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published in

Bulletin of the American Meteorological Society
2011

DOI (link to publisher)

[10.1175/2010BAMS3092.1](https://doi.org/10.1175/2010BAMS3092.1)

document version

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Bouwer, L. M. (2011). Have disaster losses increased due to anthropogenic climate change? *Bulletin of the American Meteorological Society*, 92(1), 39-46. <https://doi.org/10.1175/2010BAMS3092.1>

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HAVE DISASTER LOSSES INCREASED DUE TO ANTHROPOGENIC CLIMATE CHANGE?

BY LAURENS M. BOUWER

Lacking significant impact from anthropogenic warming so far, the best way to assess the potential influence of climate change on disaster losses may be to analyze future projections rather than historical data.

Anthropogenic climate change leads to more damage from weather disasters. This claim is made frequently in debates on the impacts of ongoing global warming. Although many other impacts and risks are associated with climate change, shifts in weather extremes are one of the most prominent anticipated impacts and of concern to many. The Intergovernmental Panel on Climate Change (IPCC) reported that the frequency of heavy rainfall and heat waves has increased, that the area affected by drought has increased in many regions, and that tropical cyclone activity has increased in the North Atlantic Ocean (Solomon et al. 2007, Table SPM.2). The recent global assessment report on natural disasters of the United Nations shows that the number of natural

disasters, economic losses, and number of people affected are increasing at a rapid rate, faster than risk reduction can be achieved (UN-ISDR 2009).

Governments are concerned about the potential economic implications of increasing risks, particularly the consequences for insurance systems for companies and households (GAO 2007; Ward et al. 2008; Botzen et al. 2010). There is clearly a need for analyses on the causes of increasing impacts from weather extremes as decision makers in government and companies plan for more frequent disasters and attempt to reduce exposure and risks. Also, better understanding of the relationship between anthropogenic climate change and disaster losses is needed to inform decisions on global climate change mitigation policy that is being negotiated and developed under the United Nations Framework Convention on Climate Change (UNFCCC). The expected impacts also indicate to what extent developed countries should financially compensate developing nations for the impacts of climate change and the costs of adaptation (Bouwer and Aerts 2006).

Some major studies on the costs of climate change have been made over the course of past years (e.g., Pearce et al. 1996; Tol 2005; Stern 2007). The costs from weather extremes, however, are generally omitted or included in a very crude manner in the models of the costs of climate change (Tol 2002;

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The abstract for this article can be found in this issue, following the table of contents.

DOI: 10.1175/2010BAMS3092.1

In final form 27 July 2010

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Hallegette et al. 2007; Tol 2008) and therefore are hardly accounted for in cost–benefit analyses of global climate policy (Van den Bergh 2010). This is mainly because the complex interaction between hazards, exposure, and vulnerability has so far not been approached in a uniform manner through impact studies that would allow inclusion in economic models and cost–benefit analyses.

Although some authors argue that anthropogenic climate change has already led to increased loss probabilities (Bruce 1999; Mills 2005; Höppe and Grimm 2009; Schmidt et al. 2009), others assert that it is too early to find trends in disaster losses due to climate change, and that increasing exposure due to population and economic growth has been a much more significant driver (Changnon et al. 2000; Pielke et al. 2005; Bouwer et al. 2007). This paper revisits this discussion by providing an overview of recent quantitative studies and by assessing the role of climate change in disaster loss increases relative to other changes.

DETECTION AND ATTRIBUTION OF DISASTER IMPACTS. The science on natural disasters and climate change is still incomplete, despite many studies. A large range of changes in biological systems, hydrology, and the cryosphere has been detected, and it has partly been attributed to anthropogenic climate change (Rosenzweig et al. 2008). These impacts are mainly related to simple climate parameters, such as average or seasonal temperature and precipitation. The IPCC Fourth Assessment Report stated that “Where extreme weather events become more intense and/or more frequent, the economic and social costs of those events will increase” (Parry et al. 2007, p. 12). To date, attribution of anthropogenic climate change has not been established for historic losses from extreme weather events.

Changes in impacts from extreme events are relatively hard to detect and attribute, because they are rare by nature, very few observational records are available for analysis, and they are the result of the complex interplay between weather extremes and socioeconomic processes (including adaptation). Also, natural climate variability (e.g., a period of high numbers of landfalling hurricanes) may lead to increases in losses, which is consistent with climate change projections; however, this should not be misinterpreted to be a manifestation of these projections. Analyses by insurance companies of past disaster losses show that direct economic losses have increased, particularly the losses that are due to weather-related hazards, such as floods, droughts, storms, and landslides (Munich Re 2010).

Losses from disasters not related to weather, such as earthquake losses, have also increased (Vranes and Pielke 2009), although at lower rates than many weather-related hazards. The fact that the number of events and losses from nonweather disasters has stayed stable compared to weather extremes has led some to conclude that climate change has been driving losses from weather-related hazards (Bruce 1999; Mills 2005). There is no indication, however, that exposure and vulnerability to weather and nonweather disasters have evolved in the same manner, given their different natures and different spatial distributions. There is empirical evidence that the impacts from earthquakes and extreme temperature evolve differently with countries’ economic development, compared to the impact from landslides, floods, and windstorms. For instance, Kellenberg and Mobarak (2008) show that socioeconomic development initially increases the occurrence and level of loss of life resulting from landslides, floods, and windstorms, whereas for earthquakes and extreme temperature it is reduced immediately. This suggests that location choices, such as settlement in coastal zones and floodplains, have influenced exposure to flooding, landslides, and windstorms. This is different from the exposure to hazards that occurs more homogenous over space, such as earthquakes and extreme temperatures. An observed increase in the number of weather-related events relative to earthquakes events is therefore no good support for claiming that anthropogenic climate change is apparent in disaster records.

NORMALIZATION OF LOSS RECORDS. Some studies have attempted to determine in detail why economic losses from weather hazards may have increased. A total of 22 studies were found through a literature search that fulfilled the following criteria (Table 1): they have systematically analyzed well-established records from natural hazard losses, they cover economic losses (monetary damages), they cover at least 30 years of data, and they are peer reviewed. Only one study has analyzed global losses from a range of different weather types—one study is on losses from non-weather events (earthquakes)—and most studies have analyzed losses in developed countries, particularly the United States. Economic impacts from drought are not well recorded, and no study on drought losses is available.

The general approach taken in these studies is to correct or normalize (Pielke and Landsea 1998) the original economic losses for inflation and changes in exposure and vulnerability that are related to

TABLE 1. Normalization studies of disaster loss records.

Hazard	Location	Period	Normalization	Normalized loss	Reference
Bushfire	Australia	1925–2009	Dwellings	No trend	Crompton et al. (2010)
Earthquake	United States	1900–2005	Wealth, population	No trend	Vranes and Pielke (2009)
Flood	United States	1926–2000	Wealth, population	No trend	Downton et al. (2005)
Flood	China	1950–2001	GDP	Increase since 1987	Fengqing et al. (2005)
Flood	Europe	1970–2006	Wealth, population	No trend	Barredo (2009)
Flood	Korea	1971–2005	Population	Increase since 1971	Chang et al. (2009)
Flood and landslide	Switzerland	1972–2007	None	No trend	Hilker et al. (2009)
Hail	United States	1951–2006	Property, insurance market values	Increase since 1992	Changnon (2009a)
Windstorm	United States	1952–2006	Property, insurance market values	Increase since 1952	Changnon (2009b)
Windstorm	Europe	1970–2008	Wealth, population	No trend	Barredo (2010)
Thunderstorm	United States	1949–98	Insurance coverage, population	Increase since 1974	Changnon (2001)
Tornado	United States	1890–1999	Wealth	No trend	Brooks and Doswell (2001)
Tornado	United States	1900–2000	None	No trend	Boruff et al. (2003)
Tropical storm	Latin America	1944–99	Wealth, population	No trend	Pielke et al. (2003)
Tropical storm	India	1977–98	Income, population	No trend	Raghavan and Rajesh (2003)
Tropical storm	United States	1900–2005	Wealth, population	No trend	Pielke et al. (2008)
Tropical storm	United States	1950–2005	Asset values	Increase since 1970; no trend since 1950	Schmidt et al. (2009)
Tropical storm	China	1983–2006	GDP	No trend	Zhang et al. (2009)
Tropical storm	United States	1900–2008	GDP	Increase since 1900	Nordhaus (2010)
Weather (flood, thunderstorms, hail, bushfires)	Australia	1967–2006	Dwellings, dwelling values	No trend	Crompton and McAnaney (2008)
Weather (hurricanes, floods)	United States	1951–97	Wealth, population	No trend	Choi and Fisher (2003)
Weather (hail, storm, flood, wildfire)	World	1950–2005	GDP, population	Increase since 1970; no trend since 1950	Miller et al. (2008)

growth in population and wealth. This correction shows losses as if all disasters occurred in the same year (i.e., with the same exposed assets). Table 1 lists the types of information for which the loss data are normalized and whether the normalized loss record derived by the studies exhibits any trends or not. When records of insured losses are used, the records are usually corrected for change in insurance portfolios (number of policyholders) and changes in insurance conditions (cover and deductibles). Economic losses may show variations related to decadal shifts in weather extremes that occur naturally or related to long-term trends in extremes. Because climate has a high variable natural component on decadal

time scales, there will be variations in losses, even after adjusting for socioeconomic changes. Anthropogenic climate change that is due to the emissions of greenhouse gases causes changes in extremes over longer periods—for detection and attribution typically longer than 30 years according to the IPCC (Houghton et al. 2001, p. 702). If after normalization no long-term trend is found in the loss record, it is unlikely that anthropogenic climate change has made an impact.

Most of the 22 studies have not found a trend in disaster losses, after normalization for changes in population and wealth (Table 1). However, eight studies have identified increases:

- 1) The Stern review (Stern 2007) concluded, on the basis of very limited evidence (Pielke 2007), that anthropogenic climate change is already leading to more frequent disaster losses. The main study supporting this (Miller et al. 2008) showed that global losses from all weather-related disasters have been increasing since 1970, when corrected for wealth and population increases, but found no trend since 1950. However, the authors indicate that the trend of 2% increase per decade they found is very sensitive to the correct adjustment of these losses, which are dominated by hurricane losses in the United States in 2004/05. Population and wealth increases in that country play a dominant role in the dataset (Miller et al. 2008). The study concludes that there is not sufficient support for an anthropogenic climate change signal in the global loss dataset.
- 2) Nordhaus (2010) asserts a significant increase in tropical cyclone (hurricane) losses in the United States since 1900 for data only corrected for national economic productivity [gross domestic product (GDP)].
- 3) Schmidt et al. (2009) also found a significant trend in U.S. hurricane losses, but only since 1970 and after correction for wealth and population. No trend was found for the entire record, since 1950. These findings from Schmidt et al. (2009) are statistically indistinguishable from different sets of normalized hurricane loss data from other authors (Miller et al. 2008; Pielke et al. 2008). The approach with the longest time series of losses (1900–2005) shows no trend, which was found to be consistent with the historical record of a lack of trend in hurricane landfall frequencies and intensities (Pielke et al. 2008).
- 4) Chang et al. (2009) found an increase in flood damage in six Korean cities since 1971, resulting from extreme precipitation in summer and deforestation, but corrected only for changes in population and not for wealth increases.
- 5) Fengqing et al. (2005) show that losses from flooding in the Xinjiang autonomous region of China have increased in response to increases in extreme rainfall and flash floods since 1987. The study, however, notes that siltation of retention reservoirs and flood control structures also play a role in the increasing incidence of flooding. Because this effect is not quantified, it is hard to conclude whether losses have increased because of an increase in extreme rainfall only.
- 6) Changnon (2001) found an increase in normalized losses from tornadoes, hail, lightning, high wind speeds, and extreme rainfall resulting from thunderstorm activity in the western part of the United States since about 1974. However, the study concludes that normalized losses also increased in areas where thunderstorm activity decreased, indicating that socioeconomic factors may cause this trend.
- 7) Changnon (2009a) found increases in insured losses from large hailstorms in the United States since about 1992 but notes that the expansion of urban areas has led to increasing exposure and vulnerability to hailstorms, whereas changes in more frequent occurrences of major hailstorm events have not been observed.
- 8) Changnon (2009b) found an increase in insured losses from windstorm in the United States during the period 1952–2006 but notes that the increase in losses is concentrated in the western part of the country and is likely related to recent increasing population and wealth.

TRENDS VERSUS VARIABILITY. All 22 studies show that increases in exposure and wealth are by far the most important drivers for growing disaster losses. Most studies show that disaster losses have remained constant after normalization, including losses from earthquakes (see Vranes and Pielke 2009). Studies that did find increases after normalization did not fully correct for wealth and population increases, or they identified other sources of exposure increases or vulnerability changes or changing environmental conditions. No study identified changes in extreme weather due to anthropogenic climate change as the main driver for any remaining trend. Pronounced upward signals can exist in the corrected loss record that mirror observed large-scale climate variability (Pielke and Landsea 1999; Lonfat et al. 2007; Crompton et al. 2010), indicating that variations in climate and weather extremes do lead to fluctuations in risks and losses. Trends that are found, for instance, since the 1970s for hurricane losses (Schmidt et al. 2009) and thunderstorm losses (Changnon 2001) and since the 1980s for flash-flood losses (Fengqing et al. 2005) are likely related to the large natural variability shown by the weather hazards. For hurricane losses in the United States, it is well established that hurricane activity was at a low point in the 1970s and was much higher in 2004/05 (Pielke et al. 2008), which explains the short-term trend found by some studies. Studies could easily misinterpret this short-term trend as a sign of anthropogenic climate change. Even when weather-related losses have grown more rapidly

than economic production and population in recent years (e.g., Mills 2005), rapid urbanization and high concentrations of population and wealth may lead to changes in losses that are larger than national GDP growth (Bouwer et al. 2007).

LOSSES FOLLOW GEOPHYSICAL CHANGE.

Losses from extreme weather may begin to show increases when changes in extreme weather events become more apparent. Neither hurricane landfall activity nor hurricane wind speeds exceed the long-term variability found in the historical record since at least 1900 (Landsea et al. 2006; Chen et al. 2009; Knutson et al. 2010). Similarly, upward trends in extreme river discharges have been found in some individual basins around the world, but no general trend toward more frequent discharge extremes or flooding has been found (Kundzewicz et al. 2005). Consequently, using the definition of detection from the IPCC, a long-term trend in weather disaster losses has not yet been detected, and it is unlikely to be found as long as the geophysical data do not show systematic trends in extremes. Increases in economic losses could be expected for weather extremes for which trends have been found with some certainty and where the trend has been attributed to anthropogenic climate change, particularly heat waves, droughts, and heavy precipitation events (Solomon et al. 2007, Table SPM.2; Stott et al. 2010).

UNCERTAINTIES AND POSSIBLE IMPROVEMENTS.

Considerable uncertainty remains in all the loss normalization studies, because loss data are often not accurate (Downton and Pielke 2005; Gall et al. 2009) and most studies have focused on average losses, whereas changes and volatility of the greatest losses are not addressed. The scale of analysis is also an issue, because aggregating to the regional or global level may have the advantage that local variability is eliminated, but one could fail to see trends because of anthropogenic climate change that may vary per location in sign and magnitude. Also, normalization procedures cannot perfectly account for the various changes in exposure and vulnerability over time. As indicated earlier, urbanization and high concentrations of population and wealth may lead to changes in losses that are larger than growth indicated by national indicators of economic and population growth. Different methods for normalization are therefore being tested and compared (Pielke et al. 2008; Schmidt et al. 2009). When society becomes wealthier and more exposed, investments are more likely to be made, to prevent

and protect against natural hazards. Normalization studies often fail to correct for measures that reduce vulnerability, because they are harder to quantify than changes in exposure. Properly setup studies would need to include aspects of the hazard (geophysical data), exposure (population and wealth), and changes in vulnerability. Some studies do take into account changing vulnerabilities. For instance, the normalization study by Crompton and McAneney (2008) corrected over time for increasing resilience of buildings to high wind speeds. A rigorous check on the potential introduction of bias from a failure to consider vulnerability reduction in normalization methods is to compare trends in geophysical variables with those in the normalized data. Normalized hurricane losses, for instance, match with variability in hurricane landfalls (Pielke et al. 2008). If vulnerability reduction would have resulted in a bias, it would show itself as a divergence between the geophysical and normalized loss data. In this case, the effects of vulnerability reduction apparently are not so large as to introduce a bias.

Normalization studies of historic loss data provide important insights into the role of changes in vulnerability and exposure. There is an extraordinary “adaptation deficit” (Burton 2004), because economic losses from weather disasters have increased fivefold over the past 30 years (Bouwer et al. 2007). This implies that society responds only slowly to the increased exposure and would need to do more adaptation if risks were to be reduced. More insight could potentially be gained from studies that assess the impact of future anthropogenic changes in weather extremes that are projected to be larger than the changes so far observed (Parry et al. 2007). In particular, in developing countries these changing hazards will coincide with changing exposure and vulnerability. Studies of projected risks (e.g., using scenarios for hazard and exposure; e.g., Maaskant et al. 2009) can help inform decision makers of their needs for risk reduction and climate adaptation.

CONCLUSIONS. The analysis of 22 disaster loss studies shows that economic losses from various weather-related natural hazards, such as storms, tropical cyclones, floods, and small-scale weather events (e.g., wildfires and hailstorms), have increased around the globe. The studies show no trends in losses, corrected for changes (increases) in population and capital at risk, that could be attributed to anthropogenic climate change. Therefore, it can be concluded that anthropogenic climate change so far has not had a significant impact on losses from natural

disasters. Considerable uncertainties remain in some of these studies, because exposure and vulnerability that influence risk can only be roughly accounted for over time. In particular the potential effects of past risk-reduction efforts on the loss increase are often ignored, because data that can be used to correct for these effects are not available. More insight into the relative contribution from climate change on disaster losses could potentially be gained from studies that attempt to project future losses. These studies can assess the impact of future climate change, which is projected to be much larger than the change so far observed. The discussion above shows the need to include exposure and vulnerability changes in future risk projections, which clearly contribute substantially to changing risks.

ACKNOWLEDGMENTS. This research is part of the project “Financial arrangements for disaster losses under climate change,” supported by the Dutch National Research Programme “Climate changes Spatial Planning” (available online at www.climatechangesspatialplanning.nl). Two anonymous reviewers, Stéphane Hallegatte, Roger Pielke Jr., Pier Vellinga, Jeroen Aerts, and Wouter Botzen provided helpful comments and suggestions. All errors and opinions are my own responsibility.

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