DEATH AND DEATH RATES DUE TO EXTREME WEATHER EVENTS: GLOBAL AND U.S. TRENDS, 1900-2004

Indur M. Goklany [1]
Office of Policy Analysis
Department of the Interior
1849 C Street, NW, Washington, DC

Abstract

Despite the recent spate of deadly extreme weather events such as the 2003 European heat wave and the hurricanes of 2004 and 2005, aggregate mortality and mortality rates due to extreme weather events are generally lower today than they used to be. Globally, mortality and mortality rates have declined by 95 percent or more since the 1920s. The largest improvements came from declines in mortality due to droughts and floods, which apparently were responsible for 95 percent of all deaths caused by extreme events during the 20th century. For windstorms, which contributed most of the remaining 5 percent of fatalities, mortality rates are also lower today but there are no clear trends for mortality. Cumulatively, the declines more than compensated for increases due to the 2003 heat wave. With regard to the U.S., current mortality and mortality rates due to extreme temperatures, tornados, lightning, floods and hurricanes are also below their peak levels of a few decades ago. The declines for the last four categories range from 55 to 95 percent. If extreme weather has indeed become more extreme for whatever reason, global and U.S. declines in mortality and mortality rates are perhaps due to increases in societies' collective adaptive capacities owing to a variety of interrelated factors — greater wealth, increases in technological options, and greater access to and availability of human and social capital — although luck may have played a role. Because of these developments, nowadays extreme weather events contribute less than 0.06 percent to the global and U.S. mortality burdens in an average year, and, by and large, seem to be declining. Equally important, mortality due to extreme weather events has declined despite an increase in all-cause mortality suggesting that humanity is adapting better to extreme events than to other causes of mortality. In summary, there is no signal in the mortality data to indicate increases in the overall frequencies or severities of extreme weather events, despite large increases in the population at risk.

Introduction

Even prior to Hurricanes Katrina and Rita striking the U.S. coast, there was speculation in medical and scientific journals, the popular press and elsewhere that climate change would exacerbate extreme weather events through, among other things, intensification of the hydrological cycle, hurricanes and other storms, and, thereby, raise deaths and death rates globally as well as in the United States (see, e.g., IPCC 2001: Table SPM-1; Patz 2004; MacMichael and Woodruff 2004; Schiermeier 2003, 2005; Trenberth and Taylor, no date).[2] Since then, this speculation — fueled by recent, somewhat controversial studies suggesting that hurricane intensities might be stronger because of climate change (e.g., Webster et al. 2005; Emmanuel 2005a, 2005b; Pielke, Jr., 2005; Landsea 2005) as well as the occurrence of recent weather related disasters ranging from the Central European floods of 2002, the 2003 European heat wave, and the back-to-back disastrous Atlantic hurricane seasons of 2004 and 2005 — has only intensified as epitomized by the recent *Time* magazine cover story warning all to worry more about global warming (Kluger 2006; see also, for example, Anderson and Bausch 2006).

This note examines whether losses due to weather-related extreme events (as measured by aggregate deaths and death rates) have increased globally and for the United States in recent decades, as they should have if — all else being equal — climate change has indeed increased the frequencies or severities of such events, as some have claimed might occur

[1] Views expressed in this article are the author's, and not of any unit of the U.S. government.

[2] This paper uses "extreme weather events" synonymously with "extreme events."

(see, e.g., IPCC 2001; Patz 2004; MacMichael and Woodruff 2004). It will also try to put these deaths and death rates into perspective by comparing them with the overall mortality burden, and briefly discuss what trends in these measures imply about human adaptive capacity.

Trends in deaths and death rates while of intrinsic interest for public policy purposes, may also have a bearing on trends in economic losses. Goklany (2000) speculates that while a wealthier society may take extra effort to limit loss of life, it may be less concerned about property losses, and that a wealthier society is also likely to have more property at risk. This suggestion finds some support in findings that the ratio of death-to-property-loss for tornadoes in the U.S. has declined in recent decades (Doswell et al. 1999, Brooks and Doswell 2001).

Trends in Mortality and Mortality Rates

GLOBAL TRENDS, 1900-2004

In general, climate change could change the frequencies, intensities and/or durations of extreme weather events such as floods, droughts, windstorms and extreme temperatures — increasing them at some locations and for some periods while decreasing them at other locations and other periods. Some of the effects of these changes will tend to offset each other and/or be redistributed over space and time. For instance, an increase in deaths due to heat waves at one location might be compensated for by a decline in deaths due to fewer or less intense cold waves at the same or another location. Alternatively, climate change might redistribute the temporal and spatial pattern of rainfall, droughts and other such events. Accordingly, to estimate the net impact, if any, of climate change on mortality, it is probably best to examine cumulative deaths at the global level aggregated over all types of extreme events. Because of the episodic nature of extreme events, such an examination should ideally be based on several decades, if not centuries, worth of data. Any such examination should, of course, be cognizant that adaptive capacity and exposure of human populations to risk also change over time.

In particular, one should examine mortality rates so as to filter out the effect of population growth on the population at risk. However, it may be argued that the use of mortality rate may be inadequate to eliminate the effect of increases in populations at risk since, as the population becomes larger, people will migrate to riskier and more vulnerable locations as the less vulnerable locations are occupied. In addition, inappropriate state policies and the availability of insurance, which allows individuals to bear less than their full burden of risk, may place even wealthier populations at greater physical risk (in addition to increasing financial risk; Goklany 2000).

Figure 1, based on data from EM-DAT, the International Disaster Database maintained by the Office of Foreign Disaster Aid and Center for Research on the Epidemiology of Disasters at the Université Catholique de Louvain, Brussels, Belgium, displays data on aggregate global mortality and mortality rates between 1900 and 2004 for the following weather-related extreme events: droughts, extreme temperatures (both extreme heat and extreme cold), floods, slides, waves and surges, wild fires and windstorms of different types (e.g., hurricanes, cyclones, tornados, typhoons, etc.).[3,4] It indicates that both death and death rates have declined at least since the 1920s. Specifically,

[3] Figure 1 is constructed using data the following sources: (1) For deaths, EM-DAT (2005). (2) For population from 1900-1925, McEvedy & Jones (1978). (3) For population from 1950-2004, World Resources Institute (2005). (4) For population from 1926-1949, estimates were based on interpolation for each year using the 1925 estimate from McEvedy and Jones and the 1950 WRI estimate, assuming exponential population growth. For 2004, I excluded the deaths due to the Boxing Day Tsunami disaster (which, according to EM-DAT killed 226,435 people). Death estimates, in particular, are approximate and, possibly, more prone to error as we go further into the past. As is evident from the following footnote, EM-DAT is not quite complete. While events in the earlier years might have been missed, EM-DAT should have captured the major natural disasters, particularly in recent years. This suggests that mortality and mortality rates might have been higher in the early decades of the 20th century than is indicated in Figure 1, and subsequent figures and tables.

[4] EM-DAT contains data on the occurrence and effects of over 12,800 mass disasters in the world from 1900 to present. The data are compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies. For a disaster to be entered into the database one or more of the following criteria must be met: (a) at least 10 people must have been reported killed, (b) at least 100 people must have been reported as affected, (c) a state of emergency must have been declared, or (d) there should have been a call for international assistance.

comparing the 1920s to the 2000-2004 period, the annual number of deaths declined from 485,200 to 19,400, a 96 percent decline, while the death rate per million dropped from 241.8 to 3.1, a decline of 98.7 percent.

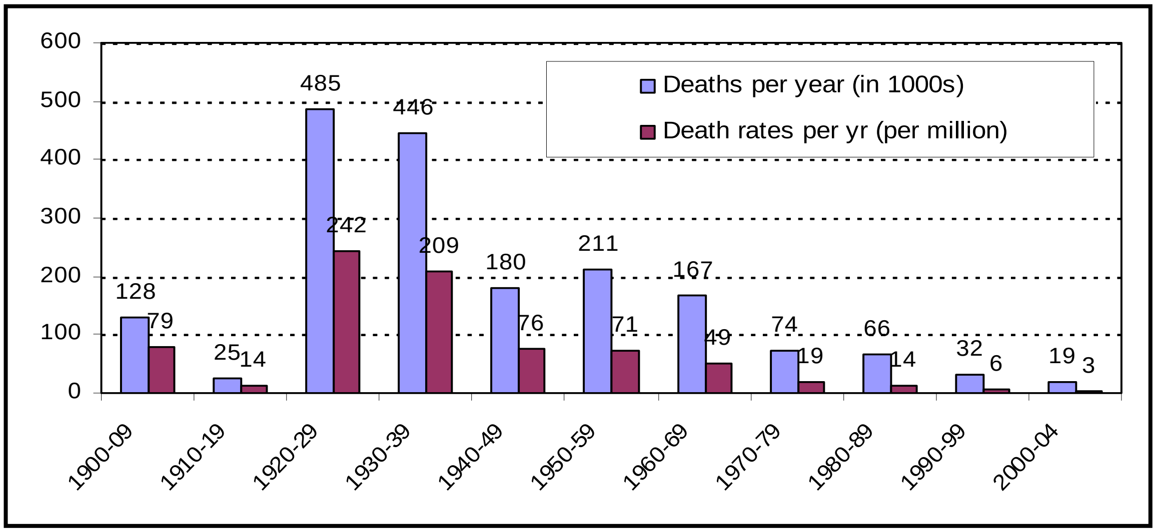

Figure 1: Global Death and Death Rates Due to Extreme Events, 1900-2004. Note that data for the last period are averaged over five years worth of data. Sources; EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

Table 1 provides a breakdown of the average annual global deaths and death rates for the various categories of extreme events for 1900–1989 and 1990–2004. The columns are arranged in order of declining mortality ascribed to the various events (highest to lowest) for the former period. This shows that:

- During much of the 20th century, the deadliest extreme events were droughts, followed by floods and windstorms. Over the 105 year record, droughts and floods were responsible for 55 and 38 percent of all fatalities worldwide due to all extreme weather events, while windstorms contributed an additional 7 percent. Thus, these three categories together accounted for over 99 percent of the fatalities due to extreme events.
- Aggregate annual mortality for the seven categories of extreme events declined by 86 percent between the 1900-1989 and 1990-2004 periods, while the annual mortality rate dropped by 94 percent.
- Mortality declines between the two periods were mainly due to declines in annual fatalities owing to droughts and floods (see also Figures 2 and 3). The remarkable 99.9 percent drop in annual drought fatalities indicates that, for whatever reason, available food supplies per capita have increased in marginal areas, possibly due to greater food production at the global level and an enhanced ability to move food from food surpluses areas to deficit areas through institutions such as international trade and governmental and nongovernmental aid agencies and philanthropies (e.g., through the World Food Program or the International Red Cross) facilitated by better transportation and communication networks, and irrigation facilities (Goklany 1998). The 89.5 percent decline in flood fatalities between the two periods possibly reflects better control, prevention and management of floods through construction of dams and other infrastructure, supplemented by better emergency response measures facilitated by improvements in transportation systems, flood forecasting, and management of water facilities, among other things.
- While average annual fatalities due to windstorms increased from around 11,000 to 15,000 per year between the two periods, the annual mortality rates declined by about a third (see also Figure 4).
- Annual mortality rates dropped for virtually every category except extreme temperatures. However, the spike in deaths and death rates owing to extreme temperatures during the 2000-2004 period, which occurred because of the 2003 European heat wave, were more than compensated for by declines in flood and drought fatalities.[5]

[5] EM-DAT (2005) ascribes over 45,700 deaths to the 2003 European heat wave.

	Deaths per year		Death Rates per yr (per million people)	
	1900-1989	*1990-2004*	*1900-1989*	*1990-2004*
Droughts	111,185	126	49.77	0.02
Floods	75,216	7,872	31.96	1.34
Windstorms	10,858	14,780	3.96	2.68
Slides	457	839	0.15	0.14
Waves/Surges	126	181	0.06	0.03
Extreme Temperatures	99	4,253	0.03	0.69
Wild Fires	21	49	0.01	0.01
TOTAL	197,963	28,099	85.94	4.92

Table 1. Global deaths and death rates for various types of events, 1900-1989 and 1990-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

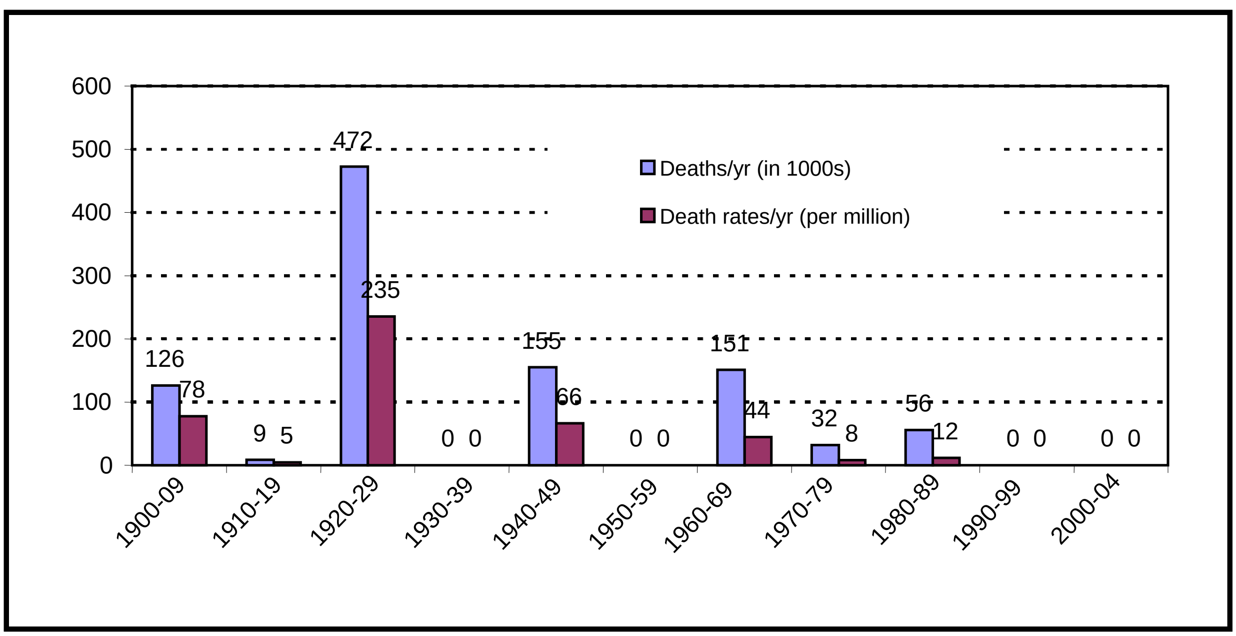

Figure 2: Droughts - Global Deaths & Death Rates, 1900-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

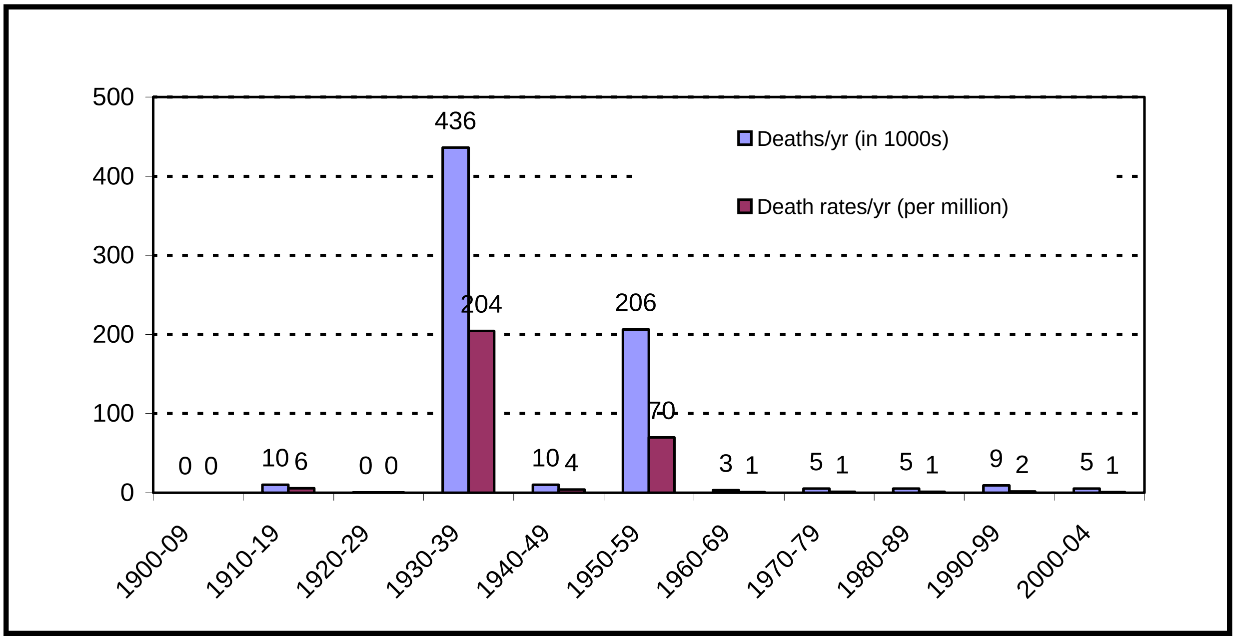

Figure 3: Floods: Global Deaths and Death rates, 1900-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

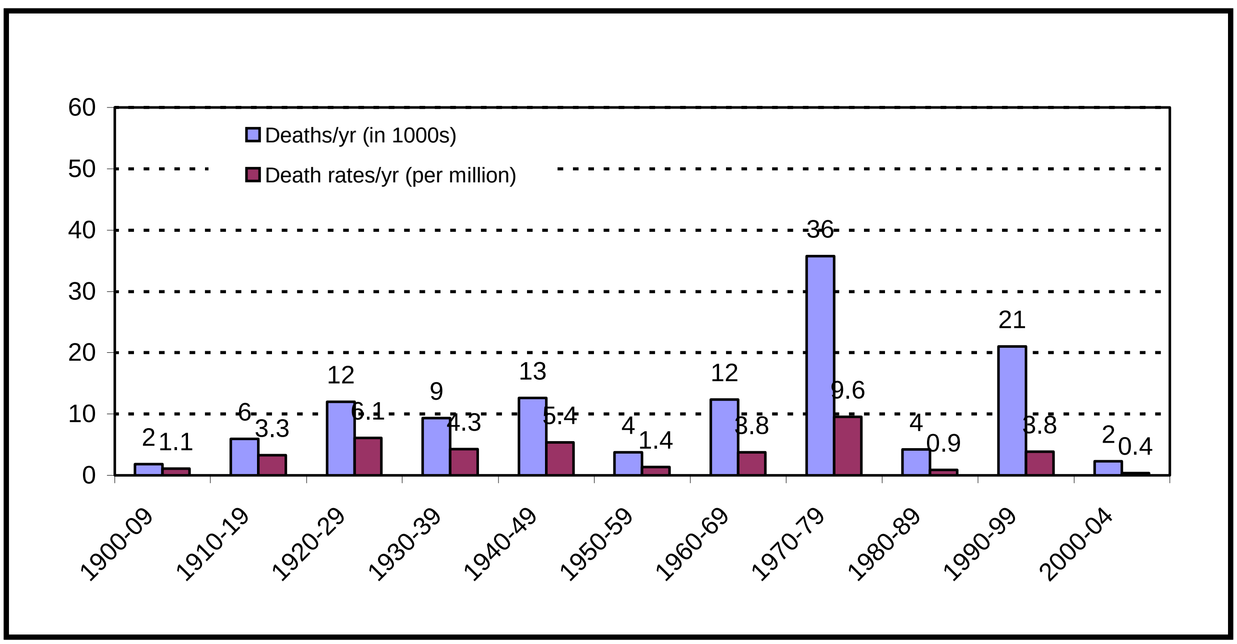

Figure 4: Windstorms: Global Deaths and Death Rates, 1900-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

Cause of Death	No. of Deaths	Percent of Total Deaths
I. Communicable Diseases	**18,324,000**	**32.13%**
Tuberculosis	*1,566,000*	*2.75%*
HIV/AIDS	*2,777,000*	*4.87%*
Diarrhoeal diseases	*1,798,000*	*3.15%*
Malaria	*1,272,000*	*2.23%*
Other tropical diseases	*129,000*	*0.23%*
Other infectious & parasitic diseases	*3,362000*	*5.90%*
Subtotal -- Infectious and parasitic diseases	*10,904,000*	*19.12%*
Respiratory infections	*3,963,000*	*6.95%*
Nutritional deficiencies	*485,000*	*0.85%*
Maternal and perinatal conditions	*2,972,000*	*5.21%*
II. Noncommunicable Conditions	**33,537,000**	**58.81%**
Malignant neoplasms	*7,121,000*	*12.49%*
Cardiovascular diseases	*16,733,000*	*29.34%*
Respiratory diseases	*3,702,000*	*6.49%*
Other noncommunicable conditions	*5,981,000*	*10.49%*
III. Injuries	**5,168,000**	**9.06%**
Road traffic accidents	*1,192,000*	*2.09%*
Violence	*559,000*	*0.98%*
War	*172,000*	*0.30%*
Extreme weather events	**19,400**	**0.03%**
All other injuries	*3,225,600*	*5.66%*

Table 2: Global deaths per year due to various causes, early 2000s. NOTE: All data are for 2002, except for deaths due to extreme weather events, which are based on the annual average from 2000-2004. Sources: WHO (2004), EM-DAT (2005).

THE GLOBAL MORTALITY BURDEN FROM EXTREME EVENTS

To place the current death toll due to all extreme weather events in a wider context, consider that the average annual death toll for 2000-2004 due to all weather-related extreme events according to EM-DAT (2005) was 19,400. By contrast, the World Health Organization (2004) estimates that in 2002 a total of 57.0 million people died worldwide from all causes, including 5.2 million from other kinds of accidents. Out of these, road traffic was responsible for 1.2 million deaths, violence (other than war) for 0.6 million, and war for 0.2 million (see Table 2). Thus, while extreme weather-related events, because of their episodic nature, garnish plenty of attention worldwide, their contribution to the global mortality burden is, at 0.03 percent of global deaths, relatively minor. Their contribution to the global burden of disease should be similarly small.

Notably, the contribution of extreme events to the mortality burden for accidental causes of death is also small (at 0.4 percent). Also, over the last fifty years at least, the general decline in annual mortality due to extreme weather events (see Figure 1) has occurred despite an increase in all-cause mortality (WRI 2005).

A recent review paper in *Nature* (Patz et al. 2005) estimates that climate change may have been responsible for over 150,000 deaths worldwide in 2000. This estimate is largely based on an analysis put out under the auspices of the World Health Organization (McMichael et al. 2004). The latter study arrived at its estimate by ascribing to climate change (a) 77,000 out of about 250,000 deaths due to protein malnutrition, 47,000 out of about 2 million deaths due to diarrheal disease, and (c) and 27,000 out of over 1 million deaths due to malaria (see WHO 2002). It also ascribed 2,000 deaths to floods in 2000, based on the EM-DAT data base. Although this study's estimates for non-flood-related deaths are problematic,[6] if one accepts them as valid, that means that climate change currently accounts for less than 0.3 percent of all global deaths. Accordingly, based on current contributions to the global mortality burden, other public health issues outrank climate change.

U.S. TRENDS IN MORTALITY AND MORTALITY RATES, 1900-2004

Among the problems in developing a long time series for U.S. deaths due to all (or most) extreme weather phenomena is that the length of the U.S. (data) record varies according to the type of event. The *Annual Summaries* (e.g., NOAA 2004, 2005) published by National Oceanic and Atmospheric Administration (NOAA) provides time series data on fatalities due to hurricanes, floods, tornadoes and lightning, respectively, from 1900, 1903, 1916 and 1959 onward. Each year's summary also gives that year's death toll due to a variety of other weather related phenomena such as extreme cold, extreme heat, drought, mudslides, winter storms, avalanches, etc., but it does not provide any time series data for these other categories of natural disasters. Another problem is that the data for several phenomena from these summaries are at variance with other data sources. Specifically, there are discrepancies between mortality data from these Annual Summaries and (a) the Hydrologic Information Center's (HIC 2005) estimates for floods, (b) the National Hurricane Center's data for hurricanes (Blake et al. 2005), and (c) CDC's WONDER database for extreme cold and extreme heat. Based on previous conversations with personnel from the various agencies (Goklany 2000), it

[6] The authors themselves note that among the challenges in developing estimates of the health impacts of climate change is that "climate change occurs against a background of substantial natural climate variability, and its health effects are confounded by simultaneous changes in many other influences on population health….Empirical observation of the health consequences of long-term climate change, followed by formulation, testing and then modification of hypotheses would therefore require long timeseries (probably several decades) of careful monitoring. While this process may accord with the canons of empirical science, it would not provide the timely information needed to inform current policy decisions on GHG emission abatement, so as to offset possible health consequences in the future. Nor would it allow early implementation of policies for adaptation to climate changes." Hence the estimates were based on modeling studies, with quantification based on anecdotal information. The temperature-disease relationship used to develop the estimate for diarrhea, for example, was based on 6 years worth of data from Lima, Peru, and 20 years of data from Fiji. In addition, the amount of climate change estimated for 2000 was based on the results of a general circulation model at resolution of 3.75o longitude and 2.5o latitude. The results of such models, which are inexact at best at the global level, tend to greater uncertainty as the resolution gets finer.

was decided to use HIC data for floods (as adjusted per Goklany 2000), and Blake et al. (2005) for hurricanes through 2004. The Center for Disease Control's WONDER database was used for extreme heat and cold, because it is based on actual death certificate records, which, in turn, are based on medical opinion as opposed to the National Weather Service's expert opinion. To date (April 2005), these data are readily available only from 1979 to 2002.[7]

Figure 5 shows the trend in cumulative deaths and death rates for a subset of extreme weather events, specifically, hurricanes, floods, tornados, lightning, and extreme heat and cold from 1979-2002.[8] It shows that despite any warming that may have occurred, both deaths and death rates have not increased over this period. If anything, they might have declined over this period, during which all-cause mortality increased by 28 percent (USCB 2004).

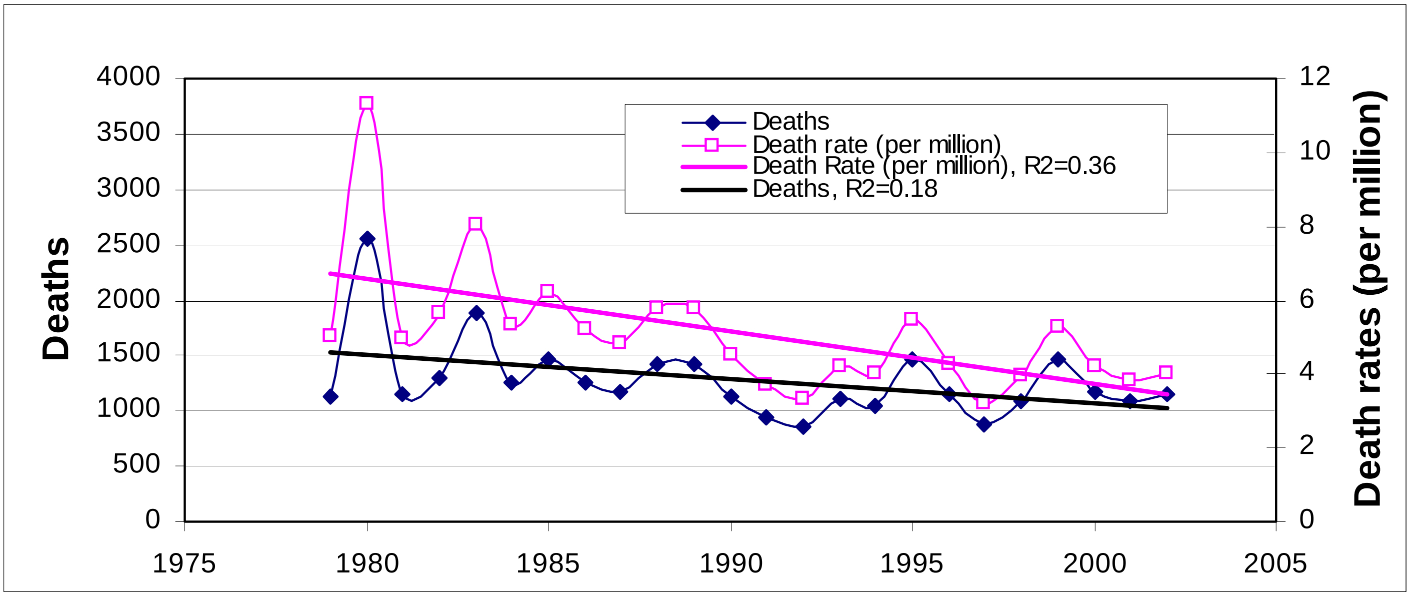

Figure 5: Cumulative U.S. Deaths and Death Rates, 1979-2002, for Hurricanes, Floods, Lightning, Tornados, Extreme Heat and Extreme Cold. Sources: for hurricanes, Blake et al. (2005); for lightning and tornados, NWS (2004, 2005) and Hinson (2005); for floods, HIC (2005); for extreme heat and cold, CDC (2005).

The linear trend lines plotted in Figure 5 (and any subsequent figures) were automatically generated by EXCEL, which uses ordinary least squares analysis. Notably, the bulk of the weather-related deaths (53 percent) during this period were caused by extreme cold. In importance, these were followed by extreme heat, floods, lightning, tornados, and hurricanes, which contributed 28, 8, 5, 4 and 2 percent, respectively. See Table 3.

[7] To further complicate matters, the NOAA website provides a "65-Year List of Severe Weather Fatalities" (from 1940-2005. Unfortunately, the data in this list for lightning is inconsistent with the data from its *Annual Summaries*. Enquiries to NOAA, so far, have not resolved these discrepancies satisfactorily.

[8] In the WONDER database, mortality data for 1979-1998 are coded using the International Classification of Disease, version 9 (i.e., ICD-9) for 1979-1998, and ICD-10 for 1999 onward. To identify deaths due to extreme heat, I used codes E900.0 and E900.9 for ICD-9 (per Goklany and Straja 2000), and X30 for ICD-10. The corresponding codes used for extreme cold were E901.0 and E901.9, and X31, respectively.

	Cumulative deaths	Deaths per year	Percent of annual all-cause deaths
Extreme cold (XC)	16,313	680	0.031%
Extreme heat (XH)	8,589	358	0.016%
Flood (F)	2,395	100	0.005%
Lightning (L)	1,512	63	0.003%
Tornado (T)	1,321	55	0.003%
Hurricane (Hu)	460	19	0.001%
Sum	30,590	1,275	0.058%
Total deaths, all causes, 1979-2002 average		2,189,000	100.000%

Table 3. US deaths due to weather-related events, 1979-2002. Sources: for extreme events, see text; for total all-cause mortality, USCB (2004).

Figures 6 (and 7) show the 10-year moving averages for deaths (and death rates) due to hurricanes from 1900-2005, floods from 1903-2004, tornados from 1916-2004, and lightning from 1959-2004, as well as for cumulative deaths (and death rates) from these four individual categories of events (from 1959 to 2004). Death rates in Figure 7 are calculated using national population estimates from the US Census Bureau (USCB).[9]

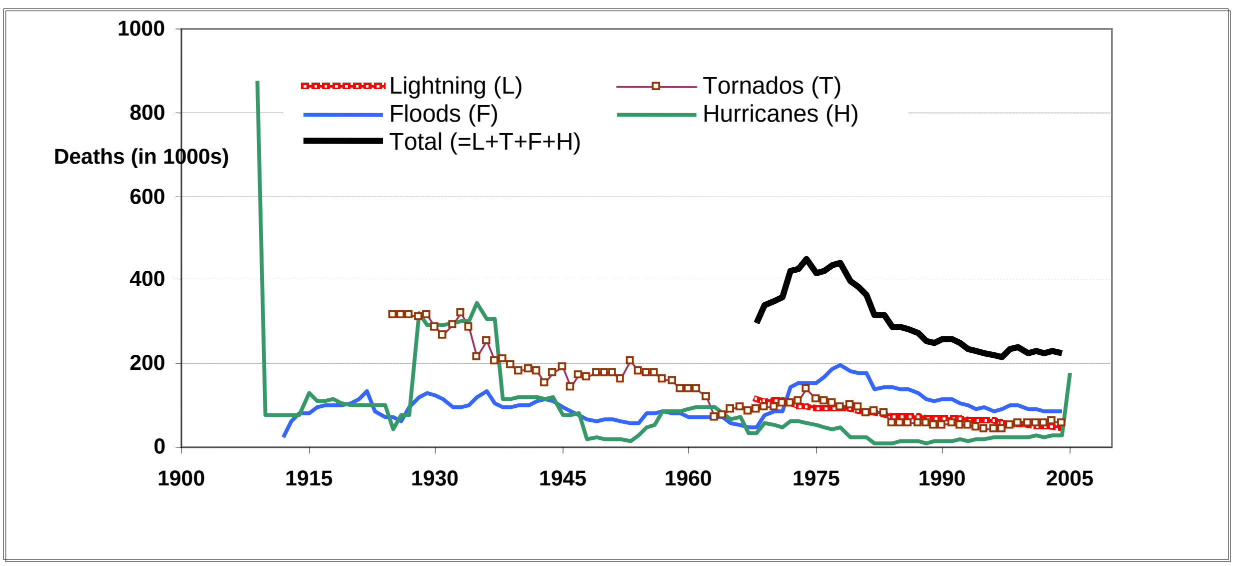

Figure 6: U.S. Deaths due to Hurricanes (1900-2005), Floods (1903-2004), Tornados (1916-2004), Lightning, (1959-2004) and Total (1959-2004); 10-year moving averages. Sources: for hurricanes, Blake et al. (2005), and NHC (2006); for lightning and tornados, NWS (2004, 2005) and Hinson (2005); for floods, HIC (2005) and Goklany (2000).

[9] For hurricanes it might have been more appropriate to use annual estimates of the coastal population to estimate death rates, but that would have complicated calculations of cumulative death rates.

Figure 6 shows that for the most recent 10-year period for which data are available or estimated (i.e., from 1996-2005 for hurricanes and 1995-2004 for the other types of events), deaths declined below their earlier peaks in the 10-year moving averages by 56 percent for floods, 58 percent for lightning, 82 percent for tornados and, despite Hurricane Katrina, 80 percent for hurricanes. Such declines are consistent with results of earlier analyses (Goklany 2000). Similarly, Figure 7 indicates that the corresponding declines for death rates (comparing their peaks with the most recent 10-year period) were 76 percent for floods, 72 percent for lightning, 95 percent for hurricanes and 93 percent for tornados.

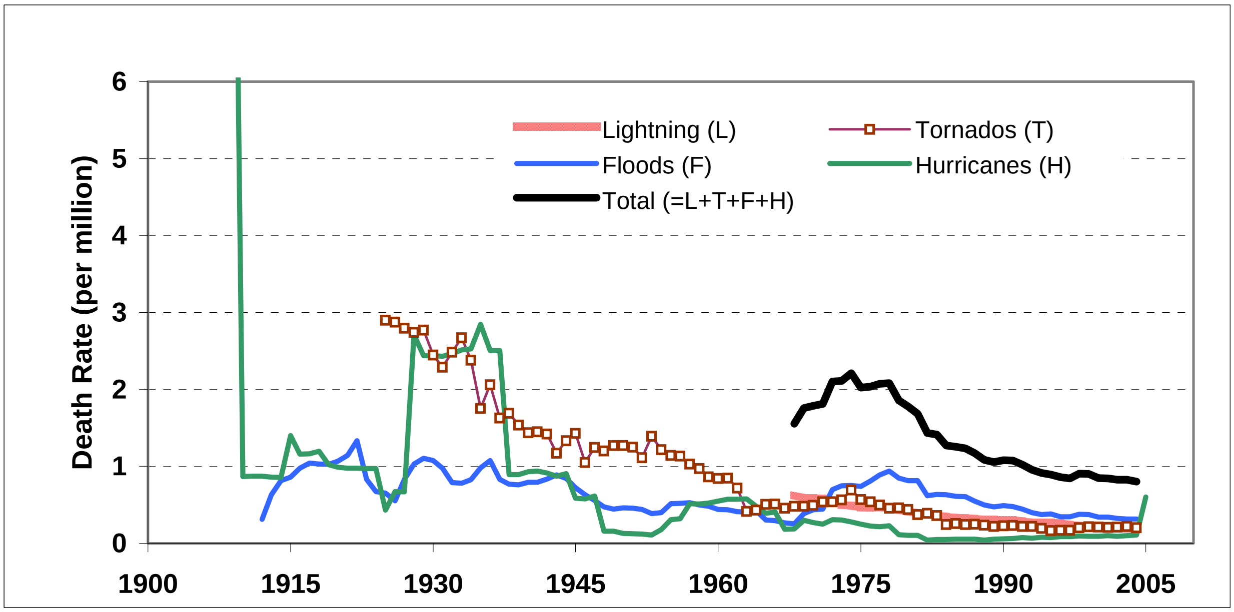

Figure 7: U.S. Deaths Rates due to Hurricanes (1900-2005), Floods (1903-2004), Tornados (1916-2004), Lightning, (1959-2004) and Total (1959-2004); 10-year moving averages. Sources: for hurricanes, Blake et al. (2005) and NHC (2006); for lightning and tornados, NWS (2004, 2005) and Hinson (2005); for floods, HIC (2005) and Goklany (2000); for population, USCB (2006).

Both figures show:

- A large spike for hurricanes at the very beginning of the record due to the Galveston Hurricane of 1900, and a smaller spike due to Hurricane Katrina at the very end punctuated by a relatively high plateau in the late 1920s which extended into the late 1930s, and troughs extending from the late 1940s to the early 1950s and, again, in the 1980s and 1990s.[10] This is also illustrated in Figure 8.[11]
- Mortality and mortality rates dropped more or less steadily for lightning and tornados over the period for which records are available. These results are consistent with earlier analyses for both sets of events by Goklany (2000), and Doswell et al (1999) for tornados.
- Mortality from floods exhibit no particular trend from 1903 to 2004, although mortality rates might have declined somewhat (see also Figure 9).[12] Mortality due to floods in 2005 is expected to be higher than in previous years because of floods related to hurricanes that year.

[10] These figures assume 1,500 deaths in 2005. As of 10 April 2006, according to the National Hurricane Center (2005) there were 1,409 confirmed deaths due to hurricanes during 2005. However, I rounded this number up because the Katrina count is not yet complete. The figures also assume a death toll of 8,000 for the 1900 Galveston Hurricane (Blake et al. 2005).

[11] Note that in Figure 8 the data for the last period is based on a six year average, while that for other periods are based on ten year averages.

[12] In Figure 9 the data for the last period is based on a five year average, while that for other periods are based on six year averages.

- Cumulative annual mortality and mortality rates for the above four categories of extreme weather events have declined since the mid-1970s. Figure 10 indicates that both deaths and death rates for these four categories declined 24 and 52 percent, respectively, from 1959-64 to 2001-04.[13]

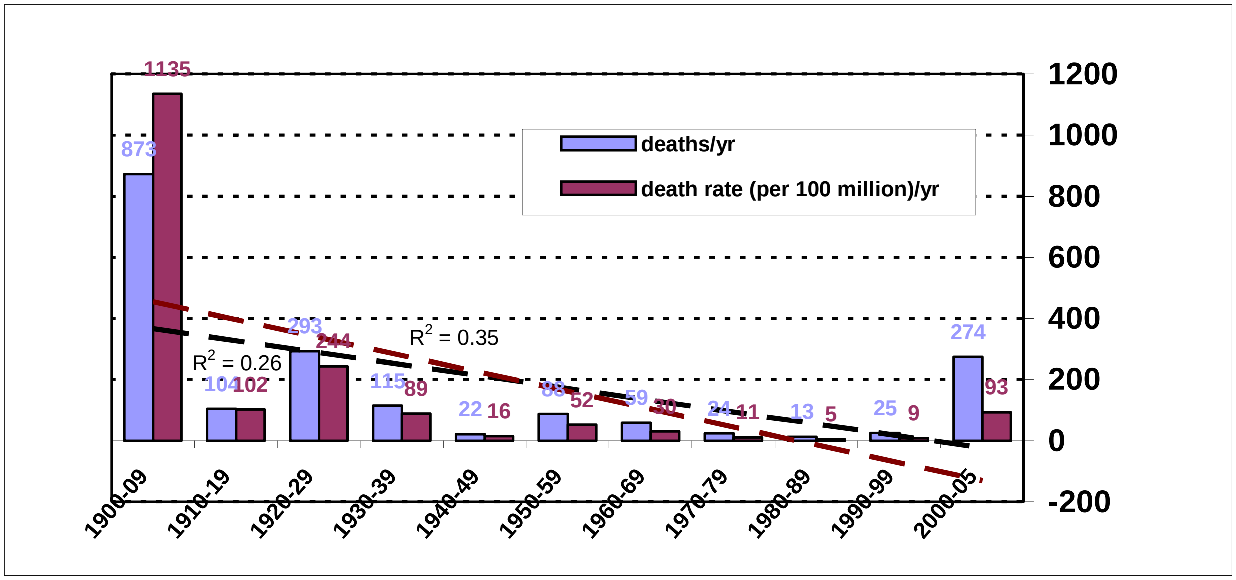

Figure 8: Annual U.S. Deaths and Death Rates due to Hurricanes, 1900-2005. Sources: Blake et al. (2005); NHC (2006); USCB (2006).

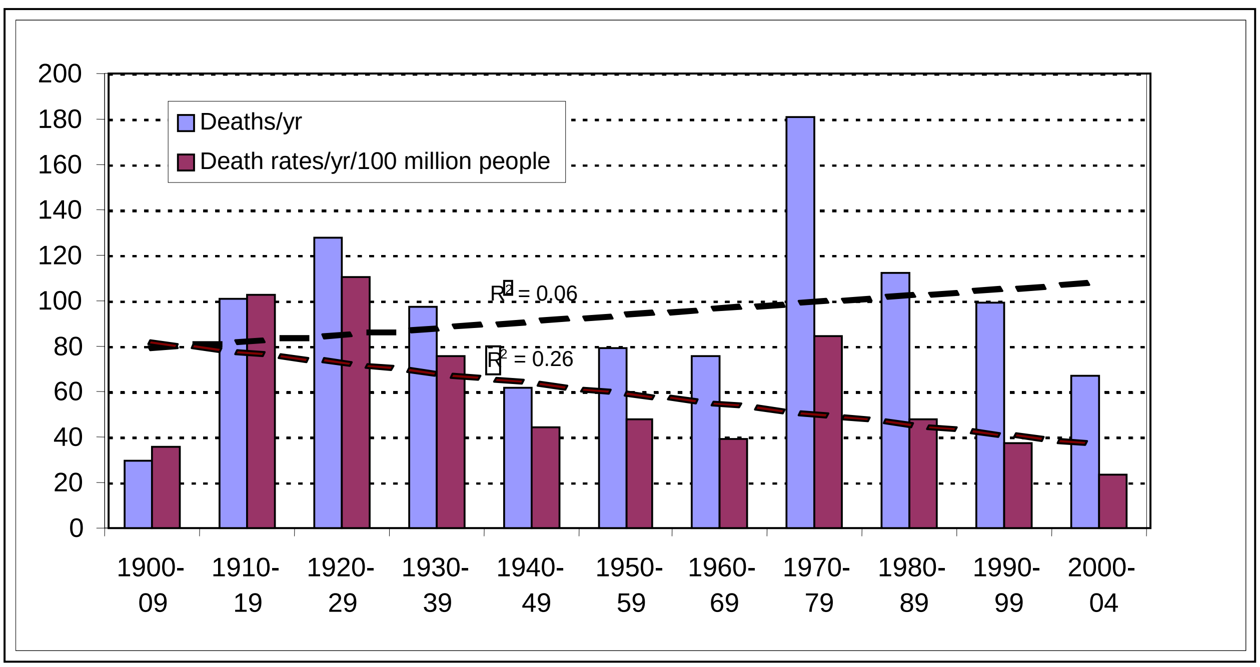

Figure 9: Annual U.S. Deaths and Death Rates due to Floods, 1903-2004. The data for 1900-1909 are based on the seven-year average from 1903 through 1909 because the HIC's series starts in 1903. Sources: HIC (2005); USCB (2006).

[13] Note that the last period spans four years, while the other periods span six years. Also, the decline between 1971-76 to 2001-04 ranges from 56 percent for mortality and 68 percent for the mortality rate.

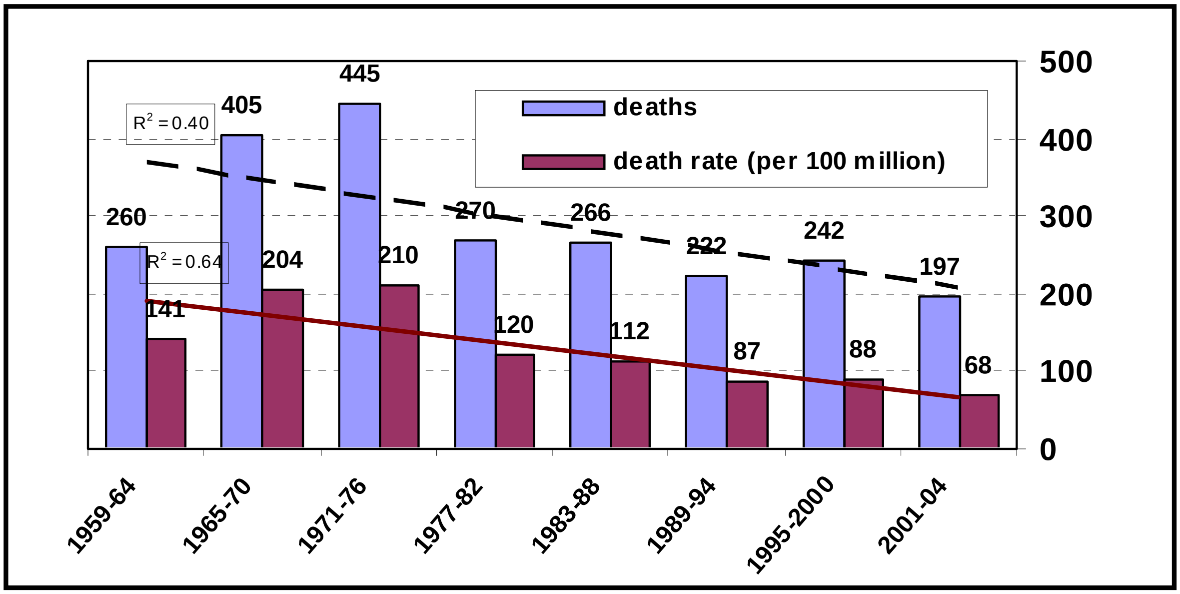

Figure 10: Cumulative Annual U.S. Deaths and Death Rates from Hurricanes, Floods, Lightning, and Tornados, 1959-2004. Sources: For hurricanes, Blake et al. (2005); for lightning and tornados, NWS (2004, 2005); for floods, HIC (2005); for population USCB (2006).

The previous figures (6 through 10) show that currently deaths and death rates are, in general, lower than they used to be in the past. Predictably, death rates have declined more rapidly than deaths per year, confirming results from previous studies (Goklany 2000).

Discussion and Conclusions

The information presented above indicates that globally as well as for the United States, the aggregate contribution of extreme weather events to the mortality burden is currently relatively minor, ranging from 0.03 to 0.06 percent.

Moreover, if the frequency, intensity and duration of extreme weather events has increased in recent decades — all empirical issues best left to climatologists — there is no signal of that in the data on either mortality rates or, more importantly, mortality despite an increase in populations at risk.

At the global level, the data, while incomplete, indicate:

- Aggregate annual mortality and mortality rates owing to extreme weather events have declined between 95 and 99 percent, respectively, since the 1920s regardless of whether the frequencies, intensities and/or durations of extreme weather events have increased (or not) due to human-induced or natural climate change.
- Much of the above improvement is due to a substantial decline in mortality due to droughts and floods, which apparently caused 95 percent of the fatalities due to extreme events between 1900 and 2004.
- Death rates for the different categories of extreme events were generally lower in the 1990s and early-2000s than in previous decades, with the notable exception of extreme temperatures, which were higher because of the 2003 European heat wave.
- Regarding windstorms, both mortality and mortality rates peaked in the 1970s. The average annual mortality due to windstorms over the past 15 years exceeded the average over the rest of the 20th century but the mortality rate was a third lower.

With respect to the United States:

- In an average year, more lives are lost to extreme temperatures — both extreme heat and extreme cold — than to more heavily publicized events such as tornados, hurricanes and floods. According to data from the Centers for

Disease Control, extreme cold, on average, claims more lives than tornados, floods, lightning, hurricanes and extreme heat, combined.

- In general, mortality and mortality rates from the various categories of extreme events examined here (tornados, hurricanes, floods, lightning and extreme temperatures) are lower today that they have been in the past. Based on 10-year moving averages, for the most recent 10-year period for which data are available (or for which data can be approximated), mortality declined by 55-80 percent for floods, lightning, tornados and hurricanes while mortality rates declined by 70-95 percent. However, there are no consistent trends for mortality due to floods, and both mortality and mortality rates for hurricanes spiked in 2005. However, these spikes are lower than levels that had been reached in previous periods.

Thus, mortality rates and, more significantly, mortality for the most deadly and destructive forms of extreme weather events have apparently declined substantially over the past several decades. This suggests that if climate change has exacerbated extreme events then either mankind has been extremely lucky in terms of where and when these events have struck or — a more likely explanation — society's ability to cope with extreme events has not only improved, it has for the most part put its increased adaptive capacity to good effect.

Several interrelated factors have contributed to this increase in adaptive capacity. First, today's societies have available to them a wider range of technological options to finesse the consequences of extreme events before they strike and to cope with their aftermath after they have struck. Such options range from early warning systems, building codes, and better meteorological forecasts to better construction, communications and transportation systems which increased the ability to transport men and materiel (including food, medical and other essential supplies) in and out of disaster zones. Second, many of these options were learnt through experience and were enabled through the ability of wealthier societies to research and develop new technologies and practices. Greater wealth also allowed them to obtain and implement more effective technologies. Once developed, it is possible for poorer societies to learn from and adapt technologies developed in wealthier, more technologically sophisticated nations. Third, societies have greater access to human and social capital to protect themselves from, and cope with, adversity in general and extreme weather events in particular (IPCC 1991; Goklany 1995, 2000, 2006; Goklany and Straja 2000).

However, as indicated by the European experience with the 2003 heat wave and the U.S. experience with Hurricane Katrina, the importance of human and social capital cannot be overemphasized. They are just as important as wealth and increased access to technology. Moreover, greater adaptive capacity is necessary but not sufficient to effectively cope with extreme events. Such capacity must be deployed more rapidly and used more fully.

Nevertheless, the decline in deaths and death rates from extreme events indicates that if the frequencies, intensities and durations of extreme events have increased then adaptive capacity has evolved even faster, and thus far wealth, technology, and human and social capital have, despite notable exceptions, have for the most part apparently trumped natural climatic variability and human-induced climatic change.

Finally, it has been suggested that declining trends for deaths (and death rates) due to extreme events might be accompanied by — or might contribute to — increasing trends in economic losses based on the general notion that individuals might accept greater financial risks provided personal safety is more assured (Goklany 2000). In addition, a wealthier society is likely to have more property at risk which, moreover, would be exacerbated by the fact that improvements in housing stock, infrastructure and support systems undertaken to cope with extreme events further adds to the property at risk.

For the U.S., results of this paper combined with previous studies of economic losses due to various categories of extreme events suggests (but does not prove) that declining mortality is indeed accompanied by higher economic losses if losses are measured in terms of real (constant) dollars for floods, hurricanes, and tornados; but this does not seem to be the case if losses are measured in terms of a fraction of wealth (measured as fixed tangible reproducible assets, which excludes land values) (Pielke and Landsea 1998, Doswell et al. 1999, Goklany 2000, Pielke, Jr, and Downton 2000, Downton et al. 2005).

Globally, the analysis in this paper and the estimates of economic losses in constant dollars provided by the IPCC's Third Assessment report suggest that declining mortality is also accompanied by increasing property losses (see also, Faust et al. 2006). However, it is impossible to say at this time whether the upward trend for economic losses would hold were global economic losses to be measured in terms of global wealth because appropriate data are lacking.

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