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# EXTREME HYDRO-METEOROLOGICAL EVENTS AND THEIR IMPACTS. FROM THE GLOBAL DOWN TO THE REGIONAL SCALE

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**Abstract:** Despite the progress in technology, the risk of weather-related disasters has not been eradicated and never will be. On the global scale, disasters are becoming both more frequent and more destructive, annually causing material losses worth tens of billions of Euros, as well as several thousand fatalities. Furthermore, catastrophic weather events have been the subject of a rapid upward trend, with the value of material damage increasing by an order of magnitude over the last four decades, in inflation-adjusted monetary units. There is now an increasing body of evidence of ongoing planetary climate change (global warming), which has brought about considerable changes where extreme hydro-meteorological events are concerned, and is likely to lead to even more marked changes in the future. Typically, changes in extremes are more pronounced and exert more impact than changes in mean values. Among the extremes on the rise are the number of hot days and tropical nights; the duration and intensity of heatwaves; precipitation intensity (and resulting floods, landslides and mudflows); the frequency, length and severity of droughts; glacier and snow melt; tropical cyclone intensity and sea level and storm surges. In turn, a ubiquitous decrease in cold extremes (number of cool days and nights, and frost days) is projected. Increases in climate extremes associated with climate change are likely to cause physical damage and population displacement, as well as having adverse effects on food production and the availability and quality of fresh water. A discussion of hydro-meteorological extremes and their impacts is therefore provided here in relation to a range of scales, and with the context for adaptation and mitigation also being alluded to.

**Key words:** extreme events; hydrometeorology; climate variability; climate change; climate change impacts

## 1. INTRODUCTION

It is normal that, at times, hydro-meteorological variables such as temperature of air, water or the ground; precipitation intensity or total; soil moisture; river flow; wind velocity; etc. attain extreme values. Such a situation may jeopardize people and their settlements.

Despite the fascinating progress in technology, humankind continues to live with the hazards of extreme hydrometeorological events, which may cause severe human and material damage. The risk of weather-related disasters has not been eradicated and never will be. In fact, on the global scale, disasters are becoming more frequent and more destructive, causing material losses of tens of billions of Euros, as well as several thousand fatalities annually. Catastrophic weather events have been exhibiting a rapid upward trend, increasing by an order of magnitude over the last four decades, when expressed in terms of inflation-adjusted monetary units.

There are several categories of factors that may explain changes in hydro-meteorological hazards, and their impacts. The principal categories of this kind are: (1) changes in the climate and atmospheric system; (2) changes in interactions between the atmosphere, the cryosphere and the oceans; (3) changes in terrestrial systems (e.g. land-cover change: urbanization and deforestation); (4) changes in socio-economic systems (e.g. land-use change, increases exposure and damages potential, changing risk perception). The relative importance of the above factors is site- and event-dependent.

The aim of this paper is to provide a short introduction to different aspects of the interrelationships between global climate changes and extreme meteorological and hydrological events and their impacts on the regional and local scales in Europe. Adaptation and mitigation attempts are also considered, with a special emphasis being put on the so-called “short memory syndrome” where severe extremes are concerned.

## 2. CLIMATE CHANGE AND ITS IMPACTS

There is an increasing body of evidence on the ongoing planetary climate change (global warming) being attributable to human activities and caused by rising emissions of greenhouse gases (carbon dioxide, methane, nitrous oxide, etc) leading to a buildup of the said gases in the atmosphere and consequent enhancement of the greenhouse effect, and causing land-use changes (e.g. deforestation in tropical areas reducing carbon sequestration). The global climate system has been driven out of its stable natural variability mode. As stated in the IPCC Fourth Assessment Report (IPCC, 2007), most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* (with a probability of over 90%) due to the observed increase in anthropogenic greenhouse gas concentrations.

The 1990s are likely to have been the warmest decade and the 20th century increase in temperature is likely to have been the largest occurring in any century over the second Millennium in the Northern Hemisphere (Watson and Core Writing Team, 2001).

Twelve of the thirteen warmest years globally in the 158-year global instrumental temperature observation period occurred in the recent twelve years (see Table 1).

Only one of the last 13 years (1996) did not make it on to the list of the top twelve hottest years. It was the 19th warmest year, still warmer by 0.137°C than the 1961–1990 mean global temperature (cf. Table 1). The year 2007 also belongs to the short list of globally warmest years (rank 8). Future warming will depend on scenarios of socio-economic development and on the mitigation policy (the curbing of greenhouse gas emissions). Projected temperature changes differ regionally, being scenario- and model-specific, with the range of global mean temperature increase for the 2090s horizon being likely from 1.0 to 6.3°C above the control period 1980–1999 (IPCC, 2007).

Beside the temperature change, there have been ongoing changes in other climate-related variables, such as sea level, precipitation (growth in some areas, decrease in other areas of the globe), river discharge, soil moisture, glacier and snow cover extents. Even more marked changes are projected for the future. Projected precipitation changes differ regionally, but are loaded with a high level of uncertainty, being model- and scenario-specific.

Table 1. Ranking of years with highest global mean annual temperature since 1860.

| Ranking of particular years with the highest global mean temperature since 1860 | Year | Deviation from the long-term mean temperature (in the reference period 1961–1990) |
|---|---|---|
| 1 | 1998 | 0.546 |
| 2 | 2005 | 0.482 |
| 3 | 2003 | 0.473 |
| 4 | 2002 | 0.464 |
| 5 | 2004 | 0.447 |
| 6 | 2006 | 0.422 |
| 7 | 2001 | 0.409 |
| 8 | 2007 | 0.403 |
| 9 | 1997 | 0.351 |
| 10 | 1999 | 0.296 |
| 11 | 1995 | 0.275 |
| 12 | 2000 | 0.270 |
| 13 | 1990 | 0.254 |
| 14 | 1991 | 0.212 |
| 15 | 1988 | 0.180 |
| 16 | 1987 | 0.179 |
| 17 | 1983 | 0.177 |
| 18 | 1994 | 0.171 |
| 19 | 1996 | 0.137 |

*Data source:* Jones (2007).

It is important to note that the Arctic system is very sensitive to climate change. Even when account is taken of the fact that the system is not located close to the territory of Poland, climate-cryosphere interactions play an important role in driving climatic changes on the global and European scales. Moreover, traditionally, Polish scientists have been active in studying the Arctic system, and their achievements are visible in the international context.

There are several important (positive) feedback mechanisms in the Polar/Arctic track in the climate system (ACIA, 2005):

- positive albedo feedback; a decrease in snow-cover area, and sea ice extent and a retreat of glaciers affect albedo on the global scale, hence reducing the reflected part of solar radiation and driving warming;
- positive methane feedback; a thawing of permafrost leads to the release of large volumes of methane (a powerful greenhouse gas), these having been previously immobilized in the frozen ground.

In addition, a dynamic response of tidewater glaciers to climatic (and sea) warming is caused by increased melting of their surface. Faster flow of glaciers induced by greater meltwater supply to their beds results in massive calving and faster transfer of ice resting previously on land into the sea. Such processes are responsible for more distinct sea-level rise. Substantial loss of mass due to melting and ice transfer into the sea from the Svalbard glaciers (Jania, 2002) and other Arctic areas has been noted during the last two decades. While global sea rise 2 mm/yr was reported over the 40 years at the end of the last century (Cabanes *et al*, 2001), the contribution due to glaciers was of the order of 0.2–0.4 mm/yr through the whole 20th century (ACIA, 2005). In this respect a special role has been played by the Greenland Ice Sheet—the largest ice mass in the Northern Hemisphere. Recently published studies

(Dowdeswell, 2006; Rignot and Kanagaratnam, 2006; Stearns and Hamilton, 2006) suggest that the ice sheet responds more rapidly to climate warming than previously thought, particularly by way of accelerated flow of several large outlet glaciers draining the southern part of the ice sheet. Extreme acceleration of Greenland ice-mass loss has been noted by the satellite gravity survey for the period April 2002–April 2006. A transfer of 248±36 km$^3$/yr of ice to the sea has been detected, and constitutes an equivalent contribution of 0.5±0.1 mm/yr to global sea-level rise (Velicogna and Wahr, 2006). The level of the contribution is ten times greater than that estimated earlier for the whole Arctic. More intense melting and accelerated glacier flow doubled the mass balance deficit of the Greenland Ice Sheet during the last decade, contributing to global sea-level rise and likely to be subject to intensification. In consequence, low-lying seashore zones will be affected more frequently and widely by storm surges.

In the longer term, a slowdown of thermohaline circulation is likely to partly compensate for further warming (ACIA, 2005). These processes operate in the North Atlantic area and influence the climate of Europe, indirectly stimulating extreme events in remote regions. Such linkages (tele-connections) are a good example of interactions between global warming and regional consequences and, in turn, show how the influence of processes observed in the Arctic on a regional scale risks increases the range of extreme events worldwide.

## 3. EXTREMES AND THEIR IMPACTS—THE GLOBAL SCALE

Ongoing climatic and non-climatic changes have already influenced environmental conditions on a global scale (and more specifically water resources) in a discernible way. Even more marked changes are projected for the future. The most certain impacts of climate change on freshwater systems are due to increases in temperature, sea level and precipitation variability. Where changes in temperature produce changes in the timing of streamflow, climate change effects are generally more marked than in areas in which hydrological regimes are more sensitive to changes in precipitation. There are generally consistent patterns to changes in runoff and water availability, with an increase at higher latitudes and in some wet tropical areas, and a decrease at mid-latitudes and in the dry tropics. Climate change may cause increased summer drying in continental interiors. Semi-arid and arid areas are particularly exposed to the impacts of climate change on freshwater. The area of the Earth's surface with a "very dry" status has been increasing and is projected to increase further. The global water cycle has accelerated, with consequences for extremes. In many areas there has been an increase in intense precipitation which can be translated into an increase in the flood hazard (Kundzewicz *et al.*, 2007).

Global warming has brought about considerable changes in extreme hydro-meteorological events and is likely to lead to even more major changes in the future. As a result, several extremes will become yet more extreme. For instance, many presently dry areas are likely to become drier, while those that are now wet may become wetter. As a rule, changes in extremes are more pronounced and exert more impact than changes in mean levels.

It can be expected that, in the warmer climate of the future, there will be a ubiquitous decrease in cold extremes (number of cool days / nights / frost days). It is projected that many areas will witness increases in extremes as regards the number of hot days and tropical nights; the duration of heatwaves; precipitation intensity; the frequency, length and severity of droughts; glacier and snow melt and tropical cyclone intensity (IPCC, 2007). Non-tropical cyclones and the most intense storms may also increase, while storm tracks may shift more poleward. Impacts on air quality are likely. Stagnation of air masses in the summer may exacerbate air pollution problems (ozone and particulate matter—soot, with cardiac and respiratory hazards), which will accumulate until a cleansing cold front comes.

Any regional increases in climate extremes (storms, floods, cyclones, droughts, etc.) associated with climate change are likely to cause physical damage, population displacement, and adverse effects on the economy of food production, freshwater availability and quality. Growing adverse health effects would include the risks of infectious disease epidemics in developing countries. It is estimated that diarrhoeal diseases attributable to unsafe water and a lack of basic sanitation already cause numerous (nearly 2 million) deaths a year worldwide. The projected increase in the frequency and severity of droughts would exacerbate the situation and exert an adverse impact on human health.

The consequences of globalization should be appreciated. As a result of the global village effect, the number of Swedish citizens (mostly Christmas tourists) killed by the tsunami disaster of December 2004 in the Indian Ocean coasts greatly exceeded the number of fatalities caused by all the natural disasters within Sweden over many decades. Polish citizens were likewise among the fatalities caused by the forest fires during the droughts in France in 2003 and in Greece in 2007.

## 4. EUROPEAN, REGIONAL AND SUB-REGIONAL SCALES

Europe has warmed up considerably, especially in the last few decades, and further, stronger, warming is projected for the future by climate models. The European Commission's perspective is focused on the juxtaposition of two scenarios: a controlled (around 2°C) warming by 2100 if global mitigation policy becomes effective, and a very much stronger (possibly 5°C) warming, if a business-as-usual approach prevails and atmospheric concentrations of greenhouse gases keep growing without effective mitigation.

Long-term precipitation trends have also been observed, and are projected for the future, in many regions of Europe. Mean annual precipitation is likely to decrease over much of Europe (in particular, over Southern and Central Europe). In much of Southern Europe, a joint effect of temperature rise and a decline in precipitation is foreseen for the summer. Global warming contributes to heat stress and more drying (evaporative demand), exacerbating water stress. The risk of drought increases substantially in summer, along with the risk of wildfires.

Mean annual precipitation is likely to increase in northern Europe. However, the intensity of rainfall events is projected to increase even in regions in which the mean annual precipitation is likely to decrease (cf. Kundzewicz *et al.*, 2006).

Extremely heavy and/or long-lasting rainfall events cause geomorphic hazards such as landslides and mud-debris flows in the mountains. The geological structure and lithological composition of the Polish Carpathians are favorable for development of landslides. More than 95% of all registered landslides in Poland are located in the Flysch Carpathians and, statistically, they are as dense as one form per 1 km$^2$. While the majority of landslides in the Carpathians occurred during the Pleistocene, the Late Glacial and the early and middle Holocene (Alexandrowicz, 1977; Margielewski, 2001), a reactivation of many of them and a creation of new forms during the last decade have been observed. Deforestation of mountain slopes and their cultivation (in cereal- and potato-growing) created favourable conditions for water infiltration into slope-cover, mantle and bedrock. Due to an increase in the number of extreme rainfall events, a rejuvenation of older forms and occurrence of new landslides has been observed since 1996 (Rączkowski and Mrozek, 2002, Starkel, 2006). Large proportions of the landslide events are associated with regional and local flood events in the area, like those in 1997, 2000, 2001, 2002 and 2005.

One of the most catastrophic landslides affected an area of 15 ha in Lachowice village in the Beskid Makowski range. Rapid displacement of slope-cover masses destroyed 14 buildings and a road during just

15 minutes on 27 July 2001. The eastern part of this landslide was reactivated again a year later and additional 4 buildings were affected then. Damage caused to buildings and roads by landslides in Małopolskie Voivodship had a value in excess of 173 million PLN (43 million Euro) in the years 2000–2001. Extremely heavy rainfall in summer 2002 again activated many landslide forms, though it concentrated its downpour in the town of Muszyna and its surroundings, causing large mud and debris flows. These damaged up to 100 buildings there (Bejgier-Kowalska, 2005).

It is worth stressing here that a large part of the material damage caused by slope mass movements in the Flysch Carpathians is co-induced by the location of new, larger and heavier brick and concrete buildings on old landslide slopes. Excavations on slopes for constructional purposes and their undercutting near the valley floor as the construction or modernization of roads takes place destabilize the slopes. Particular landslides and mudflows are damaging phenomena of relatively limited extent in comparison with floods. Nevertheless, their density in the Carpathians shows the importance of severe local events whose frequency grows with global climate change and the more frequent occurrence of extreme rainfall.

Warming leads to changes in the seasonality of river discharge in catchments in which much winter precipitation falls as snow (e.g. in the Alps). Winter flows increase, while snowmelt occurs faster and earlier (with peak flows coming earlier). There is less snow pack in spring and less soil moisture in summer, and summer and autumn flows decrease. The ongoing reduction of European glaciers will lead to gradual longer-term decreases in the contribution glaciers make to river discharge (with the possibility of a river flow increase in the short term, including flooding due to rapid melt). Similar phenomena have been observed in the majority of glacierized high mountains over the Northern Hemisphere. As decreasing groundwater recharge is projected over many areas, also in already water-stressed regions, the possibility of offsetting declining surface water availability due to increasing precipitation variability may not prove a practical one. Sea-level rise will extend areas of salinization of groundwater and estuaries, resulting in a decrease in the availability of fresh water for both people and ecosystems (Kundzewicz *et al.*, 2007). In many places, winter precipitation is increasingly likely to fall as rain, rather than snow. This may jeopardize winter sports, especially in lower skiing domains.

In much of Europe, occurrences of very wet winters and of intense rainfall events will become more frequent, with likely consequences as regards flood risk. Increasing temperature and variability of runoff are likely to lead to adverse changes in water quality (turbidity increases, algal blooms, mobilizing and washing away of pollutants, favouring of pathogens, and thermal pollution).

Very severe material flood damage (above 20 billion Euros in value) was noted on the European continent in 2002, considerably exceeding records for any single year before. The floods in Central Europe in August 2002 alone (on the rivers Danube, Labe/Elbe and their tributaries) caused damage exceeding 15 billion Euros in value. Only a year later, the summer (June to mid-August period) of 2003 brought a disastrous heatwave and drought across large parts of Europe, with temperatures exceeding the averages even by 3–5°C and annual precipitation deficits of up to 300 mm, with the result being an estimated reduction of 30% over Europe in gross primary production of terrestrial ecosystems (Ciais *et al.*, 2005). The hot and dry conditions led to many very large wildfires. Many major rivers (in particular in southern Europe) were at record low levels, resulting in a disruption of irrigation and a cooling of power plants.

The 2003 European heatwave killed tens of thousands of people (Koppe *et al.*, 2004), showing that even developed countries may not be adequately prepared to cope with extreme heat. Such extreme events are usually amplified in large urban areas due to the heat-island effect (caused by heat absorption in asphalt, concrete and building roof surfaces). Heatwaves in Poland are not yet perceived as a major disaster in the public health perspective, yet one can expect that they will increasingly become a hazard in conditions of a warming climate combined with an ageing society. Systematic studies on the influence of heat waves on the health of the urban dwellers in Poland have been initiated (e.g. Kuchcik, 2003). Summer 2006 in Poland was warmer than that of 2003 (when temperature records were broken in much of Europe) and in much of Poland, July 2006 was the warmest month in the history of observations.

Severe heatwaves in the Mediterranean region and SE Europe, often with temperatures exceeding 40°C, occurred during the summer of 2007. Usually, at least one serious heatwave occurs in Greece each summer (typically in August). However, in 2007, three such heatwaves struck the Balkan area, causing at least 700 additional deaths. Hungarian medical officials reported up to 500 heat-related fatalities across Hungary in the second half of July 2007.

Drought and heat frequently go together with wildfires, and these occurred in many places in south-eastern Europe in the summer of 2007 (Fig. 1). In Greece alone, over 3,000 wildfires were registered, causing damage to forests, pastures and farmland, and producing a loss of up to 80 lives. At least 10,000 farms were destroyed or seriously damaged. Thousands of villagers were left homeless. Fire and smoke endangered settlements and summer holiday resorts in Greece, Bulgaria, Albania and even France. Greek citizens and foreign visitors questioned the state's ability to cope with extremes. Summer months—usually a time for leisure for tourists—became a period of horror and traumatic experience.

Severe summer droughts have occurred a number of times in Poland in the last decades (e.g. in 1992 and 2006), often accompanied by violent wildfires claiming human lives.

The occurrence of a heatwave as extreme as that of summer 2003 over much of Europe would be unlikely in the absence of anthropogenic climate change (IPCC, 2007). However, an individual extreme event, such as an extreme flood or a heatwave, can never be directly attributed to climate change. What it is fair to state is that the probability of such an extreme event of a given intensity (magnitude) is likely to increase in the future. Hence, the excess deaths caused by a heatwave can be linked indirectly with climate change. An increase in the frequency or intensity of heatwaves in the future warming climate will increase the risk of mortality and morbidity, particularly in older age groups (sick people, lonely people), and among the urban poor.

Gales, the disasters causing the largest insured material damage, play havoc with northern and western Europe, at times combining with coastal flooding. The storm of 8 January 2005 blew down 75 million m$^3$ of trees in southern Sweden, breaking the all-time record. In Sweden, nearly 350,000 homes lost power and the problems persisted over a longer time, as about 10,000 homes were still without power after three weeks (Wikipedia, 2006). The death toll in Scandinavia was at least 17. Only a few days later, there was another gale across the north of the British Isles, with windspeeds of up to nearly 200 km/h, attendant fatalities and major socio-economic disruption (disrupted power supply, paralysed transport).

Gales in Poland are less frequent. However, gradual sea-level rise with superimposed storm surges is projected to cause more frequent inundations in the area of the Baltic mouths of Polish rivers. Following the beginning of the verified observation series in 1950/51, the probability of storm-surge flooding about doubled towards the end of the 20th century (Sztobryn *et al.*, 2005).

Sea-level rise and storminess are very important for the erosion of coasts and potential damage to the near-shore infrastructure. Displacements of the Polish shoreline measured in the period 1875–1979 show erosion along almost the complete length, except in the Gulf of Gdańsk segment. More intense erosion is predicted for the entire Polish

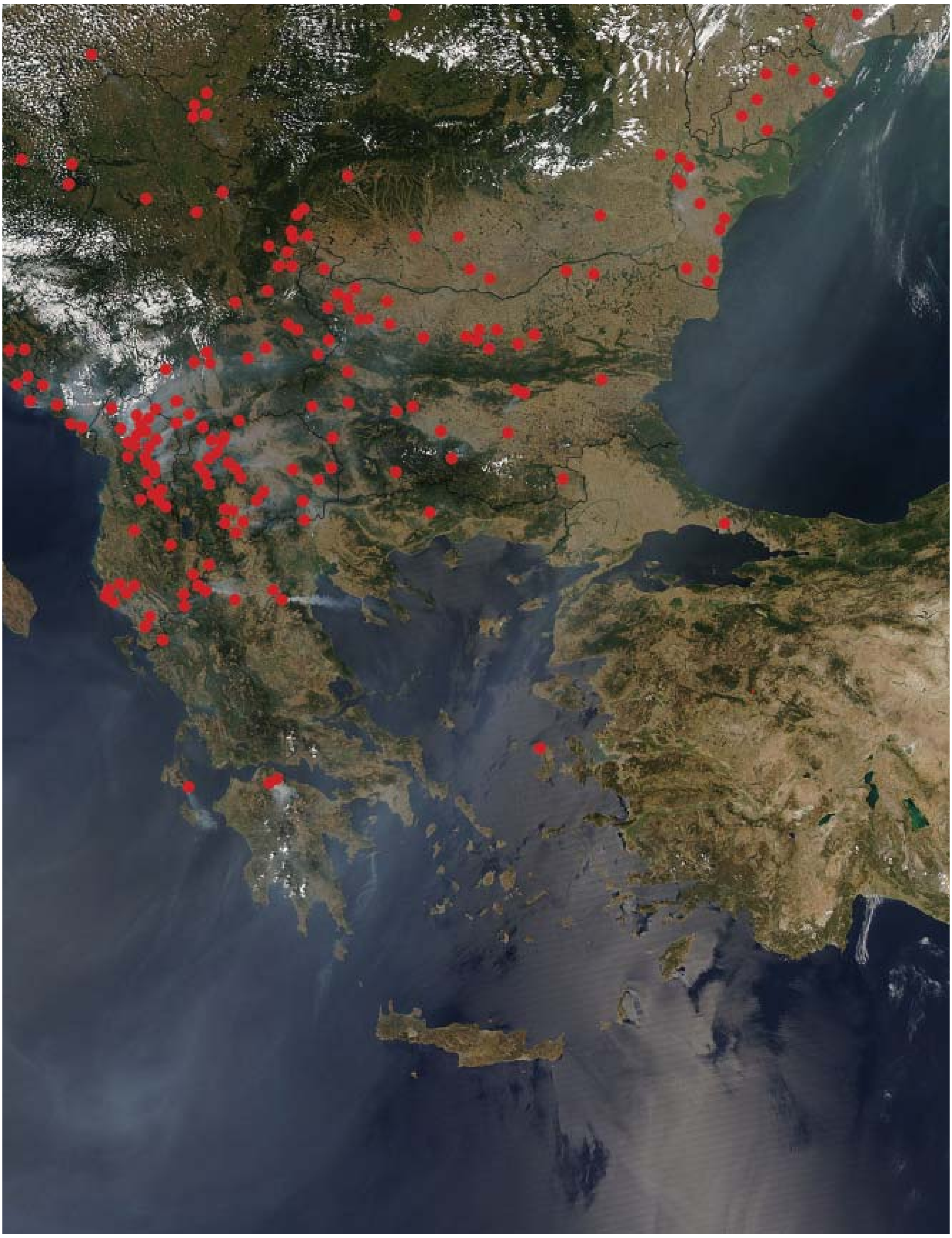

Figure 1. Wildfires (red dots) in the Southern Balkan region recorded on the MODIS satellite image taken on 25 July 2007 (© NASA, Visible Earth).

Table 2. Erosion risk on the Baltic coast of Poland and its prediction to 2050

|  | Distance along the coast[1] | Erosion rate in the period 1875–1979 (sea level rise by 2 mm/yr) |  | Prediction to 2050 (expected sea level rise by 6 mm/yr) |  |
|---|---|---|---|---|---|
| Regions and sub-regions of the coast | (km) | Rate of shoreline position change[2] m/yr | Erosion vulnerability classes | Rate of shoreline position change m/yr | Erosion vulnerability classes |
| Gulf of Gdańsk |  |  |  |  |  |
| Vistula Lagoon bar | 0.0–29.0 | +0.15 | low | -0.12 | low |
| Wisła Przekop–Władysławowo | 48.5–124.0 | +0.11 | low | -0.08 | low |
| Hel Peninsula |  |  |  |  |  |
| Gulfward shore | H36.0–71.5 | -0.21 | low | -0.30 | medium |
| Open sea shore | H0.0–36.0 | -0.46 | medium | -0.64 | medium |
| Open sea |  |  |  |  |  |
| Karwieńska bar | 134–144 | -0.42 | medium | -0.59 | medium |
| Piaśnica–Sarbsko Lake bar | 149–181.5 | -0.66 | medium | -0.93 | medium |
| Sarbsko Lake bar–Gardno Lake bar | 181.5–216 | -0.91 | medium | -1.27 | high |
| Rowy–Ustka | 217–233 | -1.33 | high | -1.86 | high |
| Ustka W–Wicko Lake bar–Kopań Lake bar–Darłowo | 233–270 | -0.37 | medium | -0.52 | medium |
| Bukowo Lake bar–Jamno Lake bar | 278–300 | -0.42 | medium | -0.59 | medium |
| Ustronie Morskie–Dźwirzyno | 319–345 | -0.45 | medium | -0.63 | medium |
| Mrzeżyno–Dziwnów | 352–386 | -0.38 | medium | -0.53 | medium |
| Wolin cliff–Pomorska Bay | 401–424 | -0.47 | medium | -0.66 | medium |

[1] beginning at the Polish-Russian border (except for the Hel Peninsula)

[2] max. values for shoreline length segments ≥ 2 km

(after Dubrawski and Zawadzka-Kahlau, 2006)

coast in future (Table 2), as a consequence of more rapid further sea-level rise.

Shore erosion, as a consequence of more frequent winter storm surges along the Polish coast, results in the shrinking of the beautiful sandy beaches available for tourists. Therefore, this process could slowly affect the attractiveness of the Baltic beaches in Poland, counteracting the positive effect of increasing temperature.

Despite the warming climate, the main killer among hydro-meteorological events in Poland remains the cold snap in winter, during which many people (some of them homeless and drunk) freeze to death. According to data assembled by CRED (2006), the 2005/6 winter killed 233, while the 2001/2 winter killed 270 people in Poland.

Fewer fatalities but far greater material damage in Poland have resulted from floods. The 1997 flood was indeed an extreme event. Four issues of the principal and most influential weekly magazine POLITYKA had flood-related cover stories (Fig. 2). Such media attention has been without precedent in Polish history. This illustrates the severity of impact of the 1997 flood (55 fatalities, 162,500 affected people and over $ 4 billion in material damage). The floods in 1998, 2001, 2002 and 2005 also caused fatalities and affected thousands of people.

## 5. WHAT CAN BE DONE? ADAPTATION AND MITIGATION

A working definition of adaptation based on the one accepted in the IPCC process is: adjustment in natural or human systems in response to actual or expected changes,

Figure 2. The July 1997 flood attracted massive media interest.

which moderates harm or exploits beneficial opportunities. The taxonomy of adaptation distinguishes classification into adaptation types (dichotomies), such as: anticipatory (proactive; adaptation to ongoing changes) or reactive (to projected changes); autonomous (spontaneous) or planned; private / public, etc.

The capacity to adapt varies greatly across regions, societies and gender and income groups (differences reflecting a number of factors, such as wealth, housing quality and location, level of education, mobility etc.). Enhanced adaptability is needed, i.e. an increase in the system's coping capacity and coping range (cf. Kundzewicz, 2007).

There can be limits to adaptation (physical, economic, socio-political, or institutional). Barriers to adaptation to floods via relocation can be external, reflecting e.g. a lack of land for relocation, as in Bangladesh; or internal, including an unwillingness on the part of people to relocate (Kundzewicz *et al.*, 2007).

Both mitigation of (the causes of) climate change and adaptation to (the effects of) climate change are needed to avert or reduce adverse impacts. Adaptation strategies can reduce vulnerability to changes in climate at the local and regional levels. Mitigation acts at a global level over longer time scales due to the inertia of the climate system, slowing the rate of climate change and thus delaying the occurrence of impact and its magnitude. Most of the benefits of mitigation will not be obtained until several decades later, thus adaptation is needed to address near-future impacts. However, without mitigation, the increasing magnitude of climate change will significantly diminish the effectiveness of adaptation.

Mitigation of climate change and adaptation to climate change and its impacts are sometimes in conflict. For instance, desalination serves adaptation, but requires a high energy input, hence adversely affecting mitigation—it drives the atmospheric greenhouse gas concentration and warming. Afforestation serves mitigation (carbon sequestration) but may play an adverse role where adaptation in some regions is concerned (due to transpiration of large amounts of increasingly precious water). Enhancing water storage in reservoirs brings co-benefits, being advantageous for both mitigation (hydropower without fossil-fuel burning) and adaptation (weakening hydrological extremes—floods and droughts), cf. Kundzewicz *et al.* (2007). Yet it may also have considerable disadvantages (barriers to fish migration, resettlement, etc).

In general, Europe has a high adaptation potential in socio-economic terms, due to its strong economies, high GDPs, stable growth, moderate changes in numbers of inhabitants, well-trained population with a capacity to migrate within the supranational organism of the European Union, and well-developed political, institutional and technological support systems. However, adaptation is generally limited in the cases of the natural systems. Equity issues also arise, since the more marginal and less wealthy areas (and groups of people within them) are less able to adapt (Kundzewicz *et al.*, 2007).

Many adaptation options address water-related problems exacerbated by climate change, in particular the increasing variability of water resources, i.e. increased frequency of occurrence of situations in which there is too little or too much water. Adaptation options for the former situation (too little water—water stress or drought) address (enhance) water supply by way of such measures as:

- the conjunctive use of surface water and groundwater;
- increased storage capacity for surface water, groundwater, and rain water;
- water transfer;
- the desalination of sea water;
- the removing of invasive non-native vegetation,

In turn, water demand may be addressed (reduced) by:

- improving the efficiency of agricultural water use (e.g. “more crop per drop”); in particular—irrigation;
- soil moisture conservation, e.g. through mulching;
- recycling water (e.g. the re-use of waste water after treatment);
- water-demand management through metering;
- promoting water-saving technologies;
- leak reduction;
- market-based instruments, e.g. water pricing;
- the re-allocation of water to high-value uses;
- awareness raising.

Adaptation to the latter situation (too much water; intense precipitation, flooding, landslides, erosion) addresses options aimed at reducing the load:

- enhanced implementation of structural/technical protection measures, such as dikes, relief channels, enhanced water storage;
- watershed management (“keeping water where it falls” and reducing surface runoff and erosion).

Resistance may in turn be increased by:

- flood forecasting and warning;
- regulation through planning, legislation, and zoning;
- flood insurance;
- the relocation of populations living in flood-risk areas;
- flood proofing on location;
- flood plain protection measures.

There are several adaptation strategies when it comes to coping with floods, these being labeled as: protect, accommodate, or retreat (relocate), cf. Kundzewicz (2007). Strategies for flood protection and management may modify either flood waters, or susceptibility to flood damage and the impact of flooding. The EU Floods Directive (Commission of European Communities, 2006) obliges EU Member Countries to prepare preliminary flood risk assessment (“taking into account long-term development including climate change”), and to develop flood risk maps and flood management plans. In some countries, such as the Netherlands and the UK, flood design values have been increased, based on early climate-change impact scenarios. In The Netherlands, measures to cope with an increase in design discharge from the Rhine from 15,000 to 16,000 $m^3/s$ must be implemented by 2015, and it is planned that design discharge be increased to 18,000 $m^3/s$ in the longer term, in order to maintain a high level of protection, including under conditions of climate change.

However, dedicated and consequent long-term disaster preparedness efforts are jeopardized by a prolonged absence of disaster. This effect can be called a short-memory syndrome. In hydrology, the vicious circle illustrated in Fig. 3 is sometimes called a hydro-illogical cycle. In many countries, the average time to the next large disaster is much longer than the duration of terms of office of elected authorities. Since a large hydrometeorological emergency is not very likely to happen during the short terms of office, the attention of decisionmakers is focused on more immediate, more burning (and more certain) needs.

Many potential current adaptations are consistent with the principle of sustainable development; that is, they can protect against both climate variability now and future climate change (this refers in particular to “no-regret” strategies—doing things that make sense anyway. It is always good to save energy and water). Improved adaptation to current climate variability would render societies better prepared to future climate change.

## 6. CONCLUDING REMARKS

Extreme meteorological and hydrological events affect human life and the environment on different spatial scales. As demonstrated in the paper, a majority of the extreme events have a direct effect locally (e.g. gales, storm surges, rain-induced local flooding, landslides and mudflows). Some extremes like heatwaves, droughts and major floods have impacts on a regional scale. Only ocean level rise and its consequences can be directly observed globally. Our knowledge of climate and environmental change on the global scale is based on millions of measurements made at particular locations, and observations of extreme events and their consequences on local and regional scales (Fig. 4). Extreme meteorological and hydrological

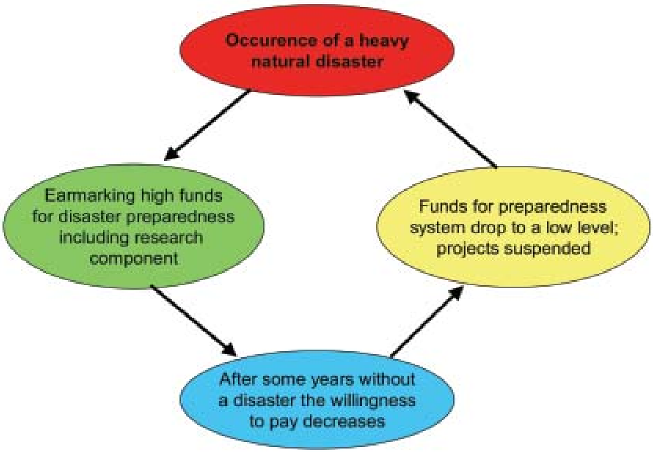

Figure 3. Illustration of the short memory syndrome related to natural disasters.

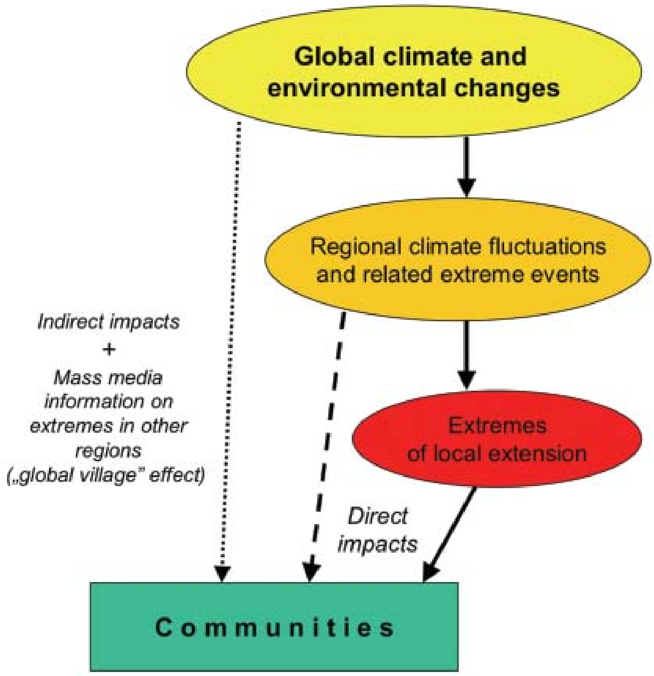

Figure 4. Mechanism of reduction of the short memory syndrome by direct and indirect impulses of impacts of the extreme events on communities with the importance of the mass media spreading information.

events with their impacts on human life conditions in public perceptions are considered a direct local experience.

The short memory syndrome influences the perspectives of local authorities and communities in particular areas. However, the media coverage of global and regional climate change enhances the awareness of threats caused by related extreme events. Timely dissemination of information on environmental disasters at different locations worldwide amplifies the societal effect of scientific reports on climate warming and its environmental consequences (e.g. IPCC, 2007).

The existence of short memory syndrome can also be observed among politicians and policymakers at the parliamentary and governmental levels. The theme of threats related to climate change and extreme events had not been not present in public political debates prior to elections in Poland.

Scientific evidence for global warming and associated extreme events has been built up as the ensemble of ground observations on a local and regional scale, combined with remote-sensing methods usually applied to supraregional areas. Positive and negative feedbacks of differing intensity and scale have been detected. Improved social awareness and understanding of such processes governing global-scale environmental changes—with a special emphasis on local and regional impacts—can help overcome short memory syndrome. In this context, the permanent care and attention of politicians, authorities at different levels and especially the mass media, devoted to information on the risk of hydrometeorological extremes is of special importance. This would create enhancing conditions for the adaptation of societies to ongoing and future climatic variability and change, preparing them to deal with extremes and to reduce their consequences.

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