Future projections of temperature-related excess out-of-hospital cardiac arrest under climate change scenarios in Japan

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Abstract

Background: Recent studies have reported associations between global climate change and mortality. However, future projections of temperature-related out-of-hospital cardiac arrest (OHCA) have not been thoroughly evaluated. Thus, we aimed to project temperature-related morbidity for OHCA concomitant with climate change.

Methods: We collected national registry data on all OHCA cases reported in 2005–2015 from all 47 Japanese prefectures. We used a two-stage time series analysis to estimate temperature-OHCA relationships. Time series of current and future daily mean temperature variations were constructed according to four climate change scenarios of representative concentration pathways (RCPs) using five general circulation models. We projected excess morbidity for heat and cold and the net change in 1990–2099 for each climate change scenario using the assumption of no adaptation or population changes.

Results: During the study period, 739,717 OHCAs of presumed cardiac origin were reported. Net decreases in temperature-related excess morbidity were observed under higher emission scenarios. The net change in 2090–2099 compared with 2010–2019 was -0.8% (95% empirical confidence interval [eCI]: -1.9, 0.1) for a mild emission scenario (RCP2.6), -2.6% (95% eCI: -4.4, -0.8) for a stabilization scenario (RCP4.5), -3.4% (95% eCI: -5.7, -1.0) for a stabilization scenario (RCP6.0), and -4.2% (95% eCI: -8.3, -0.1) for an extreme emission scenario (RCP8.5).

Conclusions: Our study indicates that Japan is projected to experience a substantial net reduction in OHCAs in higher-emission scenarios. The decrease in risk is limited to a specific morbidity cause, and a broader assessment within climate change scenarios should consider other direct and indirect impacts.

INTRODUCTION

Climate change is widely recognized as the most significant global health threat of the 21st century, and tackling climate change could be the greatest global health opportunity (Watts et al., 2015). The fifth Intergovernmental Panel on Climate Change (IPCC) report indicates that high-end emissions scenarios project increases in global mean temperatures of between 2.6 and 4.8°C by the end of the century (Pachauri et al., 2014). While a number of important human diseases have been associated with shifts in climate, a lack of long-term, high-quality data and a significant influence from socio-economic factors has led to some uncertainty in attributing any increase or re-emergence of diseases to climate change (Patz et al., 2005). Recent studies have shown that climate change has the potential to substantially increase temperature-related mortality (Benmarhnia et al., 2014; Gasparrini et al., 2017; Hajat et al., 2014; Lee and Kim, 2016). However, the future impact of health threats arising from climate change can differ quite significantly among diseases (Watts et al., 2015), and the impacts of climate change on morbidity has not been thoroughly evaluated.

Sudden cardiac arrest is a major contributor to morbidity and mortality in the general population, and accounts for almost 10–20% of all deaths (Field et al., 2010). In particular, out-of-hospital cardiac arrest (OHCA) is characterized by unexpected collapse due to a cardiac disorder (Tian and Qiu, 2017). Although resuscitation rates are generally improving globally, OHCA is a leading global cause of mortality (Nichol et al., 2008; Wissenberg et al., 2013). Coronary artery disease is a key contributor to sudden cardiac arrest (Mozaffarian et al., 2015). However, OHCA is multifactorial and complex in nature (Patz et al., 2005). Several studies that aimed to quantify the burden of OHCA have had difficulty accurately accounting for potential adaptation to climate change over time and place. Meanwhile, OHCA remains a prime and significant cause of death due to cardiovascular diseases. It is therefore paramount to focus on OHCA to improve prediction estimates and to aid in prioritizing mitigation and adaptation policies to climate change in the future.

As concerns associated with climate change have increased over the past few decades, there has been emerging evidence supporting a relationship between OHCA and environmental factors such as extreme weather conditions like heat and cold events (Onozuka and Hagihara, 2017a; Onozuka and Hagihara, 2017c; Onozuka and Hagihara, 2017e). For example, several studies have shown a positive association between extremely high and low temperatures and OHCA risk (Onozuka and Hagihara, 2017a). Moreover, recent studies have also shown that the majority of temperature-related OHCA burden is attributable to low temperatures, and that the effect of extreme temperatures is substantially lower than that of moderate temperatures (Onozuka and Hagihara, 2017c). These findings suggest that climate change may raise heat-related morbidity, while concomitantly reducing cold-related morbidity. However, future projections of temperature-related excess morbidity due to OHCA according to climate change scenarios have not been studied. Furthermore, the degree to which the anticipated reduction in cold-related morbidity can counter the rise in heat-related morbidity remains to be determined. This data will be important for the development of coordinated and evidence-based climate change and public health methods to prevent climate change-related OHCA.

Here, we aimed to project the future impact of climate change on temperature-attributable OHCA morbidity using Japanese national registry data from all OHCA cases reported in 2005–2015 that were assumed to be of cardiac origin.

METHODS

Study design

We used the same study design and statistical framework described in detail elsewhere (Gasparrini et al., 2017; Vicedo-Cabrera et al., 2019). Briefly, we used a two-stage time-series analysis to predict the association between temperature and daily morbidity due to OHCA in all 47 Japanese prefectures. Additionally, we acquired daily mean temperature time-series according to climate change scenarios of the four representative concentration pathways (RCPs), RCP2.6, RCP4.5, RCP6.0, and RCP8.5. We merged these data to estimate future projections of excess morbidity attributable to temperature.

Ethics approval

This study was approved by the Ethics Committee of the Kyushu University Graduate School of Medical Sciences. Written informed consent was not required because of the retrospective observational nature of this study, which used national registry data, and the fact that enrolled subjects were deidentified by the Fire and Disaster Management Agency (FDMA).

Data sources

We used national registry data from the FDMA regarding all OHCA cases that were reported from 2005 to 2015 in all 47 Japanese prefectures. According to Japan's Fire Service Act, municipal government-enlisted emergency medical services (EMSs) are provided at around 800 fire stations and related dispatch centers across Japan. Given that EMS providers do not have the authority to terminate resuscitation in the field, all EMS-treated OHCA cases are transported to a hospital. EMS personnel summarize each OHCA case in conjunction with the physician in charge according to the standardized Utstein-style reporting guidelines for cardiac arrest

(Hagihara et al., 2012). The physician in charge together with the EMS personnel clinically ascertained the cause of cardiac arrest (i.e., presumed cardiac or non-cardiac). All arrests were considered to be of cardiac origin unless the cause was drowning, trauma, drug overdose, exsanguination, asphyxia, or any other obvious non-cardiac cause. Fire stations with dispatch centers in the 47 prefectures send their data to the FDMA, where the data is incorporated into the national registry system on the FDMA database server. According to the Fire Service Act, all OHCA cases must be registered in Japan. The national registry data for OHCA cases is therefore regarded as comprehensive across the country. The FDMA's computer system was used to check and validate the data for consistency (Kitamura et al., 2016). We included all patients that experienced an OHCA of presumed cardiac origin, and we extracted the daily time-series of OHCA cases from the national registry database.

We also acquired data on daily mean temperatures from the Japan Meteorological Agency. Data from one weather station positioned in an urban area of the capital city was used as representative data for the region for each prefecture because these were synoptic climatological stations and intended to capture macro-scale weather for each prefecture. Daily mean temperatures were computed as 24-hour averages according to hourly measurements. Daily mean temperature was used as the main exposure index as it is indicative of exposure throughout the day and can be readily interpreted for decision-making purposes (Guo et al., 2011; Guo et al., 2014).

Scenario models

We estimated the projections of future temperature-related OHCA under four climate change scenarios using models of climate change and morbidity. First, we acquired time series data for daily mean temperatures according to four climate change scenarios of representative concentration pathways (RCPs) (van Vuuren et al., 2011a). The four RCPs (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) present rising greenhouse gas concentration trajectories: RCP2.6 models a mild emission scenario in which peaks in radiative forcing at ~3 W/m^2 before 2100 and then declines to 2.6 W/m^2 by 2100, RCP4.5 models a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level of 4.5 W/m^2, RCP6 models a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshoot pathway to 6 W/m^2, by the application of a range of technologies and strategies for reducing greenhouse gas emissions, and RCP8.5 models an extreme emission scenario in which rising radiative forcing pathway leading to 8.5 W/m^2 by 2100 (van Vuuren et al., 2011a). The RCPs were generated following collaborations between integrated assessment modelers, climate modelers, terrestrial ecosystem modelers, and emission inventory experts (van Vuuren et al., 2011a). Future projections of daily mean temperatures under each RCP were then developed using general circulation models (GCMs) (Warszawski et al., 2014). GCMs were designed to enable the quantification of representation of historical, current, and projected climate consistent with scenarios of increases in radiative atmospheric forces, summarized by RCPs. The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) database includes daily temperature series for each RCP scenario of five GCMs (GFDL-ESM2M (Dunne et al., 2012; Dunne et al., 2013), HadGEM2-ES (Jones et al., 2011), IPSL-CM5A-LR (Mignot and Bony, 2013), MIROC-ESM-CHEM (Watanabe et al., 2011), and NorESMI-M (Bentsen et al., 2013; Iversen et al., 2013)), and these five GCMs were regarded as the representatives of the full range of projections of future climate based on the current existing scientific literature within the fifth phase of the Climate Model Intercomparison Project (CMIP5) models (Taylor et al., 2012; Warszawski et al., 2014). The ISI-MIP database (https://www.isimip.org/) contains time series of daily mean temperatures for historical (1960–2005) and projected (2006–2099) periods, which are bias-corrected and downscaled to 0.5° × 0.5° spatial resolution (Warszawski et al., 2014). GCMs were generated by considering the difference in climate change impact at varying levels of global warming according to the four RCPs to produce the highest and lowest end-of-century forcings (Warszawski et al., 2014). When the modelled daily temperature series are applied to exposure-response relationships estimated using observed daily time series for daily mean temperature, deviations between the modelled and observed daily temperature series may produce biased results in the impact projections. Therefore, the modelled daily temperature series were corrected using the bias-correction method, which recalibrated using the monthly mean and the daily variability around the monthly mean of observed daily temperature series (Hempel et al., 2013). We calculated the projected daily time series of OHCAs as the mean observed count for each day of the year, and repeated this across the projection period (1990–2099).

Statistical analysis

Estimation of exposure-response relationships

We used two-stage time series analysis to predict the prefecture-specific non-linear lag impact of temperature on OHCA, as described previously (Gasparrini et al., 2016; Onozuka and Hagihara, 2017c; Zhang et al., 2019; Zhang et al., 2017). Briefly, first, we investigated the association between temperature and OHCA in individual prefectures using a time-series quasi-Poisson regression model combined with a distributed lag non-linear model, adjusting for season, long-term trends, and day of the week. We examined lag periods of up to 21 days to consider the delayed impact of low temperatures. Second, we combined prefecture-specific estimates using multivariate meta-regression models to predict the nationwide non-linear temperature-OHCA association. This method has been described in detail elsewhere (Gasparrini et al., 2017; Vicedo-Cabrera et al., 2019).

Projection of the effect on morbidity

We projected excess morbidity due to temperature using the daily temperature and morbidity time-series model according to the assumption of no adaptation or population changes, as described previously (Gasparrini et al., 2016; Onozuka and Hagihara, 2017c). Briefly, we determined the minimum morbidity temperature using the lowest value of the total cumulative relative risk between temperature and OHCA. We used the minimum morbidity temperature as a reference to compute the attributable risk by re-centering the natural cubic spline. This value was regarded as the optimal temperature. The total attributable number of OHCAs as a result of non-optimal temperatures was computed as the sum of contributions from all days in the series. The ratio of this value to the total number of OHCAs was regarded as the total attributable fraction. Components that were attributable to low and high temperatures were computed by accumulating the subsets corresponding to days with temperatures below or above the minimum morbidity temperature. First, we estimated the excess morbidity for each prefecture and combinations of GCMs and RCPs. Second, we computed attributable fractions as GCM-ensemble means according to decade and RCP using the respective total number of OHCAs as the denominator. Monte Carlo simulations were used to compute empirical confidence intervals (eCIs), calculate the uncertainty in both the estimated exposure-lag-response association and climate projections among GCMs. Details of this method were described previously (Gasparrini et al., 2017; Vicedo-Cabrera et al., 2019).

For sensitivity analysis, modeling selections were tested by controlling for different degrees of freedom for time trends (6 and 10 degrees of freedom per year), by choosing different lags (14 and 28 days), and by including or excluding different confounding factors (relative humidity, public holiday, and day of the week). All statistical analyses were conducted using R 3.5.0 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria), specifically using the *dlnm* and *mvmeta* packages.

RESULTS

A total of 739,717 OHCA cases of presumed cardiac origin were registered between January 1, 2005 and December 31, 2015 in the 47 prefectures of Japan. The daily mean temperature was 15.6°C, and the prefecture-specific daily mean temperature ranged from 9.4°C in Hokkaido Prefecture to 17.4°C in Fukuoka Prefecture (Figure 1, Figure S1 and Table S1 in the Supplement).

The variation in the mean temperature in the current period (2010–19) and the projected increase at the end of the 21st century (2090–99) in the four RCP scenarios in Japan are shown in Figure 2 and Table 1. We projected a steep rise in mean temperatures under high-end emission scenarios (RCP6.0 and RCP8.5); however, this rise slowed or tended to be reduced after a number of decades under climate change scenarios that assume greenhouse gas mitigation policies (RCP2.6 and RCP4.5) (Figure 2 and Figure S2 in the Supplement). By the end of the 21st century, a drop in greenhouse gas emissions may avert warming in Japan, with a mean rise in temperature of 0.6°C (range: 0.4–0.9) under RCP2.6 compared to 4.0°C (range: 3.0–4.9) under RCP8.5. The respective data from each prefecture are shown in Figures S2 and S3 in the Supplement.

Projected trends in heat- and cold-related excess morbidity according to three RCPs in Japan are summarized in Figure 3 and Table 1. Our findings showed a common pattern of a reduction in cold-related morbidity and mild rise in excess morbidity due to heat across the scenarios. The projected slopes were steeper under RCP8.5, while the trends were shallower throughout the 21st century under scenarios that assume mitigation strategies. Cold-related excess morbidity is projected to be reduced from 19.9% (95% eCI: -0.1, 33.4) in 2010–2019 to 13.8% (95% eCI: -2.5, 25.5) in 2090–2099 under scenarios of intense warming (RCP8.5), and there is a large degree of uncertainty for cold-related morbidity. In contrast, heat-related excess morbidity is projected to rise from 0.4% (95% eCI: 0.1, 0.6) to 2.4% (95% eCI: 0.5, 4.2) across the same period and conditions. The respective data from each prefecture are shown in Figures S4 and S5 in the Supplement.

Temporal changes in excess morbidity under three different RCPs in Japan are summarized in Figure 4 and Table 3. There was a marked net reduction in excess morbidity, ranging from -0.8% (95% eCI -1.9, 0.1) under RCP2.6 to -4.2% (95% eCI -8.3, -0.1) under RCP8.5. The respective data from each prefecture are shown in Figure S6 and Tables S2-S5 in the Supplement.

The sensitivity analysis revealed that varying the choice of model had little effect on the estimates (Supplementary Table S6).

DISCUSSION

We investigated projections of the nationwide impact of temperature on OHCA in Japan according to different climate change scenarios using recently developed study designs and advanced statistical methods. We found that temperature-related excess morbidity is expected to be reduced under higher emission scenarios. To our knowledge, our study is the first to investigate the possible impact of temperature changes according to climate change scenarios on OHCA. Our findings indicate that climate change may have positive effects on OHCA.

Our study shows that climate change may possibly result in a marked reduction in temperature-related OHCA. We also found a steep reduction in cold-related excess morbidity under higher emission scenarios of global warming, and a small increase in heat-related excess morbidity. These findings agree with those of recent studies, which predict that lower intensity warming and bigger reductions in cold-related excess mortality could stimulate a minimal negative net effect in temperate areas, including Japan (Gasparrini et al., 2017). Moreover, temperature-related mortality due to acute ischemic heart disease is projected to remain stable over time under changing climate conditions in China (Li et al., 2018). However, another study in China projected that temperature-related cardiovascular disease mortality will increase under different RCP scenarios (Zhang et al., 2018). These findings indicate that ambient temperatures may impact the various subtypes of cardiovascular diseases in differing ways (Lin et al., 2009). Further, the mechanisms governing cardiac events involve multiple factors and complex interactions (Woodhouse et al., 1994). Although the physiological mechanism underlying temperature-related cardiovascular events remains to be elucidated, our results emphasize the need for additional studies on the projections of temperature-related excess morbidity for cardiovascular diseases.

The net reduction in OHCA as a result of global warming may be explained by several mechanisms. First, increasing temperature due to global warming may reduce health problems related to low temperatures, which can lead to offset the increase in morbidity by high temperatures. A recent study has shown that, although both high and low temperatures are responsible for OHCA burden, most OHCA cases are attributable to low temperatures (Onozuka and Hagihara, 2017c). Regarding low temperature-related health problems, recent studies have indicated that circulatory and coronary heart disease and ST-elevation myocardial infarction (STEMI) mortality is increased with low temperatures (Schwartz et al., 2015). It is possible that low temperatures trigger sympathetic stimulation and a rise in cardiac workload, which could stress a person with severe coronary stenosis and/or advanced heart failure beyond their compensation threshold (Izzo et al., 1990; Schwartz et al., 2015; Wolf et al., 2009). Second, low temperatures may contribute to the cardiovascular stress response by increasing blood viscosity, changing heart rate variability, and impacting inflammatory responses (Keatinge et al., 1986). Low temperature periods have been linked to high excess risk of heart failure, arrhythmia, and atrial fibrillation (Medina-Ramon et al., 2006). Low temperatures raise sympathetic tone, blood pressure, vascular resistance, fibrinogen level, platelet count, some clotting factors, and blood viscosity, which can raise the risk of plaque rupture, thrombosis, and STEMI mortality (Izzo et al., 1990; Schwartz et al., 2015; Wolf et al., 2009). Furthermore, those with reduced vitamin D levels are vulnerable to sudden cardiac death during winter, suggesting that increasing vitamin D levels by adequate sun exposure in the winter months may be significant for decreasing sudden cardiac death (Deo et al., 2011; Drechsler et al., 2010; Giovannucci et al., 2008; Onozuka and Hagihara, 2017b; Onozuka and Hagihara, 2017d). Our findings are therefore physiologically plausible and suggest that climate change according to different levels of future global warming may markedly reduce OHCA.

Our findings suggest that variations in temperature-related excess OHCA are proportional to the degree of global warming under each of the RCP emission scenarios. We found that the largest net reduction in excess morbidity was projected under RCP8.5, which assumes very high greenhouse gas emissions (Pachauri et al., 2014). In contrast, the net reduction in excess morbidity is lower under RCP2.6, which assumes a limited increase in global mean temperatures of 2°C following climate change adaptation and mitigation policies (van Vuuren et al., 2011b). Although recent studies have reported the negative impacts of climate change on mortality (Gasparrini et al., 2017), there may be inconsistencies in the direction and magnitude of the impacts on mortality and morbidity due to climate change. Our results emphasize the importance of further investigation into projections of global warming and the associated impacts on mortality and morbidity due to different causes.

Our results have practical implications for refining or adjusting estimates for climate change-related OHCA in future public health policies. Our study projects a largest decrease in net excess OHCA morbidity due to climate change under high-emission scenarios. The majority of the excess morbidity was attributable to low temperatures, while heat was only associated with a small fraction of excess morbidity. Additionally, the reduction in temperature-related net excess morbidity is expected to be significant in scenarios of high greenhouse gas emissions. These findings are important for the development of disease-specific public health policies, and for informing the ongoing international discussion on the health impacts of climate change.

There were several limitations in our study. First, while our projections of temperature-OHCA relationships according to future warming scenarios enabled isolation of the effects of climate change, they did not account for important factors such as demographic changes and adaptation (Arbuthnott et al., 2016; Hajat et al., 2014; Nordio et al., 2015; O'Neill et al., 2014). Especially, since a recent study suggested that gender and age are vulnerability factors for the effect of temperature on OHCA (Onozuka and Hagihara, 2017c), demographic and adaptation changes in the future can alter the impact of climate change on OHCA. Therefore, our results should not be interpreted as predictions of future excess morbidity but rather possible outcomes under well-defined but hypothetical scenarios. Second, our projections of temperature-related excess morbidity are subject to considerable uncertainty, especially those associated with the net impact, because of both variability in the climate models and imprecision in the predicted exposure-response correlation (Benmarhnia et al., 2014). Third, we used available outdoor monitoring data from one representative weather station to represent population exposure to the mean temperature. Thus, exposure measurement bias and misclassification should not be ignored. These factors might affect the interpretation of our findings, and additional studies using more precise modeling methods are required to resolve these issues.

In summary, our study indicates that Japan is projected to experience a substantial net reduction in OHCA under higher-emission scenarios. The decrease in risk is limited to a specific morbidity cause, and a broader assessment of cardiovascular disease morbidity within climate change scenarios should consider other direct and indirect impacts.

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Author Contributions

DO made substantial contributions to conception and design, did the statistical analysis, took the lead in drafting the manuscript, and interpreting the results. DO, AG, and FS developed the statistical methods. MH and YH provided data and substantial scientific input in interpreting the results and drafting the manuscript. All gave final approval and agree to be accountable for all aspects of work ensuring integrity and accuracy.

Competing Interests

The authors declare that they have no competing interests.

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Figure legends

Figure 1. The geographic distribution of the 47 Japanese prefectures and climate stations. The colors represent different ranges of mean daily temperature during the study period.

Figure 2. Decadal temperature trends in Japan by scenario. The graph shows the projected increase in temperature (°C, GCM-ensemble average), averaged by decade and climate change scenario, compared to the current period (2010–2019).

Figure 3. Trends in heat-related and cold-related excess morbidity in Japan. The graph shows the excess morbidity by decade attributed to heat and cold under three climate change scenarios (RCP2.6, RCP4.5, and RCP8.5). Estimates are reported as GCM-ensemble mean decadal fractions. The shaded areas represent 95% empirical confidence intervals (eCIs). RCP=representative concentration pathway; GCM=general circulation model.

Figure 4. Temporal change in excess morbidity in Japan. The graph shows the difference in excess morbidity by decade compared with 2010–2019 under three climate change scenarios (RCP2.6, RCP4.5, and RCP8.5). Estimates are reported as GCM-ensemble means. The black vertical segments represent 95% empirical CIs (eCIs) of net difference. RCP=representative concentration pathway; GCM=general circulation model.

Tables

Table 1. Heat-related, cold-related, and net excess morbidity (%) with 95% eCI by period and climate change scenario in Japan.

Scenario	Projected increase in temperature (2090–2099 vs 2010–2019)	Effect	Period		
			2010–2019	2050–2059	2090–2099
RCP2.6	0.6 (0.4, 0.9)	Heat	0.4 (0.1, 0.6)	0.7 (0.2, 1.4)	0.6 (0.2, 0.9)
		Cold	19.9 (-0.1, 33.2)	18.6 (-0.9, 31.9)	18.9 (-0.7, 32.3)
		Net	-	-1.0 (-2.3, -0.1)	-0.8 (-1.9, 0.1)
RCP4.5	1.8 (1.4, 2.2)	Heat	0.3 (0.1, 0.5)	0.8 (0.2, 1.4)	1.0 (0.2, 1.8)
		Cold	20.1 (0.2, 33.4)	17.6 (-1.4, 30.7)	16.8 (-1.8, 29.8)
		Net	-	-2.0 (-3.1, -0.8)	-2.6 (-4.4, -0.8)
RCP6.0	2.5 (1.7, 3.0)	Heat	0.3 (0.1, 0.5)	0.6 (0.2, 1.0)	1.4 (0.3, 2.8)
		Cold	20.3 (0.3, 33.8)	18.2 (-1.1, 31.3)	15.9 (-2.1, 28.5)
		Net	-	-1.9 (-3.1, -0.9)	-3.4 (-5.7, -1.0)
RCP8.5	4.0 (3.0, 4.9)	Heat	0.4 (0.1, 0.6)	1.0 (0.3, 1.8)	2.4 (0.5, 4.2)
		Cold	19.9 (-0.1, 33.4)	16.8 (-1.8, 29.5)	13.8 (-2.5, 25.5)
		Net	-	-2.5 (-4.8, -0.5)	-4.2 (-8.3, -0.1)

Data on projected increase in temperature are average mean prefecture-specific temperature (range) as GCM-ensemble. RCP=representative concentration pathway. GCM=general circulation model.

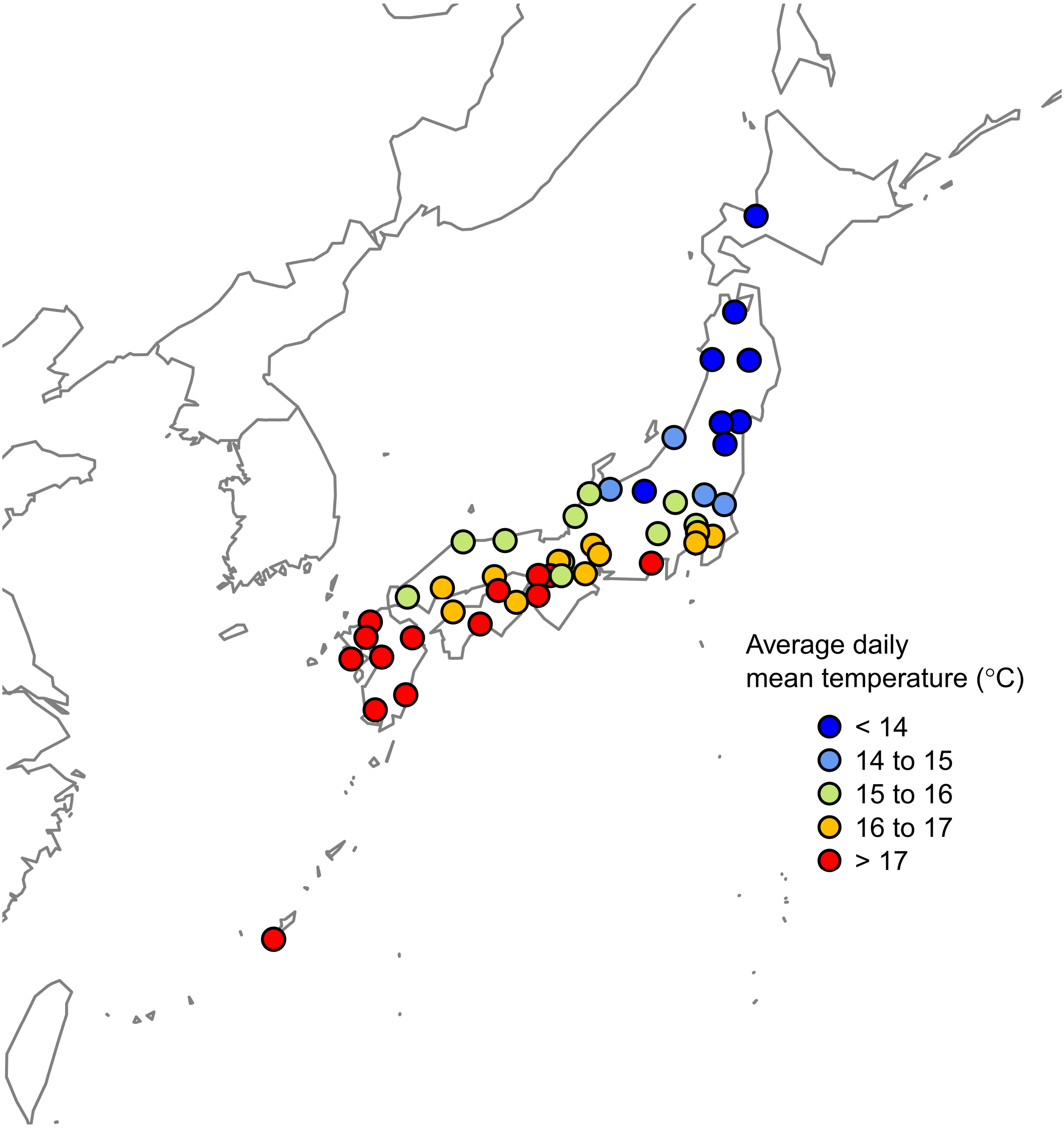
Average daily
mean temperature (°C)
● < 14
● 14 to 15
● 15 to 16
● 16 to 17
● > 17

Figure 1

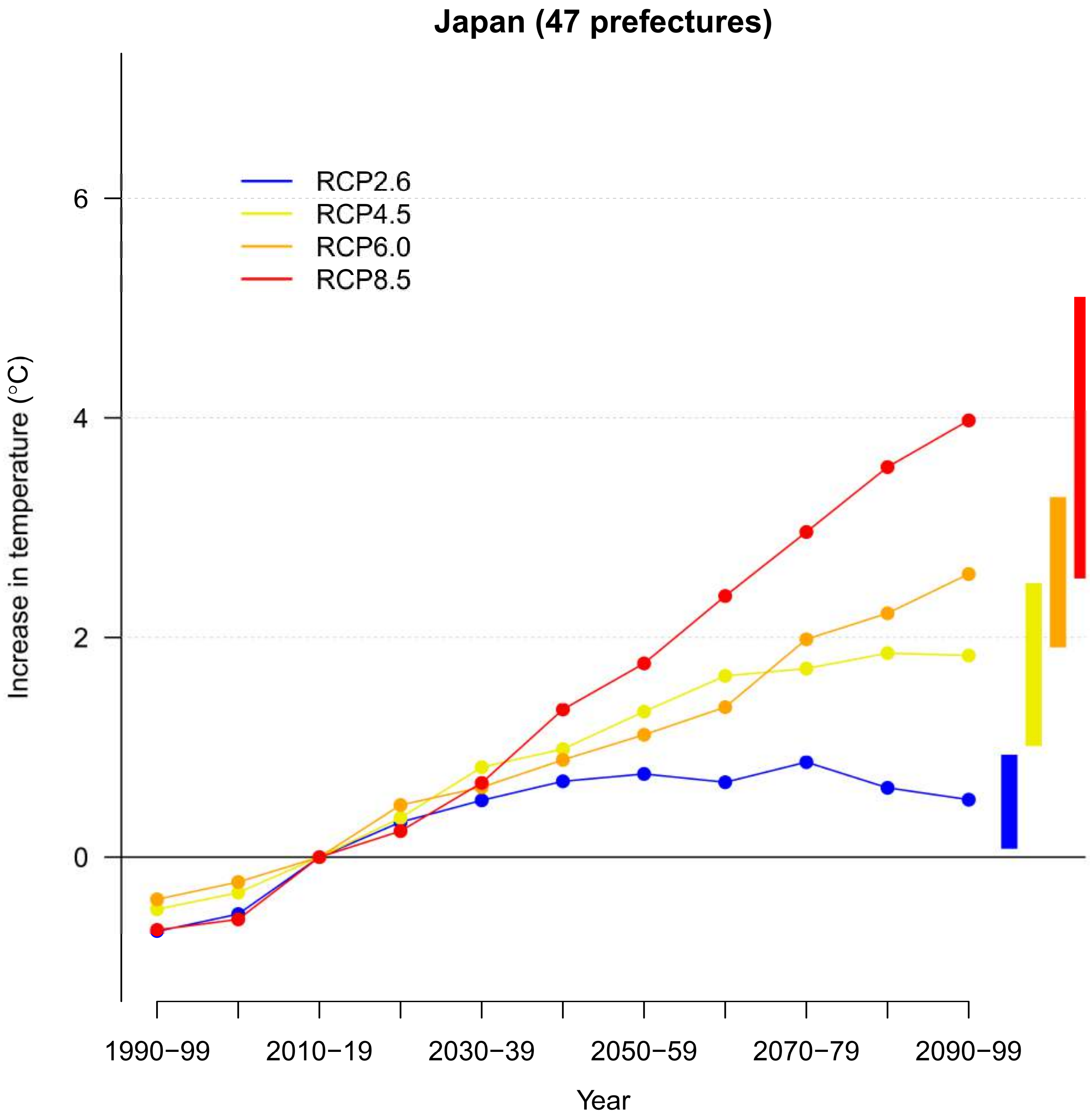
Japan (47 prefectures)
RCP2.6
RCP4.5
RCP6.0
RCP8.5
6
4
2
0
Increase in temperature (°C)
1990−99
2010−19
2030−39
2050−59
2070−79
2090−99
Year

Figure 2

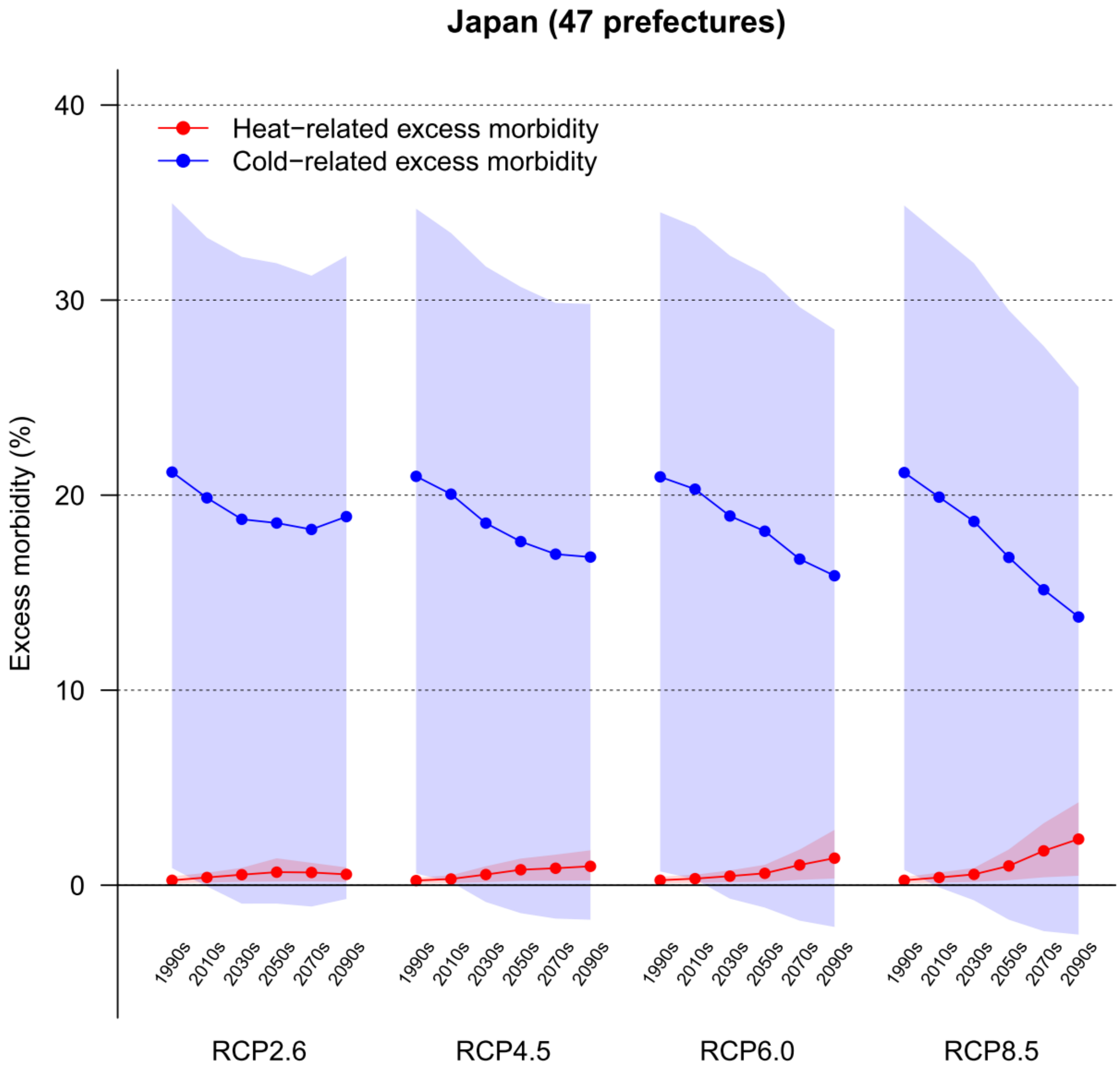
Japan (47 prefectures)
Excess morbidity (%)
40
30
20
10
0
Heat−related excess morbidity
Cold−related excess morbidity
1990s
2010s
2030s
2050s
2070s
2090s
RCP2.6
RCP4.5
RCP6.0
RCP8.5

Figure 3

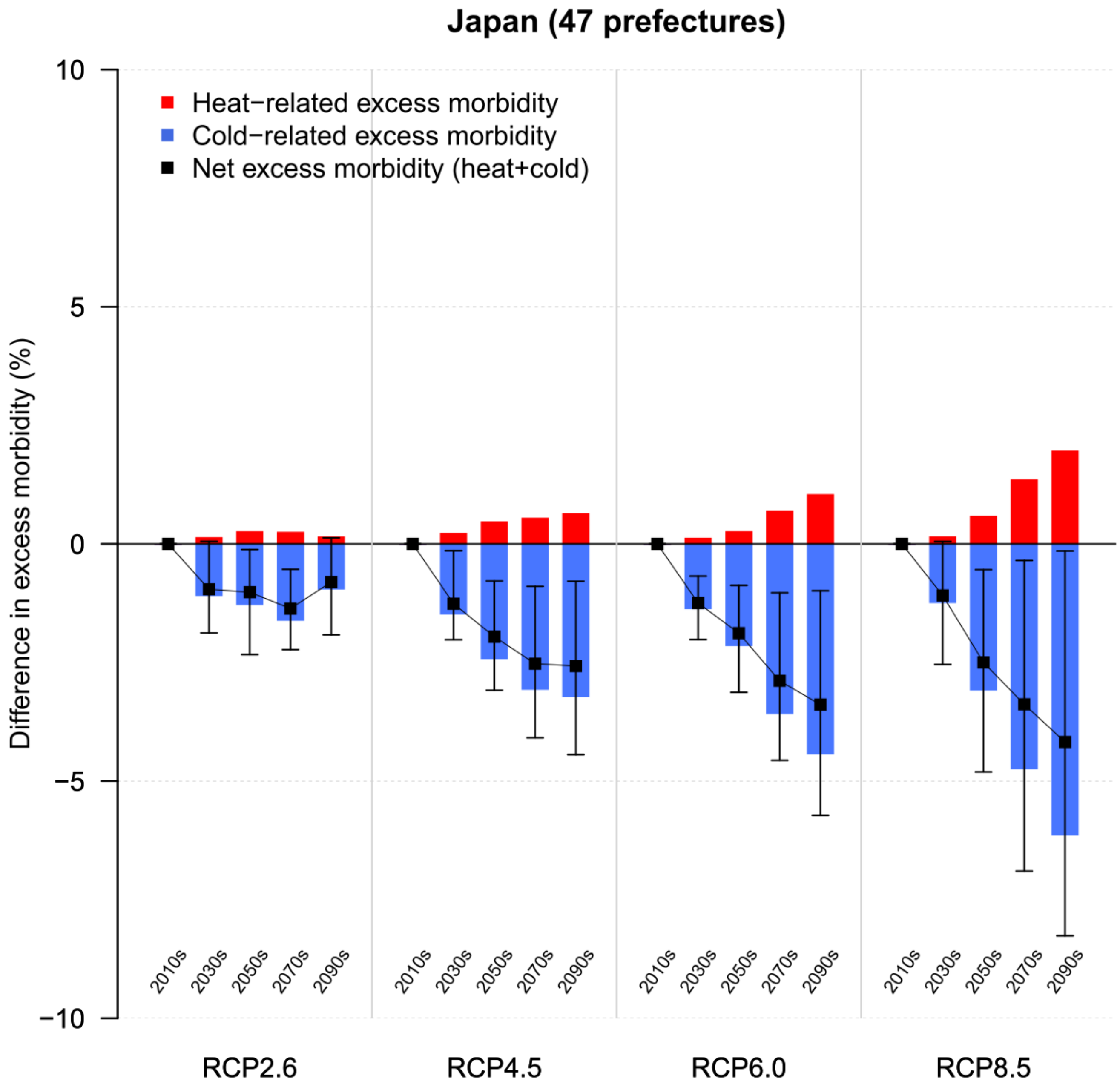
Japan (47 prefectures)
Heat−related excess morbidity
Cold−related excess morbidity
Net excess morbidity (heat+cold)
Difference in excess morbidity (%)
10
5
0
−5
−10
2010s
2030s
2050s
2070s
2090s
RCP2.6
RCP4.5
RCP6.0
RCP8.5

Figure 4