Deaths and Death Rates from Extreme Weather Events: 1900-2008

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ABSTRACT

Proponents of drastic greenhouse gas controls claim that human greenhouse gas emissions cause global warming, which then exacerbates the frequency and intensity of extreme weather events, including extreme heat, droughts, floods, and storms such as hurricanes and cyclones.

In fact, even though reporting of such events is more complete than in the past, morbidity and mortality attributed to them has declined globally by 93%–98% since the 1920s. In the U.S., morbidity and mortality from extreme weather events peaked decades ago. Depending on the category of extreme weather event, average annual mortality is 59%–81% lower than at its peak, while mortality rates declined 72%–94%, despite large increases in the population at risk. Today, extreme weather events contribute only 0.06% to global and U.S. mortality. These improvements reflect a remarkable improvement in society's adaptive capacity, likely due to greater wealth and better technology enabled in part by use of hydrocarbon fuels. Finally, mortality from extreme weather events has declined even as all-cause mortality has increased, indicating that humanity is coping better with extreme weather events than it is with far more important health and safety problems.

Background

Proponents of drastic reductions in the anthropogenic emissions of "greenhouse gases" such as carbon dioxide argue that, without such action, ever-increasing death tolls and economic losses will result. The suggested mechanism is that warmer temperatures would intensify the hydrological cycle through greater evaporation, and cyclones and hurricanes would acquire greater energy. Built-up water vapor and energy would be released in more frequent and intense rainfall and storms. At the same time, some areas would see droughts, and yet others, extreme heat waves.[1-4]

To stoke such fears, recent weather-related disasters were cited: the Central European floods of 2002, the 2003 European heat wave, and the back-to-back disastrous Atlantic hurricane seasons of 2004 and 2005. Leading popular magazines such as *Time*, for instance, warned in a special issue devoted to global warming that we should "be worried, very worried"[5] about its consequences.

These fears, predictably used by former Vice-President Al Gore to promote his case against hydrocarbon fuels,[6] have also been promulgated by nongovernmental organizations.[7] Many of them now insist that the global warming that occurred in the last century is due mainly to anthropogenic greenhouse gas emissions, despite the disagreement of many scientists, and that "climate change" will cause escalating disasters worldwide. For instance, Bekele Geleta, secretary general of the International Federation of Red Cross and Red Crescent Societies, and Sir John Holmes, United Nations undersecretary general for humanitarian affairs wrote in a letter to the UN Framework Convention on Climate Change stating that: "[I]n the coming decades, climate change is expected to exacerbate the risks of disasters, not only from more frequent and intense hazard events, but also though greater vulnerability to the existing hazards."[8]

Based partly on the notion that weather-related disasters have increased—and will continue to increase—because of global warming, Kofi Annan, erstwhile UN secretary-general and now president of Global Humanitarian Forum, declared:

> Climate change is a silent human crisis. Yet it is the greatest emerging humanitarian challenge of our time. Already today, it causes suffering to hundreds of millions of people most of whom are not even aware that they are victims of climate change. We need an international agreement to contain climate change and reduce its widespread suffering.[9]

This paper does not address the causes of any warming that may have occurred. Instead, it examines whether deaths and death rates due to weather-related extreme events have increased globally and in the United States since the beginning of the 20th century, as they should have if, all else being equal, global warming, of whatever cause, has indeed increased the frequency and severity of such events.[1,10,11] It also puts these deaths and death rates into perspective by comparing them with the total mortality burden from other causes, and briefly discusses what trends in deaths and death rates imply about human adaptive capacity.

Note that in this paper, I use crude death rates, that is, deaths for a fixed number of people. Thus trends in death rates are not adjusted for changes in the age distribution of the population.

Trends in deaths and death rates, while of intrinsic interest for public policy purposes, may also have a bearing on trends in economic losses. First, wealthier societies will inevitably have more property at risk. Second, it has been suggested that although a wealthier society may take extra effort to limit loss of life, it may also be less concerned about property losses.[12] Similarly, at the level of the individual, some may be less concerned about putting property at risk once physical safety is assured. This suggestion finds some support in findings that the ratio of death-to-property-loss for tornados in the U.S. has declined in recent decades.[13,14]

Global Trends in Mortality and Mortality Rates

In general, if a phenomenon, such as global warming, could change the frequency, intensity, and/or duration of extreme weather events such as floods, droughts, storms, and extreme temperatures, the result could be an increase in these categories of events in some locations and for some periods and a decrease 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, global warming might redistribute the temporal and spatial pattern of rainfall, droughts, and other such events. Accordingly, to estimate the net impact, if any, of global warming on mortality, it is probably best to examine cumulative deaths at the global level aggregated over all

types of extreme weather 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, recognize that the quality of the data, data coverage, 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 magnitude of the population at risk. However, use of mortality rates may be insufficient to account for the fact that 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 greater availability of insurance place people at moral hazard, encouraging them to bear less than their full burden of financial risk. This may also place even wealthier populations at greater physical risk.[12]

Data Sources

This paper uses data on deaths from all 8,498 climatological, meteorological, and hydrological events for each year from 1900 through 2008 in the EM-DAT's International Disaster Database.[15] This database is maintained by the Office of Foreign Disaster Aid and Center for Research on the Epidemiology of Disasters (CRED) at the Université Catholique de Louvain, Brussels, Belgium. Specifically, for the number of deaths, this paper uses data on droughts, extreme temperatures (both extreme heat and extreme cold), floods, wet mass movement (i.e., slides, waves, and surges), wildfires, and storms (e.g., hurricanes, cyclones, tornados, typhoons, etc.). These data are compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutes, and press agencies. For a disaster event 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.

Aggregate Trends

Figure 1 shows the average annual number of events recorded in the EM-DAT database for each "decade" since the 1900s. (Technically, the first decade of the 1900s actually started in 1901, and the last bar represents a 9-year period.) This figure shows that the average number of records (i.e., events) increased from 2.5 per year in the 1900s to 8.5 per year in the 1940s, after which the numbers escalated rapidly, reaching 354 per year in the 2000s. Some advocates of greenhouse gas controls have asserted, without proof, that much of the increases in recent decades could be due to global warming.[6,9] However, one should expect that even if there were no change in climate or climate variability, the proportion of events recorded in EM-DAT would increase over the decades with (a) the advance of telecommunications, (b) broader news coverage, (c) globalization of international aid, and (d) an increased tendency by authorities to declare natural disaster emergencies for a variety of reasons.

First, as nations become wealthier—and almost all did during the 20th century[16]—political leaders have more resources to afford emergency declarations. Second, the number of democracies has also increased during this period,[16,17] and in democracies political leaders tend to declare emergencies early and often. Politicians apparently like to be photographed emerging from a helicopter at a disaster scene.

Additionally, one should expect that since global population has quadrupled since 1900, the number of recorded events should increase at least proportionately. Not only are there four times as many people potentially exposed, but there are also four times as many observers. Thus, the number of events—and associated mortality—is likely to have been systematically under-reported in the early decades of the 20th century in the EM-DAT database; the earlier, the greater the degree of under-reporting. In fact, CRED, the keeper and compiler of the EM-DAT database, itself attributes increases until about 1995 partly to better reporting of disasters in general, and partly to real increases in certain types of disasters. It believes that "the data in the most recent decade present the least bias and reflect a real change in numbers. This is especially true for floods and cyclones. Whether this is due to climate change or not, [CRED is] unable to say."[6]

Despite EM-DAT's shortcomings and its tendency to bias long-term trends in deaths upward, I will use its death estimates in this paper.

To calculate death rates, it is necessary to estimate global population for each year from 1900 through 2008. For 1900–1925, population was computed for each year based on interpolation of McEvedy and Jones's[18] estimates for 1900 and 1925, assuming exponential growth between these two end points. For 1926–1949, population was calculated similarly, using McEvedy and Jones's 1925 estimate and the 1950 estimate from the World Resources Institute's EarthTrends database.[19] Population for 1950 through 2008 population was taken directly from the latter source.

Figure 2 shows the average annual deaths and death rates from all weather-related extreme events for each "decade" starting in 1900 through the nine-year period from 2000–2008. This figure shows that

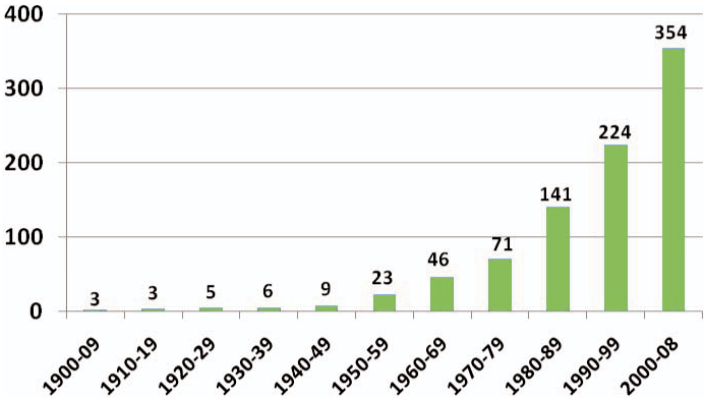

Figure 1: Average Number of Extreme Weather Events per Year by Decade, 1900–2008.[15]

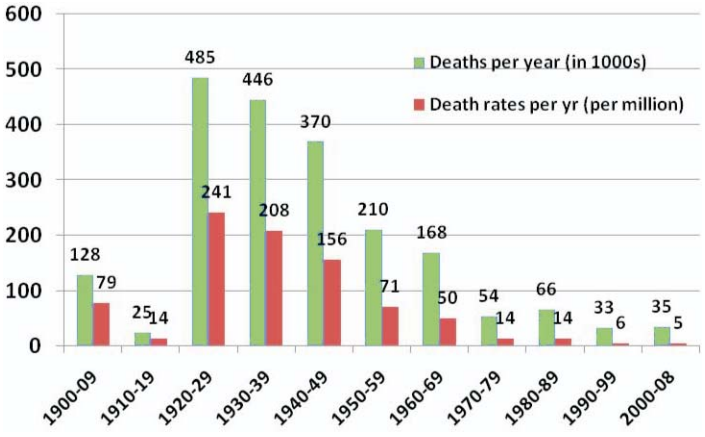

Figure 2: Global Death and Death Rates Due to Extreme Weather Events, 1900–2008.[15,18,19]

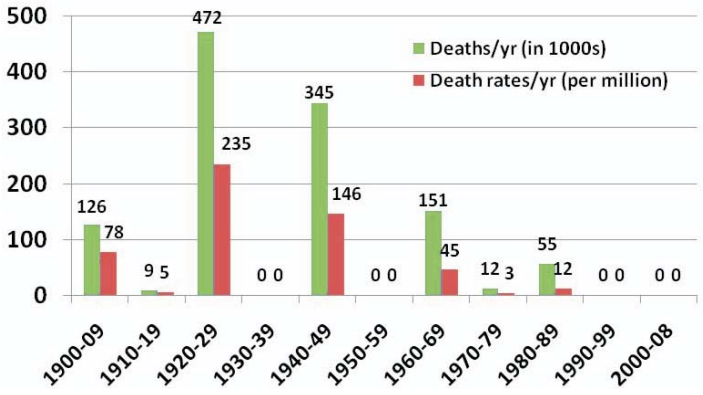

Figure 3: Droughts: Global Deaths & Death Rates, 1900–2008.[15,18,19]

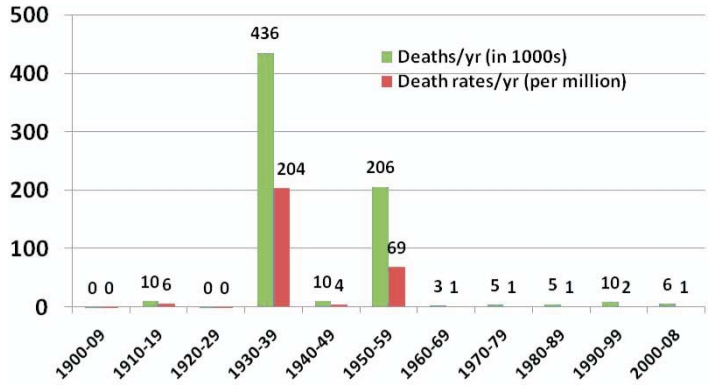

Figure 4: Floods: Global Deaths and Death Rates, 1900–2008.[15,18,19]

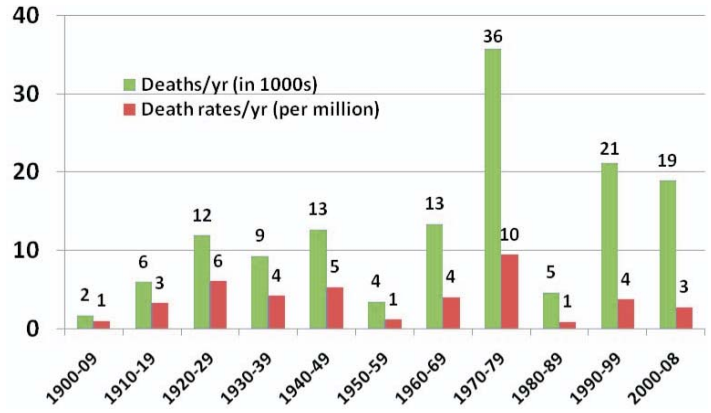

Figure 5: Storms: Global Deaths and Death Rates, 1900–2008.[15,18,19]

both death and death rates have declined at least since the 1920s. Specifically, comparing the 1920s to the latest (2000–2008) period, the annual number of deaths declined from 484,900 to 35,200, a 93% decline, while the death rate per million dropped from 241.5 to 5.4, a decline of 98%.

Figure 3 shows that for droughts, the single most deadly category for the entire period, both deaths and death rates apparently peaked in the 1920s. Since then, they have declined by 99.97% and 99.99% respectively.

Figure 4 shows that deaths and death rates for floods, the second most important category and responsible for a third of the deaths recorded in EM-DAT for the entire period, crested in the 1930s. By 2000–2008, they were down by 98.7% and 99.6%, respectively.

Figure 5 shows that deaths and death rates from storms have declined by 47.0% and 70.4%, respectively, after peaking in the 1970s.

Table 1. Global Deaths and Death Rates for Various Types of Events, 1900–1989 and 1990–2008.[15,18,19]

	Deaths per year		Death rates per year (per million people)	
	1900–1989	*1990–2008*	*1900–1989*	*1990–2008*
Droughts	130,044	225	58.19	0.04
Floods	75,169	7,676	31.87	1.28
Storms	11,018	20,079	4	3.35
Mass movement—wet	441	780	0.15	0.13
Extreme Temperatures	124	5,144	0.03	0.82
Wildfires	22	69	0.01	0.01
TOTAL	216,819	33,973	94.24	5.63

Trends for Specific Types of Extreme Events

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 1990–2008. The rows are arranged in order of declining mortality ascribed to the various events (highest to lowest) for the former period.

The deadliest extreme weather events during much of the 20th century were droughts, followed by floods and storms. Over the 109-year record, droughts and floods were responsible for 58% and 34%, respectively, of all fatalities worldwide due to all extreme weather events, while storms contributed an additional 7%. Thus, these three categories together accounted for more than 99% of the fatalities due to extreme weather events.

Aggregate annual mortality for the six categories of extreme events declined by 84% between the 1900–1989 and 1990–2008 periods, while the annual mortality rate dropped by 94%. Mortality declines between the two periods were mainly attributable to declines in annual fatalities owing to the two most deadly categories: droughts and floods. The remarkable 99.8% drop in annual drought fatalities indicates that the increases in available food supplies outstripped even the unprecedented population increases of the 20th century.

The remarkable increase in food supplies occurred for a number of reasons: (a) Greater use of existing technologies (e.g., irrigation and fertilization) and the development of new technologies (e.g., the suite of technologies constituting the Green Revolution) increased crop yields on the farm, and reduced pre-and post-harvest losses and wastage at every stage of the food chain. (b) Expanded commerce allowed food to move rapidly and in unprecedented quantities from surplus areas to deficit areas. (c) Greater wealth increased the purchasing power of consumers and governments in developing countries, allowing imports to compensate for shortfalls in production. It also allowed developed countries and charities to establish food aid programs to help out in both chronically food-short areas and during emergencies.[16,20] (d) Essential to all of these factors was increased availability of relatively cheap electricity and petroleum-based fuel and other products for transportation, fertilizer, food packaging, refrigeration, and pesticides.[16,20,21]

The 89.8% decline in annual flood fatalities between 1900–89 and 1990–2008 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 for storms, average annual mortality almost doubled from around 11,000 to 20,000 between the two periods, the annual mortality rate declined by 16%.

Annual mortality rates dropped for every category except

Table 2. Global Deaths per Year.

Cause of Deaths	Number of Deaths* (in thousands)	Percent of Total Deaths
Infectious and parasitic diseases	10,904	19.12%
Tuberculosis	1,566	2.75%
STIs excluding HIV	180	0.32%
HIV/AIDS	2,777	4.87%
Diarrheal diseases	1,798	3.15%
Childhood diseases	1,124	1.97%
Meningitis	173	0.30%
Hepatitis B and C	157	0.27%
Malaria	1,272	2.23%
Other infectious & parasitic diseases	1,857	3.26%
Respiratory infections	3,963	6.95%
Maternal conditions	510	0.89%
Perinatal conditionsg	2,462	4.32%
Hunger and malnutrition	485	0.85%
Malignant neoplasms	7,121	12.49%
Cardiovascular diseases	16,733	29.34%
Respiratory diseases	3,702	6.49%
Digestive diseases	1,968	3.45%
Other non-communicable conditions	4,012	7.04%
Injuries	5,168	9.06%
Road traffic accidents	1,192	2.09%
Fires	312	0.55%
Drowning	382	0.67%
Other unintentional injuries	1,665	2.92%
Self-inflicted	873	1.53%
Violence	559	0.98%
War	172	0.30%
TOTAL Deaths	**57,029**	**100.00%**
Extreme weather events	32	0.06%

* All data are for 2002, except that deaths due to extreme weather events are the annual average from 2000–2008.[15,26]
STIs: sexually transmitted infections; HIV: human immunodeficiency virus; AIDS: acquired immune deficiency syndrome

extreme temperatures and wet mass movement. However, the contribution of these two categories to the total mortality burden from extreme weather events is relatively minor. The spike in deaths and death rates owing to extreme temperatures during the 1990–2008 period, which occurred because of the 2003 European heat wave, was over the long term more than offset by declines in flood and drought fatalities. Notably, the latest version of EM-DAT assigns 72,225 deaths to the 2003 European heat wave. In 2005, EM-DAT had ascribed 45,700 deaths to that event.[22]

Mortality from Extreme Weather Events in Perspective

To place extreme weather events in a wider context, consider that the average annual death toll for 2000–2008 due to all weather-related extreme events, according to EM-DAT, was 31,700.[15] By contrast, the World Health Organization estimates that in 2002 a total of 57.0 million people died worldwide from all causes, including 5.2 million from various kinds of accidents.[23] 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, garner plenty of attention worldwide, their contribution to the global mortality burden is, at 0.06% of global deaths, relatively minor. Their contribution to the global burden of disease should be similarly small. Even the contribution of extreme weather events to mortality from accidental causes of death (0.9%) is small.

Additionally, over at least the last 50 years the general decline in annual mortality due to extreme weather events (see Figure 2) has occurred despite an increase in all-cause mortality.[19] That is, extreme weather events are becoming less significant as a contributor to mortality, even as people's awareness of such events seems to be have been heightened by extensive media coverage of natural disasters.

An earlier paper[24] in this journal discussed a review paper in *Nature,*[25] which estimated a global death toll of 150,000 attributable to global warming in 2000. This estimate is largely based on analyses published under the auspices of the World Health Organization (WHO),[26] which relied on the WHO 2002 Global Burden of Disease study.[27] The WHO assigns to global warming 77,000 of about 250,000 deaths from protein malnutrition; 47,000 of about 2 million deaths from diarrheal disease; and 27,000 of more than 1 million deaths from malaria. It also ascribed 2,000 deaths to floods in 2000, based on the EM-DAT database. Even using these problematic figures, global warming would currently account for less than 0.3% of all global deaths. Thus, unsurprisingly, comparative analysis of the global mortality and disease burden show that other public health issues far outrank to global warming despite claims by advocates of draconian emissions controls.[24,28]

U.S. Trends in Morbidity and Mortality Rates

Data Sources

Among the problems in developing an extended series for U.S. deaths due to all extreme weather phenomena is that the length of the U.S. data record varies according to the type of event. For instance, the *Annual Summaries* published by the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) provides time-series data on fatalities due to hurricanes, floods, tornados and lightning, respectively, from 1900, 1903, 1916, and 1959 onward.[29] Each year's summary also gives that year's death toll due to a variety of other weather-related phenomena such as extreme cold (XC), extreme heat (XH), drought, mudslides, winter storms, avalanches, etc., but it does not provide time-series data for these other categories of natural disasters.

Another problem is that the data for several phenomena from the *Annual Summaries* are at variance with other data sources. There are discrepancies between mortality data from these *Annual Summaries* and other governmental data sources, which include: (a) the Hydrologic Information Center (HIC) estimates for floods,[30] (b) Blake et al.'s data for hurricanes from the National Hurricane Center's website,[31] (c) the National Weather Service's (NWS) compilation of fatalities from a variety of extreme weather phenomena from 1940 onward,[32] and (d) CDC's Wide-ranging Online Data for Epidemiologic Research (WONDER) mortality database for extreme cold and extreme heat.[33] To further complicate matters, the first three of these alternate sources are also part of NOAA. Compilations are also available from various researchers for fatalities from floods,[12] lightning[34] and tornados,[35] which augment

Table 3. Available Data Sources for Various Categories of Extreme Weather Events.

Category of event	Data source	Period covered	Comments
Extreme heat (XH), and extreme cold (XC)	**CDC WONDER[33]**	**1979–2006**	**Based on medical opinion per death certificates, which is deemed more reliable than NOAA/NWS expert opinion on cause of death.**
	NWS[32]	XC: 1986–2008; XH: 1988–2008	Based on expert judgment per *Storm Data*
Hurricanes	NWS[32]	1940–2008	From 1940–86, data are essentially identical to NHC, except for a couple of years. After 1986 differences are larger. For 2005, this data source indicates over 500 fewer deaths than NHC.
	Blake et al.[31] (NHC)	**1900–2006**	**NHC is the official compiler of hurricane information.**
	***Annual Summaries*[29,32]**	1995–2008	Based on *Storm Data.* **Used *Annual Summaries* data for 2007–08 from NWS website.**
Lightning	NWS[32]	1940–2008	Data prior to 1995 is of uncertain provenance (Brent Macaloney, personal communication).
	Ashley & Gilson (2009)[34]	**1959–2006**	**Data from *Storm Data* supplemented by information from news services, newspapers and CDC.**
	***Annual Summaries*[29,32]**	1995–2008	Based on *Storm Data.* **Comparison with Ashley and Gilson's estimates for 1997–2006 indicate that *Summaries* underestimate fatalities by an average of 15 per year. Added 15 to 2007 and 2008 estimates from this source for use in this paper.**
Tornados	NWS[32]	1940–2008	Although data prior to 1995 is of uncertain provenance, they are identical to Brooks (2009) for most years with overlap.
	Brooks (2009)[35]	**1875–2008**	**This paper uses Brooks' data for 1900–2008.**
	Annual Summaries[29,32]	1916–2008	Identical to Brooks (2009) for most years with overlap.
Floods	NWS[32]	1940–2008	Data prior to 1995 is of uncertain provenance.
	Hydrological Information Center,[30] adjusted per Goklany[12]	**1903–2004**	**HIC is the official compiler of flood related data; see Goklany (2000)**
	***Annual Summaries*[32,39]**	1995–2008	Based on *Storm Data.* **Used this publication for 2005–2008 data.**

Bolding indicates the source used in this article. The rationale for favoring one source over another is indicated in bold letters in the comments column.

data from official sources using additional sources, e.g., newspaper reports and news services.

Table 3 summarizes information on available sources of data for fatalities from various event categories. Based on this information, it also identifies in bold the data sources used in this study for specific years using the following criteria: First, time series should ideally go back to 1900. Second, longer data series are to be preferred unless there is good reason to favor a shorter time series, for example, because data are of uncertain provenance, or data from longer series have not been independently verified.

Note that the NWS data set provides fatalities for two additional categories not identified in Table 3, namely, from 1988 onward it has data for winter storms (e.g. avalanches and icing) and from 1995 onward, it has data for wind (other than hurricanes and tornados). Based on the 10-year average from 1999–2008, these two categories contribute about 6% of the total U.S. deaths due to extreme weather events. Given the relatively short record and their small contribution, these two categories will not be discussed further in this paper.

Table 4. Cumulative U.S. Deaths from Extreme Weather Events, 1979–2006.[29,35,37-39]

Category	Deaths	Percent of deaths from extreme weather
Excess cold	18,828	50.1%
Excess heat	10,176	27.1%
Floods	2,691	7.2%
Lightning	2,289	6.1%
Hurricanes	2,069	5.5%
Tornados	1,514	4.0%
Cumulative	**37,567**	**100%**
U.S. deaths from all causes	**62,240,000**	**Not Applicable**

Table 5. Comparing U.S. Weather-related Deaths and Death Rates, 1979–92 vs. 1993–2006.[12,29-38]

	Deaths per year			Death rates per year (per million people)		
	1979–92	1993–2006	Change (%)	1979–92	1993–2006	Change (%)
Excess cold	742	603	-19%	3.1	2.2	-31%
Excess heat	366	360	-1%	1.6	1.3	-17%
Floods	108	84	-22%	0.5	0.3	-33%
Lightning	97	66	-32%	0.4	0.2	-41%
Tornados	53	56	5%	0.2	0.2	-10%
Hurricanes	15	133	814%	0.1	0.5	657%
Cumulative	1,381	1303	-6%	5.8	4.6	-20%
U.S. deaths	2,074,000	2,367,000	14%	8,660.5	8,478.1	-2%

Data on deaths from extreme cold and extreme heat used in this paper were taken from the CDC WONDER mortality database. In this database, mortality data 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),[36] and X30 for ICD-10. The corresponding codes used for extreme cold were E901.0 and E901.9, and X31, respectively.

For lightning, I used the Ashley and Gilson's compilation of fatalities from 1959–2006.[34] Comparison of their estimates against NOAA's *Annual Summaries* for 1997–2006,[29] the most recent 10-year period for which both sources present data, indicates that the latter underestimate fatalities by an average of 15 per year. Accordingly, for 2007 and 2008, I add 15 deaths to the *Annual Summaries*' estimates for each of those years.

Finally, to estimate death rates, U.S. population data were obtained from the U.S. Census Bureau. Data from 1900-99 were taken from *Historical Statistics*,[37] 2000–07 data from *USA Statistics in Brief*,[38] and 2008 data from *U.S. Interim Population Projections*.[39]

Relative Contribution of Various Categories of Events to Deaths and Death Rates

The bulk of the weather-related deaths (50%) in the 28-year period from 1979 to 2006 were caused by extreme cold. In importance, this was followed by extreme heat, floods, lightning, hurricanes and tornados, which contributed 27%, 7%, 6%, 6% and 4%, respectively. See Table 4. Notably, these extreme weather events were responsible for 0.06% of all deaths during this period.

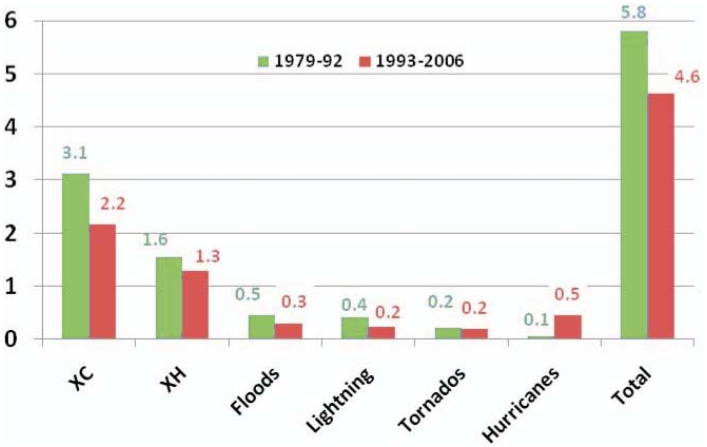

Figure 6. U.S. Death Rates from gatrome Weather Events, 1979–2006
XC: extreme cold, XH: extreme heat. Rates are per million people[12,29-35,37-39]

U.S. Trends for Various Categories of Events

Table 5 compares average annual deaths and death rates for 1979–1992 and 1993–2006 for various categories of extreme events. The rows in this table are ordered according to the contribution of the specific category of extreme event to mortality (highest to lowest) during the former period. This table shows that average annual deaths from all listed extreme events declined modestly (by 6%), whereas total number of annual deaths from all causes increased by 14%. Death rates for extreme weather events were reduced by 20% compared to a reduction of only 2% in the death rate from all causes. By these measures, the U.S. is coping more effectively with the risk of death from extreme weather events than it is with the risk of broader (and much larger) risks of death.

Figure 6 compares the individual and cumulative death rates from extreme heat and cold, floods, lightning, tornados, and hurricanes for two consecutive 14-year periods, namely, 1979–1992, and 1993–2006, based on the CDC's WONDER database.[33] It shows that despite any warming that may have occurred, death rates have decreased for each category except hurricanes (mainly because of the death toll from Hurricane Katrina, which was arguably as much man-made as natural, because of the failure of levees). The cumulative death rates for these categories dropped by 20%. By comparison, between the two periods, cumulative mortality declined more modestly, by 6%.[40,41]

Figures 7 through 12 show U.S. trends for death and death rates from various extreme events. The linear trend lines were automatically generated by Excel, which uses ordinary least-squares analysis. The data for floods (Figure 8) indicate no specific trends for average deaths for the entire period (1903–2008), but there is a relatively strong downward trend from the 1970s onward. On the other hand, there is a declining trend for death rates over the entire period. Since the 1970s, average annual deaths and death rates have been reduced by 62% and 72%, respectively. By contrast, for lightning (Figure 9), both these measures have been trending steadily downward for the entire period of record (1959–2008).

For hurricanes, Figure 10 starts with a very large spike for deaths at the very beginning of the record due to the Galveston hurricane of 1900 and a smaller spike in the 1920s. Both of these spikes exceed that caused by Hurricane Katrina during the 2000–2008 period. Average death rates were also higher during the first four decades of the 20th century than during 2000–2008. Notably, fatalities were relatively low during the 1940s, 1970s, 1980s, and 1990s. Between

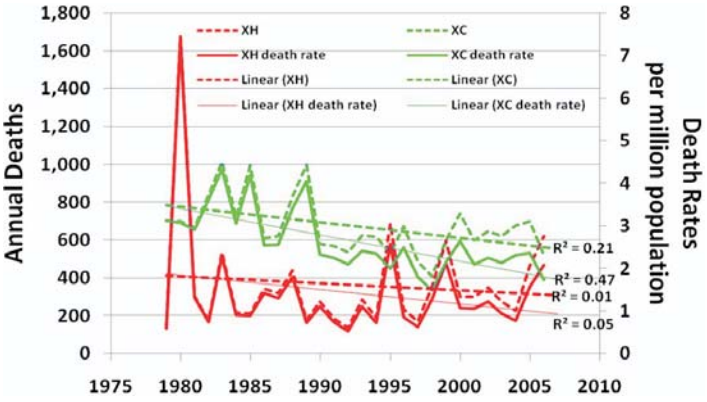

Figure 7. Cumulative U.S. Deaths and Death Rates, 1979–2006, for Extreme Heat and Extreme Cold.[33,37-39]

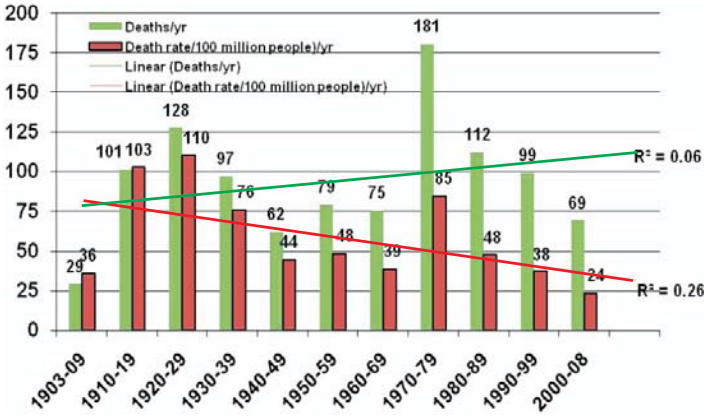

Figure 8. Average Annual U.S. Deaths and Death Rates due to Floods, 1903–2008.[12,30,37-39] The bars for 1903–1909 are based on the 7-year average from 1903 through 1909 because the data series starts in 1903.

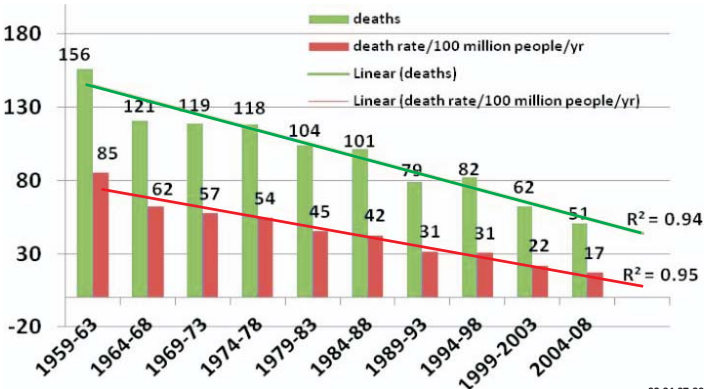

Figure 9. U.S. Deaths and Deaths Rates due to Lightning, 1959–2008.[32,34,37-39]

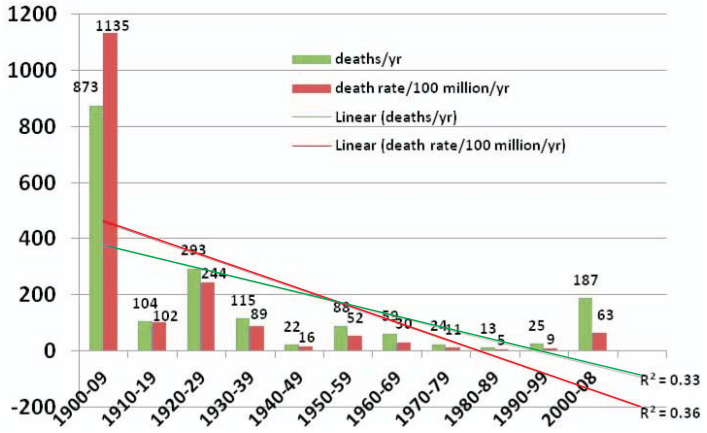

Figure 10. U.S. Deaths and Death Rates due to Hurricanes, 1900–2006.[31,21,36-38]

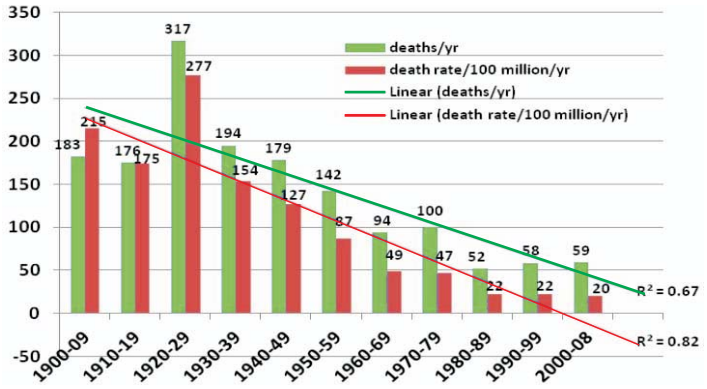

Figure 11. Average Annual U.S. Deaths and Death Rates for Tornados, 1900–2008.[32,35-38]

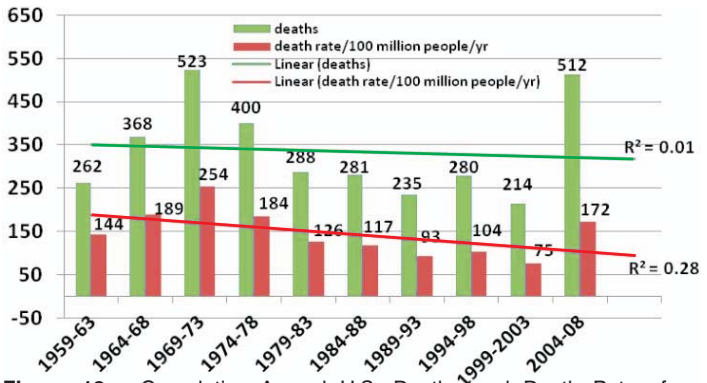

Figure 12. Cumulative Annual U.S. Deaths and Death Rates from Hurricanes, Floods, Lightning, and Tornados, 1959–2006.[12,29-35, 37-39]

1900–1909 and 2000–2008, average annual deaths and death rates for hurricanes declined by 79% and 94%, respectively.

The annual average deaths and death rates for tornados peaked in the 1920s, as shown in Figure 11. By 2000–2008, they had been reduced by 81% and 93%, respectively. These results are consistent with earlier analyses by Goklany[12] and Doswell et al.[13]

Figure 12 shows the cumulative deaths and death rates for floods, lightning, hurricanes, and tornados for each 5-year period commencing in 1959 and ending in 2008. Over these 10 periods, there is no trend for cumulative deaths in these categories, which together contribute fewer than a quarter of total U.S. deaths from extreme weather events (Table 5). Death rates, on the other hand, seem to have declined somewhat over this period, despite the 2004 and 2005 hurricane seasons.

Discussion and Conclusions

Current deaths and death rates from extreme weather events for both the U.S. and the globe are, in general, lower than in previous decades. Predictably, annual death rates have declined more rapidly than annual deaths, confirming results from previous studies.[12,22] This indicates that the total risk of death from such events has actually declined, notwithstanding any increases in the number or intensity of extreme weather events that some claim to have occurred. Globally as well as for the United States, the aggregate contribution of extreme weather events to the mortality burden is currently minor—on the order of 0.06%.

Lower mortality or mortality rate might be accompanied by or contribute to increasing property losses.[12] Additionally, a wealthier society might have more property at risk. In the U.S., higher losses in constant dollars for floods, tornados, and hurricanes do not translate into losses of a higher fraction of wealth (fixed tangible reproducible assets, excluding land values).[12,13,42-44] Appropriate data are not available to address the latter measure globally.

At the global level, available data indicate that aggregate annual mortality and mortality rates owing to extreme weather events have declined between 93% and 98%, respectively, since the 1920s. Much of this improvement represents a substantial decline in mortality from droughts and floods, which apparently caused 92% of the fatalities from extreme weather events between 1900 and 2008 recorded in the EM-DAT database. Death rates for the different categories of extreme events were generally lower in the last two decades than in previous decades, with the notable exception of extreme temperature, which was higher because of the 2003 European heat wave. Both mortality and mortality rates from storms peaked in the 1970s. The average annual mortality due to storms from 1990–2008 exceeded the average from 1900–1989 by 82%, while the mortality rate declined by 16%.

In the U.S, more lives are lost in an average year to extreme temperatures—both heat and cold—than to more heavily publicized events such as tornados, hurricanes, and floods. According to CDC data, extreme cold, on average, claims more lives than extreme heat, tornados, floods, lightning, and hurricanes combined. In general, mortality and mortality rates from the various categories of extreme events examined here are lower today than in the past. Mortality during the 2000s was lower than in earlier peak periods by 59%–81% for floods, lightning, tornados, and hurricanes, while mortality rates were 72%–94% lower. However, there are no consistent trends for mortality due to floods.

These improvements have occurred despite increases in the populations at risk, in large part because of greater access to the capital and technology necessary to protect against and to cope with adversity in general and extreme weather events in particular.[12,22,36,39,45,46] Even if the number of events has increased—and the long-term record is inadequate for ascertaining whether it has—wealth, technology, and human and social capital for the most part have, despite notable exceptions, apparently been of greater importance than any global warming or changes in climatic variability in determining mortality.

Finally, despite population increases, over the long term cumulative mortality from extreme weather events has declined both globally and for the United States, even as total (all-cause) mortality has increased. This indicates that humanity is coping better with extreme weather events than with far more important health and safety problems.

Many environmentalists and like-minded politicians have proposed the expenditure of trillions of dollars to reduce anthropogenic greenhouse gases. One stated rationale is to forestall hypothetical future increases in mortality from global warming-induced increases in extreme weather events projected by questionable climate models. The result would be to diminish, if not curtail, the economic development and hydrocarbon-fueled technology that has resulted in enormous actual reductions in such mortality.

In contrast, human well-being could be greatly improved by devoting much smaller sums to alleviating the health and safety problems responsible for most premature mortality (see Table 2).[24,28,47]

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