Relevance of Thermal Bioclimate for Tourism in Japan

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Abstract

Weather, climate and tourism are interconnected in many different ways. All of them are of both global and local significance. Weather and/or climate information is of interest for tourists and the tourism industry. Crucial for tourism is information on thermal comfort or thermal stress conditions. Thermal indices, *i.e.*, physiologically equivalent temperature, can deliver relevant information for the evaluation of the suitability of an area for tourism activities and recreation. Monthly maps of physiologically equivalent temperature were produced for Japan. They build the basis for information on tourism and recreation conditions in Japan.

Key words: bioclimate maps, Japan, physiologically equivalent temperature, thermal comfort, tourism

1. Introduction

Weather, climate and tourism are interconnected in many ways. Tourists and tour organisers need to be informed about weather and climate conditions, but tourists and tour operators are often not aware of the differences between weather and climate. A tour operator only reluctantly cancels a weekend trip because of bad weather. Moreover, what experience could be worse than a vacation with never-ending rain? Travel organisers and tour operators also know – through bad experience – about the important role that weather plays: rainy summers and less snowy winters adversely affect tourism and, consequently, have a significant effect on the schedules and turnover of tourism organisations (Matzarakis, 2006). Climate information provided in books and brochures is usually limited and provides only general information.

In the last ten years, the scientific community has focused on the effects of and interactions between climate/weather and tourism. Another factor influencing this has been discussion of climate change. The issues of climate and tourism are a combination of different scientific disciplines, including human biometeorology, applied climatology and tourism climatology (de Freitas, 2003; Matzarakis, 2006; Matzarakis *et al*., 2004, 2007a).

2. Tourism Climatology

In relation to tourism, weather and climate have the following characteristics (Matzarakis, 2006; Abegg, 1996):

2.1 Weather and climate are limiting factors in tourism

The characteristics of weather and climate rarely bring human activities to an absolute hold but do constitute a very important financial factor. When viewed in the light of tourism, this implies that from a practical standpoint some regions of the world have minimal tourism potential, as their climatic conditions do not allow for tourism. Tourism administrators do not develop such areas since this does not yield significant profit. The traveller who visits an unpopular region has to cope with high financial costs (*e.g.*, transport) or physical inconvenience (*e.g.*, body strain). Financial loss can also result from weather variations and changes. Rainy summers or less snowy winters can have significant consequences for tourism.

2.2 Weather and climate are dominating factors for tourism demand

Weather and climate not only shape tourism offers but also the demand. They influence among other factors destination decisions or the kind of activities to be carried out. Climatic factors play a significant role in the three phases of a visit: before, during and after. Meteorological conditions also affect the schedule of a tourist's holiday.

2.3 Weather, climate, health and tourism

Trips to climatically stressed areas can result in health problems (*e.g.*, heat stress, UV-exposure, illness from air pollution and heat stroke). A climate advisory service can help to prepare and protect travellers and particular risk groups (elderly people, sick people and

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children) from the above mentioned risks and negative effects.

The effects of tourism on tourists and recreation can be quantified using the human-biometeorological classification that comprises the following (VDI, 1998; Jendritzky *et al*., 1990): thermal complex, air pollution complex, actinic (UV) complex, odours, noise and wind comfort.

Another possibility for quantifying climate is by the use of facets, which include all the relevant aesthetic, physical and thermal factors. In tourism climatology, therefore, we have the linking between human-biometeorological methods and methods of applied climatology (de Freitas, 2003; Matzarakis, 2006). Several indices have been produced and applied in order to quantify climate for tourism purposes (Mieczkowski, 1985; de Freitas, 2003; Matzarakis *et al*., 2004, 2007a). In addition, new ways to quantify climate for tourism have been produced (de Freitas, 2003; Matzarakis *et al*, 2007a; Lin & Matzarakis, 2008). A lot of possibilities exist, which yield different approaches and possibilities (Matzarakis *et al*., 2004, 2007a; Lin & Matzarakis, 2008). The classifications can be used for the relationship between climate and tourism. For the characterisation of climatic and bioclimatic conditions of frequently visited areas, it is not sufficient solely to quantify climatic variables or climatic indices.

Detailed temporal and spatial bioclimatic analyses of the most important meteorological parameters (air temperature, wind speed, air humidity and short- and long-wave radiation fluxes) and thermo-physiological parameters (activity and clothing) should be included not only in the form of means but in frequencies of parameters important for tourism and recreation (Matzarakis, 2007).

In the present paper only the thermal bioclimatic complex is analysed based on existing human-biometeorological indices.

3. Human Energy Balance

The heat-balance model MEMI (Munich Energy Balance of Individuals) is based on an energy-balance equation of the human body (Equation 1) and on a number of parameters used in the Gagge two-node model (Gagge *et al*. 1971, 1986). In Equation 1 (Eq. 1), some terms are dependent on the mean clothing surface temperature, the mean skin temperature or the sweat rate, all of which are affected by ambient conditions. The physiological sweat rate (basis for the calculation of E_{Sw}) is also a function of the core temperature, which depends on both ambient conditions and activity. Therefore, in order to solve Eq. 1, the three unknown quantities have to be evaluated first, *i.e*., the mean surface temperature of the clothing (T_{cl}), the mean skin temperature (T_{sk}) and the core temperature (T_c). For the quantification of these unknown quantities, two more equations are required to describe the heat flows from the body centre to the skin surface and from the skin surface through the clothing layer to the clothing surface (Höppe, 1993, 1999).

In detail, the MEMI model is based on the energy balance equation for the human body (Eq. 1):

$$M+W+R+C+E_D+E_{Re}+E_{Sw}+S = 0 \qquad (1)$$

Where, M: the metabolic rate (internal energy production), W: the physical work output, R: the net radiation of the body, C: the convective heat flow, E_D: the latent heat flow to evaporate water diffusing through the skin (imperceptible perspiration), E_{Re}: the sum of heat flows for heating and humidifying inspired air, E_{Sw}: the heat flow due to evaporation of sweat, and S: the storage heat flow for heating or cooling the body mass. The individual terms in this equation have positive signs if they result in an energy gain for the body and negative signs in the case of an energy loss (M is always positive; W, E_D and E_{Sw} are always negative). The unit of all heat flows is in watts (Höppe, 1999).

Solving the human energy balance and under the inclusion of some thermo-physiological considerations (details in Höppe, 1984) it is possible to estimate the resulting thermal state of the body for any given combination of climatic parameters, activity and type of clothing, characterised by heat flows, body temperatures and sweat rate. MEMI therefore presents a basis for the thermo-physiologically relevant evaluation of the thermal component of the climate.

The most important differences to the Gagge two-node model are the procedure of calculating the physiological sweat rate (as a function of T_{sk} and T_c) and the separate calculation of heat flows from parts of the body surface, which are covered by clothing or unclothed. For people not familiar with thermophysiology or biometeorology, the expected body temperatures or heat flows may not be very meaningful. This fact is certainly one of the reasons why Gagge *et al*. (1971) developed the new effective temperature (ET*), which is an index based on their two-node model. Using ET* or SET* (futher development of ET*), the thermal effects of complex meteorological ambient conditions can be compared to the conditions in a standardised room with a mean radiant temperature not differing from the air temperature and a constant relative humidity of 50%.

PET, which was introduced by Mayer and Höppe, is similar in terms of the definition of ET* (Gagge *et al*., 1971), but is based on the MEMI (Mayer & Höppe, 1987; Hoppe, 1993).

4. Physiologically Equivalent Temperature

However, at present, there are some more popular physiological thermal indices derived from the human energy balance (Höppe, 1993; Tinz & Jendritzky, 2003; Spagnolo & de Dear, 2003). One of these is the Physiologically Equivalent Temperature (PET). PET is defined to be the physiologically equivalent temperature at any given place (outdoors or indoors). It is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body under standard conditions (work metabolism of 80 W (wat) of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained with core and skin temperatures equal to those under the conditions being assessed (VDI, 1998; Höppe, 1999).

The following assumptions are made for the indoor reference climate:

- Mean radiant temperature equals air temperature ($T_{mrt}=T_a$).
- Air velocity (wind speed) is fixed at $v = 0.1$ m/s.
- Water vapour pressure *VP* is set to 12 hPa (approximately, equivalent to a relative humidity of 50% at $T_a = 20$°C).

The procedure for the calculation of PET contains the following steps:

- Calculation of the thermal conditions of the body with MEMI for a given combination of meteorological parameters.
- Insertion of the calculated values for mean skin temperature and core temperature into the model MEMI and solving the energy balance equation system for air temperature T_a (with v = 0.1 m/s, VP = 12 hPa and $T_{mrt} = T_a$).
- The resulting air temperature is equivalent to PET.

Compared to other thermal indices, which are also obtained from the human energy balance, *e.g.* the predicted mean vote PMV (Fanger, 1972), PET offers the advantage of a widely known unit (degrees Celsius), which makes results more easily understandable for regional or tourism planners, who may be not so familiar with human-biometeorological terminology (Matzarakis *et al*., 1999).

Similar to the frequently used PMV index (Fanger, 1972; Jendritzky *et al*., 1990), PET is a universally used index for characterising the thermal bioclimate. It also allows the evaluation of thermal conditions in a physiologically significant manner. Matzarakis and Mayer (1996) transferred ranges of PMV for thermal perception and grade of physiological stress on human beings (Fanger, 1972; Mayer. 1993) into corresponding PET ranges (Table 1). They are valid only for the assumed values of internal heat production and thermal resistance of clothing.

It is noteworthy that VDI guideline 3787 part II "methods for the human-biometeorological evaluation of climate and air quality for urban and regional planning, part I: climate" (VDI, 1998) recommends the application of PET for the evaluation of the thermal component of different climates. This emphasises the significance of PET even further. This guideline is edited by the German Association of Engineers ('Verein Deutscher Ingenieure' VDI).

Table 1 Physiologically Equivalent Temperature (PET) for different grades of thermal sensation and physiological stress on human beings (during standard conditions: heat transfer resistance of clothing: 0.9 clo, internal heat production: 80 W) (Matzarakis & Mayer, 1996).

PET (°C)	Thermal sensation	Physiological stress level
4	very cold	extreme cold stress
8	cold	strong cold stress
13	cool	moderate cold stress
18	slightly cool	slight cold stress
23	comfortable	no thermal stress
29	slightly warm	slight heat stress
35	warm	moderate heat stress
41	hot	strong heat stress
> 41	very hot	extreme heat stress

5. RayMan Model

One of the recently used radiation and bioclimate models, RayMan, is well-suited to the calculation of radiation fluxes (Matzarakis *et al*., 1999, 2000, 2007c) and was chosen for all our calculations of mean radiant temperature and PET. The RayMan model, developed according to Guideline 3787 of the German Association of Engineers (VDI, 1998) calculates the radiation flux in simple and complex environments on the basis of various parameters, such as air temperature, air humidity, degree of cloud cover, time of day and year, albedo of the surrounding surfaces and their solid-angle proportions (Matzarakis *et al*., 2000, 2007c).

6. Data

The climate data used to fit RayMan and to calculate PET for this analysis (Matzarakis *et al.*, 2007c) were provided by the data collection program at the Climatic Research Unit (New *et al*., 1999, 2000, 2002). The required data (air temperature, relative humidity, sunshine and wind speed) are available at monthly resolution for the climate period 1961 to 1990 at a ten minute resolution for the study area (WMO, 1996). We used the existing monthly data, which of course lack the required daily resolution, but can offer mean monthly conditions of human-biometeorological conditions as basic information.

The data-set of future climatic conditions was based on an integration of the Hadley Centre's HadCM3 model forced with the SRES (Second Report on Emission Senarios). The HadCM3 model produces gridded data with a spatial resolution of 2.5° latitude × 3.75° longitude, being significantly coarser than that of the CRU (Climate Research Unit) 1.0 data-set. The HadCM3 data-set used consists of monthly averages for two time periods: 1961-1990 and 2070-2099. The uncertainties and difficulties of the climate projections data were described by Amelung (2006) and Hulme *et al*. (2002).

7. Climate of the Study Area

Japan lies in the temperate zone with four distinct seasons, but its climate varies from cool temperate in the north to subtropical in the south. The climate is also affected by seasonal winds that blow from the continent to the ocean in winter and vice versa in summer. Japan is generally a rainy country with high air humidity. Because of its wide range of latitude, Japan has a variety of climates, with a range often compared to that of the east coast of North America, from Nova Scotia to Georgia. The humid, temperate climate exhibits marked seasonal variation, which is celebrated in the country's arts and literature. Regional variations range from cool in Hokkaido to subtropical in Kyushu. The climate also varies with altitude and location, on the Pacific Ocean side or on the Sea of Japan side (Fig. 1). Northern Japan has warm summers but long, cold winters with heavy snow. Central Japan has hot, humid summers and short winters, and southwestern Japan has long, hot, humid summers and mild winters (Arakawa, 1969; Fukui, 1977; Yoshino, 1980).

Two primary factors influence Japan's climate: its location near the Asian continent and the existence of major oceanic currents. The climate from June to September is marked by hot, wet weather brought about by tropical airflows from the Pacific Ocean and Southeast Asia. These airflows are full of moisture and deposit substantial amounts of rain when they reach land. There is a marked rainy season, beginning in early June and continuing for about a month. It is followed by hot, sticky weather. Five or six typhoons pass over or near Japan every year from early August to early September, sometimes resulting in significant damage. Annual precipitation, which varies between 100 and 200 centimeters, falls mainly in the period between June and September. In fact, 70% to 80% of the annual precipitation falls during this period. In winter, a high- pressure area develops over Siberia, and a low-pressure area develops over the northern Pacific Ocean. The result is a flow of cold air eastward across Japan that brings freezing temperatures and heavy snowfalls to the central mountain ranges facing the Sea of Japan, but clear skies to areas fronting on the Pacific (Arakawa, 1969; Fukui, 1977; Yoshino, 1980).

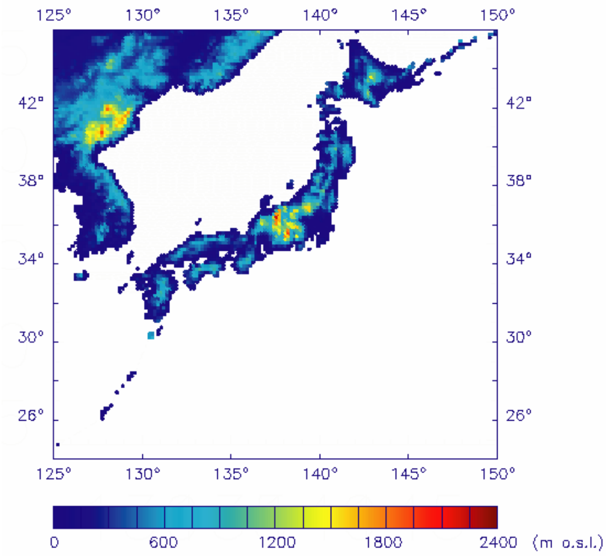

Fig. 1 Topography of Japan.

Based on the variety of the climatic conditions, it therefore follows that a variety of bioclimatic conditions exist.

8. Results and Discussion

PET mapping was performed on a monthly basis for the climate normal period of 1961-1990. The maps represent mean monthly values of PET conditions based on the parameters of air temperature, air humidity, wind speed and sunshine duration.

The mean monthly maps are shown in Figs. 2 to 13 and show PET conditions of the area from 25° to 45° latitude and from 125° to 150° longitude. The legend of

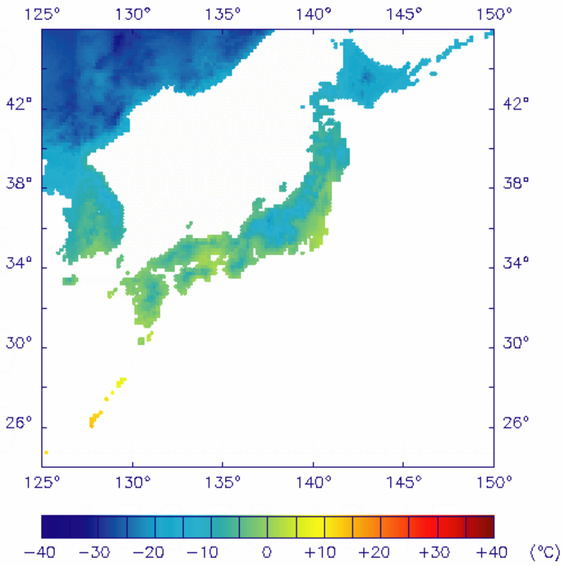

Fig. 2 PET for January (period: 1961-1990).

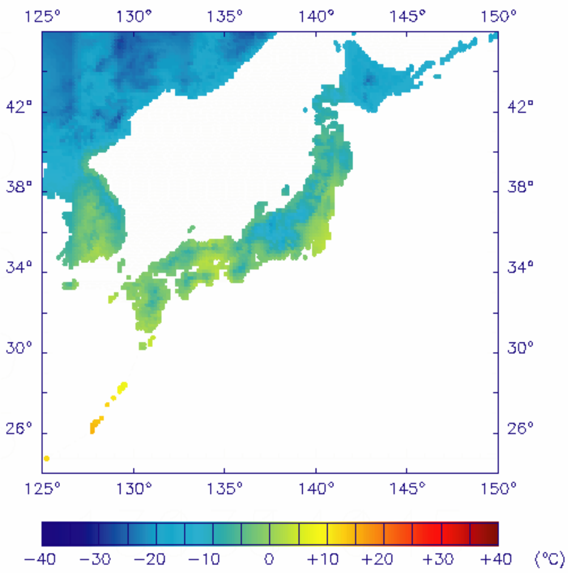

Fig. 3 PET for February (period: 1961-1990).

each map is always the same in order to allow for a better comparison of the months and seasons. The results are described here for the seasons. In winter (December, January and February, Figs. 13, 2 and 3) PET conditions for Japan range from –20°C up to +20°C. The coldest PET conditions are, as expected, in the north. The mildest PET conditions are obtained in Okinawa with 15°C. The mildest winter month is December with the lowest values in the north (about –15 °C).

Figures 4, 5 and 6 show the conditions for spring (March, April and May). The PET values for spring range between –10 or –15°C in the north to 30°C on the Okinawa islands. Thermal stress conditions in spring are not limited to the southern islands but can also occur on the main islands.

During the summer months (June, July and August) PET conditions can reach values of up to 40°C on the main islands. especially in areas that are less affected by wind. Favourable conditions with thermal comfort can be found only in higher elevated areas of the main islands and on the northern islands (Figs. 7, 8 and 9).

In autumn (September, October and November), as shown in Figs. 10, 11 and 12, PET conditions range from thermo-physiological stress levels of thermal comfort and light heat stress in October to cold in November. But September can be characterised as a milder August, with heat stress occurring in the main islands and especially in the densely populated areas.

The produced values and patterns of the human biometeorological analysis are in agreement with other similar studies (Yoshino & Miyashita, 2007; Honda 2007; Fukuoka, 1997). Yoshino and Miyashita (2007) subdivided the climate of Japan into thirteen bioclimatic classes and they show a similar pattern to that of the present study. Honda (2007) calculated the excess mortality for East Asia and Japan and his results are in general agreement with the PET pattern found here. In comparison to other regions of the world, *i.e.*, Europe (Matzarakis *et al.*, 2007b), we can summarise that PET conditions in Japan are similar to those of western and central Europe, but with a higher PET in southern Japan in winter. During summer the PET conditions in Japan are more similar to the conditions of southern Europe and the Mediterranean.

Heat stress and health is of particular importance in the context of climate change (Asanuma *et al.*, 2007). Based on climate change scenarios (A1B) (IPCC, 2000, 2001, 2007) and on other studies it can be concluded (Matzarakis, 2006) that the increase in PET in Japan will be between 5°C and 10°C for the winter season. In the southeast it will be less than 5°C. In spring, changes from the climate normal period (1961-1990) will be between 5°C and 8°C. In summer the changes will also range between 5°C and 10°C, being a little higher in the northern islands. In autumn the increase in PET will also be about 10°C. In general, we can assume that according to the thermal scale (Table 1), the changes in PET will cover two grades in the thermo-physiological stress level.

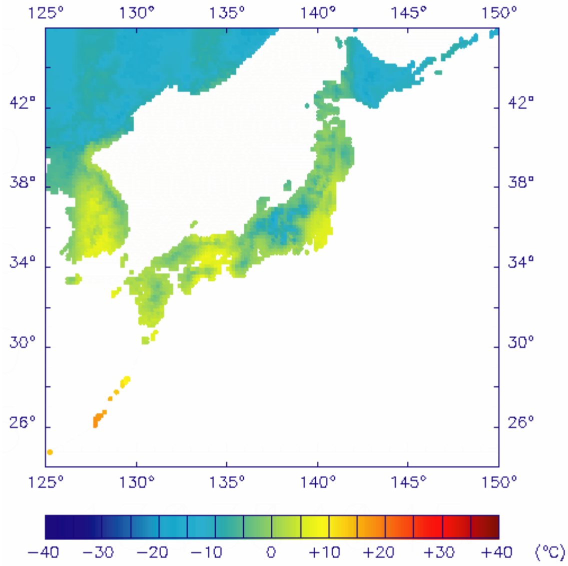

Fig. 4 PET for March (period: 1961-1990).

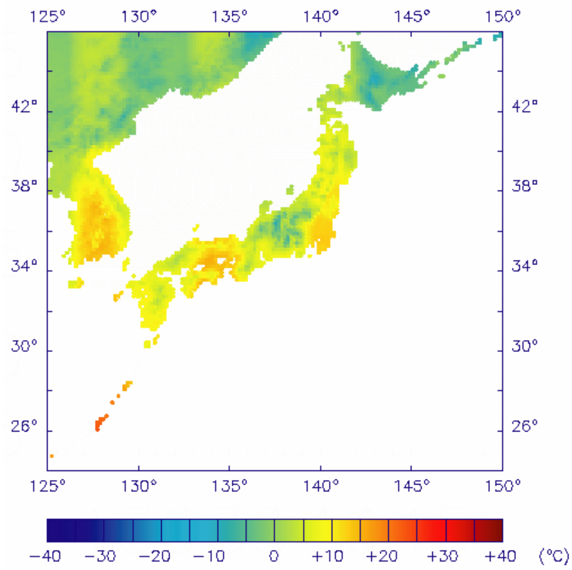

Fig. 5 PET for April (period: 1961-1990).

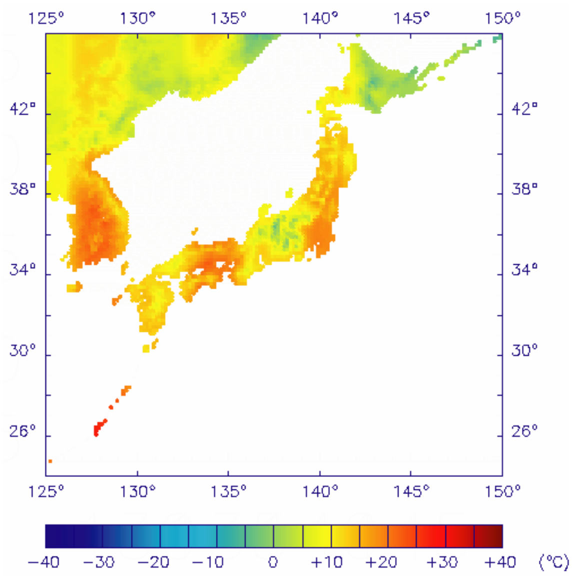

Fig. 6 PET for May (period: 1961-1990).

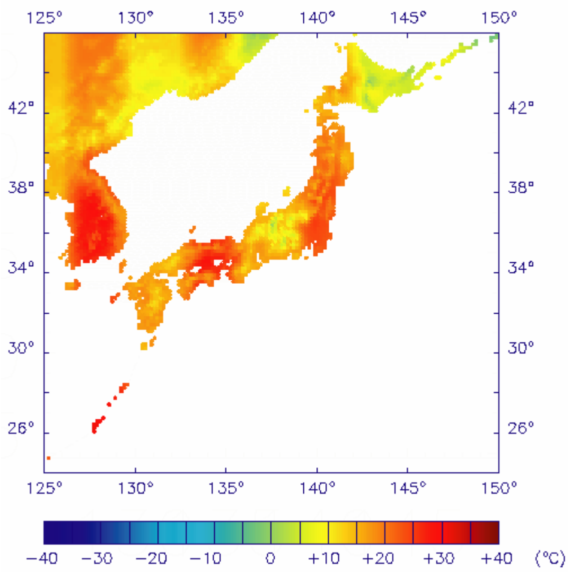

Fig. 7 PET for June (period: 1961-1990).

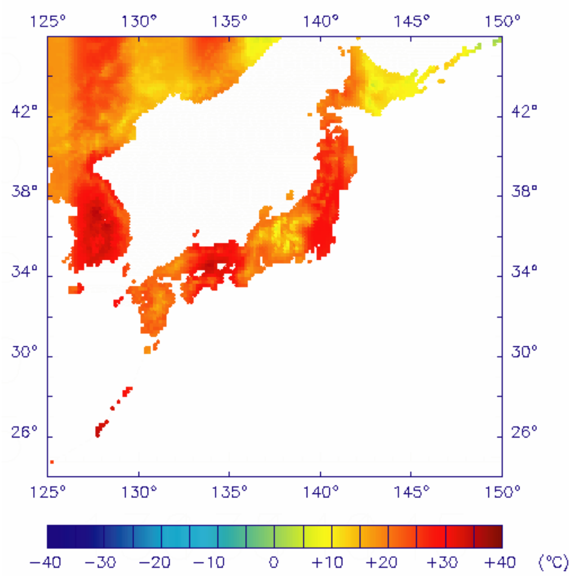

Fig. 8 PET for July (period: 1961-1990).

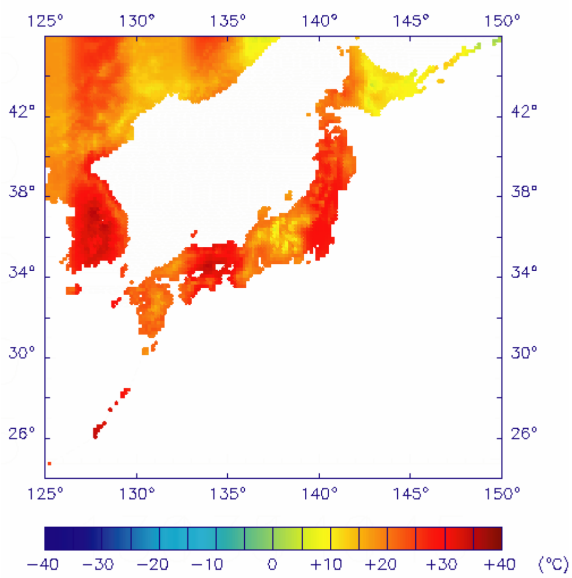

Fig. 9 PET for August (period: 1961-1990).

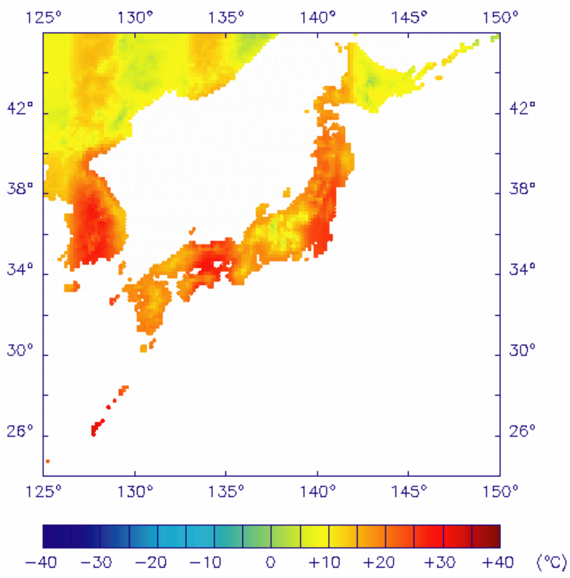

Fig. 10 PET for September (period: 1961-1990).

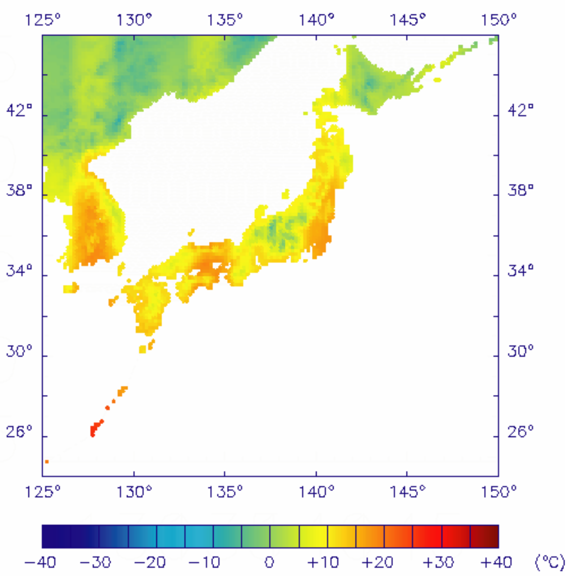

Fig. 11 PET for October (period: 1961-1990).

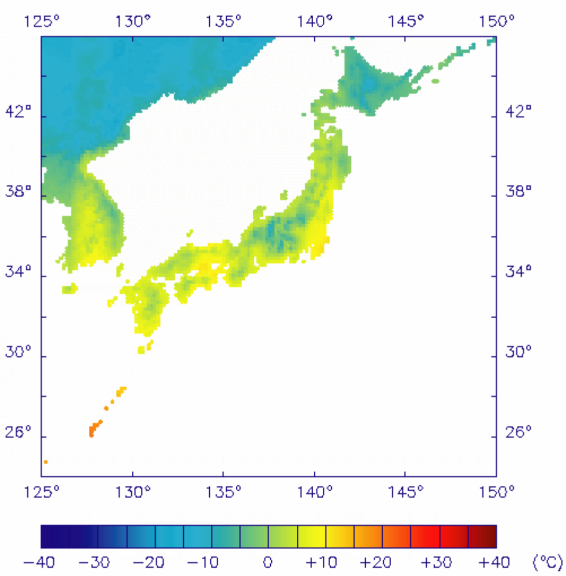

Fig. 12 PET for November (period: 1961-1990).

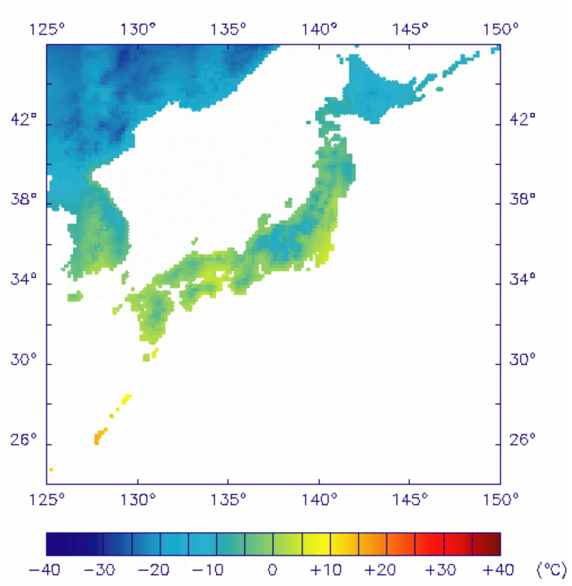

Fig. 13 PET for December (period: 1961-1990).

9. Conclusions

Existing meteorological and climatological information for tourism purposes as included in most tourism guides and books is not sufficiently helpful to tourists and tour operators. The information provided only covers simple climatological parameters like air temperature or precipitation. Spatial information with monthly resolution, including a combination of climatic parameters and thermal or climate indices as well as human biometeorological thermal indices (like PMV and PET) can describe the thermal environment of humans and give detailed meteorological and climatological information for diverse tourism purposes.

The thermal component is needed to compliment the diverse facets of tourism and recreation. Additional information about other facets of climate and local conditions at holiday destinations is also required. Other information from actinic parameters (UV radiation), air pollution, noise pollution and odours can also be very helpful to tourists, sportsmen and local authorities.

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