WMO Assessment of Weather and Climate Mortality Extremes: Lightning, Tropical Cyclones, Tornadoes, and Hail

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ABSTRACT

A World Meteorological Organization (WMO) Commission for Climatology international panel was convened to examine and assess the available evidence associated with five weather-related mortality extremes: 1) lightning (indirect), 2) lightning (direct), 3) tropical cyclones, 4) tornadoes, and 5) hail. After recommending for acceptance of only events after 1873 (the formation of the predecessor of the WMO), the committee evaluated and accepted the following mortality extremes: 1) ''highest mortality (indirect strike) associated with lightning'' as the 469 people killed in a lightning-caused oil tank fire in Dronka, Egypt, on 2 November 1994; 2) ''highest mortality directly associated with a single lightning flash'' as the lightning flash that killed 21 people in a hut in Manica Tribal Trust Lands, Zimbabwe (at time of incident, eastern Rhodesia), on 23 December 1975; 3) ''highest mortality associated with a tropical cyclone'' as the Bangladesh (at time of incident, East Pakistan) cyclone of 12–13 November 1970 with an estimated death toll of 300 000 people; 4) ''highest mortality associated with a tornado'' as the 26 April 1989 tornado that destroyed the Manikganj district, Bangladesh, with an estimated death toll of 1300 individuals; and 5) ''highest mortality associated with a hailstorm'' as the storm occurring near Moradabad, India, on 30 April 1888 that killed 246 people. These mortality extremes serve to further atmospheric science by giving baseline mortality values for comparison to future weather-related catastrophes and also allow for adjudication of new meteorological information as it becomes available.

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1. Introduction

One aspect of the ongoing discussion and exploration of climate change is the increased mortality threat of climate change on the planet's human population. As world population continues to grow along with change in global climate, a greater portion of humanity is threatened by a multitude of climate and weather phenomena (e.g., Strader and Ashley 2015; IPCC 2014; Melillo et al. 2014; Karl et al. 2008). However, vulnerability is a function of both the risk of an event and the adaptation or resilience to the event. For example, heat wave–related mortality tends to decrease as air conditioning becomes more widespread. Similarly, lightning casualties decrease when munitions storage facilities install lightning rods and athletic programs establish lightning safety protocols (Walsh et al. 2013).

Overall mortality can also decrease as a result of continuous improvement in related forecasting and warning infrastructure. For example, the MeteoAlarm system in Europe (http://www.meteoalarm.eu/) is a web-based service designed to provide real-time warning for people traveling in Europe of severe weather. Yet even with these improvements, mortality from weather-related events will continue. To put potential future weather-related catastrophes into accurate historical context, it is useful to have knowledge of baseline changes in weather-related mortality as monitored over the last 150 years of official international weather records.

As part of the ongoing work of the World Meteorological Organization (WMO) in the detection and documentation of global weather extremes, the WMO's Commission for Climatology (CCl) has created an online archive of officially recognized weather and climate extremes (e.g., highest recorded global temperature) maintained and evaluated by professional meteorologists and climatologists. A set of procedures has been established such that existing records are verified and made available to the general public and that records of future weather extremes are systematically and objectively verified and certified. The WMO Archive of Weather and Climate Extremes is available online at https://wmo.asu.edu/. Since its inception, a number of evaluations of extremes have been undertaken (e.g., El Fadli et al. 2013; Lang et al. 2017).

Recently, in response to a growing number of inquiries from media and other groups, the WMO Commission for Climatology has decided to include extremes associated with mortality due to specific weather and climate events. However, we recognize that use of mortality numbers alone to quantify a hazard/disaster is often not a full-scale assessment of the impacts of a hazard/disaster. As Jones (1993, p. 163) noted, death tolls may be "the easiest loss-statistic to produce and the most readily appreciated but are increasingly seen to be a poor measure of hazard impact significance." He noted that reliability and magnitude of mortality statistics can be influenced by 1) chance factors in determining death tolls, 2) the low value attached to life in certain areas, and 3) the ability of advanced societies to safeguard lives over less advanced societies. Detailed discussion on the reliability of disaster death tolls is given in Paul (2011).

Nevertheless, detailed databases of hazard-related mortality databases do exist [e.g., the Centre for Research on the Epidemiology of Disasters (CRED); http://emdat.be/). The problem of many such non-meteorological sources is that classification of events is not as segregated as many climate specialists would like. For example, the CRED dataset categories meteorological disasters as "storms" without differentiation by type of phenomenon (e.g., tornado, tropical cyclone, hailstorm, etc.).

Consequently, an international panel including meteorologists, climatologists, a physician, and a weather historian, among others, was convened to examine and assess the available evidence for meteorological-derived disasters. The five extremes that were examined are 1) deadliest lightning strike (indirect death), 2) deadliest lightning strike (direct death), 3) deadliest tropical cyclone, 4) deadliest tornado, and 5) deadliest hailstorm. These five disasters were selected because at this time these four aspects of meteorology (lightning, tropical cyclone, tornado, and hailstorm) currently exist in the WMO Archive of Weather and Climate Extremes and therefore provide an initial foundation for meteorologically related mortality extremes. In the future, it is likely that mortality extremes of additional meteorological categories will be added to the archive.

Initial deliberations of the WMO evaluation committee addressed the need, as much as possible, for official primary documentation of mortality associated with these five extremes. However, this requirement must be coupled with the understanding that in most cases exact numbers are not available because of the tumultuous circumstances and magnitude of the particular weather event producing the high death toll. This is particularly true of older mortality events when exact values are not available and multiple conflicting death tolls are cited in the literature. Also, it should be noted that the designations employed in this article do not imply the expression of any opinion whatsoever on the part of the WMO concerning the legal status or claims of any country, territory, city or area, or its authorities, or concerning the delimitations of its frontiers or boundaries.

2. Methods and procedures

Procedures for the evaluation of these mortality extremes followed established practices of past ad hoc committees of the WMO World Archive of Weather and Climate Extremes. Individual members received and evaluated a comprehensive background report that detailed information concerning each of the proposed mortality extremes and the potential candidates of those extremes. Following their personal evaluation, individual members discussed each of the extremes with the committee as a whole through comments, particularly as they related to the following questions and concerns:

1) Is there need for additional raw data or documentation on this event to determine its validity or invalidity?
2) Are there any concerns as to measurement procedures, or other processes/procedures associated with the measurement of the event?
3) Are there any concerns associated with the meteorological or climatological nature of the extreme that would raise questions regarding the validity of the record?
4) Are there any other concerns associated with this event that should be raised?
5) Fundamentally, does the documentation support or refute this proposed world weather record?

Following initial discussions, the committee then addressed any concerns that were raised in those discussions and reached consensus recommendations as to the validity of the each of the mortality extremes under investigation. Those consensus recommendations were made to the chief Rapporteur of Weather and Climate Extreme by the committee and a final judgment was rendered by the Rapporteur on the inclusion or exclusion of each mortality extreme into the WMO Archive of Weather and Climate Extremes. In this investigation, a majority of the effort involved primary literature and document procurement and subsequent evaluation of those documents associated with each extreme.

3. Length-of-record parameters

The WMO mortality extremes committee's concerns regarding the use of old and potentially incorrect or incomplete data are particularly relevant in its initial evaluation of the category of deadliest lightning strike (indirect death). Examples of indirect deaths would be situations where lightning ignites a supply of gunpowder that subsequently explodes and kills large numbers of people or lightning strikes an airplane leading to equipment failure that causes an airplane to crash and kill the crew and passengers.

Given the limited quantity of available information, both regarding mortality and meteorology for early historical incidents, the committee recommended to accept weather and climate extremes for consideration into the WMO Archive of Weather and Climate Extremes only for the period *after* 1873 (see the appendix for information on pre-1873 events). The year 1873 was selected as the cutoff year for accepting records into WMO Archive of Weather and Climate Extremes as that year saw the formation of the direct predecessor of the WMO, the International Meteorological Organization (IMO). The International Meteorological Organization (IMO) was founded in 1873 to facilitate the exchange of weather information across national borders.

By limiting consideration of WMO extremes to those occurrences after the formation of the IMO (1873), both the quantity—and importantly the quality—of the available meteorological data around the world dramatically increased. The WMO evaluation committee unanimously accepted this resolution and, consequently, rejected both pre-1873 claimants to the extreme of deadliest lightning strike (indirect strike) (see the appendix). That resolution led to a continued investigation of indirect-caused lightning events of high mortality after 1873.

4. Deadliest lightning strike (indirect death)

The examination of high indirect-caused lightning mortality revealed a number of potential candidates, including the 24 December 1971 crash of LANSA Flight 508 en route from Lima, Peru, to Pucallpa, Peru, killing 91 people with only one survivor. A similar event involving a flight from Puerto Rico to Maryland (Pan Am Flight 214) on 8 December 1963 was struck by lightning, killing all 81 onboard (NLSI 2017). However, the most appropriate candidate for this category was the tragedy near Dronka (alternatively Durunka), Egypt, on 2 November 1994. During a set of very severe thunderstorms over the area that caused much damage and flash flooding, a flash of lightning ignited three oil storage tanks each holding about 5000 tons of aircraft or diesel fuel. These tanks were located on a railway line that subsequently collapsed as floodwaters built up behind it. The fuel caught fire from the lightning strike and the floodwaters swept the blazing fuel into the village, killing a very large number of people.

The immediate news coverage after the Dronka event contained a number of death tolls, ranging from 200 to over 500. For example, Chris Hedges of the *New York Times* (2 November 1994) reported that ''[a]t least 200 people were killed today in southern Egypt when an explosion and floods sent blazing fuel racing through the streets of a small village.'' Similarly, Bahaa Elkoussy of

UPI (United Press International) reported on 2 November 1994 that ‘‘Egyptian security and press sources said the latest tally of deaths caused by an oil depot fire and torrential rains on Wednesday reached 292 people in two southern provinces, and many more were injured.’’

Immediately after the event, there was a wide range in estimated deaths. Grazulis (1997, p. 1444) noted that ‘‘[o]n November 2, 1994, 430 people were killed in southern Egypt when lightning struck an army fuel depot. About 15,000 tons of blazing fuel, resembling napalm, flooded the village of Durunka, a village of 10,000 people.’’ Conversely, Torres-Sanchez (2002) cited that 530 people were killed in Dronka, Egypt, when lightning struck a petroleum tank. A number of studies after the year 2000 cite a specific number, 469 dead, but give no reference for that value (e.g., Ash 2006; Evans 2008; Fagel 2011). A significant reason for the wide variation in death toll numbers is the discrimination (or lack thereof) between deaths associated with the oil tank fire and those associated with flash flooding from the severe thunderstorms that caused the lightning.

Fortunately, one of the WMO committee members uncovered an official document from the Egyptian Ministry of Health and Population dating to that time period that reads in part (in Arabic translated to English): ‘‘Health sector officials said that hospitals in the region had received 469 bodies from the stricken village of Dronka. Security sources said the floods caused by the storm killed [an additional] 63 people in Assiut and neighboring provinces.’’

Consequently, the WMO evaluation committee recommended to accept the ‘‘highest mortality directly associated with an indirect lightning flash’’ as the lightning flash that killed 469 people (as noted by the Egyptian Ministry of Health and Population) in an oil tank fire in Dronka, Egypt, on 2 November 1994.

5. Deadliest lightning mortality (direct strike)

The claimant for ‘‘highest mortality associated with a direct strike from lightning’’ is the least officially documented incident of the five mortality investigations. In contrast to indirect death, the committee understood ‘‘direct strike’’ to refer to death resulting directly from the effects of the lightning itself. Consequently, the above-mentioned 24 December 1971 crash of LANSA Flight 508 en route from Lima, Peru, to Pucallpa, Peru, killing 91 people with only one survivor, would therefore not be considered for this category.

At the beginning of the investigation, the best claimant that could be identified for highest direct mortality from lightning was the lightning flash that killed 21 people in a hut in Manica Tribal Trust Lands in eastern Rhodesia (now Zimbabwe) on 23 December 1975. With regard to this event, the primary sources of information consisted of 1) a news release from the Reuters News Service for 24 December 1975 and 2) a listing in the *Guinness Book of World Records* for 1977. With regard to the first source, the Salt Lake City *Tribune* Newspaper for 25 December 1975 (p. 12A) states ‘‘Bolt of Lightning Kills 21. Reuters New Agency. Salisbury, Rhodesia—Lightning killed 21 people when it struck a hut in which they were seeking shelter from rain, Rhodesian police said here Wednesday. The dead included 14 children. Three people survived the incident, which occurred Tuesday in the Manica Tribal Trust Lands in eastern Rhodesia. The total number of people killed by lightning in Rhodesia since Oct. 1 is now 53—one of the worst periods on record.’’

Contact with the *Thomson Reuters News Service* yielded the following response from David Cutler (Assistant Archivist, Thomson Reuters): ‘‘... I am sorry to say that we do not have that story any more. We have political stories from Zimbabwe from before then but unfortunately not that story. However I have found some later non-Reuters stories which confirm the event but give a different date. In fact most mentions do give December 23’’ (D. Cutler 2016, personal communication).

Our contact at the *Guinness Book of World Records* responded to our inquiry with the following information, ‘‘the earliest reference I could find of the death of 21 people by a single bolt on 23 Dec 1975—that's the 24th/1978 edition, printed and distributed in 1977 edition—therefore, although my book archive search is very manual, this was very likely the first time this record was printed’’ (C. Valerio 2016, personal communication). The record was reprinted in the 1978 edition with the event being reported as having occurred in ‘‘Hut in Chinamasa Kraal nr. Umtali, Rhodesia.’’ Subsequent editions replaced Rhodesia with Zimbabwe, while the 1986 edition replaced ‘‘Kraal’’ with ‘‘Krael’’ and the 1988 edition saw ‘‘Umtali’’ replaced with ‘‘Matari.’’ He noted that ‘‘[a]s regards the original sources of the record: unfortunately we do not keep a paper archive of evidence from so far back, and not all evidence has been scanned.’’

Although this evidence is far from ideal, the consensus of the committee was that this record would be accepted until and if more information is obtained (e.g., one of the committee members believes that he saw an African newspaper report indicating 25 people died from the event but at this time cannot locate the specific newspaper) or another event with a greater death toll is uncovered.

The question can be raised as to whether all of the deaths can directly be linked to the lightning strike or died from secondary causes. In developing countries, there are many reports of 10 or more deaths per incident, sometimes with reporter statements of ''charred bodies'' or people ''burned beyond recognition.'' Reporters in developing countries seldom have firsthand information or the opportunity to interview witnesses in many cases, so that it has previously been unclear whether these phrases reflect fact or only what the reporter expected to be the outcome of lightning strike. While ground current, side-flash, or other combinations of mechanisms could cause multiple victims among larger groups of people, the prominent mention of a ''hut'' in the Zimbabwe report provided the committee with a vital clue.

Nearly 90% of sub-Saharan buildings, especially homes, are not lightning safe, leaving entire families, classrooms, and workers constantly vulnerable. In particular, schools and homes tend to be mud-brick with thatch or sheet metal roofs held down by rocks. Lightning often causes keraunoparalysis, paralysis that may take minutes to hours to resolve, sometimes with permanent pain or weakness in the areas affected (Cooper 1980). The mention of a hut opens the possibility that the victims were inside the hut at the time of their injury. Keraunoparalysis can result in otherwise healthy people being unable to evacuate or escape while the thatch, often generations old and tinder dry, burns and falls on them, causing charred bodies. There are several newspaper reports, including in Africa and the Caribbean, of pictures of fire-destroyed buildings that support this as a cause of multiple deaths in developing countries.

Consequently, it was the recommendation of the WMO evaluation committee to accept the ''highest mortality directly associated with a single lightning flash'' as the lightning flash that killed 21 people in a hut in Manica Tribal Trust Lands in eastern Rhodesia (now Zimbabwe) on 23 December 1975.

6. Deadliest tropical cyclone

The claimant for ''highest mortality associated with a tropical cyclone'' is the Bangladesh (at time of incident, East Pakistan) cyclone of 12–13 November 1970. This notorious tropical cyclone is sometimes referred to as the ''Great Bhola Cyclone'' with an estimated 300 000 (low end) to 500 000 (high end) storm-related fatalities (mostly the result of a large storm surge overwhelming the islands and tidal flats along the shores of the Bay of Bengal). Frank and Husain (1971) note that the origin of the Great Bhola Cyclone can be traced back to the remnant of a tropical storm that moved westward across the Malayan Peninsula on 5 November. This system spawned a depression over the south central Bay of Bengal on 8 November 1970. That depression strengthened and likely attained storm intensity on 9 November, while continuing to drift very slowly northward. An estimated maximum wind of 100 kt ($51.4\,\mathrm{m\,s^{-1}}$) in the November 1970 cyclone corresponded to a central pressure between 950 and 960 hPa.

Two major concerns were raised by the committee in the investigation of this proposed extreme. First, do the official records match the high range in death tolls (300 000 to 500 000) for this incident? Second, are there other tropical cyclones that could potentially have had a higher death toll?

As with any disaster of this magnitude, exaggerated death tolls are frequently common and official values difficult to obtain (Paul 2011). For example, online sources and published sources often differ significantly in numbers associated with specific disasters (e.g., Terry et al. 2012). One of the first professional articles addressing the death toll of this 1970 tropical cyclone was by Frank and Husain (1971, p. 438) They explicitly state, ''On 12 November 1970, a severe tropical cyclone of moderate strength riding the crest of high tide lashed East Pakistan with a 20-ft storm surge and killed approximately 300,000 people. The official figures show 200,000 confirmed burials and another 50,000 to 100,000 missing.'' Similarly, Sommer and Mosley (1972, p. 1029) state based on the two site surveys that the mean mortality was ''16.5%, representing a minimum of 224,000 deaths.''

A recent official WMO source (WMO 2012) also cites that mortality value of 300 000 as an official death toll. During the course of the investigation, members of the WMO evaluation committee have also uncovered many recent professional documents citing the 300 000 mortality values. For example, Ali (1979), Murty (1984), Murty et al. (1986), Dube et al. (2008), and Nott et al. (2014) consistently cite a mortality value of 300 000.

However, less regulated sites such as Wikipedia consistently state 500 000 people dead. Unfortunately, these sites claiming a 500 000 death toll list as source web links that are dead or inactive or, as one committee member noted, ''part of the 'grey' literature.'' Consequently, given the consistency in the reviewed professional literature (particularly articles dating to times just after the catastrophe), the committee recommended acceptance of the estimated 300 000 value as best available estimate of the Great Bhola Cyclone mortality.

However, the question remains as to whether other cyclones might have produced equal or larger death tolls. For example, in their review of the Great Bhola Cyclone, Frank and Husain (1971) directly state in the text that the ''Bakerganj'' cyclone in 1876 killed between 100 000 and 400 000 people. However, as one committee member noted, they listed only the lower estimate in their own table (Table 1 of Frank and Husain 1971) by declaring a value of only 100 000 dead for the Bakerganj cyclone. Other claimants such as the potential 300 000 deaths in the typhoon of 1923 for Japan have difficulties in that many of those deaths were likely caused by the Great Kanto (Tokyo) Earthquake, which occurred almost at the same time when the typhoon hit Japan.

Similarly, although online sources cite the death toll due to the Haiphong Typhoon in Vietnam in 1881 as up to 300 000, a recent study by Terry et al. (2012) reported that this horrendous figure does not match with the population in Haiphong at the time and probably contains an error that mixes up the number of death and the cost of damages. Another contender that is also commonly mentioned in online sources is the Super Typhoon Nina in China in 1975. The torrential rain of the storm caused the collapse of the Banqiao Dam, resulting in severe flooding in Henan province, China. While some online sources suggest the death toll of the event may have reached up to 230 000, more professional sources state that the flooding killed 26 000 people and another 100 000 died of subsequent disease and famine (Yang et al. 2017).

Even fairly recent tropical cyclone mortality values are quite variable. Committee members identified mortality values for Cyclone Nargis in 2008 varying from "more than 100,000" (Webster 2008) to 146 000 people with a commonly quoted range of 130 000 to 140 000. However, the death toll of Cyclone Nargis is unlikely to affect the consensus on the Great Bhola Cyclone event with an estimated death toll of 300 000 people.

Finally, there were some discussions among committee members regarding the uncertainty in the primary cause and mortality figure of the Great Bengal Cyclone of 1737 (e.g., Bilham 1984; Chakrabarti 2013). While some sources list that cyclone as having a death toll comparable to the Great Bhola Cyclone of 1970, committee members with particular expertise in tropical cyclones noted that death counts from large killer cyclones in historical times, particularly before modern records, are highly uncertain. This corresponds to the recommendation that only values after 1873 be accepted into the WMO Archive of Weather and Climate Extremes.

Consequently, it was the unanimous recommendation of the WMO evaluation committee to accept the "highest mortality associated with a tropical cyclone" as the Bangladesh (at time of incident, East Pakistan) Cyclone of 12–13 November 1970 with an estimated death toll of 300 000 people.

7. Deadliest tornado

The claimant for "highest mortality associated with a tornado" is the tornado that destroyed the Manikganj district, Bangladesh [23°50′N, 90°5′E, elevation: 9 m (30 ft)]. This tornado occurred on 26 April 1989 leaving the towns of Saturia and Manikgank Sadar completely destroyed and about 80 000 people were made homeless. This violent storm injured over 12 000 and purportedly killed a large number of people. The storm struck at around 18:30 local time (1230 UTC). The tornado cut a long track, up to a mile wide, about 50 miles northwest and north of Dhaka. The towns of Salturia and Manikganj were leveled and about 80 000 people were made homeless.

In an evaluation of the event, Hossain and Karmakar (1989, p. 110) noted that "the type of damage, the length and breadth of the path of its travel indicated that the intensity of the tornado was of the order of F3.5 in the Fujita scale and the corresponding wind was calculated around 338–418 km/hr." A total area of about 150 km^2 was impacted by the tornado. Details of the synoptic situation are given in Harman (1971).

Accurate death tolls were difficult to obtain but committee members (some with direct access to data for Bangladesh) located several newspapers citing growing death tolls. For example, the *New York Times* for 28 April 1989 stated (citing the Associated Press) that "A tornado in central Bangladesh killed 600 people, injured 12,000 and devastated more than 20 villages, the Government said today. At least 200 people were reported missing. The tornado Wednesday night blew away people, houses and animals as it whirled through the Manikganj area, 25 miles northwest of Dhaka, the capital." Other newspapers also report on 27 and 28 April 1989 (Associated Press, *The Herald*, and a local Bangladesh newspaper) about 500–600 confirmed fatalities (or number of recovered bodies) with at least 200 missing. Later newspaper reports on 30 April and 2 May 1989 (a Bangladesh newspaper and the *Chicago Tribune*) estimated an unofficial death toll reaching at least 1000.

However, as a committee member noted, the significance of "only" a death toll of 500–600 is that the death toll associated with the infamous 1925 "Tri-State tornado" (traveling from Ellington, Missouri, to Princeton, Indiana) in the United States (Johns et al. 2013) was 695 people, "so to accept the Bangladesh event as a world record we would need to be confident that the number of deaths was greater than that."

Consequently, the committee scoured the available literature to ascertain the source of the commonly quoted death toll of 1300. The most prominent secondary professional source for the Saturia Tornado's 1300-person mortality value is given by noted tornado historian Thomas P. Grazulis (Grazulis 1993, 2001). The committee directly contacted Grazulis and he stated that he believed that he had obtained that value from articles in the London *Times*.

Upon exploration of that newspaper's archives, committee members located a number of articles relating to the Saturia tornado. Specifically, a set of articles starting on 28 April 1989 and continuing to 2 May 1989 were all apparently written by the *Times* correspondent in Bangladesh, Ahmed Fazl. Of particular note, on 2 May 1989, Fazl wrote in a short *Times* article: "Storm hits survivors. Dhaka—Thousands of survivors in the devastated town of Shaturia [Saturia] in central Bangladesh passed their fifth night in the open as a fresh storm swept away the few structures left standing after last week's tornado (Ahmed Fazl writes). Yesterday a convoy of army lorries arrived in the town with supplies to stave off starvation and epidemics. About 1,300 people are thought to have died in the tornado. Some 80,000 people have been living in the open." As far as can be established, that value cited by Fazl is the best available mortality tally for this event.

Consequently, it was the unanimous recommendation of the WMO evaluation committee to accept the "highest mortality associated with a tornado" as the 26 April 1989 tornado that destroyed the Manikganj district, Bangladesh [23°50′N, 90°5′E, elevation: 9 m (30 ft)] with an estimated death toll of 1300 individuals.

8. Deadliest hailstorm

The primary claimant for "highest mortality associated with a hailstorm" is the storm occurring near Moradabad, India, on 30 April 1888. This hail event is said to have killed as many as 246 people with hailstones as large as "goose eggs and oranges" and cricket balls. A secondary event (discovered by one of the committee) in Nanking, China, in 1932 reported that 200 people were killed and thousands injured by a hailstorm that struck in Honan Province (NCAR 1970; Pickard 1932). But the NCAR (1970, p. 4) information release that mentioned the 1932 Chinese hailstorm also cites the 1888 Moradabad, India, hailstorm as having "the greatest recorded loss of life" with a death toll of 246.

Early sources to the event confirm a high fatality value for the event in Moradabad, India. The London *Times* (10 May 1888) reported that "India has been visited by a series of phenomenal storms, partaking very much of the character of the Dacca tornado. At Moradabad 150 deaths are reported, caused chiefly by hailstones . . . In Lower Bengal, at Rayebati, 2000 huts were destroyed, while 20 persons were reported to have been killed and 200 severely injured." The journal *Nature* reported on the same day (10 May 1888) citing the same information as given in the London *Times*.

However, one of earliest and most complete references to this event was given in A. W. Greely's 1888 book *American Weather*. At the time, Greely was the general in charge of the U.S. Signal Corps, one of the predecessors of the U.S. Weather Bureau, later to become the U.S. Weather Service. Greely gives verbatim the account by J. S. MacIntosh, C.S., which he said was "furnished [to] the author through the courtesy of John Eliot, Esq., Meteorological Reporter to the Government of India." Committee members confirm that Sir John Eliot later became the first Director General of Meteorology, India Meteorological Department.

Eliot (through Macintosh) (in Greely 1888) gives the following account: "A terrific storm of hail followed, breaking all the windows and glass doors. The verandas were blown away by the wind. A great portion of the roof fell in, and the massive pucca portico was blown down. The walls shook. It was nearly dark outside, and hail-stones of an enormous size were dashed down with a force which I have never seen anything to equal. As soon as the storm abated I went out . . . There was also long ridges of hail on the higher ground (of the racecourse) one or two feet or more in depth . . . There is not a single house in the civil station which did not sustain the most serious injury . . . the really destructive hail seems to have been confined to a very small area, about six or seven miles around Moradabad.

"Two hundred and thirty deaths in all have been reported up to the present time. The total number may be safely put as under two hundred and fifty. The majority of the deaths were caused by the hail. Men caught in the open and without shelter were simply pounded to death by the hail. Fourteen bodies were found in the racecourse . . . Most of the deaths were on the bare and level plains round the station, where people were caught unawares. More than one marriage party were caught by the storm near the banks of the river, and were annihilated. No Europeans were killed. The police report that 1600 head of cattle, sheep, and goats were killed."

One of our committee members has also uncovered Sir John Eliot's official daily weather observations for this time. During the period of this severe hailstorm (30 April to 1 May 1888), Sir John Eliot was working in the office of Meteorological Reporter Mr. H. F. Blanford. After the establishment of India Meteorological Department in 1875, Blanford had been appointed Meteorological Reporter to the Government of India (15 January 1875 to 8 May 1889). In May 1889, Sir John Eliot was appointed the first Director General of Observatories, India Meteorological Department at Calcutta headquarters and he continued to serve in that position until 31 December 1903 (http://www.imd.gov.in/pages/about_ex_dgms.php).

Although Eliot's daily documents do not specifically mention a death toll, they do note that "the [weather] conditions are very abnormal today, and weather is generally disturbed over the whole of Northern and Central India" (Eliot 1888). Modern professional accounts appear to employ or confirm the value cited in the Greely book based on Eliot's comments. Noted hail expert Snowden Flora in his well-recognized book *Hailstorms of the United States* stated that in the 30 April 1888 hailstorm, 230 people were killed at Moradabad and 16 others died at Bareilly to give a combined death toll of 246 people. This figure has been also cited by other meteorologists including C. F. Talman in his 1931 book *The Realm of the Air* (Talman 1931) and noted weather historian Patrick Hughes in the magazine *Weatherwise* (Hughes and Wood 1993).

This event falls within the time range recommended for adjuration of extremes for the WMO Archive of Weather and Climate Extremes (i.e., 1873 to the present). Consequently, it was the unanimous recommendation of the WMO evaluation committee to accept the "highest mortality associated with a hailstorm" as the storm occurring near Moradabad, India, on 30 April 1888 that killed 246 people with hailstones as large as "goose eggs and oranges" and cricket balls.

9. Conclusions

A WMO Commission for Climatology international panel of meteorologists, climatologists, a physician, a historian, and others associated with weather-related mortality was convened to examine and assess the available evidence associated with the following five mortality extremes selected for inclusion: 1) lightning (indirect), 2) lightning (direct), 3) tropical cyclones, 4) tornadoes, and 5) hail.

Because of the conflicting evidence associated with early meteorological data prior to the 1873 formation date of the predecessor of the World Meteorological Organization and the associated formalization of international sharing of meteorological information, the Committee agreed to only evaluate events occurring after 1873. The impacts of this decision are twofold: first, the evidence is more consistent so it is easier to reliably differentiate mortality between different events, and, second, it means that some earlier events might well have had greater mortality than the official record even if we cannot reliably determine which event was indeed the deadliest. After an in-depth analysis of available evidence, the committee recommended to accept five mortality records (Fig. 1):

1) Highest mortality (indirect strike) associated with lightning: 469 people killed (as noted by the Egyptian Ministry of Health and Population) in a lightning-caused oil tank fire in Dronka, Egypt, on 2 November 1994 (Fig. 1a).
2) Highest mortality directly associated with a single lightning flash: the lightning flash that killed 21 people in a hut in Manica Tribal Trust Lands in eastern Rhodesia (now Zimbabwe) on 23 December 1975 (Fig. 1b).
3) Highest mortality associated with a tropical cyclone: the Bangladesh (at time of incident, East Pakistan) Cyclone of 12–13 November 1970 with an estimated death toll of 300,000 people (Fig. 1c).
4) Highest mortality associated with a tornado: the 26 April 1989 tornado that destroyed the Manikganj district, Bangladesh, with an estimated death toll of 1300 individuals (Fig. 1d).
5) Highest mortality associated with a hailstorm: the storm occurring near Moradabad, India, on 30 April 1888 which killed 246 people (Fig 1e).

A critical point is that the potential always exists for reassessments to be undertaken should new evidence emerge about any of the events documented above, or of other post-1873 events currently unknown to the committee. The latter is potentially most likely for the lightning (direct) category, as the relatively modest scale of the events under consideration in that category makes it possible that events of similar or greater scale have occurred which have not been reported outside local or national channels, especially in regions with limited communications and in the earlier part of the post-1873 period, and are consequently currently unknown outside their region of occurrence.

A key consideration is that these extremes, now listed in the WMO Archive of Weather and Climate Extremes (https://wmo.asu.edu/) are accepted and listed until evidence is presented to either refute an existing record or substantiate a new mortality record. These mortality extremes serve to further atmospheric science by giving baseline mortality values for contrast and comparison to future weather-related catastrophes and also allow for discovery and adjudication of new meteorological information as it becomes available. Consequently, in order to put potential future catastrophes into accurate historical context, it is useful to have knowledge of baseline changes in both weather and weather-related mortality as monitored over the last 150 years of official international weather records.

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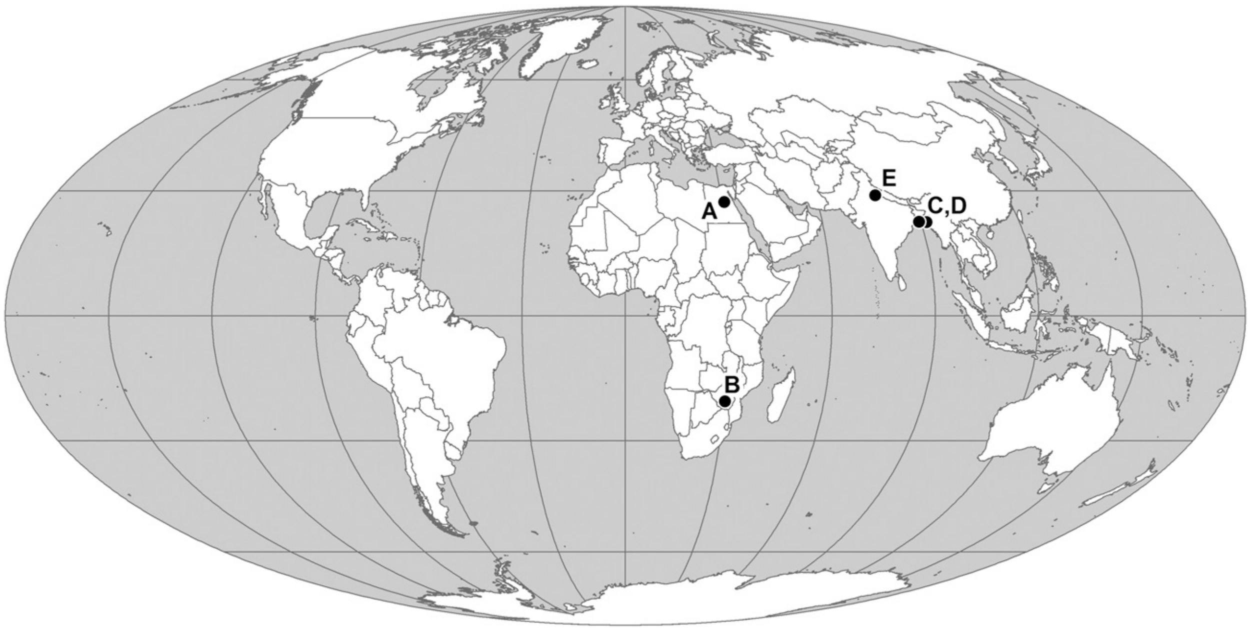

FIG. 1. (a) Highest mortality (indirect strike) associated with lightning (since 1873): 469 people killed (as noted by the Egyptian Ministry of Health and Population) in a lightning-caused oil tank fire in Dronka, Egypt, on 2 Nov 1994. (b) Highest mortality directly associated with a single lightning flash (since 1873): the lightning flash that killed 21 people in a hut in Manica Tribal Trust Lands in eastern Rhodesia (now Zimbabwe) on 23 Dec 1975. (c) Highest mortality associated with a tropical cyclone (since 1873): the Bangladesh (at time of incident, East Pakistan) cyclone of 12–13 Nov 1970 with an estimated death toll of 300,000 people. (d) Highest mortality associated with a tornado (since 1873): the 26 Apr 1989 tornado that destroyed the Manikganj district, Bangladesh, with an estimated death toll of 1300 individuals. (e) Highest mortality associated with a hailstorm (since 1873): the storm occurring near Moradabad, India, on 30 Apr 1888, which killed 246 people, most of whom were "simply pounded to death by the hail" (Greely 1888, p. 236).

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APPENDIX

Pre-1873 Events

During the course of the evaluation, two possible (pre-1873) candidates for the indirect lightning death extreme were initially uncovered and evaluated. First, a lightning event that occurred at Brescia, Italy, on 18 August 1769 was identified and evidence evaluated. Lightning struck the 80-ft. stone tower (St. Nazaire) built into the medieval defensive walls around the town of Brescia, killing an estimated 3000 people. One of the earliest professional discussions of this event was made by the noted lightning expert W. Snow Harris in 1820 when he wrote: "In August, 1769, lightning struck the tower of the church of St. Nazaire in Brescia, Italy, and the current passed through vaults where 207,000 pounds of gunpowder had been stored for safe-keeping; the resulting explosion killed about 3000 people and destroyed one-sixth of the city" (Harris 1843, p. 163).

A few years later in 1839, the illustrious meteorologist D. F. J. Arago addressed the event when he wrote: "In speaking of [lightning] damage, I should not forget that which lightning sometimes occasions when it strikes powder magazines. On the morning of the 18th of August 1769, lightning fell upon the tower of St. Nazaire at Brescia. This tower stood upon a subterranean magazine, which contained 2,076,000 pounds of powder belonging to the Republic of Venice. This immense mass of powder ignited in a moment. The sixth part of the edifices in the great and beautiful town of Brescia were overturned, and the rest were much shaken and threatened with destruction. Three thousand persons perished." (Arago 1839, p. 120).

The order of magnitude difference in the amount of gunpowder stored in these different accounts highlights the problem of assessing historical events. Following those citations, other meteorologists also cited the Brescia event, including Towbridge (1875), Molloy (1882, 1890), and Tomlinson (1889). All mentioned deaths in the thousands with most citing the 3000 figure given by Harris and Arago.

However, the committee also uncovered mention of another lightning-induced gunpowder explosion that occurred in Rhodes (in present-day Greece), 6 November (although some sources indicate October) 1856. In this event, lightning sparked an explosion of a gunpowder depository in the Church of St. John (Jean) on the island of Rhodes with a purported death toll of 4000. However, this event is listed as having multiple dates and a wide range of casualties. The value of 4000 dead is only seen in documents dated after 1905.

In particular, the great nineteenth century meteorologist Camille Flammarion wrote: ‘‘At four o'clock in the afternoon of October 6, 1856 lightning penetrated the vaults of the church of St. Jean, at Rhodes, setting fire to an enormous quantity of powder. Four or five thousand people lost their lives in the catastrophe'' (Flammarion 1905, 224–225).

A diligent search of the literature by committee members found a wide range of cited mortality numbers associated with the Rhodes event. One of the earliest mentions of the catastrophe is found in the *Illustrated London News* (3 January 1857, Vol. 29) where it is stated: ‘‘On the 2nd of November there was a tremendous earthquake in Rhodes, which partially destroyed the town; and, on the 6th, 32,000 pounds of powder, which had been placed, by order of the Turkish Government, in the Church of St. John (that edifice being built of stone and therefore not being liable to take fire), was ignited by a thunderbolt or the lightning during a storm, and blew up, destroying with it the palace of the Grand Master and two hundred houses built of stone, the fragments of which descended on the other parts of the town, and more or less destroyed it; hardly anything remaining of it except some few houses, some cottages, and the fortifications seaward.''

Similarly, in the *Nautical Magazine* (‘‘On Ships and Buildings,'' 1857, p. 580), it is written that ‘‘if we look to the last year [1856], here again we find awful examples of destructive action of lightning. Again another magazine struck and blown up at Rhodes in November and a portion of the town laid in ruins, with frightful loss of life.'' In 1860, Charles Tomlinson wrote: ‘‘In 1856, November 6th, lightning fell upon the church of St. John, in the island of Rhodes, the ancient cathedral of the knights of Rhodes. A large collection of gunpowder had been deposited in the vaults of the church: this was ignited; the building was reduced to a mass of ruins, a large portion of the town was destroyed, and a considerable number of the inhabitants were killed'' (Tomlinson 1860, p. 159).

The first numerical death tolls for this event apparently were given in a publication by Cornelius Walford in his article ‘‘The Increasing Number of Deaths from Explosions, with an Examination of the Causes,'' in the *Journal of the Society of Arts* in 1881 (Walford 1881). Specifically, under the section on ‘‘Gunpowder,'' the Table of ‘‘Explosions of Gunpowder from Earliest Records down to Present Time in Various Parts of the World; Cause being stated where practicable,'' the Rhodes lightning event is listed twice (6 November 1855, 300 dead and 6 November 1856, no death toll given). In his book *The Aerial World*, noted American meteorologist George Hartwig lists a date of 6 November 1856 and states ‘‘more than 200 corpses were found in the ruins'' (Hartwig 1887, p. 556) while Gerald Molloy in 1890 states that the destruction of Church of St. John on Rhodes killed a ‘‘considerable number'' of people. Of available professional literature from the late nineteenth and early twentieth century, only Flammarion (1905) gives a mortality of ‘‘four to five thousand.''

The weight of the available evidence suggests a realistic mortality of 3000 people for the Brescia event but the conflicting values of the Rhodes incident put the question of ‘‘deadliest'' into question. In the opinion of several committee members, the mortality values given by an illustrious early meteorologist such as Camille Flammarion should not be disregarded while others noted the large time difference between the incident (1856) and Flammarion's cited values (1905). Consequently, it was recommended that only events after 1873, the formation of the predecessor of the World Meteorological Society, be accepted in the WMO Archive of Weather and Climate Extremes.

REFERENCES

Ali, A., 1979: Storm surges in the Bay of Bengal and some related problems. Reading University, Ph.D. dissertation, 227 pp.

Arago, D. F. J., 1839: On thunder and lightning. Edinburgh New *Philos. J.*, **26**, 81–144, 275–291.

Ash, J. W., 2006: Mitigation of the catastrophic failure of the primary containment in the bulk storage industry. Liverpool John Moore University, Ph.D. dissertation, 100 pp.

Bilham, R., 1984: The 1737 Calcutta earthquake and cyclone evaluated. *Bull. Seismol. Soc. Amer.*, **84**, 1650–1657.

Chakrabarti, R., 2013: The Kolkata cyclone/earthquake of 1737: Random scribbles. *Vidyasagar Univ. J. Hist.*, **1**, 1–16. [Available online at http://inet.vidyasagar.ac.in:8080/jspui/bitstream/123456789/1242/2/1.pdf.]

Cooper, M. A., 1980: Lightning injuries: Prognostic signs for death. *Ann. Emerg. Med.*, **9**, 134–138, doi:10.1016/S0196-0644(80)80268-X.

Dube, S. K., A. D. Rao, P. C. Sinha, and P. Chittibabu, 2008: Storm surges: Worst coastal marine hazard. *Modelling and Monitoring of Coastal Marine Processes*, C. R. Murthy, P. C. Sinha, and Y. R. Rao, Eds., Springer, 125–140.

El Fadli, K., and Coauthors, 2013: World Meteorological Organization assessment of the purported world record 58°C temperature extreme at El Azizia, Libya (13 September 1922). *Bull. Amer. Meteor. Soc.*, **94**, 199–204, doi:10.1175/BAMS-D-12-00093.1.

Eliot, J., 1888: *India Daily Weather Report*. [Available upon request from the corresponding author.]

Evans, D. J., 2008: An appraisal of underground gas storage technologies and incidents, for the development of risk assessment methodology. Research Rep. RR605, 350 pp. [Available online at http://www.hse.gov.uk/research/rrhtm/rr605.htm.]

Fagel, M., 2011: *Principles of Emergency Management: Hazard Specific Issues and Mitigation Strategies*. CRC Press, 585 pp.

Flammarion, C., 1905: *Thunder and Lightning*. Chatto and Windus, 312 pp.

Flora, S. D., 1956: *Hailstorms of the United States*. University of Oklahoma Press, 201 pp.

Frank, N. L., and S. A. Husain, 1971: The deadliest tropical cyclone in history? *Bull. Amer. Meteor. Soc.*, **52**, 438–445, doi:10.1175/1520-0477(1971)052<0438:TDTCIH>2.0.CO;2.

Grazulis, T. P., 1993: *Significant Tornadoes*. The Tornado Project of Environmental Films. [Available online at http://www.tornadoproject.com/index.html.]

——, 1997: *Significant Tornadoes* (update to 1995 storms). Tornado Project of Environmental Films. [Available online at http://www.tornadoproject.com/index.html.]

——, 2001: *The Tornado, Nature's Ultimate Windstorm*. University of Oklahoma Press, 352 pp.

Greely, A. W., 1888: *American Weather: A Popular Exposition of the Phenomena of the Weather (Including Chapters on Hot and Cold Waves, Blizzards, Hail-Storms and Tornadoes, etc., etc.)*. Dodd, Mead & Company, 286 pp.

Harman, J. R., 1971: Tropospheric waves, jet streams, and United States weather patterns. Resource Paper 11, Association of American Geographers, Commission on College Geography, 37 pp.

Harris, W. S., 1843: *On the Nature of Thunderstorms; and on the Means of Protecting Buildings and Shipping Against the Destructive Effects of Lightning*. John W. Parker, 226 pp.

Hartwig, G., 1887: *The Aerial World: A Popular Account of the Phenomena and Life of the Atmosphere*. Green and Co., 607 pp.

Hossain, M. D. A., and S. Karmakar, 1989: Some meteorological aspects of the Saturia tornado, 1989—A case study. *J. Bangladesh Acad. Sci.*, **22**, 109–122.

Hughes, P., and R. Wood, 1993: Hail: The white plague. *Weatherwise*, **46**, 16–21, doi:10.1080/00431672.1993.9930228.

IPCC, 2014: *Climate Change 2014: Synthesis Report*. IPCC, 151 pp. [Available online at http://www.ipcc.ch/report/ar5/syr/.]

Johns, R. H., D. W. Burgess, C. A. Doswell III, M. S. Gilmore, J. A. Hart, and S. F. Piltz, 2013: The 1925 Tri-State tornado damage path and associated storm system. *Electron. J. Severe Storms Meteor.*, **8** (2). [Available online at http://ejssm.org/ojs/index.php/ejssm/article/viewArticle/109.]

Jones, D., 1993: Environmental hazards: The challenge of change—Environmental hazards in the 1990s: Problems, paradigms and prospects. *Geography*, **78** (2), 161–165.

Karl, T. R., G. A. Meehl, C. D. Miller, S. J. Hassol, A. M. Waple, and W. L. Murray, Eds., 2008: Weather and climate extremes in a changing climate. Regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. U.S. Climate Change Science Program Rep., NOAA/NCDC, 164 pp. [Available online at http://data.globalchange.gov/report/ccsp-sap-3_3-2008.]

Lang, T. J., and Coauthors, 2017: WMO world record lightning extremes: Longest reported flash distance and longest reported flash duration. *Bull. Amer. Meteor. Soc.*, doi:10.1175/BAMS-D-16-0061.1, in press.

Melillo, J., T. C. Richmond, and G. Yohemore, 2014: *Climate Change Impacts in the United States: The Third National Assessment*. U.S. Global Change Research Program, 440 pp., doi:10.7930/J0Z31WJ2.

Molloy, G., 1882: Lightning conductors. *Ir. Ecclesiastical Rec.*, **3**, 193–208.

——, 1890: *Lightning, Thunder and Lightning Conductors.* Humboldt Publishing Company, 62 pp.

Murty, T. S., 1984: *Storm Surges: Meteorological Ocean Tides.* Department of Fisheries and Oceans (Ottawa), 897 pp.

——, R. A. Flather, and R. F. Henry, 1986: The storm surge problem in the Bay of Bengal. *Prog. Oceanogr.*, **16**, 195–233, doi:10.1016/0079-6611(86)90039-X.

NCAR, 1970: Hail Research 1970. Information release 1970-13, National Center for Atmospheric Research, 10 pp.

NLSI, 2017: Aviation losses from lightning strikes. National Lightning Safety Institute, accessed 9 January 2017. [Available online at http://lightningsafety.com/nlsi_lls/avaition_losses.html.]

Nott, J., C. Green, I. Townsend, and J. Callaghan, 2014: The world record storm surge and the most intense Southern Hemisphere tropical cyclone: New evidence and modeling. *Bull. Amer. Meteor. Soc.*, **95**, 757–765, doi:10.1175/BAMS-D-12-00233.1.

Paul, B. K., 2011: *Environmental Hazards and Disasters: Contexts, Perspectives and Management.* John Wiley & Sons, 322 pp.

Pickard, E. W., 1932: Chronology of the year 1932. *The Cambridge Sentinel*, **27** (52), p. 6.

Sommer, A., and W. H. Mosley, 1972: East Bengal Cyclone of November, 1970: Epidemiological approach to disaster assessment. *Lancet*, **299**, 1030–1036, doi:10.1016/S0140-6736(72)91218-4.

Strader, S. M., and W. S. Ashley, 2015: The expanding bull's-eye effect. *Weatherwise*, **68**, 23–29, doi:10.1080/00431672.2015.1067108.

Talman, C. F., 1931: *The Realm of the Air: A Book about Weather.* Bobbs-Merrill, 318 pp.

Terry, J. P., N. Winspear, and T. Q. Cuong, 2012: The 'terrific Tongking typhoon' of October 1881—Implications for the Red River Delta (northern Vietnam) in modern times. *Weather*, **67**, 72–75, doi:10.1002/wea.882.

Tomlinson, C., 1860: *The Thunder-Storm: An Account of the Properties of Lightning and of Atmospheric Electricity in Various Parts of the World*. Society for Promoting Christian Knowledge, 348 pp.

——, 1889: On lightning and gunpowder magazines. *Philos. Mag.*, **28**, 368–375, doi:10.1080/14786448908619877.

Torres-Sanchez, H., 2002: Protection of petroleum facilities against lightning. *Proc. GROUND'2002 (International Conference on Grounding and Earthing) and Third WAE (Third Brazilian Workshop on Atmospheric Electricity)*, Rio de Janeiro, Brazil, Brazilian Society for Electrical Protection, 229–231.

Towbridge, J., 1875: Lightning and lightning rods. *Atlantic Monthly*, **36** (issue 213, July 1875), 38–47.

Walford, C., 1881: The increasing number of deaths from explosions, with an examination of the causes. *J. Soc. Arts*, **29**, 399–429.

Walsh, K. M., M. A. Cooper, R. Holle, V. A. Rakov, W. P. Roeder, and M. Ryan, 2013: National Athletic Trainers' Association position statement: Lightning safety for athletics and recreation. *J. Athletic Train.*, **48**, 258–270, doi:10.4085/1062-6050-48.2.25.

Webster, P., 2008: Myanmar's deadly daffodil. *Nat. Geosci.*, **1**, 488–490, doi:10.1038/ngeo257.

WMO, 2012: Atlas of mortality and economic losses from weather, climate and water extremes (1970–2012). WMO-1123, 44 pp. [Available online at https://public.wmo.int/en/resources/library/atlas-mortality-and-economic-losses-weather-and-climate-extremes-1970-2012.]

Yang, L., M. Liu, J. A. Smith, and F. Tian, 2017: Typhoon Nina and the August 1975 flood over central China. *J. Hydrometeor.*, **18**, 451–472, doi:10.1175/JHM-D-16-0152.1.