Glacio-hydrological projections with downscaled climate data

Megumi Watanabe and Shinjiro Kanae
Tokyo Institute of Technology
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Current assessments and our objective
Current assessments for impact of climate change
(NATIONAL INTEGRATED WATER RESOURCES MANAGEMENT PLAN 2016)

Projected changes in precipitation for RCP4.5

Rainfall

<table>
<thead>
<tr>
<th>Change (%)</th>
<th>&lt; 0</th>
<th>0 - 3</th>
<th>3 - 7</th>
<th>7 - 10</th>
<th>&gt; 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change 2015 - 2030 (%)</td>
<td></td>
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<tr>
<td>Change 2015 - 2060 (%)</td>
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</tbody>
</table>

OBJECTIVE
To estimate of river discharge taking into account glacier melt with a regional climate projection
Research flow
Research flow

Multiple climate data at high elevations
Precipitation, air temperature and etc.

Initial glacier data

Case 1
Temperature index glacier model

Case 2
Energy balance glacier model with debris effect

Runoff from glaciers (Case 1, 2)

Hydrological model

River discharge (Case 1, 2)
Research flow

1. Multiple climate data at high elevations
   - Precipitation, air temperature and etc.

2. Initial glacier data
   - Case 1: Temperature index glacier model
   - Case 2: Energy balance glacier model with debris effect

3. Runoff from glaciers (Case 1, 2)

4. Hydrological model

5. River discharge (Case 1, 2)
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glacier model

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model with debris effect

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Research flow

Multiple climate data at high elevations
Precipitation, air temperature and etc.

Past period
- Uncertainty
- Data
  - Air temperature
  - Precipitation

Future period (GCMs)
- Uncertainty
- Bias correction
- Multi-model

Runoff from glaciers (Case1,2)

Hydrological model

River discharge (Case1,2)
Uncertainty of climate data for the past period

The number of gauge (APHRODITE)

The scarcity of in-situ observations (for temperature and precipitation) at high elevations
Temperature data for the past

**TA1** H08
(Hirabayashi et al., 2008)

Thermometer

http://www.ushistory.org/franklin/fun/thermometer.htm

**TA2** ERA-Interim
(Dee et al., 2012)

Sparse stations at elevations

Rennie et al. (2014)

https://serc.carleton.edu/eet/envisioningclimatechange/part_2.html

Reanalysis
Hybrid of observations and model

It could be applied to sparsely observed regions
Precipitation data for the past

**PR1** APHRODITE

Gauge

**PR2** Sakai

Gauge

**PR3** MSWEP

Gauge  Satellite  Reanalysis

**PR4** MSWEP+PR (This study)

Gauge  Satellite  Reanalysis

http://www.stuffintheair.com/rain-gauge.html
Precipitation data for the past

PR1 APHRODITE

Gauge

PR2 Sakai

Inverse estimation using glacier elevation

Gauge

PR3 MSWEP

Gauge Satellite Reanalysis

©JAXA

PR4 MSWEP+PR (This study)

Gauge Satellite Reanalysis

©JAXA

Inverse estimation using discharge

Directly detect rain drop using satellite radar

©NASA
Precipitation data for the past

**PR1** APHRODITE

Gauge

**PR2** Sakai

Inverse estimation using glacier elevation

**PR3** MSWEP

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**PR4** MSWEP+PR (This study)

Gauge Satellite Reanalysis

Inverse estimation using discharge

Directly detect rain drop using satellite radar
Sakai et al. (2015)

Satellite derived glacier elevation

Correct

Gauge

Inversely estimate

Accumulation zone

Ablation zone

Melting water
**PR3 MSWEP** (Beck et al., 2015)

\[ P = E + Q + \Delta S \]

- **P**: Precipitation; **Q**: Observed discharge; **E**: Evaporation; **\Delta S**: changes in water storage

Gauged discharge

Correct

Multi

Global Runoff Data Centre

http://www.bafg.de/GRDC/EN/02_srvcs/21_tmsrs/riverdischarge_node.html

©JAXA
Precipitation data for the past

- **PR1**: APHRODITE
- **PR2**: Sakai
- **PR3**: MSWEP
- **PR4**: MSWEP+PR (This study)

**Instruments and Methods**
- **Gauge**: Directly detect rain drop using satellite radar
- **Satellite**: Inverse estimation using glacier elevation
- **Reanalysis**: Inverse estimation using discharge
Microwave Infrared Radar (PR)

High emissivity from the ground More sensitive over land as well as ocean

Yamamoto et al. (2011)
The peak local-time distribution of precipitation showed a relationship with the topography in the order of precipitation radar (strongest relationship), microwave radiometer, and infrared products.
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Runoff from glaciers (Case1,2)

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River discharge (Case1,2)
Projected change in temperature for RCP4.5 (NIWRNP 2016)

Projected annual total precipitation from CMIP5 GCMs (RCP8.5)

Climate models

- Coarse spatial resolution & bias
- Spread among models

Spread of climate models

Bias correction

Multi-model
Projected air temperature in 2080-2010 by INM-CM4, RCP8.5

Bias correction

"Original"

"Downscaled"

Bias correction

【Baseline period】

Compare statics

【Projection period】

Correct statics

!! Can be different depending on data for the past !!
Multi-scenario, Multi-model

Scenarios
GHG emission level

High
Mid
Low

RCP2.6-8.5

ΔTemperature(°C)
(2070-2099 to 1950-1979)

ΔSnowfall(%)

Eastern Himalaya

Various climate models

CMIP5 GCMs

GCM1
High temperature

GCM2
Median temperature & snowfall

GCM3
More snowfall
Research flow

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3. Temperature index
   - Glacier model
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5. Hydrological model
6. River discharge (Case1,2)
Initial glacier data
The latest glacier inventory

“Randolph Glacier Inventory”

- A globally complete inventory of glacier outlines using modern satellite (such as Landsat or ASTER) imagery
- Information
  - Glacier shape
  - Location (latitude & longitude)
  - Glacier area
  - Altitude
  - Length

Glacier shape by RGI 6.0

Altitude (m)

Legend

- Glacier_BH
- TM_WORLD_BORDERS-0.3
- n25e090_dem.tif
- <cell-value>
  - -12.17773819 - 1,000
  - 1,000.000001 - 2,000
  - 2,000.000001 - 3,000
  - 3,000.000001 - 3,500
  - 3,500.000001 - 4,000
  - 4,000.000001 - 4,500
  - 4,500.000001 - 5,000
  - 5,000.000001 - 5,500
  - 5,500.000001 - 6,000
  - 6,000.000001 - 8,839.171875

-Landsat ©NASA-
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Temperature index
glacier model
Glacier model – mass balance -

(Hirabayashi et al., 2013)

Snow pack is transformed into glacier ice

\[ \text{Snowfall} = \begin{cases} & \text{Precipitation} \times C_p \\ & \text{(if } T_i + dT \leq 2) \\ & 0 \text{ (if } T_i + dT > 2) \end{cases} \]

\begin{align*}
\text{Accumulation} \\
\text{Ablation}
\end{align*}

\[ (T_i + dT - T_0) \times \text{DDF} \]

Surface-air temperature \([\degree C]\) 0 \([\degree C]\)

Adjustment factor

Melt factor \([\text{mm/} \degree C/\text{day}]\)
Summary
Today’s summary

• Multiple climate data for the past period
  • Air temperature (In-situ / Reanalysis)
  • Precipitation (In-situ / Reanalysis / Inverse estimations)

• Climate data for the future period
  • Bias correction of GCMs
  • Multi-GCMs

• Initial glacier data from the inventory

• Temperature index glacier model

• Uncertainty range of climate data

• Uncertainty range of glacier projections