Prologue: La Canicule

The unseasonably warm weather throughout Great Britain in the spring of 2003 was embraced by a population accustomed to the persistently overcast and damp conditions of a Northern European winter. Although still cold, February and March of that year had yielded an unusual number of sunny days, with relatively few rainstorms and periods of overcast skies. In April, Britons flocked to beach communities for the Easter holiday, taking advantage of temperatures reaching into the 70s, a generous 10 degrees above normal for that month.[1] As one media report noted at the time, "An unexpected glimpse of sunshine could brighten the weekend for millions of people in southern England" [1]. Another concluded that not even Miami, Florida, could muster the same tropical conditions experienced in Northern Europe at times that year. Mother Nature, it seemed, was smiling on the island kingdom.

The explanation for Britain's good fortune was to be found in the presence of a stationary high-pressure weather system centered over Scandinavia, which was drawing in warmer air from farther afield and elevating temperatures across Europe. The warm weather that Easter weekend was enjoyed in several European capitals, where long-shut windows were opened to blue skies and winter layers removed. In the spring of most years, momentary glimpses of the Sun over Northern Europe are to be celebrated; this year, however, the Sun was here to stay.

Although no one recognized it at the time, Europe was experiencing the early stages of a heat wave so extreme that it would far surpass any comparable weather event in more than three centuries of record keeping. Since temperature observations were first maintained in 1659, a period when Louis XIV ruled France and the Pilgrims occupied

[1] Unless otherwise indicated, all temperatures are reported in degrees Fahrenheit.

Plymouth, not a single summer had produced temperatures so intense and over such an extended period of time. Maintained by a succession of stationary weather systems over the Northern Atlantic and Central Europe, conditions of excessive heat and drought would persist for almost eight months. By summer's end, the heat wave had reduced ancient rivers to non-navigable streams, consumed in fire an area larger than some European nations, and claimed more lives than the United States lost in a decade of warfare in Vietnam.

The heat wave of 2003 would constitute the single most catastrophic weather event to be visited on Europe – and, arguably, any modern nation – during the period in which weather observations have been recorded. Less than a decade since its occurrence, however, many reading these pages will not recall having heard of the event.

This perhaps was the central lesson of the crisis: heat kills quietly.

By April 2003, the heat wave was well underway. Long accustomed to soggy winters and persistent overcast conditions, Western and Central Europe had instead received relatively little precipitation during the month of February. For example, rainfall that month in Frieburg, Germany, was about 60% less than the long-term average, and would continue to fall significantly below average levels for the following seven months. By May, large expanses of Europe were experiencing a rainfall deficit between 50–75% of the long-term average, symptomatic of a deepening drought.

Although heat waves are most directly characterized by a succession of excessively hot days, such elevated temperatures over an extended period are often a response to longer term deficits in rainfall. Moisture, in this sense, is a critical regulator of climate. As the landscape is depleted of moisture, a larger percentage of energy received from the Sun is converted into heat at the Earth's surface, serving to increase temperatures. By working against the upwelling of water vapor to the atmosphere, the subsiding air mass of a high-pressure weather system over Europe was effectively robbing the atmosphere of moisture needed for rainfall. As can be experienced in any desert climate, a landscape starved of moisture is prone to temperature extremes.

By May, the anomalous warm spells of March and April had developed into a persistent warming trend, with temperatures across much of Europe registering more than 7°F higher than long-term averages for the month. By June, the development of a fully fledged heat wave was widely apparent. Temperatures soared in the south of France, where daily

maximum temperatures were averaging more than 10°F above normal and reached as high as 104°F. Switzerland suffered through its hottest June in more than 250 years of record keeping, with nighttime temperatures in Geneva rarely falling below 80°F. As temperatures climbed to 90°F in Britain, local bookies starting taking bets on a statistical outcome that had never before seemed worthy of a wager: that England could reach an unimaginable 100°F. By July, the odds of such an event were 14–1, and falling [2].

The first signs of the developing public health emergency were the gradually increasing number of patients arriving at large urban hospitals complaining of general fatigue and shortness of breath. Because such symptoms are indicative of a wide range of potential ailments, they were hardly sufficient to alert doctors and public health officials to the wave of fatalities that was soon to come. As a French official observed somewhat bitterly at the height of the heat wave, "People don't come in with 'dying of heat' on their foreheads" [3]. Yet those symptoms would later be linked directly to the excessive temperatures outdoors and in buildings lacking air conditioning. And the most vulnerable populations were already succumbing to the heat. In Paris, a social services organization would report the deaths of two homeless men from no obvious cause following a string of excessively hot days in early August. The cause would soon become apparent.

The human body can tolerate surprisingly high temperatures. With a warm-blooded core temperature of 98.6°F, the very baseline temperature for human survival is considerably warmer than most outdoor environments. However, the tolerable deviation from this core temperature for more than a brief period of time is quite limited, and such deviation is managed more easily in environments that are somewhat cooler than this threshold. As environmental temperatures approach 98.6°F, the human body is increasingly required to cool itself through the release of water in the form of perspiration. At temperatures above this threshold, sweating assumes the urgency of life support.

The importance of moisture in cooling the human body is really no different than its role in regulating the temperature of ambient air. Moisture offsets heat gain through the process of evaporation. As water evaporates, it makes use of heat energy received from the Sun or ambient air to convert water to water vapor. Through this conversion process, heat energy that would otherwise contribute to an increase in skin temperature is effectively locked up in the vaporized water molecules and

transported away. Moisture availability in the human body, therefore, is a critical factor in the body's ability to cope with rising environmental temperatures.

High temperatures stress the human body by overworking the heart and other organs. As temperatures rise, blood must be pumped faster throughout the body to distribute the water needed for perspiration. As long as these lost fluids are continuously replenished, the body can continue to cool itself through perspiration indefinitely. However, the heart is increasingly stressed by the need to circulate blood at an elevated rate. Other organs can be stressed by the loss of sodium, which is also released through the sweating process. If fluids are not replenished, the circulating blood begins to thicken, elevating the risk of clotting and, in the most severe cases, heart attack or stroke. If salts are not replenished, muscles begin to cramp and organs cease to function normally.

The significance of moisture availability to thermoregulation of the human body illuminates a central paradox of heat waves: many victims succumb to heat exhaustion or heat stroke during the night, when temperatures are lower than during the day. Because heat waves are characterized not only by above-average maximum temperatures during the day but also by above-average minimum temperatures during the night, the body may not be afforded sufficient time to recover from heat exposure during a 24-hour period. This is particularly true for vulnerable populations who lack access to air conditioning during the nighttime hours. If the body continues to perspire during the night as a person sleeps, the heart must continue to function at elevated levels and fluids must continue to be replenished. A failure to do so, particularly over a string of several days during a heat wave, can result in a gradual increase in the body's core temperature. If this temperature increases beyond a very limited range – 4 to 5 degrees – the likely result is death.

If a gradual increase in the number of patients admitted to hospitals for heat-related ailments was not sufficient to alert public health officials to an imminent emergency, stress on the natural and physical environments from the relentless heat should have left few doubts as to the severity of the heat wave. By the middle of July, the intensity of the drought, now in its sixth month, was revealing itself in a growing number of wildfires and falling water tables. Sparked by lightning and, in several instances, arson, fires in France, Portugal, Switzerland, and Spain spread rapidly through wilting croplands and forests. By the end of July, 2,300 firefighters were combating 72 separate blazes in Portugal

alone [4]. Fires raging across the French Riviera were characterized as the worst in a generation.

In response to the worsening drought, some of Europe's major rivers fell to historically low levels, greatly limiting the availability of water for irrigation and shipping. By July, the River Po, which provides irrigation water for about a third of all agriculture in Italy, was measured to be 24 feet below its normal flow, its lowest level in 100 years [5, 6]. Diminished levels of the Danube required ships departing Austria to be loaded at no more than 50% capacity [7], and shipping elsewhere on the river was forced to cease altogether [6]. Water flows became so diminished along several Belgian rivers that not even kayakers could safely navigate the channels. Elsewhere, receding waters would reveal unanticipated hazards for shipping and recreation. Four unexploded bombs from World War II were exposed by the retreating waters of Lake Constance in Germany, and the long entombed hulls of ships sunk by bombs during the same conflict jutted forth from the Danube near the Balkans.

Much like the human body, urban infrastructure can become stressed during prolonged periods of intense heat exposure. It is the failure of infrastructure in the form of transportation and electrical power systems that can pose one of the most significant – and the least anticipated – threats of rising temperatures to urban populations. One unanticipated outcome of the 2003 heat wave was the buckling of rail systems and roadways. In July, a freight train carrying a shipment of Guinness beer outside of London derailed as a result of a section of steel rail that had been physically warped by the intense heat. Because all metals are subject to expansion or contraction in response to temperature changes, the steel used for train tracks must be engineered to tolerate a wide range of thermal conditions. An article from the BBC shortly after the derailment explains well the hazard of heat for rail transit systems:

> To prevent [derailments]. . . . the track is "pre-stressed" or stretched, so that when it gets hot, the metal cannot expand any further. It is designed to cope with temperatures up to 30 degrees centigrade (86°F). "Ah," say the armchair engineers, "why not stretch it more so it can take more heat?" The problem is that the stretching makes it more likely to crack in cold weather – British track can take our coldest winters. The main problem is that it is currently much hotter than normal, not just in Britain but across the rest of Europe. The temperature of the track can reach 50 degrees (122°F) [8].

Similar to steel rails, the concrete or asphalt of paved surfaces may also expand beyond engineering thresholds in response to intense and prolonged heat. Over a threshold temperature, asphalt can literally melt, while concrete ruptures, rendering streets impassable. The buckling of rail and roads in several instances across Europe in the summer of 2003 would intermittently delay and force closures of critical infrastructure. In some instances, the heat alone was sufficient to shut down transit systems absent a failure in infrastructure or equipment. Suffering through cabin temperatures as high as 120°F, a tram operator in Helsinki, Finland, lost consciousness, causing him to run a red light and strike a motorcyclist (killing him) before crashing into the wall of a department store [9]. Although no one on the tram was critically injured, the incident revealed yet another unanticipated threat of extreme heat to urban populations: transport system failures.

Undoubtedly the most critical infrastructure during a heat wave is that involved in power generation and transmission. Air-conditioned environments must be accessible to enable the human body to cool during periods of intense heat. Yet, the very conditions that give rise to an urgent demand for electricity can greatly stress the infrastructure delivering that electricity. This was certainly the case in July and August 2003, when the demand for energy soared throughout Europe to meet the cooling needs of homes, offices, and hospitals.

In some instances, operating temperatures within nuclear power plants approached thresholds that would have required an immediate shutdown. One plant near Strasbourg, France, had to be manually hosed down to avoid the violation of safe operating standards as plant temperatures reached 119°F [10]. Elsewhere, plants were taken offline entirely because of an insufficiency of cooling water from drought-stricken rivers. During the height of the heat wave, France, Europe's chief exporter of energy, was required to reduce energy exports by more than 50% to account for the shutdown of numerous power plants and the spiking domestic demand for electricity [11]. Together, these events highlight an obvious but widely underappreciated threat of extreme weather to human health: the reliability of essential infrastructure tends to decline at the very moment population vulnerability rises.

By August, the European heat wave had reached the height of its intensity. During the first two weeks of that month were recorded temperature extremes that had not been experienced in almost 350 years of record keeping – surpassing the longest running set of direct temperature measurements in existence. On August 10, the United Kingdom would reach

an all-time record temperature of 101.3°F, exceeding by several degrees the previous high set a few decades earlier. Michael McCarthy, a columnist for *The Independent*, described well the significance of this event:

> The point about 100 was, it was off the map. . . . It was off the scale completely. But never mind it not being in the meteorological history; it wasn't in the cultural history. There was no cultural reference point for it: no stories, no memories, no jokes, no newspaper headlines. In the temperate Britain for which we all have an instinctive feel, this land of showers and cool summers, this land on the latitude of Labrador only kept from freezing by the Gulf Stream, an air temperature of 100° Fahrenheit represented an unknown country, an elsewhere. The round figure helped with that, to be sure. In Centigrade terms, 100°F is 37.8, and of course 37.8 as such isn't any sort of figure the mind will register, any sort of boldly-marked frontier whose breaching will seem significant; but once you represent it in Fahrenheit, the move up from two digits to three has a symbolical significance of real power. It is a true cultural border, as well as a meteorological one. Above 100 is new territory [12].

Britain was not the only country to reach new territory. On August 11, the high temperature in Switzerland, land of the glacial Alps, would reach an unimaginable 107°F. Between August 7 and 14, minimum temperatures in Paris never dipped below the mid-70s, with the city's hottest night on record suffered through on August 11–12, registering a minimum temperature of almost 80°F. Satellite measurements of temperature across Europe during the height of the heat wave reveal the extremity of the event, with many areas exhibiting temperatures almost 20°F above normal (Figure P.1).

To fully appreciate the gravity of these numbers, it must be noted that air conditioning remains a luxury throughout much of Europe – particularly in individual homes. In 2004, for example, only about 7,500 homes in the United Kingdom – far below the size of a single London borough – were found to be equipped with central air conditioning [13]. Likewise, air conditioning in France, even in the south of France, is not commonly found in homes. As a result, during a two-week period in August, many Europeans were enduring outdoor temperatures in excess of 100°F during the day and close to 80°F in the dead of night, with unventilated indoor temperatures reaching much higher. Because the human body generally can only endure about 48 hours of exposure to excessive heat before suffering effects of heat exhaustion or stroke, the heat wave

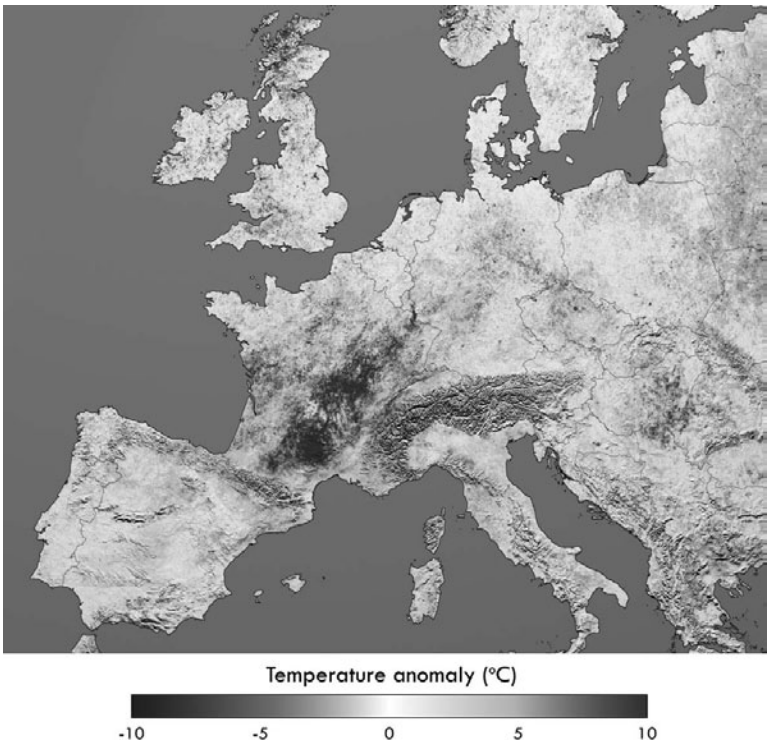

Figure P.1 Temperature anomalies (degrees above or below normal) across Europe on July 31, 2003. *Source:* Adapted from the NASA Earth Observatory http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=11972. (*A color version of this figure can be found in the color plate section after page 86.*)

of August 2003 had become for many a deadly serious weather event. It had become, in short, a natural disaster.

As with all natural disasters, the number of lives lost in a heat wave has as much to do with the adequacy of the emergency response system in place as with the severity of the event itself. In August 2003, European governments were poorly prepared for the public health emergency brought on by the heat wave. Much of the insufficiency of the response was a product of the governments having never contemplated heat as a genuine threat to their populations and therefore having not developed emergency response plans. Also problematic was the timing of the event, which occurred during the height of the summer holiday season

in Europe, when much of the workforce, including medical personnel, was on vacation.

The rapidity with which a public health emergency was unfolding became apparent in the first days of August. At a number of hospitals in France, patient admissions spiked by 20% to 30% over a two-day period, quickly overwhelming understaffed emergency personnel. In one hospital, 20 patients died from heat exhaustion or stroke in a single weekend – a 10-fold increase in the typical number of deaths. As the initial death toll attributed to the heat wave in France reached 50, the president of the French Association of Accident and Emergency Doctors sounded an alarm in the media. "The weakest are dropping like flies," he protested. Government officials "dare to say these deaths are natural. I absolutely do not agree. No statistics are being gathered. There is no general information, nothing" [3].

At the time, it was observed that the majority of those dying were over the age of 65, and a disproportionate number of these individuals lived alone. Less perceptive to the initial symptoms of heat-related health conditions and less mobile in general, older populations have been found in past heat-wave events to be more susceptible to heat exhaustion and stroke. This baseline vulnerability was aggravated in the summer of 2003 because many family members were away on holiday during August and were unable to check in on elderly relatives during the height of the event. It was also found that elderly victims were less likely to open windows at night – a fact attributed to a greater fear of crime – and thus were exposed to dangerously high indoor temperatures.

By the second week of August, the swelling number of patients suffering from heat-related illnesses was overtaxing medical facilities throughout European cities. Yet, unconvinced of the severity of the event, government officials refused to recall vacationing doctors and medical staff home to their hospitals. The inability of the French medical system to cope with the increased numbers of patients is illustrated by the experience of a woman who had taken an elderly aunt suffering from a heat-related pulmonary condition to a hospital. She recounts the following:

> At first [my aunt] was put in an air-conditioned revival room but then she was abruptly transferred to a ward where it was 50°C [122°F]. I talked to two nurses. One said: "I don't have time to bother with her." The other said: "Get her out of here." But the doctors would not let her go. Three days later, she died [14].

What such anecdotal observations cannot convey is the sheer number of people who were dying from heat exposure during the middle of August. Studies commissioned by European governments after the heat wave would find that literally thousands of victims had died over just a handful of days as extreme temperatures persisted unabated. In France alone, it is estimated that approximately 2,200 heat-related deaths occurred on a single day in August [15]. Another 600 had perished that day in Spain and more than 250 in just four Italian cities [16, 17].

The rate at which people were succumbing to the heat in hospitals and in their homes was overwhelming the governments' ability to manage the most tragic aspect of a natural disaster: how to dispose of the growing number of corpses. A newspaper account from late August describes the inability of morgues and undertakers to cope with the bodies of heat-wave victims:

> Nine refrigerator trucks, containing more than 100 unclaimed bodies, have been parked under police guard in a municipal car park in Ivry-Sur-Seine, a southern suburb of the capital, it was revealed yesterday. Others are being kept in a cold store at the Rungis vegetable market and in a morgue normally used for murder victims. Forty other bodies have already been buried in individual graves in the paupers' section of a cemetery east of Paris. City officials said that the bodies could be exhumed and buried elsewhere, or cremated, when relatives are traced. They denied press reports that some bodies had been placed in a mass grave [18].

Yet those press reports were not far off the mark. Under city law, any body unclaimed by relatives after a period of six days must be placed in a "common section" of a municipal cemetery in Paris. Despite an extension of this period in the aftermath of the heat wave to 10 days, many victims of the heat wave, never identified or claimed by family members or friends, were interred in these unmarked graves (Figure P.2).

Unadorned by headstones or statuary, these already forgotten paupers' graves in the far reaches of Parisian cemeteries constitute the first undeniable monuments to a shifting environmental order, and attest to a simple but largely unappreciated truth: our affluence, science, and civil institutions are no match for changing weather. So extreme were the events of August 2003 in France, as throughout Europe, that the language used to describe the event was altered in simple but profound ways. In much the same way as the date 9/11 has come to assume a deeper meaning to Americans, the French term for heat wave – "canicule" – would come in the aftermath to refer to a particular,