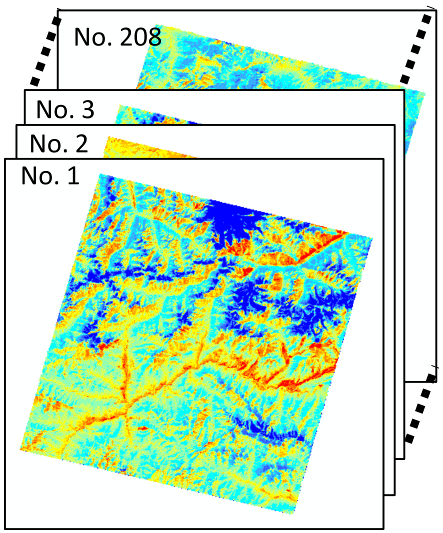
- Q_g :Heat flux into glacier [Wm^{-2}]
- R_n :Net Radiation [Wm^{-2}]
- LE :Latent heat flux [Wm^{-2}]
- H :Sensible heat flux [Wm^{-2}]

Flow of calculation



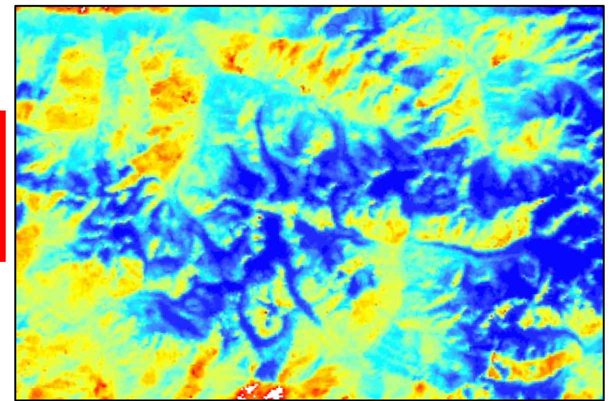
Flow of calculation

① TR

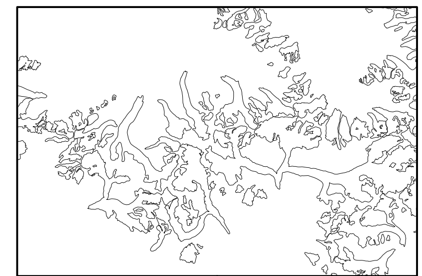


Eliminate cloud/snow

②Large area map of TR

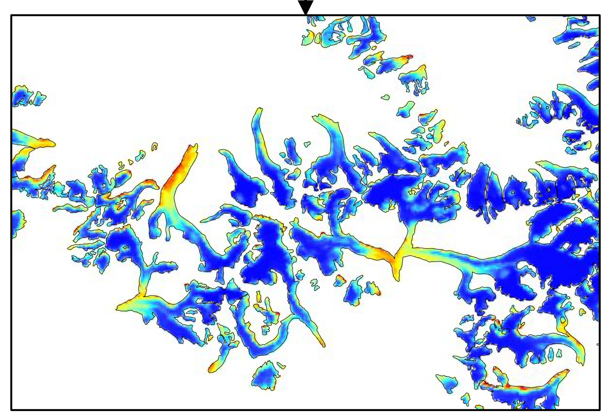


Glacier Outline



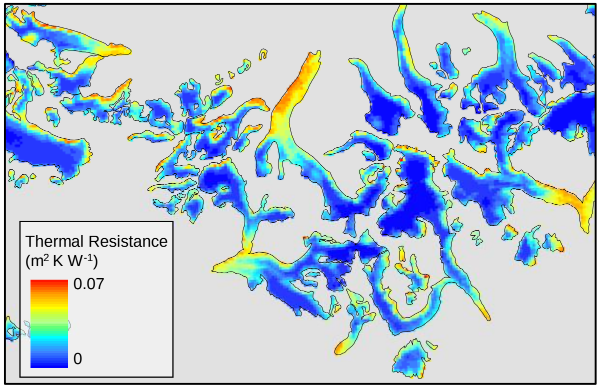
Thermal Resistance
[Km²/W]

③Extract glacier area

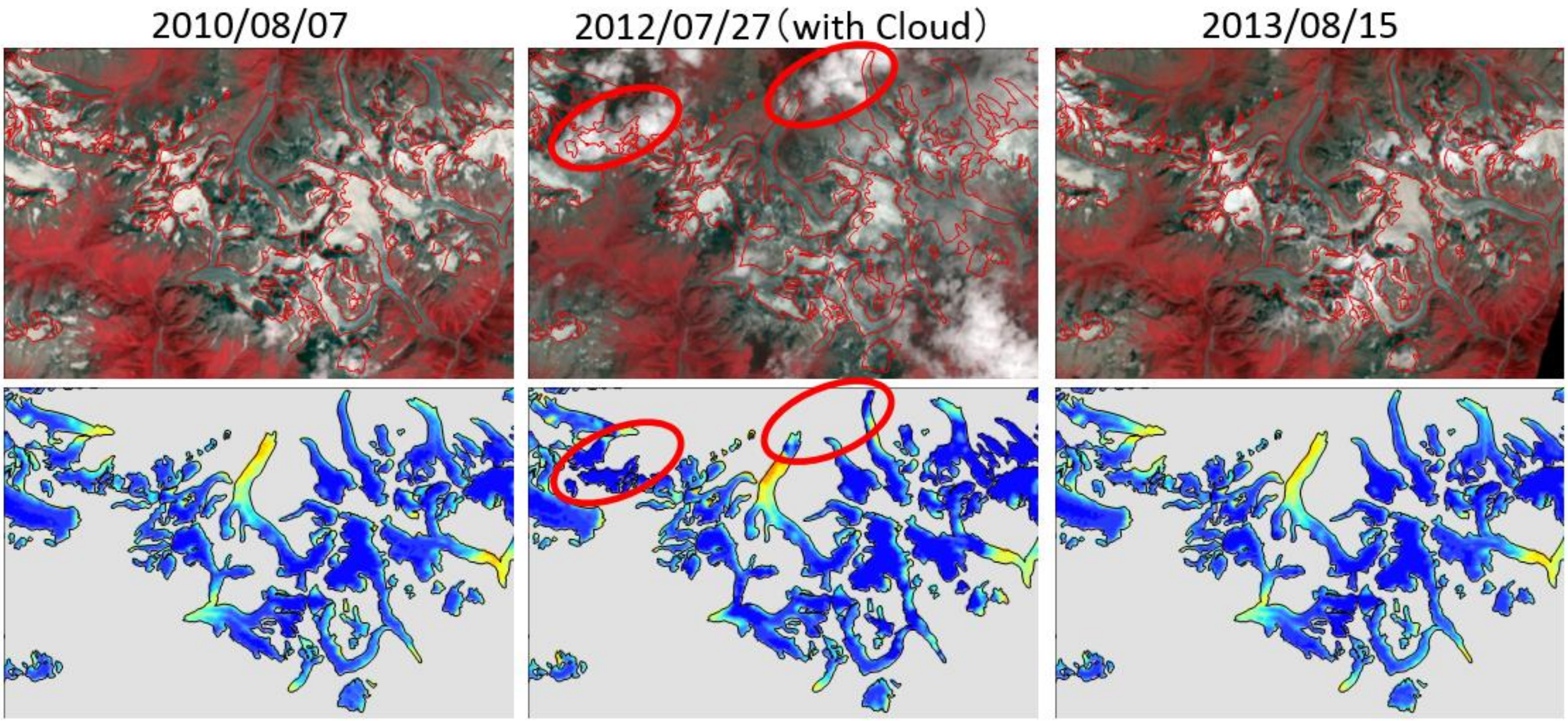


90m resolution distribution map of thermal resistance

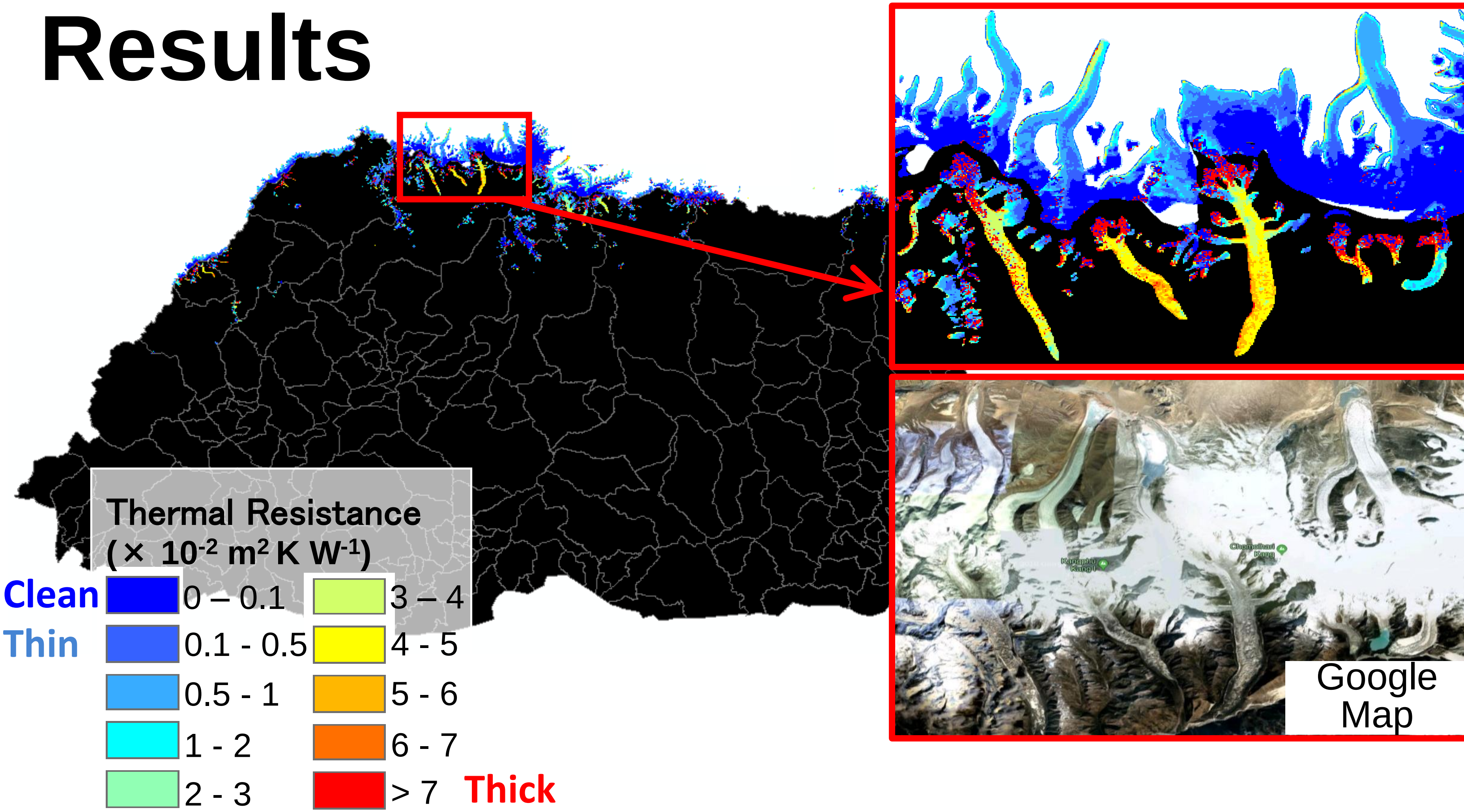
How to eliminate cloud and snow



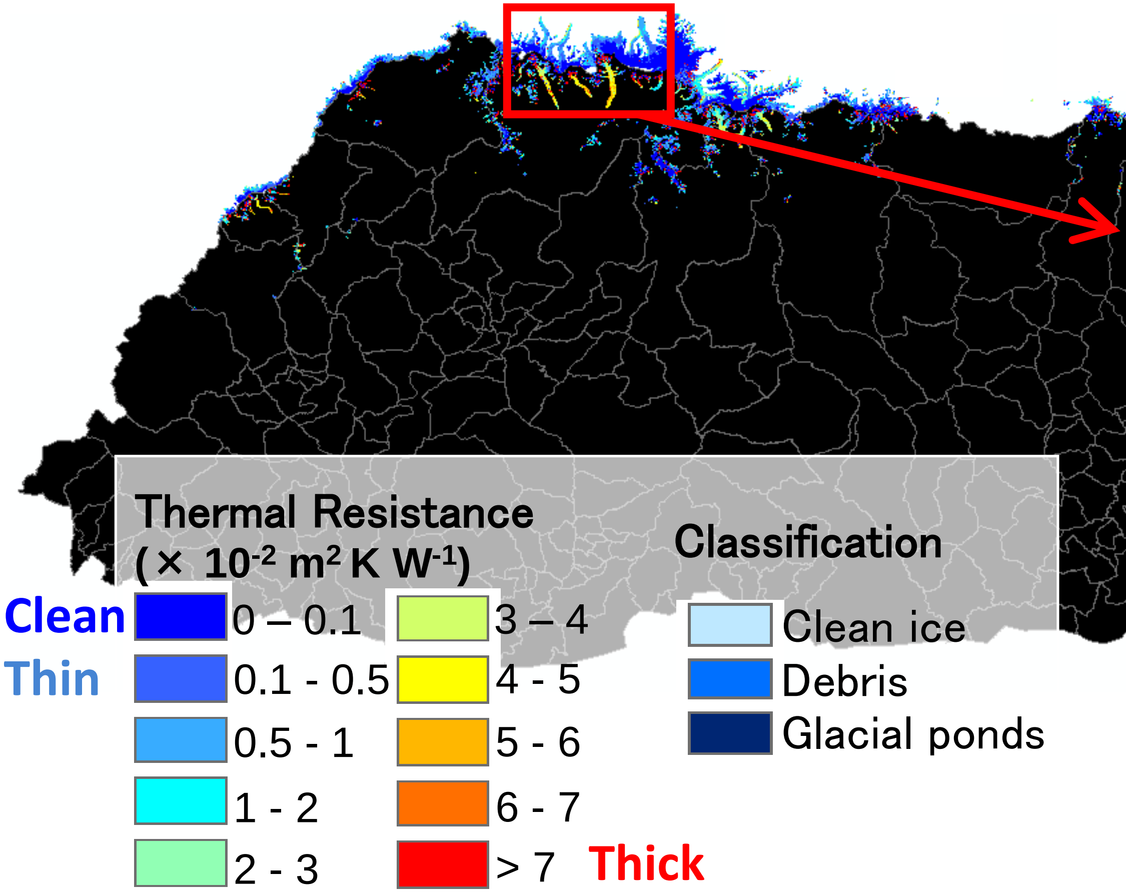
① Cloud and snow makes TR lower
⇒ select maximum value
② Interannual variation can be neglected

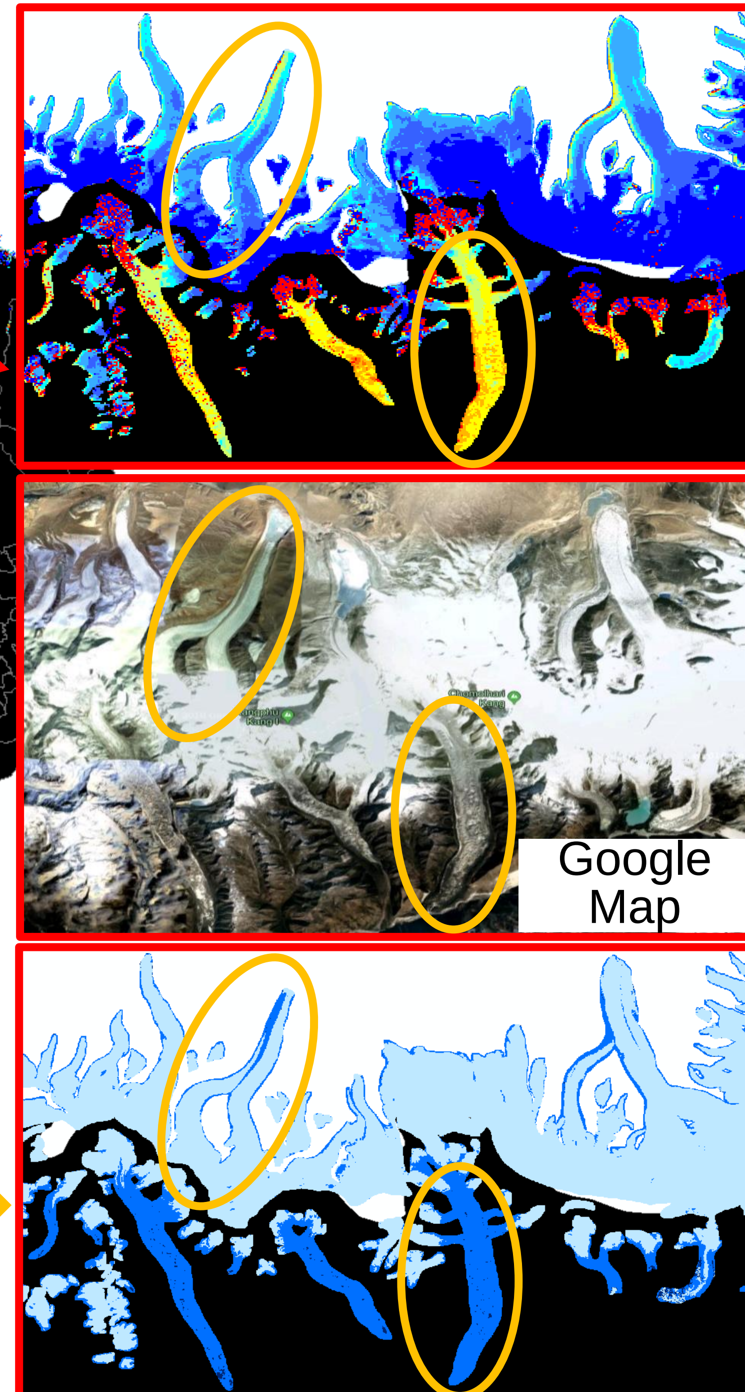


Results


Thermal Resistance
(× 10-2 m2 K W-1)
Clean
Thin
0 – 0.1
0.1 - 0.5
0.5 - 1
1 - 2
2 - 3
3 – 4
4 - 5
5 - 6
6 - 7
> 7
Thick
Google Map

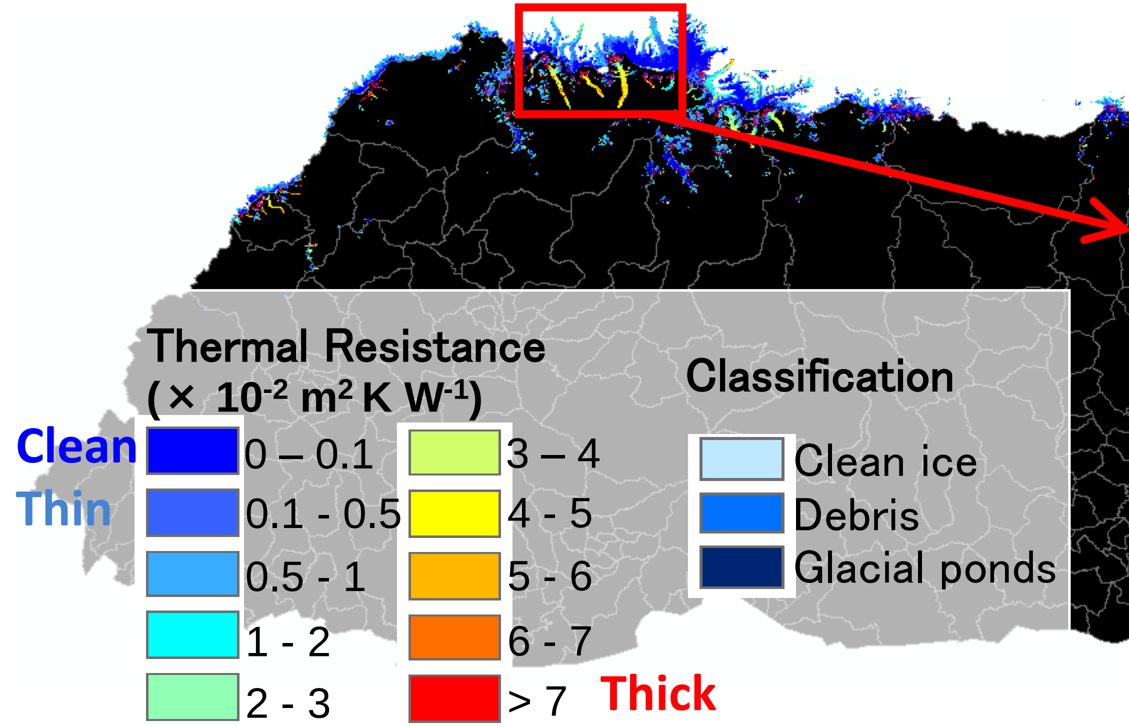
Results

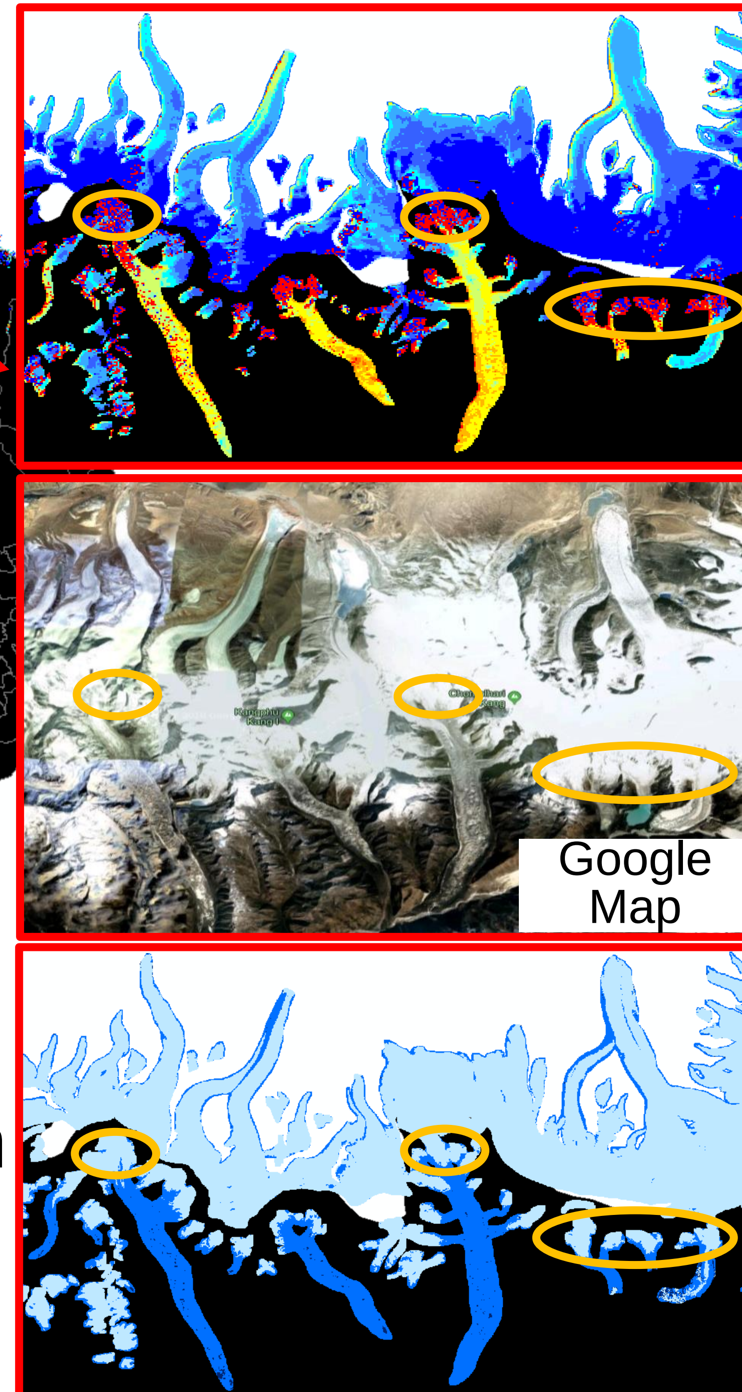




Classification by Landsat 8 (Kraaijenbrink et al., 2017)

Results





- Several large glaciers has <u>much debris</u>.
- There are small patches which has <u>erroneous high TR value</u>. (should be corrected)

2. Model Structure

Base Model

Glacier Model by Fujita et al., 2014 (Fujita model)

- Developed for **Trambau glacier** （located in Nepal Himalaya）
- **Energy Balance Model** with Debris effect

Hydrol. Earth Syst. Sci., 18, 2679–2694, 2014
www.hydrol-earth-syst-sci.net/18/2679/2014/
doi:10.5194/hess-18-2679-2014

Hydrology and Earth System Sciences
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Modelling runoff from a Himalayan debris-covered glacier

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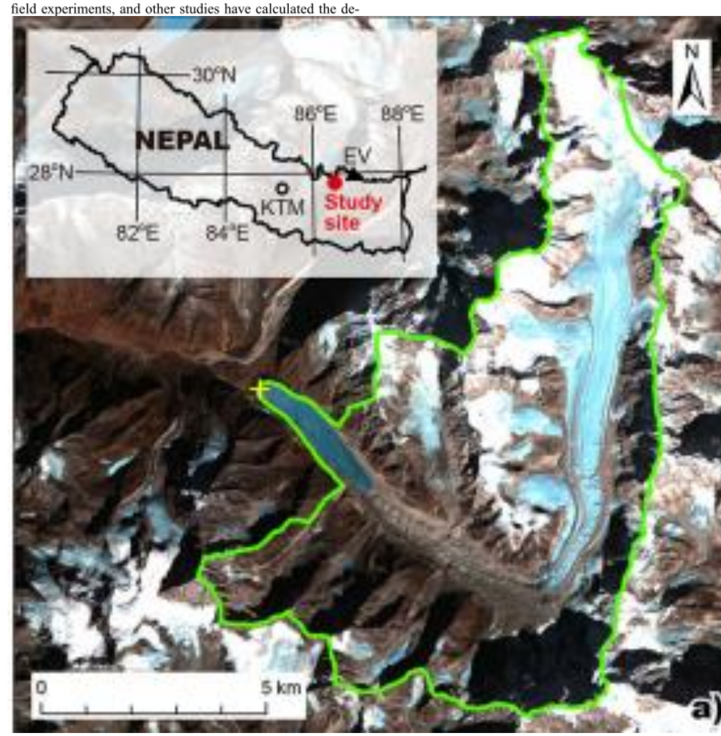
Received: 16 January 2014 – Published in Hydrol. Earth Syst. Sci. Discuss.: 26 February 2014
Revised: 28 April 2014 – Accepted: 24 May 2014 – Published: 24 July 2014

Abstract. Although the processes by which glacial debris mantles alter the melting of glacier ice have been well studied, the mass balance and runoff patterns of Himalayan debris-covered glaciers and the response of these factors to climate change are not well understood. Many previous studies have addressed mechanisms of ice melt under debris mantles by applying multiplicative parameters derived from field experiments, and other studies have calculated the de-

tal runoff to changing precipitation is complex because of the different responses of individual components (glacier, debris, and ice-free terrain) to precipitation.

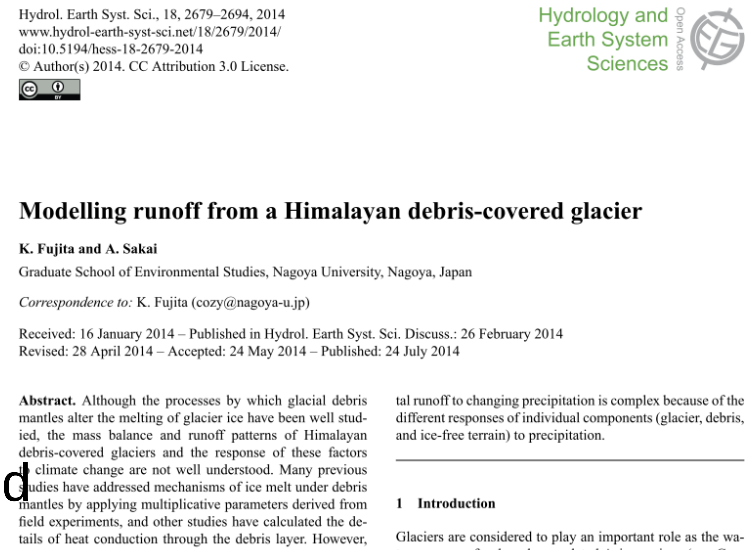
1 Introduction



Base Model

Glacier Model by Fujita et al., 2014 (Fujita model)

- Developed for **Trambau glacier** （located in Nepal Himalaya）
- **Energy Balance Model** with Debris effect
- Glacier area is divided into **(i) Clean ice** and **(ii) Debris-covered ice**.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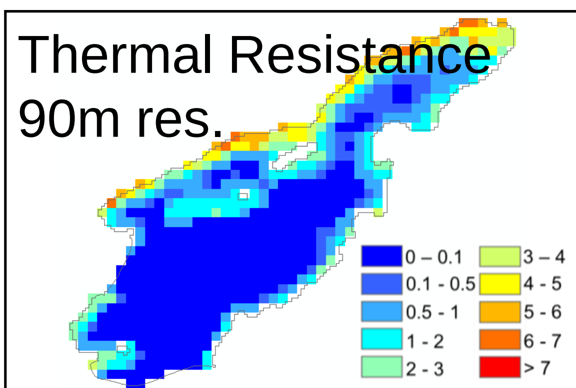
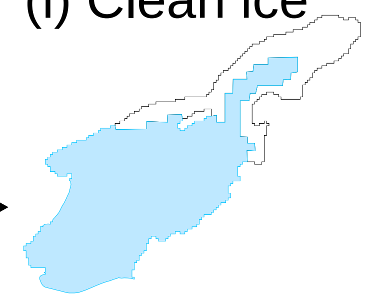
1 Introduction

Glaciers are considered to play an important role as the wa-

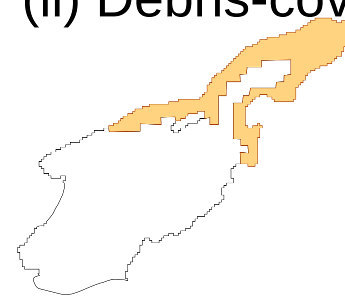
By using Landsat data (Kraaijenbrink et al., 2017)



(i) Clean ice



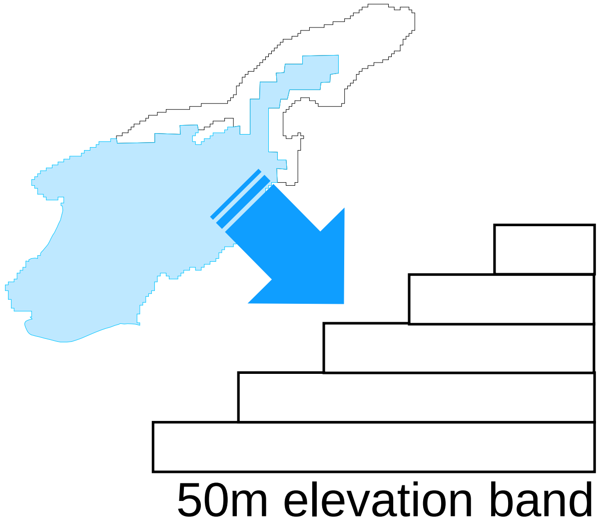
(ii) Debris-covered ice



Model Structure

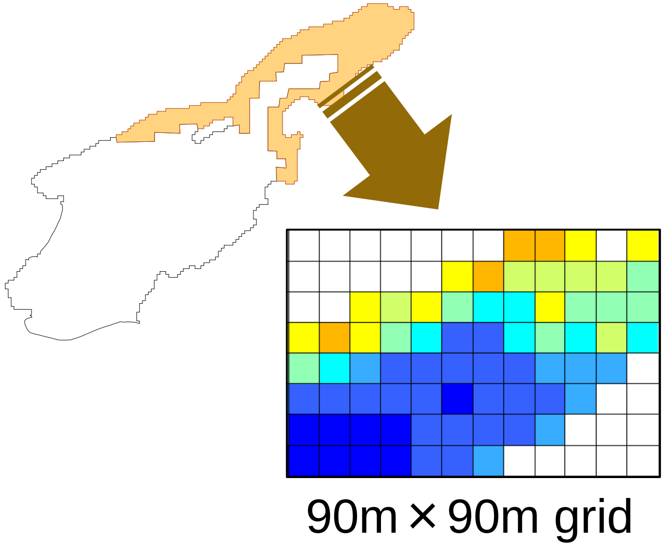
Mass balance was calculated in clean ice part and debris-covered part separately.

(i) Clean ice



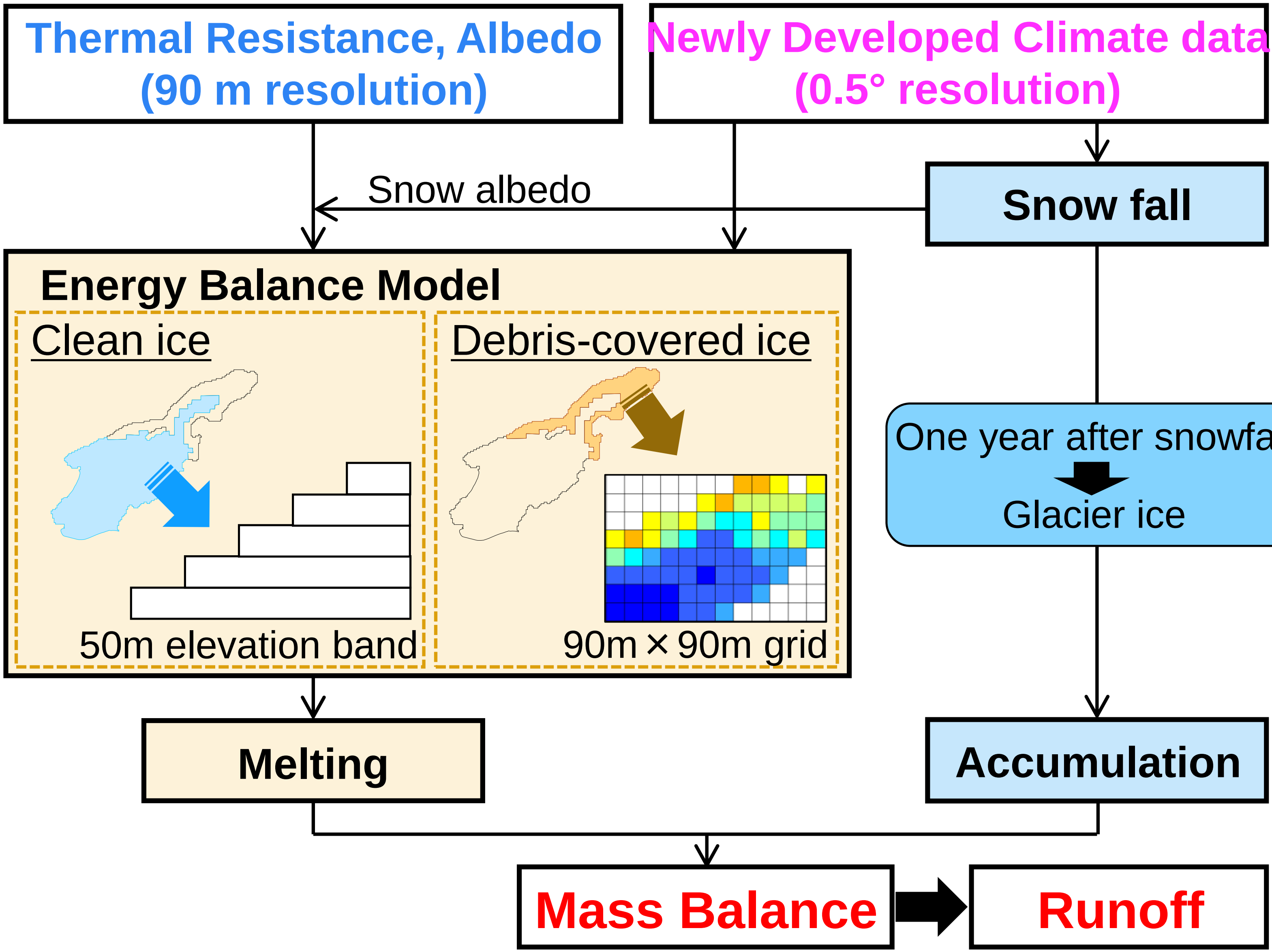
Each grid is sorted into 50m elevation band.
Mass balance was calculated in each band.

(ii) Debris-covered ice



Mass balance was calculated in each 90m grid.

Model Structure



Glacier area evolution

Area change is calculated from mass change.

Step 1. Initial value

Initial area A_0: from **RGI6.0**

Initial volume V_0: $V_0 = c_v A_0^{\gamma}$

(Volume-Area scaling, Bliss et al., 2013)

Parameters

Mountain glaciers:

$c_v = 0.2055\, m^{3-2\gamma}$, $\gamma = 1.375$

Ice caps:

$c_v = 1.7026\, m^{3-2\gamma}$, $\gamma = 1.250$

↓

Step 2. Calculation of mass balance

Mass balance B_i:

calculated for each grid(debris) or elevation band(clean ice)

↓

Step 3. Set new area and volume

$V_t = V_{t-1} + 1/\rho_{ice} \cdot \sum_{i=1}^{n} B_i A_i$

$A_t = (V_t / c_v)^{1/\gamma}$

Parameters

ρ_{ice}: Density of ice ($= 900\, kgm^{-3}$)

Repeat for N years (Step 3 → Step 2)

Calibration method

Local

Local model

Calibration by using ground observation data of each glacier

Large scale

Global Glacier Models (~2015)

Extrapolating limited direct observation data
（Radic and Hock, 2011; Radic et al., 2013; Hirabayashi et al., 2010, 2013; Marzeion et al., 2012; Bliss et al., 2014）

Global Glacier Model (Huss et al., 2015)

Extrapolating is problematic.

- Direct observation data is restricted to rather small glaciers

Each individual glacier's mass balance ΔM_g is assumed to be same as **the average regional mass balance** ΔM_{reg}

$$\Delta M_g = \Delta M_{reg}$$

Calibration Flow

Calibration method:

$$\Delta \boldsymbol{M}_{\boldsymbol{g}} = \Delta \boldsymbol{M}_{\boldsymbol{reg}}$$

$\Delta \boldsymbol{M}_{\boldsymbol{reg}}$: Average regional mass balance in whole Asia (2003-2009) (Gardner et al., 2013)

⇒Observation data of Bhutan glacier will improve model performance.

Calibration period: 2003-2009

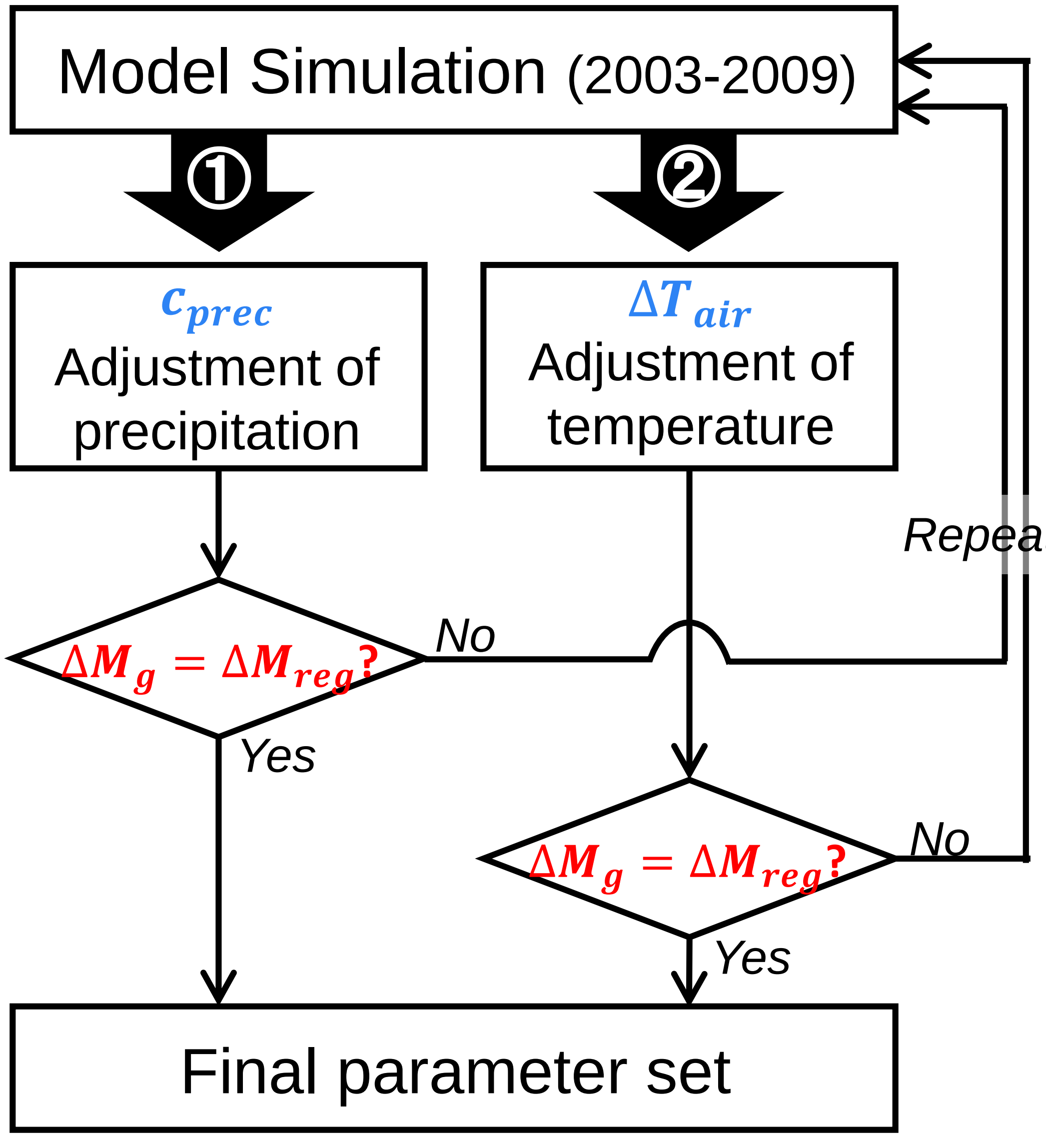
Calibration parameters:

c_{prec} : Precipitation ratio [%] （0.8<c_{prec}<2.0）

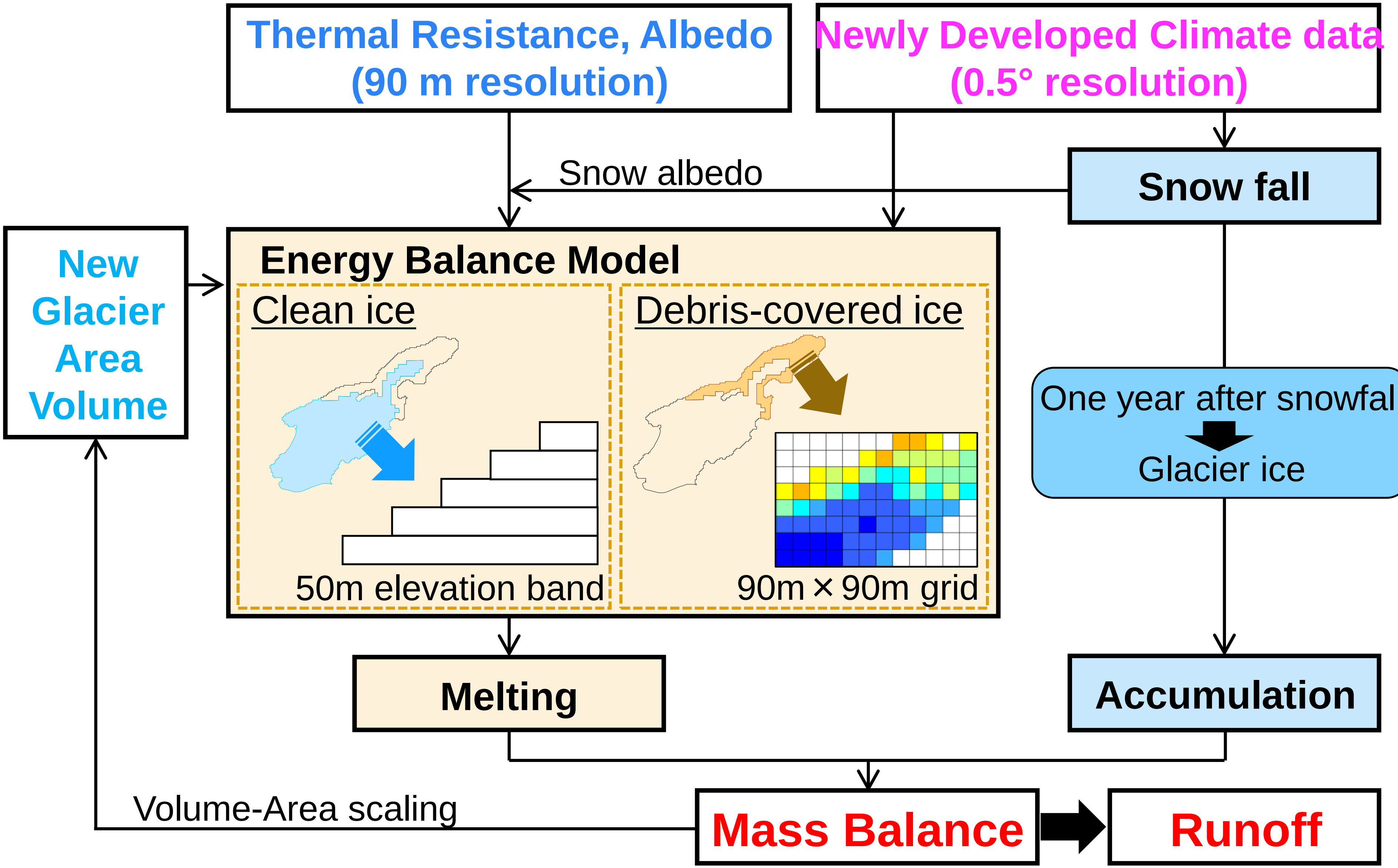
ΔT_{air}: Air temperature [℃]

Initial value:

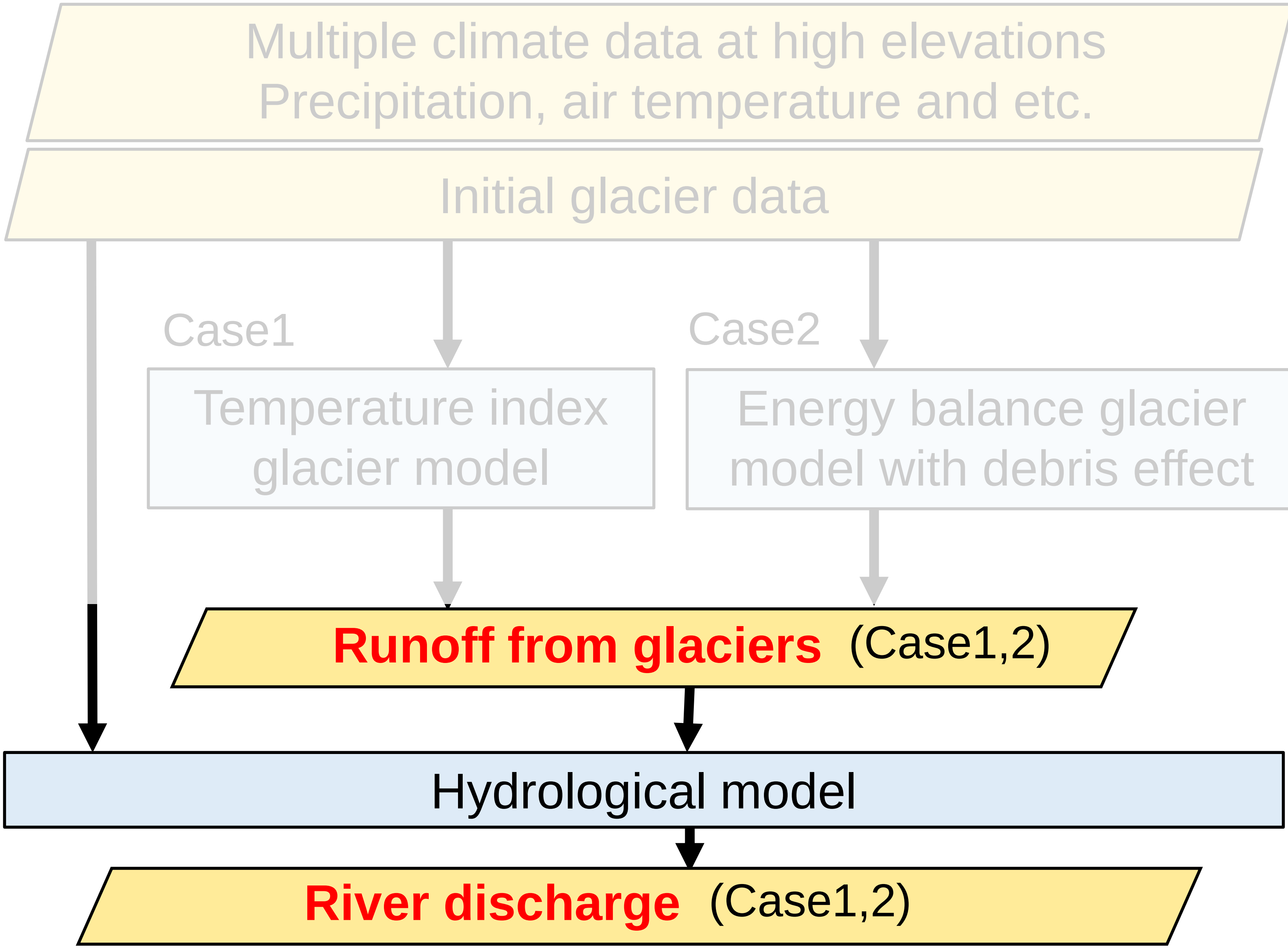
$c_{prec} = 1.0, \quad \Delta T_{air} = 0.0$



Model Structure



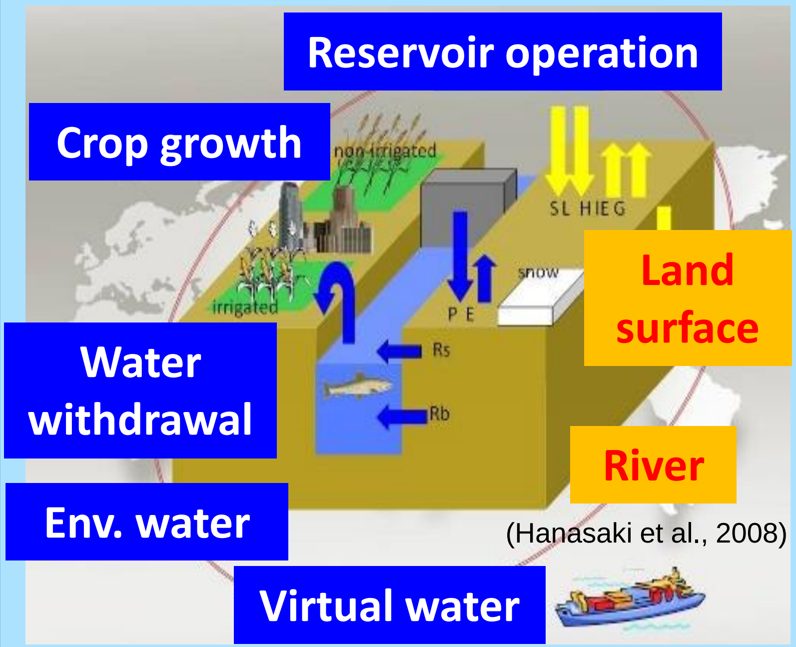
Research flow



River Discharge (H08)

Runoff from Glaciers (Case1, Case2) → **Input**

Newly Developed Climate data → **Input**



Model "H08"

Output

River discharge
(Case1, Case2)

- Consisted of 7 modules
- Use 2 modules
  - **River**
  - **Land surface**

Two type of river discharge will be obtained.
(from case1 & case2)

↓

Uncertainty range

Summary

- The distribution of **thermal resistance of debris on glaciers** has been detected in Bhutan by using **remote-sensing data**.

- A **glacier model with energy balance and debris effects** was developed.

- **Observation data of Bhutan glaciers** will improve model performance.

Next Steps

- Historical and future simulation of **glacier runoff** for all glaciers in Bhutan (**Glacier model**).

- Simulation of **river discharge** including the effects of glacier melts (**H08**).

Thank you for your kind attention