HEAT MORTALITY VERSUS COLD MORTALITY

A Study of Conflicting Databases in the United States

BY P. G. DIXON, D. M. BROMMER, B. C. HEDQUIST, A. J. KALKSTEIN, G. B. GOODRICH, J. C. WALTER, C. C. DICKERSON IV, S. J. PENNY, AND R. S. CERVENY

Studies of heat- and cold-related mortality in the United States produce widely ranging results due to inconsistent data sources, and this paper describes the methods, assets, and limitations of the most common temperature-related mortality sources.

When set against the backdrop of the massive death toll associated with the August 2003 heat wave in Europe, weather-related mortality and the comparison of the various causes is important in regard to preparation, policy determination, and the allocation of resources. However, discussion of cross-disciplinary statistics is difficult due to the lack of knowledge and communication between different areas of interest. Even in a country such as the United States, where substantial documentation of mortality exists, significant errors and marked differences can occur. A classic case is the number of fatalities associated with "excessive cold" or "excessive heat," where statistics have been independently compiled by weather sources of information (e.g., National Climatic Data Center) and by medical authorities (e.g., Centers for Disease Control and Prevention's National Center for Health Statistics). Such comparisons set the number of heat stroke victims, and other sources of life-ending heat-related conditions, against hypothermia and other sources of life-ending cold-related conditions. The adequate allocation of medical resources, formulation of advance warning and prediction systems, and other policy decisions are fundamentally linked to questions of the following type: "Do more people die from heat than die from cold?" and even more basically, "How many people die due to heat or cold?"

Interestingly, depending on the database used and the compiling U.S. agency, completely different results can be obtained. Several studies show that heat-related deaths outnumber cold-related deaths, while other studies conclude the exact opposite. We are not suggesting that any particular study is consistently inferior to another, but, rather, that it is absolutely critical to identify the exact data source, as well as the benefits and limitations of the database, used in these studies.

AFFILIATIONS: DIXON, BROMMER, HEDQUIST, KALKSTEIN, GOODRICH, WALTER, DICKERSON, PENNY, AND CERVENY—Office of Climatology, Department of Geography, Arizona State University, Tempe, Arizona
CORRESPONDING AUTHOR: Randy Cerveny, Department of Geography, Arizona State University, P.O. Box 870101, Tempe, AZ 85287-0104
E-mail: cerveny@asu.edu
DOI:10.1175/BAMS-86-7-937

In final form 19 January 2005

DISCUSSION OF DATABASES. *Centers for Disease Control and Prevention.* The Centers for Disease

Control and Prevention's (CDC's) National Center for Health Statistics (NCHS) maintains electronic records for identified causes of death. Each state is responsible for compiling their death certificates and entering the information into a series of computer programs—such as the Automated Classification of Medical Entities (ACME); Translation of Axis, (TRANSAX); Mortality Medical Indexing, Classification, and Retrieval system (MICAR); and Super MICAR. Such programs scan for common terms and then code the data based on keywords. In some cases, however, such as those with multiple causes of death, human review may be necessary. Additionally, in a few cases, human evaluation under strict regulations might reorder the cause of death as stated on the death certificate and override the examining doctor's diagnosis of ultimate cause of death.

To quote a practicing physician, "death certificates are pretty straightforward." Much like any other official paperwork, the death certificate consists of a series of blanks that must be filled with specific information regarding the deceased. The forms tend to vary by state and are meant to record the fundamental cause of death, as well as unambiguously identify the person in question. The space on the certificate that is provided to state the cause of death is not particularly large. Rather, there is generally a single blank for the "immediate cause," as well as another small space used to list any underlying causes that may have led to the immediate cause. There may also be a small space for the explanation of other contributing factors (e.g., substance abuse, disease, smoking, etc.) that were not related to the immediate cause. However, each of these spaces is separate, and mortality compilations based on the immediate cause usually exclude information about underlying or complicating factors. Unfortunately, for most users the acquisition of death certificate copies is cost prohibitive, and the use of a secondary dataset, a codified analysis of death certificates such as the Compressed Mortality Index, is necessary.

Consequently, the CDC NCHS maintains a database that is structured on the cause of death as denoted by the deceased's death certificate. Deaths are classified as to the underlying cause, using the International Classification of Disease (ICD) [ninth edition for 1979–98 (ICD-9) and tenth edition for 1999–present]. The World Health Organization (1992) defines the underlying cause of death as "the disease or injury that initiated the train of events leading directly to death, or the circumstances of the accident or violence, which produced the fatal injury." Weather-related mortality categories according to the ICD-9 classification scheme include "excessive heat," "excessive cold," "lightning," and "high and low air pressure and changes in air pressure" (Table 1) among others. Most of the excessive cold and excessive heat mortality studies presented in the CDC's publication *Morbidity and Mortality Weekly Report* employ this database (Donoghue et al. 2003; Grey et al. 2002; Mirchandani et al. 2003; Sathyavagiswaran et al. 2001).

Table 1. Selected categories of various databases containing weather-related mortality.

Selected major categories of the ICD-9	Selected weather categories from NCDC's *Storm Data*
Excessive heat	Drought
Excessive cold	Dust storm
High and low air pressure and changes in air pressure	Fog
Hunger, thirst, exposure, and neglect	Hail
Lightning	Hurricane/tropical storm
Cataclysmic storms, and floods resulting from storms	Lightning
Cataclysmic Earth surface movements and eruptions	Tornado
Accidental drowning and submersion	Wild/forest fire
Struck accidentally by falling object	Ocean/lake surf
Exposure to radiation	Precipitation
Overexertion and strenuous movements	Snow/ice
Other and unspecified environmental and accidental causes	Temperature extremes
Late effects of accidental injury	Thunderstorms and high winds

Kalkstein (1991) proposed the use of standardized gross mortality values as a method to determine the number of people dying from heat-related events. Using this method, total daily mortality within a metropolitan area is standardized first for population change, and then for time of year, because more deaths occur during the winter months (Fig. 1). A residual is then computed from the difference of the specific date/year of mortality and its standardized counterpart. It has been shown that heat waves exhibit an increased number of deaths over the standardized values (excess deaths), and this excess will be more reflective of the actual number of heat-related deaths (Kalkstein 1991). It is important to note that the gross mortality method takes all causes of death into account, and evidence has shown that overall mortality rates of numerous causes, such as heart attack and stroke, increase during heat waves. Thus, there is no need for stratification by cause of death.

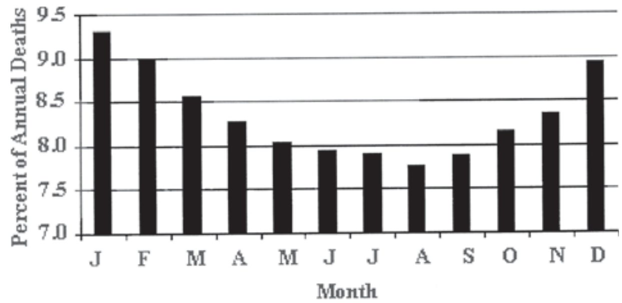

Fig. 1. Gross mortality (in percentage of annual deaths) for 12 cities across the United States for 1975–98.

Storm Data *index.* *Storm Data,* maintained by the National Climatic Data Center (NCDC), lists mortality values that are compiled (based on reports from trained spotters, law enforcement agents, emergency managers, and various media sources) by local National Weather Service (NWS) offices. *Storm Data* publications are easily accessible online through the NCDC Web site for 1994–present. However, a search function allows users to query the Storm Events Database for certain weather phenomena back to 1950, with more detailed information from *Storm Data* comprising all of the years since 1993. Included in both the online *Storm Data* publications and the Storm Events Database is the number of direct weather-related casualties, injuries, and property damage, including the location and date of each event. Also included for significant weather events are narratives that provide detailed information regarding casualties, weather records, and other anecdotal information. The Storm Events Database is updated monthly and generally lags 90–120 days behind the current month. The coupling of online data with the relatively quick updates makes *Storm Data* a very accessible data source. An example of a study based on *Storm Data* information is Curran et al.'s (2000) study on lightning deaths across the United States.

Because the source of each event is not given in the database, users of *Storm Data* must be cautious. The NWS cannot verify the accuracy and validity of all events. Once data from the various NWS offices are compiled, they are categorized by weather event type (Table 1). While data regarding tornadoes, thunderstorm winds, and hail are available from the 1950s, all other weather events in Table 1 are only available since 1993.

In contrast to CDC reports, the operation manual for NCDC's *Storm Data* (Mandt 2002) includes detailed instructions on how to categorize direct and indirect causes for dozens of weather-related deaths. Regardless of the type of weather event, the manual clearly indicates that only deaths caused directly by the given weather event can be entered into the *Storm Data* archive. Any death that is indirectly caused by a weather event will be noted in the narrative that accompanies each entry, but will not be entered into the database.

For excessive heat to be considered the direct cause of a death in *Storm Data,* there must be a "fatality where heat-related or heat stress was the primary, secondary, or major contributing factor as determined by a medical examiner or coroner" (Mandt 2002). Hypothermia and cold-related deaths must meet similar criteria. The weather event itself must also achieve locally established values for heat or cold for the death to be considered direct. Deaths due solely to exposure to excessive temperatures are found in the "temperature extremes" category. Another category in *Storm Data* that can include excessive cold deaths is "snow and ice." If the death was the result of excessive cold and there were other weather conditions that led to the disorientation of the individual (such as blowing snow or icy roads), the death is not counted under the temperature extremes category and is, instead, listed under the category of snow and ice, which includes deaths by blizzards, heavy snow, and winter storms. For example, if the individual dies of exposure to cold after a traffic accident, the death is counted as a direct cause under snow and ice, but not temperature extremes.

Indirect deaths that are related to excessive cold and heat include those due to man-made heat or cold or, for example, when an individual dies of a heart attack while shoveling snow. Also included as indirect deaths are those related to excessive cold and heat that occur when the ambient weather conditions do

Table 2. Total number of heat-related deaths reported by the media (*Chicago Sun-Times*) for the Chicago 1995 heat wave event.

Date	Total deaths reported
13 Jul 1995	20
15 Jul 1995	56
16 Jul 1995	116
17 Jul 1995	179
18 Jul 1995	376
19 Jul 1995	402
20 Jul 1995	456
21 Jul 1995	457
22 Jul 1995	466
23 Jul 1995	468
25 Jul 1995	484
27 Jul 1995	529
3 Aug 1995	549
10 Aug 1995	562
30 Aug 1995	568

not surpass the locally established thresholds for an excessive cold or heat event. *Storm Data* also considers deaths from snow- or ice-related traffic accidents where exposure to excessive cold is not a factor in the death to be indirectly caused by weather, and, thus, they are not counted in the database. Therefore, defined criteria for death by heat or cold must be considered before data selection can begin.

Unfortunately, even with a well-defined standard for classifying direct and indirect causes of death, it is possible for problems to occur. There are several instances in *Storm Data* where traffic-related deaths were classified as directly caused by weather in contrast to the official guidelines. A random sample of two months from early 1995 snow and ice deaths shows that three deaths in January in Kentucky, two in February in Pennsylvania, and six in February in Texas were all from traffic accidents where exposure to excessive cold was not a factor in the death. These 11 incorrectly labeled deaths make up more than half of the total (17) snow-and-ice-related deaths during January/February 1995.

Media reports. Media accounts of heat- or cold-related deaths are primarily comprised of mortality numbers obtained from pertinent authorities and, given the nature of the media, are obtained quickly after, or even during, a given event. For example, the media-reported mortality numbers during the Chicago, Illinois, heat wave of 1995 were primarily made up of daily reports from the Cook County Chief Medical Examiner. During that event, the media reported daily heat-related death statistics (Table 2). In addition to medical examiners, the media also garnered death statistics from personal interviews with local funeral homes.

A common problem with the use of weather-related death totals as reported in the media is that major events are often underreported and rarely revised after publication. Further, because the media use county medical examiners as primary information sources, it should be noted that a medical examiner generally is involved only with deaths of an unknown cause or of a suspicious nature. Consequently, many heat-related deaths are not sent for collaboration to the medical examiner. Also, as with other methods, media reports can be taken out of context and tend to lack reliable evidence of direct or indirect causes of death. See Changnon et al. (1996) for a comprehensive discussion of media reporting on the Chicago 1995 heat wave.

COMPARISON OF DATABASES FOR HOT/COLD DEATHS. *Compressed Mortality Index.* Using CDC NCHS's compressed mortality database during the 21-yr period of 1979–99 (the most recent years for which national data are available), a total of 8015 deaths in the United States were heat related (Fig. 2). Of that total, 3829 (47.8%) were "due to weather conditions," while 3809 (47.5%) were "of unspecified origin" and 377 (4.7%) were "of man-made origins" (e.g., heat generated in vehicles, kitchens, boiler rooms, furnace rooms, and factories) (Donoghue et al. 2003; Sathyavagiswaran et al. 2001). Consequently, the CDC NCHS dataset's category of "excessive heat resulting from weather conditions" creates an average of 182 deaths per year.

Conversely, again using the compressed mortality database during the 21-yr period of 1979–99, a total of 13,970 deaths were attributed to hypothermia (excluding anthropogenic cold deaths) (Grey et al. 2002; Mirchandani et al. 2003) (Fig. 2). In 1999, exposure to excessive natural cold was listed as the underlying

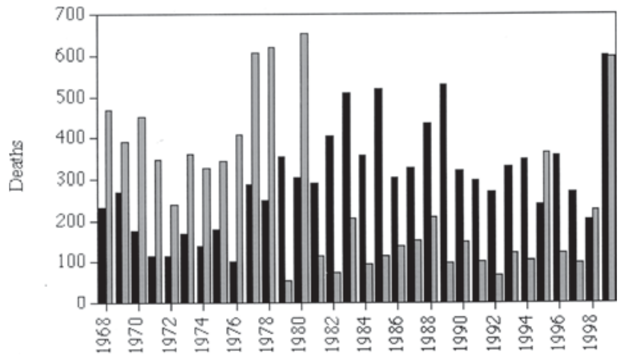

Fig. 2. CDC NCHS Compressed Mortality Index. Total deaths by excessive heat (gray bars) and total deaths by excessive cold (black bars) for 1968–99.

cause of death for 598 persons in the United States, and hypothermia was listed as a "nature" of injury (i.e., an injury that occurred to the deceased) in 1139 deaths. Totaling these numbers, the database lists a total of 15,707 people who have died from extreme cold from 1979 to 1999. Therefore, this dataset's category of "excessive cold resulting from weather conditions" lists an average of 748 persons killed per year.

Storm Data. Temperature extreme deaths listed in NCDC's *Storm Data* are skewed heavily toward heat-related deaths (Fig. 3). Even when snow and ice events are combined with cold temperature extremes, the number of heat-related deaths far outweighs cold-related deaths during the period 1993–2003 by a 3-to-1 margin. Of course, the data are heavily linked to two specific heat-wave events in 1995 and 1999. If these events are removed from the list, the numbers of hot and cold extreme deaths are nearly equal.

Gross mortality. Daily gross mortality data from 12 cities (Fig. 4) across the United States were provided by the CDC NCHS for the years 1975–98. The data are organized by age group, and daily mortality is broken down into those younger than 65 and those 65 and older. A simple linear regression was conducted for each of the metropolitan areas to adjust for any changes in population.

One of the key points regarding total, or gross, mortality is the prevalence of higher deaths in the winter months (Fig. 3). Such deaths cannot be solely linked to atmospheric conditions (i.e., cold) and are a function of socioeconomic conditions, psychological state, influenza, etc. (Kalkstein 1991). Therefore, before performing analyses of mortality associated with abnormal hot/cold conditions, gross mortality numbers must be detrended to account for population change and a strong seasonal cycle.

For this study, gross mortality numbers were detrended using two methods. The first is based on computing the residual of the actual day's mortality for a specific year from its long-term mean mortality. For example, to calculate the residual for 1 January 1975, its mortality is subtracted from the average mortality value for every 1 January from 1975 to 1998. The second method utilizes a first-order harmonic wave fitted to the annual mortality data and computes the residual of the actual day's mortality for a specific year from the harmonic.

Once detrended, excess heat- or cold-related deaths can be analyzed more effectively, and specific heat waves and cold events between 1975 and 1998 were examined for each of the cities. Severe heat waves often produce large "spikes" in mortality, especially during the 1995 heat wave across the Midwest. However, abnormally cold conditions have little effect on the standardized daily mortality. For example, February 1996, a cold period across much of the United States, produced no spikes in winter mortality levels.

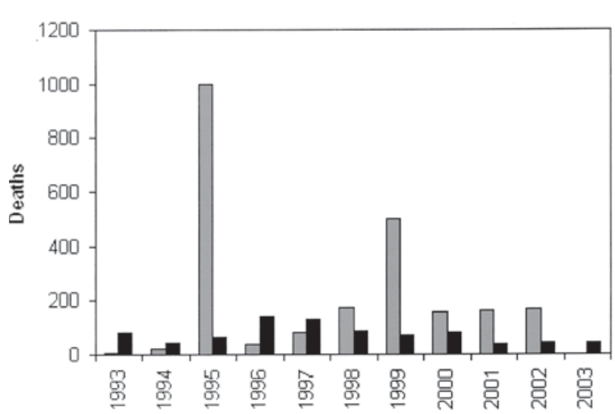

Fig. 3. NCDC *Storm Data*. Total deaths by excessive heat (gray bars) and total deaths by excessive cold (black bars) for the period of 1993–2003.

Fig. 4. Twelve cities for which gross mortality data (see Fig. 1) were used in this study.

Overall. It is apparent from the numbers shown above that these databases have different degrees of "correctness," and this is likely due to multiple methodological differences. For example, *Storm Data*, which is often based on media reports, tends to be biased to the media's (and consequently the public's) overall awareness of the event. As such, weather-related catastrophic "group kills" rather than "individual kills" are more likely to be included in *Storm Data*. Therefore, this may tend to give more complete numbers for weather-related categories, such as tornadoes, hurricanes, or heat waves, than for deaths from winter cold, and the multiple categories for excessive cold deaths can also introduce an underreporting of cold deaths. However, *Storm Data* is updated each month, and consequently, information on a given weather event is added into the database fairly quickly after its occurrence.

The CDC NCHS's Compressed Mortality Database is, in general, a more comprehensive database. As such, it would more likely include weather-related "single kills" than would *Storm Data*. However, the Compressed Mortality Database is limited by the medical personnel's actual determination of the "weather relatedness" of death, and the database often runs years behind current events. The latest mortality values that are used in recent medical studies are from 1999 (Donoghue et al. 2003; Grey et al. 2002; Mirchandani et al. 2003; Sathyavagiswaran et al. 2001).

The calculation of deviations from the daily norm in gross mortality does not suffer from many of the subjective death determinations associated with other datasets. However, it can be problematic to classify the causes of death using these data. In addition, gross mortality data are generally available only for metropolitan areas and are not easily obtainable on a daily time scale for large regions.

CHICAGO 1995 HEAT WAVE. As an example of the disparity between datasets, we review the wide range of mortality numbers reported for the Chicago 1995 major heat-wave event. By 27 July 1995, the media (*Chicago Sun-Times*) reported 529 heat-related deaths in the Chicago metropolitan area (Table 2). *Storm Data* lists 583 heat-related deaths in Illinois for the entire month of July 1995 (heat-related deaths from Chicago are erroneously placed under the state of Idaho in the online NCDC database). However, a subsequent NOAA natural disaster survey report lists 465 heat-related deaths for Chicago for the period 11–27 July (NOAA Disaster Survey Team 1995). Yet, according to the CDC NCHS Compressed Mortality Index, the total number of reported deaths due to "excessive heat" in Cook County, Illinois for all of 1995 was only 85.

When gross mortality values are examined in Cook County for the period associated with the 1995 heat wave, a tremendous spike in daily mortality is indeed apparent (Fig. 5). While the background "baseline" mortality for that time of year is around 120 deaths per day, the daily total mortality greatly exceeds that baseline value for five days (14–18 July) by approximately 840 individuals.

Certainly, if such a wide range of values exists for a single event in a single city, compiled mortality databases are more likely to have even greater disparity. Fundamentally, the vast differences in these mortality numbers exist because of the various sources on which the mortality databases rely. For example, mortality numbers coming from a medical examiner are limited to only the cases in which that medical examiner was involved. The markedly low number of deaths reported by the CDC NCHS also suggests that, on many death certificates, the cause of death was likely determined not to be directly heat related.

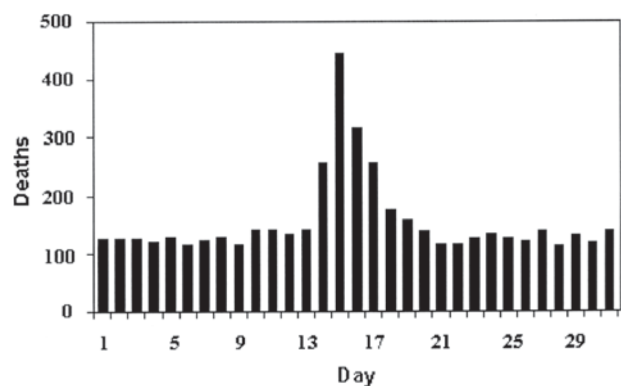

Fig. 5. Gross mortality (number of deaths) for July 1995 in Chicago, IL. (Adapted from Whitman et al. 1997.)

CONCLUSIONS. Depending on the compilation nature of the dataset, the numbers of heat- or cold-related mortality are quite divergent. Consequently, in general, these separate mortality datasets should not be combined or compared in policy determination, and the specific dataset used in a given study should be clearly identified. All of the datasets suffer from some major limitations, such as the potential incompleteness of source information, long compilation time, limited quality control, and subjective determination of the direct versus indirect cause of death. These factors must be considered if the data are used in policy determination or resource allocation.

Of the datasets identified in this study, the one that appears to be least influenced by the above limitations is gross mortality. However, the gross mortality data must be detrended in order to remove a persistent winter-dominant death maximum. Another major limitation of gross mortality is in obtaining regional daily mortality as opposed to only daily mortality for metropolitan areas. Therefore, any users of weather-related mortality data must determine which source is most suitable for their needs, and they should fully understand the limitations associated with the data.

ACKNOWLEDGMENTS. We greatly appreciate the information and comments provided by Dr. Edmund R. Donoghue, Dr. R. C. Patel, Dr. David Berglund, D. Kenneth Kochanek, Pamela Monroe, and Charles J. Dastych.

REFERENCES

Changnon, S. A., K. E. Kunkel, and B. C. Reinke, 1996: Impacts and responses to the 1995 heat wave: A call to action. *Bull. Amer. Meteor. Soc.,* **77**, 1497–1506.

Curran, E. G., R. L. Holle, and R. E. Lopez, 2000: Lightning casualties and damages in the United States from 1959 to 1994. *J. Climate,* **13**, 3448–3464.

Donoghue, E. R., M. Nelson, G. Rudis, R. I. Sabogal, J. T. Watson, G. Huhn, and G. Luber, 2003: Heat-related deaths—Chicago, Illinois, 1996–2001, and United States, 1979–1999. *Morbid. Mortal. Weekly Rep.,* **52**, 610–613.

Grey, T. C., R. Rolfs, M. A. Chambers, and A. S. Niskar, 2002: Hypothermia-related deaths—Utah, 2000, and United States, 1979–1998. *Morbid. Mortal. Weekly Rep.,* **51**, 76–78.

Kalkstein, L. S., 1991: A new approach to evaluate the impact of climate on human mortality. *Environ. Health Perspectives,* **96**, 145–150.

Mandt, G. A., 2002: *Storm Data* preparation. National Weather Service, National Oceanic and Atmospheric Administration, Department of Commerce, National Weather Service Instruction 10-1605, NWSFD 10-16, 79 pp.

Mirchandani, H., C. Johnson, C. Newbern, and C. Canchez, 2003: Hypothermia-related deaths—Philadelphia, 2001, and United States, 1999. *Morbid. Mortal. Weekly Rep.,* **52**, 86–87.

NOAA Disaster Survey Team, 1995: July 1995 Heat Wave. Natural Disaster Survey Report, 52 pp.

Sathyavagiswaran, L., J. E. Fielding, and D. Dassy, 2001: Heat-related deaths—Los Angeles County, California, 1999–2000, and United States, 1979–1998. *Morbid. Mortal. Weekly Rep.,* **50**, 623–626.

World Health Organization, 1992: *International Statistical Classification of Diseases and Related Health Problems.* World Health Organization, 1243 pp.