Global and Planetary Change 119 (2014) 71–84

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Projections of heat waves with high impact on human health in Europe

A. Amengual [a,*], V. Homar [a], R. Romero [a], H.E. Brooks [b], C. Ramis [a], M. Gordaliza [c], S. Alonso [a,d]

[a] Grup de Meteorologia, Departament de F´ısica, Universitat de les Illes Balears, Palma, Mallorca, Spain
[b] NOAA/National Severe Storms Laboratory, Norman, OK, USA
[c] Facultad de Farmacia, Instituto de Estudios de la Ciencia y la Tecnología, Universidad de Salamanca, Salamanca, Spain
[d] Departament de Recerca en Canvi Global, Institut Mediterrani d'Estudis Avançats, Palma, Mallorca, Spain

ARTICLE INFO

Article history:
Received 9 January 2014
Received in revised form 21 May 2014
Accepted 26 May 2014
Available online 2 June 2014

Keywords:
Climate change
Heat waves
Human health
Physiologically equivalent temperature
Regional climate modeling
Statistical adjustment
Ensemble strategy

ABSTRACT

Climate change will result in more intense, more frequent and longer lasting heat waves. The most hazardous conditions emerge when extreme daytime temperatures combine with warm night-time temperatures, high humidities and light winds for several consecutive days. Here, we assess present and future heat wave impacts on human health in Europe. Present daily physiologically equivalent temperatures (PET) are derived from the ERA-Interim reanalysis. PET allows to specifically focus on heat-related risks on humans. Regarding projections, a suite of high-resolution regional climate models – run under SRES A1B scenario – has been used. A quantile–quantile adjustment is applied to the daily simulated PET to correct biases in individual model climatologies and a multimodel ensemble strategy is adopted to encompass model errors. Two types of heat waves differently impacting human health – strong and extreme stress – are defined according to specified thresholds of thermal stress and duration. Heat wave number, frequency, duration and amplitude are derived for each type. Results reveal relatively strong correlations between the spatial distribution of strong and extreme heat wave amplitudes and mortality excess for the 2003 European summer. Projections suggest a steady increase and a northward extent of heat wave attributes in Europe. Strong stress heat wave frequencies could increase more than 40 days, lasting over 20 days more by 2075–2094. Amplitudes might augment up to 7 °C per heat wave day. Important increases in extreme stress heat wave attributes are also expected: up to 40 days in frequency, 30 days in duration and 4 °C in amplitude. We believe that with this information at hand policy makers and stakeholders on vulnerable populations to heat stress can respond more effectively to the future challenges imposed by climate warming.

1. Introduction

Climate change is one of the major social, economic and environmental concerns of the twenty-first century. Observations show that global mean air surface temperature has notably increased during the last century (IPCC, 2007). Europe emerges as an especially responsive area to temperature rise, particularly during the warm season (Giorgi, 2004). European warming is projected to continue at a rate somewhat greater than the global mean (IPCC, 2007). Furthermore, projections indicate that heat waves will become more intense, more frequent and longer lasting (Meehl and Tebaldi, 2004). Together with a general mean warming over Europe, changes in temperature variability could exacerbate heat waves: even small increases in temperature variability could produce significant changes in heat wave attributes as a consequence of its threshold-based definition (Schär et al., 2004; Beniston et al., 2007; Kjellström et al., 2007; Fischer and Schär, 2009).

Population is highly vulnerable to changes in heat wave attributes. These may lead to increased mortality, mainly among the elderly, children and people with pre-existing health risks (Basau and Samet, 2002; Koppe et al., 2004). The 2003 European summer heat wave exemplifies possible social impacts, with a death toll exceeding 70,000 (Robine et al., 2008). Some studies have analyzed the link among climatic factors and mortality excess under heat wave conditions. For instance, heat-related mortality has been studied through a combination of extreme high daytime and over-night temperatures (Changnon et al., 1996; Trigo et al., 2009). By using the daily maximum apparent temperature (AT), Fischer and Schär (2010) projected the severest heat wave impacts on human health in southern Europe and the Mediterranean. After linking AT and mortality, Ballester et al. (2011) projected an increase in heat-related death toll for Europe, and suggested a shift in seasonality of maximum monthly mortality from winter to summer. But the thermal environment for humans encompasses both the thermal stress – i.e. the atmospheric heat exchanges with the body – and the thermal strain – i.e. the body's physiological response – (Jendritzky and Tinz, 2009).

Besides maximum and minimum temperatures and saturation deficit, other atmospheric variables also have an important role on

* Corresponding author at: Dept. de F'ısica, Universitat de les Illes, Balears, 07122 Palma, Mallorca, Spain.
E-mail address: arnau.amengual@uib.es (A. Amengual).

http://dx.doi.org/10.1016/j.gloplacha.2014.05.006
0921-8181/

human thermal comfort. Wind speed, solar heat load and radiation exchange fluxes should be considered to assess as accurately as possible heat stress impacts under heat wave conditions. Furthermore, thermo-physiological parameters are a key factor to determine thermal stress impacts on human health. The human body balances heat production – and additional environmental heat gains – with heat loss. Heat production is a result of the metabolic activity required to perform mental and physical activities. Most of the energy that the body uses is released to the environment as heat through convection, conduction, radiation, respiration and evaporation (Koppe et al., 2004). Under heat wave conditions, heat loss is severely reduced and heat production can eventually exceed environmental losses. When internal mechanisms regulating body temperature are stressed and cannot cope with thermo-regulatory demands, the body temperature increases. This can lead to excessive strain on the body and ultimately cause heat illness and an increase on heat-related excess mortality and morbidity.

We study heat wave impacts on human health in Europe by using the physiologically equivalent temperature (PET). PET is a thermal index based on a complete heat budget of the human body and encompasses both meteorological and thermo-physiological aspects (Mayer and Höppe, 1987; Höppe, 1999; Matzarakis et al., 1999). PET has already been used to assess the relationship between heat stress and mortality in Europe. Matzarakis et al. (2011) found a significant impact of heat stress on human health after evaluating a 37-year period of daily data in the federal state of Vienna, Austria. In particular, an enhanced risk of mortality to heat stress was found due to cardiovascular and respiratory diseases. Matzarakis and Nastos (2011) analyzed heat wave impacts on humans for the Greater Athens Area during the 1955–2001 period. Impacts on human health were described through the intensity and duration of the heat waves by using daily physiologically equivalent and minimum air temperatures. An increase in the average duration of heat waves was found for this period. These authors also revealed the relevance for humans of the intra-annual variation of heat stress conditions. The association between daily mortality and thermal conditions has also been recently examined by Nastos and Matzarakis (2012) for Athens, Greece. After analyzing 10-year daily series of minimum and maximum temperatures and the PET and Universal Thermal Climate (UTCI; see special issue of Int. J. Biometeorol. 56, 2012) indices, mortality was found closely related to all these parameters. In addition, the authors showed strong statistical relationships between mortality and air temperatures, PET and UTCI on the same day. Thus, we first derive daily PETs from the ECMWF ERA-Interim reanalysis. Next, we define strong and extreme stress heat waves by combining different daily maximum and minimum PET and duration thresholds. This allows to analyze the spatial distribution of European heat wave attributes for the current climate.

Regarding future scenarios, reliable projections of climatic variables from Regional Climate Models (RCMs) are required to properly assess regional and local impacts. Such evaluation is made by driving impact models with RCM outputs. However, it would be advisable to previously

Table 1
Physiological equivalent temperature ranges, in °C, for different grades of thermal stress.
Adapted from Matzarakis and Mayer (1997).

Thermo-physiological stress	PET thresholds
Extreme cold stress	<4
Strong cold stress	4–8
Moderate cold stress	8–13
Slight cold stress	13–18
No thermal stress	18–23
Slight heat load	23–29
Moderate heat load	29–35
Strong heat load	35–41
Extreme heat load	>41

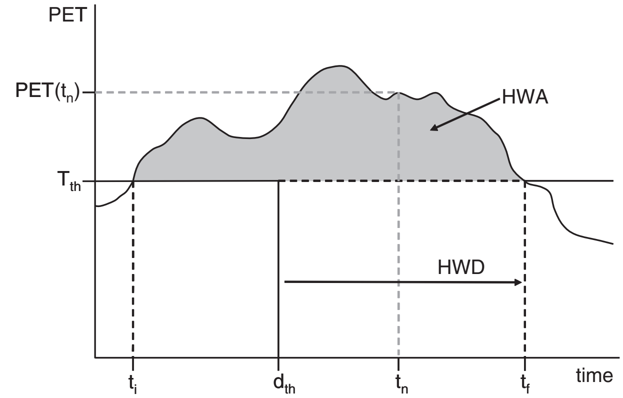

Fig. 1. Graphical sketch of heat wave duration (HWD) and amplitude (HWA, gray shading) exceedances. T_{th} and d_{th} denote the thermal stress and duration thresholds, respectively.

calibrate the simulated variables – or their derivatives – in order to correct model biases, rather than to drive impact models with raw RCM outputs. Systematic discrepancies occur between simulated and observed climate. Model errors arise from inaccuracies in the physical and sub-grid scale parametrizations and uncertainties in the boundary forcing. Among the different correction techniques, quantile–quantile mapping adjustments are one of the most suitable (Wood et al., 2004; Boé et al., 2007; Déqué, 2007; Amengual et al., 2012). Prior to examining future changes in heat wave attributes, we apply the quantile–quantile adjustment described in Amengual et al. (2012) to the daily PET cumulative distribution functions (CDFs) of each individual RCM. These RCMs were run under the SRES A1B scenario and by considering a diversity of RCMs and parent GCMs in a regional multimodel ensemble, we naturally account for and potentially smooth out model errors.

The structure of the paper is as follows: Section 2 introduces the physiologically equivalent temperature and provides a definition of heat waves; Section 3 describes the observed and simulated databases, the thermal sensation derivation and the quantile–quantile adjustment; Section 4 evaluates the link between heat waves and mortality excess for the 2003 European summer and describes present and projected changes in heat wave attributes; finally, Section 5 summarizes the main results and conclusions, offering some additional remarks.

2. Definitions

2.1. Physiologically equivalent temperature

Energy balance models of the human body take all mechanisms of heat exchange into account, being thermo-physiologically relevant to

Table 2
List of transient RCM experiments driven within the ENSEMBLES European project for the 1951–2100 period. Note that all models have a spatial resolution of 25 km and were run under the SRES A1B.

Driving GCM	RCM	Acronym	Institute
ECHAM5	RCA3	C4IRCA3	C4I
ARPEGE	HIRLAM	DMI-HIRLAM5	DMI
ECHAM5	HIRLAM	DMI-HIRLAM5	DMI
BCM	HIRLAM	DMI-HIRLAM5	DMI
HadCM3	CLM	ETHZ-CLM	ETHZ
ECHAM5	RegCM	ICTP-REGCM	ICTP
ECHAM5	RACMO	KNMI-RACMO	KNMI
HadCM3	HadRM3Q0	METO-HC-HadCM3Q0	HC
HadCM3	HadRM3Q3	METO-HC-HadCM3Q3	HC
HadCM3	HadRM3Q16	METO-HC-HadCM3Q16	HC
BCM	RCA	SMIRCA	SMHI
ECHAM5	RCA	SMIRCA	SMHI
HadCM3	RCA	SMIRCA	SMHI