GLOBAL WARMING RESPONSE OF SNOWPACK IN HOKKAIDO, NORTHERN ISLAND OF JAPAN

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ABSTRACT: The seasonal snowpack over Hokkaido, Japan, responding to the global warming in a decade when the global-mean air temperature would increase by 2 K relative to 1990s, was estimated with a physical snowpack model driven by multiple dynamically downscaled (DDS) data, after the snowpack model validation by comparing between the snow-pit observation and the hindcast simulation at 28 sites in a late-winter date and between the automatic observation and the DDS-forced simulation at 108 sites. The validation assured that the snowpack model succesfsully reproduced height of snowcover (HS), snow water equivalent (SWE), and snow-covered days (SCD) over Hokkaido. Responding to the global warming, the annual maximum HS and SWE would largely decrease by 30% in western and eastern Hokkaido following a decrease in precipitation amount during the accumulation period. SCD would be also shortened by about a month over Hokkaido.

KEYWORDS: Global warming impact, Seasonal snowpack, Snowpack modeling, Uncertainty

1. INTRODUCTION

Global warming would basically reduce the amount of snowpack (e.g. Kawase et al., 2013) and likely change its quality (e.g. Rasmus et al., 2004). In the previous studies, the snowpack response to the warming has been generally estimated by forcing the climate change projection, which is dynamically downscaled (DDS) into finer data with regional atmospheric model (RAM) from a coarse-resolution data provided by general circulation model (GCM), to a physical snowpack model, after the models have been validated by comparing with observations (Rasmus et al., 2004). However, the snowpack response was considerably uncertain affected by the uncertain future atmospheric projections among GCMs (Katsuyama et al., 2017). Although the uncertain snowpack projection was not spatially uniform because the local atmospheric response would be also uncertain introduced by the GCMs, the target locations had been limited because the calculated snowpack parameters such as snow water equivalent (SWE) was difficult to be validated in large region due to insufficient observation (e.g. Katsuyama et al., 2017). In this study, we validate a physical based snowpack model and estimate the global warming response of snowpack along with the uncertainty over Hokkaido, the northern island of Japan (Figure 1).

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2. MODEL AND DATA

2.1 Snowpack model

SNOWPACK model, a multi-layered Lagrangian model, basically solving the mass and energy conservations (Bartelt and Lehning, 2002), was used in this study as the physical snowpack model. The metamorphism scheme was set to an NIED option for Japanese snow (Hirashima et al., 2004). Snowfall/rainfall was continuously discriminated from surface air temperature and relative humidity (Matsuo and Sasyo, 1981). A simple soil-layer model was included with the bottom boundary fixed to the climatological air temperature at the target site.

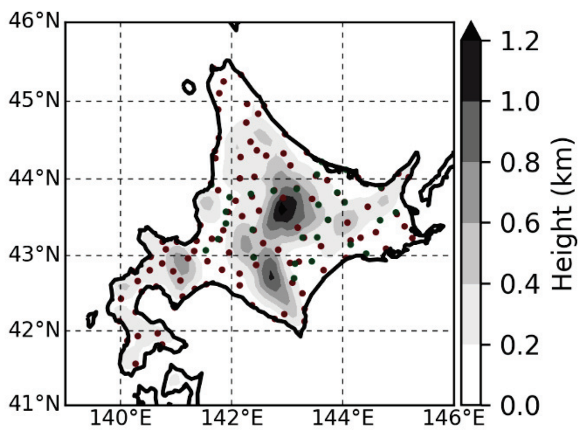

Figure 1 The topography of regional atmospheric model (RAM) providing the dynamically downscaled (DDS) data (grey scale) and positions of the Automated Meteorological Data Acquisition System (AMeDAS) stations (red dot) and the snow pit observations (green dot).

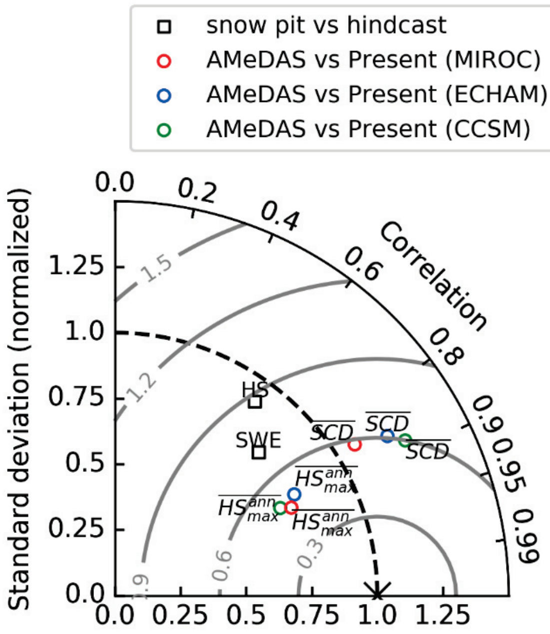

Figure 2 Taylor diagram describing the hindcast simulation (black square) and the calculated snowpack from the DDS-forced simulation under the present climate (colored circle) compared with the observations. The reference point is pointed by a cross mark. The standard deviation is normalized with the observation. The variable name of height of snow-cover (HS), snow water equivalent (SWE), the 10-year climatology of annual maximum HS ($\overline{\mathrm{HS}_{\mathrm{max}}^{\mathrm{ann}}}$), and that of snow-covered days ($\overline{\mathrm{SCD}}$) are denoted next to the scattered mark, respectively.

2.2 Global warming response

The global warming response of snowpack was estimated by forcing the dynamically downscaled (DDS) data from three GCMs, MIROC, ECHAM, and CCSM, which had been participated in the Coupled Model Inter-comparison Project, in the 1990s present climate and in the future climate defined as a decade when the global mean air temperature would increase by 2 K compared with the present climate (Kuno and Inatsu, 2014). The selection of +2 K warming enables us to separate the uncertainty of global change from that of the change in synoptic phenomena such as storm tracks, winter monsoon, and topographical precipitation (Inatsu et al., 2015).

2.3 Snowpack model validation

SNOWPACK model was validated by a comparison between snow-pit observation (Shirakawa and Kameda, 2018) and hindcast simulation at 28 locations in a beginning date of snow melting season during 2014-2017 (Figure 1). The hindcast simulation was performed by forcing atmospheric observation collected by Automated Meteorological Data Acquisition System (AMeDAS) to SNOWPACK at the nearest station to the snow pit observation. Additionally, height of snow-cover (HS) and snow-covered days (SCD) calculated from the DDS-forced simulation under the present climate was compared with the AMeDAS observation at 108 locations (Figure 1).

3. RESULTS

3.1 Snowpack model validation

The 10-year climatology of annual maximum HS and that of SCD, which were calculated from the DDS data of the present climate, was reproduced with the spatial correlation of 0.9 and the root mean square error of 50% compared with the AMeDAS observations, respectively (Figure 2). HS and SWE reproduced by the hindcast simulation were also comparable to the snow-pit observation.

3.2 Global warming response

Responding to the +2 K warming, the 10-year climatology of annual maximum SWE significantly decreased by 30-40% for all the GCM in the eastern and western Hokkaido (Figure 3). Similarly, the climatology of annual maximum HS also significantly decreased in the areas (not shown). In the northern Hokkaido, the decrease in the SWE and HS were uncertain with large variability among GCMs. The climatology of SCD would be also shortened by about a month over Hokkaido with moderate uncertainty in the east.

In order to clarify the source of the large snowpack decrease and uncertainty,

Table 1 The difference of annual-maximum area-averaged SWE (Q) and that of area-averaged precipitation (P) and runoff (R) amount integrated for the accumulation period between the future and present climate.

(kg/m2)	MIROC			ECHAM			CCSM		
	Q	P	R	Q	P	R	Q	P	R
W	−98	−71	+32	−88	−80	+9	−73	−63	+12
N	−67	−42	+37	−102	−71	+35	−41	−3	+43
E	−46	−32	+21	−59	−55	+8	−57	−61	+1

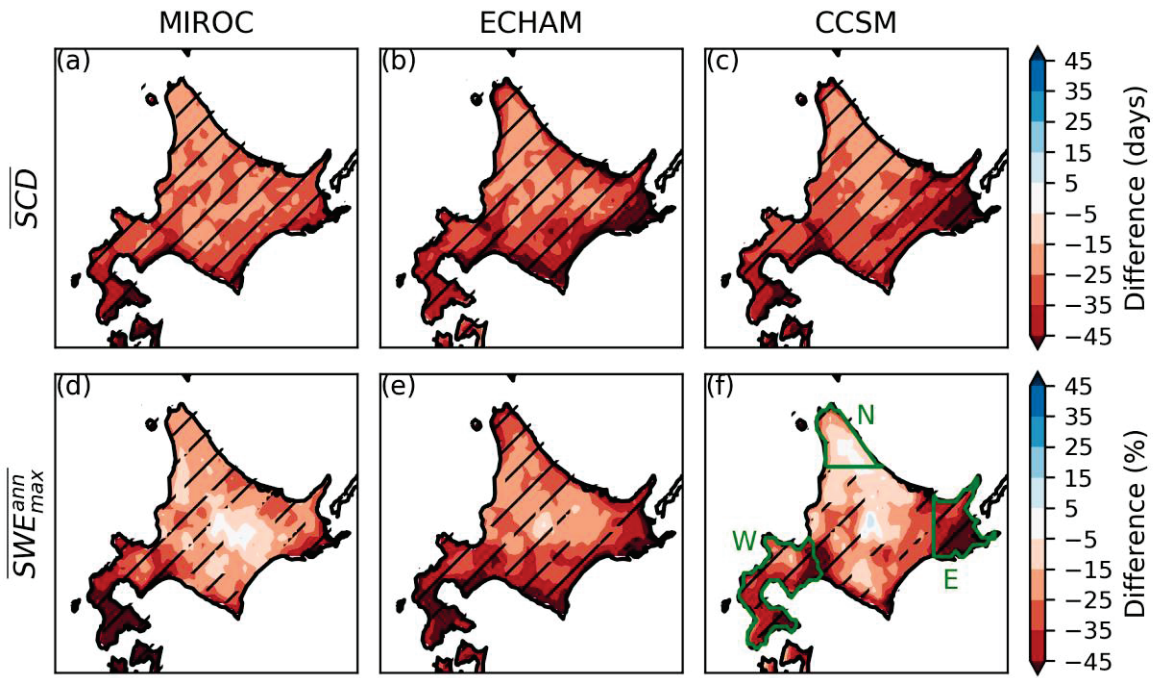

Figure 3 The difference of (a-c) $\overline{\mathrm{SCD}}$ (days) and (d-f) the 10-year climatology of SWE ($\overline{\mathrm{SWE}^{\mathrm{ann}}_{\mathrm{max}}}$; %) between future and present climates. The difference is normalized with the present climate. The area where the difference exceeds a 5% significant level is hatched. The marks of E, N, and W denote regions enclosed by green solid lines in (f).

precipitation and runoff amounts integrated for the accumulation period, which was defined as a beginning of snow-cover to a day when SWE became maximum in a season, in the west (W), north (N), and east (E) (Figure 3f), were investigated. Then, the decrease in the precipitation amount was the major contiribution to the decrease in the annual maximum SWE except for CCSM-boundary in N (Table 1).

4. CONCLUSION

We validated the SNOWPACK model by comparing with both the snow pit observation and AMeDAS observation. The results showed that the HS, SWE, and SCD were significantly reproduced over Hokkaido. After the validation, we estimated the global warming response of snowpack under the +2 K warming. The large decrease in the snowpack quantity was then estimated in W and E, while the decrease was uncertain in N with large variability among GCMs. Their decrease and uncertainty would be mainly caused by the uncertainty of a decrease in the precipitation amount in the accumulation period. The SCD would be shortened by about a month over Hokkaido.

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