Evaluation of the Tourism Climate Index over Japan in a Future Climate Using a Statistical Downscaling Method

Hiroyasu KUBOKAWA

Atmosphere and Ocean Research Institute, the University of Tokyo, Kashiwa, Japan

Tsuyoshi INOUE

Mitsubishi Research Institute Inc., Tokyo, Japan

and

Masaki SATOH

Atmosphere and Ocean Research Institute, the University of Tokyo, Kashiwa, Japan

(Manuscript received 2 April 2013, in final form 3 October 2013)

Abstract

The tourism sector is sensitive to the effects of climate change. This is the first study that examines the relationship between tourism and climate change over Japan using data from projections of future climate. We apply a statistical downscaling method to climate model data and estimate how tourism on a city-scale over Japan may be affected by the expected near-future global warming. We used the tourism climate index (TCI) to evaluate the effect of meteorological factors on tourism. We estimated TCI using data from observatories of the Japan Meteorological Agency (JMA), and compared it with monthly changes in tourist number at Morioka city, and annual variations in tourists at 38 areas in Japan. In general, TCI shows a positive correlation with tourists numbers, although the correlation depends on location. In mountainous regions such as Osorezan and Tsurugizan, TCI is clearly correlated with the number of tourists. As expected, TCI under present climate conditions identifies summer as the most comfortable season for tourism.

We also estimate TCI under future climate conditions (around the year 2040) using data from the Model for Interdisciplinary Research on Climate (MIROC) and five climate models from the Coupled Model Intercomparison Project Phase 3 (CMIP3). For future climate over large areas of Japan, TCI generally increases in spring/autumn and decreases in summer because effective temperature move into the comfortable and uncomfortable range, respectively. This indicates that the comfortable season for tourists will change in the future from summer to spring and autumn. TCI in the winter season showed large variance between models owing to differences in predicted temperatures in the models.

Keywords downscaling; tourism; global warming

1. Introduction

Japan has a variety of climate zones, including

Corresponding author: Hiroyasu Kubokawa, University of Tokyo, 5-1-5, Kashiwanoha, Kashiwa-shi, Chiba 277-8568, Japan
E-mail: kubok@aori.u-tokyo.ac.jp
©2014, Meteorological Society of Japan

subtropical, extratropical, and subarctic areas. Since the climate change due to future global warming might differ among these zones, local differences in climate change need to be understood in Japan. However, most existing climate models have a horizontal resolution that is too coarse to examine local climate change. To overcome the resolution gap, the technique of downscaling has been developed to subdivide data in both

time and space (e.g., Storch et al. 1993; Willby et al. 1998). Such a technique enables us to obtain detailed information about future climate at both temporally and spatially finer scales from climate models. For example, in Japan, Iizumi et al. (2006) examined the change in rice production in a future climate using daily surface maximum and minimum temperature, and daily solar irradiance data. Hara et al. (2008) argued that snow amounts below 500 m height will decrease under future global warming. In Europe, there have been many downscaling studies on social and economic issues associated with global warming. For example, Amelung and Moreno (2009) estimated the impact of future climate on tourism, using the TCI developed by Mieczkowski (1985), which is estimated from meteorological surface data, and the authors argued that tourism in northern Europe will suffer in the future. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (IPCC AR4 2007), identified the tourism sector as being sensitive to global warming. Future changes in tourism will be strongly related to climate change. The present research is the first to examine possible changes in tourist activity in Japan under future climate conditions. Using the downscaling method, we estimate TCI of local areas in Japan to infer possible changes in tourist activity. As mentioned above, TCI is defined using only meteorological variables. The remainder of this manuscript is organized as follows. We describe the methodology and data in Section 2 and present the applicability of TCI in Japan under the present climate in Section 3. The response of TCI to future climate change using climate model data is discussed Section 4, and summary and conclusions are given in Section 5.

2. Methodology

2.1 The Tourism climate index

We first describe TCI, which was introduced by Mieczkowski (1985), to evaluate the effect of meteorological conditions on tourism. The index is calculated using monthly averaged meteorological surface data. Another index is proposed to discuss meteorological conditions for the tourism industry. Yu et al. (2009) developed another index, the Modified Climate Index for Tourism (MCIT), which is calculated using daily temperature, wind, weather information, and visibility. They used it in a study of tourism in Alaska and Florida. Although this index can be used for daily tourism conditions, it is not suitable for application to future climate data because daily data are not available for the CMIP3 models in general. Note that recent

CMIP5 models provide daily data, which enables a more detailed comparison; this will be the subject of a future study.

TCI is based on the physiological reaction of a human body to climate. Effective temperature (Gagge et al. 1986) is generally used to represent the temperature felt by a person. Mieczkowski (1985) formalized TCI by adding the influence of rain, wind, and solar radiation to the effective temperature. These effects are important for tourists when taking part in outdoor activities.

TCI is determined only by meteorological conditions and is expressed as the sum of five subindices related to comfort: (1) daytime effective temperature (CID: calculated from the daily maximum temperature and daily minimum humidity), (2) daily average effective temperature (CIA: calculated from daily mean temperature and humidity), (3) rain (R: monthly total precipitation), (4) sunshine hours (S), and (5) wind (W). Effective temperature is calculated by using the method proposed by Gagge et al. (1986). Each index has a score between -3 and 5 points (see Table 1). Using these five indices, TCI is expressed as follows.

$$TCI = 8CID + 2CIA + 4R + 4S + 2W \quad (1)$$

When all indices have the value 5 , TCI is equal to 100 . Since tourist activity is high during daytime, the effective temperature in the daytime is thought to be the main factor influencing TCI. Secondary factors are precipitation (R) and hours of sunshine (S). These indices are estimated from monthly averaged data.

The most comfortable temperature zone is set to $20\text{--}27^\circ\text{C}$. If the effective temperature deviates from this temperature zone, CID or CIA fails. Less rain and more solar insolation are both considered as more comfortable. The valuation method for the wind index (W) changes with temperature: windy conditions are considered comfortable for high temperatures but uncomfortable for lower temperatures owing to the wind-chill effect. TCI of 50 and above is considered suitable for tourists. The above definition was chosen by Mieczkowski (1985) for his study but should also be applicable for different target areas or countries. We use the original definition of TCI and examine how it explains the distribution of tourists in Japan.

Globe temperature (T_g) and radiation temperature (T_r) are required for the calculation of effective temperature. The following empirical formulae (Horie and Fujiwara 2009) are used for the calculation of these temperatures. First, globe temperature is given by

Table 1. TCI sub-index scoring table (see the text). After Amelung and Moreno. (2009)

Score	Equivalent Temperature (°C)	Monthly Precipitation (mm/month)	Sunshine hours (hours/day)	Wind Speed (km/hour)			Wind Chill Rate by Wind (w/m ² /hour)
				Normal	Trade	Tropical	
5	20~27	0~14.9	>10	<2.88	12.24~19.79		
4.5	19~20	15~29.9	9~10	2.88~5.75			
	27~28						
4	18~19	30~44.9	8~9	5.76~9.03	9.04~12.23		<500
	28~29				19.80~24.29		
3.5	17~18	45~59.9	7~8	9.04~12.23	5.76~9.03		
	29~30				24.30~28.79		
3	15~17	60~74.9	6~7	12.24~19.79	2.88~5.75		500~625
	30~31						
2.5	10~15	75~89.9	5~6	19.80~24.29	<2.88	<2.88	
	31~32				28.80~38.52		
2	5~10	90~104.9	4~5	24.30~28.79		2.88~5.75	625~750
	32~33						
1.5	0~5	105~119.9	3~4	28.80~38.52		5.76~9.03	750~875
	33~34						
1	-5~0	120~134.9	2~3			9.04~12.23	875~1000
	34~35						
0.5	35~36	135~149.9	1~2				1000~1125
0.25							1125~1250
0	-10~-5	>150	<1	>38.52	>38.52	>12.24	>1250
-1	-15~-10						
-2	-20~-15						
-3	<-20						

$$Tg = T + 12.1 + 0.0067S - 2.4V^{\frac{1}{2}} (S \leq 400), \quad (2)$$

$$Tg = T - 0.3 + 0.0256S - 0.81V^{\frac{1}{2}} (S > 400),$$

where T is temperature [°C], V is wind speed [m s^{-1}], and S is global solar irradiance [W m^{-2}]. Radiation temperature is calculated from globe temperature by using following relationship (Horie and Fujiwara 2009):

$$Tr = \left((Tg + 273)^4 + \frac{0.25 \times 10^8}{\varepsilon} \left(\frac{|Tg - T|}{d} \right)^{0.25} \times (Tg - T) \right)^{\frac{1}{4}} - 273 (V \leq 0.15 \text{ m s}^{-1}) \quad (3)$$

$$Tr = \left((Tg + 273)^4 + \frac{1.1 \times 10^8 V^{0.6}}{\varepsilon d^{0.4}} \times (Tg - T) \right)^{\frac{1}{4}} - 273 (V > 0.15 \text{ m s}^{-1})$$

where ε and d are the emissivity and diameter of the sensor, respectively. We used following standard value of $\varepsilon = 0.95$, and $d = 0.15$ [m].

2.2 Data

To calculate TCI under the present climate, we considered surface meteorological data from 156 JMA observatories that are located at intervals of approximately 40 km on average and for which hourly data are available. At some observatories, sunshine hours are not observed; hence, we only used data from the 66 observatories that observe sunshine hours to calculate TCI.

We used future projection data from climate models to calculate TCI under a future climate. First, we used high spatial and temporal resolution data from the Model for Interdisciplinary Research on Climate 3.2 (MIROC-3.2) (Hasumi and Emori 2004). The horizontal resolution of this model is 1.125° , and we used surface data at 3-hour intervals. The future data are based on scenario A1B of IPCC AR4, (IPCC AR4 2007). Hereafter, we refer to these data as MIROC.hires.1. In this study, we used the data between 1998 and 2007 for the present climate, and between 2041 and 2050 for future climate. Five publically available climate model datasets from the Coupled

Model Intercomparison Project phase 3 (CMIP3) (i.e., CSIRO-MK3.5, MPI-ECHMAN5, GFDL-CM2.0, CSIRO-MK3.0, and MIROC-3.2-HIRES) were also used. Note that for these models, only daily output data were available. The horizontal resolutions of CSIRO-MK3.5, MPI-ECHMAN5, GFDL-CM2.0, CSIRO-MK3.0, and MIROC-3.2-HIRES are 1.875°, 1.875°, 2.5°, 1.875°, and 1.125°, respectively. Of all available climate model data under the A1B scenario, these models, with the exception of MIROC-3.2-HIRES, showed the highest or lowest temperatures in the Asian region (120°–150°E, 25°–50°N) under the present climate. While 3-hourly data are available for MIROC.hires.1, we also use the publically available CMIP3 MIROC-3.2-HIRES data for comparison with MIROC.hires.1. Hereafter, we refer to the CMIP3 MIROC-3.2-HIRES daily data as MIROC.hires.2. Using data from these five CMIP3 climate models and MIROC.hires.1, we calculate the variance of TCI in future climate.

Note that the calculation method for TCI with these CMIP3 data is different from that used for MIROC.hires.1, as follows. (1) Instead of the surface specific humidity, which is not available in CMIP3, we used 1000 hPa specific humidity data. Since CMIP3 data are archived in the form of daily averages, the daily maximum temperature and minimum humidity data are not available. Therefore, we used the JMA observations of the present climate to construct the relationships between daily mean and maximum temperatures, and between daily mean and minimum humidities for each month at all the observatories using the JMA data. We produced daily mean temperature and humidity data using the downscaling technique described in Section 4, and applied the relationship obtained above to generate daily maximum-temperature and daily minimum humidity data. (2) For MIROC.hires.1, we used the data for the period between 2041 and 2050 as the future climate data; however, since no data are available before 2046 in CMIP3 data, we regarded the data for the period 2046–2055 as future climate data. TCI is compared for the common period of 2046–2050 for MIROC.hires.1 and CMIP3 data. As for the CMIP3 data, we constructed the statistical relationship by using the twentieth-century historical experiment (20C run) for the period 1991–2000 and the JMA observational data for the period 1998–2007. Note that these two datasets cover different periods. (3) The data at 1000 hPa are used for the calculation of TCI using CMIP3 data. Therefore data is absent in some areas where the topography is elevated, such as the Tohoku and Chugoku districts.

As mentioned previously, solar radiation is not

observed at some observatories. In addition, the sunshine hours data are not archived for CMIP3. In this study, the following empirical rules (Kondo 1994) were used to estimate the sunshine hours from solar radiation data.

$$\begin{aligned} N &= \frac{No}{b} \cdot \frac{So}{Sod} - No \cdot a \\ No &= \frac{2H}{0.2618} \\ \sin \frac{H}{2} &= \left(\frac{A}{\cos \phi \cos \zeta} \right)^{\frac{1}{2}} \\ A &= \sin \left(\frac{\pi}{4} + \frac{\phi - \zeta + \gamma}{2} \right) \sin \left(\frac{\pi}{4} - \frac{\phi - \zeta + \gamma}{2} \right) \end{aligned} \quad (4)$$

where N , So , and Sod are sunshine hours, amount of solar irradiance at the top of the atmosphere, and average daily amount of global solar irradiance, respectively. H is an hour angle from sunrise to crossing the meridian, taking account of an index of refraction (γ) from the horizon. We set $\gamma = 0$ in this study for simplicity. The values of a and b depend on the type of pyrheliometer. We use $a = 0.244$ and $b = 0.511$ in this study. The following empirical rules are used (Kondo 1994) to estimate solar irradiance at the top of the atmosphere (So):

$$\begin{aligned} Sod &= Ioo \left(\frac{do}{d} \right)^2 \cos \theta, \quad \cos \theta = \sin \phi \sin \zeta \\ &\quad + \cos \phi \cos \zeta \cos h \\ \left(\frac{do}{d} \right)^2 &= a_1 + a_2 \cos \eta + 0.00128 \sin \eta \\ &\quad + 0.000719 \cos 2\eta + 0.000077 \sin 2\eta \\ \zeta &= \sin^{-1} (0.398 \times \sin a_3), \quad a_3 = 4.871 + \eta \\ &\quad + 0.033 \sin \eta \\ \eta &= \left(\frac{2\pi}{365} \right) i, \quad i = 30.36(M-1) + DAY, \\ a_1 &= 1.00011, \quad a_2 = 0.034221 \end{aligned} \quad (5)$$

Here, Ioo , θ , ϕ , ζ , and h are solar constant, zenith angle, latitude, celestial declination, and hour angle, respectively; d and do are the distance and average distance from the Sun to the Earth, respectively; η is a day number parameter (e.g., February 2 correspond to $i = 32$), and M is month (from 1 to 12) and DAY is the date within each month. It should be noted that sunshine hours include the effects of clouds, because global solar irradiance data used in this calculation include the effects of clouds. We compared estimated sunshine hours with observatory data. Differences lay mainly in

Table 2. Location and available data periods for the tourist resorts. Columns (from left to right) are resort number, resort name, longitude, latitude, and period of data.

Num	Name	Longitude	Latitude	Data
01	Syari Town	144.4°E	43.54°N	1989–2007
02	Rausu Town	145.1°E	44.1°N	1989–2007
03	Osorezan	141.5°E	41.19°N	1989–2007
04	Tsukimino Forest Park	140.87°E	40.71°N	1989–2007
05	Koiwai Farm	141.1°E	39.44°N	1989–2007
06	Matsushima	141.4°E	38.22°N	1989–2007
07	Mogami park	140.29°E	38.76°N	1989–2007
08	Handayama Nature Park	140.49°E	37.87°N	1989–2007
09	Rabisupa Lirabanon	140.01°E	37.65°N	1997–2007
10	Bandai Plateau	140.4°E	37.39°N	1989–2007
11	Disney Land	139.52°E	35.37°N	1989–2007
12	Yamatake City	139.56°E	35.14°N	1989–2007
13	Tachiguchi Hill Park	138.32°E	36.26°N	1989–2007
14	Kenrokuen	138.39°E	36.33°N	1989–2007
15	Suma Taisya	138.7°E	35.59°N	1996–2007
16	Utsukushigahara Plateau	138.6°E	38.13°N	1996–2007
17	Figu Family Park	136.49°E	35.3°N	1998–2007
18	Hirugano Plateau	136.54°E	36.0°N	1998–2007
19	Shirakawagou	136.9°E	36.27°N	1998–2007
20	Shito Rain Land	136.87°E	35.09°N	1998–2007
21	Omarasahi Forest Park	137.05°E	35.23°N	1989–2007
22	Shima Soain Village	136.5°E	34.21°N	1994–2007
23	Mie Forest Park	136.49°E	34.64°N	1991–2007
24	Kushimoto	135.4°E	33.3°N	1989–2007
25	Kouyasan	135.35°E	34.12°N	1989–2007
26	Furusato Forest Park	132.89°E	35.38°N	1994–2007
27	Kurashiki Chibori Park	133.45°E	34.36°N	1997–2007
28	Kourakuen	133.56°E	34.4°N	1997–2007
29	Bihoku Hill Park	132.59°E	34.5°N	1997–2007
30	New Zealand Village	132.41°E	34.43°N	1990–2007
31	Akiyoshida Safari Land	131.19°E	34.17°N	1990–2007
32	Green Oasis	132.5°E	34.07°N	1998–2007
33	Tsurugizan	134.5°E	33.51°N	1989–2007
34	Yashima	134.6°E	34.21°N	1989–2007
35	Kurubayashi Park	134.2°E	34.19°N	1989–2007
36	Green Land	130.28°E	35.59°N	1989–2007
37	Tategamikyoku Park	130.7°E	32.55°N	1989–2007
38	Okinawa Prefecture	127.68°E	26.21°N	1989–2007

the range 0.4–1.5 hours, with the largest differences observed at higher latitudes (2.0 hours maximum). This difference corresponds to 2 points in TCI value, and the effect is considered as small.

To compare TCI with the actual number of tourists, we use data at the 38 tourist resorts listed in Table 2. These data are annual total number of tourists at the respective locations. We also use the monthly tourist resort data at Morioka city (141.09°E, 39.7°N) from 1989 to 2007. This is a unique dataset because monthly tourist number data are not generally available at most

of the locations.

The statistical downscaling method used in this study is based on Iizumi et al. (2011) and will be described in Section 4. This method corrects the model bias using the observation. We will calculate the variation of TCI for future climate condition using the output from several climate models.

3. TCI under the present climate condition

3.1 Overall distribution in Japan

We calculate TCI at the JMA observatories. First, to

Table 3. Annually and seasonally averaged values of variables that make up TCI. Upper: present climate calculated from JMA data, averaged over all the stations; lower: same as the upper table, except for future climate (period 2041–2050) calculated from MIROC.hires.1 with the CDF-based method.

Present	Annual Average	DJF	MAM	JJA	SON
CIA [°C]	15.22	4.62	12.48	25.96	17.83
CID [°C]	18.52	8.05	16.33	28.52	21.16
Rain [mm/month]	145.16	93.65	129.65	193.64	163.69
Sunshine Hours [hr]	3.77	0.98	5.21	6.57	2.33
Wind [m s^{-1}]	3.30	3.60	3.47	2.95	3.17
Future	Annual Average	DJF	MAM	JJA	SON
CIA [°C]	18.77	7.79	16.33	30.05	20.89
CID [°C]	21.68	11.12	19.97	32.11	23.52
Rain [mm/month]	160.54	97.02	154.57	241.90	148.70
Sunshine Hours [hr]	5.05	3.45	6.31	5.85	4.57
Wind [m s^{-1}]	3.26	4.02	3.61	2.70	2.73

give a general impression of each factor constituting to TCI, Table 3 shows annually and seasonally averaged values of CID, CIA, R, S, and W averaged over all the observatories. CID is about 3°C warmer than CIA. Rain and sunshine hours are low (high) in winter (summer). There is a small seasonal variation in wind speed (about 3 m s^{-1}), with slightly weaker winds in the summer. Figure 1 shows the horizontal distribution of CID, rain, and sunshine hours for the JMA observatories annually averaged between 1998 and 2007. CID is colder than 15 °C (warmer than 15 °C) over most of the four main islands of Japan north of 30°N (south of 40°N) in DJF (JJA). In JJA, CID is as low as 21 °C at some observatories, but this is because of altitude (e.g., Nikko, Asosan). In DJF, precipitation is heavier over the observatories facing the Sea of Japan, because persistent low cloud develops over the Sea of Japan and leads to heavy snowfall in this season (Ohtake et al. 2009). In JJA, rainfall is high over most of Japan, except north of 40°N, because of the Meiyu–Baiu front (e.g., Ninomiya 2009; Shibagaki et al. 2000). Sunshine hours are longer (shorter) in JJA (DJF), and regional differences in sunshine hours and wind are small. Figure 2 shows the horizontal distributions of TCI for the four seasons. In DJF, TCI is less than 40 over all four main islands of Japan north of 30°N and is only higher than 40 in the Ryukyu islands at latitudes south of 30°N. Horizontal distributions of TCI in MAM and SON are similar, and TCI increases as latitude decreases. In JJA, TCI increases with latitude and is more than 50 (i.e., comfortable) north of 35°N. The areal fields and the seasonal change in TCI are almost consistent with those of comfortable effective temperatures (CIA and CID). TCI is low at obser-

vatories where the effective temperature lies outside the range 20°–27°C (see Table 1).

3.2 Comparison between the TCI and number of tourists

a. Monthly data at Morioka City

In this section, we compare TCI values with monthly data for tourist numbers at Morioka. We chose Morioka because monthly data for tourist numbers are available for a relatively long period between 1989 and 2007. In addition, Morioka is a typical and popular tourist destination without special factors or events, so meteorological effects are likely to be more directly related to tourist numbers. We use meteorological data at Miyako (141.6°E, 39.4°N), which is the JMA observatory closest to Morioka, to calculate TCI. Although the two sites are geographically close, we need to account for the difference in locations: Morioka is located inland and Miyako lies on the Pacific coast. However, since we compare monthly average values, we think that the meteorological conditions are not too different.

Figure 3a compares monthly tourist number at Morioka and TCI at Miyako for the period 1989–2007. Note that the data between October and December 1998 at Miyako are missing. At first, both tourist numbers and TCI have a similar and clear seasonal variation: they are low in winter (DJF) and high in summer (JJA). This characteristic is clearly seen in the scatter diagram shown in Fig. 3b. Although it was expected that tourist numbers in winter would be affected by winter sports such as skiing, the data do not show a clear signal. Tourist number increase in summer and clearly correspond to the seasonal cycle of CIA and CID (see Fig. 2b). Standard deviation in

Fig. 1. Horizontal fields of seasonally averaged (from top) CID [°C], rain [mm], and sunshine hours [hr] under the present climate, for winter (DJF) and summer (JJA). (a), (c), and (e) correspond to DJF; (b), (d), and (f) correspond to JJA. Horizontal fields for Ryukyu islands are shown in upper-left side of each panels.

tourist numbers also increases in summer (about 30 thousand tourists) compared with winter (about 25 thousand tourists) (Fig. 3b). In particular, the standard deviation is highest in May and June, with a value reaching 35 thousand tourists. Since the decrease in tourists in winter might be explained by difficulties in access resulting from heavy snowfall, our discussion

is limited to the summer season. The correlation coefficient between tourist numbers and TCI in Fig. 3a is 0.50.

The seasonal cycle in tourist numbers clearly changes around 1997 or 1998. Figure 3c shows the annually averaged monthly variation in tourist numbers and TCI. Tourist numbers peak in May, August, and

Fig. 2. Horizontal distributions of TCI under the present climate, calculated at 66 JMA observatories. (a) DJF, (b) MAM, (c) JJA, (d) SON. Horizontal fields for Ryukyu islands are shown in upper-left side of each panels.

October. However, in May and October, the number of tourists falls by 40 thousand in the period 1998–2004 compared with 1989–1997 (not shown). Such a large difference is not seen in any other month. Note that TCI shows no clear difference between these two periods. Therefore, we conclude that this difference is not caused by meteorological conditions, but by other factors, such as economic influences.

Next, to investigate the relationship between each meteorological index (e.g., CIA, CID) and tourist numbers, we examine the interannual time variation of these variables. Because the change in tourist numbers after 1998 is not related to meteorological conditions, we only use the data for the period 1989–1997 in this analysis. We found small interannual variations for CIA, CID, sunshine hours, and wind (not shown). Therefore, it is thought that these meteorological indices are not related to the interannual change in tourist numbers (see Figs. 3a and 3b). However, a large interannual variation is found in rain (monthly total precipitation), so it is possible that rain affects the

tourist numbers. Figure 4 compares rainfall and tourist numbers for the period 1989–1997. Tourist numbers decrease as rain increases in warmer seasons from April to October, except for July and August. In particular, this correlation is clearest in April, June, and October (Fig. 4). According to the linear regression coefficient for each month (not shown), tourist numbers are expected to decrease by about 20 thousand when total monthly rainfall increases by 100 mm. In the summer at Morioka, the average tourist numbers are 35.2 thousand and the maximum rainfall exceeds 300 mm. Thus, the rainfall results in a reduction in tourist by about 60 thousand, which is about 17% of the total. Note that for July and August, the change in tourist numbers is not clearly related to the change in rainfall. These two months correspond to the long vacation in Japan, and it is thought that at this time social influence has a greater effect than meteorological factors on tourist numbers.

We found a clear relationship between tourist numbers and TCI at Morioka and also that rainfall is a major factor controlling tourist numbers in the warm

Fig. 3. (a) Time series of tourist numbers at Morioka City (solid line) and TCI at Miyako (dotted line). (b) Scatter diagram of tourist numbers and TCI for 1989–2007. The red stars in the figure indicate average values for each season (DJF, MAM, JJA, and SON). (c) Seasonal variation of monthly averaged tourist numbers (solid line) and TCI (dotted line). Shading and error bars in (c) correspond to the standard deviations of tourist numbers and TCI, respectively.

season. However, we should view these results with caution. The meteorological data used in this section are based on monthly averages. Although there are more tourists during holidays and the long vacation, this analysis does not include such factors. The effect of rainfall might be examined more precisely if daily data for the rainy season (June and July) were available. Nevertheless, this is the first study to evaluate the

influence of meteorological factors on tourist numbers for a city in Japan, so the relation found with the monthly data is encouraging.

b. Annual data at major tourist resorts

In this section we use the annual total number of tourists visiting the major tourist resorts listed in Table 2 to examine the relationship with TCI. Before

Fig. 4. (a) Scatter diagram for rainfall and tourist numbers in October for the period 1989–1997. The solid line is a least-squares regression line.

proceeding to the analysis, we note that the annual data tend to show a weaker relation between TCI and tourist numbers than the monthly data, analyzed in the previous section for Morioka city. For example, the correlation coefficient changes from 0.5 for the monthly data to 0.34 for the annually averaged data at Morioka city. Details of the seasonal variation of effective temperature are missing (see previous section) and the amount of data has been reduced.

Figure 5a shows the horizontal distribution of correlation coefficients between tourist numbers at resorts (listed in Table 2) and TCI at the observatories geographically closest to those resorts. Resorts that show a positive correlation at a statistically significant level are found in the Tohoku district (Osorezan (Fig. 5b), Tsukimino forest park) and The Chugoku–Shikoku district (Tsurugizan (Fig. 5c), Bihoku hill park). Sunshine hours and rain are factors that increase the correlation coefficients. It is thought that since these resorts are in mountainous areas or in natural parks, the weather greatly affects tourist numbers. There are also resorts with a statistically significant negative correlation caused by a clear decrease in tourist numbers in the second half of the 1990s. Other non-weather factors, such as economic conditions might be responsible for this decrease. It is clear that a full quantitative explanation of the variations in tourist numbers is a difficult challenge.

4. TCI under a future climate

In this section, we apply the cumulative distribution function (CDF)-based statistical downscaling method

proposed by Iizumi et al. (2011) to the CMIP3 data for the future climate scenario, and discuss how TCI over Japan will change in the future. Iizumi et al. (2011) compared four dynamical downscaling methods and a statistical downscaling method for the characteristics of precipitation over Japan. Although each downscaling method has its particular strengths and weaknesses, the seasonally averaged precipitation calculated from the statistical downscaling is in good agreement with observations. The dynamical downscaling methods tend to simulate fewer rain days in the summer season. As discussed in Section 2, TCI consists of five meteorological indices. Since the indices which constitute TCI suffer from the same bias as would the dynamical models, dynamical downscaling is not necessarily superior to statistical downscaling. Although it is better to use an ensemble mean of many dynamical models to reduce uncertainties, this requires considerable computer resources. The statistical downscaling method also has a weakness: it can not determine which weather phenomena are related to the change in TCI. However, this method requires fewer computer resources makes obtaining results using different climate models easier. Since the purpose of this study is to examine the applicability of TCI, we use the less computationally demanding, statistical downscaling method.

Here, we introduce the CDF-based method. First, we relate observation to climate model data under present-day conditions. We create a CDF for a target variable using the observations (from the JMA observatories in this study) and climate model (MIROC.hires.1) data. Figure 6 shows the CDFs of monthly total precipitation calculated from MIROC.hires.1 and JMA observatories between 1998 and 2007. In this figure, the CDFs are produced by using data from all the observatories (66 points). In Fig. 6, the two curves cross at about 200 mm and 80% cumulative frequency, indicating that precipitation heavier than 200 mm is more frequent in the model. Precipitation in the domain exceeds 200 mm (in the horizontal axis), and more precipitation is found in the observational data. Next, we create a CDF for future climate using climate model data. Then, by adding the difference between CDFs of observations and model data under the present-day climate, we obtain the bias-corrected CDF for future climate. Finally, using the bias-corrected future CDF and the time series of future climate model data, we obtain the corresponding bias-corrected time series for future climate. For other variables, we use the same downscaling method. We investigated the model (MIROC.hires.1)-observed (JMA observation) discrepancies for

Fig. 5. (a) Horizontal distribution of correlation coefficients between the tourist numbers listed in Table 2 and TCI at the geographically closest observatories. Each annual total number of tourists and annually averaged TCI between 1989 and 2007 is used to calculate the correlation coefficient. Red (blue) circles indicate positive (negative) significance at the 90% level. Correlation coefficients shown as black circles are not significant at this level. (b) (upper) Time variation of annual total number of tourists (solid) and the annual average TCI (dashed) at Osorezan between 1989 and 2007, and (lower) scatter diagram of the data in the upper panel. The dashed line in the figure indicates the least-squares regression line. (c) Same as (b), but for Tsurugizan.

Fig. 6. Cumulative distribution function for total precipitation between 1998 and 2007. Data were averaged over all the stations. The solid (dashed) line corresponds to JMA (MIROC.hires.1) data.

TCI under present-day climate (not shown). The distributions of model's present-day TCI values are very similar to those compared with observationally-derived TCI (Fig. 1), especially in DJF and SON. In DJF and SON, the future change of the model-derived TCI is much larger than the model-observed discrepancies of TCI under the present-day condition, suggesting the robustness of the future change of TCI. In MAM and JJA, the model shows a relatively larger bias under the present day condition. Since any model has some biases, we eventually introduce a correction method such as the cumulative pdf approach used in this study, together with the use of the model ensemble data to obtain a more reliable result. This statistical relationship is created for the six climate models (see Section 2.2) using data from the observatories.

We discuss the importance of the bias-correction briefly. The bias-corrected TCI values from the models agree perfectly with the observed values under the present climate condition when considering the annual average. However, the seasonal dependence is not taken into account in the method used to calculate the CDF, so that the seasonal maps would show a slight difference. However, we found the difference to be very small.

The lower part of Table 3 shows the annually and seasonally averaged variables calculated from MIROC.hires.1 for future climate. A comparison with data under the present condition, Table 3 upper shows that CIA and CID increase by about 3°C in the future. In particular,

the increase in CIA in JJA reaches about 4°C. Rainfall generally increases, especially for JJA, but decreases by about 15 mm for SON. Kimoto (2005) investigated changes in precipitation around Japan using the MIROC and coupled general circulation models (CGCMs), and argued that precipitation decreases in DJF because it is associated with weakening of the monsoon circulation, and that it increases in JJA because of it is associated with the strengthening of east Asian monsoonal rain band. In our study, while rain scarcely changes in DJF, the increases in JJA are consistent with Kimoto (2005). The difference between our result and Kimoto (2005) in DJF may be caused by the downscaling method used in this study. In our study, the increase in rain is small because of bias correction. Sunshine hours increase in all seasons except for JJA. In DJF and MAM, while rain increases, sunshine hours increase; this may be due to an increase in shorter-duration rains. Wind shows no clear difference.

Figure 7 shows the horizontal distribution of the difference in CID, rain, and sunshine hours calculated from MIROC.hires.1 between the future and present climates in DJF and JJA. CID increases in both DJF and JJA throughout Japan. In particular, the increase is large at higher latitudes. In DJF, precipitation decreases on the Sea of Japan coast; this might be related to a possible weakening of the flow over the Sea of Japan in winter. Rainfall increases throughout Japan in JJA, particularly in the Kinki and Shikoku districts. Sunshine hours increase by about 1 hour on the Sea of Japan coast, and by about 2 hours or more in the remaining domains. Since rain generally increases by about 30 mm, it is suggested that the duration of rainfall decreases in these areas. Sunshine hours in JJA decrease throughout Japan except for higher latitudes.

Figure 8 shows the horizontal distribution of the difference in TCI between the present climate calculated from the data at the JMA observatories and for future climate calculated using MIROC.hires.1 with the CDF-based method. Figure 9 also shows how TCI changes at major cities over Japan from the present to future climates. TCI mainly increases at lower latitudes because the temperature increases and the effective temperatures (CIA and CID) move into the comfortable range. Although the area where TCI exceeds 50 is restricted to latitudes south of 25°N in the present-day climate, it spreads northward in future climate (see also Fig. 9a: Kochi, Kagoshima, Naha). In JJA, TCI decreases throughout Japan except for the Hokkaido district (Asahikawa) (see also Fig. 9b). Such decreases in TCI are caused by the increase in temperature, and

Fig. 7. Same as Fig. 1, but for the difference between the present climate calculated from JMA data and future climate calculated from MIROC.hires.1 data with the CDF-based method.

thus by the shift of CIA and CID into the uncomfortable range. Moreover, in the Kinki district, TCI is further reduced because of the increase in rainfall (see also Fig. 9b: Nara). In MAM and SON, the future TCI exceeds 50 at many locations. The change from present to future climate is accompanied by change in the number of locations where TCI exceeds 50 from 6 to 11 (in DJF), 28 to 53 (in MAM), 43 to 13 (in JJA),

and 29 to 58 (in SON), respectively. MAM and SON become the most suitable seasons for tourists in future climate, whereas the most comfortable season under the present climate is JJA. Under future conditions, JJA and DJF are relatively uncomfortable seasons.

To evaluate uncertainties in the climate model projection data, we then used data from five CMIP3 climate models to estimate the standard deviation of

Fig. 8. Same as Fig. 2, but for the difference between the present climate calculated from JMA data and future climate calculated from MIROC.hires.1 data with the CDF-based method. Positions where TCI exceeds 50 are shown as large dots.

TCI. However, the standard CMIP3 do not contain detailed surface data, such as sunshine hours, as discussed in Section 2. Furthermore, the values of CIA and CID calculated from MIROC.hires.1 tended to be low for observatories at high altitude (not shown). In addition, the difference in the time periods gives a difference in meteorological indices such as rainfall, as confirmed by the comparison between MIROC.hires.1 and MIROC.hires.2; MIROC.hires.1 provides 3-hourly data while MIROC.hires.2 provides daily data. Figure 10 shows the horizontal distributions of the difference in TCI between MIROC.hires.1 and MIROC.hires.2. At about half of the observatories, the difference in TCI is less than 10 in all seasons. The MIROC.hires.2 TCI is smaller than that of MIROC.hires.1 in the domain enclosed by the square labeled (1) in Fig. 10a, since MIROC.hires.2 has more rainfall. In other areas, TCI is higher for MIROC.hires.2 because there is less rainfall. In MAM and SON, TCI increases throughout Japan because of drier conditions.

However, TCI decreases at lower latitudes because the effective temperatures, CIA and CID, increase (shown by the domains (2) and (4) in Figs. 10b and d, respectively). In JJA, TCI increases in the domain enclosed by the square labeled (3), because rainfall decreases and the effective temperature falls. To summarize, TCI tends to be higher with MIROC.hires.2 data. In particular, the difference tends to be higher at more northerly latitudes for all the seasons except DJF. The results using CMIP3 data in Fig. 9 show that the change in average TCI value from the present to future climates is similar in MIROC.hires.1 and CMI3 data (6-model averages). TCI tends to increase in DJF and decrease in JJA throughout Japan for future climate, although the number of observatories where TCI exceeds 50 is small for future climate. In general, the standard deviation of TCI is higher in DJF than JJA. In particular, it is higher at higher latitudes, because of the difference in effective temperatures among the models. The low standard deviation at lower latitudes in both DJF and

Fig. 9. TCI at major cities under the present climate (JMA) and future climate (MIROC.hires.1 and six models, see the text). Error bars in the figure indicate standard deviations of average values of TCI calculated from six future climate models. (a) DJF, (b) JJA.

JJA indicates that the future TCI has lower uncertainties at lower latitudes.

5. Summary and concluding remarks

We discussed the change in tourism at a city level over Japan considering future climate using a statis-

tical downscaling method. We introduced TCI to estimate the effects of meteorological conditions on the tourism industry in Japan. We examined the characteristics of TCI over Japan using JMA observational data. This index is evaluated from monthly averaged meteorological data.

Fig. 10. Same as Fig. 2, but for difference of TCI between MIROC.hires.1 and MIROC.hires.2 (horizontal distribution of $\text{TCI}_{\text{MIROC.hires.1}} - \text{TCI}_{\text{MIROC.hires.2}}$).

The areas where TCI exceeds 50 (suitable for tourists) are found in the Kyusyu-Shikoku districts and Ryukyu islands in MAM and SON, and in the northern part of Japan (e.g., Hokkaido district) in JJA, under the present-day climate. In these areas, CIA and CID, which contribute to TCI, have values corresponding to a comfortable zone. This result was consistent with expectations.

We compared TCI with tourist numbers at Morioka city. There is a clear seasonal cycle: tourist numbers are higher in the summer season and decrease in the winter season. This seasonal cycle is also seen in TCI, and the correlation coefficient is 0.5. The standard deviation of tourist numbers is also high in the summer season. We found that the interannual variation of rainfall and number of tourists are high and that rainfall influences the number of tourists; the contribution of rainfall to the number of tourists is approximately 17% at maximum. We also compared the annual total tourist number at 38 tourist resorts with annually averaged TCI from the closest observatory to each resort.

Statistically significant correlations were found in the Tohoku and Chugoku-Shikoku districts. These tourist resorts are located in parks or mountainous areas, and changes in rain and sunshine hours have a strong influence on TCI. The change in tourist numbers can be evaluated using TCI even though it depends on place and time. Some deviations are also found between TCI and the tourist number. Other non-weather factors, such as economic conditions, might be responsible. It is clear that a full quantitative explanation of the variations in tourist numbers is a difficult challenge including non-weather factors.

We applied a statistical downscaling method to data from six climate models to calculate TCI for future climate. Although JJA is the most suitable season for tourists under the present climate, JJA will become an uncomfortable season for tourists. The number of sites where TCI exceeds 50 will generally increase in MAM and SON. These results show that spring and autumn may become the preferred seasons for tourists. Using CMIP3 data, the standard deviation of TCI for

future climate becomes higher in DJF than in JJA. In particular, the standard deviation (i.e., the uncertainty) increases with latitude. This is caused by the spread in effective temperatures among the climate models. At lower latitudes, the standard deviation of the effective temperatures decreases in both DJF and JJA, indicating that the predictions of change in effective temperature are more reliable at lower latitudes.

In this study, we have applied TCI to Japan for the first time, and we investigated the characteristics of TCI for present and future climates. Although the change in tourist numbers is consistent with the change in TCI, it is possible that a more appropriate TCI for Japan can be constructed. Future work will involve developing such an index. Because tourists are influenced by shorter time-scale weather conditions, such as tropical cyclones or low atmospheric pressure, it would be better to use an index based on shorter-term data rather than to use TCI (which uses monthly averages). Our approach using TCI also isolates model characteristics from a unique perspective. Comparison between TCI calculated from models and TCI calculated from observations gives a new view-point of model biases. Use of TCI reveals the characteristics of climate that affect tourism. Other indices derived from meteorological conditions, as well as TCI, can be used to improve the climate models themselves.

Acknowledgments

We would like to thank Masahide Kimoto and members of the MIROC team. We also wish to acknowledge valuable discussions with Hozuma Sekine, Yoshiaki Kinehara, Shintaro Bunya, and Megumi Matsuda at Mitsubishi Research Institute, Inc. (MRI). The authors acknowledge two anonymous reviewers and the editor for improving the manuscripts. We acknowledge the modeling groups, the Program for Climate Model Diagnosis and intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modeling (WGCM) for the WCRP CMIP3 multi-model dataset. These climate model datasets are supported by the Office of Science, U.S. Department of Energy. Tourist numbers data were provided by the Japan Tourism Agency, and by the city hall of Morioka City (<http://www.city.morioka.iwate.jp/>). This work was also supported by the Innovative Program of Climate Change from the 21st Century ("Kakushin" program) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan. Figures 1–10 and Tables 1–3 were produced using the GFD-DENNOU Library.

References

- Amelung, B., and A. Moreno, 2009: *Impacts of Climate Change in Tourism in Europe. PRESTA-tourism Study*. JRC Scientific and Technical Reports, Joint Research Centre, Spain.
- Gagge, A. P., A. P. Fobelets, and L. G. Berglund, 1986: A standard predictive index of human response to the thermal environment. *ASHRAE Trans.*, **92**, 709–731.
- Hara, M., T. Yoshikane, H. Kawase, and F. Kimura, 2008: Estimation of impact of global warming snow depth in Japan by the pseudo-global-warming method. *Hydrol. Res. Lett.*, **2**, 61–64.
- Hasumi, H., and S. Emori, 2004: K-1 coupled model (miroc) description. *Center for Climate System Research, University of Tokyo*, K-1 Tech. Rep., **1**, 1–34.
- Horie, Y., and H. Fujiwara, 2009: *Sapporo kanku kisyō dai ni okeru kokkyū ondo no kansoku hōkoku oyobi WBGT no kakusyū suiteishiki no tokusei ni suite*. The second meeting for presenting research papers program, Hokkaido branch of Meteor. Soc. Japan (in Japanese).
- Iizumi, T., M. E. Hori, M. Yokozawa, H. Nakagawa, Y. Hayashi, and F. Kimura, 2006: Impact of global warming on rice production in Japan based on five coupled atmosphere-ocean GCMs. *SOLA*, **2**, 156–159.
- Iizumi, T., M. Nishimori, K. Dairaku, S. A. Adachi, and M. Yokozawa, 2011: Evaluation and intercomparison of downscaled daily precipitation indices over Japan in present-day climate: Strengths and weaknesses of dynamical and bias correction-type statistical downscaling methods. *J. Geophys. Res.*, **116**, doi:10.1029/2010JD014513, 2011.
- IPCC, 2007: *Climate change, 2007—the physical science basis: contribution of working group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S. et al. (eds.), Cambridge, University Press, 966 pp.
- Kimoto, M., 2005: Simulated change of the east Asian circulation under global warming scenario. *Geophys. Res. Lett.*, **32**, L16701, doi:10.1029/2005GL023383, 2005.
- Kondo, J., 1994: *Mizu Kankyō no Kisyō-gaku*. Asakura Shoten, 348 pp (in Japanese).
- Mieczkowski, Z., 1985: The tourism climatic index: A method of evaluating world climates for tourism. *The Canadian Geographer*, **29**, 220–233.
- Ninomiya, K., 2009: Characteristics of precipitation in the meiyu-baiu season in the CMIP3 20th century climate simulations. *J. Meteor. Soc. Japan*, **87**, 829–843.
- Ohtake, H., M. Kawashima, and Y. Fujiyoshi, 2009: The formation mechanism of a thick cloud band over the northern part of the sea of Japan during cold air outbreaks. *J. Meteor. Soc. Japan*, **87**, 289–306.
- Shibagaki, Y., M. D. Yamanaka, S. Shimizu, H. Uyeda, A. Watanabe, Y. Maekawa, and S. Fukao, 2000: Meso- β to γ -scale wind circulations associated with

- precipitating clouds near baiu front observed by the mu and meteorological radar. *J. Meteor. Soc. Japan*, **78**, 69–91.
- Storch, H. V., E. Zorita, and U. Cubasch, 1993: Downscaling of global climate change estimates to regional scales: An application to Iberian rainfall in wintertime. *J. Climate*, **6**, 1161–1171.
- Wilby, R. L., T. M. L. Wigley, D. Conway, P. D. Jones, B. C. Hewitson, J. Main, and D. S. Wilks, 1998: Statistical downscaling of general circulation model output: A comparison of methods. *Water Resour. Res.*, **34**, 2995–3008.
- Yu, G., Z. Schwartz, and J. E. Walsh, 2009: A weather-resolving index for assessing the impact of climate change on tourism related climate resources. *Climatic Change*, **95**, 551–573.