

ANALOG EUROPEAN HEAT WAVES FOR U.S. CITIES TO ANALYZE IMPACTS ON HEAT-RELATED MORTALITY

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Air-mass based analogs of the unprecedented 2003 conditions in Paris show the potential for the highest heat-attributable excess mortality in decades if similar weather occurred in U.S. cities.

During the summer of 2003, western Europe was affected by an excessive heat event (EHE) of historic proportions. For most of that summer, temperatures were well above average across a broad region extending from the British Isles to the Iberian Peninsula and eastward to Germany and Italy, but the most extreme conditions centered in France. In Paris, France, maximum temperatures equaled or exceeded 38°C (100°F) for 6 days, and the heat broke long-standing maximum and minimum temperature records during 3–13 August (S. Planton et al. 2004, personal communication; see online at http://unfccc.int/files/meetings/workshops/other_meetings/application/vnd.ms-powerpoint/planton.ppt). The return period of a heat wave of this magnitude is estimated at between 9,000 and 46,000 yr (Schar et al. 2004).

The temporal extent of the EHE was also unprecedented. From 1 June to 31 August 2003, maximum temperatures were above average for all but 8 days in Paris and, for at least half of those days, average maximum temperatures were exceeded by 6°C (10°F) or more (Fig. 1). Minimum daily temperatures were also abnormally above average.

This EHE also impacted public health. Heat-related deaths were very high, with estimates for France alone approaching 15,000 (Koppe et al. 2004; Valleron and Mendil 2004). In Paris, there were at least 3 days when the baseline mortality of about 50 deaths more than tripled (Fig. 2).

Even though an analysis of the European EHE of 2003 indicates that its duration and magnitude is beyond anything that has occurred in either the United States or Europe over the last 150 yr, there is still a well-documented pattern of increased mortality in U.S. cities as a result of EHEs (e.g., St. Louis, Missouri, 1966, 1980; New York, New York, 1975, 1984; Philadelphia, Pennsylvania, 1991, 1993; Chicago, Illinois, 1995). The toll of the European EHE raises the question of what the health impacts of a similar EHE would be in the United States.

The goal of this paper is to develop meteorological analogs of the Paris EHE for five major U.S. cities: Detroit; New York; Philadelphia; St. Louis; and Washington, D.C. This work also estimates mortality for these U.S. cities for a scenario in which an EHE of the magnitude of the 2003 European event occurs

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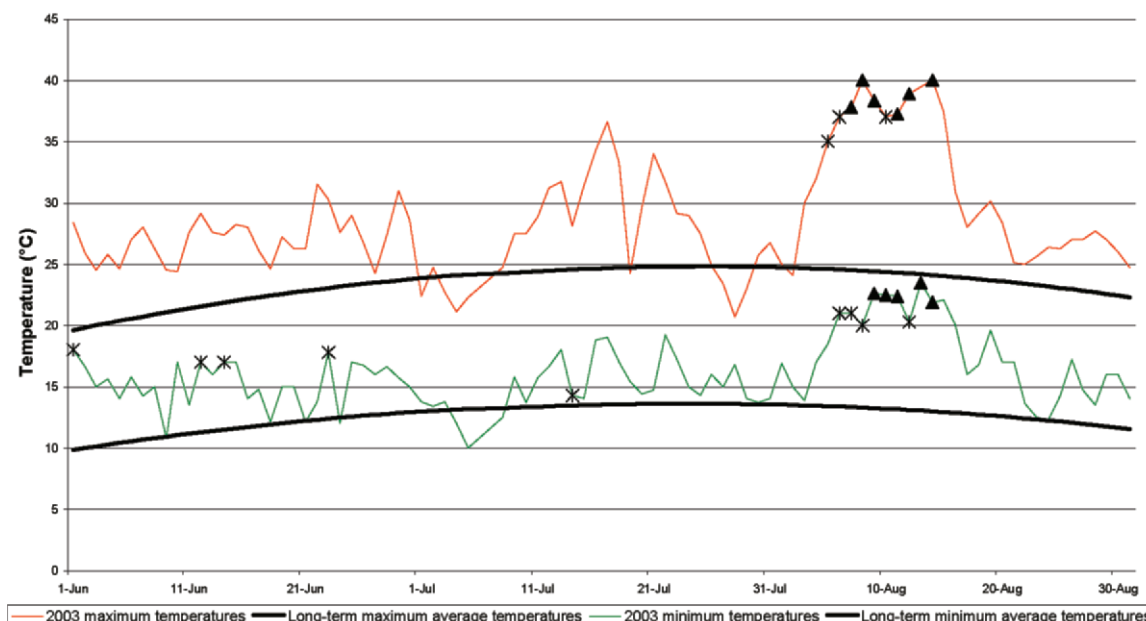


FIG. 1. Actual 2003 vs average maximum and minimum temperatures for Paris during summer. Days with stars exceed the daily record; days with triangles exceed the all-time Aug record.

in each city. Since this unprecedented heat event is not a model but an actual event, we were able to use a plausible analog to assess the risk of increasing heat on these cities instead of an analog that is dependent on general circulation (GCM) modeling or the development of arbitrary scenarios.

These U.S. cities were selected because they are all frequently exposed to irregular and intense heat waves, and their mortality totals have increased dramatically during EHEs (Kalkstein and Greene 1997; Davis et al. 2003, 2004).

METHODS. The analogs are based on actual meteorological conditions in Paris during the 2003 EHE between 1 June and 31 August. We identified 12 key meteorological variables for each day during the EHE in Paris, and transferred those values to the five U.S. cities, based on variation (in standard deviation units from the mean character for each variable) to develop an airmass calendar:

- temperature every 6 h (0400, 1000, 1600, and 2200 LT),
- dewpoint temperature for the same 6-h periods
- mean daily cloud cover,
- mean daily sea level pressure,
- diurnal temperature range of 6-h values,
- diurnal dewpoint temperature range of 6-h values.

Maximum and minimum temperatures for each day during the analog event were also determined.

Once the new variables were derived for each U.S. city (the Paris “analogs”), an airmass calendar was developed for each city. These analogs were employed to develop mortality estimates for the five U.S. cities using procedures that have been applied to our heat–health warning systems (Kalkstein et al. 1996; Ebi et al. 2004; Sheridan and Kalkstein 2004).

The analogs for the U.S. cities were developed using a two-step process. First, the event was characterized statistically, and these characteristics were transferred to the selected U.S. cities. Statistical characteristics for a range of related meteorological variables (those listed above, plus apparent temperature; Steadman 1984) were computed for each day in Paris based on an analysis of the available meteorological data (the French use a base period of 1936–2000; M. Schneider 2006, personal communication). Second, the new meteorological dataset for each city was converted into a daily airmass calendar using the spatial synoptic classification (SSC; Sheridan and Kalkstein 2004). A large body of literature suggests that humans respond negatively to certain “offensive airmasses,” which envelop the body during stressful conditions (Kalkstein et al. 1996; Sheridan and Kalkstein 2004). Thus, rather than responding in isolation to individual weather elements, we are affected by the interactions from a much larger suite of meteorological conditions that constitute an air mass.

The standard deviations for the meteorological variables in Paris were transferred to each U.S. city. For example, if on 1 June 2003, Paris’s 0400 LT tem-

perature was 2.00 standard deviations above the day's average, then each U.S. city would have a 0400 LT temperature that was 2.00 standard deviations above the average. This would be repeated for each day and each of the meteorological variables for each U.S. city, so that a complete set of meteorological conditions analogous to Paris 2003 was developed for each city. Clearly, a day on 1 June with a +2.00 standard deviation for 0400 LT temperature would vary considerably in character between Detroit, St. Louis, and the other three U.S. cities. For the U.S. cities, the means and standard deviations for the meteorological variables were computed based on data for the standard meteorological period of 1971–2000.

After each U.S. city had a meteorological analog for the 12 variables for summer 2003 in Paris, the newly developed dataset was transposed to a daily airmass calendar for each city using the SSC procedure. This calendar could then be compared to the Paris summer 2003 airmass calendar, and to typical frequencies of the summer air masses in each U.S. city. Airmass frequency comparisons can also be made with the hottest summers over the past 60 yr, since historical SSC calendars have been derived for U.S. cities since 1945, the point where digital data are available.

The following airmass categories are identified by the SSC:

- dry polar (DP),
- dry moderate (DM),
- dry tropical (DT),
- moist polar (MP),
- moist moderate (MM),
- moist tropical (MT),
- moist tropical plus (MT+),
- transition (T).

Daily mortality data were obtained from the National Center for Health Statistics (NCHS), and include information on cause, place, and date of death; age; and race of every individual who has died in the United States (NCHS 1998). These mortality data are adjusted to account for changes in the total population of the individual cities during the period of record

(refer to Sheridan and Kalkstein 2004 for further details).

For each U.S. city, the mean daily mortality for each airmass type, along with the standard deviation, were determined to ascertain whether particular air masses exhibited statistically significantly elevated mortality values. Once each “offensive” air mass was identified (typically DT and MT+), the average number of deaths for each daily offensive airmass occurrence was computed using an offensive airmass–specific algorithm (the algorithm was based on a pooled total of all offensive airmass days) derived via a stepwise regression analysis. Meteorological variables and nonmeteorological variables were included in this regression analysis. The nonmeteorological variables are “time of season” and “day in sequence.” The time of season evaluates the intra-seasonal timing of a weather event, because a heat wave in August usually exerts less influence on heat-related mortality than a similar one in June because of acclimatization and mortality displacement [a larger susceptible population is available to die of the heat in June; Sheridan and Kalkstein (2004)]. The day-in-sequence variable determines if several consecutive days of the offensive category have a greater impact on mortality than an individual, isolated day. Several meteorological variables were also included, such as temperature and dewpoint at 0500 and 1700 LT, and apparent temperature at 1700 LT.

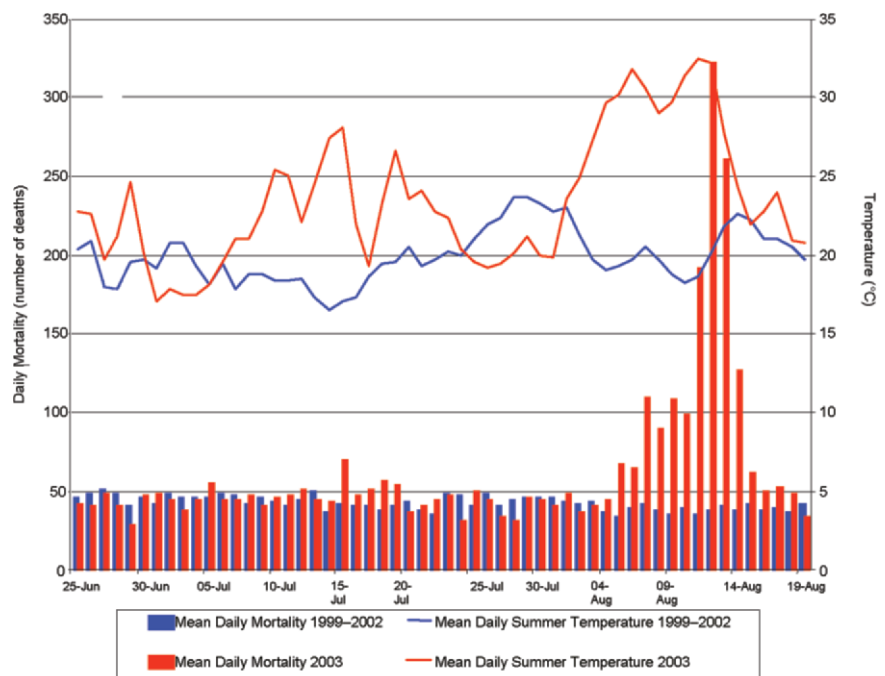


FIG. 2. Mean temperature and associated mortality for Paris: summer 2003 and average summers, 1999–2002.

The derived algorithms (Table 1) included all of the statistically significant variables ($p < 0.05$) for each U.S. city. These algorithms were used for each of the five U.S. cities on offensive airmass days during the analog 2003 summer to estimate the number of deaths that would occur on each of these days in each city.

Two sets of rules were used to define daily mortality for each city: the “lower-limit” mortality estimates, which are particularly conservative;¹ and the “revised” estimates.

We have concern that this might underestimate the heat-related mortality total, as it is unfeasible that a single, nonoffensive day imbedded within a long string of offensive days does not produce any deaths. In addition, if the nonoffensive day is still relatively warm, such as an MT, transition, or DM day, our research suggests that excess deaths can still occur on those days, and the consecutive day counter should not be reset to 0, as a single day break does not end the impact of an extended heat event (Kalkstein et al. 1996).

Thus, the revised set of mortality estimates is derived with somewhat looser rules than the lower-limit estimates in terms of dealing with consecutive day counts. In the revised estimates, unlike the lower limit, the consecutive day counter is not set to 0 when there is a single day break in a long, consecutive day string of offensive air masses (the counter is set to 0 if the break is greater than 1 day). Rather, the counter is reduced by 1 day, and then recounts from that point when the offensive airmass series starts again.

Although reducing the counter by 1 is admittedly a value judgment (yet based on our long experience), it is quite clear that a single-day break does not end the impact of an extended heat event. For the looser rules, assume the following sequence of airmass days: DT, DT, MT+, MT, DT, DT, DT, and MT+. The revised counter for consecutive days would be 1, 2, 3, 2, 3, 4, 5, and 5 (the counter never exceeds 5, since we have found that beyond this many days, the impact of consecutive days is no longer significant in most U.S. cities). Thus, for the MT day, the counter only goes down 1 and resumes on the next offensive day. In addition, for the MT day, a mortality total using the offensive airmass algorithm for the particular city is calculated. This only occurs if MT, transition, or DM air masses intrude on the consecutive string for 1 day. If DP, MM, or MP are within the string, the counter is set to 0 even for the revised set, and no mortality is calculated for that day.

RESULTS. Meteorological evaluation of the analogs. The summer of 2003 in Paris was exceptional in offensive airmass frequency (Table 2). On average, 10% of all summer days in Paris are within offensive air masses (7.0% DT, 3.0% MT+). The DT is commonly more frequent in the summer than MT+ in Paris, and during 2003, the percentage frequency of both offensive air masses increased dramatically, and one-third of the summer days in Paris were within the DT air mass, over 4 times the average. Almost half (46%) of all 2003 summer days were within offensive air masses.

The hottest previous summer in Paris, 1990, had a combined DT/MT+ frequency of 32%, much less than the 2003 frequency.

An evaluation of the airmass frequencies for the analogs to the 2003 Paris EHE in the five U.S. cities provides a clear picture of how exceptional this event would be (Table 2). For example, during an average summer, New York City experiences offensive air masses MT+ or DT on 12.5% of the days. Applying the 2003 analog to New York City, the summer value increases to over 56% for the two offensive air masses combined, a frequency of over

TABLE 1. Mortality algorithms for the five U.S. cities.

City	Equation
New York	$-4.394 + 8.343 \text{ DIS} - 0.082 \text{ TOS} + 0.33 \text{ AT17}$
Philadelphia	$-1.625 + 0.835 \text{ DIS} - 0.018 \text{ TOS} + 0.086 \text{ T17}$
St. Louis	$0.023 - 0.012 \text{ TOS} + 0.13 \text{ T17}$
Detroit	$-0.653 + 3.183 \text{ DIS}$
Washington, D.C.	$1.538 + 0.065 \text{ AT17} - 0.006 \text{ TOS} + 0.281 \text{ DIS}$
Where	
TOS = Time of season (1 = 1 May, 32 = 1 Jun, and so on).	
DIS = Day in sequence (day 1 = 1, day 5 = 5, cannot exceed 5).	
T17 = 1700 LT temperature °C.	
AT17 = 1700 LT apparent temperature °C.	

¹ The lower-limit estimates are extremely conservative, and whenever there was a break in the offensive airmass consecutive-day sequence of even a single day, the sequence was reset to 0 before the next offensive airmass day occurred. For example, assume the following sequence of airmass days: DT, DT, MT+, MT, DT, DT, DT, and MT+. Using the lower-limit approach, the consecutive-day series used in the algorithms for each day is 1, 2, 3, 0, 1, 2, 3, and 4. Thus, the lower-limit mortality estimates assume that a break in the sequence of even 1 day totally ends the heat impact, and the heat mortality total is reset to 0 on the nonoffensive day (in this case, the MT day). In addition, the next DT day begins the consecutive day count at 1.

TABLE 2. Summer percentage frequencies of offensive airmass days for the five U.S. cities and Paris.
(Source: <http://sheridan.geog.kent.edu/ssc.html>.)

City	Avg DT*	Avg MT+*	Analog DT	Analog MT+	Diff analog vs avg DT	Diff analog vs avg MT+	DT hottest summer	MT+ hottest summer	Diff analog vs hottest summer DT	Diff analog vs hottest summer MT+
Detroit	2.7	6.6	25.3	11.0	837.0	66.7	29.4	8.8	-13.9	22.7
New York	5.7	6.8	37.4	18.7	556.1	175.0	14.1	16.3	165.2	14.7
Philadelphia	6.0	8.4	35.1	20.9	485.0	148.8	10.9	30.4	222.0	-31.2
St. Louis	4.9	12.8	31.9	22.0	551.0	71.9	22.8	19.6	39.9	12.2
Washington, D.C.	4.7	9.0	24.2	8.8	414.9	-2.2	21.7	13.0	11.5	-34.3
Paris	7.0	3.0	33.0	13.0	371.4	333.3	26.0	6.0	26.9	116.7

*Avg for period 1945–2003.

4 times greater than average. The extreme nature of the analog is apparent when compared to the actual summers in New York City from 1945 to 2003, when the hottest summer in New York, 2002, demonstrated a combined total summer frequency of MT+ and DT of about 30%. Thus, the combined frequency of these air masses during the analog summer was over 80% higher than the next hottest year over almost 60 yr. The analog summers for the other U.S. cities demonstrated very high frequencies of offensive air masses as well, and they all exceeded the mean frequencies by 300% or more.

There are noteworthy similarities and differences between Paris during the summer of 2003 and the five U.S. analogs:

- All cities show somewhat similar frequencies in the offensive air masses during average summers, although the U.S. cities generally have a higher prevalence of MT+, rather than DT, air masses, while the reverse is true in Paris.
- All cities show dramatic frequency increases for 2003: Philadelphia, New York City, and St. Louis demonstrate analog summers with over 50% frequency of the offensive air masses (a bit higher

than Paris's 46%), while Detroit and Washington, D.C., show more modest, but still sizable, increases in frequencies.

- Philadelphia, New York City, St. Louis, and Paris possess considerably higher offensive airmass frequencies during 2003 (or the 2003 analog) than the hottest summer (second hottest summer for Paris) during the almost 60-yr period. Detroit and Washington, D.C., show similar frequencies of these air masses during the analog and the hottest recorded summer.
- For all analogs and for Paris in 2003, the frequency of DT air masses exceeds that for MT+ by a sizable margin. For Detroit, St. Louis, and Washington, D.C., the hottest summer possessed more DT than MT+ days. For New York City and Philadelphia, the most eastern of the cities, the opposite was true.²

The number of consecutive days within offensive air masses is also very unusual for the analog summer. For New York City, there is a consecutive day string of DT air mass days (one imbedded transition day) between 2 and 16 August. For Philadelphia, this string extends to 17 August (with no intervening transition

² There is some question whether the analog summer frequencies of DT air masses in Philadelphia and New York City are realistic, considering their magnitude and the distance between these eastern cities and DT source regions in western North America. First, the airmass-based system, as defined by the SSC, is not concerned with source region, but is dependent exclusively on airmass character. Thus, consider that air descending the lee of the Appalachians is both warmed and dried when it drops 1000 m or more; this explains why high temperature/low dewpoint situations occur with some frequency east of the mountains, from Maine to Georgia. Second, there have been numerous summers when DT airmass frequencies have exceeded MT+ and MT frequencies in these eastern cities. For example, during summer 1953 in Philadelphia, DT frequencies exceeded 22%, while MT+ and MT frequencies during the same year were only 5% and 10%, respectively. Thus, it is not uncommon (see online at <http://sheridan.geog.kent.edu/ssc.html>) for DT to be the predominant offensive air mass in East Coast cities. Finally, although DT airmass frequencies in New York City and Philadelphia are particularly high during the analog summer, they are not out of line with the increases between typical summers in Paris and that of 2003 (Table 2). For Paris, this increase is 26% (ranging from 7% to 33%), for Philadelphia it is 29.1%, and for New York City it is 31.7%. Thus, we believe that it is climatologically feasible for the East Coast cities to have DT airmass frequencies approaching 30%, if a summer like 2003 were to occur in the area.

day), which represents a previously unheard-of string of 16 consecutive DT days; strings of this length have historically not occurred east of Little Rock (see online at <http://sheridan.geog.kent.edu/ssc.html>). The strings are shorter, but still considerable, for the other cities. A second consecutive-day period of offensive air masses occurs in mid-July. New York City has the longest string of consecutive days during this period, extending from 8 to 22 July, with one nonoffensive day (MT) imbedded. Finally, in June of the analog summer, there is a long period of

consecutive MT+ days in St. Louis and New York City. Thus, the cities had up to three periods during the analog summer with sizable periods of consecutive offensive air mass days, just as Paris did; this exceeds the hottest year during the period of record.

Maximum and minimum temperature records during summer 2003 in Paris and for the analog summers for the U.S. cities exceeded anything in recorded history (Figs. 1 and 3). In Paris, the all-time August maximum temperature record, set in 1911, was broken by almost 2°C six times during

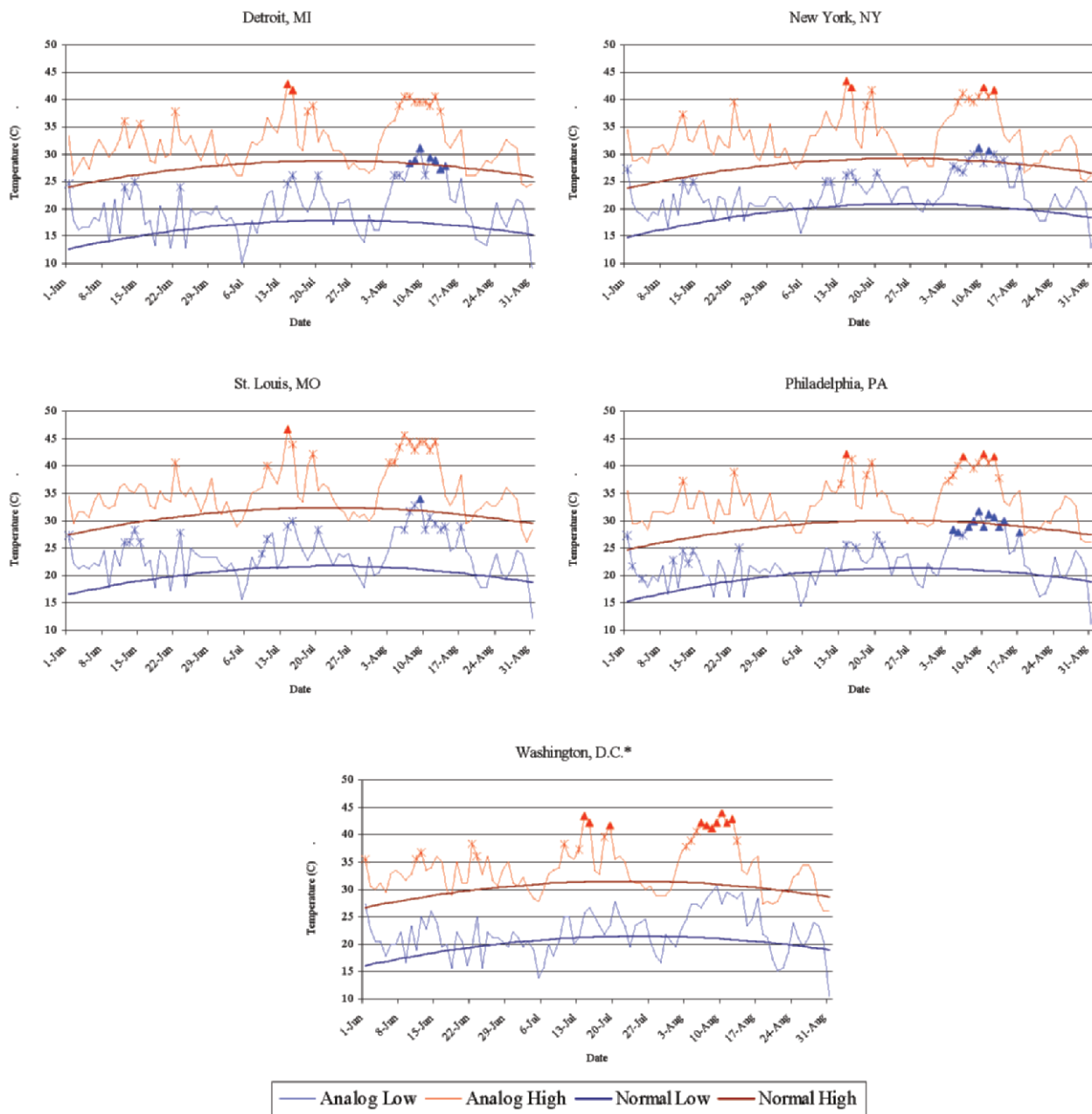


FIG. 3. Maximum and minimum temperatures for the analog summer for the five U.S. cities. Days with stars exceed the daily record; days with triangles exceed the all-time Aug record. The asterisk signifies record-minimum temperature data missing for Washington, D.C.

the month, during two 3-consecutive day periods. From 6 to 14 August, each day broke a daily maximum temperature record. For the U.S. analogs, a similar number of maximum temperature records were broken. Philadelphia had 4 days that broke the all-time maximum temperature record for August, although, unlike the actual event in Paris, there were no 3-consecutive-day strings (see online at www.erh.noaa.gov/er/phi/climate/phlclimate.html).

Minimum temperatures are equally oppressive during summer 2003 in Paris and the analog summers. In Paris, the all-time summer high-minimum temperature record was broken by 1.5°C, and the all-time August record was broken by almost 3°C (M. Schneider 2006, personal communication). Five days broke the all-time August high-minimum temperature record, comprising a consecutive 3- and 2-day string. Seven days in August broke the daily high-minimum temperature record during 8 days between 5 and 12 August. A large number of records were also broken at each U.S. city (Fig. 3). Heat-related illnesses and deaths are generally more sensitive to minimum, rather than maximum, temperatures, since higher overnight temperatures provide little relief in non-air-conditioned dwellings.

Excess mortality in the analog events. During an average summer, using an airmass-based evaluation similar to the one employed here, approximately 1,000 people die of heat-related causes in the 44 largest cities in the United States, and this number jumps to between 1,500 and 2,000 for the entire country (Kalkstein and Greene 1997; Epstein and Mills 2005). Thus, the number of excess deaths estimated for each of the five cities under analog heat wave conditions is very high, although not as extreme as the number of deaths in Paris (Fig. 4). For New York City, excess mortality during the analog summer is over 2,000, using either the lower limit or revised means of calculating deaths. The New York Standard Metropolitan Statistical Area contains about 4% of the nation's population, yet the analog heat wave produces excess deaths in this region that exceed the national average for the 44 largest cities during a typical summer.

During the most severe month of the analog, August, excess deaths are in the hundreds for all

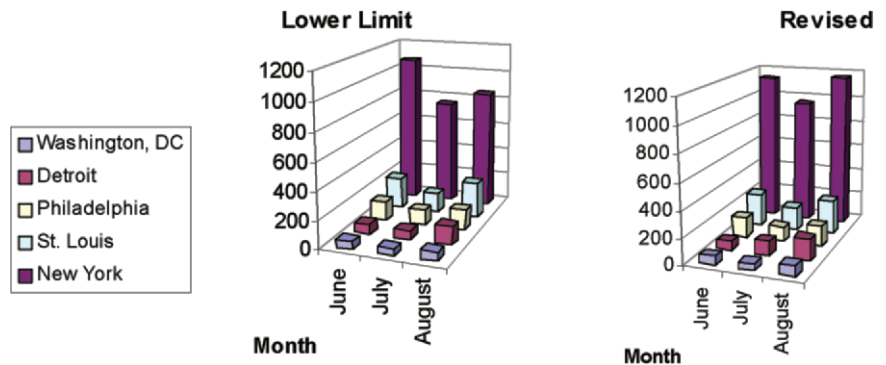


FIG. 4. Monthly excess deaths in the five U.S. cities for the analog summer: lower limit and revised.

five cities. New York City's number is greater than 1000 excess deaths in this month using the revised estimation. Even June and July have very high excess death numbers; in U.S. cities, early-season heat is more dangerous than late-season events because of acclimatization issues and the larger vulnerable population early in the summer (Kalkstein 1993).

Some of the most oppressive days in New York City during the analog summer have excess mortality totals that are up to 65–70 deaths above the baseline. In the New York City area during summer, there are approximately 325 deaths day⁻¹ on average, based on the 2000 metropolitan area population of about 9.3 million (see online at www.census.gov/population/cen2000/phc-t3/tab01.txt), with an average summer death rate of 3.5 people per 100,000 (McMichael et al. 1996). Thus, the excess death numbers for these days represent over 20% of total daily mortality from all causes in New York City, and would render heat one of the top three killers in the city on those days. In addition, our estimates show that there are several consecutive 3-day periods in July and August that accumulate about 200 excess deaths from heat.

A comparison between average summer heat-related mortality and the analog summer mortality totals is striking (Table 3). During an average summer, there are 47 excess deaths attributed to heat in Detroit; for New York City, this number is 10 times higher. An evaluation of death rates from heat per 100,000 population indicates that St. Louis is the most sensitive city of the group, with a death rate of 8.30 during an average summer. New York City is also quite sensitive, while Philadelphia, Washington, D.C., and Detroit are somewhat less sensitive. However, all five cities have sensitivities well above the national average. For the analog summer, death totals and rates increase dramatically. The most impacted city is New York, with 3,253 deaths, and a death rate of 34.98 per 100,000. For comparison purposes, the annual death rate from

TABLE 3. Heat-related mortality (expressed as excess deaths) during the average, analog, and hottest historical summer. The rules for lower-limit and revised mortality estimates are discussed in text.

	Detroit	New York	Philadelphia	St. Louis	Washington
Metropolitan area population ^a	4.4 million	9.3 million	5.1 million	2.6 million	4.9 million
Avg summer heat-related mortality ^b	47	470	86	216	81
Avg summer mortality rate per 100,000 population	1.07	5.05	1.69	8.30	1.65
Analog summer heat-related mortality	342	3253	432	688	191
Analog summer mortality rate per 100,000 population	7.77	34.98	8.47	26.46	3.89
Hottest historical summer mortality ^c	308	1277	412	533	188
Hottest historical summer mortality rate per 100,000 population	7.00	13.73	8.08	20.50	3.84
Year of hottest historical summer occurrence	1988	1995	1995	1988	1980
Analog percent deaths above hottest historical summer	11.0	154.7	4.9	29.1	1.6

^aBased on U.S. Census Bureau data (see online at www.census.gov/population/cen2000/phc-t3/tab01.txt).

^bNumbers represent revised values.

^cBased on the period from 1961 to 1995.

all accidents for the age group 45–64 is 30.4, which is slightly less than the analog summer's heat death rate [Centers for Disease Control (CDC) 1997]. Accidents rank as the third greatest cause of death for this age group. The analog summer death rate is high for the other cities as well, with St. Louis just slightly behind New York City.

We determined heat-related excess mortality for a 35-yr summer period from 1961 to 1995 using the same procedure employed for the analog city summer. The years 1980, 1988, and 1995 rank as three of the hottest over the past century and excess mortality for those years is considerably less than the analog summer. For New York City, the analog summer mortality rate is more than 150% greater than the hottest year in that period, 1995, and for all five cities, the analog summer produces higher mortality rates than the hottest summer in a 35-yr period.

One could argue that the regression equations developed for the five cities were based on meteorological conditions far removed from the extreme weather of the analog summer, and thus, the mortality estimates are unrealistic. However, based on a study we helped construct for Rome, Italy, where we developed a heat–health warning system (HHWS), it is clear that, if anything, mortality from heat may be underestimated in this study for the analog summer. In Rome, the HHWS was established in 2002, and all heat-mortality algorithms were redeveloped after the very hot summer of 2003 after it was apparent that the older algorithms were underestimating mortality for summer 2003 (deDonato et al. 2004). The Rome heat event was as intense as the Paris event, but in relative terms, was a

bit less extreme because of the warmer climate in this Mediterranean city. Obviously, we cannot develop new algorithms for the five U.S. cities, since the analog summer is not a real event. However, the Rome study clearly points out that the older algorithms, based on more benign meteorology than the 2003 EHE, underestimated the true impact of summer 2003 in that city, and this may also be the case for the U.S. cities.

DISCUSSION. It is clear that the analog summer would have an unprecedented impact on heat-related health in all five U.S. cities, although none of the cities show mortality rates as high as Paris during August 2003. However, there is a noticeable difference in the health impacts among the five cities. Detroit appears least affected by excessive heat, with a death rate during an average summer that is one-fifth of the response in New York City, one-eighth of the response in St. Louis, and about one-half lower than Philadelphia and Washington, D.C. However, under analog conditions, Detroit responds in a more extreme fashion, exceeding the response in Washington, D.C., and similar to the response in Philadelphia. Detroit has the coolest summer climate of the five cities, and extended consecutive-day periods of the offensive air masses are rare. Four of the five cities' algorithms have "day in sequence" as a statistically significant variable (refer to Table 1). Detroit's coefficient of +3.183 for this variable is second only to New York's, and of course, New York City represents a much larger population. Considering the enormous string of consecutive offensive air mass days in mid-July and mid-August of the analog summer, the excess mortality number

in Detroit rose to very high levels because of the magnitude of the day-in-sequence coefficient.

The population of St. Louis has historically been disproportionately impacted by heat, and an EHE similar to the Paris event in 2003 would be devastating. The 688 estimated deaths would approach the totals of the terrible Chicago heat event of 1995, but in a much smaller metropolitan area. Temperatures would be the highest of any city evaluated here, and apparent temperatures would exceed 49°C (120°F), values far in excess of National Weather Service traditional guidelines used to determine excessive heat warnings. Once again, the algorithm for St. Louis, based on historical heat–health relationships, explains this. Afternoon apparent temperature is a statistically significant variable in four of the five city algorithms, and the coefficient for St. Louis is double Washington, D.C.’s, and much higher than Philadelphia’s, two significantly larger metropolitan areas. Compared to many Midwestern cities with similar climate conditions, St. Louis has a large percentage of older, brick housing, along with an older population with lower income that is less well housed than those in the surrounding counties (Smoyer 1997).

New York City appears to be the most impacted city by the analog heat wave, both in terms of raw mortality numbers and death rates. By our estimates, a summer similar to the 2003 event in Paris would be associated with mortality totals over 150% above the next highest summer since 1961. In 1995, the number of excess deaths attributed to heat in New York City was approximately 1,300; the analog summer number exceeds 3,200. Part of this may be driven by the algorithms, where day in sequence possesses a coefficient 10 times that of Philadelphia and 30 times that of Washington. But it is apparent that something else is at play here, probably related to urban structure; New York demonstrated unusually high heat sensitivity in an earlier study (Kalkstein and Greene 1997). The unique housing in poor areas, dominated by many high-rise brick buildings, and city density may play a role; New York has, by far, the greatest population density (people per square mile) of any city in the United States (over double any of the 20 largest cities except San Francisco; Gibson 1998). Ironically, heat intervention activities in the city do not approach levels found in Philadelphia or many other large cities [U.S. (Environmental Protection Agency) EPA 2006].

Philadelphia and Washington, D.C., are less affected than New York City and St. Louis under Paris analog conditions;

however, consequences of such a heat wave in these cities would be disastrous. Washington, D.C.’s, mortality would approach 190, which is slightly higher than the hottest summer, 1980. Philadelphia’s excess death total during the 2003 analog would exceed 430, about 5 times the heat-related death total for an average summer. Philadelphia has an elaborate heat intervention plan that has saved lives (Ebi et al. 2004), but considering the magnitude of the analog heat event, it is uncertain whether the present mitigation measures would be capable of averting a health disaster in the city.

There are some differences in the responses between the U.S. cities and Paris during an EHE like the 2003 event. For example, Paris’s mortality is much higher during the August portion of the heat wave (Fig. 2), while most of the U.S. cities show lesser extreme mortality peaks during August as opposed to the earlier months (Fig. 4). Keeping in mind that the Paris numbers are based on actual mortality counts while the U.S. city numbers are estimates derived from historical algorithms, there are some explanations for this. The first is a unique feature in U.S. cities: most of the susceptible people die in early-season heat waves, leaving a smaller vulnerable population later in the season. Four of the five U.S. city algorithms possess a time of season variable that is statistically significant with an inverse coefficient, indicating the importance of early season heat on the population. In Paris, as shown in Fig. 2, the early season EHE did not appear to be of the magnitude to create a similar response.

Additionally, the differential between the U.S. cities and Paris might be partially attributed to the development of the analogs themselves (Fig. 5).

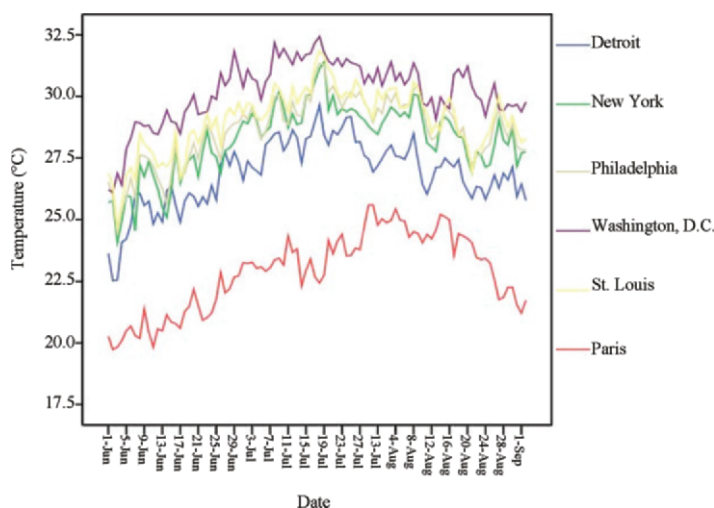


FIG. 5. Mean summer maximum temperature for the U.S. cities and Paris.

Average maximum temperatures in the U.S. cities peak in mid-July, while the marine influences in Paris delay this peak until August. In addition, temperature standard deviations in most of the U.S. cities are much higher in the early part of the summer and achieve a minimum in August (Fig. 6). The temperature standard deviation for Paris is much higher in August than for any of the U.S. cities. This impacts the construction of the analog summer, which explains why the U.S. cities have quite similar mortality rates for all 3 months, while those for Paris are skewed highly to August.

Since the peak summer temperatures reach their maximum earlier in the U.S. cities than in Paris, this explains why the temperatures in June and July are closer to the August values in the U.S. cities than in Paris. The higher early-season standard deviations for the U.S. cities also had an amplifying effect on early summer season temperatures and a dampening effect on August temperatures. This may represent an imperfection in the expression of the analogs, because it accentuates the heat of the analog period early in the summer and suppresses it in August for the U.S. cities. However, it would be illogical not to use the actual mean temperature and standard deviation curves for these U.S. cities. If anything, our approach leads to more conservative mortality values for the U.S. cities during the extended August EHE period, since that was the episode when the consecutive-day period was at its maximum and temperatures were suppressed slightly because of this differential.

CONCLUSIONS. Key findings include the following:

- Summer frequencies of the offensive air masses ranged from over double to more than triple the average during analog summer in the five U.S. cities. Frequencies also exceeded the hottest summer over the past 59 yr for all cities but Washington, D.C.
- Offensive airmass consecutive-day strings of unprecedented length were a hallmark of both the Paris 2003 EHE and the analogs.
- All-time August records for maximum and high-minimum temperatures were broken in all cities, and in some locales, consecutive days broke all-time records.
- Excess deaths were very high for the analog summer, with an estimated total across all locations that was more than 5 times the average calculated for summer. New York City's total exceeded the national summer average for heat-related deaths.
- New York City and St. Louis had the highest death rates for the analog summer, approaching annual mortality rates for common causes of death, such as accidents.
- For three of the five cities, mortality rates from the heat during the analog summer were over 10% or greater than the hottest summer from 1961 to 1995 (New York City's rates were over 150% higher).
- The U.S. cities demonstrated greater anomalous mortality during the July portion of the analog EHE than did Paris, but a smaller anomaly during the August portion. Part of this is attributed to very significant negative health responses early in the summer in U.S. cities, which is less pronounced in Paris.
- Because of summer temporal differences in the shape of the mean temperature and standard deviation curve, the analog EHEs were comparatively more extreme in July in the U.S. cities and worse in August in Paris.

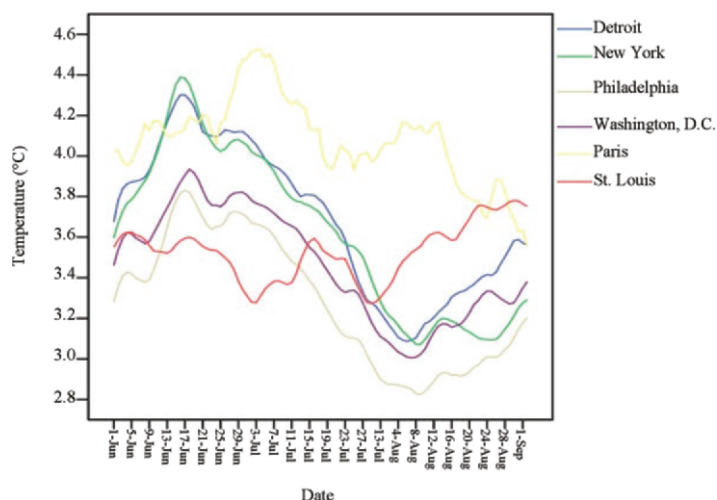


FIG. 6. Std dev for mean summer temperature for the U.S. cities and Paris.

The meteorological dataset representing the Paris analog EHE developed for the five U.S. cities can have broad application for evaluating environmental problems relating to extreme weather. For example, how would these conditions impact water resource or animal management? What effects might these extremes have on electricity generation and transmission? These analogs can be used much like modeled meteorological datasets that are

most commonly used in applied studies of this type. Certainly the procedure can be expanded to include more cities in North America or other midlatitude locations worldwide.

Finally, there are potential climate-change implications related to analog EHE development. Some can assume that, if the climate warms as many expect, more summers will approximate the extreme characteristics of the analog EHE. Since this is a historical event, we have a real-time analog of potential conditions under a climate-change scenario. Thus, this paper tries to answer a small portion of the following question: What would the social and environmental impacts be if these conditions were approximated in other locales?

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