UW Medicine
DEPARTMENT OF EMERGENCY MEDICINE

Heat-related Morbidity and Mortality

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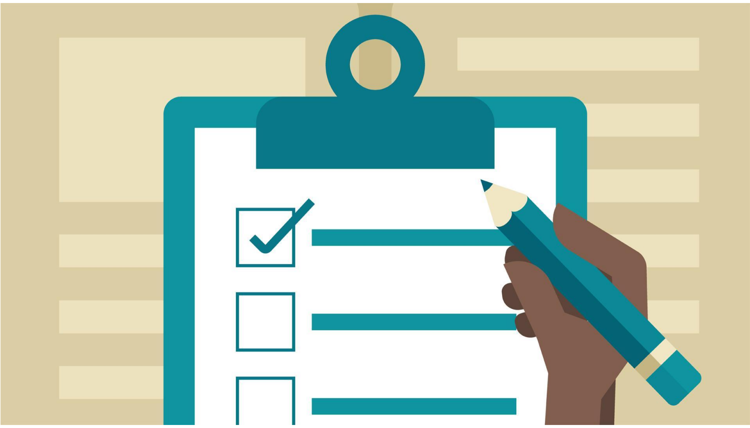
Overview

- > Learning objectives
- > Rationale
- > The health effects of extreme heat
- > Prevention, diagnosis, and treatment
- > Impacts at different scales
- > Questions and discussion

LEARNING OBJECTIVES



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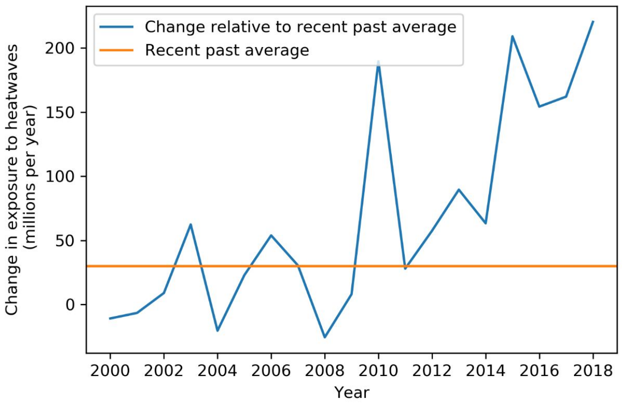
After Today's Session, You Will Be Able To:

- Articulate why extreme heat exposure can endanger people's health;
- Explain how excess heat exposure can overload physiological systems;
- Describe the presentation and management of acute heat illnesses;
- State how an extreme heat event stresses health system operations;
- List groups of people at higher risk from heat exposure;
- Describe strategies for reducing health risks related to heat exposure in the short- and long-term

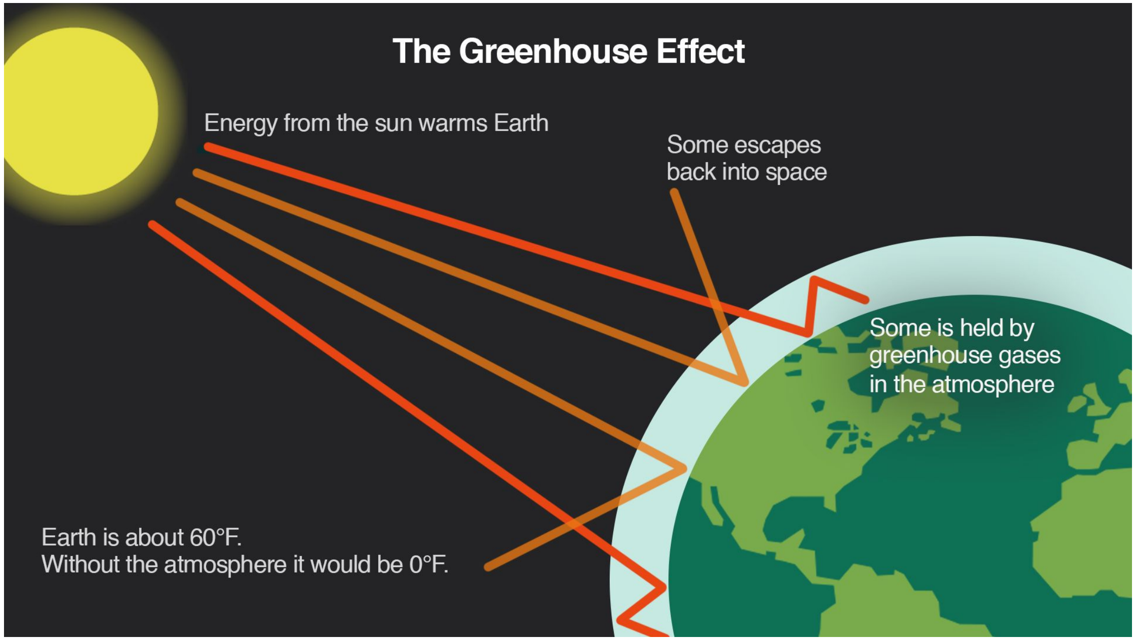
RATIONALE



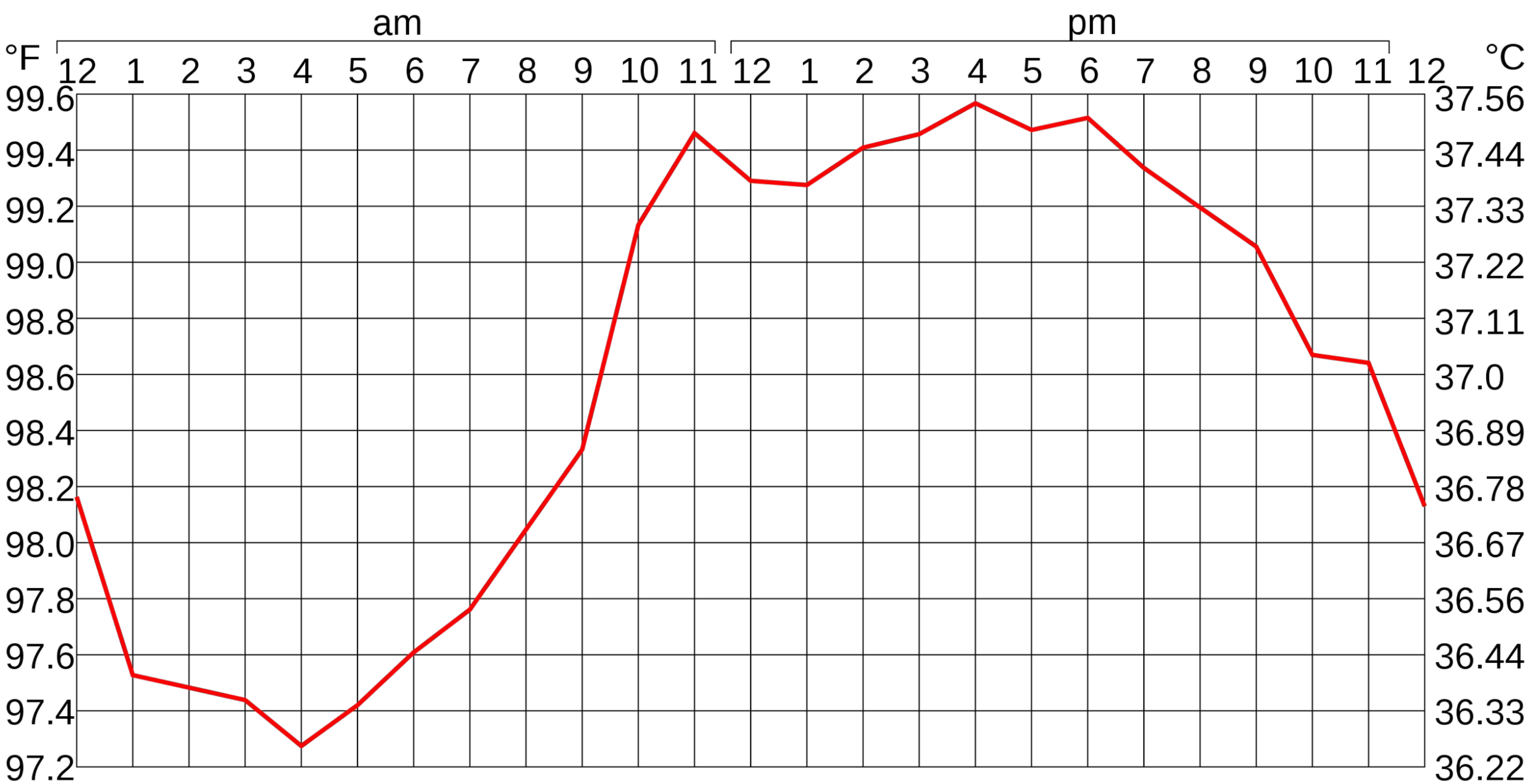
Watts et al. 2019

Heat Is Central to Climate Change

Fundamentally, climate change is driven by increased retention and re-radiation of heat by the Earth's atmosphere

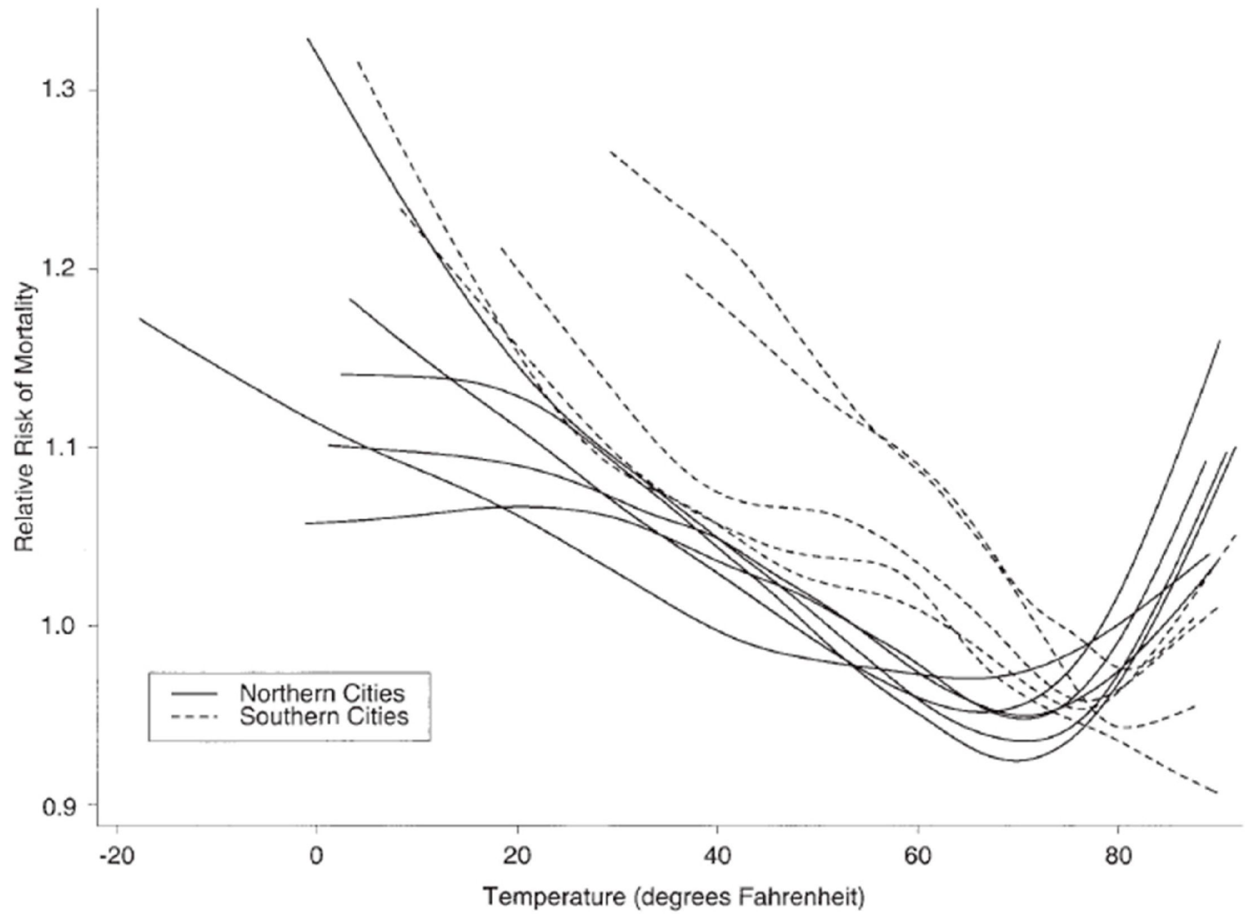


Humans are Euthermic



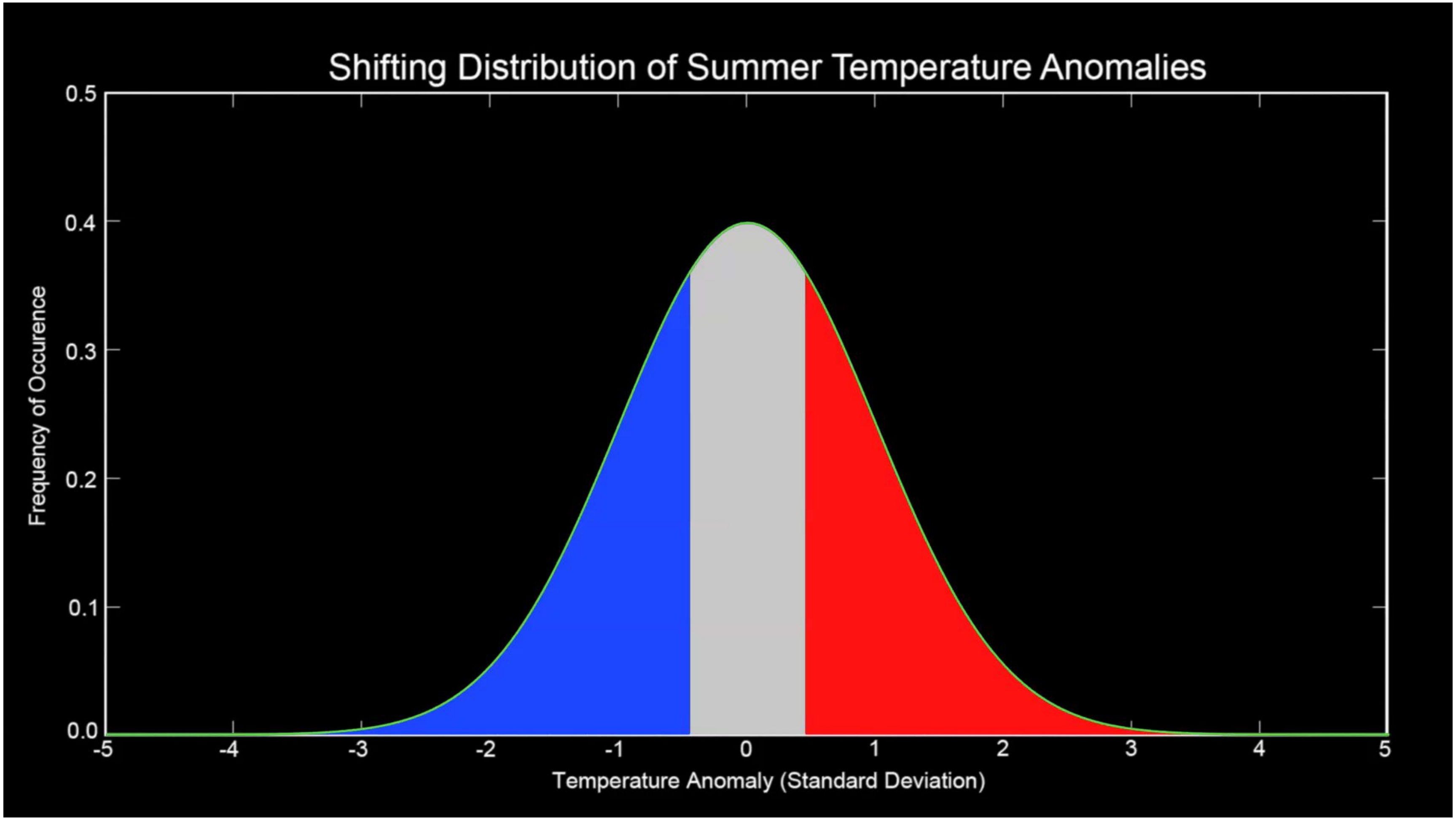
By Crossover1370 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=111100008

We Have a Minimum Mortality Temperature



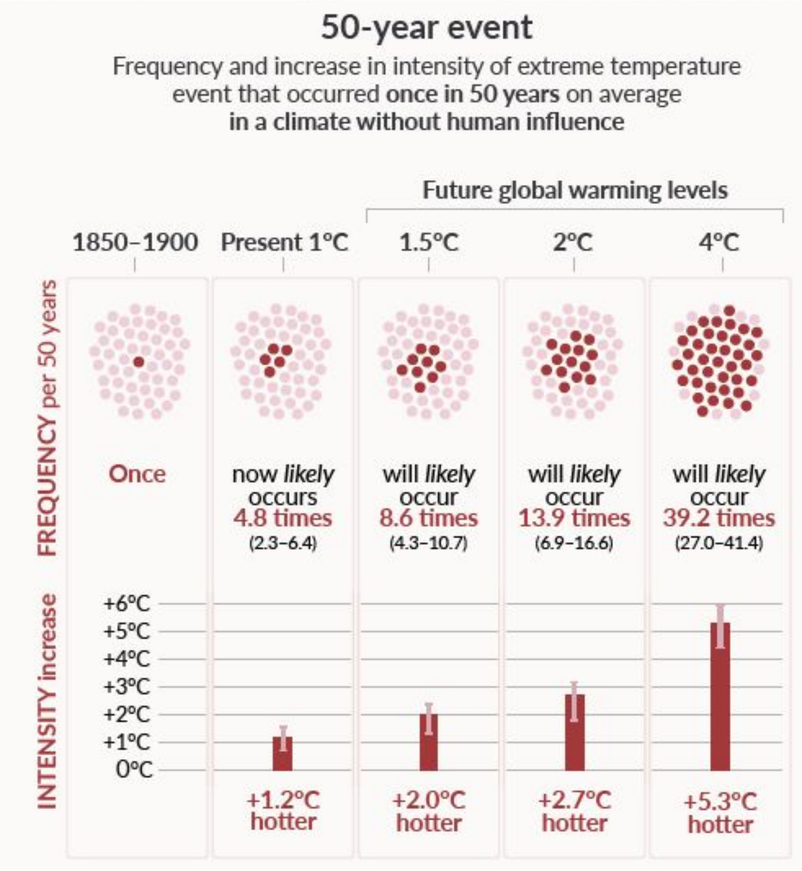
Curriero et al. 2002

Shifting Temperature Distributions



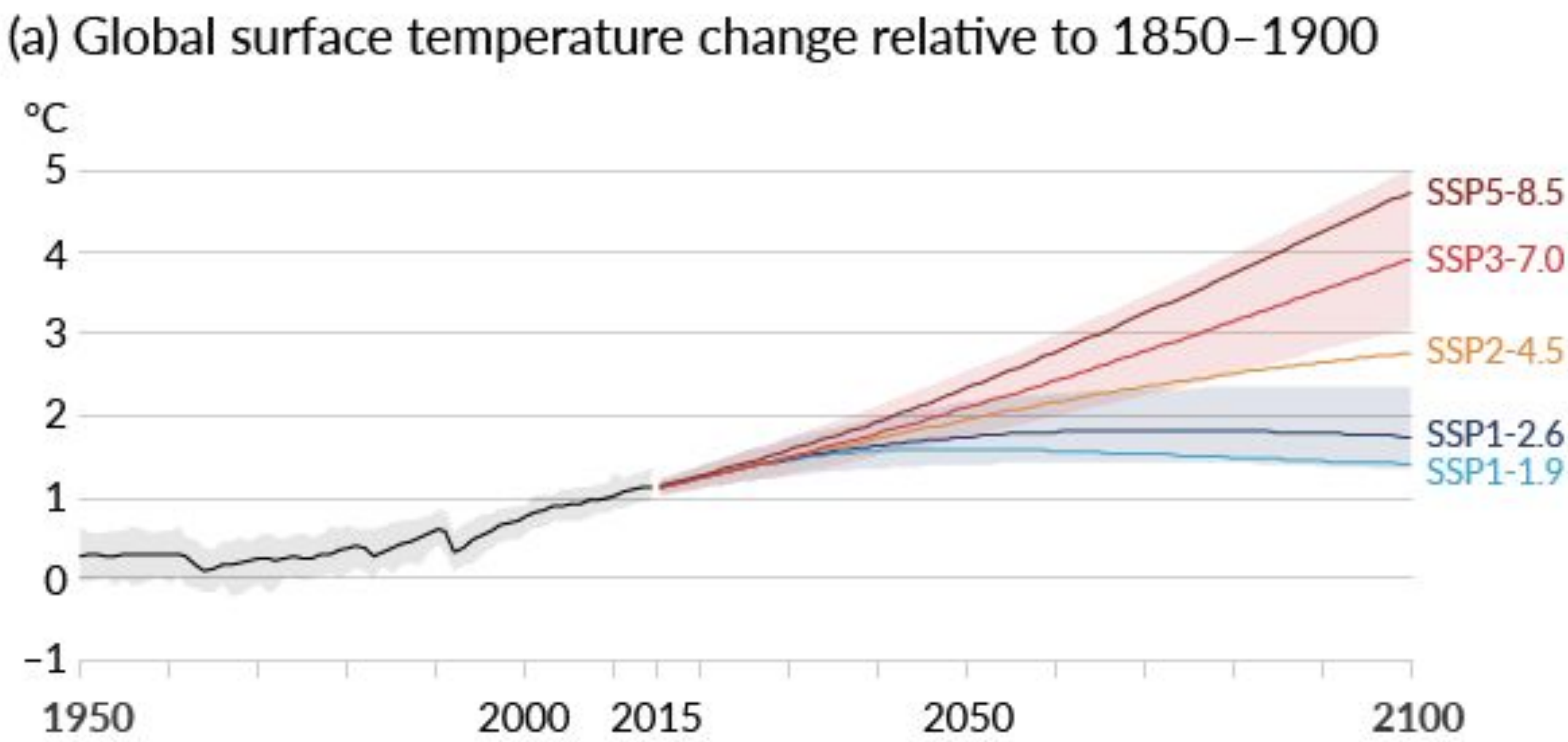
Implications for Extreme Events

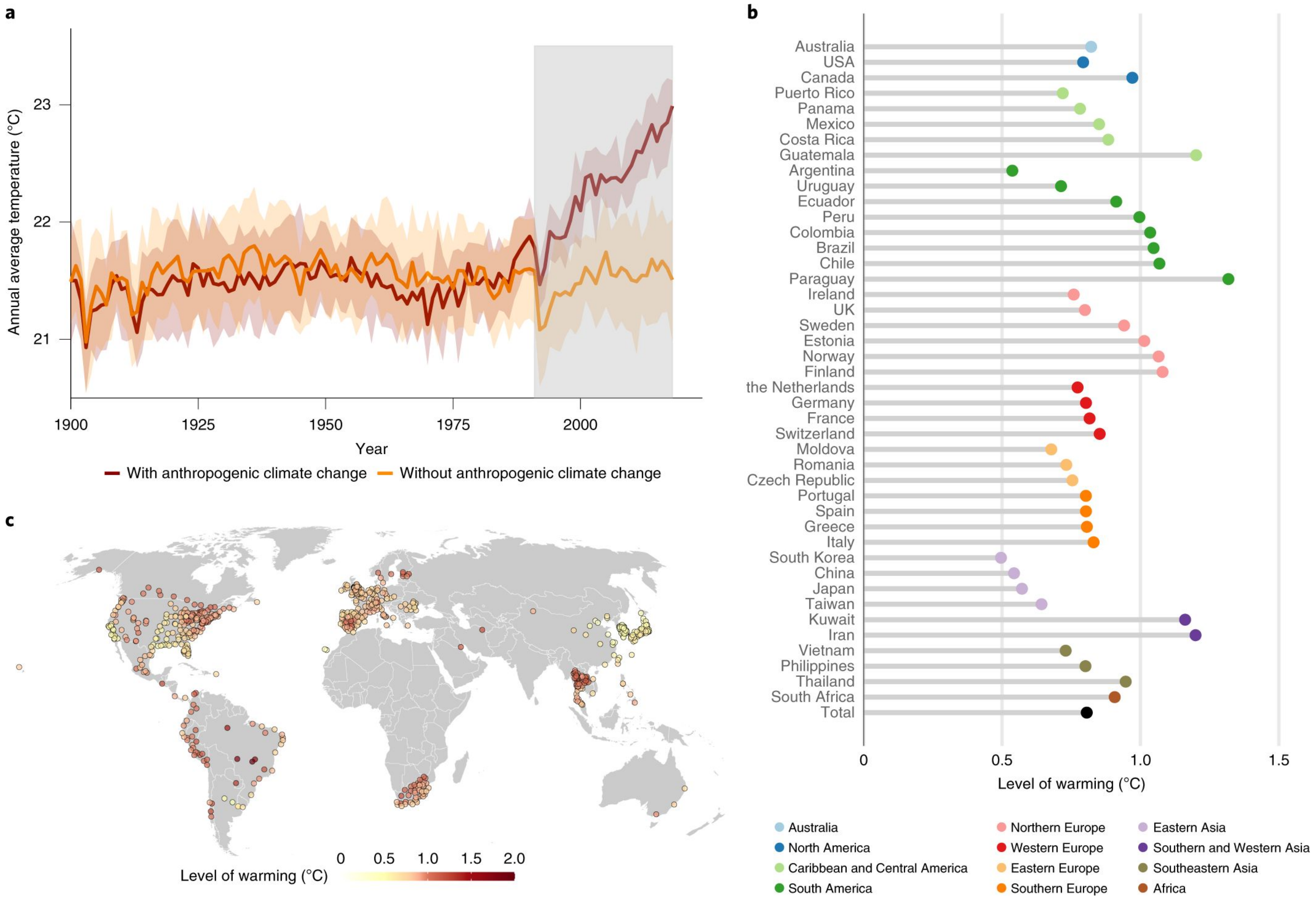
- An extreme heat event with a 10-year return period in the historic climate now occurs 2.8 times as often
- An extreme heat event with a 50y-ear return period now occurs 4.8 times as often



IPCC AR6 WG1 SPM

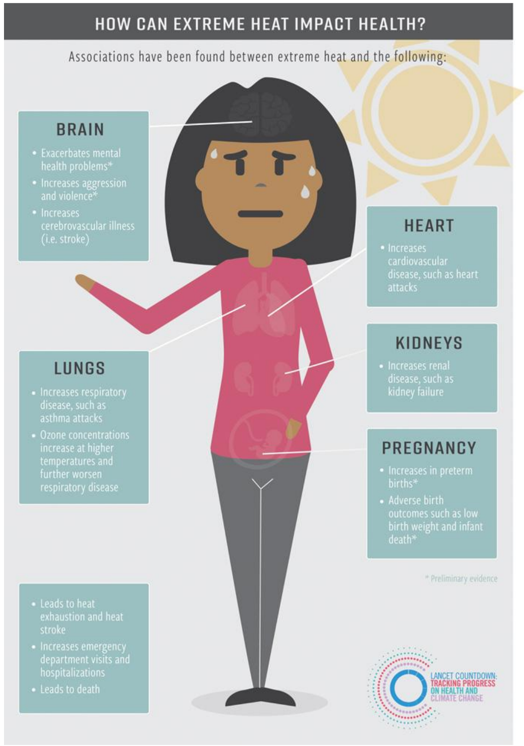
Projected Warming





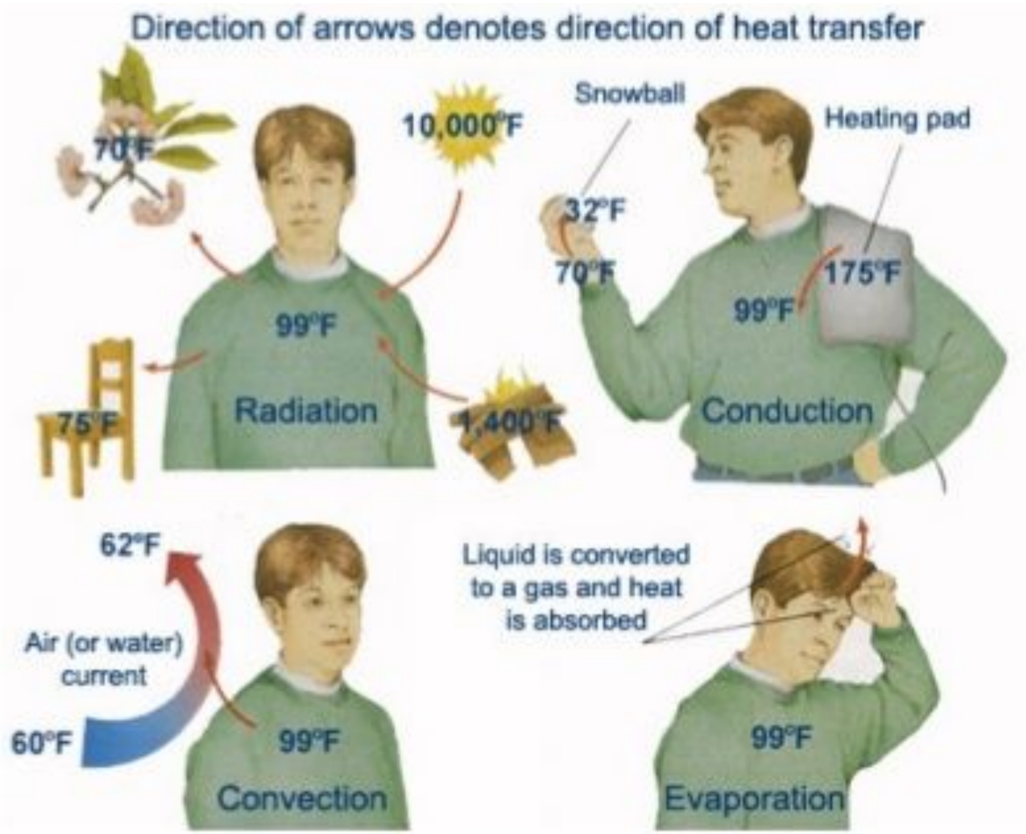
Vicedo-Cabrera et al. 2021

HEALTH EFFECTS OF EXTREME HEAT



Heat Transfer and Heat Balance

- Narrow temperature range
  - Behavioral maintenance
  - Physiological maintenance
- Exogenous heat
  - Solar radiation
  - Environment
- Endogenous heat
  - Baseline metabolic activity
  - Additional physical activity
- Heat Dissipation
  - Radiation
  - Conduction
  - Convection
  - Evaporation



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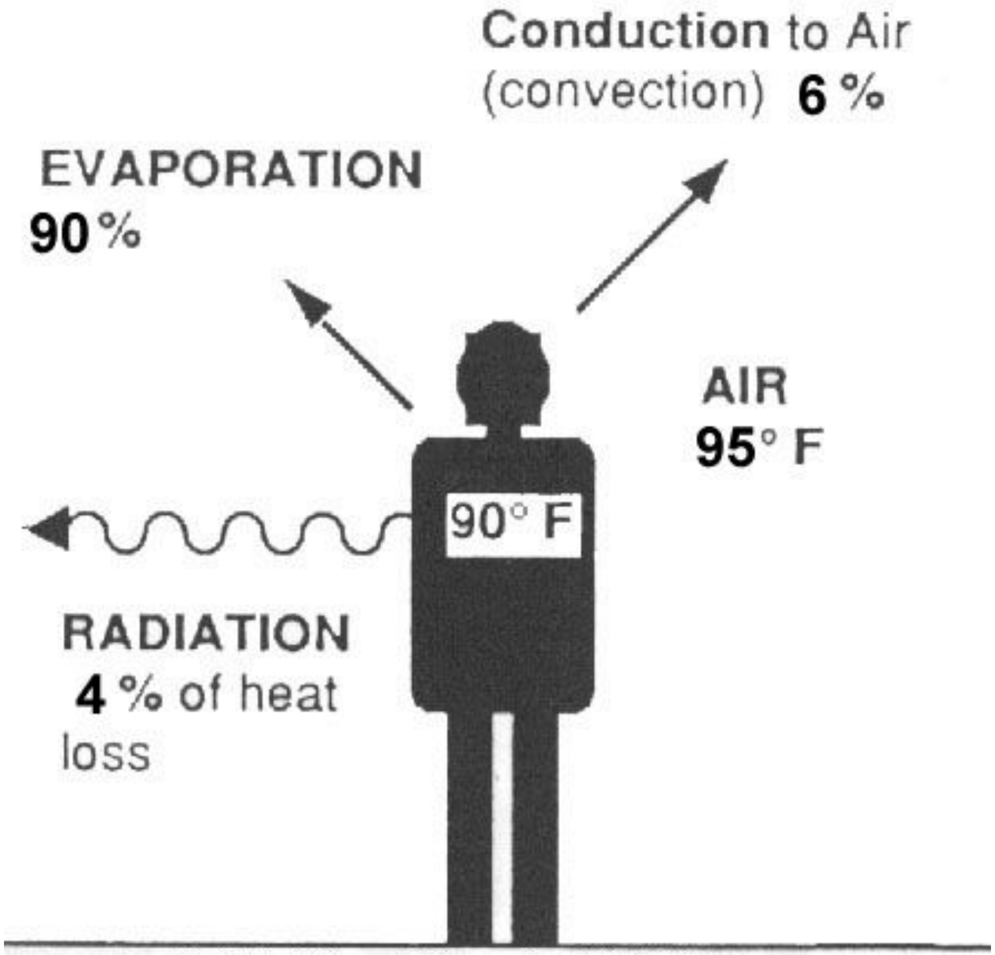
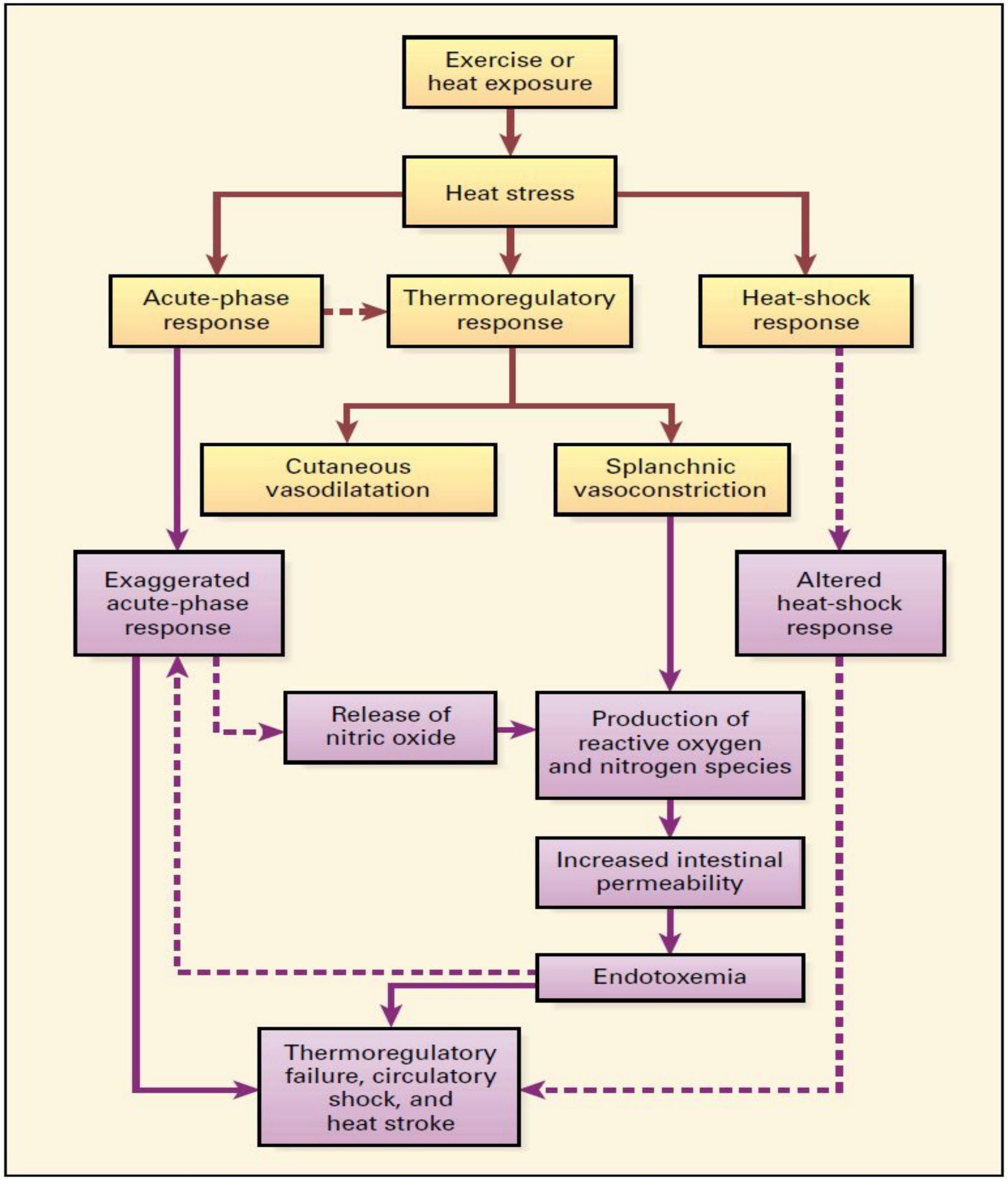
Thermoregulation at 35°C



Modified from Frisancho 1993:33

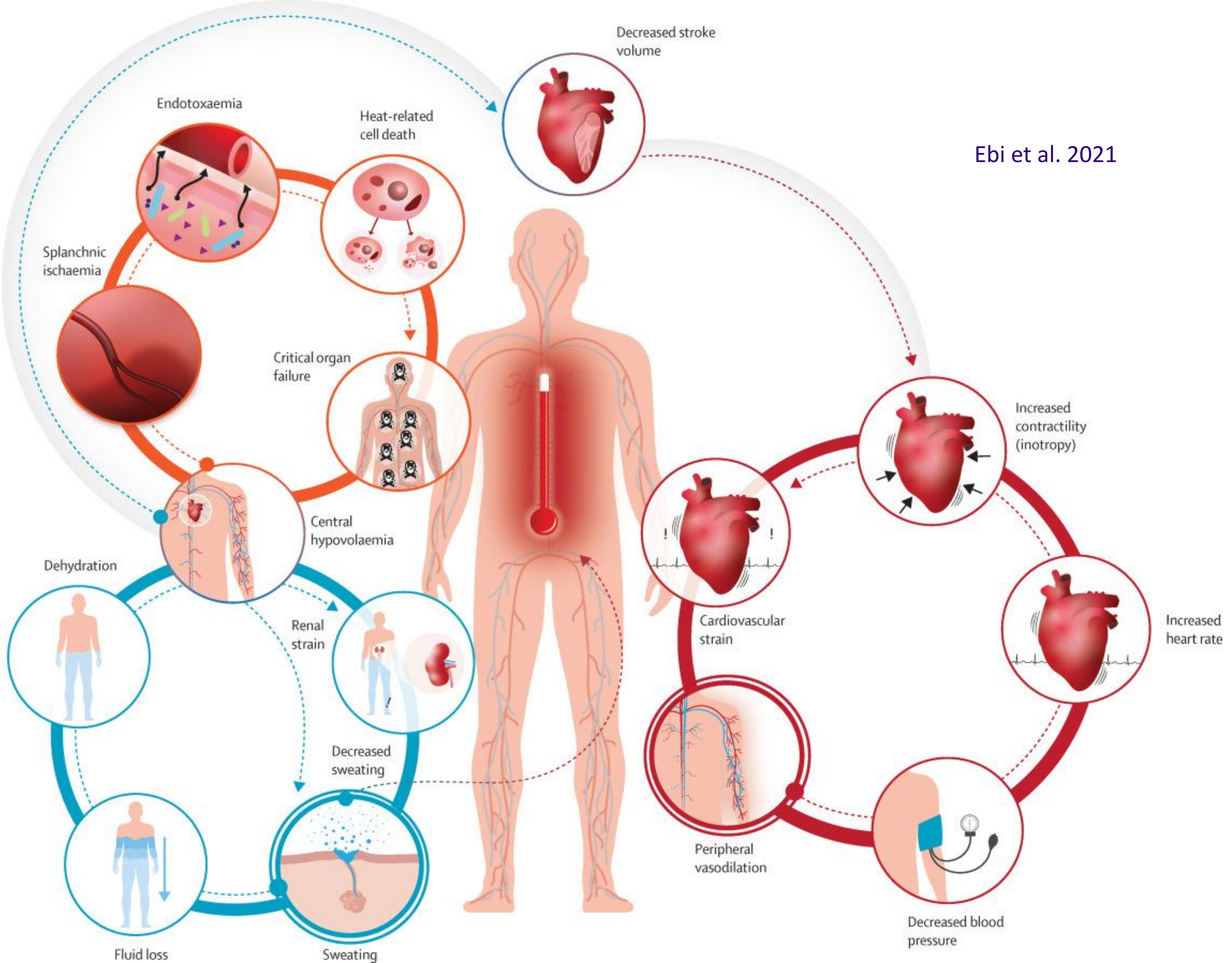
Air Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116
5	78	80	81	83	84	86	88	89	91	93	94	96	97	99	101	102	104	105	107
10	78	80	81	83	84	86	88	89	91	93	95	97	99	101	103	105	107	109	111
15	78	80	81	83	84	86	88	90	92	94	96	98	100	103	105	108	111	113	116
20	79	80	81	83	85	86	88	90	93	95	97	100	103	131	109	112	115	119	122
25	79	80	82	83	85	87	89	91	94	97	100	103	106	110	113	117	121	125	129
30	79	80	82	84	86	88	90	93	96	99	102	106	110	114	118	122	127	132	137
35	80	81	83	85	87	89	92	95	98	102	106	110	114	119	123	129	134	140	146
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136	142	148	
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	143			
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137					
55	81	84	86	89	93	97	101	106	112	117	124	130	137						
60	82	84	88	91	95	100	105	110	116	123	129	137							
65	82	85	89	93	98	103	108	114	121	128	136								
70	83	86	90	95	100	106	112	119	126	134									
75	84	88	92	97	103	109	116	124	132										
80	84	89	94	100	106	113	121	129											
85	85	90	96	102	110	117	126	135											
90	86	91	98	105	113	122	131												
95	86	93	100	108	117	127													
100	87	95	103	112	121	132													



Bouchama and Knochel 2002

Ebi et al. 2021



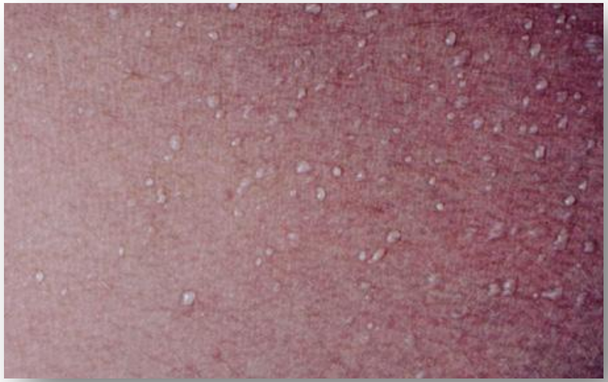
System	Physiology	Mechanisms	Compensation	Decompensation	Outcomes
Cardiac	Increased cardiac output to meet increased metabolic demand	Increased inotropy and chronotropy via baroreceptors and other pathways	Maintained or increased cardiac output via increased heart rate and contractility	Decreased cardiac output due to decreased stroke volume	Peripheral, central hypoperfusion; acute coronary syndrome; myocardial infarction
Vascular	Peripheral vasodilation, central vasoconstriction	Sympathetic nervous system and local reflex pathways	Enhanced peripheral blood flow to facilitate cooling and sweating	Decreased splanchnic blood, tissue hypoxia, endotoxemia, bloodstream infection	Sepsis and septic shock
Renal	Increased reabsorption to compensate for insensible water and electrolyte losses	Vasopressin, Renin-angiotensin-aldosterone system, renal sympathetic nerve activity	Increased free water retention, increased electrolyte retention, decreased renal blood flow	Insufficient renal perfusion, inability to maintain adequate water and electrolyte reabsorption rates	Dehydration, electrolyte abnormalities, acute kidney injury

System	Physiology	Mechanisms	Compensation	Decompensation	Outcomes
Immune	Activation of coordinated stress response	Endothelial, epithelial, leukocyte response via cytokines, heat shock proteins	Protection against tissue injury, enhanced repair	Increased hypoxemia, cytotoxic injury lead to dysregulated immune response	Distributed shock similar to systemic inflammatory response syndrome
Hemato-logic	Initial increase, then decrease, in plasma volume	Sympathetic nervous system, activation of coagulation and fibrinolytic pathways	Support cardiac output, insensible water losses	Increased viscosity, altered coagulation	Disseminated intravascular coagulation, tissue hypoxemia and cell death

System	Physiology	Mechanisms	Compensation	Decompensation	Outcomes
Central Nervous System	Behavioral and physiologic responses to reduce exogenous heat exposure, increase heat loss	Multiple thermoregulatory pathways coordinated by the preoptic hypothalamus	Behavioral, physiologic responses that reduce heat load and increase heat loss	Cerebral hypoperfusion and dysregulation of thermal homeostasis	Confusion, delirium, dizziness, weakness, agitation, combativeness
Repro-ductive	Reduced placental blood flow to support peripheral vasodilation	Sympathetic nervous system and local reflex pathways	Reduced placental blood flow with relative preservation of nutrient transfer to fetus	Dysregulation of thermal homeostasis leading to core temperature over teratogenic threshold	Miscarriage, pre-term labor

Heat Edema

Variations of Heat Rash



Miliaria Crystalline

Miliaria Rubra

Miliaria Pustulosa

Miliaria Profunda

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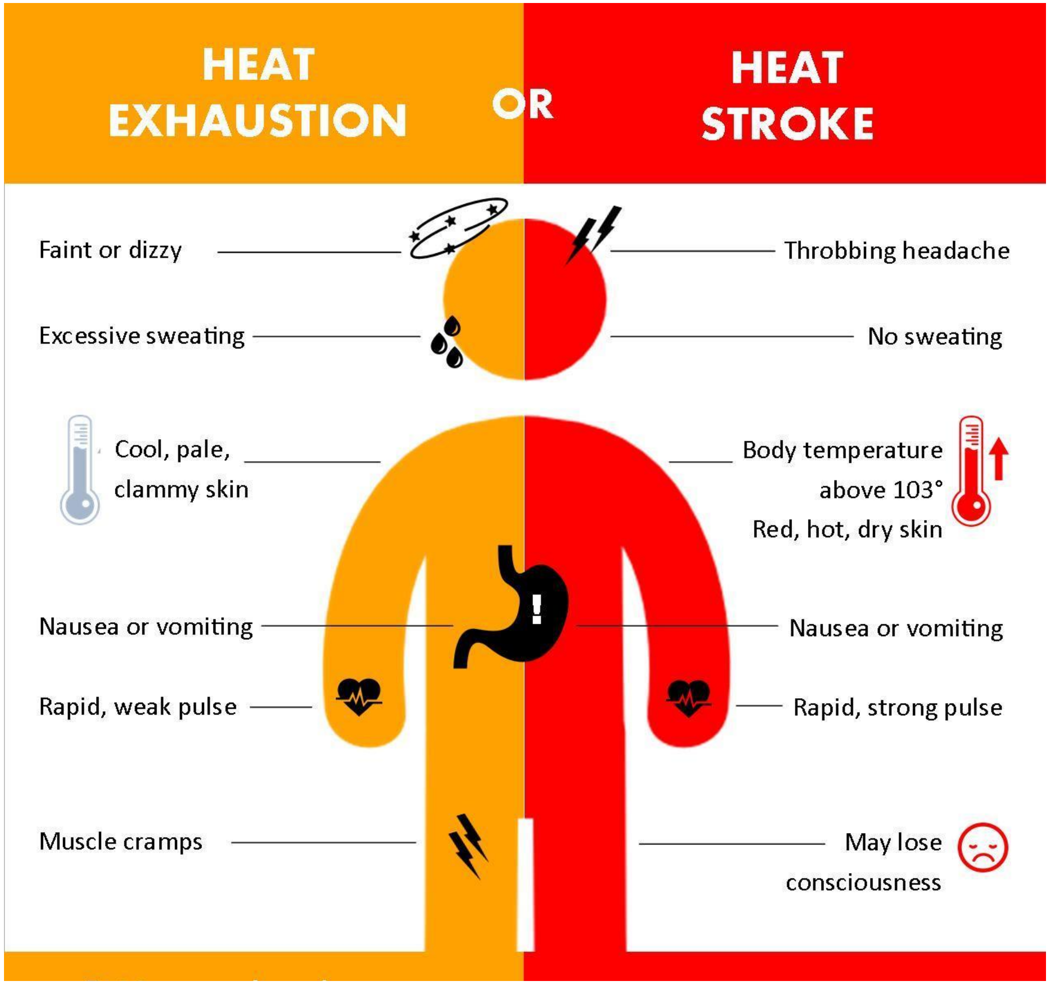
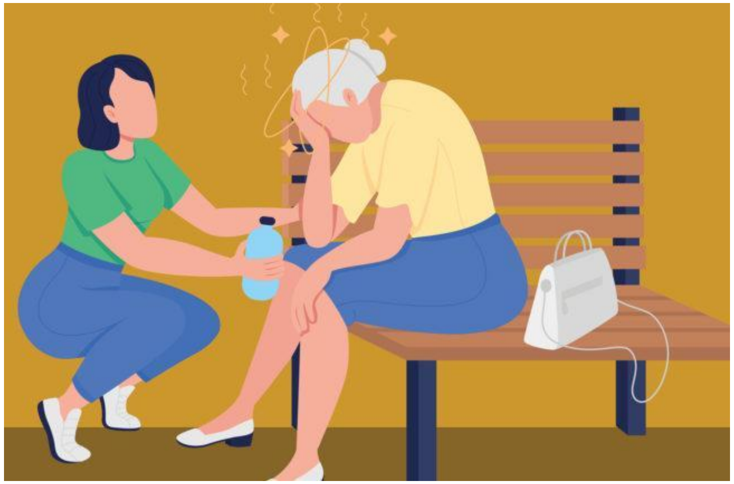
Acute Heat Illness Spectrum



Entity	Case Definition
Heat rash	Diffuse, pruritic, maculopapular or vesicular rash in the setting of heat exposure, often with insulating clothing or swaddling
Heat edema	Mild edema on dependent areas, often seen during early heat acclimitization, resolves spontaneously in a few days
Heat tetany	Rare, self-limiting condition in patients with short, intense heat exposure, with hyperventilation, paraesthesias
Heat cramps	Painful contractions of frequently-used muscle groups
Heat syncope	Brief loss of consciousness in the setting of heat exposure without evidence of seizure activity, stroke, or overdose
Heat exhaustion	Syndrome with generalized weakness, exhaustion, lightheadedness, nausea, limiting function, without recent infection. May or may not be exertional
Heat stroke	Altered mental status (including disorientation, delirium, seizure, obtundation), with elevated core body temperature ≥40°C, in the setting of heat exposure, without signs of stroke, history of infection, or signs of overdose. May or may not be exertional

PREVENTION, DIAGNOSIS, AND TREATMENT



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Primary Prevention

- Acclimatize – risks are greatest at beginning of heat season
- Prevent exposure on hot days – heed warnings
- Prevent over-exertion
- Prevent exposure to heat sources
- Discuss heat relief plans with employers, supervisors, employees

Secondary Prevention

- Know early symptoms of heat illness
- Take time to cool down
- Monitor hydration, e.g., look for dark urine
- Provide for cooler, shaded places to rest, drinking water
- Be ready to call for help

Tertiary Prevention

- Call for prompt medical attention, e.g. 911
- ABCs
- Rapid cooling: Expose, wet, evaporate
- Targeted passive cooling: ice packs in groin, axilla
- Rule out alternative causes

Heat Illness Diagnosis

- Primarily clinical
- History is often very important
  - Includes history of time, location, exogenous heat sources, activities, cooling measures
  - For more severe forms, pertinent negatives (infection, overdose, known seizure history) are also important to rapidly ascertain
- Laboratory and imaging tests are often used to support clinical diagnosis and guide therapy

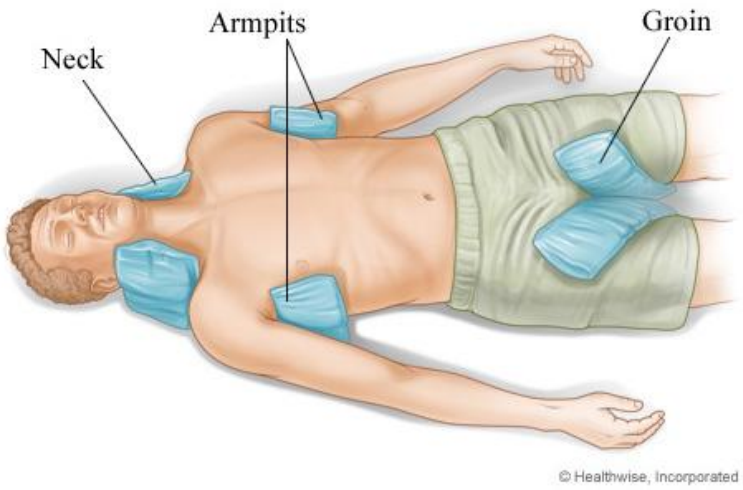
Treatment

- Acute syndrome often primarily related to heat dissipation more than dehydration
- More chronic presentations typically related to dehydration more than elevated temperature

Condition	Intervention	Goal
Out of hospital		
Heat stress (due to heat wave, summer heat, or strenuous exercise), with changes in mental status (anxiety, delirium, seizures, or coma)	Measure the patient's core temperature (with a rectal probe)	Diagnose heat stroke†
	If the core temperature is >40°C, move the patient to a cooler place, remove his or her clothing, and initiate external cooling‡: cold packs on the neck, axillae, and groin; continuous fanning (or opening of the ambulance windows); and spraying of the skin with water at 25°C to 30°C	Lower the core temperature to <39.4°C, promote cooling by conduction, and promote cooling by evaporation
	Position an unconscious patient on his or her side and clear the airway	Minimize the risk of aspiration
	Administer oxygen at 4 liters/min	Increase arterial oxygen saturation to >90%
	Give isotonic crystalloid (normal saline)	Provide volume expansion
	Rapidly transfer the patient to an emergency department	
In hospital		
Cooling period	Confirm diagnosis with thermometer calibrated to measure high temperatures (40°C to 47°C)	
Hyperthermia	Monitor the rectal and skin temperatures; continue cooling	Keep rectal temperature <39.4°C§ and skin temperature 30°C–33°C
Seizures	Give benzodiazepines	Control seizures
Respiratory failure	Consider elective intubation (for impaired gag and cough reflexes or deterioration of respiratory function)	Protect airway and augment oxygenation (arterial oxygen saturation >90%)
Hypotension¶	Administer fluids for volume expansion, consider vasopressors, and consider monitoring central venous pressure	Increase mean arterial pressure to >60 mm Hg and restore organ perfusion and tissue oxygenation
Rhabdomyolysis	Expand volume with normal saline and administer intravenous furosemide, mannitol, and sodium bicarbonate	Prevent myoglobin-induced renal injury: promote renal blood flow, diuresis, and alkalization of urine
	Monitor serum potassium and calcium levels and treat hyperkalemia	Prevent life-threatening cardiac arrhythmia
After cooling Multiorgan dysfunction	Supportive therapy	Recovery of organ function

Bouchama and Knochel 2002

Rapid Passive Cooling



PUTTING IT ALL TOGETHER

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2006 California Heat Wave

Background: Climate models project that heat waves will increase in frequency and severity. Despite many studies of mortality from heat waves, few studies have examined morbidity.

Objectives: In this study we investigated whether any age or race/ethnicity groups experienced increased hospitalizations and emergency department (ED) visits overall or for selected illnesses during the 2006 California heat wave.

Methods: We aggregated county-level hospitalizations and ED visits for all causes and for 10 cause groups into six geographic regions of California. We calculated excess morbidity and rate ratios (RRs) during the heat wave (15 July to 1 August 2006) and compared these data with those of a reference period (8–14 July and 12–22 August 2006).

Results: During the heat wave, 16,166 excess ED visits and 1,182 excess hospitalizations occurred statewide. ED visits for heat-related causes increased across the state [RR = 6.30; 95% confidence interval (CI), 5.67–7.01], especially in the Central Coast region, which includes San Francisco. Children (0–4 years of age) and the elderly (≥ 65 years of age) were at greatest risk. ED visits also showed significant increases for acute renal failure, cardiovascular diseases, diabetes, electrolyte imbalance, and nephritis. We observed significantly elevated RRs for hospitalizations for heat-related illnesses (RR = 10.15; 95% CI, 7.79–13.43), acute renal failure, electrolyte imbalance, and nephritis.

Conclusions: The 2006 California heat wave had a substantial effect on morbidity, including regions with relatively modest temperatures. This suggests that population acclimatization and adaptive capacity influenced risk. By better understanding these impacts and population vulnerabilities, local communities can improve heat wave preparedness to cope with a globally warming future.

Chronic Disease Exacerbations

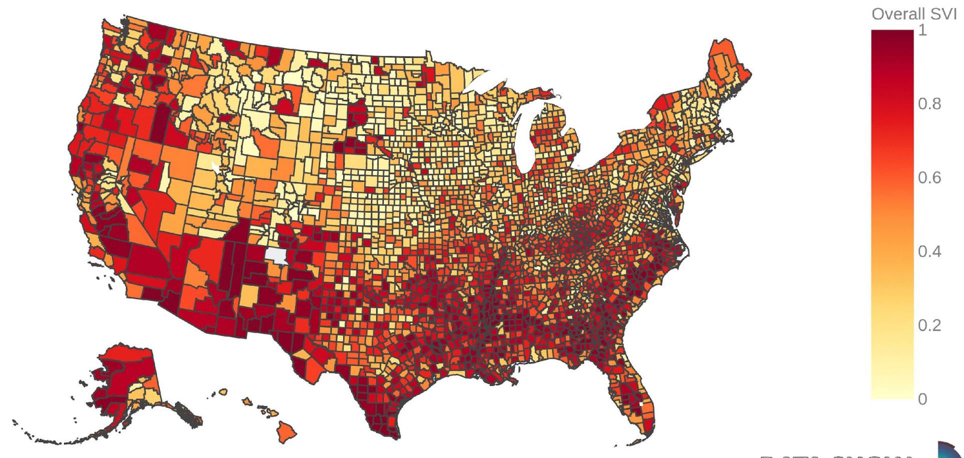
Table 2. Statewide ED visits and hospitalization RRs, for all ages, all race/ethnicity groups combined, during the 2006 California heat wave (15 July to 1 August 2006), versus the reference period (8–14 July and 12–22 August 2006), evaluated from combined primary and secondary diagnoses.

		ED visits			Hospitalizations		
Diagnosis	ICD-9-CM code	Reference period	Heat-wave period	RR (95% CI)	Reference period	Heat-wave period	RR (95% CI)
All causes	All	485,785	501,951	1.03 (1.02–1.04)	191,826	193,008	1.01 (1.00–1.01)
Internal causes	0–799.9	386,229	399,699	1.03 (1.03–1.04)	172,864	173,843	1.01 (1.00–1.01)
Diabetes	250	37,321	38,315	1.03 (1.01–1.04)	27,644	27,920	1.01 (0.99–1.03)
Electrolyte imbalance	276	30,076	35,020	1.16 (1.15–1.18)	25,647	28,003	1.09 (1.07–1.11)
Cardiovascular diseases	390–398, 402, 404–429, 440–448	45,613	46,515	1.02 (1.01–1.03)	48,327	48,821	1.01 (1.00–1.02)
Acute MI	410	2,822	2,869	1.02 (0.96–1.07)	3,630	3,688	1.02 (0.97–1.06)
Cerebrovascular disease	430–438	7,397	7,250	0.98 (0.95–1.01)	8,266	8,138	0.98 (0.95–1.02)
Respiratory illnesses	460–519	64,051	64,213	1.00 (0.99–1.01)	36,753	37,226	1.01 (1.00–1.03)
Nephritis and nephrotic syndrome	580–589	12,185	12,935	1.06 (1.04–1.09)	14,118	14,801	1.05 (1.02–1.07)
Acute renal failure	584	5,085	5,839	1.15 (1.11–1.19)	6,541	7,288	1.11 (1.08–1.15)
Heat-related illnesses	992	403	2,537	6.30 (5.67–7.01)	61	619	10.15 (7.79–13.43)

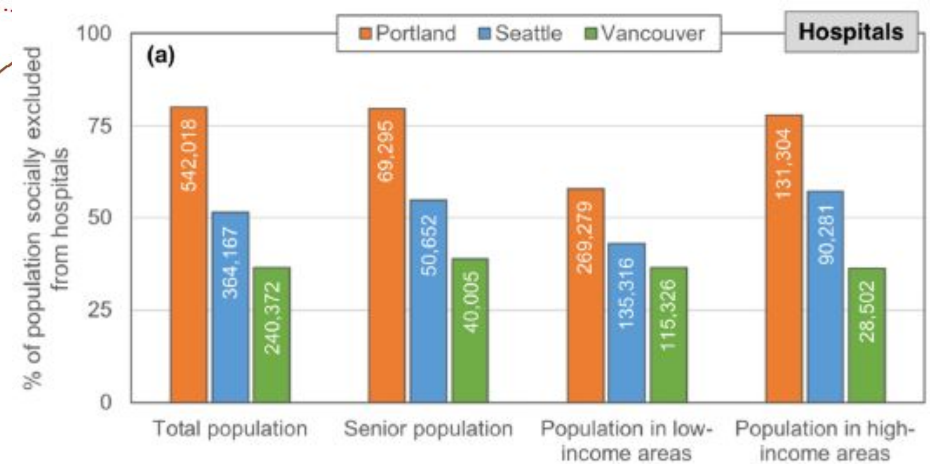
Our Experience

20% OVER 18 MONTHS

- Historically unprecedented extreme heat event
- Relatively short advance warning
- Acute-on-chronic capacity constraints
- Large vulnerable populations, insufficient protections



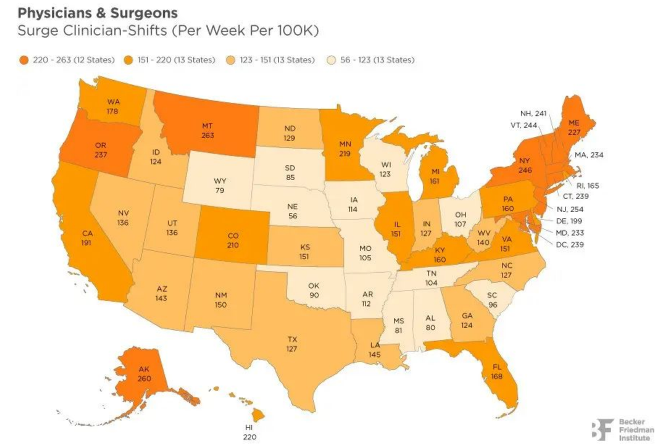
CDC/ATSDR

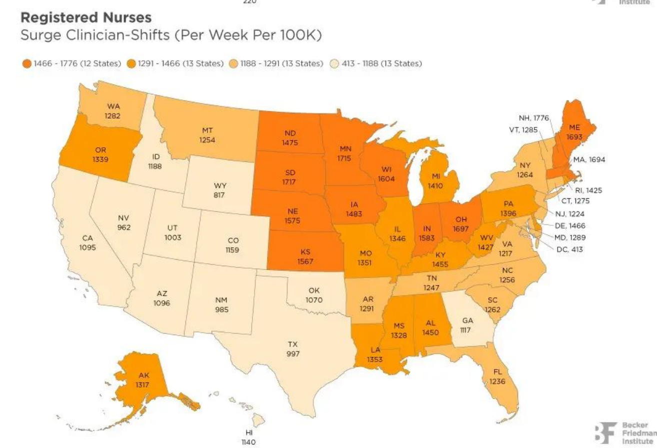


Mayaud et al. 2019

Population Vulnerability

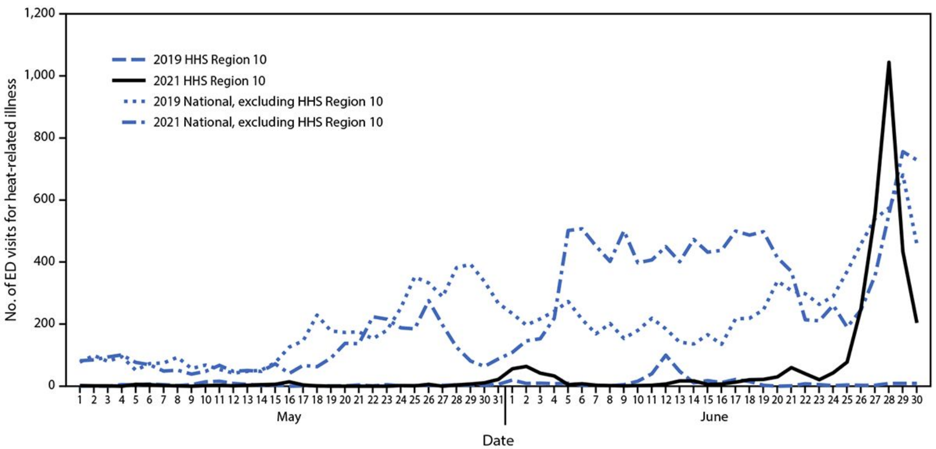
- Historically cool regional climate
  - Housing built for heat retention
  - Relatively low AC prevalence
- Little lived experience with heat
  - Relatively low population and health sector awareness
- Population growing faster than health care capacity
  - Differentially constrained by SES
  - Acute staffing from COVID



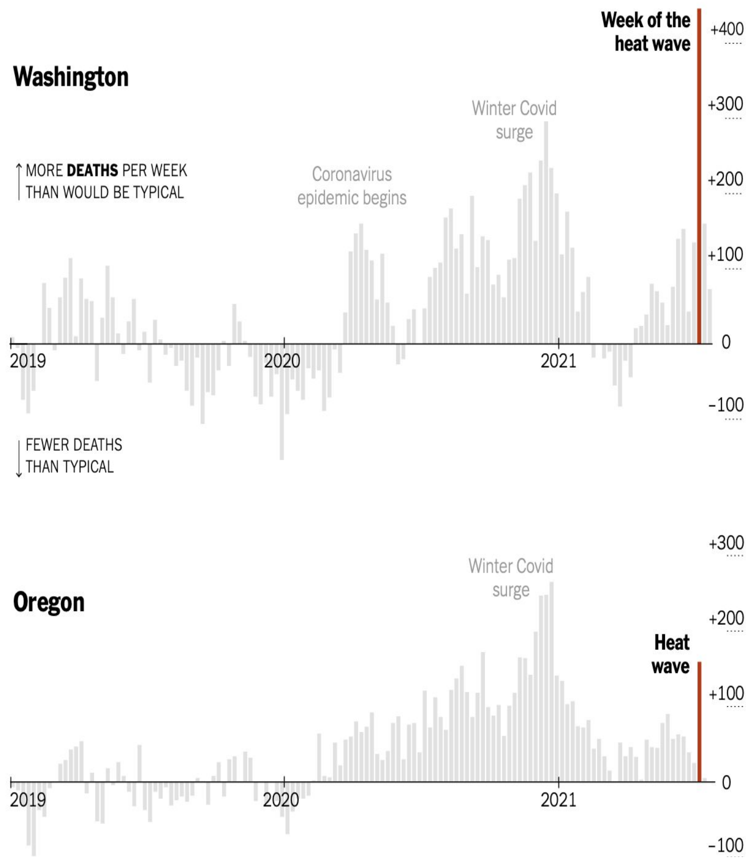


Health Impacts

- Deadliest weather-related event in Washington history
- At least 3,500 ED visits in four-state region (CDC); 100-fold increase in heat-related ED visits on 6/28



[Schramm et al. 2021](#)



[New York Times](#)

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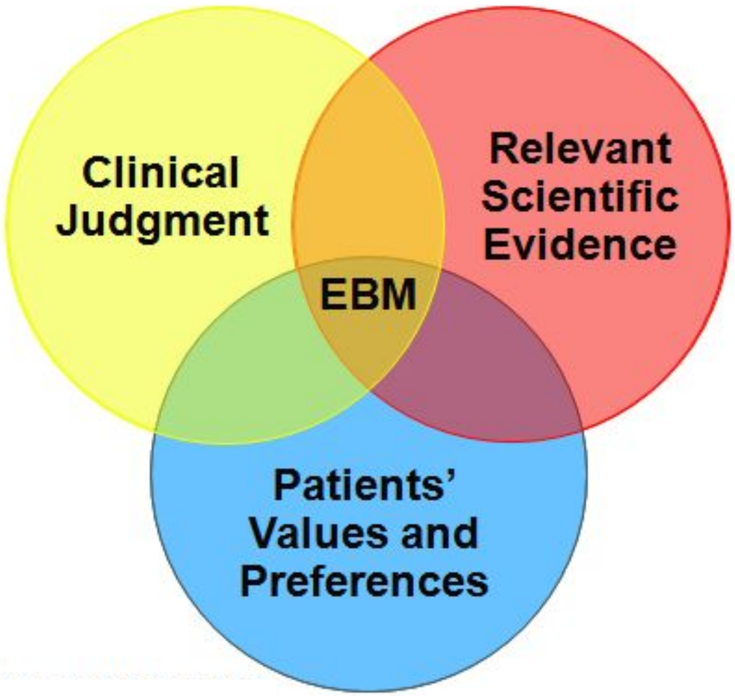
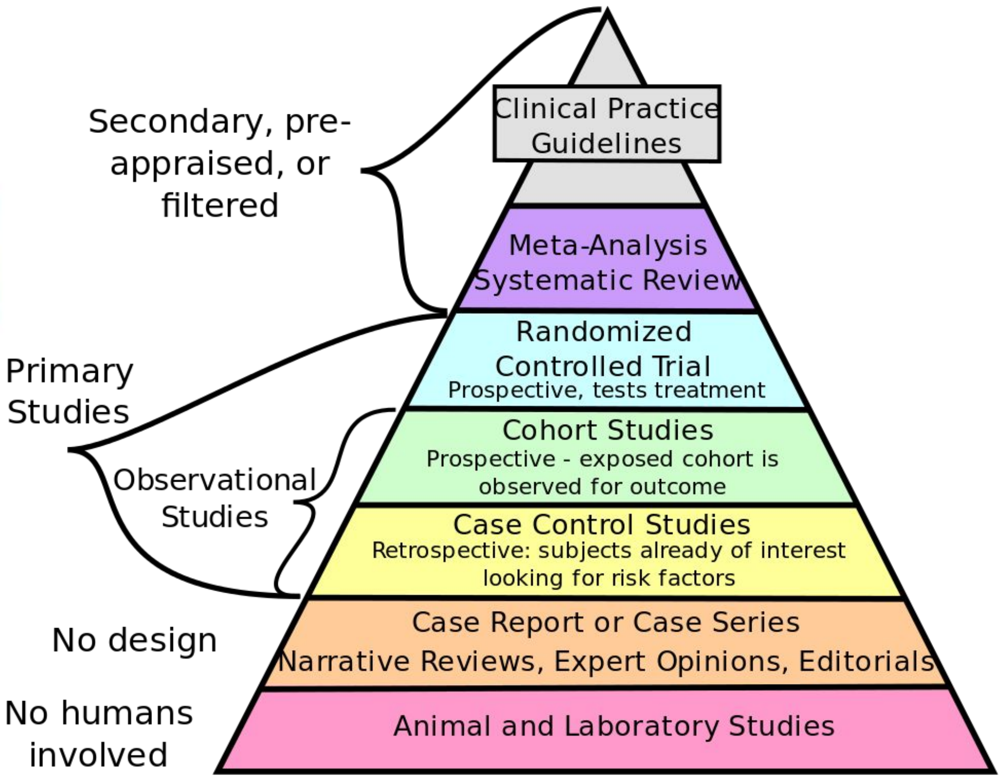
Preparedness and Learning

- We are well prepared for the clinical impacts we will see
- We are less prepared for:
  - Presentations outside our expectations
  - Events beyond our experience
  - Combinations that overwhelm the systems we have developed
- We need information systems that:
  - Give us insight into changing risk distributions
  - Strategies for reducing emerging risks as they occur
  - Methods for implementing quickly and at scale
- Assuming current trends persist, we will very likely need to prepare for a new risk regime circa 2050

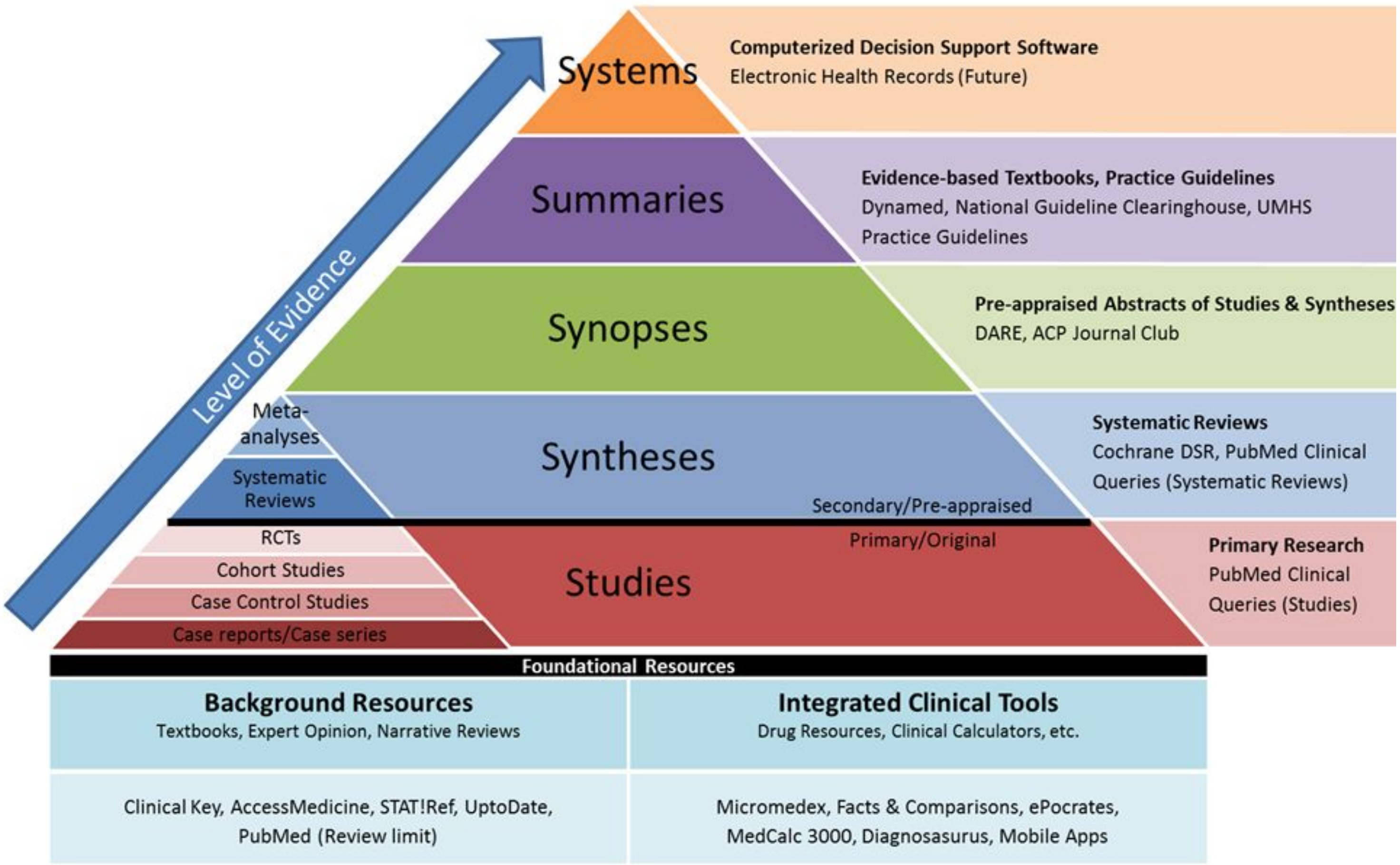
The Tools We Have





Sacket et al., 1996

Evidence-based Practice Support



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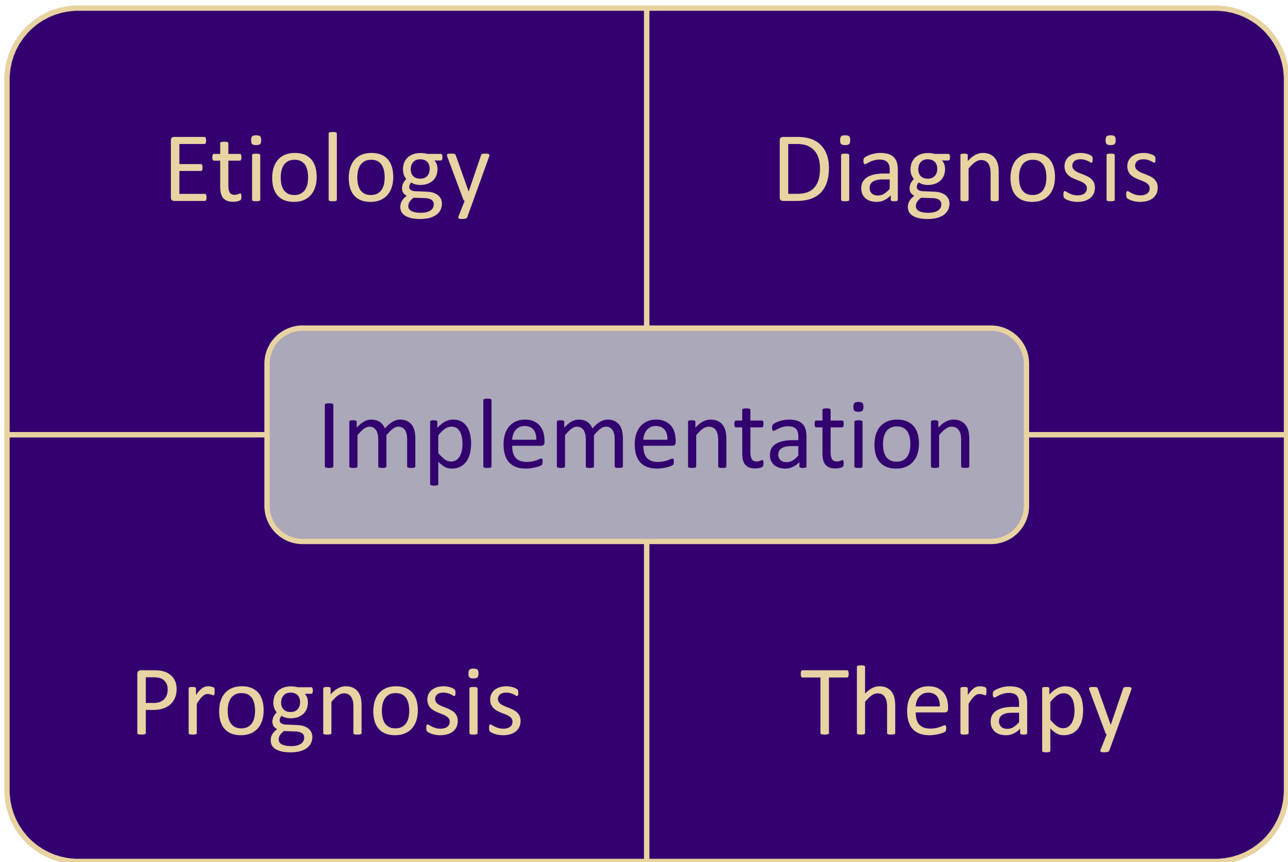
From Etiology to Therapy



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Units of Analysis

Individual

System

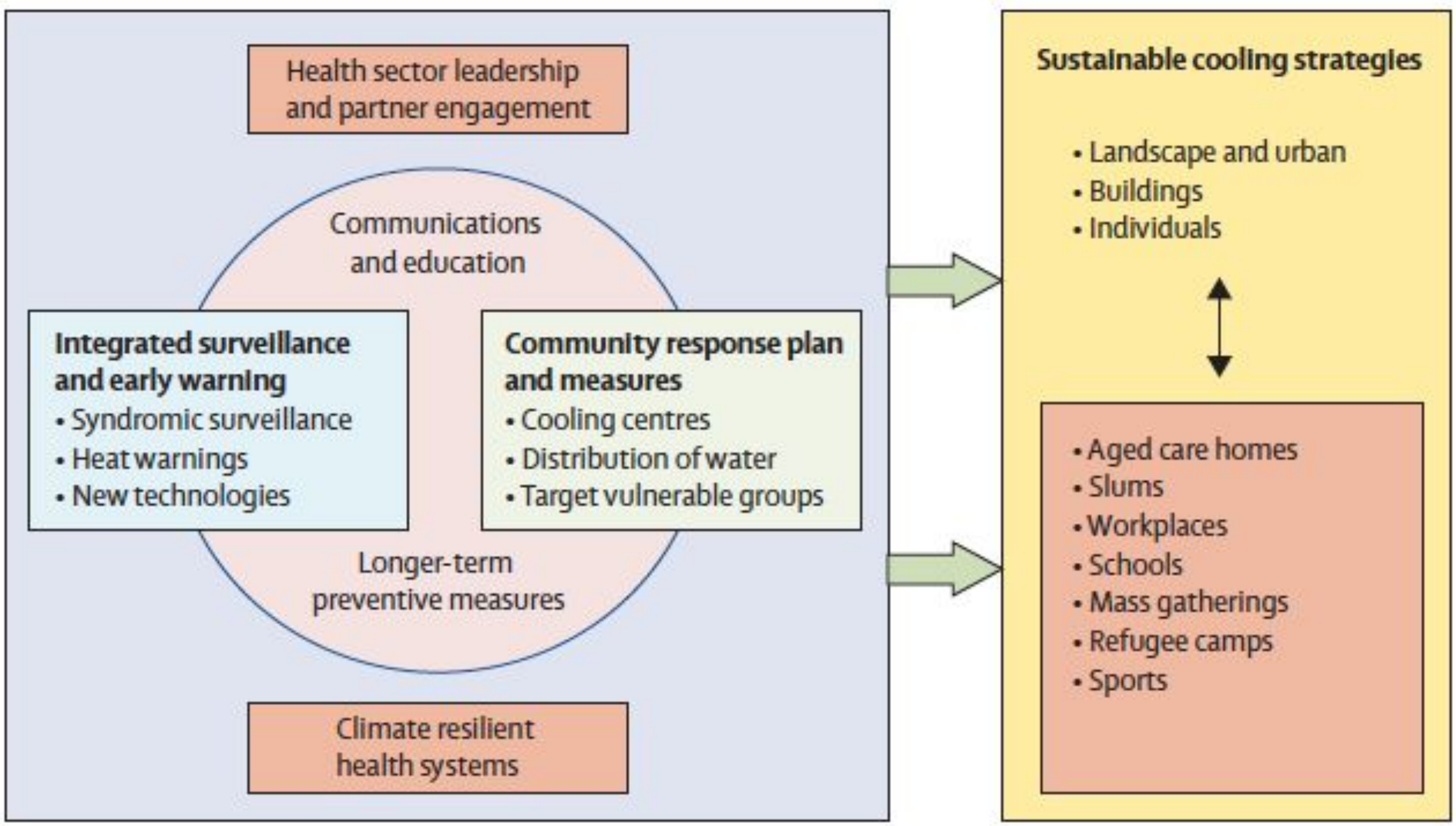
Population

Individual-level Interventions

- Expert-opinion guidance regarding risk reduction
- Based on understanding of physiology and principles of sustainability
- No generalizable estimates of risk reduction potential

Jay et al. 2021

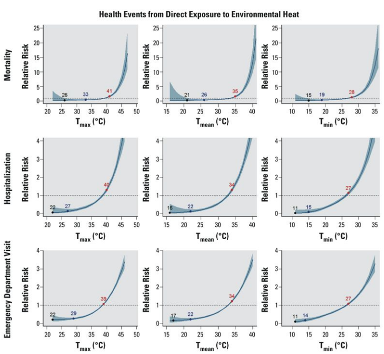
Systems-level Interventions



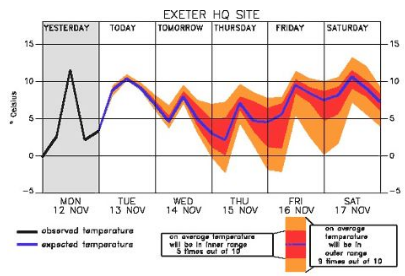
Jay et al. 2021

Population-level Interventions

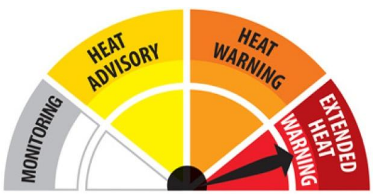
Identify temperature thresholds (harm)



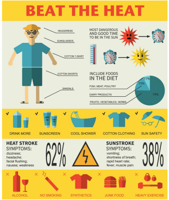
Forecast likelihood of crossing threshold(s)



Issue warning based on risk assessment (prognosis)



Interventions (therapy)



Home Energy Assistance Program

HOME VISITING COALITION

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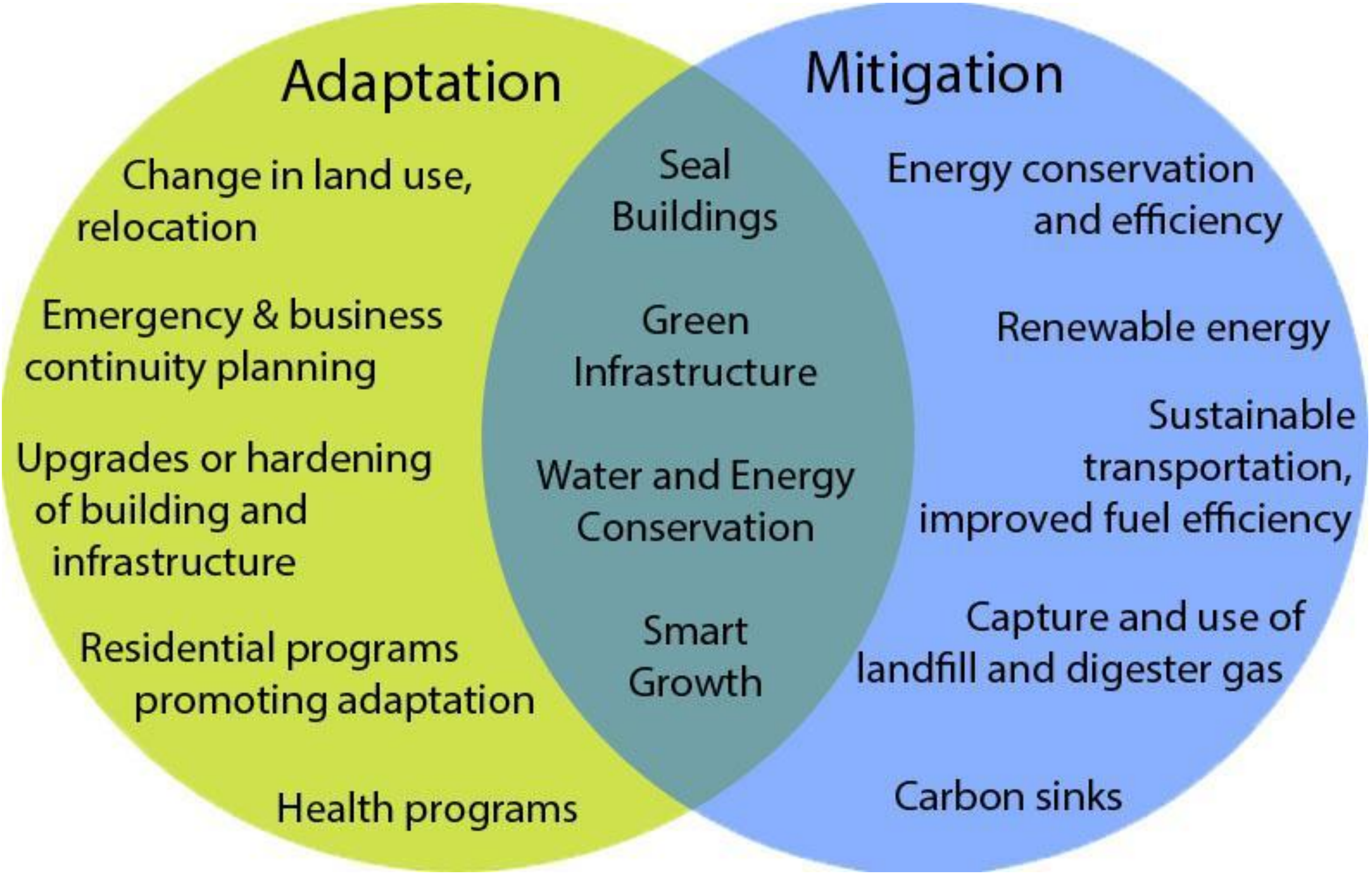
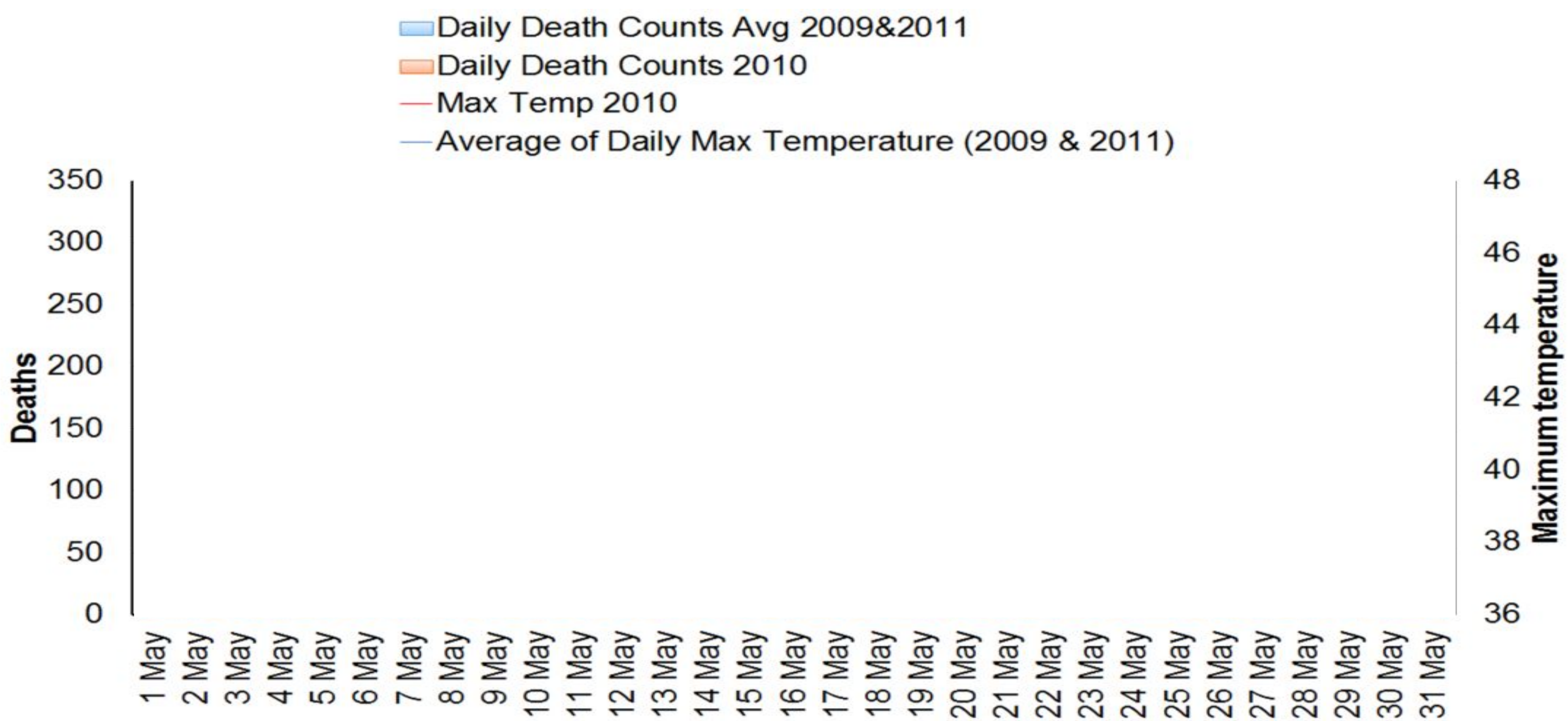
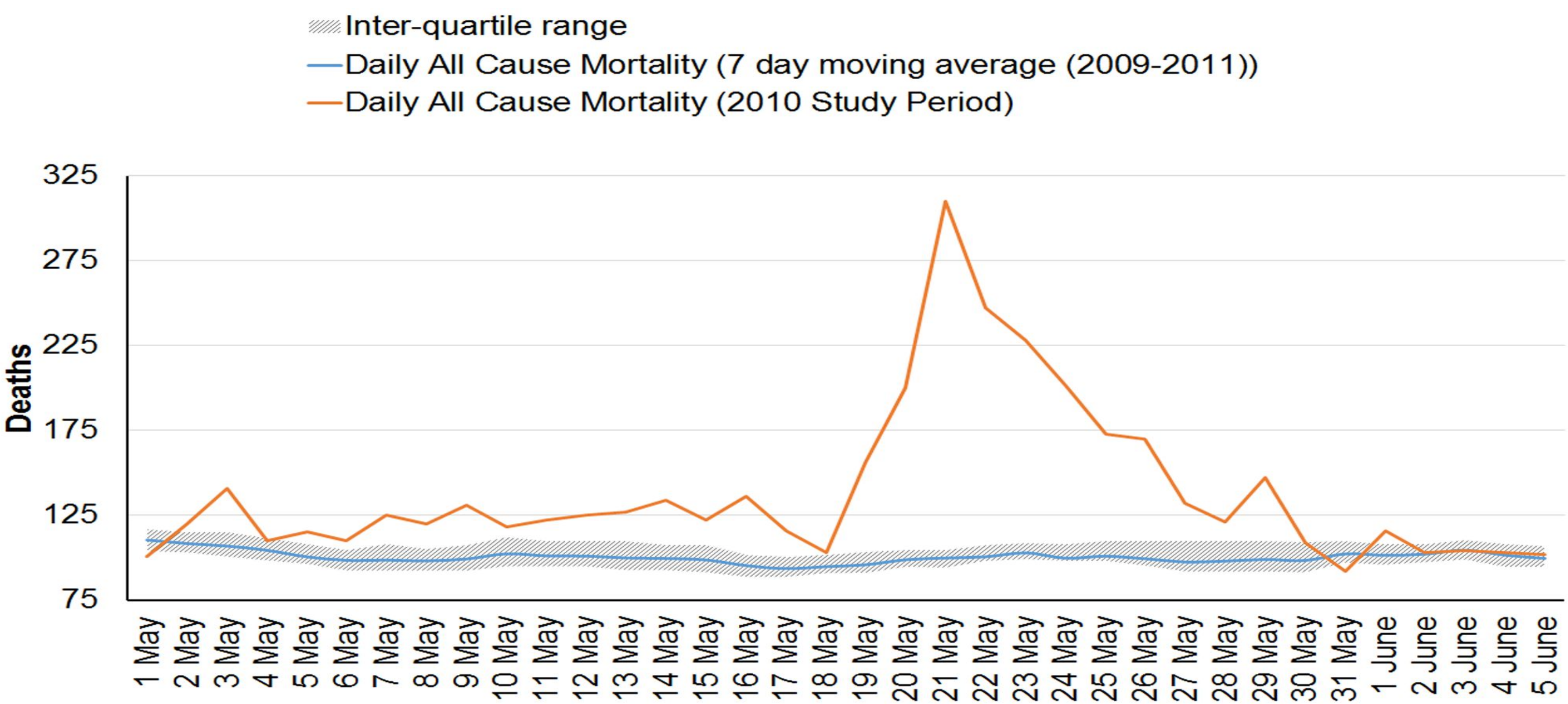
Building Resilience



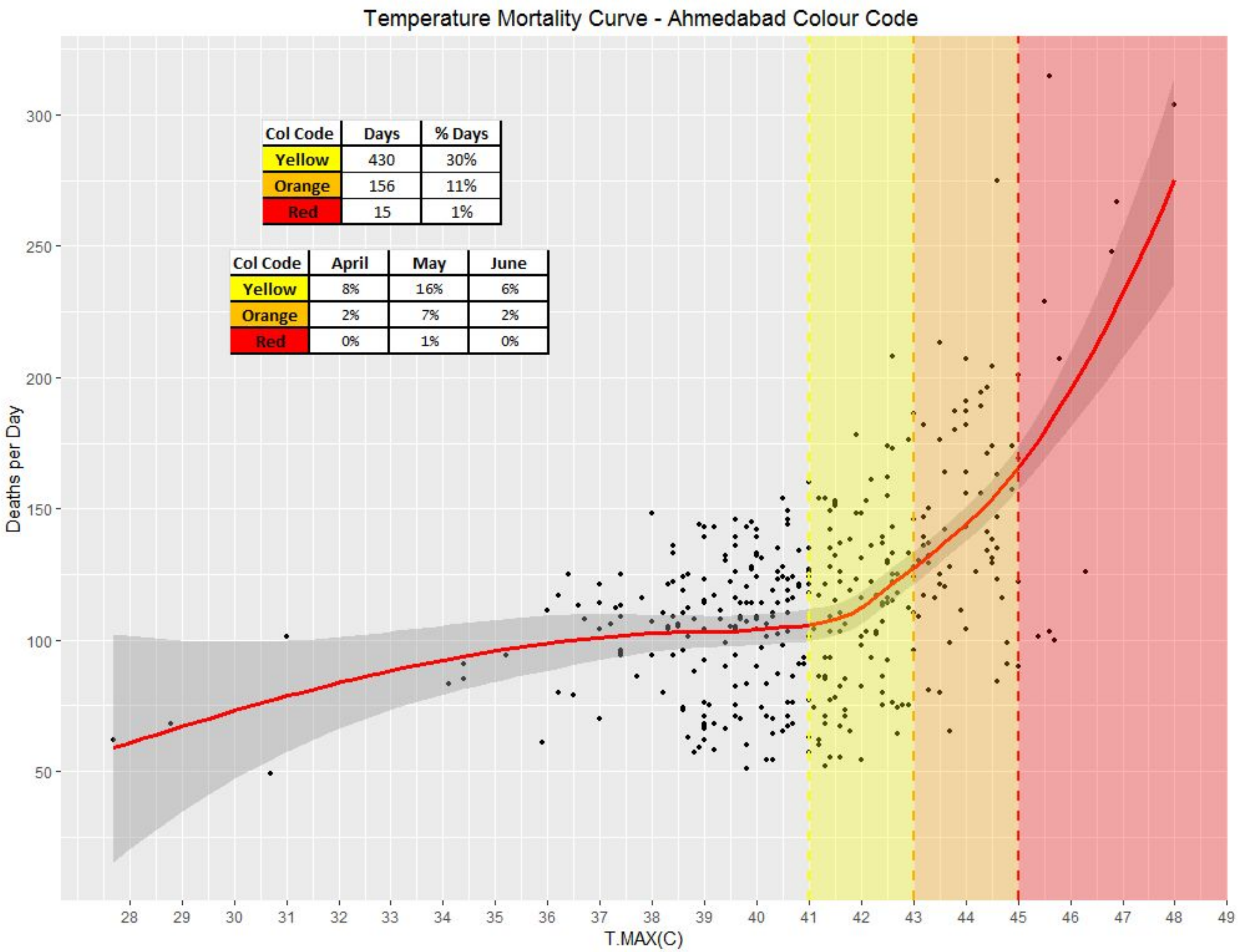
Baseline Risk 1



Baseline Risk 2



Setting the Thresholds



Col Code	Days	% Days
Yellow	430	30%
Orange	156	11%
Red	15	1%

Col Code	April	May	June
Yellow	8%	16%	6%
Orange	2%	7%	2%
Red	0%	1%	0%

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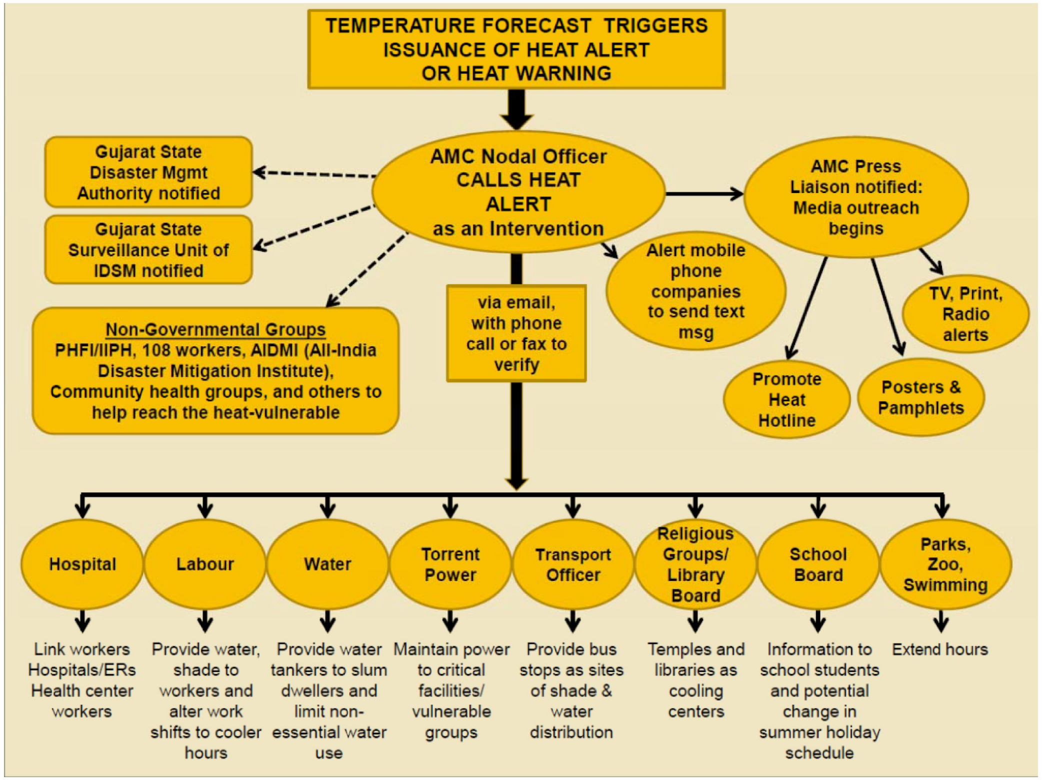
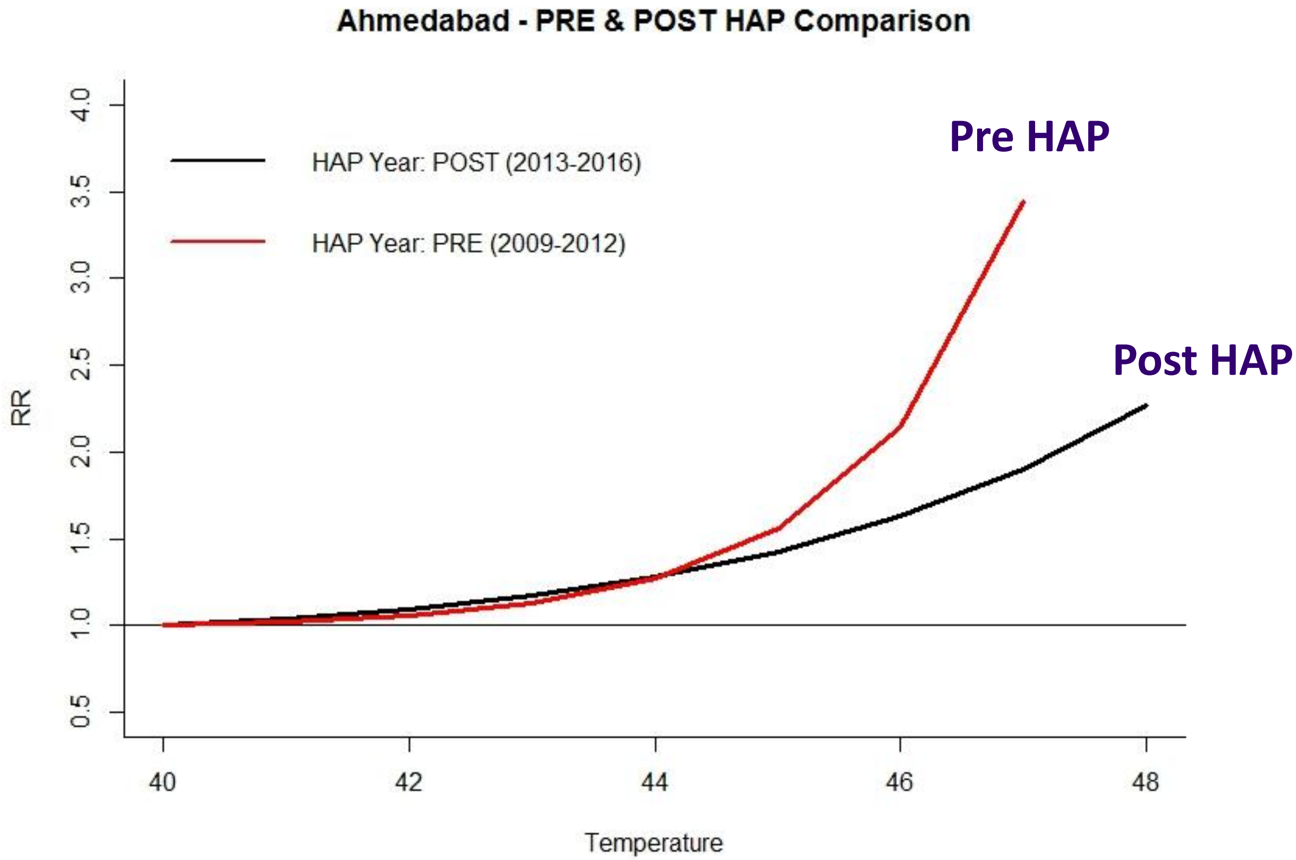
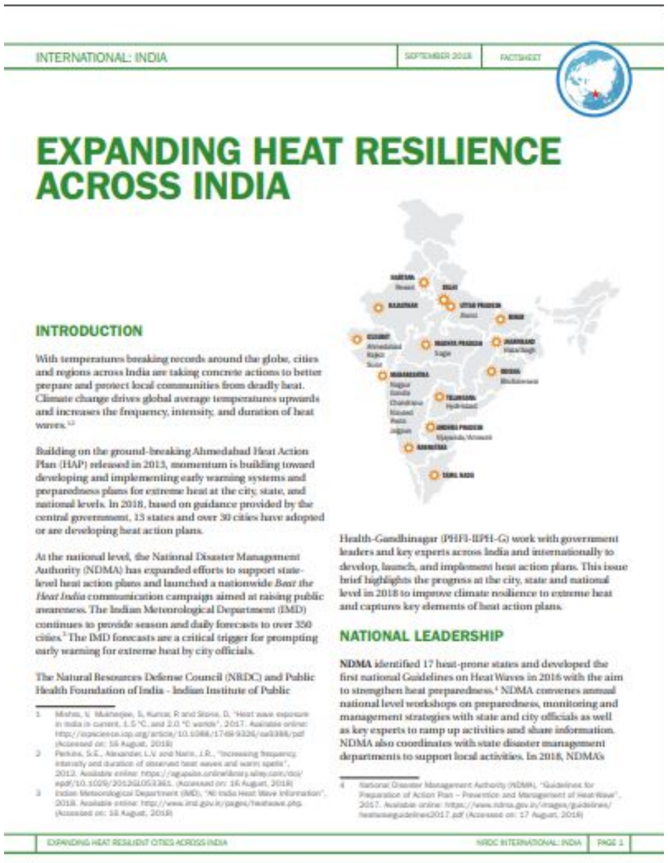
Ahmedabad Heat Action Plan



Relative Risk of Death Pre- and Post-HAP



Scaling Up Effective Interventions



INTERNATIONAL: INDIA | SEPTEMBER 2018 | FACTSHEET

EXPANDING HEAT RESILIENCE ACROSS INDIA

INTRODUCTION

With temperatures breaking records around the globe, cities and regions across India are taking concrete actions to better prepare and protect local communities from deadly heat. Climate change drives global average temperatures upwards and increases the frequency, intensity, and duration of heat waves.[1,2]

Building on the ground-breaking Ahmedabad Heat Action Plan (HAP) released in 2013, momentum is building toward developing and implementing early warning systems and preparedness plans for extreme heat at the city, state, and national levels. In 2018, based on guidance provided by the central government, 13 states and over 30 cities have adopted or are developing heat action plans.

At the national level, the National Disaster Management Authority (NDMA) has expanded efforts to support state-level heat action plans and launched a nationwide *Beat the Heat India* communication campaign aimed at raising public awareness. The Indian Meteorological Department (IMD) continues to provide season and daily forecasts to over 350 cities.[3] The IMD forecasts are a critical trigger for prompting early warning for extreme heat by city officials.

The Natural Resources Defense Council (NRDC) and Public Health Foundation of India - Indian Institute of Public Health-Gandhinagar (PHFI-IIPH-G) work with government leaders and key experts across India and internationally to develop, launch, and implement heat action plans. This issue brief highlights the progress at the city, state and national level in 2018 to improve climate resilience to extreme heat and captures key elements of heat action plans.

NATIONAL LEADERSHIP

NDMA identified 17 heat-prone states and developed the first national Guidelines on Heat Waves in 2016 with the aim to strengthen heat preparedness.[4] NDMA convenes annual national level workshops on preparedness, monitoring and management strategies with state and city officials as well as key experts to ramp up activities and share information. NDMA also coordinates with state disaster management departments to support local activities. In 2018, NDMA's

Summary

- Humans are euthermic and maintain heat balance
- Excess heat threatens normal function
- Climate change is warming environments rapidly
- Body systems attempt to compensate; this can stress body systems
- Decompensation leads to heat stroke
- Diagnosis is clinical; rapid cooling is essential
- Health systems and larger communities are at risk
- Broad efforts, e.g. HAPs, can reduce risks

Thank You!

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