ISSN 0354-8724 (hard copy) | ISSN 1820-7138 (online)

Evaluation of Outdoor Thermal Comfort Conditions in Northern Russia over 30-year Period (Arkhangelsk Region)

Pavel Konstantinov[A,C*], **Natalia Shartova**[A], **Mikhail Varentsov**[A,C,D], **Boris Revich**[B]

Received: January 20, 2020 | Revised: September 22, 2020 | Accepted: September 28, 2020
doi: 10.5937/gp24-24738

Abstract

The aim of the current paper is to evaluate spatial and temporal characteristics of the distribution of bioclimatic comfort within the Arkhangelsk region (Russian Federation) with two modern indices of thermal comfort: PET and UTCI. Its average values calculated for the modern climatic period (1981-2010) in the monthly mean give a clear picture of spatial heterogeneity for the warmest month (July) and for the coldest one (January). The spatial picture of both indices in July allows us to distinguish three large internal regions: the Arkhangelsk province, the continental part of the Nenets Autonomous Okrug (NAO) and Novaya Zemlya islands (NZ). Winter distribution of thermal discomfort is fundamentally different: the coldest regions (with extreme cold stress) are equally NZ and the eastern half of NAO; intermediate position is occupied by the west of the NAO and the extreme north-east of the Arkhangelsk region, the highest winter UTCI values are observed in the rest of the region. In Archangelsk-city extreme cold stress in January has repeatability 6.7%, in February - 4%, in December - 2.2%, respectively. The average number of time points during the year at which thermal stress is not observed is only 19%. Obtained results will be the basis for planning relevant health measures and providing reliable forecasts of the effects of climate change in the Arctic region.

Keywords: PET; UTCI; Thermal comfort; Arctic region; climate change

Introduction

Climate warming in the Arctic is proceeding faster than in other parts of the Russian Federation (Streletskiy, Shiklomanov, & Nelson, 2012); therefore, an assessment of existing and predicted climate risks is necessary. Arkhangelsk region is one of the most climate-depending in Russian Arctic, so it is needed to better understand the possible effects on public health in harsh climates. In the 21st century the Arkhangelsk region became one of the most significant regions of the Russian Arctic: "Arctic Gate". This was facilitated by the variety of natural conditions: from temperate to arctic type of climate and from forest zone to arctic deserts. Also, the Arkhangelsk region is the most populated of the Arctic regions of Russia: the population

---

[A] Faculty of Geography / Research Computing Center, Lomonosov Moscow State University, 119991 Leninskie Gory d.1 Moscow, Russia
[B] Institute of Economic Forecasting, Russian Academy of Sciences, Environmental Health Laboratory, 117418, Nakhimovsky prospekt, 47 Moscow, Russia
[C] RUDN University, Laboratory of smart technologies for sustainable development of urban environment under global changes, 117198, Miklukho-Maklaya str. 8k2 Moscow, Russia
[D] A. M. Obukhov Institute of Atmospheric Physics, RAS, 119017, Pyzhevskii per., 3, Moscow, Russia
* Corresponding author: Pavel Konstantinov; email: kostadini@mail.ru

(2019) is about 1,144,000 people. This population is involved both in tourism and in fishing, transport, military and industrial spheres. The history of the region is also rich: Arkhangelsk was the first seaport in the Russian Empire in the 17-18 centuries.

Thus, it is reasonable to begin the assessment of the bioclimatic potential in the Russian Arctic precisely from the Arkhangelsk region. Episodic assessments have already been made recently in the Arctic zone of the Russian Federation - in the neighboring Murmansk region, in urban conditions (Gommershtadt et al., 2020). These were both assessments of thermal comfort and the nature of the urban heat islands (Varentsov et al., 2018; Konstantinov et al.2015), which, of course, were more likely to be made in urban cores. Assessment of modern thermal comfort indices (e.g. PET) in Russia in winter extreme climate conditions was also performed for Russian Far East urban conditions (Bauche, Grigorieva, & Matzarakis, 2013) in 2013 and for Russian South (Shartova, Shaposhnikov, Konstantinov, & Revich, 2019).

It is important to note that, despite the promising nature of the topic, there is not a large number of overlapping works in the world scientific literature either. Trends of meteorological parameters in North of Siberia was discussed in (Maksyutova & Bashalkhanova, 2019); in Finland some trends of air temperature and WCT (Wind Chill Temperature) described in (Founda et al., 2017), outdoor thermal comfort assessment for Sweden in (Yang et al., 2017). The connected urban climate research: Surface Urban Heat Island review for Fennoscandia was performed in (Miles & Esau, 2020), assessment of Arctic cities as an anthropogenic object in (Laruelle et al., 2019). Western Arctic trends and statistics of thermal indices PET and UTCI were illustrated for Canadian Quebec in (Provençal et al., 2016). Extreme-high latitude assessment was made for Franz Josef Land in (Araźny et al., 2019).

Also some recent study aimed to assess the impact of meteorological conditions on the use of public space in Scandinavia and Canada. Overall results showed that the most significant meteorological enablers for the use of outdoor public spaces in winter were solar gain, snowfall and snow-covered surfaces. Authors showed (Larsson & Chapman, 2020) that winter public space has a higher climatic design requirement to be successful than streets and pathways that are mainly used for soft mobility.

So, aim of this research paper is an evaluation of the spatiotemporal variability of thermal comfort throughout the Arkhangelsk region using different sources of meteorological data, namely, the gridded reanalysis data for the period of 1981-2010 with spatiotemporal resolution of (0.75°x0.75°x3 hours), and regular weather observations for a longer period of 53 years (1966-2018), which are available in some cities.

Materials and Methods

Arkhangelsk-city (64°33'N 40°32'E) is located in a temperate climate zone with some features of the marine one, with short cool summers and long moderately cold winters. Like the entire territory of the Arkhangelsk region, the city belongs to the Arctic zone of Russian Federation. The proximity of the Arctic Circle allows to observe white nights phenomenon from May 17 to July 26. Due to the coastal location, fast changes in weather conditions are habitual (e.g. cold invasions from the Kara Sea are possible). The annual temperature amplitude is 29.1 °C (Climate and weather of Russia, 2019), summing up the average monthly temperature of the coldest month - January (-12.7 °C) and the warmest - July (16.3 °C). The minimum of all the recorded temperatures was reached in 1885 and amounted to -45.2 °C; maximum 34.4 °C in 1972. The average annual rainfall is 606 mm per year.

Within the scope of this study, both spatial and temporal characteristics of the distribution of bioclimatic comfort within the Arkhangelsk region was decided to evaluate by most commonly used technologies. Two modern indices of thermal comfort were used as the main parameters: PET (Physiologically Equivalent Temperature) and UTCI (Universal Thermal Climate Index).

PET index (Höppe, 1984; Mayer & Höppe, 1987; Matzarakis et al., 1999) is calculated using the Human Energy-Balance Models for Individuals (MEMI). It can be defined as the air temperature at which, for ordinary room conditions, the thermal balance of the human body remains unchanged with the temperature of the internal organs and skin temperature. In addition to standard meteorological parameters (air temperature, wind speed and relative humidity, radiation and cloud cover), calculation of PET takes into account the processes of human metabolism, activity and thermal insulation properties of clothes. Currently, PET is one of the most commonly used indicators of human comfort. It is widely used in the field of biometeorology, especially for calculating the characteristics of the tourist climate, heat stress values, and also for urban planning in Europe, Asia and South America (Höppe, 2002; Lin & Matzarakis, 2011; Lopes et al., 2011; Matzarakis & Nastos, 2011; Mayer & Höppe, 1987; Milošević et al., 2016; Muthers et al., 2010; Paramita & Matzarakis, 2019; Unger et al., 2018).

Figure 1. Location of the study area - Arkhangelsk region of Russian Federation: Archangelsk province, the continental part of the Nenets Autonomous Okrug (NAO) and Novaya Zemlya islands (NZ)

UTCI is also based on the model of human heat budget (Bajšanski et al., 2015; Havenith et al., 2012; Jendritzky et al., 2012; Lam & Lau, 2018; Milošević et al., 2017; Weihs et al., 2012). It is expressed as the equivalent ambient temperature of the reference environment, providing the same physiological reaction of the reference person in a real environment. In contrast to PET, when calculating UTCI, not only the heat-insulating properties of clothes are taken into account, but also the vapor tightness and insulation of the air surface layers. These parameters are exposed to changing wind speed and the movement of the human body and, as a consequence, affect physiological reactions. Thus, the modified insulating properties of clothing in a real environment are taken into account.

Table 1. Gradations of PET and UTCI indices (Matzarakis A.;Mayer H., 1996)

Thermal perception	Grade of physiological stress	PET-values (Western and Eastern Europe), °C	UTCI-values, °C
Extreme cold	Extreme cold stress		< -40
Very cold	Very strong cold stress	< 4	-40 – -27
Cold	Strong cold stress	4-8	-27 – -13
Cool	Moderate cold stress	8-13	-13 – 0
Slightly cool	Slight cold stress	13-18	0 – 9
Comfortable	No thermal stress	18-23	9 – 26
Slightly warm	Slight heat stress	23-29	26 – 32
Warm	Moderate heat stress	29-35	32 – 38
Hot	Strong heat stress	35-41	38 – 46
Very Hot	Extreme heat stress	> 41	> 46

The gradations of both indices are shown in the Table 1[1]*:

---

[1] In current study slightly cool stress is joined with moderate one.

PET and UTCI indices were calculated using the Rayman Pro 3.1 diagnostic model (Matzarakis et al., 2010) and meteorological data from the reanalysis database ERA-Interim (Dee et al., 2011) or from observations at WMO weather stations. ERA-Interim reanalysis database includes information about state of the Earth's atmosphere up to 10 hPa with a frequency of 3 hours (surface data) with a horizontal resolution of 0.75×0.75 degrees of the grid (1979-2018 period).

The original algorithm of processing the gridded reanalysis data using RayMan software was developed by the authors. The reanalysis data in NetCDF format was downloaded from ECMWF data portal (https://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/) and used to assess the following atmospheric variables: the 2 m air temperature and 2 m dew point temperature, wind speed at a height of 10 m, total cloud cover fraction, and surface temperature. These variables were further processed to fit the RayMan input data requirements, which included calculation of the relative humidity from the dew point using the Magnus equation, unit conversation for the cloud fraction, and bringing the wind from a height of 10 m to a height of 1.1 m using the logarithmic wind profile and fixed roughness length parameter z0= 0.01 m, which corresponds to a short cut meadow. After preliminary processing, reanalysis data was saved in column-separated text files (with columns that corresponds to data & time, longitude, latitude, elevation and listed meteorological variables) and used as input for RayMan. The thermophysiological parameters in RayMan were set up as follows: male, 35 years old, 1.75 m tall, with a weight of 75 kg, with an internal heat production of 80 W, and a heat transfer resistance of the clothing of 0.9 clo. Total computing time of the algorithm for the whole territory of the Arkhangelsk region (including Arkhangelsk-province, NAO and NZ) demanded 138 hours. After running the RayMan, output text files with PET and UTCI indices were converted back to gridded NetCDF format. Routines for the listed data conversation operations were developed in Matlab software. Further statistical processing of obtained data included the calculation of a set of statistical parameters on PET and UTCI contemporary climatology for each reanalysis grid cell, including the mean values, repeatability of the different thermal stress categories and linear trend slope coefficients for the means and as well as for repeatabilities.

During the calculations, blocks of PET and UTCI containing fields zipped to 9.6 GB files were formed.

Results

Traditional UTCI-comfort diagram for Arkhangelsk, based on WMO station in city for period 1966-2015 can be seen on Figure 2. According to this graph, it is clear that there are no cases of two extreme "warm" gradations of stress, at all, only in July the frequency of periods with moderate thermal stress is 1.7%, in June and August it is less than 1%. But cases of extreme cold stress in January are well seen: 6.7%, in February - 4%, in December - 2.2%, respectively. The average number of time slots during the year at which thermal stress is not observed is only 19%. The most frequent PET-class during summer is "*no Thermal stress*" during winter - "*Strong cold stress*". Typical picture for city of moderate climatic zone situated on Arctic ocean board, where March is rather cold as November.

The values of the indices calculated for the climatic period (1981-2010) in the monthly averaging give a quite clear picture (Figure 3) of spatial heterogeneity for the warmest month (July) and for the coldest one (January). Thus, during summer, in July it is possible to distinguish three large quasihomogeneous regions: directly the Archangelsk province, the continental part of the NAO and NZ/ In opposite the winter picture is fundamentally different. Namely the coldest regions (with extreme cold stress) are both Novaya Zemlya and the eastern half of the NAO, the intermediate position is for the western part of the NAO, and the extreme north-east of the Archangelsk province. Highest winter UTCI values are observed in the western part of the region. Due to the low information content of the PET index during cold season, the map for its distribution is not shown there.

The spatial distribution of various "cold" gradations in the winter (Figure 4) confirms the above pattern, especially for the most dangerous values – for extreme cold stress. The east of the NAO is sharply contrasted with NZ (repeatability above 70%) and the Archangelsk province (35% and lower); an intermediate position is occupied by the western part of the NAO with the Kanin Nos Peninsula. The situation is similar for the

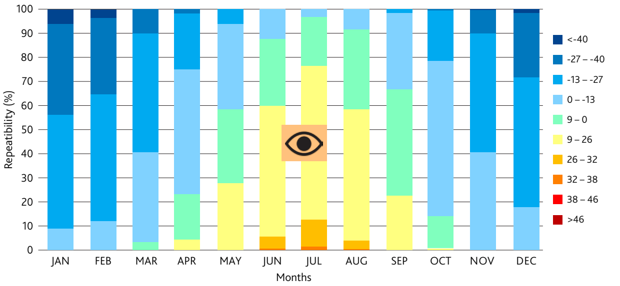

Figure 2. The repeatability of various UTCI gradations in Arkhangelsk-city (Period from 1966 to 2015). Based on data from WMO-stations

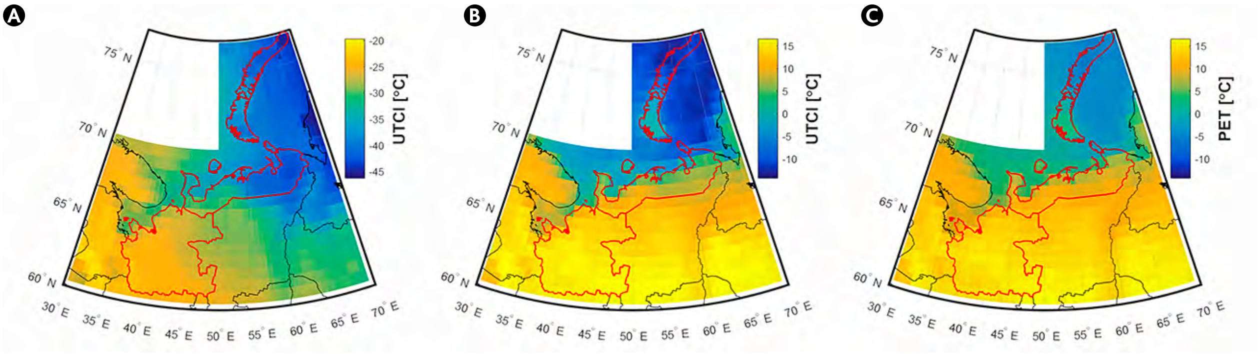

Figure 3. Mean UTCI-values in January (A) and July (B), mean PET-values in July (C)

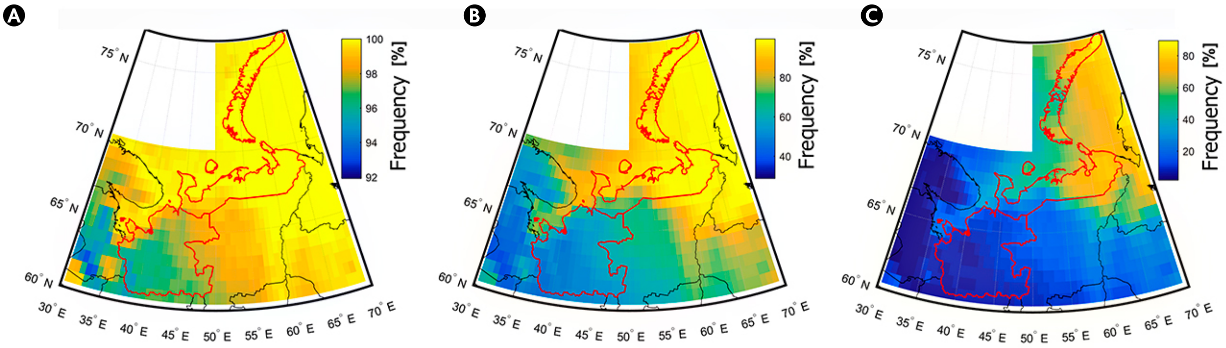

Figure 4. Spatial distribution of cold stress occurrence according to UTCI for the winter period (December-February) with gradations: strong cold stress (A) , very strong cold stress (B) and extreme cold stress (C)

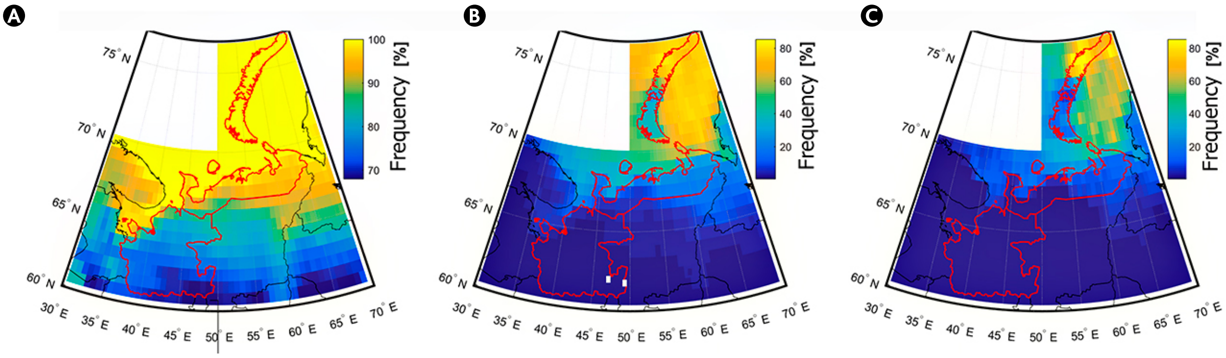

Figure 5. Spatial distribution of cold stress occurrence according to UTCI for the summer period (June-August) with gradations: moderate cold stress (A), strong cold stress (B) and very strong cold stress (C)

next discomfort gradation: “very strong cold stress”. But for “moderate cold stress” the frequency of occurrence in whole research area is close to 100%.

Cold stress gradations (Fig.5) during summer period have a completely different geographical pattern: high repeatability of very strong cold stress (above 70%) is observed in the northern half of the NZ archipelago. The intermediate zone from 20 to 50% covers the east of the NAO and the southern part of NZ. In western part of the NAO and of Archangelsk province, the recurrence of very strong cold stress does not exceeds 10%. The same values of repeatability in Archangelsk province has “strong cold stress”, but “moderate cold stress” on Novaya Zemlya is observed in 100% of cases, and in the rest of the region not less than in 70% of cases.

Summing up the above patterns, we computed the repeatability of days during which the PET and UTCI parameters did not exceed the comfortable values for the period under consideration (1981-2010) (Fig. 6)

Since the nature of the PET-index makes it more “narrow” when calculating comfortable conditions, its results differs with UTCI significantly. According to the PET analysis of “completely comfortable” days in the region, authors can state its complete absence. In the same time “completely comfortable” days according to the UTCI methodology are absent only in White Sea coast and on Novaya Zemlya. On the south

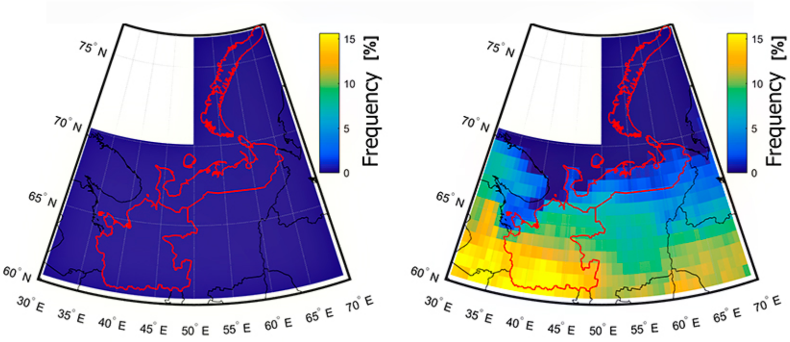

Figure 6. The spatial distribution of the frequency of days without heat stress (when the daily minimum and daily maximum both simultaneously satisfy the conditions) according to the PET (a) and UTCI (b) index

of the Archangelsk province there are no more than 15% of such days.

Discussing the spatial heterogeneity of the rates of change of climatic comfort parameters over the past 53 years, we consider trends in the main six WMO stations of the region. In Archangelsk province these are Arkhangelsk, Kargopol', Kotlas and Mezen', in the NAO – Narjan-Mar and in Novaya Zemlya - Malie Karmakuly station (Figure 7). Moreover, we consider here together both the trends in the average annual air temperature, measured at a height of 2m above ground, and the trends in the average annual value of the UTCI index (since the trends are also estimated not only for summer but also for winter period, for which the PET index is not applicable).

Discussing spatial inhomogeneity of trends we can see from Figure 7 that in settlements Malie Karmakuly and Mezen', the positive trend of both parameters is increasing approximately the same way, in the rest cities - the UTCI increases more intensively over time than air temperature. In all area UTCI and air temperature trends are both positive: for UTCI trend is from 0.4°C/10 years in Malie Karmakuly up to 2°C/10 years in Narjan Mar and for air temperature doesn't exceed 0.6°C/10 years.

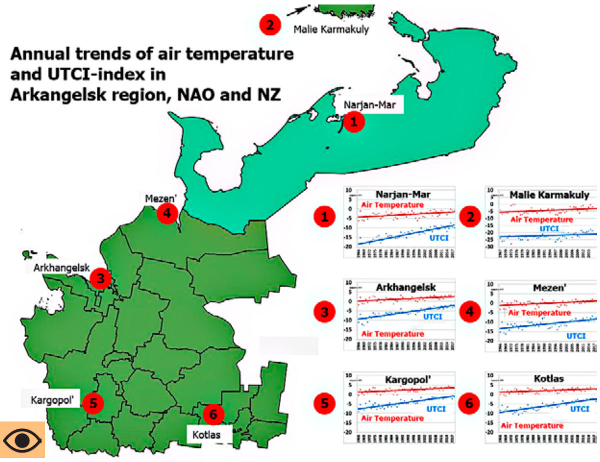

Figure 7. Spatial variability of 2m air temperature trends (annual means) and UTCI-trends (annual means) for Arkhangelsk province, NAO and NZ archipelago (far north). Trends were calculated based on data on WMO-stations for 1966-2018 period

Discussion and Conclusion

As a result of the study, the spatio-temporal variability of modern bioclimatic conditions of the Arkhangelsk region was analyzed According to the methodology of the PET analysis, "completely comfortable" days in the region are not observed at all; according to the UTCI method, it can be stated that there are no "completely comfortable" days only on the White Sea coast and Novaya Zemlya Archipelago (NZ). In the south of the Arkhangelsk region there are no more than 15% of such days. At most stations in the region, the growth rate of the average annual UTCI exceeds the growth rate of the average annual air temperature (excluding NZ region). On average, in Arkhangelsk for a year, extremely "warm" gradations of stress are not observed at all, only in July the frequency of periods with moderate heat stress is 1.7%, in June and August it is less than a percent. But cases of extreme cold stress can be observed: in January - 6.7%, in February 4%, in December 2.2%, respectively. The average number of time slots during the year at which thermal stress is not observed is 19%.

The few existing studies of thermal comfort in the Arctic show a rather variegated picture in different polar regions. Thus, an example of analysis of climatic conditions on the North of Siberia shown that slight warming (a rise of the air temperature) and small wind speed variability during the period from October to April in 1981–2015 resulted in a certain decrease in weather severity in relation to the period 1966–1980. However, the period 1981–2015 did not go beyond limit of the interannual variability. Despite the stable increase in the air temperature in 1981–2015, no tendency to reduction of the number of days limiting human's stay in the open air was noted (Maksyutova & Bashalkhanova, 2019). In Quebec City, Canada, a city with a strong seasonal climatic variability, the UTCI was found to be slightly more sensitive to mean radiant temperature, moderately more sensitive to humidity and much more sensitive to wind speed than the PET. This dynamic changed slightly depending on the environment and the season. In hot weather, the PET was found to be more sensitive to mean radiant temperature and therefore reached high values that could potentially be hazardous more frequently than the UTCI. In turn, the UTCI's stronger sensitivity to wind speed makes it a superior index to identify potentially hazardous weather in winter compared to the PET. The urban environment produced favorable conditions to sustain heat stress conditions, where the indices reached high values more frequently there than in suburban locations, which advocates for weather monitoring specific to denser urban areas (Provençal et al., 2016).

Significant differences, mainly the variability of meteorological conditions: air temperature, wind speed and relative air humidity; and biometeorological indices: wind chill temperature, predicted clothing insulation and accepted level of physical activity were noticed on Franz Josef Land (in Teplitz Bay and Calm Bay) in the years 1899–1931. It employs meteorological measurements taken during four scientific expeditions to the study area. The analysis mainly covered the period October–April, for which the most complete data set is available. For that period of the year, which includes the part of the year with the Franz Josef Land's coldest air temperatures, the range and nature of changes in meteorological and biometeorological conditions between historical periods and the modern period (1981–2010) were studied. The data analysis revealed that during the three oldest expeditions (which took place in the years 1899–1914), the biometeorological conditions in the study area were more harsh to humans than in the modern period (1981–2010) or similarly harsh. In contrast, during the 1930/1931 expedition, which represents the Early Twentieth Century Warming (ETCW), conditions were clearly more favourable (including predicted clothing insulation being 0.3 clo lower and 4.0 °C higher wind chill temperature than conditions observed nowadays) (Araźny et al., 2019).

In European region at higher latitudes cities like Helsinki and Oulu exhibit particularly large warming trends in both Tmax and Tmin during the cold period of the year. Specifically, the warming rates of Tmin in winter is outstanding, exceeding 1 °C per decade. Lower but statistically significant positive trends are also observed in spring and summer. The frequency of cold-related discomfort conditions in northern cities dropped by more than 20% in the last decade compared to the decade 1976–1985. The decline is much higher in risk or high-risk levels (WCT < –28 °C) ranging from 36% at Oulu to 45% at Helsinki, also in agreement with the increasing trends in the 2nd percentile corresponding to high risk values. Caution heat conditions are becoming increasingly more frequent during the last decade. Such conditions are almost missing in the 1970s, while 'extreme caution' cases are not observed. Cities with colder local climates become markedly less cold in winter and autumn, with the warming rates in Tmax exceeding 0.7 °C/decade since the mid-1970s. The warming trends are even more striking in the winter Tmin though, exceeding 1 °C/decade and reaching up to 1.4 °C/decade since the mid-1970s (Founda et al., 2019).

For concluding it could be noticed that in Arkhangelsk region, mainly, throughout the year, the conditions of cold stress of varying intensity have a greater frequency in the region. But in the same time the geographical location of the districts allocated according to the conditions of discomfort does not coincide in the summer and winter, respectively.

Acknowledgements

The bulk of the research was supported by the Grant program of Russian Foundation of Basic Research (project no. 18-05-60146 Arctika). The work of Mikhail Varentsov (parallel computing and visualization of spatial data) was supported by the grant program of Russian Science Foundation (project no. 17-77-20070 "An initial assessment and projection of the bioclimatic comfort in Russian cities in XXI century against the context of climate change").

References

Araźny, A., Wyszyński, P., & Przybylak, R. (2019). A comparison of bioclimatic conditions on Franz Josef Land (the Arctic) between the turn of the nineteenth to twentieth century and present day. *Theoretical and Applied Climatology*, 137(3–4), 2623–2638. https://doi.org/10.1007/s00704-018-02763-y

Bajšanski, I. V., Milošević, D. D., & Savić, S. M. (2015). Evaluation and improvement of outdoor thermal comfort in urban areas on extreme temperature days: Applications of automatic algorithms. *Building and Environment*, 94, 632–643. https://doi.org/10.1016/j.buildenv.2015.10.019

Bauche, J. P., Grigorieva, E. A., & Matzarakis, A. (2013). Human-biometeorological assessment of urban structures in extreme climate conditions: The example of birobidzhan, Russian far east. *Advances in Meteorology*, 2013. https://doi.org/10.1155/2013/749270

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M.A., Balsamo, G., Bauer, D.P. & Vitart, F. (2011). The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. *Quarterly Journal of the Royal Meteorological Society*, 137(656), 553–597. https://doi.org/10.1002/qj.828

Founda, D., Pierros, F., Katavoutas, G., & Keramitsoglou, I. (2019). Observed trends in thermal stress at European cities with different background climates. *Atmosphere*, 10(8). https://doi.org/10.3390/atmos10080436

Gommershtadt, O., Konstantinov, P., Varentsov, M., & Baklanov, A. (2020). Modeling Technology for Assessment of Summer Thermal Comfort Conditions of Arctic City on Microscale: Application for City of Apatity. In *Springer Geography* (pp. 66–75). https://doi.org/10.1007/978-3-030-16091-3_10

Havenith, G., Fiala, D., Błazejczyk, K., Richards, M., Bröde, P., Holmér, I., Rintamaki, H., Benshabat, Y. & Jendritzky, G. (2012). The UTCI-clothing model. *International Journal of Biometeorology*, 56(3), 461–470. https://doi.org/10.1007/s00484-011-0451-4

Höppe, P. (2002). Different aspects of assessing indoor and outdoor thermal comfort. *Energy and Buildings*. https://doi.org/10.1016/S0378-7788(02)00017-8

Jendritzky, G., de Dear, R., & Havenith, G. (2012). UTCI-Why another thermal index? *International Journal of Biometeorology*, 56(3), 421–428. https://doi.org/10.1007/s00484-011-0513-7

Konstantinov, P. I., Grishchenko, M. Y., & Varentsov, M. I. (2015). Mapping urban heat islands of arctic cities using combined data on field measurements and satellite images based on the example of the city of Apatity (Murmansk Oblast). *Izvestiya - Atmospheric and Ocean Physics*, 51(9), 992–998. https://doi.org/10.1134/S000143381509011X

Lam, C. K. C., & Lau, K. K. L. (2018). Effect of long-term acclimatization on summer thermal comfort in outdoor spaces: a comparative study between Melbourne and Hong Kong. *International Journal of Biometeorology*, 62(7), 1311–1324. https://doi.org/10.1007/s00484-018-1535-1

Larsson, A., & Chapman, D. (2020). Perceived impact of meteorological conditions on the use of public space in winter settlements. *International Journal of Biometeorology*, 64(4), 631–642. https://doi.org/10.1007/s00484-019-01852-5

Laruelle, M., Esau, I., Miles, M., Miles, V., Kurchatova, A. N., Petrov, S. A., Soromotin, A., Varentsov, M. & Konstantinov, P. (2019). Arctic cities as an anthropogenic object: a preliminary approach through urban heat islands. *Polar Journal*, 9(2), 402–423. https://doi.org/10.1080/2154896X.2019.1685171

Lin, T. P., & Matzarakis, A. (2011). Tourism climate information based on human thermal perception in Taiwan and Eastern China. *Tourism Management*. https://doi.org/10.1016/j.tourman.2010.03.017

Lopes, A., Lopes, S., Matzarakis, A., & Alcoforado, M. J. (2011). The influence of the summer sea breeze on thermal comfort in funchal (Madeira). A contribution to tourism and urban planning. *Meteorologische Zeitschrift*, 20(5), 553–564. https://doi.org/10.1127/0941-2948/2011/0248

Maksyutova, E. V., & Bashalkhanova, L. B. (2019). Severity of the present-day climate in the Polar regions of Siberia. *Led i Sneg*, 59(2), 258–266. https://doi.org/10.15356/2076-6734-2019-2-402

Matzarakis A. & Mayer H. (1996). Another kind of environmental stress. Thermal stress. *WHO News* 18:7–10.

Matzarakis, A., Mayer, H., & Iziomon, M. G. (1999). Applications of a universal thermal index: Physiological equivalent temperature. *International Journal of Biometeorology*, 43(2), 76–84. https://doi.org/10.1007/s004840050119

Matzarakis, A., & Nastos, P. T. (2011). Human-biometeorological assessment of heat waves in Athens. *Theoretical and Applied Climatology*, 105(1), 99–106. https://doi.org/10.1007/s00704-010-0379-3

Matzarakis, A., Rutz, F., & Mayer, H. (2010). Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. *International Journal of Biometeorology*, 54(2), 131–139. https://doi.org/10.1007/s00484-009-0261-0

Mayer, H., & Höppe, P. (1987). Thermal comfort of man in different urban environments. *Theoretical and Applied Climatology,* 38(1), 43–49. https://doi.org/10.1007/BF00866252

Miles, V., & Esau, I. (2020). Surface urban heat islands in 57 cities across different climates in northern Fennoscandia. *Urban Climate*, 31. https://doi.org/10.1016/j.uclim.2019.100575

Milošević, D. D., Bajšanski, I. V., & Savić, S. M. (2017). Influence of changing trees locations on thermal comfort on street parking lot and footways. *Urban Forestry and Urban Greening,* 23, 113–124. https://doi.org/10.1016/j.ufug.2017.03.011

Milošević, D. D., Savić, S. M., Marković, V., Arsenović, D., & Šećerov, I. (2016). Outdoor human thermal comfort in local climate zones of Novi Sad (Serbia) during heat wave period. *Hungarian Geographical Bulletin*, 65(2), 129–317. https://doi.org/10.15201/hungeobull.65.2.4

Muthers, S., Matzarakis, A., & Koch, E. (2010). Summer climate and mortality in Vienna - A human-biometeorological approach of heat-related mortality during the heat waves in 2003. *Wiener Klinische Wochenschrift*, 122(17–18), 525–531. https://doi.org/10.1007/s00508-010-1424-z

Paramita, B., & Matzarakis, A. (2019). Urban morphology aspects on microclimate in a hot and humid climate. *Geographica Pannonica,* 23(4), 398–410. https://doi.org/10.5937/gp23-24260

Provençal, S., Bergeron, O., Leduc, R., & Barrette, N. (2016). Thermal comfort in Quebec City, Canada: sensitivity analysis of the UTCI and other popular thermal comfort indices in a mid-latitude continental city. *International Journal of Biometeorology*, 60(4), 591–603. https://doi.org/10.1007/s00484-015-1054-2

Shartova, N. V., Shaposhnikov, D. A., Konstantinov, P. I., & Revich, B. A. (2019). Air Temperature And Mortality: Heat Thresholds And Population Vulnerability Study In Rostov-On-Don. *Fundamental and Applied Climatology*, 2, 66–94. https://doi.org/10.21513/2410-8758-2019-2-66-94

Streletskiy, D., Shiklomanov, N., & Nelson, F. (2012). Permafrost, infrastructure, and climate change: A gis-based landscape approach to geotechnical modeling. *Arctic, Antarctic, and Alpine Research*, 44(3), 368–380. https://doi.org/10.1657/1938-4246-44.3.368

Unger, J., Skarbit, N., & Gál, T. (2018). Evaluation of outdoor human thermal sensation of local climate zones based on long-term database. *International Journal of Biometeorology*, 62(2), 183–193. https://doi.org/10.1007/s00484-017-1440-z

Varentsov, M., Konstantinov, P., Baklanov, A., Esau, I., Miles, V., & Davy, R. (2018). Anthropogenic and natural drivers of a strong winter urban heat island in a typical Arctic city. *Atmospheric Chemistry and Physics*, 18(23), 17573–17587. https://doi.org/10.5194/acp-18-17573-2018

Weihs, P., Staiger, H., Tinz, B., Batchvarova, E., Rieder, H., Vuilleumier, L., Maturilli, M., & Jendritzky, G. (2012). The uncertainty of UTCI due to uncertainties in the determination of radiation fluxes derived from measured and observed meteorological data. *International Journal of Biometeorology*, 56(3), 537–555. https://doi.org/10.1007/s00484-011-0416-7

Yang, B., Olofsson, T., Nair, G., & Kabanshi, A. (2017). Outdoor thermal comfort under subarctic climate of north Sweden – A pilot study in Umeå. *Sustainable Cities and Society*, 28, 387–397. https://doi.org/10.1016/j.scs.2016.10.011

~

Internet 1: Climate and weather of Russia http://www.pogodaiklimat.ru/climate/22550.htm (2019.12.02.)