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EXTREME WEATHER EVENTS AND THEIR CONSEQUENCES

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ABSTRACT: The damage (in real terms after adjusting for inflation) caused by extreme weather events globally has increased dramatically over the past few decades. This is a result of an increase in the amplitude and frequency of weather extremes, as well as of human factors causing a widespread increase in levels of exposure and vulnerability. There are a number of reasons to consider that, in many regions of the globe, weather extremes (e.g. heat waves, droughts, forest fires, intense rainfall, floods and landslides) are becoming both yet more extreme and more frequent. Projections for the future based on climate and impact models point to a further strengthening of this trend. There has already been an increase in rainfall intensity in conditions of a warmer climate, and a continuation of this trend is expected, with adverse consequences for flood risk. However, the development of flood-prone areas and increase in damage potential are often the dominant factors underpinning growing flood damage and flood risk. In warmer climates, an increased risk of river and flash flooding caused by heavy rainfall, as well as an increasing risk of coastal flooding associated with sea level rise can be expected over large areas. By the same token, a reduction in the risk of snowmelt flooding events is projected in the warmer climate. Projections also indicate an increased risk of drought in many areas. The projections for climate change in Poland point to several risks associated with an increase in the frequency, intensity and severity of weather extremes (heat waves, intensive rainfall, flooding and landslides, coastal surges, drought during the growing season and winter, strong winds and pathogens associated with warming). Heat waves will become more frequent, more intense and more troublesome for the ageing population of Poland.

KEY WORDS: weather extremes, climate change impacts, heat waves, floods.

INTRODUCTION

Changes in many extreme weather events have been observed in recent decades. Some of these have been linked to anthropogenic climate change, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in coastal surges and an increase in the number of heavy precipitation events arising in many regions.

Geophysical variables can assume extremely low or extremely high values, but by no means all such occurrences involving the weather prove disastrous, and not all result in losses. For instance, the occurrence of an extremely high temperature by the standards of February (e.g. 20°C) is unlikely to be the direct cause of any dramatic events. However, if vigorous vegetation growth commences for this reason, and this is later interrupted by a severe frost, then damage is likely to ensue. Thus extreme weather events and extreme consequences due to them are clearly two different things, with the latter depending on exposure, damage potential and vulnerability.

Extreme natural phenomena in Poland relate to temperature (very low or very high), fog, strong wind, intense rainfall, flooding, landslides, mudslides, icing, extreme snow cover (or an extreme lack of snow cover), snow avalanches, drought, forest fires, lightning, and seismic phenomena. All but the last phenomena are related to weather.

Nowadays, extreme weather events are reported frequently. For example, in the last two months prior to the submission of this paper, there has been a major flood event in Europe and a record-breaking wild fire in Canada.

In late May and early June 2016, destructive flooding caused by a spell of heavy rain occurred in many European countries (primarily Germany and France, but also Austria, Belgium, Moldova, The Netherlands, Romania, and the UK). There were more than 20 fatalities.

In turn, May 2016 had brought a major wildfire in Canada which started to the southwest of Fort McMurray, Alberta, sweeping through the community, destroying approximately 2 400 homes and buildings, and forcing the largest wildfire evacuation in the history of the province. The fire then spread across northern Alberta and into Saskatchewan, consuming forested areas and impacting on operations in the Athabasca oil sands. This is likely to be become the costliest disaster in Canadian history. Initial insurance payouts are estimated to total as much as CAN$ 9 bn, if the entire affected community has to be rebuilt. This would be a sum 12 times greater than the previous record wild fire disaster affecting Canada (i.e. the 2011 Slave Lake wildfire, which cost approximately CAN$ 750 million). A mandatory evacuation order was issued for the entire locality of Fort McMurray and nearby communities. The climatic background to this event is clear – the fire risk index was very high due to hot and dry antecedent weather. A record temperature for Fort McMurray, of 32.8°C, was reached on 3 May and the relative humidity was of the order of 12%. On 4 May, it was hot and windy, with gusts reaching velocities of 72 km/h serving to enhance rapid growth of the fire. The winter preceding the fires had been drier than usual, and the less-abundant snowpack had melted away rapidly.

TEMPERATURE EXTREMES

Distinct warming took place over almost the entire land and ocean surface of the Earth in the period 1901–2012, with the only exceptions being an area south of Greenland and small areas north of the Gulf of Mexico (IPCC 2013).

In its recent report, the IPCC (2013) stated that it is very likely that the number of cold days and nights has already decreased under the influence of global warming, and that the number of warm days and nights has increased. It is likely that the frequency, intensity and duration of heat waves has increased over large parts of Europe and some other continents, resulting in increases in mortality and morbidity, while impacts vary according to people's age, health status, location and socio-economic factors.

As for the attribution statement, human influence (anthropogenic global warming via an increase in greenhouse gas emissions and land-use and land-cover change) has very likely contributed to the observed global-scale changes in the frequency and intensity of daily temperature extremes, with human influence already likely to have more than doubled the probability of heat waves occurring in some locations. There is a medium level of confidence that the warming observed has increased heat-related human mortality and decreased cold-related human mortality in some regions.

Table 1 shows a list of the twenty warmest years on record, globally, ranked on terms of anomalies (departures of annual global mean temperatures from the long-term average for the reference period 1910–2000). All twenty of the warmest years on record globally are seen to have occurred since 1990.

The aggregation of warmer years in the last few decades is without precedent (Tab. 1). Fifteen out of 16 of the warmest years on record (in 1880–2015) have occurred since 2001. This means that each of the years since 2001 has been warmer by at least 0.54°C than the long-term average for 1910–2000. The three last years are likewise among the four warmest years on record and all four occurred very recently (in 2010, 2013, 2014 and 2015). The annual global mean temperature record for the 20th century (set in 1998) has been beaten four times since 2005 (in 2005, 2010, 2014 and 2015). It is also worth noting that the 2015 record was exceptionally (by 0.16°C) higher than the former record, established in 2014.

A strong El Niño state (as the warm phase of the ENSO or El Niño Southern Oscillation) that evolved in 2015 and can be associated with the global temperature record established in 2015, continued to exert a distinct impact upon global temperature in the first four months of 2016. After NOAA, the combined average temperature over global land and ocean surfaces for each of the first three months of 2016 was the highest in the 137-year period of records (1880–2016). For April, March, February, and January 2016 it was, respectively, at 1.10°C, 1.22°C, 1.21°C, and 1.04°C above the 20th century average for the month. The March record surpassed the previous record for this month set in 2015 by an extraordinarily large value of 0.32°C and represents the highest monthly temperature departure among all 1636 months on record. Overall, as of April 2016, the ten highest monthly temperature departures on record have all occurred in the ten months from July 2015 to April 2016. April 2016 also marks the

12th consecutive month in which a monthly global temperature record has been broken. This has been the longest such streak in 137 years of record keeping (NOAA 2016).

An exceptionally hot summer for Europe was that of 2003. Temperature anomalies in June 2003 in Switzerland exceeded the long-term average by some five standard deviations. Mortality during a heat wave in Paris increased dramatically in comparison with "normal" conditions. Summer 2010 was even warmer, on average, over the whole European continent. Projections indicate that such an exceptionally hot summer as occurred in 2003 or 2010 can become commonplace later in the present century, even looking quite cool by the standards likely to be set towards the end of this century. Both heat waves were indeed devastating. According to Robine *et al.* (2008), the 2003 heat wave may have caused 70 000 deaths in 12 countries in Western Europe. The *Munich Re* Group in turn estimates that the 2010 heat wave affecting the eastern part of the continent could have caused 56 000 deaths. For many decades, no natural disaster in Europe (including earthquake) has caused such a large number of fatalities. Indeed, heat waves are currently Europe's most deadly natural disasters.

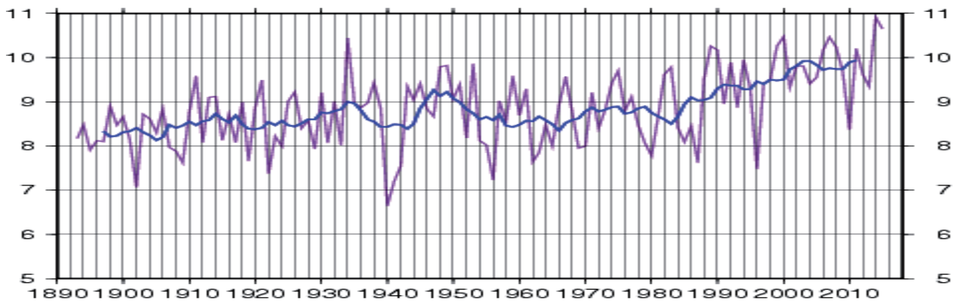
Table 1. List of the twenty warmest years globally based on the observation records available in 1880–2015. Air temperature anomaly is understood as excess of the global annual air temperature for a given year from the long-term average for 1910–2000

Rank	Year	Air temperature anomaly [°C]
1	2015	0.90
2	2014	0.74
3	2010	0.70
4	2013	0.67
5	2005	0.66
6–7	2009	0.63
	1998	0.63
8	2012	0.62
9–11	2006	0.61
	2003	0.61
	2007	0.61
12	2002	0.60
13–14	2004	0.58
	2011	0.58
15–16	2001	0.54
	2008	0.54
17	1997	0.52
18	1995	0.46
19	1999	0.44
20	1990	0.43

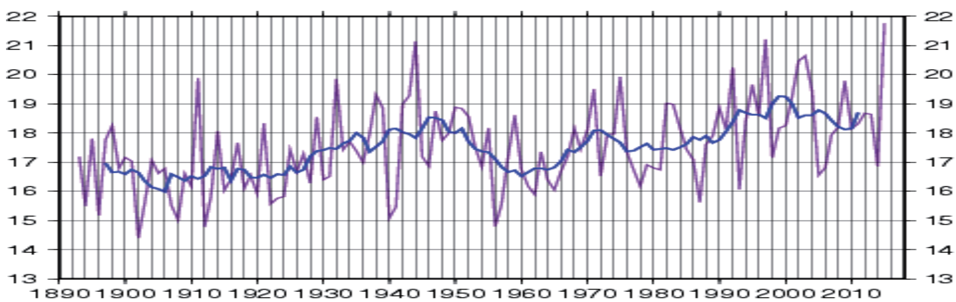
Source: https://www.ncdc.noaa.gov/cag/time-series/global/globe/land_ocean/ytd/1

Increased numbers of fatalities associated with heat waves can also be noted in Poland (cf. Graczyk *et al.* 2016). However, the main weather-related killer in Poland remains frost in winter. Even if warming in winter is leading to a decrease in the numbers of days with frost and ice, people still freeze to death almost *en masse* in Poland (with more than 200 fatalities per winter).

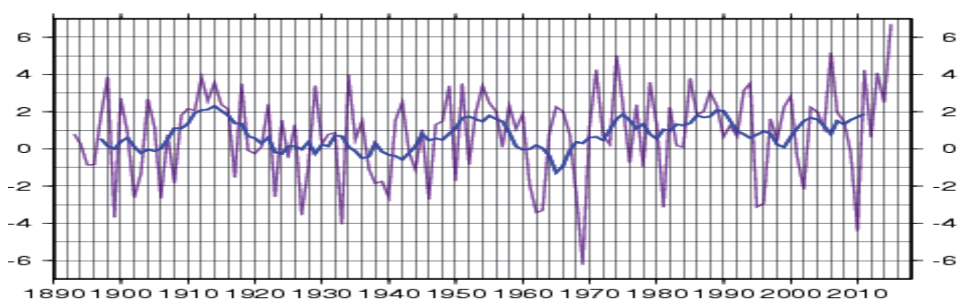
Figure 1 illustrates observed changes for average temperature in the year as a whole, in August, and in December since 1893, in the case of the weather station in Potsdam. This dataset demonstrates that how it was in the whole year 2015 that the highest



(a) Annual air temperature [°C]



(b) Monthly air temperature, August [°C]



(c) Monthly air temperature, December [°C]

Figure 1. Observed changes in average annual and monthly (August and December) temperatures in Potsdam, in the years since 1893, for (a) – annual values, (b) – August, (c) – December (source: www.klima-potsdam.de)

temperature values ever were observed. Likewise, the categories of mean monthly temperature for August and December saw records broken by a large margin in 2015.

WATER-RELATED EXTREMES

It is very likely that global near-surface and tropospheric air specific humidity has increased since the 1970s. According to the Clausius-Clapeyron law, there is more room for water vapour in a warmer atmosphere, hence an increased potential for intensive precipitation. Indeed, data for the frequency and intensity of heavy precipitation events are showing increases in many places. Attribution is possible: anthropogenic forcing has likely contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century (IPCC 2013).

However, there remains only low confidence in the claim that anthropogenic climate change has affected the frequency and magnitude of river floods on a global scale. Here, the situation is less transparent, due to the complexity of the coupled nature of the atmosphere–hydrosphere system. There are several climatic and non-climatic factors influencing floods, hence it remains difficult to attribute detected changes to climate change. However, the recent detection of upward trends for extreme precipitation and discharge in some catchments would imply a greater risk of flooding on a regional scale. In their rigorous attribution study looking at the flood events in England and Wales in autumn 2000, Pall *et al*. (2011) concluded that the probability of severe events occurring has likely increased because of anthropogenic warming. There is no doubt that costs relating to flood damage, worldwide, have been increasing, though this is partly due to the increasing exposure of people and assets (Kundzewicz *et al.* 2014).

Changes in the risk of flooding are known to depend on atmospheric/climatic, hydrological/terrestrial and socio-economic factors. The first group of factors includes such atmospheric/climatic variables as: precipitation, soil moisture and groundwater level, the state of retention of surface and ground water, snow cover, temperature, and sea level). The second group of factors includes such hydrological/terrestrial characteristics as: water level in rivers and lakes, the flow of a given river – its amplitude, frequency of exceedance, seasonality and changes in the land surface related to changes in land use (i.e. decreased retention, increased drainage rate increase, and reduced surface permeability). Finally, the third group of factors includes such socio-economic characteristics as population growth, deforestation or afforestation, urbanization, river regulation, human encroachment in areas at risk of potential losses, adaptation potential and risk awareness.

Compared with rural areas, urban areas are characterized by peak flows corresponding to a given rainfall that arrive faster and reach higher values. Since urban areas have been growing dynamically, the risk of urban flooding in a warmer climate is increasing.

The several recent studies of model-based flood-hazard projections have yielded results cited from Jiménez *et al.* (2014), and drawing from Hirabayashi *et al.* (2013) – see also: Döll *et al.* (2015) as shown in Figure 2. This particular study shows that the flood

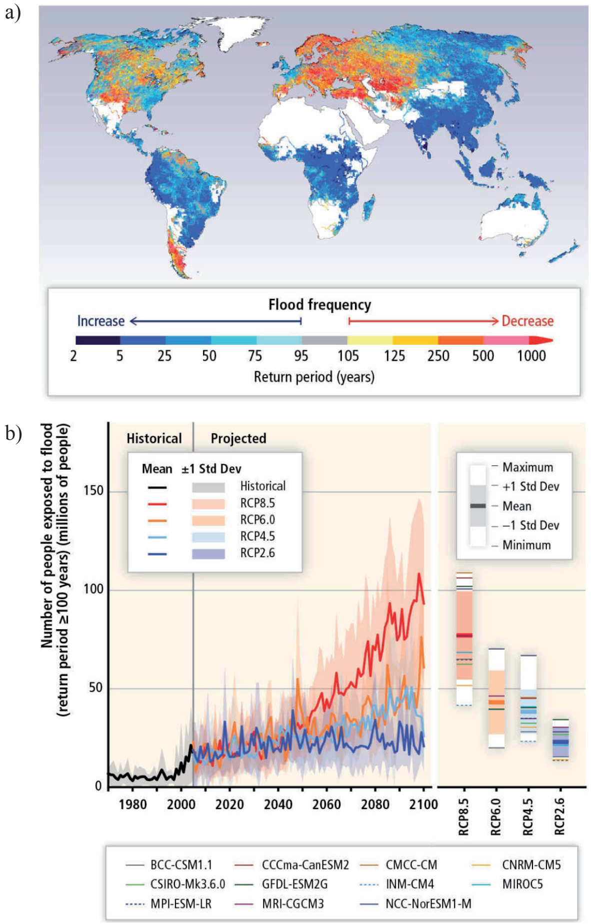


Figure 2. (a) – Multi-model median return period (years) in the 2080s for the 20th century 100-year flood (Hirabayashi *et al.* 2013), based on one hydrological model driven by 11 Coupled Model Intercomparison Project Phase 5 (CMIP5) General Circulation Models (GCMs) under Representative Concentration Pathway 8.5 (RCP8.5). At each location the magnitude of the 100-year flood was estimated by fitting a Gumbel distribution function to time series of simulated annual maximum daily discharge in the 1971–2000 period, with the return period of that flood in 2071–2100 being estimated by fitting the same distribution to discharges simulated for that period. Regions with mean runoff less than 0.01 mm day^{-1}, as well as Antarctica, Greenland, and small islands are excluded from the analysis and indicated in white. (b) – Global exposure to the 20th-century 100-year (or greater) flood in millions of people (Hirabayashi *et al.* 2013). Left: Ensemble means of historical simulation (thick black line) and future simulation (thick colored line) for each scenario. Shading denotes ±1 standard deviation. Right: Maximum and minimum (extent of white), mean (thick colored lines), ± 1 standard deviation (extent of shading), and projections of each GCM (thin colored lines) averaged over the 21st century. The impact of 21st century climate change is emphasized by fixing the population to that of 2005. Annual global flood exposure increases 4–14-fold over the century, as compared with the 20th century (4 ± 3 (RCP2.6), 7 ± 5 (RCP4.5), 7 ± 6 (RCP6.0), and 14 ± 10 (RCP8.5) times, or by 0.1 to 0.4 to 1.2% of the global population in 2005). Under a scenario of moderate population growth (UN 2011), the global number of exposed people is projected to increase by a factor of 7 to 25, depending on the RCP, with strong increases in Asia and Africa due to high population growth. Source: Jiménez *et al.* (2014)

hazard is projected to increase over about half of the globe, but with great variability on the catchment scale. Projections of increased flood hazard are consistent for parts of south and Southeast Asia, tropical Africa, northeast Eurasia, and South America, while decreases are projected in parts of northern and eastern Europe, central Asia, central North America, and southern South America. However, in comparison with other large-scale studies, the work yielding the results in Figure 2 cannot be considered robust. There is, for example, a lack of agreement between regional projections in large-scale studies, see Kundzewicz *et al.* (2017), who discuss and interpret differences in flood hazard projections in Europe, their causes, and the consequences for decisionmaking.

Coastal flooding (of the storm surge kind) has increased, mainly as a consequence of gradual sea level rise.

There is also low confidence underpinning the observed global-scale trends for drought, due to a lack of direct observations, a lack of commonly agreed indices, and geographical inconsistencies as regards trends (IPCC 2013). However, the tragic death due to starvation of some 250 000 people in the Sahel region in the years 1968–1973 shows sensitivity to extensive drought and desertification taking place. Overall, both the frequency and intensity of drought in this region is tending to grow.

WIND AND SNOW

Trend detection is difficult in the case of wind data due to the scarcity of observations. Nevertheless, many strong-wind episodes have been observed recently, leading to severe damage. At times, there are "wet storms", i.e. strong winds – hurricanes, tornadoes, typhoons, with intense precipitation. The two costliest flood events were in fact hurricane/cyclone/typhoon-related floods. The 2005 Katrina event costed over 100 billion USD (adjusted to 2015 USD), while the price tag in the case of the Sandy event of 2012 was 47.5 billion USD (adjusted to 2015 USD) (OECD 2016).

Even if such storms do not occur in Europe, there may also be strong and destructive gusts of wind over the continent. For instance, the Erwin (Gudrun) storm hit Denmark and Sweden on January 8, 2005. The speed of the wind during gusts reached 165 km/h (equivalent to a hurricane, category 1). The number of fatalities in that storm was at least 17, while the losses in forests due to windbreak or windthrow equated to at least 75 000 000 m^3 of wood. As a result, the world's largest supply of wood became available (and had to be managed). The storm deprived about 341 000 homes of electrical power, with approximately 10 000 homes still lacking electricity three weeks later. To further interpret this, it is worth recalling how the heating systems in many houses in Sweden run on electricity.

Strong gusts of wind have also occurred in Poland (and even more so in neighbouring areas of Slovakia), causing massive damage to forests. A rare, deadly, white squall hit Poland's Mazurian Lake District during the summer holiday season, in the early afternoon of 21 August 2007. Wind speeds were of up to 130 km/h, generating wave heights on lakes of up to 3 m. Over 40 yachts and boats capsized as a result, with the associated death toll being 12.

Notwithstanding these examples, the determining of overall trends from the observation records proves difficult. There is low confidence associated with information on changes in tropical cyclone activity, though the intensity of tropical cyclones in the North Atlantic has increased.

Projections remain very uncertain, though poleward shifts of hurricane paths are possible, as well as an increased frequency of occurrence of strong gusts of wind. It is important to note that the link between wind-induced damage and wind speed is strongly nonlinear. However, for orientation purposes, it is sometimes assumed that damage induced by wind is approximately proportional to the wind speed to the power three.

As far as changes in snow cover are concerned, ongoing warming is reducing this, given that winter precipitation is increasingly in the form of rain in many areas, while precipitation in the form of snow occurs less frequently. Among other things, this constitutes a threat to winter sports, especially in resorts at lower altitudes.

However, given that snow can fall at various temperatures, countries like Poland continue to experience falls of snow (if less and less frequently), and these can at times be heavy. In the city of Katowice on January 28, 2006, the roof of the hall used by the International Katowice Fair collapsed under the weight of snow (in the circumstances of an exhibition of post pigeons). The death toll on that occasion was 65.

DISCUSSION AND FINAL REMARKS

As is noted regularly, the occurrence of any specific extreme weather event may not be attributed to climate change. Rather, a different framing is needed, with a demonstration that the probability of a concrete value of a geophysical variable (e.g. one that actually occurred) being exceeded would be significantly different in two cases, i.e. without climate change, or with climate change due to increased atmospheric greenhouse gas concentrations.

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability. Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, an increase in human morbidity and mortality, as well as consequences for human mental health and wellbeing. For countries at all levels of development from least developed to most developed, these impacts are consistent with a significant lack of preparedness for current climate variability.

There has been a dynamic increase in the frequency of occurrence of climate-related disasters (e.g. those exceeding a given damage threshold, inflation-adjusted), as well as the levels of (inflation-adjusted) economic loss that those disasters cause. However, the spatio-temporal variability associated with these indices (including the multi-annual and multi-decadal patterns) remains very marked.

Direct and insured losses ascribable to weather-related disasters have increased substantially on any spatial scale, while in many cases an increased exposure of people and economic assets has been the major cause of long-term increases in economic losses.

The number of fatalities caused by weather disasters is much higher in less-developed countries than in developed countries. In the period 1970–2008, more than 95% of the victims of natural disasters were inhabitants of less-developed countries (IPCC 2012).

The prospect of an increase in the frequency of occurrence and degree of severity of extreme weather events related to climate change must be seen a reason for the utmost concern.

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