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FORECAST CHANGES FOR HEAT AND COLD STRESS IN WARSAW IN THE 21ST CENTURY, AND THEIR POSSIBLE INFLUENCE ON MORTALITY RISK

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ABSTRACT: This paper presents the results of research dealing with forecast changes in the frequency of occurrence of heat and cold stress in Warsaw (Poland) in the years 2001–2100, and the possible influence these may exert on mortality risk. Heat and cold stress were assessed by reference to the **U**niversal **T**hermal **C**limate **I**ndex (UTCI), for which values were calculated using meteorological data derived from the MPI-M-REMO regional climate model, at a with spatial resolution of 25×25 km. The simulations used boundary conditions from the ECHAMP5 Global Climate Model, for SRES scenario A1B. Predictions of mortality rate were in turn based on experimental epidemiological data from the period 1993–2002. Medical data consist of daily numbers of deaths within the age category above 64 years (TM64+). It proved possible to observe a statistically significant relationship between UTCI and mortality rates, this serving as a basis for predicting possible changes in mortality in the 21st century due to changing conditions as regards heat and cold stress.

KEY WORDS: mortality, heat stress, cold stress, Warsaw, UTCI, climate change scenario.

INTRODUCTION

Climate and weather exert a strong influence on human health and wellbeing, and several weather conditions entailing acute effects on health have been reported (Fers 1995, Douglas 1996, Kalkstein 1998, Kuchcik 2001, McGregor 2001, Laaidi *et al.* 2006, Błażejczyk 2009, Michelozzi *et al.* 2009, Nastos and Matzarakis 2012). While the attention of most researchers has focused on the heatwaves capable of influencing mortality and morbidity rates dramatically (Kuchcik and Błażejczyk 2001, Dessai 2002, Laschewski and Jendritzky 2002, Diaz *et al.* 2006, Tan *et al.* 2007, Kysely and Kriz 2008, Plavcova and Kysely 2010, Tong *et al.* 2010), it is nevertheless cold-related health disturbances that are mainly noted at mid or northern latitudes (Herring and Hoppa 1997, Eng and Mercer 1998, Gyllerup 1998, Keatinge and Donaldson 1998, Miron *et al.* 2012, Ma *et al.* 2013). Furthermore, while the majority of previous research has been based on relationships between mortality/morbidity rates and individual meteorological elements or simple biometeorological indices, consideration of human heat balance offers another approach by which to assess individuals' relationships with outdoor climate. The components of human heat balance and the indices derived from it are thus measures of meteorological impacts on human beings that help explain the physiological processes leading to acute effects on health (Matzarakis and Mayer 1991, Błażejczyk *et al.* 2000, Laschewski and Jendritzky 2002, Błażejczyk and McGregor 2008, Muthers *et al.* 2010, Matzarakis and Nastos 2011).

If the human heat budget as a whole is taken into account, marked differences between cold and hot environments can be observed. In hot conditions, heat balance is mainly regulated by increased evaporation of sweat from the body; evaporative heat loss representing 75% of overall heat loss. However, intensive evaporation can give rise to hazardous health disorders, on account of the attendant dehydration, and the great burden imposed on the circulatory system engaged in the elimination of heat from the body core. The heart must pump more blood (up to 3–4 litres per minute) to intensify heat transfer from the body core to the skin (*Heat waves*… 2004, Fiala *et al.* 2012).

In a cold environment, the main route to heat loss is increased convection, which represents some 80% of total heat expenditure. The thermoregulatory system seeks to minimise the loss of heat from the body through a reduction of peripheral blood flow. That leads to a decrease in skin temperature and consequently to an increase in the thermal insulation skin tissue can offer. Additionally, in severe cold, shivering thermogenesis is activated (Fiala *et al.* 2012).

Various indices are in use to assess the intensity of heat and cold stress. Recent reviews of heat-stress indices were carried out by Epstein and Moran (2006), and Błażejczyk *et al.* (2012). The Heat Index (HI) – Rothfusz 1990, Humidex (Masterson and Richardson 1979), Wet-Bulb Globe Temperature (WBGT) – Yaglou and Minard 1957 and Apparent Temperature (AT) – Steadman 1984 are simple indices widely used in regard to hot conditions. Wind Chill Temperature (WCT) – Osczevski and

Bluestein 2005, Shitzer 2006 is in turn the most popular index assessing cold stress. However, Perceived Temperature (PT) – Jendritzky (1990), VDI (2008), Physiologically Equivalent Temperature (PET) – Höppe (1999), Physiological Subjective Temperature (PST) – Błażejczyk and Twardosz (2010) and Standard Effective Temperature (SET*) – Pickup and de Dear (2000) are newgeneration indices derived from simple human heatbalance models. They can also be used across a wide range of thermal conditions, from very cold to very hot.

The last few years have seen several studies published in regard to the relationship between anticipated climate change and human health. Beyond that, Błażejczyk (2009) offered a general overview of the possible consequences of climate change for human health on the global scale, while Gosling *et al.* (2007) came up with a general scheme for research dealing with predictions of future climate-related mortality, their model being validated by reference to the six cities of Boston, Budapest, Dallas, Lisbon, London and Sydney (Gosling *et al.* 2009). In general, the research methodology has two stages: a first in which empirical mortality and climate data with daily resolution are used to find a statistical model of past relationships, and a second whereby the statistical relationships model is applied in assessing potential impacts of climate change on climate-related mortality (Fig. 1).

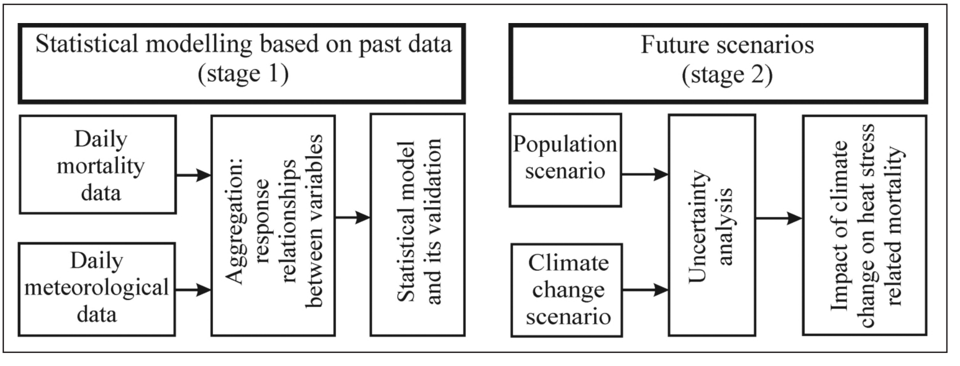

Figure 1. Methodology scheme for the generation of scenarios regarding climate-related mortality (adapted from Gosling *et al.* 2007)

The above methodology has been used in researching the impacts of future changes in air temperature in the summer and winter seasons on human health and mortality risks in Australia (Darbyshire *et al.* 2013), Canada (Martin *et al.* 2012) and Spain (Ostro *et al.* 2012).

In turn, the aim of this paper is to present possible changes in mortality risk in the 21st century, in both cold and warm periods of the year, in line with changes in the frequency of days with heat or cold stress (defined by the UTCI), as forecast for the years 2001–2100. The analysis applies the aforementioned methodological approach proposed by Gosling *et al.* (2007).

DATA AND METHODS

In the first stage of research we sought out relationships between specific weather conditions and daily numbers of deaths. Medical and meteorological datasets were analysed to this end, the medical dataset comprising daily statistics for total mortality elderly (people over 64 – TM64+, deaths per day) in the case of Poland's Warsaw Agglomeration. These data cover the period 1993–2002. The meteorological data in turn comprised daily values for air temperature and humidity, wind speed and cloudiness recorded at the Warszawa Okęcie meteorological station in the years 1993–2002. The data refer to midday (12:00 UTC).

For each day of the studied period a Universal Thermal Climate Index (UTCI) was then calculated using the BioKlima 2.6 software package. The UTCI represents a newly-developed index that can be used to assess the heat and cold stress arising in given meteorological conditions. The UTCI derives from the Fiala multi-node model (Fiala *et al.* 2012), simulating heat transfer inside the body and at its surface. UTCI is defined as the air temperature (Ta) of the reference condition causing the same physiological response (in terms of sweat production, shivering, skin wettedness and skin blood flow, as well as rectal, mean skin and face temperatures) as the actual conditions (Błażejczyk *et al.* 2010, Bröde *et al.* 2012). The offset, i.e. the deviation of UTCI from air temperature, depends on the actual values for air and mean radiant temperatures (Tmrt), wind speed (va) and water vapour pressure (vp). This may be written as:

$$\text{UTCI} = f\,(\text{Ta; Tmrt; va; vp}) = \text{Ta} + \text{Offset (Ta; Tmrt; va; vp)}$$

The offsets of UTCI to Ta can be approximated by a polynomial function in: Ta, va, vp, Tmrt-Ta, including all main effects and interaction terms up to the 6th order. At least the UTCI regression model consists of 210 coefficients (Błażejczyk *et al.* 2010). The root mean squared error of approximation is 1.1°C, and 50% of all observed errors are within ±0.6°C, 80% within ±1.3°C and 90% within ±1.9°C (Bröde *et al.* 2012).

The UTCI is categorised in term of the intensity of the heat/cold stress evoked in an organism by given meteorological conditions. Heat stress occurs where there is high air temperature accompanied by intensive solar radiation. In turn, cold stress dominates on days with low air temperature accompanied by a high wind speed. Specific physiological responses are observed across particular ranges of ambient conditions defined by the UTCI, these making it necessary for different protections to be applied against overheating or overcooling of the organism (Tab. 1). The heat stress category (SC) was defined for each day of the studied periods, i.e. both 1993–2002 (experimental stage) and 2001–2100 (simulation stage).

The observed daily mortality rates were assigned to the five classes of:

- normal mortality – lower or at least 5% higher than the average mortality for a given month,

- slightly increased mortality – 5-10% higher than average for a given month,
- high mortality – 10-20% higher than average for a given month,
- very high mortality – 20-25% higher than average for a given month,
- extremely high mortality – more than 25% above average for a given month.

Table 1. UTCI categories of heat/cold stress

UTCI (°C) range	**Stress Category (SC)**	**Physiological responses**	**Recommendations for protection**
above +46	4 – extreme heat stress	Increase in rectal temperature (*Tre*) time gradient. Steep decrease in total net heat loss. Averaged sweat rate >650 g/h, steep increase.	Periodical cooling and drinking of water necessary. Stay without activity.
+38 to +46	3 – very strong heat stress	Core to skin temperature gradient < 1K (at 30 min). Increase in *Tre* at 30 min.	Periodical use of air conditioning or shaded sites and drinking of water necessary. Reduce activity.
+32 to +38	2 – strong heat stress	Dynamic Thermal Sensation (DTS) at 120 min >+2. Averaged sweat rate >200 g/h. Increase in *Tre*. Instantaneous change in skin temperature > 0 K/min.	Drinking of water necessary, use shade places and reduce activity.
+26 to +32	1 – moderate heat stress	Moderate increase in sweat rate, *Tre* and skin temperature: mean (*Tskm*), face (*Tskfc*), hand (*Tskhn*). Occurrence of sweating. Steep increase in skin wettedness.	Drinking of water necessary.
+9 to +26	0 – no thermal stress	DTS between –0.5 and +0.5 (averaged value). Latent heat loss >40 W. Plateau in *Tre* time gradient.	Physiological thermoregulation sufficient to keep comfort.
+9 to 0	–1 – slight cold stress	DTS < -1. Local minimum of *Tskhn* (use gloves).	Use gloves and cap.
0 to –13	–2 – moderate cold stress	DTS < -2. Vasoconstriction. Averaged *Tskfc* <15°C (pain). Decrease in *Tskhn*. *Tre* time gradient <0 K/h. Face skin temperature < 15°C (pain). *Tmsk* time gradient <–1 K/h.	Increase activity, protect extremities and face against cooling.
–13 to –27	–3 – strong cold stress	Averaged *Tskfc* < 7°C (numbness). *Tre* time gradient < -0.1 K/h. Increase in core to skin temperature gradient.	Strongly increase activity, protect face and extremities. Use better-insulated clothing.
–27 to –40	–4 – very strong cold stress	*Tskfc* <0°C (frostbite). Steeper decrease in *Tre*. *Tskfc* <7°C (numbness). Occurrence of shivering. *Tre* time gradient < –0.2 K/h.	Strongly increase activity, protect face and extremities. Use better-insulated clothing Reduce stays outdoors.
below –40	–5 – extreme cold stress	*Tre* time gradient < –0.3 K/h. *Tskfc* < 0°C (frostbite).	Stay indoors or use heavy, wind-protected clothing.

Source: adapted from Błażejczyk *et al.* 2010 and Bröde *et al.* 2012.

Regression analysis and Pearson correlation coefficients were used to find relationships between mortality rates and UTCI. The Pearson correlation coefficients were calculated including one-, two- and three days delay of mortality in relation to the appearance of biothermal conditions. *Statistica 7* software was used for the calculations. We also calculated mean, maximum and minimum values of TM64+ for particular classes (categories) of UTCI. The results of epidemiological research were applied in simulating the possible influence of changes in frequencies of occurrence of cold/heat stress on climate-related mortality in Warsaw in the years 2001–2100.

In the second stage of the research the simulations of meteorological elements necessary for the calculations of UTCI for the years 2000–2100 were done. These were based on the MPI-M-REMO regional climate model with a spatial resolution of 25×25 km. Simulations used boundary conditions proposed in the ECHAMP5 Global Climate Model for emission scenario A1B (*Special Report*… 2000). The A1B scenario considers a relatively mild increase in GHGs this century, and is used frequently in climate-change predictions. In the present study, the daily meteorological data for air temperature, wind speed, relative air humidity and global solar radiation were used for in calculations of UTCI for the period 2001–2100. The data were extracted for the Warsaw Agglomeration, which covers two E-OBS (http://eca.knmi.nl/) grid squares. The data were processed at the Interdisciplinary Centre for Mathematical and Computational Modelling (ICM) of the University of Warsaw by M. Liszewska, within the framework of the KLIMADA project. They use simulations done under the EU ENSAMBLES project (http://ensemblesrt3.dmi.dk).

It is well known that, in spite of improved parameterization of physical and chemical processes, climate models provide much differentiated data. For example, air temperature predictions taken from various models for the A1B emission scenario differ markedly (IPCC 2007, Błażejczyk and Żmudzka 2013). Such uncertainty is caused by differences in parameterisation of particular components of climate models both global and regional. However, the temperature data used in the present research, taken from MPI-M-REMO-ECHAMP5, fit very well with reference data derived from ERA40 reanalysis (the correlation coefficient is 0.98). In the case of daily values concordance between modelled and reference data is only slightly weaker, and the correlation coefficient is 0.95 (Liszewska *et al.* 2012).

To validate the uncertainty of modelled UTCI values we also analysed how they fit to observed values during the common period 1993–2002. The obtained correlation coefficient of 0.75 is statistically significant at the 99% confidence level, and thus indicates moderately strong relationships between modelled and observed values of the index. The relatively high standard error of estimation (11.2) can be the effect of great differences between the observed and modelled values for wind speed, which exert a strong influence on UTCI, especially at low air temperature (Fiala *et al.* 2012). However, the error of the modelled UTCI does not change significantly the frequencies of occurrence of the particular UTCI categories considered in the present study (Tab. 2).

Table 2. Frequencies of occurrence of particular heat stress categories for observed (obs) and modelled (mod) UTCI values, 1993–2002

UTCI category	Winter		Spring		Summer		Autumn	
	obs	mod	obs	mod	obs	mod	obs	mod
Extreme cold stress	0.1	.	.	.	.	.	.	.
Very strong cold stress	4.1	3.3	0.3	.	.	.	0.3	0.1
Strong cold stress	36.3	35.8	4.1	3.2	.	.	8.1	4.2
Moderate cold stress	49.8	58.9	24.9	20.5	0.9	0.3	26.5	27.0
Slight cold stress	9.2	1.8	21.0	28.6	8.8	5.0	27.8	29.3
No thermal stress	0.6	0.2	38.0	44.2	58.4	72.1	35.7	38.0
Moderate heat stress	.	.	6.2	3.3	24.8	19.3	1.5	1.2
Strong heat stress	.	.	5.4	0.2	6.5	3.0	.	0.1
Very strong heat stress	.	.	.	.	0.7	0.2	.	.
Extreme heat stress	.	.	.	.	.	.	.	.

RESULTS

EPIDEMIOLOGICAL RESEARCH

Mean daily values for total mortality in Warsaw fluctuated from 30 to 60. The highest TM64+ appeared in the winter months (maximum in the last third of January, 50 daily) and the lowest in the summer months (minimum in the second third of June, 39 daily). However, maximum daily values for TM64+ varied between 50 and 90 per day, the highest values of all being those characterising the period from the last third of December through to the second third of February. High daily TM64+ totals also appeared in the second and last thirds of March as well as in the last thirds of June and July. An absolute maximum was observed in the first ten days of August (85). Minimum daily mortality was in turn between 10 and 30. The highest minimum value was noted in the last third of November (28), while the lowest minimum related the 10 deaths observed in the last third of December (Fig. 2).

To determine the influence of biothermal conditions (as indicated by UTCI values) on mortality levels, we compared daily TM64+ rates with UTCI on the actual day, as well as with index values observed 1, 2 or 3 days before. Coefficients for the correlation between TM64+ and UTCI on particular indicate only weak relationships, though these only fail to achieve statistical significance in the autumn months. The strongest relationships between TM64+ and UTCI are in turn present for summer data, especially with a 1-day delay. In winter, the relationships are again weaker, with the strongest correlations noted where a 3-day delay are taken into account. While in the year as a whole, as well as in spring and winter, numbers of deaths increase where UTCI is lower, in summer TM64+ was higher in line with increased values for UTCI (Tab. 3).

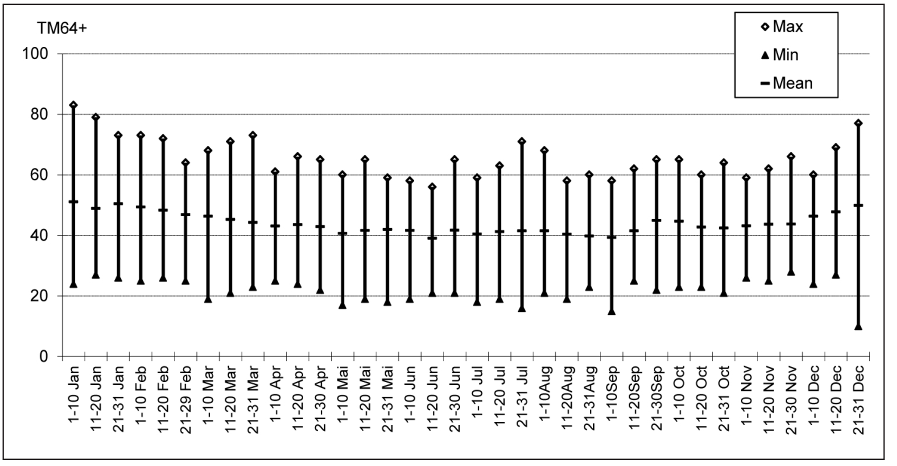

Figure 2. Maximum (Max), minimum (Min) and mean daily mortality rates (TM64+) recorded for Warsaw in consecutive 10-days periods of the year, 1993–2002

Table 3. Correlation coefficients between daily TM64+ mortality and UTCI values observed on particular days, Warsaw, 1993–2002

UTCI on:	Spring	Summer	Autumn	Winter	Year
actual day	–0.09*	0.18*	–0.01	–0.09*	–0.23*
1 day before	–0.07*	0.23*	–0.01	–0.12*	–0.23*
2 days before	–0.09*	0.18*	–0.07	–0.12*	–0.25*
3 days before	–0.11*	0.09*	–0.08*	–0.14*	–0.27*

* Indicates statistical significance at the 95% confidence level.

Each day of the studied period was then classified as a day with normal, slightly increased, high, very high or extremely high mortality. In winter, spring and summer in Warsaw it was normal or slightly increased levels of mortality that appeared most often, on about 70% of days. High and very high mortality are in turn noted on about 20% of days in total. However, extremely high mortality only characterised 10% of days.

Autumn proved exceptional. Although after the class of normal and slightly increased mortality (accounting for almost 66% of days), the class of high mortality was recorded relatively often (14%). The classes of very high and extremely high mortality were in turn observed with a frequency of about 10% each (Fig. 3).

The analysis of the numbers of deaths daily in the different UTCI classes revealed no deaths in circumstances of extreme cold stress or extreme heat stress. Rather, the mean numbers of deaths in reached there highest values in the very strong heat stress and very strong cold stress categories, with 63 and 54 deaths per day respectively. In the face of such biothermal conditions, daily numbers of deaths were on average 31% or 54% higher than in neutral conditions (with "no thermal stress", characterised

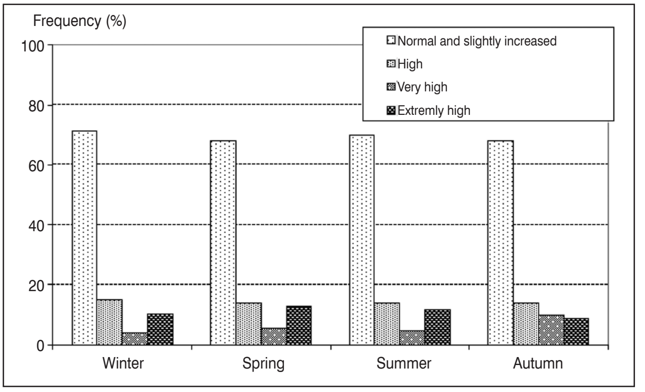

Figure 3. Frequency of occurrence of days with different classes of daily mortality rates, Warsaw, 1993–2002

by 41 deaths per day on average). For the strong heat and cold stress categories the relative increase in mortality was of about 16%. In the case of extreme UTCI values TM64+ varied between 10 in the "strong cold stress" class and 85 in "very strong heat stress" and "very strong cold stress" categories (Fig. 4). The relationships between heat stress categories and average mortality risk are explained by a 2nd-order polynomial statistical model, as follows:

$$TM64+ = 1.3572 \cdot SC^2 + 1.9772 \cdot SC + 41.593$$

where SC is the numerical value of the stress category (see Tab. 1).

The correlation coefficient for variables is 0.93 and the coefficients of the regression model achieve statistical significance at the 99% confidence level.

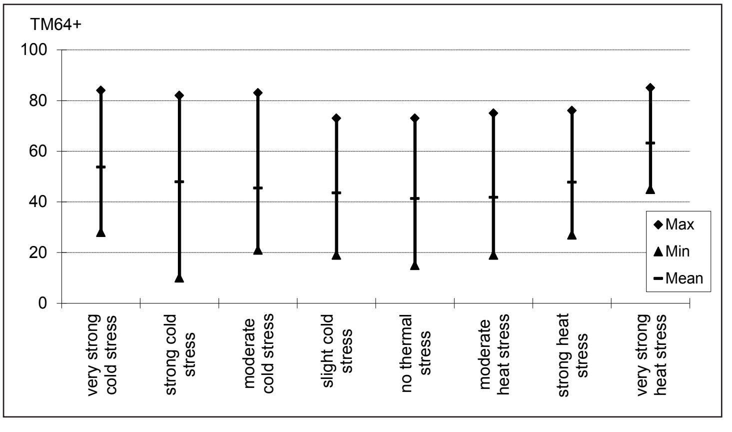

Figure 4. Maximum (Max), minimum (Min) and mean daily values for total mortality rates (TM64+) in relation to particular categories of heat and cold stress (as defined by the UTCI), Warsaw, 1993–2002

HEAT STRESS SIMULATIONS FOR THE YEARS 2001–2100

Taking into consideration the results of epidemiological research carried out in the Warsaw Agglomeration, we have assumed that a very crucial factor in estimating mortality risk is the occurrence of extreme biothermal conditions. In the cold period of the year, mortality is more likely when daytime UTCI values fall within the categories of "strong", "very strong" or "extremely strong" cold stress (i.e. SC from -3 to -5, UTCI <-13ºC). In turn, in the warm period of the year, mortality can increase considerably when UTCI enters the categories of "strong", "very strong" or "extremely strong" heat stress (SC from 2 to 4, UTCI >32ºC).

In the first decade of the 21st century the annual frequencies of occurrence of the two UTCI categories under consideration were of the order of 4 heat stress days (1%) and 53 cold stress days (14%). In particular seasons, the structure of days with specific UTCI values is differentiated. In winter more than 46% of days were assigned to the strong, very strong and extreme cold stress categories. In summer months only 4% of days were classified as characterised by strong, very strong and extreme heat stress. In turn, during the transient seasons days with cold and heat stress account for 4–7% of the total. In both spring and autumn days with cold stress occurred relatively frequently (accounting for 6–7%).

In turn, the forecast for the last decade of the current century predicts a markedly changed UTCI structure for Warsaw. The annual number of coldstress days should by then be down to about 20 (5%), while days with heat stress will be more frequent (up to 12 a year on average, i.e. 3%). Particular seasons will also have experienced changes, with only about 20% of the days in winter featuring cold stress, while more than 11% of summer days will be characterised by heat stress. In autumn, both days with heat stress and cold stress will be very rare (about 1%) – Table 4.

While great year-on-year variability is to be noted as the detailed picture for changes in the annual frequency of occurrence of days in the two discussed UTCI categories, namely <–13ºC (cold stress days) and >32ºC (heat stress days) is analysed, it is nevertheless possible to note a statistically significant upward trend for numbers of heat stress days over time, as well as a significant downward trend for cold stress days. The predicted rate of increase in numbers of days with UTCI >32ºC is of about 0.9 for each decade of the century, while the anticipated decrease in the number of cold stress days is of about 3.7 per decade (Fig. 5).

As was mentioned in the introduction, the necessity that an organism adapt to extreme ambient meteorological conditions involves different physiological reactions which burden the circulatory and respiratory systems. The results of reported epidemiological research indicate that both heat and cold stress generate increased risk of mortality. Taking into account the epidemiological data obtained for Warsaw, we have calculated possible changes in mortality caused by cold stress (CSM) and heat stress (HSM). With this aim in mind, each day was assigned to a particular stress category and the statistical polynomial model derived from the experimental data

Table 4. The frequency of occurrence of days manifesting different UTCI categories in Warsaw in the first and last decades of the 21st century

Stress category	Winter		Spring		Summer		Autumn	
	2001–2010	2091–2100	2001–2010	2091–2100	2001–2010	2091–2100	2001–2010	2091–2100
Extreme cold stress	0.1	.	.	.	.	.	.	.
Very strong cold stress	5.7	2.0	0.1	.	.	.	0.1	.
Strong cold stress	39.8	17.5	5.9	1.5	.	.	6.7	0.5
Moderate cold stress	52.9	69.0	23.4	15.8	0.2	.	26.3	20.2
Slight cold stress	1.6	10.9	23.7	24.6	5.8	2.6	32.4	29.6
No thermal stress	.	0.7	43.3	50.2	73.7	63.7	32.2	42.9
Moderate heat stress	.	.	3.2	7.0	16.6	22.7	1.1	4.6
Strong heat stress	.	.	0.5	1.0	3.2	8.9	0.1	1.1
Very strong heat stress	.	.	.	.	0.5	1.6	.	.
Extreme heat stress	.	.	.	.	.	0.4	.	.

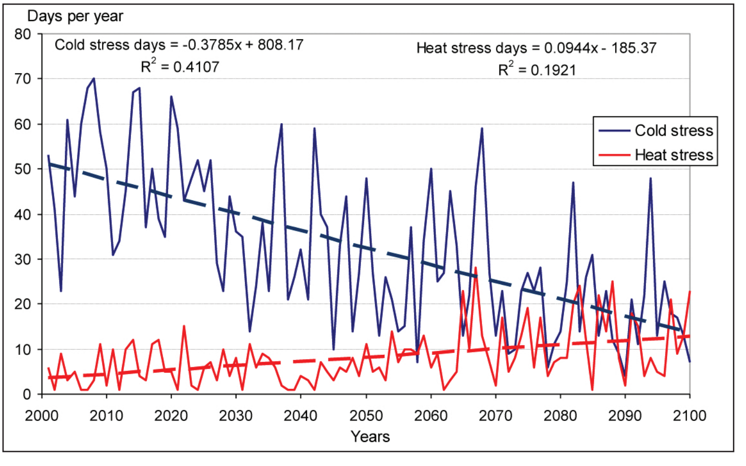

Figure 5. Annual frequency of occurrence of days in the coldand heat stress categories in Warsaw in the period 2001–2100

was then used to predicted daily mortality rates by means of calculations. The daily values obtained were then aggregated for whole years and decades. While in the first decade of the present century we might expect about 200 deaths per year related to heat stress and 2500 deaths per year reflecting cold stress, by the end of the present century the death count due to heat stress may have risen to 600 per year, while cold stress fatalities may have gone down to about 900 per year. Taking observed mortality rates in the decade 1993–2002 as 100%, the relative HSM increase can be c. 2.6-fold (levels at 258% of those in the reference period), while the relative CSM decrease can be 2.3-fold (levels down to just 42% of those in the reference period) – Figure 6.

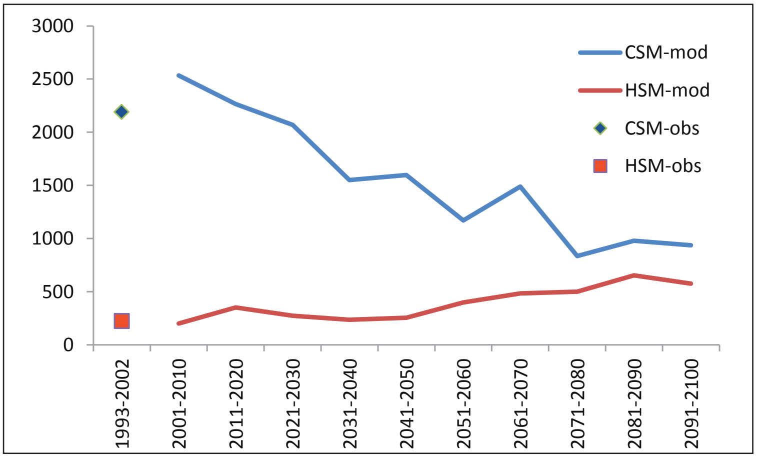

Figure 6. Mean annual modelled values for cold stress (CSM-mod) and heat stress (HSM-mod) mortality in particular decades of the 21st century in the Warsaw Agglomeration, in comparison with observed cold-related (CSM-obs) and heat-related (HSM-obs) mortality in the period 1993–2003

CONCLUSIONS

Meteorological conditions are important agents influencing the functioning of the human organism. Extreme ambient conditions, denoting both strong cold and heat stress, lead to significant increases in mortality risk. In the Warsaw Agglomeration, days with neutral biometeorological conditions (no thermal stress) are associated with around 40 registered deaths each, on average, while each day with at least strong cold or heat stress (UTCI <–13 or >32°C) is characterised by an average of 48 deaths noted. This is thus a 16% increase in mortality risk as compared with conditions of "no thermal stress".

Simulations of the frequencies of occurrence of the aforementioned UTCI categories for the years 2001–2100 point to a significant increase in heat stress days (of about 0.9 per decade) and a marked decrease in cold stress days (of about 3.7 per decade). In summer we should thus expect 9% more days with at least strong heat stress, while in winter the decrease in numbers of days with at least strong cold stress may be of as much as 30%.

The changes in the frequency of occurrence of days with extreme biothermal conditions will lead to marked changes in climate-related mortality risks, in relation to both cold stress and heat stress mortality. By the last decade of 21st century we may well be experiencing summers and springs in which mortality related to heat is 260% of the level experienced recently. On the other hand, winters by then may be expected to be associated with greatly reduced cold-related mortality (to just around 43% of its level in the 1993–2002 reference period).

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