3.8. METEOROLOGICAL RISK: TEMPERATURE EXTREMES

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ABSTRACT

Temperature extremes are rare high or low temperature events that may occur over a range of time and geographical scales. Temperature extremes are usually defined in terms of their position in a distribution of observed temperature values or as a threshold value. If defined in terms of a distribution of temperature values, extremes are expressed as probabilities or return periods, such as 5 percent probability of occurrence or a 1 in 20 year event. A threshold value will be a specific high or low temperature value, above or below which there is a discernible impact.

Temperature extremes usually occur because of a change in the weather pattern over a few days or a longer period such as several weeks. High or low temperature extremes that last for longer than 2 – 3 days are often referred to as heat- or cold-waves. Phenomenon such as the North Atlantic Oscillation (NAO) or the El Nino Southern Oscillation (ENSO) can be important in changing the probability of temperature and other climate extremes. Because of improvements in medium to long-range forecasting, it is becoming increasingly possible to predict the occurrence of temperature extremes and thus integrate predictions into early warning systems. Human induced climate change may well change the likelihood of high and low temperature extremes in the future which may have a number of impacts on society.

Amongst a range of possible physical, socio-economic and environmental impacts of extreme temperatures, human health is of particular concern. Building knowledge about human vulnerability to and probability of temperature extremes will assist with establishing general levels of risk associated with periods of extreme heat or cold now and in the future.

KEYWORDS

temperature extremes, probability, percentiles, heat waves, cold waves, climatic variability, medium and long range forecasting, impacts

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Key Messages

3.8.1 Temperature Extremes in a DRM Context

**Temperature extremes, although by definition rare, are important from a DRM perspective as they can lead to a range of substantive direct and indirect impacts on human activity and other systems.**

Understanding temperature extremes in a DRM context involves getting to know how often temperature extremes occur, the conditions under which they occur and establishing associated direct and indirect societal impacts. Knowledge about temperature extremes can inform the development of strategies for managing the risk associated with this type of natural event. That temperature extremes do result in disastrous consequences, in terms of lives lost, is manifest via the observed impacts of a range of extreme temperature events over the last few decades (Table 3.8.1). Noteworthy is that all top ten disasters are related to extreme high as opposed to low temperatures. Table 3.8.1: Top 10 extreme temperature disasters and associated death toll by country and date. (Source: <http://www.emdat.be/> - Accessed September 22, 2016)1

|  |  |  |  |
| --- | --- | --- | --- |
| Country | Disaster Type | Date | Total Deaths |
| Russian Federation | Extreme high temperature | 00-06-2010 | 55736 |
| Italy | Extreme high temperature | 16/07/2003 | 20089 |
| France | Extreme high temperature | 01/08/2003 | 19490 |
| Spain | Extreme high temperature | 01/08/2003 | 15090 |
| Germany | Extreme high temperature | 00-08-2003 | 9355 |
| France | Extreme high temperature | 29/06/2015 | 3275 |
| Portugal | Extreme high temperature | 00-08-2003 | 2696 |
| India | Extreme high temperature | 26/05/1998 | 2541 |
| India | Extreme high temperature | 20/05/2015 | 2248 |
| France | Extreme high temperature | 15/07/2006 | 1388 |

1The EM-DAT International Disasters Database is widely referred to by the disaster risk community for establishing nature and frequency of a range of past and present disasters (Ono and Naigaishi, 2015).

3.8.2 What are Temperature Extremes?

**There are a range of temperature extreme metrics. Statistical measures including probabilities, return periods and percentiles can be used to describe their occurrence. Knowledge gaps exist concerning extreme urban temperatures.**

Temperature extremes can occur over a range of temporal (e.g. daily, monthly, seasonal, annual, decadal) and geographical scales (e.g. local to regional to global). They are usually defined in terms of their position in a distribution of observed temperature values or as a threshold value recorded at a meteorological or climate station.

If defined in terms of a distribution of values, extremes are expressed as probabilities, such as 5 percent probability of occurrence. Probabilities can also be expressed in another way as a return period such as 1 in 20 years (5 percent probability). Occasionally the term return period is misinterpreted to mean an event of a particular magnitude, for example a daily temperature of -10oC or 40oC with a return period of 1 in 20 years, once having occurred will only occur again after 20 years has passed. This is incorrect as return periods are just another way of expressing probabilities such that at any one time the occurrence of a particular temperature will have associated with it a specific probability. Given this it is entirely possible to have two 1 in 20 year events in successive years or indeed in the same year.

A threshold value will be a specific high or low temperature value, above or below which there is a discernible impact. These can be described in terms of percentiles, for example the 5th or 95th percentile meaning that for all the temperature observations recorded for a location the highest or lowest set of temperatures are considered to fall within the lowest or highest 5 percent of values. Percentiles are a relative measure of extreme values as the value associated with a particular percentile will vary from location to location. For example the 95th percentile value for a location in southern Europe may be 35oC while for a northern European location it may be 28oC.

Probabilities, return periods and percentiles are just a few of a wide range of possible measures of temperatures extremes. For example Table 3.8.2 lists a set of measures of temperature extremes considered relevant to a range of sectors of the economy and society (Donat et al., 2013). Amongst these are some which refer to the duration of high or low temperatures over several days. These are often referred to as heat waves or cold waves. Although these terms are applied extensively in a range of fora, there is no standard definition of what a heat wave or cold wave is, despite a number of attempts to develop “universal” heat wave and cold wave definitions (Allen and Sheridan, 2016; Lhotka and Kysely, 2015; Perkins and Alexander, 2013; Robinson, 2001; Tong et al., 2010).

Building a picture of the nature of temperature extremes for a particular location or region is dependent on measurements from daily weather and climate observing stations. Accordingly a number of daily temperature data sets that can be used for risk analysis have been constructed based on available station data (Klok and Tank, 2009; Menne et al., 2012). In addition to observational data, that assembled via data rescue and reconstruction projects, as well as the analysis of diaries and other historical documents, are being increasingly used to develop extreme temperature climatologies (McGregor, 2015). Considerable effort has also gone into constructing gridded temperature data sets with a variety of spatial and temporal resolutions (Donat et al., 2013). In the case of data-sparse regions stochastic weather generators have also been applied to the analysis of temperature extremes (Rahmani et al., 2016; Steinscheider and Brown, 2013; Wilks, 2012). A range of re-analysis products such the 20th century (100-year) reanalysis produced by the ECMWF (ERA-20C - <http://www.ecmwf.int/en/research/climate-reanalysis/era-20c>) also offer considerable potential of extreme temperature analyses. Because weather and climate stations were originally located to be representative of atmospheric processes over large regions there are very few long term urban weather stations. This has constrained the development of a full understanding of the complexities of urban temperature fields and associated extremes (Chen et al., 2012). Accordingly attention is now being turned to the development of urban climate networks and information systems (Chapman et al., 2015; Choi et al., 2013; Honjo et al., 2015; Hu et al., 2016; Muller et al., 2013a, 2013b). Further, satellite based high spatial resolution surface temperature observations are also being applied in the analysis of urban surface temperature fields (Azevedo et al., 2016; Hu et al., 2015; Jin, 2012) as well as the output from urban climate numerical models (Best and Grimmond, 2015; Loridan and Grimmond, 2012).

Table 3.8.2: List of the temperature indices recommended by the ETCCDI (Expert Team on Climate Change Detection and Indices) and calculated based on GHCN (Global Historical Climatology Network)-Daily station data. Percentile values used as threshold for some of the indices are calculated for the base period 1961–90. See http://cccma.seos.uvic.ca/ETCCDI/list\_27\_indices.html. (Adopted from: Donat et al., 2013)

|  |  |  |  |
| --- | --- | --- | --- |
| Identifier | Indicator Name | Indicator Definiton | Units |
| TXx | Hottest day | Monthly maximum value of daily max temperature | oC |
| TNx | Warmest night | Monthly maximum value of daily min temperature | oC |
| TXn | Coldest day | Monthly minimum value of daily max temperature | oC |
| TNn | Coldest night | Monthly minimum value of daily min temperature | oC |
| TN10p | Cool nights | Percentage of time when daily min temperature<10th percentile | % |
| TX10p | Cool days | Percentage of time when daily max temperature<10th percentile | % |
| TN90p | Warm nights | Percentage of time when daily min temperature>90th percentile | % |
| TX90p | Warm days | Percentage of time when daily max temperature>90th percentile | % |
| DTR | Diurnal temperature range | Monthly mean difference between daily max and min temperature | oC |
| GSL | Growing season length | Annual (1st Jan to 31st Dec in NH, 1st July to 30th June in SH) count between first span of at least 6 days with TG>5 oC and first span after July 1 (January 1 in SH) of 6 days with TG<5 oC (where TG is daily mean temperature) | days |
| ID | Ice days | Annual count when daily maximum temperature <0 oC | days |
| FD | Frost days | Annual count when daily minimum temperature <0 oC | days |
| SU | Summer days | Annual count when daily max temperature >25 oC | days |
| TR | Tropical nights | Annual count when daily min temperature >20 oC | days |
| WSDI | Warm spell duration index | Annual count when at least six consecutive days of max temperature >90th percentile | days |
| CSDI | Cold spell duration index | Annual count when at least six consecutive days of min temperature <10th percentile | days |

**3.8.3 Climatic Variability and Change and Temperature Extremes**

**Unusual atmospheric circulation patterns, often related to major modes of climatic variability, spawn extreme temperature events. There is mounting evidence that human related climate change is affecting extreme temperature occurrence.**

Climatic variability refers to variations in climate conditions from time period to time period (e.g. intra-seasonal, inter-annual climate, inter-decadal). In general climatic variability is connected with variations in the state of the atmospheric and ocean circulation and land surface properties (e.g. soil moisture) at the intra-seasonal to inter-decadal time scales. Climate change in contrast refers to a systematic change in the statistical properties of climate (e.g. mean and standard deviation etc.) over a prolonged period (e.g. several centuries) as manifest by an upward or downward trend in, for example, extreme temperature values. For the majority of the earth’s climate history systematic changes of climate have occurred because of natural causes such as variations in the nature of the earth’s orbit around the sun or solar output. However, there is now mounting evidence that humans are an important climate agent.

Weather experienced at the surface of the earth is very much influenced by the atmospheric circulation and the pattern of air and moisture flow above a location or region. Many extreme temperature events can therefore be explained in terms of unusual patterns of atmospheric circulation, such as ‘blocking’, the term given to a situation when a high pressure system becomes ‘stuck’ and does not move for several days. Blocking results in the flow of either very warm or cold air over a region or cloudless skies that enhance heat gain or heat loss from the earth’s surface. For example Della-Marta et al., (2007) have shown that heatwaves over Europe are related to persistent and large-scale high pressure systems..

Alterations to the usual pattern of atmospheric circulation and thus the occurrence of blocking and associated extreme temperature events can often be traced back to interactions between the ocean and atmosphere or modes of climatic variability, such as the El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) (Donat et al., 2014; Hoy et al., 2013; Scaife et al., 2008). For example there is evidence that extreme maximum temperatures can be significantly influenced by ENSO for a range of regions across the world (Arblaster and Alexander, 2012; Kenyon and Hegerl, 2008; Parker et al., 2014) as well as Madden Julian Oscillation related anomalies in tropical convection (Cassou et al., 2005; Matsueda and Takaya, 2015). Similarly the NAO has been found to influence the occurrence of both high and low temperature extremes across Europe (Burgess et al., 2015; Hoy et al., 2013; Kenyon and Hegerl, 2008; Moore and Renfrew, 2012; Scaiffe et al., 2008). Changes in the position of the Inter-Tropic Convergence Zone (ITCZ) also seem to alter the possibility of temperature extremes in France and Egypt (Boe et al., 2010).

The Intergovernmental Panel on Climate Change has concluded that there is unequivocal evidence that humans, through a range of activities and an intensification of the Greenhouse Effect, are having an impact on the climate of the earth (IPCC, 2013). This is most evident through an increase of the global mean temperature of about 0.8°C since 1880 with two-thirds of that increase occurring since 1975, at a rate of roughly 0.15-0.20°C per decade (NASA, 2016). Understandably this observed increase and that projected for the next several decades holds implications for the occurrence of high and low temperature extremes (IPRusso et al., 2014; Seneviratne et al., 2012). That changing global temperatures appear to be already manifesting themselves in an altered occurrence of temperature extremes and heat and cold waves is evident at a range of geographical scales (Fischer, 2014; Schar, 2016;). Further there is emerging evidence that a number of recent extreme temperature events are in part attributable to human related changes in global temperatures (Easterling et al., 2016Kim et al., 2015; Mitchell et al., 2016).

**3.8.4 Health Impacts of Temperature Extremes**

**The health impacts of temperature extremes, which can be direct or indirect, are moderated by a range of social determinants, which can be broadly referred to as vulnerability and resilience,**

Both high and low temperatures, indoors and outdoors, pose substantial risks to human health, including increases in mortality, morbidity and health service use (Ryti et al., 2016; WMO, 2015). In many countries, the health impacts of cold temperatures substantially outweigh those of heat (Gaspirini et al., 2015).

The scale and nature of the health impacts observed depends on the timing, intensity and duration of the temperature event, the level of acclimatisation and adaptation of the local population, infrastructure and institutions to the prevailing climate, as well as the definitions and methodologies used for scientific research. As such, health effects of temperature extremes and determinants of vulnerability are, to some extent, context specific.

Population health impacts start to be observed at winter and summer temperatures that are considered moderate for the season and then increase as temperatures become more extreme, variously described as a U, V or J shaped curve. The precise threshold temperatures for health impacts vary by region and country, as do the scale of the health impacts by degree change in temperature, but the overall pattern remains similar wherever it has been studied.

For both heat and cold, the impact of the temperature is more marked for deaths than for hospitalisations (Hjat et al., 2016; Linares and Diaz, 2008); this may suggest that individuals die before they reach health care. Temperature extremes may also result in illness that is not severe enough to require hospital attention, but has not been captured by these studies.

For heat, deaths and hospitalisations occur extremely rapidly (same day), may be followed by a degree of impact displacement (health impacts in the frail brought forward) and return to normal within a matter of days (Basu, 2009). The onset of health impacts for cold are slower, persist for longer (up to 4 weeks) with short-term displacement effects not apparent (Analitis et al., 2008).

Longer heat events are associated with greater health effects because of the longer period of exposure (D’Ippoliti et al., 2010), but this has not been consistently observed for cold (Ryti et al., 2016).

Severe heat events that occur towards the beginning of a season have greater health impacts; likely to be partly due to loss of the most vulnerable members of the population during the first episode and partly due to population adaptation for subsequent events (Baccini et al., 2008). This pattern is less clear for severe cold, with some authors indicating that cold weather events towards the end of the season are associated with greater mortality (Montero et al. 2010a).

There is evidence that there has been a reduction in health effects from heat extremes over recent years in some countries, which suggests that there has been some individual and institutional adaptation (Arbuthnott et al., 2016). This is less well-established for cold risks.

**Health impacts**

Health impacts may be direct (caused by the direct effect of the hazard) or indirect (caused by the consequences of the hazard such as changes in behaviour or impact on services) (Table 3.8.3).

**a) Direct impacts**

As the ambient temperature changes, the human body’s physiology adapts in order to maintain a stable body temperature. This includes changes to the circulatory, respiratory, and nervous systems to allow cooling or to protect vital organs (Ryti et al., 2016; WMO, 2015).

Direct health impacts occur when a stable body temperature cannot be maintained (for example where temperatures are too extreme), where clothing or shelter is not suitable, where physiological responses are impaired (for example through disease, normal aging or when using some medications), or where other demands are also placed on the body, such as during strenuous activity or drug/alcohol use). This produces classical temperature-related disease, such as hypothermia and heat stroke, both of which may have a rapid onset, may not be quickly identified, and may be fatal.

However, classical hypothermia and heatstroke are not the major cause of health impacts from temperature extremes; most temperature-related deaths and illness are from chronic diseases such as heart and lung disease (Bunker et al., 2016), which form an important proportion of the background disease burden in European populations. This is because an already impaired physiological system is less able to adapt to the ambient temperature, and the physiological changes needed to regulate temperature may worsen pre-existing disease.

**b) Indirect impacts**

Temperature extremes also have indirect impacts on health for example through impacts on services or changes in individual behaviour as a result of the temperature.

Impact on health services may be mediated through increasing demand for care, direct and indirect impacts on staff affecting their ability to work, or ambulance response times (Thornes et al., 2014). Temperatures extremes may have impacts on wider infrastructure which is essential for health such as power, water and transport (Anderson, ???).

Behavioural changes may have inadvertent negative health consequences, replacing one risk with another, which is an important explanation for the increase in injuries associated with hot and cold weather (Bulajic-Kopjar, 2000; Otte et al., 2016).

Determinants of vulnerability

The major determinants of vulnerability of a population to temperature extremes relate to the features of the population exposed, and their capacity to respond and adapt to the temperature conditions over long and short-time frames. Determinants of vulnerability can be broadly categorised by demographic, health, physical, socioeconomic, and institutional factors (Table 3.8.4), many of which are inter-related and dynamic.

Temperature extremes rarely occur in isolation and related hazards such as snow/ice, drought/wildfires, poor air quality or other unrelated disasters may coincide in time and geography. Responses to these additional hazards may alter existing vulnerabilities and the capacity to adapt to temperature extremes.

**a) Demographic**

The physiology of older people and the very young renders them more vulnerable to temperature extremes. They may also be less able to adapt their behaviours or environmental conditions and may be more dependent on others (Collins, 1986; Hansen eta la., 2011).

New migrants or tourists may not understand warnings or how to seek help. Some studies have suggested increased risk by gender (female) and race (black and minority ethnic groups) but this may be explained by alternative factors such as age, income, education, underlying disease and access to health care.

**b) Health status**

Many physical and mental health conditions increase vulnerability to adverse temperatures by a direct effect on the body’s physiology or through the effect of certain medications (Hajat et al., 2007). People with poor health or disability may be less aware of warnings, less able to adapt their behaviours or environmental conditions, and may be more dependent on others.

**c) Physical**

People spend approximately 80% of their time indoors, with the elderly or unwell spending longer periods indoors. Buildings (including homes, hospitals, schools and prisons) are not always adapted for temperature extremes and may have insufficient heating/energy efficiency or cooling measures (Conlon et al., 2011; Hansen et al., 2011).

People who have inadequate shelter (eg displaced or homeless populations) may be particularly exposed to temperature extremes, and often have associated vulnerabilities such as poor health or economic circumstances.

**d) Socioeconomic**

People who are socially isolated are more at risk from temperature extremes because they are less able to access community support, and may also have additional health or other vulnerabilities (Bouchama et al., 2007; Tod et al., 2012) .

Low income groups may be less able to adapt to their behaviours or environment. Certain occupational groups, such as labourers, may not always be afforded adequate protection from temperature extremes (eg undertaking strenuous physical work during very hot periods) (Hanna et al., 2011).

**e) Behavioural/cultural**

When temperatures become more extreme, most people take some action to adapt to the conditions. However some factors limit the ability to adapt such as age, poor health or economic circumstances, and certain belief or value systems may also mean that appropriate action is not taken in response to the temperature conditions (Hansen et al., 2011; Todd et al., 2012).

Certain behaviours, intended as protective, may inadvertently increase health risks, (for instance swimming in unsupervised open waters (Fralick et al., 2013), shovelling snow (Franklin et al., 1996), or using unsafe heating appliances (Ghosh et al., 2015).

**f) Institutional**

Health services need robust plans in order to manage the potential disruption and increased demand during and following temperature extremes; their ability to respond influences population vulnerability. This also applies to supporting infrastructure such as power, water, communication and transport systems. Mass gatherings can place additional strains on services, especially if they coincide with temperature extremes (Soomaroo and Murray, 2012).

Employers should take action to ensure that employees are able to take necessary protective actions, such as increasing fluid intake, having access to adequate rest and shade and restricting strenuous activity to cooler parts of the day.

Many countries have formal plans and policies which promote actions to reduce the risk of temperature extremes, such as the Heatwave and Cold Weather Plans for England (see Section 3.8.6.2).

**Table 3.8.3 Direct and Indirect Health Impacts of Temperature Extremes**

|  |  |  |
| --- | --- | --- |
| **Health Impacts** | **Heat** | **Cold** |
| **Direct** | Increased risk of classical heat illness:   * Dehydration * Heat cramps * Heat exhaustion * Heatstroke   Increased risk of death from:   * Respiratory disease * Cardiovascular disease * Other chronic disease eg mental health and renal disease   Increased risk of hospitalisation particularly from:   * Respiratory disease * Diabetes mellitus * Renal disease * Stroke * Mental health conditions   Increased risk of poor outcomes from pregnancy outcomes | Increased risk of classical cold illness:   * Hypothermia * frostbite   Increased risk of death from:   * Cardiovascular disease * Respiratory disease * Other chronic disease eg stroke and dementia   Increased risk of hospitalisation particularly from:   * Respiratory disease * Cardiovascular disease * Stroke   Increased risk of poor outcomes from pregnancy |
| **Indirect** | Impact on health services including:   * increased ambulance call-outs and slower response times * increased numbers of emergency department attendances * increased number of hospital admissions * storage of medicines   Increased risk of accidents:   * drowning * work-related accidents * injuries and poisonings   Increased risk of:   * outbreaks of gastrointestinal disease * marine algal blooms   Potential disruption to infrastructure:   * power * water * transport * productivity | * Impact on health services including: * increased ambulance call-outs and slower response times * increased numbers of emergency department attendances * increased number of hospital admissions   Increased risk of accidents:   * injuries from falls * traffic accidents * carbon monoxide poisonings   Increased risk of:   * outbreaks of gastronintestinal disease * social isolation   Potential disruption to infrastructure:   * power * water * transport |

**Table 3.8.4 Determinants of vulnerability to Temperature Extremes**

|  |  |  |
| --- | --- | --- |
|  | **Heat** | **Cold** |
| **Demographic** | * Older (age 65 and over) * Younger (less than 5 particularly) * Immigrants (from cooler climates, language barriers) | * Older (age 65 and over) * Younger (less than 5 particularly) * Immigrants (from warmer climates, language barriers) |
| **Health status** | * Cardiac disease * Respiratory disease * Cerebrovascular disease * Neurological disease * Diabetes mellitus * Kidney disease * Mental health conditions * Cognitive impairment * Poor mobility/frailty * Certain medications (eg diuretics, antipsychotics) * Drug or alcohol dependency | * Cardiac disease * Respiratory disease * Cerebrovascular disease * Neurological disease * Diabetes mellitus * Mental health conditions * Cognitive impairment * Poor mobility/frailty * Drug or alcohol dependency |
| **Physical** | * Occupants of buildings with insufficient passive or active cooling mechanisms (design/retrofit/maintenance/use) * Urban areas (urban heat island) * Insufficient green infrastructure | * Occupants of buildings with insufficient heating and/or energy efficiency measures (design/retrofit/maintenance/use) * Rural/lower population density areas |
| **Socioeconomic** | * Socially isolated * Low income * Low educational level * Homeless * In an occupation that requires high levels of physical exertion in hot environments | * Socially isolated * Low income * Low educational level * Homeless |
| **Behavioural/cultural** | * Insufficient information on heat protective behaviours * Unable or unwilling to modify behaviour or environment to reduce risks * Not self-identifying as ‘at risk’ * Risk taking when cooling down | * Insufficient information on cold protective behaviours * Unable or unwilling to modify behaviour or environment to reduce risks * Not self-identifying as ‘at risk’ * Risk taking when heating homes |
| **Institutional** | * Insufficient heat warning system * Lack of implementation at community, employer and institutional level * Poor management of mass gatherings during severe heat events | * Insufficient cold warning system * Lack of implementation at community, employer and institutional level |

* + 1. **Other Impacts of Temperature Extremes**

**Non-health impacts of temperature extremes are not particularly well understood which is a concern as in combination they possess the potential to create complex disasters and thus far-reaching societal impacts.**

To date the human health impacts of high and low temperatures have received most attention in both the academic and technical literature related to DRM compared to ‘other’ impacts. In general ‘other’ direct and indirect impacts tend to be less well understood compared to those related to human health. This however does not make them less important as heat or cold related impacts may conspire and lead to complex disasters, for example as may arise from malfunction of energy supply systems that lead to failure of critical infrastructure necessary for maintaining a range of human activity systems and most importantly the emergency services. Table 3.8.5 attempts to summarise other impacts arising from low and high temperature extremes.

Table 3.8.5: Summary of heat and cold impacts by sector other than the health sector

|  |  |  |
| --- | --- | --- |
| **Sector** | **Heat Impacts** | **Cold Impacts** |
| Power outages | Failure of air conditioning  Failure of power dependent critical infrastructure | Failure of heating systems  Failure of power dependent critical infrastructure |
| Water security | Water scarcity if heat event embedded in period of severe drought | Water supply if freezing leads to burst or blocked water mains |
| Impact on transport (rail, road, air) | Rail-track buckling, melting of tarmac  Decreased air density and consumption of more fuel by aircraft | Surface ice on paths, roads, rail and runways.  Vehicle and aircraft icing requiring application of de-icing chemicals |
| Water temperature | Increased risk of algal blooms and fall in water quality and aesthetics  Decreased efficiency of water-cooled machinery (e.g. water cooled power plants leading to shutdown) |  |
| Air quality | Ozone pollution | Nox, SO2 and Particulate matter pollution |
| Impacts on ecosystems | Anoxic waters  Wildfires  UV damage  Increase in activity of some disease vectors  Animal (domestic and wild) health due to hyperthermia  Vegetation health – productivity and dieback due to lack of water | Frost- and ice-kill of vegetation  Hypothermia in animals  Animal and insect food supply deterioration |
| Major sports and cultural events | Players, performers and spectators affected by hyperthermia | Cancellation of events due to snow cover on playing fields no transport access to events  Possible hypothermia effects on players and spectators |
| Impacts on retailing | Increase or decrease in sale of hot-weather sensitive retail items (e.g. clothing and food)  Food quality (perishable items) and storage  Food transport  Efficiency of refrigeration systems | Increase or decrease in sale of cold-weather sensitive retail items (e.g. clothing, food and fuel) |
| Social unrest, crime and violence | Mass gatherings and rioting  Increase in burglary, gun crime, road rage  Domestic violence |  |
| Insurance | Hot weather perils | Cold weather perils |

* + 1. **Managing Temperature Extremes**

**Managing temperature extremes can be approached from a number perspectives including using forecasting technology, the development of early warning systems and heat/cold action plans and urban design and town planning.**

3.8.6.1 Forecasting

Forecasting extreme temperatures on the medium (more than 3 days) to seasonal (up to 6 month) scale is an important tool for civil protection (Mayes, 2012; Ilkka et al., 2012). However, forecasts on this time range are uncertain and therefore multiple scenarios, so called ensembles, are used. Figure 3.8.1 shows such a forecast out to 15 days for the city of Durham (UK). This plot clearly shows that the further ahead a forecast is issued the more uncertain it becomes with a range of possible values as shown in Figure 3.8.1. This poses a challenge for forecasting heat and cold waves beyond the medium time scale.

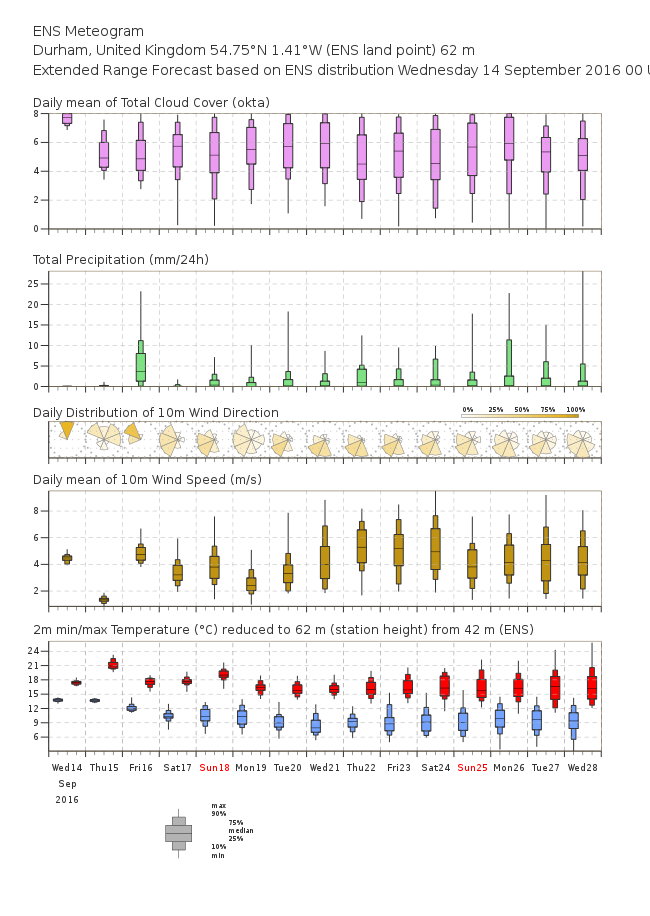


Figure 3.8.1 Ensemble forecast for maximum and minimum temperature in Durham, United Kingdom issued on the 14/09/2016, 00 UTC. The figure illustrates the maximum and minimum daily temperature for each day, shown as a box plot giving a range of possible maximum and minimum temperatures and therefore the uncertainty in the forecast; the further ahead a forecast is issued, the more uncertain it becomes.

Heat and cold wave predictability is also linked to a forecast model’s ability to predict transitions between circulation patterns such as blocking and phases of modes of climatic variability such as ENSO and the NAO as described in Section 3.8.3. Because of their low-frequency nature and their teleconnections, modes of climatic variability can exhibit predictability on the sub-seasonal time scale. A further source of predictability also arises from the effect of soil moisture conditions in the amplification of the temperature anomalies (Quesada et al. 2012). Therefore accurate skill in predicting persistent large-scale high pressure systems is fundamental to forecasting heat and cold waves..

The ideal method to evaluate the skill of the an extended range ensemble in predicting heat and cold waves is to use a selection of objective verification measures for probabilistic forecasts. In reality verification requires a far larger sample than what is available. This is typically the case for any investigation that involves extreme events. Here we show the evaluation of indvidual heat waves, as shown in Figure 3.8.2a, as an example. The 2m temperature composites, based on weekly mean anomalies of ensembles forecasts at 12-18 days, are shown in Figure 3.8.2b. Comparing the forecsts (Figure 3.8.2b) with the observations (F igure 3.8.2a) generally the forecasts identify, with a certain degree of accurracy, the location of warm anomalies although the amplitude is underestimated. Overall the successful predictions reflect a persistent anti-cyclonic circulation already present in the initial conditions. This testifies to the criticality of an extended range forecast model to represent transitions to anti-cyclonic circulation regimes, which is consistent with the cause of so-called medium-range forecast ‘busts’(Rodwell et al.,2013).

Careful calibration and judicious combination of ensembles of forecasts from different models into a larger ensemble can give higher skill than that from any single model. Comparing, verifying and testing multi-model combinations from these forecasts, quantifying their uncertainty as well as the handling of such a massive dataset is however challenging and the subject of the **ECMWF sub-seasonal to seasonal (S2S) prediction project. This is a WWRP/THORPEX-WCRP joint research project established to improve forecast skill and understanding on the S2S time scale, and promote uptake of its forecast products by operational centres and the applications community. Examples of some of S2S’s products can be found at** <http://www.ecmwf.int/en/research/projects/s2s/charts/s2s/>. The Extreme Forecast Index (EFI) is one such product (Figure 3.8.3). This is an integral measure of the difference between the ensemble forecast distribution and the model climate distribution. The EFI takes values from -1 to +1. An EFI of 1 (red) indicates a heat wave, whilst and EFI of -1 (blue) shows a cold spell. Experience suggests that EFI magnitudes of 0.5 - 0.8 (irrespective of sign) can be generally regarded as signifying that "unusual" weather is likely whilst magnitudes above 0.8 usually signify that "very unusual" or extreme weather is likely. Although larger EFI values indicate that an extreme event is more likely, the values do not represent probabilities as such.



Figure 3.8.2a: 2m temperature composites from ERA-Interim weekly mean anomalies for heat wave events: Western Europe (left) , Northern Europe (centre) and Russia (right).

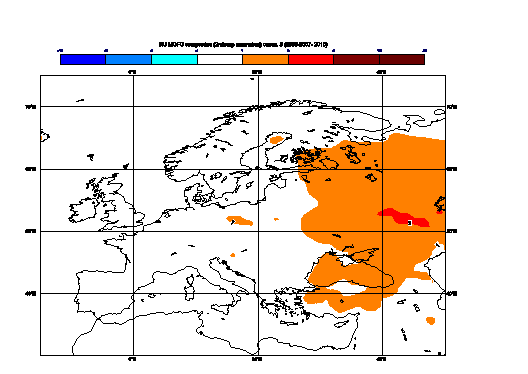
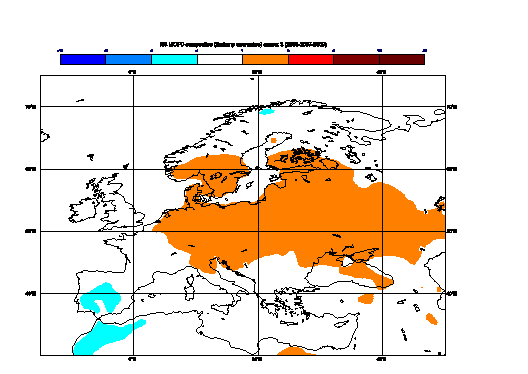
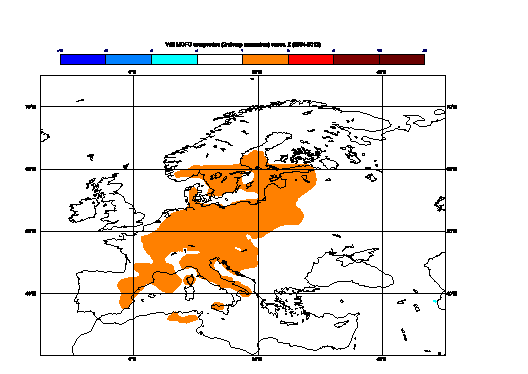


Figure 3.8.2b: 2 m temperature composites from the ensembles forecast at 12-18 days verifying on the same events as in Figure 3.2.8a. Western Europe (left), Northern Europe (centre) and Russia (right)

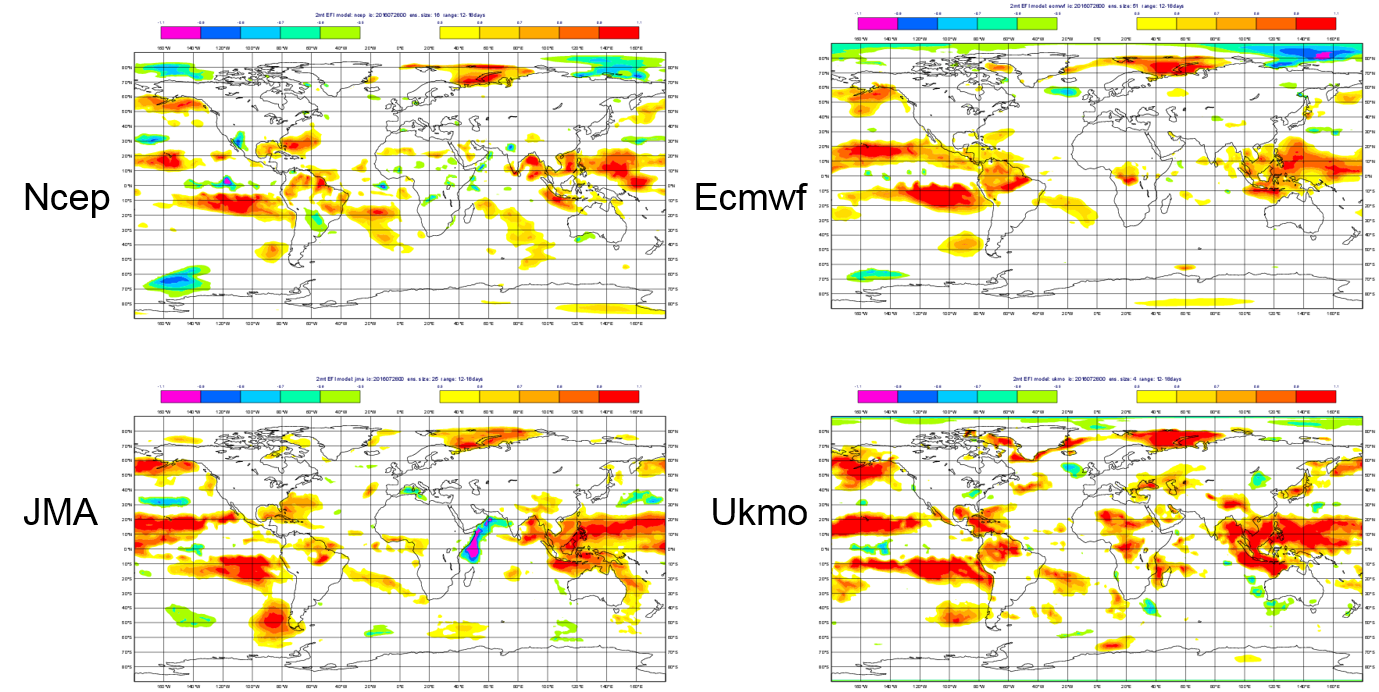


Figure 3.8.3: Extreme Forecast Index (EFI) of 2m temperature with a forecast range:12-18 days verifying the week 8-14 August 2016. Four different forecast systems are shown. Blue areas indicate a cold spell whilst red areas indicate a heat wave (on a weekly average). Ncep is National Centre for Environmental Prediction, Ecmwf is European Centre for Medium Range Weather Forecasting, JMA is Japan Meteorological Agency, Ukmo is United Kingdom Meteorological Office.

3.8.6.2 Early Warning Systems

Early warning systems (EWS) have been developed for a number of extreme climate events and are gaining traction in the area of temperature extremes (Carmona et al., 2016; Kalkstein et al., 2011; Kovats and Ebi, 2006; Lowe et al., 2016; McGregor et al., 2015;). Such warning systems take the output from short to medium range forecasting models (Lowe et al., 2016; McGregor et al., 2006;), such as described above and usually use a threshold temperature or some related index to trigger an alert and/or issue a heat or cold warning (Antics et al., 2013; Nairn et al., 2015; Pascal et al., 2013). More often than not, a weather or climate based early warning system for heat or cold, which is composed of a number of components, is nested within a wider heat or cold action plan (WHO, 2008, 2011; WMO, 2015) (Figure 3.8.4).

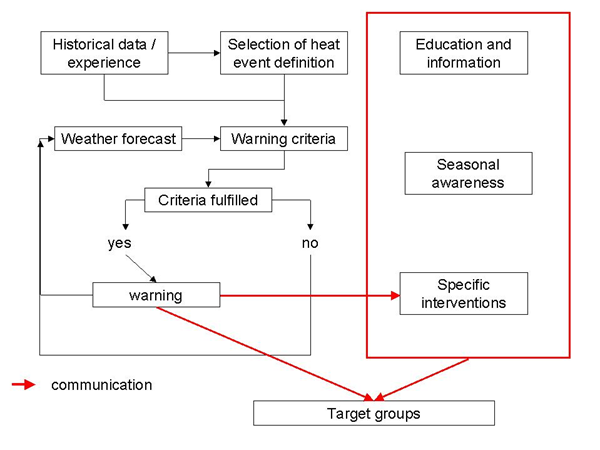


Figure 3.8.4 Generic structure of a heat health warning system (HHWS). The components bounded by red comprise part of a wider heat health action plan (HHAP). This overall structure can also be applied to cold related warning systems (Source: McGregor et al., 2015).

The normative view regarding heat/cold early warning systems is that they should deliver discernible benefits for the management of heat and cold related risk across a range of sectors (Fouillet et al., 2008). Given this heat/cold EWS are increasingly subject to evaluation which can consider EWS processes and/or outcomes, using a variety of criteria. To date such evaluations indicate that heat/cold EWS yield discernible benefits in relation to DRM but, notwithstanding this, there is room for improvement, especially as a successful EWS depends heavily on a well-designed set of risk mitigating and operationalisable intervention strategies being in place (Bassil and Cole, 2010; Chiu et al., 2014; Ebi, 2007; Hajat et al., 2010; Kalkstein et al., 2011; Montero et al., 2010b; Toloo et al., 2013a, 2013b;).

For low temperature extremes a range of EWS and forecast products have been developed. Many of these are focused on forecasting snow storms (Nakai et al., 2012; Wang et al. 2013) and ice storms with an emphasis on critical infrastructure such as roads (Berrocal et al., 2010; Degaetano et al., 2008; Fu et al., 2009; Palin et al., 2016; Riehm and Nordon, 2012 and power lines (Cerruti et al., 2012; Nygard et al., 2015; Roldsgaard et al., 2015).

Although EWS are considered a plausible disaster risk management tool, developers and users of EWS should be aware of some of the generic “dos and don’ts” of such systems as outlined by Glantz (2004).

3.8.6.2 Urban Design and Planning

Cities have received a lot of attention in the DRM literature because this is where large numbers of people are concentrated and therefore potentially at risk to heat and cold related disasters.

In the case of heat, cities represent a distinct problem because of the so called urban heat island (UHI) effect which, during periods of high temperatures, can lead to air temperatures in cities being several degrees above those for surrounding rural areas, especially during the nocturnal hours (Arnfield, 2003). This “extra’ heat has the potential to place a large number of vulnerable people in cities at risk to heat related illness (Wolf and McGregor, 2013; Wolf et al., 2014).

The UHI develops because urban materials are efficient at absorbing and storing heat from the sun during the day and releasing that heat back into the urban atmosphere at night leading to higher nocturnal urban compared to rural temperatures. A further factor is the low evaporation rates in cities; evaporation is an energy consuming and thus cooling process. Significant quantities of so called anthropogenic heat from air conditioning systems and vehicles can add to the energy available for raising urban air temperatures (Allen et al., 2011; Offerle et al., 2005; Smith et al., 2009). For example in London it has been estimated that approximately 80 percent of the anthropogenic heat produced from human activities goes into sensible heating of the atmosphere (Iamarino et al., 2012) with greatest contributions from London’s central activity zone, where the service sector is predominant. Given that large cities, such as London, will grow over the coming decades, anthropogenic heat is likely to become an important heat risk management issue for large cities.

Given the processes that generate the UHI, strategies that focus on managing urban heat, via controlling for building material absorption and storage of energy from the sun, ensuring evaporation is promoted through providing moist surfaces and developing green infrastructure and reducing anthropogenic heat release, can range from the scale of the individual building to the city. While the specific approaches to managing urban heat are potentially wide ranging (Alexander et al., 2016; Eliasson, 2000; Mills et al., 2010; Phelan et al., 2015), the degree of benefit (the intensity of cooling and improvements to human thermal comfort) arising from urban design and city planning related heat mitigation measures (Norton et al., 2015; Sharma et al., 2016; Sun et al. 2016;) depends on considering a multitude of interacting and potentially conflicting factors (Coutts et al., 2013; Hamilton et al., 2014). Aside from the scientific challenges (Chen et al., 2012) the actual mainstreaming of urban climate design and adaptation principles into city planning can sometimes become stalled because of a range of institutional barriers (Lenzholzer and Brown, 2011; Reckien et al., 2014; Ugolini et al., 2015; Uittenbroek et al., 2013; Wolf et al., 2015).

Relatively speaking urban design for low temperature extremes has received less attention in the recent DRM literature, no doubt as a result of a perception that in the near future heat, as opposed to cold, will pose a greater risk management problem. Interestingly a consequence of the urban heat island effect, especially the role of anthropogenic heat, may bring some positive benefits in cities that possess harsh winter climates.

**Key Messages**

Partnerships

Cooperation between regional, national and international research communities and climate monitoring agencies and citizen scientists is required to construct internally consistent extreme temperature data bases and meaningful sector relevant extreme temperature metrics. This is especially the case for urban environments where there is an ever increasing concentration of people who are potentially at risk to temperature extremes as a result of the urban heat island. A systematic approach at the national and local levels and across all sectors, and involving state, private, voluntary and community actors, is required to understand the wider societal impacts of temperature extremes. Partnerships formed between stakeholders in the risk management of temperature extremes should adopt ‘a communities of practice model’ in order to develop integrated heat and cold action plans that transcend, vulnerability assessment, weather forecasting, intervention strategies, urban design and city planning.

Knowledge

An enhanced understanding of the physical origins of temperature extremes as well their changing magnitude and frequency, especially under climate change, is required. Where possible, historic non-instrument based temperature records as captured in diaries and other documents could be used to augment the understanding of the climatology of temperature extremes from the local to regional level. Long-term observational series need to be sustained through commitment of resources to climate monitoring. Research should be undertaken to improve our understanding of the effectiveness and cost-effectiveness of extreme temperature related interventions in a variety of different climatic, socioeconomic and cultural contexts with learning shared widely. Conceptual risk models of complex disasters related to temperature extremes are required so as to scope out agendas for knowledge development.

Innovation

In the absence of observed weather station based temperature data the use of weather generators for the creation of temperature time series for extreme value analysis and alternative temperature observation platforms such as satellites in addition to the output from urban climate numerical models should be considered as input into DRM analyses. The idea of drawing on multiple sources of information from data networks, as encapsulated by the concept of ‘the internet of things’, offers considerable potential for managing disaster risk related to temperature extremes. High resolution intra-urban mapping of population vulnerability to heat and cold integrated with information on building type and air and surface temperature is an innovation that is likely to yield gains for extreme temperature related DRM.

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