MIROC5 predictions of Yamase (cold northeasterly winds causing cool summers in northern Japan)

著者	KANNO Hiromitsu, KANDA Eiji, Watanabe Masahiro
出版者	Japan Climatology Seminar
journal or publication title	Japanese progress in climatology
volume	2013
page range	41-49
year	2013-12
URL	http://hdl.handle.net/10114/10929

Reprinted from *J.Agric.Meteorol.*,69-3,p117-125,2013.

Full Paper

J. Agric. Meteorol. 69 (3): 117-125, 2013

MIROC5 predictions of Yamase (cold northeasterly winds causing cool summers in northern Japan)

Hiromitsu KANNO*, †, Masahiro WATANABE**, and Eiji KANDA*

(*NARO Tohoku Agricultural Research Center, Morioka, Iwate, 020-0198, Japan
**Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Chiba, 277-8564, Japan)

Abstract

Cold northeasterly winds, called *Yamase*, which cause the summertime weather of northern Japan to be unusually cool, have often damaged the rice crop in northern Japan, both historically and recently. To estimate future Yamase event occurrences, we used the new version of the MIROC5 atmosphere-ocean general circulation model and predicted the frequency of future Yamase events from the pressure difference index (pressure difference between Wakkanai and Sendai; PDWS). In a 20th-century experiment (1980-2005), the PDWS simulated by the MIROC5 model reproduced well the Yamase events in the JRA-25 reanalysis data. In a future climate experiment (2006-2100), the predicted occurrence frequency of Yamase events is low around the 2030s and from the 2080s onward, but in other periods, Yamase events are predicted to occur at about the same frequency as during the 20th-century experiment (1980-2005). Therefore, even under global warming, Yamase winds can be expected to affect agriculture in northern Japan in the 21st century.

Key words: Cool summer, MIROC5, Northern Japan, PDWS, Yamase wind.

1. Introduction

Cold northeasterly winds, called *Yamase* winds, sometimes blow across northern Japan from the Bai-u season (Japanese rainy season between spring and summer) through the following summer. The continuously blowing Yamase winds cause the summertime weather to be cool, which reduces rice production.

During a typical Yamase event, the temperature in northern Japan is lower on the eastern (Pacific) side of the central mountain range than on the western (Japan Sea) side, because westward movement of the cold air mass is blocked by the mountains (Kudoh, 1984). Moreover, because Yamase clouds are also blocked by the mountains, few clouds are observed on the western side of the range (Bokura, 1975). Yamase winds are produced by a characteristic atmospheric pressure pattern in which an anticyclone is located over the Sea of Okhotsk and a cyclone and front are located along the southern Japanese coast. In July of a cool summer year (Fig. 1), a polar maritime (Pm) air mass extending from the Sea of Okhotsk to the Bering Sea moves across northern Japan, causing Yamase winds and low temperatures, and a frontal zone forms where the Pm air mass encounters the tropical maritime (Tm) air mass. Above northern Japan, the Pm air mass is characterized by a thin lower mixed layer and an upper stable layer, and because its height is less than about 2000 m (Kanno, 1997; Kodama, 1997; Kanno *et al.*, 2000), it is easily blocked by the mountains, which are 1000-2000 m above sea level. Yamase winds are responsible for large summer weather variations in northern Japan (Ninomiya and Mizuno, 1985), and cyclic variations in summer temperatures, with frequent cool summers caused by Yamase events, have been observed in recent years (Kurihara, 2003; Kanno, 2004).

Rice productivity in northern Japan is high, accounting for 34% of the total Japanese rice production, and the rice from this area is famous for its delicious taste. Therefore, future climate changes, especially whether Yamase events will continue to occur, are of particular interest from the point of view of northern Japanese agriculture. Endo (2012) used the Coupled Model

Received; June 21, 2012.
Accepted; February 9, 2013.
† Corresponding Author: kanno@affrc.go.jp

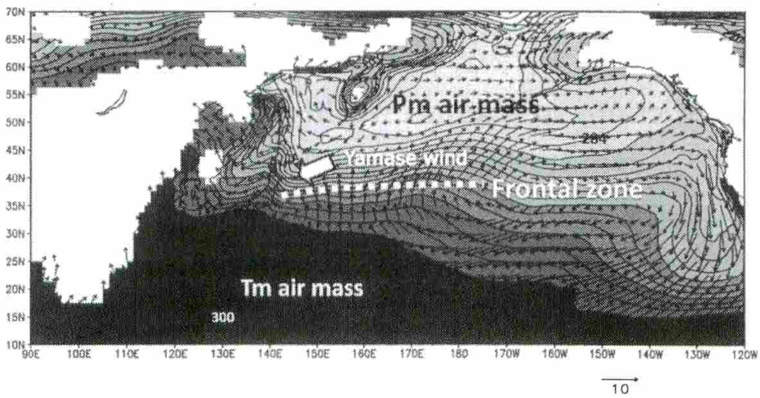

Fig. 1. Monthly mean temperatures (K, contours and shading) and winds (vectors) at 1000 hPa during a cool summer (July 2003). Contour interval is 1 K. The large white arrow indicates Yamase winds. Pm, polar maritime; Tm, tropical maritime. JRA-25 data were used in this figure.

Intercomparison Project Phase 3 (CMIP3) multi-model to investigate future changes in Yamase events and reported that future Yamase seasons over northern Japan would be delayed, occurring more frequently in August. Kitoh and Uchiyama (2006), using almost the same CMIP3 data set as that used by Endo (2012), also found that the Bai-u rainy season would be delayed in the future. These findings indicate that future summers in northern Japan will be characterized by less sunshine and more precipitation, which will lead to more crop pests and reduced harvests. However, Endo (2012) focused on the far future (2081-2100). From the viewpoint of the development of agricultural technologies to prevent weather damage under climate change, however, the likelihood of Yamase events in the near future is of greater importance, because improvement of available technologies to cope with abnormal weather is feasible on a decadal time scale. Moreover, understanding year-to-year variations in the occurrence of Yamase events is very important for agricultural technology in both the near and far future.

Recently, a new version of the Model for Interdisciplinary Research on Climate (MIROC5), an atmosphere-ocean general circulation model, has been cooperatively developed by the Japanese research community. In MIROC5, many schemes of the old version (MIROC3.2) have been improved, including the dynamical core and radiation, cumulus convection, cloud and cloud microphysics, turbulence, aerosols, and ocean components (Watanabe *et al.*, 2010). As a result, treatment of climatological precipitation and sea surface temperature (SST) has been improved by the incorporation of a single Intertropical Convergence Zone, by more realistic treatment of the zonal SST gradient at the equator, and by topographic anchoring of precipitation associated with the Asian monsoon. Thus, MIROC5 simulates El Niño—Southern Oscillation (ENSO) notably more realistically than earlier versions of the model (Watanabe *et al.*, 2010). This more realistic simulation of ENSO is very important because a cool summer in northern Japan is sometimes produced by fluctuations in Rossby wave propagation caused by ENSO variations. These improvements suggest that MIROC5 is suitable for the analysis of future occurrences of Yamase events. The objective of this study was to use MIROC5 to examine the likelihood of future Yamase events. We expect our results not only to contribute to a better understanding of the improvements in agricultural technology necessary to adapt to these events under future climate change, but also to try to estimate the reproduction of future climate connecting to the climate system.

2. Materials and Methods

For surface air temperature and air pressure observations, we used data from the meteorological observation stations of the Japan Meteorological Agency (JMA); for the current 1000 hPa temperature and wind analyses, we used the JRA-25 reanalysis data (Onogi *et al.*, 2007); and we defined Yamase events in simulations on the basis of the first-run results of MIROC5. MIROC5 simulations were performed with T85L40 resolution (about 150 km square mesh size and 40 vertical levels using a hybrid $\sigma - p$ coordinate) for the atmospheric component and a resolution of approximately 1° for the ocean component. For the atmospheric concentrations of well-mixed greenhouse gases and surface emissions of tropospheric aerosols from 2006, we used data provided by the International Working Group on Representative Concentration Pathways (RCP), specifically the RCP 4.5 scenario (Allison *et al.*, 2011). In his recent study of future Yamase events employing a multi-model ensemble analysis with CMIP3, Endo (2012) found that the differences in the ensemble results were not small. However, we believe that although a multi-model analysis can represent general features well, it at the same time includes statistical uncertainties derived from the differences among the models. Therefore, in this study, we present the simple result of a single model analysis to contribute to the present discussion about the future climate. A multi-model analysis is planned as the next step for a future paper.

To define Yamase events in northern Japan, we used temperature data from the Hachinohe meteorological observation station (Fig. 2), because the Yamase wind strength at this site is representative (Kanno, 1993). Nevertheless, each climate model has its peculiar biases, which are commonly corrected by using dynamical or statistical downscaling methods (*e.g.*, Iizumi *et al.*, 2012). To address the uncertainties introduced by dynamical downscaling, a multi-model analysis is strongly recommended (Iizumi *et al.*, 2012). However, in this study, we used single-point temperature data from Hachinohe only to confirm the future increase in temperature, so it was not necessary to apply dynamical downscaling with a regional climate model. Instead, we directly adopted the T85 grid data nearest to Hachinohe station as the Hachinohe temperature data and then statistically compensated for the temperature bias between the observation data and the simulation data at Hachinohe as follows. First, we conducted a 20th-century experiment (1980-2005) with MIROC5 and used the averaged data as "normal in the 20th-century" data. Next, we calculated the daily difference between the simulated 20th-century normal values and future values (from 2006 to 2100) to determine the increase (or decrease) rate. Finally, we added these rates to the observed normal values at Hachinohe (1981-2010).

Kanno (2004) has shown that the pressure difference between the Wakkanai and Sendai meteorological observation stations (PDWS; Fig. 2) can be effectively used to define a Yamase event. Therefore, we used the PDWS index to confirm that MIROC5 could simulate cool summers due to Yamase events. To calculate the PDWS, the sea level pressure data in the T85 grid cells nearest the Wakkanai and Sendai meteorological observation stations were used directly.

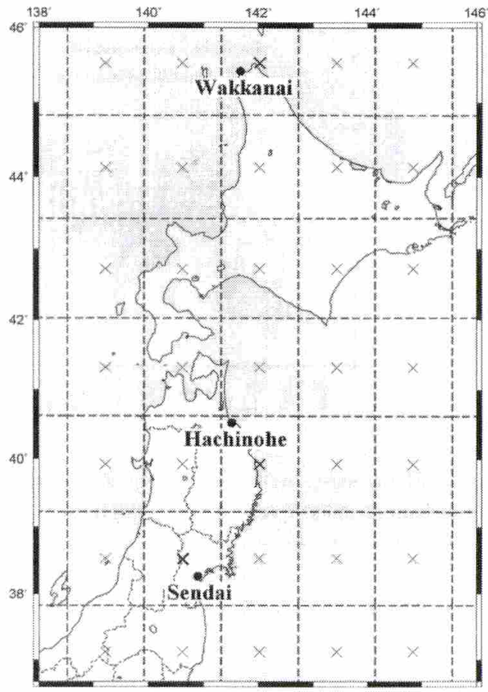

Fig. 2. Locations of meteorological observation stations (●) and MIROC5 data points (X). Thick X marks indicate the data points used as the observation station data.

3. Results

3.1 Time variations in air temperature at Hachinohe

First, we examined the time series of air temperature from the present to the future at the Hachinohe meteorological observation station (Fig. 3). During the 20th-century experiment (1980-2005), the MIROC5 June-July-August (JJA) mean temperature varied over nearly the same range as the observed values except during the extremely cool summers of 1993 and 2003. Thus, the reproduction of northern Japan's summer weather by MIROC5 is adequate. In the time series of

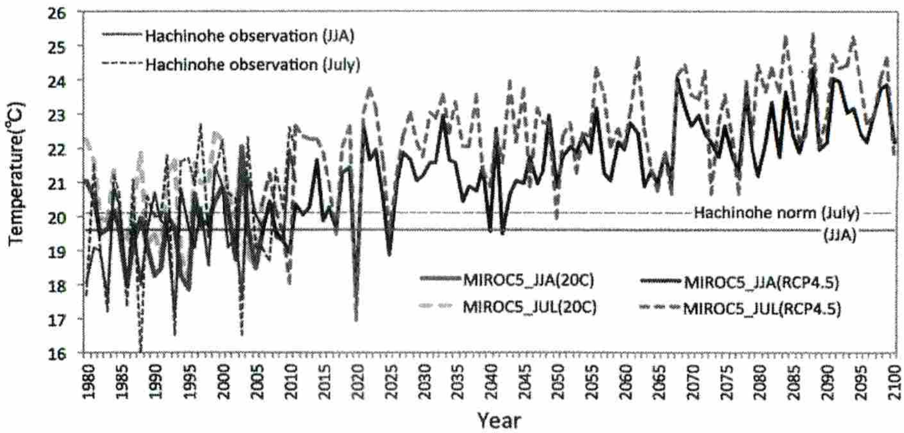

Fig. 3. Time series of July and June-July-August (JJA) mean temperatures at the Hachinohe meteorological observation station from 1980 to 2100. Observed temperatures (red curves) and normal mean values (gray horizontal lines) for 1981 to 2010 are also shown.

air temperature in July (Fig. 3), however, the most important month for rice productivity in northern Japan, MIROC5 did not reproduce the observed temperatures in the years in which extremely low temperatures were found. In particular, the observed temperatures during the cool summers of 1993 and 2003 were much lower than those simulated by MIROC5, whereas the simulated high temperatures agreed well with the observations. Summer temperatures in recent years, especially since the late 1970s, have tended to fluctuate greatly in northern Japan (*e.g.*, Kanno, 2004), and such large fluctuations might be difficult for MIROC5 to simulate.

From 2006 to 2100, the simulated temperature at Hachinohe increased at a rate of about 3.3℃ (JJA) and 2.9℃ (July) per 100 years, based on fitted linear regression equations. A few extremely cool summers were simulated in the 2020s, with low temperatures nearly equal to the recently observed cool summer temperatures, but no such extremely low temperatures were projected to occur after that, although the simulated temperatures occasionally fall below normal until about 2050. Therefore, from an agricultural perspective, cool summers that might damage the rice crop are a possibility until about 2050.

3.2 The PDWS index and temperature relationships

We next examined the relationship between the observed PDWS and the Hachinohe observed temperature and that between the observed PDWS and the MIROC5-simulated temperature (Fig. 4). From 1980 to 2005, the observed PDWS and Hachinohe temperature in JJA were significantly and positively correlated ($r=0.77$, $p<0.01$), consistent with the results reported by Kanno (2004). The correlation between the MIROC5-simulated PDWS and temperature, however, was much stronger ($r=0.83$, $p<0.01$). This finding suggests that MIROC5 can adequately simulate the relationship between a Yamase-type pressure pattern (*i.e.*, a positive pressure gradient between a northern high and a southern low) and low temperatures at Hachinohe.

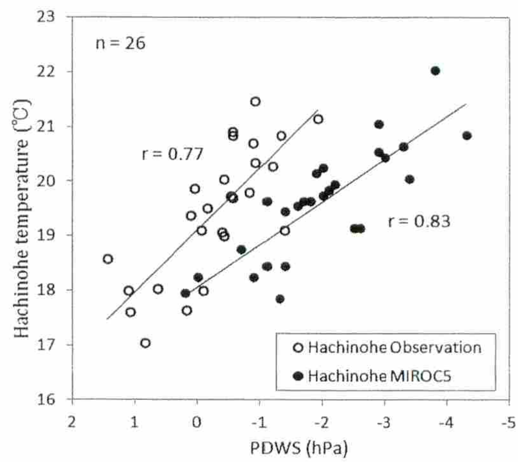

Fig. 4. Scatter plots of temperature at Hachinohe versus the PDWS during JJA from 1980 to 2005. White circles, observation data; black circles, MIROC5-simulated data.

We regressed the present observed (JRA-25) and MIROC5-simulated PDWS against the 1000 hPa temperature and wind fields (Fig. 5), and both the JRA-25 and MIROC5 results showed that significantly low temperatures around northern Japan and northeasterly Yamase winds were correlated with high PDWS values. In other areas, temperature and wind distributions differed greatly between the two analyses. In the JRA-25 result, significant positive temperature correlations are seen southwest of Japan (Fig. 5a), reflecting a Pacific-Japan teleconnection pattern (Kurihara and Tsuyuki, 1987; Nitta, 1987; Nitta and Yamada, 1989), whereas the MIROC5 result showed positive correlations with temperature and southwesterly winds southeast of Japan (Fig. 5b). Thus, although the general temperature and wind distributions differed, the distributions of Yamase winds and low temperatures over northern Japan were well simulated by MIROC5, which indi-

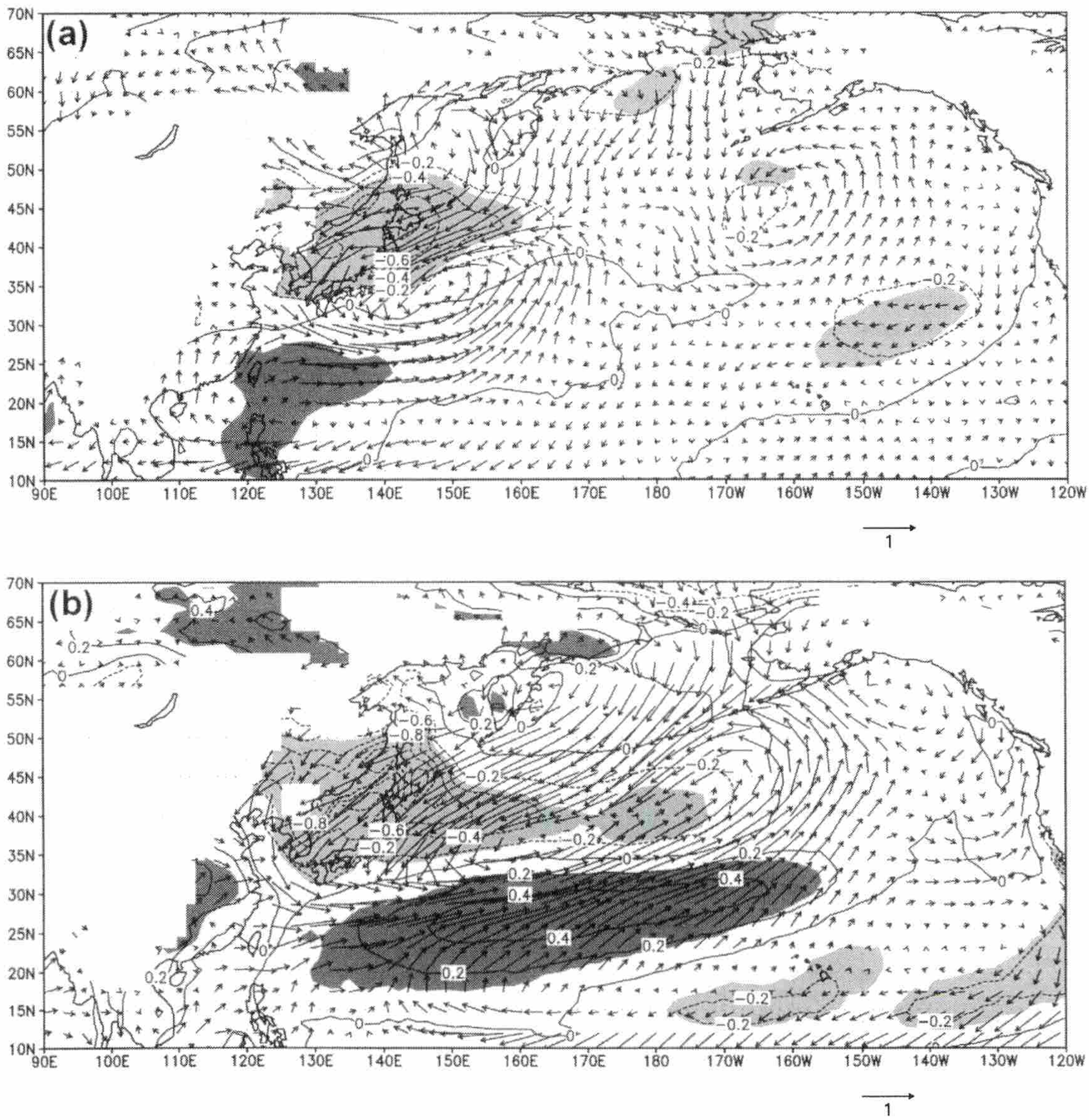

Fig. 5. Results of the regression of the PDWS against 1000 hPa temperature (℃) and wind fields during JJA. a) JRA-25 data from 1979 to 2011, b) MIROC5-simulated data from 1980 to 2005. Contour interval is 0.2 ℃. Shading indicates PDWS-temperature correlations significant at the 5% level.

cates that, for the present climate, the PDWS can be used as a Yamase index in MIROC5.

In the MIROC5 simulation results for the period from 2006 to 2100, the correlation between the PDWS and Hachinohe temperature ($r=0.61$), although lower than that for the period before 2005, was still high and significant at the 1% level (Fig. 6). Regression of the PDWS against the simulated 1000 hPa temperature and wind fields (Fig. 7) also showed that low temperatures and northeasterly Yamase winds over northern Japan were correlated with high PDWS values. Low temperatures (negative correlation with the PDWS) extending eastward from northern Japan showed that westward movement of the cold air mass was blocked by the central mountain range, an important characteristic of a Yamase event. Watanabe *et al.* (2010) has reported that MIROC5 simulates topographically anchored precipitation well, and our result indicates that the blocking of the cold air mass is similarly well reproduced. Therefore, in terms of the PDWS index, MIROC5 is very capable of simulating cool summers in northern Japan caused by Yamase events.

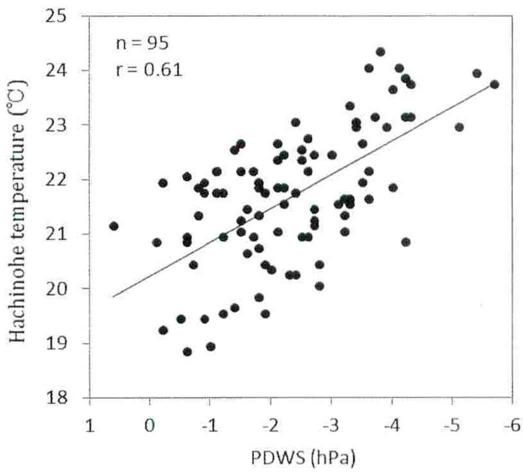

Fig. 6. Scatter plot of MIROC5-simulated temperature at Hachinohe versus the MIROC5-simulated PDWS during JJA from 2006 to 2100.

2.3 Time variations in the PDWS

As described in Section 3.1 (Fig. 3), the temperature increases in the future in the MIROC5 simulation. Since the Yamase effect on summer weather each year in the future will be influenced by the rising temperature trend, to characterize the Yamase effect quantitatively, the long-range trend of rising temperature must be removed before further analysis. Therefore, we first fitted an equation by linear regression to the yearly temperatures during JJA from 2006 to 2100 at Hachinohe as follows:

$$Y = 0.0327X + 20.135 \quad (1)$$

where Y is the linearly regressed temperature and X is

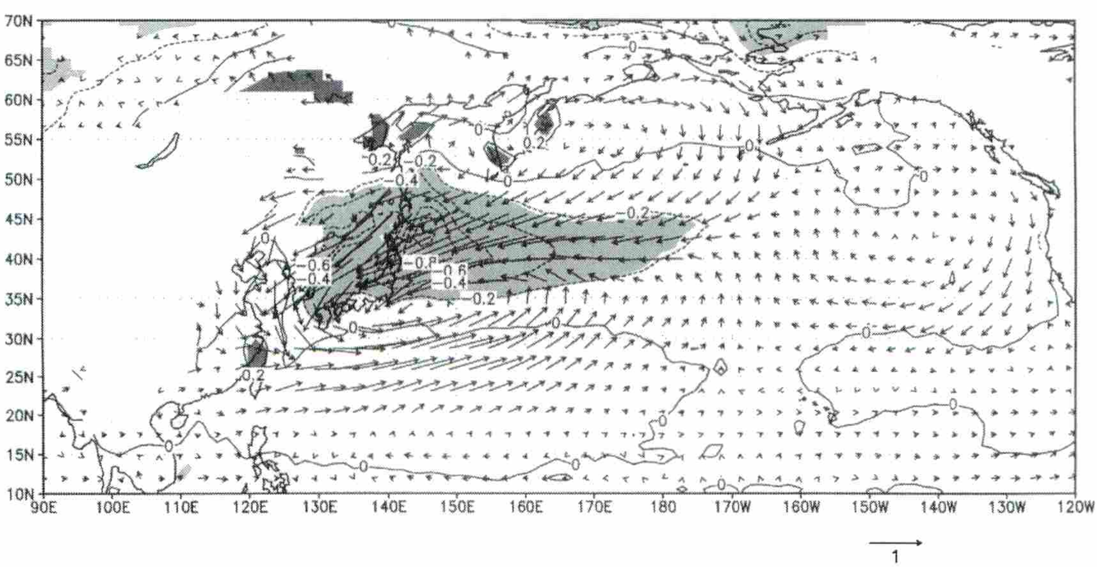

Fig. 7. Regression of the PDWS against the MIROC5-simulated 1000 hPa temperature and wind fields during JJA from 2006 to 2100. Other information is as in Fig. 5.

the number of the year from 2006. The correlation coefficient of this regression is 0.70, and it is statistically significant at the 1% level. From this equation, we estimated that the rate of temperature increase will be about 3.3℃ per 100 years at Hachinohe. Next, we calculated the temperature deviations from the rising temperature trend estimated by using Eq. (1) and examined the relationship between the calculated temperature deviations and the PDWS (Fig. 8). The correlation coefficient of this relationship is 0.71 ($p<0.01$), compared with 0.61 for the MIROC5-simulated temperature and PDWS (Fig. 6), indicating that the temperature deviations might be more appropriate than the simulated temperatures themselves for analyzing Yamase phenomena.

This negative correlation between Hachinohe temperature deviations and the PDWS is also obvious in the time series of these data (Fig. 9). However, because the linear regression of the PDWS was not statistically significant, we examined the PDWS trend over time by calculating the 13-year running mean. The result showed that from the 2080s onward, the PDWS trend is decreasing, but during other periods, except around the 2030s, the mean value of the PDWS remains at about the same level as during the 20th-century experiment (1980-2005). Consequently, around the 2030s, Yamase winds can be expected to be less frequent than before or after that period, and the summertime temperature at Hachinohe will be relatively higher. Subsequently, however, Yamase winds can be expected to recur until the 2080s.

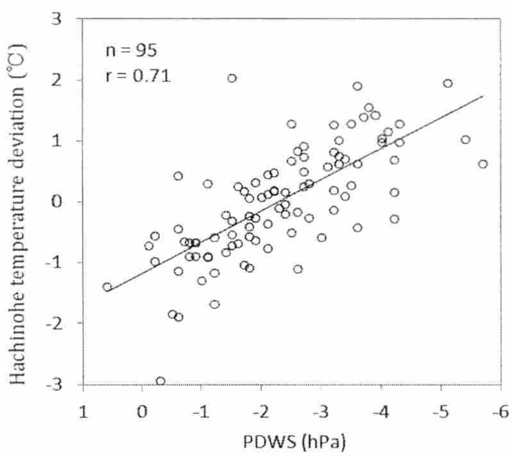

Fig. 8. Scatter plot of MIROC5-simulated temperature deviation at Hachinohe versus the MIROC5-simulated PDWS during JJA from 2006 to 2100.

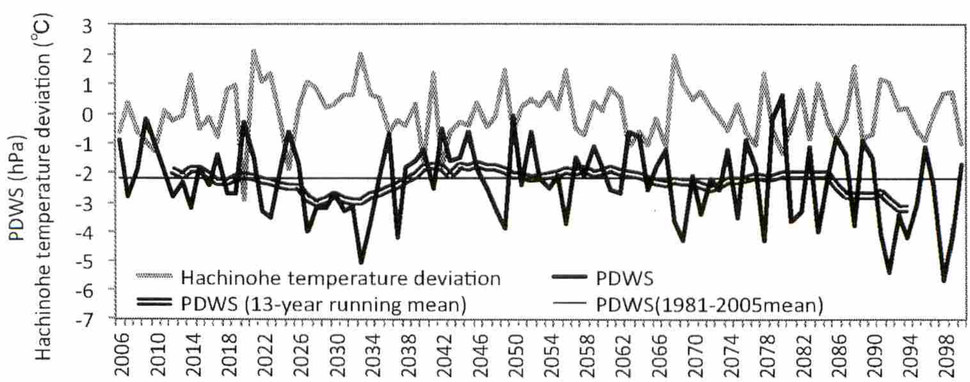

Fig. 9. Time series of PDWS and temperature deviations at Hachinohe during JJA from 2006 to 2100. The double line indicates the 13-year running mean, thin solid line indicates 1980-2005 mean of the PDWS.

4. Conclusion

In a 20th-century experiment, MIROC5, the newest version of this atmosphere-ocean general circulation model, was able to reproduce Yamase events over northern Japan and simulated well the topographic blocking of the cold Pm air mass associated with Yamase events, indicating that this model is likely to be useful for predicting future Yamase events.

We interpreted the PDWS time series obtained from a future climate analysis (2006-2100) to infer the future likelihood of Yamase events. Although around the 2030s and from the 2080s onward, the occurrence frequency of Yamase events should be lower than at present, in other periods, it is likely to remain about the same as during the 20th-century experiment (1980-2005). Therefore, even under global warming, Yamase winds can be expected to affect agriculture in northern Japan during the 21st century. Indeed, even though the temperature will rise continuously into the future, the results of this study suggest that a Yamase-type pressure pattern will also continue to appear. As a result, relatively cool summer weather will continue to occur frequently in the future. Our results also suggest that switching to crops and varieties adapted to rising temperatures may be dangerous, because such crops are more likely to be damaged by the continuing large temperature variations brought by Yamase winds.

In the future, increasing populations and food scarcity are expected to be serious problems worldwide. Therefore, models that can be used to predict dangerous weather patterns affecting agricultural productivity will become even more important. Our results show that MIROC5 has this predictive ability and should thus be useful for estimating the likelihood of crop damage caused by future adverse weather conditions and assessing the necessity of improving agricultural technology to prevent such damage. As a result, estimation of regional food production seems likely to increase by using the newest climate model, and so adapting the methods in this study, including atmospheric circulation analysis, to the other areas implies that the potential practical use of the climate model will increase.

Acknowledgments

This research was partly supported by a MAFF (Ministry of Agriculture, Forestry and Fisheries, Japan) project, "Development of Mitigation and Adaptation Techniques for Global Warming in the Sectors of Agriculture, Forestry, and Fisheries," and a MEXT (Ministry of Education, Culture, Sports, Science and Technology, Japan) project, "Research Program on Climate Change Adaptation (RECCA)."

References

Allison, M. T., Calvin, K. V., Smith, S. J., Kyle, G. P., Volke, A., Patel, P., Delgado-Aries, S., Bond-Lamberry, B., Wise, M. A., Clarke, L. E., and Edmonds, J. A., 2011: RCP4.5: a pathway for stabilization of radiative forcing by 2100. *Clim. Chang.*, **109**, 77–94.

Bokura, T., 1975: Observations of the special clouds on the lee side of Yamase wind. *J. Agric. Meteorol.*, **31**, 1–5 (In Japanese with an English abstract).

Endo, H., 2012: Future changes of Yamase bringing unusually cold summers over northeastern Japan in CMIP3 multi-models. *J. Meteorol. Soc. Jpn.* **90A**, 123–136.

Iizumi, T., Uno, F., and Nishimori, M., 2012: Climate downscaling as a source of uncertainty in projecting local climate change impacts. *J. Meteorol. Soc. Jpn.* **90B**, 83–90.

Kanno, H., 1993: Differences of temperature and humidity between Yamase and sea breeze and their seasonal variations at Hachinohe in Aomori Prefecture. *Tenki*, **40**, 751–757 (in Japanese).

Kanno, H., 1997: Classification of the Yamase (cold northeasterly wind around northeastern Japan) based upon its air-mass vertical structures. *J. Meteorol. Soc. Jpn.* **75**, 1053–1071.

Kanno, H., 2004: Five-year cycle of north-south pressure difference as an index of summer weather in northern Japan from 1982 onwards. *J. Meteorol. Soc. Jpn.* **82**, 711–724.

Kanno, H., Jianqing, X., and Ozawa, K., 2000: Localized meteorological features of Yamase and sea breezes and their movements to hilly mountain area (Kuji City and Yamagata Village in Iwate Prefecture). *J. Agric. Meteorol.*, **56**, 11–23 (In Japanese with an English abstract).

Kitoh, A. and Uchiyama, T., 2006: Changes in onset and withdrawal of the East Asian summer rainy season by multi-model global warming experiments. *J. Meteorol. Soc. Jpn.* 247–258.

Kodama, Y., 1997: Airmass transformation of the Yamase air-flow in the summer of 1993. *J. Meteorol.*

Soc. Jpn. **75**, 737–751.

Kudoh, T., 1984: Characteristics of Okhotsk air mass during the typical Yamase period (1981.6.18-21). *Tenki*, **31**, 411–419 (In Japanese).

Kurihara, K., 2003: Quasi-six-year fluctuation in summer surface air temperature in Japan, *J. Meteorol. Soc. Jpn.* **81**, 1289–1297.

Kurihara, K. and Tsuyuki, T., 1987: Development of the barotropic high around Japan and its association with Rossby wave-like propagation over the North Pacific: Analysis of August 1984. *J. Meteorol. Soc. Jpn.* **65**, 237-246.

Ninomiya, K. and Mizuno, H., 1985: Anomalously cold spell in summer over Northeastern Japan caused by northeasterly wind from polar maritime air-mass. Part 1. EOF analysis of temperature varia tion in relation to the large-scale situation causing the cold summer. *J. Meteorol. Soc. Jpn.* **63**, 845–857.

Nitta, T., 1987: Convective activities in the tropical western Pacific and their impact on the Northern Hemisphere summer circulation. *J. Meteorol. Soc. Jpn.* **65**, 373–390.

Nitta, T. and Yamada, S., 1989: Recent warming of tropical sea surface temperature and its relationship to the Northern Hemisphere circulation. *J. Meteorol. Soc. Jpn.* **67**, 375–383.

Onogi, K., and coauthors, 2007: The JRA-25 reanalysis *J. Meteorol. Soc. Jpn.* **85**, 369–432.

Watanabe, M. and coauthors, 2010: Improved climate simulation by MIROC5: Mean states, variability, and climate sensitivity. *J. Clim.*, **23**, 6312–6335.

Reprinted from *J.Agric.Meteorol.*,69-3,p117-125,2013.