

Death and Death Rates Due to Extreme Weather Events

Global and U.S. Trends, 1900–2006

Indur M. Goklany



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By Indur M. Goklany

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International Policy Network
Third Floor, Bedford Chambers
The Piazza
London WC2E 8HA UK
t: +4420 7836 0750
f: +4420 7836 0756
e: info@policynetwork.net
w: www.policynetwork.net

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info@macguru.org.uk

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The Civil Society Coalition on Climate Change seeks to educate the public about the science and economics of climate change in an impartial manner. It was established as a response to the many biased and alarmist claims about human-induced climate change, which are being used to justify calls for intervention and regulation.

The Coalition comprises over forty independent civil society organisations who share a commitment to improving public understanding about a range of public policy issues. All are non-profit organizations that are independent of political parties and government.

About the author

Dr. Indur M. Goklany has worked on environmental and energy policy issues for over three decades in federal and state governments, and the private sector. He has written over one hundred monographs, book chapters and papers on topics ranging from climate change, human well-being, economic development, technological change, and biotechnology to sustainable development.

He has worked for the U.S. Department of the Interior, which manages 20 percent of the U.S. land area, and associated mineral, energy and water resources, the U.S. Environmental Protection Agency and the State of Michigan. He is the winner of the 2007 Julian Simon Prize. He was a visiting fellow with the American Enterprise Institute, and the Julian Simon Fellow at the Property and Environment Research Center in Bozeman, Montana. He has represented the U.S. at the Intergovernmental Panel on Climate Change and in the negotiations leading to the UN Framework Convention on Climate Change. His degrees, all in electrical engineering, are from the Indian Institute of Technology, Bombay, and Michigan State University.

He is the author of *Clearing the Air: The Real Story of the War on Air Pollution*, and *The Precautionary Principle*, and *The Improving the State of the World*, all published by the Cato Institute. Opinions and views expressed by Dr. Goklany are his alone, and not necessarily of any institution with which he is associated.

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Executive summary

Despite the recent spate of deadly extreme weather events – such as the 2003 European heat wave and the 2004 and 2005 hurricane seasons in the USA – 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 93 percent of all deaths caused by extreme events during the 20th Century. For windstorms, which, at 6 percent, contributed most of the remaining 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 in annual mortality for the last four categories range from 62 to 81 percent, while mortality rates declined 75 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. This enhanced adaptive capacity is associated with 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 seem to be declining in general. 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).¹

This speculation has been 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). Moreover, 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 suspicions. All of this was epitomized by a recent *Time* magazine cover story warning all to worry more about global warming (Kluger 2006; see also, for example, Anderson and Bausch 2006).

Some have claimed that, all else being equal, climate

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change will increase the frequency or severity of weather-related extreme events (see, e.g., IPCC 2001; Patz 2004; MacMichael and Woodruff 2004). This study examines whether losses due to such events (as measured by aggregate deaths and death rates²) have increased globally and for the United States in recent decades. It will also attempt 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 invest more in limiting loss of human lives, it may be less concerned about property losses, even though a wealthier society is also likely to have more property at risk. This suggestion finds some support in data which show 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, 1900–2006

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.

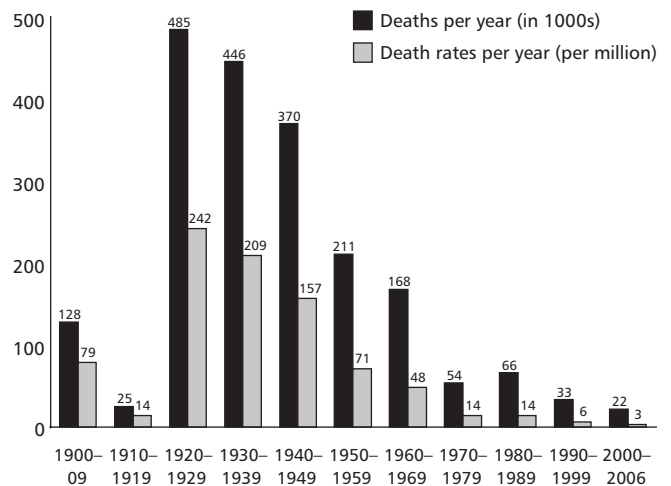
Accordingly, to estimate the net impact of climate change on mortality (if any), it is probably best to examine cumulative deaths at the global level aggregated over all types of extreme events. Because of

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 rates is 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, some state policies may inappropriately create a "moral hazard" situation in which individuals have incentives to bear less than their full burden of risk, effectively transferring portion of their risk to other segments of society; this may place even wealthier populations at greater physical risk (in addition to increasing financial risk; Goklany 2000).

Figure 1 displays data on aggregate global mortality and mortality rates between 1900 and 2006 for the following weather-related extreme events: droughts, extreme temperatures (both extreme heat and extreme cold),

Figure 1 **Global death and death rates due to extreme events, 1900–2006**



Note that in figures 1 through 4, data for the last period are averaged over seven years worth of data.
Sources: EM-DAT (2007); McEvedy and Jones (1978); WRI (2005, 2007)

Table 1 **Global deaths and death rates for various types of events, 1900–1989 and 1990–2006**

	<i>Deaths per year</i>		<i>Death Rates per year (per million people)</i>	
	<i>1900–1989</i>	<i>1990–2006</i>	<i>1900–1989</i>	<i>1990–2006</i>
Droughts	130,042	185	57.99	0.03
Floods	75,212	7,637	31.95	1.29
Windstorms	10,856	13,650	3.96	2.45
Slides	469	868	0.16	0.15
Waves/Surges	128	207	0.06	0.03
Extreme Temperatures	110	5,671	0.03	0.91
Wild Fires	21	47	0.01	0.01
TOTAL	216,839	28,266	94.16	4.87

Sources: EM-DAT (2007); McEvedy and Jones (1978); WRI (2007)

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, comparing the 1920s to the 2000–2006 period, the annual number of deaths declined from 485,200 to 22,100 (a 95 percent decline), while the death rate per million dropped from 241.8 to 3.5 (a decline of 99 percent).

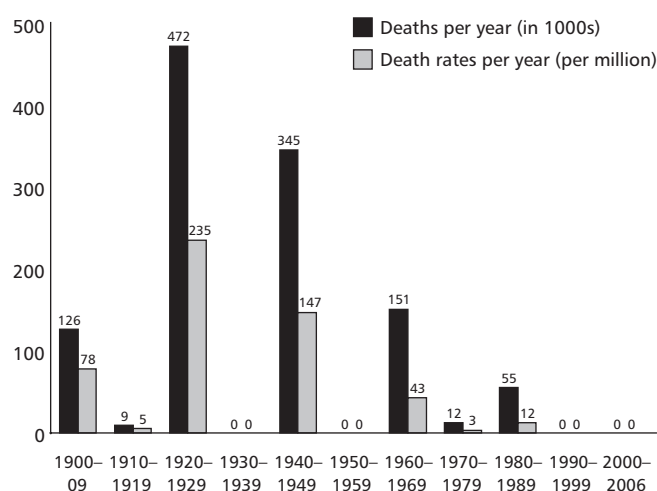
Table 1 provides a breakdown of the average annual global deaths and death rates for the various categories of extreme events for 1900–1989 and 1990–2006. The columns are arranged in order of declining mortality ascribed to the various events (highest to lowest) for the former period. This shows that:

- During much of the 20th Century, the deadliest extreme events were droughts, followed by floods and windstorms. Over the 107-year record, droughts and floods were responsible for 59 and 35 percent of all fatalities worldwide due to all extreme weather events, while windstorms contributed an additional 6 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 87 percent between

the 1900–1989 and 1990–2006 periods, while the annual mortality rate dropped by 95 percent.

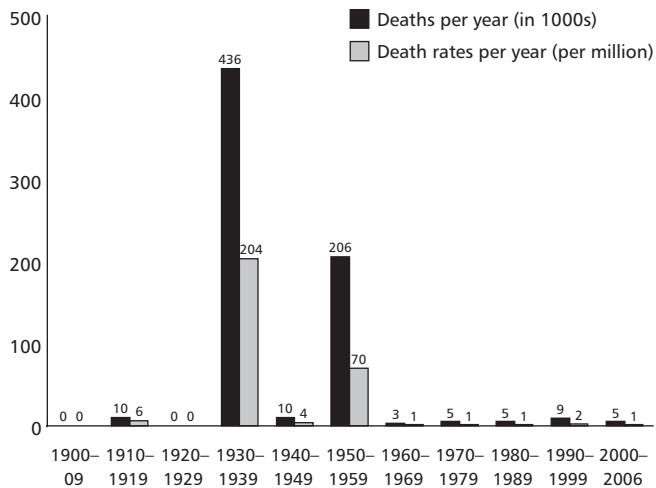
- Declines in mortality between the two periods were mainly due to declines in annual fatalities owing to droughts and floods (see also Figures 2 and 3). The remarkable 99.9 percent drop in annual drought fatalities indicates that, for whatever reason,

Figure 2 **Droughts: global deaths & death rates, 1900–2006**



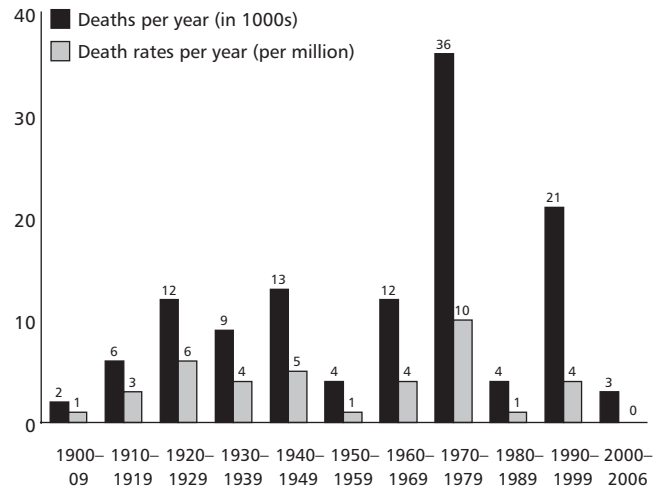
Sources: EM-DAT (2007); McEvedy and Jones (1978); WRI (2005, 2007)

Figure 3 **Floods: global deaths and death rates, 1900–2006**



Sources: EM-DAT (2007); McEvedy and Jones (1978); WRI (2005, 2007)

Figure 4 **Windstorms: global deaths and death rates, 1900–2006**



Sources: EM-DAT (2007); McEvedy and Jones (1978); WRI (2005, 2007)

available food supplies per capita have increased in marginal areas. This is possibly due to greater food production at the global level, and an enhanced ability to move food from food surplus 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). All of this is facilitated by better transportation and communication networks, and irrigation facilities (Goklany 1998).

The 89.8 percent decline in annual 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 14,000 per year between the two periods, the annual mortality rates declined by 38 percent (see also Figure 4).
- Annual mortality rates dropped for virtually every category except extreme temperatures and slides.

The spike in deaths and death rates owing to extreme temperatures during the 1990–2006 period occurred because of the 2003 European heat wave. However, these fatalities were more than compensated for by declines in flood and drought fatalities.⁵

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 2000–2006 due to all weather-related extreme events according to EM-DAT (2007) was 19,900. 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 garnish plenty of attention worldwide because of their episodic and telegenic nature, their contribution to the global mortality burden is relatively minor: 0.03 percent of global deaths. Their contribution to the global burden of disease should be similarly small.

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 2000–2006**

<i>Cause of death</i>	<i>No. of deaths</i>	<i>Percent of total deaths</i>
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	3,362,000	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. Non-communicable 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 non-communicable 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	19,868	0.03%
All other injuries	3,225,600	5.66%

Sources: WHO (2004), EM-DAT (2007)

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 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, (b) 47,000 out of about 2 million deaths due to diarrhoeal disease,

and (c) 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 database.

Although the review paper'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.

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U.S. trends in mortality and mortality rates, 1900–2006

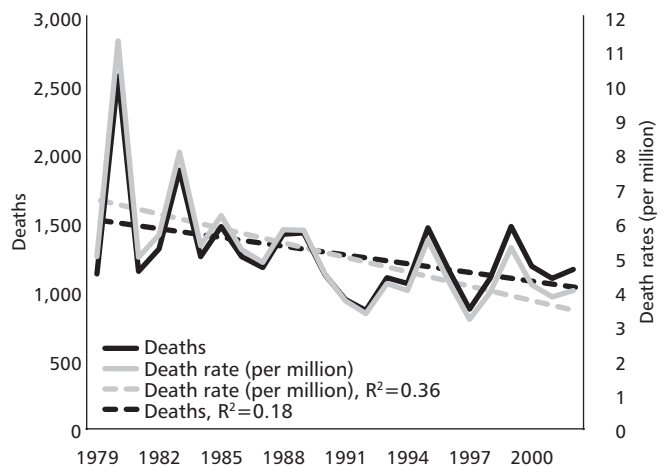
Among the problems in developing a long time series for U.S. deaths due to all (or most) extreme weather phenomena is that the length of the U.S. (data) record varies according to the type of event.

The *Annual Summaries* (e.g., NCDC 2004, 2007) published by National Oceanic and Atmospheric Administration’s National Climatic Data Center (NCDC) 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 2007) estimates for floods, (b) the National Hurricane Center’s data for hurricanes (Blake et al. 2007), 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 was decided to use HIC data for floods (as adjusted per Goklany 2000), and Blake et al. (2007) for hurricanes through 2006. The

Figure 5 Cumulative U.S. deaths and death rates, 1979–2002, for hurricanes, floods, lightning, tornados, extreme heat and extreme cold



Linear trend lines were generated using EXCEL. Sources: for hurricanes, Blake et al. (2007); for lightning and tornados, NCDC (2004, 2007) and Hinson (2005); for floods, HIC (2007); for extreme heat and cold, CDC (2005)

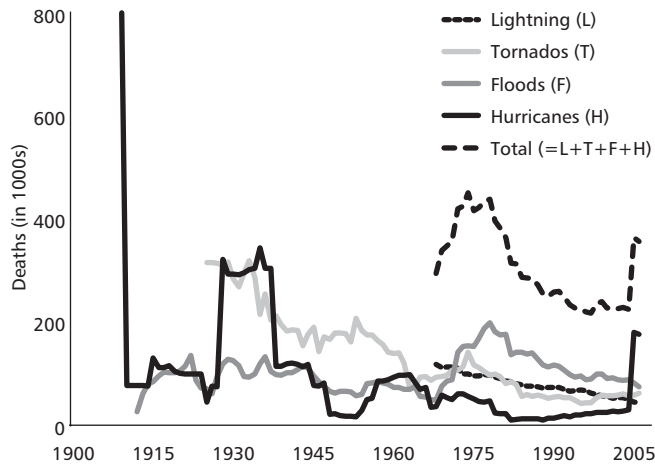
Center for Disease Control’s WONDER database was used for extreme heat and cold, because it is based on actual death certificate records, which, in turn, are based on medical opinion as opposed to the National Weather Service’s expert opinion.⁷

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

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

	<i>Cumulative deaths</i>	<i>Deaths per year</i>	<i>Percent of annual all-cause deaths</i>
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%

Figure 6 **U.S. Deaths due to hurricanes (1900–2006), floods (1903–2006), tornados (1916–2006), lightning, (1959–2006) and total (1959–2006) 10-year moving averages**



Sources: for hurricanes, Blake et al. (2007); for lightning and tornados, NCDC (2007) and NWS (2007); for floods, HIC (2007) and Goklany (2000)

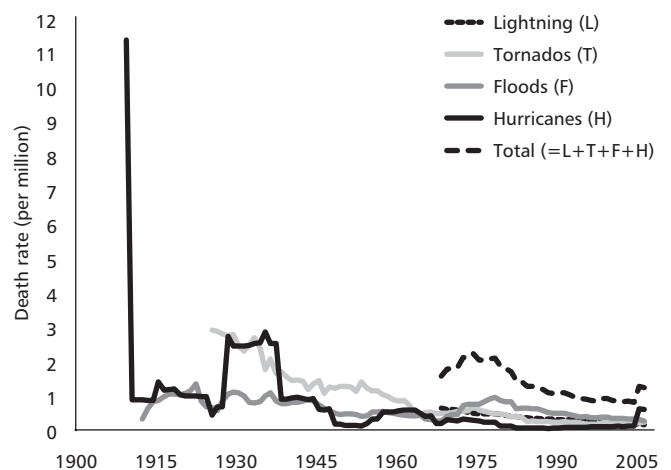
deaths and death rates have not increased over this period. If anything, they might have declined over this period, during which all-cause mortality increased by 28 percent (USCB 2004).

Notably, the bulk of the weather-related deaths (53 percent) during this period were caused by extreme cold. In rank of 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.)

Figures 6 and 7 show the 10-year moving averages for deaths (and death rates) due to hurricanes from 1900–2006, floods from 1903–2006, tornados from 1916–2006, and lightning from 1959–2006, as well as for cumulative deaths (and death rates) from these four individual categories of events (from 1959 to 2006). Death rates in Figure 7 are calculated using national population estimates from the US Census Bureau (USCB).⁹

Figure 6 shows that for the most recent 10-year period for which data are available, average annual deaths declined below their earlier peaks in the 10-year moving averages by 62 percent for floods, 63 percent for lightning, 81 percent for tornados and – despite

Figure 7 **U.S. deaths rates due to hurricanes (1900–2006), floods (1903–2006), tornados (1916–2006), lightning, (1959–2006) and total (1959–2006) 10-year moving averages**



Sources: for hurricanes, Blake et al. (2007), for lightning and tornados, NCDC (2007) and NWS (2007); for floods, HIC (2007) and Goklany (2000); and for population, USCB (2007)

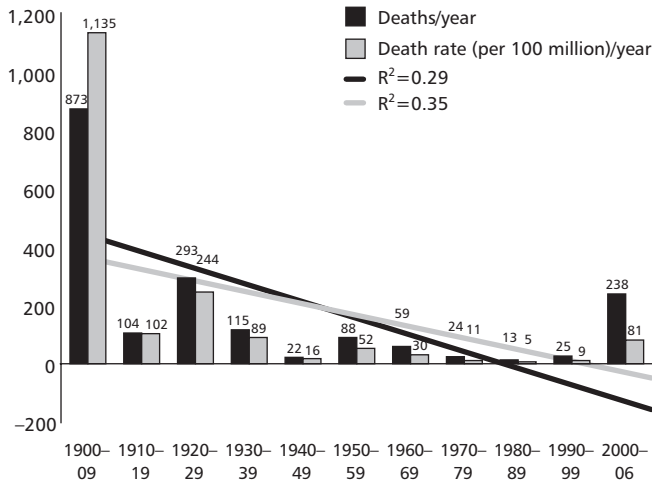
Hurricane Katrina – 80 percent for hurricanes. Such declines are consistent with results of earlier analyses (Goklany 2000).

Similarly, Figure 7 indicates that the corresponding declines for death rates (comparing their peaks with the most recent 10-year period) were 80 percent for floods, 75 percent for lightning, 95 percent for hurricanes and 92 percent for tornados.

Both figures show:

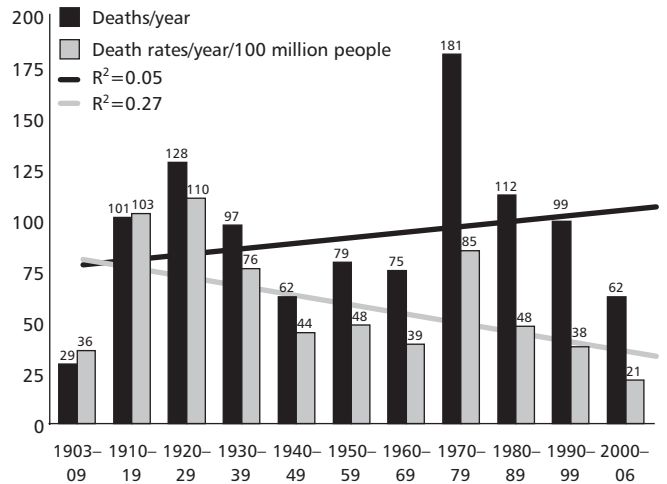
- A large spike for hurricanes at the very beginning of the record due to the Galveston Hurricane of 1900, and a smaller spike due to Hurricane Katrina at the very end. This is punctuated by a relatively high plateau in the late 1920s which extended into the late 1930s, and troughs extending from the 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

Figure 8 Annual U.S. deaths and death rates due to hurricanes, 1900–2006



Linear trend lines were generated using EXCEL. Sources: Blake et al. (2007); USCB (2007)

Figure 9 Annual U.S. deaths and death rates due to floods, 1903–2006



Linear trend lines were generated using EXCEL. 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 (2007); Goklany (2000); USCB (2007)

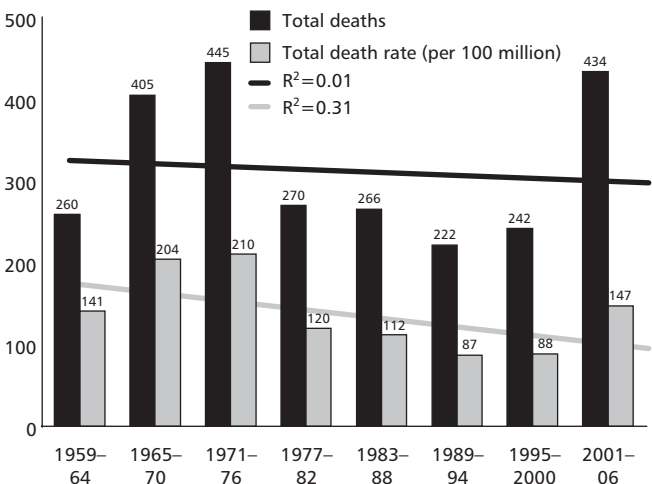
events by Goklany (2000), and Doswell et al. (1999) for tornados.

- Mortality from floods exhibits no particular trend from 1903 to 2006, although mortality rates might

have declined somewhat (see also Figure 9). Once final figures are compiled, mortality due to floods in 2005 may be higher than in other recent years because of floods related to hurricanes that year.¹²

- Cumulative annual mortality and mortality rates for the above four categories of extreme weather events also indicate no specific trend from 1959–64 to 2001–06, although death rates may have declined (Figure 10; see also Figures 6 and 7).

Figure 10 Cumulative annual U.S. deaths and death rates from hurricanes, floods, lightning, and tornados, 1959–2006



Linear trend lines were generated using EXCEL. Sources: For hurricanes, Blake et al. (2007); for lightning and tornados, NCD (2004, 2007) and NWS (2007); for floods, HIC (2007); for population USCB (2007)

The previous figures (6 through 10) show that current deaths and death rates are, in general, lower than 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 relatively minor at present, 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.

The data at the global level, 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 93 percent of the fatalities due to extreme events between 1900 and 2006.
- Death rates for the different categories of extreme events were generally lower in the 1990s and early-to mid-2000s than in previous decades – with the notable exception of death rates for 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 from 1990–2006 exceeded the average over 1900–1989 by 26 percent, but the mortality rate was 38 percent 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, on average extreme cold 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 than they have been in the past. Based on 10-year moving averages,

comparing the most recent 10-year period against the peak periods, mortality declined by 60–80 percent for floods, lightning, tornados and hurricanes, while mortality rates declined by 75–95 percent. However, there are no consistent trends for mortality due to floods, and both mortality and mortality rates for hurricanes spiked in 2005. Nevertheless, these spikes are lower than levels than were reached in previous periods.

Thus, it appears that mortality rates and – more significantly – mortality for the most deadly and destructive forms of extreme weather events have declined substantially over the past several decades. This suggests two possibilities if indeed climate change has exacerbated extreme events. One possibility is that humanity has been extremely lucky in terms of where and when these events have struck. The other possibility, a more likely explanation, is that society's ability to cope with extreme events has not only improved, it has also put its increased adaptive capacity to good effect.

Several interrelated factors have contributed to this increase in adaptive capacity. First, today's societies have a wider range of technological options at their disposal, enabling them 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, all of which have increased the ability to transport people 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 those technologies and practices have been developed in wealthier, more technologically sophisticated nations, it is possible for poorer societies to learn from and adapt them to their own circumstances.

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

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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. Thus far wealth, technology, and human and social capital have for the most part (despite notable exceptions) 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. This idea is 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.

For the U.S., results of this paper, combined with previous studies of economic losses due to various categories of extreme events, suggest (but do 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. However, 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.

Notes

- 1 This paper uses “extreme weather events” synonymously with “extreme events.”
- 2 The risk of death due to any cause, e.g., floods, is estimated by the number of deaths caused by floods divided by the magnitude of the population potentially exposed to floods. Thus the death rate for floods (measured as the number of flood deaths either per 1,000 people or per million people) is a measure of the risk due to floods. If the risk of floods increases, then if all else stays the same, the flood death rate should increase. But, in fact, all else rarely stays the same. Increases in the frequencies and magnitudes of floods may be offset by better protection from floods or disaster preparedness, for instance. Thus trends in death rates from floods tell us whether overall risk to populations from floods are increasing, decreasing or staying constant.
- 3 Figure 1 is constructed using data the following sources: (1) For deaths, EM-DAT (2007). EM-DAT is 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. (2) For population from 1900–1925, McEvedy & Jones (1978). (3) For population from 1950–2006, World Resources Institute (2007). (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 estimate from WRI (2005), 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 7,700 hydro-meteorological disasters in the world from 1900 to present. Specifically, these disasters are due to drought, extreme temperatures, floods, slides, waves and surges, wildfires, and wind storms. 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.
- 5 EM-DAT (2005) ascribed over 45,700 deaths to the 2003 European heat wave, while EM-DAT (2007) assigns over 72,200 deaths to that event.
- 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 time series (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 3.750 longitude and 2.50 latitude. The results of such models, which are inexact at best at the global level, tend to greater uncertainty as the resolution gets finer.
- 7 To further complicate matters, the NWS website provides a “67-Year List of Severe Weather Fatalities” (from 1940–2006. 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.
- 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.
- 10 These figures are based on an estimate of 1,525 deaths in 2005 per Blake et al. (2007). The figures also assume a death toll of 8,000 for the 1900 Galveston Hurricane (Blake et al. 2007).
- 11 Note that in Figure 8 the data for the last period is based on a seven-year average, while that for other periods are based on ten-year averages.
- 12 There is a probably an unavoidable degree of subjectivity involved in assigning deaths from hurricane-initiated events to either the hurricane or flood categories.

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