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ダイナミカルダウンスケール手法による過去 20 年の気候再現性及び冬季積雪量予測の評価

Reproducibility of Past 20 Years Climate Using Dynamical Downscaling Method and Future Prediction of Snow Cover in Winter

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Abstract

This study conducted dynamical downscaling for Japan using a regional atmospheric model (TERC-RAMS) to create the spatially detailed meteorological data for the impact assessment of global warming on the surrounding fields including farming and hydrological cycle. In the first half of this paper, the downscaling for past 20-years climate was conducted and compared with the observational data. The simulated temperature was higher (lower) than the observed one in summer (winter) season, although the bias of temperature in most areas was less than 1℃ throughout year. Precipitation calculated by the model tended to overestimate, except for the summer rainfall in Kyushu and Okinawa. However, the simulated climate by the model was able to reproduce the past climate. In the second half, the snow cover change in 2070s was estimated by using the pseudo global warming method with regard to the low and high snow-cover years. The model results showed that the snow cover decreased over a large area. The snow cover in the low snow-cover year remained only in a part of Hokkaido. The snow cover in the high snow-cover year was limited in the regions with an altitude higher than 500 m. This result agrees with that of Hara *et al.* (2008). This study indicates that TERC-RAMS is available to predict inter-annual variation of snow cover. However, the results suggest that the simulation on the coarser horizontal resolution tends to underestimate the amount of snow cover and overestimate the impact of global warming on snow cover change.

要　旨

本研究は，将来の気候変化が農業や水循環に及ぼす影響を評価するための空間詳細な気象データを作成するため，日本域を対象として領域気候モデル（TERC-RAMS）を用いた力学的ダウンスケールを行った．論文の前半では，過去 20 年の気候を対象としたダウ

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ンスケール実験を行い，観測データとの比較を行った．夏季（冬季）の気温は観測に比べ高温（低温）バイアスであるが，多くの地域で気温バイアスは1℃以内であった．モデルで再現された降水量は九州と沖縄の夏季を除き，過大評価する傾向にあった．しかしながら，モデルは過去の気候を比較的よく再現出来ることが確認された．

論文後半では，疑似温暖化手法を用いて，2070年代の積雪量変化を評価した．積雪は広い範囲で減少がみられ，2070年代の少雪年は北海道を除くほとんどの地域で積雪が見られなかった．多雪年でも積雪は標高500 m以上の地域に限定される．この結果はHara *et al.*（2008）と一致するものの，TERC-RAMSは積雪量の年々変動は再現できるが，空間解像度が20 kmと粗いため積雪量を少なく見積もる傾向があることが示された．

I Introduction

Temperature rising following the increase of anthropogenic green house gases was observed all over the world. The Intergovernmental Panel on Climate Change (IPCC)'s 'Fourth Assessment Report (AR4)' shows the results of future climate projections estimated using general circulation models (GCMs), based on several future emission scenarios involving greenhouse gases and aerosol precursor (IPCC, 2007). Most of them indicated the global warming trend would continue.

Surface temperature had increased at rate of 1.11℃ per 100 years, during the 111 years from 1898 to 2008 in Japan (JMA, 2008). It is suspected that the global warming causes not only a higher frequency of extremely hot days and a change in the distribution of precipitation, but also influences on farming, fishing and forestry. Recently, a lot of papers have reported on the impacts of global warming on surrounding fields, such as those mentioned above, using future climate data projected by GCMs. However, the following problems with this approach are worth noting. The first one is a scale gap in spacial resolution between GCM and the impact assessment. For example, climate data with at least 1km or 10km resolution is needed to evaluate crop productivity in future climate (Iizumi *et al.*, 2008; Okada *et al.*, 2009), while the resolution of GCM is mainly 250km. The second one is that the important variables for the assessment fields are not always provided in appropriate frequency. This is because the saving frequency is not enough and the saved variables are limited due to storage limitation, since the GCM output needs too large content to save. In such a case, impact assessment researcher must estimate the needed value using another valuable.

Dynamical downscaling and statistical downscaling methods are utilized as methods for bridging the gap between GCM and the impact assessment study. Both are the methods for estimating spacial and temporal high resolution data from the coarse resolution data of GCM. Our study carried out dynamical downscaling simulation with a regional climate model, in order to create detailed meteorological data in the future for Japan. We will evaluate the reproducibility of past climate in the simulation in section III. Then, we perform the future climate simulation of snowfall and snow cover, which are important as water resource, in 2070s and discuss the projected change of distribution of snow cover.

II Data and method

1. Dynamical downscaling simulation with using a regional climate model

The Terrestrial Environment Research Center (TERC) Regional Atmospheric Modeling System (RAMS) (Sato *et al.*, 2007; Inoue and Kimura, 2007) was adopted for the climate simulation. The original RAMS was developed by Pielke *et al.* (1992). Model settings are described in Table 1. The model domain has 130 x 140 grids with a 20 km horizontal interval, and covers the while of Japan as shown in Fig. 1. The vertical grid system is terrain following coordinate system, which has 30 layers with depth of 65 m at the lowest layer and stretching depth at maximum of 1100 m. Arakawa-Schubert convective parameterization (Arakawa and Schubert, 1974) and microphysics parameterization (Walko *et al.*, 1995) were used to calculate precipitation. Fluxes between air and land at ground surface were evaluated by Louis (1979). Soil and vegetation temperature, moisture are calculated by the soil model developed by Tremback and Kessler (1985) and the vegetation model constructed by Avissar and Pielke (1989). The calculation of longwave and shortwave radiation was done by following the Nakajima radiation scheme (Nakajima *et al.*, 2000).

Numerical simulations were conducted for two cases listed in Table 2. First case involves

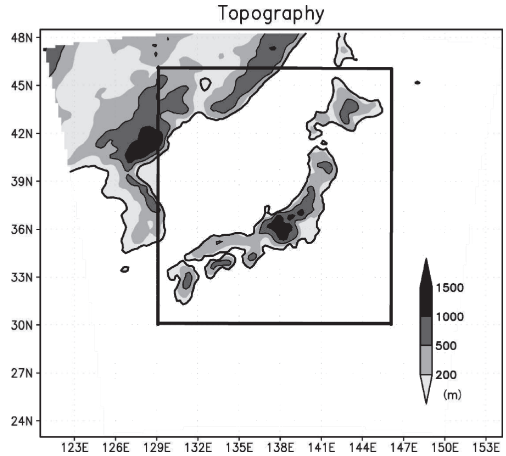

Fig. 1 Calculation domain. Horizontal grid number is 130 x 140 grids with a 20 km horizontal interval. The inside square indicates the illustrated area in Figs. 3-5.

Table 1 Description of regional climate model

Horizontal grid	130 x 140 grids Center coordinate 137.5° E, 36.0° N 20 km horizontal resolution
Vertical grid	30 layers with 65 m thickness in lowest layer, maximum thickness is 1100 m
Soil layers	0.00, 0.02, 0.11, 0.18, 0.30, 0.50, 0.70, 0.90, 1.80, 2.50, 2.75 m below ground
Vegetation type	Tall grass
Soil texture	Silt loam
Sea surface temperature	10 days mean SST of JRA25

Table 2 List of numerical experiments

Run name		Calculation Period
CTL20	Hindcast using reanalysis data (JRA25/JCDAS)	1985-2004
PGW-LS	Pseudo global warming experiment in low snow-cover year	1993
PGW-HS	Pseudo global warming experiment in high snow-cover year	2000

a 20-year present climate simulation (CTL20) from January 1979 to December 2004. Japanese 25-year ReAnalysis (JRA25)/JMA Climate Data Assimilation System (JCDAS) (hereafter JRA together) was used for initial and boundary conditions (Onogi *et al.*, 2007). Atmospheric boundary data was given by a 6-hourly interval with 1.25 x 1.25 horizontal resolution, including variables of: RH (relative humidity), T (temperature), U (the x-component of velocity), V (the y-component), and Z (elevation). Sea surface temperature (SST) on T106 Gaussian coordinate was converted to 1.25 x 1.25 lat/lon coordinate and averaged over 10 days. During the simulation, SST was replaced in an interval of 10 days to next one. The 20-year simulation was calculated by 60 time-slice experiments. Each simulation period was 6 months; from November to April, from March to August, and from July to December. The first two months are a spin-up period and the last four months are analyzed.

The second experiment is a future climate simulation. In this study, the Pseudo Global Warming (PGW) downscale method was adopted (Kimura and Kitoh, 2007; Sato *et al.*, 2007; Kawase *et al.*, 2008) instead of the direct downscaling method. The difference between the two methods relates to how they provide the boundary condition. The PGW data is obtained by the reanalysis data adding the difference between the monthly mean of future climate in the 2070s and that of present climate in the 1990s simulated by GCM. The climate data used in this study was gained from the MIROC-medres output following the A2 scenario, provided from the World Climate Research Programs (WCRP) Coupled Model Intercomparison Project (CMIP3) multi-model dataset. The A2 scenario is one of the future emission scenarios in IPCC Special Report on Emissions Scenarios (SRES). The scenario assumes that social economy will develop under the concept of self-reliance and preservation of local identities. Four dimensional data assimilation by the newtonian relaxation method was applied to all experiments to avoid the bias of calculated variables in a regional climate model. The outermost 8 grids were nudged with a 10 minute time constant, while the inner area used the weak nudging time constant of 5 days.

2. Validation tool for model results

The evaluation tool for past climate experiments was developed by Tanaka (2008). The tool calculates model biases of temperature and precipitation on every prefecture or river-system basis. That enables us to check the model biases as mosaic map. The observation data provided by the Automated Meteorological Data Acquisition System (AMeDAS), distributed with an interval of about 17 km throughout Japan, was used as an evaluation data. In the first stage of the tool, the AMeDAS station located in each model grid is detected. If several AMeDAS stations are found in a certain grid, the average of the usable data except for missing data is defined as the evaluation data. When there is no observation point in a model grid, the grid is excluded from the validation process.

In the second stage, the model biases are calculated. From both model and observation data, the 20 year means of monthly temperature and monthly accumulated precipitation are calculated, when both data are available. The model temperature is corrected for the difference of elevation from the observation point. The bias of temperature is defined as the difference between the monthly mean temperature simulated by model and the one provided from actual observation. The bias of precipitation is a ratio of the monthly accumulated precipitation calculated by the model to one provided via observation.

Ⅲ Reproducibility of present climate

The biases of 20 year means of simulated temperature and precipitation are shown in Fig. 2. The prefecture with the negative bias more than −1 and −0.1℃ are shown by white and light gray, respectively, while one with the positive bias more than 0.1 and 1℃ are indicated by gray and dark gray, respectively. The temperature in winter has negative bias, while the one in summer shows positive bias. However, the biases in most areas are limited to 1℃, except for June, November, and December (Fig. 2a). There are higher temperature biases in Hokkaido and Tohoku regions in January and February. The reason presumed for this is that the model weakly estimates the effect of radiation cooling enhanced by snow cover.

The bias of precipitation is indicated in Fig. 2b. The color shows the ratio of model to observation. White and light gray mean underestimate, while gray and dark gray indicate overestimate. The TERC-RAMS tends to underestimate precipitation in Shikoku, Kyushu, and Okinawa in Baiu-summer season, that is

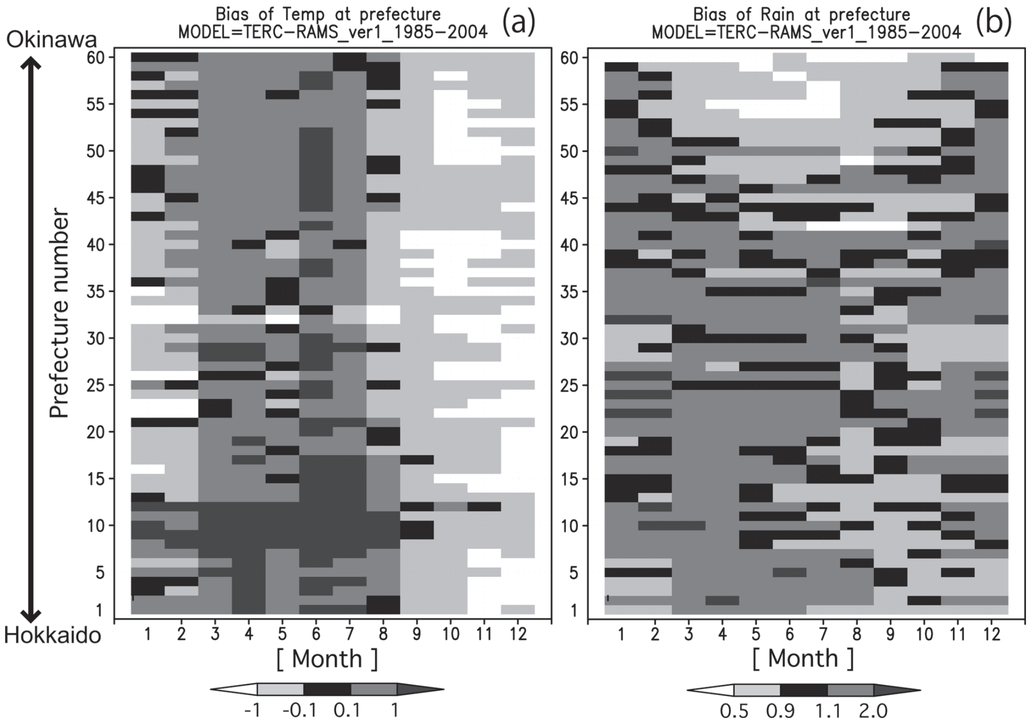

Fig. 2 Biases of 20 year means of (a) simulated temperature and (b) simulated precipitation by TERC-RAMS. The bias of temperature is defined as the difference between the monthly mean temperature simulated by model and the one provided from observation. The bias of precipitation is a ratio of the monthly accumulated precipitation of model to the one provided from observation.

eguivalent to about half of the observations. This is because the model reproduces a relatively small amount of rain associated with the baiu rain band and typhoons.

The temperature bias has seasonal dependence, however the dependence of the bias on prefecture is small. In addition, the precipitation bias is small throughout Japan. Thus, the climatology estimated by model was able to reproduce the present climate, although the simulated results include the biases described above.

Ⅳ Future prediction of winter snow cover change

Fig. 3 shows the observed and simulated

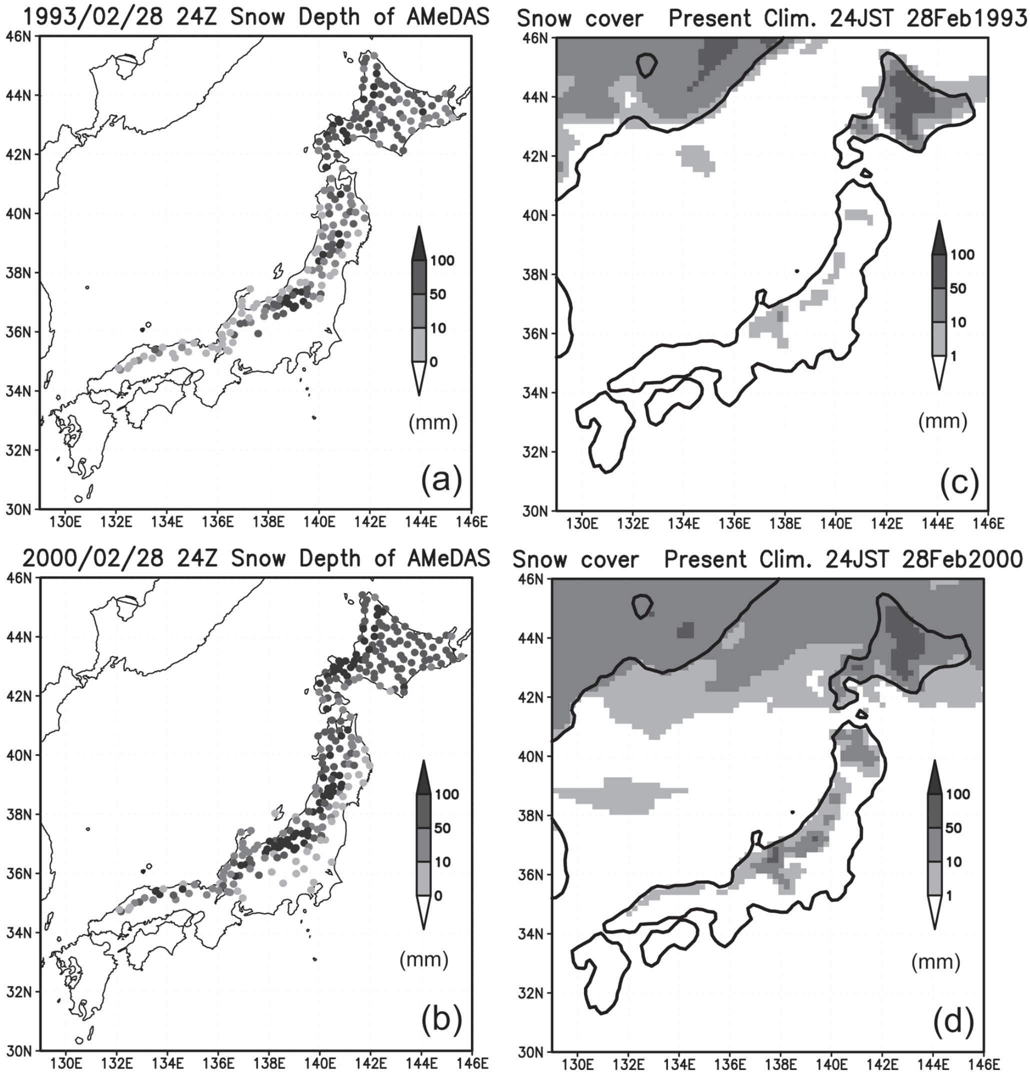

Fig. 3 Observed and simulated snow cover at 24 JST on 28th February in the low snow-cover year (1993) and the high-snow cover year (2000); (a) and (b) observed by AMeDAS and (c) and (d) simulated by TERC-RAMS.

snow cover at 24 JST on 28th February in the low snow-cover year (1993) and the high snow-cover year (2000). The temperature in the low snow-cover year was 1 ～ 1.5℃ higher than the one in the high snow-cover year (Fig. 4). Snow cover depth of model was calculated from the water equivalent of the snow cover under the assumption that snow cover density is 300 kg/m^3. In the low snow-cover year, snow cover was distributed from Hokkaido to the Chugoku region, while the areas with snow cover of more than 100 cm are limited to part of Hokkaido, Tohoku, and Hokuriku (Fig. 3a). In the high snow-cover year, the area with snow cover of more than 100 cm is widely distributed in the Sea of Japan side. The snow cover evaluated by the model is largely underestimated compared to AMeDAS, both in low and high snow-cover years. This is

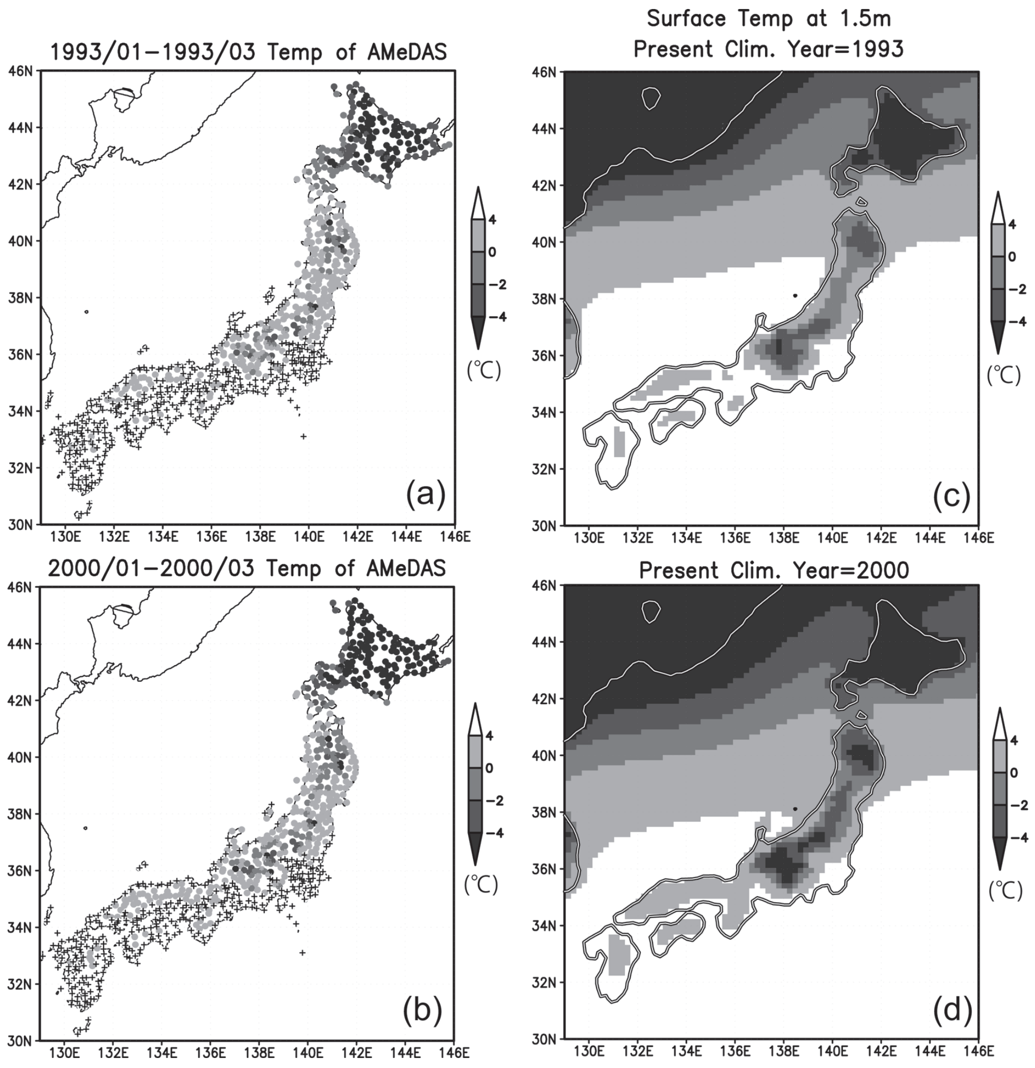

Fig. 4 Seasonal averaged temperature in DJF in the low snow-cover year (1993) and the high snow-cover year (2000); (a) and (b) observed by AMeDAS and (c) and (d) simulated by TERC-RAMS. The plus signs in (a) and (b) indicate the stations with temperature more than 4℃.

because the 20km horizontal resolution of RAMS has a lower peak of elevation and cannot express detailed topography. The smooth topography makes the ratio of snow to rain decrease and the snow more soluble. However, RAMS can reproduce the characteristics of interannual variation in each year.

The difference of snow cover between the CTL run and PGW run is shown in Fig. 5, which equals snow cover change in the 2070s compared with the 1990s. A decrease of snow cover is detected over a large area. The snow cover of the PGW-LS run (Fig. 5a) remains only in a part of Hokkaido. The PGW-HS run indicates snow cover in the high snow-cover year is distributed in Hokkaido, Aomori and Hokuriku, although snow cover in Honshu island is less than 10 cm and decreases about 50 cm from the CTL run.

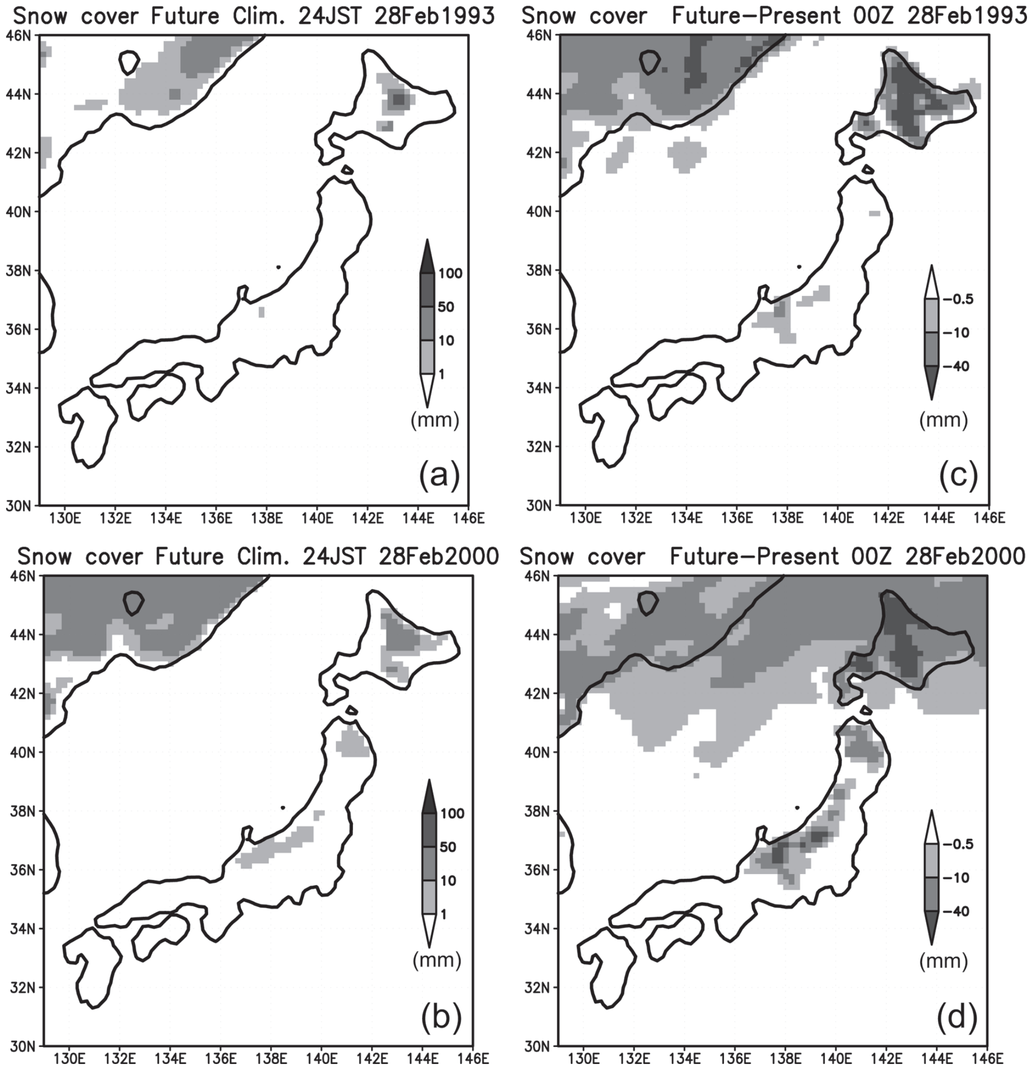

Fig. 5 Snow cover in future climate of 2070s simulated in (a) PGW-LS, (b) PGW-HS, and snow cover change in (c) the low snow-cover year and (d) high snow-cover year.

The areas with snow cover in the 2070s (Figs. 5a and 5b) are confined to regions with an altitude higher than 500 m. This result agrees with that of Hara *et al.* (2008). However, the impact of global warming on the amount of snow cover (snow cover change from the CTL run to the PGW run) is extremely large compared to Hara *et al.* (2008). It is speculated that coarser horizontal resolution evaluates smaller snowfall, and smoother topography enhances melting of accumulated snow.

V Conclusion

This study conducted downscaling simulation of past climate in Japan during 20 years from 1985 to 2004, using the TERC-RAMS with a 20km horizontal resolution. The simulated temperature was higher than the observed one in summer season, while the temperature in winter was lower than observation. However, the bias of temperature in most areas was less than 1℃ throughout year. Precipitation calculated by RAMS tended to overestimate, except for the summer rainfall in Kyushu and Okinawa. However, the simulated climatology could reproduce the past climate. The snow cover change in 2070s was estimated by using the pseudo global warming method with regard to the low and high snow-cover years. The RAMS is available to predict inter-annual variation of snow cover although the amount of calculated snow cover was lower than observation. The reason for this is that the topography of the model is smoother than the real topography and is thus unable to express detailed land shape. Our study suggested that coarse horizontal resolution and smooth topography in the model overestimate the impact of global warming on snow cover change.

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