Application of Physiologically equivalent temperature for assessment of extreme climate regions at the Russian Far East

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Abstract

Assessment of climatic conditions at the southern part of the Russian Far East has been carried out by the use of the physiologically equivalent temperature (PET) based on the body-atmosphere energy balance; results are presented as bioclimatic maps for spatial assessment of climate. The spatial patterns for all southern part of the Russian Far East are constructed to get general (on the climatic data) and more or less adequate bioclimate information for areas with low density of hydrometeorological stations. They allow identifying areas with extreme and uncomfortable thermal conditions for every season and every month. The results of the present study can be helpful in applied climatology especially in tourism and recreation researches, in regional planning and environmental medicine as well.

1. Introduction

Many different models and indices were developed during the second half of the 20th century for estimating the complex influence of atmospheric thermal environment on human being. Assessment of thermal bioclimate may be done by using climate indices, e.g. Heat stress index, Discomfort index (Thom, 1959), Wind-chill index (Steadman, 1971) or similar ones that are based on atmospheric parameters such as air temperature, humidity, wind speed etc. But they did not include the effect of radiation fluxes, did not account thermo-physiological regulatory processes and had a lot of various limitations (Mayer and Höppe, 1987; Höppe, 1999).

To estimate relations between atmospheric environment and human health in a more relevant way the methods of heat balance of humans are used (Burton and Edholm 1955; Fanger, 1972; Höppe, 1999). Physiologically equivalent temperature (PET) is developed on the base of body-atmosphere energy balance and may be calculated by the RayMan model which has been developed for applied climate studies. The main feature and advantage of RayMan to other similar models is the calculation of short- and long-wave radiation fluxes and the possibility to evaluate thermal environment throughout the whole year and use of commonly known unit (^{o}C). RayMan has a boarder use for a variety of application: for assessing climate in human biometeorology, in applied climatology, and for recreational issues and environmental medicine (Matzarakis et al., 2007b).

The objective of the present paper is to give an application of PET for the assessment of the thermal environment for the extreme thermal climate of the Russian Far East located at the temperate monsoon climatic zone characterized by an extreme continental regime of annual temperatures. Spatial visualization on monthly and seasonal PET bioclimate maps is constructed on the base of climatic values, for the whole study area, where territories with extreme and uncomfortable thermal bioclimatic conditions and heat stress affection are identified.

2. Methods and study area

The RayMan model is based on the energy-balance equation of the human body and is evolved founded on (VDI, 1994; VDI, 1998). The model is developed for urban climate studies and has a broader use in applied climatology and tourism investigations as well. Finally several thermal indices such as Predicted Mean Vote (PMV), Physiologically Equivalent Temperature (PET) and Standard Effective Temperature (SET*) may be calculated for the assessment of human bioclimate in a physiologically relevant manner as shown in several applications (Matzarakis et al., 1999; Blazejczyk, Matzarakis, 2007; etc). All indices have the known grades of thermal perception for human beings and physiological stress (Höppe, 1999).

PET is defined as a certain air temperature related to fixed standard indoor conditions at which the heat balance of the human body is maintained with core and skin temperature equal to those under the conditions being assessed (VDI, 1998; Höppe, 1999). Compared to other thermal indices it has the advantage of commonly known unit (^{o}C) which makes results to be easily understandable to people unfamiliar with the human-biometeorological terminology. Other advantage of PET is that values may be calculated for each day and time of the year in different climates with easy and complex environment (Matzarakis et al., 1999; Matzarakis et al., 2007b). They can be attributed for different grades of thermal perception and physiological stress with a valid assumption for standard person with the definite internal heat production (80 W) and thermal resistance of the clothing (0.9 clo) (Matzarakis and Mayer, 1996).

All meteorological parameters influence the human energy balance including air temperature, vapor pressure, wind speed, as well as short- and long-wave radiation parameterized by the mean radiation temperature (MRT) of the surroundings. Data on short- and long-wave radiation are generally not available in climate records. In the case of the absence of radiation data, MRT may be estimated by cloud cover, time of the year and type of surface cover (Matzarakis et al., 2007b).

In the current study, spatial distribution of PET is used to assess thermo-physiologically the thermal conditions of meteorological environment in the Far-Eastern Federal Okrug of the Russian Federation. The study area is situated at the northern latitude from 40^{o} to 60^{o} and at the eastern longitude from 125^{o} to 145^{o} in Khabarovsky Krai, Primorsky Krai (Primorye), Amursk Region, Jewish Autonomous Region and is named as the southern part of the Russian Far East. The topography of the area is varied, comprising extensive mountainous regions stretching mainly from south-west to north-east. It has temperate monsoon climate characterized by an extreme continental regime of annual temperatures. The annual air temperature range is near 45-50 ^{o}C, which characterizes the continentality of Middle Siberia; the annual mean temperatures are between -7.3 ^{o}C and 5.0 ^{o}C. Annual precipitation varies between 400 and 1000 mm, and nearly 80 % of it falls in the period of summer monsoon from June till September.

Several authors (e.g. Gorbatcevich, 1894; Matukhin, 1971) have highlighted the extreme bioclimates found in these areas: conditions in the southern Far East in long cold winter are similar to that in Siberia; and in summer, like that of the warm, humid tropics. Human discomfort in monsoon climatic conditions of the Far East is a combination of the low temperatures and wind in winter and of high air temperatures with high relative humidity creating an unpleasant, sultriness feeling, in summer (Grigorieva, 2007).

Standard climate data such as air temperature, relative air humidity, wind speed and cloud cover are used to quantify the thermal bioclimatic conditions. These data are available through the International Water Management Institute World Water and Climate Atlas (New et al., 2002): the climatology was interpolated from a data set of station means for the climate normal period centered on 1961 to 1990 and was constructed of a 0.1° latitude (longitude) data set of mean monthly surface climate.

3. Results

The spatial visualization of thermal conditions for human-biometeorological significant analysis may be obtained from spatial distribution of PET; for this purpose monthly and seasonal PET bioclimate maps are constructed including a combination of climate parameters. Thus, instead of daily resolution we may offer only mean monthly and season conditions as basic information of average state of thermal bioclimatic conditions.

The map for the winter period (December, January and February) shows that PET values vary from -15 to -40 ^{o}C increasing from south-east to north-west of thermo-physiological extreme cold stress level (Fig. 1). Low values in the north-western part of the study area (up to -45 ^{o}C in high mountains) reflect the great continentality of this region. The coastal locations along the coasts of the Japanese sea show the maritime influence of the Pacific Ocean with sufficiently high values near -15 ^{o}C at the extreme south. Comparatively high air temperatures in the lowlands at the Amur River basin give low PET values due to the impact of the strong winds.

During spring (March, April and May) PET values range from -5 to +15 ^{o}C in the range of thermo-physiological extreme cold stress level at the north and in mountainous regions (e.g. in Dzugdzur Mountain Range along the coasts of the Okhotsk sea PET reaches -5 to -10 ^{o}C) to slight cold stress at the south continental regions. Plane areas are expressed in comparatively high PET values close to favorable bioclimate conditions.

In summer months (June, July and August), PET conditions may reach values from 5 to 25 ^{o}C (Fig. 2). Particularly in summer, the dependence of PET value on the location results in a marked variation between PET values calculated for different places. Plane sites with slight heat stress show much higher thermal stress than mountainous ones. Favorable conditions with thermal comfort (PET values without thermal stress) are obtained only in higher elevated areas but only at the central part of the study area; northern mountains are situated in the zones with thermal moderate cold stress even in the summer period.

In autumn (September, October and November), PET ranges from -30 to 0 ^{o}C. The spatial distribution is similar to that in summer. The highest values characterize the southern locations and sites along the coasts of the Japanese Sea. The coldest parts are at the elevated locations at the north-west and in the mountains. As a whole autumn is much colder than spring that may be explained by the cold (air temperatures are very close to winter values) and windy November.

In all seasons, the lowest PET values are observed in elevated areas, e.g. in Sikhote-Alin and Dzugdzur; the highest at the continental lowlands near the Middle Amur and at extreme south at the coastal region of the Japanese Sea.

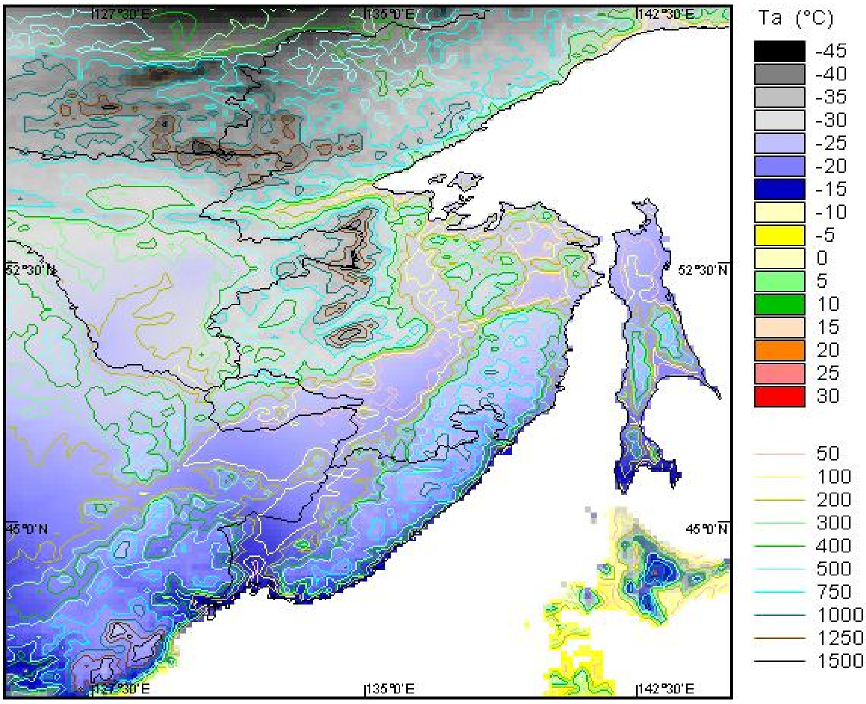

Fig. 1: Physiologically equivalent temperature for winter (December, January, February in the Far East Russia for the period 1961-1990

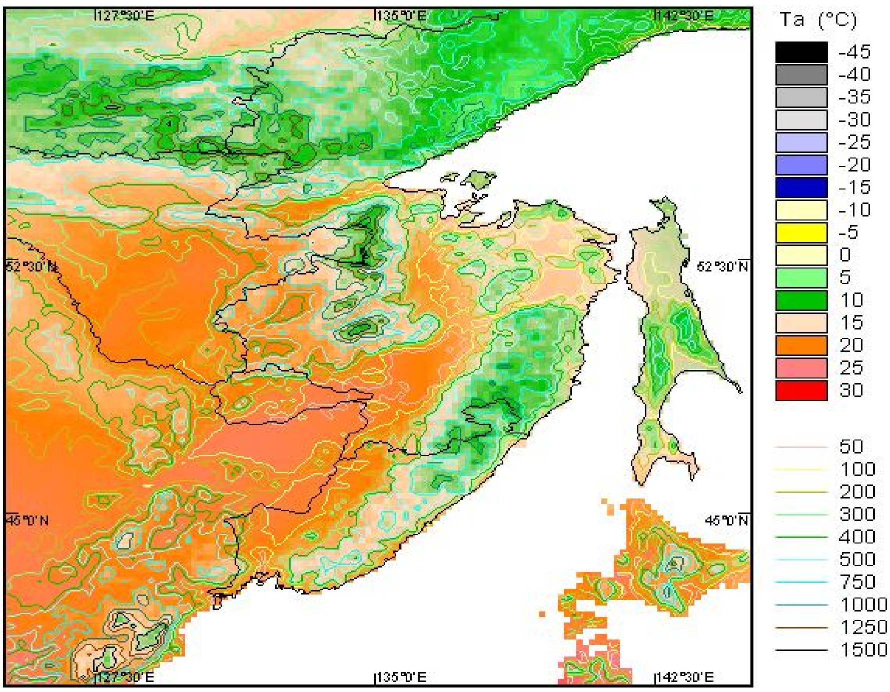

Fig. 2: Physiologically equivalent temperature for summer (June, July, August) in Far East Russia for the period 1961-1990

4. Discussion

Human-biometeorological assessment of climatic conditions at the southern part of the Russian Far East has been carried out by using the physiologically equivalent temperature based on the body-atmosphere energy balance; results are presented as bioclimatic maps for spatial assessment of climate.

As it was shown earlier (Matzarakis et al., 1999) one of the main advantages of PET is that it may be used for any time of the year in different climates and in temperate as well. We use it successfully for bioclimatic evaluation of temperate monsoon climatic zone with extreme thermal regime of the Russian Far East. The spatial patterns are constructed to get general (on the climatic data) and more or less adequate bioclimate information about areas with low density of hydrometeorological stations. They allow to identify regions with extreme and uncomfortable thermal conditions for every season and every month. We assume that this approach gives a method for the solution of a concrete task using meteorological information for example in assessment of heat (or cold) waves that may influence additional mortality in humans at the study area.

We may compare spatial distribution of PET with other regions of the world i.e. with Europe (Matzarakis et al., 2007a) or with Japan (Matzarakis, 2008). The PET conditions in winter in studied locations in Russia are considerably lower in comparison even to Northern Europe. Only PET values for the extreme southern part of the target area are similar for the northern Europe and Japan. During summer, the PET conditions in the southern and central parts of the study area are more similar to the conditions of central and northern Europe and Japan. We assume that this approach gives a method to get general and more or less adequate bioclimate information for areas with low density of climate stations. Bioclimatic maps are of interest because they can be applied in climate and health and also in climate impact research for analyzing thermal stress situations, in tourism and recreation for selection of holiday destination.

5. Conclusion

Physiologically equivalent temperature is well suited for the human-biometeorological evaluation of the thermal environment of different climates including extreme climate regimes of the Russian Far East. Spatial visualization on seasonal PET bioclimate maps gives a general evaluation of thermo-physiologically relevant information. Nevertheless we may assume more or less detail spatial assessment when territories with extreme and uncomfortable thermal conditions and heat stress affection may be identified. The results of the present study can be helpful in applied climatology especially in tourism and recreation researches, in regional planning and environmental medicine as well.

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