The Effects of Climate Change

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Executive Summary

Climate change is a change in the statistical distribution of weather over periods of time in which range from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events around an average ; for example, greater or few or extreme weather events. Climate change can be limited to a specific region, or may occur across the whole Earth.

In recent usage, especially in the context of environment policy climate change usually refers to changes in modern climate. It may be qualified as anthropogenic climate change, more generally know as global warming or anthropogenic global warming. Many elements of human society and the environment are sensitive to climate variability and change. Human health, agriculture, natural ecosystems, coastal areas, and heating and cooling requirements are examples of climate-sensitive systems. Rising average temperatures are already affecting the environment. Some observed changes include shrinking of glaciers, thawing of permafrost, later freezing and earlier break up of ice on rivers and lakes, lengthening of growing seasons, shifts in plant and animal ranges and earlier flowering of trees. The extent of climate change effects, and whether these effects prove harmful or beneficial, will vary by region, over time, and with the ability of different societal and environmental systems to adapt to or cope with the change. The extent of climate change effects, and whether these effects prove harmful or beneficial, will vary by region, over time, and with the ability of different societal and environmental systems to adapt to or cope with the change.

Human beings are exposed to climate change through changing weather patterns, for example, more intense and frequent extreme events, and indirectly through changes in water, air, food quality and quantity, ecosystems, agriculture, and economy. At this early stage the effects are small but are projected to progressively increase in all countries and regions.

Climate change may directly affect human health through increases in average temperature. Such increases may lead to more extreme heat waves during the summer while producing less extreme cold spells during the winter. Rising average temperatures are predicted to increase the incidence of heat waves and hot extremes. Particular segments of the population such as those with heart problems, asthma, the elderly, the very young and the homeless can be especially vulnerable to extreme heat.

Extreme weather events can be destructive to human health and well being. The extent to which climate change may affect the frequency and severity of these events, such as hurricanes and extreme heat and floods, is being investigated by the U.S Climate Change Science Program. An increase in the frequency of extreme events may result in more event related deaths, injuries, infectious diseases, and stress related disorders.

Climate change may increase the risk of some infectious diseases, particularly those diseases that appear in warm areas and are spread by mosquitoes and other insects. These ‘vector borne’ diseases include malaria, dengue fever, yellow fever, and encephalitis. Also, algal blooms could occur more frequently as temperatures warm — particularly in areas with polluted waters — in which case diseases (such as cholera) that tend to accompany algal blooms could become more frequent.

Higher temperatures, in combination with favorable rainfall patterns, could prolong disease transmission seasons in some locations where certain diseases already exist. In other locations, climate change will decrease transmission via reductions in rainfall or temperatures that are too high for transmission. For example, temperature and humidity levels must be sufficient for certain disease-carrying vectors, such as ticks that carry Lyme disease, to thrive. Climate change could push temperature and humidity levels either towards or away from optimum conditions for the survival rate of ticks.

Though average U.S. and global temperatures are expected to continue to rise, the potential for an increase in the spread of diseases will depend not only on climatic but also on non climatic factors, primarily the effectiveness of the public health system.

The IPCC has noted that the global population at risk from vector-borne malaria will increase by between 220 million and 400 million in the next century. While most of the increase is predicted to occur in Africa, some increased risk is projected in Britain, Australia, India and Portugal .

Tick borne Lyme disease also may also expand its range in Canada. However, socioeconomic factors such as public health measures will play a large role in determining the existence or extent of such infections. Water borne diseases may increase where warmer air and water temperatures combine with heavy runoff from agricultural and urban surfaces, but may be largely contained by standard water-treatment practices.

A. FINDINGS

1. Weather has a profound effect on human health and well being. It has been demonstrated that weather is associated with changes in birth rates, and sperm counts, with outbreaks of pneumonia, influenza and bronchitis, and is related to other morbidity effects linked to pollen concentrations and high pollution levels.

2. Large increases in mortality have occurred during previous heat and cold waves, It is estimated that 1,327 fatalities occurred in the United States as a result of the 1980 heat wave; the number occurring in Missouri alone accounted for over 25% of the total.

3. Hot weather extremes appear to have a more substantial impact on mortality tan cold wave episodes. Most research indicates that mortality during extreme heat events varies with age, sex, and race. Factors associated with increased risk

from heat exposure include alcoholism, living on higher floors of buildings, and the use of tranquilizers. Factors associated with decreased risk are use of air conditioning, frequent exercising, consumption of fluids, and living in shaded residences. Acclimatization may moderate the impact of successive heat waves over the short term.

4. Threshold temperatures for cities, which represent maximum and minimum temperatures associated with increases in total mortality, have been determined. These threshold temperatures vary regionally; for example, the threshold temperature for winter mortality in mild southern cities such as Atlanta is 0deg.C and for more northerly cities, such as Philadelphia, its -5deg.C.

5. Humidity has an important impact on mortality since it contributes to the body's ability to cool itself by evaporation of perspiration.It also has an important influence on morbidity in the winter because cold, dry air leads to excessive dehydration of nasal passages and the upper respiratory tract and increased chance of microbial and viral infection.

6. Precipitation in the form of rainfall and snow is also associated with changes in mortality. In New York City, upward trends in mortality were noted the day after snowfalls that had accumulated 2 inches or more. In Detroit where snow is more common, the snowfall accumulation exceeded 6 inches before mortality increases were noted.

7. If future global warming induced by increased concentrations of trace gases does occur, it has the potential to significantly affect human mortality. In one study, total summertime mortality in New York City is estimated to increase by over 3,20 0 deaths per year for a 7deg.F trace gas induced warming without acclimatization. If New Yorkers fully acclimatize, the number of additional deaths are estimated to be no different than today. It is hypothesized that, if climate warming occurs, some additional deaths are likely to occur because economic conditions and the basic infrastructure of the city will prohibit full acclimatization even if behavior changes.

8. Two areas of important future research include investigation of morbidity impacts and the costs to society of indirect impacts e.g., costs associated with modifying living and working areas, decreases productivity, and other climate/stress induced impacts.

B. INTRODUCTION

There is a large body of literature devoted to the impact of variable climate on human well being. Most of the research has been done by medical scientists, and a minor amount of the work has been performed by climatologists. This section will attempt to describe much of the relevant research that has been published to date. Topics will be subdivided on the basis of weather events, as many of the manuscripts evaluated employ a regression technique to determine the impacts of one or more climatic events on human health.

There appears to be general agreement that weather has a profound impact on human health, but scientists do not agree on the precise mechanisms involved. For example, some of the research suggests that extreme weather events appear to have the greatest influence on health. Driscoll correlated daily mortality for 10 cities with weather conditions in January, April, July, and October and found that large diurnal variations in temperature, dew point and pressure were associated with many high mortality days. In addition, hot, humid weather with concomitant high pollutant concentrations were also contributory mechanisms. Other studies do not attribute large variations in mortality to extreme events, but rather to the normal seasonal changes in weather.

The importance of determining the role of weather in human health cannot be understood. Reports of large increases in mortality during heat and cold waves are commonplace; for example, the National Oceanic and Atmospheric Administration , estimated that 1,327 fatalities in the United States were directly attributed to the 1980 heat wave; fatalities in Missouri alone accounted for over 25% of the total excess death. During a heat wave in 1963, more than 4,600 deaths above a computed mean occurred in June and July in the eastern United States. The impact of weather on human well being goes beyond mortality; even birth rates and sperm counts appear to be affected by meteorological phenomena .

This report concentrates on the effects of weather upon human mortality. However, there are numerous other impacts of weather on the general health of the population, including morbidity, short term changes in mood, emotional well being, and aberrations from normal behavior. For example, asthma attacks, many of which occur from inhalation of airborne agents such as spores and molds, appear to be related to various meteorological variables. Goldstein found that clusters of attacks are preceded by the passage of a cold front followed by a high pressure system. Morbidity attributed to pneumonia, influenza, bronchitis, and probably many other illnesses is also weather related.

In addition, several atmospheric phenomena that are indirectly related to weather and might have an impact on mortality (the most notable being atmospheric pollutants and pollen concentrations) are not included in this review. A partial annotated bibliography of pollen concentration is presently available, but there is little research comparing relationships to human health. Meteorologic conditions exert a large influence on pollution concentrations and decipher ions and they also affect the impact of pollution on mortality and morbidity. Much of the literature on this topic has already been summarized .

Probably the most intensively studied weather element that affects human mortality is air temperature, especially the impact of summer heat. A detailed description of temperature/mortality relationships follows.

C. General Impacts

The impact of temperature on morbidity and mortality can be assessed at both the seasonal and daily level. The variability in occurrence of numerous illnesses is linked to somewhat predictable seasonal trends in temperature, although significant year to year differences do occur. Medical disorders such as bronchitis, peptic ulcer, adrenal ulcer, glaucoma, goiter, eczema, and herpes zoster are related to seasonal variations in temperature . Heart failure (most often myocardial infarction) and cerebrovascular accidents represent two general mortality categories that have been correlated many times with ambient monthly temperatures. Complications from these disorders can be expected at higher temperatures since the body responds to thermal stress by forcing blood into peripheral areas to promote heat loss through the skin. This increases central blood pressure and encourages constriction of blood vessels near the core of the body. However, increases in heart disease are also noted at very cold temperatures as well. Strong negative correlations have been found between winter temperature and deaths in certain North American, northern Asian, and European countries.

The degree of seasonality in the climate of a region also appears to affect mortality rates. Katayama and Momiyama-Sakamoto reported that countries with smaller seasonal temperature ranges exhibit steeper regression lines in temperature mortality correlations than do countries with greater temperature ranges. Maximum death rates in warmer countries are found at below normal temperatures, and in cooler countries similar temperatures will produce no appreciable rise in mortality.

There is conflicting evidence concerning the impact of daily temperature fluctuations on human mortality. Some studies contend that mostly long term (i.e., monthly and annual) fluctuations in temperature affect mortality and only small, irregular aberrations can be explained by daily temperature variability. However, Kalkstein and Davis report that daily fluctuations in temperature can increase mortality rates by up to 50% in certain cities. This has been corroborated in a detailed study of New York City mortality where large increases in total and elderly mortality occurred during the 1980 heat wave.

2. Impacts of Hot Weather

a. General Relationships

Much of the temperature mortality research has concentrated on heat and cold wave episodes. It appears that hot weather extremes have a more substantial impact than cold, and many "heat stress" indices have been developed to assess the degree of impact. Driscoll related 19 different meteorological variables with total mortality and other more specific mortality classes (cause of death, age) and identified high temperature as the most important causal mechanism in summer. Many other studies support this relationship between temperature and mortality. Interestingly, a majority of studies have found that most of the excess deaths that occurred during periods of intense heat were not attributed to causes traditionally considered to be weather-related, such as heat stroke (Gover, 1938). Consequently, many researchers continue to utilize total mortality figures in their analyses, as deaths from a surprisingly large number of causes appear to escalate with increasing temperature.

Although most researchers have preferred the use of maximum temperature as the primary predictor of mortality, others continue to utilize average daily temperature as their primary weather statistic.Those who use daily averages cite the importance of warm nights in contributing to mortality, something that is neglected when utilizing maximum temperatures alone (Ellis et al., 1975). However, others report that daily averages tend to m ask the effect on mortality of large daily oscillations in temperature .

A number of studies compare death rates for extreme periods with those encountered during normal meteorological periods; this approach has met with some success . Jones et al , in summarizing the work of others, found that high temperature, the number of days that the temperature is elevated, high humidity, and low wind velocity are all found within the climate/mortality models of various researchers.

Rather than incorporating daily death totals, many heat wave/mortality studies have utilized weekly mortality totals compiled by the Centers for Disease Control for their primary input.Scientists calculated expected weekly death rates based on a 5-year moving mean, and periods of weekly excess mortality were isolated and also compared weekly mortality rates to weather for 10 U.S. cities and uncovered some large weather induced fluctuations. In general, studies incorporating weekly data sets are less revealing than their daily counterparts, as extreme episodes are often dampened when time scales are increased. One of the most commonly reported findings in heat wave mortality studies involves the lag time between the temperature event and the mortality response. Temperature affects not only mortality, but also morbidity.

b. Responses of the Population

Kilbourne et al. conducted a case study in which a number of heat factors associated with heat stroke were identified. Factors found to be associated with an increased risk of heat stroke included alcoholism, living on higher floors of buildings, and the use of tranquilizers. Factors found to be associated with a decreased risk were use of air conditioning, frequent exercising, consumption of fluids, and living in a well shaded residence. During extreme heat episodes, heat stroke risk is increased as demonstrated by the 1980 heat wave in St. Louis, which resulted in a ten-fold increase in total deaths.

Most research indicates that mortality rates during extreme heat vary with age, sex, and race. Oechsli and Buechley (1970) found that mortality rates during heat waves increase with age. This is supported by the work of others. The elderly seem to suffer from impaired physiological responses and often are unable to increase their cardiac output sufficiently during extremely hot weather. In addition, sweating efficiency de creases with advancing age, and many of the medications commonly taken by the elderly have been reported to increase the risk of heat stroke. Certain researchers have determined slight rises in mortality rates of infants during heat waves , but this is not a universal finding.

Studies relating mortality to gender also yield conflicting results. Studies in which increased mortality rates were found among females during hot weather include those of Applegate et al. Studies of the role of race have also produced conflicting results. Schuman (1972) found that blacks appear more susceptible to heat-related deaths in St. Louis and whites are more susceptible in New York . However, Ellis et al. (1975) and Bridgeretal. (1976) have discovered that white mortality rates are higher than black's under all examined conditions. Rather than race, socioeconomic status may have an influence on weather/mortality relationships. Large numbers of deaths during heat waves are found among poor inner-city residents who have little access to cooler environments (Jones et al., 1982).

Initial observations of daily standardized deaths vs. maximum temperature suggest that weather has an impact on only the warmest 10-20% of the days; however, the relationship on those very warm days is impressive . During warm periods, a "threshold temperature," which is the maximum temperature above which mortality increases, can be determined. The threshold temperature can be calculated objectively by using a sums of squares technique (Kalkstein, 1986). The threshold temperature for deaths in New York, above which mortality increases dramatically, is 92deg.F. This procedure can be repeated for winter, as discussed later in this section, where the threshold temperature represents the minimum temperature below which mortality increases.

c. Acclimatization

Several studies have evaluated acclimatization as a factor contributing to heat-related deaths. Gover (1938) reported that excess mortality during a second heat wave in any year will be slight in comparison to excess mortality during the first, even if the second heat wave is unusually extreme. Two possible explanations for this phenomenon are provided. First, the weak and susceptible members of the population die in the early heat waves of summer, thus lowering the population of susceptible people who would have died during subsequent heat waves. Second, those who survive early heat waves become physiologically acclimatized and hence deal more effectively with later heat waves (Marmor, 1975). Rotton (1983) suggests that geographical acclimatization is al so significant, and people moving from a cool to a subtropical climate will adapt rather quickly, often within two weeks. However, the population must still make behavioral and cultural adjustments (Ellis, 1972). Further support for geographical acclimatization is provided by Kalkstein and Davis (1985), who noted that mortality increased dramatically during heat waves in northern cities but not in southern cities.

There is some research that implies that the effect of acclimatization has been overstated by many scientists. The use of the wind chill index in winter and the temperature humidity index in summer by many meteorologists seems to indicate that they believe acclimatization may have minimal impact on human activities. Both indices are based on absolute values only: a temperature of 93deg.F with a humidity of 43% yields the same temperature humidity index value whether it occurs in New Orleans or Duluth. The hot weather indices most widely accepted by the National Weather Service are all absolute, and they include the temperature humidity index, humiture, humidex, the discomfort index, and apparent temperature. The only geographically relative index that has been published, the weather stress index, is only beginning to be utilized to evaluate a variety of the impacts that climate has on humans.

One cultural adjustment that may have an impact on heat wave related mortality is the use of air conditioning. Some Predictive Equations

Several general algorithms have been developed to predict mortality changes during heat waves. Buechley et al. developed the following algorithm for heat related mortality at temperatures above 90deg.F:

TMR = cycle + 0.10e[0.2(F[1] - 90)] (1)

where TMR is the temperature specific mortality ratio (the predicted mortality for the day divided by the average annual daily mortality), cycle is the expected mortality ratio for that day of the year (an attempt to account for the impact of seasonality on mortality), and F[1] is yesterday's temperature. Cycle is computed from several years of mortality data and varies in a sinusoidal fashion, peaking in the winter and reaching a minimum at the end of the summer. Each day has a distinctive cycle value de pending upon the mean mortality rate for that time of year. The following example represents a hypothetical calculation of TMR. Assume that the maximum temperature on a given day is 100deg.F, and the cycle is 0.95. TMR = 0.95 + 0.1e[0.2(100 - 90)], which equals 1.70. Thus the equation predicts that mortality on the day following the 100deg. maximum temperature will equal 170% of the annual mean daily mortality. Oechsli and Buechley (1970) had previously developed a related algorithm, the age- and temperature-specific mortality ratio model (ATMR):

$$ATMR = 98.806 + e[(-15.23 + .0385\ Age + .1655\ F)] \quad (2)$$

where F is the present day's maximum temperature.

In a more recent study, Marmor (1975) attempted to develop a model that accounted for acclimatization effects. This led to his sensitivity index, which decreased as the population was exposed to more hot days during the season. Sensitivity (S[d]) equals:< p> $1 / (1 + e[(Ad - 6) / 0.46)] \quad (3)$

where Ad is the total number of previous days with temperatures over 90deg.F.

This sensitivity value was added to a newer version of the TMR algorithm, producing the following:

$$TMR = cycle + (0.05 + 0.06\ sensitivity)\ e[(F[1] - 90)0.2] + 0.05e[(F - 90)0.2] + 0.07\ e[(f - 75)0.2] \quad (4)$$

where f is the previous day's minimum temperature, F[1] is the previous day's maximum temperature, and F is the present day's maximum temperature (Marmor 1975).

3. Impact of Cold Weather

a. General Relationships

Many studies have provided evidence that mortality rates increase during periods of cold weather. In general, total mortality is about 15% higher on an average winter day than on an average summer day (National Center for Health Statistics, 1978). However , increases in mortality during exceedingly cold periods are less dramatic than their hot weather counterparts. The impact of cold on human well-being is highly variable. Not only is cold weather responsible for direct causes of death such as hypothermia, influenza, and pneumonia, it is also a factor in a number of indirect ways. Death and injury from falls, accidents, carbon monoxide poisoning, and house fires are all partially attributable to cold.

Hypothermia occurs when the core body temperature falls below 35deg.C. Certain sectors of the population appear more susceptible to hypothermia than others. Most victims fall in one or more of the following categories: the elderly, newborns, the unconscious, alcoholics, and people on medications. In addition, malnourishment, inadequate housing, and high blood ethanol levels increase the incidence of hypothermia.

Sex and race appear to be related to susceptibility to hypothermia. Nonwhite elderly men generally constitute the highest risk group, while white women comprise the lowest risk group. Women possess a higher skin temperature to core temperature gradient, suggesting that they are better able to maintain a higher body core temperature during periods of cold stress . Some studies contend that the difference in the response of men and women to cold is related to the amount of subcutaneous fat within the body, but other studies have failed to confirm this hypothesis. Although women are less susceptible to hypothermia, they appear to be more susceptible to peripheral cold injuries such as frostbite .

Age appears to have an even greater impact upon hypothermia sensitivity than gender, and the elderly display the highest mortality rates of all groups. Vasoconstriction and shivering, two primary cold adaptive measures, appear to be reduced in many elderly persons. In addition, many of the elderly do not discriminate changes in temperature well and are thus less able to adjust to them .

One of the first efforts to predict the impact of a severe cold wave was published by NOAA using algorithms developed by Kalkstein. Seven cities in the eastern and southern United States exhibited significant relationships between winter weather and mortality, and the following regression equations were developed for each:

Atlanta: MORT = C - .11 MT
Chicago: MORT = C - .08 MT
Cincinnati: MORT = C - .21 MT - .01 CDH + .13 HRS
Dallas: MORT = C - .12 MT - .13 MIN - .02 CDH
Detroit: MORT = C - .11 MT
Oklahoma City: MORT = C - .16 MT
Philadelphia: MORT = C + .09 MD + .01 CDH + .06 WAM - .08 WPM,

Where MORT is the daily standard deviation increase in mortality above the mean, C is a constant (different for each city), MT is daily maximum temperature, HRS is the total hours in the day with temperatures below 32deg.F, MIN is daily minimum temperature, MD is daily minimum dewpoint, WAM is 3AM windspeed, WPM is 3PM windspeed, and CDH is a measure of the day's coldness and is calculated as follows:

$$CDH = \sum_{i=1}^{N} (32-5), \text{ where } T \leq 32.$$

T represents the hourly temperature and N represents total hours in a day with temperatures below 32deg.F. A map of predicted mortality increases during the January 1985 cold wave showed potentially significant increases in the eastern and central United States. Data limitations have precluded these predictions from being verified to date.

b. Adaptation

It appears that adaptation to cold temperatures can occur through repeated exposures. Radomski and Boutelier noted that men who had bathed in 15deg.C water for one-half hour over nine consecutive days before a trip to the Arctic showed less signs o f cold induced stress than non treated men.

There appears to be a cold adaptive mechanism influencing mortality as well. In a study comparing winter mortality rates for 13 cities in different climates around the U.S., a large differential response was noted. The southern cities seemed to exhibit the greatest increases in mortality during cold weather, while little or no response was found in northern cities. In a city such as Minneapolis, no increase in mortality was noted at temperatures down to 40degrees C, but in Atlanta, mortality increases were evident if the maximum temperature did not exceed 0deg.C. Of the 13 cities studied, 7 demonstrated a statistically significant relationship between winter cold and mortality. The six non significant cities included cold weather locations (Minneapolis) and mild West Coast locations where very cold weather is virtually unknown (Los Angeles and San Francisco). Threshold temperatures, which represent temperatures below which notable increases in mortality occur, were established for the seven cities . The threshold temperatures were comparatively mild for the more southerly cities and somewhat colder for the more northerly cities (-5deg.C for Philadelphia). This differential geographical response seems to add credence to the importance of relative, rather than absolute weather conditions.

There is evidence that a lag time of two to three days exists between the offending cold weather and the ultimate mortality response. Deaths did not necessarily rise on the day of the coldest temperatures, but in many cases, the sharpest increases were noted three days after the coldest weather occurred. A similar lag time was not noted after extremely hot summer days; the impact appears more immediate in summer.

D. HUMIDITY AND PRECIPITATION EFFECTS

1. Effects of Humidity

Humidity has an important impact on mortality since it influences the body's ability to cool itself by means of evaporation of perspiration. In addition, humidity affects human comfort, and the perceived temperature by humans is largely dependent upon atmospheric moisture content.

The effects of low humidity can be especially dramatic in winter, when low moisture content induces stress upon the nasal pharynx and trachea. When very cold, dry air passes through these organs, warming occurs and air temperatures in the pharynx can reach 30deg.F. The ability of this warmer air to hold moisture increases dramatically, and moisture is extracted at a prodigious rate from the nasal passages and upper respiratory tract, leading to excessive dehydration of these organs. This appears to increase the chance of microbial or viral infection since a rise in the viscosity of bronchial mucous seems to reduce the ability of the body to fight offending microorganisms that may enter the body from the atmosphere. This may explain why Green found negative correlations between relative humidity and winter absenteeism in a number of Canadian schools.

In the summer, high moisture content during hot periods can lessen the body's ability to evaporate perspiration, possibly leading to heat stress. Recent weather/mortality models developed for the National Oceanic and Atmospheric Administration indicate that dew point temperature is directly related to mortality in several eastern cities when temperatures are very hot . Another summer study indicated that mental well-being may also be influenced by summer relative humidity. Persinger found significant negative relationships between relative humidity and "mood scores," which represent a measure of happiness. Sanders and Brizzolara found relative humidity to be significantly related to a linear combination of three mood variable s.

Most of the precipitation/mortality research to date has concentrated on the impact of snow and other forms of severe winter weather. In an ongoing study on the effects of snow accumulation in five U.S. cities, Kalkstein has determined threshold values of accumulated snow above which mortality rates appear to rise. In New York, significant upward trends in mortality were noted the day after snowfalls if two or more inches of snow had accumulated. In Detroit, where snow is more common, the snowfall accumulation exceeded six inches before mortality increases were noted. No significant relationship between snowfall accumulation and mortality was apparent in Chicago. Anderson and Rochard found increases in deaths from ischemic heart disease on, and for three days after, a four inch or greater snowfall in Toronto. Major peaks in cardiovascular deaths in Minneapolis-St. Paul also appeared to follow days with heavy snows, with the rise most rapid the day after the storm.

Summer rainfall appears to have a limited impact on mortality. Kalkstein has shown that a significant decline in mortality is experienced the day after summer precipitation events in all of five U.S. cities studied (New York, Philadelphia, Chicago, Atlanta, Detroit). The precipitation event itself might have an indirect impact, as the cooler temperatures coinciding with a summer rainfall provide relief from excessively warm weather. However, in certain specific cases, rainfall might induce increase s in mortality. Mack found that fatal automobile accidents increased in frequency during very light rain episodes (less than .01 inch) and heavy rainfalls (greater than 0.1 inch per hour).

E. FRONTAL PASSAGES, SUNSHINE, AND CLOUD COVER IMPACTS

Frontal passages may have a profound impact on well-being and mortality as large variations in weather conditions can occur in a very short time. Rapid changes in temperature have been shown to produce a number of physiological changes in the body. Rapid drops may affect blood pH, blood pressure, urinatian volume, and tissue permeability. Outbreaks of epidemics may also be related to frontal passage. In his study of 59 years of data, Donle noticed sudden large increases in influenza outbreaks in Germany, Norway, and Switzerland often followed the passage of a surface trough. In general, these outbreaks occurred simultaneously with the influx of cold air over northern and western Europe (the passage of a surface wave is often followed by a rapid influx of cold air). The influenza outbreaks in Europe most frequently occurred between January and March, when cold air masses most commonly intruded over the area.

A number of studies have also found relationships between the numbers of reported migraine attacks and rapid changes in barometric pressure. Cull found fewer occurrences of attacks when barometric pressure was low. This was partially attributed to a decrease in sunshine during low-pressure intrusions, as solar radiation is a suspected triggering mechanism for migraine onset. However, a Canadian Climate Center study found that migraines were most likely to occur on days with falling pressure, rising humidity, high winds, and rapid temperature fluctuations.

Rosen cites some startling relationships between pressure changes and human well being. He describes research that indicates that cancer mortality rates seem to increase during low pressure fluctuations, and deaths from circulatory diseases seem to increase during high pressure fluctuations. He notes that rapid pressure fluctuations may penetrate buildings and propagate wave energy from their source like ripples in a pond. Humans appear to be quite sensitive to such changes.

The reduction of solar radiation by cloud cover may also have effects on well-being. By increasing the brightness level, the autonomic nervous system is affected by constriction changes in the eye pupil. According to Persinger, this increases the r ate of physical activity and leads to a general feeling of well-being. Wolfe notes that the sun's rays cause chemical changes in neurotransmitter or hormone synthesis in the brain, perhaps stimulating production of the hormone epinephrine, which stimulates the mind and body. Conversely, very low light intensities are often associated with states of relaxation, tiredness, and sleepiness.

F. POTENTIAL EFFECTS OF GLOBAL CLIMATE CHANGE ON FUTURE HUMAN MORTALITY

Kalkstein estimated the potential effects of global warming on New York City. The study indicated that summer weather appears to have a significant impact on New York's present mortality rates, and a "threshold temperature" of 92deg.F was uncovered , suggesting that mortality increases quite rapidly when the maximum temperature exceeds this value. Days with low relative humidities appear to increase mortality most dramatically. Five climatic scenarios were developed to estimate New York's future weather assuming that warming does occur, and 'acclimatized" and "unacclimatized" mortality rates were estimated for each scenario. The unacclimatized rates were computed by utilizing New York's weather/mortality algorithm developed from the historical analysis. Acclimatized rates were computed by selecting present day "analog cities" which resemble New York's predicted future weather, and developing weather/mortality algorithms for them.

Results shown in indicate that the number of additional deaths at temperatures above the threshold could increase by over tenfold if New Yorkers do not become acclimatized to the warming. The elderly will constitute an increasing proportion of these deaths. However, if full acclimatization occurs, the number of additional deaths above the threshold temperature might be no different than today. It is likely, however, that economic conditions, as well as the basic structure of the city, will prevent full acclimatization; therefore, actual mortality may fall somewhere in between the estimated values. A similar procedure developed for winter indicated that mortality is minimally affected by severe winter weather in New York.

17A preliminary precipitation/mortality analysis was also undertaken, and summer days following a precipitation event had significantly lower mortality rates than summer days without precipitation. In the winter, these results were reversed, and days follow ing rain (but not snow) had significantly higher mortality rates than non-precipitation days.

G. SUMMARY

Although there is much literature concerned with the impact of weather on human mortality and well being, it appears that the contributing researchers often disagree on the magnitude and specific nature of the impact, as well as on the role of acclimatization. General areas of agreement include:

1. Temperature extremes (both hot and cold) appear to increase mortality, although there is disagreement about which sex, age group, or race seems most affected.
2. Low relative humidities in winter appear to be directly related to frequencies of various illnesses and mortality.
3. Winter snowfall accumulations appear to correspond with periods of high mortality.
4. Rapid changes in the weather often induce a series of negative physiological responses from the body.

There is a great need to quantify much of the subjective and intuitive information that has been published on climate/mortality relationships. Considering the enormous amount of mortality and morbidity data presently available from the National Center for Health Statistics, the Centers for Disease Control, and other agencies, more precise weather/health relationships should be uncovered in the near future. Perhaps one of the greatest challenges and areas of future research is determining the necessary cos t to society to overcome climate stress. Changes in interior environments may be needed to overcome potential direct climate change impacts on living and working environments. Indirect impacts (e.g., the loss of productivity resulting from new climate conditions and increased insurance costs) have not been estimated. It is these impacts indirectly associated with human health/climate stress that remain important areas of research.

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