The historical socioeconomic cost of earthquakes vs. other natural disasters types globally – an argument for greater funding for research and prevention

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ABSTRACT: For the first time, a breakdown of losses from 1900-2015 is given based on increased analysis within the CATDAT Damaging Natural Disaster databases. Using country-CPI and GDP deflator adjustments, over $7 trillion (2015-adjusted) in losses have occurred; over 40% due to flood/rainfall, 26% due to earthquake, 19% due to storm effects, 12% due to drought, 2% due to wildfire and under 1% due to volcano. In terms of fatalities, over 8 million deaths can be attributed to the disaster types (without drought/temperature).

Trends are shown from 1500 onwards for earthquake to examine the long-run effects of earthquakes in terms of the number of fatalities and relative risk vs. other involuntary types of death. From 1960 onwards, earthquakes have caused the highest percentage of deaths from all disaster types in this analysis.

A normalisation methodology using the exposure databases within CATDAT is shown. This demonstrates clear trends in the improvement of building stock towards natural disasters and a decreasing trend in some fields, yet shows the high human, built and productive capital effects of earthquake losses. This historic analysis shows the need for greater funding for research and prevention of earthquake losses.

1 INTRODUCTION

1.1 Background

Since the 2010 AEES Perth conference paper about the CATDAT Damaging Earthquakes Database (Daniell, 2010 and the update Daniell et al., 2011a), many developments have been produced in the damaging earthquakes database as well as the integration of the other natural disaster databases into a homogenised working document. It was decided that it is time for an update of the original paper in terms of statistics, but also to show some of the comparisons and new sources within the database.

Currently, over 40,000 events are recorded since 1900, of which **9,774** are earthquake events (as of 12th September 2016). Before 1900, there are an additional 15,000+ events of which 7,100 are earthquake events (given the focus of these in the original databases).

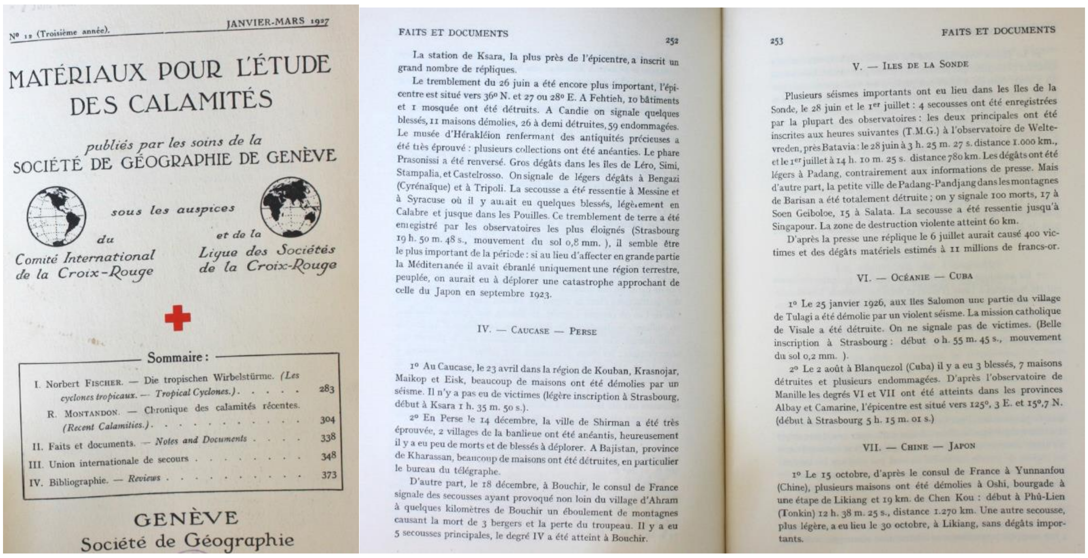
Since 2003, the CATDAT Database has been built from information out of Online Archives, books, reports from institutions, publications and other databases around the world, with original sources in over 90 languages. In Daniell (2014), the development of a global rapid loss estimation model for earthquake, using empirical data from the over 8000 earthquakes since 1900 and the associated socioeconomic climate over time, was shown. Using this basis, a death toll estimate and economic loss estimate for each event since late 2009 was given. The databases have been produced in order to give an insight for countries, individuals and companies into the number of damaging events in certain locations in the world. Up until 2010, most of the effort was indeed based on collecting the damage statistics themselves rather than hazard metrics to describe them, with the exception of some of the main earthquake events which aided the production of the first estimates of CATDAT EQLIPSE-Q and EQLIPSE-R (Daniell et al., 2011b – AEES).

From 2010 onwards, a lot of the collection has been focussed on hazard metrics as well as to improve some of the spurious results from historical studies. The isoseismal reports collected in this time have been mostly digitised, giving a huge database of historical events for comparison. Where available, point based intensities have also been collected along with ground motion data.

Since 2013, Jens-Udo Skapski has collected his database of fatalities and injuries from earthquake events globally in conjunction with Earthquake Report, and this shows the increase in the detail of coverage of damaging earthquake events when using different languages, having a reporting platform where many people contribute, and having increased global connectivity. Historically, many events were simply not recorded or reported in some countries despite causing damage. Today, an earthquake affecting a village on a small island or some remote location is reported, and the effects published, whereas even 10 years ago the reporting mechanism was not as widespread.

Thus, although the collection of damaging earthquakes in the period from 1900-1970 has improved, it can still be recognised that damaging events have been underestimated by as much as 70% in any one year. We expect that fatal events for earthquake could be underestimated by as much as 40%, even though this database is a huge advance on other existing databases.

Of course, this is not the case for all countries, as Australia had a wide network of newspapers earlier in the century in each country town providing a treasure trove (trove.gov.au) of information for recording earthquakes.



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La station de Ksara, la plus près de l'épicentre, a inscrit un grand nombre de répliques.

Le tremblement du 26 juin a été encore plus important, l'épicentre est situé vers 36° N. et 27 ou 28° E. A Fehtieh, 10 bâtiments et 1 mosquée ont été détruits. A Candie on signale quelques blessés, 11 maisons démolies, 26 à demi détruites, 59 endommagées. Le musée d'Hérakléion renfermant des antiquités précieuses a été très éprouvé : plusieurs collections ont été anéanties. Le phare Prasonissi a été renversé. Gros dégâts dans les îles de Léro, Simi, Stampalia, et Castelrosso. On signale de légers dégâts à Bengazi (Cyrénaïque) et à Tripoli. La secousse a été ressentie à Messine et à Syracuse où il y aurait eu quelques blessés, légèrement en Calabre et jusque dans les Pouilles. Ce tremblement de terre a été enregistré par les observatoires les plus éloignés (Strasbourg 19 h. 50 m. 48 s., mouvement du sol 0,8 mm.), il semble être le plus important de la période : si au lieu d'affecter en grande partie la Méditerranée il avait ébranlé uniquement une région terrestre, peuplée, on aurait eu à déplorer une catastrophe approchant de celle du Japon en septembre 1923.

IV. — Caucase — Perse

1° Au Caucase, le 23 avril dans la région de Kouban, Krasnojar, Maikop et Eisk, beaucoup de maisons ont été démolies par un séisme. Il n'y a pas eu de victimes (légère inscription à Strasbourg, début à Ksara 1 h. 35 m. 50 s.).

2° En Perse le 14 décembre, la ville de Shirman a été très éprouvée, 2 villages de la banlieue ont été anéantis, heureusement il y a eu peu de morts et de blessés à déplorer. A Bajistan, province de Kharassan, beaucoup de maisons ont été détruites, en particulier le bureau du télégraphe.

D'autre part, le 18 décembre, à Bouchir, le consul de France signale des secousses ayant provoqué non loin du village d'Ahram à quelques kilomètres de Bouchir un éboulement de montagnes causant la mort de 3 bergers et la perte du troupeau. Il y a eu 5 secousses principales, le degré IV a été atteint à Bouchir.

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V. — Iles de la Sonde

Plusieurs séismes importants ont eu lieu dans les îles de la Sonde, le 28 juin et le 1er juillet : 4 secousses ont été enregistrées par la plupart des observatoires : les deux principales ont été inscrites aux heures suivantes (T.M.G.) à l'observatoire de Weltevreden, près Batavia : le 28 juin à 3 h. 25 m. 27 s. distance 1.000 km., et le 1er juillet à 14 h. 10 m. 25 s. distance 780 km. Les dégâts ont été légers à Padang, contrairement aux informations de presse. Mais d'autre part, la petite ville de Padang-Pandjang dans les montagnes de Barisan a été totalement détruite ; on y signale 100 morts, 17 à Soen Geiboloe, 15 à Salata. La secousse a été ressentie jusqu'à Singapour. La zone de destruction violente atteint 60 km.

D'après la presse une réplique le 6 juillet aurait causé 400 victimes et des dégâts matériels estimés à 11 millions de francs-or.

VI. — Océanie — Cuba

1° Le 25 janvier 1926, aux Iles Salomon une partie du village de Tulagi a été démolie par un violent séisme. La mission catholique de Visale a été détruite. On ne signale pas de victimes. (Belle inscription à Strasbourg : début 0 h. 55 m. 45 s., mouvement du sol 0,2 mm.).

2° Le 2 août à Blanquezol (Cuba) il y a eu 3 blessés, 7 maisons détruites et plusieurs endommagées. D'après l'observatoire de Manille les degrés VI et VII ont été atteints dans les provinces Albay et Camarine, l'épicentre est situé vers 125°, 3 E. et 15°,7 N. (début à Strasbourg 5 h. 15 m. 01 s.)

VII. — Chine — Japon

1° Le 15 octobre, d'après le consul de France à Yunnanfou (Chine), plusieurs maisons ont été démolies à Oshi, bourgade à une étape de Likiang et 19 km. de Chen Kou : début à Phû-Lien (Tonkin) 12 h. 38 m. 25 s., distance 1.270 km. Une autre secousse, plus légère, a eu lieu le 30 octobre, à Likiang, sans dégâts importants.

Figure 1: A collation of various sources collected by Montandon et al. from 1924 onwards, which are being digitised into the database.

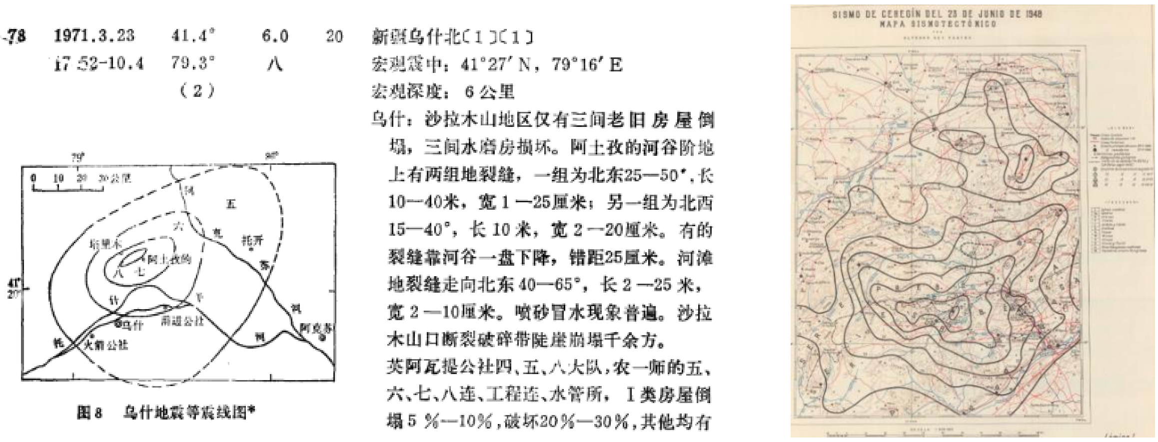
2 ADDING FOOTPRINT INFORMATION GLOBALLY TO THE DATABASES

Adding hazard information for each past event has inherent difficulties. Although one may come across historical information on damage, deaths or some form of estimate, geolocating this damage can prove problematic, given the lack of reports in the early part of the 20th century.

2.1 Earthquake Footprints

Macroseismic intensities from many sources are used for the purposes of this study. In the first minutes after an earthquake, the magnitude of larger events is generally underestimated, and only a point source location can be provided as there is often a lack of information about the finite fault. Further study is needed on this aspect and continues with every new research paper globally. However, for past events, intensity data is available which allows for more accurate analysis of past events, and this should lead to a better fit of a function.

In the locations where macroseismic intensity points are present, interpolation techniques have been looked at in order to create consistent assessments of the exposed population to those intensities. Kriging techniques were used to determine the intensity across the area affected. A few different forms were tested in order to get the best fit of intensities.



-78 1971.3.23 41.4° 6.0 20 新疆乌什北〔1〕〔1〕

17 52-10.4 79.3° 八

（2）

宏观震中：41°27′N，79°16′E

宏观深度：6公里

乌什：沙拉木山地区仅有三间老旧房屋倒塌，三间水磨房损坏。阿土孜的河谷阶地上有两组地裂缝，一组为北东25—50°，长10—40米，宽1—25厘米；另一组为北西15—40°，长10米，宽2—20厘米。有的裂缝靠河谷一盘下降，错距25厘米。河滩地裂缝走向北东40—65°，长2—25米，宽2—10厘米。喷砂冒水现象普遍。沙拉木山口断裂破碎带陡崖崩塌千余方。

英阿瓦提公社四、五、八大队，农一师的五、六、七、八连、工程连、水管所，Ⅰ类房屋倒塌5%—10%，破坏20%—30%，其他均有

图8 乌什地震等震线图*

Figure 2: Intensity maps - 1971 China earthquake (Gu, 1984b) (Left); 1948 Cenegin earthquake (Pastor and Instituto Geográfico y Catastral, 1949) (Right)

A compendium of isoseismal maps has been collected and produced for the thesis of Daniell (2014). Figure 2 shows an example of the intensity maps for the 1948 and 1971 China earthquakes. The work of digitising the 2000+ isoseismals collected by the author during the above study was then shared. The author was aided by Jonathan Gonzalez Santiago (ca. 450 isoseismals) and Apoorv Sharma (ca. 150 isoseismals) in addition to the digitisation of around 900 by the author. These form an important part of the analysis along with macroseismic intensity data points, in order to establish relationships of historical earthquake events in today's terms.

Previously, USGS released a compendium of Shakemaps from 1973-2007 (Allen et al., 2008), containing intensity maps of historical events with approximately 450 events, using finite fault sources, macroseismic data points or ground motions from various articles and from the Swiss Seismological Agency. These are summarised below. Over the time period, in EXPO-CAT, 5500 events had shakemaps (many being smaller events in USA), with 1914 being able to be joined to a damaging earthquake within the CATDAT database. However, of these, only 29 main events had shakemaps pre-1973.

It should be noted that this dataset of EXPO-CAT uses Shakemap Atlas v1.0 (Allen et al., 2008) which does not include earthquakes since 2008. However, as of August 2016, this is still the version available on the USGS website. Table 1 shows the data and information quality in Shakemap Atlas v1.0.

Table 1: The number of earthquakes in the Shakemap Atlas v1.0 that contain checked data against historical earthquakes in terms of possible intensities.

Information used.	Quality	No. of earthquakes within the EXPO-CAT database (Allen et al., 2008) of the 449 with source information
Ground motion only	Adequate, ground motion to MMI has a huge distribution as per Figure 4	231 (52%)
Macroseismic intensity only	Very good, but still needs to be constrained	44 (10%)
Fault source only	Adequate – allows for better determination	36 (8%)
Fault source + Macroseismic	Very good, constrains the macroseismic data well.	31 (7%)
Ground motion + Macroseismic	Very good, constrains the macroseismic data well.	27 (6%)
Ground motion + fault source	Good – still lacks macroseismic determination	47 (10.5%)
All three types	Best – very well constrained	29 (6.5%)
Point source		5100

Of the 9700+ major damaging earthquakes in the CATDAT Damaging Earthquakes Database since

1900, 2151 of these were joined to a USGS Shakemap either within the Atlas, or in the last few years; however, these were then questioned critically. In many cases it was found that small magnitude earthquakes cause intensities of VII or VIII due to having shallow hypocentres. These types of events do not always make it into the Shakemap catalogue. Utilising the USGS shakemaps produced without historical intensities or source functions also carries with it large uncertainties, as 3 intensity prediction equations are used to produce the isoseismals and the ground motion and finite fault data in v1.0. Within the database created in this study, these are slowly being changed to make use of the observed isoseismals, as reported by the CEA studies etc., but it will likely be until the year 2020 before these are fully digitised.

Where no other information could be sourced, the USGS Shakemap was taken where it was reasonable, as this is the only available source for most global earthquakes, and then it was calibrated to observed intensities in some cases; however, as much effort as possible was undertaken to source additional intensities, isoseismals or historical records of felt intensities in order to fill in the gaps, as shown in Table 2. It should be noted that data for many pre-1900 events was also collected; however, as these were not within the scope of this study, they will not be further discussed. In addition, many articles that contain isoseismals and macroseismic intensity points in various languages have been collected in the course of this study. About 4000 earthquake isoseismals and intensity maps have been digitised, adapted or converted from lists and pictures and this digitisation will continue after the end of this study.

Table 2: The main isoseismal/shakemap catalogues from which a significant number of damaging events were sourced. Many other sources were used for smaller numbers of isoseismals.

Location, no. isoseismals outputted	No. Damaging Events after 1900	Author
Worldwide	29 (1960-1972) 2151 (1973-2016)	USGS, Allen et al. (2008), see notes above as to inclusion
China (中国地震目录: 公元前1831—公元1969年) and also 1970-1979	297 (1900-1979)	Gu (1983a; 1984b)
Turkey (Türkiye Büyük Depremleri Makrosismik Rehberi)	118 (1900-1988)	Eyidogan et al. (1991)
New Zealand (Atlas of Isoseismal Maps of New Zealand Earthquakes)	116 (1900-1990)	Downes (1995b)
Colombia, Venezuela, Ecuador, Peru	41 (1900-2004)	Prieto et al. (2011)
Mexico	Numerous	Figueroa (1963a), Figueroa (1970b)
South America	Numerous	CERESIS (1985) catalogue
Indonesia, Myanmar, Malaysia, The Philippines, Southeast Asia	Numerous	SEASEE catalogues (1980s) - Garcia (1985), Soetardjo and SEASEE (1985), Leyu (1985), Nutalaya et al. (1985)
Peru	Numerous	REDACIS (2013), Silgado (1978b)
Australia, Fiji, Solomon Islands	55	McCue (1996a; 1996b; 2014 additions), Everingham et al. (1982), Everingham (1988), Blong and Radford (1993)
Iran	59 (1900-1995)	Berberian (1976a; 1976b-1977; 1976c; 1976d; 1976e; 1976f; 1976g; 1977h; 1978j; 1994k; 2005m) and others
Algeria, Morocco	Numerous	Benouar (1994)
Worldwide (Egypt, Red Sea, Persian earthquakes, Mediterranean, Central America)	Numerous	Ambraseys (1963a; 2006;); Ambraseys and Adams (1991); Ambraseys and Bilham (2003a); Ambraseys and Melville (2005)
Greece	Numerous	Papazachos and Papazachou (1997)
Balkan region	Numerous (1900-1970)	Shebalin (1974c)
Russia, Eastern Europe	Numerous	Kondorskaya and Shebalin (1982), Procházková and Kárník (1978)

Japan	Numerous	Usami (2003)
Italy	Numerous	INGV, Postpischl
Haiti, Caribbean, Cuba, Jamaica	Numerous	Alvarez et al. (1990), Rodriguez (2008), ten Brink et al. (2011) and others
China	Numerous	CEA (2016), Lunwen and others.

The following Table 3 shows the maximum number of earthquakes where intensity boundaries from the isoseismals were collected and produced in the study. It should be noted that of the 3697 fitted isoseismals (ca. 1250 of which are from USGS, given removal of the doubles) of the 9700+ damaging earthquakes from 1900-2012, an additional 1951 have been collected but have not yet been added into the database as of August 2016. 2233 fatal earthquakes have been examined from 1900-2016. Of these, 1842 have had shaking fatalities. 1426 have been joined into the isoseismal estimation, including over 99% of fatalities. Of these, 1311 have had shaking fatalities.

Table 3: The number of damaging earthquakes included in the GIS system in this study.

Update of the 9774 damaging earthquakes as of August 2016	Collected and linked to database and in GIS System	Collected in addition	Maximum Possible
Isoseismals and intensity boundaries	3697 (5122 – 1425 alternatives)	1951	9700+
Maximum Intensity	4122	ca. 6600	9700+
Fatal Earthquakes (All)	1486	1721 (some repeats)	2200+
Shaking Fatality Earthquakes	1371	1543 (some repeats)	2000+

The additional events from 1900-1973 in this database and improved later fatality data give the increase in this study shown in Table 3. However, given the additional older events, an added parameter was needed, as the vulnerability had to be looked at by taking into account the difference in historical conditions. The numbers above do not include double counting where fatalities occurred in multiple locations. Figure 3 shows where isoseismal maps were created and collected worldwide correlated to damaging earthquakes in the database with an intensity greater than 5.

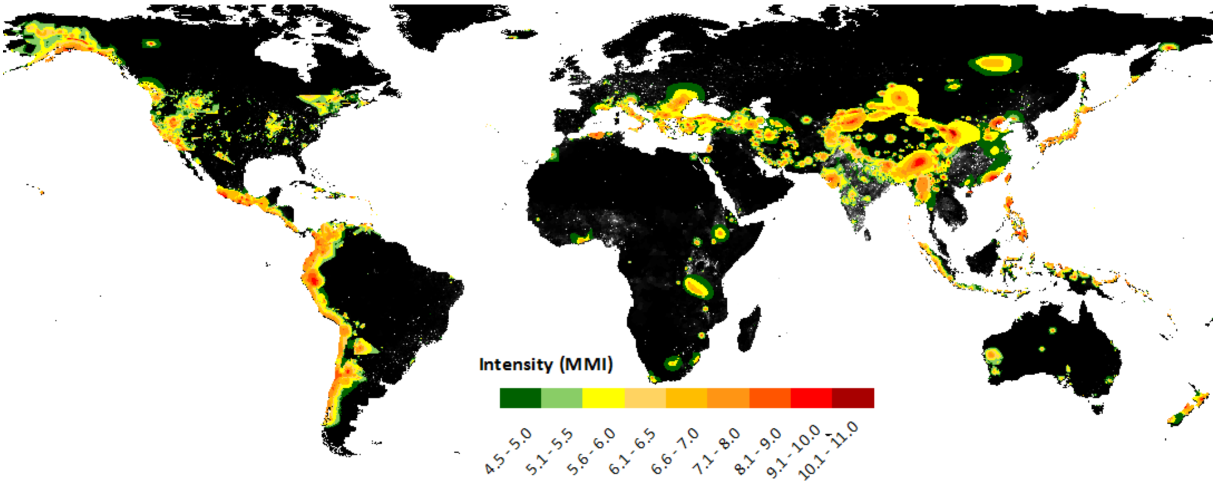


Figure 3: Isoseismal maps created and collected worldwide correlated to damaging earthquakes in the database with an intensity greater than 5 (as portrayed in Aug 2013).

As an example of the analysis procedure, the Indian earthquake shakemaps of USGS were replaced by kriging technique shakemaps produced from the intensity data points, as there was a difference of around 1-2 intensity points in nearly all cases between the USGS intensity maps and those of Martin and Szeliga

(2010), as shown in Figure 4. The residual error shown in the figure is the intensity difference between the kriging technique and the original Shakemap. This was done for other earthquakes, especially in China, South America, Australia and New Zealand where data could be collected from other sources.

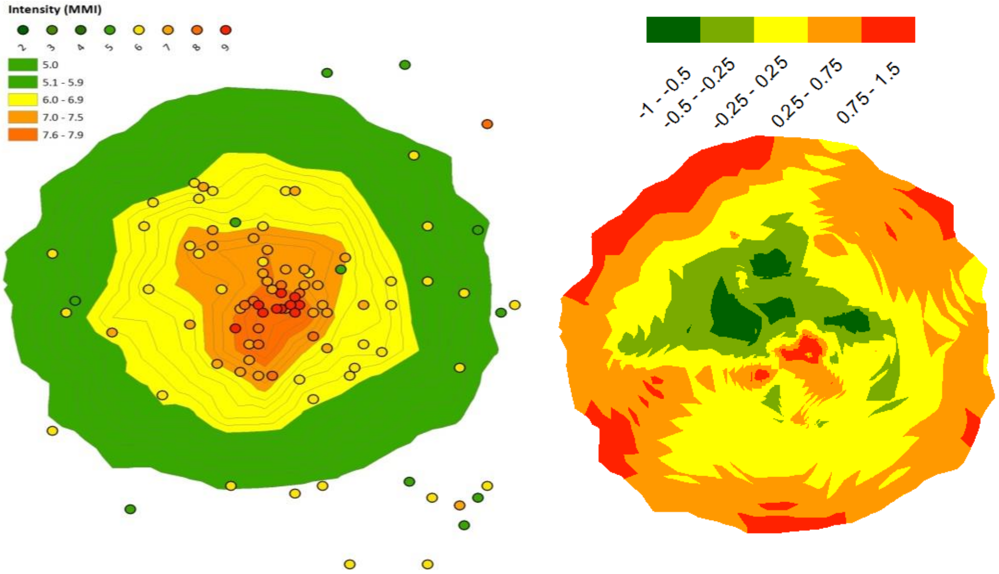


Figure 4: The comparison between the USGS Shakemap (maximum intensity 7.9), and the 1993 Latur earthquake intensities (up to 9) observed via Martin and Szeliga (2010). The residual error is the intensity difference between the kriging technique and the original shakemap.

Where ground motion data is able to be sourced for various events this is also being collected, but is not actively used currently as part of the database.

2.2 Other footprints for disaster types

A number of sources have been used to produce a homogenised footprint catalogue for the disaster events in the catalogue. This is ongoing work and, given the focus on earthquakes in this conference, will not be greatly discussed except to give a brief insight into what is being done in this respect.

Volcanoes have been derived from global databases, and footprint extents of eruptions are often available from national and international sources post-eruption. In Daniell et al. (2011), the GIS database of the volcanic eruptions has been shown. This has since been combined with the work of Leder et al. (2016), in order to derive for each event the locations. The extents of the eruptive matter are, however, not recorded as yet in the database.

For hurricanes, each of the track databases (IBTRACS etc.) have been examined, with best tracks being looked at and attempted to be assigned to each damaging event. These have then been converted to a 2D representation using the wind speed as a proxy. In addition, the work of authors like Kubota and Chan (2009) as well as the Seiga (1934) chronology have been used for Asia. For the Caribbean and Central America, historical damaging events were sourced from local sources as part of World Bank work, and a final database derived and joined. The splits of storm surge, flood and wind for the hurricanes, however, have only been tackled on the losses side and not on the footprints.

For floods, the OFDA databases, although providing some details as to flood heights historically in some sporadic cases, do not provide extents. The work of Brakenridge et al. (2016) from 2000 onwards, and from 1985-2015 as part of the Dartmouth Flood Observatory database, gives over 5000 generalised extents of floods (without the inundation area). NASA for the last 3 years have derived flood extents and MODIS Surface water has been given since the year 2000. The changing nature of global rivers means that the use of water height or flow measurements at various locations often becomes quickly outdated, especially with the use of flood control structures. Databases such as the "Global Maximum Observed Floods" are currently being digitised. In addition, many Chinese floods so far from historic records such as the Yearbooks of Typhoons and Floods have been also collected and digitised.

3 EARTHQUAKE LOSSES

3.1 *Earthquake Fatalities in CATDAT*

The earthquake losses over the past 117 years have been aggregated up to the Amatrice earthquake in Italy in August 2016. When examining the death tolls of all events since 1900, there is a large range associated with the death tolls when looking at the extremes of the fatality estimates globally (Global upper and lower).

If we focus just on the top 100 earthquakes over time, around 2.19 million fatalities are recorded since 1900. Earthquakes have caused over 2.31 million fatalities since 1900 in 2233 fatal events, with many of these coming through large, infrequent events. In fact, since 1900, 58% of these fatalities have occurred in just 10 events. The top 100 events account for 93.23% of fatalities. A list of the top 10 fatal earthquakes since 1900 are included with the approximate breakdown of primary and secondary effects.

Many of these fatalities were as a result of secondary effects like tsunami, fire and landslide, as can be seen in the below table. However, most were due to non-engineered collapse of masonry buildings. A distinction has been attempted to be made, examining the death toll of each event and the various literature values. “Global Upper” and “Global Lower” refer to the highest and lowest estimates found in all literature (removing typos), regardless of whether reasonable or not. “CATDAT Upper” and “CATDAT Lower” refer to the preferred upper and lower bound of all death tolls or economic losses globally, removing implausible results. “CATDAT Preferred” is the median death toll

Table 4: The top 10 fatal events since 1900

Date and Time	**Name**	**CATDAT Pref. Deaths**	**Associated deaths**	**Shaking Deaths**	**CATDAT Upper**	**CAT-DAT Lower**	*Global Upper*	*Global Lower*
16/12/1920 12:05	Haiyuan	**273400**	136700	136700	280000	270000	*273400*	*100000*
27/07/1976 19:42	Tangshan	**242419**	Possibly some due to landslide or fire	242419	250000	240000	*655237*	*240000*
26/12/2004 0:58	Indian Ocean	**228194**	227054	1140	230100	227898	*297248*	*227898*
1/09/1923 2:58	Great Kanto	**105385**	94299	11086	143000	105385	*143000*	*99331*
5/10/1948 20:12	Ashgabad	**100000**	Fire?	100000	122000	48000	*176000*	*10000*
12/05/2008 6:28	Sichuan	**88287**	26486	61801	89000	88000	*88287*	*69165*
8/10/2005 3:50	Kashmir	**87367**	26500	60867	87367	74648	*87367*	*60361*
28/12/1908 4:20	Messina	**85926**	2578	83348	90000	80000	*200000*	*46869*
12/01/2010 21:53	Haiti	**80000**	6	79994	167082	70000	*316000*	*46000*
31/05/1970 20:23	Ancash	**66794**	26717	40077	96794	52000	*100000*	*52000*
	SUM	1357772	540340	817432	1555343	1255931	*2336539*	*951624*

It should be noted that as of v6.34, the value of Ashgabad 1948 has been changed to 100,000 pending a further in-depth analysis. If we now look at all casualty-bearing earthquakes since 1900, there have been 2233 fatal events (range 2195 to 2238 depending on some secondary-effect inducing events). There have been an additional 1398 casualty/injury-bearing earthquakes, which brings the total to 3631 events causing some form of casualty.

Table 5: The summary of earthquake death tolls since 1900 including 1st row: no. of deaths, and 2nd row: no. of fatal events

CATDAT Preferred Deaths	**CATDAT Upper**	**CATDAT Lower**	*Global Upper*	*Global Lower*
2308623	2645324	2136679	4004312	1567374
2233	2233	2225	2238	2195

When removing such fatality estimates that are spurious or otherwise (range of 1.56 million to 4.00

million fatalities), there is a current range in the database of 2.14 million – 2.65 million, with a preferred value of around 2.31 million deaths.

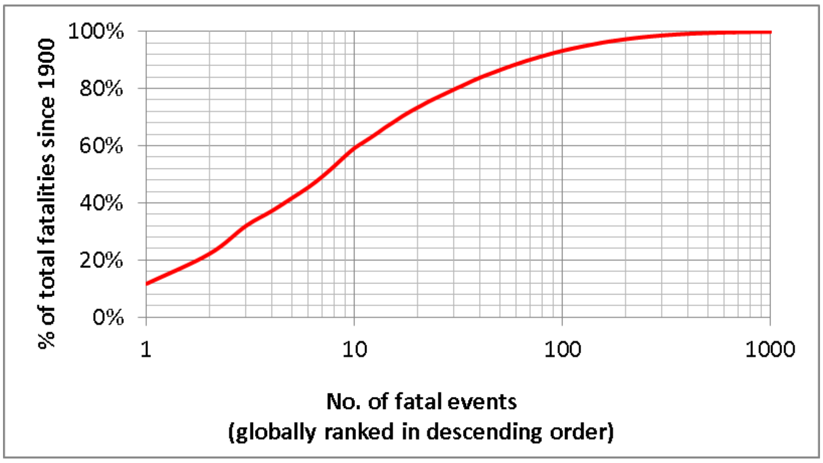


Figure 5: Number of fatal events vs. % of the total fatalities. It can be seen that the top 1000 events cover 99.9% of fatalities. The top 200 cover 97%.

The death tolls from each year as a percentage of worldwide deaths are shown as red points, with a 10 year and cumulative average shown. When compared to the global population, a slightly downward trend is seen but, given the large influence of big events, it is difficult to statistically assign a trend to the series.

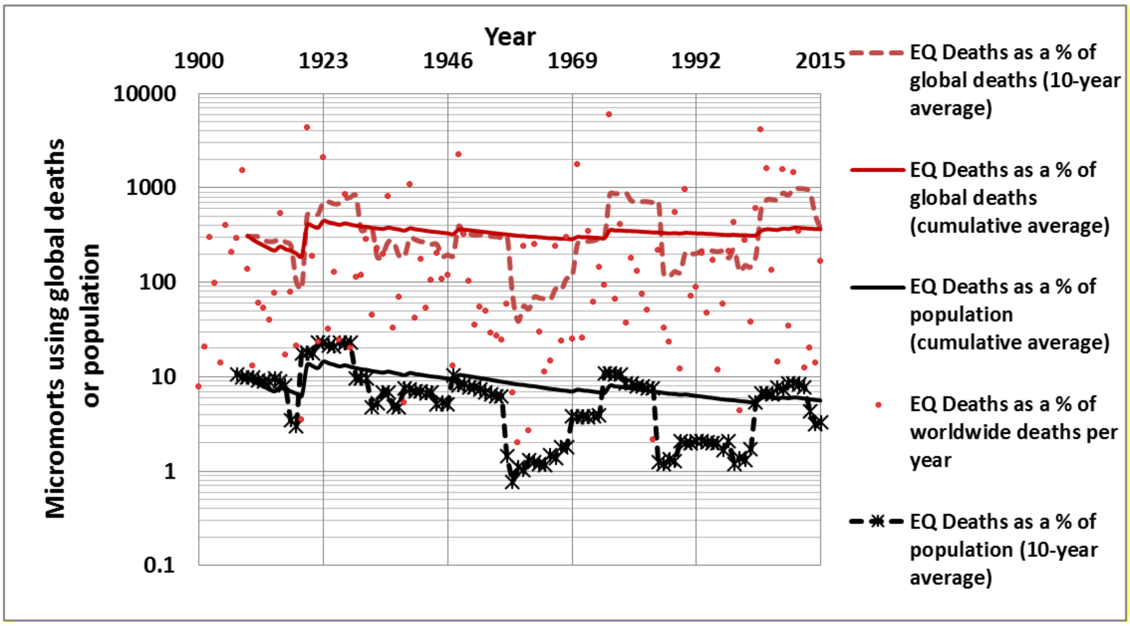


Figure 6: CATDAT Death tolls from 1900-2015 from earthquakes vs. metrics (2.31 million deaths)

Table 6 shows the top 10 events through time, but also the global range and the CATDAT range. Observing data from 1500 to now, the event of the 1556 earthquake with 830,000 deaths is a stand out in terms of deaths from a single event. Many of these were due to collapses from loess caves. The population of the globe at the time was estimated to be around 520 million people, which would result in a total of 0.16% of the global population being killed, and 3.7% of all deaths within the year. The work of Daniell et al. (2016) went into further detail about the fatality curves of each country with respect to some stochastic modelled curves. In Figure 7, the global fatality-return period curve is modelled for all earthquakes from 1500, using a year by year probability (of course using an extreme value distribution would give a very different curve on the upper end). It is important to remember that as we examine death tolls further back to 1500, loss events become increasingly sparse, as only the larger events or events near major population centres are reported.

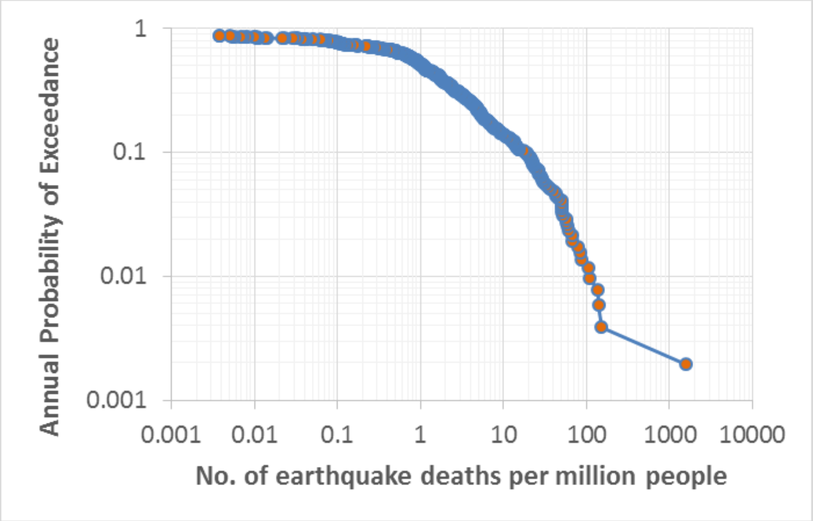


Figure 7: Global F-N curve for earthquake deaths per million people per year built from CATDAT from 1500 onwards.

In contrast, since 1900, no year has recorded over 1% of global deaths due to earthquake. 3 of the top 11 (over 0.2% of global deaths) have occurred in the 1900s, but the 1600s and 1700s also have had 3 of the highest years.

Table 6: The most fatal yearly death rate vs. population from earthquake years since 1500.

Year	Global deaths (mn ppl)	Population (mn ppl)	Earthquake Deaths	% of global deaths
1556	22.4	523	832330	3.72%
1976	48.2	4158	284222	0.59%
1920	63.2	1961	276133	0.44%
2004	55.3	6387	229136	0.41%
1667	28	644	97093	0.35%
1693	29.2	672	93000	0.32%
1721	30.5	717	77555	0.25%
1718	30.2	711	75060	0.25%
1923	55.1	2021	115449	0.21%
1780	35.7	876	73406	0.21%
1668	28	646	56244	0.20%

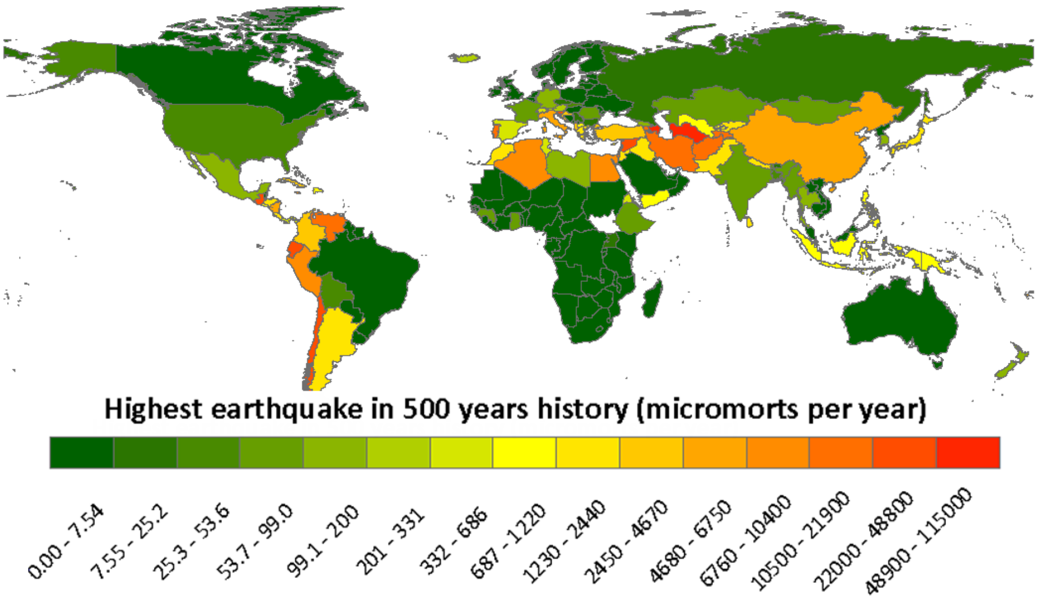


Figure 8: The highest earthquake since 1500 per country in terms of death tolls in terms of micromorts per year/event.

3.2 *Earthquake Losses in CATDAT since 1500*

From 1900 onwards, the costs of earthquakes have been released previously in the AEES and other conferences (see: Daniell et al., 2015; Daniell et al., 2014); thus this will not be dwelled upon in this paper. An updated version of this for the last few years, and taking into account changes, is shown below. The Tohoku event is still (but only just) the highest direct economic loss from an earthquake event. It should be noted that metrics for 2015 and 2016 are still being calculated, given the volatility in the USD and in the GDP deflator for the last 2 years, and thus the 2014 values are presented.

In terms of losses due to earthquake, the year 2016 has had some significant events such as the Kumamoto earthquakes, Ecuador earthquake and Amatrice earthquake. With the Kumamoto earthquake being estimated at around $20-30 billion currently, the total economic cost of earthquakes since 2000 has totalled $920 billion USD in direct losses out of around $3.34 trillion across the perils.

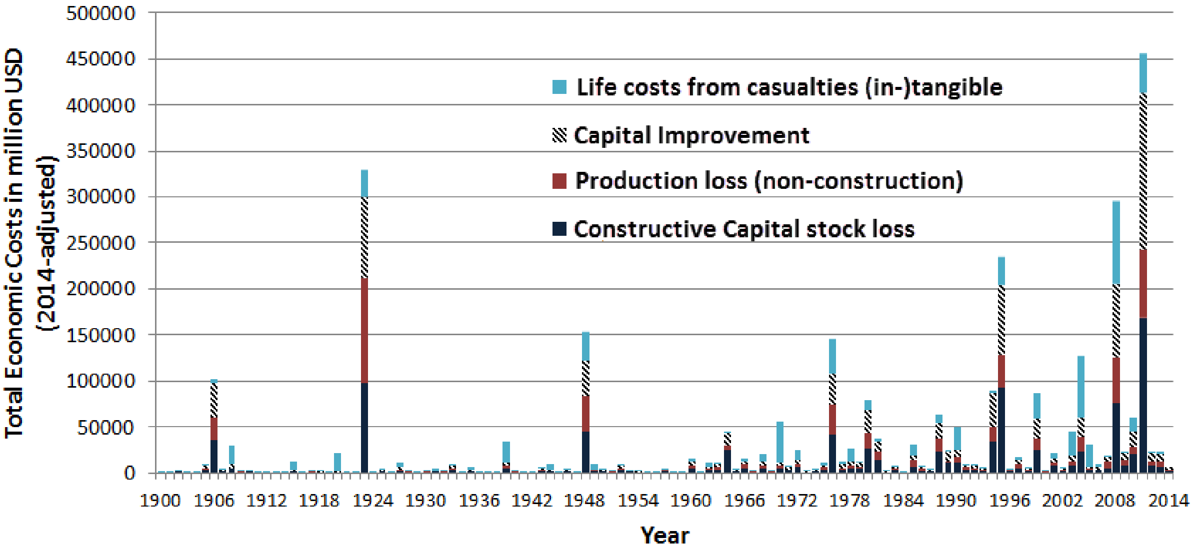


Figure 9: The economic costs of earthquakes from 1900 onwards (Daniell et al., 2015)

The economic costs of earthquakes pre-1900 are notoriously difficult to quantify, as often the details of the economic loss estimates are unclear. Where details exist they are slowly being added into the database. Older currencies such as “scudi” (shields/crowns) were mostly tied to gold or silver standards, making it reasonably easy to translate to pounds of the time. Certain locations such as Europe and the Middle East are well covered through the work of Ambraseys et al. (2009), as well as Italy via Guidoboni and Valensise (2011).

The Chinese earthquakes were recorded as part of the Ming Dynasty disaster relief fund work, measured often in silver taels. i.e. for 1556, at least 42000 silver taels were given in relief. The reconstruction totals are available for some of the 1700 and 1800 events, but are unavailable for many. Similarly, in the old records of Usami (2003) there are some economic estimates, but it is very difficult to glean what the actual impact was.

Estimates from about 1850 onwards are available for most of the US (i.e. 1886 Charleston - $4.7 million reconstruction (USGS, 1986)) and Chilean events; however, there are often great uncertainties in figures. One of example of this may be:-

“El terremoto, los incendios que estallaron a consecuencia del sismo y luego el maremoto dejaron en Arica un saldo de alrededor de trescientos muertes y más de cinco millones y medio de pesos en pérdida. Sólo en la aduana los daños en mercaderías fueron de más de cuatro millones de pesos” (5.5 million pesos damage in Arica due to the earthquake, tsunami and fire; customs losses in the markets (production) were more than 4 million pesos.) (Barriga, 1951) vs. the 1868 value of $25 million+ in 1990 dollars from NGDC…

Often the “reconstruction cost” via the aid of the government gives a good indication as to the possible loss. This was often quoted in news reports, or government budgets. In monarchist countries, often the “donation” by the royal family was compared to the disaster losses.

A more useful or less disputed metric is likely the number of damaged and destroyed houses or housing equivalents (Blong, 2003) for the capital stock losses that were seen in an earthquake. Thus, for the future, a hybrid disaster cost will be given which will use the “building cost” as a metric of the undamaged and damaged housing equivalents. This will be done, as these statistics were often quoted as part of the losses at the time, and figures of destroyed and damaged buildings as a proxy as to the possible loss via reports in local towns or councils were often the only statistics collected.

4 COMPARISON TO OTHER LOSSES

Earthquake losses have been presented in the section above and therefore a comparison of the losses due to earthquake vs. those of the other sources since 1900 is now to be shown. As the database is constantly changing, and definitions of events such as the 1938 flood/dam burst/man-made event are constantly adapting, the losses are in constant movement. In addition to this, the current economic climate means that in order to bring forward losses into the same year dollars, some countries change greatly with respect to their losses relative to other countries.

A good example of this movement is shown with the changes in the last couple of years due to market changes (as well as influencing factors on the markets – political, social, economical etc.).

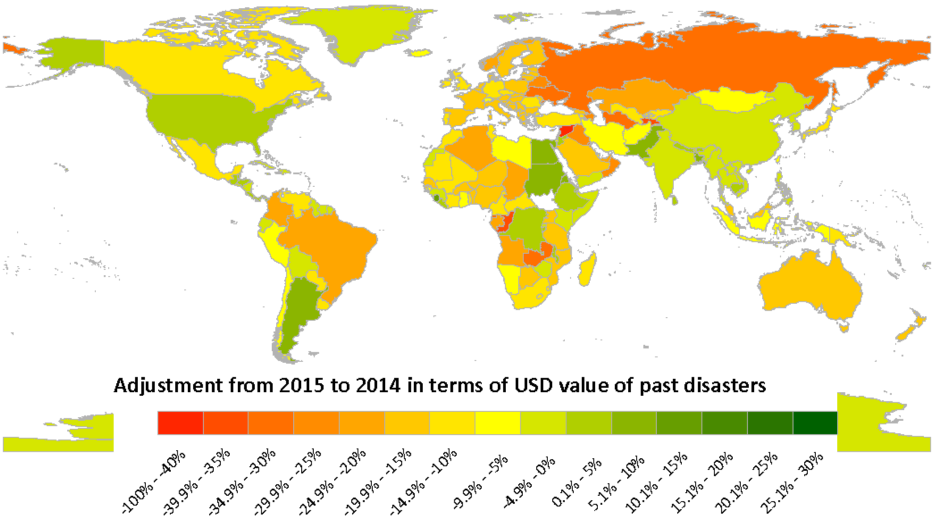


Figure 10: Adjustment of the value of natural disasters from 2015 USD vs. 2014 USD

Over 8 million deaths are shown in the CATDAT database since 1900 for earthquake, flood, storm, volcano and bushfires (without counting deaths due to long term effects or drought/famine).

The number of deaths due to earthquake between 1900 and 2016 from the database is at around 2.32 million. Around 59 percent of the earthquake deaths came as a result of the collapse of masonry buildings, and 28% of them due to secondary effects such as tsunami or landslides. Volcanic eruptions in the same time period have killed only 98,000 people (range: 83,000-107,000). However, volcanic eruptions before 1900, like the Tambora 1815 event, have the possibility to cause massive death tolls and also cause lower temperatures around the world, leading to food security issues (Cole-Dai et al., 2009).

The absolute total of deaths through natural catastrophes has remained reasonably constant, with a slight decrease. Around 50,000 people on average die each year. However, relative to population, death tolls have decreased significantly from 1900-2015.

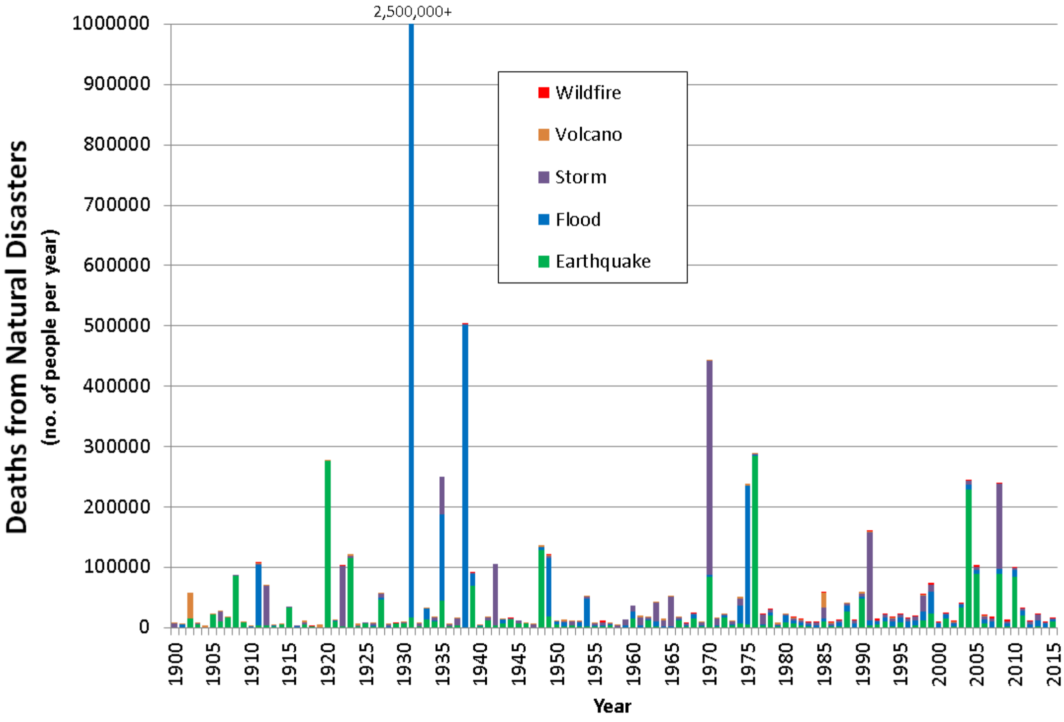


Figure 11: Deaths from all natural disaster types from 1900-2015: NB: 1938 and other years include indirect deaths and/or man-made induced flood events.

Over the entire time period, 40% of the people died due to flood. However, with better planning, warnings and preventive measures, the death rate due to floods is significantly decreasing. Since 1960, earthquakes have caused the highest death percentage, with around 40% of disaster deaths. Compared to the global death rate due to all causes, the rate of deaths due to natural disasters has remained quite constant.

With each event over 100,000 deaths, the 2004 Indian Ocean tsunami (around 230,000) and 2008 Cyclone Nargis (around 140,000) in Myanmar are the largest disasters since the year 2000 in terms of deaths. The event with the highest death toll to date is the Great Floods of 1931 in China, with a mean estimate around 2.5 million deaths.

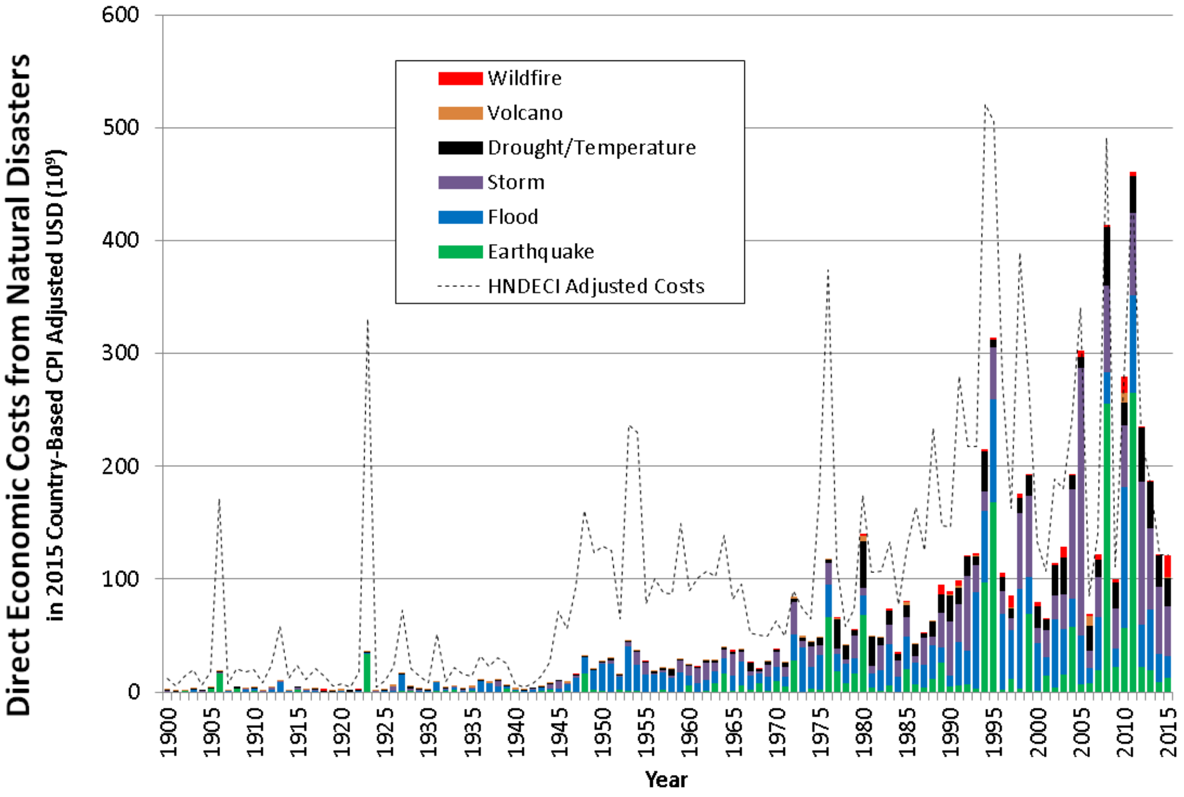


Figure 12: Direct Economic Costs from Natural Disasters (measured in 2015 Country-based CPI USD) from 1900-2015

Around a third to around 40% of economic losses between 1900 and 2015 have been caused via floods. Earthquakes have caused around 26 percent of losses, Storms around 19 percent, and Volcanic eruptions around 1 percent. Over the last 100+ years the economic losses via natural disasters, in absolute terms, have increased. Over the whole time period, floods have caused the highest amount of economic losses; however, in recent times, since 1960, the highest percentage has switched to storm (and storm surge), with around 30% of losses.

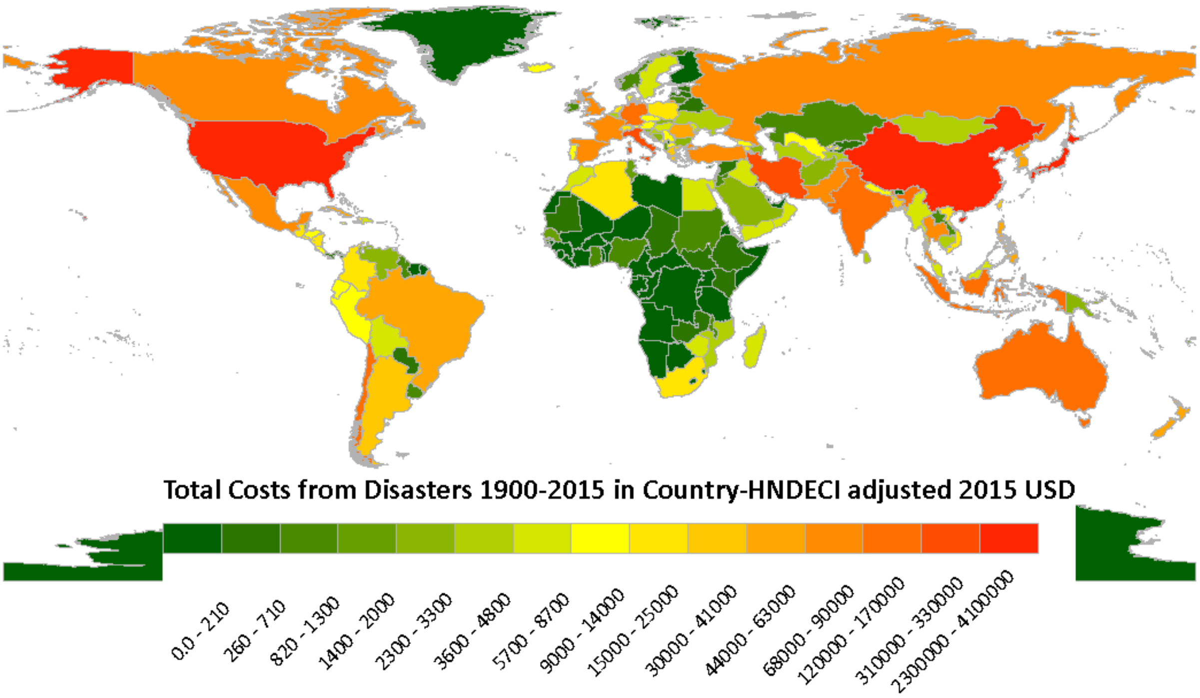


Figure 13: Total aggregated costs from all disaster types from 1900-2015 in country HNDECI adjusted USD (2015)

In relation to the current capital value of infrastructure and buildings in each country, the damage is reducing from natural catastrophes. Less developed nations are often more vulnerable towards catastrophes – i.e. relative to population and capital – and more deaths and higher economic losses are expected post-event. One common reason is the building quality itself in that building regulations and disaster codes, even if present, are often not adhered to. In addition, the locations where people work (like in Bangladesh on the coasts) are economic centres and highly populated due to this, and the financial gains or livelihoods often outweigh the potential disaster risks.

Over the past 7 years, within the studies there have been many socioeconomic indices for the world created and collected in countries and often even in provinces, such as human development, GDP, capital stock, exchange rates, price indices and data on security, building inventory and vulnerability in all countries exposed to disasters. In order to examine the trend of vulnerability over time, the losses have been normalised to the year 2016 by examining the effect of historic events for today's conditions. Here there is a clear trend: that many (but not all) countries are protecting themselves better against disasters by building better, and therefore are reducing their risk of high losses. The improvements in flood protection are the most prominent when looking at the trends, as through the 1900-1960 time period many huge events occurred, but from 1960 onwards, the normalised losses steadily reduce. The most visible reduction is seen in China and Japan.

Depending on the metric used to convert event-year dollars to current 2015 dollars (i.e. consumer price index, building cost index or otherwise), the natural disaster damage bill is between 6.5 and 14 trillion USD. The 7 trillion USD bill is based on a country-by-country GDP-deflator based price index; however, the components of loss from natural disasters often differ significantly in addition to the loss estimate itself. It is often impossible to get one exact value for a disaster event, as economic losses are often difficult to quantify, and death tolls are often overestimated (for example, the Haiti earthquake in 2010), or underestimated (like Uzbekistan in 1966), and therefore provides a lower and upper bound to estimates of each past events from literature.

Looking at the largest economic losses, the year 2011 with major earthquakes in Japan and New Zealand is the highest loss to date. With around 335 billion USD direct damage, the Tohoku earthquake-tsunami-nuclear sequence on 11 March 2011 is the highest single-event natural catastrophe loss. From the earthquake and following tsunami, around 18500 people died and around 450,000 became homeless, Subsequently, an additional 3500 people have died of indirect causes over the past 5 years.

By using the normalisation from 1950-2015 via capital stock, the methodology of which is detailed in the paper of Daniell et al. (2012), it can be seen that there is a significant drop-off in flood losses (mainly explained through better flood management). These losses are mostly associated with China, Japan and the US; but improved flood practices and great investment in prevention and research has led to much reduced losses (if we were not to take the vulnerability change into account). If we were to normalize with vulnerability change due to these improved vulnerabilities, then the events throughout the 1950s and 1960s before major changes would likely be in the order of tens of billions of dollars rather than in the hundreds to thousands of billion dollars.

The normalisation was calculated using the following formula:-

$$\mathrm{NormD}_{2016,loc} = \mathrm{D}_{y,loc} \times \mathrm{CSF}_{y,loc}$$

Where, $\mathrm{CSF}_{y,loc}$ = Capital Stock $\mathrm{Value}_{2016,\ location}$ / Capital Stock $\mathrm{Value}_{year\ of\ event,\ loc.}$

$\mathrm{D}_{y,loc}$ = Event-Year Economic Loss from each historic disaster in CATDAT

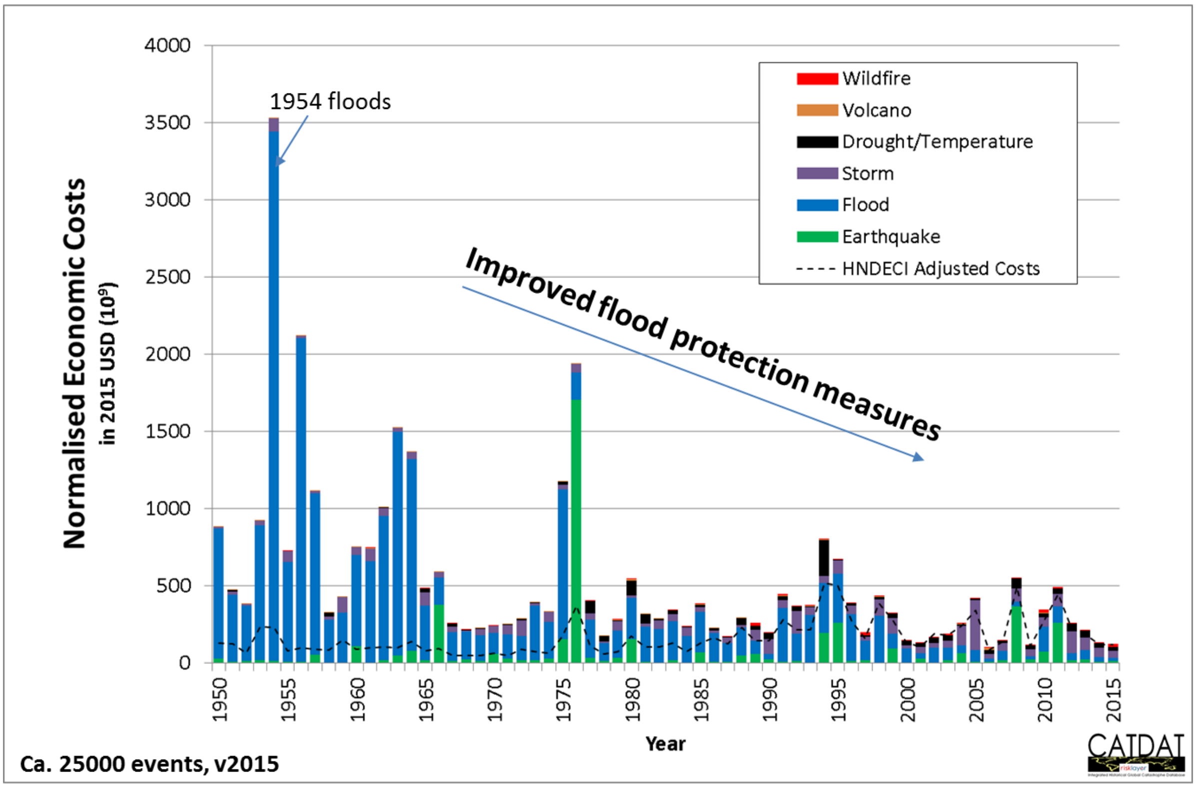


Figure 14: Total normalised costs due to disasters from 1950-2015

5 CONCLUSION

The continued development of the CATDAT Natural Disasters Database has allowed for new trends to be gleaned in terms of disaster losses. It can be seen that relative to the number of global deaths, disaster deaths are staying reasonably constant, but there are improving trends versus population. The economic costs due to natural disasters can be seen to be increasing in absolute terms, whereas relative to capital stock is decreasing. However, of course, this is disaster-specific, with various disaster types showing increasing and decreasing trends in locations around the world.

It is hoped that providing side-by-side metrics of disasters can show in which countries we have increasing risk, and those countries where risk is being mitigated through good practices in building for disasters, as well as effective disaster management. Although in their infancy, the effects of earthquake-resistant codes on building typologies in various countries such as USA, Greece, Turkey, Japan etc. have shown that where a code exists, and is adhered to, in general, there will be lower losses comparatively via these trends. The effect of this change would only be able to be seen by pure normalisation if more earthquake events were available in each country over the time of the seismic code implementation. Flood losses show a much higher impact with the flood control structures employed in various countries showing a significant reduction in the normalised flood losses in some countries. Of course, in countries with little flood management, the opposite trend is seen.

The database continues to be dynamic and the collection of hazard footprints for not only earthquakes, but also for other disaster types continues and will probably be another few years before all major events are covered. Trends will hopefully therefore be able to be created with less and less uncertainty for the period from 1900 to 2016. It has become abundantly clear that completeness is likely globally for damaging events only since 2010 or so; with the reporting via internet showing a massive increase in collected damaging events. Looking at larger events, it is likely that this is only complete since 1900. Thus, the focus will continue on these events since 1900, with only limited focus on events before this. It is hoped that by presenting historic metrics in a simplified online interface (eventually!), decision makers can get the key information of their historic exposure and risk as well as their current and future risks.

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