Heat and cold waves at the South of the Russian Far East in 1999-2017

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Abstract. Threshold values of 3% and 97% percentiles of annual distribution of mean daily temperature are used to determine the cold and heat waves, respectively, for weather stations in the southern part of the Russian Far East for the period from December 1999 to 2017. Cold waves are identified mainly in December and January. The coldest winter seasons with the longest cold waves, up to 11 days, were observed in 2000/2001 and 2012/2013; the maximum total excess of negative temperatures over the threshold value was 116°C in weather station Poliny Osipenko. Heat waves were registered mainly in July. The hottest summer was in 2011, when heat wave was observed during July and August, with the longest wave at the northern Nikolaevsk-on-Amur; the maximum total excess of positive temperatures over the threshold was 74°C in Poliny Osipenko. There was no clear trend in the inter-annual dynamics of mean temperatures of winter and summer, but temperature variations can reach ±6°C and ±4°C, respectively. Climate extremes vary significantly during the study period, but usually rarely go beyond two standard deviations. Taking into account the possible impact of extreme temperatures on human health, their effect on the increase of mortality in Khabarovsk is discussed.

1. Introduction
In recent years, a significant number of researches have appeared demonstrating a V-or U-shaped relationship between air temperature and mortality in population with increased health risk at extreme temperatures [5, 11]. Cold and heat waves are defined as periods with low and high temperatures, respectively, recorded for several days, during which there may be additional threats to the human health due to excessive strain of thermoregulation systems and increased demand for medical care [1, 4, 6, 15]. First of all, the elderly people and those suffering from cardio-respiratory diseases fall into the risk group [5, 6, 11, 18].

In connection with global climate change, there is a great concern about the increasing influence of temperature waves on human health, associated with the possible raising in the intensity of these phenomena, especially heat waves [3, 5, 11, 12, 18, 20]. For the Amur River basin in the southern part of the Russian Far East, periods of cold and/or heat waves, as well as dramatic fluctuations in daily mortality caused by extreme temperatures are relevant and poorly studied. This is really important at any given time, especially now, in the period of climate change. The aim of the research work is to provide a detailed temporal assessment of extreme temperature changes in the Amur River basin over the past decades, and their possible impact on human health, taking mortality in Khabarovsk as a case study.
2. Materials and methods
Data on population mortality (total, cardiovascular and respiratory (CR), and for separate age cohorts, primary the elderly population 65 years and older) in Khabarovsk for 2000-2017 were provided by the Information and Publishing Center “Statistics of Russia”, to identify the relationship between waves and human health. Temperature exposure is often masked, so the fatal outcome can be registered for other causes of mortality, which are not directly related to the influence of the temperature factor [64]. In this regard, it is justified to use the total mortality as an indicator of the influence of the thermal environment and the resulting physiological strain in the human body.

To find the temperature at which mortality is minimal, a curve is pictured: using the time series method, a study of the temperature dependence of mortality is carried out, showing a characteristic “temperature curve of mortality” [13]. In addition, the Seasonality Index (SI) is used to demonstrate the monthly dynamics of population health over a long period of time [2]. For the calculation of SI, the mortality data are summarized separately for each month for all years of the analyzed multi-year period. The resulting total data is divided by the number of years of observations, resulting in 12 monthly average values. To calculate the total average, the sum of the monthly averages is divided by 12. If the value of the Seasonality Index for a month exceeds 100%, it is considered that seasonal factors have become active in this month.

Data on the mean daily air temperature, the period from 1 December 1999 to 31 December 2017, for weather stations in the Amur River basin, including Khabarovsk as the administrative center of Khabarovsk Krai, are provided by RIHMI – WDC (http://meteo.ru/data). The study area has a monsoon climate of temperate latitudes, characterized by significant seasonal contrasts [7-9]. The threshold values for cold and heat waves are 3% and 97% percentiles of the annual distribution of mean daily temperatures, respectively [14, 16, 17]. The application of the definition proposed by Revich and co-authors [14] will allow us to further compare our findings about the impact of waves on health with the results obtained by colleagues in other areas in Russia. In this method, the mean daily temperature is based on 8 three-hourly observation, taken every 3 hours.

The main characteristics of cold and heat waves are their duration and intensity. The wave intensity is determined by the sum of temperatures exceeding the base value for each wave separately and the total for the entire study period during the waves. In addition, the number of days with temperatures below (above) the threshold is determined, as well as the cumulative sum of temperatures exceeding the baseline, to know about the entire situation during the season [14]. In this case, a wave ratio coefficient is estimated as a proportion between the cumulative sum and the intensity of all waves during the season. A wave is estimated to be short if its duration is from 5 to 8 consecutive days, and long if its duration is from 8 days and more [14, 16, 17].

Temperature waves in Khabarovsk were examined alongside “excess” mortality; that is, the number of deaths above the period mean, to show a relationship between cold and heat waves, and mortality. Period mean mortality was defined for the whole study period, as well as for winter and summer separately. Winter months are December, January and February; June, July and August are taken as the summer season.

3. Results and discussion
3.1. Mortality in Khabarovsk
The yearly mean total mortality in Khabarovsk is 21.7 cases per day with low inter-annual dynamics; cardiovascular and respiratory (CR) mortality is 12.8 cases per day, which averages 59% of the total mortality; mortality of elderly people is 11.5 cases per day. Seasonal mortality statistics give the highest values for winter (22.4, 13.7 and 12.1 cases per day) and lowest for summer (21.0, 11.7 and 10.9 cases per day) for total, CR and elderly mortality, respectively.

SI shows the maximum level of total, CR and elderly mortality in winter, and the minimum in summer, August (figure 1), which corresponds to the previously noted seasonal dynamics of mortality
in Khabarovsk, typical for other countries, and other regions of Russia [2, 16, 17]. In the transitional seasons, the index is almost the same for spring and autumn.

Figure 1. Seasonality Index for mortality in Khabarovsk, 2000-2017.

The temperature curve of mortality, for both total and elderly mortality, in Khabarovsk is approximated by a classical V-shaped plot with two linear sections, respectively, below and above the minimum point of the temperature curve, as shown in figure 2(a) and 2(b). The minimum mortality occurs at +18.6°C; above and below this temperature threshold, mortality rate increases quite dramatically in summer and steadily to negative temperatures in winter. It reaches 29.5 cases per day at a temperature of +29°C, and gradually increases to 24.8 cases at a temperature of −28°C.

In general, the temperature of the minimum mortality is higher the warmer the climate of the area [13]. The minimum elderly mortality at 22.3°C reaches 9.5 cases per day: aged people of 65 years and older are more sensitive than total population. This age cohort is characterized by an eager mortality increase during transition to the hot season: it is much higher than when the temperature drops to negative values. The death rate is 17.3 cases per day at a temperature of +30°C and is 13.4 at a temperature of −28°C.

3.2. Cold and heat waves
Thermal environment is cold in winter and hot in summer, making special requirements on the human body and its adaptive thermoregulatory mechanisms: the study area is characterized by significant seasonal contrasts, with severe Siberian winters and tropical hot humid summers [7-10, 19]. Table 1 shows weather statistics for the period from 1 December 1999 to 31 December 2017.
Figure 2. The temperature curve of mortality, Khabarovsk, 2000-2017: (a) total and (b) elderly mortality.

Table 1. Weather statistics for weather stations in the Amur River basin, 1999–2017

| No. WMO | Lat. | Long. | Alt., m | Temperature, °C | mean | SD | min | abs min | max | abs max | 3% perc. | 97% perc. |
|---------|------|-------|---------|-----------------|------|----|-----|--------|-----|--------|---------|----------|
| Nikolaevsk-on-Amur | 31369 | 53°09' | 140°42' | 67 | -1.4 | 14.5 | -33.0 | -37.3 | 25.8 | 34.0 | -26.5 | 19.8 |
| Poliny Osipenko | 31416 | 52°25' | 136°30' | 69 | -1.5 | 16.8 | -41.6 | -47.7 | 30.1 | 39.3 | -31.7 | 22.0 |
| Bogorodskoe | 31439 | 52°23' | 140°28' | 33 | -0.6 | 15.5 | -35.8 | -39.9 | 26.8 | 35.3 | -28.0 | 21.0 |
| Elabuga | 31733 | 48°48' | 135°52' | 62 | 2.2 | 15.6 | -33.8 | -40.0 | 29.7 | 37.0 | -24.5 | 23.7 |
| Khabarovsk | 31735 | 48°31' | 135°52' | 75 | 2.7 | 15.3 | -34.4 | -40.0 | 30.6 | 36.4 | -23.5 | 24.0 |
| Ekaterino-Nikolske | 31707 | 47°44' | 130°58' | 72 | 2.3 | 15.1 | -31.0 | -37.2 | 29.5 | 39.6 | -22.9 | 23.7 |
The average temperature for the study period in Khabarovsk is 2.7±15.29°C, being the highest in the study area (table 1). The absolute minimum of minimum night temperature of 40.0°C was recorded on January 14, 2011. The hottest day was on June 26, 2010 with a maximum temperature of 36.4°C. The amplitude of absolute temperature fluctuations over the study period is 76.4°C, being adequate to the conditions of the ultra-continental climate. The annual temperature amplitude is very high for all weather stations with the highest record of 87.0°C in Poliny Osipenko, and the lowest average temperature of the year 1.5°C.

A temperature regime in Khabarovsk shows a positive trend with a regression line slope of 0.37/10 years for mean temperature in both winter and summer. Inter-annual temperature fluctuations reached ±6°C and ±4°C for winter and summer, respectively, i.e. in winter the thermal variability was slightly higher than in summer, rarely exceeding ±2 standard deviations.

The threshold of 3% percentile for determining cold waves was 23.5°C in Khabarovsk, and 31.7°C in Poliny Osipenko. Cold waves were recorded mainly in December and January. Most waves were observed in the period from 10 to 20 January. The absence of cold waves was found from December 2006 to February 2009 and from December 2014 to February 2017.

In Khabarovsk, the winter of 2010/2011 was the coldest for the study period with one wave in January, its duration was 12 days; the maximum total excess of negative temperatures over the threshold was 38.9°C. The second coldest was the winter season of 2000/2001, when during the three winter months, three waves were recorded with a total excess of negative temperatures of 42.5°C; of these, in January, one episode of low temperatures lasting 8 days; the temperature excess over the threshold was 29.6°C.

As for the entire study area of the Amur River basin, the winter of 2012/2013 was the coldest. Poliny Osipenko at north had one CW in December and one CW in January, each lasting 11 days with a total temperature excess of 116°C. Two CW were registered in Bogorodskoye in the north and Ekaterino-Nikolskoe in the south, with a long CW in January; the cumulative temperature excess was 75°C and 60°C, respectively. CW in the 2000-2001 season were recorded throughout all winter months, with a total 26-day and 70°C temperature excess in Ekaterino-Nikolskoe in the south. No CW was recorded during the 2014-2017 winter seasons. In general, wave ratio coefficient in winter period was 0.37, that is, almost 40% of all excessively cold days were registered during cold waves.

The 97% percentile threshold for determining the heat wave was the highest 24.0°C in Khabarovsk, and the lowest 19.8°C in Nikolaevsk-on-Amur. Heat waves were recorded throughout all summer months, but most of them occurred in July, the hottest month of the year.

The hottest summer in Khabarovsk was recorded in 2010: in June and July there were two waves, 14 days a total, and the second wave in June-July with duration of 9 days; the HW intensity was 31.6°C. In 2011, one long wave lasted 14 days in July with an intensity of 24.6°C.

For the entire study area, the hottest season was 2011 with the longest duration of HW and the highest temperature excess: 28 days of HW in Nikolaevsk-on-Amur and 18 days in Ekaterino-Nikolskoe. During summers from 2001 to 2004, and from 2014 to 2016, HW was not detected. Overall, the summer wave ratio coefficient was 0.35, which means that 35% of all excessively hot days were registered during heat waves.

The study for 6 weather stations in the Amur River basin shows that in winter, about 60 cold waves are recorded with a total duration of almost 400 days and more than 1200°C of temperature intensity. In total, during summers of 2000-2017, 55 HW are registered with duration of 420 days and temperature intensity of less than 800°C. In general, winter excess below the threshold temperature of 3% percentile is significantly higher in absolute value, than summer excess over the threshold temperature above the 97% percentile: 2500°C in winters against 1600°C in summers, which indicates a stronger intensity of hyper-cold during winters in the study area.

3.3. Cold and heat waves and human mortality
Temperature waves for Khabarovsk are considered along with “excess” mortality; that is, the numbers of deaths above the period mean, as well as mean value for both winter and summer, for total, CR and
elderly mortality. The results show a strong relationship between heat waves and mortality. As a whole, mortality is high during both cold and heat waves reaching 23, 14 and 12 cases per day with waves for total, CR and elderly mortality, respectively. During the cold waves, the mortality was 5% higher for both total and CR mortality, and 2% higher than elderly mortality when compared with mean winter mortality; excess mortality is 7% for total and elderly, and 12% for CR mortality. The reason is a relatively high mortality rate in winter, as it was shown by Seasonality Index (Fig. 1). In summer, the excess mortality rate is 16% for total, 21 for the elderly and 25% for CR mortality, compared to the mean summer values; the excess mortality rate is 12, 15 and 15% compared to mean annual records.

The main findings show that, despite the thermal surplus of negative temperatures in winter, the mortality rate during heat waves is much higher, reaching 25% for people with cardio-respiratory disease, which indicates an intense thermal strain on the human body in short periods with abnormally hot temperatures. At the same time, a high Seasonality Index in winter implies almost 15% higher mortality in the cold season in general, with strong pressure on thermoregulatory system of the human body during the entire winter season in the cold environments of the Russian Far East.

Expected climate changes may lead to an increase in the frequency of extreme weather events with pathological effects on the population health, including periods of heat or cold waves, which is observed for many territories [3, 6, 11, 12, 18, 20]. It is necessary both to carry out research to determine the physiological mechanisms of the influence of meteorological factors on human health, and to develop programs to correct the impact at the individual and population levels [1, 14, 19].

4. Conclusion

The impact of temperature waves on human mortality in cities has been widely studied; however, little work has focused on places of the Russian Far East, characterized by very hot summers and extremely cold winters. The study site is Khabarovsk, a regional capital in this area, and the nearest part of the Amur River basin. The city’s population may be expected to have become habituated to high temperatures in summer and low temperatures in winter. The study examines the extent to which both cold and heat waves contribute to mortality over winter and summer, for the years from 1999 to 2017, with a focus on Khabarovsk.

The dynamics of cold and heat waves in Khabarovsk and for the whole study area of the Amur River basin, for the period from December, 01, 1999 to December, 31, 2017, is reckoned; the coldest and hottest seasons are determined. Mortality can be as much as 25% higher than the average for the period during times of excessively hot summer temperatures. The findings are important for the elderly population, as well as for people with cardio-respiratory mortality.

Acknowledgements

The reported study was performed according to the topic research of ICARP FEB RAS.

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