Future changes in snowfall and snow cover at high Japanese mountain ranges

ICRC-CORDEX2019
(Oct. 14-18, 2019, Beijing)

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Japan has many mountains. About 75% of whole Japan is mountainous areas.

Mountain ranges in the central Japan are called as Japan’s Alps, which is named after European Alps.

Japan’s Northern Alps has enormous snow cover.
Japan’s Northern Alps
Tateyama Mt. Range 2450 mASL
(Apr. 22, 2019)

16 m
(seasonal snow)
Japan’s Northern Alps

Tateyama Mts. area 2450 mASL
(Apr. 22, 2019)

16 m
(seasonal snow)

577 cm
Mechanism of heavy snowfall in Japan

Similar to the lake effect in snowfall of the Great Lakes
Impact of global warming on the Japanese snow

- East Asian Winter Monsoon will weaken due to global warming, resulting in a decrease in winter precipitation along the Sea of Japan side.  

- Weakening winter monsoon and temperature rise will reduce total snowfall in Japan, especially lower elevations.  
  \[ Hara \text{ et al. 2008; JMA* 2017; Kawase \textit{et al.}, 2015] \\

- Over the Colorado Headwaters region, global warming enhanced snow melting at lower-elevations, while increased snowfall at higher elevations.  
  \[ Rasmussen \text{ et al.}, 2011; 2014] \\

- In Europe and the U.S., large reductions in extreme snowfalls are projected due to global warming, except for the coldest areas such as the European Alps and the Rocky Mountains  
  \[ de \text{ Vries \textit{et al.} 2014; Lute \textit{et al.} 2015] \\

Introduction
Impact of global warming on the Japanese snow

- East Asian Winter Monsoon will weaken due to global warming, resulting in a decrease in winter precipitation along the Sea of Japan side.
  
  \[Hu\ et\ al.\ 2000;\ \textit{Kimoto}\ \textit{et\ al.}\ 2005;\ \textit{Hori}\ \textit{and}\ \textit{Ueda}\ 2006\]

- Weakening winter monsoon and temperature rise will reduce total snowfall in Japan, especially lower elevations.
  
  \[Hara\ et\ al.\ 2008;\ \textit{JMA}\*\ 2017;\ \textit{Kawase}\ \textit{et\ al.},\ 2015\]

Purpose

To evaluate the impact of global warming on winter snowfall and snow cover at \textbf{high elevations of Japan’s Alps} using the regional climate model with \textbf{1 km grid spacing}.
Global climate experiments (MRI-AGCM3) 60km

- Historical experiments (60yrs, 100 member) 6000 years
  SST: COBE-SST2 1951～2010 (with 100 initial perturbations)

- Future experiments (60yrs, 90/54 member) 5400/3240 years
  SST: Historical SST plus six SST anomalies of CMIP5 models between past and future climate assuming 2K/4K warming (RCP8.5)

Regional climate experiments (NHRCM with 20km)

NHRCM is Nonhydrostatic Regional Climate Model developed by MRI, JAPAN.

[Mizuta et al., 2017; Fujita et al. 2019]
Topography in RCMs

20km  5km  1km

Realistic Japan’s Alps
Additional downscaling and selection of years

NHRCM with 5km ~400yrs.
* Historical: 372 years (31 years x 12)
* 2K warming: 372 years (31 years x 12)
* 4K warming: 372 years (31 years x 12)

Calculation of annual maximum snow cover at Japan’s Alps above 1,000m in each climate

Selection and dynamical downscaling

Top 5 years: **Heavy snow**-covered years
Median 5 years: **Medium snow**-covered years
Bottom 5 years: **Light snow**-covered years
(15 yrs. x 3 clim.) ➔ Downscaling using 1km NHRCM

Kawase et al. (2019, submitted)
Seasonal variation of snow depth over Northern Alps

Heavy Snow-covered years

Light Snow-covered years over 2000m

High elevation above 2000m

Historical
2K warming
4K warming

6-7m

Heavy snow-covered years
Mid-winter snow depths under 2K/4K warming experiments are comparable to snow depth in the historical experiment.

Light snow-covered years
Snow depth will decrease even in mid-winter due to global warming.

The difference of snow cover between heavy and light snow-covered years gets larger due to global warming.
Snowfall over 2000 m ASL

**Seasonal variation of half-monthly snowfall**

**Heavy Snow-covered years**

**Light Snow-covered years**

**Increase in mid-winter snowfall due to global warming**

- Similar snow depth in the three experiments.

**Decrease in mid-winter snowfall due to global warming**
Seasonal variation of SST, air temperature, and snowfall

Heavy snow-covered years (high elevation > 2000m)

Surface air temperature (TAS) (°C)

SST

TAS

Historical

2K warming

4K warming

Snowfall

Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug
Surface wind (synoptic condition) and precipitation

Historical exp. (5-year-mean) [DJF]

Heavy snow-covered year

Median snow-covered year
Surface wind (synoptic condition) and precipitation

4K warming exp. – Historical exp. [DJF] (5-year-mean)

Heavy snow-covered year

- No changes in northwesterly
- Enhanced convergence

Median snow-covered year

- Weakened northwesterly (= weaken winter monsoon) similar to climatological change
Summary

We evaluated future changes in snowfall and snow cover at high elevations of the Japan’s Northern Alps using a regional climate model with 1 km grid-spacing.

- In heavy snow-covered years, mid-winter snowfall increases at high elevations of Japan’s Northern Alps due to global warming. Mid-winter snow depth is comparable to present one in the 4 K warming climate.

- In light snow-covered years, mid-winter snow cover largely decreases due to global warming.

- A contrast of mid-winter snow cover between heavy and light snow-covered years gets larger due to global warming.

- Changes in synoptic condition are different between the heavy snow-covered years and medium snow-covered year.
Thank you
**Dynamical downscaling**

NHRCM with 5km  
\[ \sim 400 \text{ yrs.} \]

- **Historical**: 372 years (31 years x 12)
- **2K warming**: 372 years (31 years x 12)
- **4K warming**: 372 years (31 years x 12)

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**Physical processes in 1km NHRCM**

<table>
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<tr>
<th>Microphysics</th>
<th>Bulk-type cloud microphysics (Ikawa et al. 1991)</th>
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Future changes in precipitation and synoptic circulation

**Heavy snow-covered year**

- Historical (5-year-mean)
  - 4K warming minus Historical
    - Enhanced convergence
    - Weakened monsoon

Kawase et al. (2019, submitted)
Japan has many mountains. About 75% of whole Japan is mountainous areas.

Mountain ranges in the central Japan are called as Japan’s Alps, which is named after European Alps. 

Japan’s Northern Alps has enormous snow cover.
Future changes in **daily snowfall intensity**

### Heavy snow-covered years

- **Over 2000 mASL**
  - Historical
  - 2K warming
  - 4K warming

- **0-500 mASL**
  - Historical
  - 2K warming
  - 4K warming

### High-elevations
- Weak daily snowfall decreases.
- Heavy daily snowfall over about 50 cm/day occurs more frequently under 4K warming.

### Low-elevations
- Under 4K warming, daily snowfall frequency decreases in all range of snowfall intensity.
- Heavy snowfall over 40 cm/day increases under 2K warming.
Seasonal variation of half-monthly snowfall and rainfall

Snowfall

Rainfall

Heavy Snow-covered years

Light Snow-covered years

Historical
2K warming
4K warming

Over 2000 mASL

Snowfall (mm)

Over 2000 mASL

Rainfall (mm)
Remarkable increase in daily snowfall around Central Japan, Hokkaido, and eastern parts of Asian continent.
Many mountainous areas in Japan

Mountain ranges in the central Japan are called as *Japan’s Alps*, which is named after the European Alps.

*Japan’s Northern Alps* has enormous snow cover every year.

⇒ Mechanism of snowfall in Japan
## Specification of NHRCM01

### Physical processes in NHRCM01

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Seasonal variation of SST, air temperature, and snowfall

Heavy snow-covered years (high elevation > 2000m)

Kawase et al. (2019, in prep.)
SI-CAT contributes to the development of adaptation plans by local governments and the creation of new enterprises, in consideration of the steady adaptation of various needs to climate change.

For projections of future snow cover changes over high mountainous areas.
Future changes in synoptic circulation

Heavy snow-covered years (composite)

Future Change in DJF surface wind and precipitation under +4K climate

Composite of heaviest 50 daily snowfall events (20km NHRCM)

Intensified convergence zone
Development of cumulonimbus

Present climate

- Cold northwesterly
- Snowing

Future climate

- Cold northwesterly (warmer than present climate)
- More developed cumulonimbus
- Heavy snowing

Siberia
Sea of Japan
Coastal area
Mountainous area
Pacific

Siberia
warmer Sea of Japan
Coastal area
Mountainous area
Pacific
Precipitation (snowfall+rainfall) and surface wind

**Historical experiments**

- Increased precipitation around JPCZ.
- Intensification of JPCZ

**Future exp. – Historical exp.**

- Increased precipitation around JPCZ.
- Intensification of JPCZ

**JPCZ:** Japan sea Polar air mass Convergence Zone
Why increase? Composites of top 50 heavy snowfall events

Precipitation (snowfall + rainfall) and surface wind

Mean vertical wind and differences

Future exp. – Historical exp.

Enhancement of JPCZ
(convergence)
Why increase? Composites of top 50 heavy snowfall events

Precipitation (snowfall + rainfall) and surface wind

Mean vertical wind and differences

Future exp. – Historical exp.

Enhancement of JPCZ (convergence)
Similar to the lake effect in snowfall of the Great Lakes
現在
かなり冷たい空気
北西季節風
積雲発達

将来
冷たい空気
北西季節風
積雲発達

松江地方気象台より引用、一部改変
15-year-mean annual maximum snow depth

5km NHRCM
(historical 15 year mean)

1km NHRCM
(historical 15 year mean)
Future changes in 15-year-mean maximum snow depth

Snow cover change (cm)

2K warming climate

Snow cover change (%) [cm]

4K warming climate

Snow cover change (cm)

Snow cover change (%) [cm]