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Mapping of Japanese areas susceptible to snow cover change

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Abstract Many of the Japanese regions subject to seasonal snow cover are characterized by low elevations and relatively high winter temperatures. A small change in winter temperatures could render many of these areas susceptible to snow cover change and consequently affect water resources management. This paper describes a climatological approach combined with an AGCM output to identify the regions and main river basins most sensitive to snow cover change in the case of climate change in Japan. It was found that a 1°C rise in temperature during the winter season could increase the snow-free area of Japan by 6%. The snow cover of Tohoku region and Mogami and Agano river basins was found to be the most sensitive to climate change. The AGCM output for a future scenario presents a reduction in total snowfall and an earlier peak in snowmelt for all regions.

Key words snow cover; climate change; AGCM; AMeDAS; APHRO_JP; Japan

Cartographie des régions du Japon sensibles aux changements de la couverture nivale

Résumé La plupart des régions japonaises soumises à une couverture nivale saisonnière sont caractérisées par de faibles altitudes et des températures hivernales relativement élevées. Dans ces régions, un petit changement des températures hivernales peut modifier le régime de la couverture nivale et par conséquent avoir une incidence sur la gestion des ressources en eau. Cet article décrit une approche climatologique combinée avec une sortie de MCGA (Modèle de circulation générale atmosphérique) pour identifier les régions et les bassins les plus sensibles aux changements de la couverture nivale provoqués par le changement climatique au Japon. On a constaté qu'1°C de température en plus au cours de l'hiver pourrait augmenter la surface dépourvue de neige du Japon de 6%. Les couvertures nivales de la région de Tohoku et des bassins du Mogami et de l'Agano se sont révélées être les plus sensibles au changement climatique. La sortie MCGA d'un scénario futur présente une réduction du total des chutes de neige et un maximum plus précoce de la fonte des neiges pour toutes les régions.

Mots clefs couverture nivale, changement climatique; MCGA; Système d'acquisition automatique de données météorologiques; APHRO_JP; Japon

INTRODUCTION

Many areas of Japan are subject to seasonal snow cover, including some with the heaviest snowfall in the world (Akiyama 1981, Suzuki 2011). These areas (located in the mid-latitudes, with low elevations and relatively high winter temperatures) are very susceptible to climate change, because small changes in winter average temperatures could transform them from seasonal-snow dominated to rainfall-dominated areas (Ishizaka 2004, Nolin and Daly 2006). Transformations in the spatial and temporal distributions of the snow cover can have serious effects on water resources management and food production in a highly populated country like Japan (Inoue and Yokoyama 2003, Kim *et al*. 2010b, Ma *et al*. 2010).

In the past century, a decrease in snow accumulation has been observed in Japan and this is mainly attributed to a rise in winter temperatures. The largest decrease was observed in the northwestern Japanese coastal area (Ishizaka 2004, Takeuchi *et al*. 2008, Ishii and Suzuki 2011, Suzuki 2011). This area is highly affected by the winter monsoon; air masses coming from the Asian continent pick up moisture in the Japan Sea and precipitation is enhanced by the orographic effect of the coastal mountain range (Akiyama 1981, Iwamoto *et al*. 2008).

Several studies using high-resolution general circulation models (GCMs) and atmospheric general circulation models (AGCMs) have been carried out to analyse climate change impacts on precipitation and temperature at the end of the 21st century in Japan using emissions scenarios such as SRES-A2 or SRES-A1B. The introduction of smaller topography in models with 20-km resolution allows simulation of realistic precipitation patterns in Japan (Mizuta *et al*. 2006). However, those models still represent regional precipitation averages better than point estimates (Kitajima *et al*. 2010). Despite the model bias of not representing extreme rainfall well, Mizuta *et al*. (2005) found that precipitation indices should increase, especially in western Japan and Hokkaido, and that the changes in other areas were insignificant. Kurihara *et al*. (2005) showed that the precipitation increase would be concentrated in the summer months, while winter precipitation would have no change or a slight decrease. Much of this possible increase in precipitation is related to the summer typhoon season (Kitoh *et al*. 2009).

Temperatures in Japan are also expected to rise when considering the future emissions scenarios (Kurihara *et al*. 2005, Mizuta *et al*. 2005, Kitoh *et al*. 2009). The number of frost days is expected to decrease and the growing season length is expected to increase in Japan (Mizuta *et al*. 2005). The temperature changes are neither spatially nor temporarily uniform over Japan. The temperature in higher latitude areas, e.g. Hokkaido, are projected to increase more (by up to 4°C) than at lower latitudes (by up to 3°C), and this is expected to happen especially in the winter season, which may be due to a feedback of future snow and ice cover reduction (Kurihara *et al*. 2005, Mizuta *et al*. 2005).

If the average temperatures increase as indicated above, the seasonal snow cover over large areas of Japan would be affected, due to temperatures being above the rain *vs* snow temperature threshold. Ogawa and Nogami (1997) utilized observed temperature and precipitation with seven different scenarios of uniform increase in temperature and increase/decrease in precipitation, which resulted in a significant decrease in snow cover and snowmelt. As Inoue and Yokoyama (2003) noted, those changes in temperature and precipitation are not spatially uniform; they applied instead the decadal results of five sets of GCM to analyse the impacts on future snow depth. Hara *et al*. (2008) used dynamical downscaling and focused on the early winter season of a year with high and another one with low snow cover. Hara *et al*. (2008) found that snow depth decreases more drastically in areas with elevation lower than 500 m, and the decrease was significant over all areas of Japan, while Inoue and Yokoyama (2003) found little to no change in Hokkaido and the mountain area of Honshu. Hosaka *et al*. (2005) showed that the snow water equivalent (SWE) decreases in the heavy snow areas. Analysing the results from a high-resolution AGCM, Kim *et al*. (2010a) found that snowfall amounts between Kyushu and Kansai will become negligible. All results suggested that temperature is the major factor determining the changes in snowfall and snow cover.

These studies on temporal and spatial changes in snow cover have some discrepancies which can be partly related to differences in the methods they adopted. Ogawa and Nogami (1997) disregarded the spatial variability of the projected climate changes. Hara *et al*. (2008) used snow cover projections limited to December and relied on two years of observations, disregarding the inter-annual variability of the winter seasons. Inoue and Yokoyama (2003) classified and compared the snow environment based on only five years of observation and decadal future point predictions.

In this paper, we reconcile some of the above-mentioned methods by using a climatological snow classification system (Sturm *et al*. 1995, Nolin and Daly 2006) to address the following question: Which seasonal snow covered regions and main river basins of Japan are more sensitive to climate change? We compare the snow classification results by using long-term observed meteorological data and scenarios of spatially-uniform increases in air temperature and the output from a high-resolution AGCM. This method allows us to consider the core winter season, the influence of spatially-uniform or distributed temperature projections, and the inter-annual variability of meteorological factors. By focusing on snow mapping and classification, we try to elucidate which areas in Japan should be considered hotspots for future studies.

METHODOLOGY

Observed and simulated climate data

Our analysis is based on the core winter months (December, January and February, hereafter DJF) of the two periods we defined as present (1979–2003) and future (2075–2099). We used the freely-available daily precipitation product APHRO_JP (Kamiguchi *et al*. 2010; http://www.chikyu.ac.jp/precip). The APHRO_JP product is a daily historical (1900–2009) precipitation data set prepared with a resolution of 0.05° × 0.05° over Japan. These data show good results for mean and extreme precipitation statistics (Kamiguchi *et al*. 2010). However, wind-induced undercatch is not considered and could result in an underestimation of winter precipitation.

Daily mean temperature data was collected from the Automated Meteorological Data Acquisition System, AMeDAS, maintained by the Japan Meteorological Agency (JMA; http://www.jma.go.jp). The AMeDAS point data were interpolated to the same APHRO_JP grid using the natural neighbour interpolation. After quality control, an average of 830 stations over the Japanese territory were used for each winter. The daily mean temperature was used to calculate the mean DJF temperature for each winter at each grid cell (T_{mean}). Most of these stations are in lower, less snowy and therefore warmer locations, which can have the effect of average temperatures in higher locations being overestimated.

To consider future climate projection, we used precipitation and temperature output from the 20-km resolution AGCM (hereafter AGCM20) of the Meteorological Research Institute (MRI) of the JMA. The AGCM20 is based on the operational numerical weather prediction model of the JMA (Mizuta *et al*. 2006, Kitoh *et al*. 2009) and uses sea-surface temperature projections based on the SRES A1B emissions scenario. The high spatial resolution of this GCM allows for orographic effects, which are very important in the climate of Japan. The meteorological outputs of this model are separated into three periods of 25 years each: present (1979–2003), near future (2015–2039) and future (2075–2099). We also used spatially-uniform increases of temperature over the observed (AMeDAS) and simulated (AGCM20) present period to compare with the results from the AGCM20 future period.

Snow cover mapping

Sturm *et al*. (1995) proposed a classification system for seasonal snow cover with six different classes. Based on the assumption that unique snow cover attributes are dependent on the climate, the classes can be derived directly from winter meteorology (e.g. air temperature, precipitation and wind). Areas with high winter snowfall and high winter precipitation are classified as maritime snow in that system. Nolin and Daly (2006) explored how climate change might alter the distribution of snow classes in the Pacific Northwest of the USA. That study focused especially on the maritime class because areas with this type of snow cover are considered to be at risk of conversion to rainfall-dominated winters.

The snow cover over Japan was classified with a binary decision tree using the meteorological data of DJF. Following Sturm *et al*. (1995) and Nolin and Daly (2006), we used the first three steps of their classification process (Table 1). A grid cell is considered to be:

(a) snow-dominated if T_{mean} is below the rain *vs* snow temperature threshold value (T_{thresh}), it is rain-dominated otherwise;
(b) cold snow climate if T_{mean} is less than T_{thresh} – 2.0°C;
(c) high winter precipitation climate if the mean DJF precipitation, $P_{mean} > 2$ mm d^{-1}.

We did not use the wind in this classification since it is not considered a determinant factor for the classification of maritime snow (Sturm *et al*. 1995). The maritime snow, which falls in the warm snow with high winter precipitation areas (Table 1), is also referred as “at-risk snow” since these areas are “at

Table 1 Threshold values used for the snow classification (adapted from Nolin and Daly 2006).

Criteria	Threshold
Rain *vs* Snow dominated	DJF $T_{mean} \leq T_{thresh}$ for –3.5°C ≤ $T_{thresh} \leq 3.5$°C
Cold *vs* Warm snow	$T_{thresh} = 2.0$°C for –3.5°C ≤ $T_{thresh} \leq 3.5$°C
High *vs* Low winter precipitation	$P_{mean} \geq 2.0$ mm d^{-1}

risk" of converting from being snow-dominated to rainfall-dominated (Nolin and Daly 2006).

The T_{thresh} value is variable depending on the region and atmospheric conditions. Snow can fall at ground temperatures higher than 0°C, and rain can fall at temperatures lower than 0°C. To account for and explore this uncertainty in precipitation types, we decided to use a range of T_{thresh} values varying from –3.5°C to 3.5°C. Similar to Ogawa and Nogami (1997) and Nolin and Daly (2006), one of the warming scenarios we used is the uniform increase in winter temperatures (0.5°C to 3.5°C in 0.5°C intervals). The other way was the use of AGCM20 output temperature for the future scenario. Our choice of using both uniform increase in temperature and AGCM output was to compare the significance of spatially-distributed temperature in relation to a more realistic atmospheric model. The more realistic representation of the AGCM20 is important in accounting for the changes in atmospheric moisture which could increase snowfall even though temperatures increase.

Frequency of cold winters

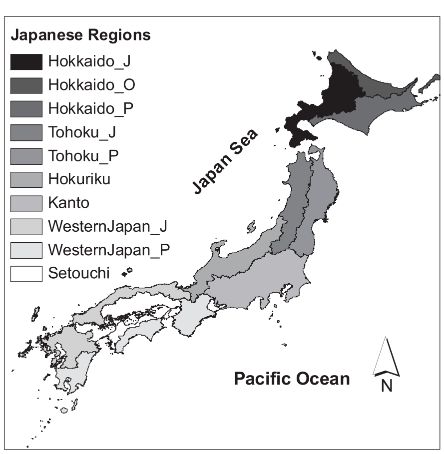
Depending on climatic variability, places with the same average temperatures could have completely different numbers of cold and warm winters. Therefore, the frequency of cold winters is an important parameter for analysing the distribution and changes of temperatures during the study periods. For each grid cell, the relative frequency of cold winter for each data set and period was calculated by dividing the number of winters when $T_{mean} < T_{thresh}$ by the total number of winters (i.e. 24 complete DJF periods in 25 years).

Main Japanese regions and river basins

Japan is an archipelago of 377 944 km^2 composed of four main islands (Honshu, Hokkaido, Kyushu and Shikoku) and the Okinawa region in the south of the country. The population is about 128 million and is concentrated in about 30% of the territory. The country is very mountainous and about 70% of the area is covered by forest. In this analysis, we divided the four main islands into 10 regions (Fig. 1(a)) related to the main climatic influences of the Sea of Japan (with heavy snowfall in the winter) and the Pacific Ocean (high summer rainfall). We did not consider Okinawa in the analysis, since snowfall is negligible in its tropical to subtropical climate.

Hokkaido, in the north, is the second largest island with relatively cool summers and cold winters. Hokkaido was subdivided into the Japan Sea, the Pacific Ocean and the Okhotsk Sea areas. The Tohoku region is located in the northeast of the Honshu (Japanese main island). Tohoku is divided from north to south by the Ou Mountain range. The Kanto region includes approximately one third of the Japanese population and is where the capital Tokyo is located. The Hokuriku region has the highest snowfall in Japan and the some of the highest in the world (Suzuki 2011); e.g. in the Murodo-daira area of Tateyama, average snow depths reach 7 m. The Western Japan region was divided into three parts, and Setouchi is the Inland Sea region and has moderate climate with relatively low precipitation.

To classify and analyse basin-wide snow cover sensitivity, we selected 10 main river basins (Fig. 1(b)) considering basin area, geographical location and social and economic importance. These rivers are considered first-class river systems and



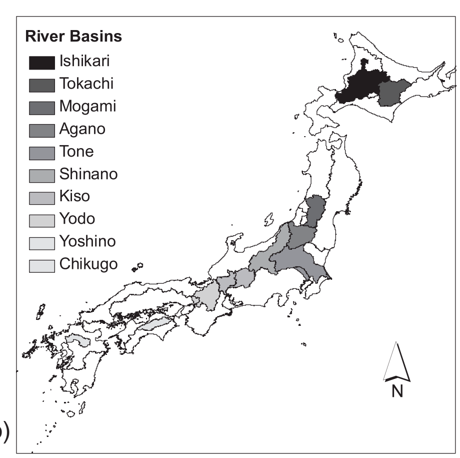


Fig. 1 (a) Main Japanese regions and (b) river basins.

should be prioritized for conservation. Japanese rivers are characterized by mountainous topography and steep gradients. Most are highly controlled with dams used for water supply, electricity generation and flood control. That is the case of the Tone River that drains into the Pacific and has the largest basin in Japan. The Yodo River basin supplies water for up to 16 million people in the Kansai region.

Industrialization and urbanization were a main source of river pollution and, during the 1960s and 1970s, major environmental pollution control laws were established. Changes in snowmelt regimes could affect sediment transport and water quality in Japanese rivers. Ishikari River, located in Hokkaido has one of the largest basin areas in Japan and the sediment transport occurs mainly due to snowmelt (Le *et al*. 2006).

RESULTS AND DISCUSSION

Snow cover mapping of Japan

The snow cover classification for the present period with two different snow *vs* rainfall temperature values (T_{thresh}) is shown in Fig. 2(a). The maps display the classification for T_{thresh} of 0°C and 2°C using AMeDAS interpolated temperature and APHRO_JP rainfall data, AGCM20 temperature for the present period with APHRO_JP rainfall (AGCM20-P.Aphro) and AGCM20 temperature and rainfall output for the present period (AGCM20-P). We classified the snow in Japan using T_{thresh} values ranging from –3.5°C to 3.5°C, but we display the maps for 0°C and 2°C because they are the most commonly adopted in modelling studies.

The grey areas are classified as snow-free area. The areas in red are the warm snow with high precipitation during the winter season, also referred as at-risk snow. AMeDAS presents a much higher snow-free area than AGCM20 output. This is because the meteorological stations are usually located in the lower areas and the interpolation method might be deficient in representing the temperatures in areas with higher elevation.

With an increase in T_{thresh}, more areas become classified as having seasonal snow. This parameter controls snow-free area, while precipitation amount controls the high precipitation category. The AGCM20 usually overestimates the total precipitation and Fig. 2 shows that AGCM20-P has more areas classified as high precipitation and consequently more at-risk snow areas.

Since temperature rise in future simulated scenarios varies by up to 4°C, the results using a uniform increase of 3°C are displayed in Fig. 2(b). The scenarios presented are: interpolated AMeDAS temperature plus spatially-uniform 3.0°C increase and Aphrodite precipitation data (AMeDAS.gw3); present period AGCM20 simulation with a spatially-uniform 3.0°C temperature increase (AGCM20-P.gw3) and future period AGCM20 simulation (AGCM20-F).

The pattern of snow cover is very similar between AGCM20-P.gw3 and AGCM20-F, which suggests that using scenarios with uniform temperature increase is a reasonable option. Snow class with high precipitation is larger in AGCM20-F, such as the case in Hokkaido. This means that the model simulates more precipitation in the winter, but not necessarily more snowfall (Fig. 7(a)). For all data sets, the snow-free areas increase compared to the present. However, as for the present scenario, AMeDAS has much more snow-free area than the other data sets.

By varying T_{thresh} values, we can analyse the sensitivity of total at-risk snow area and snow-free area in Japan. Figure 3(a) shows the variation of total at-risk snow area with the different T_{thresh} values. At-risk snow area increases close to T_{thresh} of 0°C for AMeDAS and AGCM20-F, but decreases for AGCM20-P. For comparison, we plotted the results using AGCM20 present and future output of temperature and precipitation (AGCM20-P and AGCM20-F), and AGCM20 temperature using APHRO_JP precipitation (AGCM20-P.Aphro and AGCM20-F.Aphro). The AGCM20 tends to overestimate precipitation and, as a result, there is a larger at-risk snow area. However, the sensitivity pattern resulting from using either APHRO_JP or AGCM20 precipitation is not affected.

The total Japanese area classified as at-risk snow by using the AMeDAS temperature with the APHRO_JP data set varies from 3.3% with the lowest T_{thresh} to 10.9% when $T_{\text{thresh}} = 0.5$°C. This variation is smaller for the AGCM20 output. It ranges from 8.1% to 12.7% for the AGCM20-P and 5.9% to 9.7% for the AGCM20-P.Aphro. In the future scenario using AGCM20, the values of total at-risk snow area peak for $T_{\text{thresh}} = 1$°C and they range from 7.9% to 12.3% for AGCM20-F and 5.7% to 9.8% for AGCM20-F.Aphro.

Figure 3(b) shows the variation in snow-free area with T_{thresh}. The area classified as snow-free by using AMeDAS is about 10% more than using AGCM20-P. There is no difference between the variation of snow-free area obtained by using

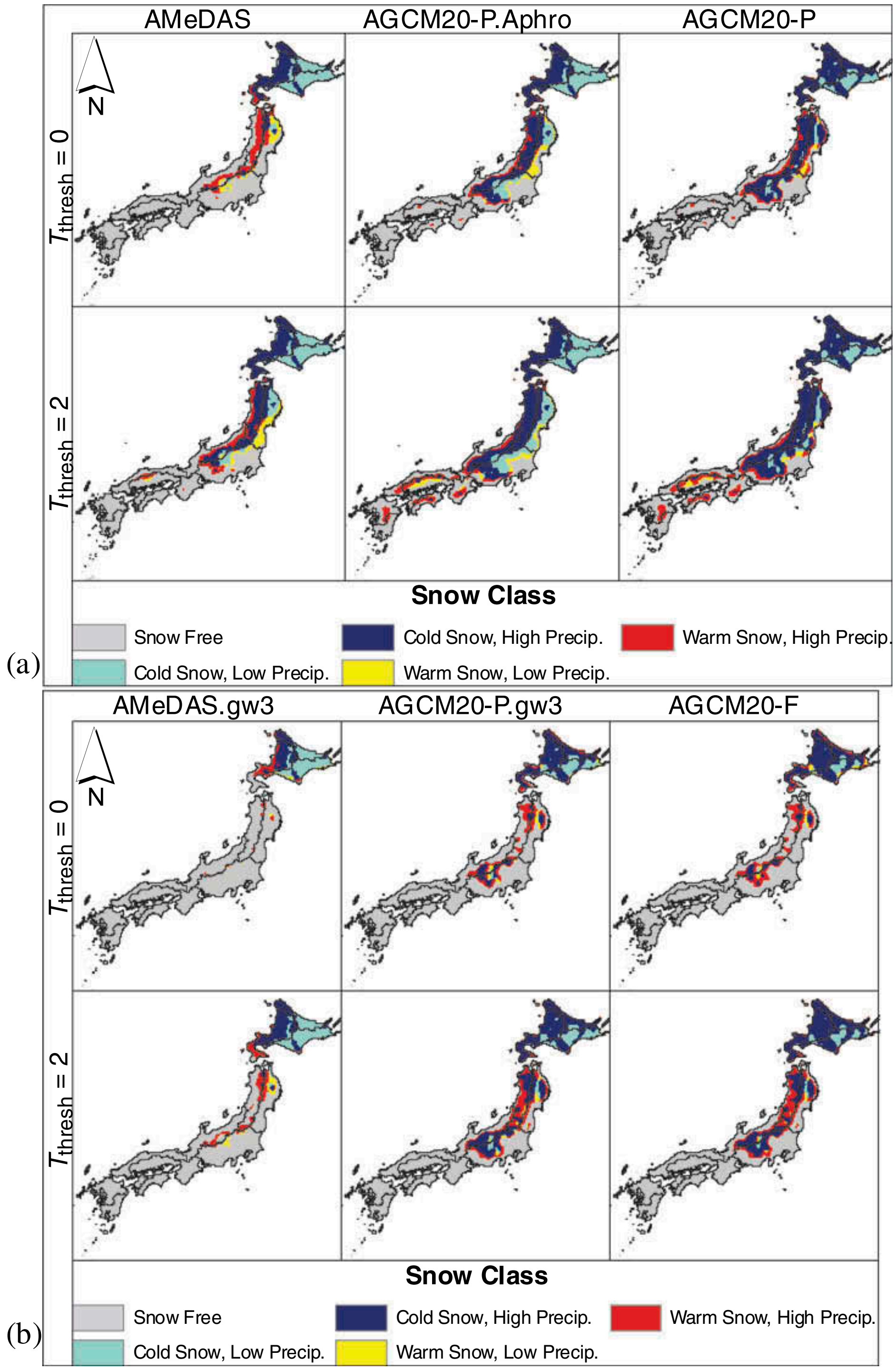


Fig. 2 Maps of present snow cover class using two different rain *vs* snow temperature threshold values (T_{thresh}): (a) present snow cover class; and (b) future snow cover class. AMeDAS: interpolated AMeDAS temperature and Aphrodite precipitation data; AGCM20-P.Aphro: present period AGCM20 temperature output and Aphrodite precipitation data; AGCM20-P: present AGCM20 temperature and precipitation output data; AMeDAS.gw3: interpolated AMeDAS temperature plus spatially-uniform 3.0°C increase and Aphrodite precipitation data; AGCM20-P.gw3: present period AGCM20 simulation plus spatially-uniform 3.0°C increase; and AGCM20-F: future period AGCM20 simulation.

either the APHRO_JP precipitation or the output from AGCM20, which shows that temperature is the controlling factor for snow-free classification. All data sets demonstrate that the snow-free area increases by about 6%, with a 1°C increase in temperature.

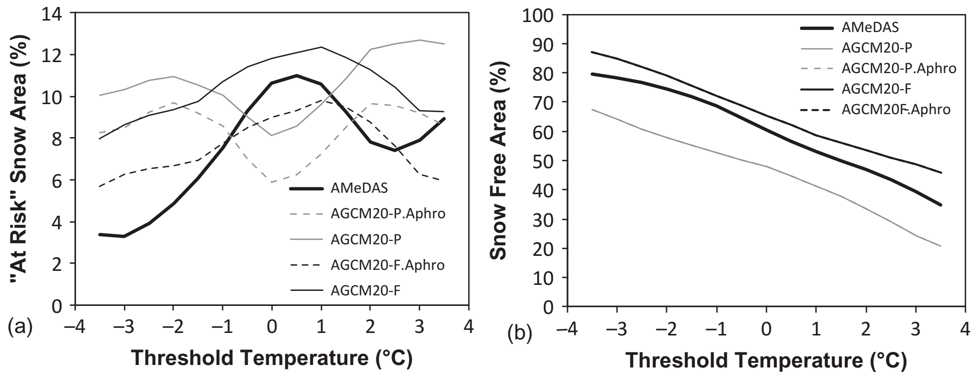


Fig. 3 Sensitivity of (a) total at-risk snow area and (b) snow-free area in relation to the snow *vs* rain threshold values. The lines for AGCM20-P and AGCM20-P.Aphro coincide, so do the lines for AGCM20-F and AGCM20-F.Aphro.

Sensitivity of regional and basin-wide snow cover

The regional variation of at-risk snow area and snow-free area with T_{thresh} is shown in Fig. 4. By analysing this graph, it is possible to distinguish the snow cover of the regions that are more sensitive to climate change. We display the sensitivity results for the AMeDAS and APHRO_JP data set and for the AGCM20 outputs using present and future periods (AGCM20-P and AGCM20_F, respectively). It is clear that, although the total at-risk snow area covers only about 10% of Japan, this class is very concentrated and covers greater regional percentages.

Very similar patterns can be seen for present (AMeDAS and AGCM20-P) and future conditions (AGCM20-F). In all cases, Tohoku on the Japan Sea side is the region that displays higher sensitivity to climate change; the smallest increase in temperature has the sharpest increase in snow-free area. Also, depending on the adopted T_{thresh}, up to 70% of the region could be classified as at-risk snow. Hokuriku has the highest snowfall, but the snow-free area decreases much less with the increase in temperature. The snow covered areas of Hokkaido seem much more stable and would only start converting into snow-free areas if the rise in temperature were more than predicted for the future.

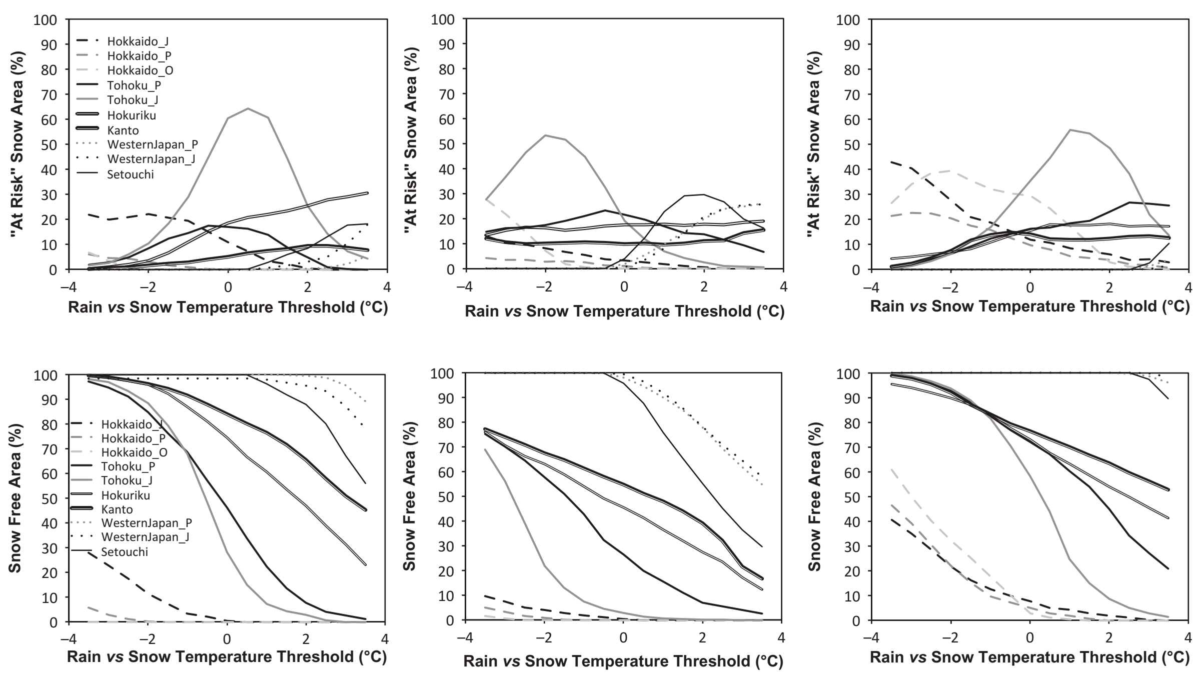


Fig. 4 Sensitivity of regional at-risk snow area (top panel) and snow-free area (bottom panel) in relation to the snow *vs* rain threshold values.

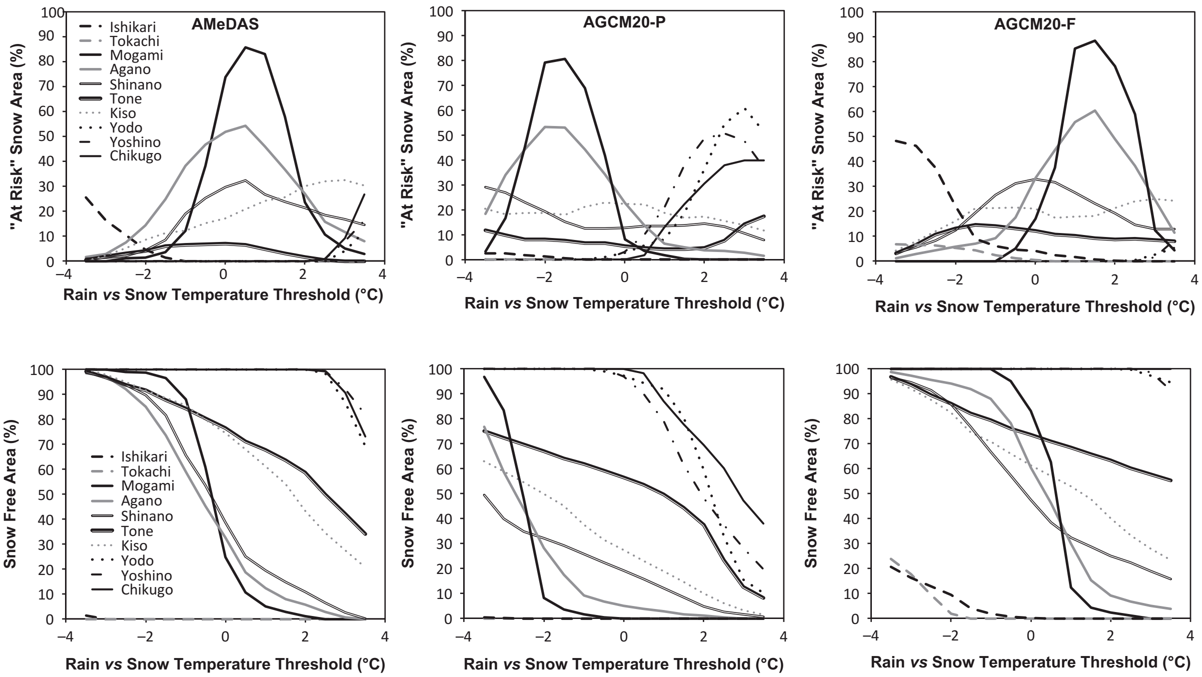


Fig. 5 Sensitivity of basin-wide at-risk snow area (top panel) and snow-free area (bottom panel) in relation to the snow *vs* rain threshold values.

The basin-wide variation of at-risk snow area and snow-free area with T_{thresh} are shown in Fig. 5. The Mogami River basin located in Tohoku is the most sensitive, with a total at-risk snow area of up to 86%, depending on T_{thresh}. When considering only the results derived with AMeDAS data, the at-risk snow areas of Agano, Shinano and Kiso river basins are also sensitive to changes in temperature. The Tone River basin, despite having a small area classified as at-risk, has a considerable change of snow-free area with changes in temperature. In the classification by AGCM20-P, which is the colder data set, it can be observed that Chikugo, Yoshino and Yodo river basins are also sensitive to temperature changes. These river basins are known for having seasonal snow areas, but the classification with AMeDAS did not capture them well.

Relative frequency of cold winters

Snow cover classification and changes are related to the frequency of cold winters. Figure 6 shows the spatial differences in the relative frequency of cold winters for the different data sets and present and future periods. As discussed earlier, the AMeDAS data set presents much higher temperatures than AGCM20-P in the mountainous regions and, consequently, a lower frequency of cold winters (Fig. 6, column 1). Using AMeDAS and the uniform increase scenario of 3°C, the differences in the relative frequency of cold winters concentrate in Tohoku and the coastal area of Hokkaido for $T_{\text{thresh}} = 0$°C; however, for $T_{\text{thresh}} = 2$°C, the frequency changes mainly in Tohoku and Hokuriku.

The patterns of difference in the relative frequency of cold winters are very similar for the AGCM20 output using either AGCM20-F or AGCM20-P with the spatially uniform increase of 3°C (AGCM20-P.gw3). Different to AMeDAS, the pattern is spread much more along the entire country. The last column of Fig. 6 shows the difference in the frequency of cold winters between AGCM20-P.gw3 and AGCM20-F. The differences are usually less than 10%, suggesting that the spatially-uniform rise in temperature is a reasonable scenario, even for calculating the relative frequency of cold winters in Japan.

Projections of SWE and peak time of snowmelt

To test if there would be more or less snowfall in the future period, we analysed the snowmelt output of the AGCM20 for present and future scenarios. The total SWE yearly value was estimated by summing up the output variable snowmelt water to the soil. Figure 7(a) shows that the simulated SWE for the future scenario

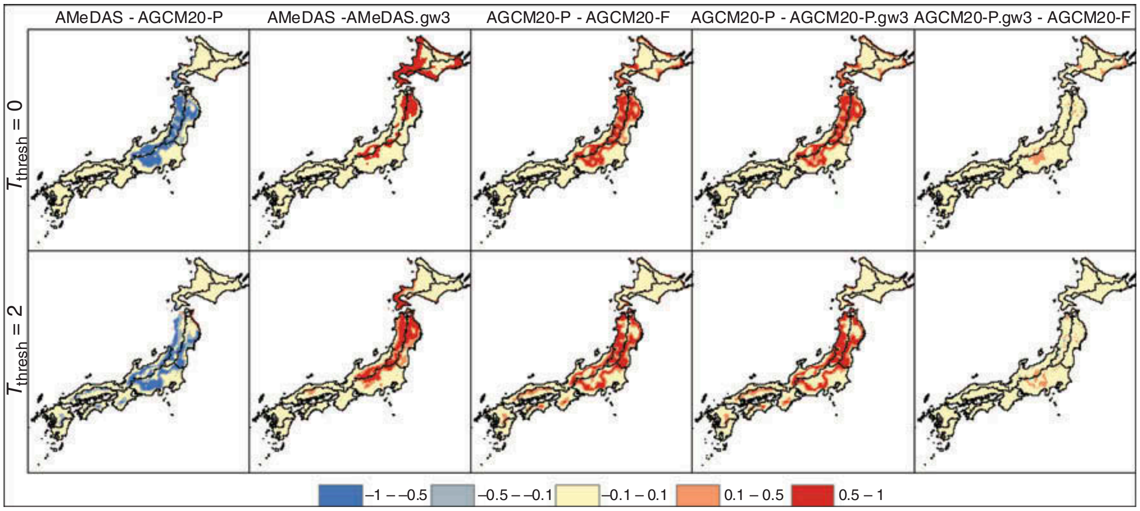


Fig. 6 Differences in relative frequency of cold winters between the data sets used. The legend indicates the range of absolute difference values.

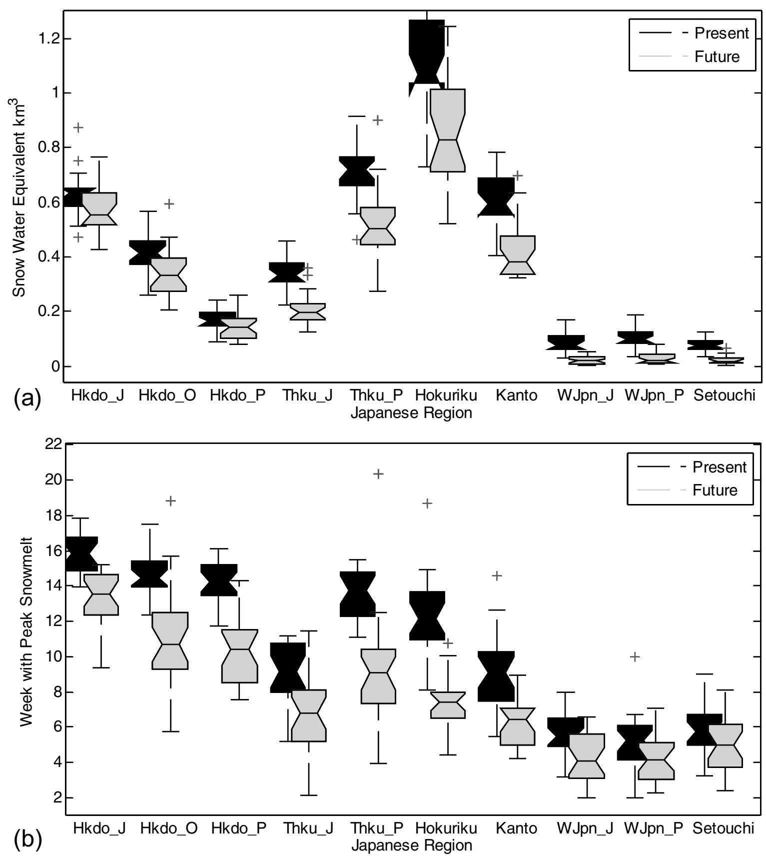


Fig. 7 Total snow water equivalent from AGCM20 output for present and future periods (a), and week starting from the first week of the year with the highest snowmelt (b). The boxes indicate the 25th and 75th percentiles, the notch indicates the median value, the whisker lengths correspond to approximately $\pm 2.7\sigma$, and "+" indicates the outliers.

will decrease. The simulated variability in total yearly SWE for the future period seems to increase on the Pacific side of Tohoku and in Hokuriku, but decreases in Western Japan.

The week with the peak volume of snowmelt simulated for the present and future periods is shown in Fig. 7(b). In the future scenario, the total yearly SWE of all regions is smaller than in the present. The week with peak snowmelt occurs earlier, but becomes more variable in Hokkaido and Tohoku. Despite the snow classification approach being less sensitive, it seems that Hokkaido inter-annual variability in snowmelt could increase.

CONCLUSIONS

In this paper, we combined the seasonal snow cover classification system of Sturm *et al*. (1995) and Nolin and Daly (2006) with the output of the AGCM20 to analyse winter hydrological conditions in Japanese regions and river basins sensitive to climate change. The identification of sensitive regions was done by mapping the at-risk snow regions and the snow-free areas with several rain *vs* snow temperature thresholds (T_{thresh}). We used AMeDAS interpolated temperature data, APHRO_JP precipitation data and the temperature, precipitation and snowmelt outputs from AGCM20 for present and future periods. Several spatially-uniform warming scenarios were also tested.

In general, we found that a temperature rise of 1°C could increase the seasonal snow-free area of Japan by about 6%, and that the average at-risk snow area of Japan was 8%. The at-risk snow area is concentrated in Tohoku. The snow cover of the Tohoku region was found to be the most sensitive to climate change, since a large portion of its area was classified as at-risk snow; a small change in T_{thresh} had a significant impact on the snow-free area. The Mogami and Agano river basins in the Tohoku and Hokuriku regions were the most sensitive of the 10 major river basins analysed in this study.

The patterns of relative frequency of cold winter changed most in the northeast mountainous regions of Japan. This is very significant since those are the areas with the highest seasonal snowfall, and the frequency of cold winters could influence the snow accumulation and melt patterns. Analysing the total snowmelt output from the AGCM20, we found that the total snow water equivalent in the future period scenario decreases for all regions of Japan and that the week with the peak snowmelt happens earlier. Hokkaido seasonal snow cover was found to be less sensitive using the snow classification method. However, the output from the AGCM20 indicates that the week with peak snowmelt in Hokkaido occurs earlier and is more variable in general for the future scenario.

Despite the robustness of the method when comparing sensitivity between areas, some sources of uncertainty remain. Some of the uncertainties are the choice of the interpolation scheme for temperature data, the averages and the time step used for snow cover analysis and the future scenarios output from the AGCM. Consideration of the influence of bias in AMeDAS and AGCM data in snow classification should be taken into account. It is also important to include snow water equivalent or snow depth measured on the ground in order to check the changes in snow-covered area.

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