Module 6:
Thermal extremes
Key messages in Module 6

• Extreme thermal events cause excess morbidity & mortality
  – All adverse health outcomes are preventable
  – Worker productivity likely to be adversely affected

• Climate change is projected to increase health risks with more, more severe, & longer heatwaves
  – Larger & older populations could increase the risk for additional adverse health impacts

• Adaptation can reduce current & future risks in morbidity & mortality due to temp extremes

This slide notes some of the key concepts that we’ll cover in Module 6
This module’s goal is to help participants start to think about:

- What defines an extreme thermal event;
- Who is at greatest risk during these events;
- How should the health impact of these events be measured;
- How climate change could affect the future risk of these events.

These elements will build to a consideration of how adaptation measures, particularly early warning and response programs for extreme thermal events, could help reduce future adverse health outcomes.
Understanding thermal extremes
A critical element when evaluating thermal extremes is to remember the differences between short term weather anomalies vs. longer term changes in seasonal conditions. Thermal extremes, including extremely cold and heat, are by definition relatively rare. What is extreme in one location is not necessarily extreme elsewhere, hence the need for local definitions of what constitutes an extreme event.

CLICK to show ‘Excess health outcomes’. Excess health outcomes also is a critical concept. Death certificates and visits to health care providers rarely include temperature extremes as an underlying cause, so it is difficult to determine the exact number of adverse health events. Instead, the number of excess health outcomes determines the impact of an event; this is the difference in the number or rate of outcomes during the event, compared with what would have been expected if the event had not occurred. Not all observed health outcomes during an event should be attributed to the weather conditions.

Differences from that baseline during and shortly after the extreme thermal event provide a means to
measure the event’s severity and an opportunity to evaluate who was most vulnerable to the event.
This schematic shows how climate change could increase not only mean temperatures, but also more record hot weather and less record cold weather. This figure assumes the variance remains the same, the only change is a shift in mean temperatures.

However, observations indicate that both the mean and variance of temperature are changing. This means the curve is being flattened and extended further to the right, resulting in even more hot and record hot weather. At the same time, the risk of very cold weather remains.

Source: IPCC 2007
The 2003 heatwave in India

- Temperature climbed as high as 50°C, some 10° degrees higher than normal
- Heat waves claimed more than 1,900 lives across India, 70 in Pakistan & 40 in Bangladesh in three weeks
- Of the 1,900 in India, Andhra Pradesh alone saw over 1,300 deaths
- Women, children & the elderly were among the most who died

Heatwaves cause excess mortality in every country that has analyzed data, including countries not traditionally thought of as places where heatwaves would be a concern. As shown on the slide, a heatwave occurred in India in 2003 that resulted in more than 1,900 excess deaths in India.

Higher temperatures increase the occurrence of heat-related illnesses such as heat exhaustion and heat stroke, and exacerbate existing conditions related to circulatory, respiratory, and nervous-system problems. An increase in heatwaves, particularly in urban areas, could significantly increase deaths. Higher overnight temperatures during heatwaves are a concern for human health, as cooler temperatures at night offer much-needed relief from the heat of the day.

Recent analyses show that human-induced climate change is increasing the frequency, intensity, and duration of heatwaves (IPCC SREX 2012).

Eighteen heatwaves were reported in India between 1980 and 1998. A heatwave in 1988 caused 1,300 deaths (De et al. 2004), while another one in 2003 caused more than 3,000 deaths (Government of Andhra Pradesh 2004). High mortality occurred in rural populations and among the elderly and outdoor workers.

Photo credit: Refugee Study Centre (RSC), http://www.rsc.ox.ac.uk/
Impacts of thermal extremes

The health impacts of thermal extremes are not limited to mortality. There are significant adverse social impacts with reduced worker productivity.

It's too hot to work for cart pullers in New Delhi

Photo: CBS News (2002)  

Photo: BBC News (2000)

These images are from heat events in India. This slide also points out that while there is a tendency to focus on the mortality impact of thermal extremes, these events also have significant impacts on morbidity and can reduce productivity as people limit activities in an attempt to control exposure to the heat.
What thermal extremes are you observing in your country?

Have you noticed any health impacts from thermal extremes?

We’ve looked at an example for India. I’m interested in recent thermal extremes you might have experienced in your own countries, and any impacts you’re seeing.

Please find two people at your table or a nearby table to chat with, and discuss these two questions over the next four minutes. This is a good opportunity to stand and stretch while you talk, if anyone would like to have a standing discussion.

Give time reminder: 3 mins – “You have another minute to finish off your discussion. Make sure you’ve learnt from everyone in the group.”
4 mins – “Ok I’ll ask you to go back to your seats”

Q: Did you learn about thermal extremes that are occurring in other people’s countries? Would anyone like to share what they learnt from someone else?
Gather 3 – 4 quick examples. Thank those who presented.
Here’s another example, this time from China.

These figures show the mean daily excess mortality associated with daily maximum temperature in four Chinese cities: Harbin, Nanjing, Shenzhen, and Chongqing. The increase in mortality with increasing temperature is evident, as is the variability across regions in the temperature thresholds at which mortality begins to increase significantly.

The temperature thresholds for all-cause mortality were 29°C, 35°C, 33°C and 34°C for Harbin, Nanjing, Shenzhen and Chongqing, respectively. After adjusting for potential confounders including air pollution, strong associations between daily maximum temperature and daily mortality from all-cause, cardiovascular, endocrine and metabolic outcomes, and particularly diabetes, were observed in different geographical cities, with increases of 3.2-5.5%, 4.6-7.5% and 12.5-31.9% (with 14.7-29.2% in diabetes), respectively, with each 1°C increment in the daily...
maximum temperature over the threshold. A stronger temperature-associated mortality was detected in females compared to males. Additionally, both the population over 55 years and younger adults aged 30 to 54 years reported significant heat-mortality associations.

India and Bangladesh are among the countries most vulnerable to extreme thermal conditions.

Using population estimates that are consistent with the time period covered by these tables (India 1,050 million and Bangladesh 144 million), these results suggest roughly 273 heat-related deaths per year for India and 43 for Bangladesh.

Critical features of these events include that they do not follow a predictable temporal distribution and that impacts can vary widely by event. While across India there is relatively consistent reporting of extreme heat events each year, the number deaths and location of the events vary widely.

Source: EM-DAT 2008
These graphs illustrate several issues with studying the impacts of thermal extremes:

Hot and cold extreme temperatures increase mortality even in a warm city such as Chiang Mai.

The study found non-linear effects of temperature on all mortality types and age groups, with excess deaths starting to occur on the same or subsequent day of an extreme event. Generally, the hot effects on various cause of mortality and age groups were short-term, while the cold effects lasted longer. There often was a decrease in mortality several days after an event, so-called mortality displacement, that reflects that some of the deaths during the event were in individuals who would have died within a short time period anyway. This displacement needs to be taken into consideration when estimating total excess mortality from an event; the reduction in deaths needs to be included in any analysis.
The relative risk of mortality associated with cold temperatures (19.35° C, 1st %ile of temperature) relative to 24.7° C (25th %ile of temperature) was 1.29 (95% confidence interval (CI): 1.16, 1.44) for lags 0–21. The relative risk of mortality associated with high temperature (31.7° C, 99th %ile of temperature) relative to 28° C (75th %ile of temperature) was 1.11 (95% CI: 1.00, 1.24) for lags 0–21.

How to identify thermal extremes
Identifying extreme thermal conditions

- Evaluating meteorological data against established criteria (e.g. threshold temperatures, comfort indices, historical distributions)
- Analyzing observed health impacts
- Combining meteorological & health impact assessment

There are several approaches for identifying extreme thermal events, as listed on the slide.

The results of using different approaches as well as their relative advantages and drawbacks are presented in the following slides.
Meteorological options to identify extreme thermal conditions

Fixed threshold criteria
Extreme thermal conditions exist when criteria are exceeded at any point in time, for example:

- Extreme heat if temperature is > 40°C
- Extreme cold if temperature is < -10°C
- Temperatures exceed a seasonal distribution value (e.g. 5th or 95th percentile)
- A temperature threshold is associated with increased adverse health outcomes

There are two broad categories of approaches to identifying thermal extremes using observed/forecast meteorological conditions: Fixed threshold criteria and relative threshold criteria.

Fixed threshold criteria use non-varying values for temperature, or combined measures such as humidex or apparent temperature, to define when conditions would be defined as extreme heat or extreme cold. The humidex, heat index, apparent temperature, and other combined variable measures combine temperature, humidity, and other variables to provide a measure of how the temperature feels and/or to quantify the associated physical discomfort and health risk for hot weather. Estimates of the temperature adjusted for wind chill provide a similar example of an index used for extremely cold temperatures.
Meteorological options to identify extreme thermal conditions

Relative threshold criteria
Criteria for extreme thermal conditions vary by location and/or time of season
• Recognize that perceptions of what is exceptionally “hot” & “cold” vary across locations

Relative criteria use threshold measures that vary by location and time of season to identify extreme thermal conditions. In areas with minimal thermal variation, where there is also generally low health risk and minimal health impacts from extreme thermal events, there might be no effective difference in a fixed or relative threshold. In areas where “normal” conditions vary over the course of a season, the use of relative thresholds can result in criteria that also vary considerably within a season.
This hypothetical example shows how the use of fixed and relative thresholds would result in different periods within a summer meeting the criteria for “extremely hot”. Extreme thermal event conditions and impacts are measured against local baselines. In this example, the relative threshold is based on the daily maximum temperature. The threshold value initially increases in the early part of the summer season and then declines from roughly mid-July through the end of September. As a result, a number of days in September would fail to satisfy the established fixed threshold criteria, yet would satisfy the relative threshold criteria for being considered extremely hot.

Source: US EPA 2006
Upper image shows the start of an Indian heat wave in May 2005 when compared with the same area at the same time in 2004.

Note the expanded yellow areas in 2005.

This provides an example of how relative thresholds could be used to identify extreme thermal conditions. This figures compare satellite-based thermal images for part of Southeast Asia from the end of May in 2004 (bottom image) and 2005 (top image). The contrast shows the increased area of yellow throughout Northern and Western India. These regions would be considered “hot” by many, with the heatwave further pushing up temperatures to over 50C in many regions. This heatwave was responsible for over 200 deaths across the region (EM-DAT, 2008).

Source: NASA 2008
India in 2003 had the same temperature signal as the Sahara desert: >50ºC

Source: NASA (2008)

Unlike other extreme weather events, it is difficult to visually convey the conditions during an extreme thermal event on the ground (e.g. heat ripples coming off surfaces, potential warping of train rails). These images attempt to visually convey what an extreme heat event in India during May 2003 looked like using satellite data for land temperatures. The focus is on the comparison of thermal images for part of India, in the box in the top image and the whole bottom image, with the temperatures recorded in the Sahara desert in Africa. During this event in India, temperatures in both areas were similar and were above 50ºC.

This is an example of using a fixed threshold criteria to identify extreme thermal conditions.

Source: NASA 2008
Identifying thermal extremes based on health impacts

- Significant increases in health outcomes can be used to identify thresholds for extreme thermal conditions
- Increases should be evaluated vs. localized norms that account for the time of year
- Evaluate the historical relationship between weather & health outcomes (e.g. daily mortality) to establish criteria for extreme conditions

A more direct approach to identifying extreme thermal conditions is to consider health outcome data along with meteorological data to identify when excess health outcomes are observed. This approach looks for anomalies in health outcome data and then decides if the conditions are extreme. This can be used to identify thresholds for use in early warning systems.

This approach is similar to the relative threshold idea but by considering health outcomes, it provides a focus on identifying conditions that are exceptional in a meteorological sense and that carry increased risk of adverse health risks/impacts.
This example shows how a scatter plot of total daily deaths versus daily maximum temperature could be used to identify a city-specific threshold of summertime temperature that was used to define extreme heat conditions when developing an early warning system.

As you can see, daily mortality starts increasing rapidly at about 35° C. This is an initial value to consider in setting an extreme heat threshold for Shanghai.

Source: L.Kalkstein, personal communication, 2002
Options for identifying extreme thermal conditions: Using observed health outcomes

**Strengths:**
- Certain: if you observe ‘significant’ impacts you know extreme thermal conditions exist

**Weaknesses:**
- Reactive: need to rely on real-time data to identify dangerous conditions
- Requires accurate, comprehensive & timely health outcome reporting systems
- Lagged notification & response: outcomes a result of exposure so dangerous conditions already experienced before warning is provided
- Short term resource commitment to monitoring vs response might be better balanced

What are the strengths and weaknesses of using observed health outcomes to identify extreme thermal conditions?

**Strengths (CLICK to appear)**

Relying solely on observed health outcome data to identify extreme thermal conditions has the advantage of certainty. However, this comes at a price in terms of the sensitivity of results to the accuracy of the data provided and foregoing opportunities to identify extreme thermal conditions in advance.

**Weaknesses (CLICK to appear)**

Considering the relative ease of access to accurate long-range meteorological forecasts (i.e., conditions two to three days out) this is an extremely high price to pay for certainty. At the same time, programs designed to address these events should work to ensure the availability of health outcome data during an event.
because they can be used to help adjust the level and location of resources being committed to managing the event.
Options for identifying extreme thermal conditions: Using combined meteorological & health impact data

Strengths:
• Accurate: any criteria will be based on periods of interest where weather significantly increased health impacts
• Flexible: various assessment methods can be used depending on available data (visual evaluation, regression)
• Proactive: with criteria established, it is possible to evaluate weather forecasts for dangerous conditions

Weaknesses:
• Approach can be difficult to explain
• Outreach & education messaging can be complicated

The recommended approach to identifying extreme thermal events is to consider health outcome data along with meteorological data whenever possible. This approach has the advantage of combining all available and relevant information to identify conditions of interest while having a range of options for actually completing the evaluation.

Strengths (CLICK to appear) – read
Weaknesses (CLICK to appear) – read

Results from these assessments can still be combined with weather forecasts to provide advance warning of conditions that are expected to be dangerous. Depending on the nature of the evaluation, the study results also could be combined with forecasts to predict the severity of the conditions based on past outcomes, to help guide resource allocation decisions for notification and response programs.
Who is vulnerable to thermal extremes?
Factors associated with increased vulnerability

- Extreme age: older & younger individuals
- Poverty
- Lack of technology/adaptability
- Low level of fitness
- Physical or mental impairment
- Social isolation
- Chronic conditions
- Use of specific medications
- Extended direct exposure to ambient heat/cold

This slide provides a summary of characteristics that epidemiological studies, physiological studies, and studies of particular extreme heat events have identified as placing individuals at risk of experiencing adverse health outcomes during extreme thermal conditions, particularly extreme heat. Generally, any combination of factors that either increases exposures to high ambient temperatures or limits either the physical ability to respond to the conditions or the types of responses undertaken, will increase the risk of an adverse health outcome.
Managing the risks of thermal extremes

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Risk management / adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of access to cooling</td>
<td>• Cooling in public facilities</td>
</tr>
<tr>
<td></td>
<td>• Changes in urban infrastructure</td>
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<tr>
<td>Age</td>
<td>• Heatwave early warning systems</td>
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<tr>
<td>Pre-existing health</td>
<td>• Social care networks</td>
</tr>
<tr>
<td>conditions</td>
<td></td>
</tr>
<tr>
<td>Poverty &amp; isolation</td>
<td>• Urban green spaces</td>
</tr>
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</table>

There are a wide range of options for managing the risk of thermal extremes; some are shown on this slide.

This slide can be used to ask participants what their city or country is doing to increase resilience to extreme temperatures, heat and cold.
In considering future health impacts of extreme thermal conditions, it is important to recognize that anticipated trends will increase many of the factors that affect the risk of experiencing adverse health outcomes, as listed on this slide. Larger and older populations, with more individuals at increased vulnerability because of chronic diseases, obesity, and other factors means more morbidity and mortality from extreme thermal events without climate change.
A number of factors will work to reduce the risks of thermal extremes. A major issue with projecting future health outcomes from extreme thermal conditions is that the nature and effectiveness of future adaptation to these events is uncertain. Increases in standards of living, greater implementation of early warning and response systems, and adaptive responses can minimize future risks.

A critical element of the success of these programs is how well any messages and program activities reach the most vulnerable, and how well these are taken up by vulnerable individuals and communities.
Assessing the health risks & impacts of thermal extremes
As discussed earlier, excess health outcomes are the appropriate measure for quantifying the impacts of extreme thermal conditions. A significant drawback in basing estimates of health impacts attributable to the thermal exposure on only those health outcomes coded as being attributable to thermal conditions in ICD-10 codes is that they are generally believed to undercount the relevant health outcomes. Outcomes will be missed when, for example, high ambient temperature exacerbated a heart condition, causing a heart attack. Health care professionals would record the heart attack but are highly unlikely to include the heat as a contributing factor. Using all recorded outcomes and looking for the variation from baseline levels will provide a more comprehensive assessment of the total number of outcomes attributable to the heat.
Air mass based studies approach the task of identifying thermal extremes and quantifying their impacts by first categorizing weather into combinations of characteristics distinguished mostly by heat and humidity levels. Different air mass groups are then evaluated for their relationship with health outcomes, with those having such a relationship being used to identify thermal extremes.

Results of the analyses can then be used in early warning systems based on forecast weather data.
Example reflects extreme thermal conditions that result in excess mortality (A) followed by reduced mortality (B), indicating ‘mortality displacement’

This figure provides a hypothetical representation of what might be seen during and after an extreme thermal event. Note that EHE stands for extreme heat event. Key elements to note are the increase in daily mortality at approximately the start of the event with a peak at some point during the event (area marked in Blue as “A”). The height of the peak and the width of the base will generally be functions of the severity and duration of the event.

Following the return to expected mortality at the end of an event, there is a smaller decrease in mortality below baseline conditions (area in yellow marked as “B”). This decline in mortality is because some of the individuals who died in the event would have died anyway within a few days; the event brought their deaths forward. This effect is described in the epidemiology literature as “mortality displacement” or “harvesting”. The greater the relative size of area “A” to area B, the greater the overall impact of the event.

Note that while thermal extremes are expected to affect morbidity and mortality in a population, research has tended to focus on mortality. In large part this reflects the relative quality and accessibility of mortality data compared with acute health outcome data (e.g., emergency room or hospital visits).
Potential impacts of thermal extremes
These figures show how maximum temperatures could change in summer months (June, July, and August – JJA) over the course of the century under two emission scenarios. The analysis first determined the maximum temperature that occurred once every 20 years during the period 1985-2005. Then for the months June, July, and August for the time periods shown (next few decades, mid-century, and end of century), under a moderate and high emission scenario, the experiments determined how often that temperature could occur. The color bar at the bottom shows the absolute occurrences as the percent of years in each 20-year period. The frequency of occurrence of the 1986–2005 maximum JJA seasonal temperature value is, by definition, 5 % at each grid point during the 20-year 1986–2005 period.

Within the next few decades, many regions in the low and mid-latitudes could experience the 1 in 20 year temperature up to every other year. By mid-century, even under the moderate emissions scenario, the temperature could occur every year. By the end of the century for both scenarios and under a high emissions
scenario by mid-century, that temperature could occur every year.

The panels show the absolute occurrences as the percent of years in each 20-year period. The frequency of occurrence of the 1986–2005 maximum JJA seasonal temperature value is, by definition, 5% at each grid point during the 20-year 1986–2005 period.

Climate change will fundamentally change the nature of summer months.

Source: Diffenbaugh NS, Giorgi F. Climate change hotspots in the CMIP5 global climate model ensemble. Climatic Change 2012. DOI 10.1007/s10584-012-0570-x
These figures show historical and projected changes in heatwaves in India using three emission scenarios; projections are for changes in the frequency, duration, and intensity. Heatwaves are projected to be more intense, have longer durations and occur at a higher frequency and earlier in the year. Projections indicate that a sizable part of India will experience heat stress conditions in the future. Southern India, currently not influenced by heatwaves, is expected to be severely affected by the end of the twenty-first century. In northern India, the average number of days with extreme heat stress condition during pre-monsoon hot season could reach 30. The intensification of heat waves might lead to severe heat stress and increased mortality.

In addition to increasing temperature, climate change also is increasing absolute humidity. As shown previously, the combination of heat and humidity is one approach for determining the impact of extreme temperatures on health. With continued warming, the increase in humidity has been shown to pose increasingly severe limitations on human activity in tropical and mid-latitudes during peak months of heat stress.

This study combined wet bulb globe temperatures from climate historical reanalysis and projections with industrial and military guidelines for an acclimated individual’s capacity to safely perform sustained labor under environmental heat stress (labor capacity); this was defined as a global population-weighted metric fixed at the 2010 distribution. The figure shows population-weighted individual labor capacity (%) during annual minimum (upper lines) and maximum (lower lines) heat stress months. The authors estimate that environmental heat stress has reduced labor capacity to 90% in peak months over the past few decades.
Projections indicate reductions in labor capacity to 80% in peak months in 2050. Under the highest emission scenario considered, projections indicate reductions in labor capacity to less than 40% by 2200, with most tropical and mid-latitudes experiencing extreme climatological heat stress.

The inset graph shows labor capacity by wet bulb globe temperature.

Elements of successful early warning & response systems for thermal stress

- Strong collaboration between health & meteorological services & implementing organizations
- Provide clear advice of actions to take & avoid
- Know who & where the most vulnerable are located
- Help provide relief from the heat

Recognizing the potential for effective programs to minimize the public health impact of extreme thermal conditions, elements of successful programs are summarized in this slide. A growing number of guidance documents are available from WHO European Regional Office (2008), US EPA (2006), US Centers for Disease Control and Prevention, Health Canada, UK Health Protection Agency, and others.

This slide can be used to ask participants if any of these have been used in their city or country and, if so, what the experience has been.
Elements of successful early warning & response systems for thermal stress

- Provide opportunities to request assistance or evaluation
- Be creative in use of available resources
  - Short term assignment changes for some public sector staff
- Review response to events to identify successes & areas for improvement
- Revise program as needs/opportunities change

Recognizing the potential for effective programs to minimize the future public health impact of extreme thermal conditions, elements of successful programs are summarized in this slide. A growing number of guidance documents are available from WHO European Regional Office (2008), US EPA (2006), US Centers for Disease Control and Prevention, Health Canada, UK Health Protection Agency, and others.

This slide can be used to ask participants if any of these have been used in their city or country and, if so, what the experience has been.
This module’s goal was to help you start to think about:

- What defines an extreme thermal event;
- Who is at greatest risk during these events;
- How should the health impact of these events be measured;
- How climate change could affect the future risk of these events.
Learning from Module 6

- Extreme thermal events cause excess morbidity & mortality
  - All adverse health outcomes are preventable
  - Worker productivity likely to be adversely affected
- Climate change is projected to increase health risks with more, more severe, & longer heatwaves
  - Larger & older populations could increase the risk for additional adverse health impacts
- Adaptation can reduce current & future risks in morbidity & mortality due to temp extremes

This slide notes some of the key concepts and highlights some of the lessons that should have been learned through the presentation.
What action will you take in your work, given what you learnt in Module 6?
Coming up next...

Module 7:
Extreme weather events